ANTENNAS & WAVE PROPAGATION

PREPARED
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COURSE OUTCOMES

C312.1	**Explain the basics of antenna parameters & radiation pattern**
C312.2	Analyze the radiation resistance & pattern of loop antenna, yagiuda array, folded dipole antenna, Helical antenna & Horn antennas
C312.3	Analyze the construction of micro strip, flat sheet, corner antennas and parabolic reflector antennas.
C312.4	Design and analyze the antenna arrays and discuss the techniques to measure the radiation pattern, directivity and gain of antenna.
C312.5	Explain the mechanism of the atmospheric effects on radio wave propagation.

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR

B. Tech III-I Sem. (ECE) **L T P C**

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15A04501 ANTENNAS & WAVE PROPAGATION

- **Course Objectives:**
- ㄱㅅ Fundamentals of electromagnetic radiation: Maxwell's equations, potential
- functions, wave equation, retarded potential, short current element, near and
- far fields, Poynting's theorem.
- ㄱㅅ Design of antenna arrays: principle of pattern multiplication, broadside and
- end fire arrays, array synthesis, coupling effects and mutual impedance,
- parasitic elements, Yagi-Uda antenna.

- **UNIT - I**
- **Antenna Basics & Dipole antennas: Introduction, Basic antenna parameters- patterns**
- Beam Area, Radiation Intensity, Beam Efficiency, Directivity-Gain-Resolution, Antenna

  Apertures, Effective height, Fields from oscillating dipole, Field Zones, Shape-

  Impedance considerations, Polarization – Linear, Elliptical, & Circular polarizations,

  Antenna temperature, Antenna impedance, Front–to-back ratio, Antenna theorems,

  Radiation – Basic Maxwell's equations, Retarded potential-Helmholtz Theorem,

  Radiation from Small Electric Dipole, Quarter wave Monopole and Half wave Dipole –

  Current Distributions, Field Components, Radiated power, Radiation Resistance, Beam

  width, Natural current distributions, far fields and patterns of Thin Linear Center-fed

  Antennas of different lengths, Illustrative problems.

- **UNIT- II**
- **VHF, UHF and Microwave Antennas - I:Loop Antennas - Introduction, Small Loop**

Comparison of far fields of small loop and short dipole, Radiation Resistances and Directives of small and large loops (Qualitative Treatment), Arrays with Parasitic Elements -Yagi - Uda Arrays, Folded Dipoles & their characteristics. Helical Antennas-Helical Geometry, Helix modes, Practical Design considerations for Monofilar Helical

Antenna in Axial and Normal Modes. Horn Antennas- Types, Fermat‟s Principle,

Optimum Horns, Design considerations of Pyramidal Horns, Illustrative Problems.

- **UNIT - III**
- **VHF, UHF and Microwave Antennas - II: Micro strip Antennas- Introduction, features**

advantages and limitations, Rectangular patch antennas- Geometry and parameters,

characteristics of Micro strip antennas, Impact of different parameters on

characteristics, reflector antennas - Introduction, Flat sheet and corner reflectors,

parabola reflectors- geometry, pattern characteristics, Feed Methods, Reflector Types -

Related Features, Lens Antennas - Geometry of Non-metallic Dielectric Lenses, Zoning

, Tolerances, Applications, Illustrative Problems.

- **UNIT- IV**
- **Antenna Arrays: Point sources - Definition, Patterns, arrays of 2 Isotropic sources-** Different cases, Principle of Pattern Multiplication, Uniform Linear Arrays – Broadside Arrays, End fire Arrays, EFA with Increased Directivity, Derivation of their characteristics and comparison, BSA with Non-uniform Amplitude Distributions – General considerations and Binomial Arrays, Illustrative problems.
- **Antenna Measurements: Introduction, Concepts- Reciprocity, Near and Far Fields:** Coordination system, sources of errors, Patterns to be Measured, Pattern Measurement Arrangement, Directivity Measurement , Gain Measurements (by comparison, Absolute and 3-Antenna Methods).
- **UNIT – V**
- **Wave Propagation: Introduction, Definitions, Characterizations and general** classifications, different modes of wave propagation, Ray/Mode concepts, Ground wave propagation (Qualitative treatment) - Introduction, Plane earth reflections, Space and surface waves, wave tilt, curved earth reflections, Space wave propagation - Introduction, field strength variation with distance and height, effect of earth's curvature, absorption, Super refraction, M-curves and duct propagation, scattering phenomena, tropospheric propagation, fading and path loss calculations, Sky wave propagation -

- Introduction, structure of Ionosphere, refraction and reflection of sky waves by Ionosphere, Ray path, Critical frequency, MUF, LUF, OF, Virtual height and Skip distance, Relation between MUF and Skip distance, Multi-HOP propagation, Energy loss in Ionosphere, Summary of Wave Characteristics in different frequency ranges,

  Illustrative problems.

UNIT-I
Antenna and its parameters
(**Antenna Basics**)

What is an Antenna?

An antenna is a way of converting the guided waves present in a waveguide, feeder cable or transmission line into radiating waves travelling in free space, or vice versa.

Field Regions

Two fields regions:

- **Near field or Fresnel region:** The region within the radius of the smallest sphere which completely encloses the antenna is called Fresnel region.

In sitting an antenna ,it's crucial to keep objects out of the near field region to avoid coupling the currents in the antenna with objects.

- **Far Field or Fraunhofer region:** The region beyond Fresnel region is called Fraunhofer region

Antenna Parameters

Antenna parameters are:

1.Radiation Pattern
2.Directivity
3.Radiation Resistance and Efficiency
4.Power Gain
5.Bandwidth
6.Reciprocity
7.Effective Aperture
8.Beamwidth and Directivity
9.The Friis Formula: Antennas in Free Space
10.Polarisation Matching

Radiation Pattern

I. The radiation pattern of an antenna is a plot of the far-field radiation from the antenna.

II. More specifically, it is a plot of the power radiated from an antenna per unit solid angle, or its radiation intensity U [watts per unit solid angle.

III. This is arrived at by simply multiplying the power density at a given distance by the square of the distance r, where the power density S [watts per square meter is given by the magnitude of the time-averaged Poynting vector:

$$U=r^{\wedge 2}S$$

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Directivity

The directivity D of an antenna, a function of direction is defined by the ratio of radiation intensity of antenna in direction to the mean radiation intensity in all directions.

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Radiation Resistance and Efficiency

- The resistive part of the antenna impedance is split into two parts, a radiation resistance Rr and a loss resistance Rl.
- The power dissipated in the radiation resistance is the power actually radiated by the antenna, and the loss resistance is power lost within the antenna itself.
- This may be due to losses in either the conducting or the dielectric parts of the antenna. Radiation efficiency e of the antenna as e is the ratio of power radiated to the power accepted by antenna
- antenna with high radiation efficiency therefore has high associated radiation resistance compared with the losses. The antenna is said to be resonant if its input reactance Xa =0.

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Power Gain

- The power gain G, or simply the gain, of an antenna is the ratio of its radiation intensity to that of an isotropic antenna radiating the same total power as accepted by the real antenna.
- When antenna manufacturers specify simply the gain of an antenna they are usually referring to the maximum value of G.

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Bandwidth

- The bandwidth of an antenna expresses its ability to operate over a wide frequency range.
- It is often defined as the range over which the power gain is maintained to within 3dB of its maximum value, or the range over which the VSWR is no greater than 2:1, whichever is smaller.
- The bandwidth is usually given as a percentage of the nominal operating frequency. The radiation pattern of an antenna may change dramatically outside its specified operating bandwidth

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Reciprocity

Reciprocity theorem:

If a voltage is applied to the terminals of an antenna A and the current measured at the terminals of another antenna B then an equal current will be obtained at the terminals of antenna A if the same voltage is applied to the terminals of antenna B.

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Effective Aperture

- If an antenna is used to receive a wave with a power density S [W m2], it will produce a power in its terminating impedance (usually a receiver input impedance) of Pr watts.
- The constant of proportionality between Pr and S is Ae, the effective aperture of the antenna in square metres:

$$Pr = AeS$$

- For some antennas, such as horn or dish antennas, the aperture has an obvious physical interpretation, being almost the same as the physical area of the antenna, but the concept is just as valid for all antennas.
- The effective aperture may often be very much larger than the physical area, especially in the case of wire antennas. Note, however, that the effective aperture will reduce as the efficiency of an antenna decreases.

The antenna gain G is related to the effective aperture as follows

G=4pi/ (lamda)2Ae

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Beamwidth and Directivity

The directivity of an antenna increases as its beam width is made smaller, as the energy radiated is concentrated into a smaller solid angle

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Friss Formula

$$\frac{P_r}{P_t} = G_a G_b \left(\frac{\lambda}{4\pi r} \right)^2 \qquad (4.22)$$

'his is the *Friis transmission formula* and its consequences for the range of wireless ommunication systems will be thoroughly explored in later chapters. If this same derivation ; applied, but with *B* transmitting and *A* receiving, then exactly the same result is obtained as ı (4.22), in accordance with the reciprocity theorem. The Friis formula exhibits an *inverse quare law*, where the received power diminishes with the square of the distance between the ntennas.

In practical free space conditions, the received power may be less than that predicted by 1.22) if the polarisation states of the antennas are not matched or if the source and load npedances do not match the antenna impedances.

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Polarization Matching

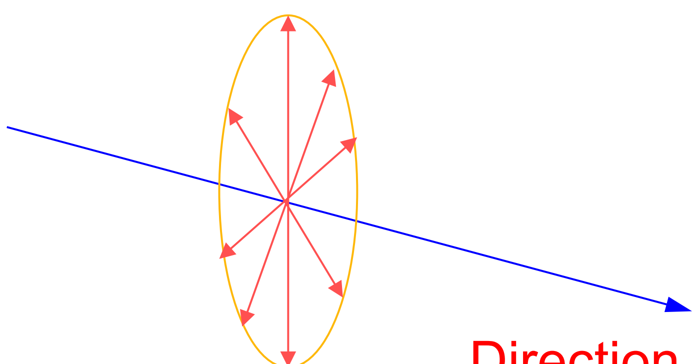
The polarization mismatch loss is the ratio between the power received by the antenna and the power which would be received by an antenna perfectly matched to the incident wave

$$L = \frac{P_{received}}{P_{matched}} = \left| \frac{\mathbf{p}_w \bullet \mathbf{p}_a^*}{|\mathbf{p}_w| \times |\mathbf{p}_a|} \right|^2 \tag{4.25}$$

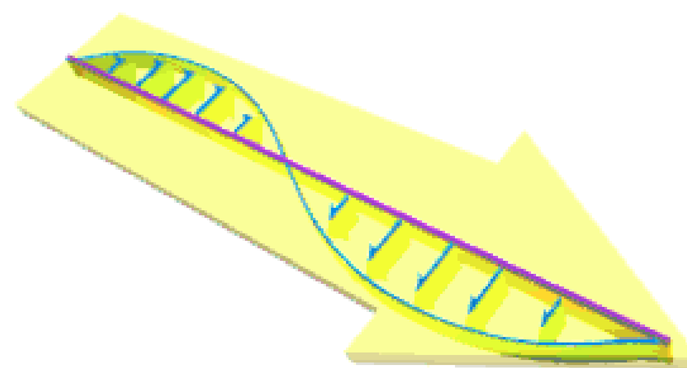
where $\bullet$ denotes the vector dot product. The Friis formula (4.22) must be multiplied by this formula whenever $\mathbf{p}_a \neq \mathbf{p}_w$.

Polarization

- *Polarization* is a characteristic of all transverse waves.
- Oscillation which take places in a transverse wave in many different directions is said to be *unpolarized*.
- In an unpolarized transverse wave oscillations may take place in any direction at right angles to the direction in which the wave travels.

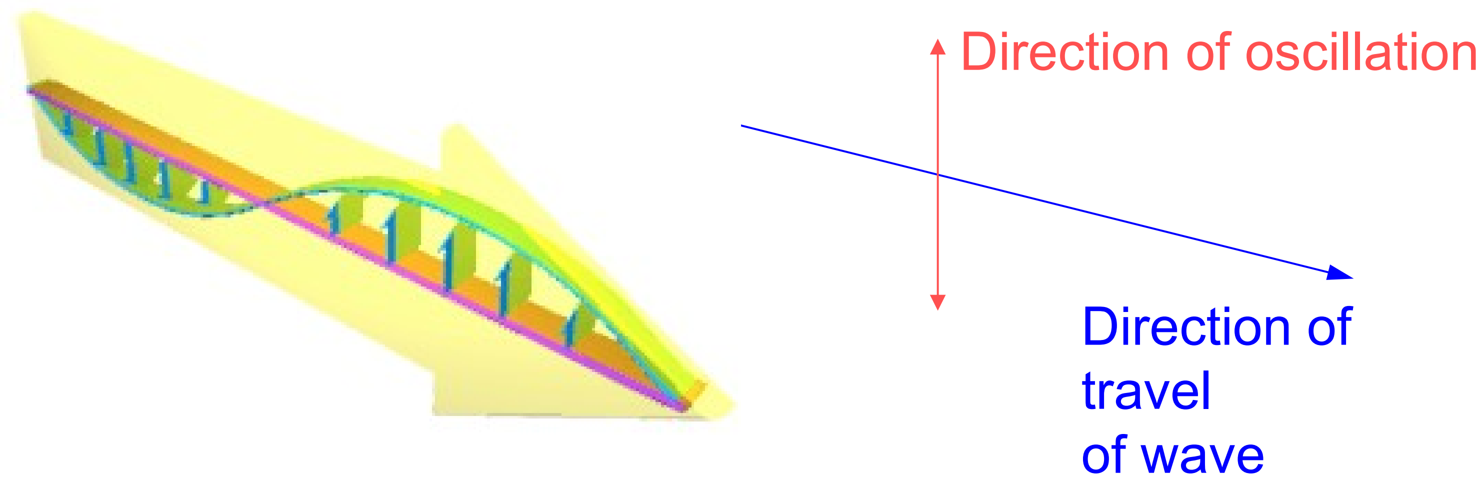


Direction of propagation of wave



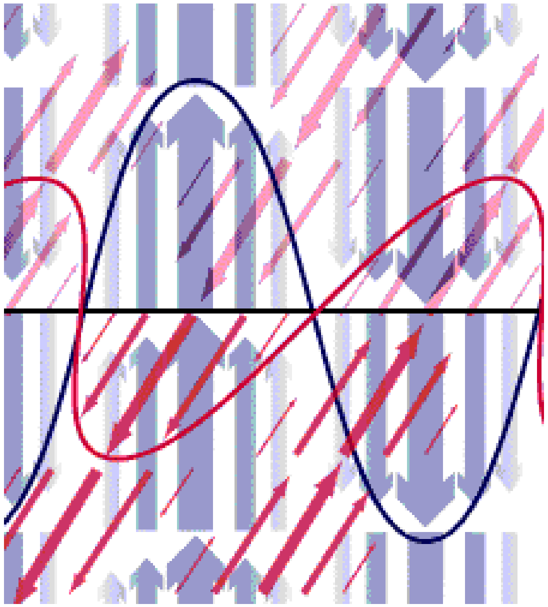
Linear Polarization

- If the oscillation does take place in only one direction then the wave is said to be linearly polarized (or plane polarized) in that direction.



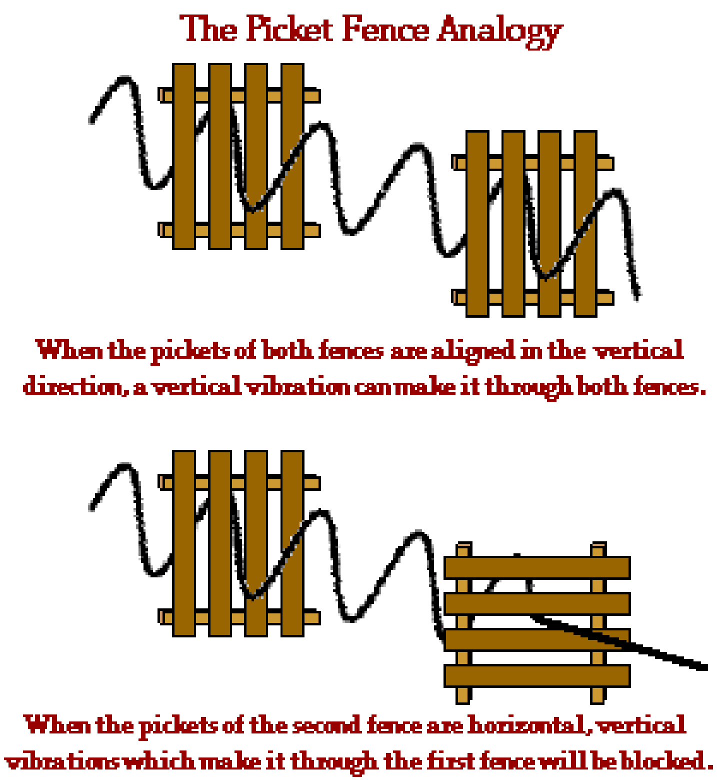
Polarization of Electromagnetic Waves

- Any electromagnetic wave consists of an electric field component and a magnetic field component.
- The electric field component is used to define the plane of polarization because many common electromagnetic-wave detectors respond to the electric forces on electrons in materials, not the magnetic forces.



