NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE
(NAAC Accredited)
(Approved by AICTE, Affiliated to APJ Abdul Kalam Technological University, Kerala)

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

COURSE MATERIALS

EC 306:ANTENNA & WAVE PROPAGATION

VISION OF THE INSTITUTION

To mould true citizens who are millennium leaders and catalysts of change through excellence in education.

MISSION OF THE INSTITUTION

NCERC is committed to transform itself into a center of excellence in Learning and Research in Engineering and Frontier Technology and to impart quality education to mould technically competent citizens with moral integrity, social commitment and ethical values.

We intend to facilitate our students to assimilate the latest technological know-how and to imbibe discipline, culture and spiritually, and to mould them in to technological giants, dedicated research scientists and intellectual leaders of the country who can spread the beams of light and happiness among the poor and the underprivileged.

ABOUT DEPARTMENT

- Established in: 2002
- Course offered : B.Tech in Electronics and Communication Engineering

  M.Tech in VLSI
- Approved by AICTE New Delhi and Accredited by NAAC
- Affiliated to the University of Dr. A P J Abdul Kalam Technological University.

DEPARTMENT VISION

Providing Universal Communicative Electronics Engineers with corporate and social relevance towards sustainable developments through quality education.

DEPARTMENT MISSION

1) Imparting Quality education by providing excellent teaching, learning environment.

2) Transforming and adopting students in this knowledgeable era, where the electronic gadgets (things) are getting obsolete in short span.

3) To initiate multi-disciplinary activities to students at earliest and apply in their respective fields of interest later.

4) Promoting leading edge Research & Development through collaboration with academia & industry.

PROGRAMME EDUCATIONAL OBJECTIVES

PEOI. To prepare students to excel in postgraduate programmes or to succeed in industry/ technical profession through global, rigorous education and prepare the students to practice and innovate recent fields in the specified program/ industry environment.

PEO2. To provide students with a solid foundation in mathematical, Scientific and engineering fundamentals required to solve engineering problems and to have strong practical knowledge required to design and test the system.

PEO3. To train students with good scientific and engineering breadth so as to comprehend, analyze, design, and create novel products and solutions for the real life problems.

PEO4. To provide student with an academic environment aware of excellence, effective communication skills, leadership, multidisciplinary approach, written ethical codes and the life-long learning needed for a successful professional career.

PROGRAM OUTCOMES (POS)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOMES (PSO)

PSO1: Facility to apply the concepts of Electronics, Communications, Signal processing, VLSI, Control systems etc., in the design and implementation of engineering systems.

PSO2: Facility to solve complex Electronics and communication Engineering problems, using latest hardware and software tools, either independently or in team.

COURSE OUTCOMES

EC 306

SUBJECT CODE: EC 306	
COURSE OUTCOMES After the completion of the course student will be able to:	
C306.1	understand the basic antenna parameters
C306.2	understand the basic principle of electromagnetic radiation and will be able to deduce the electric fields and magnetic fields radiated by a Hertzian dipole
C306.3	design antenna arrays
C306.4	learn the working different antenna types and their applications
C306.5	Learn principle of various antennas including smart antennas and design rectangular patch antenna
C306.6	understand the various modes of radio propagation and relate it to real communication instances

MAPPING OF COURSE OUTCOMES WITH PROGRAM OUTCOMES

CO'S	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
C306.1	3	3										
C306.2	3	3										
C306.3	3	3	3	2			1					
C306.4	3	3	2									
C306.5	3	3	3	2			1					
C306.6	3	3										

CO'S	PSO1	PSO2
C306.1	2	
C306.2	2	
C306.3	3	1
C306.4	2	
C306.5	3	1
C306.6	2	

SYLLABUS

COURSE CODE	COURSE NAME	L-T-P-C	YEAR OF INTRODUCTION
EC306	**Antenna & Wave Propagation**	**3-0-0-3**	**2016**

Prerequisite: EC303 Applied Electromagnetic Theory

Course objectives:

- To learn the basic working of antennas.
- To study various antennas, arrays and radiation patterns of antennas.
- To understand various techniques involved in various antenna parameter measurements.
- To understand the propagation of radio waves in the atmosphere.

Syllabus:

Antenna and antenna parameters, Duality of antennas, Derivation of electromagnetic fields and directivity of short dipole and half wave dipole, Measurement of antenna parameters. Antenna arrays and design of Endfire, broadside, binomial and Dolphchebyshev arrays, Principles of practical antennas. Traveling wave antennas, principle and applications of V and rhombic antennas Principles of Horn, Parabolic dish antenna and Cassegrain antenna, Log periodic antenna array and Helical antenna. Design of rectangular Patch antennas. Principle of smart antenna, Radio wave propagation, Different modes, effect of earth's magnetic field. Fading and diversity techniques.

Expected outcome:

The student will be able to know:

i. The basic working of antennas.
ii. Various antennas, arrays and radiation patterns of antennas
iii. Various techniques involved in various antenna parameter measurements.
iv. The propagation of radio waves in the atmosphere.

Text Books:

1. Balanis, Antenna Theory and Design, 3/e, Wiley Publications.
2. John D. Krauss, Antennas for all Applications, 3/e, TMH.

References:

1. Collin R.E, Antennas & Radio Wave Propagation, McGraw Hill. 1985.
2. Jordan E.C. & K. G. Balmain, Electromagnetic Waves & Radiating Systems, 2/e, PHI.
3. Raju G.S.N., Antenna and Wave Propagation, Pearson, 2013.
4. Sisir K.Das & Annapurna Das, Antenna and Wave Propagation, McGraw Hill,2012
5. Terman, Electronics & Radio Engineering, 4/e, McGraw Hill.
6. Thomas A. Milligan, Modern Antenna Design, IEEE PRESS, 2/e, Wiley Inter science.

Course Plan			
Module	**Course content**	**Hours**	**End Sem. Exam Marks**
I	Basic antenna parameters - gain, directivity, beam solid angle, beam width and effective aperture calculations. Effective height - wave polarization - antenna temperature - radiation resistance - radiation efficiency - antenna field zones - principles of reciprocity. Duality of antennas.	7	**15**
II	Concept of retarded potential. Field, directivity and radiation resistance of a short dipole and half wave dipole. Measurement of radiation pattern, gain, directivity and impedance of antenna	7	**15**
	FIRST INTERNAL EXAM		
III	Arrays of point sources - field of two isotropic point sources - principle of pattern multiplication - linear arrays of 'n' isotropic point sources. Grating lobes.	4	**15**
	Design of Broadside, Endfire & Binomial arrays. Design of DolphChebyshev arrays.	4	
IV	Basic principle of beam steering. Travelling wave antennas. Principle and applications of V and rhombic antennas. Principles of Horn, Parabolic dish antenna, Cassegrain antenna (expression for E, H andGain without derivation).	6	**15**
	SECOND INTERNAL EXAM		
V	Principle of Log periodic antenna array and Helical antenna. Antennas for mobile base station and handsets.	3	**20**
	Design of rectangular Patch antennas. Principle of smart antenna.	3	
VI	Radio wave propagation , Modes , structure of atmosphere, sky wave propagation , effect of earth's magnetic field, Ionospheric abnormalities and absorption, space wave propagation, LOS distance	4	**20**
	Field strength of space wave, duct propagation, VHF and UHF Mobile radio propagation, tropospheric scatter propagation, fading and diversity techniques.	4	
	END SEMESTER EXAM		

Question Paper Pattern (End semester exam)

Max. Marks : 100 **Time : 3 hours**

The question paper shall consist of three parts. Part A covers modules I and II, Part B covers modules III and IV, and Part C covers modules V and VI. Each part has three questions uniformly covering the two modules and each question can have maximum four subdivisions. In each part, any two questions are to be answered. Mark patterns are as per the syllabus with 50% for theory and 50% for logical/numerical problems, derivation and proof.

QUESTION BANK

MODULE I

1. Differentiate between beamwidth & bandwidth of an antenna(2)
2. What is the physical significance of radiation resistance(2)
3. A thin dipole antenna is $\lambda/15$ long. If its loss resistance is 1.5 Ω, find its radiation resistance(5)
4. Derive expression for the relation between directivity & effective area of an antenna(5)
5. Explain the difference between gain & directivity of an antenna(2)
6. Derive expression for effective aperture of an antenna in terms of radiation resistance(2)
7. An antenna has a loss resistance of 10 ohms, power gain of 20 & directivity of 22. Calculate its radiation resistance(2)
8. Define & prove reciprocity theorem. Discuss the applications of reciprocity theorem.
9. Write brief notes on the following a) beam solid angle b) radiation resistance c) measurement of antenna gain(10)
10. Compute the directivity of a current element Idl(2)
11. An antenna has directivity of 20. & a radiation efficiency of 90%. Compute the gain of the antenna(2)
12. State & explain reciprocity theorem(4)
13. What is the significance of radiation resistance(4)
14. Derive the relationship between effective aperture & directivity of an antenna(4)
15. Explain on field zones of an antenna(4)
16. A uniform plane wave is incident on a short lossless dipole. Find its effective aperture(10)
17. State reciprocity theorem. Write its significance(2)
18. An antenna has directivity of 20 & a radiation efficiency of 80%. What is the gain of the antenna in dB.(2)
19. Show the development of a a dipole antenna from a 2 wire open circuited transmission line(2)
20. Define & explain effective area of an antenna. Compute effective area for dipole antenna(10)
21. State & derive the reciprocity theorem for the antennas
22. State & explain the significance of polarization. Explain the types of polarization. Derive an expression for polarization ellipse(10)
23. Write a note an basic antenna parameters(10)
24. State & prove the reciprocal theorem with regards to antennas(10)
25. Find the relation between maximum effective aperture & directivity(5)

26. An antenna has a field pattern given by $E(\theta) = \cos\theta\cos 2\theta$ for $0\leq\theta\leq 90$. Find a) HPBW b) BWFN(5)
27. Show that a linearly polarized wave is a combination of two circular polarized waves(2)
28. Define directive gain of an antenna & express it in decibels(2)
29. A transmitting antenna having an effective height of 100m has a current at the base 100A at the frequency of 300KHz. Calculate the field strength at a distance of 100Km.
30. Derive an expression for the gains of a half wavelength antenna
31. A transmitting antenna having an effective height of 61.4 m takes a current of 50A(rms) at a wavelength of 625m. Find a) radiation resistance of the antenna b) power radiated c) antenna efficiency for a total antenna resistance of 50 ohms(10)
32. Derive the relation between maximum aperture & gain or directivity(10)
33. Define directivity & BWFN of an antenna(4)
34. Define effective aperture & scattering aperture of an antenna(4)
35. A thin dipole has length λ/y a) Calculate radiation resistanc b) Calculate antenna efficiency if loss resistance is 2 ohm(4)
36. Explain antenna temperature(4)
37. An antenna has a far field electric field given by $F(\theta,\emptyset)=I_0 \sin\theta \cos\emptyset \, e^{j\omega(t-r/c)} \, (a_\theta)$. Where I0 is the r m s value of the current at input terminals of the antenna. A) calculate farfield magnetic field b) Directivity of the antenna c) Radiation resistance(10)
38. Derive reciprocity theorem (5)
39. Define the terms a) antenna efficiency b)effective area(4)
40. Derive an expression for effective height of an antenna(4)
41. State & prove reciprocity theorem(10)
42. Calculate the effective length of a $\lambda/2$ antenna given $A_{em} = 0.13\lambda^2$
43. Explain duality theorem(4)
44. If $E_x= 3\cos wt$ & $E_y = 3\sin wt$ are the components of a wave travelling in the negative z direction, then what will be the type of antenna used for intercepting this wave(2)
45. What are the gains associated with an antenna(4)
46. The radiation intensity of main to be an antenna is $u = B\cos\theta$ where B is the maximum radiation intensity existing in the upper hemisphere$(0\leq\theta\leq\pi/2)$&$(0\leq\phi\leq 2\pi)$ Find directivity by using beam solid angle expression & by exact value

MODULE II

1. Derive expressions for directivity & radiation resistance of short dipole(10)
2. Explain on methods used for the measurement of directivity & impedance of an antenna(10)
3. Discuss the importance of retarded potentials in antenna analysis(2)
4. Derive expressions for the directivity &radiation resistance of a half wave dipole(10)
5. What is retarded potential(4)
6. Derive the far electric & magnetic field components of λ/2 antenna & hence obtain its radiation resistance(10)
7. Explain the methods for the measurement of impedance & gain of an antenna(10)
8. Derive the expressions for the electromagnetic fields of a short dipole(10)
9. Describe the method for the measurement of gain & impedance of an antenna(10)
10. Derive the radiation resistance of a quarter wave monopole antenna(10)
11. Draw a neat block diagram for the measurement of antenna gain. Explain the procedure in detail.
12. Prove that effective aperture of half wave dipole antenna is 0.13λ2 (10)
13. Radiation resistance of antenna is 72Ω & low resistance is 8 Ω. What is the directivity if the power gain is 16.(10)
14. Ilustrate with sketches at different time instants how a dipole radiates in free space(10)
15. Derive the expression for directivity & radiation resistance for a half wave dipole working out from infinitesimal dipole field expression(10)
16. Explain the methods used for measurement of directivity & impedance of an antenna(10)
17. Define short dipole/ hertzian dipole(2)
18. Show that the directivity of an electric current element is 3/2. Obtain its value in dB. (10)
19. Explain the concept of retarded potential(5)
20. Explain measurement of gain of an antenna(6)
21. Derive expressions for far field pattern & directivity of a short dipole antenna(10)
22. What is retarded potential(4)
23. Describe the method for the measurement of radiation pattern & gain of an antenna(10)
24. Derive expression for radiation resistance of half wave dipole(10)

MODULE III

1. What are grating lobes(2)
2. What are the advantages of dolph chebyshev method in designing arrays(2)
3. Explain grating lobes(2)
4. Explain the principle of pattern multiplication(2)
5. What do you mean by binomial arrays(2)
6. What is pattern multiplication(2)
7. Using pattern multiplication. Find the resultant pattern of 2 element array of infinitesimal horizontal dipoles of spacing $\lambda/4$ & $\beta = -90(2)$
8. Find the resultant pattern of uniform linear array with $n=4$, $d= \lambda/4$ & $\alpha=\pi$(10)
9. What is mean by directivity & power gain of an antenna? Show how the directivity can be increased by using a number of antennas in a suitable array(10)
10. Explain the principle of pattern multiplication & find the array factor of two element array(12)
11. Describe the principles of end fire & broad side arrays(8)
12. Explain the properties of binomial array(2)
13. Differentiate between broadside array & end fire array(10)
14. An array of n isotropic sources of equal amplitude & spacing are arranged as a broadside array. Calculate the pattern minima & maxima(10)
15. Derive the expression for the field intensity in the case of n number of isotropic source with equal spacing(10)
16. List the various forms of antenna arrays(2)
17. Show the arrangement of antennas in collinear arrays(2)
18. Calculate the directivity of a broadside array of two identical isotropic in phase point sources spaced $\lambda/2$ apart along the polar axis, the relative field pattern being given by $E = Cos(\pi/2Cos\theta)$ where θ is the polar angle(15)
19. Derive the expression for the resultant field of a linear array of n isotropic point sources. Under what conditions does the array act as an end fire array & a broadside array(10)
20. Design a 5 element Dolph chebyshev array with a spacing of $d= \lambda/2$. The pattern is to be optimum with a side l;obe level of 21.5dBdown the main lobe maximum.(10)
21. Sketch the resultant pattern of an array of 2 short vertical dipole with $d= \lambda/4$, $\alpha= 0$ using pattern multiplication principle(2)
22. What are Dolph chebyshev arrays. Design an array with $n= 4$ & $d= \lambda/2$.
23. Explain the significance of antenna arrays. Derive an expression for antenna array factor.
24. How the end fire array differs from a broadside array(4)
25. Find the resultant radiation pattern of uniform linear array with $n = 4$, $d= \lambda/4$, $\alpha= \pi$ using pattern multiplication
26. How the dolph chebyshev array differ from binomial arrays? Illustrate
27. What is a grating lobe(2)
28. Enumerate the features of binomial array(2)

29. Explain the construction & principle of operation of BSA & binomial array with a diagram. Analyze it mathematically.(10)
30. Define & explain array factor. Derive an expression for antenna array factor(5)
31. Derive the expressions for beamwidth of BSA & EFA patterns. Compare them(5)
32. Differentiate between broadside array & endfire array(10)
33. An array of n isotropic point sources of equal amplitude & spacing are arranged as a broadside array. Calculate the pattern minima & maxima(10)
34. Derive the expression for the field intensity in the case of n number of isotropic source with equal spacing(10)
35. Find the resultant pattern of uniform linear array with n= 4, d= λ/4 & α= π(10)
36. What is mean by directivity & power gain of an antenna? Show how the directivity can be increased by using a number of antennas in a suitable array.(10)
37. Explain the principle of pattern multiplication & find the array factor of two element array(12)
38. Describe the principles of end fire & broadside arrays(8)
39. Derive expression for the resultant field of a linear array of n isotropic point sources. Under what conditions does the array act as an end fire array and a broadside array.
40. Design a 5 element Dolph Chebyshev array with a spacing of d= λ/2. The pattern is to be optimum with a side lobe level of 21.5 dB down the main lobe maximum.
41. List the various forms of antenna arrays(2)
42. Show the arrangement of antennas in collinear arrays(2)
43. What is grating lobes(2)
44. Discuss the construction of an end fire array & sketch its directivity patterns(10)
45. Derive an equation for the directivity characteristics of a uniform linear antenna array with delyas(10)
46. Calculate the directivity of a broadside array of two identical isoptropic in phase point sources spaced λ/2 along the polar axis, the relative field pattern being given by E =cos(π/2cos θ) where θ is the polar angle(15)
47. Explain the principle of pattern multiplication(4)
48. Find the position of nulls for a four element broadside array with spacing d= λ/4(4)
49. Explain end fire array & derive array factor, position of nulls, position of major lobes & HPBW of the end fire array(5)
50. Design a 5 element dolph chebyshev arraywith spacing d =λ/2. The pattern is to be optimum with a side lobe of 21.5 dB down the main lobe maximum(10)
51. What is pattern multiplication(4)
52. Differentiate between uniform linear array & bilinear array(4)
53. Derive expressions for radiation pattern of endfire array with n vertical dipoles & sketch the radiation pattern for n = 4 , d= λ/2(10)
54. Sketch the radiation pattern of 8 antenna elements with d = λ/2 & fed in phase(10)

MODULE IV

1. What are the applications of rhombic antennas?(2)
2. What is the basic principle of beam steering?(4)
3. Find the gain , beamwidth & capture area for a parabolic antenna with a 6 meters diameter dish & dipole feed at a frequency of 10GHz(10)
4. Explain the working of parabolic dish antenna. What is the significance of f/D ratio? (10)
5. Explain the principle of horn antenna & give expression for E, H & gain(10)
6. Explain the principle & application of V antenna(10)
7. What are the other two names of rhombic antenna(2)
8. What is beam steering? Comment briefly on its principle(5)
9. Write short notes on the following a) Construction & working of rhombic antenna b) Principle of operation of parabolic dish antenna(10)
10. A certain antenna is used to radiate a 0.2 GHz signal to a satellite in space. The radiation resistance of the antenna is 31.6ohms. What is the type of antenna(2)
11. Design a horn antenna (find the dimensions) to give a half power beamwidth of 30 deg. In both E & H planes at a frequency of 9GHz. The horn is to be mounted on an X band waveguide. Assume the flare angle to be 15 degree. Calculate the gain of the horn.
12. Mention the applications of V antenna(4)
13. What are the applications of rhombic antenna(2)
14. Explain the principle of horn antenna& give expression for E, H & gain
15. Explain the principle & application of V antenna
16. Find the gain , beamwidth & capture area for a parabolic antenna with a 6 meter diameter dish & dipole feed at a frequency of 10GHz(10)
17. Explain the working of parabolic dish antenna. What is the significance of f/D ratio(10)
18. Write short notes on the following a) Construction & working of Rhombic antenna b) Principle of operation of parabolic dish antenna(10)
19. What are the other two names of rhombic antenna(2)
20. Discuss the beam formation of parabola reflctor by showing its geometry & draw its radiation pattern(10)
21. Describe the principle of operation of the rhombic antenna, explaining how the various parameters of the antenna control the radiation pattern(10)
22. Obtain the power gain of optimum horn antenna approximately with a square of 10λ on a side(3)
23. What is beam steering? Comment briefly on its principle(5)
24. For a parabolic dish antenna with isotropic feed, and diameter of the aperture 2λ. Calculte a) Directivity b) HPBW c) BWFN
25. Why log periodic antenna is called frequency independent antenna(4)
26. What is secant law(4)
27. Draw the diagram of helical antenna & explain the different modes of operation(10)

Module V

1. Write short note on broadband antennas & antennas for mobile communication.(10)
2. Write note on helical antenna working on axial mode & normal mode(10)
3. Write note on rectangular patch antenna with diagram indicating field distributions(10)
4. Explain smart antenna(2)
5. Explain the features of helical antenna & its practical design considerations(10)
6. Explain on antennas for mobile base station & handsets(4)
7. Name the antennas that are used in mobile handsets & mobile base stations(2)
8. Draw the diagrams & explain the working of helical antenna(10)
9. Draw log periodic antenna array for UHF & nVHF ranges. Explain their applications.(2)
10. A mobile phone base station transmitter delivers 20W into a 10dB gain antenna at 900 MHz. Compute the power in "W" available from a receiving antenna 30KM away with a gain of 5dB(10)
11. Draw the diagram of a log periodic antenna & explain its working(10)
12. What are the limitations of smart antenna(2)
13. What are the advantages & applications of offset feed reflector geometry(2)
14. Explain the concept of smart antenna with a diagram. Derive an expression for beam steering angle.(5)
15. Enumerate & explain the key benefits & potential applications of smart antenna technology(5)
16. Draw the structure of LPDA. Explain its radiation mechanism. Derive its design equations.(12)
17. Design a rectangular microstrip patch with dimensions W & L over a single substrate, whose center frequency is 10GHz. The dielectric constant of the substrate is 10.2 & the height of the substrate is 0.127cm. Determine the physical dimensions W & L of the patch taking into account fringing fields.(8)
18. Explain features of helical antenna & its practical design consideration(10)
19. Explain on antennas for mobile base station & handsets(10)
20. Write note on helical antenna working on normal mode & axial mode(10)
21. Write note on rectangular patch antenna with diagram indicating field distributions(10)
22. Write short note on broadband antennas & antennas for mobile communication(10)
23. Name the antennas that are used in mobile handsets & mobile base stations(2)
24. Show the construction of microwave dish & obtaon the BWFN & power gain(10)
25. Calculate in dB the directivity of 20 turn helix having α = 12 degrees circumference equal to one wavelength(7)
26. Explain normal mode operation of helical antenna(5)
27. Explain log periodic dipole antenna & its design steps(10)

Module VI

1. What is duct propagation(2)
2. Define the terms MUF & OWF(2)
3. What is virtual height & how it is measured(2)
4. Derive the expression for critical frequency(2)
5. Derive the expression for effective earths radius(10)
6. Explain the effects of earths maghnetic field(5)
7. A transmitter transmits signal with power P = 40K watts. The directive gain of the antenna is 1.74. Calculate the electric field intensity at a distance of 30km from the transmitter.(5)
8. Explain on a) VLF & ELF propagation in sea water b) VHF & UHF mobile radio propagation(10)
9. Discuss the structure of the ionosphere(2)
10. Find the range of a LOS system when the receive & transmit antenna heights are 10m & 100m respectively. Take the effective earth's radius into consideration(2)
11. Write short notes on duct propagation(2)
12. Explain the practical significance of ionospheric propagation. Derive expressions for the effective refractive index of the ionosphere. (10)
13. Explain the difference between MUF & critical frequency(5)
14. What do you mean by skip distance.? Derive expressions for skip distance interms of maximum usable frequency(5)
15. Explain the salient features of space wave propagation. Derive expressions for field strength of space wave propagation(10)
16. Derive an expression for LOS propagation distance(2)
17. Enumerate the characteristics of ionized region(2)
18. What are the advantages & applications of multihop propagation(2)
19. Explain the characteristics of ionosphere. Derive the characteristic equations of ionosphere(10)
20. What is troposcatter propagation(5)
21. Derive the expression for field strength of space wave.
22. At a 300KM height in ionosphere, the electron density at night is about 3×1012 m-3 & the signal MUF is f= 2fcr for a transmission distance of 600kM Compute fcv , εr , η, β, Vp , Vg & θt (10)
23. What is tropospheric scatter propagation(4)
24. What is the importance of gyro frequency in sky wave communication(4)
25. Define the terms MUF & OWF(4)
26. Explain the effect of earths magnetic field on ionospheric propagation(10)
27. Derive the expression for field strength of space wave(10)
28. Explain the effect of ionospheric abnormalities & absorption in sky wave communication(10)

29. A transmitting antenna with a 300MHz carrier frequency produces 2.5 kW of power. If both antennas have unity power gain, what is the power received by another antenna at a distance of 1.5km?(2)
30. Draw the structure of ionospheric profile(2)
31. What is gyro frequency? What is its significance(2)
32. Discuss the factors involved in the propagation of the radio waves. Compare & contrast them.(10)
33. Draw the ray model of space wave propagation & explain. Derive an expression for its received field strength(10)
34. Define an explain a) MUF b) Critical Frequency c) Skip zone d) Multihop Propagation(12)
35. Explain the characteristics of ionosphere. Derive the characteristic equations of ionosphere. Explain their significance(8)
36. Derive the relation between MUF & critical frequency(2)
37. Explain skip distance(2)
38. Explain the characteristics of ionized region(2)
39. Define virtual height(@)
40. Write a note on UHF mobile radio propagation(2)
41. What are the effects of earth's magnetic field on propagation of radio waves(10)
42. Derive the expression for critical frequency of a ionized layer(10)
43. Explain modes of propagation (10)
44. A VHF communication is to be established at 90MHz, with the transmitter power of 35 watts. Calculate the LOS communication distance, if the heights of transmitter & receiver antennas are 40m & 25m respectively.(10)
45. Derive the relation between MUF & critical frequency(2)
46. Derive the expression for effective earths radius(10)
47. Explain how earths magnetic field effects the propagation of radio wave in the ionosphere. Discuss its effects on polarization absorption of radio waves(10)
48. Describe how the ionospheric layers are formed & how they affect the propagation of radio waves(10)
49. Derive the expression for refractive index of ionospheric neglecting earth's magnetic field on ionosphere(10)
50. Explain the practical significance of ionospheric propagation. Derive expressions for the effective refractive index of the ionosphere(10)
51. Explain the difference between maximum usable frequency & critical frequency
52. What do you mean by skip distance? Derive expressions for skip distance in terms of maximum usable frequency
53. Explain the salient features of space wave propagation. Derive expressions for field strength of space wave propagation.
54. Give the list of prominent modes of wave propagation(2)
55. Write the formula that defines the field strength for ground wave propagation for a flat earth in accordance with sommerfield(2)

56. Explain the phenomenon of ionospheric reflection & derive an expression for the critical frequency of an ionospheric region(10)
57. Write short notes on Luxemburg effect & sudden ionosphere disturbances(10)
58. What is duct propagation? With the neat diagrams of surface duct, elevated duct & ground based duct discuss the importance of duct phenomenon in UHF(10)
59. What is skip distance? Derive & obtain its expression(10)
60. Derive the expression for MUF for ionospheric propagation(4)
61. Derive expression for effective refractive index for ionospheric propagation(4)
62. For a television transmission, the signal is to be received from a transmitter station at a distance 60Km. The height of the transmitted antenna is 160 meter. Calculate the height of the receiver antenna(4)
63. Derive expression for range of space wave propagation
64. A transmitter transmits signal with power P =30kWatt. The directive gain of the transmitter antenna is 1.64. Calculate the electric field intensity at a distance 20km from the transmitter(5)
65. Explain the structure of ionosphere(5)
66. A high frequency radio link has to be established on the earth 230km away. The reflection region of the ionosphere is at a height 200km & has a critical frequency of 6MHz. Calculate MUF for the given path.(5)
67. Explain duct propagation (2)
68. Derive expression for field strength of space or tropospheric wave propagation.(5)
69. Explain effective earth's radius(2)
70. What is the significance of virtual height(4)
71. What is duct propagation(4)
72. Derive the expression for line of sight distance(4)
73. Explain the different modes of propagation(10)
74. Derive the expression for refractive index of ionosphere(10)
75. Explain on VHF & UHF mobile radio propagation(10)
76. A radio wave is incident on a layer of ionosphere at an angle of 30 degrees with the vertical. If the critical frequency is 1.2 MHz , What is the MUF? (10)

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NOTES

MODULE 1,2 & 3

Duality of antennas.

INTRODUCTION

The basic Defenition of an antenna is a metallic device in the form of either wire or rod used for radiating or receiving radio waves.

According to IEEE standard defenition of terms for antennas, an antenna or aerial is a means for radiating.

An antenna can also be defined as a transducer which converts radio frequency electrical current into an electromagnetic wave of the same frequency as that of an electrical current.

Basic Antenna Elements:

i) Alternating current element (Hertzian dipole):
It is the basic short linear antenna. It is assumed that the current along the length of linear antenna is constant.

ii) Short dipole: It is a linear antenna with a length less than $\lambda/4$. The current distribution of short dipole is assumed to be triangular.

iii) Short Monopole : It is also be a linear antenna ; Length < λ/8 ; Current dbn Triangular

iv) Half wave dipole : Linear antenna Length = λ/2. This is generally centerfed and its current distribution is sinusoidal.

v) Quarter wave monopole : Length = λ/4 ; It is fed at one end with respect to gnd or earth ; sinusoidal current distribution.

Isotropic Radiator :-

It is a hypothetical or fictitious radiator. The isotropic radiator is defined as a radiator which radiates energy in all directions uniformly. It is also called Isotropic source.

As it radiates uniformly in all directions, it is also called omnidirectional radiator or unipole.

Basically it is a lossless ideal radiator or antenna

Generally all the practical antennas are compared with the characteristics of the istropic radiator.

It is used as reference antenna.

practically it doesnot exist. That means none of the antenna radiate energy in all directions uniformly.

M-P-1

2) Gain 3) Directivity 4) Beam solid angle
5) Beam width and effective aperture calculations
6) Effective height 7) Wave polarization
8) Antenna temperature 9) Radiation Resistance
10) Radiation Efficiency 11) Antenna field zones
12) Principles of reciprocity 13) Duality of antennas

Radiation pattern: It is a graph which shows the variation of actual field strength of electromagnetic field at all the points equidistant from the antenna. Hence it is a three dimensional graph.

- There are two basic radiation patterns

If the radiation of the antenna is represented graphically as a function of direction it is called radiation pattern.

- If the radiation of the antenna is expressed in terms of the field strength E(in v/m), then the graphical representation is called field strength pattern or Field Radiation pattern.

- If the radiation of the antenna is expressed in terms of the power per unit solid angle, then the graphical representation is called power Radiation pattern or simply power pattern or simply power pattern.

Radian, Steradian and Beam solid Angle (Ω_A)

The basic difference between radian and steradian is that the radian is the measure of a plane angle, while the steradian is the measure of a solid angle.

One radian is defined as the plane angle with its vertex at the centre of a circle with radius 'r' that is subtended by an arc whose length is also r. It is represented as unit rad.

y of
ircle.

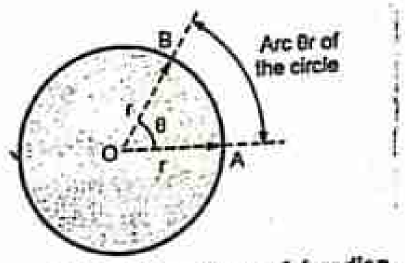


Fig. 1.4.8 Representation of 1 radian plane angle

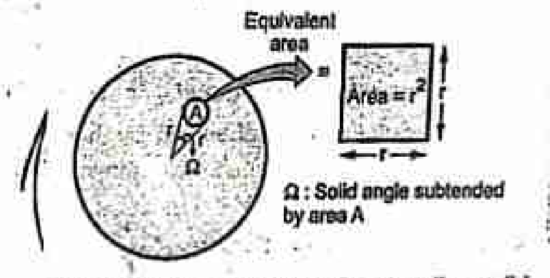


Fig. 1.4.9 Representation of 1 steradian solid angle

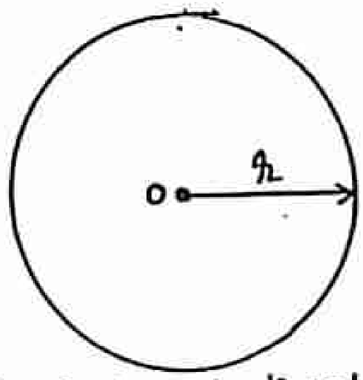
Fig: Representation of 1 radian plane angle.

Refer figure. The total circumference 'C' of a circle with radius 'r' is given by

$$C = 2\pi r$$

Thus over a complete circle there are 2π radians.

The Measure of a solid angle is defined as steradian. One steradian is defined as a solid angle with its vertex at the centre



Isotropic radiator placed at centre of Sphere with radius 'r'

Consider that an Isotropic radiator is placed at the centre of sphere of radius r as shown in fig. Then all the power radiated by the Isotropic radiator passes over the surface area of the sphere given by $4\pi r^2$, assuming zero absorption of the power. Then at any point on the surface, the poynting Vector $\bar{P}$ gives the power radiated per unit area in any direction. But radiated power travels in the radiate direction. Thus the magnitude of the poynting Vector $\bar{P}$ will be equal to radial component as the components in θ and ϕ direction are zero.

ie $P_\theta = P_\phi = 0$. Hence we can write

$$|\bar{P}| = P_r \quad \text{---(1)}$$

The total power radiated is given by

M-I-2

$$P_{rad} = \iint \bar{P} \cdot \bar{ds}$$
$$= \iint P_r \, ds$$
$$= P_r \iint ds \qquad \because P_\theta = P_\phi = 0$$

Now this radial component P_r is the average power density component which can be denoted as P_{avg}

$$P_{rad} = P_{avg} (4\pi r^2)$$

where $\iint ds$ = surface area $= 4\pi r^2$

$$\therefore \boxed{P_{avg} = \frac{P_{rad}}{4\pi r^2} \; W/m^2 \quad \text{——} \quad (2)}$$

where P_{rad} = Total power radiated in watts

P_{avg} = Radial component of average Power density in W/m^2

r = Radius of sphere in meters.

Basic Antenna Parameters :

An antenna is the basic fundamental Component of the communication system. But irrespective of antenna types and applications, all the antennas posses certain fundemental properties as listed below.

1) Radiation pattern — i) Field Radiation pattern
ii) power radiation pattern

of the sphere with radius 'r' that is subtended by a spherical surface area equal to that of a square with each side equal to r. The angle in steradian is expressed in sr.

Refer fig, The area of a complete sphere with radius r is given by

$$A = 4\pi r^2$$

$A = 4\pi r^2$ $(rad)^2 = \frac{(180)^2}{\pi^2}$ $1sr$

Thus over a closed sphere with radius r, the solid angle subtended by it is 4π steradian.

Now $\boxed{1 \text{ steradian} = 1 sr = \frac{\text{Solid angle of sphere}}{4\pi}}$

$\therefore$ $1 sr = 1 rad^2 = \left(\frac{180}{\pi}\right)^2 (deg)^2 = 3282.81$ square degree

The infinitesimal area 'ds' on the surface of a sphere with radius r is given by

$$ds = r^2 \sin\theta \, d\theta \, d\phi \ m^2$$

$ds = r^2 \sin\theta \, d\theta \, d\phi$. $d\Omega = \frac{ds}{r^2}$

Hence the element of solid angle $d\Omega$ of a sphere is given by :

$$d\Omega = \frac{ds}{r^2} = \sin\theta \, d\theta \cdot d\phi \ m^2.$$

Hence the element of solid angle $d\Omega$ of a sphere is given by

$$\boxed{d\Omega = \frac{ds}{r^2} = \sin\theta \, d\theta \cdot d\phi \ \text{steradian}}$$

Beam solid Angle (or Beam Area) Ω_A

Generally in the antenna pattern the beam area or beam solid angle is expressed in steradian. It is defined as the integral of normalized power pattern over a sphere. It is denoted by Ω_A and is given by

$$\Omega_A = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} P_{dn}(\theta,\phi)\sin\theta\, d\theta\, d\phi$$

But $d\Omega = \sin\theta\, d\theta\, d\phi$. Hence beam area is given by

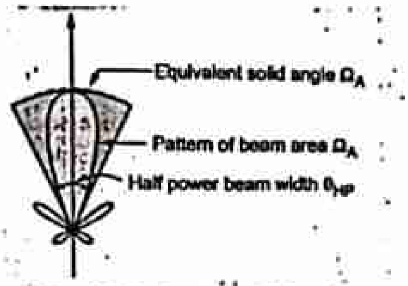
$$\Omega_A = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} P_{dn}(\theta,\phi)\, d\Omega \text{ steradian.}$$

Many times, the beam area Ω_A is described in terms of the angles subtended by half power points of the main lobe as shown in the fig

Thus beam area can be written as,

Beam area $= \Omega_A = \theta_{HP}\,\phi_{HP}$ steradian.

→ θ_{HP} and ϕ_{HP} are half power beam widths



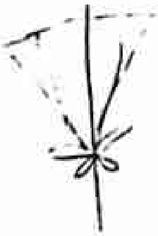


Fig. 1.4.10 Representation of equivalent solid angle

Directive Gain ($G_D(\theta, \phi)$) and Directivity (D)

An isotropic antenna is the omnidirectional antenna. If the antenna were isotropic i.e if it were to radiate uniformly in all directions, then the power density at all the points on the surface of a sphere will be same. The average power can be expressed in terms of the radiated power as

$$\boxed{P_{avg} = \frac{P_{rad}}{4\pi r^2} \ W/m^2}$$

The directive gain is defined as the ratio of the power density $P_d(\theta, \phi)$ to the average power radiated. For isotropic antenna, the value of the directive gain is unity

$$G_D(\theta, \phi) = \frac{P_d(\theta, \phi)}{P_{avg}} = \frac{P_d(\theta, \phi)}{\frac{P_{rad}}{4\pi r^2}}$$

Rearranging the terms

M-T-5

$$\boxed{G_D(\theta,\phi) = \frac{P_d(\theta,\phi)\cdot r^2}{\left(\frac{P_{rad}}{4\pi}\right)}}$$

The numerator in the above ratio is the radiation intensity, while the denominator is the average value of the radiation intensity. Hence the directive gain can be written as

$$\boxed{G_D(\theta,\phi) = \frac{U(\theta,\phi)}{U_{avg}} = \frac{4\pi\, U(\theta,\phi)}{P_{rad}}}$$

Thus the directive gain can be defined as a measure of the concentration of the radiated power in a particular direction (θ,ϕ)

The Ratio of max power density to the average power radiated is called "maximum directive gain or directivity of the antenna. It is denoted by G_{Dmax} or D

$$\boxed{D = G_{Dmax} = \frac{P_{dmax}}{\frac{P_{rad}}{4\pi r^2}}}$$

The directivity can alternatively defined as

$$\boxed{D = G_{Dmax} = \frac{U_{max}}{U_{avg}} = \frac{4\pi\, U_{max}}{P_{rad}}}$$

The directivity of an antenna is dimensionless quantity. The directivity can also be expressed in term of the electric field intensity as

$$D = G_{Dmax} = \frac{4\pi |E_{max}|^2}{\int_0^{2\pi}\int_0^{\pi} |E(\theta,\phi)|^2 \sin\theta \, d\theta \, d\phi}$$

We know that average power density P_{avg}

$$P_{avg} = \frac{1}{4\pi}\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} P(\theta,\phi) \sin\theta \cdot d\theta \cdot d\phi$$

We know that $d\Omega = \sin\theta \cdot d\theta \cdot d\phi$

$$\therefore P_{avg} = \frac{1}{4\pi}\iint_{4\pi} P(\theta,\phi)\, d\Omega \text{ watt/sr}$$

Thus from equation $D = G_{Dmax} = \dfrac{P_{dmax}}{\frac{P_{rad}}{4\pi r^2}}$

and again $\dfrac{P_{rad}}{4\pi r^2} = P_{avg}$

$$\boxed{D = G_{Dmax} = \frac{P_{dmax}}{P_{avg}} = \frac{P(\theta,\phi)_{max}}{\frac{1}{4\pi}\iint_{4\pi} P(\theta,\phi)\, d\Omega}}$$

Re arranging terms

$$D = \frac{1}{\frac{1}{4\pi}\iint\limits_{4\pi}\left[\frac{P(\theta,\phi)}{P(\theta,\phi)_{max}}\right]d\Omega}$$

But $\dfrac{P(\theta,\phi)}{P(\theta,\phi)_{max}} = P_n(\theta,\phi)$ = Normalized power pattern

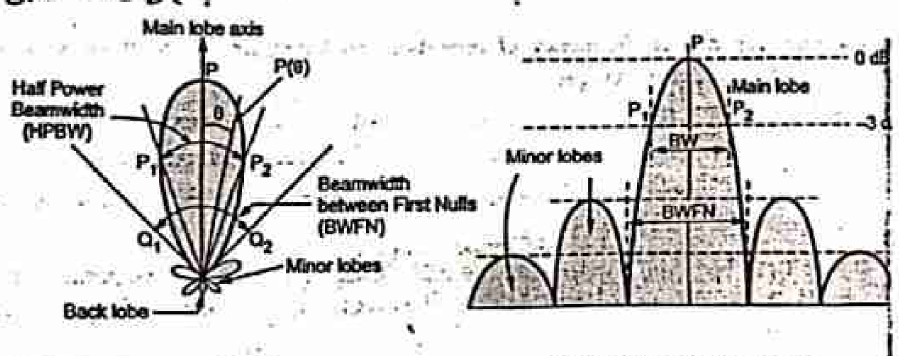
$$\therefore\ \boxed{D = \frac{4\pi}{\iint\limits_{4\pi} P_n(\theta,\phi)\,d\Omega} = \frac{4\pi}{\Omega_A}}$$

So alternatively we can define the directivity as the ratio of area of a sphere ($4\pi Sr$) to the beam area Ω_A of an antenna.

Antenna Beam Width:

Basically it is the measure of the directivity of the antenna. The antenna beam width is an angular width in degrees.

It is measured on a radiation pattern on major lobe.



(a) Antenna power pattern in polar co-ordinates

(b) Antenna power pattern in rectangular co-ordinates and logarithmic scale

Fig. 1.4.11 Measurement of antenna beamwidth

The antenna beam width is defined as the angular width in degrees between the two points on a major lobe of a radiation pattern where the radiated power decreases to half of its maximum Value.

The beamwidth is also called "Half power Beamwidth (HPBW)" because it is measured between two points on the major lobe where the power is half of its maximum power, From figure it is clear that the power is maximum at point P_1 and P_2 is noting but antenna beawidth or Half power Beamwidth (HPDW)

— The beamwidth is also called 3-dB beamwidth

— Many times, the antenna radiation pattern is described in terms of the angular width btwn first nulls or first side lobes. Then such an angular beamwidth is called Beamwidth between first nulls or first side lobes. Then such an angular beamwidth is called Beamwidth between First nulls (BWFN)

— The directivity (D) of the antenna is related with beam solid angle Ω_A or beam area B through expression

$$\boxed{D = \frac{4\pi}{\Omega_A} = \frac{4\pi}{B}}$$

B = Beam area
$\approx$ (HPBW) in horizontal plane E plane X
(HPBW) in vertical plane H - Plane.

or $B \approx \theta_E \times \theta_H$.

$$\therefore D = \frac{4\pi}{\theta_E \theta_H}$$

$$1 rad = \frac{180^\circ}{\pi} = 57.295^\circ \simeq 57.3^\circ$$

$$\text{Then } D = \boxed{\frac{4\pi (57.3)^2}{\theta_E^\circ \theta_H^\circ} = \frac{41257^\circ}{\theta_E^\circ \theta_H^\circ}}$$

The beamwidth of the antenna is affected by the shape of the radiation pattern, wavelength and dimensions.

Effective Aperture Calculations:

Effective Aperture or Effective Area (A_e)

– In general this term is used in relation with the receiving antenna.

The Effective aperture is the ability of an antenna to extract energy from the electromagnetic wave. It is also called effective area.

Effective aperture is defined as the ratio of Power received in the load to the average

Power density produced at the point

$$\boxed{A_e = \frac{P_{received}}{P_{avg}} \; m^2}$$

$\frac{P_{in}}{P_{avg}}$

$P_{received} \rightarrow$ Watts

$P_{avag} \rightarrow$ Watts/m^2

In Otherwords we can explain effective aperture as an area which extracts energy from the electromagnetic wave, Out of the total area of antenna.

Hence under maximum power transfer condition, the power received is maximum and hence the effective aperture is maximum

Calculations: Let us calculate effective aperture for the Hertizian dipole. When the Hertizian dipole is used as the receiving antenna, it extracts power from the incident waves and delivers it to the load, producing Voltage in it The Equivalent Ckt is shown in fig.

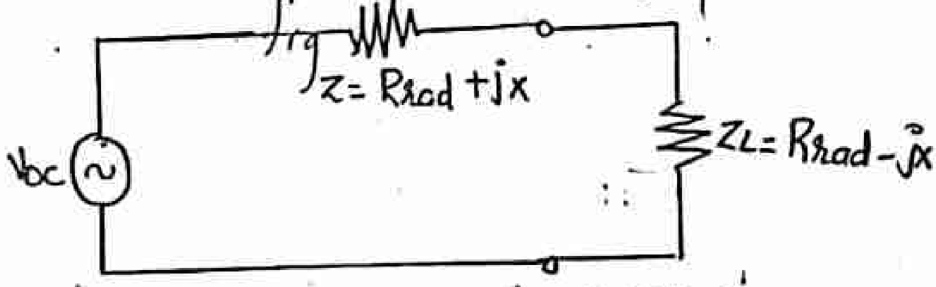


Fig: Equivalent Circuit of the receiving antenna.

The Voltage induced in antenna is given by

$$V_{oc} = |\bar{E}| \cdot dL \quad \text{--- (1)}$$

$|\bar{E}|$ = Magnitude of the electric field intensity produced at the receiving point

dL = Length of the Hertizian dipole.

Then current flowing the load

$$I = \frac{V_{oc}}{Z + Z_L} \quad \text{--- (2)}$$

→ For maximum power transfer condition, load is selected as the complex conjugate of the antenna impedance ($Z_L = Z^*$)

— Substituting the values of Impedances Z & Z_L

$$I = \frac{V_{oc}}{(R_{rad} + jX) + (R_{rad} - jX)} \quad \text{--- (3)}$$

$$\therefore I = \frac{V_{oc}}{2 R_{rad}} \quad \text{--- (4)}$$

Then the power delivered to the load is given by

$$P_R = I^2_{rms} R_{rad} = \left(\frac{\frac{V_{oc}}{2 R_{rad}}}{\sqrt{2}} \right)^2 \cdot R_{rad} \quad \text{--- (5)}$$

$$\boxed{\therefore P_R = \frac{V_{oc}^2}{8 R_{rad}}} \quad \text{--- (6)}$$

Substituting the value of V_{oc} from (1)

$$P_R = \frac{|E|^2 \cdot dL^2}{8 \cdot R_{rad}} \quad \text{——— (7)}$$

The maximum Effective aperature is given by

$$A_{em} = \frac{\text{Maximum power received}}{\text{Average power density}} = \frac{P_{R\,max}}{|\bar{P}_{avg}|}$$

$$\therefore A_{em} = \frac{\frac{|\bar{E}|^2 \cdot dL^2}{8 \cdot R_{rad}}}{\frac{1}{2}\frac{|\bar{E}|^2}{\eta_0}} \qquad \frac{1}{2}\frac{|E|^2}{\eta_0}$$

$$\therefore A_{em} = \frac{dL^2 \cdot \eta_0}{4 \cdot R_{rad}} \quad \text{——— (8)}$$

Substituting values of R_{rad} and η_0, we get

$$\therefore A_{em} = \frac{dL^2 \cdot (\cancel{120}\,\cancel{\pi})}{\cancel{4}\left[8\cancel{0}\pi^2\left[\frac{dL}{\lambda}\right]^2\right]} = \frac{3\lambda^2}{8\pi}$$

$$\boxed{\therefore A_{em} = 1.5\,\frac{\lambda^2}{4\pi}}$$

Above equation represents the maximum effective aperture of the Hertizian dipole. But the directivity of the Hertizian dipole is 1.5.

$\therefore$ Maximum Effective aperture

$$A_{em} = (G_{D\,max})\frac{\lambda^2}{4\pi}$$

Different Types of Antenna Apertures:

Other than the effective aperture (A_e) there are other apertures as explained below

M-1-9

A. Scattering Ratio (A_s):

It is defined as the ratio of power received by radiation resistance Rrad to the average power density produced at point. Denoted by A_s and is measured in m^2

Mathematically $A_s = \frac{I_{rms}^2 \cdot R_{rad}}{|P_{avg}|}$

$$= \frac{I_{rms}^2 \cdot R_{rad}}{P_{avg}}$$

Using and Equivalent circuit of antenna

$$|I_{rms}| = \frac{V_A}{\sqrt{(R_L+R_A)^2+(X_L+X_A)^2}}$$

$$A_s = \frac{V_A^2 \cdot R_{rad}}{[(R_L+R_A)^2+(X_L+X_A)^2] \cdot P_{avg}}$$

For maximum power transfer condition, $R_L = R_A = R_{rad}$; $R_{loss} = 0$; $X_L = -X_A$

$$(A_s)_{max} = \frac{V_A^2}{4 \cdot R_{rad} \cdot P_{avg}} = (A_e)_{max}.$$

Thus it is observed that under maximum power transfer condition, the maximum scattering aperture $(A_s)_{max}$ of an antenna is same as maximum effective aperture $(A_e)_{max}$.

The Ratio of scattering aperture of an antenna to its effective aperture is known as scattering Ratio. It is denoted by 'β' and its value lies between 0 and ∞.

$$\boxed{\beta = \frac{A_s}{A_e}}$$

Loss Aperture: It is related to the loss resistance. It is defined as the ratio of power dissipated by the loss resistance of an antenna to the average power density at a point. It is called loss aperture and is denoted by A_l

$$\therefore \quad A_l = \frac{I_{rms}^2 \cdot R_{loss}}{|P_{avg}|} = \frac{I_{rms}^2 \cdot R_{loss}}{P_{avg}}$$

putting value of I_{rms}, we get alternative expression for A_l as.

$$A_L = \frac{V_A^2 \cdot R_{loss}}{[(R_L + R_A)^2 + (X_L + X_A)^2] \cdot P_{avg}}$$

$$R_A = R_{rad} + R_{loss}$$

$$A_l = \frac{V_A^2 \cdot R_{loss}}{[(R_L + R_{rad} + R_{loss})^2 + (X_L + X_A)^2] \cdot P_{avg}}$$

M-1-10

Collecting Aperture: (A_c)

The collecting aperture (A_c) is the sum of effective aperture, scatting aperture and loss aperture of an antenna.

Hence we can write

$$A_c = A_e + A_s + A_l$$

$$A_c = \left[\frac{I_{rms}^2 \cdot R_L}{P_{avg}}\right] + \left[\frac{I_{rms}^2 \cdot R_{rad}}{P_{avg}}\right] + \left[\frac{I_{rms}^2 \cdot R_{loss}}{P_{avg}}\right]$$

$$A_c = \frac{I_{rms}^2 (R_L + R_{rad} + R_{loss})}{P_{avg}}$$

$P_{avg} \rightarrow$ Magnitude of average power density at point.

substituting I_{rms}

$$A_c = \frac{V_A^2 (R_L + R_{rad} + R_{loss})}{\left[(R_L + R_{rad} + R_{loss})^2 + (X_L + X_A)^2\right] \cdot P_{avg}}$$

Physical Aperture: Denoted by A_p, which deals with the actual physical size or cross-section of an antenna.

It is defined as the actual physical cross-section of an antenna normal to the direction of propagation of electromagnetic waves towards an antenna which is set for its maximum response.

It is observed that the physical aperture Ap for large cross-section antennas is > their respective effective aperture i.e.

— When the losses are assumed to be zero

$$\boxed{A_p = A_e}$$

– The Ratio of maximum effective aperture to the physical aperture of an antenna is known as absorption ratio. It is denoted by 'γ' It is dimensionless quantity and its value lies between 0 and ∞

$$\boxed{\gamma = \frac{(A_e)_{max}}{A_p}}$$

Effective Height :-

Effective Length (OR) Effective Height (l_{eff})

The effective length of an antenna carrying peak current I_m is defined as the length of an antenna carrying peak current I_m is defined as the length of an imaginary linear antenna with a uniformly distributed current, such that both the antennas have the same far field in $\theta = \pi/2$ plane. It is represented by l_{eff}.

For practical antenna

$$E_\theta = j\frac{\eta_0\beta}{4\pi r}e^{-j\beta r}\int_{-l/2}^{l/2} I(z).dz \quad \text{— (1)}$$

For practical antenna, variation of current can have any distribution. But for an imaginary antenna current is assumed to be uniformly distributed over the length

Hence for Imaginary antenna

$$E\theta = j\frac{\eta_0 \cdot \beta}{4\pi r} e^{-j\beta r} I_m \int_{-l_{eff}/2}^{l_{eff}/2} dz \quad (2)$$

$$\therefore E\theta = j \cdot \frac{\eta_0 \cdot \beta}{4\pi r} \cdot e^{-j\beta r} I_m [l_{eff}]$$

But for practical and Imaginary antenna should produce same electric field at far poin

So equating equations (1) and (2)

$$\boxed{l_{eff} = \frac{1}{I_m}\int_{-l/2}^{l/2} I(z) \cdot dz \quad — (3)}$$

Equation (3) represents the effective length o a transmitting antenna.

The effective length of a receiving antenn is defined as the ratio of the open circuit voltage Voc induced at the open terminals an antenna to the incident electric field intensity Ei producing Voc

$$\therefore \boxed{l_{eff} = \frac{V_{oc}}{E_i}}$$

- Wave polarization :

Polarization is nothing but the physical Orientation of the electromagnetic wave in the free space.

- The antenna polarization in a given direction refers to the polarization of an EM wave radiated or rxed by the antenna.
- Conventionally the polarization is described in terms of the electric field vector $\bar{E}$. The polarization of the electric field $\bar{E}$ can be obtained by observing the field along the direction of propagation.

Note: polarization can be defined as the figure traced as a function of time by the tip of the instantaneous electric field vector at a fixed location in free space observed along the direction of propagation.

- The polarization of EM wave incident from specified direction which results in the max power at antenna terminals is called polarization of the receiving antenna.

→ polarization can be classified as

a) Linear polarization
b) Circular polarization
c) elliptical polarization.

M-1-12

a) Linear polarization: E.F vector at any pt in the free space is the fn of 't' and it is directed always along the line, then the polarization is called Linear.

- Then the EM wave; the field vector $\bar{E}$ lies in the vertical plane, then the wave is said to be vertically polarized wave.

→ Similarly $\bar{E}$ lies in the horizontal plane then the wave is said to be horizontally polarized. (ordinarily)

b) Elliptical polarization: When the instantaneous electric field vector traces is an ellipse, the field is said to be elliptically polarized field and the polarization is called elliptical polarization.

c) Circular polarization: When the instantaneous electric field vector traces a circle, the polarization is called circular polarization and field is said to be circularly polarized wave.

Depending upon the direction of the Orientation of an electric field vector, two cases are possible.

case1: If the Electric field Vector (EFV) is oriented in the clockwise direction then the polarization is called Right hand polarization.

Case II : If the Electric field Vector is Oriented in anticlockwise or counter clockwise direction then the polarization is called Left hand polarization.

Ordinary simple antennas Txit or Rxve Linearly polarized wave.

- But at VLF, horizontally polarized waves are not Suitable but the the Vertically polarized waves are best suited.

— For μwave frequencies — circularly polarized

Antenna Temperature : It is denoted by T_A.

— Any object with physical temperature above absolute zero (ie above 0 °K or −273°c) radiates energy 38.6c

— Antenna temperature is not the inherent property of the antenna ; it is related to the temperature of the surrounding coupled to the antenna through radiation resistance.

— So we can consider the Rxing antenna as a remote temperature sensing and measuring device.