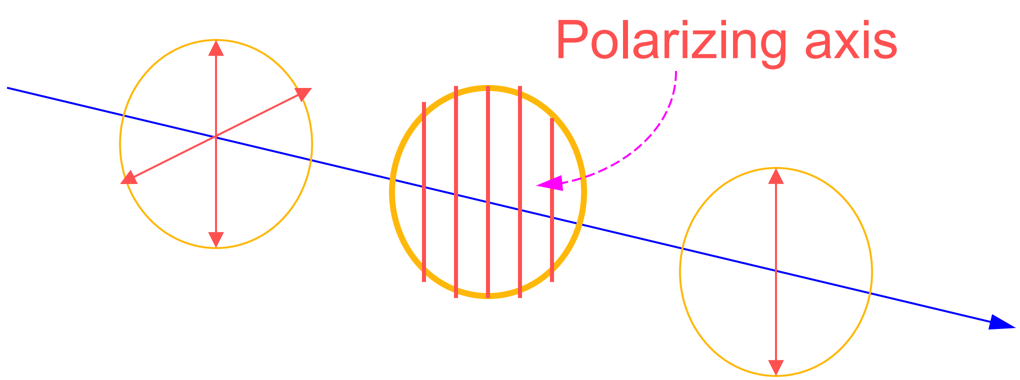
Polarization by Selective Absorption

- Polarization of light by selective absorption is analogous to that shown in the diagrams.



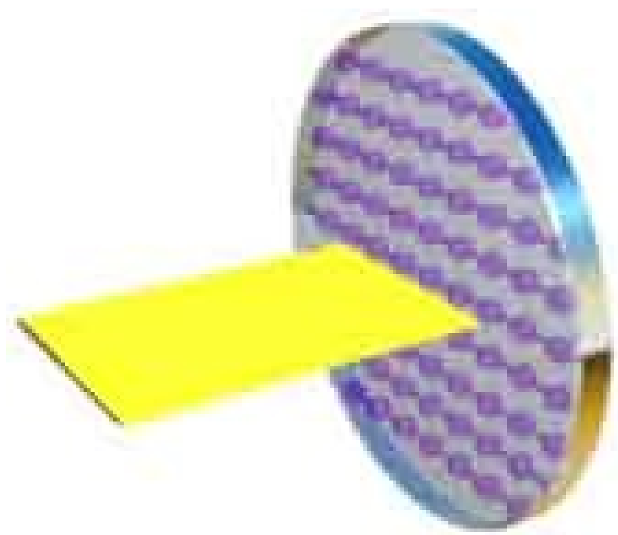
Polaroid

- A Polaroid filter transmits 80% or more of the intensity of a wave that is polarized parallel to a certain axis in the material, called the *polarizing axis*.
- Polaroid is made from long chain molecules oriented with their axis perpendicular to the polarizing axis; these molecules preferentially absorb light that is polarized along their length.



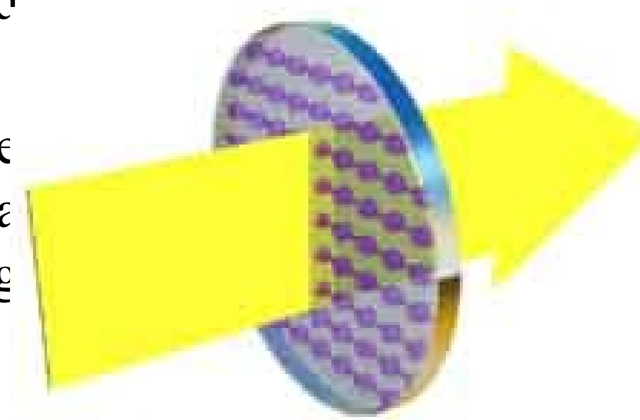
Explanation of Polarization at the Molecular Level (1)

- An electric field E that oscillates parallel to the long molecules can set electrons into motion along the molecules, thus doing work on them and transferring energy. Hence, E gets absorbed.



Explanation of Polarization at the Molecular Level (2)

- An electric field *E* perpendicular to the long molecules does not have this possibility of doing work and transferring its energy, and so passes through freely.
- When we speak of the axis of a Polaroid, we mean the direction which *E* is passed, so a polarizing axis is perpendicular to the long molecules.

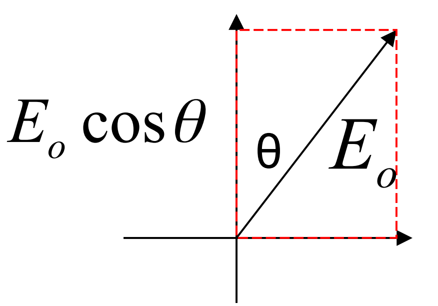


Intensity of Light transmitted through a Polarizer (1)

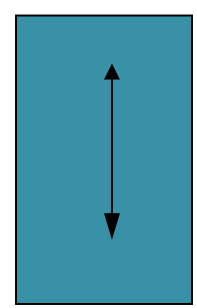
- An ideal polarizer passes 100% of the incident light that is polarized in the direction of the polarizing axis but completely blocks all light that is polarized perpendicular to this axis.
- When unpolarized light is incident on an ideal polarizer, the intensity of the transmitted light is exactly half that of the incident unpolarized light, no matter how the polarizing axis is oriented.

Intensity of Light transmitted through a Polarizer (2)

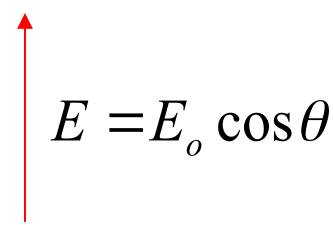
- If a beam of plane-polarized light strikes a polarizer whose axis is at an angle of θ to the incident polarization direction, the beam will energy plane-polarized parallel to the polarizing axis and its amplitude will be reduced by cos θ.



Incident beam of Amplitude



Vertical Polaroid



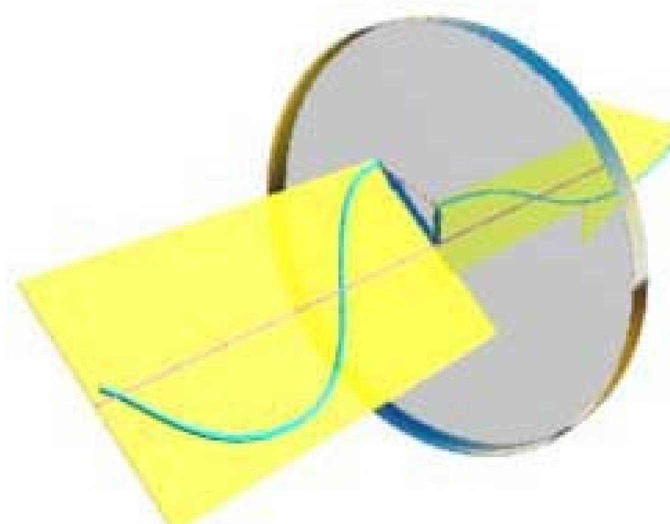
Transmitted wave

Intensity of Light transmitted through a Polarizer (3)

- A Polaroid passes only that component of polarization that is parallel to its axis.
- As the intensity of a light beam is proportional to the square of the amplitude, and $E = E_o \cos\theta$

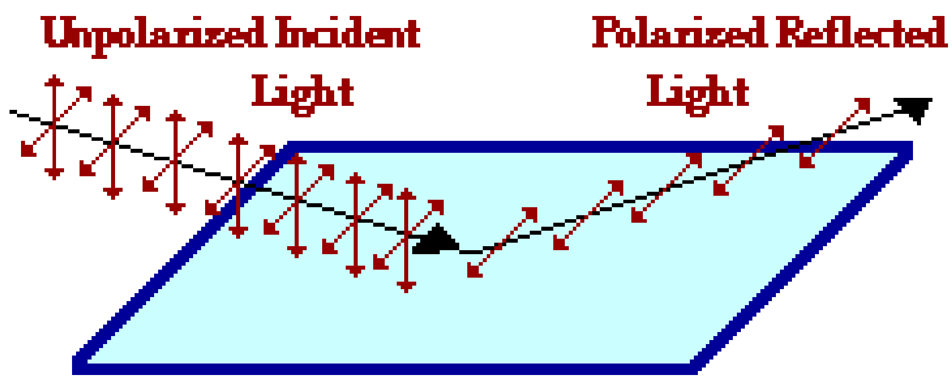
Hence the intensity of a plane-polarized beam
transmitted by a polarizer is

$$I = I_o \cos^2\theta$$



Polarization by Reflection

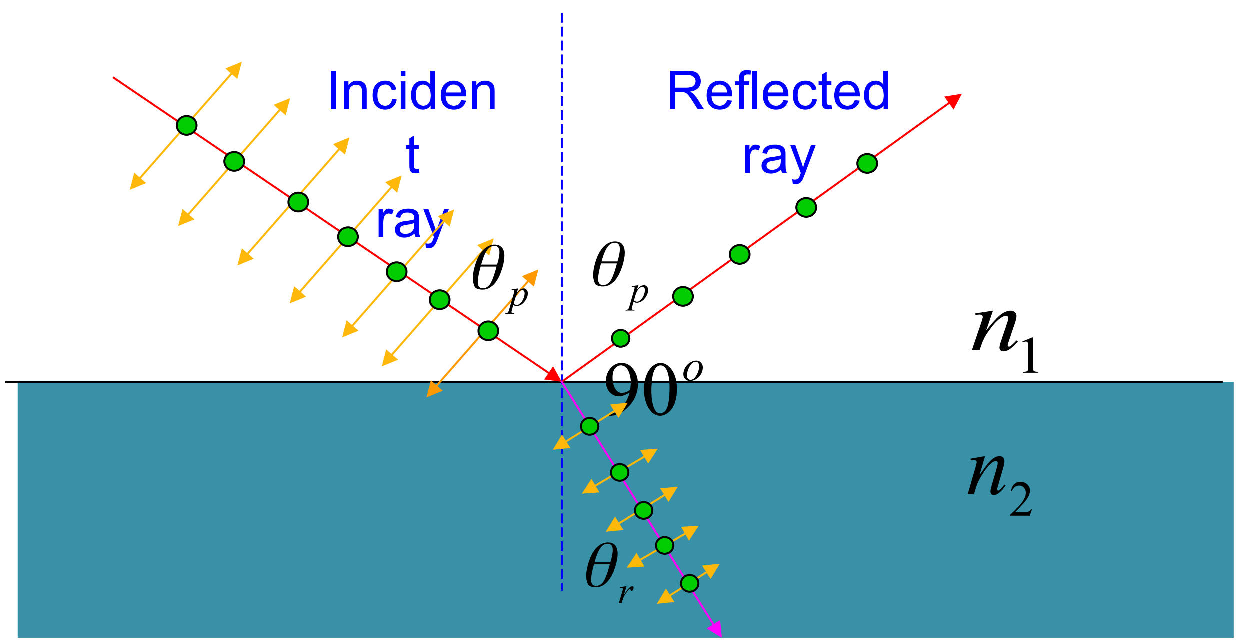
- Unpolarized light can be polarized, either partially or completely, by reflection.
- The amount of polarization in the reflected beam depends on the angle of incidence.



Reflection of light off of non-metallic surfaces results in some degree of polarization parallel to the surface.

Brewster's law

- It is found that experimentally when the reflected ray is perpendicular to the refracted ray, the reflected light will be completely plane-polarized.



Polarizing angle (Brewster's angle)

- The angle of incidence at which the reflected light is completely plane-polarized is called the polarizing angle (or Brewster's angle).

By Snell's law, $n_1 \sin\theta_p = n_2 \sin\theta_r$

Sinc e $_{o}06 = {}^{ɹ}\theta + {}^{d}\theta$ and

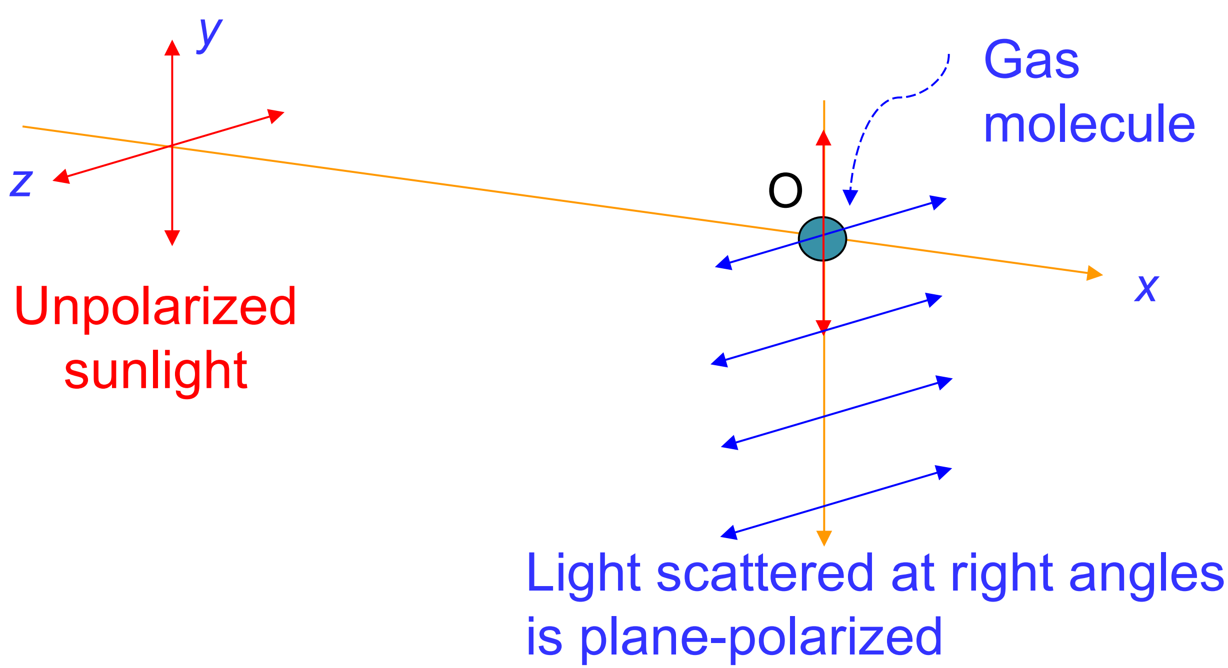
$$\sin\theta_r = \sin(90^o - \theta_p) = \cos\theta_p$$

Then we get

$$\tan\theta_p = \frac{n_2}{n_1}$$

Polarization by Scattering (1)

- When a light wave passes through a gas, it will be absorbed and then re-radiated in a variety of directions. This process is called *scattering*.



Polarization by Scattering (2)

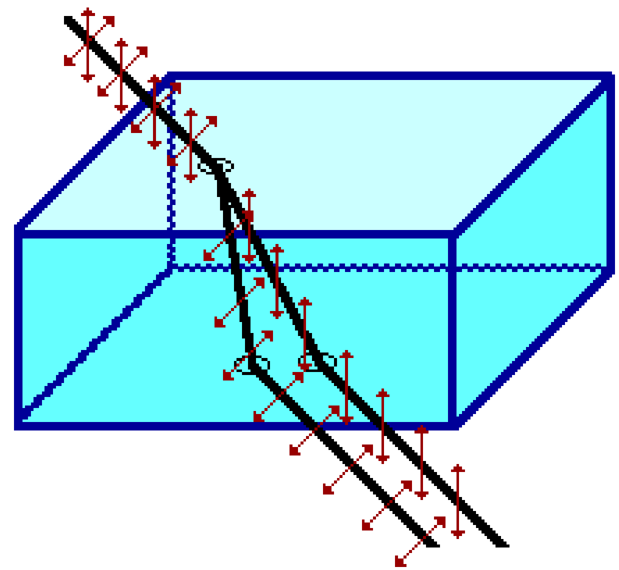
- Consider a gas molecule at point O. The electric field in the beam of sunlight sets the electric charges in the molecule into vibration.
- Since light is a transverse wave, the direction of the electric field in any component of the sunlight lies in the yz-plane, and the motion of charges take place in this plane.
- There is no electric field, and hence no motion of charge in the *x*-direction.

Polarization by Scattering (3)

- The molecule reemits the light because the charges are oscillating. But an oscillating charge does not radiate in the direction of its oscillation so it does not send any light to the observer directly below it.
- Therefore, an observer viewing at right angles to the direction of the sunlight will see plane-polarized light.

Polarization by Refraction

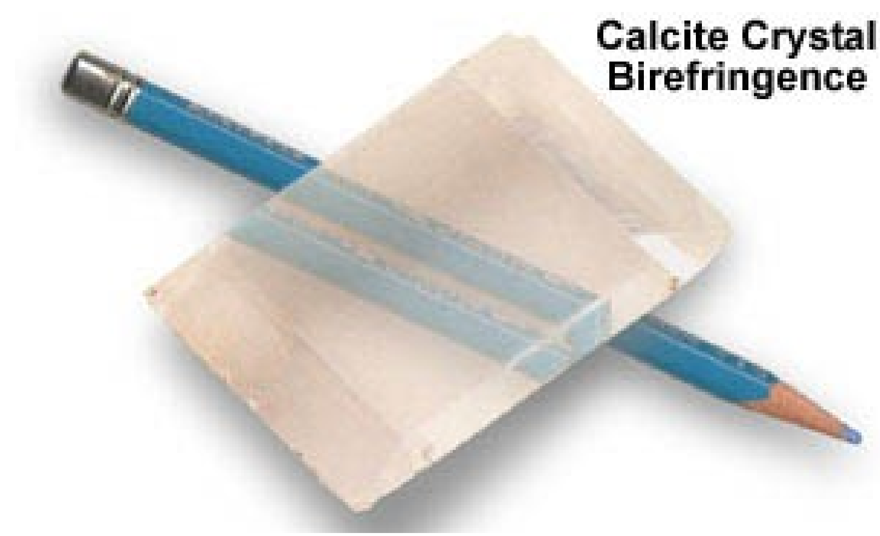
- When an incident unpolarized ray enters some crystals it will be split into two rays called ordinary and extraordinary rays, which are plane-polarized in directions at right angles to each other.