— Consider a simple resistor at temperature T_R as shown in the fig. By the Nyquist relation the noise power per unit bandwidth available across the terminals is given by

M.1-13

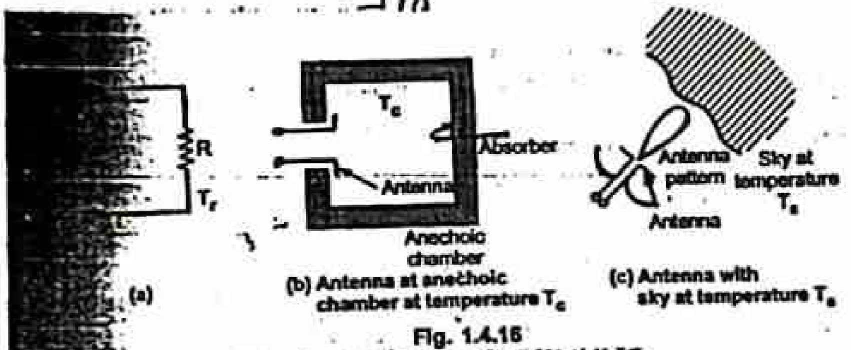


Fig. 1.4.16

$P = K \cdot T_r$ ← Boltzmann const ; temperature of the resistor

$P \rightarrow$ Noise power per unit bandwidth W/Hz
$K \rightarrow 1.38 \times 10^{-23}$ J/K
$T_r \rightarrow$ Absolute T of resistor in K. (Kelvin)

- If we replace a resistor by a lossless antenna of the radiation resistor R in an anechoic chamber at temperature T_c, then under condition $T_r = T_c$, the noise power / unit bandwidth remains as shown in fig b
- Finally if we remove antenna from anechoic chamber and kept pointing to the sky at temperature T_s as shown in the fig (c) then the noise power / unit bandwidth remains unchanged if the temperature T_s and T_r are same.
- In this way antenna can be used to measure distinct temperature and it is called passive remote sensing
- The Antenna used for remote sensing i

called Radio Telescope

- For a practical antenna used for remote sensing, the noise power / unit B.W.

$$P = KT_A \text{ Watt/Hz} \quad (1)$$

TA → Antenna Temperature or Antenna noise temperature which is equal to the temperature of the radiation resistance of the antenna.

- The total power available can be obtained by multiplying RHS of equation (1) by bandwidth 'B' in Hz

$$P = K T_A \cdot B \text{ W} \quad (2)$$

- Let Ae → Effective aperture, Then the power density / unit B.W is produced in the direction of the radiation, This is called flux density and it is denoted by S

- Hence available power

$$P = S \cdot A_e \cdot B \text{ W} \quad (3)$$

flux density

$$\boxed{S = \frac{K \cdot T_A}{A_e} \text{ W/m}^2 \text{ Hz}} \quad (4)$$

From ~~equation~~ (4); The antenna temperature from the source as

$$\boxed{T_A = \frac{S A_e}{k}} \quad (5)$$

From (5) It is clear that the dimensions of th flux density & poynting vector / unit Bandwidth

M-1-14

are same.

→ so we can express flux density s as the measure of the poynting vector / unit bandwidth

– If the size of the source is small compared to the beam solid angle Ω_A; Then the source temperature can be given by

$$\boxed{T_s = \frac{\Omega_A}{\Omega_s} T_A \cdot K} \quad \text{———} \quad (6)$$

Ω_A → Beam solid angle in steradian

Ω_s → Source " " "

– practically the thermal noise in the components in the RXR s/m, itself has certain noise temperature T_R

so the total noise power at the terminals of the receiver

$$\boxed{P_s = K(T_A + T_R) B = K T_{sys} B \, W}$$

P_s = system (s/m) noise power

$T_A + T_R$ = Effective s/m noise Temperature = T_{sys}

(7) <u>Equivalent noise temperature:</u>

– The noise introduced by the antenna can be considered as effective noise temperature denoted by T_e.

- It is defined as the fractional temperature at the input of antenna which accounts for fractional noise at output.
- The noise figure F is related to the effective noise temperature T_e by

$$\boxed{F = 1 + \frac{T_e}{T_0}} \quad \text{— (1)}$$

T_e = Effective noise temperature in K
T_0 = Room temperature ($273^\circ + 17^\circ$)
= 290 K.
F = Noise figure.

simplifying

$$F - 1 = \frac{T_e}{T_0} \quad \text{— (2)}$$

$$T_e = (F-1)\,T_0 \quad \text{— (3)}$$

From (1) F in dB

$$\boxed{F_{(in\ dB)} = 10 \log_{10} F}$$

<u>Radiation Resistance</u> :- It is denoted by (R_{rad}) :

In general, an antenna radiates power into free space in the form of electromagnetic wave

so $P_{rad} = I^2 R$ — (1).

- Assuming all the power dissipated in the form of EM waves

M-1-15

fraun

then $R = \frac{P_{rad}}{I^2}$ — (2)

— The resistance which relates power radiated by radiating antenna and the current flowing through the antenna fictious resistance. such resistance is called "radiation resistance" of an antenna and it is denoted by R_{rad} or R_a or R_0

Note: The Radiation resistance is a fictitious resistance such that when it is connected in series with antenna dissipates same power as the antenna actually radiates.

— practically there are certain radiation losses due to the loss resistance denoted by R_{loss}

— Thus the total power $P = P_{rad} + P_{loss}$

Radiation loss + ohmic loss

$P = I^2 R_{rad} + I^2 . R_{loss}$

$$\boxed{P = I^2 (R_{rad} + R_{loss}) \quad \text{— (3)}}$$

The Radiation Resistance of an antenna depends on :-

1. Antenna Configuration
2. Length and diameter ratio of Conductor used
3. Location of the antenna w.r.p to ground
4. Other Objects.

Radiation Efficiency:-

Power Gain $[G_p(\theta, \phi)]$ and Radiation (or Antenna) Efficiency

– If the practical antenna has ohmic losses (I^2R) represented by P_{loss}, then the P_{rad} is < the i/p power P_{in}.

$$P_{rad} = \eta_r \cdot P_{in} \quad —(1)$$

$P_{rad} < P_{in}$

η_r = Radiation Efficiency

$P_{rad} = \eta_r P_{in}$

$$\eta_r = \frac{P_{rad}}{P_{in}} \quad —(2)$$

$\eta_r = \frac{P_{rad}}{P_{in}}$

$P_{in} = P_{loss} + P_{rad}$

P_{in} = Total input power to the antenna

$$P_{in} = P_{rad} + P_{loss}.$$

$P_{in} = P_{rad} + P_{loss}$

$$\therefore \eta_r = \frac{P_{rad}}{P_{rad} + P_{loss}}.$$

P_{rad} and the P_{loss} can be expressed in terms of r.m.s. current as

$$P_{rad} = I^2_{rms} \cdot R_{rad}$$

$$P_{loss} = I^2_{rms} \cdot R_{loss}.$$

$P_{rad} = \eta_r P_{in}$

$\eta_r = \frac{P_{rad}}{P_{in}}$

$P_{rad} = I^2_{rms}(R_{rad})$

$P_{loss} = I^2_{rms} R_{loss}$

$$\eta_r = \frac{I^2_{rms} \cdot R_{rad}}{I^2_{rms}[R_{rad} + R_{loss}]}$$

$\eta_r = \frac{P_{rad}}{P_{rad} + P_{loss}}$

$$\boxed{\eta_r = \frac{R_{rad}}{(R_{rad} + R_{loss})}}$$

N-1-16

- The Ratio of the power radiated in a particular direction (θ, ϕ) to the actual power input to the antenna is called power gain.
- It is denoted by $G_p(\theta, \phi)$

$$G_p(\theta, \phi) = \frac{P_d(\theta, \phi)}{P_{in}} \left\{ \frac{\text{max. rad. intensity}}{\text{rad. due to isotropic radiator}} \right\}$$

- The Maximum power gain can be defined as the ratio of the maximum radiation intensity to the radiation intensity due to Isotropic lossless antenna.

$$\boxed{G_{pmax} = \frac{\text{Maximum Radiation Intensity}}{\text{Radiation Intensity due to Isotropic lossless antenna.}}}$$

$$\therefore G_{pmax} = \frac{U_{max}}{\left(\frac{P_{in}}{4\pi}\right)}$$

$$U_{max} = \frac{P_{rad}}{4\pi} G_{Dmax} = \frac{(\eta_r P_{in})}{4\pi} \cdot G_{Dmax}$$

$$= \frac{(\eta_r \cdot P_{in})}{4\pi} D$$

Substituting Value of U_{max}

$$G_{pmax} = \frac{\frac{(\eta_r \cdot P_{in}) \cdot D}{4\pi}}{\left(\frac{P_{in}}{4\pi}\right)}$$

$$= \eta_r \cdot \left(\frac{P_{in}}{4\pi}\right) D$$

max power gain $\left(\frac{P_{in}}{4\pi}\right)$ directivity. P_{rad} | $P_{rad} + P_{loss}$. (radiation efficiency) max. directive gain

$$\boxed{G_{pmax} = \eta_R \, \eta_r \cdot D = \eta_r G_{Dmax}}$$

— Generally both power gain and the directional gain are expressed in dB.

Antenna Field Zones :

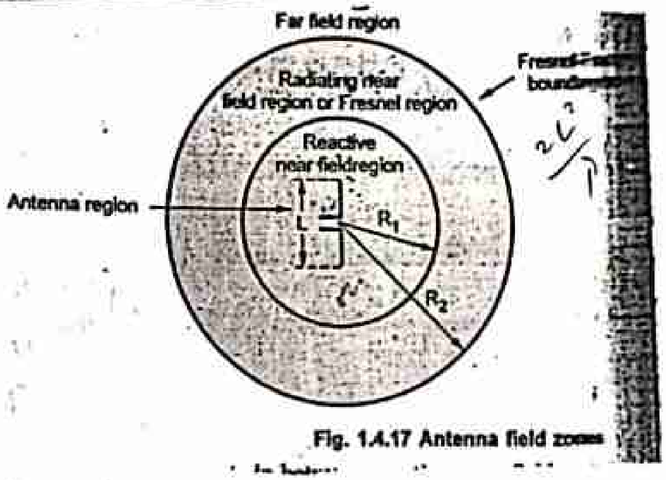


Fig. 1.4.17 Antenna field zones

There are mainly two principle regions or Zones of the antenna fields namely near field or Fresnel region and Far field or Fraunhofer region.

→ The near field region may be further classified as a) Reactive near field region
b) Radiating near field region.

Reactive Near field Region :

This region is the portion of near field region very close to antenna where the reactive

M-1-17

field is dominating.

- For most of the antenna used, the boundary of reactive near field exists $\boxed{R < 0.62\sqrt{\frac{L^3}{\lambda}}}$

L - Largest dimension of antenna

But for the short dipole, the boundary exists at $R < \frac{\lambda}{2\pi}$

Radiating near field or Fresnel region.

- The region exists in between reactive field and far field regions
- For this region, the distance from the antenna is taken to be $\boxed{0.62\sqrt{\frac{L^3}{\lambda}} \le R < \frac{2L^2}{\lambda}}$
- In this region radiating field dominates reactive field. Also the antenna patterns starts taking shape in this region but it is not completed. The distance from the antenna decides the angular field distribution.
- This region may not exist if the maximum dimension of antenna is not large compared to the wavelength. $L \neq \lambda$

Far Field or Fraunhofer region:

- The angular field distribution is independent of distance from antenna.
- The boundary for this region exists at $R_2 = \frac{2L^3}{\lambda}$

$R_2 = \frac{2L^3}{\lambda}$

- In this region, the radiation pattern is completely formed. The electric and magnetic field vectors are orthogonal to each other and the wavefront becomes planar approximately.

Principles of Reciprocity:-

Statement: If an emf is applied to the terminals of an antenna A and the current measured at the terminals of another antenna B, then an equal current (in both amplitude and phase) will be obtained at the terminals of antenna A if the same emf is applied to the terminals of antenna B.

It is assumed that the emfs are of the same frequency and that the media are linear, passive and also isotropic.

- An important consequence of this theorem is that fact that under these conditions the transmitting and receiving patterns of an antenna are the same.
- Also, for matched impedances, the power flow is the same either way.

An illustration of the reciprocity theorem for antennas, consider the following two cases:

M-1-18

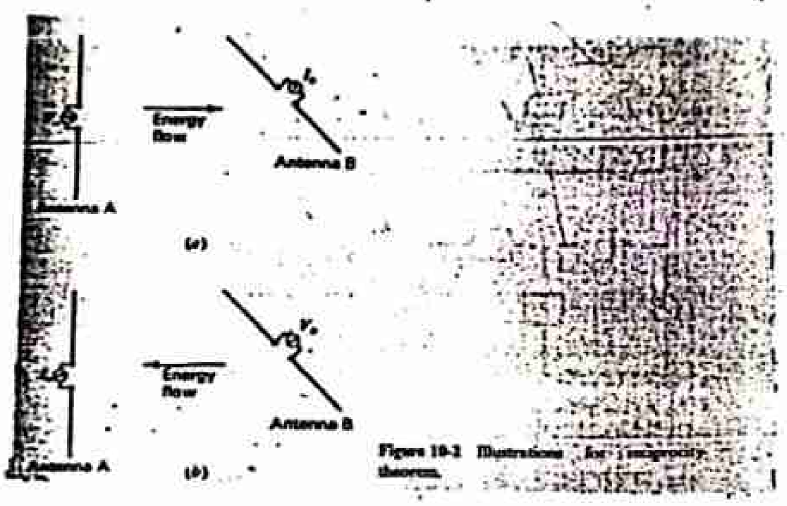


Figure 10-2 Illustrations for reciprocity theorem.

Case1: Let an Emf Va be applied to the terminals of antenna A as shown in fig (a), This antenna acts as a Txing antenna, and energy flows from it to antenna B, which may be considered as Rxing antenna, producing a current I_b at its terminals.

- Assume that the generator and ammeter impedances are equal.

case 2: If an emf V_b is applied to the terminals of antenna B, then it acts as a transmitting antenna and energy flows from it to antenna A as in fig b. producing a current Ia at its terminals.

Now If $V_b = V_a$, then by the reciprocity theorem
$I_a = I_b$.

→ The Ratio of an emf to a current is an impedance

→ case I: $\frac{V_a}{I_b}$ — Transfer Impedance ; Z_{ab}

→ case 2 : $\frac{V_b}{I_a}$ → Transfer Impedance ; Z_{ba}.

∴ According to Reciprocity Theorem.

$$\frac{V_a}{I_b} = Z_{ab} = Z_{ba} = \frac{V_b}{I_a} \quad \text{——} \quad (1).$$

Proof : 1. Let the antenna and the space between them replaced by a n/w of linear, passive, bilateral impedances.

2. Any 2-terminal n/w can be reduced to an equivalent T, the antenna arrangement of case 1 can be replaced by the n/w of fig below a

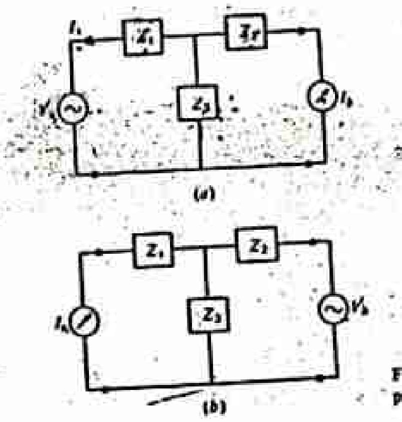


Figure 10-3 Equivalent circuits used in proof of reciprocity theorem.

M-1- 19

The current through the meter.

$$I_b = I_1 \cdot \frac{Z_3}{Z_2 + Z_3} \quad -(2)$$

where $V_a \ni I_1 = \dfrac{V_a}{Z_1 + [Z_2 Z_3 / (Z_2 + Z_3)]}$

$$= \frac{V_a (Z_2 + Z_3)}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1} \quad -(3)$$

→ (3) into (2)

$$I_b = \frac{V_a \cdot (Z_2 + \cancel{Z_3})}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1} \cdot \frac{Z_3}{(\cancel{Z_2 + Z_3})}$$

$$I_b = \frac{V_a \cdot Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 \cdot Z_1} \quad -(4)$$

→ If the location of the emf and current meter are interchanged as in fig (b) we obtain

$$I_a = \frac{V_b \cdot Z_3}{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1} \quad -(5)$$

comparing (4) and (5), it follows that if $V_a = V_1$ then $I_a = I_b$

∴ Hence the proof

Duality of Antennas :-

The duality of an antenna, as a circuit device on the one hand and a space device on the other i illustrated schematically in fig shown in below

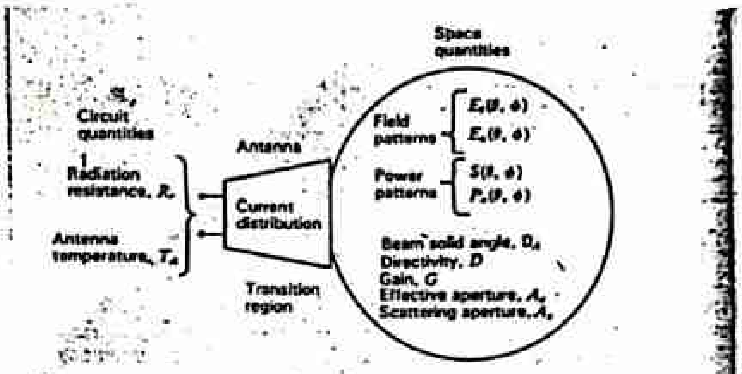


Figure 2-18 Schematic diagram of basic antenna parameters, illustrating the duality of an anten a circuit device (with a resistance and temperature) on the one hand and a space device (with ation patterns, beam angles, directivity, gain and aperture) on the other.

N-1-20

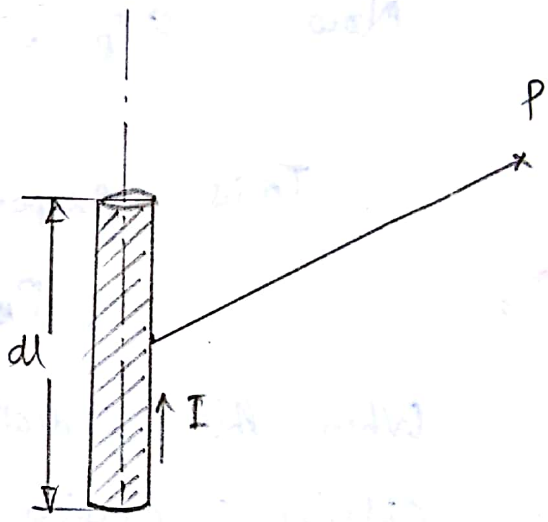
Retarded potentials

A vector potential expression denotes the exact position of potential due to various current elements (I dl), at a point P at a distance r from the centre point as shown in fig. Therefore if the expression for vector potential is calculated it follows that potential due to various current elements are added up.

Let I be instantaneous current in elements and is a sinusoidal function of time.

$I = I_m \sin \omega t$

Here the assumption made is that the field effects superposed at time 't' all



Current element

Static from current elements of same value of current and time. Here the finite time of propagation has been ignored. (8)

Actually the field effect reaching a distant point 'p' from a given current element at an instant t is due to a current value at an earlier instant. i.e. Retardation time.

Then the retarded current

$$[I] = I_m \sin\omega\,(t - r/c)$$

where c = velocity of ~~light~~ propagation
r = distance from current element to the point p.

we know vector potential $A = \int \frac{\mu J\,dv}{4\pi r}$.

retarded VP ; $[A] = \frac{\mu}{4\pi}\int \frac{J\,[t - r/c]}{r}\,ds.\,dl.$

$$= \frac{\mu}{4\pi}\int \frac{I\,(t - r/c)}{r}\,dl$$

for Sinusoidal current element

$$[A] = \frac{\mu}{4\pi}\int \frac{I_m \sin\omega\,(t - r/c)\,dl}{r}.$$

For retarded vector potential along z direction V.P along x & y is zero

$$A_z = \frac{\mu}{4\pi}\int_{-l/2}^{l/2} (I/r)\,dz = \frac{\mu}{4\pi}\int_{-l/2}^{l/2} \frac{I_m e^{j\omega(t - r/c)}}{r}\,dz$$

$$A_z = \frac{\mu I_m L}{4\pi r}\,e^{j\omega(t - r/c)}$$

Dipole Antenna

A dipole antenna may be defined as ~~that~~ a symmetrical antenna in which the two ends are at equal potential relative to mid point.

A $\lambda/2$ antenna is the fundamental radio antenna of metal rod which has a physical length of half wave length in free space at the frequency of operation. It is also known as Hertz antenna or Half wave doublet.

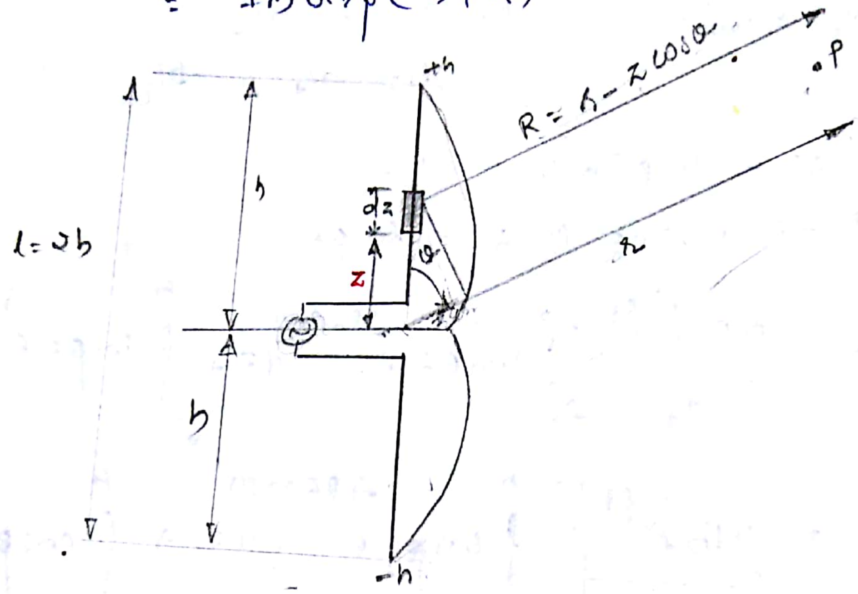
Radiation from a half wave dipole.

The dipole is usually feed at the centre having maximum current at the centre & maximum radiation in the plane normal to the axis.

Here Sinusoidal current distribution is assumed

$$I = I_m \sin\beta(h-z) \quad \text{for} \quad z>0$$
$$= I_m \sin\beta(h+z) \quad \text{for} \quad z<0.$$

$\beta = \frac{\omega}{c} = \frac{2\pi}{\lambda}$



Now vector potential at a distant point P due to current element Idz is given by

$$dA_z = \frac{\mu I dz.\, e^{-j\beta R}}{4\pi R}.$$

Vector potential due to all such current elements is given by

$$\int dA_z = \int_{-h}^{0} \frac{\mu I dz.\, e^{-j\beta R}}{4\pi R} + \int_{0}^{+h} \frac{\mu I dz.\, e^{-j\beta R}}{4\pi R}$$

$$A_z = \frac{\mu}{4\pi}\int_{-h}^{0} \frac{I_m \sin\beta(h+z).\, e^{-j\beta R}}{R}\, dz + \frac{\mu}{4\pi}\int_{0}^{+h} \frac{I_m \sin\beta(h-z)\, e^{-j\beta R}}{R}.\, dz$$

$R = r - z\cos\theta$

$R \cong r$

$$\therefore A_z = \frac{\mu}{4\pi r}\int_{-h}^{0} I_m \sin\beta(h+z)\, e^{-j\beta(r-z\cos\theta)} .dz + \frac{\mu}{4\pi r}\int_{0}^{h} I_m \sin\beta(h-z)\, e^{-j\beta(r-z\cos\theta)} .dz$$

$$\because e^{-j\beta(r-z\cos\theta)} = e^{-j\beta r}.\, e^{j\beta z\cos\theta}$$

$$A_z = \frac{\mu I_m e^{-j\beta r}}{4\pi r}\left[\int_{-h}^{0} \sin\beta(h+z)\, e^{j\beta z\cos\theta} \cdot dz + \int_{0}^{h} \sin\beta(h-z)\, e^{j\beta z\cos\theta} \cdot dz\right]$$

for $\lambda/2$ antenna $\quad l = 2h = \lambda/2$

$$\boxed{h = \lambda/4 = \pi/2}$$

$\lambda/4 = \pi/2$

$$\sin\beta(h+z) = \sin\beta(h-z)$$

$$\sin\beta(\pi/2+z) = \sin\beta(\pi/2-z) = \cos\beta z$$

$$\therefore\ A_z = \frac{\mu I_m e^{-j\beta r}}{4\pi r}\left[\int_{-h}^{0} \cos\beta z\, e^{j\beta z\cos\theta}\, dz + \int_{0}^{h} \cos\beta z\, e^{j\beta z\cos\theta} \cdot dz\right]$$

$$= \frac{\mu I_m e^{-j\beta r}}{4\pi r}\left[\int_{0}^{h} \cos\beta z\, e^{-j\beta z\cos\theta} \cdot dz + \int_{0}^{h} \cos\beta z\, e^{j\beta z\cos\theta} \cdot dz\right]$$

$$= \frac{\mu I_m e^{-j\beta r}}{4\pi r}\left[\int_{0}^{h} \cos\beta z \left\{ e^{+j\beta z\cos\theta} + e^{-j\beta z\cos\theta}\right\} dz\right]$$

$$A_z = \frac{\mu I_m e^{-j\beta r}}{4\pi r}\left[\int_{0}^{h} \cos\beta z \left\{ 2\cos(\beta z\cos\theta)\right\} dz\right]$$

$$\because\ 2\cos A\cos B = \cos(A-B) + \cos(A+B)$$

$$A_z = \frac{\mu I_m e^{-j\beta r}}{4\pi r}\left[\int_{0}^{\lambda/4} \cos\{\beta z(1+\cos\theta)\} + \cos\{\beta z(1-\cos\theta)\}\, dz\right]$$

$$= \frac{\mu I_m e^{-j\beta r}}{4\pi r}\left[\frac{\sin\{\beta z(1+\cos\theta)\}}{\beta(1+\cos\theta)} + \frac{\sin\{\beta z(1-\cos\theta)\}}{\beta(1-\cos\theta)}\right]_0$$

$$= \frac{\mu I_m e^{-j\beta r}}{4\pi r\beta}\left[\frac{(1-\cos\theta)\sin\beta z(1+\cos\theta) + (1+\cos\theta)\sin\beta z(1-\cos\theta)}{(1+\cos\theta)(1-\cos\theta)}\right]_0$$

$\beta = \frac{2\pi}{\lambda}$

$$\beta z = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{4} = \frac{\pi}{2}$$

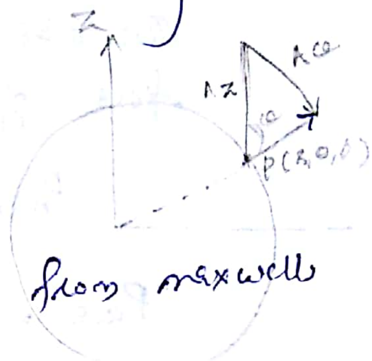
$$A_z = \frac{\mu I_m e^{-j\beta r}}{4\pi\beta r}\left[\frac{(1-\cos\alpha)\sin(\pi/2 + \pi/2\cos\alpha) + (1+\cos\alpha)\sin(\pi/2 - \pi/2\cos\alpha)}{1-\cos^2\alpha}\right]$$

$$= \frac{\mu I_m e^{-j\beta r}}{4\pi\beta r}\left[\frac{(1-\cos\alpha)\cos(\pi/2\cos\alpha) + (1+\cos\alpha)\cos(\pi/2\cos\alpha)}{\sin^2\alpha}\right]$$

$$= \frac{\mu I_m e^{-j\beta r}}{4\pi\beta r}\left[\frac{\cos(\pi/2\cos\alpha)\left[1 - \cancel{\cos\alpha} + 1 + \cancel{\cos\alpha}\right]}{\sin^2\alpha}\right]$$

$$A_z = \frac{\mu I_m e^{-j\beta r}}{2\pi\beta r}\left[\frac{\cos(\pi/2\cos\alpha)}{\sin^2\alpha}\right]$$

$A_\alpha = -A_z \sin\alpha$



But for a current element along z axis from maxwells eqn

$$\nabla \times A = \mu H$$

$$\mu H_\phi = (\nabla \times A)_\phi = 1/r\left[\frac{\partial}{\partial r}(A_\alpha \cdot r)\right] = 1/r\left[\frac{\partial}{\partial r}(-A_z\sin\alpha \cdot r)\right]$$

$$\mu H_\phi = -\frac{\sin\alpha}{r}\frac{\partial A_z}{\partial r}\cdot r$$

$$\mu H_\phi = -\frac{\sin\alpha}{r}\frac{\partial}{\partial r}\left[\frac{\mu I_m e^{-j\beta r}}{2\pi\beta \cancel{r}}\left\{\frac{\cos(\pi/2\cos\alpha)}{\sin^2\alpha}\right\}\cdot \cancel{r}\right]$$

$$= -\frac{\mu I_m e^{-j\beta r}}{2\pi\beta r}(-j\beta)\cdot\left\{\frac{\cos(\pi/2\cos\alpha)}{\sin\alpha}\right\}.$$

$$H_\phi = j\frac{I_m e^{-j\beta r}}{2\pi r}\left\{\frac{\cos\pi/2\cos\alpha}{\sin\alpha}\right\}$$

$$|H_\phi| = \frac{I_m}{2\pi r}\left\{\frac{\cos\pi/2\cos\alpha}{\sin\alpha}\right\}. \quad \text{Ampere/metre}^2$$

This is the magnetic field intensity expression for dipole

$$\frac{E_\theta}{H_\phi} = \eta = 120\pi$$

$$|E_\theta| = 120\pi \, |H_\phi|$$

$$= 120\pi \frac{I_m}{2\pi r} \left\{ \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \right\}$$

$$= \frac{60 I_m}{r} \left\{ \frac{\cos\frac{\pi}{2}\cos\theta}{\sin\theta} \right\} \text{ volt/meter}$$

This is the expression for electric field intensity for radiation field of $\lambda/2$ antenna or $\lambda/4$ monopole.

$$P_{max} = |E_\theta||H_\phi|$$

$$P_{avg} = \frac{E_\theta}{\sqrt{2}} \cdot \frac{H_\phi}{\sqrt{2}} = \frac{1}{2} E_\theta \cdot H_\phi = \frac{P_{max}}{2}.$$

$$= \frac{1}{2} \frac{I_m}{2\pi r} \cdot \frac{60 I_m}{r} \left\{ \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \right\}^2$$

$$= \frac{15 I_m^2}{\pi r^2} \left\{ \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \right\}^2$$

$\sqrt{2} \cdot I_{rms} = I_m.$

$$= \frac{15 \left(\sqrt{2} I_{rms}\right)^2}{\pi r^2} \left\{ \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \right\}^2$$

$$P_{avg} = \frac{30 I_{rms}^2}{\pi r^2} \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin^2\theta} \quad W/m^2$$

Radiation Resistance of a Half wave dipole

$$W = \oint_s P_{avg} \cdot ds = \int_0^{\pi} \frac{30 I_{rms}^2}{\pi r^2} \left\{ \frac{\cos^2(\pi/_2 \cos\theta)}{\sin\theta} \right\} 2\pi r^2 \sin\theta \, d\theta$$

$$= 60 I_{rms}^2 \int_0^{\pi} \frac{\cos^2(\pi/_2 \cos\theta)}{\sin\theta} d\theta$$

$\because 2\cos^2\theta = 1 + \cos 2\theta$

$$W = 60 I_{rms}^2 \int_0^{\pi} 1/_2 \left\{ \frac{1+\cos(\pi \cos\theta)}{\sin\theta} \right\} d\theta$$

$$= 60 I_{rms}^2 \cdot I \qquad \text{where } I = \frac{1}{2}\int_0^{\pi} \frac{1+\cos(\pi\cos\theta)}{\sin\theta} d\theta$$

$$= 60 I_{rms}^2 \times 1.219$$

$I = 1.219$ by Simpson's rule or Trapezoidal rule.

$$= 73.140 \, I_{rms}^2$$

$$R_r = \frac{W}{I_{rms}^2} = 73.140$$

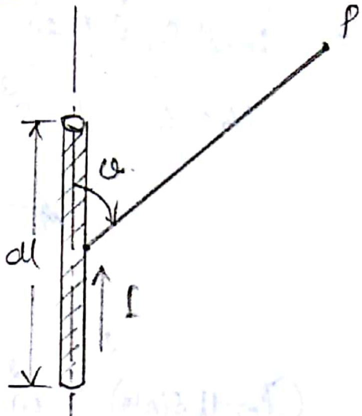
$$\simeq 73$$

Radiation from quarter wave monopole

The quarter wave monopole consists of one half of a half wave dipole antenna located on a conducting ground plane. The monopole antenna $\perp^r$ to the plane which is usually assumed to be infinite & perfectly conducting.

Using image theory, perfectly conducting ground plane is replaced with image of monopole

Power Radiated & Radiation Resistance of Current Element



If an infinitesimal dipole has infinitesimally small length (dl) and current I, then Idl is called current element.

Since $I = I_m \sin\omega t$

Current element $I\,dl = I_m dl \sin\omega t$

When a current starts to flow in one direction, one half of the dipole acquires an excess charge and other half a deficit, thereby causing a potential difference b/w two halves of dipole. When direction of current changes, first charge imbalance is neutralized and then changed. Thus the oscillating current results in oscillating voltage & vice versa. As electric charge oscillates in such a short dipoles, they may be called as oscillating electric dipoles.

By poynting theorem power flow in radial component is given by $P_{av} = \bar{E}_\theta \times \bar{H}_\phi$

$$P_{av} = \left[\frac{I_m dl \sin\theta}{4\pi\varepsilon} \left\{ \frac{-\omega \sin\omega t_1}{c^2 r} + \frac{\cos\omega t_1}{c r^2} + \frac{\sin\omega t_1}{\omega r^3} \right\} \right] \cdot$$

$$\left[\frac{I_m dl \sin\theta}{4\pi} \left\{ \frac{-\omega \sin\omega t_1}{c r} + \frac{\cos\omega t_1}{r^2} \right\} \right]$$

$$= \left[\frac{(I_0 dl \sin\alpha)^2}{16\pi^2\varepsilon} \left\{ \frac{-\omega \sin\omega t_1}{c^2 r} + \frac{\cos\omega t_1}{c r^2} + \frac{\sin\omega t_1}{\omega r^3} \right\} \left(\frac{-\omega\sin\omega t_1}{c r} + \frac{\cos\omega t_1}{r^2} \right. \right.$$

$$= \frac{(I_0 dl \sin\alpha)^2}{16\pi^2\varepsilon} \left\{ \frac{\omega^2 \sin^2\omega t_1}{c^3 r^2} - \frac{\omega \sin\omega t_1 . \cos\omega t_1}{c^2 r^3} - \frac{\omega \sin\omega t_1 . \cos\omega t_1}{c^2 r^3} + \frac{\cos^2\omega t_1}{c r^4} \right.$$

$$\left. - \frac{\cancel{\omega}\sin^2\omega t_1}{\cancel{\omega} c r^4} + \frac{\sin\omega t_1 \cos\omega t_1}{\omega r^5} \right\}.$$

$$= \frac{(I_0 dl \sin\alpha)^2}{16\pi^2\varepsilon} \left\{ \frac{\omega^2 \sin^2\omega t_1}{c^3 r^2} - \frac{2\omega \sin\omega t_1 \cos\omega t_1}{c^2 r^3} + \frac{\cos^2\omega t_1 - \sin^2\omega t_1}{c r^4} + \frac{\sin 2\omega t_1}{2 . \omega r^5} \right\}.$$

$$= \frac{(I_0 dl \sin\alpha)^2}{16\pi^2\varepsilon} \left\{ \frac{\omega^2 \sin^2\omega t_1}{c^3 r^2} - \frac{\omega \sin 2\omega t_1}{c^2 r^3} + \frac{\cos 2\omega t_1}{c r^4} + \frac{\sin 2\omega t_1}{2 . \omega r^5} \right\}$$

$$= \frac{(I_0 dl \sin\alpha)^2}{16\pi^2\varepsilon} \left\{ \frac{\omega^2}{c^3 r^2} \left(\frac{1-\cos 2\omega t_1}{2} \right) - \frac{\omega \sin 2\omega t_1}{c^2 r^3} + \frac{\cos 2\omega t_1}{c r^4} + \frac{\sin 2\omega t_1}{2 . \omega r^5} \right.$$

$$P_{avg} = \frac{(I_0 dl \sin\alpha)^2}{16\pi^2\varepsilon} \left\{ \frac{\omega^2}{2 c^3 r^2} + \text{terms of } (\sin 2\omega t_1 \text{ \& } \cos 2\omega t_1) \right\}$$

Average value of $\cos 2\omega t_1$ and $\sin 2\omega t_1$ over a complete cycle is zero. then

$$P_{avg} = \frac{(I_0 dl \sin\alpha)^2}{16\pi^2\varepsilon} \cdot \frac{\omega^2}{2 c^3 r^2}$$

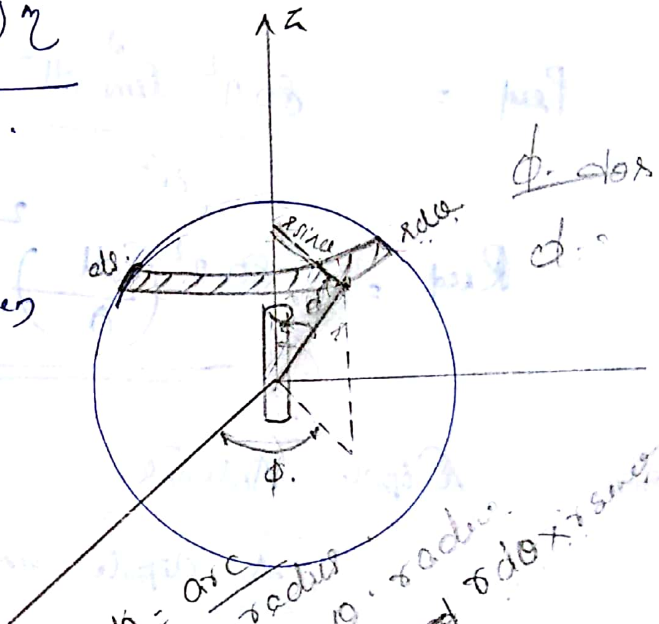
$$P_{av} = \frac{(I_m dl \sin\theta)^2}{16\pi^2 \varepsilon} \cdot \frac{(2\pi f)^2}{2c^3 r^2} = \frac{I_m dl \sin\theta}{4\varepsilon} \cdot \frac{f^2}{2c^3 r^2}$$

$$= \frac{(I_m dl \sin\theta)^2 f^2}{8\varepsilon c^3 r^2} \quad ; \quad \text{put } \frac{f^2}{c^2} = \frac{1}{\lambda^2}$$

$$= \frac{(I_m dl \sin\theta)^2}{8\varepsilon \lambda^2 c r^2} \quad ; \quad \text{put } \eta = \frac{1}{c\varepsilon}.$$

thus

$$P_{av} = \frac{(I_m dl \sin\theta)^2 \eta}{8\lambda^2 r^2}.$$



Power radiated (P_{rad}) is given by the surface integral of radial poynting vector over surrounding surface.

$\phi = \frac{arc}{radius}$

$arc = \theta \cdot radius$

$dS = r d\theta \times r \sin\theta$

$$dS = 2\pi (r \sin\theta) r \, d\theta.$$

$$= 2\pi r^2 \sin\theta \, d\theta$$

$$P_{rad} = \int_0^\pi P_{avg} \cdot dS = \int_0^\pi P_{avg} \cdot 2\pi r^2 \sin\theta \, d\theta$$

$$= \int_0^\pi \frac{(I_m dl \sin\theta)^2 \eta}{8\lambda^2 r^2} \cdot 2\pi r^2 \cdot \sin\theta \, d\theta$$

$$= \int_0^\pi \frac{I_m^2 dl^2}{8\lambda^2 r^2} \cdot \eta \, 2\pi r^2 \sin^3\theta \, d\theta$$

$$= \frac{I_m^2 dl^2}{8\lambda^2 r^2} \cdot \eta \, 2\pi r^2 \cdot \int_0^\pi \sin^3\theta \, d\theta$$

$$= \eta \frac{(I_m dl)^2 \pi}{4\lambda^2} \int_0^\pi \sin^3\theta \, d\theta$$

$$= \frac{\eta (I_m dl)^2 \pi}{4 \lambda^2} \cdot 2 \int_0^{\pi/2} \sin^3 a \cdot da.$$

Using Willi's formula

$$\int_0^{\pi/2} \sin^n a \, da = \frac{n-1}{n}$$

$$= \frac{\eta (I_m dl)^2 \pi}{2 \lambda^2} \cdot \frac{(3-1)}{3}$$

$$= \eta \frac{120 \pi^2 I_m^2 dl^2 \times 2}{6 \lambda^2} = \frac{40 \pi^2 (\sqrt{2} \cdot I_{rms})^2 dl^2}{\lambda^2}$$

$$P_{rad} = \frac{80 \pi^2 I_{rms}^2 dl^2}{\lambda^2}$$

$$\because R_{rad} = \frac{P_{rad}}{I_{rms}^2}$$

$$R_{rad} = 80 \pi^2 \left(\frac{dl}{\lambda}\right)^2 \Omega$$

Antenna Arrays.

The field radiated by small linear antenna is non uniformly distributed in the plane ⊥ to the axis of antenna. Non uniform radiation pattern is preffered in many broadcast services but not desirable in point to point services.

The field strengths can be increased in preffered directions by group or array of antennas simultaneously.

Array of antennas is an arrangement of several individual antennas so spaced and phased and their individual contributions coming in one preffering direction is added up and cancel in all other direction to get greater directive gain or directivity.

An antenna array is a system of similar antennas oriented similarly to get greater directivity in desired direction.

A radiating sm consisting of several several spaced and phased directors.

Antenna array is the common method of combining the radiations from a group of array of similar antennas in which phenomenon of wave interference is involved. The total field produced by an antenna array sm at a great distance from it is the vector

Sum of the fields produced by the individual antennas of the array system. The relative phases of individual field components depend on the relative distance of the individual antennas of the array and in turn depends on directions.

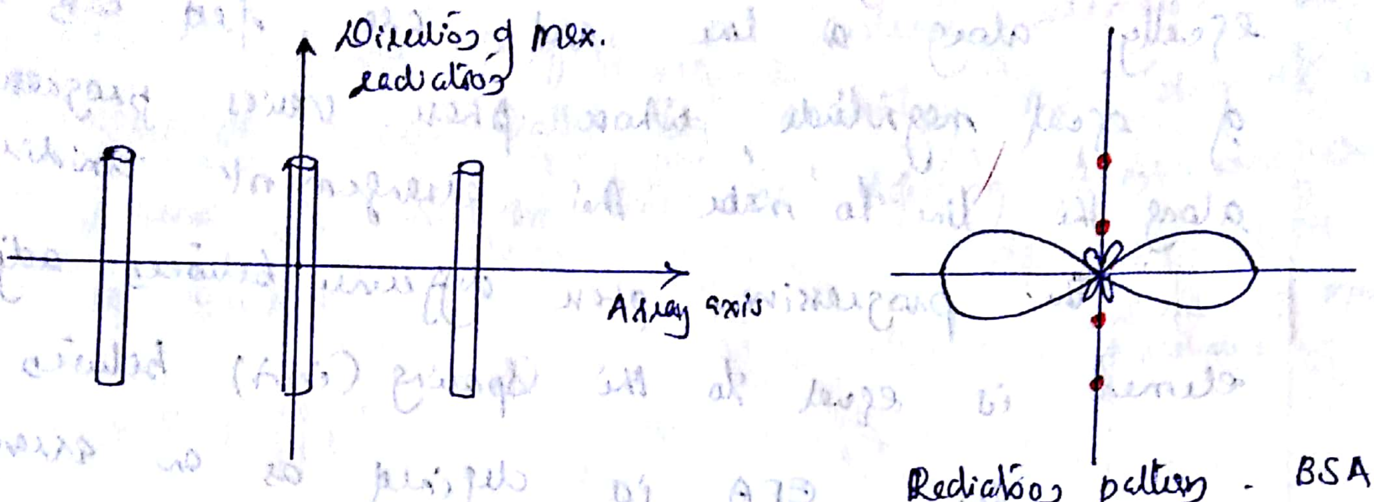
Antenna array is said to be linear if the individual antennas of array are equally spaced along the straight line. Individual antennas of array is termed as ELEMENTS.

A uniform linear array is one in which the elements are fed with a current of equal magnitude with uniform progressive phase shift along the line. The element in a multi element is generally a $\lambda/2$ dipole antenna.

Various forms of Array.

* Broad side array
* End fire Array
* Co linear array
* parasitic array.

Broad Side Array



Broad Side array is one in which a number of identical parallel antennas are set up along a line drawn $\perp^r$ to their axis.

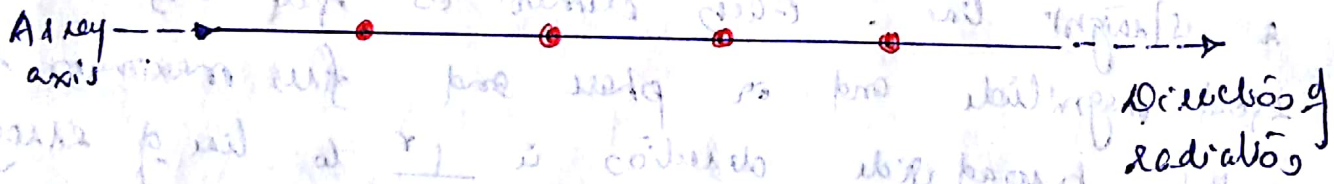
Here the antenna elements are equally spaced along a straight line. Each element is fed with currents of equal magnitude and in phase and fires maximum radiation in the broad side direction i.e $\perp^r$ to line of array axis. as the radiation in other directions is relatively very small, the pattern is bidirectional.

The bidirectional pattern can be converted into unidirectional one by installing an identical array behind this array at a distance of quarter wavelength from it and exiting by a current leading in phase by $\pi/2$ or $90°$.

End fire Array

This arrangement is same as that of BSA except that the individual elements are fed with currents out of phase by $180°$. In this arrangement a number of identical elements are spaced equally along a line and are fed with currents of equal magnitude, whose phase varies progressively along the line to make the arrangement unidirectional. The progressive phase difference between adjacent elements is equal to the spacing (in λ) between them.

The EFA is defined as an arrangement in which the principal direction of radiation coincides with the direction of the array axis.

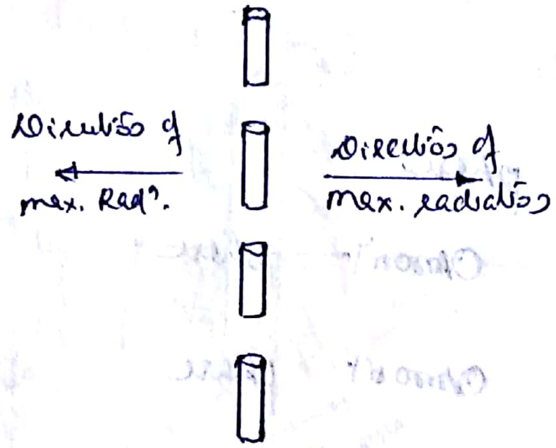


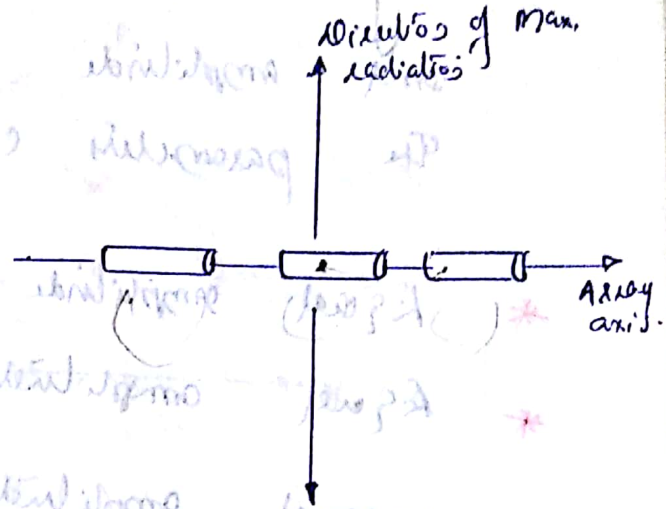
The radiation pattern of EFA can be made bidirectional by a two elements array, fed with currents of equal magnitude but 180° out of phase.

An end fire couplet is said to be formed of two equal radiators operated in phase quadrature with a spacing of quarter wavelength between them.

Co-linear arrays.

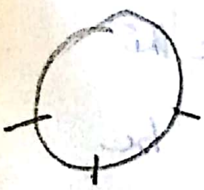
In this category the antenna elements are arranged co-axially by mounting the elements end to end in straight line or stacking them one over another.





Here the individual antenna elements are fed with currents as in BSA.

Its radiation pattern has a circular symmetry with its main lobe at all points perpendicular to the principal axis. Hence a colinear array is also called as broadcast or Omnidirectional array.



Parasitic Arrays.

In this type of arrays the elements are fed parasitically, to reduce problem of feed line. The parasitic element is not fed directly, instead it derives power from the radiation of near by driven element, through electromagnetic coupling because of its proximity to driven element.

Arrays of point Sources

The directivity of point source can be increased by increasing the number of point sources together with various parameters such as phase and amplitude relationship in currents.

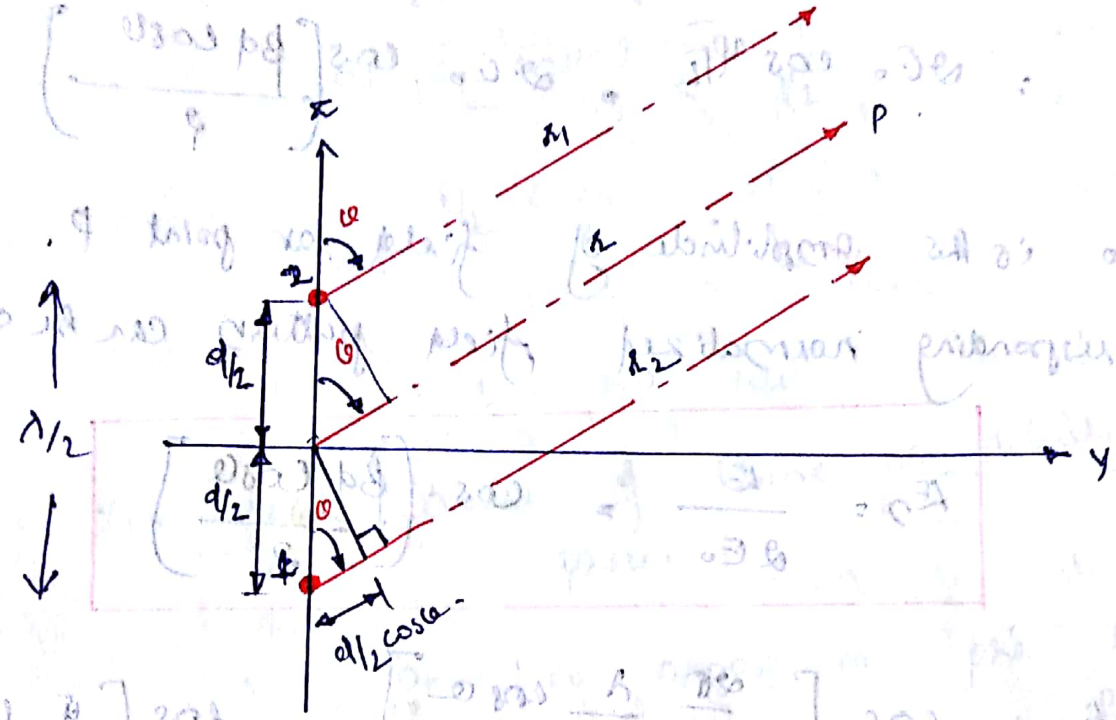
The parameters can be

* Equal amplitude and phase
* Equal amplitude and opposite phase
* unequal amplitude and opposite phase

Two point sources of same amplitude and phase.

Consider two isotropic sources placed symmetrically with respect to origin of z axis and are excited with currents having same amplitude and phase. Let P be the far distant point where total field is to be calculated.

Let E_0 be the strength of E field at point P due to either of point sources, this total field at point P can be calculated by taking vector sum of fields taking into account phase differences arising due to path difference the path difference between the two sources with respect to point P is given by



path difference $= \frac{d}{2}\cos\theta + \frac{d}{2}\cos\theta = d\cos\theta$.

corresponding phase difference can be calculated from relation

phase difference $= \frac{2\pi}{\lambda} \times$ path difference

$$\psi = \frac{2\pi}{\lambda} d\cos\theta = \beta d\cos\theta$$

The local field at point P is given by

$$E = E_0 e^{-j\frac{\psi}{2}} + E_0 e^{+j\frac{\psi}{2}}$$

Here $\psi/2$ is the phase difference at point P due to

On Source axis measurement is w.r.to origin

$$E = E_0\left[e^{-j\psi/2} + e^{j\psi/2}\right] = 2E_0\left[\frac{e^{-j\psi/2} + e^{j\psi/2}}{2}\right]$$

$$= 2E_0 \cos\psi/2 = 2E_0 \cos\left[\frac{\beta d \cos\theta}{2}\right]$$

$2E_0$ is the amplitude of field at point P. The corresponding normalized field pattern can be obtained as

$$\boxed{E_n = \frac{E}{2E_0} = \cos\left[\frac{\beta d \cos\theta}{2}\right]}$$

$$E_n = \cos\left[\frac{\frac{2\pi}{\lambda}\,\frac{\lambda}{2}\cos\theta}{2}\right] = \cos\left[\frac{\pi}{2}\cos\theta\right]$$

Direction of maximum field

$$\cos\left(\frac{\pi}{2}\cos\theta\right) = \pm 1$$

$$\pi/2 \cos\theta = 0$$

$$\cos\theta = 0$$

$$\theta = 90^\circ, 270^\circ$$

Direction of Nulls.

$$\cos\left[\pi/2(\cos\theta)\right] = 0$$

$$\pi/2 \cos\theta = \pm \pi/2$$

$$\cos\theta = \pm 1$$

$$\theta = 0^\circ, 180^\circ$$

Scanned by CamScanner

Half power points :

power is half of maximum value or field power is half of maximum value.

or $\frac{1}{\sqrt{2}}$ of maximum value.

$$\cos\left(\frac{\pi}{2}\cos\theta\right) = \frac{1}{\sqrt{2}}$$

$$\frac{\pi}{2}\cos\theta = \pm \pi/4$$

$$\cos\theta = \pm 1/2$$

$$\theta = 60^\circ, 120^\circ$$

② Two point Sources of Same amplitude But Opposite phase

Source 1 is opposite in phase to source 2.

If there is a maximum value for one field by one source at any point, there will be minimum value of field at that point by the Other Source

The Superposition of field is given by

$$E = E_0 e^{j\psi/2} - E_0 e^{-j\psi/2}$$

$$= E_0\left[e^{j\psi/2} - e^{-j\psi/2}\right]$$

(j represents 90° phase shift)

$$E = j2E_0 \sin(\psi/2) = j2E_0 \sin\left[\frac{\beta d\cos\theta}{2}\right]$$

$$E = 2E_0 \sin\left(\frac{\pi}{\lambda} d\cos\theta\right)$$

Normalized pattern is given by $E_n = \frac{E}{2E_0} = \sin\left(\frac{\pi}{\lambda} d\cos\theta\right)$

for $d = \lambda/2$ normalized pattern becomes

$$E_n = \sin\left(\frac{\pi}{2}\cos\theta\right)$$

Direction of maximum radiation

$$\sin\left(\frac{\pi}{2}\cos\theta\right) = \pm 1$$

$$\frac{\pi}{2}\cos\theta = \pm \frac{\pi}{2}$$

$$\cos\theta = \pm 1$$

$$\theta = 0^\circ, 180^\circ$$

Direction of Nulls.

$$\sin\left(\frac{\pi}{2}\cos\theta\right) = 0$$

$$\frac{\pi}{2}\cos\theta = 0$$

$$\theta = 90^\circ, \cancel{270^\circ}$$

Half power points

$$\sin\left(\frac{\pi}{2}\cos\theta\right) = \pm\frac{1}{\sqrt{2}}$$

$$\frac{\pi}{2}\cos\theta = \pm\frac{\pi}{4}$$

$$\cos\theta = \pm\frac{1}{2}$$

$$\theta = 60^\circ, \pm 120^\circ$$

ii) Two point sources of unequal amplitude and phase

Let us consider a general condition in which the amplitudes of two point sources are not equal and have phase difference δ.

Let E_1 and E_2 be amplitudes of fields at point P. Let δ be the phase angle by which the current source 2 leads by that source 1. Then phase difference b/w the two sources is given by

$$\psi = \frac{2\pi}{\lambda} d\cos\theta + \delta = \beta d\cos\theta + \delta.$$

The resultant field can be written as

$$E = E_1 e^{-j\psi/2} + E_2 e^{+j\psi/2}$$

Further for simplicity let the system be displaced so that the source 1 coincides with origin. Then above eqn becomes

$$E = E_1 e^{j0} + E_2 e^{j\psi} = E_1\left[1 + \frac{E_2}{E_1} e^{j\psi}\right]$$

$$= E_1\left[1 + K e^{j\psi}\right] \qquad , \quad K = \frac{E_2}{E_1}$$

magnitude

$$E = \left| E_1 \left(1 + K(\cos\psi + j\sin\psi)\right)\right|$$

phase

$$E = E_1 \sqrt{(1 + K\cos\psi)^2 + (K\sin\psi)^2}$$

ψ = phase angle at P.

phase angle $\psi = \tan^{-1}\left(\dfrac{K \sin\psi}{1 + K\cos\psi}\right)$

Arrays of Non isotropic Sources. [Principle of Pattern Multiplication]

Non isotropic source is that source which sends more or less radiation in a particular direction. Example for non isotropic source is Hertz dipole.