The two refracted rays passing through the Iceland Spar crystal are polarized with perpendicular orientations.

Double Refraction

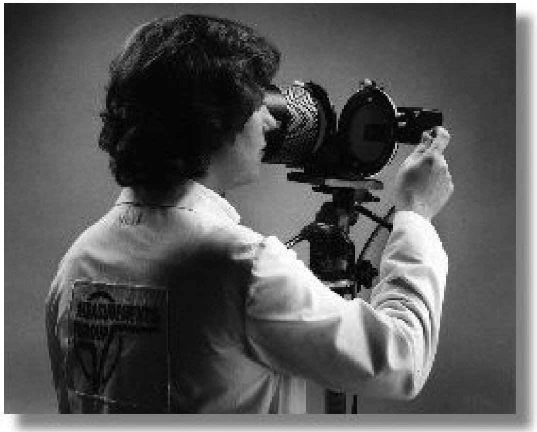
- When light is refracted into two rays each polarized with the vibration directions oriented at right angles to one another, and traveling at different velocities. This phenomenon is termed "**double**" or "**bi**" **refraction.**

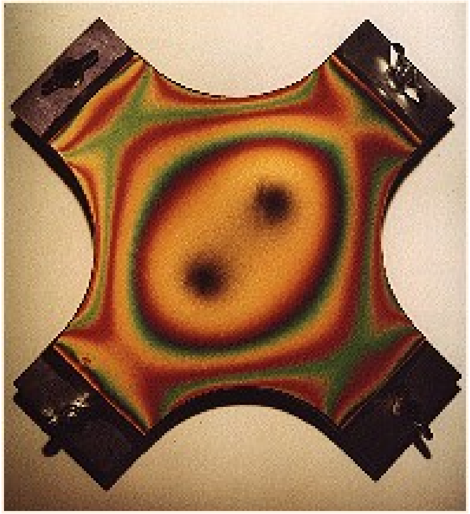


Applications of Polarizations (1)

- Polaroid sunglasses
  - The glare from reflecting surfaces can be diminished with the use of Polaroid sunglasses.
  - The polarization axes of the lens are vertical, as most glare reflects from horizontal surfaces.

Applications of Polarization (2)





- Stress Analysis
  - Fringes may be seen in the parts of a transparent block under stress, viewing through the analyzer.
  - The pattern of the fringes varies with the stress.

Applications of Polarization (3)

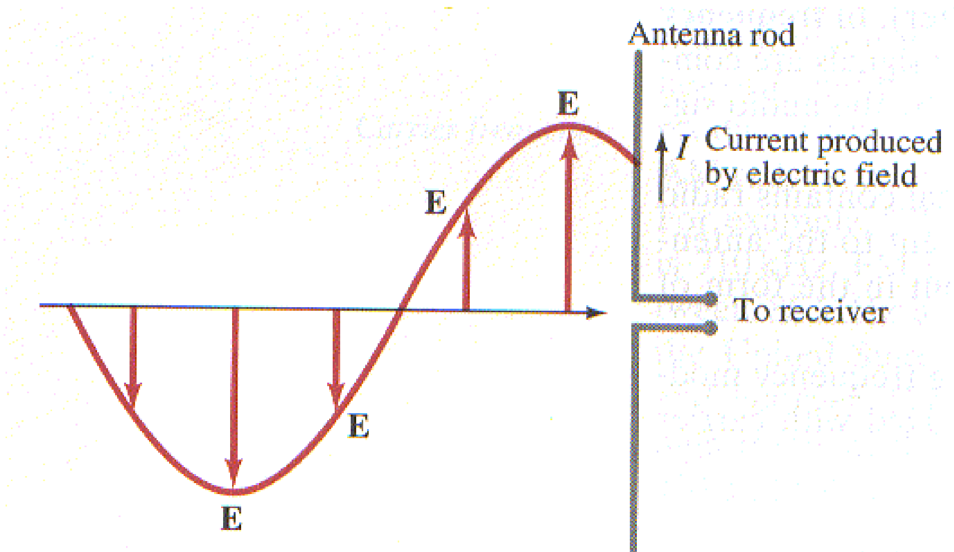
- Liquid Crystal Display (LCD)

Applications of Polarization (4)

- VHF and UHF antennas (aerial)
  - Radio waves can be detected either through their E-field or their B-field.
  - Stations transmitted radio waves which are plane-polarized.

Applications of Polarization (5)

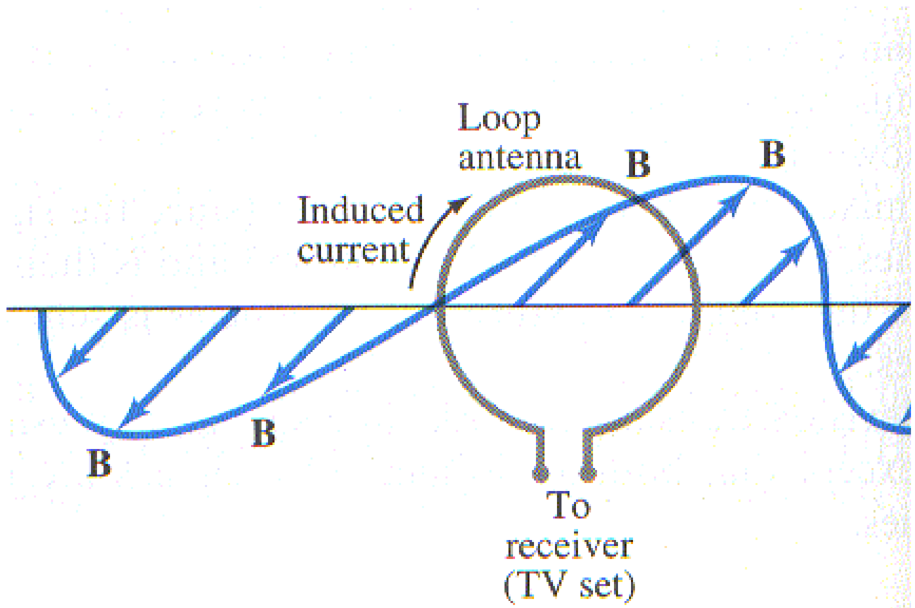
- Electric field of EM wave produces a current in an antenna consisting of straight wire or rods.



(a)

Applications of Polarization(6)

- Changing magnetic field induces an emf and current in a loop antenna.



(b)

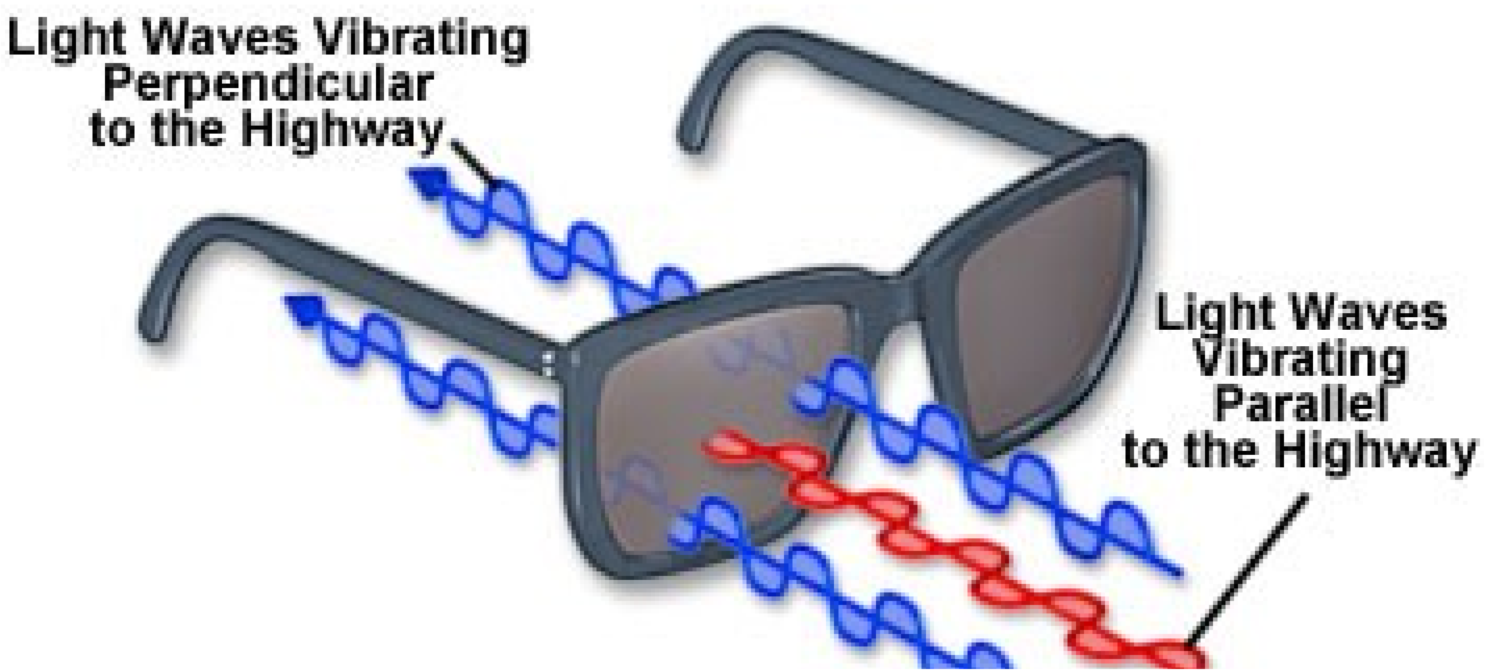
Blue Sky

- The blue color of the sky is caused by the scattering of sunlight off the molecules of the atmosphere. This scattering, called Rayleigh scattering, is more effective at short wavelengths

Sunset

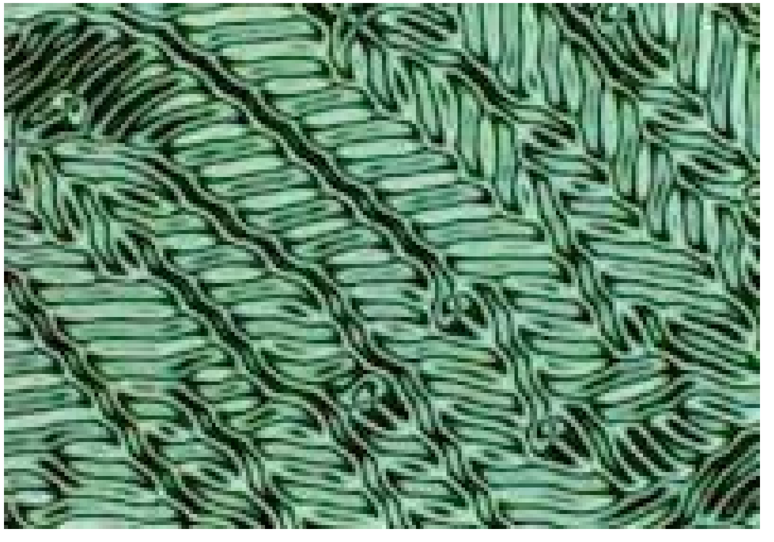
- As incoming sunlight passes through a more dense atmosphere, shorter wavelengths of light (violet and blue) are efficiently scattered away by particles suspended in the atmosphere. This allows predominantly yellow and red wavelengths of light to reach the observer's eyes, producing a yellowish-red sunset.

Polaroid Sunglasses



Liquid Crystal

- Liquid crystal is a substance that behaves something like a liquid and something like a solid.
- The shape of its molecules are long and thin.

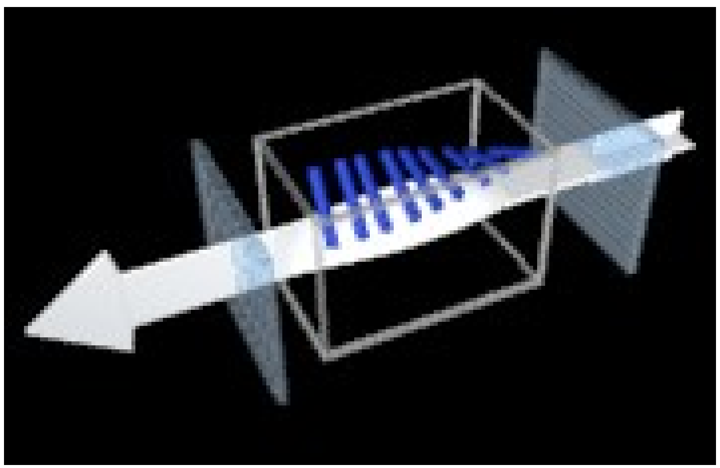


Properties of LCD

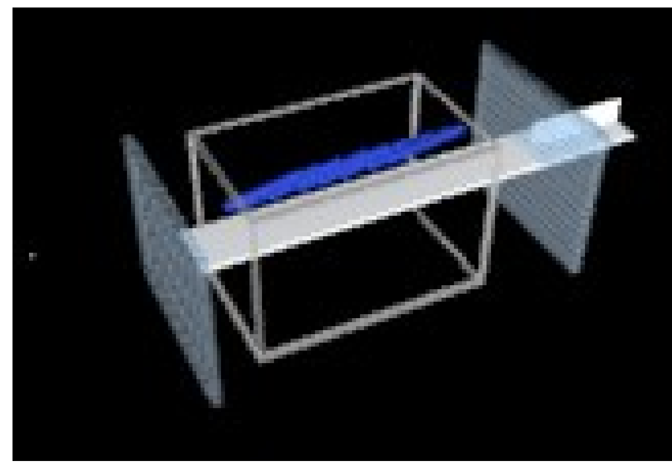
- Their orientations can be aligned with one another in a regular pattern.
- A particular sort of liquid crystal, called twisted nematics, (TN), is naturally twisted. Applying an electric current to these liquid crystals will untwist them to varying degrees, depending on the current's voltage.

Twisted Nematics

- They can rotate the plane of oscillation of polarized light passing through them.

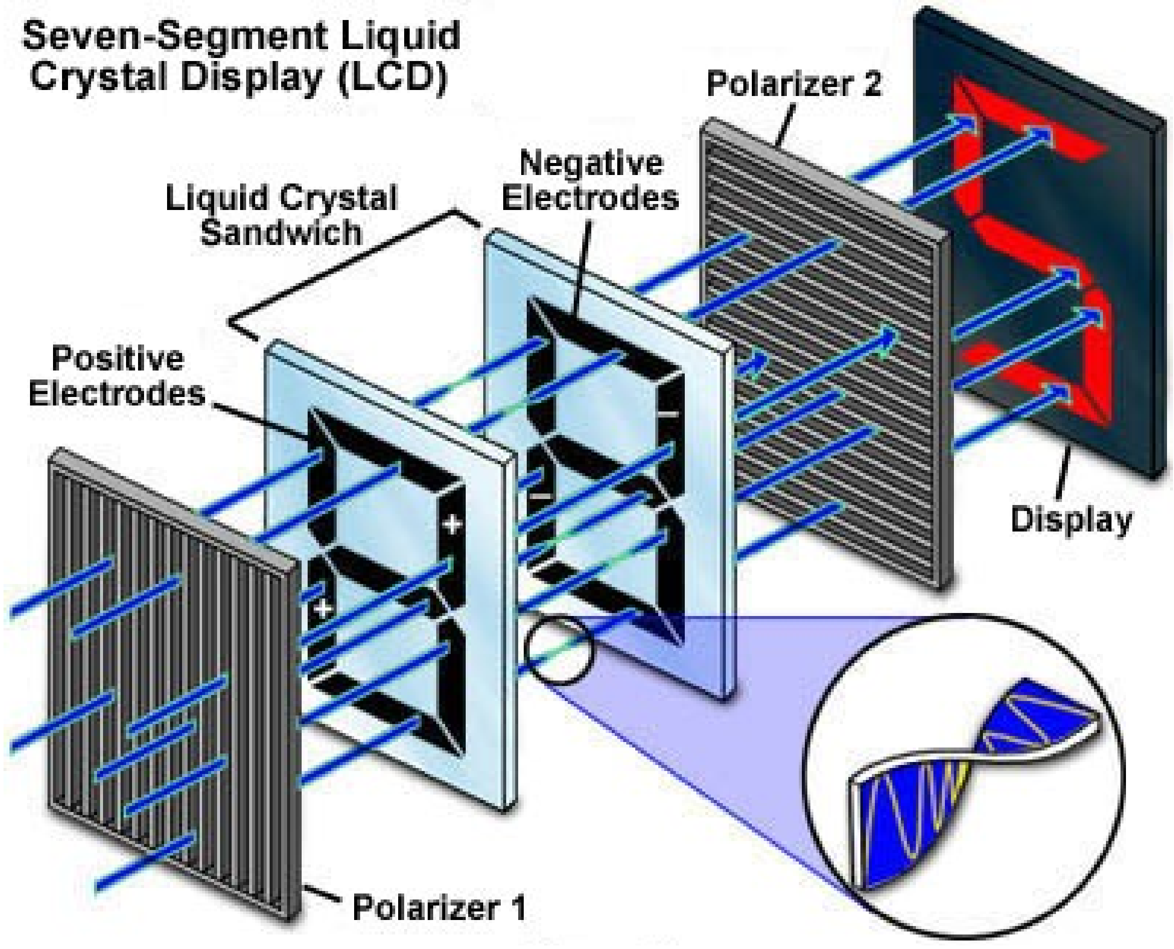


Light passes through the cell with its plane of polarization turned through 90°



Light cannot pass through since the line does not rotate the plane of polarization

Liquid Crystal Display



UNIT-II

VHF, UHF and Microwave Antennas – I

Different Kinds of Antennas

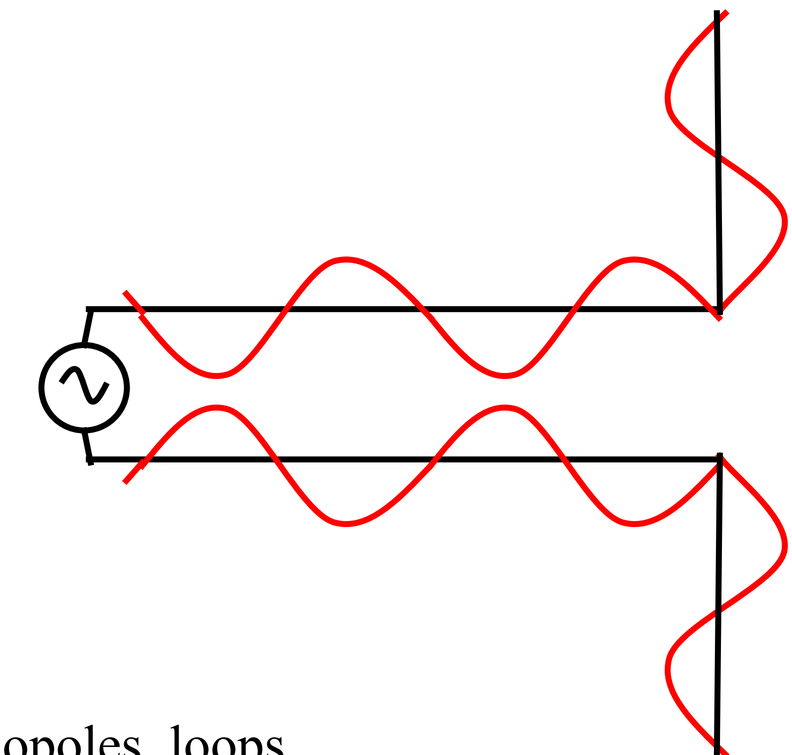
We will see main families of antenna used to create a radiated radio wave:

- wire antennas (dipole, monopole Yagi)
- slot antennas (half or quarter wave)
- patch antennas (planar)
- aperture antennas (horn)
- reflector antennas (dishes)

We conclude this chapter by the principle of arrays of elementary antennas and beam forming techniques.

Wire antennas

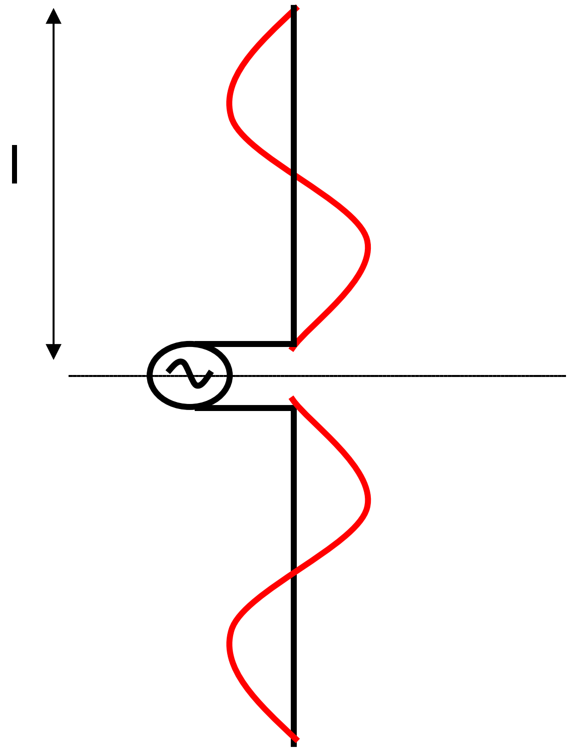
By definition, the category of wire antennas includes all antennas formed of a conductor structure where, due to small diameter of cables, we consider only the linear current densities.



The basic antennas are: dipoles, monopoles, loops.
More advanced structures: helical, Yaguis, the log-periodic ...

RADIATING DIPOLE

The dipole antenna is a wire composed of two conductive strands apart in opposite directions. The source is most often presented in the center of the structure which gives a symmetrical system.



Current distribution:

$$\boxed{I(z) = I_m \sin\left(\frac{2\pi}{\lambda}(l - z)\right)}$$

We can calculate the radiated field as the sum of contributions of elementary dipoles driven by an intensity I(z)

CHARACTERISTIC FUNCTION OF THE DIPOLE

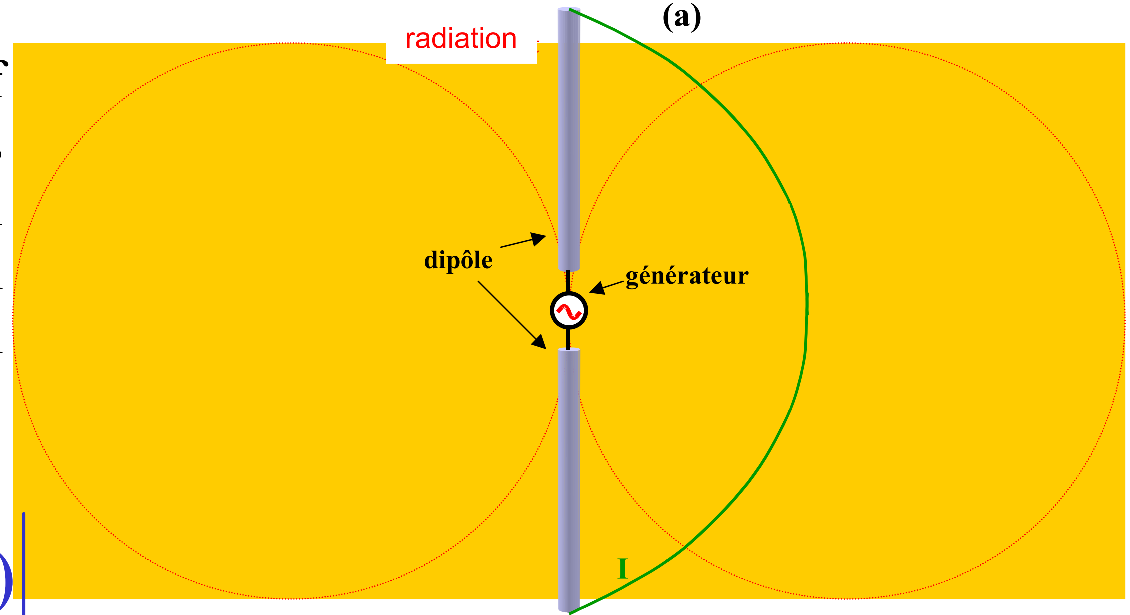
To visualize the radiation: $$\left|F\,(\theta,\varphi)\right| = \frac{r}{60I}\cdot\left|E(\theta,\varphi)\right|$$

with $$E(\theta,\varphi) = \int dE.dz$$

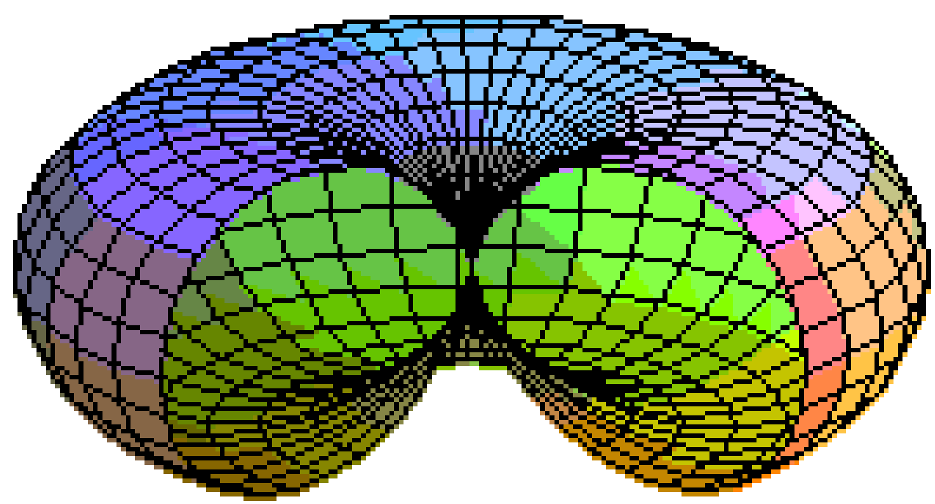
$$F(\theta) = \frac{2\pi}{\lambda}\left|\sin\theta\right|\left|\int_0^l \sin\left(\frac{2\pi}{\lambda}(l - z)\right).\cos(\beta z\cos\theta)dz\right|$$

HALF-WAVELENGTH DIPOLE

The simpliest form of the radiating dipole is an antenna of total length l/2, also known as half-wavelength dipole.



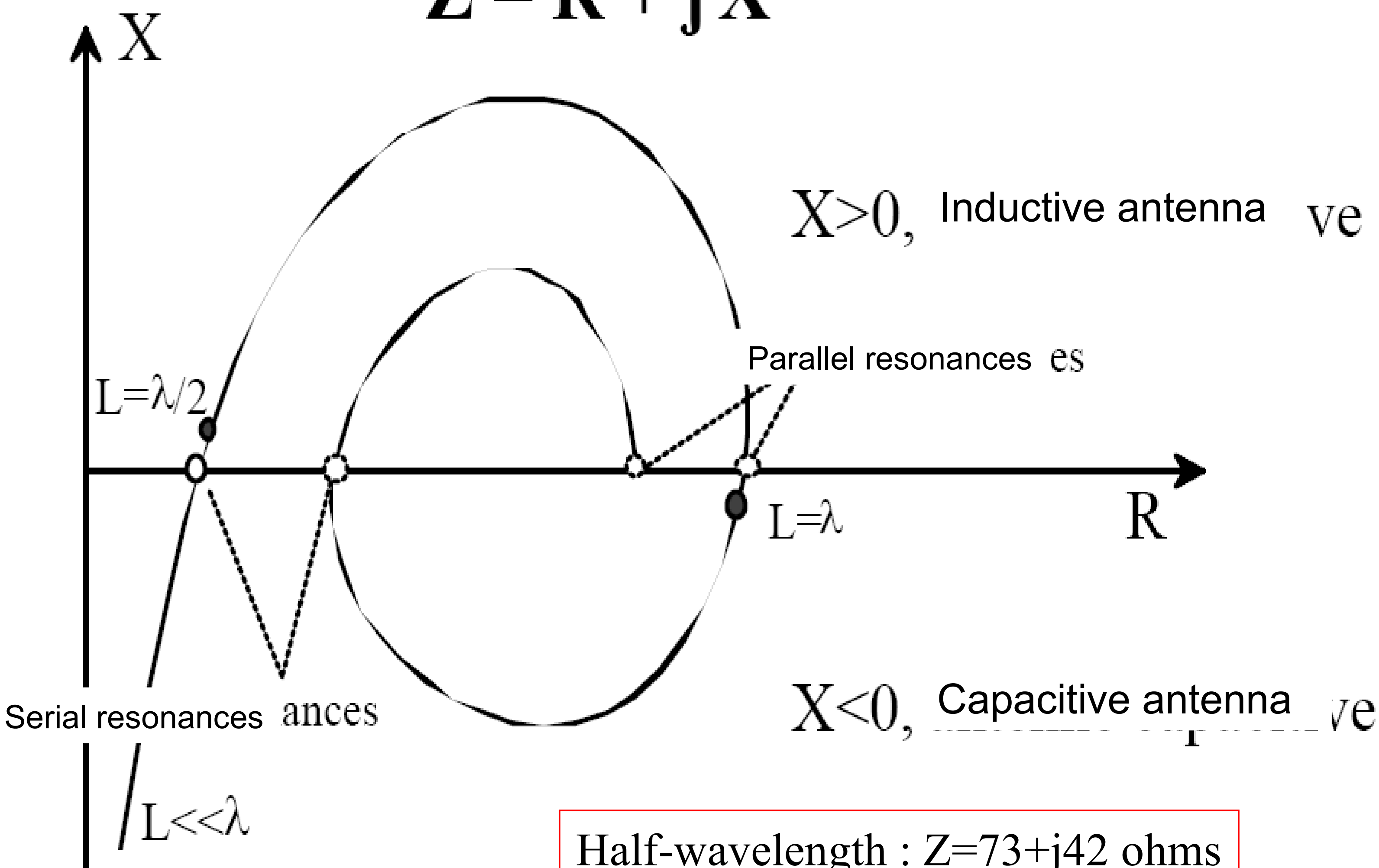
$$F(\theta)=\left|\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right|$$



The maximum directivity obtained is 1,64 so 2,15 dBi or 0 dBd

IMPEDANCE OF THE DIPOLE

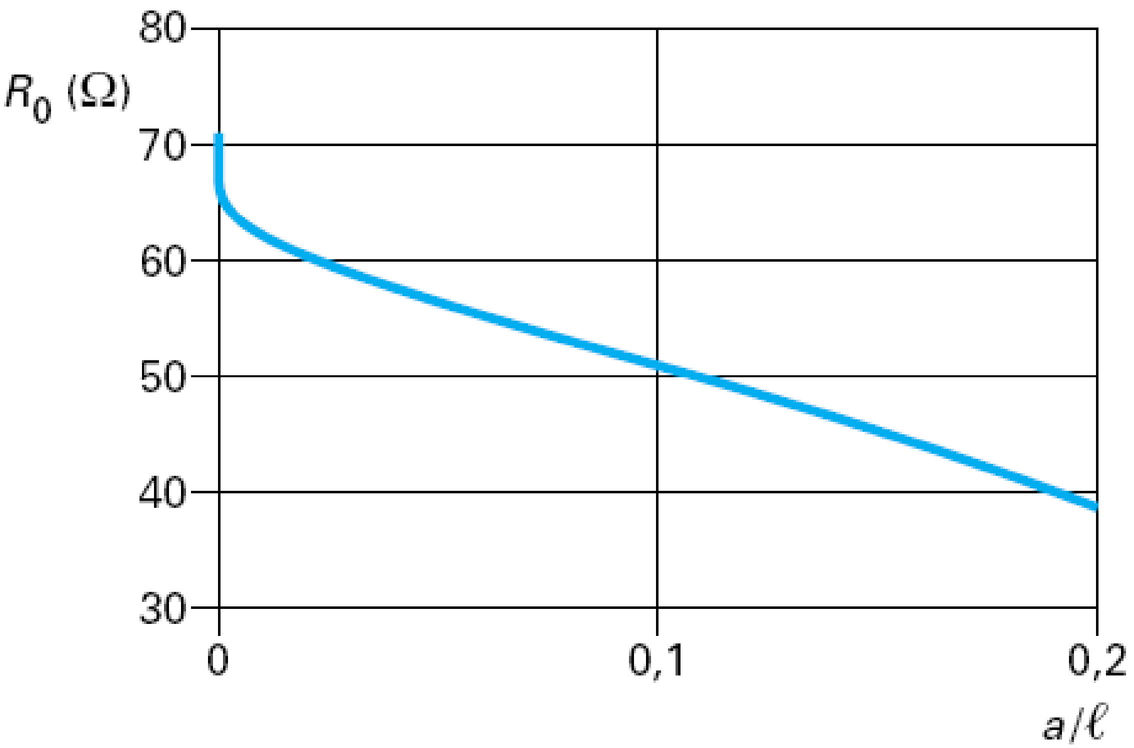
$$Z = R + j \cdot X$$



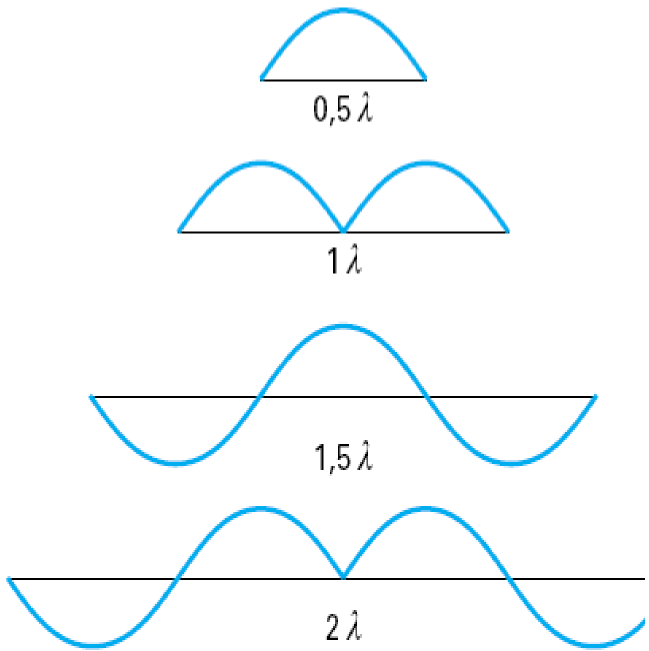
Half-wavelength : Z=73+j42 ohms

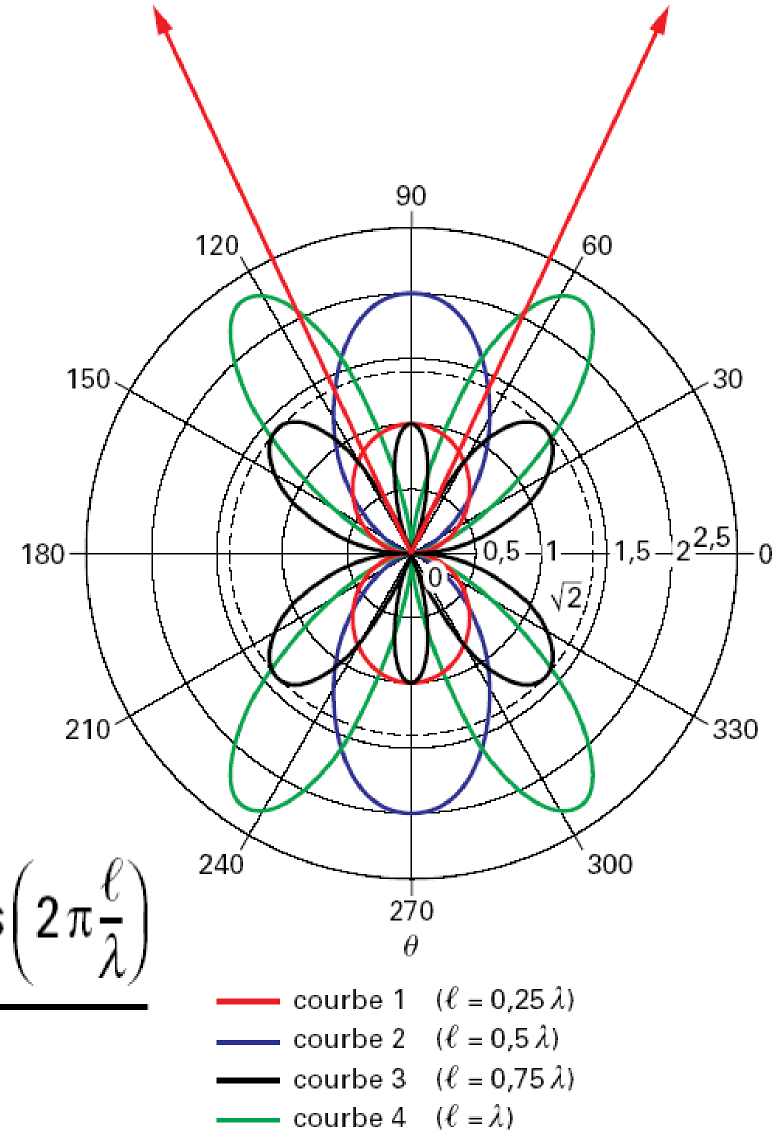
THICK DIPOLE

To match the dipole, we can adapt the diameter of wires (a) with respect to the length of the arms (l).