Non isotropic source provide field pattern similar to isotropic in shape and orientation. It is not necessary that amplitude be equal.

We has already been derived that field at a given far distant point due to two isotropic point sources having phase difference δ as

$$E = 2E_0 \cos\psi/2 \quad ; \quad \psi = \beta d\cos\theta + \delta.$$

For a Hertzian dipole field varies with angle θ

$$E = E_0 \sin\theta$$

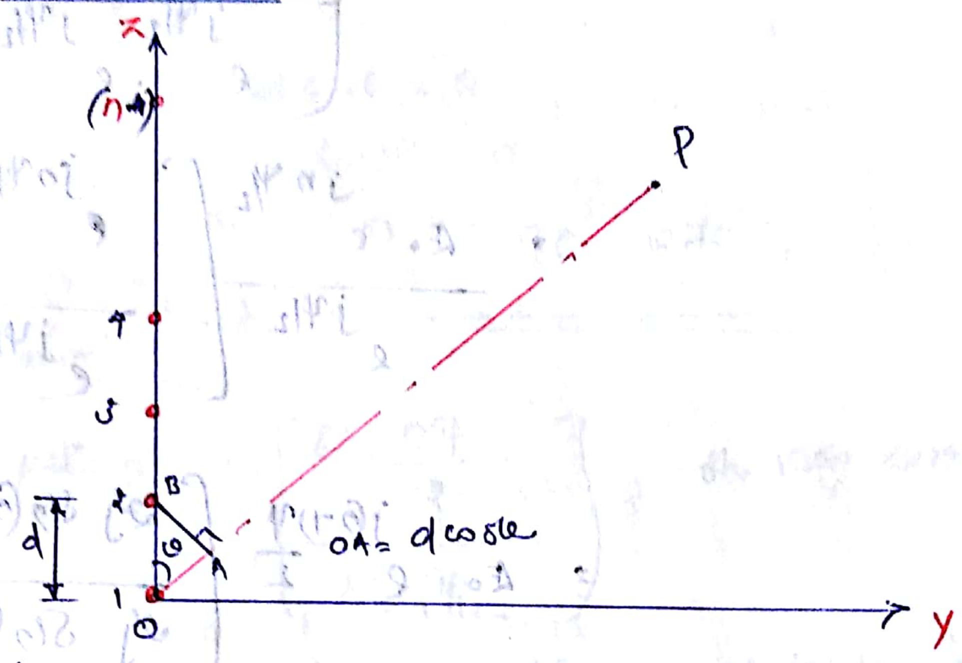
So resultant field for the case of array of non-isotropic sources becomes

$$E = 2E_0 \sin\theta \cdot \cos\psi/2$$

Normalized field pattern $E_n = \dfrac{E}{2E_0} = \sin\theta \cos\psi/2$

E_n = [pattern of individual non isotropic sources] × [pattern of isotropic point sources]

Arrays of n- isotropic point sources of Equal amplitude & spacing



The resultant field at p is given by

$$E = E_0 e^{j0\psi} + E_0 e^{j\psi} + E_0 e^{j2\psi} + \dots + E_0 e^{j(n-1)\psi}.$$

$$E = E_0 \left[e^{j0\psi} + e^{j\psi} + e^{j2\psi} + \dots e^{j(n-1)\psi} \right] \quad \text{—— (1)}$$

xing both side by $e^{j\psi}$

$$E e^{j\psi} = E_0 \left[e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \dots + e^{jn\psi} \right] \quad \text{—— (2)}$$

(2) − (1) ⇒

$$E \left[e^{j\psi} - 1 \right] = E_0 \left[e^{jn\psi} - 1 \right]$$

$$E_0 \left[\frac{e^{jn\psi} - 1}{e^{j\psi} - 1} \right]$$

$$= E_0 \left[\frac{e^{jn\psi/2} \cdot e^{jn\psi/2} - 1}{e^{j\psi/2} \cdot e^{j\psi/2} - 1} \right]$$

$$= \frac{E_0 \, e^{jn\psi/2}}{e^{j\psi/2}} \left[\frac{e^{jn\psi/2} - e^{-jn\psi/2}}{e^{j\psi/2} - e^{-j\psi/2}} \right]$$

$$= E_0 \, e^{j\frac{(n-1)\psi}{2}} \left[\frac{2j \sin(n\psi/2)}{2j \sin(\psi/2)} \right]$$

$$E = E_0 \, e^{j\frac{(n-1)\psi}{2}} \left[\frac{\sin\left(\frac{n\psi}{2}\right)}{\sin \psi/2} \right]$$

$$E = E_0 \, e^{j\phi} \left[\frac{\sin\left(\frac{n\psi}{2}\right)}{\sin \psi/2} \right] \qquad \phi = \frac{(n-1)\psi}{2}$$

If the array is placed symmetrically about origin then

$$E = E_0 \left[\frac{\sin\left(\frac{n\psi}{2}\right)}{\sin(\psi/2)} \right]$$

$$\boxed{AF = \frac{\sin \frac{n\psi}{2}}{\sin \psi/2}}$$

For Broad side Array

Field pattern

For broad side array $\delta = 0$.
$\psi = 0$.

$$\psi = \beta d \cos\theta + \delta$$

$$\psi = \beta d \cos\theta$$

Since sources are in phase

$\psi = 0$. so $\beta d \cos\theta = 0$.

$$\cos\theta = 0$$

$$\theta = 90^\circ, 270^\circ.$$

~~prejous~~ minor. ~~Minor~~ lobe Maximum

Normalized ~~Secondary~~ pattern $= \left[\dfrac{\sin \frac{n\psi}{2}}{\sin \psi/2}\right]$ ~~the secondary maxima~~

Field will be maximum when numerator is maximum i.e

$$\sin\left(\frac{n\psi}{2}\right) = 1$$

$$\frac{n\psi}{2} = \pm(2m+1)\pi/2 \qquad m = 1, 2, 3, \ldots$$

$$\psi = \pm(2m+1)\frac{\pi}{n}.$$

$$\beta d \cos\theta = \pm(2m+1)\pi/n$$

$$\cos\theta = \pm\frac{1}{\beta d}(2m+1)\pi/n$$

Take $n = 4$, $d = \lambda/2$

$$\cos\theta = \pm \frac{1}{\frac{\pi}{2} \times \frac{2}{\pi}} (2m+1)\frac{\pi}{4}$$

$$= \pm \frac{(2m+1)}{4}$$

m can have only value = 1. For higher values $\cos\theta$ becomes greater than 1 which is meaningless.

$$\cos\theta = \pm 3/4$$

$$\theta = \pm 41.4^\circ, \pm 138.6^\circ$$

Minor lobe Minimum

$$\sin\left(\frac{n\psi}{2}\right) = 0$$

$$\frac{n\psi}{2} = \pm m\pi \qquad m = 1, 2, 3 \ldots$$

$$\psi = \pm \frac{2m\pi}{n}$$

$$\beta d \cos\theta = \pm \frac{2m\pi}{n} \qquad n = 4 \quad \& \quad d = \lambda/2$$

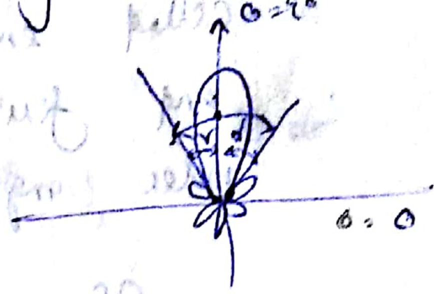
$$\cos\theta = \pm \frac{m}{2} \qquad m = 1$$

$$\cos\theta = \pm 1/2$$

$$\theta = \pm 60^\circ, \pm 120^\circ, 180^\circ, 0^\circ.$$

First Null Beam Width:-

It is the angle b/w first nulls of major lobe or twice the angle b/w first null and major lobe maximum direction.



$$FNBW = 2\gamma = 2\times(90-\theta)$$

Now $\quad \beta d\cos\theta = \pm\frac{2m\pi}{n}$

$\cos\theta = \frac{2m\pi}{\beta d\, n}$

$= \frac{2m\pi}{\frac{2\pi}{\lambda}\cdot d\, n}$

$\cos\theta = \frac{\lambda m}{dn}$

$\cos(90-\gamma) = \frac{\lambda m}{dn}$

$\sin\gamma = \frac{\lambda m}{dn}$

$\gamma = \pm\frac{\lambda}{dn}$

$2\gamma = \pm\frac{2\lambda}{dn}$

$$\theta = \cos^{-1}\left[\pm\frac{1}{\beta d}\cdot\frac{2m\pi}{n}\right]$$

$$= \cos^{-1}\left[\pm\frac{\lambda m}{dn}\right]$$

$$90-\gamma = \cos^{-1}\left[\pm\frac{\lambda m}{dn}\right]$$

$$\cos(90-\gamma) = \pm\frac{\lambda m}{dn} \quad i.e. \quad \sin\gamma = \pm\frac{\lambda m}{dn}$$

γ is very small $\quad \sin\gamma = \gamma$

$m = 1$

$$\therefore \quad \gamma = \pm\frac{\lambda m}{dn}$$

$$\gamma = \pm\frac{\lambda}{dn}$$

$$FNBW = 2\gamma = \pm\frac{2\lambda}{dn}$$

For End fire Array

The line joining the axis of array is called end fire side and this array is called end fire array. For end fire array value of polar angle $\theta = 0°$ or $180°$.

$$\psi = 0 , \quad \theta = 0°$$

i.e.

$$\beta d \cos\theta + \delta = 0$$

$$\psi = \beta d + \delta \Rightarrow \boxed{\psi = \beta d \cos\theta - \beta d}$$

$$\delta = -\beta d = \frac{2\pi}{\lambda} d$$

Direction of Maximum Radiation of Side Lobes

$$\sin \frac{n\psi}{2} = 1$$

$$\frac{n\psi}{2} = \pm \frac{(2m+1)\pi}{2} \qquad m = 1, 2, 3, \ldots$$

~~mere~~ for major lobe maxima

$$\psi = \pm \frac{(2m+1)\pi}{n}$$

$$\beta d \cos\theta - \beta d = \pm \frac{(2m+1)\pi}{n}$$

$$\beta d\left[\cos\theta - 1\right) = \pm\frac{(2m+1)\pi}{n}$$

$$\cos\theta = \pm\frac{1}{\beta d}\frac{(2m+1)\pi}{n} + 1$$

$$\theta = \cos^{-1}\left\{\pm\frac{1}{\beta d}\frac{(2m+1)}{n}\pi + 1\right\}$$

$n = 4 \; ; \; d = \frac{\lambda}{2} \; ; \; \delta = -\beta d = -\pi$

$$\theta = \cos^{-1}\left\{\pm\frac{1}{\pi}\frac{(2m+1)}{m}\pi/4 + 1\right]$$

$\Gamma - 5/4$

for $m = 1$ $\quad \theta = \cos^{-1}\left[7/4 \, , \, 1/4\right]$

$m = 2$

$\theta = \cos^{-1}\left[\pm 5/4 + 1\right]$

$= \cos^{-1}\left[9/4, -1/4\right]$ $\quad \cos^{-1}\left[1/4\right]$

$\theta = 104.5°$ $\quad \theta = 75.5°$

Direction of Minima for side lobes

$$\sin\left(\frac{n\psi}{2}\right) = 0$$

$$\frac{n\psi}{2} = m\pi \qquad \psi = \frac{2m\pi}{n}$$

$$\beta d\cos\theta - \beta d = \frac{2m\pi}{n}$$

$$\beta d\left[\cos\theta - 1\right] = \frac{2m\pi}{n}$$

$$\cos\theta - 1 = \pm \frac{1}{\beta d}\left[\frac{2m\pi}{n}\right]$$

$$1 - 2\sin^2\frac{\theta}{2} - 1 = \pm \frac{1}{\beta d}\left[\frac{2m\pi}{n}\right]$$

$$2\sin^2\frac{\theta}{2} = \mp \frac{1}{\beta d}\left[\frac{2m\pi}{n}\right]$$

$$\sin\frac{\theta}{2} = \mp \sqrt{\frac{1}{\beta d}\,\frac{m\pi}{n}}$$

$n = 4 \quad d = \lambda/2$

$$\sin\frac{\theta}{2} = \mp\sqrt{\frac{m}{4}}$$

$m = 1, 2, 3, 4.$

$$\frac{\theta}{2} = \sin^{-1}\left[\mp\sqrt{1/4}, \sqrt{1/2}, \sqrt{\tfrac{3}{4}}, 1\right]$$

$$\frac{\theta}{2} = \mp(30^\circ, 45^\circ, 60^\circ, 90^\circ)$$

$$\theta = \mp(60^\circ, 90^\circ, 120^\circ, 180^\circ)$$

First Null Beam Width-

$$FNBW = 2\theta$$

$$\theta = 2\sin^{-1} \pm\sqrt{\frac{1}{\beta d}\,\frac{m\pi}{n}}$$

$$= 2\sin^{-1} \pm\sqrt{\frac{m\lambda}{2nd}}$$

$\beta = \frac{2\pi}{\lambda}$

$$\sqrt{\frac{m\pi}{\frac{2\pi}{\lambda}\, d\, n}}$$

$$\frac{2m\lambda}{d}$$

putting $n=1$ $\quad \theta = 2\sin^{-1}\left[\pm\sqrt{\frac{\lambda}{2nd}}\right]$

If θ is small $\quad \sin\theta = \theta$

$$\boxed{\sqrt{\frac{\lambda}{2nd}} = \sin\sqrt{\frac{\lambda}{2nd}} \qquad \theta = 2\sin^{-1}\left[\pm\sin\sqrt{\frac{\lambda}{2nd}}\right]}$$

$$\sin\theta = 2\pm\sqrt{\frac{\lambda}{2nd}}$$

$$\theta = 2\pm\sqrt{\frac{\lambda}{2nd}}$$

$$= \pm 2\sqrt{\frac{\lambda}{2nd}}$$

$$= \pm\sqrt{\frac{2\lambda}{nd}}$$

$$= \pm\sqrt{\frac{2\lambda}{nd}}$$

$$\gamma = 2\alpha$$

$$FNBW = \pm 2\sqrt{\frac{2\lambda}{nd}}$$

$$\gamma = 2\alpha$$

$$FNBW = \pm 2\sqrt{\frac{2\lambda}{nd}}$$

Array of n isotropic point sources of equal amplitude and spacing with increased directivity

The maximum radiation can be obtained towards the end side of array by adjusting $\delta = -\beta d$ for $\theta = 0$ and $\delta = \beta d$ for $\theta = 180°$. However this condition does not give maximum directivity as compared to broad side array. Hansan & Woodyard suggested that if the value excitation phase angle is increased by an amount equal to $\frac{2.94}{n}$ directivity can be increased.

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So new excitation phase angle becomes

$$\delta = \begin{cases} -\left(\beta d + \frac{2.94}{n}\right) & \text{for } \theta = 0^\circ \\ \left(\beta d + \frac{2.94}{n}\right) & \text{for } \theta = 180^\circ. \end{cases}$$

where n is number of elements in array.

Since 2.94 is close to $\pi = 3.14$ the above eqn can be re written as

$$\delta = \begin{cases} -\left(\beta d + \frac{\pi}{n}\right) & \text{for } \theta = 0^\circ \\ \left(\beta d + \pi/n\right) & \text{for } \theta = 180^\circ. \end{cases}$$

Normalized field pattern.

$$E_n = \frac{E}{n} = \frac{\sin\left(\frac{n\psi}{2}\right)}{n \sin(\psi/2)}.$$

where $\psi = \beta d \cos\theta + \delta$ the above eqn becomes.

$$E_n = \frac{E}{n} = \frac{\sin\left[\frac{n}{2}(\beta d \cos\theta + \delta)\right]}{n \sin\left[\frac{\beta d \cos\theta + \delta}{2}\right]}$$

$\sin \psi/2 \simeq \psi/2$

$$E_n = \frac{E}{n} = \frac{\sin\left[\frac{n}{2}\left(\beta d \cos\theta + \delta\right)\right]}{n/2 \left(\beta d \cos\theta + \delta\right)}$$

Let $\delta = -pd$ yields maximum possible directivity here p is constant to be calculated.

$$E_n = \frac{E}{n} = \frac{\sin\left[\frac{n}{2}(\beta d\cos\theta - pd)\right]}{n/2\,(\beta d\cos\theta - pd)}$$

$$E_n = \frac{E}{n} = \frac{\sin\left[q(\beta\cos\theta - p)\right]}{q(\beta\cos\theta - p)} \quad ; \; q = \frac{nd}{2}$$

put $q[\beta\cos\theta - p] = z$

maximum value of z is z' occurs at $\theta = 0°$.

$$q(\beta - p) = z'$$

$$E_n = \frac{\sin z}{z}$$

Radiation intensity is proportional to $|E_n|^2$ is

$$U = K|E_n|^2 = K\left|\frac{\sin z}{z}\right|^2$$

The corresponding maximum value of radiation intensity is given by

$$U_{max} = K\left|\frac{\sin z'}{z'}\right|^2$$

Normalized radiation intensity

$$U_n = \frac{U}{U_{max}} = \left|\frac{\sin z}{z} \cdot \frac{z'}{\sin z'}\right|^2$$

Directivity along $\theta = 0°$

$$D_0 = \frac{4\pi\, U_{max}}{P_{rad}} = \frac{U_{max}}{\frac{P_{rad}}{4\pi}} = \frac{U_{max}}{U_{avg}}$$

Average radiation intensity is given by

$$U_{av} = \frac{P_{rad}}{4\pi} = \frac{\int_{\phi=0}^{2\pi} d\phi . \int_{\theta=0}^{\pi} U \sin\theta\, d\theta}{4\pi}$$

$$U = U_{max} . \left| \frac{\sin z}{z} \cdot \frac{z'}{\sin z'} \right|^2$$

$$U_{av} = \frac{P_{rad}}{4\pi} = \frac{\int_{\phi=0}^{2\pi} d\phi \int_{\theta=0}^{\pi} U_{max} . \left| \frac{\sin z}{z} \cdot \frac{z'}{\sin z'} \right| \sin\theta . d\theta}{4\pi}$$

$$U_{av} = \frac{\int_{\theta=0}^{\pi} U_{max} . \left| \frac{\sin z}{z} \cdot \frac{z'}{\sin z'} \right|^2 \sin\theta\, d\theta}{2}$$

$$= \frac{1}{2} \left[\frac{q(\beta - p)}{\sin q(\beta - p)} \right]^2 . \int_{\theta=0}^{\pi} \frac{U_{max} . \left(\frac{\sin q(\beta\cos\theta - p)}{q(\beta\cos\theta - p)} \right)^2 \sin\theta\, d\theta}{4}$$

For maximum directivity, value of U_{av} must be minimum.

It can be shown that integral yield minimum value when

$$z' = q(\beta - p) = -1.47$$

$$\frac{2\beta d}{2} - \frac{2\beta d}{2} = -1.47$$

$\delta = -\beta d$ this

$$\frac{2\beta d}{2} + \frac{2\delta}{2} = -1.47$$

$$\beta d + \delta = \frac{-1.47 \times 2}{2}$$

$$\delta = -\left[\beta d + \frac{2.94}{2}\right]$$

Similarly for $\theta = 180^\circ$

$$\delta = \left[\beta d + \frac{2.94}{2}\right]$$

Binomial Array

If the source of current used for excitation is according to binomial series, then it is called binomial array.

Binomial array is an array in which the amplitude of current in the array elements satisfies binomial coefficients.

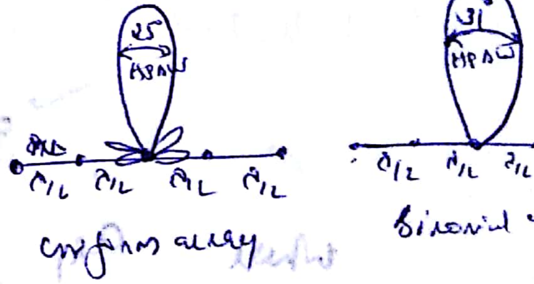
$$(a+b)^{n-1} = a^{n-1}b^0 + \frac{(n-1)a^{n-2}b^1}{1!} + \frac{(n-1)(n-2)a^{n-3}b^2}{2!} + \cdots$$

Secondary lobes can be eliminated if

- Spacing b/w consecutive radiating source does not exceed $\lambda/2$
- The current amplitudes are proportional to coefficients of binomial

coefficients can be obtained using pascal's Δ

1
1 1
1 2 1
1 3 3 1
1 4 6 4 1
1 5 10 10 5 1



$E = 2E_0 \cos\left(\frac{n\psi}{2}\right)$; $E_n = \left(\cos(n\psi/2)\right)$

* HPBW increases ∴ directivity decreases

* For design of large array, larger amplitude ratio of sources ...

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Super Directive Arrays.

Array of Antennas which has directivity above a specific value of existing distribution is called super directive arrays.

Such designs have very low efficiency and hence very low power gain. due to Ohmic losses.

Dolph - Tchebyshev (or Chebyshev) Array.

The directivity of linear broad side array can be optimized at the specified side lobe level for all the side lobes. This means we can set any desired value of side lobe level at high value of directivity.

Dolph - Tchebyshev antenna arrays follows chebyshev polynomial

i.e.

$$T_m(x) = \begin{cases} \cos(m\cos^{-1}x) & \text{for } -1 < x < +1 \\ \cosh(m\cosh^{-1}x) & \text{for } |x| > 1 \end{cases}$$

When $m = 0, 1, 2, 3 \ldots$

Let $\delta = \cos^{-1}x$, where $\delta = \frac{\psi}{2}$

$x = \cos\delta$.

$m=0 \quad T_0 = 1$

$m=1 \quad T_1(x) = x$

$m=2 \quad T_2 = \cos(2\cos^{-1}x) = \cos 2\delta$

$T_2 = \cos 2\delta = 2\cos^2\delta - 1$

$\therefore T_2(x) = 2x^2 - 1$

$m=3 \quad \therefore T_3 = \cos 3\delta = 4\cos^3\delta - 3\cos\delta$

$T_3(x) = 4x^3 - 3x$

$\therefore T_m(x) = 2x\, T_{(m-1)}(x) - T_{(m-2)}(x)$

putting $m = 4, 5, \ldots$

$T_4(x) = \cos 4\delta = 8x^4 - 8x^2 + 1$

$T_5(x) = \cos 5\delta = 16x^5 - 20x^3 + 5x$

$T_6(x) = \cos 6\delta = 32x^6 - 48x^4 + 18x^2 - 1$

It provides optimum beam width for a specified degree of side lobe level reduction.

$x = \cos \psi/2$

$T_m(x) = \cos\left[m(\cos^{-1}x)\right]$

$= \cos m(\psi/2)$

MODULE 4,5 & 6 NOTES

Types of Antennas

Classification of Antennas

Based on Frequency:

Band	Frequency range	Wavelength range
Extremely low frequency (ELF)	< 3 kHz	>100 km
Very low frequency (VLF)	3 - 30 Hz	10 - 100 krn
Low frequency(LF)	30 - 300 kHz	1 - 10 km
Medium frequency (MF)	300 kHz - 3 MHz	100m - 1km
High frequency (HF)	3 - 30 MHz	10 - 100m
Very high frequency (VHF)	30 - 300 MHz	1 - 10m
Ultra high frequency (UHF)	300 MHz - 3 GHz	10cm - 1m
Super high frequency (SHF)	3 - 30 GHz	1 - 10cm
Extremely high frequency (EHF)	30 - 300 GHz	1mm - 1cm

- There are many types of antennas depending upon the applications

Type of antenna	Examples	Applications
Wire Antennas	Dipole antenna, Monopole antenna, Helix antenna, Loop antenna	Personal applications, buildings, ships, automobiles, space crafts
Aperture Antennas	Waveguide (opening), Horn antenna	Flush-mounted applications, air-craft, space craft
Reflector Antennas	Parabolic reflectors, Corner reflectors	Microwave communication, satellite tracking, radio astronomy
Lens Antennas	Convex-plane, Concave-plane, Convex-convex, Concave-concave lenses	Used for very high-frequency applications
Micro strip Antennas	Circular-shaped, Rectangular-shaped metallic patch above the ground plane	Air-craft, space-craft, satellites, missiles, cars, mobile phones etc.
Array Antennas	Yagi-Uda antenna, Micro strip patch array, Aperture array, Slotted wave guide array	Used for very high gain applications, mostly when needs to control the radiation pattern

- Resonant Antenna
  - Unterminated
  - Standing waves
  - Bidirectional radiation Pattern

- Non resonant Antenna
  - Terminated
  - Travelling wave
  - Unidirectional Radiation Pattern

Standing Wave Antenna

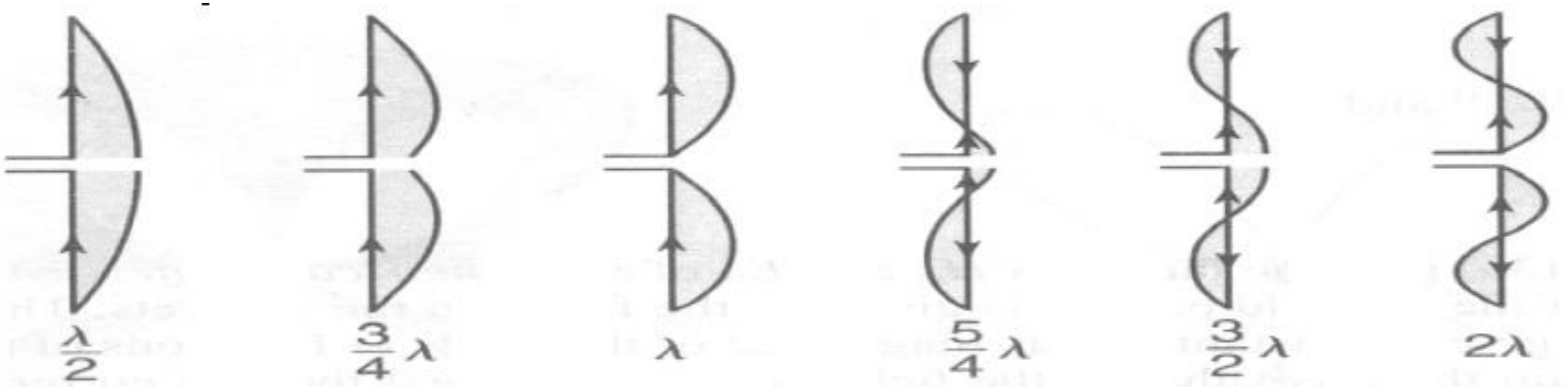
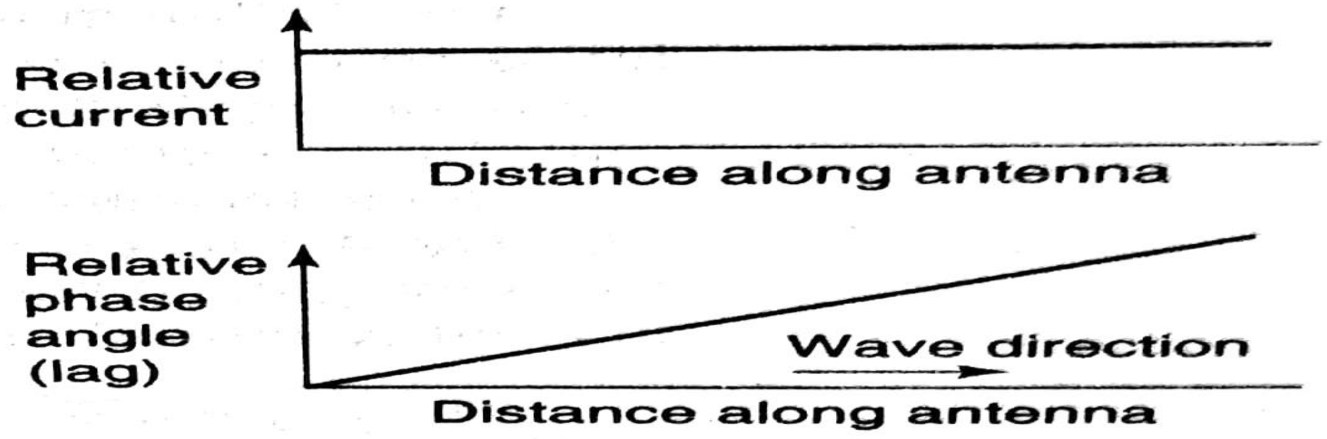


Figure 3.7: Approximate natural current distribution for thin linear center fed antenna of various length.

Travelling wave Antenna

- Here a sinusoidal current distribution can be regarded as the standing wave produced by 2 uniform travelling waves of equal amplitude moving in opposite directions along the antenna.
- If only one such wave is present on the antenna the current distribution is uniform means the amplitude is constant.
- A single wire antenna terminated in its characteristic impedance can be considered as a classical example of travelling wave
- Such antenna is known as Beverage or wave antenna
- A travelling wave can be classified as a slow wave if its phase velocity is smaller than the velocity of light in free space otherwise it is known as fast wave

- Travelling wave antenna can be classified as surface wave antenna and leaky-wave antenna
- Surface wave antenna is a slow wave structure whose phase velocity is equal to or less than c
- Leaky wave antenna is a fast wave structure in which it continuously lose energy due to radiation.

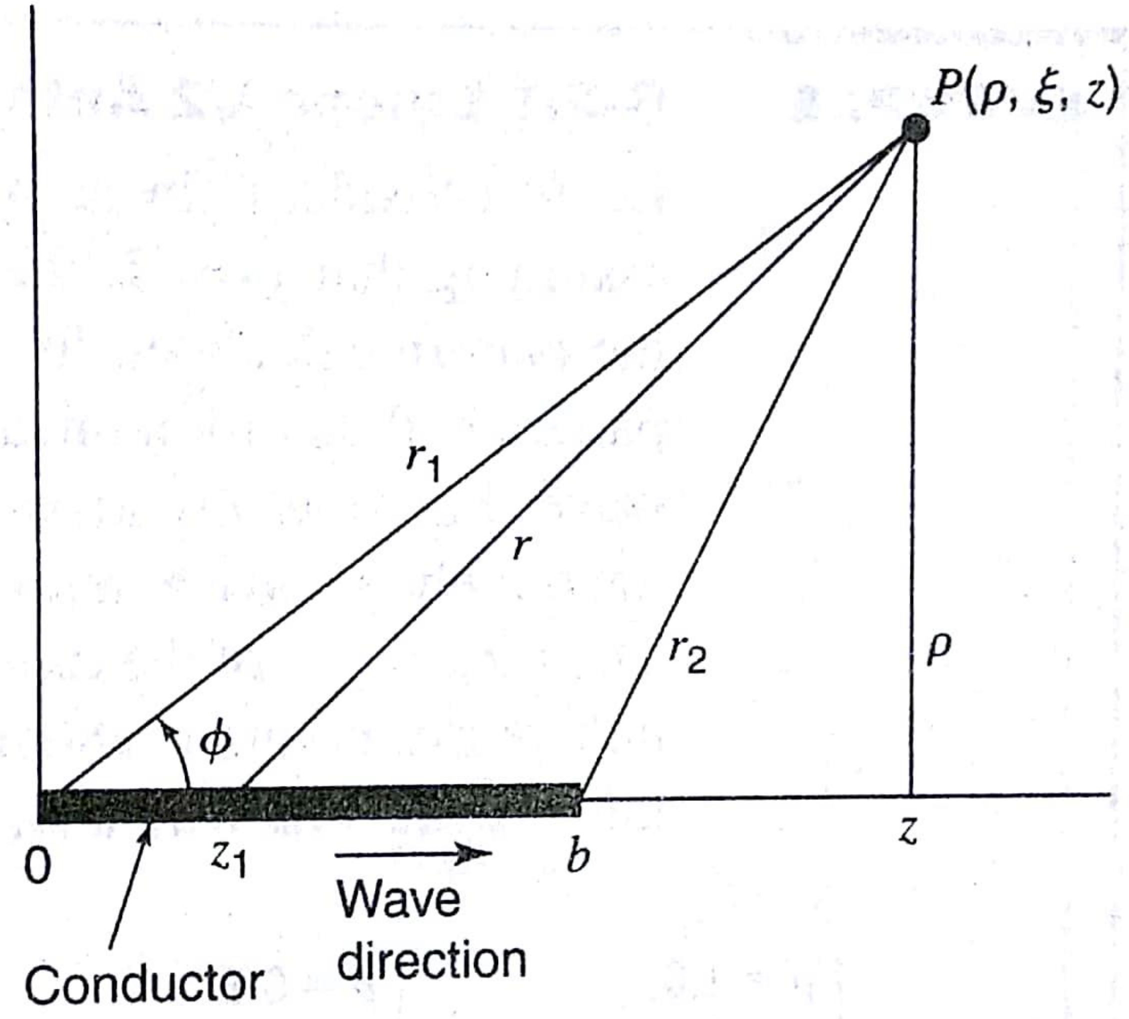


Fields from travelling wave

$$H_\xi = \frac{I_0 p}{2\pi r_1}\left\{\frac{\sin\phi}{1 - p\cos\phi}\sin\left[\frac{\omega b}{2pc}(1 - p\cos\phi\right.\right.$$

$$\Big/\left[\omega\left(t - \frac{r_1}{c}\right) - \frac{\omega b}{2pc}(1 - p\cos\phi)\right]$$

- Where P is the relative phase velocity v/c



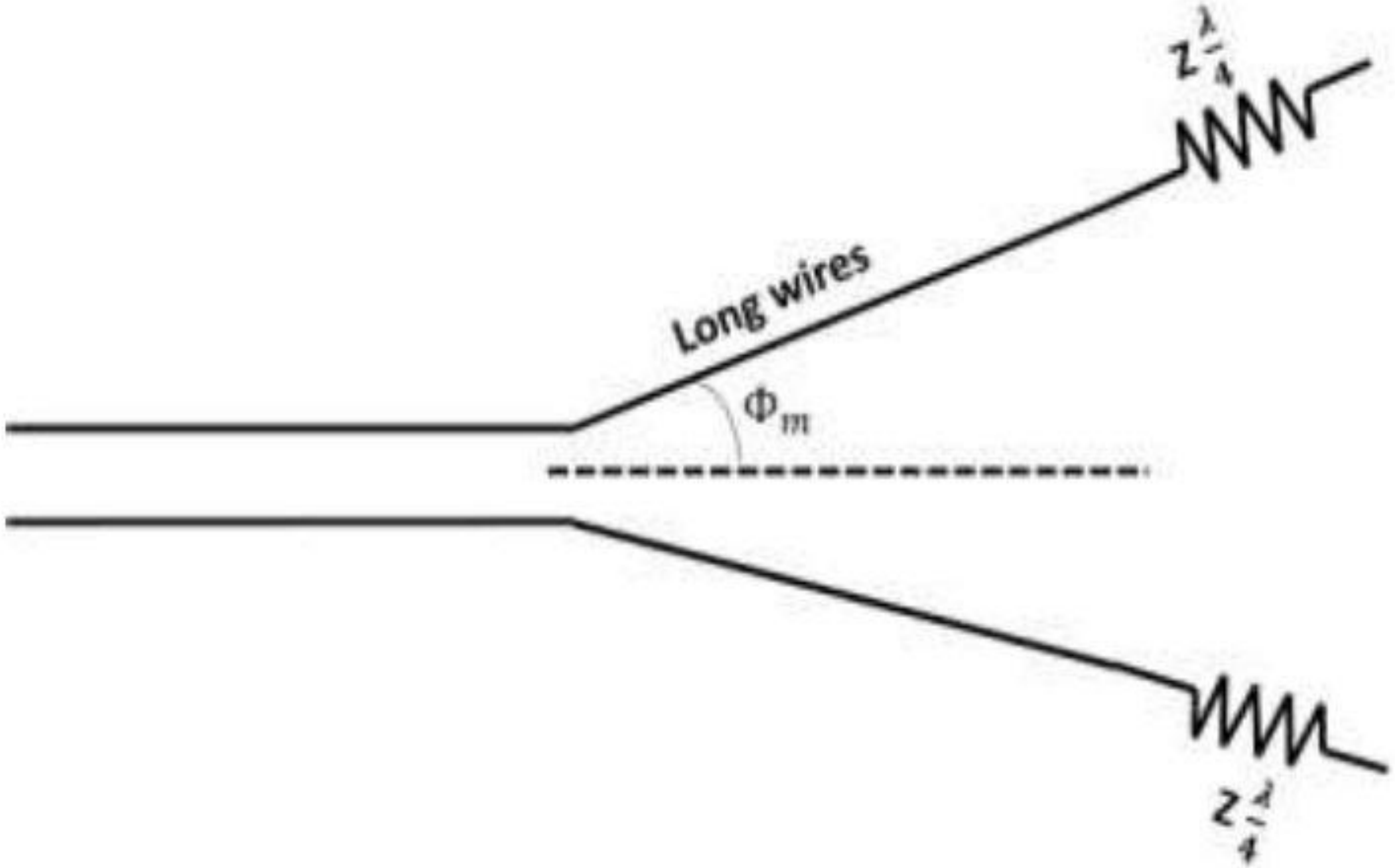
- Since the current is considered only in z direction magnetic field has only one component H_ξ where ξ direction is normal to the page at P.
- The electric field component $\boldsymbol{E_\varphi}$ is obtained from H_ξ by $\boldsymbol{E_\varphi = Z \cdot} H_\xi$

V-ANTENNA

- This antenna is formed by arranging 2 long wire antennas in a V-shape.
- The end wires are called as legs.
- This antenna can be a bi-directional resonant antenna or unidirectional non resonant antenna.
- The frequency range of operation of V-antenna is around 3 to 30 MHz. This antenna works in high frequency range.

Construction & Working of V - Antennas

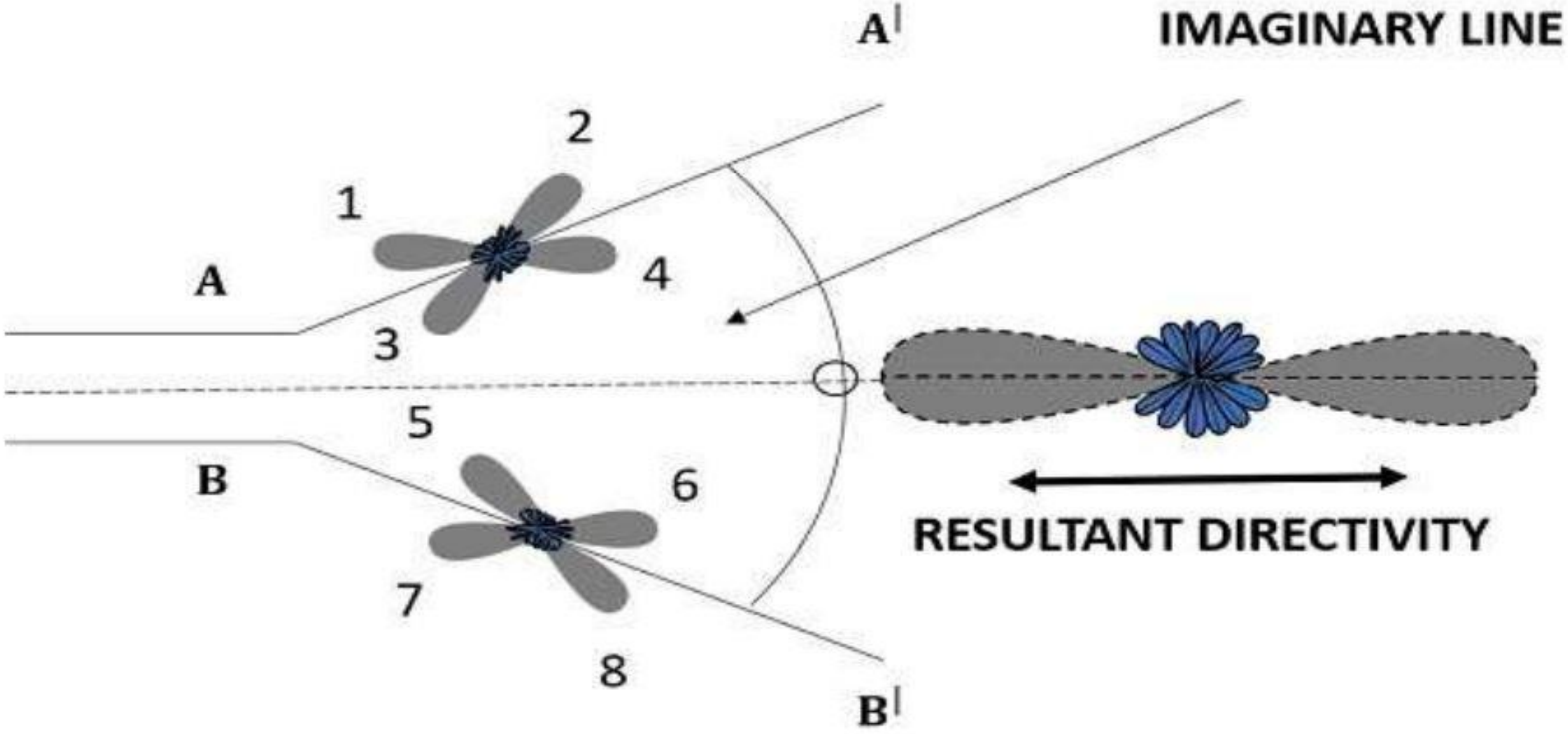
- Two long wires are connected in the shape of V to make a V-antenna.
- The two long wires are excited with 180˚ out of phase.
- As the length of these wires increases, the gain and directivity also increases.
- The following figure shows a V-antenna with the transmission line impedance z and the length of the wire λ/2, making an angle Φ_m with the axis, which is called as apex angle.
- The gain achieved by V-antenna is higher than normal single long wire antenna.
- The gain in this V-formation is nearly twice compared to the single long wire antenna, which has a length equal to the legs of V-antenna.



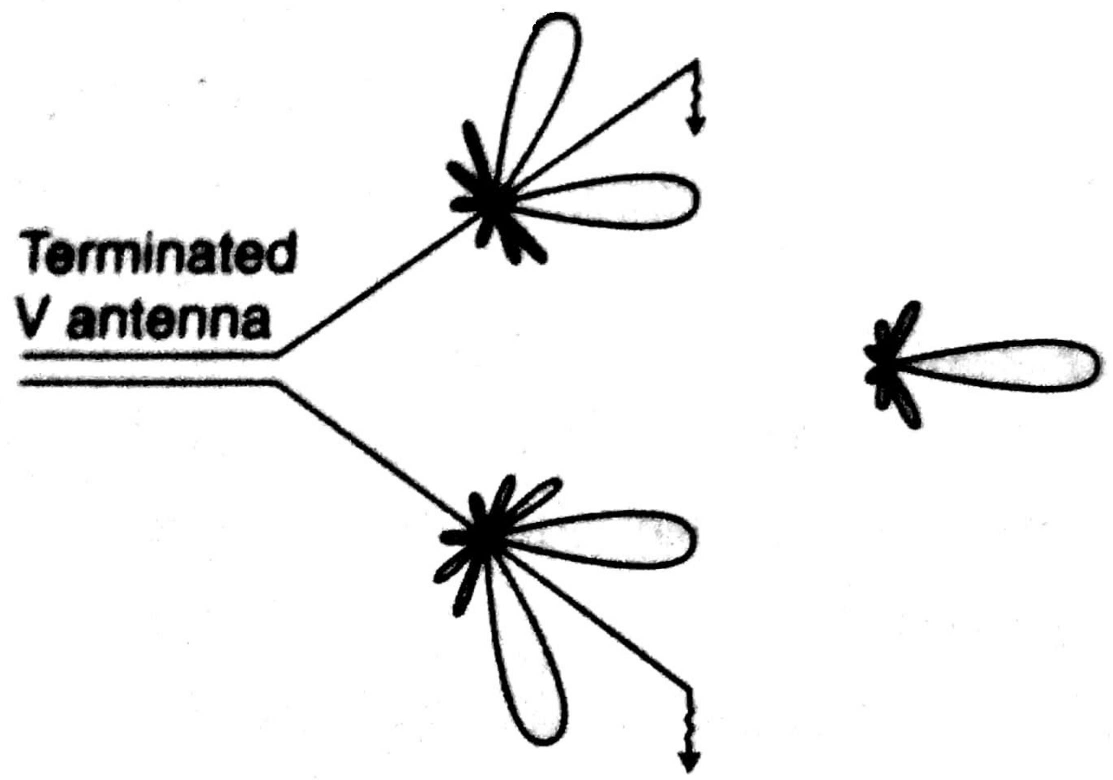
Long wires
Φ_m
$Z\frac{\lambda}{4}$
$Z\frac{\lambda}{4}$

Radiation Pattern

- The radiation pattern of a V-antenna is bi-directional/ uni directional.
- The radiation obtained on each transmission line is added to obtain the resultant radiation pattern.



Unidirectional radiation pattern



- The patterns of individual transmission lines and the resultant pattern are shown in the figure.
- The two transmission lines forming V-pattern are AA’ and BB’.
- This pattern resembles the broad-side array.
- If another V-antenna is added to this antenna and fed with 90˚ phase difference, then the resultant pattern would be end-fire, doubling the power gain.
- The directivity can be further increased by adding the array of V-antennas.

Advantages

- Construction is simple
- High gain
- Low manufacturing cost

Disadvantages

- Standing waves are formed
- The minor lobes occurred are also strong
- Used only for fixed frequency operations

Inverted V - Antenna

- Operating frequency of V-antenna is limited.
- This can be modified by using another antenna, which is a non-resonant antenna or a travelling wave antenna.
- The antenna is placed in the shape of an inverted V, with its two transmission lines or legs bent towards the ground making 120° or 90° angle between them.
- The angle made by one of the legs with the axis of the antenna, is known as the tilt angle and is denoted by θ

Advantages

- Occupies less horizontal place
- No standing waves are formed
- High gain

Disadvantages

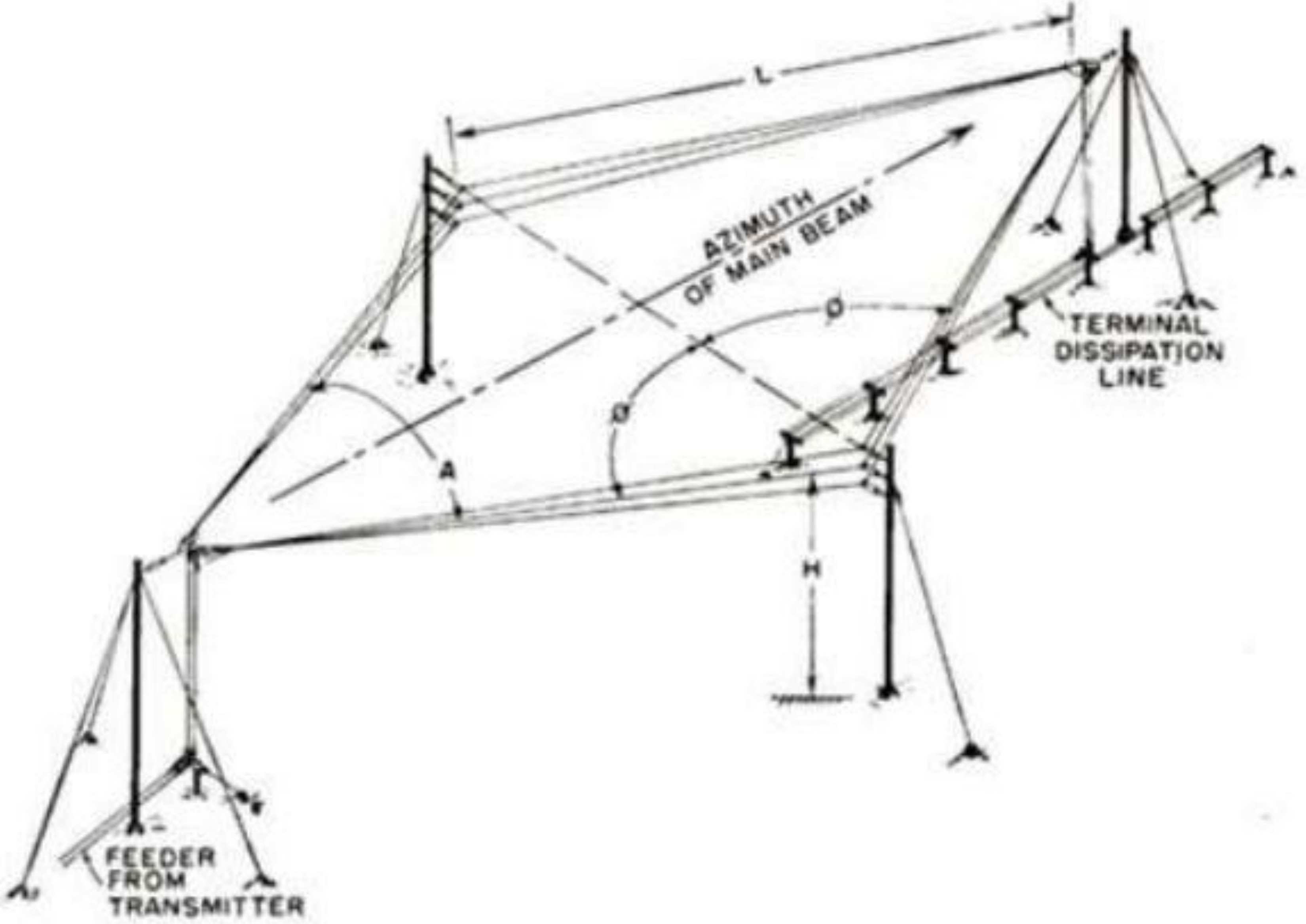
- It has considerable undesired minor lobes
- Minor lobes create horizontally polarized waves

Rhombic Antenna

- The Rhombic Antenna is an equilateral parallelogram shaped antenna.
- Rhombic antenna works under the principle of travelling wave radiator.
- It is arranged in the form of a rhombus or diamond shape and suspended horizontally above the surface of the earth.
- The frequency range of operation of a Rhombic antenna is around 3MHz to 300MHz. This antenna works in HF and VHF ranges.

Construction of Rhombic Antenna

- Rhombic antenna can be regarded as two V-shaped antennas connected end-to-end to form obtuse angles
- The construction of the rhombic antenna is in the form a rhombus, as shown in the figure


L
AZIMUTH
OF MAIN BEAM
D
Ø
A
H
TERMINAL
DISSIPATION
LINE
FEEDER
FROM
TRANSMITTER

- The two sides of rhombus are considered as the conductors of a two-wire transmission line.
- Generally, it has two opposite acute angles. The tilt angle, θ is approximately equal to 90° minus the angle of major lobe.
- When this system is properly designed, there is a concentration of radiation along the main axis of radiation.
- In practice, half of the power is dissipated in the terminating resistance of the antenna. The rest of the power is radiated.
- The wasted power contributes to the minor lobes.
- The maximum gain from a rhombic antenna is along the direction of the main axis,
- which passes through the feed point to terminate in free space.
- The polarization obtained from a horizontal rhombic antenna is in the plane of rhombus, which is horizontal.

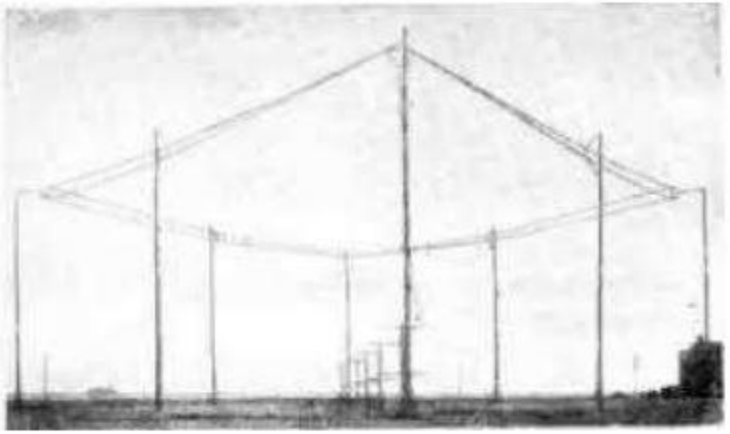


Figure 1

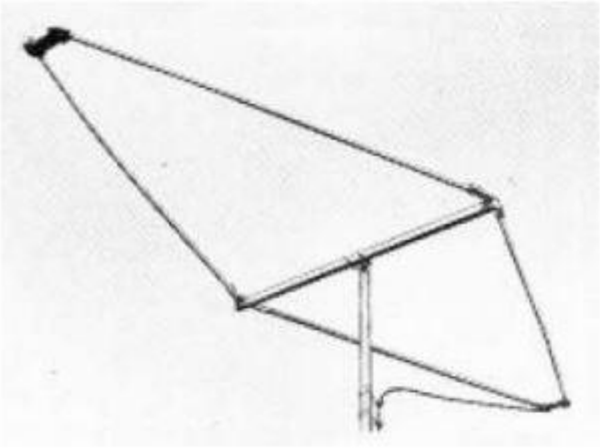
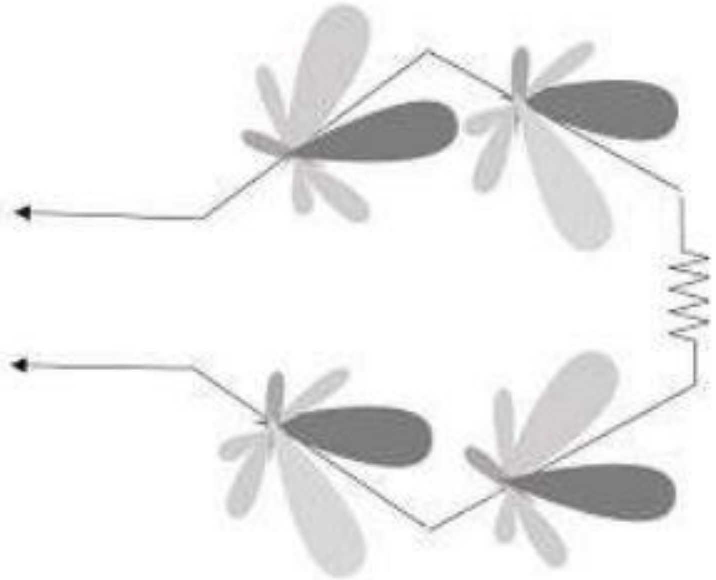


Figure 2

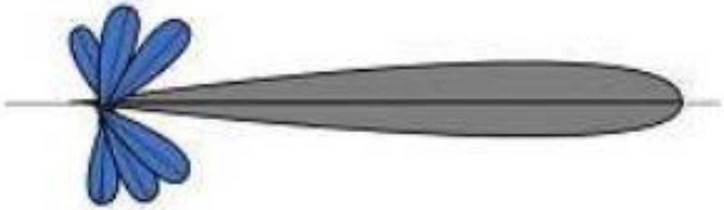
- Figure 1 shows the construction of rhombic antenna for point-to-point communication in older days.
- Figure 2 shows the rhombic UHF antenna for TV reception, used these days

Radiation Pattern

- The radiation pattern of the rhombic antenna is shown in the figure.
- The resultant pattern is the cumulative effect of the radiation at all four legs of the antenna.
- This pattern is uni-directional, while it can be made bi-directional by removing the terminating resistance.
- The main disadvantage of rhombic antenna is that the portions of the radiation, which do not combine with the main lobe, result in considerable side lobes having both horizontal and vertical polarization.



INDIVIDUAL RADIATION PATTERNS



RESULTANT RADIATION PATTERNS

Field from Rhombic antenna

- The field pattern of a horizontal rhombic antenna of perfectly conducting wire above perfectly conducting ground may be calculated as a sum of patterns of 4 tilted wires each with single outgoing travelling waves

$$E = \frac{(\cos\phi)[\sin(H_r \sin\alpha)][\sin(\psi L_r)]^2}{\psi}$$

α = elevation angle with respect to ground
ϕ = half included side angle of rhombic antenna
$H_\lambda = H/\lambda$ = height of rhombic antenna
$L_\lambda = L/\lambda$ = leg length
$H_r = 2\pi H_\lambda = 2\pi(H/\lambda)$
$L_r = 2\pi L_\lambda = 2\pi L/\lambda$
$\psi = (1 - \sin\phi\cos\alpha)/2$

Advantages

- Input impedance and radiation pattern are relatively constant
- Multiple rhombic antennas can be connected
- Simple and effective transmission

Disadvantages

- Wastage of power in terminating resistor
- Requirement of large space
- Reduced transmission efficiency

Applications

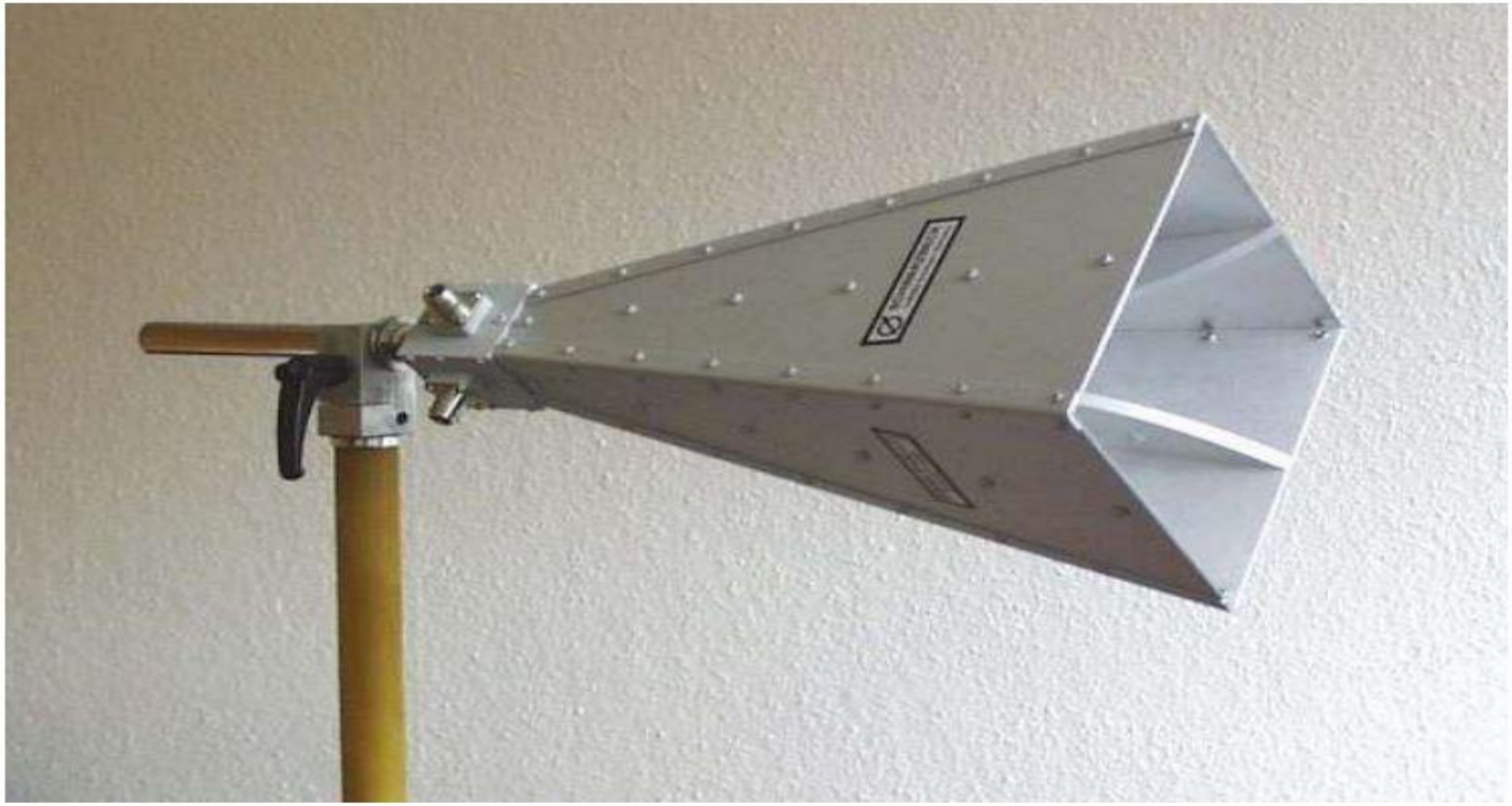
- Used in HF communications
- Used in Long distance sky wave propagations
- Used in point-to-point communications

Horn Antenna

- To improve the radiation efficiency and directivity of the guided beam, the wave guide should be provided with an extended aperture to make the abrupt discontinuity of the wave into a gradual transformation.
- So that all the energy in the forward direction gets radiated. This can be termed as Flaring
- This is the working principle of horn antenna.
- The operational frequency range of a horn antenna is around 300MHz to 30GHz. This antenna works in UHF and SHF frequency ranges.

Construction & Working of Horn Antenna

- The energy of the beam when slowly transform into radiation, the losses are reduced and the focusing of the beam improves.
- A Horn antenna may be considered as a flared out wave guide, by which the directivity is improved and the diffraction is reduced.



Types of Horn

Sectoral horn

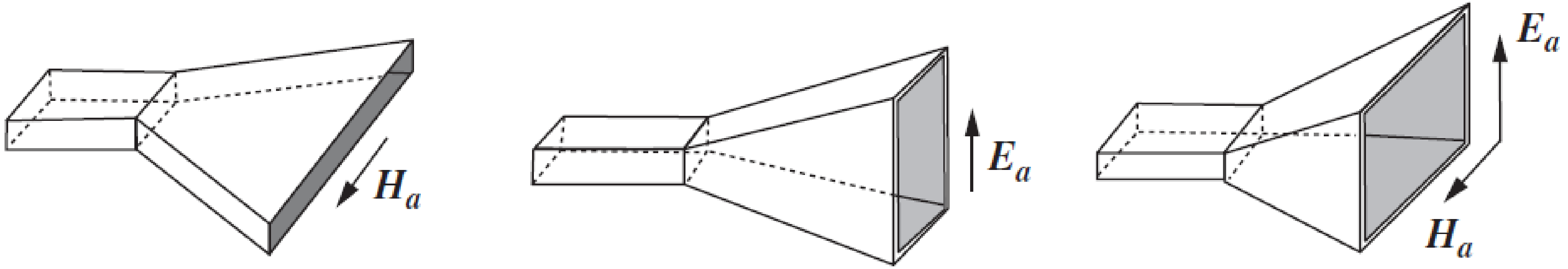
- This type of horn antenna, flares out in only one direction.
- Flaring in the direction of Electric vector produces the sectorial E-plane horn.
- Similarly, flaring in the direction of Magnetic vector, produces the sectorial H-plane horn.

Pyramidal horn

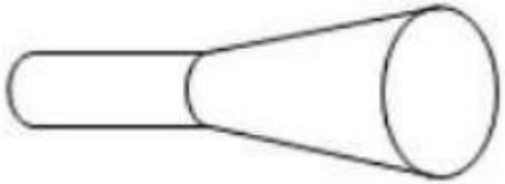
- This type of horn antenna has flaring on both sides.
- If flaring is done on both the E & H walls of a rectangular waveguide, then pyramidal horn antenna is produced.
- This antenna has the shape of a truncated pyramid.

Conical horn

- When the walls of a circular wave guide are flared, it is known as a conical horn. This is
- a logical termination of a circular wave guide.



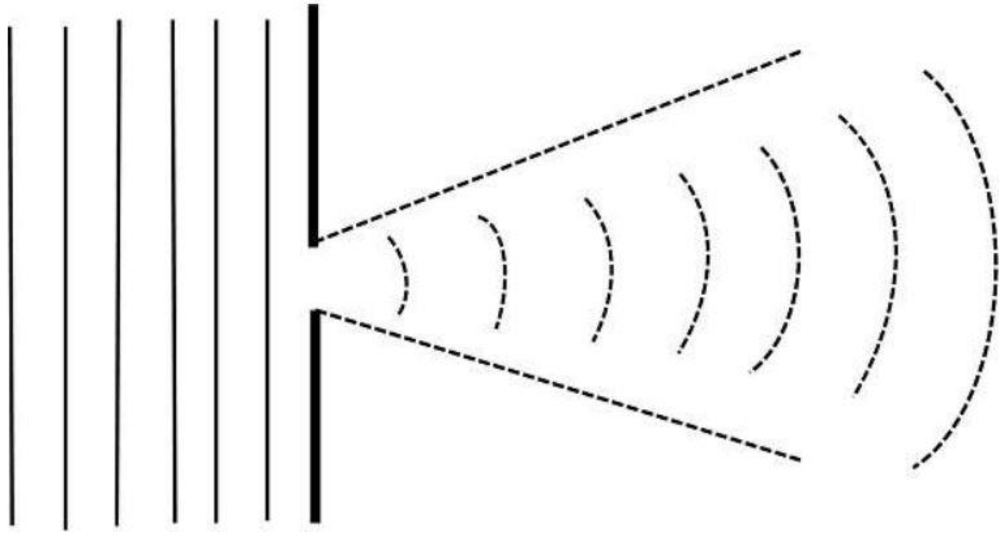
H-plane sectoral horn *E-plane sectoral horn* *Pyramidal horn*



Conical Horn Antenna

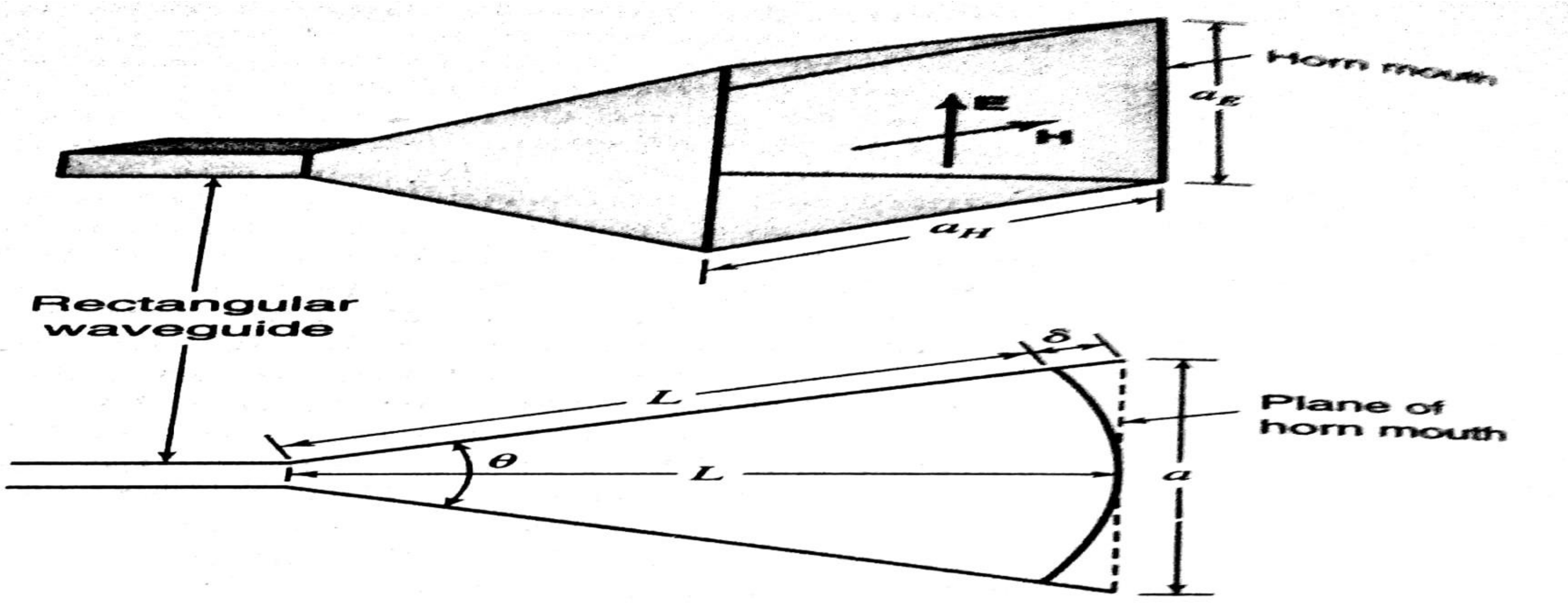
Radiation Pattern

- The radiation pattern of a horn antenna is a Spherical Wave front.
- The following figure shows the radiation pattern of horn antenna. The wave radiates from the aperture, minimizing the diffraction of waves.
- The flaring keeps the beam focused. The radiated beam has high directivity.



Dimensions of horn

- The phase across the horn may deviate, but less than a specified amount δ, which is equal to path length difference between a ray travelling along side and along the axis of the horn.



- From figure

$$\cos\frac{\theta}{2} = \frac{L}{L+\delta}$$

$$\sin\frac{\theta}{2} = \frac{a}{2(L+\delta)}$$

$$\tan\frac{\theta}{2} = \frac{a}{2L}$$

where

θ = flare angle (θ_E for E plane, θ_H for H plane), deg
a = aperture (a_E for E plane, a_H for H plane), m
L = horn length, m
δ = path length difference, m

From the geometry we have also that

$$L = \frac{a^2}{8\delta} \qquad (\delta \ll L)$$

and

$$\theta = 2\tan^{-1}\frac{a}{2L} = 2\cos^{-1}\frac{L}{L+\delta}$$

- For E plane Horn δ is usually 0.25λ or less
- For H plane Horn δ is can be larger (about 0.4λ)

Optimum horn dimensions

$$\delta_0 = \frac{L}{\cos(\theta/2)} - L = \text{optimum } \delta$$

$$L = \frac{\delta_0 \cos(\theta/2)}{1 - \cos(\theta/2)} = \text{optimum length}$$

Field and Directivity of Horn

$$E_y(x,y) = E_0 \cos\left(\frac{\pi x}{A}\right) e^{-j(\pi/2)\sigma_a^2 (2x/A)^2} e^{-j(\pi/2)\sigma_b^2 (2y/B)^2}$$

$$H_x(x,y) = -\frac{1}{\eta} E_0 \cos\left(\frac{\pi x}{A}\right) e^{-j(\pi/2)\sigma_a^2 (2x/A)^2} e^{-j(\pi/2)\sigma_b^2 (2y/B)^2}$$

$$D = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \varepsilon_{ap} A_p}{\lambda^2}$$

where

A_e = effective aperture, m^2
A_p = physical aperture, m^2
ε_{ap} = aperture efficiency = A_e/A_p
λ = wavelength, m

- Assuming ε_{ap} = 0.6 we get

- $$D \simeq \frac{7.5 A_p}{\lambda^2}$$

Where Ap = aE * aH for rectangular horn

Ap = πr^ 2 for conical horn

or

$$D \simeq 10 \log \left(\frac{7.5 A_p}{\lambda^2} \right) \qquad \text{(dBi)}$$

For a pyramidal (rectangular) horn (3) can also be expressed as

$$D \simeq 10 \log(7.5 a_{E\lambda} a_{H\lambda})$$

where

$a_{E\lambda}$ = E-plane aperture in λ

$a_{H\lambda}$ = H-plane aperture in λ

Advantages

- Small minor lobes are formed
- Impedance matching is good
- Greater directivity
- Narrower beam width
- Standing waves are avoided

Disadvantages

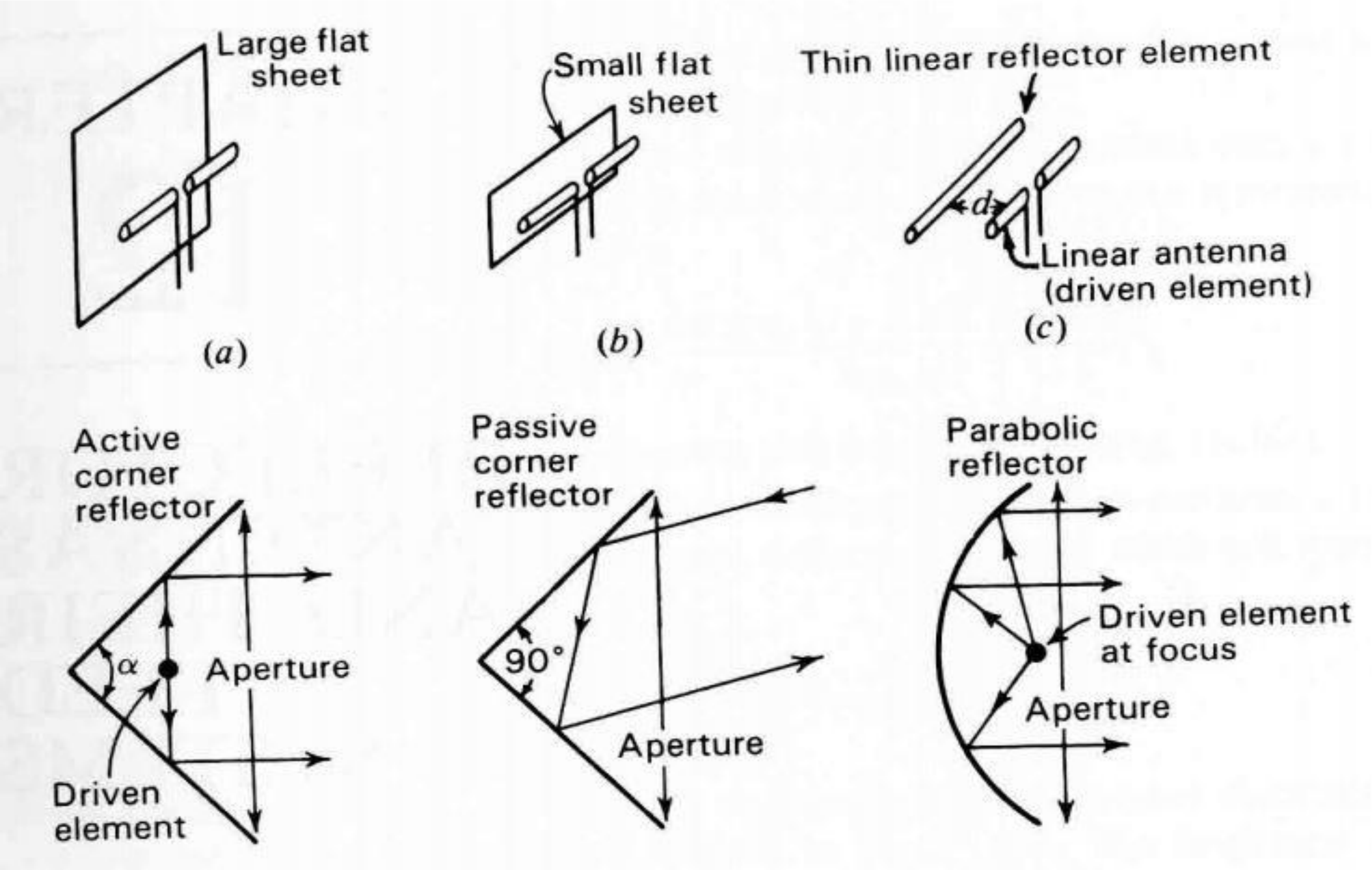
- Designing of flare angle, decides the directivity
- Flare angle and length of the flare should not be very small

Applications

- Used for astronomical studies
- Used in microwave applications

Reflector Antennas

- Reflectors can be used to modify radiation pattern of a radiating element.
- Reflector antennas can offer much higher gains than horn antennas and are easy to design and construct.
- These antennas are widely used for radio and wireless applications
- The most popular shape is the paraboloid – because of its excellent ability to produce a pencil beam (high gain) with low sidelobes and good cross-polarisation characteristics
- The frequency range used for the application of Parabolic reflector antennas is above 1MHz.



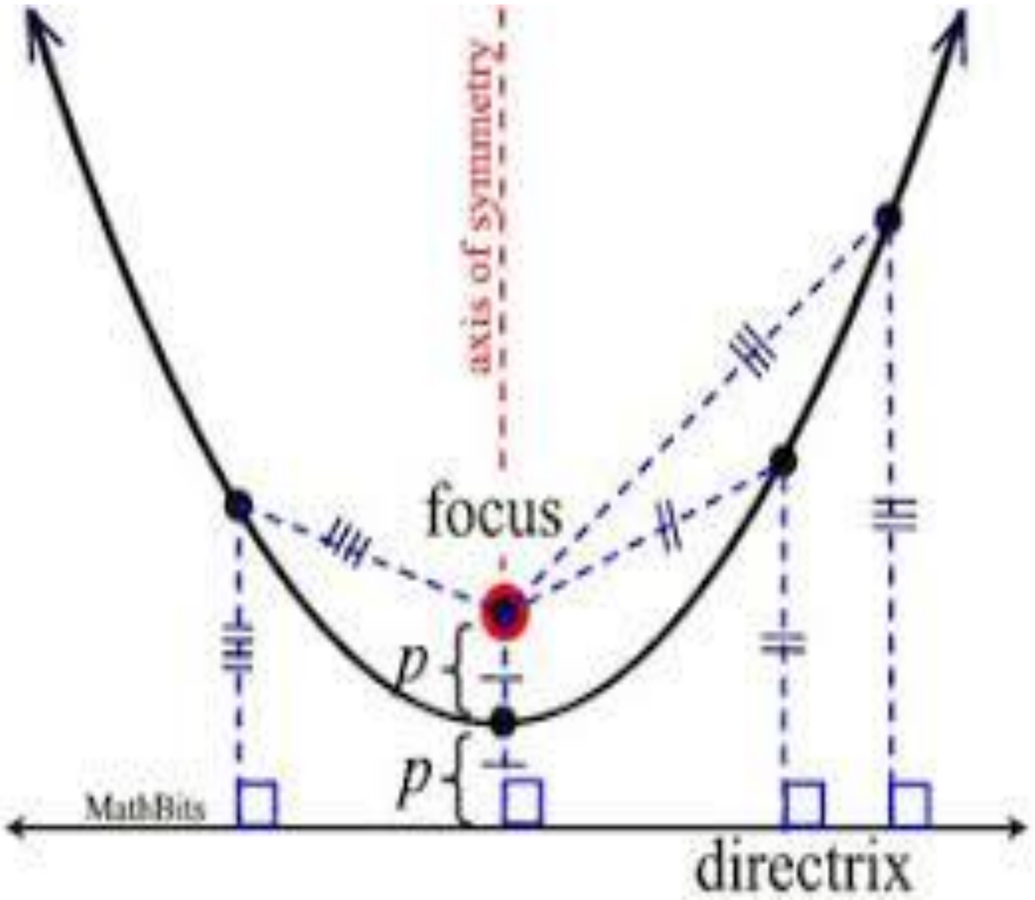
Large flat sheet
Small flat sheet
Thin linear reflector element
d
Linear antenna (driven element)
(a)
(b)
(c)
Active corner reflector
α
Aperture
Driven element
Passive corner reflector
90°
Aperture
Parabolic reflector
Driven element at focus
Aperture

Parabolic Refflector

- The law of reflection states that the angle of incidence and the angle of reflection are equal.
- This law when used along with a parabola, helps the beam focus.
- The shape of the parabola when used for the purpose of reflection of waves, exhibits some properties of the parabola, which are helpful for building an antenna, using the waves reflected

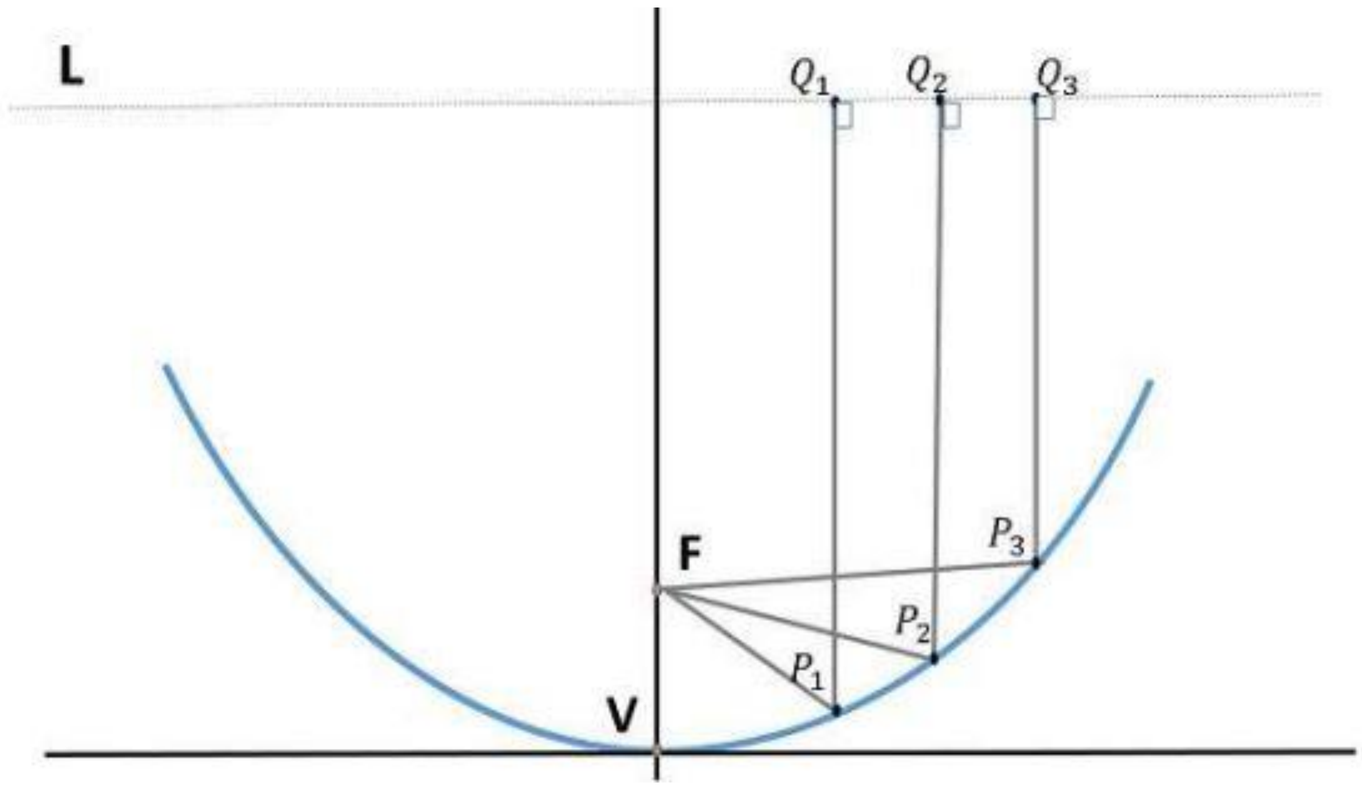
Properties of Parabola

- All the waves originating from focus, reflects back to the parabolic axis. Hence, all the waves reaching the aperture are in phase.
- As the waves are in phase, the beam of radiation along the parabolic axis will be strong and concentrated.
- Following these points, the parabolic reflectors help in producing high directivity with narrower beam width.


axis of symmetry
focus
p
p
MathBits
directrix

Principle of Operation

- The standard definition of a parabola is - Locus of a point, which moves in such a way that its distance from the fixed point (called focus) plus its distance from a straight line (called directrix) is constant.
- The figure shows the geometry of parabolic reflector. The point F is the focus (feed is given) and V is the vertex.
- The line joining F and V is the axis of symmetry. PQ are the reflected rays where L represents the line directrix on which the reflected points lie (to say that they are being collinear).
- Hence, as per the above definition, the distance between F and L lie constant with respect to the waves being focused
- The reflected wave forms a colllimated wave front, out of the parabolic shape



L
Q_1
Q_2
Q_3
F
P_3
P_2
P_1
V

- The ratio of focal length to aperture size (ie., f/D) known as “f over D ratio” is an important parameter of parabolic reflector.
- Its value varies from 0.25 to 0.50

Construction & Working of a Parabolic Reflector

- If a Parabolic Reflector antenna is used for transmitting a signal, the signal from the feed, comes out of a dipole or a horn antenna, to focus the wave on to the parabola.
- It means that, the waves come out of the focal point and strike the Paraboloidal reflector.
- This wave now gets reflected as collimated wave front, as discussed previously, to get transmitted.
- The same antenna is used as a receiver. When the electromagnetic wave hits the shape of the parabola, the wave gets reflected onto the feed point.
- The dipole or the horn antenna, which acts as the receiver antenna at its feed, receives this signal, to convert it into electric signal and forwards it to the receiver circuitry.

- The gain of the paraboloid is a function of aperture ratio (D/λ).
- The Effective Radiated Power (ERP) of an antenna is the multiplication of the input power fed to the antenna and its power gain.

Field of Refflector antenna

$$E_\theta = -j\,\frac{e^{-jkr}}{\lambda r}\,\frac{1+\cos\theta}{2}\left[f_A(\theta)+f_B(\theta)\right]\sin\phi$$

$$E_\phi = -j\,\frac{e^{-jkr}}{\lambda r}\,\frac{1+\cos\theta}{2}\left[f_A(\theta)-f_B(\theta)\right]\cos\phi$$

Advantages

- Reduction of minor lobes
- Wastage of power is reduced
- Equivalent focal length is achieved
- Feed can be placed in any location, according to our convenience
- Adjustment of beam (narrowing or widening) is done by adjusting the reflecting surfaces

Disadvantages

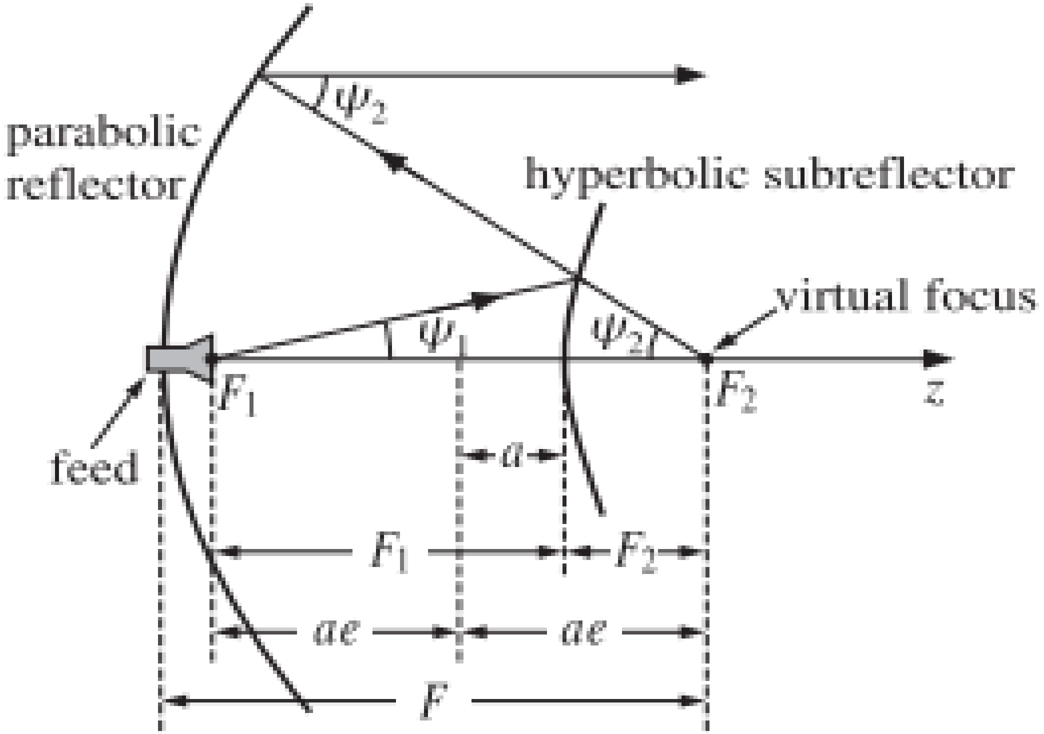
- Some of the power that gets reflected from the parabolic reflector is obstructed.
- This becomes a problem with small dimension paraboloid.

Applications

- The parabolic reflector is mainly used in satellite communications.
- Also used in wireless telecommunication systems.

Cassegrain Antenna

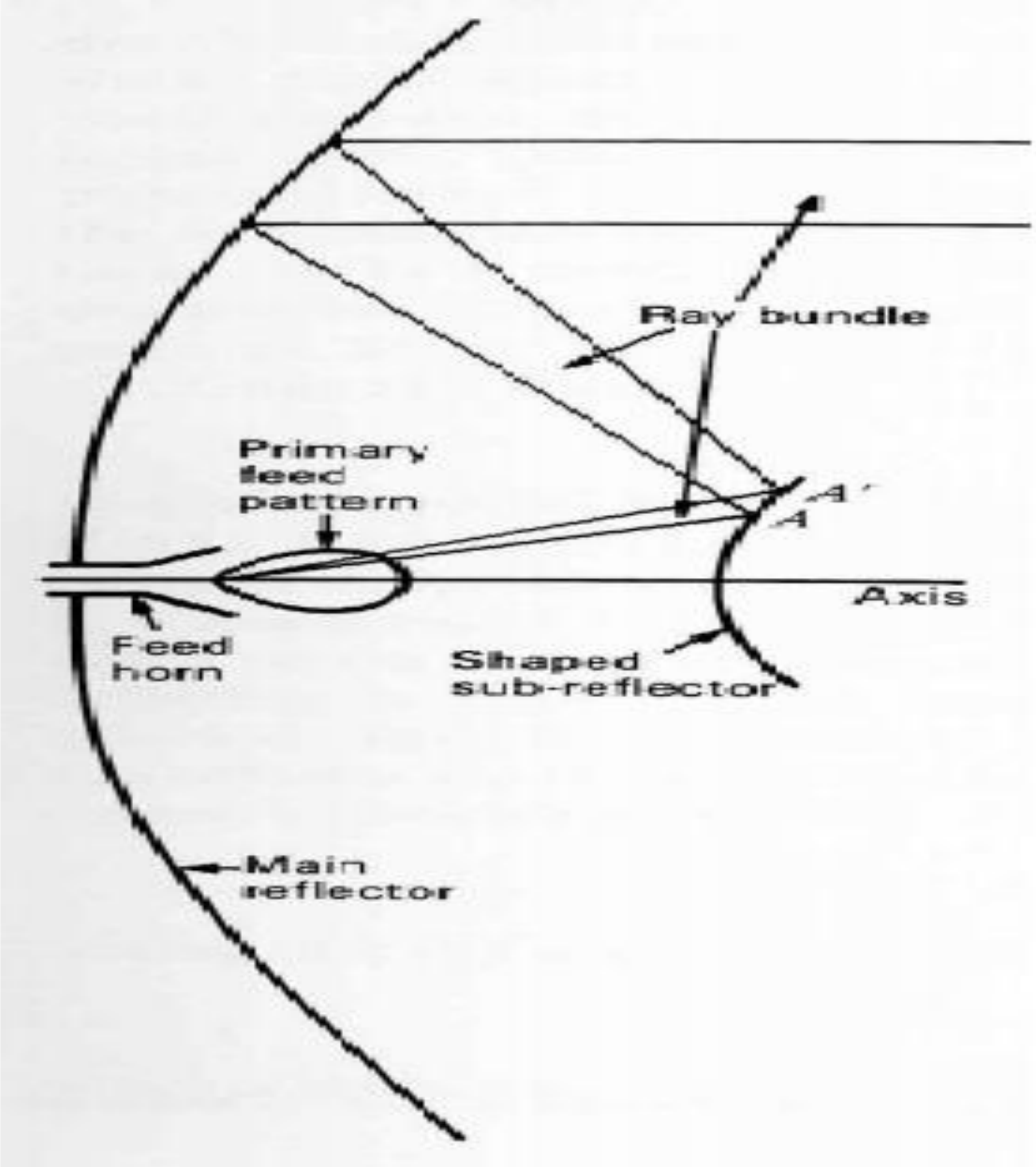
- Cassegrain is another type of feed given to the reflector antenna.
- In this type, the feed is located at the vertex of the paraboloid, unlike in the parabolic reflector.
- A convex shaped reflector, which acts as a hyperboloid is placed opposite to the feed of the antenna.
- It is also known as secondary hyperboloid reflector or sub-reflector.
- It is placed such that, its one of the foci coincides with the focus of the paraboloid.
- Thus, the wave gets reflected twice.



parabolic reflector
hyperbolic subreflector
virtual focus
feed
ψ_2
ψ_1
ψ_2
F_1
F_2
z
a
F_1
F_2
ae
ae
F

Working of a Cassegrain Antenna

- When the antenna acts as a transmitting antenna, the energy from the feed radiates through a horn antenna onto the hyperboloid concave reflector.
- which again reflects back on to the parabolic reflector.
- The signal gets reflected into the space from there. Hence, wastage of power is controlled and the directivity gets improved.
- When the same antenna is used for reception, the electromagnetic waves strike the reflector, gets reflected on to the concave hyperboloid and from there, it reaches to the feed.
- A wave guide horn antenna presents there to receive this signal and sends to the receiver circuitry for amplification



Ray bundle
Primary
feed
pattern
A'
A
Axis
Feed
horn
Shaped
sub-reflector
Main
reflector

- The focus F2 is referred to a “virtual focus” of the parabola.
- Any ray originating from the point F1 will be reflected by the hyperbola in a direction that appears to have originated from the focus F2, and therefore, it will be re-reflected parallel to the parabola’s axis.
-

Field of Cassegrain Antenna

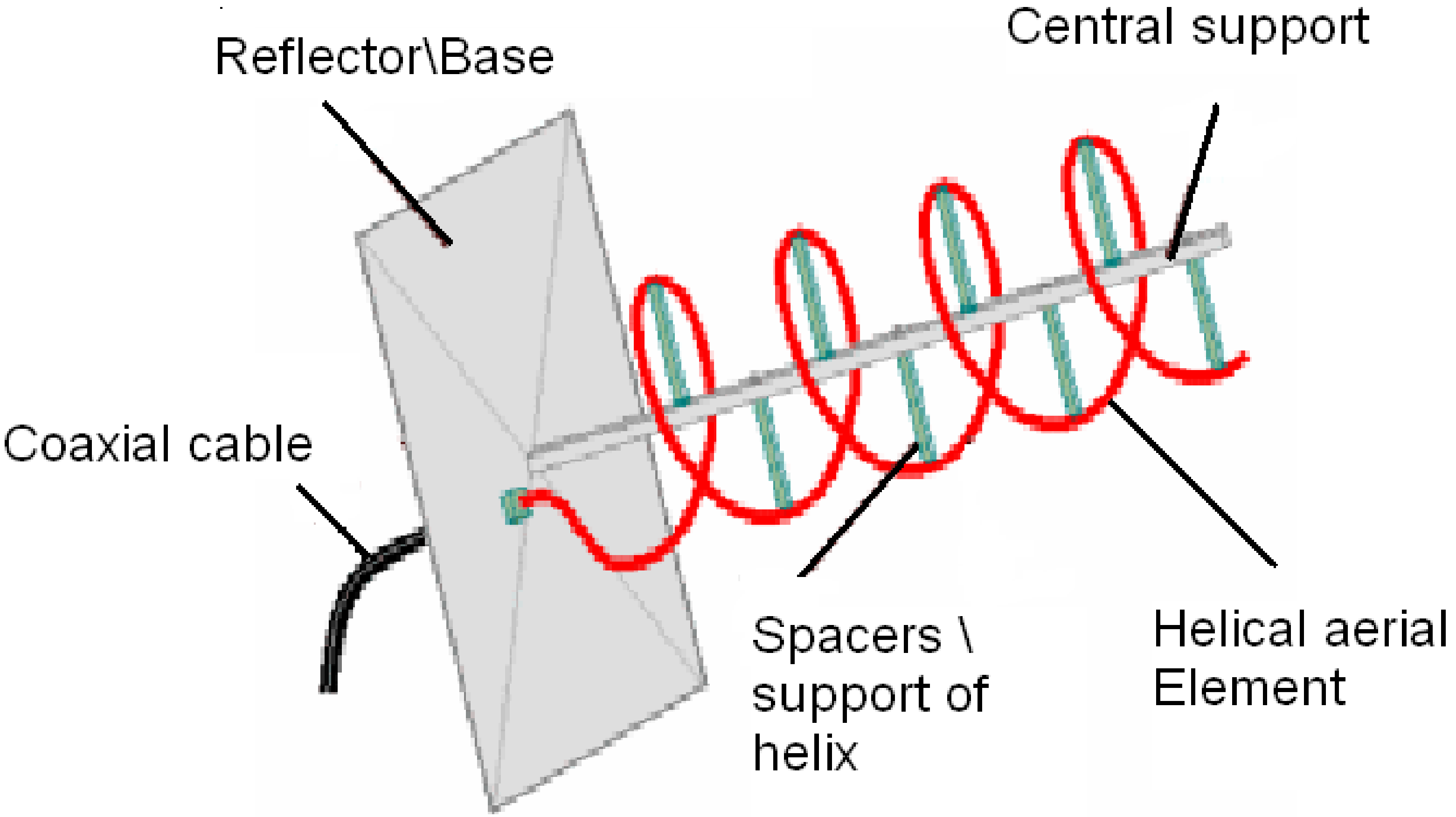
$$|\boldsymbol{E}_a| = \frac{1}{2F}\,(1+\cos\psi_2)\,\sqrt{2\eta U_2(\psi_2,\chi)}$$

Helical Antenna

- Helical antenna is an example of wire antenna and itself forms the shape of a helix.
- This is a broadband VHF and UHF antenna.
- The frequency range of operation of helical antenna is around 30MHz to 3GHz. This antenna works in VHF and UHF ranges.
- Helical antenna or helix antenna is the antenna in which the conducting wire is wound in helical shape and connected to the ground plate with a feeder line.
- It is the simplest antenna, which provides circularly polarized waves. It is used in extra-terrestrial communications in which satellite relays etc., are involved.


www.antenna-theory.com

Construction



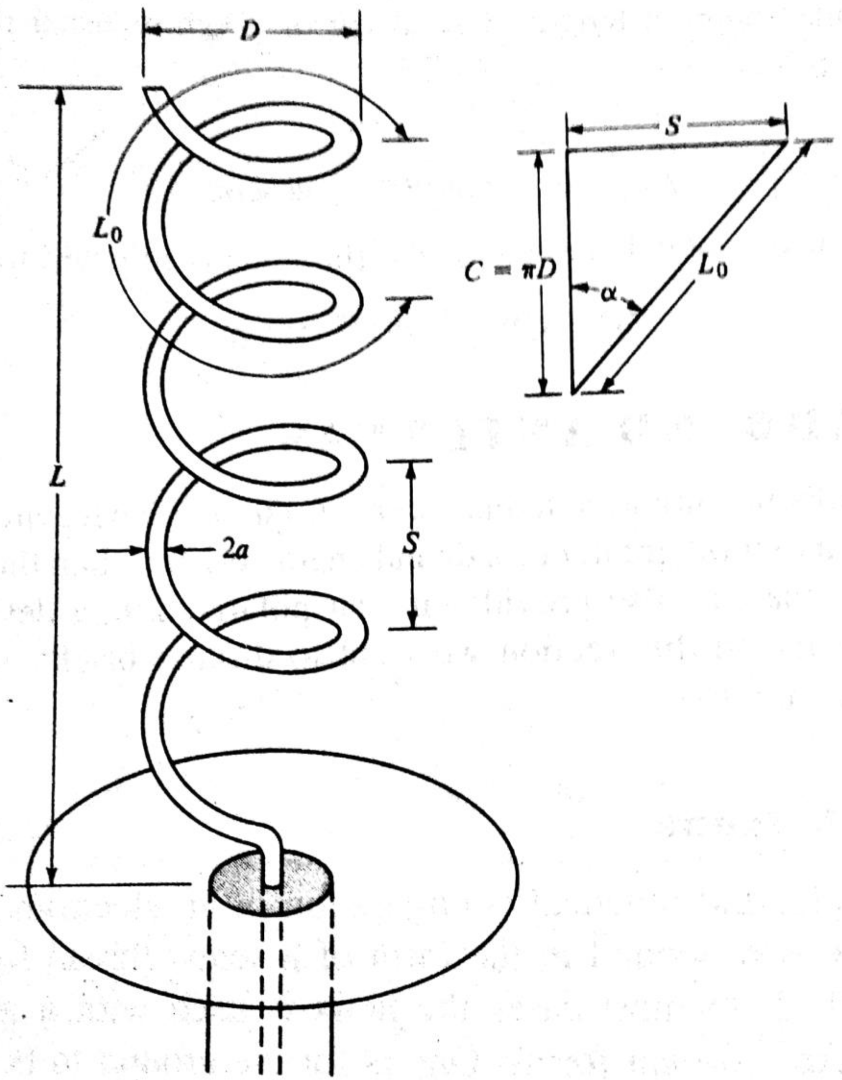


Figure 10.13 Helical antenna with ground plane.

- These antennas require wider outdoor space
- It consists of a helix of thick copper wire or tubing wound in the shape of a screw thread used as an antenna in conjunction with a flat metal plate called a ground plate.
- One end of the helix is connected to the center conductor of the cable and the outer conductor is connected to the ground plate.
- The radiation of helical antenna depends on the diameter of helix, the turn spacing and the pitch angle.
- Pitch angle is the angle between a line tangent to the helix wire and plane normal to the helix axis.

Pitch Angle

$$\alpha = tan^{-1}\left(\frac{s}{\pi d}\right)$$

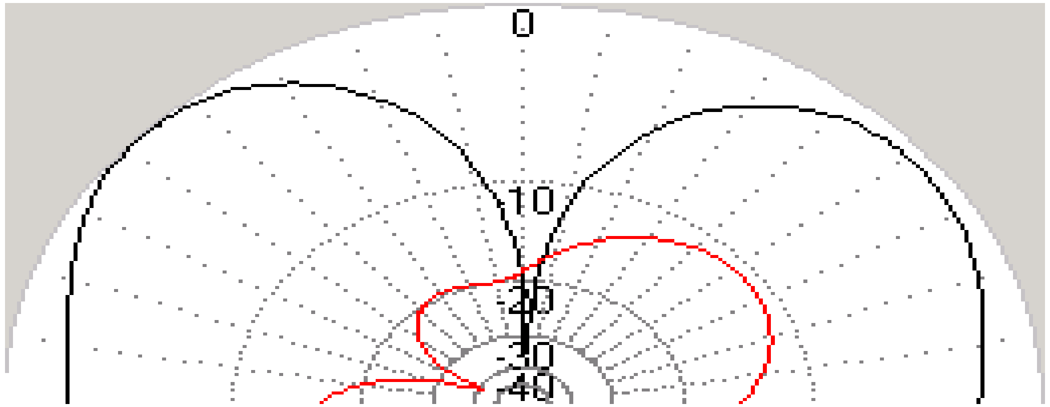
where,

- d is the diameter of helix.
- S is the turn spacing (centre to centre).
- α is the pitch angle .

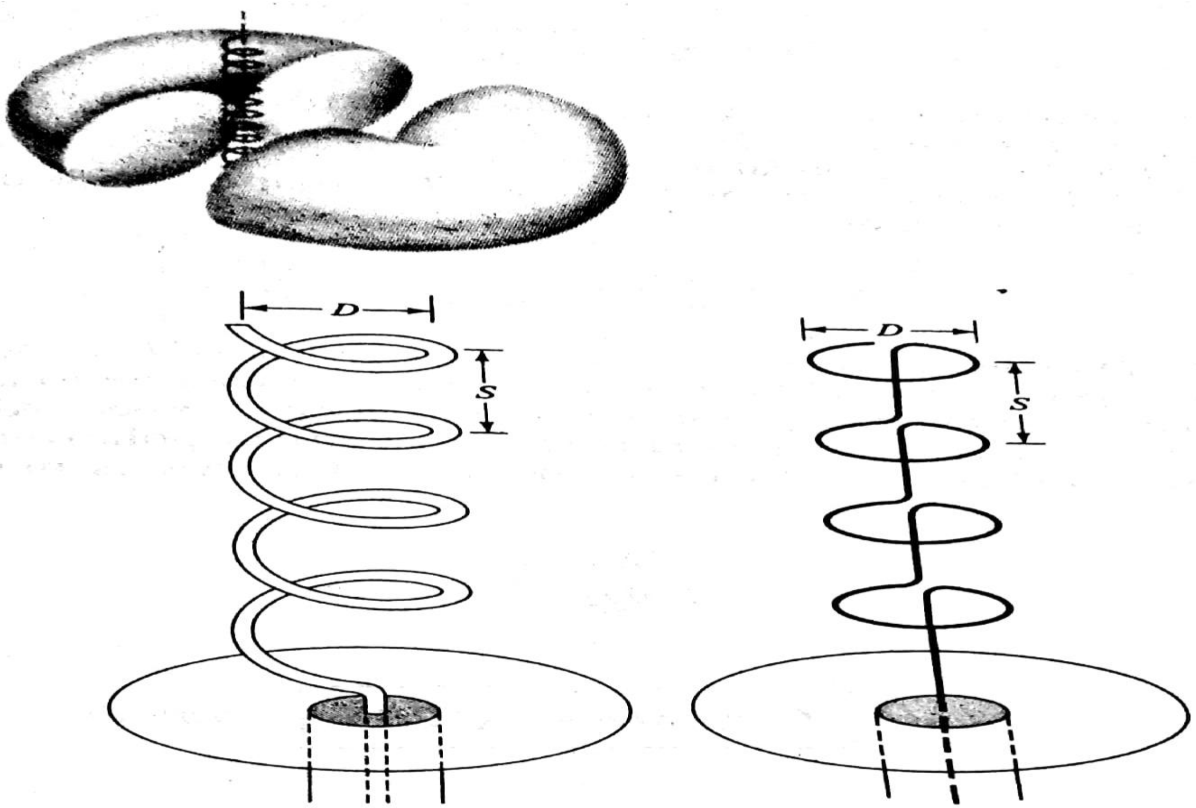
Modes of Operation

- The predominant modes of operation of a helical antenna are
- Normal or perpendicular mode of radiation.
- Axial or end-fire or beam mode of radiation.
- In **normal mode** of radiation, the radiation field is normal to the helix axis.
- The radiated waves are circularly polarized. This mode of radiation is obtained if the dimensions of helix are small compared to the wavelength.
- The radiation pattern of this helical antenna is a combination of short dipole and loop antenna.
- Typically used mobile communication

- It depends upon the values of diameter of helix, D and its turn spacing, S.
- Drawbacks of this mode of operation are low radiation efficiency and narrow bandwidth. Hence, it is hardly used.



Normal Mode

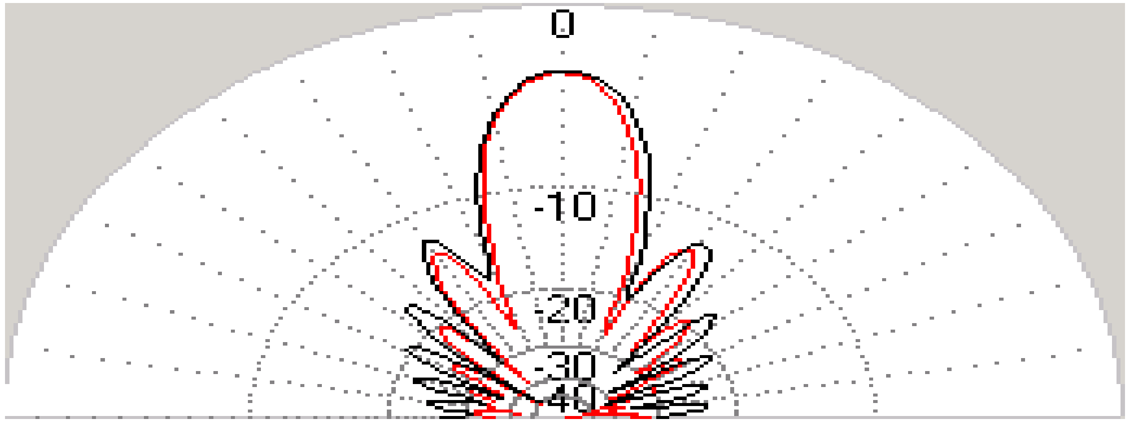


(a) Normal mode (b) Equivalent

Figure 10.14 Normal (broadside) mode for helical antenna and its equivalent.

- In axial mode of radiation, the radiation is in the end-fire direction along the helical axis and the waves are circularly or nearly circularly polarized.
- This mode of operation is obtained by raising the circumference to the order of one wavelength (λ) and spacing of approximately λ/4.
- The radiation pattern is broad and directional along the axial beam producing minor lobes at oblique angles.
- These antenna are best suited for space communication

- If this antenna is designed for right-handed circularly polarized waves, then it will not receive left-handed circularly polarized waves and vice versa.
- This mode of operation is generated with great ease and is more practically used.



Axial Mode

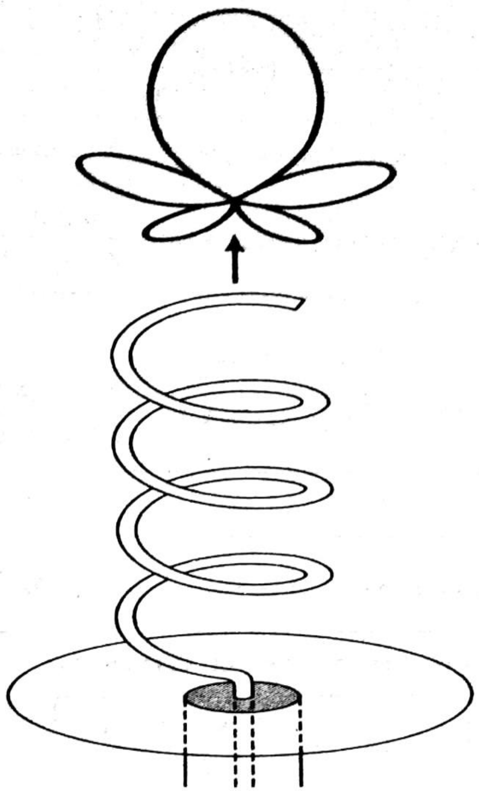


Figure 10.15 Axial (endfire) mode of helix.

Field From a Helical antenna in Normal Mode

$$E = \sin\left(\frac{\pi}{2N}\right) \cos\theta \frac{\sin[(N/2)\psi]}{\sin[\psi/2]}$$

where

$$\psi = k_0\left(S \cos\theta - \frac{L_0}{p}\right)$$

$$p = \frac{L_0/\lambda_0}{S/\lambda_0 + 1}$$

For ordinary end-fire radiation

Field from a helical antenna in axial Mode

$$E_\phi = \eta \frac{k^2(D/2)^2 I_0 e^{-jkr}}{4r} \sin\theta$$

$$E_\theta = j\eta \frac{kI_0Se^{-jkr}}{4\pi r} \sin\theta$$

Axial ratio

$$\boxed{\mathrm{AR} = \frac{|E_\theta|}{|E_\phi|} = \frac{4S}{\pi k D^2} = \frac{2\lambda S}{(\pi D)^2}}$$

Beam widths

$$\boxed{\text{HPBW (degrees)} \simeq \frac{52\lambda^{3/2}}{C\sqrt{NS}}}$$

$$\boxed{\text{FNBW (degrees)} \simeq \frac{115\lambda^{3/2}}{C\sqrt{NS}}}$$

Where

$$C = \pi D = \sqrt{2S\lambda}$$

Directivity

$$D_0 \text{ (dimensionless)} \simeq 15N\frac{C^2S}{\lambda^3}$$

Advantages

- Simple design
- Highest directivity
- Wider bandwidth
- Can achieve circular polarization
- Can be used at HF & VHF bands also

Disadvantages

- Antenna is larger and requires more space
- Efficiency decreases with number of turns

Applications

- A single helical antenna or its array is used to transmit and receive VHF signals
- Frequently used for satellite and space probe communications
- Used for telemetry links with ballistic missiles and satellites at Earth stations
- Used to establish communications between the moon and the Earth
- Applications in radio astronomy

Log Periodic Dipole Array

- One form of antenna that is able to provide gain and directivity along with a wide bandwidth is known as the log periodic antenna or Log periodic dipole array.
- It provides the capability to operate on many different frequencies.
- The antenna is frequency independent
- The antenna should expand or contract its electrical length in proportion to wavelength
- The basic idea is that a gradually expanding periodic structure
- The array radiates most effectively when array elements are near resonance.
- With respect to the changing frequency active region moves along the array.