OTHER SIZE OF DIPOLES

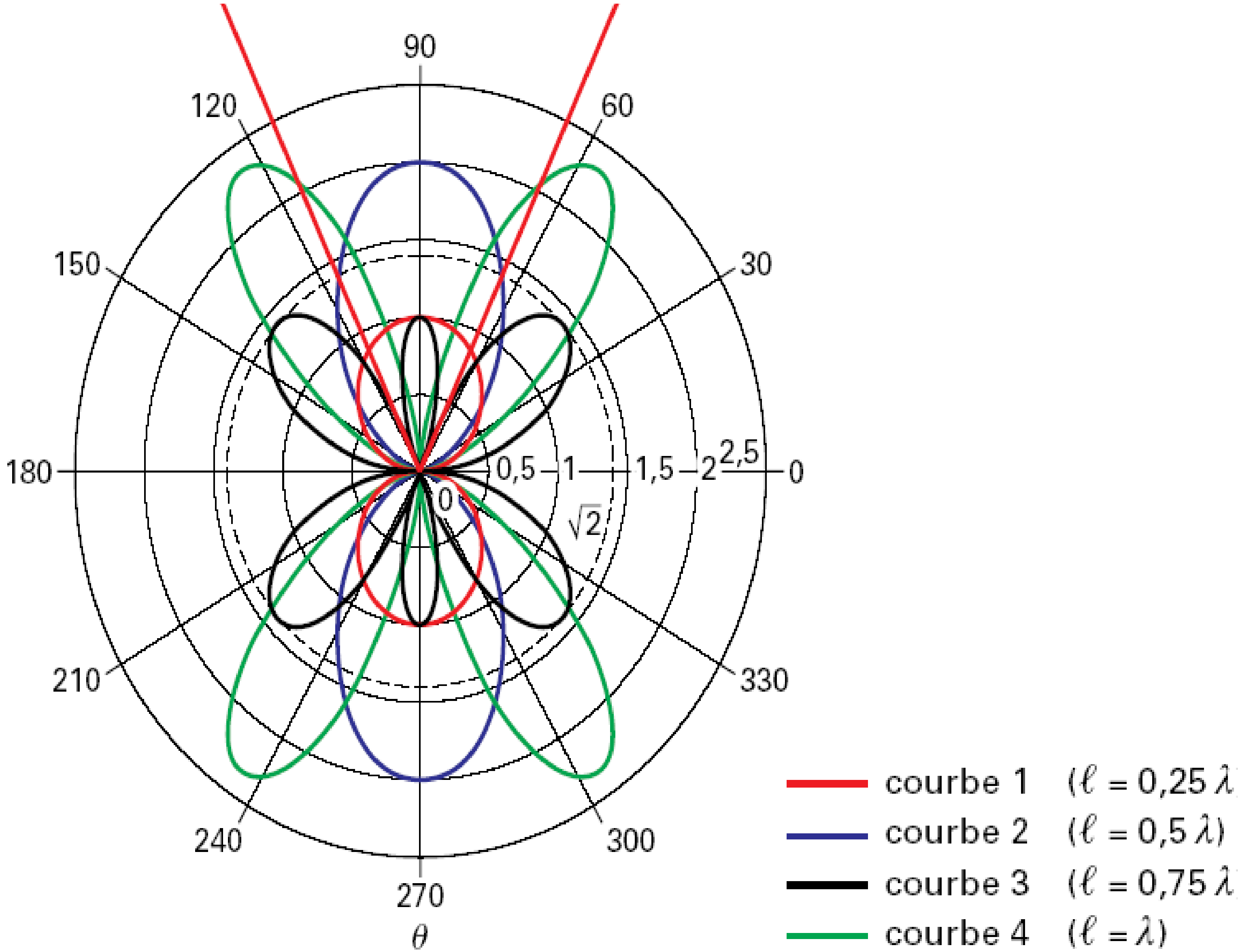




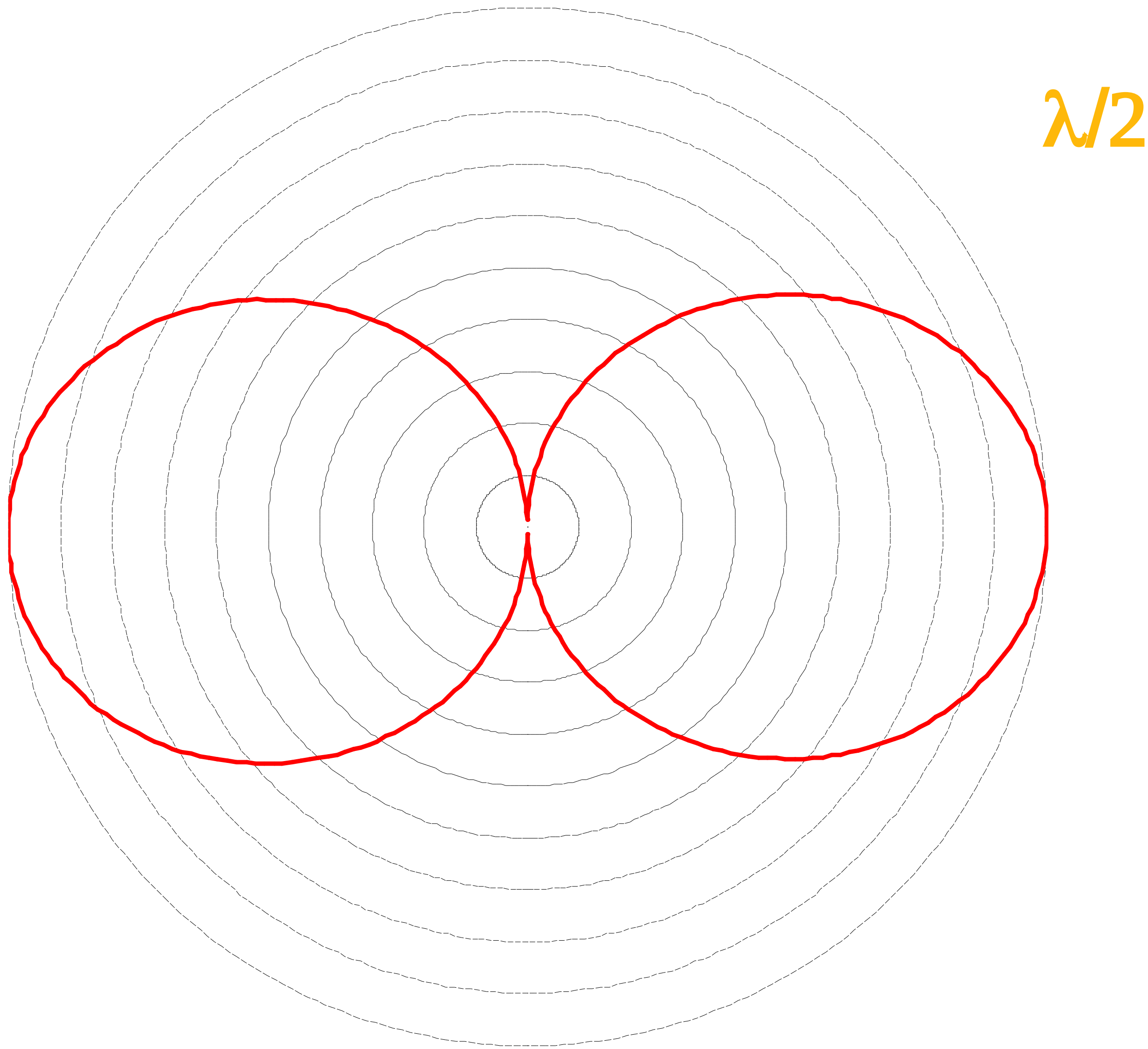
General characteristic function:

$$f\left(\theta, \frac{\ell}{\lambda}\right) = \frac{\cos\left(2\pi\frac{\ell}{\lambda}\cos\theta\right) - \cos\left(2\pi\frac{\ell}{\lambda}\right)}{\sin\theta}$$