Structure of Log Periodic Dipole Array

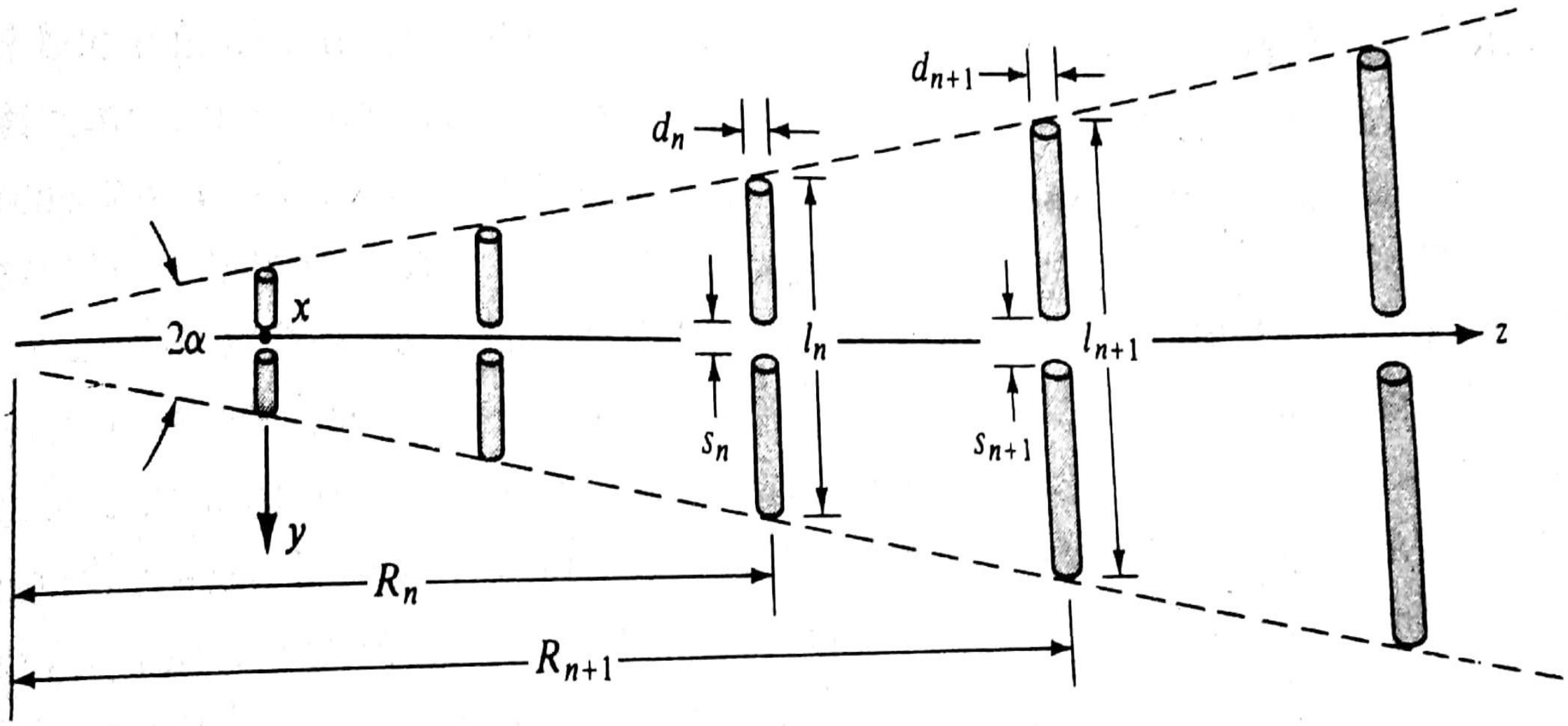
- The lengths, spacing, diameters, gap spacing at dipole centers of LPDA increase logarithmically as defined by inverse logarithmic ratio τ

$$\boxed{\frac{1}{\tau} = \frac{l_2}{l_1} = \frac{l_{n+1}}{l_n} = \frac{R_2}{R_1} = \frac{R_{n+1}}{R_n} = \frac{d_2}{d_1} = \frac{d_{n+1}}{d_n} = \frac{s_2}{s_1} = \frac{s_{n+1}}{s_n}}$$

- Another parameter associated with dipole array is spacing factor σ

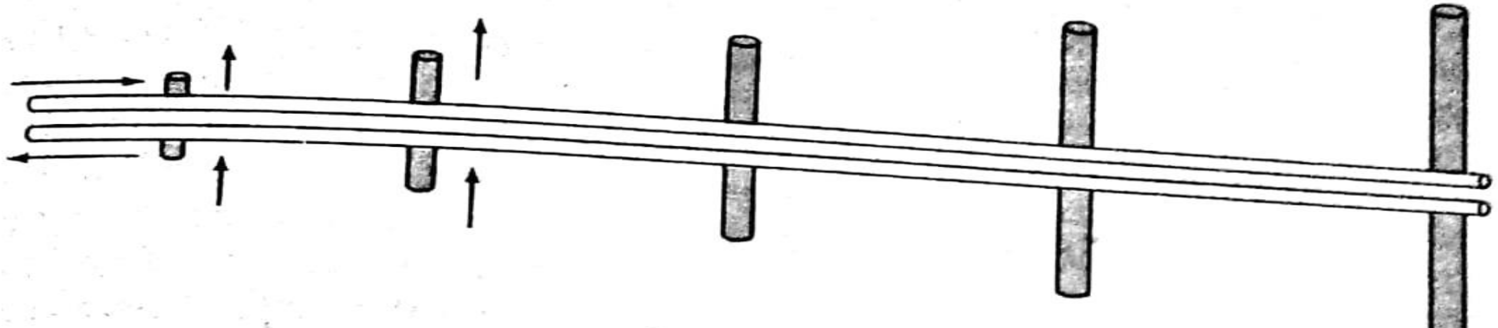
$$\boxed{\sigma = \frac{R_{n+1} - R_n}{2l_{n+1}}}$$

- For Practical dipole arrays the diameters and dipole center gap spacing are kept constant since it is very difficult to keep and also these factors willnot sufficientrly degrade the overall performance

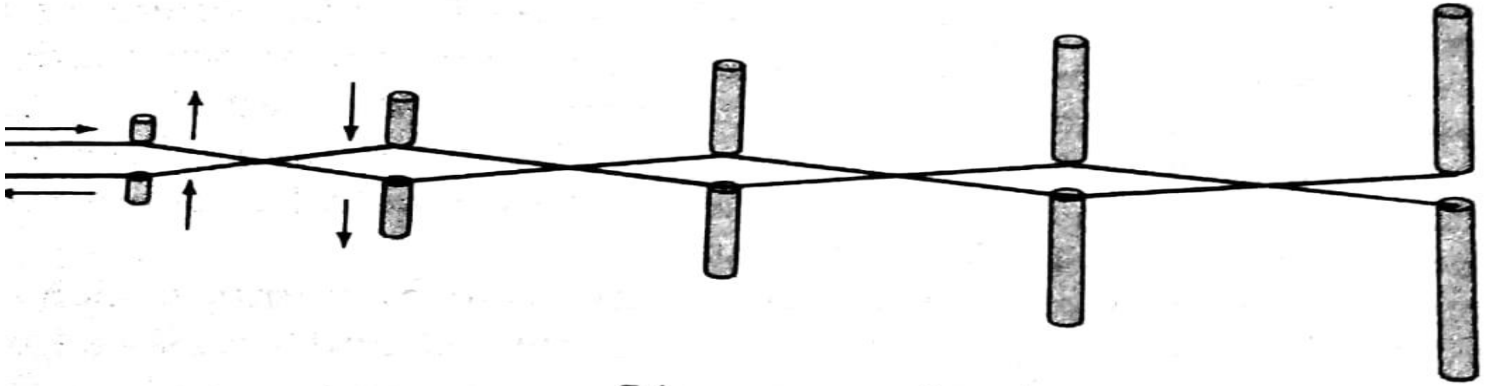


Dipole array

- All the elements of LPDA are connected to the feeder
- The feeding can be of 2 types

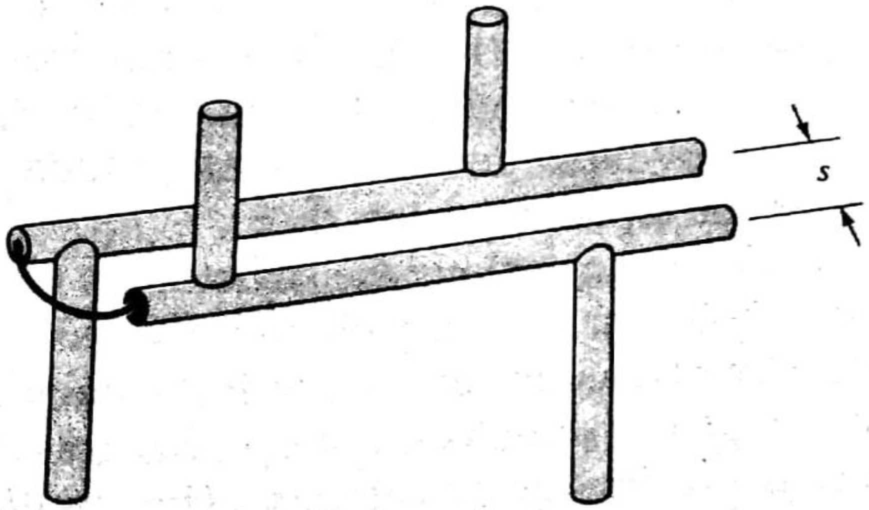


Straight connection

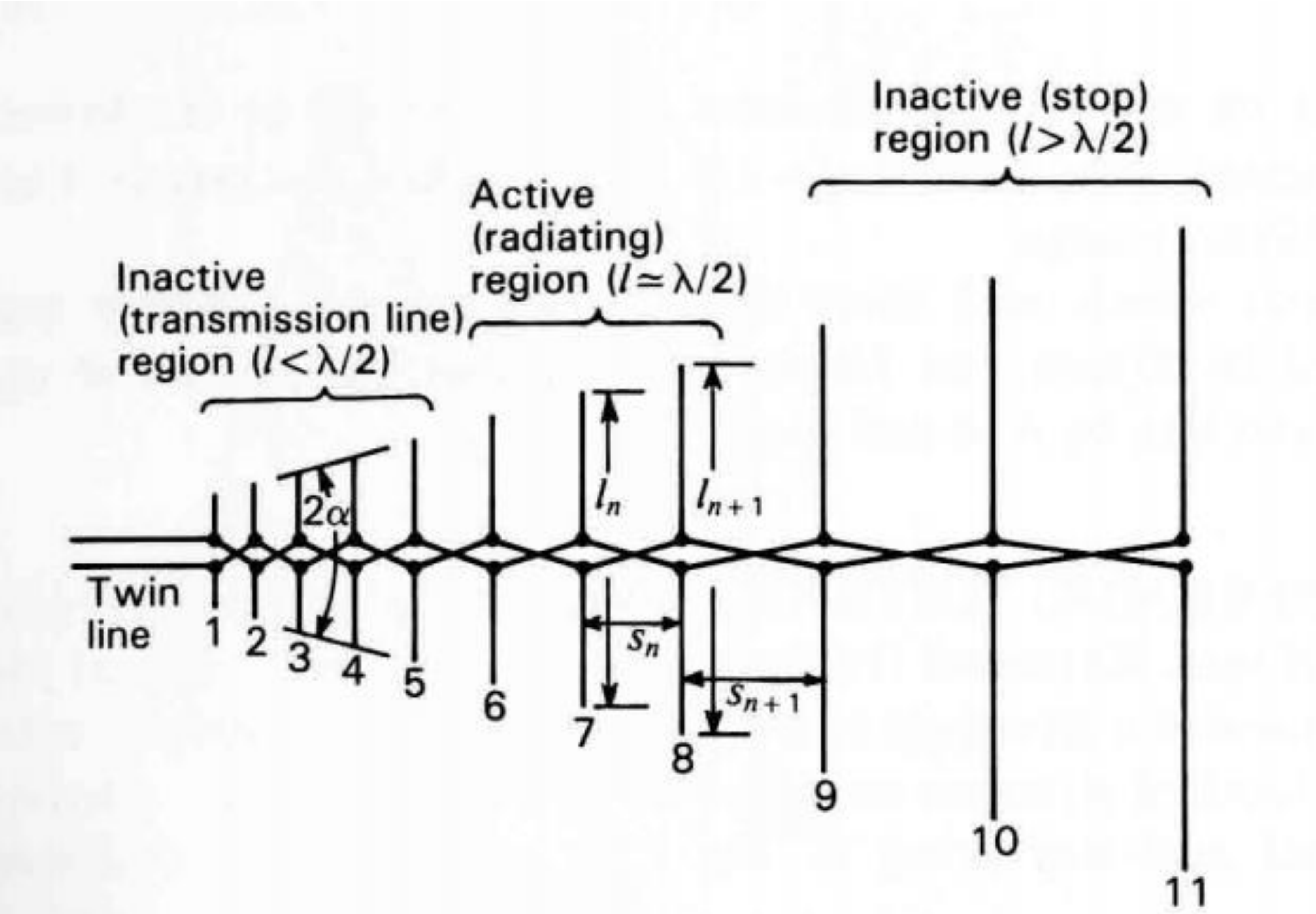


Crisscross connection

- In **straight connection** all the elements fed with in-phase current
- The radiation will be endfire beam in the direction of longer elements
- In **crisscross connection** elements fed with 180 degree out of phase current
- The radiation will be endfire beam in the direction of Shorter elements with less interference
- For feeder lines coaxial cables can also be used



Coaxial connection


Inactive (stop)
region ($l > \lambda/2$)
Active
(radiating)
region ($l \simeq \lambda/2$)
Inactive
(transmission line)
region ($l < \lambda/2$)
2α
l_n
l_{n+1}
Twin
line
1
2
3
4
5
6
7
8
9
10
11
s_n
s_{n+1}

- At wavelength nearer to middle of operating range radiation occurs primarily from the central region of the antenna as shown in figure, known as active region
- The elements on right side of active region have larger electrical dimension (order of 1λ) and they carry smaller current and present more inductive reactance ,thus weak radiation.
- Elements on left side of active region have dimension less than λ/2 present a large capacitive reactance to the line hence current is small and radiation is weak.

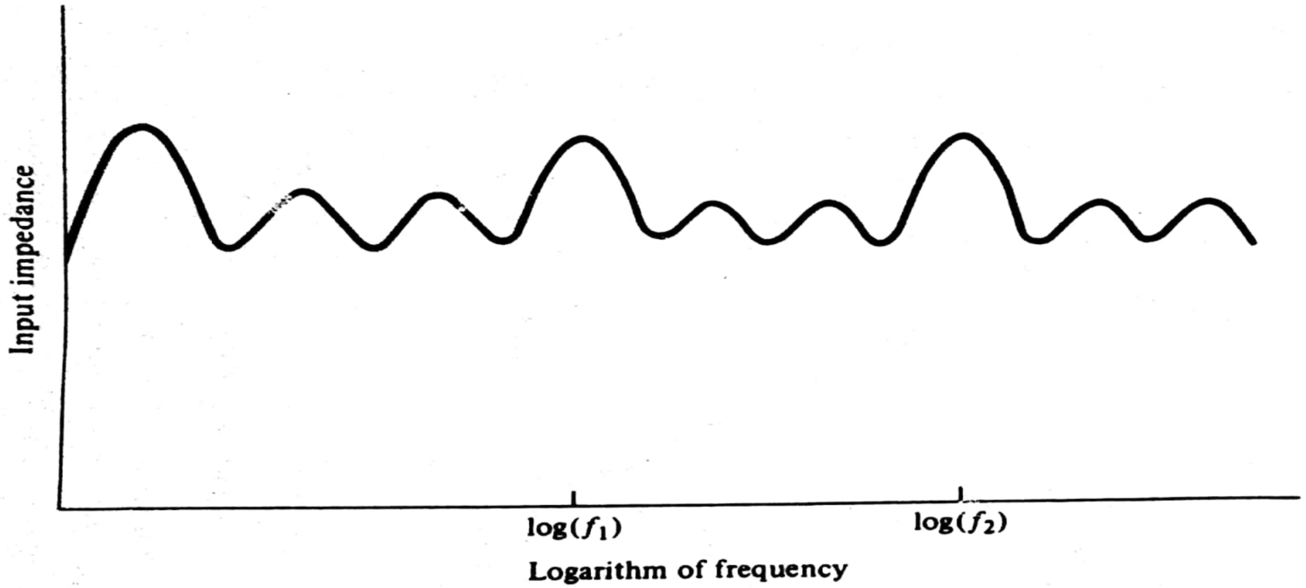
Regions of operation

- Inactive Transmission line region (L < λ/2)
    - Antenna elements are electrically shorter than resonant length
    - Present capacitive impedance to the transmission line
    - Since the smaller element current leads the supply voltage by 90 degree
    - Since the current is small this region present a small radiation
- Active Region (L = λ/2)
    - Antenna elements having near resonant length
    - Impedance offered by dipole elements of this region is resistive in nature
    - Element current is large and in-phase with supply voltage
    - Thus will radiate a strong beam

- Inactive reflective region (L > λ/2)
  - Element length is longer than resonant length
  - Current lag base voltage
  - Impedance becomes inductive
- Radiate small beam
- The cut-off frequencies of LPDA can be determined by electrical lengths of longest and shortest elements of the structure
- The higher cutoff is when shortest element is near λ/2
- The lower cutoff is when highest element is near λ/2
- The radiated wave of a LPDA is linearly polarized, it has horizontal polarization when plane of antenna is parallel to ground

Periodicity of LPDA

- If the input impedance of LPDA is plotted as a function of logarithm of frequency then it will be periodic hence the name
- Pattern, directivity, beam width and side lobe level also follows the same



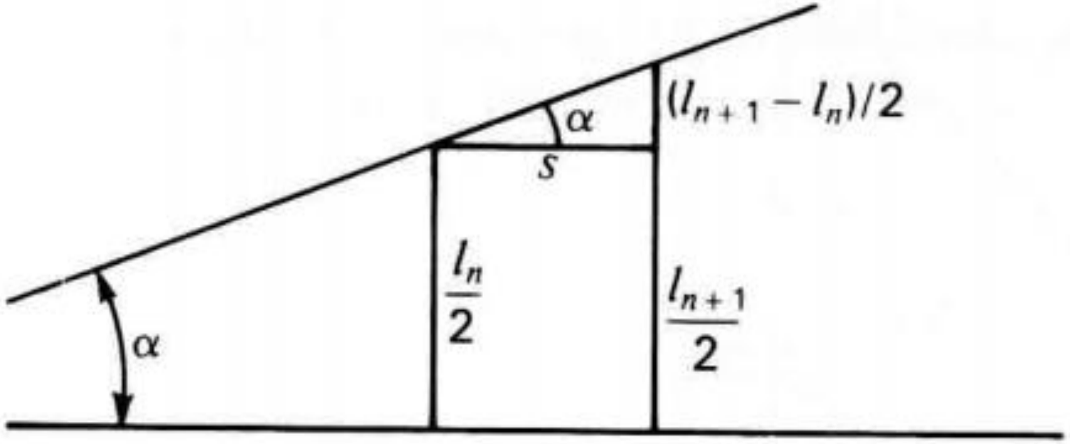
- The relative frequency period (Δ) is given as

$$\Delta = \log(f2) - \log(f1)$$

$$\Delta = \log(f2/f1)$$

$$\Delta = \log(1/\tau) \text{ where } f2/f1 = 1/\tau$$

- Typical values of α lies between 10 degree and 45 degree
- Typical values of τ lies between 0.7 and 0.95
- As α increases corresponding τ decreases and viceversa



$(l_{n+1} - l_n)/2$
α
s
$\frac{l_n}{2}$
$\frac{l_{n+1}}{2}$
α

- When the wavelength increases the radiation zone moves to the right when the wavelength is decreased it moves to the left with maximum radiation toward the apex or feed point of the array
- At any given frequency only a fraction of the antenna is used, where the dipoles are about λ /2 long.
- From design,

$$\tan \alpha = \frac{(l_{n+1} - l_n)/2}{s}$$

$$\tan \alpha = \frac{[1 - (1/k)](l_{n+1}/2)}{s}$$

Taking $l_{n+1} = \lambda/2$ (when active) we have

$$\tan \alpha = \frac{1 - (1/k)}{4s_\lambda}$$

where α = apex angle
k = scale factor
s_λ = spacing in wavelengths shortward of $\lambda/2$ element

Antennas for Mobile Communication Systems

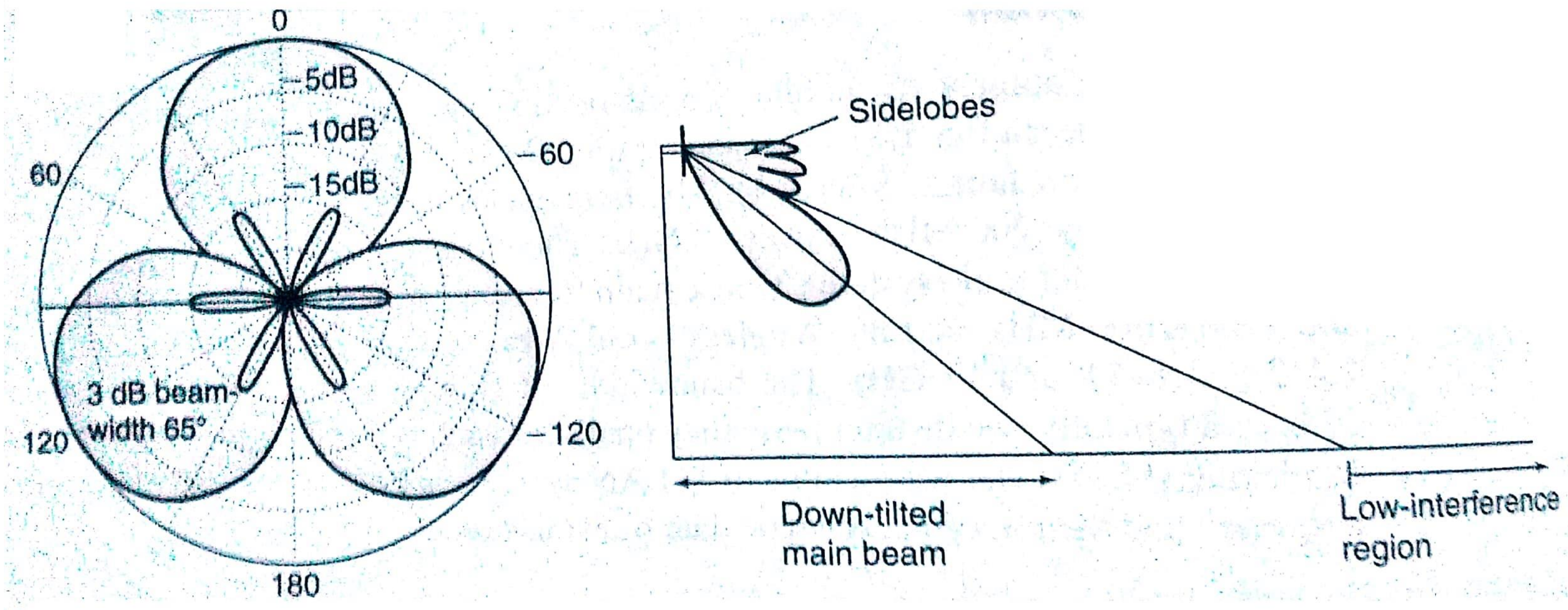
- The revolution of mobile communication systems has led to the use of novel antennas for base stations (BS) and mobile station/ handset (MS)
- For terrestrial mobile communication the frequencies ranges from 200 MHz to 60 GHz
- In Cellular mobile communication frequency ranges from 800-1000 MHz and 1700-2200 MHz
- In WLAN around 2.4-2.5, 5.1-5.8 and 17 GHz
- In mobile communication the BS antennas must be highly directive and handset antennas must be compact

Base Station Antennas

- The BS antennas should direct the signals to the wanted coverage area as effectively as possible
- But the distribution of power must be restricted accurately in order to minimize the frequency reuse distance in the system
- Base station antennas can be classified into adaptive base station antenna and non adaptive base station antenna
- In non adaptive BS antennas the antenna performance is fixed and won’t change according to the instantaneous requirements of the system
- But the adaptive BS antenna Changes its parameters to improve Signal-to-Interference and noise ratio (SINR)

Non Adaptive BS antennas

- Typical values of gain is 5 to 17 dB
- The horizontal plane beam width varies between 50 degrees and 360 degrees
- Vertical beam width varies between 10 degree and 70 degree
- For making the coverage area high, the horizontal beam width is increased(Horizontal directivity is reduced) at the expense of vertical beam width
- The beam of BS antennas maybe tilted down (typically less than 15 degrees) to reduce the interference level in neighboring cells.



Typical beam patterns for base station antennas: (*a*) horizontal plane pattern for a 3-sector base station site, (*b*) vertical plane pattern.

- Common aspects of BS antennas are Weight, wind load, size, appearance, radiation characteristics and bandwidth
- Common types are dipoles, corner reflectors, patch antenna arrays and horn antennas
- In indoor environments leaky lines can be employed as BS antenna
- A leaky line is a coaxial cable with leaky outer conductor
- To reduce the multipath effects diversity techniques are employed in BS receivers
- Antenna diversity is a prominent diversity technique employed in wireless receivers.
- Several receiving antennas are employed to obtain independent samples of the incoming field
- It is extremely to unlikely to occur deep fading in all these samples simultaneously

- The diversity gain depends on probability distribution of fading, number of diversity branches, correlation between signals in each diversity branches, signal level and diversity combining technique employed
- The maximal ratio combining method will give highest diversity gain
- The most popular diversity technique used in BS are Space and polarization diversity
- In Space diversity the low correlation between signals are obtained by locating antennas far enough from each other
- In Polarization diversity each diversity antenna is employed with differently polarized waves which is more suitable in urban area in which the antennas are closely placed

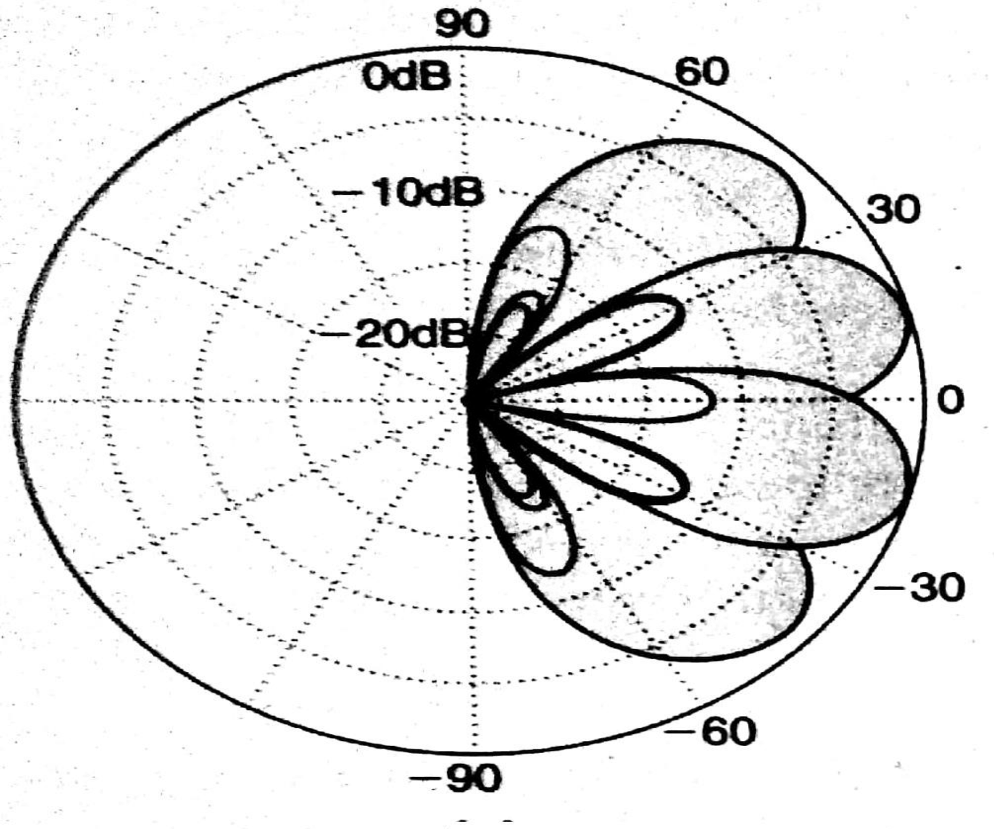
Adaptive BS antennas

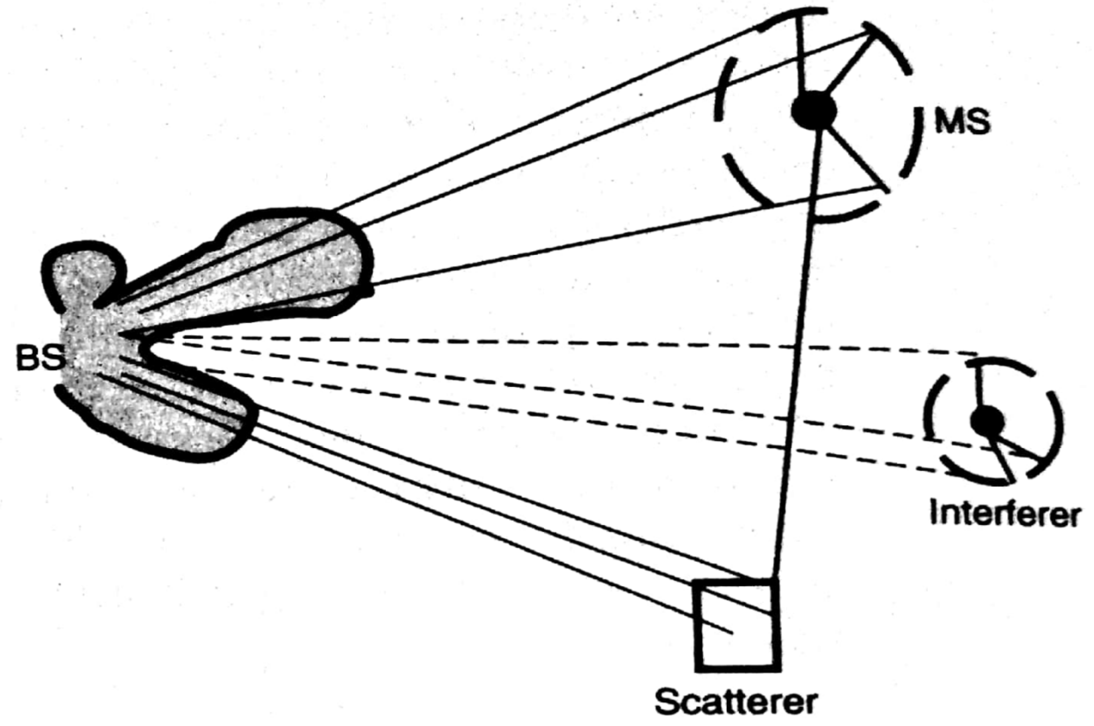
- Adaptive BS antenna will improve SINR of single connection to maximize the coupling between the BS and the wanted user while minimizing the coupling with other user
- This is accomplished in both uplink and downlink
- But In downlink the optimization is more critical since the MS cannot detect the channel fully
- Advantages
  - Increased capacity due to Increased SINR
  - Increased coverage due to higher gain
  - Reduced output power

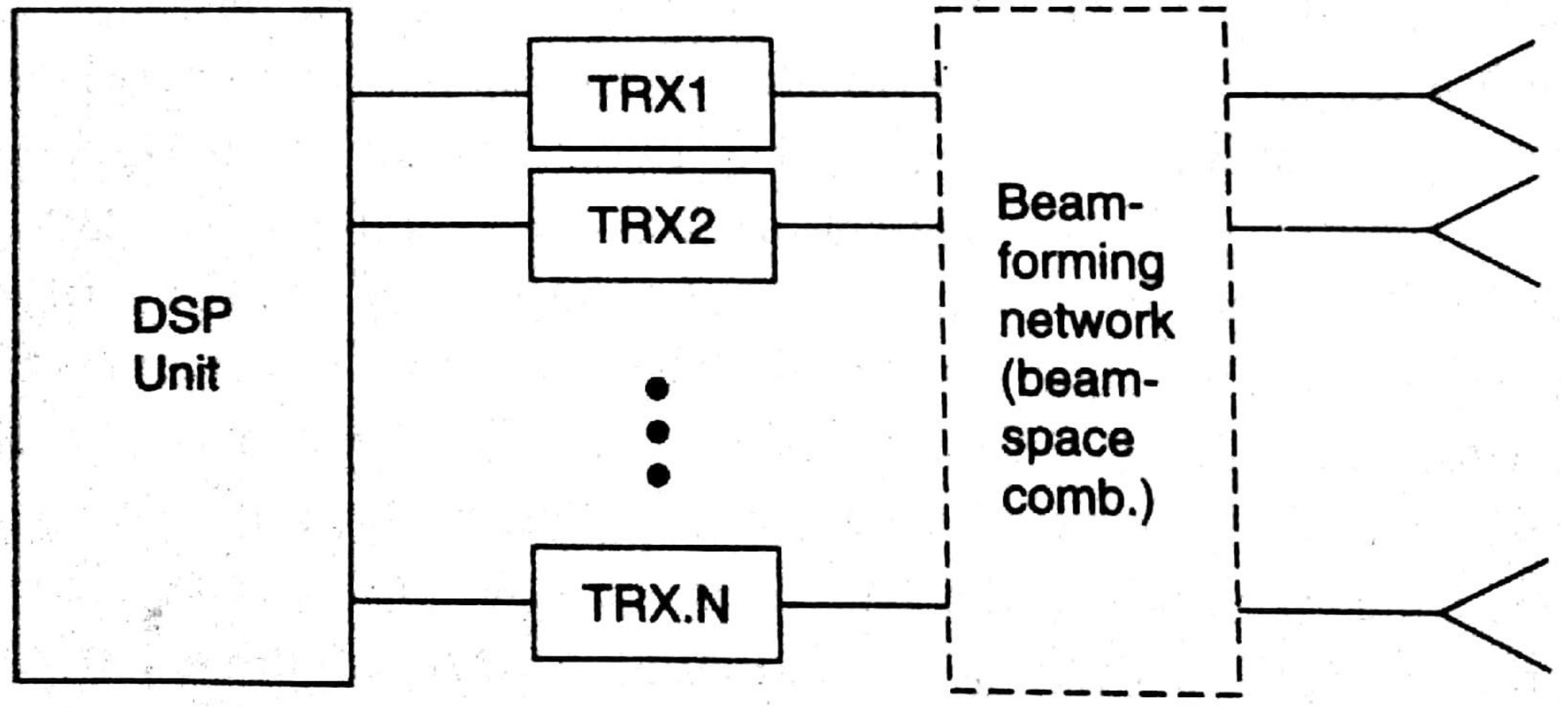
Types

- **Switched beam antenna:**
- The adaption in changing MS distribution is done using a BS antenna with several selectable beams
- Fairly simple RF signal processing is required
- Limited adaptivity
- **Beamforming:**
- Adaption is done using beamforming in which form pattern maxima to wanted directions and nullls to unwanted directions

- **Adaptive Array:**
- Here an adaptive array is employed in which each array element is connected to a separate transceiver and a DSP Unit is used to control signal weigths







DSP
Unit
TRX1
TRX2
TRX.N
Beam-
forming
network
(beam-
space
comb.)

Mobile Station Antennas

- The antenna for mobile phone should enable connection to the base station in all location and orientation of mobile unit.
- For small cellular hand sets incoming field consists of several multipath signals with random directions of arrival and polarization.
- So stating any clear requirement for handset antenna is impossible
- Most preferable antennas are vertically polarized omnidirectional antennas such as vertical dipole
- The most critical goals for MS antenna design are adequate bandwidth and high efficiency, which are difficult to achieve simultaneously for smaller antennas

Bandwidth of smaller antennas

$$BW = \frac{S-1}{Q_u\sqrt{S}} \tag{1}$$

where

BW = relative impedance bandwidth, dimensionless
S = $VSWR$ at the edge of the frequency band, dimensionless
Q_u = unloaded quality factor of the antenna, dimensionless

Types of antennas in Cellular Handsets

- Since the volume of Cellular Handset is very smaller the antenna volume should be very smaller for a compact Phone.
- This smaller size makes it difficult to achieve system bandwidths 10% without inducing currents on entire handset chassis.
- For overcoming the situation earlier handsets make use of retractable antennas which can provide large bandwidth with comparatively smaller effective volume.

Antennas for mobile handsets

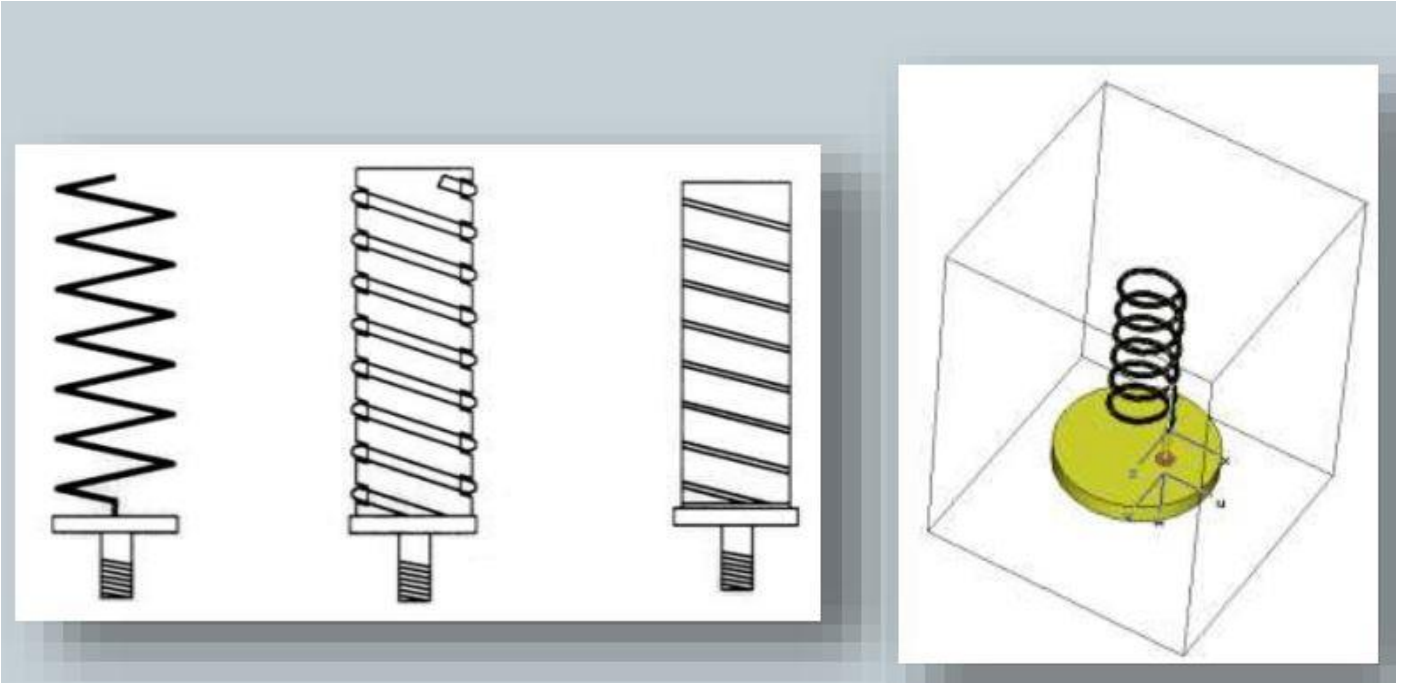
- Following are some of the antennas used in cellular phones:
- External Antennas
  - Retractable whip antennas
  - Helical antennas
- Internal Antennas
  - Planar antennas
  - Chip antennas

Retractable Monopole Antenna

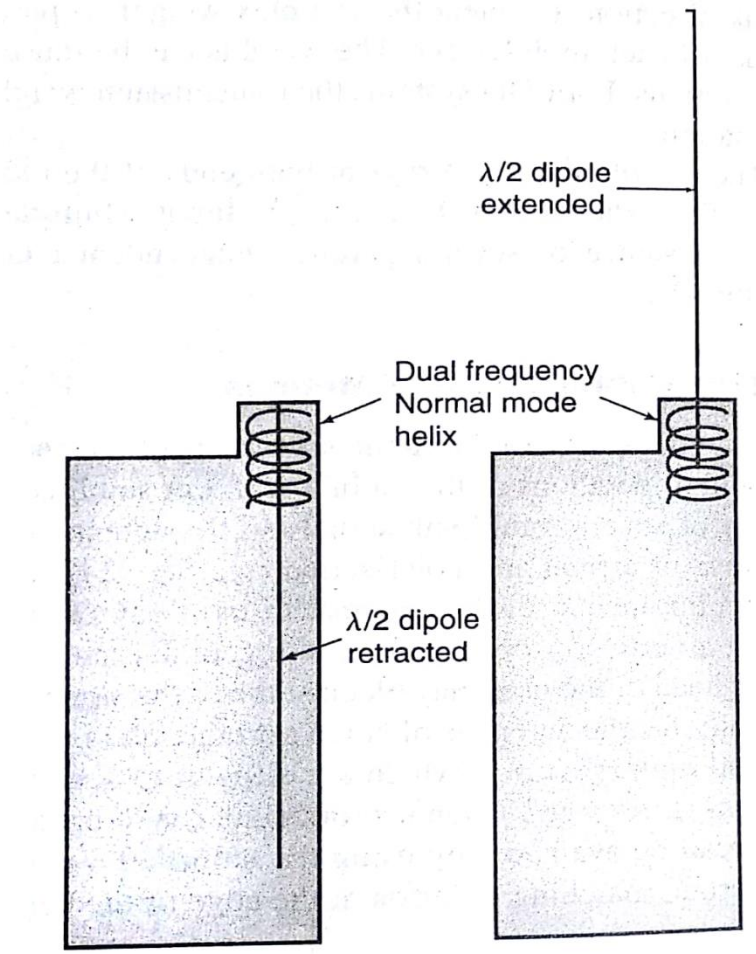
- An antenna that we can retract.
- Retractable whip antenna can be considered as a monopole with phone chassis as the ground plane or an unsymmetrical dipole whose other half is the phone chassis
- Typical length of whip is λ/4 or 3λ/8, these lengths are chosen such that the current maxima should be farther away from the user and to reduce current in phone chassis.

Normal Mode Helical Antenna

- A normal mode helical antenna can be used for circular polarization
- Dual band operation is obtained by using 2 different pitch angles
- It is convenient for users.



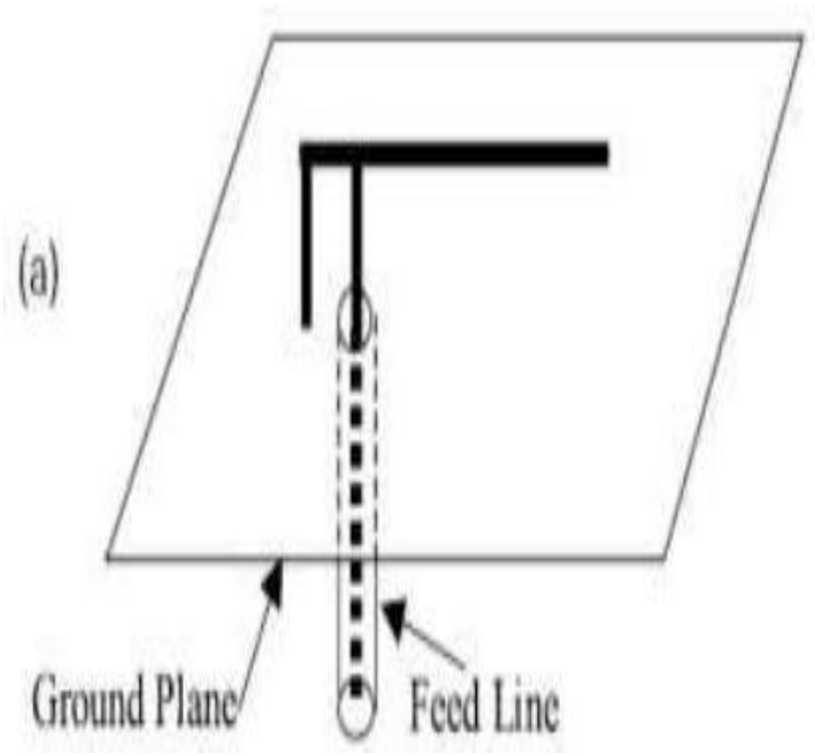
Handset with dual frequency normal-mode helix and λ/2 dipole extended

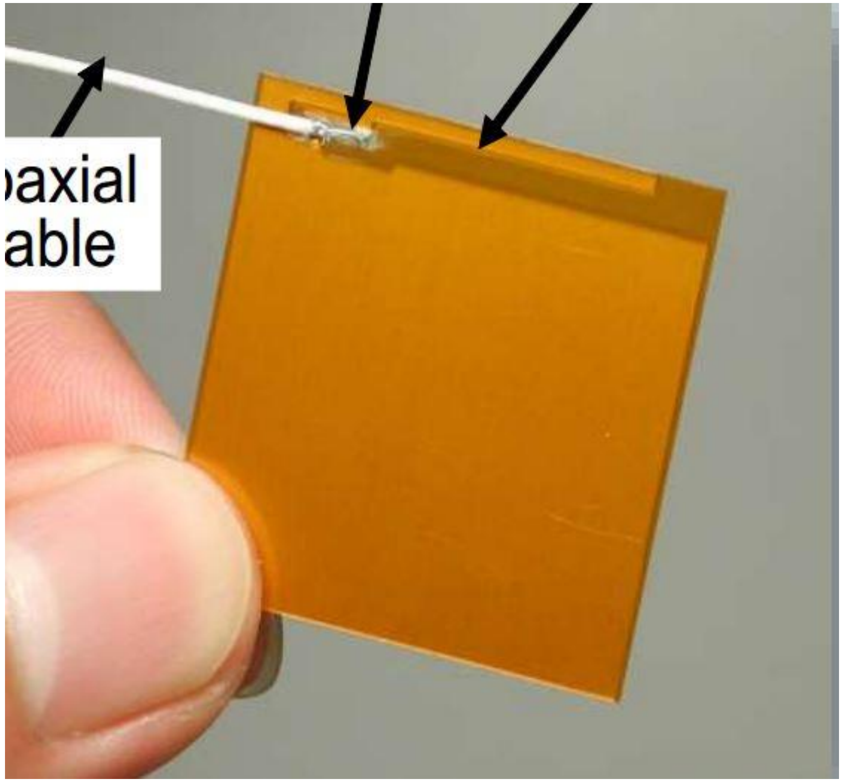


Internal Antenna

- **Planar antenna** is usually a λ/4 micro strip mounted on the conducting chassis of the handset.
- One example is Planar Inverted F Antennas (PIFA).
- **Chip antennas** are very small and mounted on circuit board of phone.
- Internal antennas reduce the size of the phone by sacrificing the performance, especially when hand is over the antenna or the unit is close to the head.

Planar Inverted F Antenna (PIFA)





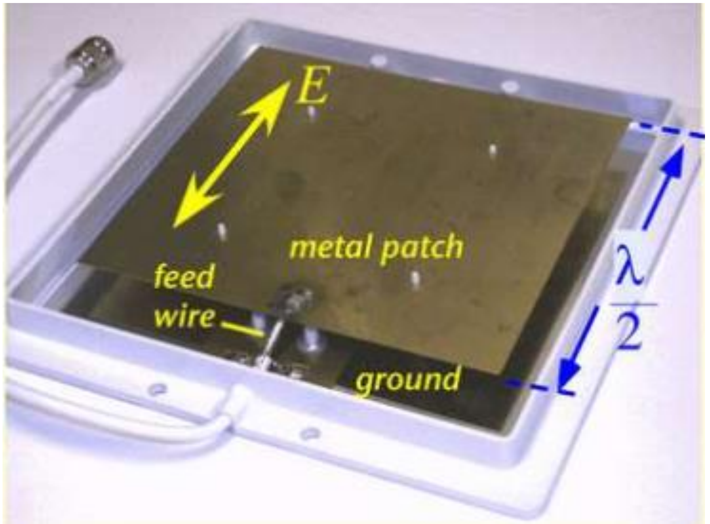
Chip antennas

Antenna diversity for Mobile stations

- The limited size makes difficulty to implement antenna diversity in mobile handsets
- So simpler methods like selection combining are preferred
- For reducing the correlation between diversity signals in cellular handsets the antenna spacing is made less than 0.2λ

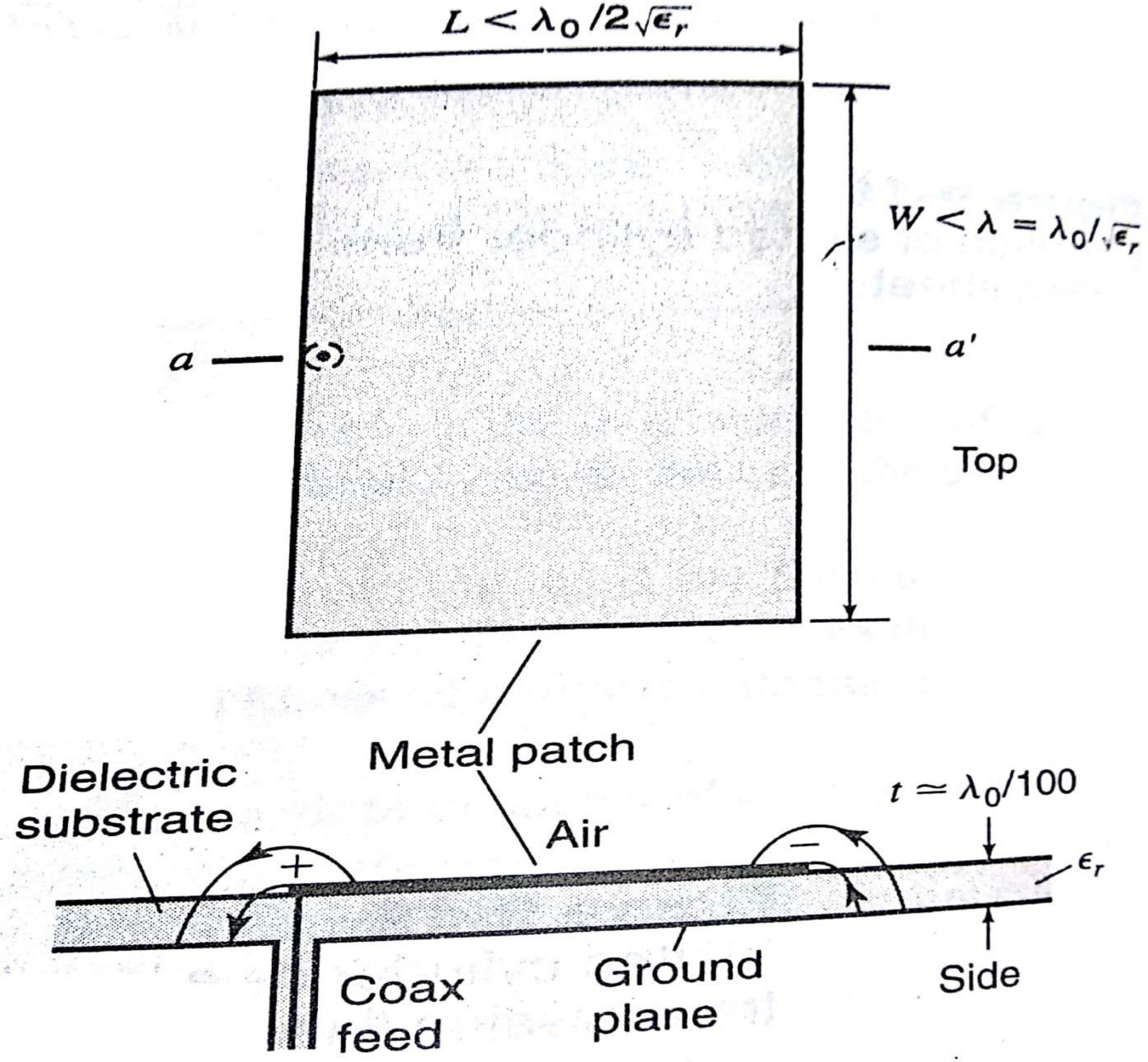
Rectangular Patch antenna

- Also called as microstrip antenna
- These are very low size antennas having low radiation.
- These antennas are popular for low profile applications at frequencies above 100 MHz or wavelengths below 3 m.



Construction & Working of Rectangular Patch Antenna

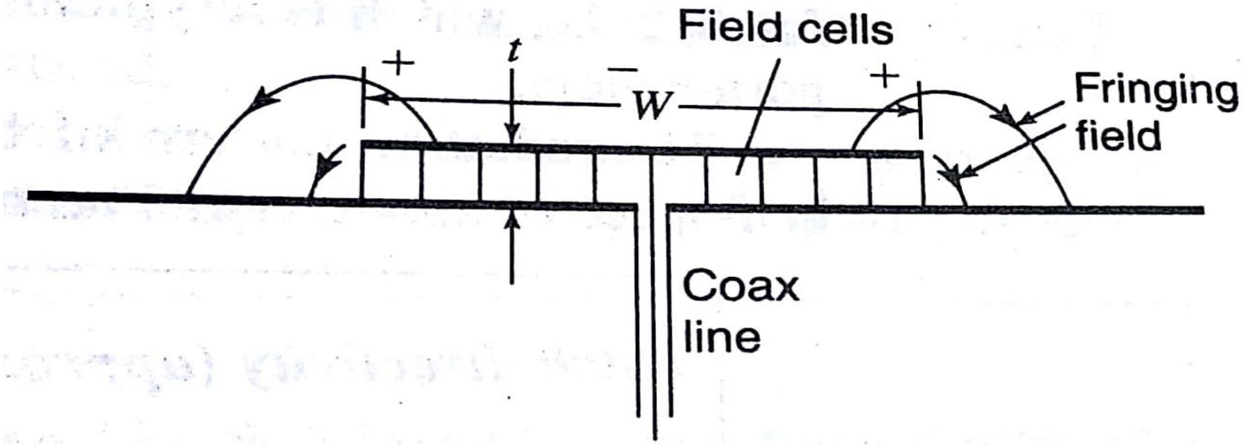
- Antenna consists of a rectangular or square metal patch on a thin layer of dielectric called as substrate on a ground plane.
- The radiating element and feed lines are placed by the process of photo-etching on the di-electric material.
- Usually, the patch or micro-strip is chosen to be square, circular or rectangular in shape for the ease of analysis and fabrication.
- When the antenna is excited, the waves generated within the di-electric undergo reflections and the energy is radiated from the edges of the metal patch, which is very low.



$L < \lambda_0 / 2\sqrt{\epsilon_r}$
$W < \lambda = \lambda_0 / \sqrt{\epsilon_r}$
a
a'
Top
Metal patch
Dielectric substrate
Air
$t \simeq \lambda_0 / 100$
ϵ_r
+
−
Coax feed
Ground plane
Side

Design of rectangular patch antenna

- Typical values of length L, Width W, and thickness t are indicated in the figure with feed from coaxial line at the center of the left edge.
- The horizontal components of electric field at both left and right edges are in same direction, giving in-phase linearly polarized radiation with maximum at the broadside direction of patch.
- The patch acts as a resonant λ/2 parallel plate microstrip transmission line with characteristic impedance equal to the number n of parallel-field cell transmission line
- Each field cell has characteristic impedance of $Z_i = \sqrt{\frac{\mu}{\varepsilon}}$ = $Z_o\sqrt{\frac{\mu_r}{\varepsilon_r}}$
- For air μ_r= ε_r= 1 and $Z_i = Z_o$= 377 Ω



- Figure shows the side view (left) of rectangular patch in which the patch is divided into 10 parallel field-cell transmission lines.
- For ε_r= 2 microstrip characteristic impedance is given as

$$Z_c = \frac{Z_o}{n\sqrt{\varepsilon_r}} = \frac{377}{10\sqrt{2}} = 26.7\ \Omega$$

- Since n=W/t a more general relation is

$$Z_c = \frac{Z_o t}{W\sqrt{\varepsilon_r}}$$

- Considering the fringing of fields at the edges as 2 additional field-cells more accurate equation is

$$Z_c = \frac{Z_o}{[\left(\frac{W}{t}\right)+2]\sqrt{\varepsilon_r}}$$

- The radiation pattern of patch antenna is broad.
- The beam area is π Sr
- Approximate Patch directivity $D = \frac{4\pi}{\Omega_A} \approx \frac{4\pi}{\pi} \approx 4$

the radiation resistance of a resonant half-wave patch ($L = 0.49\lambda_0/\sqrt{\varepsilon_r}$),

$$R_r = 90\left(\varepsilon_r^2/(\varepsilon_r - 1)\right)(L/W)^2\ \Omega$$

- Typically the impedance bandwidth is much lower than pattern bandwidth since it depends on thickness t which is much smaller
- For VSWR < 2

$$\text{Bandwidth} = 3.77\left((\varepsilon_r - 1)/\varepsilon_r^2\right)(W/L)(t/\lambda_0)$$

Effective Height

$$h_e = \sqrt{\frac{2R_r A_e}{Z_0}}$$

where

R_r = radiation resistance, Ω
A_e = effective aperture, λ^2
Z_0 = intrinsic impedance of space, Ω

If we take $D = 4$ and $R_r = 50\ \Omega$ for a typical patch we have as its effective aperture

$$A_e = \frac{D\lambda_0^2}{4\pi} = \frac{\lambda_0^2}{\pi}$$

and as its effective height

$$h_e = \sqrt{\frac{2 \times 50\lambda_0^2}{377\pi}} \simeq 0.3\lambda_0$$

- **Advantages**
- Light weight
- Low cost
- Ease of installation
- **Disavantages**
- Inefficient radiation
- Narrow frequency bandwidth
- **Applications**
- Used in Space craft applications
- Used in Air craft applications
- Used in Low profile antenna applications

Smart Antennas

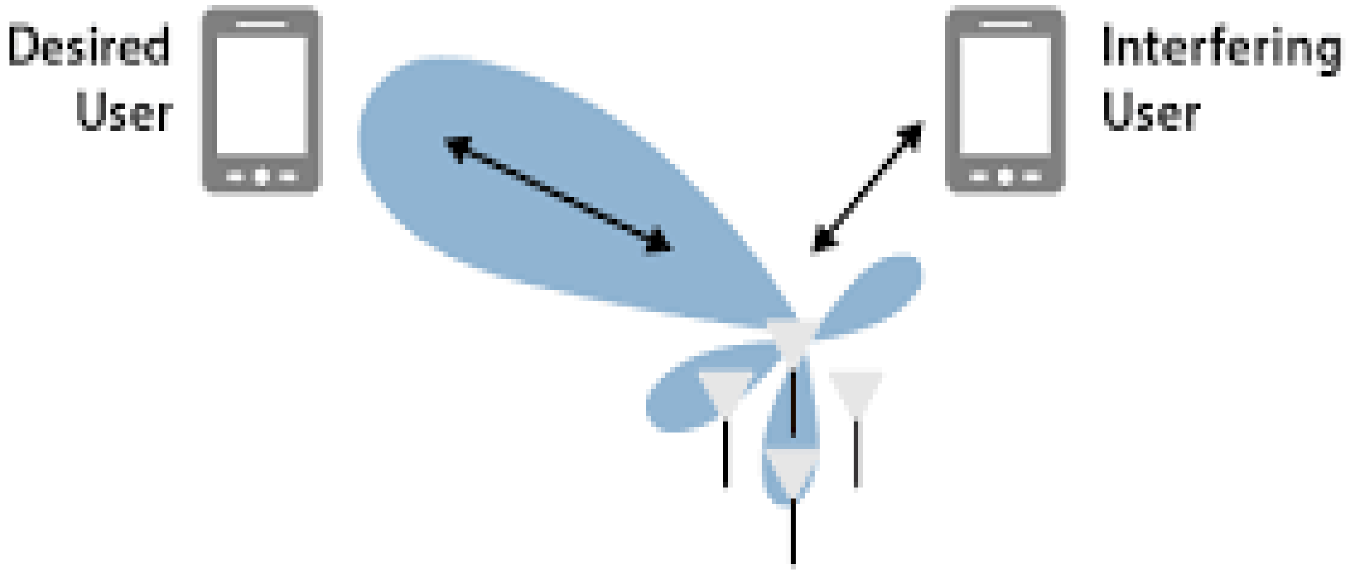
- These systems of antennas include a large number of techniques that attempt to enhance the received signal, suppress all interfering signals and noises, and increase capacity, in general.
- The first smart antennas were developed for military communications and intelligence gathering.
- The growth of cellular telephone in the 1980s attracted interest in commercial applications.
- The upgrade to digital radio technology in the mobile phone, indoor wireless network, and satellite broadcasting industries created new opportunities for smart antennas in the 1990s, culminating in the development of the MIMO (multiple input multiple-output) technology used in 4G/5G wireless networks.