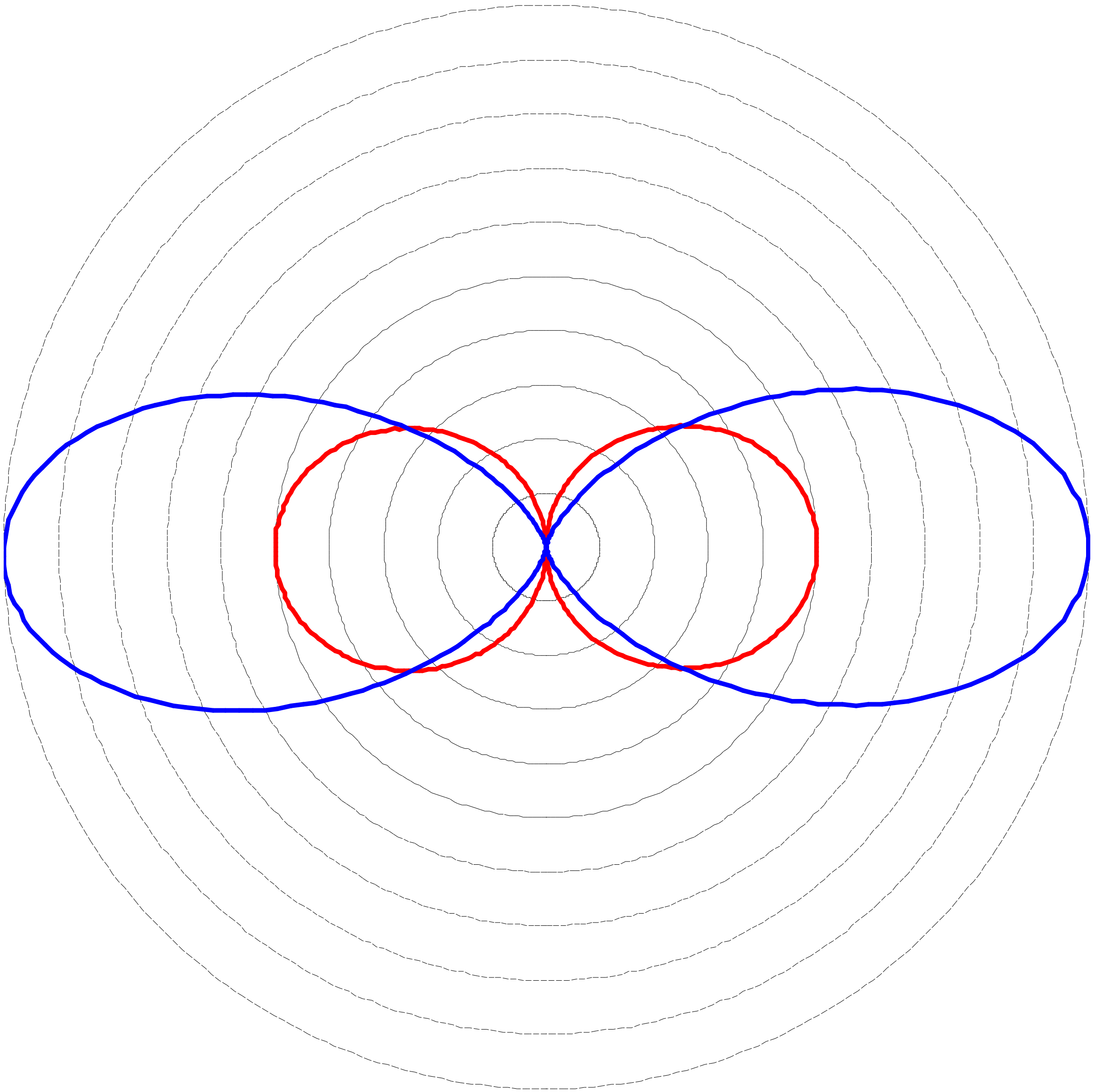
OTHER SIZE OF DIPOLES



OTHER SIZE OF DIPOLES



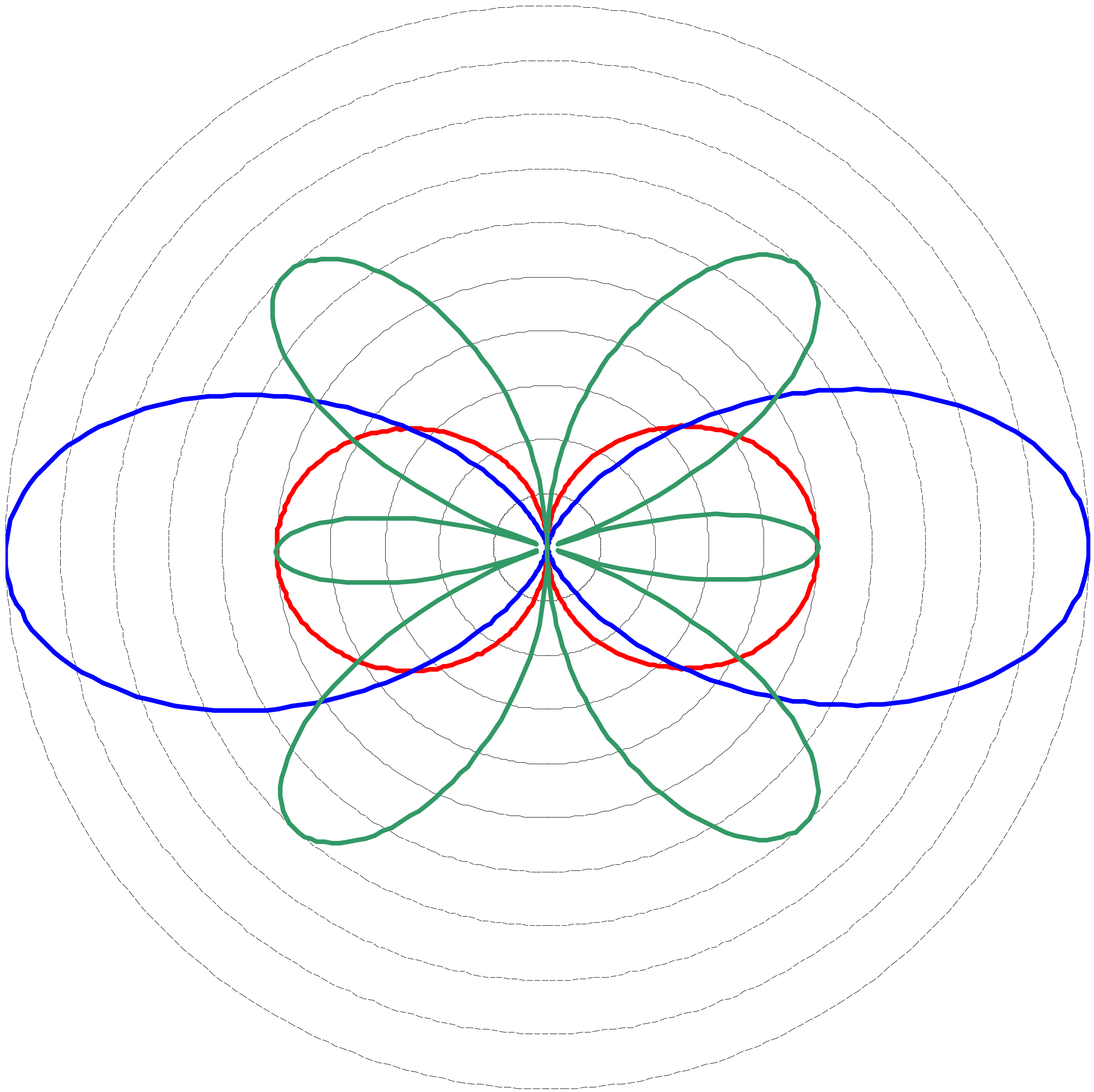
OTHER SIZE OF DIPOLES



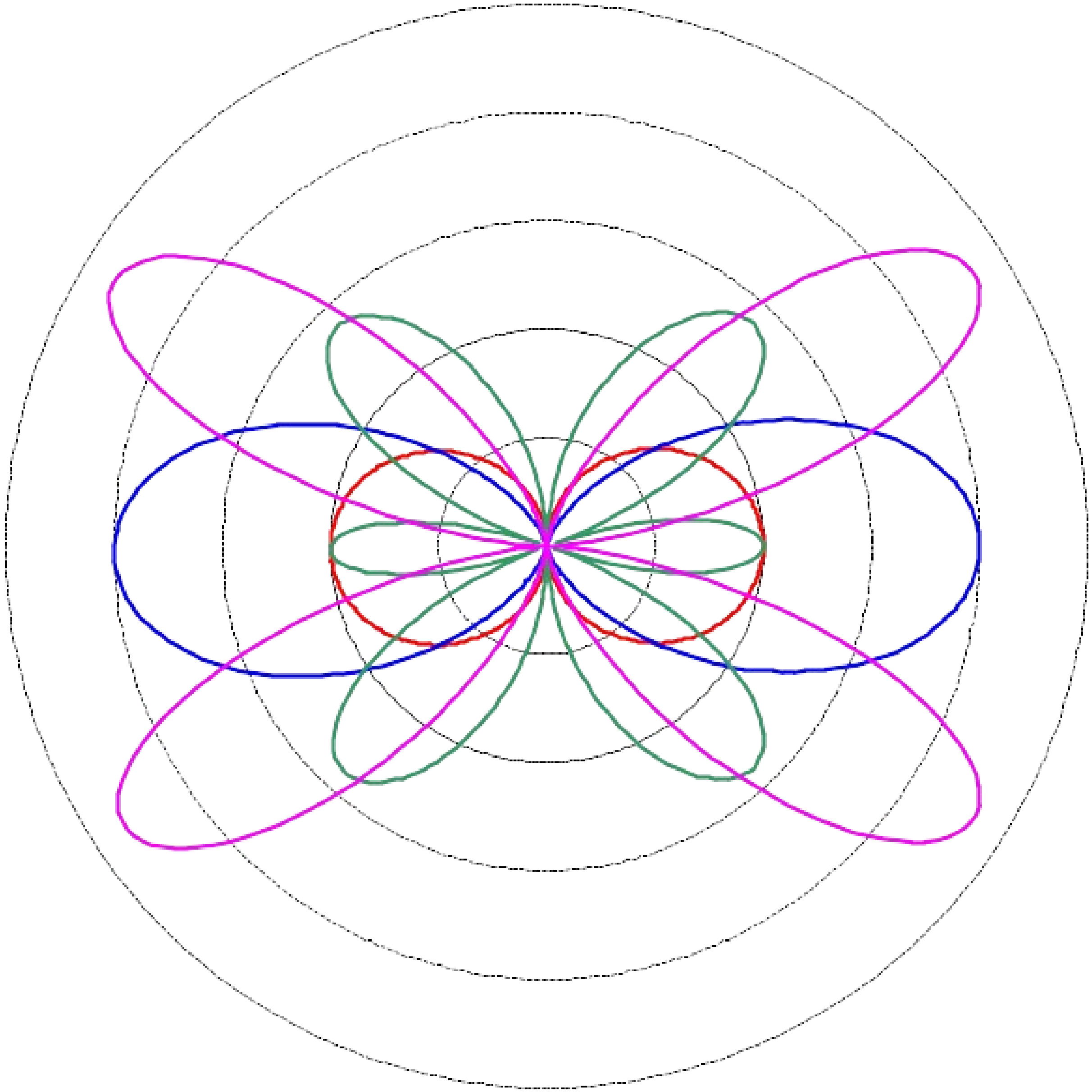
λ

OTHER SIZE OF DIPOLES

3λ/2



OTHER SIZE OF DIPOLES



2λ

MONOPOLE ANTENNA

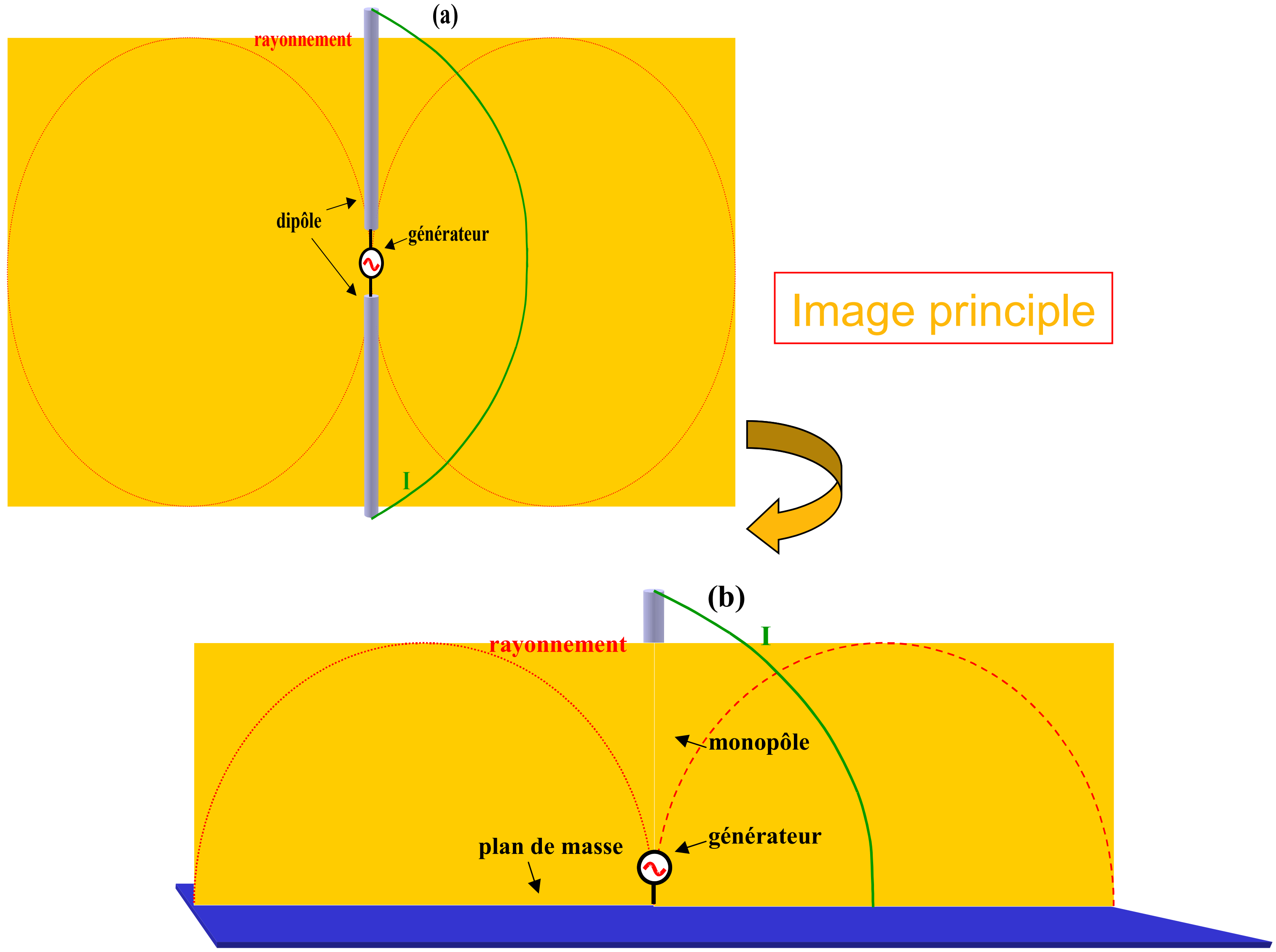
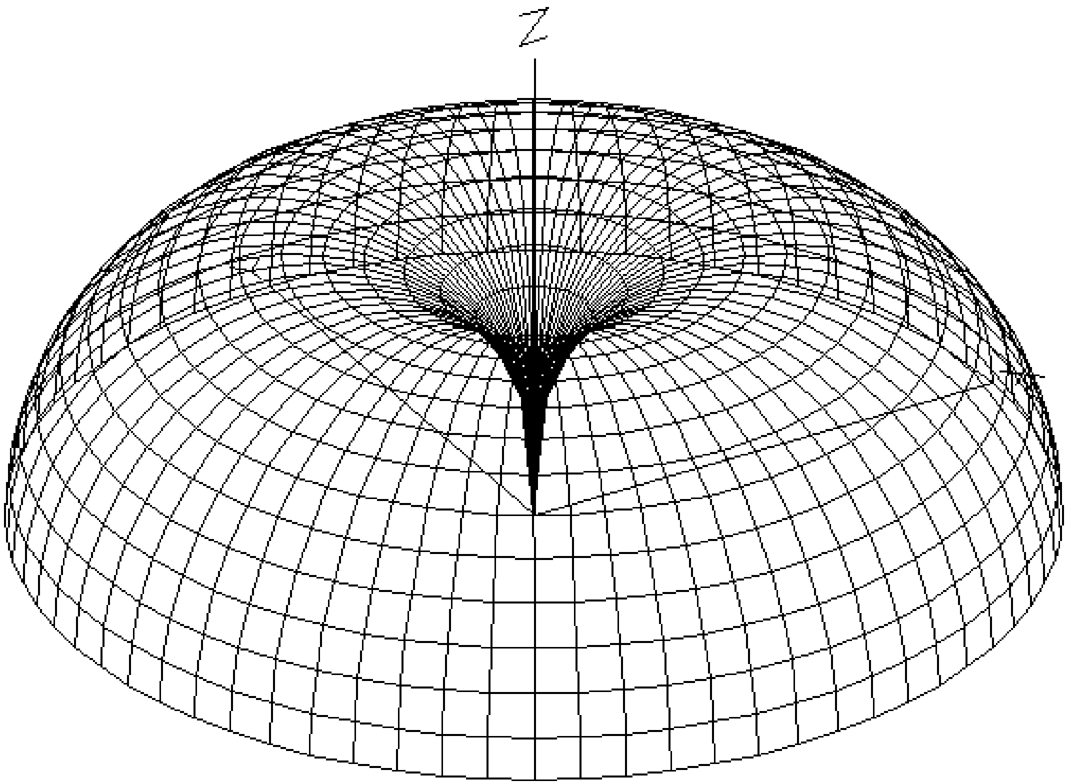