Features of Smart Antenna

- The idea of smart antennas is to use base station antenna patterns that are not fixed, but adapt to the current radio conditions.
- This can be visualized as the antenna directing a beam toward the communication partner only.
- The main difference with normal antenna is related with the way both the systems deal with the problems caused by multipath wave propagation
- Smart Antennas can null out interference from other nodes.
- Smart antenna contains an array of antennas elements and decide on which elements to receive signals (or transmit on) from and how much power to use on each element.

Smart Antennas

- *Definition:* 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.
- In fact, antennas are not smart—antenna systems are smart. Generally co-located with a base station, a smart antenna system combines an antenna array with a digital signal-processing capability to transmit and receive in an adaptive, spatially sensitive manner
- Thus the main aim of SA is to maximize the antenna gain in the desired direction and to minimize the gain in directions of interferers.



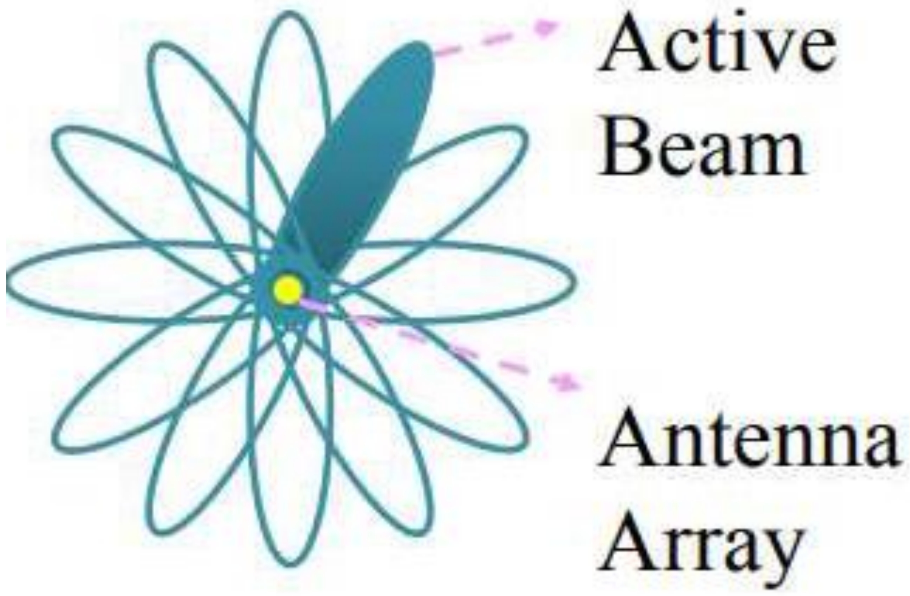
•Smart Antennas forms a radiation pattern towards the desired user and nullifying at the interferers.

Types of Smart antennas

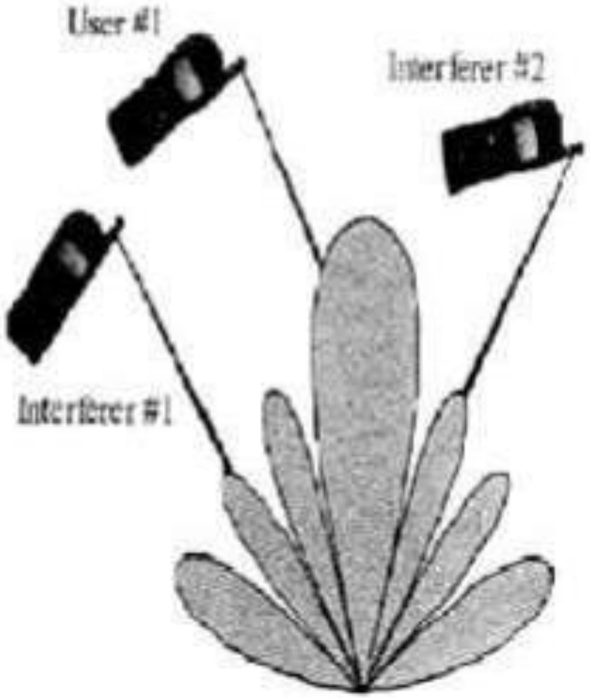
- Smart antennas are customarily divided as Switched Beam/ Phased Beam Antenna and Adaptive Array.
- In switched beam smart antennas a finite number of fixed ,predefined patterns will be there
- In adaptive array an infinite number of patterns (scenario based) that are adjusted in real time based on some signal processing algorithm.

SWITCHED BEAM ANTENNAS

- This systems form multiple fixed beams with heightened sensitivity in particular directions.
- When incoming signal detected it determines the beam which is best aligned based on SOI and switches to that beam to communicate with user.
- As the mobile unit moves throughout the cell, the switched beam system detects the signal strength and continually switches the beams as necessary.

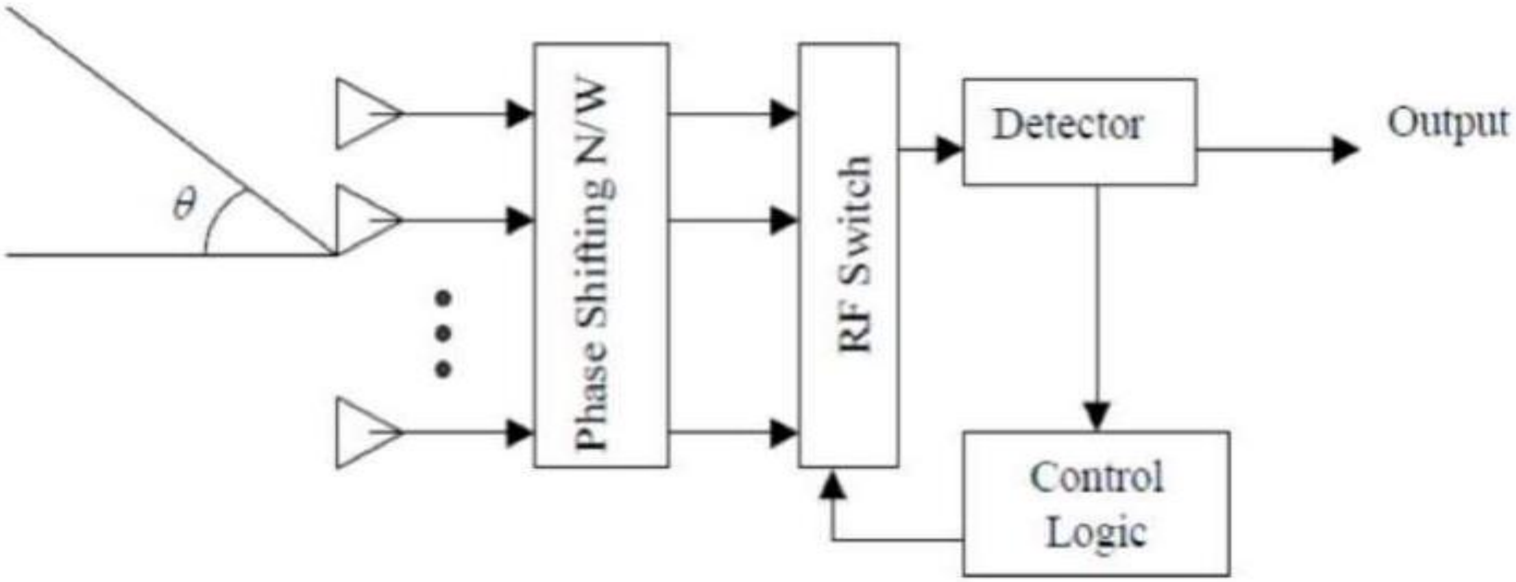


Coverage pattern



Block diagram

Block diagram of Switched Beam Antenna

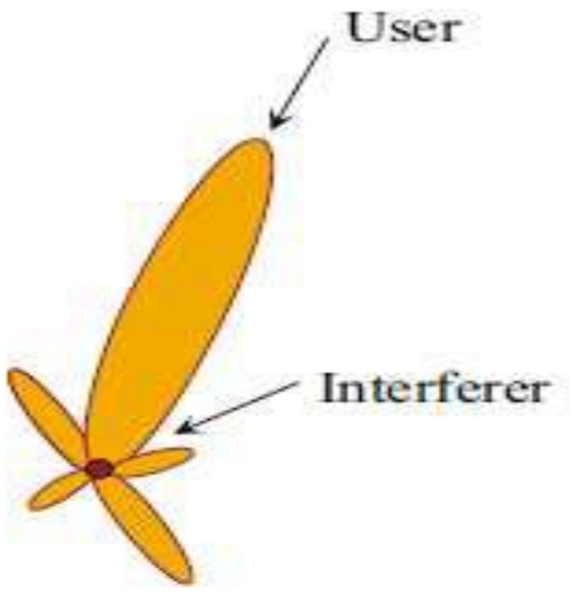


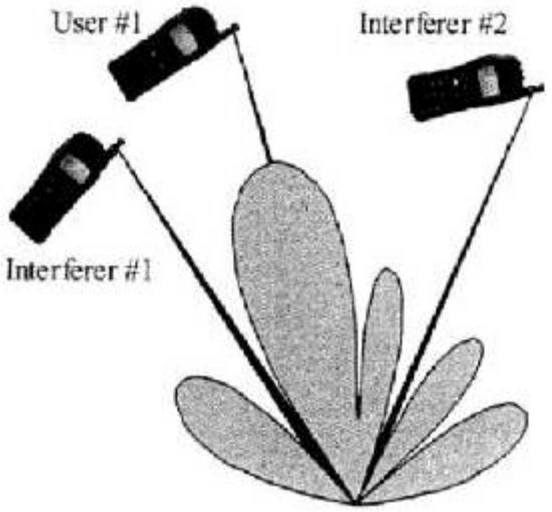
- PSN, which forms multiple beams looking in certain directions.
- RF Switch actuates the right beam in the desired direction
- The selection of right beam is made by control logic which is governed by an algorithm.
- The algorithm which scans all the beams and selects the one strongest receiving signal based on a measurement made by the detector.
- The overall goal of the switched-beam system is to increase the gain according to the location of the user.

Adaptive Array

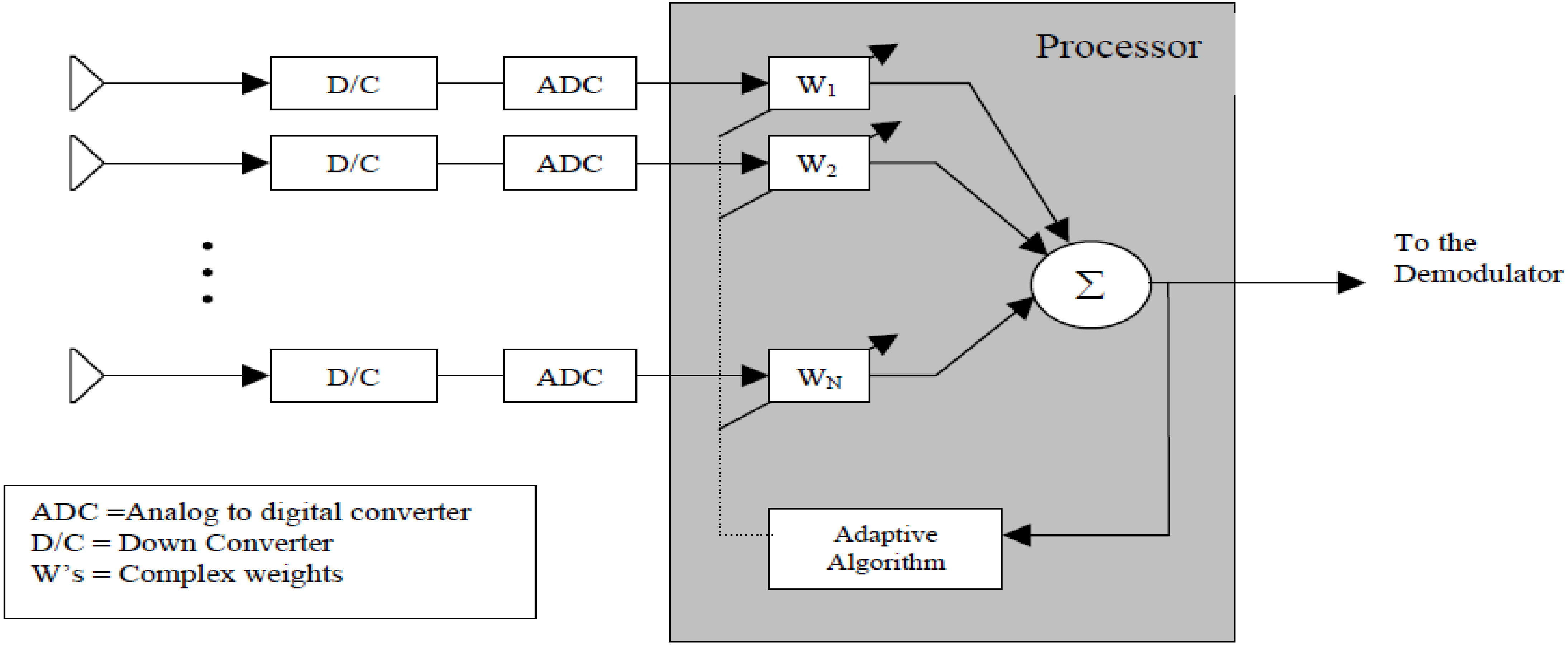
- Systems are really smart because they are able to dynamically react to the changing RF environment with its infinite scenario based patterns.
- They can direct the main beam toward the SOI while suppressing the antenna pattern in the direction of the interferers.
- It can customize an appropriate radiation pattern for each individual user.
- Dynamically adjust the antenna pattern to enhance reception while minimizing or fully rejecting interference.
- This provides optimal gain while simultaneously identifying, tracking, and minimizing interfering signals.

Adaptive Array System Coverage Pattern



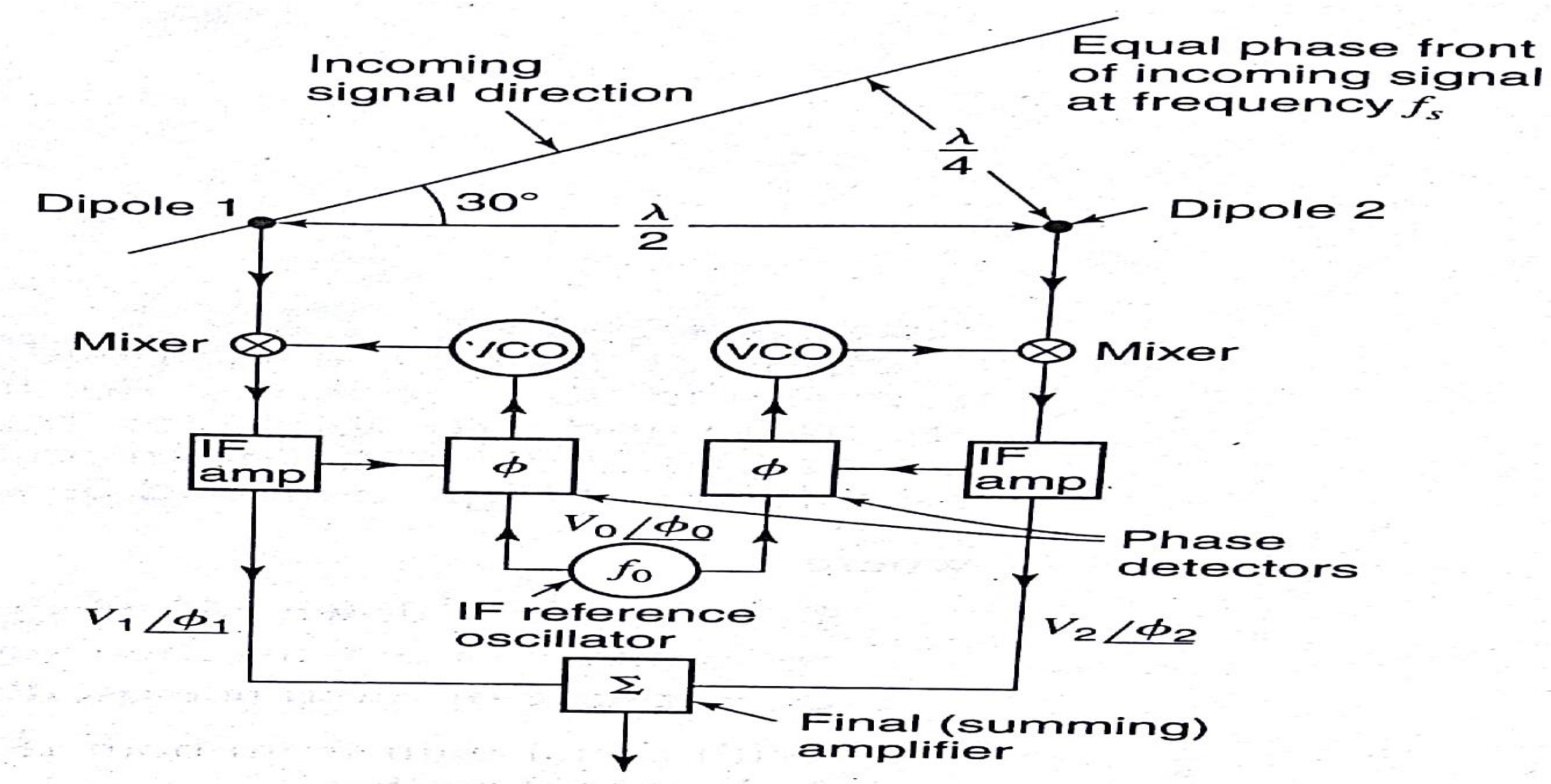


Block diagram of Adaptive array systems



- D/C : Converts from RF to IF.
- ADC : Converts Analog to Digital for further processing.
- W's : It contains amplification and phase information

2 element adaptive array with signal processing circuitry



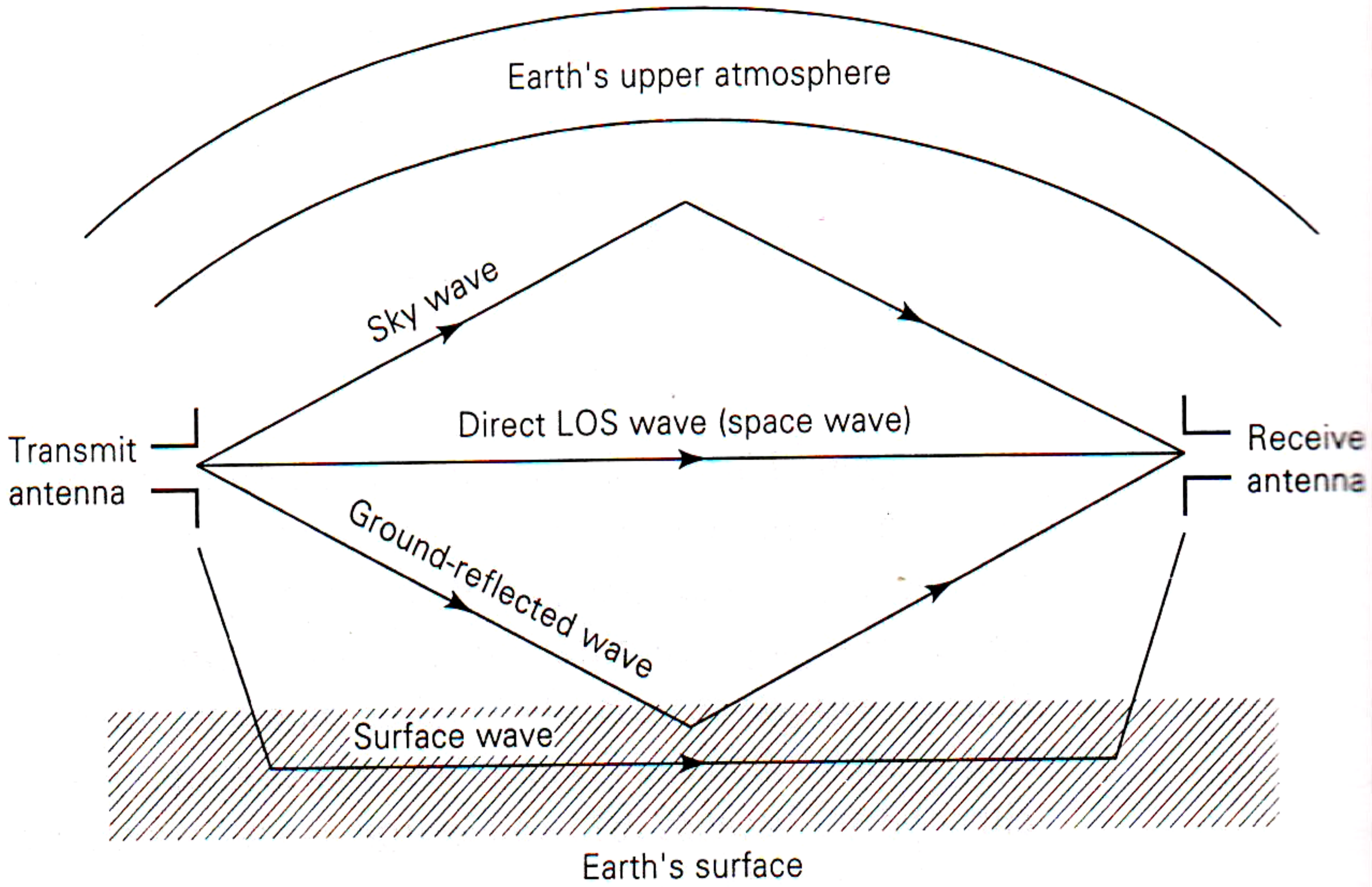
- Consider is at 30 degree so that wave arriving at element 2 travel λ/4 farther than to element 1, thus retards phase of the signal by 90 degrees at antenna 2.
- Each element is equipped with its own mixer, VCO, IF amplifier and Phase detector.
- An oscillator at the IF is connected to each phase detector as reference.
- The PD compares the phase of down converted signal with reference signal and produces voltage corresponds to the phase difference.
- This voltage in turn advances or retards the phase of VCO output and thus achieve phase lock.
- The voltage for VCO 1 would ideally be equal in magnitude but of opposite sign to the voltage of VCO 2 so that downshifted signals from both elements are locked in phase

- $\phi1 = \phi2 = \phi0$
- Where
- $\phi1$= Phase of down shifted signal from element 1
- $\phi2$= Phase of down shifted signal from element 2
- $\phi0$= phase of reference oscillator
- With equal gain from both IF amplifiers the voltages V1 and V2 from both elements should be equal
- $V1 \angle \phi1 = V2 \angle \phi2$
- Making the voltage from summing amplifier proportional to 2V1 and thus maximizing the response of array to incoming signal by steering the beam onto incoming signal

Module 6

Radio Wave propagation

- Electromagnetic Wave radiated by a transmitting antenna is a transverse wave.
- Wave propagation can be classified into 3
  - Ground Wave or Surface wave
  - Space wave or tropospheric wave
  - Sky wave or ionospheric wave


Earth's upper atmosphere
Sky wave
Direct LOS wave (space wave)
Transmit antenna
Receive antenna
Ground-reflected wave
Surface wave
Earth's surface

Ground Wave Propagation/ Surface wave propagation

- A portion of the wave which travels along or near the surface of earth. This wave is called GW or SW.
- This mode of propagation is exists when transmitting and receiving antennas are close to earth and are vertically polarized.
- Surface wave is an Earth-guided electromagnetic wave that travels over the surface of Earth.
- Surface wave can follow the contours of the Earth because of the process of diffraction.
- When a surface wave meets an object and the dimensions of the object do not exceed its wavelength, the wave tends to curve or bend around the object.
- The smaller the object, the more pronounced the diffractive action will be.

- As a surface wave move over Earth’s surface, it is accompanied by charge induced in the Earth.
- The charges move with the wave, producing a current.
- The Earth offers resistance to the flow current, energy is dissipated in a manner very similar to those in transmission line.
- To reduce the attenuation, the amount of induced voltage must be reduced.
- This is done by using vertically polarized waves that minimize the extent to which the electric field of the wave is in contact with the Earth.
- When a surface wave is horizontally polarized, the electric field of the wave is parallel with the surface of the Earth and, therefore, is constantly in contact with it. The wave is then completely attenuated within a short distance from the transmitting site.
- When the surface wave is vertically polarized, the electric field is vertical to the Earth and merely dips into and out of the Earth's surface. For this reason, vertical polarization is vastly superior to horizontal polarization.

- The energy is replenished by diffraction of energy downward from the portions of the ground wave immediately above Earth’s surface.
- GW is useful at low frequency broadcast applications
- GW signals are limited to only a few kilometers

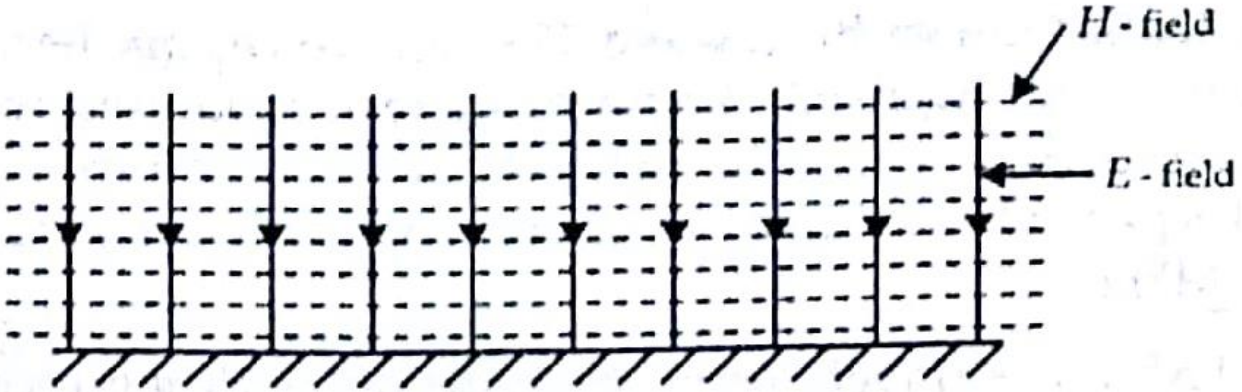
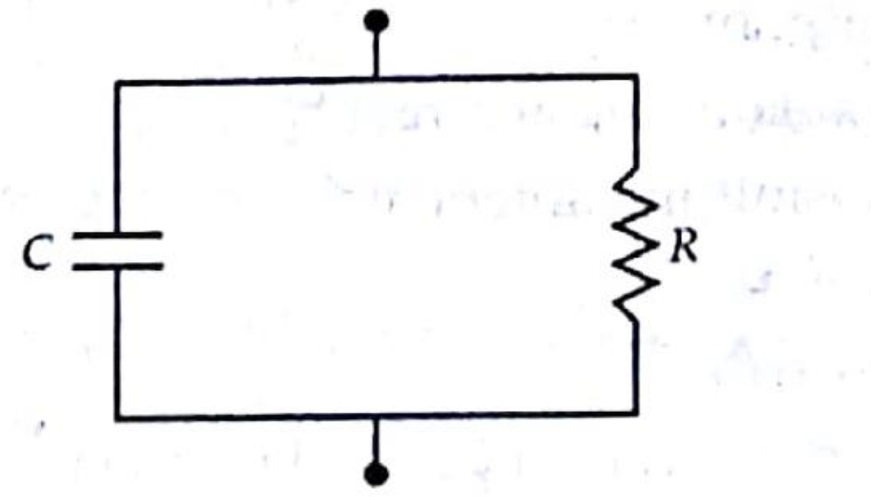


Fig. 9.1 *Vertically polarised wave*



- The above figure shows the equivalent circuit of earth for a vertically polarized wave
- The earth behaves like a leaky capacitance in carrying the induced current
- The electrical characteristics of earth depends on fundamental constants such as permittivity, conductivity and permeability

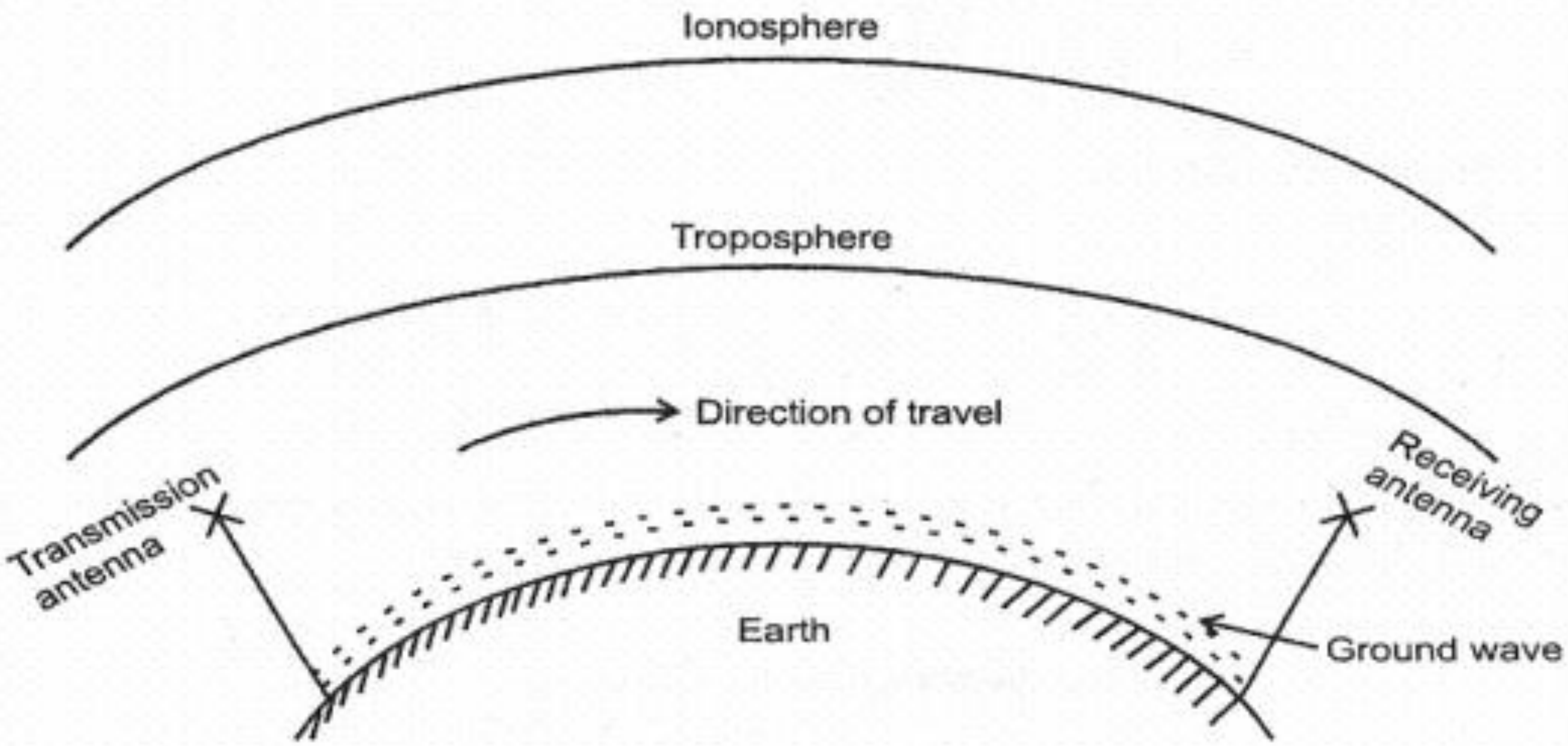


fig 4.1 Ground Wave Propagation

Ground Wave Field strength

$$E = \frac{120\ \pi h_t h_r I_s}{\lambda d}$$

h_t, h_r= Effective heights of transmitting and receiving antenna

I_s= Antenna currents

λ =wavelength

d=distance between transmitting and receiving points

Ground Wave Field strength

- According to Sommerfield

$$E = \frac{AE_o}{d}$$

E= Field strength at a point, V/m

E_o=Field strength of wave at a unit distance from the transmitting antenna, neglecting earth's losses (V/m)

A = Factor of ground losses

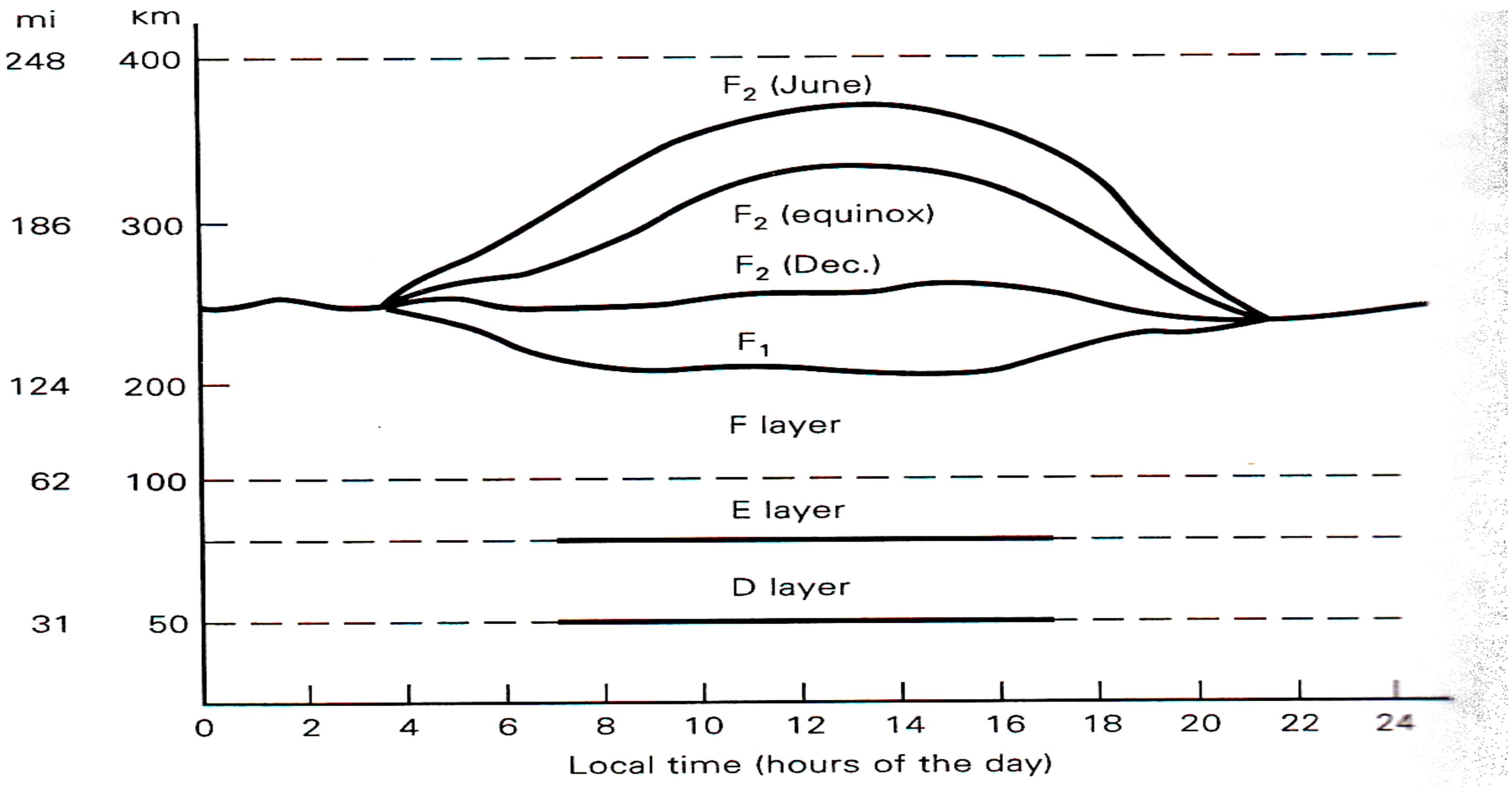
D = distance of the point from transmitting antenna

Sky wave Propagation

- Electromagnetic waves that are directed above the horizon level are called sky waves.
- Sky waves are radiated toward the sky, where they are either reflect back to Earth by the ionosphere.
- The ionosphere is the region of space located approximately 50 -400 km above the Earth’s surface.
- The ionosphere layer absorbs large quantities of the sun’s radiant energy, which ionizes the air molecules and creating free electron.
- When, a radio wave passes through the ionosphere, the electric field of the wave exerts a force on the free electrons, causing them to vibrate.

- The vibrating electrons decrease current, which is equivalent to reducing the dielectric constant.
- Reducing the dielectric constant increases the velocity of propagation and causes electromagnetic waves to bend away from the regions of high electron density toward regions of lower density.
- As the wave moves farther from Earth, ionization increases; however, there are fewer air molecules to ionize.
- Therefore, the upper ionosphere has a higher percentage of ionized molecules than the lower atmosphere.
- The higher the ion density, the more refraction.

Layers of Ionosphere



Characteristics of ionosphere’s layers

D Layer

- The lowest layer of the ionosphere and is located approximately between 50-100 km above the Earth’s surface.
- Average height 70 Km
- Thickness 10 Km
- Little ionization.
- Very little effect on the direction of propagation of radio waves.
- The amount of ionization in D layer depends on the altitude of the sun above the horizon.
- Disappears at night.
- Reflects VLF and LF waves and absorb MF and HF waves (not useful for these ranges).
- Electron density, N= 400 electron / cc
- Critical frequency =180 KHz

E Layer

- 100-140 km above Earth's surface next to D layer.
- Also called as Kennelly-heaviside layer.
- Average height 100 Km
- Thickness – 25 Km
- Totally disappears at night since ions recombine to molecules in the absence of sun.
- Aids MF surface wave propagation and reflects HF waves during daytime.
- Electron density, N =2 x 10^5 electrons / cc
- Critical frequency =4 MHz

Es Layer

- Sporadic E layer since appearance is irregular
- If at all it appears, it exists in both day and night
- It is a thin layer
- Ionization density is high
- Appears close to E layer
- Provide good reception
- Not dependable layer for communication

F1 Layer

- Appears at a height of about 180 Km in day time
- Its thickness is about 20 Km
- It combines with F2 Layer during Nights
- HF waves are refflected to some extend
- It passes some some HF towards F2 layer and absorbs some.
- Critical frequency 5 MHz

F2 Layer

- Topmost layer and most important layer for HF communication
- Average height is 325 Km in day-time
- Thickness is about 200 Km
- IT falls at a height of 300 Km at nights as it combines with F1 layer
- Height of F2 layer varies depending upon time, average ambient temperature and sunspot cycle
- Exists at night also
- Highly ionized
- Electron density, N = 2 x 10^6electrons / cc
- Critical frequency 8 MHz

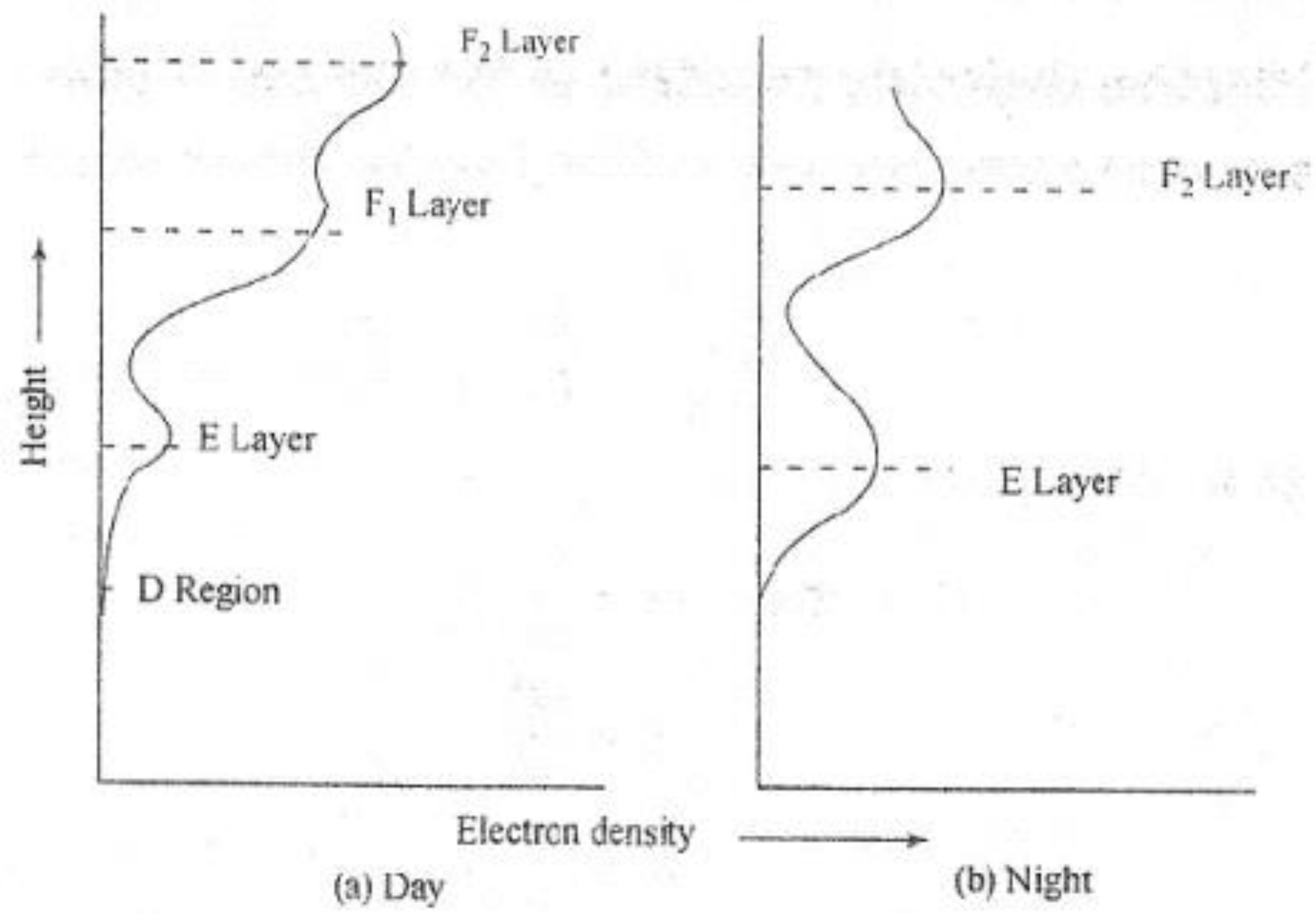


fig 2.2 Electron density of ionosphere layers

Propagation of Radio waves through the Ionosphere

- Ionosphere contains ions and free electrons, when radio wave passes through it both ions and electrons will vibrate.
- Since ions are heavy compared to electrons its motion can be neglected
- The electron motion is along the path parallel to electric field and represent an ac current proportional to velocity of vibration.
- The effect of earth's magnetic field on the vibrations of ionospheric electrons lags behind the E field of wave, thus resulting current is inductive
- The capacitive current flowing through a volume of space in the ionosphere leads the voltage by 90^0 and electron current lags the voltage by 90^0hence subtracted from capacitive current

- Thus free electron decreases thus dielectric constant will decrease
- The reduction in dielectric constant causes the path of radio waves to bent towards earth due to total internal reflection
- Let the electric field E = $E_m Sin\ (\omega t)$ is acting across a a unit volume of ionosphere
- Force exerted by electric field on each electron be

$$F = -e\ E \qquad \text{N}$$

Let us assume that there is no collision,

$$F = m\ a$$

$$-e\ E = m\ \frac{dv}{dt}$$

$$\frac{dv}{dt} = -\ \frac{eE}{m}$$

$$dv = -\ \frac{eE}{m}\ dt$$

- Integrating both sides,

$$\int dv = -\int \frac{eE}{m}\, dt$$

$$= -\frac{e}{m}\int E_m Sin\,(\omega t)dt$$

$$= \frac{eE_m\, Cos\,(\omega t)}{m\omega}$$

$$v = \left(\frac{e}{m\omega}\right) E_m\, Cos\,(\omega t)$$

- Electric current due to travel of N electrons per cubic meter with velocity v

$$i_e = -N\,e\,v \qquad (\text{amp}/m^2)$$

$$i_e = -\,N\,e\,.\left(\frac{e}{m\omega}\right) E_m\, Cos\,(\omega t)$$

$$= -\frac{Ne^2}{m\omega} E_m\, Cos\,(\omega t)$$

- Besides this inductive current there is usual capacitive current

$$i_c = \frac{dD}{dt} = \frac{d\,(\varepsilon_0 E)}{dt}$$

- Where ε_0 = 80854 x 10^{-12} F/m is capacitance of unit volume of air

$$i_c = \varepsilon_0 \frac{d\,(E)}{dt}$$

$$= \varepsilon_0 \frac{d\,(E_m Sin\,(\omega t))}{dt}$$

$$= \varepsilon_0 E_m Cos\,(\omega t).\,\omega$$

- Total current

$$i = i_c + i_e = \varepsilon_0 E_m Cos\,(\omega t).\,\omega - \frac{Ne^2}{m\omega} E_m\,Cos\,(\omega t)$$

$$= E_m Cos\,(\omega t).\,\omega[\varepsilon_0 - \frac{Ne^2}{m\omega^2}]$$

The effective di-electric constant ε of the ionosphere

$$\varepsilon = \varepsilon_0 - \frac{Ne^2}{m\omega^2}$$

$$= \varepsilon_0 [1 - \frac{Ne^2}{m\omega^2 \varepsilon_0}]$$

- Relative dielectric constant

$$\varepsilon_r = \varepsilon / \varepsilon_0 = [1 - \frac{Ne^2}{m\omega^2 \varepsilon_0}]$$

- Refractive index μ= $\sqrt{\varepsilon_r} = \sqrt{\varepsilon / \varepsilon_0} = \sqrt{[1 - \frac{Ne^2}{m\omega^2 \varepsilon_0}]}$
- Applying m = 9.107 x 10^{-31} Kg

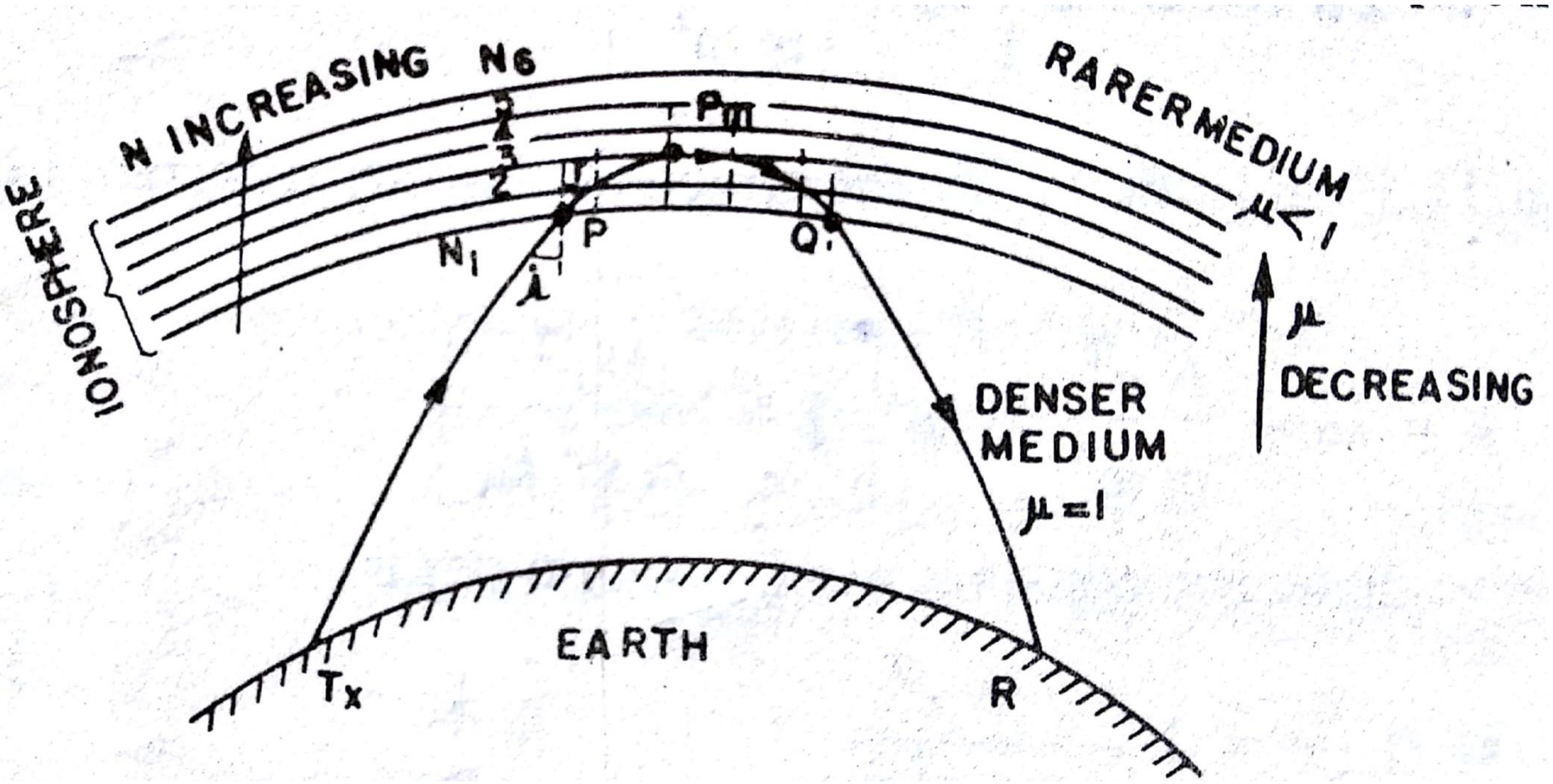
  e = 10602 x 10^{-18} C

  ε_0 = 8.854 x 10^{-12} F/m

- We get

$$\boxed{\boldsymbol{\mu} = \sqrt{\mathbf{1} - \frac{\mathbf{81}\boldsymbol{N}}{\boldsymbol{f}^{\mathbf{2}}}}}$$

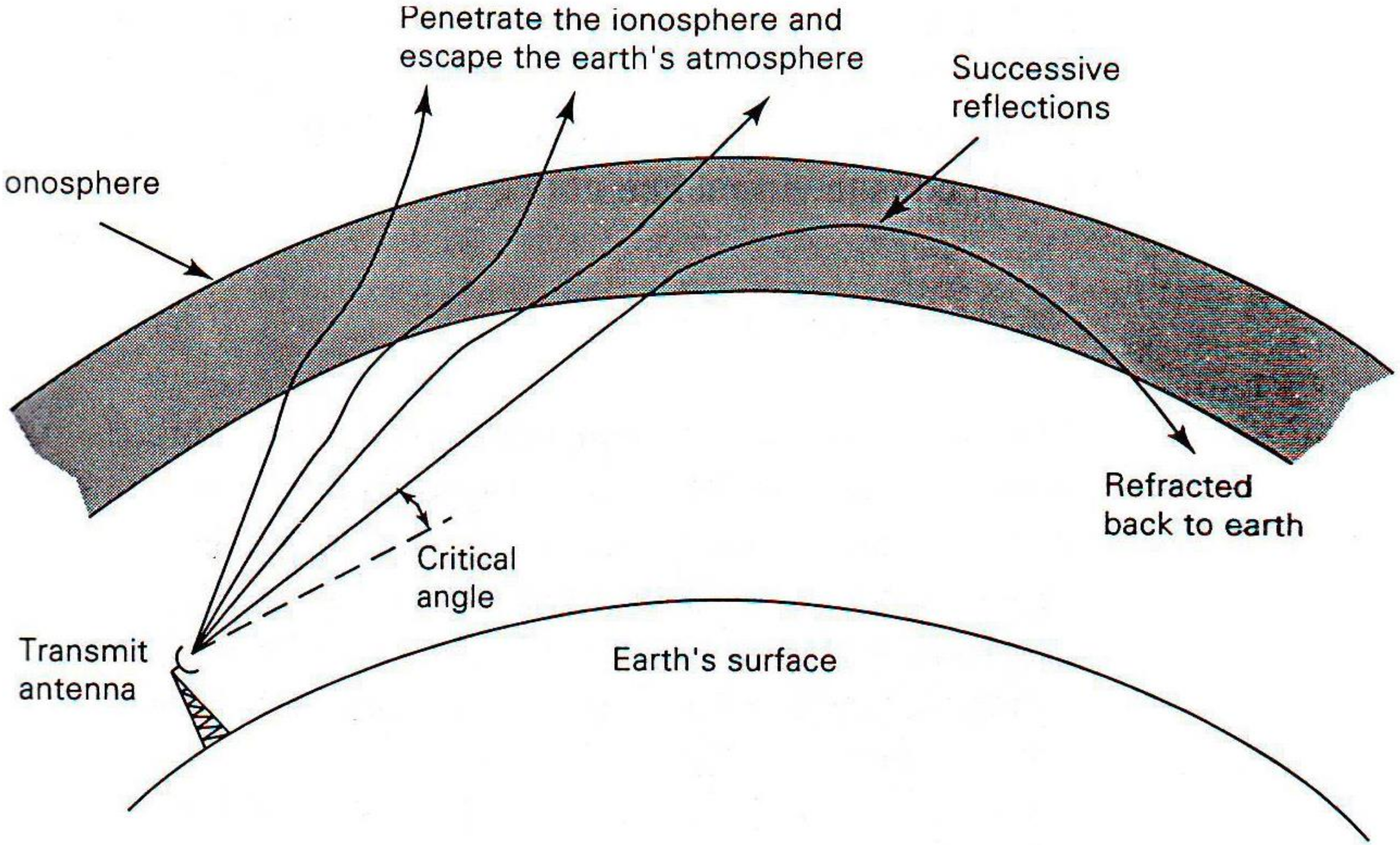
- IF $f^2 < 81N$ then μ is imaginary under such conditions ionosphere can't bend the signal and signals get attenuated
- So for ionospheric reflection the condition is $f^2 > 81N$
- According to snell's law **μ =** $\frac{\boldsymbol{Sin\ i}}{\boldsymbol{Sin\ r}}$
- Since **μ < 1 ,** $\boldsymbol{Sin\ i} < \boldsymbol{Sin\ r}$ condition for reflection



N INCREASING
Ns
RARERMEDIUM
P_m
IONOSPHERE
P
Q
N_1
$\mu < 1$
μ
DECREASING
DENSER
MEDIUM
$\mu = 1$
EARTH
T_x
R

Critical Frequency

- Critical frequency (f_c) is defined as the highest frequency that can be propagated directly upward(Vertical incidence) and still be returned to Earth by the ionosphere.
- fc is depends on the ionization density and therefore varies with the time of day and the season.
- If the vertical angle of radiation is decreased, frequency at or above the fc can still be refracted back to Earth’s surface because they will travel a longer distance in the ionosphere and thus, have a longer time to be refracted.
- Every frequency has a maximum vertical angle at which it can be propagated and still can be refracted back by the ionosphere. This is called critical angle.