Image principle

CHARACTERISTICS OF THE MONOPOLE

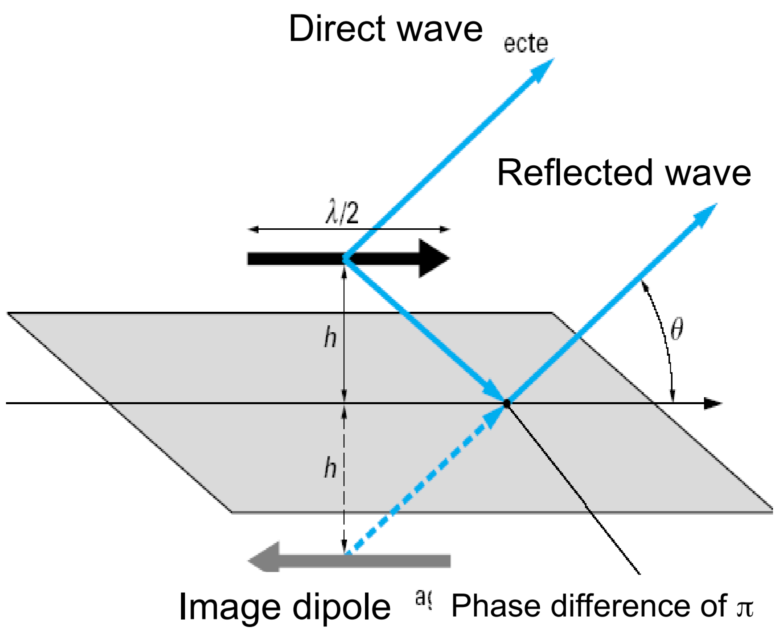
Half-space radiation

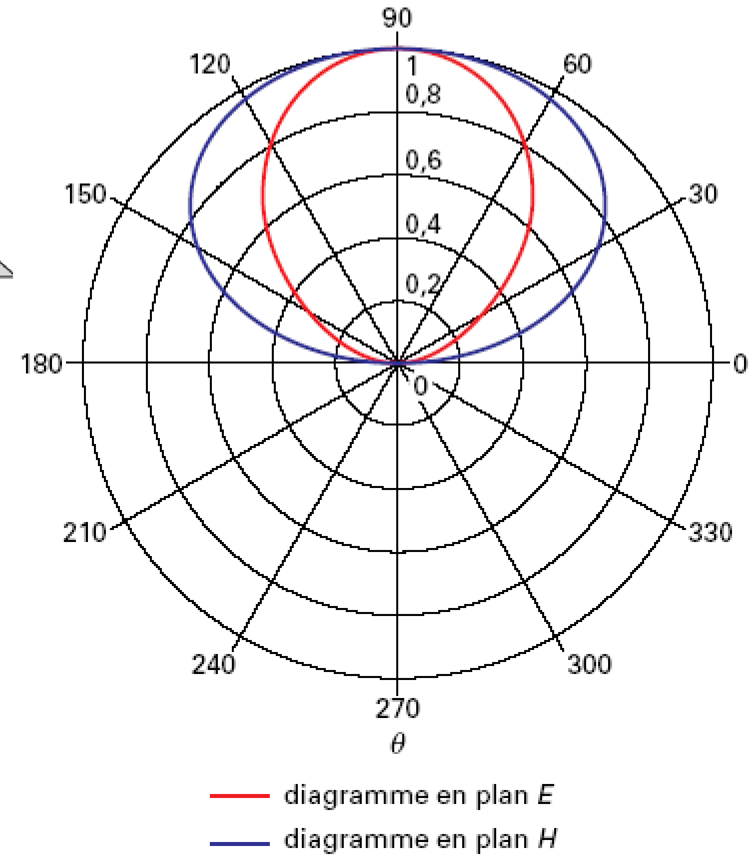
Gain increased by 3 dB



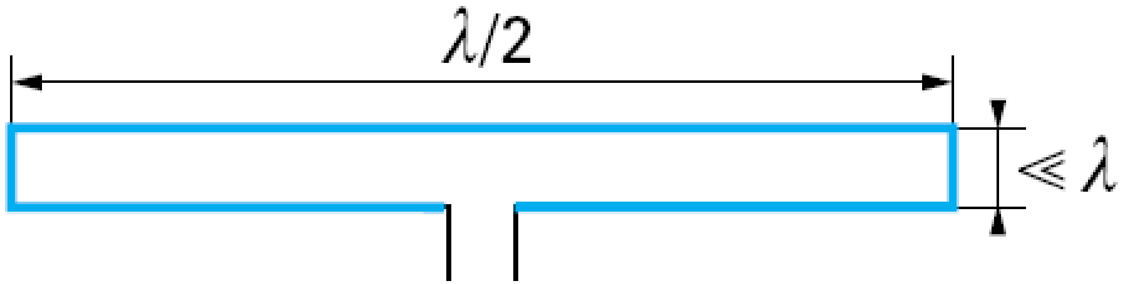
Quarter-wavelength: Z=36,5+j21 ohms

DIPOLE ABOVE A PERFECT REFLECTOR





FOLDED DIPOLE



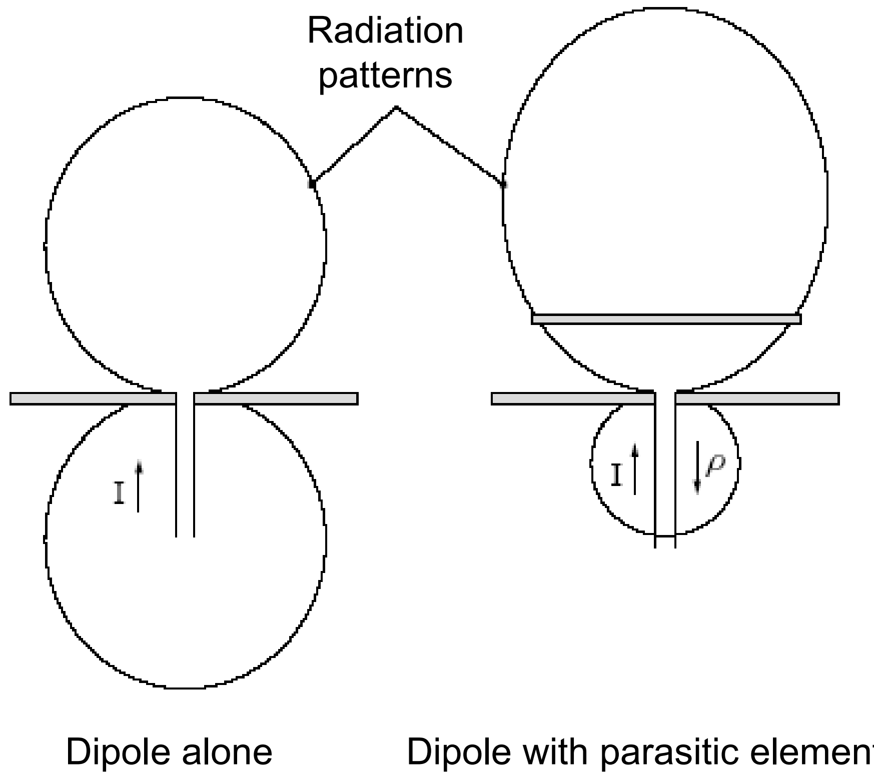
Same radiation characteristics

Impedance 300 ohms

Higher bandwidth

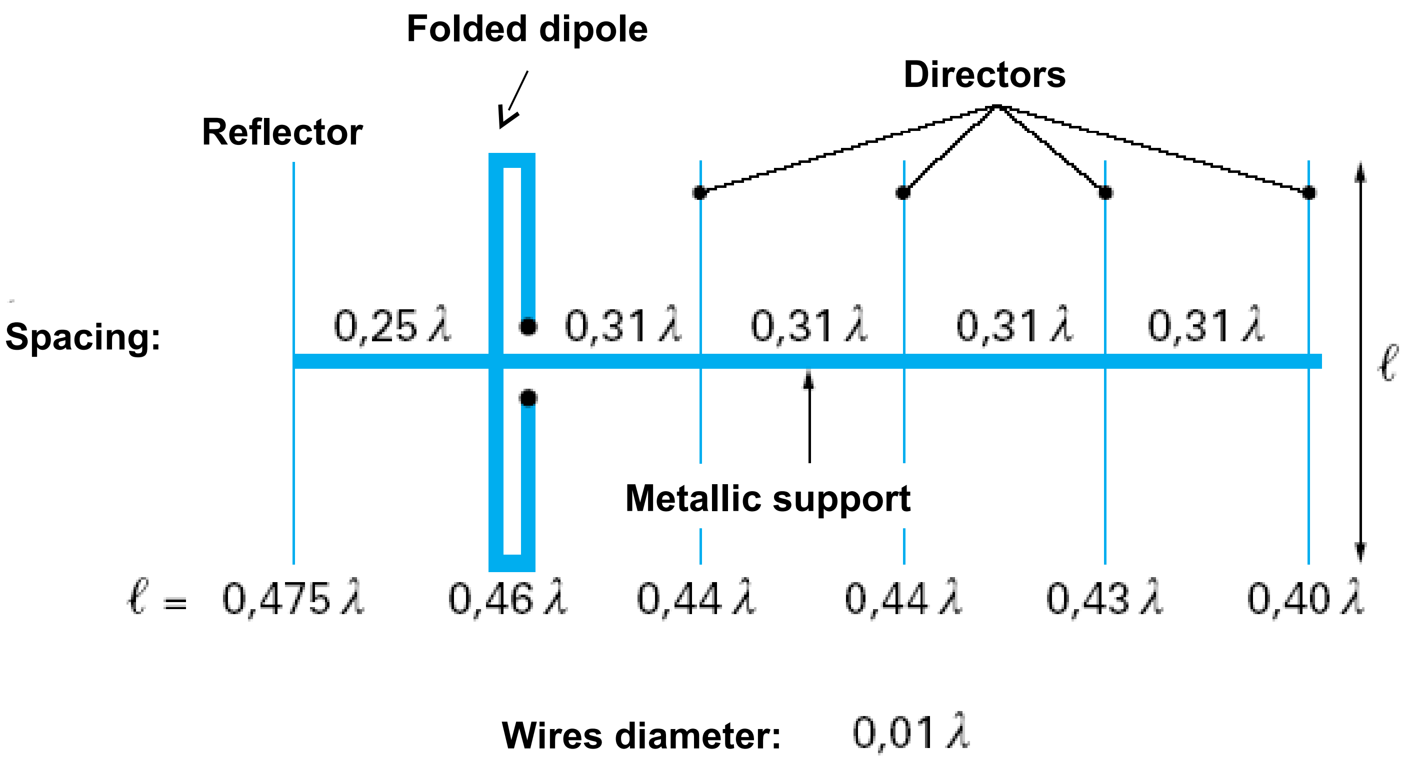
EFFECT OF PARASITIC ELEMENTS

If we place a passive element close to the feeded dipole, a coupling effect is established. By choosing slightly different sizes of these parasites, you can create behaviors like reflector or director.

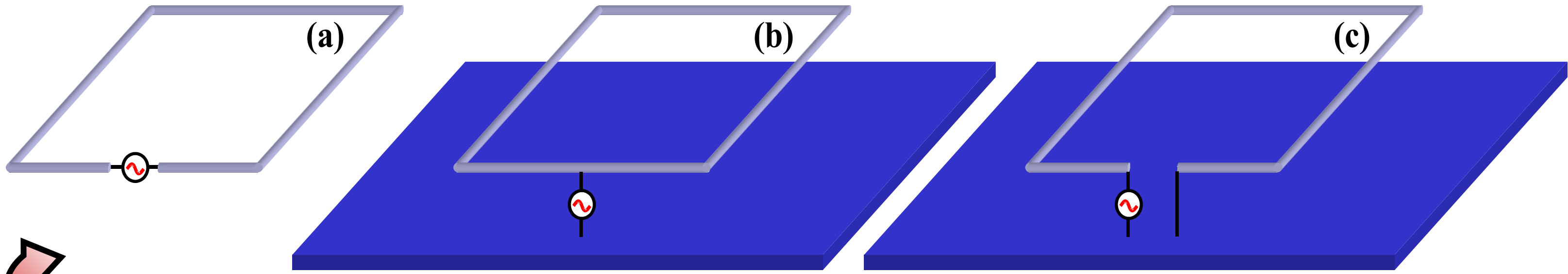


YAGI-UDA ANTENNA

Combining the effect of reflectors and directors elements, a highly directional antenna is obtained: the Yagi.

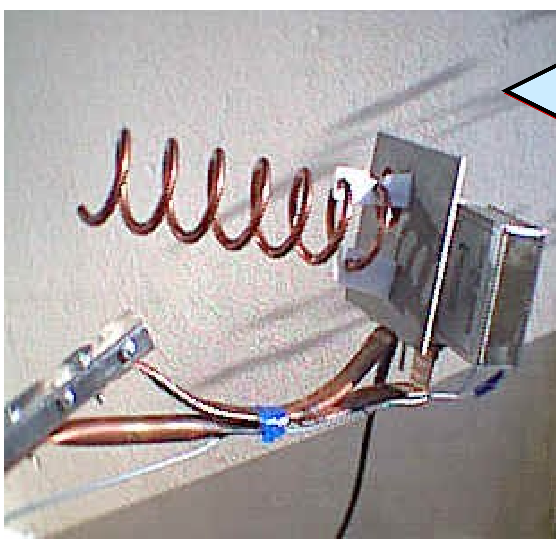


OTHER WIRE ANTENNAS



Resonating loop antenna

Helical antenna



Simple Helix

- Radial mode
- Axial mode

ltiple Helix

SLOT ANTENNAS

Illustration of Babinet's principle

Dual of the dipole

$\lambda/2$ $\lambda/4$

Same behavior than the dipole antenna but changing the laws for E and H (therefore V and I). By the way, inversion of impedance varaitions.

$$Z_f Z_d = \frac{Z_0^2}{4}$$

with Z_f Impedance of the slot ,

Z_d Impedance of the equivalent dipole

Z_0 Impedance of vacuum (377 ohms)

COMPARISON DIPOLE-SLOT

Dimensions	Impedance of the dipole (Ω)	Impedance of the slot (Ω)
$2\ell = \frac{\lambda}{2}$ $a = 0$	73 + j 42,5	363 – j 271
$2\ell = 0{,}475\,\lambda$ $a = 0{,}05\,\lambda$	67	530
$2\ell = 0{,}925\,\lambda$ $a = 0{,}033\,\lambda$	710	50

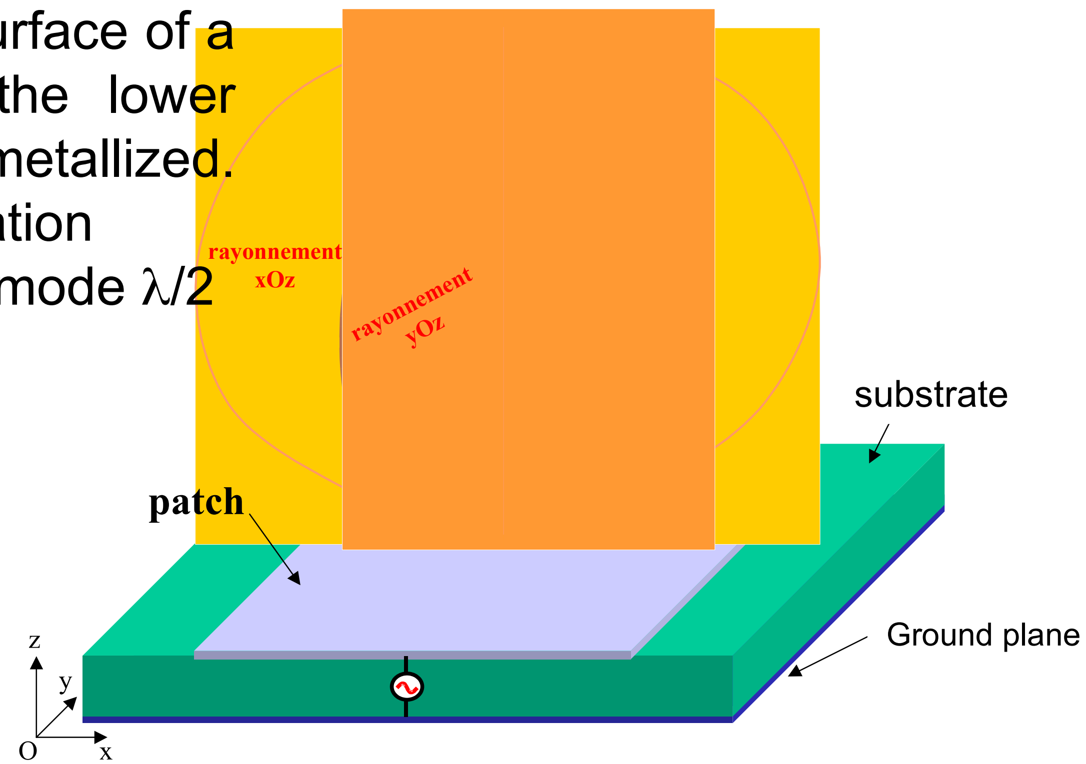
PLANAR ANTENNAS

Patch Antenna

Metallization on the surface of a dielectric substrate, the lower face is entirely metallized.

⇨ Directive radiation

⇨ Fundamental mode λ/2



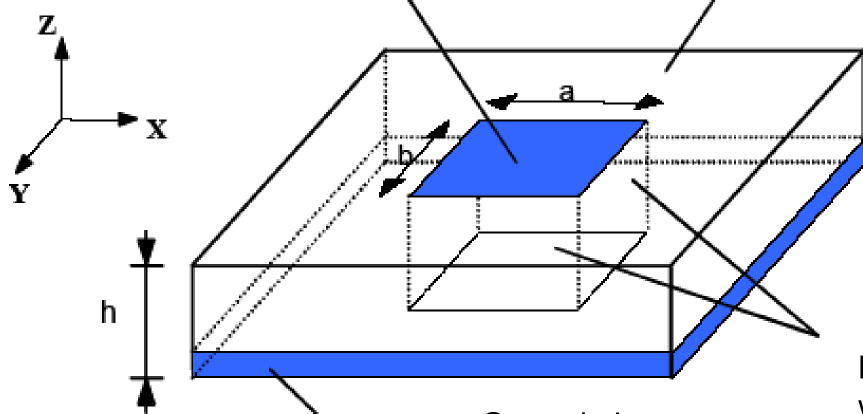
PATCH ANTENNAS

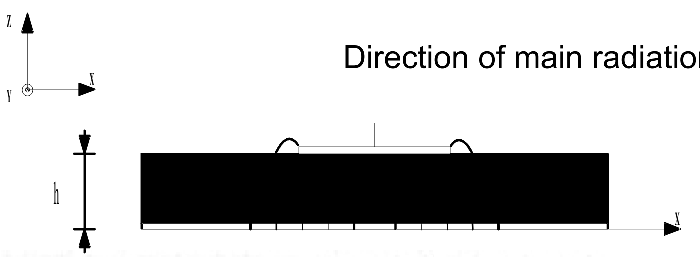
Principle of operation:

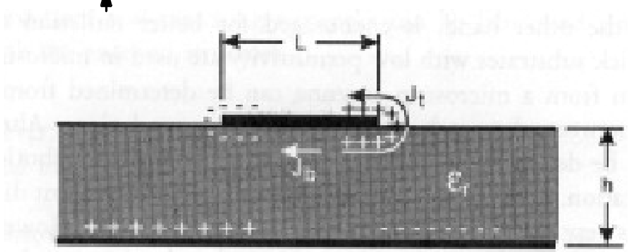
Leaky-cavity

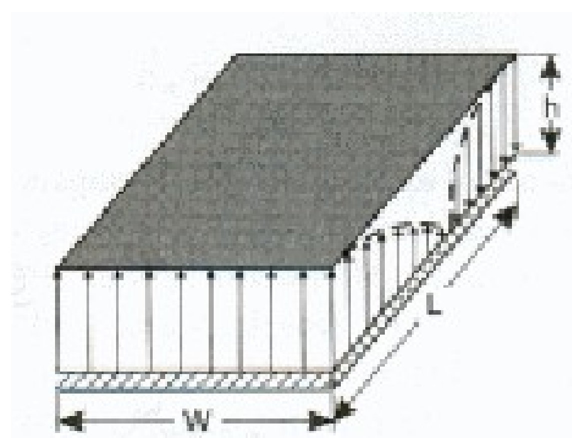
$$E_z(x,y) = E_0 \cos\left(\frac{m\pi}{L}x\right)\cos\left(\frac{n\pi}{l}y\right)$$

$$f_{mn0} = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m\pi}{L}\right)^2 + \left(\frac{n\pi}{l}\right)}$$



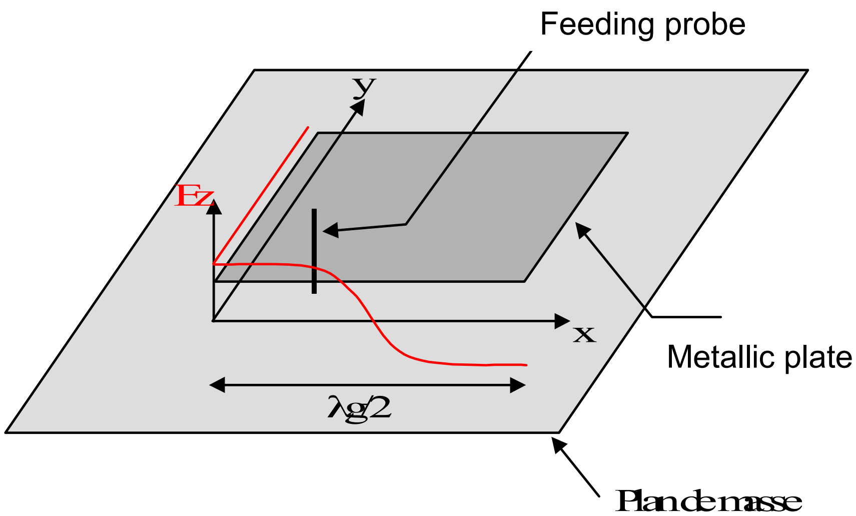


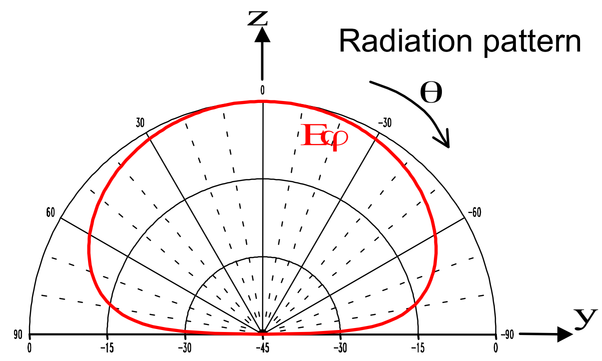




PATCH ANTENNAS

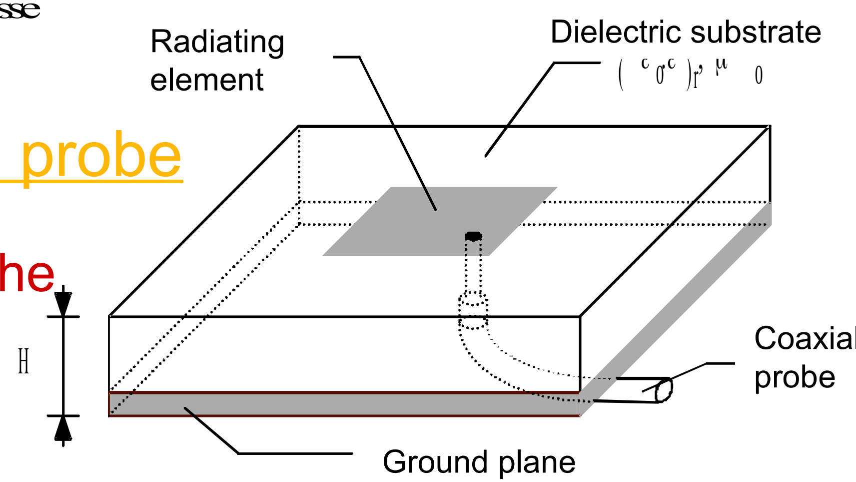
Feeding systems:





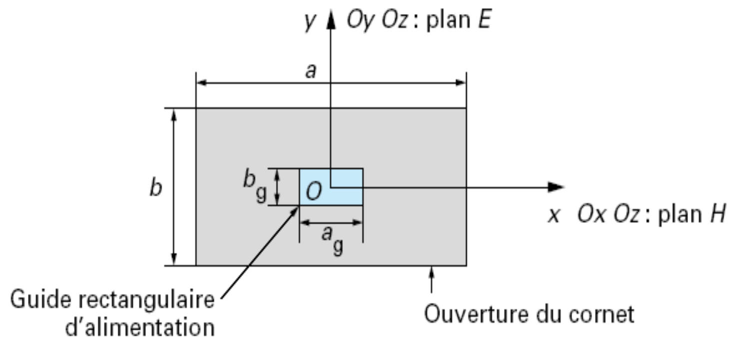
Classical system: coaxial probe

Placement in order to match the desired mode



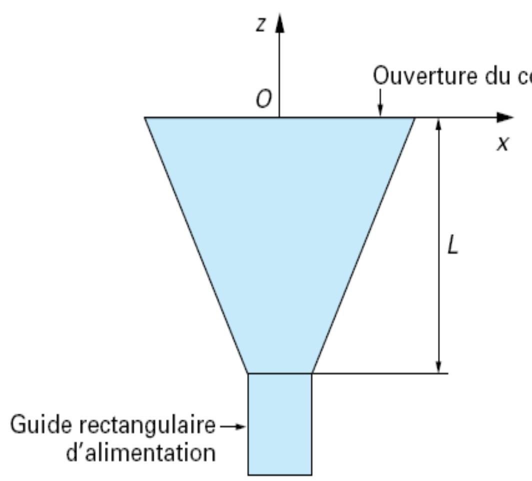
APERTURE ANTENNAS

Progressive aperture of a waveguide to free space conditions : the Horn antenna.