Penetrate the ionosphere and
escape the earth's atmosphere
Successive
reflections
onosphere
Refracted
back to earth
Critical
angle
Transmit
antenna
Earth's surface

$$\mu = \frac{Sin\ i}{Sin\ r} = \sqrt{1 - \frac{81\ N}{f^2}}$$

At vertical incidence i(angle measure from vertical) = 0 ; N=N_{max} and f=f_c

As we go up the ionosphere μ *becomes* 0 in which the wave having highest frequency will reflect back

$$\mu = \sqrt{1 - \frac{81\ N_m}{{f_c}^2}} = 0$$

$$1 - \frac{81\ N_m}{{f_c}^2} = 0$$

$$1 = \frac{81\ N_m}{{f_c}^2}$$

$${f_c}^2 = 81\ N_m$$

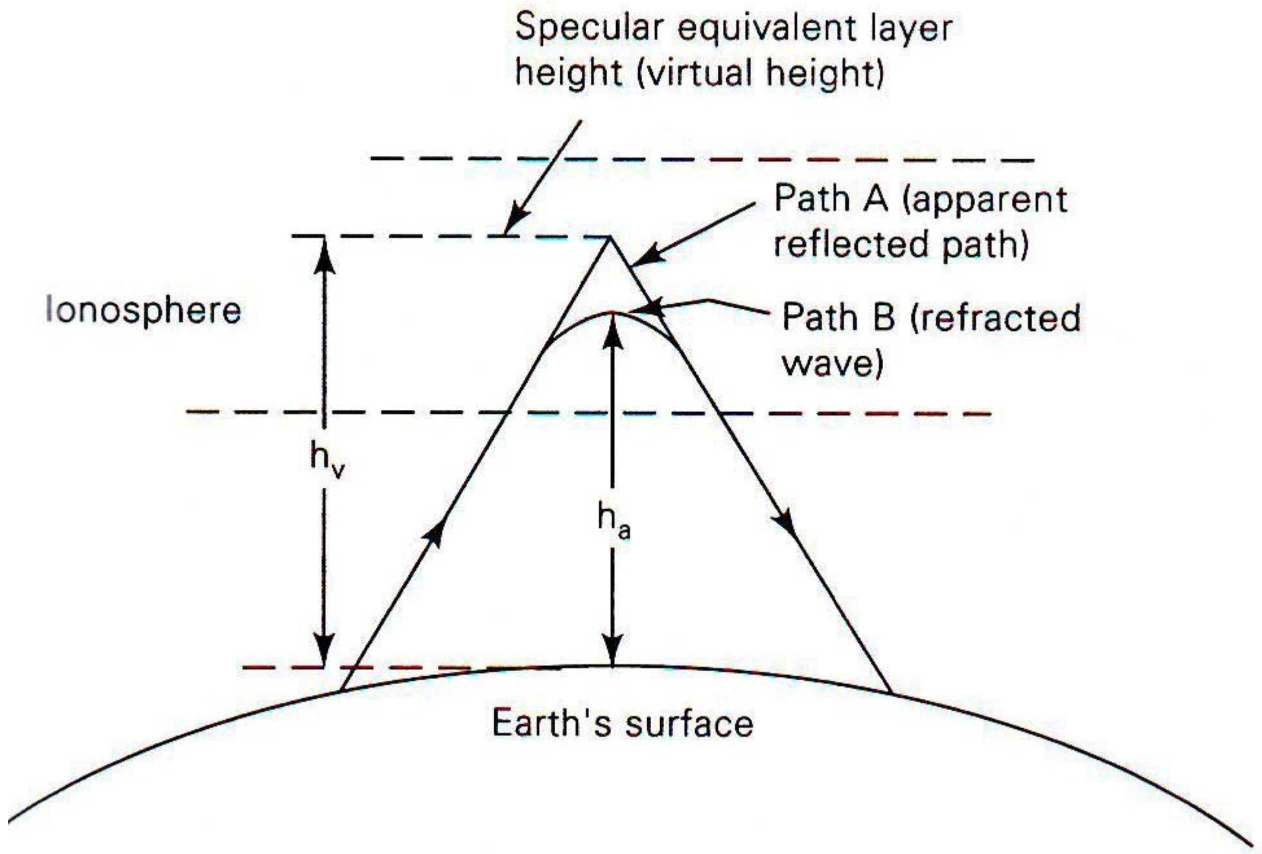
$$f_c = \sqrt{81\ N_m}$$

$$\boldsymbol{f_c = 9\sqrt{N_m}}$$

Virtual height

- Virtual height is the height above Earth’s surface from which a refracted wave appears to have been reflected.
- The radiated wave is refracted back to Earth and follows path B.
- The actual maximum height that the wave reached is height ha.
- However, path A shows the projected path that a reflected wave could have taken and still be returned to Earth at the same location.
- The maximum height that this hypothetical reflected wave would have reached is the virtual height (hv).

Virtual height



MAXIMUM USABLE FREQUENCY

- MUF is the limiting frequency which can be reflected back to earth but for a specific angle of incidence.
- The Maximum possible value of frequency for which reflection takes place for a given distance of propagation is MUF for that distance
- Another definition is that: The maximum usable frequency (MUF) is the highest frequency that can be used for sky wave propagation between two specific points on Earth’s surface.

$$\mu = \frac{Sin\ i}{Sin\ 90} = \sqrt{1 - \frac{81\ N_m}{{f_{muf}}^2}}$$

$$\mu = \sin i\ = \sqrt{1 - \frac{81\ N_m}{{f_{muf}}^2}}$$

We know that ${f_c}^2 = 81\ N_m$

$$\sin i\ = \sqrt{1 - \frac{{f_c}^2}{{f_{muf}}^2}}$$

$$\sin^2 i\ = 1 - \frac{{f_c}^2}{{f_{muf}}^2}$$

$$\frac{{f_c}^2}{{f_{muf}}^2} = 1\text{-}\sin^2 i$$

$$\frac{{f_c}^2}{{f_{muf}}^2} = \cos^2 i$$

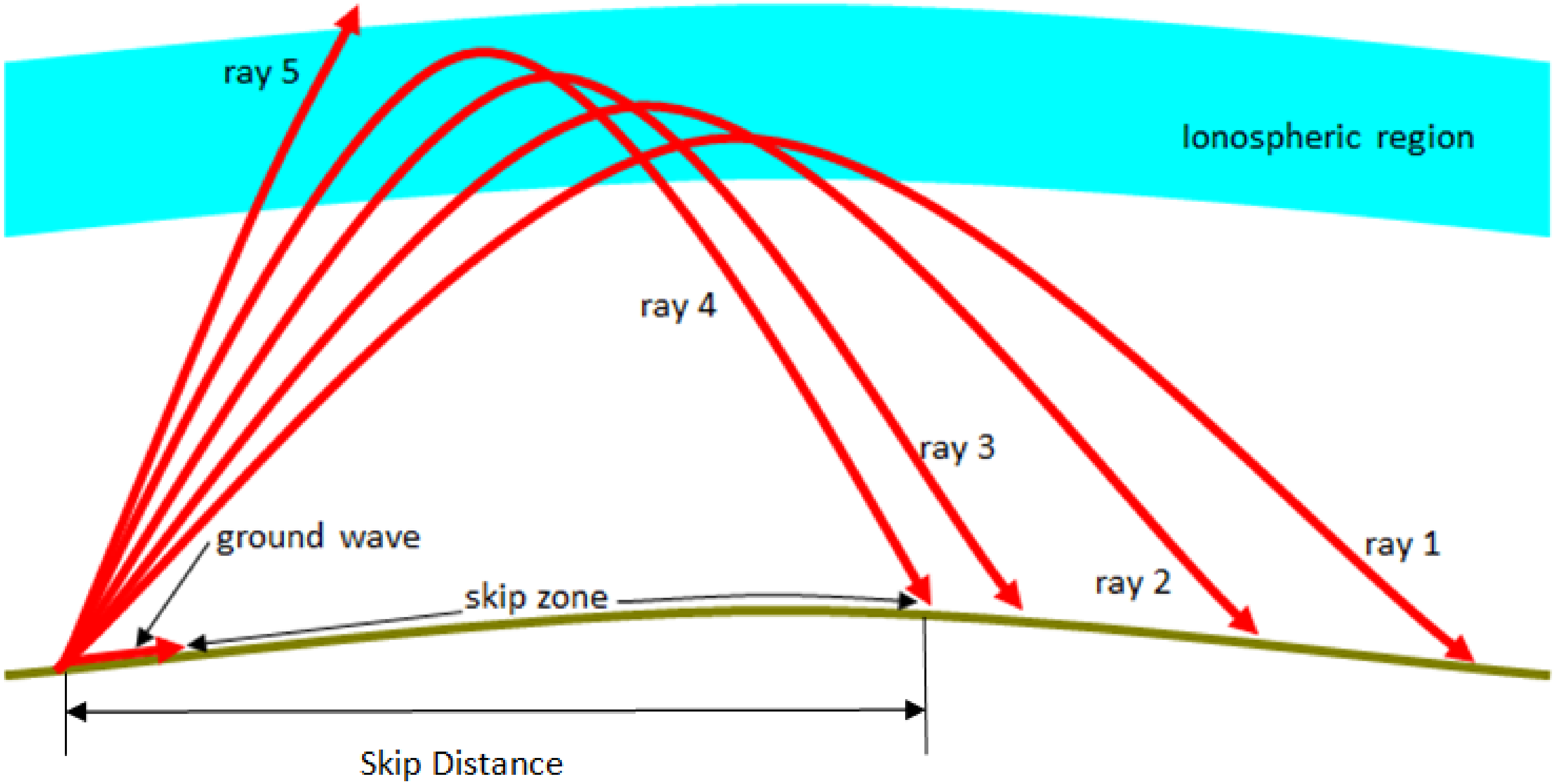
$${f_{muf}}^2 = {f_c}^2 .\ \sec^2 i$$

$$\boldsymbol{f_{muf} = f_c .\ sec\ i}$$

SKIP DISTANCE & SKIP ZONE

- Radio waves transmitted horizontally will undergo surface wave propagation
- Radio waves radiated at high angles may not reflect back in ionosphere
- The angles in between horizontal and high angle will provide ionospheric communication.
- just high enough to escape absorption by earth will enter the lower layer of ionosphere and reflect back to earth suffering high attenuation.
- The distance at which surface wave becomes negligible and the distance at which first sky wave returns to earth from the ionospheric layer, there is a zone which is not covered by neither ground wave nor sky wave .This is called Skip zone and the distance across it is skip distance

- Usually the skip distance is considered as the distance between transmitter and the point where first sky wave is received, since the range of surface wave is small
- Skip distance is the distance skipped by the sky wave


ray 5
Ionospheric region
ray 4
ray 3
ray 2
ray 1
ground wave
skip zone
Skip Distance

Effect of Earth’s Magnetic Field on Ionospheric wave propagation

Splitting of Incident Wave

- A radio wave propagating in atmospheric regions which are not ionized will not be affected by Earth’s magnetic field
- The earth’s magnetic field splits up the incident radio waves into 2 components, this phenomenon is called Magneto ionic splitting
- Ordinary Waves
- Extra ordinary waves
- The properties of ordinary waves are same as the waves without superimposed magnetic field.
- The extra ordinary wave is distinguishable from the ordinary wave only in the upper region of F2 layer

- The amplitude of extra ordinary wave relative ordinary wave depends on the magnitude of magnetic field
- 2 rays bend different amounts by ionosphere and hence they travel through it along slightly different paths.
- The rates of energy absorption and velocities of 2 rays are different
- Both the waves have elliptical polarization but rotates in opposite direction.
- The critical frequency of extra ordinary wave is always higher than critical frequency of ordinary wave by half the gyro frequency, gyro frequency is the **frequency** of a moving charged particle or ion in a magnetic field.

Effect on Polarization of incident wave

- The electrons set in simple harmonic motion in the absence of magnetic field will modified as elliptical or spiral motion in presence of earth's magnetic field.

Effect on attenuation of incident wave

- The earth's magnetic field causes the electron in ionosphere to trace the complex trajectory, the frequency of movement depends on field and charge to mass ratio (e/m) of the particle.
- This frequency is called gyro-frequency ($\boldsymbol{f_g}$)
- If frequency of incident wave is equal or nearly equal to $\boldsymbol{f_g}$ then there is resonance phenomenon and oscillating electrons receive more energy from incident wave which in turn increase its velocity hence chances of inelastic collision increases and hence attenuation is high

$$\omega_B = B\left(\frac{e}{m}\right)$$

$$2\pi\, f_g = B\left(\frac{e}{m}\right)$$

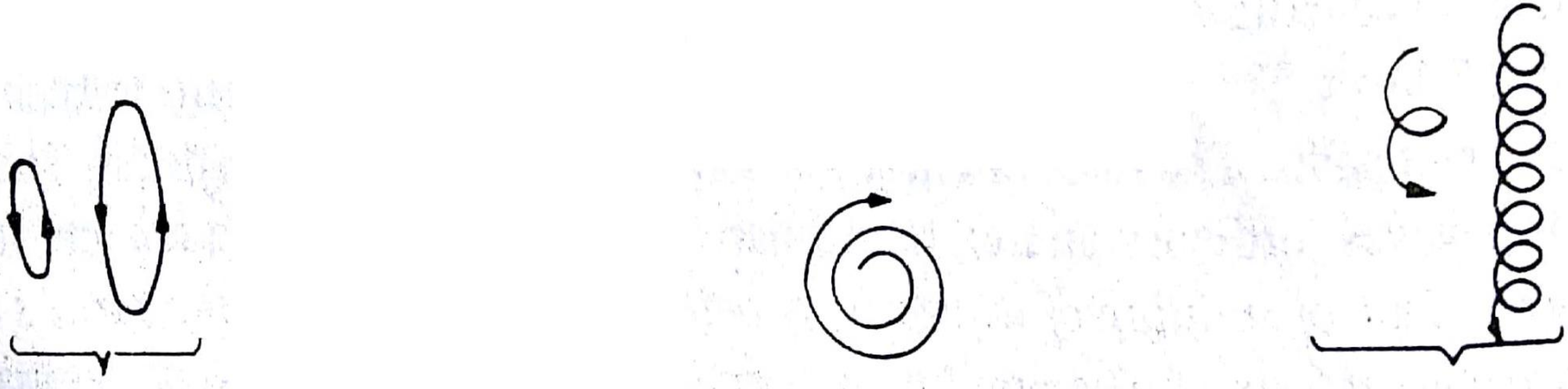
$$f_g = (1/2\pi)\, B\left(\frac{e}{m}\right) = \frac{Be}{2\pi m}$$

B = 0.5 x 10^{-4}W/m

m = 9.107 x 10^{-31}

e = 1.602 x 10^{-19}

f_g = 1.417 MHz



(a)
High frequency $f > f_g$

(b)
Critical frequency $f = f_g$

(c)
low frequency $f < f_g$

$$\text{where } f_g = \text{Gyro–frequency} = \frac{Be}{2\pi m}$$

Path followed by an electron while vibrating under earth's magnetic field.

Effect of Earth's magnetic field on attenuation of incident wave

$$\mu^2 = \left[1 - \frac{2}{2\alpha - \frac{Y_T^2}{(\alpha - 1)} + \sqrt{\frac{Y_T^4}{(\alpha - 1)^2} + 4 Y_L^2}} \right]^{1/2}$$

or alternatively in slightly different notations, the Appleton Hartree formula is

$$\mu^2 = 1 - \frac{X}{1 - \frac{Y_T^2}{2(1 - X)} \pm \sqrt{\frac{Y_T^4}{4(1 - X)^2} + Y_L^2}}$$

where $\alpha = \dfrac{\varepsilon_0 m \omega^2}{N e^2} = \dfrac{f^2}{f_c^{\,2}}$

$$Y_T = \frac{\alpha B_T \cdot e}{\omega m}$$

$$Y_L = \frac{\alpha B_L \cdot e}{\omega m} \quad \text{and} \quad Y = \sqrt{Y_T^2 + Y_L^2}$$

B_L = Component of earth's magnetic field intensity (B) along the direction of propagation

B_T = Component of earth's magnetic field intensity transverse to the direction of propagation

$B = \mu_0 H$ The notation for eqn. 11.48 (b) stands for as in eqn. 11.6

μ_0 = Permeability of free–space = $4\pi \times 10^{-7}$ H/m.

m = mass of electron = 9.1×10^{-31} kg.

e = charge of electron = 1.6×10^{-19} coulomb.

$\omega = 2\pi f$ = Angular frequency.

N = Electron density.

ε_0 = dielectric constant of space

Ionospheric Abnormalities

- The ionosphere higly depends on Sun and hemce its conditions vary continuously
- Variations can be classified into two

1. **Normal variations** : diurnal, seasonal height, & thickness variation
2. **Abnormal Variations**: Sudden Ionospheric disturbances, Ionospheric storms, Sporadic E layer reflections, Tides and winds, Sunspot cycle, fading and whistlers

Sudden Ionospheric Disturbances

- Due to sudden appearance of solar flares, which are bright spots on solar disc due to gigantic emissions of hydrogen from the sun
- The flares are sudden and unpredictable, more likely during peak solar activity
- The flares increases ionization density below D layer which change MUF. Resulting in complete blackout of all high frequency communication through ionosphere.
- It is also referred to as Monger-Dellinger effect

Ionospheric storms

- Due to rapid change in Earth’s magnetic field ionospheric storm occurs
- Which is the disturbance in the ionosphere
- The ionospheric storm causes abnormal decrease in the critical frequency and hence corresponding virtual height increases

Tides and Winds

- Atmosphere experiences tidal pulls of the sun and moon.
- For atmosphere tidal pulls affect more severely than sea
- This becomes more important and complicated by thermal heating of the atmosphere by the sun rays which have a 24 hours time period, which is twice that of tidal period(Which is 12 hours).
- The F2 layer has the highest speed of tidal motion with lowest particle density sighted at the height level.
- Hence, F2 layer suffers maximum from effect of tides and result in irregularities in its layer and causes a small peak of maximum ionization density in F2 layer at midnight.
- Motion of ionized particles in ionosphere is wind, which is due to tides.
- Due to wind the turbulence in F2 layer will move

.

Sunspot Cycle

- Sun has 11 years cycle over which its output varies tremendously
- Light variations are slight but solar output of UV rays, coronae, flares, particles radiation and sunspots may vary
- The extent of solar disturbances are measured by a method of sunspot counting.
- Sunspot number is a quantity that measures the **number** of sunspots and groups of sunspots present on the surface of the **sun**.
- In the graph below, critical frequency of the ionosphere are highest during sunspot maxima and lowest during sunspot minima.
- Critical frequency of F2 layer is minimum at 6 MHz and maximum at 10MHz

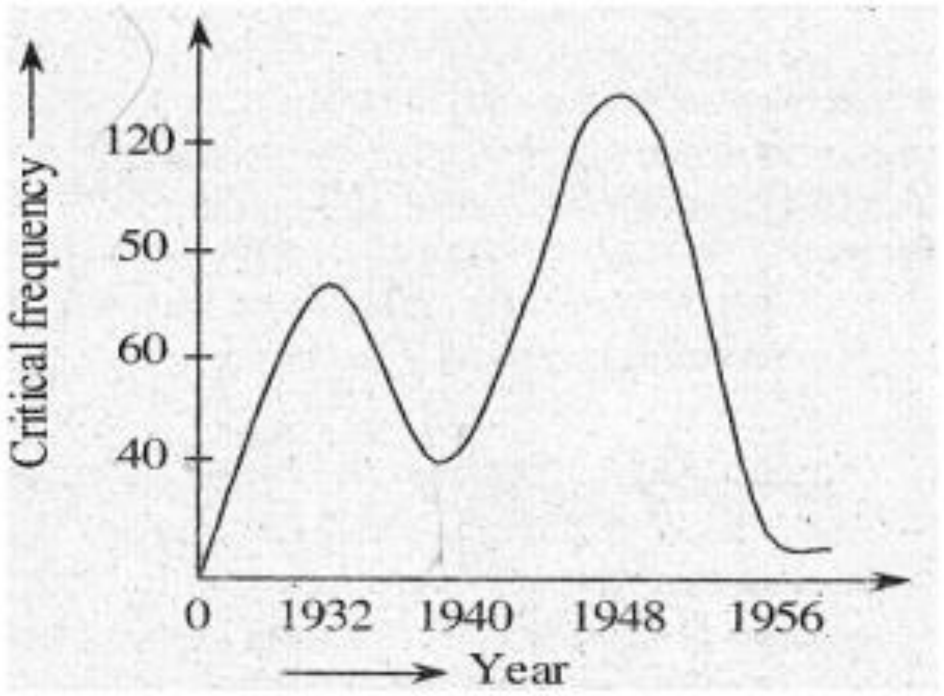


fig 8.1 (a) Sun Spot Number

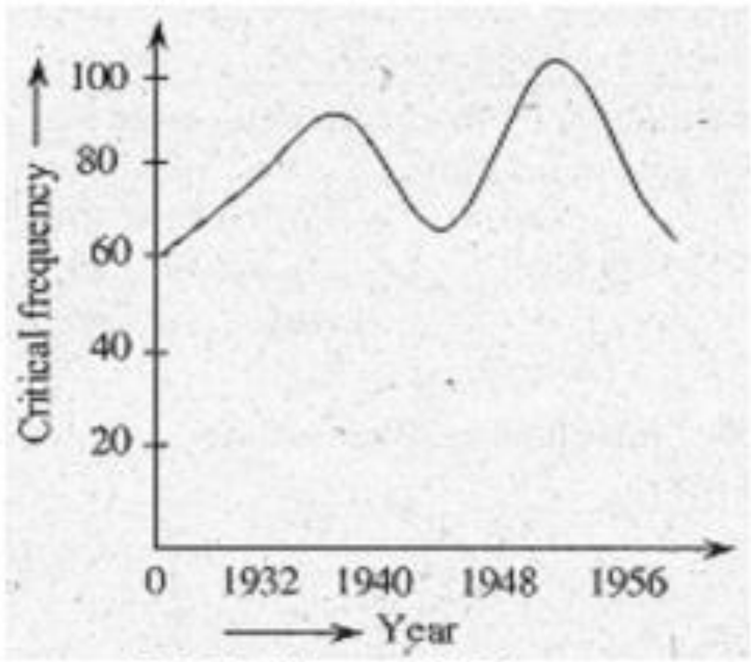


fig 8.2 Critical Frequency of F2 layer

Fading

- Sky wave propagation largely suffers from fading variations or a fluctuation in the received signal strength is defined as fading.
- Wherever the signals that are propagated through sky wave propagation, at the receiver end the signals or wave follow different paths due to variations in the height and density of the ionization layer.
- Fading is one of the important parameter in sky wave propagation and occurs due to reflections from the earth.
- Fading can be classified as Frequency selective fading, interference fading, absorption fading, polarization fading and skip fading
- Fading can be reduced by using diversity reception

Whistlers

- Whistlers are lightening discharges generate the pulses which may bounce back and forth several times which makes whistling tones with gradually falling pitch in the receivers.
- These are naturally occurring transient electromagnetic disturbances
- Various whistlers are long whistlers, short whistlers and noise whistlers

Atmospheric noise or Atmospherics

- Noise picked by receiving antenna due to natural causes are atmospheric noises
- It is due to natural phenomena like thunder storm and other electrical disturbances.

Ionospheric Absorption

- When radio waves pass through an ionized layer, it cause electrons to vibrate
- These vibrating electrons give some of its energy by colliding with neighboring molecules and ions
- This energy heating up the air and hence wasted
- This loss is severe when signal travels more distance through ionosphere
- During day time the number of electrons will be high and hence absorption will be much high
- Absorption is much high around gyro frequency 1.4 MHz

Types of Ionospheric Absorption

1. Non deviative Absorption

- Absorption which occurs in lower region where refractive index is nearly equal to unity.
- Which is the absorption happened in the lower portion of ionosphere
- Which is maximum at lowermost D region since collisional frequency is highest
- The absorption increases with decrease of frequency
- If earth,s magnetic field is neglected the absorption coefficient

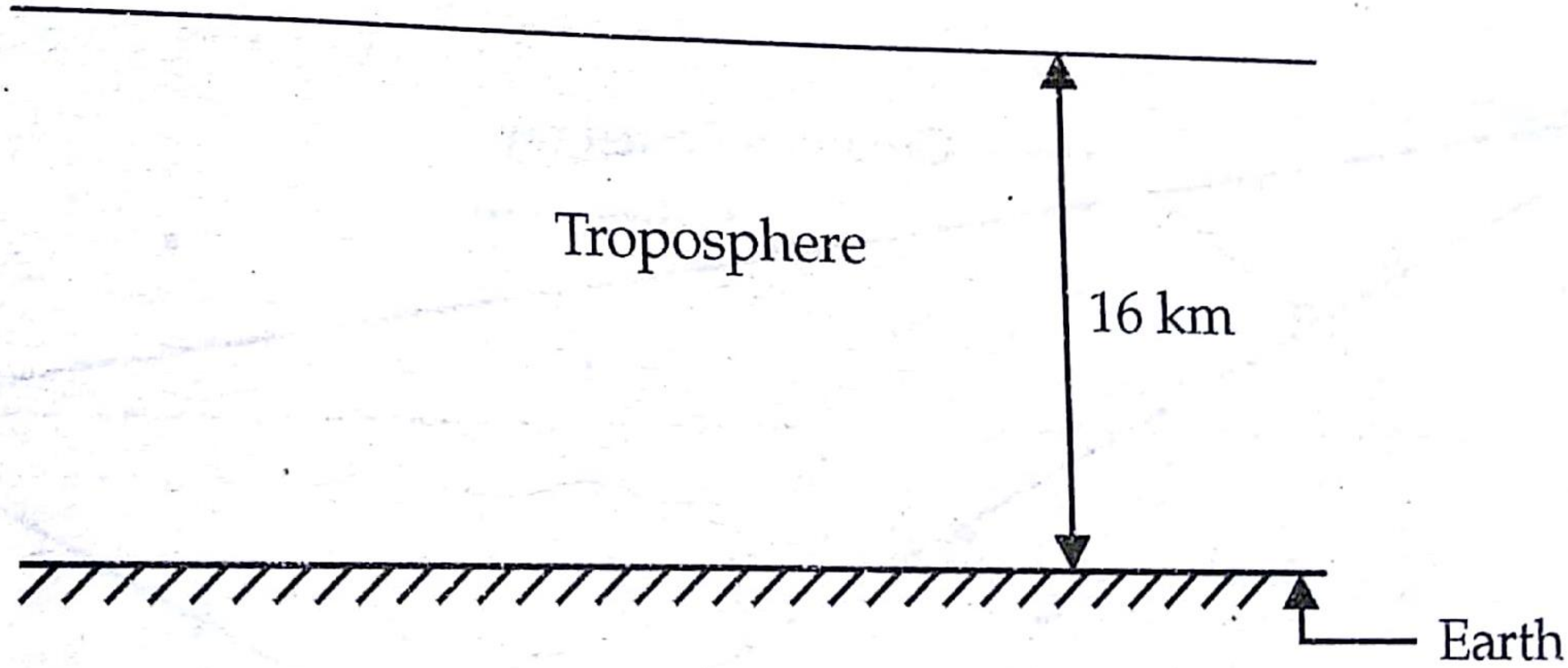
- $k = \frac{v f_c^2}{2 c f^2}$
- $k \propto \frac{1}{f^2}$
- $k \propto$ v
- Where v is the collision frequency
- The increase in collision frequency decreases wave frequency
- Which in turn increases the absorption
- Hence it is necessary to use a high transmission frequency

2. Deviative Absorption

- It is the absorption which occurs in the region where the value of refractive index is appreciably less than unity

Space Wave Propagation/ Tropospheric Wave propagation

- Signals in the VHF and higher range are not usually returned to earth by the ionosphere
- The Electromagnetic wave that propagates from transmitter to receiver in earth's troposphere is called space wave propagation.
- It is also known as Line of Sight propagation Troposphere is the region of atmosphere within 16 Km above surface of the earth.
- Space wave propagation is useful at frequencies above 30 MHz(HF, VHF , UHF bands and microwave)
- In these high frequencies both ground and sky wave propagation modes will fail
- Space wave propagation have high range, it is limited to LOS distance which is limited by curvature of earth.
- It is useful for FM, TV and Radar applications


Troposphere
16 km
Earth

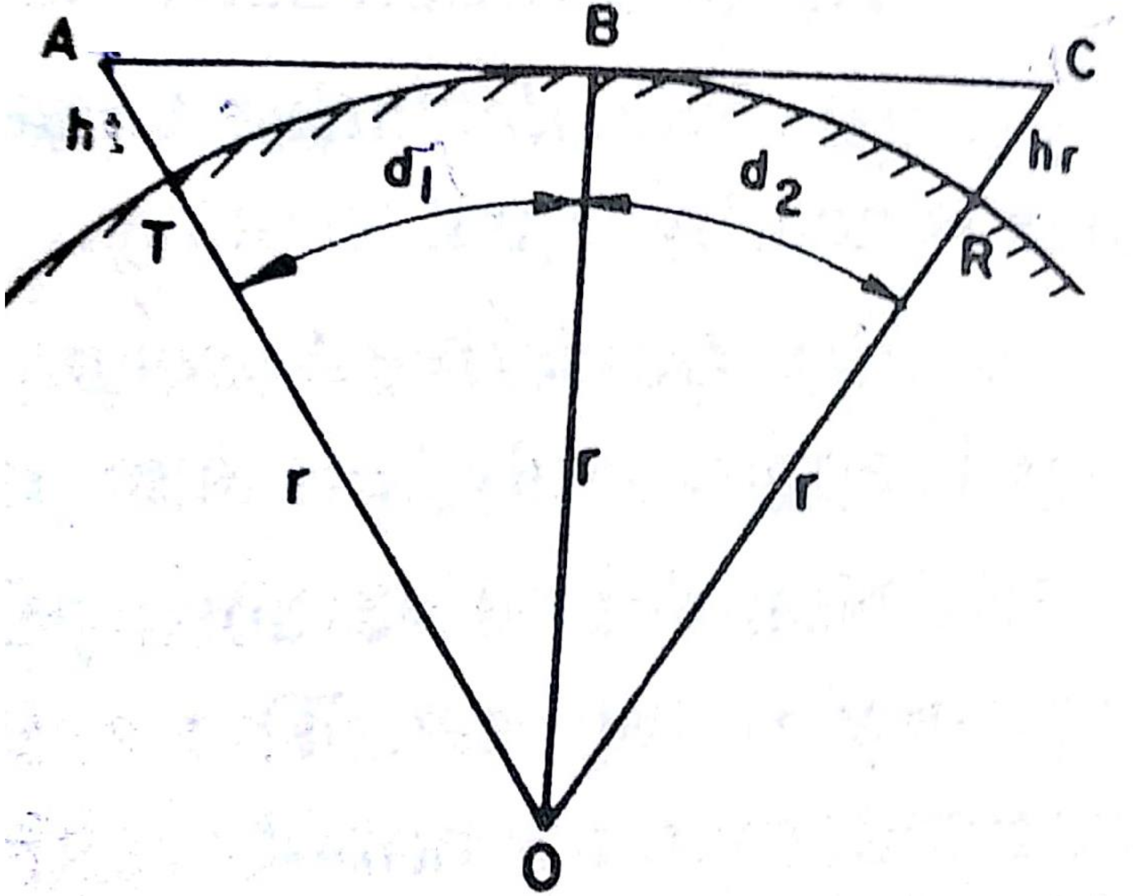
Factors affecting field strength of Space wave

1. Direct ray from transmitter
2. Ground reflected ray
3. Reflected and refracted rays from troposphere
4. Diffracted rays around the curvature of earth, hills and so on

- The effect of first two rays are prominent

LOS Distance / Range of Space Wave

- LOS distance is the distance between transmitting antenna and receiving antenna.
- If a direct ray passes from transmitter to receiver without being intercepted by the bulge of earth's surface
- The range of SWC is slightly beyond LOS distance which depends on height of transmitting and receiving antennas.
- Let d be the distance between transmitter and receiver and $h_t \; and \; h_r$ are the height of antennas above the ground then


A
B
C
ht
hr
d1
d2
T
R
r
r
r
O

LOS distance is

$$d = d_1 + d_2$$

If r be the radius of earth = 6370 km

From ΔABO

$$(h_t + r)^2 = d_1^2 + r^2$$

$$d_1 = \sqrt{(h_t + r)^2 - r^2}$$

$$= \sqrt{{h_t}^2 + r^2 + 2h_t r - r^2}$$

$$\approx \sqrt{2\,r\,h_t} \text{ (since } {h_t}^2 \ll 2h_t r \text{)}$$

$$d_2 = \sqrt{(h_r + r)^2 - r^2}$$

$$\approx \sqrt{2\, r\, h_r}$$

d = $d_1 + d_2 = \sqrt{2\, r\, h_t} + \sqrt{2\, r\, h_r}$

$=\sqrt{2\, r}\,(\sqrt{h_r} + \sqrt{h_t})$

$= \sqrt{2 * 370 * 10^3}\left(\sqrt{h_r} + \sqrt{h_t}\right)$

$= 3.57(\sqrt{h_r} + \sqrt{h_t})$ Km

Considering effective radius of earth $r' = \frac{4}{3}$r

d $=\sqrt{2\, r'}\,(\sqrt{h_r} + \sqrt{h_t})$

$= 4.12(\sqrt{h_r} + \sqrt{h_t})$ Km

Field Strength of Space Wave propagation

$$E = \frac{2E_0}{d} \sin \frac{2\pi h_t h_r}{\lambda d}$$

$$E \approx \frac{4\pi h_t h_r}{\lambda d^2} E_0$$

E_0 = field strength due to direct ray at unit d
on directivity of transmitting antenna a
$E_0 = 137.6 \sqrt{P_{kW}}$ mV/m at one mile for l
antenna.

h_t = height of the transmitting antenna

h_r = height of the receiving antenna

d = distance between the two antennas.

The field strength at the receiver is mostly contributed by direct and ground eflected rays. These two rays are shown in Fig. 9.8.

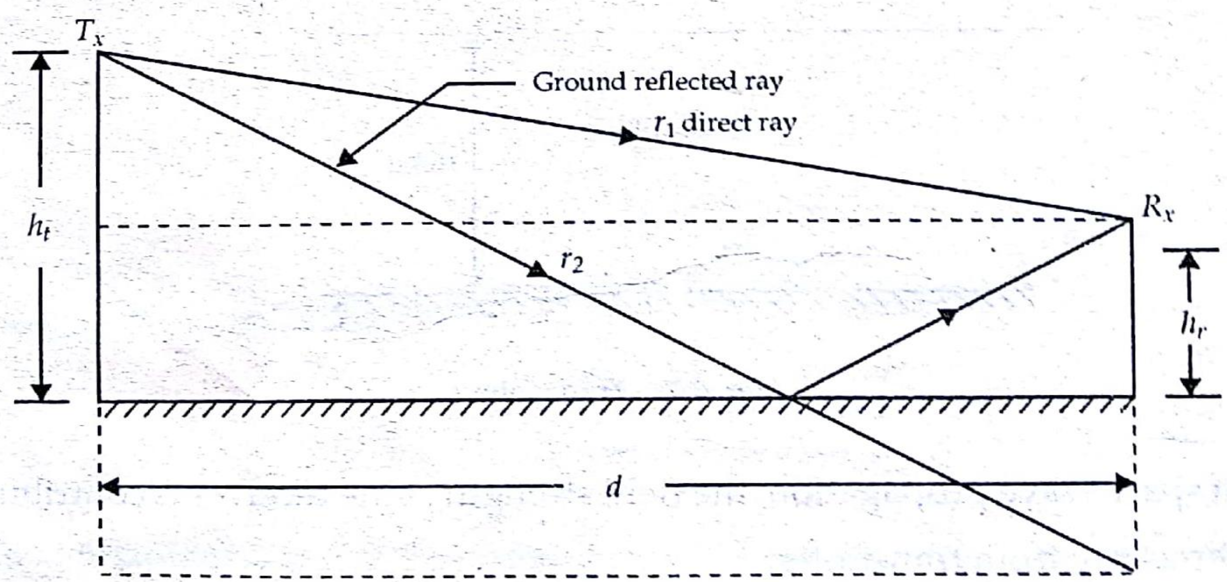


Fig. 9.8 *Direct and ground reflected rays in space wave*

From Fig. 9.8, we have

$$r_1^2 = (h_t - h_r)^2 + d^2$$

or

$$r_1 = d\left[1 + \left(\frac{h_t - h_r}{d}\right)^2\right]^{1/2}$$

From Binomial series, we have

$$(1 \pm x)^{1/2} = 1 \pm \frac{1}{2} x - \frac{1}{2.4} x^2 + \ldots$$

If x is small, the higher order terms can be neglected. Then

$$(1 \pm x)^{1/2} \approx 1 \pm \frac{1}{2} x$$

Therefore Equation (9.13) can be written as

$$r_1 = d \left[1 + \frac{1}{2} \left(\frac{h_t - h_r}{d} \right)^2 \right]$$

$$\approx \left[d + \frac{(h_t - h_r)^2}{2d} \right]$$

Similarly,

$$r_2^2 = d^2 + (h_t + h_r)^2$$

$$r_2^2 = d^2 \left[1 + \frac{(h_t + h_r)^2}{d} \right]$$

So,

$$r_2 \approx \left[d + \frac{(h_t + h_r)^2}{2d} \right]$$

the path difference between the two ray is given by

$$r_2 - r_1 = d + \frac{(h_t + h_r)^2}{2d} - d - \frac{(h_t - h_r)^2}{2d}$$

$$= \left(\frac{h_t^2 + h_r^2 + 2h_t h_r}{2d}\right) - \left(\frac{h_t^2 + h_r^2 - 2h_t h_r}{2d}\right)$$

or

$$r_2 - r_1 = \frac{4h_t h_r}{2d} = \frac{2h_t h_r}{d}$$

The corresponding phase difference(α) is

$$\alpha = \frac{2\pi}{\lambda} . \left(\frac{2\, h_t h_r}{d}\right)$$

$$= \frac{4\, \pi h_t h_r}{d\lambda} \text{ radians}$$

- This phase difference is due to path difference. Another phase difference of β will be introduced due to reflection from ground
- Hence total phase difference θ = α + β
- Resultant Field strength

$$E_R = E_0(1 + ke^{-j\theta})$$

$$E_R = E_0(1 + (\cos\theta) - j\sin\theta))$$

$$= E_0\sqrt{(1 + k\cos\theta)^2 - ((jk sin\,\theta)^2)}$$

$$= E_0\sqrt{1 + k^2\cos^2\theta \quad + 2\,k\cos\theta + k^2\sin^2\theta}$$

$$= E_0\sqrt{1 + k^2 \quad + 2\,k\cos\theta}$$

If earth is assumed to be perfect k =1 and β = 180^o

- Substituting we get

$$\left| E_R \right| = E_0 \sqrt{1 + 1^2 + 2.1\left(2\cos^2\frac{\theta}{2} - 1\right)} \qquad [\because \cos\theta = 2\cos^2\theta/2 - 1]$$

$$= E_0 \sqrt{2 + 4\cos^2\frac{\theta}{2} - 2} = E_0\, 2\cos\frac{\theta}{2}$$

$$\left| E_R \right| = 2E_0 \cos\left(\frac{\alpha + \pi}{2}\right) = 2E_0 \sin\frac{\alpha}{2} \qquad \begin{vmatrix} \because \theta = \alpha + \beta = \alpha + \pi \\ \because \cos\left(\frac{\pi}{2} + \frac{\alpha}{2}\right) = \sin\frac{\alpha}{2} \end{vmatrix}$$

$$\left| E_R \right| = 2E_0 \sin\left(\frac{4\pi h_t \cdot h_r}{2d\lambda}\right)$$

$$d >> h_t \text{ or } h_r$$

$$\sin\frac{4\pi h_t h_r}{2d\lambda} \cong \frac{4\pi h_t h_r}{2d\lambda}$$

$$\boxed{\left| E_R \right| = 2E_0 \cdot \frac{4\pi \cdot h_t h_r}{2d\lambda} = \frac{E_0\; 4\pi h_t h_r}{d\lambda}}$$

If E_f = Field strength of the direct ray *i.e.* free space field strength at a unit distance, then

$$E_0 = \frac{E_f}{d}$$

$$E_f = 7\sqrt{P} \text{ volt/metre}$$

$$P = \text{Effective power radiated, in Watts}$$

$$\boxed{E_0 = \frac{7\sqrt{P}}{d}}$$

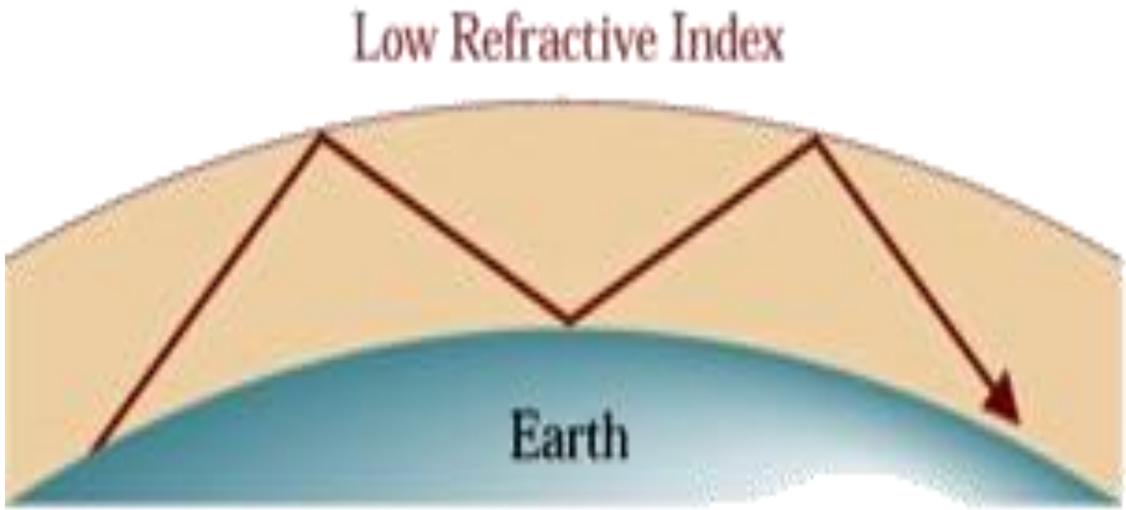
$$|E_R| = \frac{7\sqrt{P}}{d} \cdot \frac{4\pi h_t \cdot h_r}{d \cdot \lambda} = \frac{7 \times 4 \times 3.14 \sqrt{P}\, h_t \cdot h_r}{d^2 \lambda} = \frac{87.92 \sqrt{P}\, hsubt \cdot h_r}{d^2 \lambda}$$

$$\boxed{|E_R| \cong \frac{88\sqrt{P}\, h_t h_r}{\lambda d^2} \text{ volt/metre}}$$

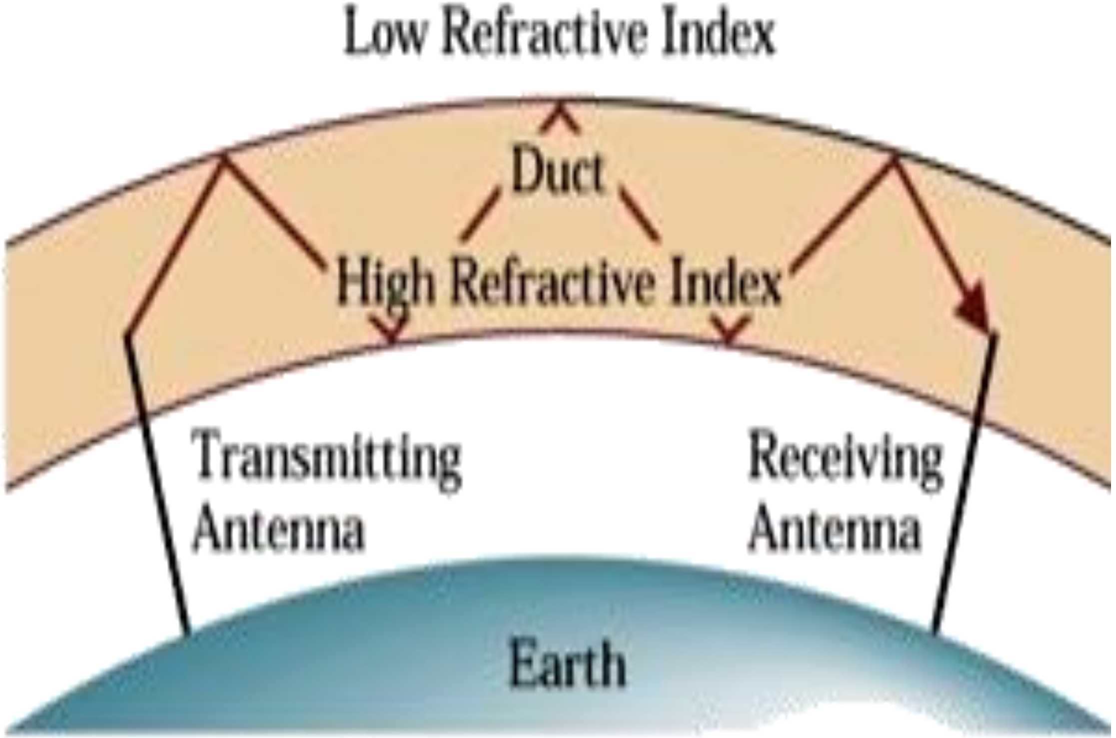
Duct propagation

- In troposphere under normal conditions the air pressure water vapor pressure and temperature reduces with the increase of height above earth. As a result of this the refractive index also reduces with the increase of height
- Under the above conditions, especially over water, a *superrefractive* layer can form in the troposphere and return signals to earth
- The signals can then propagate over long distances by alternately reflecting from the earth and refracting from the superrefractive layer
- A related condition involves a thin tropospheric layer with a high refractive index, so that a *duct* forms which behaves as a leaky waveguide.
- Which is helpful for transmission to occur much beyond LOS distance using refraction
- This propagation is known as duct propagation

- In standard atmosphere dielectric constant decreases uniformly with the increase of height.
- Under abnormal conditions variation of dielectric constant of the troposphere with height departs considerably from the standard condition.
- Thus under certain special conditions the dielectric constant may not decrease at all with height or may even increase with height resulting in the radio wave following the straight line path or curving away from the earth respectively.
- The layers of air one over other having different temperatures and water vapor contents give a new phenomenon called super refraction or duct propagation
- The high frequency waves undergo continuous refraction in the duct or refraction with reflection from the ground as shown in first figure



Ground based duct



Elevated Duct

- Ducts can be classified into
  1. Ground based duct
  2. Elevated duct

- Ground based duct is formed mostly over water especially over ocean
- Although ground based duct also occur on land but less frequently and temporarily
- The elevated ducts are typically found in coastal areas at an elevation of 1000 – 5000 feet having width about 1000 feet

- The transmission can be done over a large distance even 1000 Km is possible
- The main requirement for the formation of duct is temperature inversion(increase in temperature as height increases)
- Under this condition, the refractive index of atmosphere at height h will modify as

$$N = \mu + (h/r)$$

This value is closer to unity the change in refractive index is

$$M=(N-1) \times 10^6 = (\mu-1 + (h/r)) \times 10^6$$

Where μ is refractive index, r is the radius of earth and h is height above ground

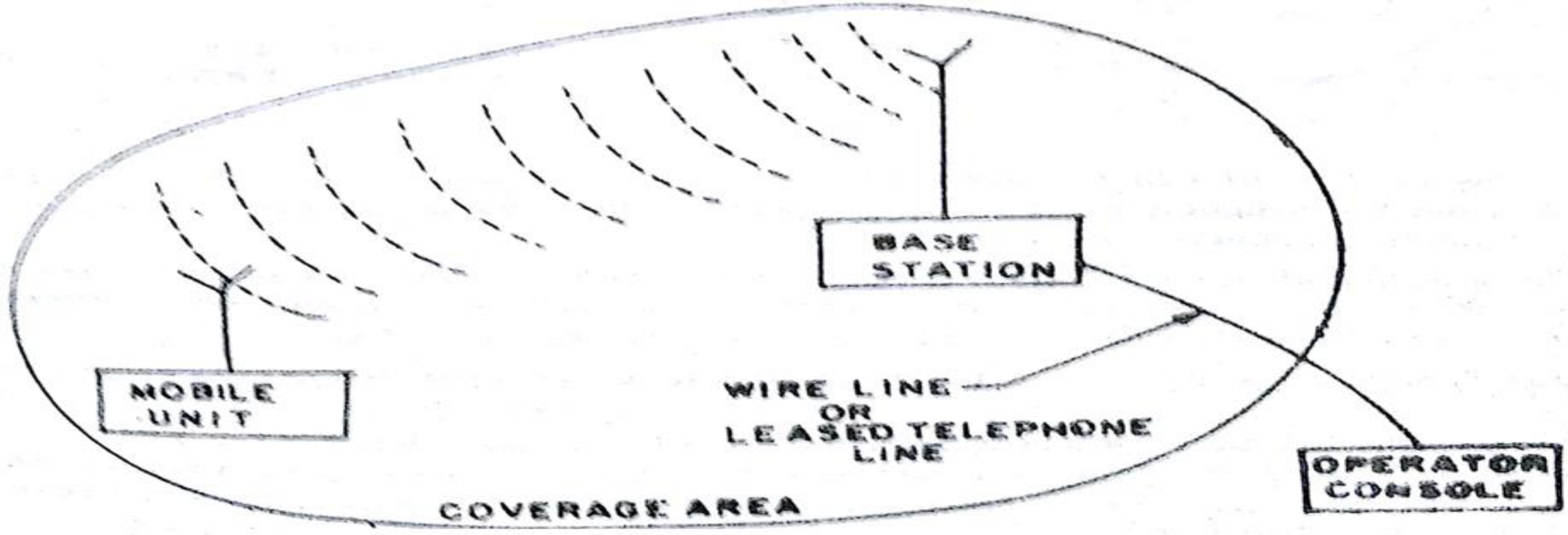
- Only when dM/dh is negative the duct will form, means when h-M curve have negative slope
- In this condition the ray enters the duct with sufficiently small angles which is less than critical angle are bent until they become horizontal
- These rays are trapped between upper and lower walls of the duct
- Operation of duct is similar to a waveguide in which itbehave as a high pass filter
- Thus signals having wavelength higher than λ_{max}

$$\lambda_{max} = 0.084 d^{3/2}$$

Where d is duct height in metres

VHF and UHF Mobile radio Communication

- Radio communication in VHF and UHF bands between 30 MHz and 30000 MHz takes place in the troposphere.
- The main application of VHF/UHF bands in communication between a fixed base station and many mobile stations
- Such as Aircraft controllers, Police control stations, Armed force communication, Fire department, Ship control , Railways and highway maintenance etc…
- VHF and UHF radio frequencies propagate principally along LOS paths.
- On the other hand, HF waves, those below 30 MHz it is possible beyond the line of sight (BLOS) communication.


BASE
STATION
MOBILE
UNIT
WIRE LINE
OR
LEASED TELEPHONE
LINE
OPERATOR
CONSOLE
COVERAGE AREA

Range of VHF/UHF Mobile radio Communication

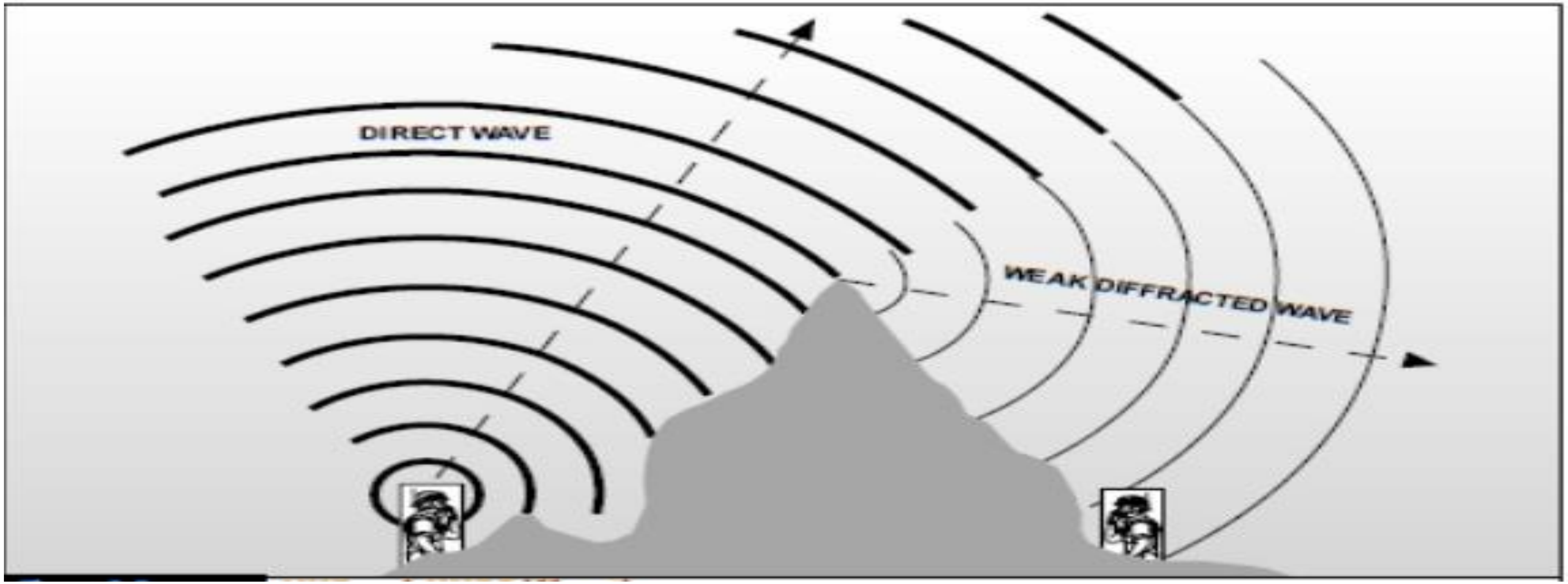
- VHF and UHF waves are also attenuated with every mile of distance.
- it is most often the shadowing effects of irregular terrain, buildings, and other objects that limit the effective range and not transmit power.
- In order to avoid shadowing and distorted reflection patterns by huge buildings and hilltops in big cities, It is normally a practice to install the base station antenna on top of high building or hilltop so that radio horizon will also increase without any obstacle.
- The visible horizon observed at approximately five feet above a flat surface of earth is less than 2.7 miles away.
- This is approximately the maximum LOS radio range from a radio on the back of a standing man to another radio that is lying on the ground

- It is clear that the elevation of both the transmitting and receiving antennas is crucially important.
- For example if the receiving antenna were mounted on a 26-foot tower, the total LOS distance would be increased to 9 miles.
- Of course if the radiomen were both located on the tops of mountains, the LOS range might be as much as from 50 to hundred miles.
- A restricted number of channel assignments are available within VHF/UHF frequency spectrum mostly within the bands 148 MHz 174 MHz and 450 MHz to 470 MHz in which channel spacing is 15 KHz
- FM is used in VHF/UHF mobile communication for noise free reception

VHF and UHF Radio Reception Behind Ridges

- For the most part, ridges and hills form shadows of VHF and UHF radio waves.
- However, there is an important exception when it comes to very sharp ridges or other kinds of abrupt barriers.
- This is caused by a phenomenon known as Diffraction.
- When a VHF or UHF wave comes to a sharp edge, a portion of the wave bends around the edge and continues propagation as if a very low power radio was placed at the top of the ridge.
- It is important that the ridge be relatively sharp. A well-rounded hill or the curvature of the earth is not sufficient to cause this effect.
- This effect is important in a battle field situation where a soldier must seek shelter behind a ridge.

Diffraction



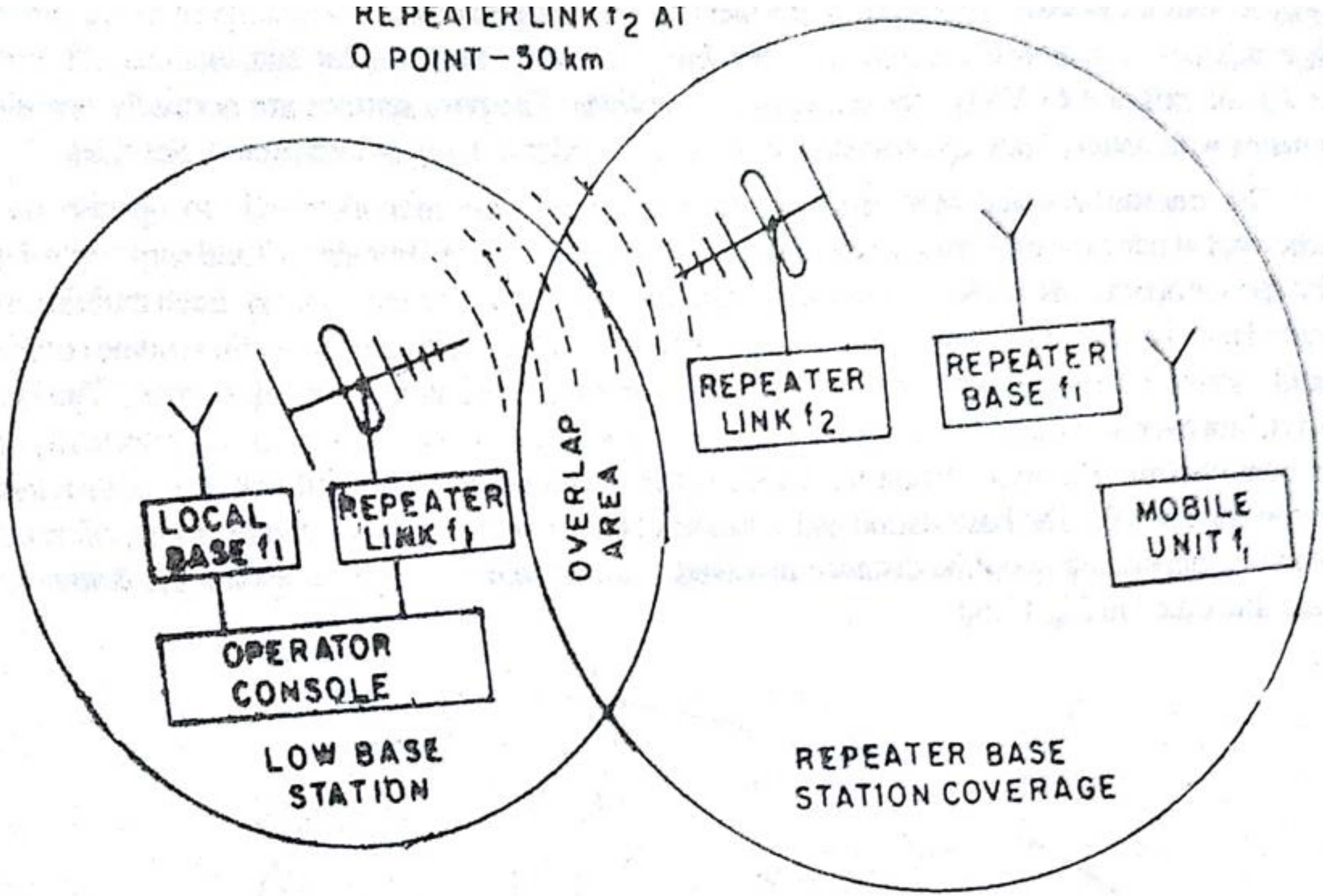
Reflections and Multipath Distortion

- VHF and UHF waves can be reflected off of dense surfaces like rocks or conductive earth, just like a beam of light can be reflected off a wall or a ceiling.
- Sometimes several paths exist between a transmitting and receiving antenna
- There is direct LOS path between two radios, but there is also a reflected path from the bottom of a valley between them.
- It is clear that these two paths are of different length, and that the direct path is the shorter of the two. Since radio waves travel at a constant velocity, the direct path wave arrives at the receiver before the reflected path.
- This means that the same broadcast information reaches the receiver at two different times. The effect of this is much like echoes that one hears in an acoustically poor room.
- If the echoes are close enough to each other, it is hard to understand what is being said. In radio terminology, this is called multipath distortion.

- It is prevalent with VHF and UHF. The higher the frequency, the more pronounced the effect is. It is usually caused by interference or reflections of signals from man-made objects such as buildings, houses, and other structures

VHF/UHF extended coverage area

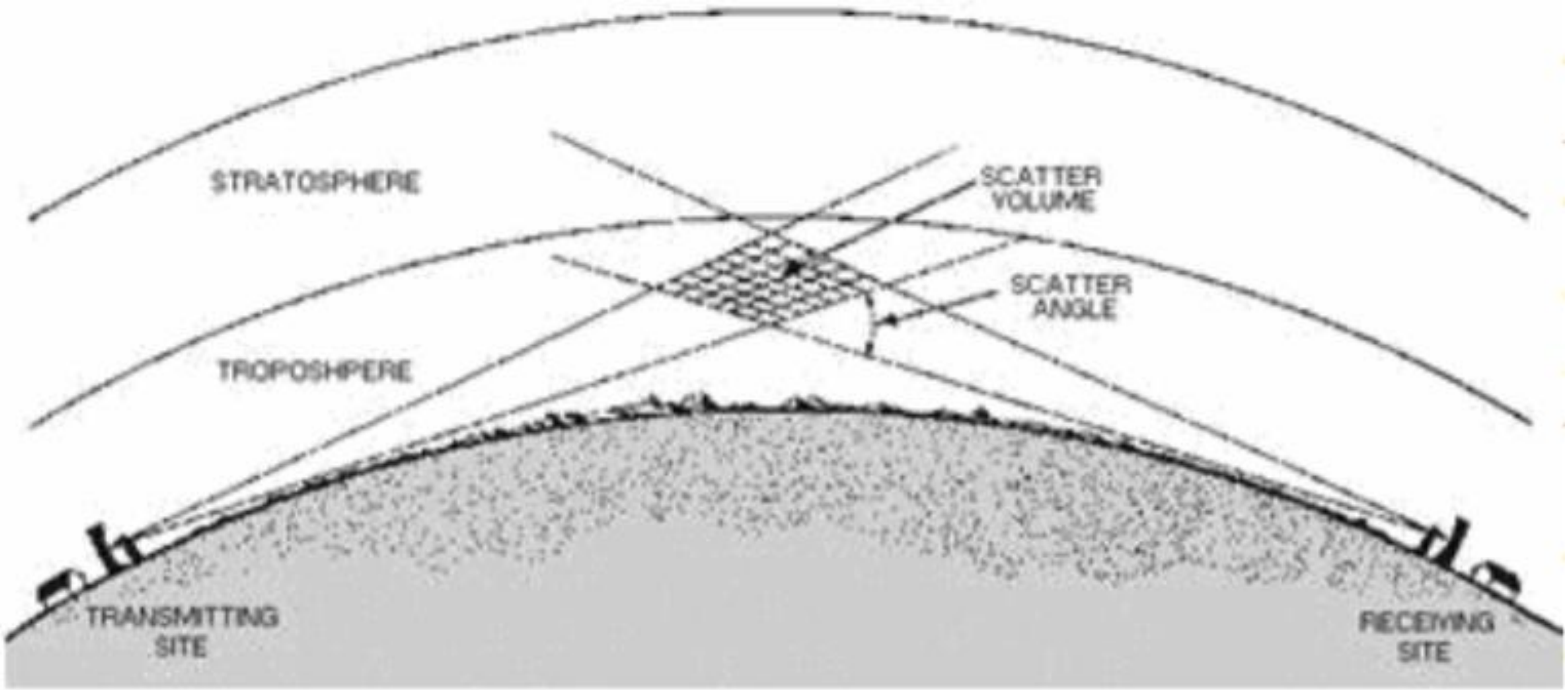
- To extend the coverage additional base stations are used which are connected to each other of operator’s console by overhead wire lines.
- These base stations are then operated independently by the operator or alternatively radio repeater’s link can also be used
- In this case another frequency is used to between main station and repeater station.


REPEATER LINK f2 AT
0 POINT – 50km
LOCAL BASE f1
REPEATER LINK f1
OPERATOR CONSOLE
OVERLAP AREA
REPEATER LINK f2
REPEATER BASE f1
MOBILE UNIT f1
LOW BASE STATION
REPEATER BASE STATION COVERAGE

Tropospheric Scatter propagation

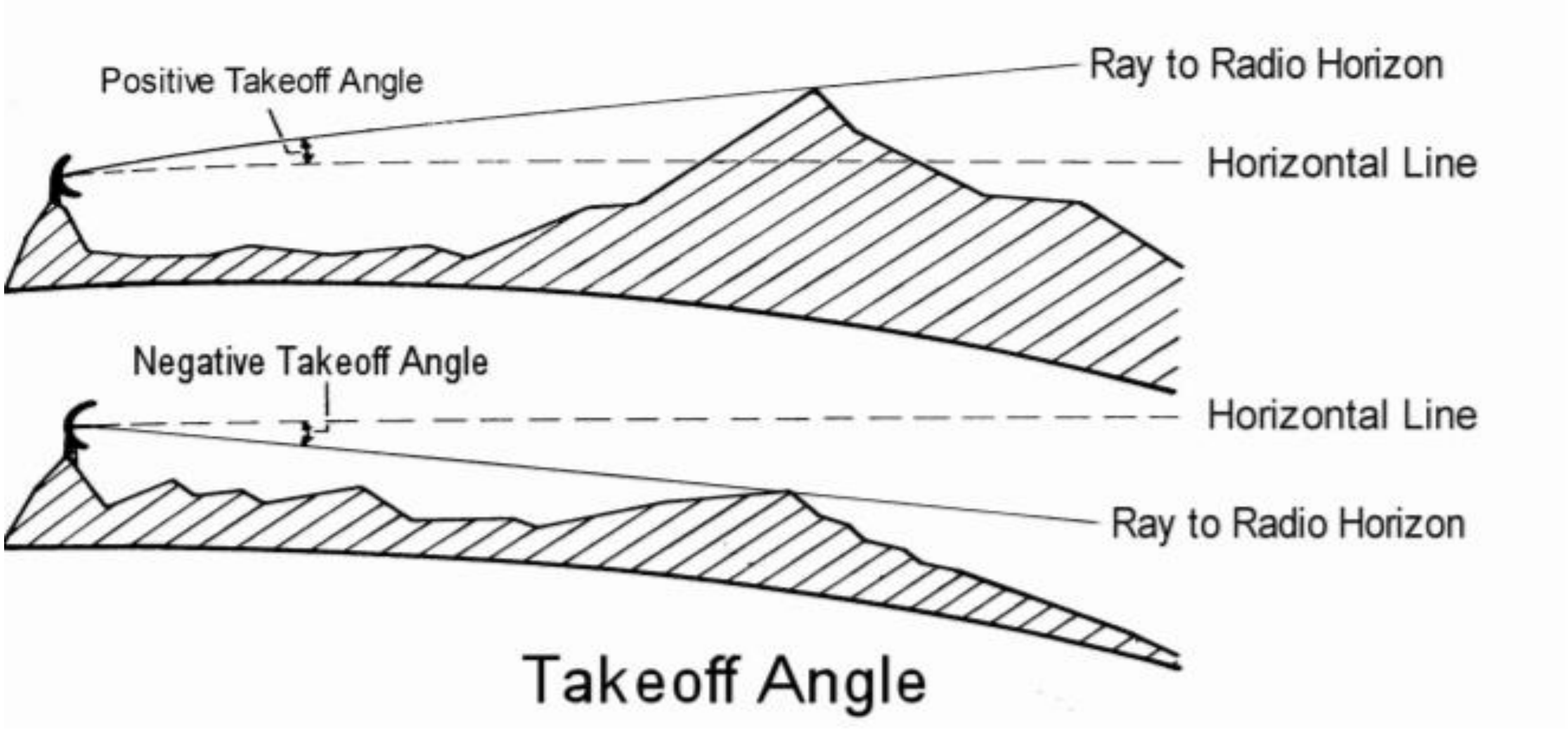
- The troposphere is the lowest portion of the atmosphere. Most of our weather takes place in the troposphere.
- It contains 80% of the atmosphere's mass and 99% of its water vapour. The troposphere begins at ground level, and its height varies from about 20 km near the equator to 17 km in the mid-latitudes to 9 km near the poles in summer.
- Tropospheric scatter occurs when two stations both point their antennas at a common volume in the troposphere, and that volume of the troposphere redirects the signal directed into it by one station towards the receiving antenna of the second station.
- The useful range of troposcatter is roughly 100 to 700 km, and it can be used from 144 MHz through 10 GHz.
- Troposcatter was widely used by the military prior to the availability of satellite communications systems

TROPOSCATTER

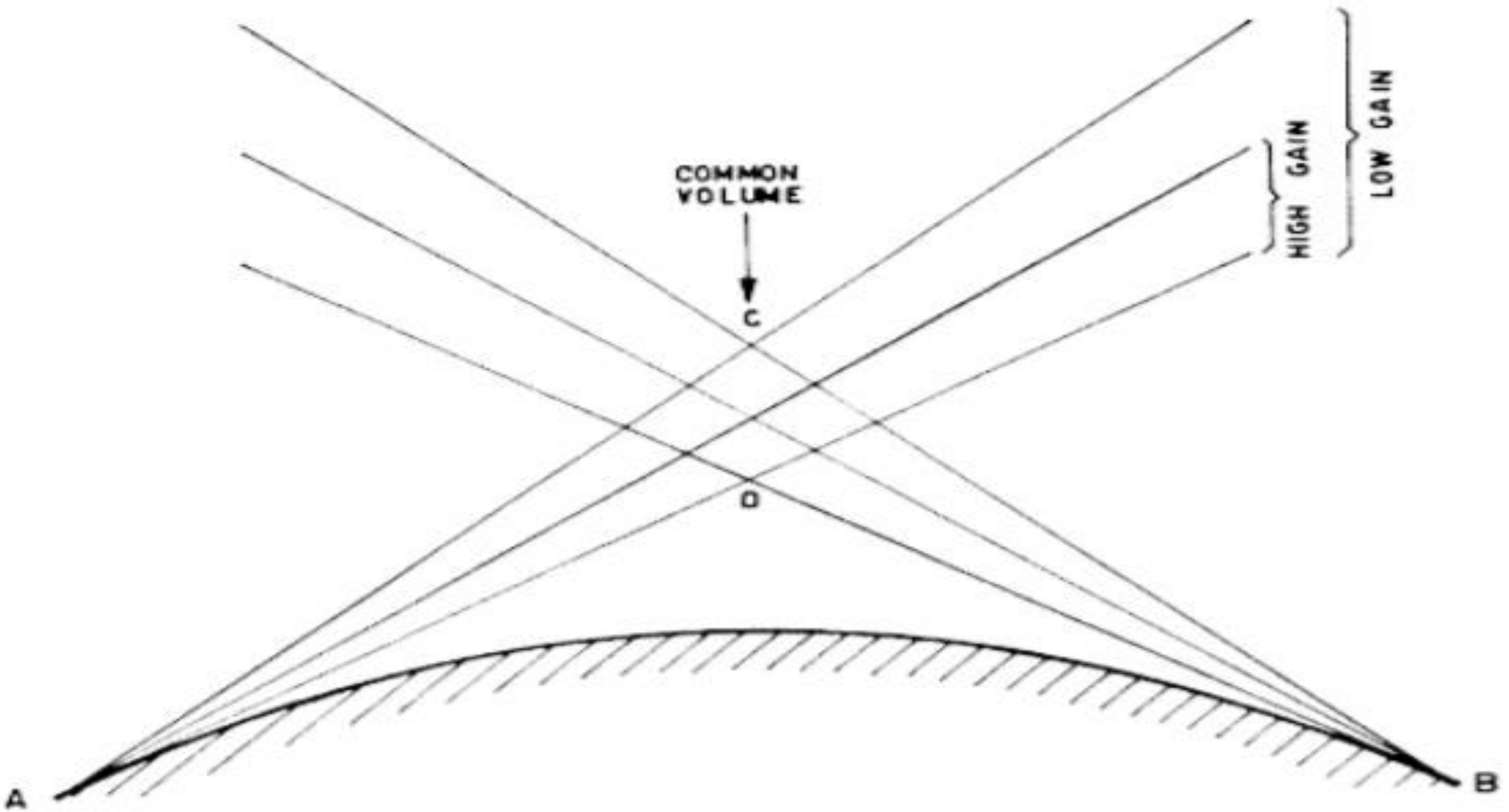


- The illustration on the figure shows a troposcatter path between two sites. The scatter volume is marked by cross-hatching, and the scatter angle, which is the angle between the radio horizon rays of the two stations, is labelled as "scatter angle".
- The radio horizon ray for an antenna is the ray that marks what is called the "take-off angle" for the antenna, which is the lowest elevation angle that will clear all obstructions in the direct path to the other station.
- The take-off angle depends on the relative heights of the antenna and the obstruction and the distance between them. Take-off angle can be either positive or, with favorable geography, negative, as shown in figure

Take Off Angle



Relation between gain of antenna and Troposcatter



- As is shown on the figure, high-gain antennas with smaller beam widths will illuminate a smaller scatter volume than will low-gain antennas with larger beam widths.
- Thus high-gain antennas would be expected to result in less scattered signal due to the smaller volume, and thus more troposcatter loss
- The tropospheric scatter links are similar to microwave link with the difference that larger output powers and lower receiver noise figures, very useful where difficult terrain are involved and microwave communication is costlier or not possible
- In India , there exists a tropospheric link with Soviet union, The link employs troposcatter mode of propagation keeping in view the high mountainous terrain between Srinagar(India) and Dushanbe (USSR)

Troposcatter link Model

$$\overline{P(r)} = P(t) - L(t)$$

- Where $\overline{P(r)}$ is received power level, P(t) is transmitted power level and L(t) is transmission path loss
- The transmission loss is the resultant sum of various losses and gains along the radio link between transmitter and receiver
- If transmitting and receiving antennas having gains G(t) and G(r) respectively then,

$$L(t) = L(p) + L(f) - G(t) - G(r)$$

Where L(p) is the annual median path loss between 2 antennas

- Path loss have different components L(s) is spatial path loss, scattering loss L(sc).
- Annual median path loss can be obtained as

$$L(p) = L(s) + L(sc) + L(misc)$$

- The output power level generated by the transmitter

$$P(t) = P(g) - L(f\ t)$$

Where L(f t) = is the portion of the feeder loss associated with transmitting antenna

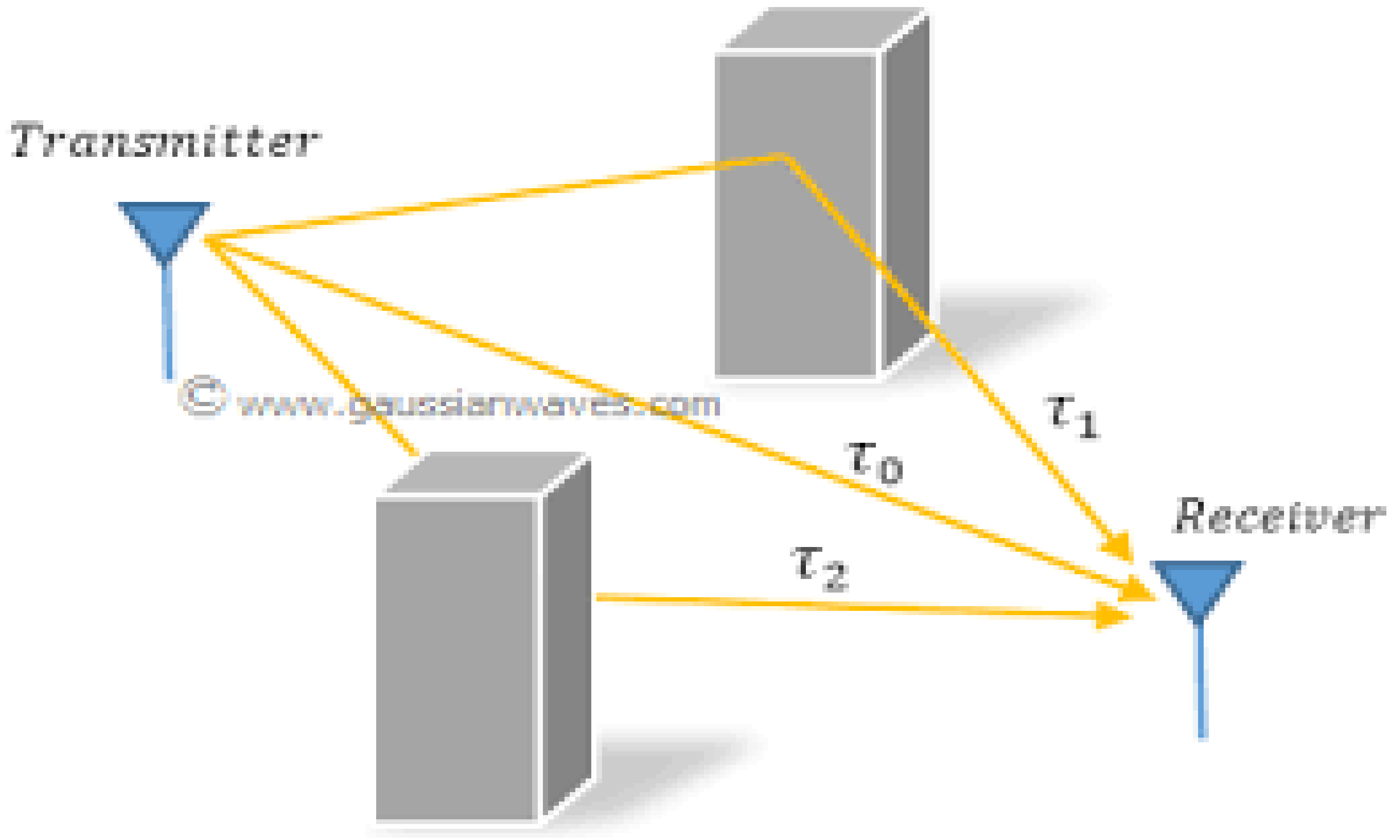
The gain of antenna if antenna used is paraboloidal reflector

$$G(t) = G(r) = 20 \log f(\text{MHz}) + 20 \log D\ (\text{m})$$

Where f is frequency and D is diameter of paraboloidal reflector

Fading

- In a typical wireless communication environment, multiple propagation paths exist between transmitter and receiver due to scattering by different objects.
- Thus, copies of the signal following different paths can undergo different attenuation, distortions, delays and phase shifts.
- Constructive and destructive interference can occur at the receiver.
- When destructive interference occurs, the signal power can be significantly diminished. This phenomenon is called fading.


Transmitter
© www.gaussianwaves.com
τ_1
τ_0
Receiver
τ_2

Types of fading

Frequency Selective fading:

- The transmitted signal reaching the receiver through multiple propagation paths, having a different relative delay and amplitude.
- This is called multipath propagation and causes different parts of the transmitted signal spectrum to be attenuated differently, which is known as frequency-selective fading.
- In this, the channel spectral response is not flat. It has dips or fades in the response due to reflections causing cancellation of certain frequencies at the receiver

- **Frequency Non-Selective fading/ Flat fading:**
- If all the frequency components of the signal would roughly undergo the same degree of fading, the channel is then classified as frequency non-selective (also called flat fading).
- **Slow fading:**
- Slow fading is a long-term fading effect changing the mean value of the received signal.
- Slow fading is usually associated with moving away from the transmitter and experiencing the expected reduction in signal strength.
- Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver.

- **Fast fading:**
- Fast fading is the short term component associated with multipath propagation.
- It is influenced by the speed of the mobile terminal and the transmission bandwidth of the signal.

Flat Fading	Freq. Selective Fading
BW of signal < BW of channel	BW of signal > BW of channel
Delay spread < Symbol period	Delay spread > Symbol period

Fast Fading	Slow Fading
High Doppler spread	Low Doppler spread
Coherence time < Symbol period	Coherence time >> Symbol period

Parameters of fading

Coherence Bandwidth:

- The coherence bandwidth of a wireless channel is the range of frequencies that are allowed to pass through the channel without distortion.
- Thus, it is the bandwidth over which the channel transfer function remains constant

Coherence time:

- The coherence time is the time over which a propagating wave may be considered coherent means predictable.
- In long-distance transmission systems, the coherence time may be reduced by propagation factors such as dispersion, scattering, and diffraction.

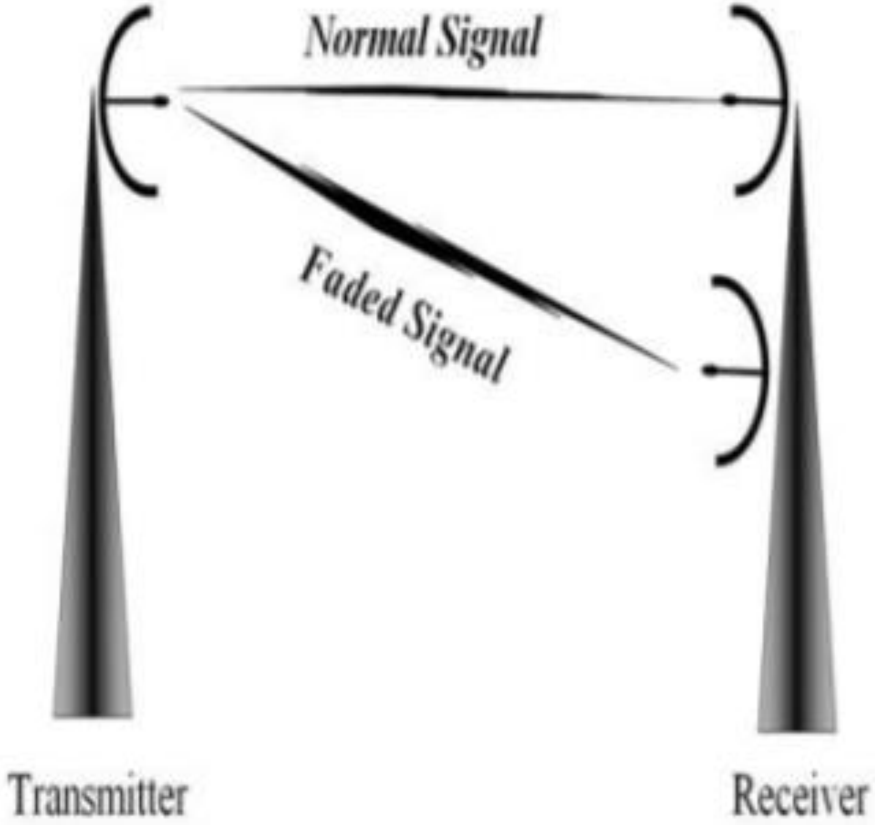
Diversity Techniques

- It is the technique used to compensate for fading channel impairments.
- It is implemented by using two or more receiving antennas.
- While Equalization is used to counter the effects of ISI, Diversity is usually employed to reduce the depth and duration of the fades experienced by a receiver in a flat fading channel.
- These techniques can be employed at both base station and mobile receivers.
- A diversity scheme is a method that is used to develop information from several signals transmitted over independent fading paths.
- It exploits the random nature of radio propagation by finding independent (uncorrelated) signal paths for communication.

Types of Diversity

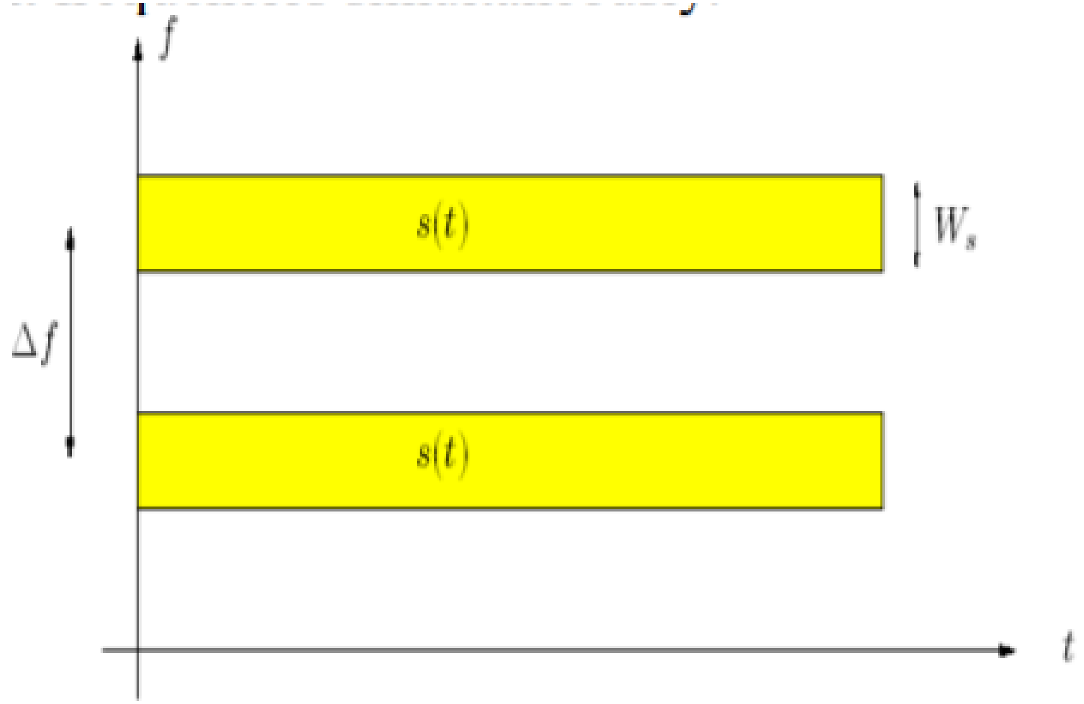
Space Diversity:

- The most common diversity scheme is space or spatial diversity. In this, no. of antennas is used to achieve different copies of the transmitted signal.
- Using two antennas with a distance between them the phase delay makes multi-path signals arriving at the antennas differ fading.
- Space diversity is nowadays in focus because of the higher frequencies used for transmission making it possible to apply this kind of diversity mechanics in smaller terminals.


Normal Signal
Faded Signal
Transmitter
Receiver

Frequency Diversity:

- Frequency diversity utilizes transmission of the same signal at two different, spaced, frequency carriers achieving two independently fading versions of a signal.
- It is a costly mechanism to use because of the difficulties to generate several transmitted signals and the combining signals received at several different frequencies simultaneously

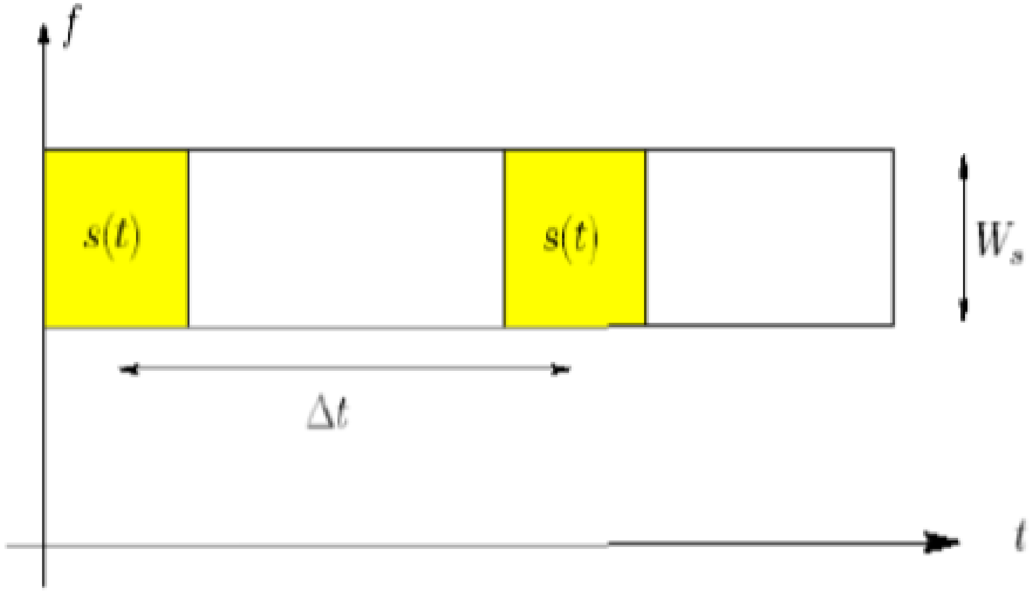


Angle Diversity:

- Signals arriving at the antennas are coming from different directions. Being independent in their fading variations these signals can be used for angle or angular diversity.
- At a mobile terminal angle diversity can be achieved using two Omni directional antennas acting as parasitic elements to each other changing their patterns to manage the reception of signals at different angles.
- As shown in fig., two orthogonal antennas are employed on a single base at different angles.

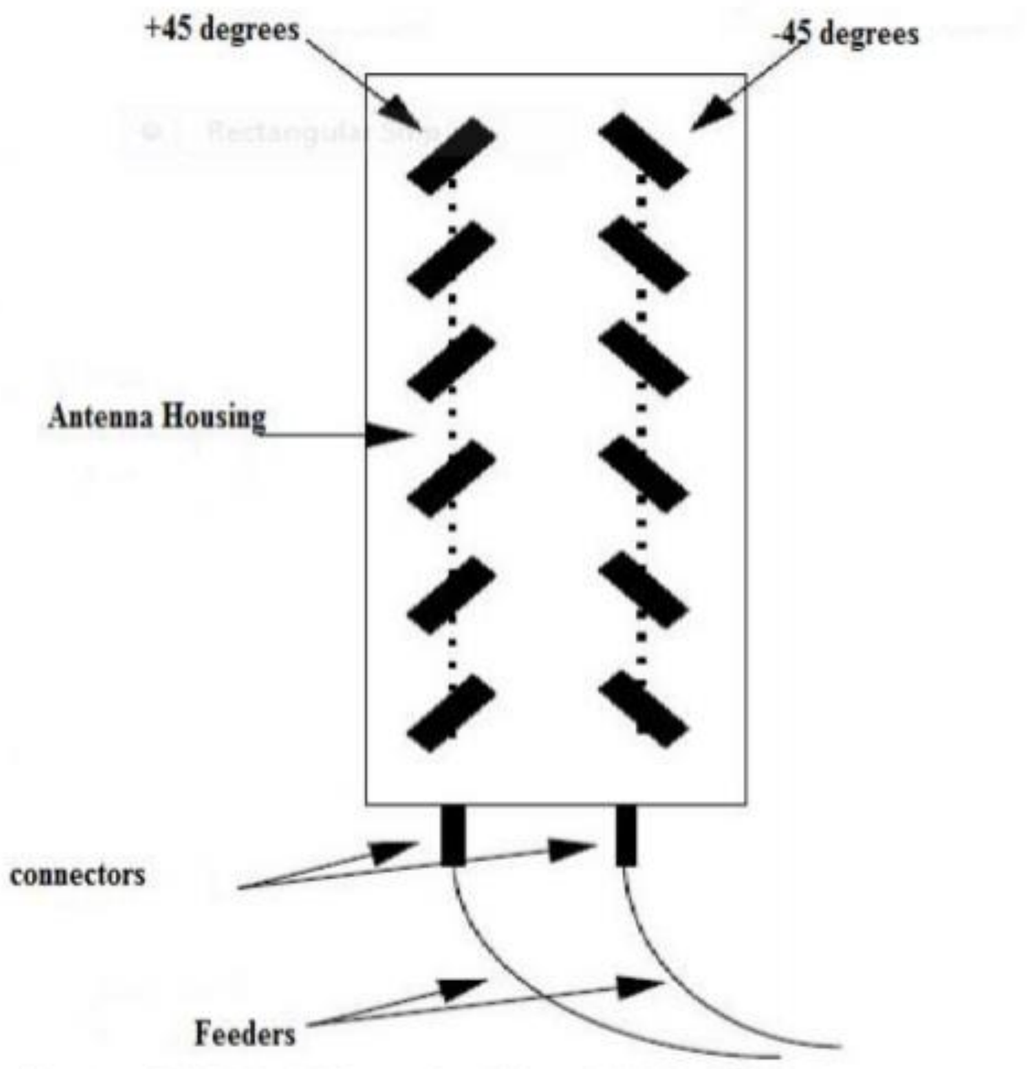
Time Diversity:

- Time diversity is mostly applicable in the digital transmission. Time diversity is achieved by transmitting the same bit of information repetitively at short time intervals.
- A redundant forward error correction code is added and the message is spread in time by means of bit-interleaving before it is transmitted. Thus, error bursts are avoided, which simplifies the error correction.
- As shown in fig., same bit s(t) is transmitted after a time interval Δt.



Polarization Diversity:

- Multiple versions of a signal are transmitted and received via antennas with different polarization.
- A diversity combining technique is applied on the receiver side. This diversity mechanism is very practical because of the very small size of antennas that can be used.
- It is mostly combined with space diversity. As shown in fig., two antennas are employed with different polarization and then are connected to receiver through feeders and connectors.


+45 degrees
-45 degrees
Antenna Housing
connectors
Feeders

Diversity Processing Techniques

Switching:

- In a switching receiver, the signal from only one antenna is fed to the receiver for as long as the quality of that signal remains above some prescribed threshold.
- If and when the signal degrades, another antenna is switched in. Switching is the easiest and least power consuming of the antenna diversity processing techniques but periods of fading and de-synchronization may occur while the quality of one antenna degrades and another antenna link is established.

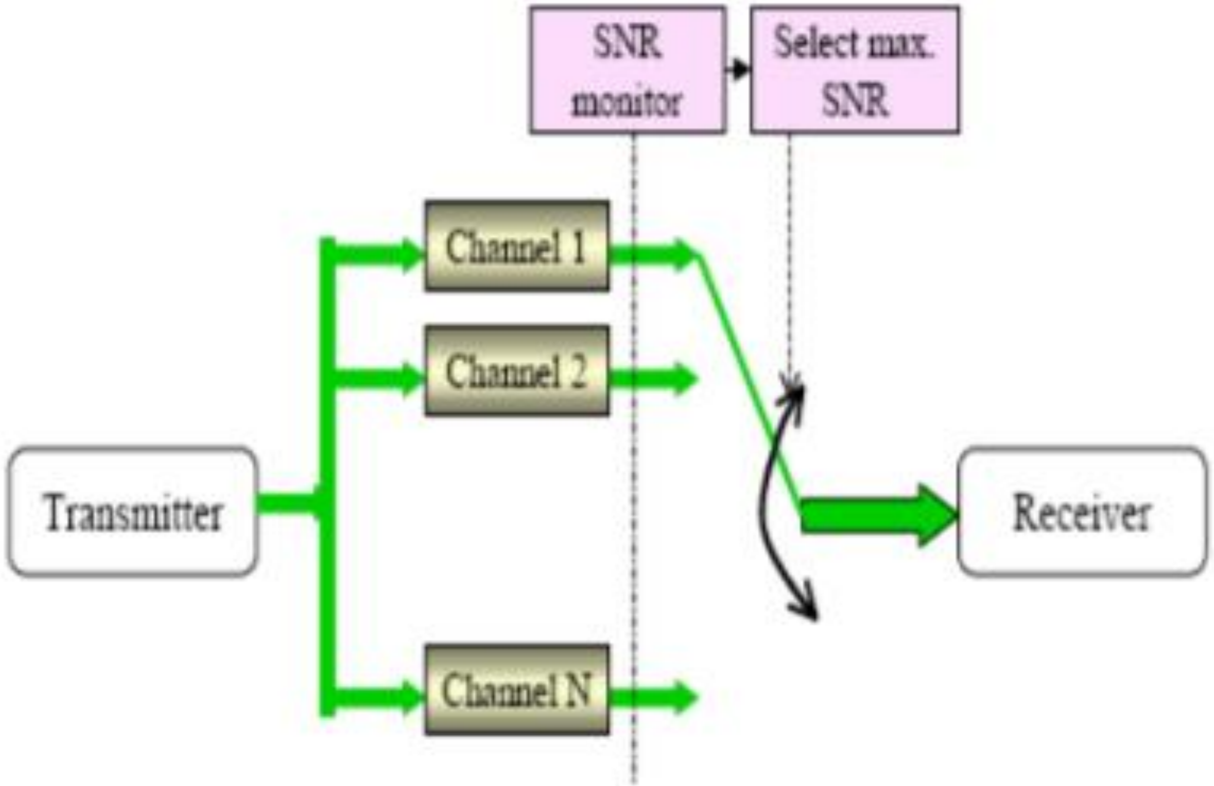
Selecting:

- Selection processing presents only one antenna's signal to the receiver at any given time.
- The antenna chooses the best signal-to-noise ratio (SNR) among the received signals. The actual selection process can take place in between received packets of information.
- The diversity technique comes under selecting scheme is selection diversity

Combining:

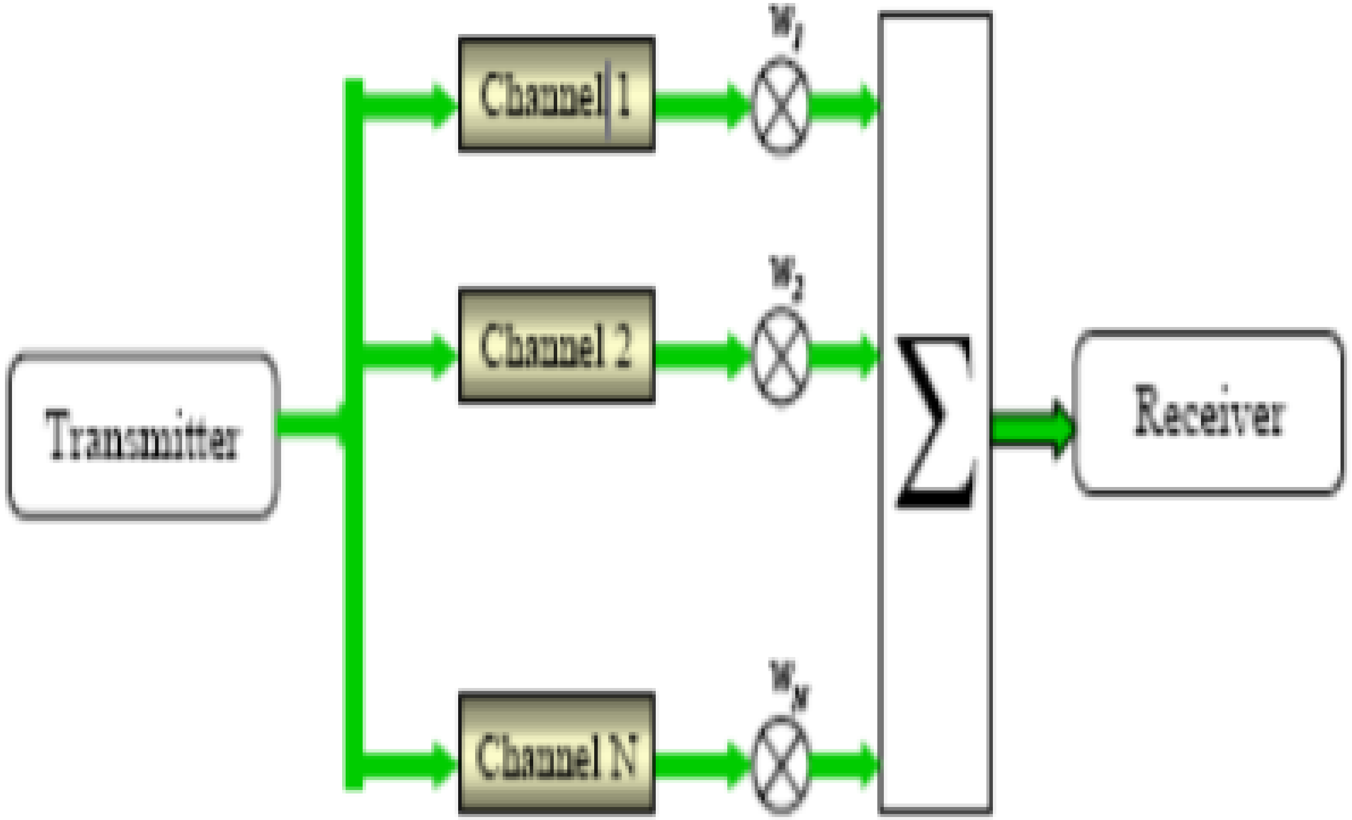
- In combining, all antennas maintain established connections at all times. The signals are then combined and presented to the receiver.
- Depending on the sophistication of the system, the signals can be added directly (equal gain combining) or weighted and added coherently (maximal-ratio combining).
- Such a system provides the greatest resistance to fading but since all the receive paths must remain energized, it is also consumes the most power.

Selecting

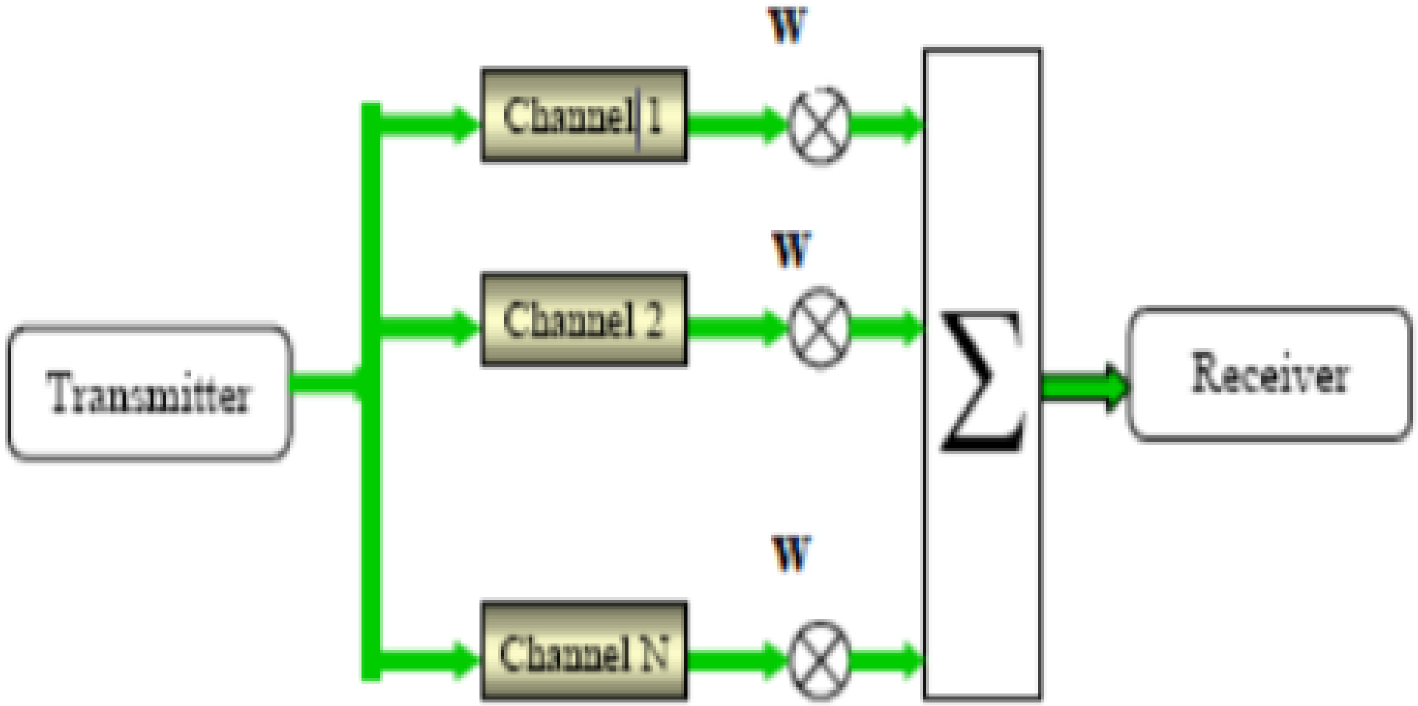


SNR monitor
Select max. SNR
Channel 1
Channel 2
Channel N
Transmitter
Receiver

MAXIMAL RATIO COMBINING



EQUAL GAIN COMBINING



Module 3

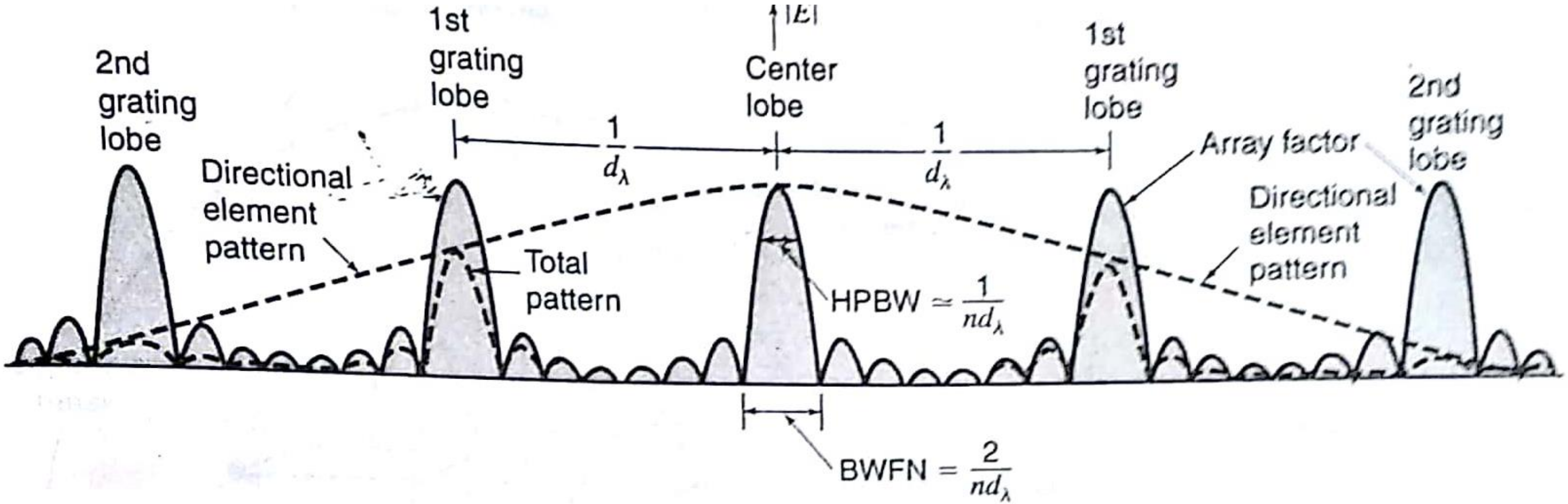
Grating lobes

- If the Uniform linear array of n elements has a spacing d_{λ}>1λ then the sidelobes will have similar amplitude of main lobe.
- These are called grating lobes
- It might limit our System performance
- Similar to aliasing in signal processing
- The spacing of grating lobe from the main lobe is

$$\Phi_G = Sin^{-1}\frac{m}{d_{\lambda}} \quad \text{(rad)} \qquad \text{where m=1,2,3.....}$$

With d_{λ} >> 1, this reduces approximately to

$$\Phi_G = \frac{m}{d_{\lambda}} \qquad \text{(rad)}$$



Grating lobes with array of *n* widely spaced elements. Solid line: pattern with isotropic elements (array factor). Dashed line: total pattern with directional elements, each with pattern of dotted line.

Methods to suppress Grating lobes

- Implement sub arrays of un-equal size, with random location of sub arrays with respect to center of array.
- Overlapping sub arrays architecture to push the grating lobes away from main beam.
- Two-way pattern design.
- Grating lobes produced by widely-spaced sub arrays can be suppressed using the principle of pattern multiplication by intentional placement of nulls coincident to grating lobe locations

Basic Principle of Beam Steering

Basic Principle of Beam Steering/ Phased array antenna

- In some applications the goal is to direct the main lobe of the radiation pattern at an angle other than the broadside or end-fire direction.
- The scan angle of the pattern dictates this steered angular location.
- The scan pattern can be obtained by introducing a phase difference to elements of the antenna array.
- This is the basic principle of electronic scanning for phased arrays/ beam steering.
- When the scanning is required to be continuous, the feeding system must be capable of continuously varying the progressive phase between the elements
- This can be accomplished by ferrite or diode shifters (varactors).

- Let us assume that the maximum radiation of the array is required to be oriented at angle θ_0.
- To accomplish this, the progressive phase excitation β between the elements must be adjusted so that

$$\psi = \beta + kd \cos \theta_0$$

- In the required direction $\psi = 0$
- Hence

$$\beta = -kd \cos \theta_0$$

- Thus by controlling the progressive phase difference between the elements, the maximum radiation can be squinted in any desired direction to form a scanning array. This is the basic principle of scanning array operation.

- Lots of techniques have been used to steer an antenna’s radiation pattern

1. Mechanical steering.
2. Beamforming.
3. Reflect array.
4. Parasitic steering.
5. Integrated lens antennas (ILAs).
6. Switched beam antennas.
7. Traveling wave antennas.
8. Retro-directive antennas.
9. Metamaterial Antennas

Phased array Antenna

- A phased array antenna is composed of lots of radiating elements each with a phase shifter.
- Beams are formed by shifting the phase of the signal emitted from each radiating element, to provide constructive/destructive interference so as to steer the beams in the desired direction.
- In the figure 1 (left) both radiating elements are fed with the same phase.
- The signal is amplified by constructive interference in the main direction. The beam sharpness is improved by the destructive interference.
- In the figure 1 (right), the signal is emitted by the upper radiating element with a phase shift of 22 degrees later than of the lower radiating element. Because of this the main direction of the emitted sum-signal is moved slightly upwards.

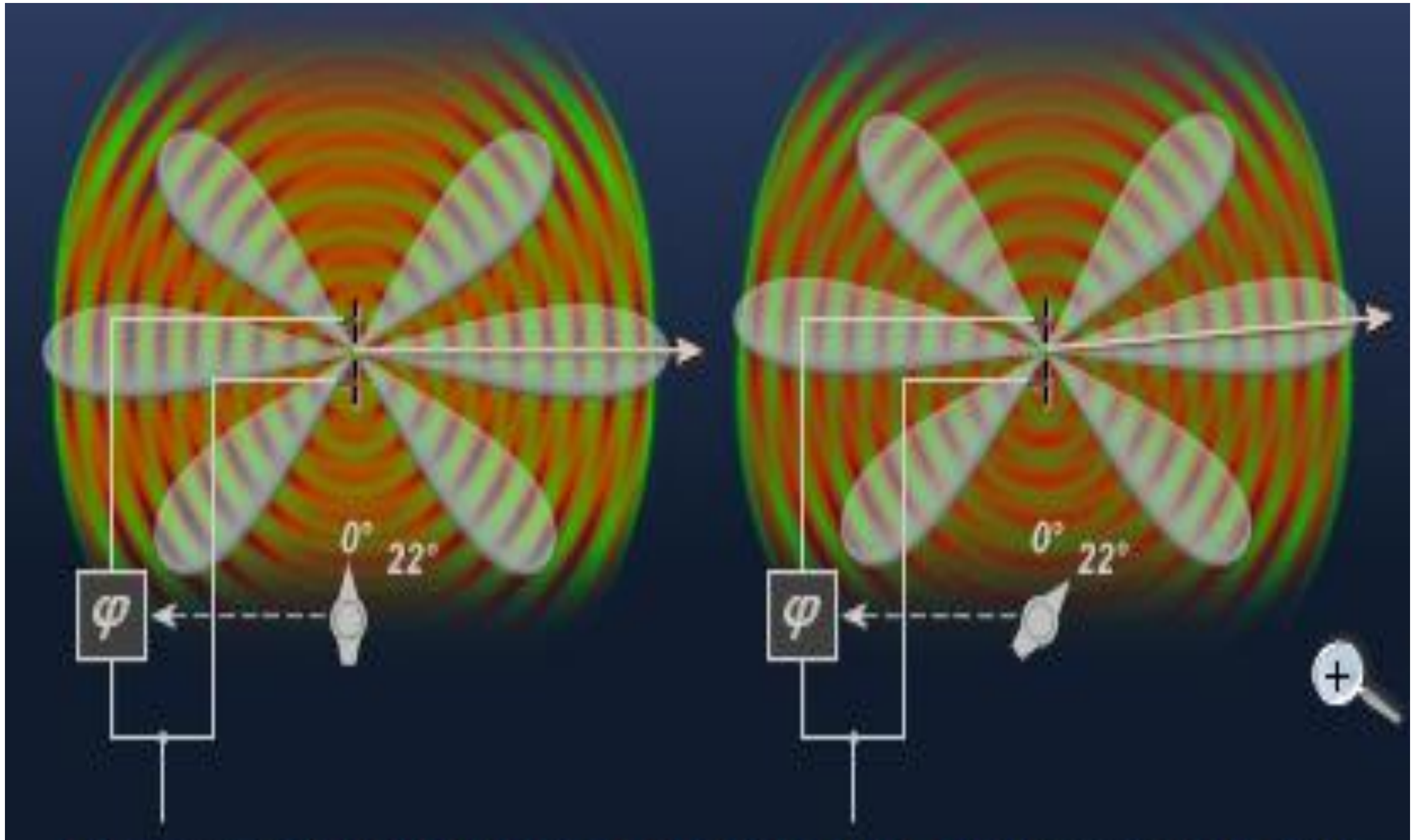


Figure 1: left: two antenna elements, fed with the same phase,
right: two antenna elements, fed with different phase shift

- The main beam always points in the direction of the increasing phase shift.
- If the signal to be radiated is delivered through an electronic phase shifter giving a continuous phase shift then the beam direction will be electronically adjustable.
- However, this cannot be extended unlimitedly. The highest value, which can be achieved for the Field of View (FOV) of a planar phased array antenna is 120° (60° left and 60° right).

Advantages

- High gain width side lobes
- Ability to permit the beam to jump from one target to the next in a few microseconds
- Ability to provide an agile beam under computer control
- Arbitrarily modes of surveillance and tracking
- Multifunction operation by emitting several beams simultaneously
- Fault of single components reduces the capability and beam sharpness, but the system remains operational

Disadvantages

- The coverage is limited to a 120 degree sector in azimuth and elevation
- Deformation of the beam while the deflection
- Low frequency agility
- Very complex structure (processor, phase shifters)
- Still high costs