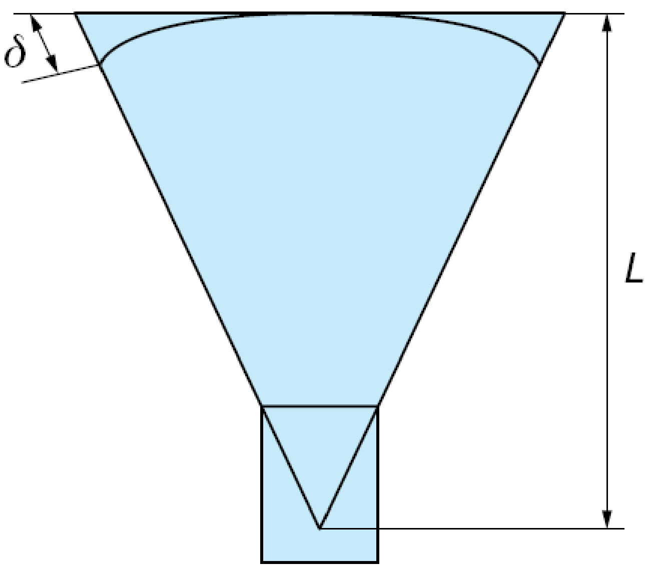


Vue de dessus

Example of rectangular horn



Coupe



HORN CHARACTERISTICS

Radiation :

H plane: $$F(\theta_x) = \frac{\cos\left(\pi\frac{a}{\lambda}\sin(\theta_x)\right)}{\left(\frac{\pi}{2}\right)^2 - \left(\pi\frac{a}{\lambda}\sin(\theta_x)\right)^2}$$

E plane: $$F(\theta_y) = \frac{\sin\left(\pi\frac{b}{\lambda}\sin(\theta_y)\right)}{\pi\frac{b}{\lambda}\sin(\theta_y)}$$

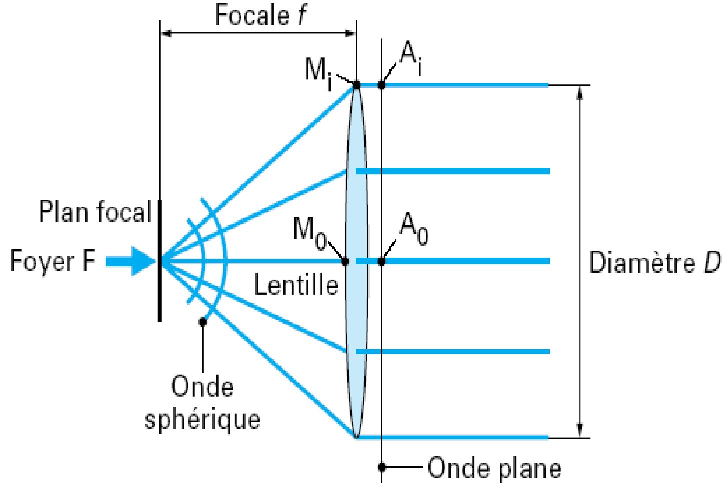
$$D \approx 10.\log\left(\frac{7.5\,Ap}{\lambda^2}\right) \quad (dBi)$$

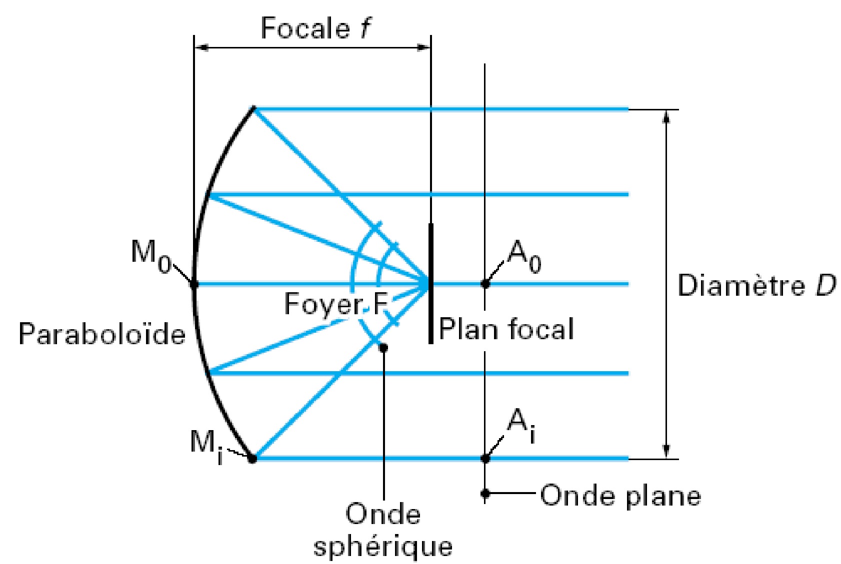
ANTENNAS WITH FOCUSING SYSTEM

The focusing systems use the principles of optics:
a plane wave is converted into a spherical wave or vice versa.

Lens : focusing system in transmission

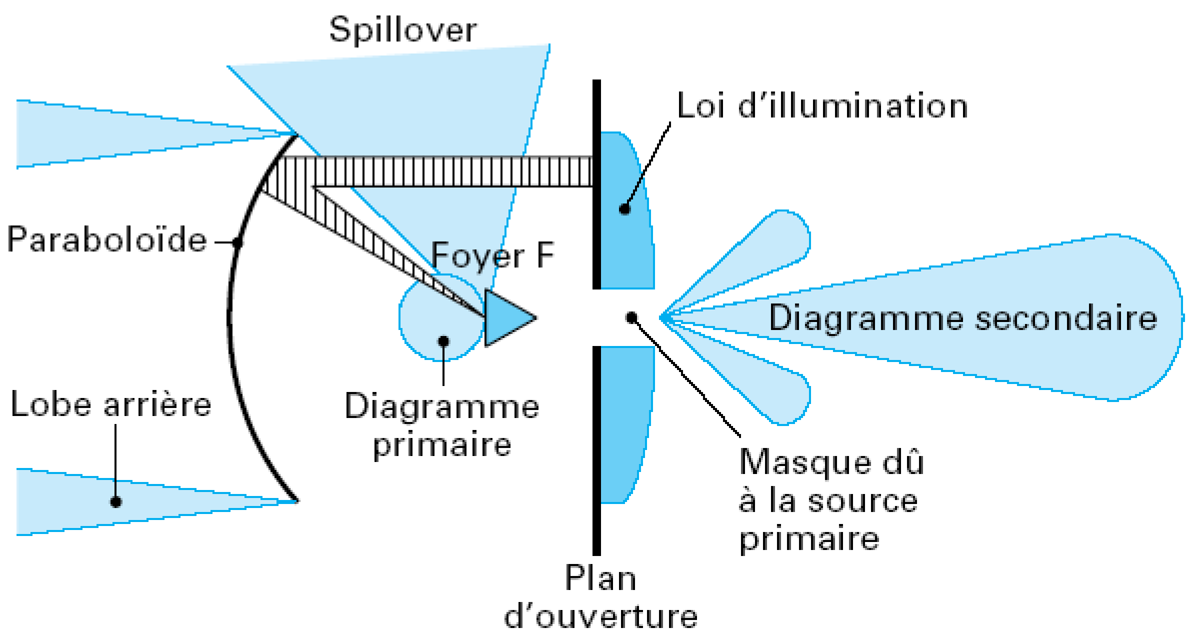
Parabolic : focusing system in reflection





PARABOLIC DISH

A reflector is used to focus the energy to an antenna element placed at the focal point.



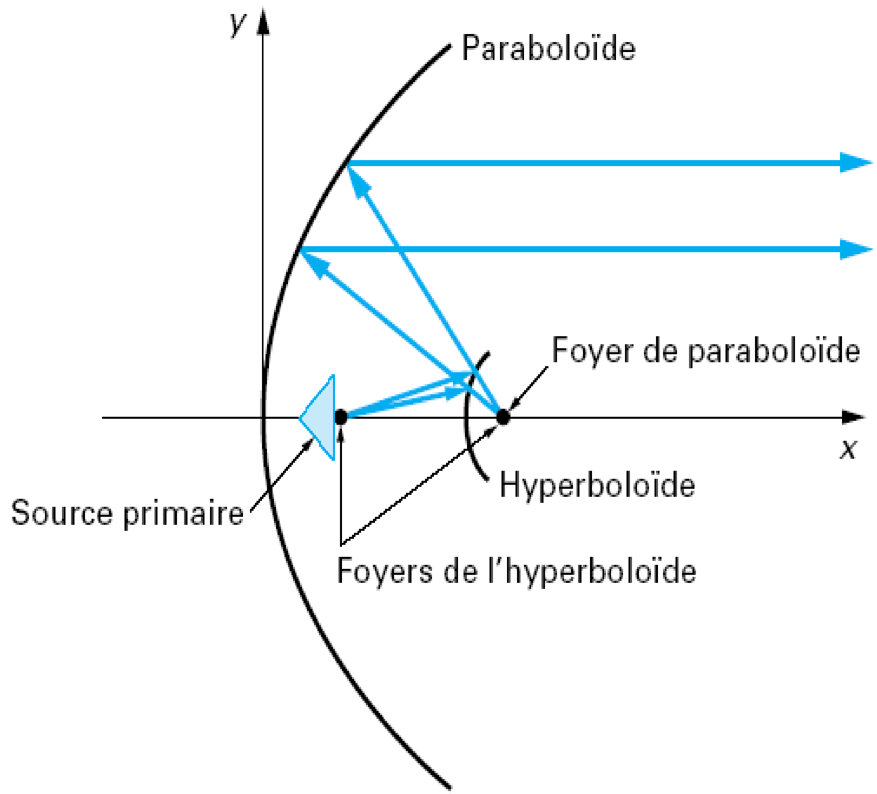
Approximation :

$$G_0 = k \cdot \left(\frac{\pi \cdot D}{\lambda} \right)^2$$

with k between 0.5 and 0.8

DOUBLE REFLECTOR SYSTEM

To improve the focusing, it is also possible to use two levels of reflectors: the principle of the Cassegrain antenna.



ANTENNA ARRAYS

- When calculating the radiation of a resonant antenna, we sum the contributions of the elementary dipoles that provide radiation of the assembly. We are then constrained by the pre-determined laws of distribution of these currents (amplitude and phase).

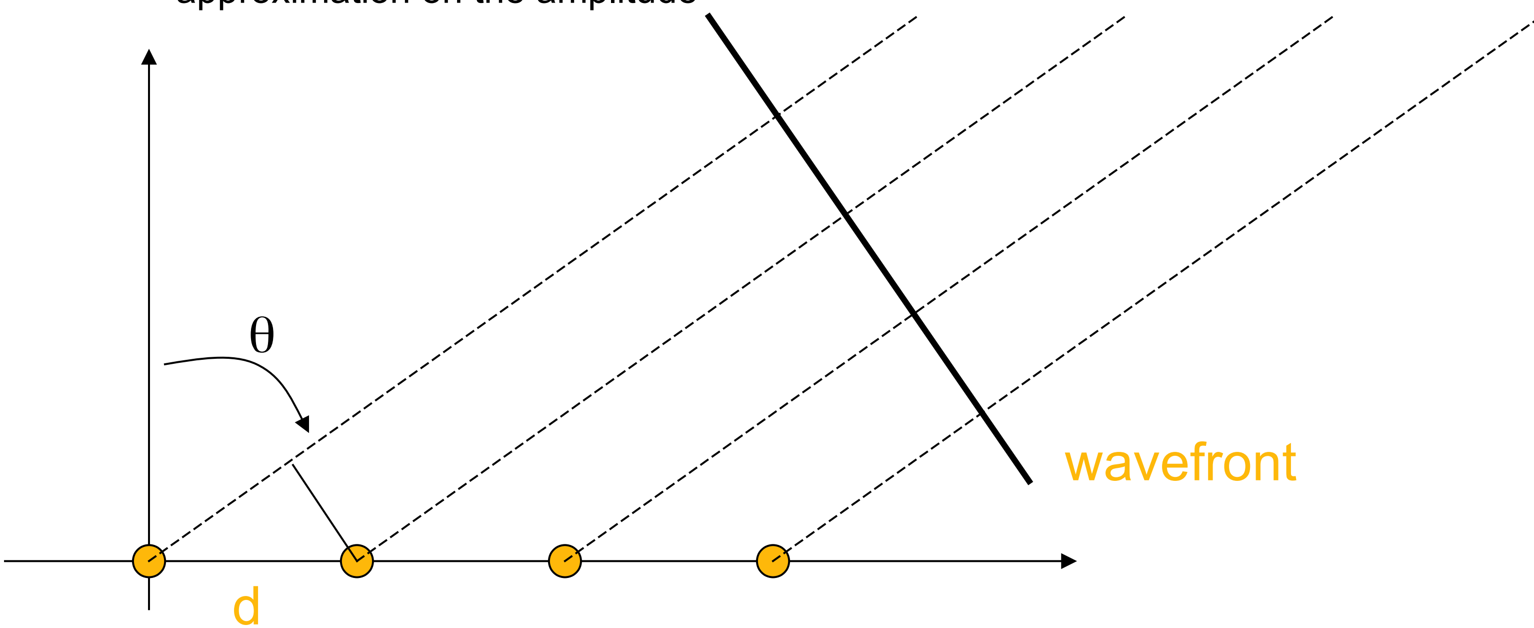
- The array principle is to use single antennas whose contributions are summed by controlling the amplitudes and phases with which they are fed.

COMBINATION PRINCIPLE

If we consider the combination of isotropic elementary sources supplied with the same amplitude and the same phase, the sum of the fields becomes:

$$\vec{E} = \frac{e^{-j\beta r}}{r}\left[1 + e^{-j\beta d \sin\theta} + e^{-j2\beta d \sin\theta} + e^{-j3\beta d \sin\theta} + \ldots + e^{-j(n-1)\beta d \sin\theta}\right].\vec{e}_p$$

approximation on the amplitude



ARRAY FACTOR

The principle of combination of the fields is the same regardless of the source radiation pattern. We then multiply by the characteristic function of the source.

$$\boxed{F_g(\theta,\varphi)=F(\theta,\varphi)\cdot\underbrace{\left|1+e^{-j\beta d\sin\theta}+e^{-j2\beta d\sin\theta}+e^{-j3\beta d\sin\theta}+\ldots+e^{-j(n-1)\beta d\sin\theta}\right|}_{}}$$

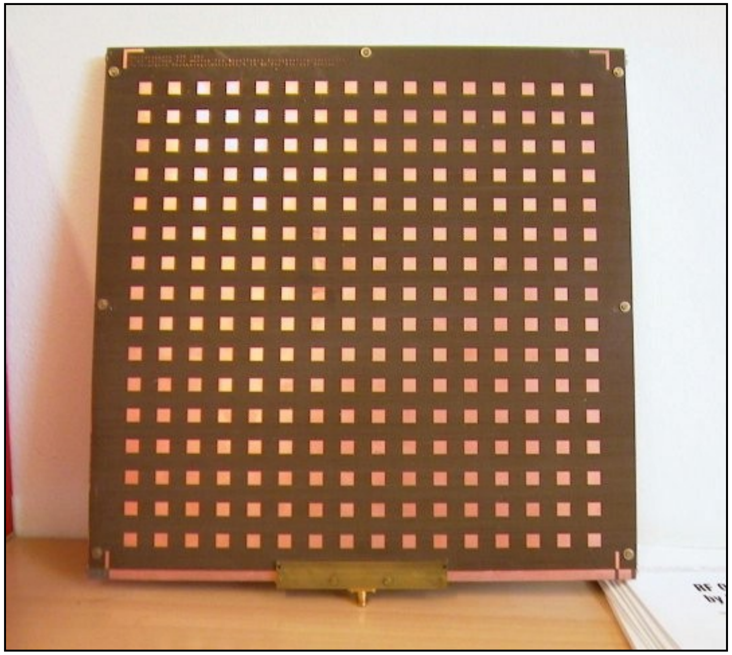
R(θ)
Array factor or grouping factor

➡ Pattern Multiplication

GAIN INCREASE

We can use the combination to increase the gain of an antenna.
From a basic directional antenna, the doubling of the number of elements increases the directivity by two.

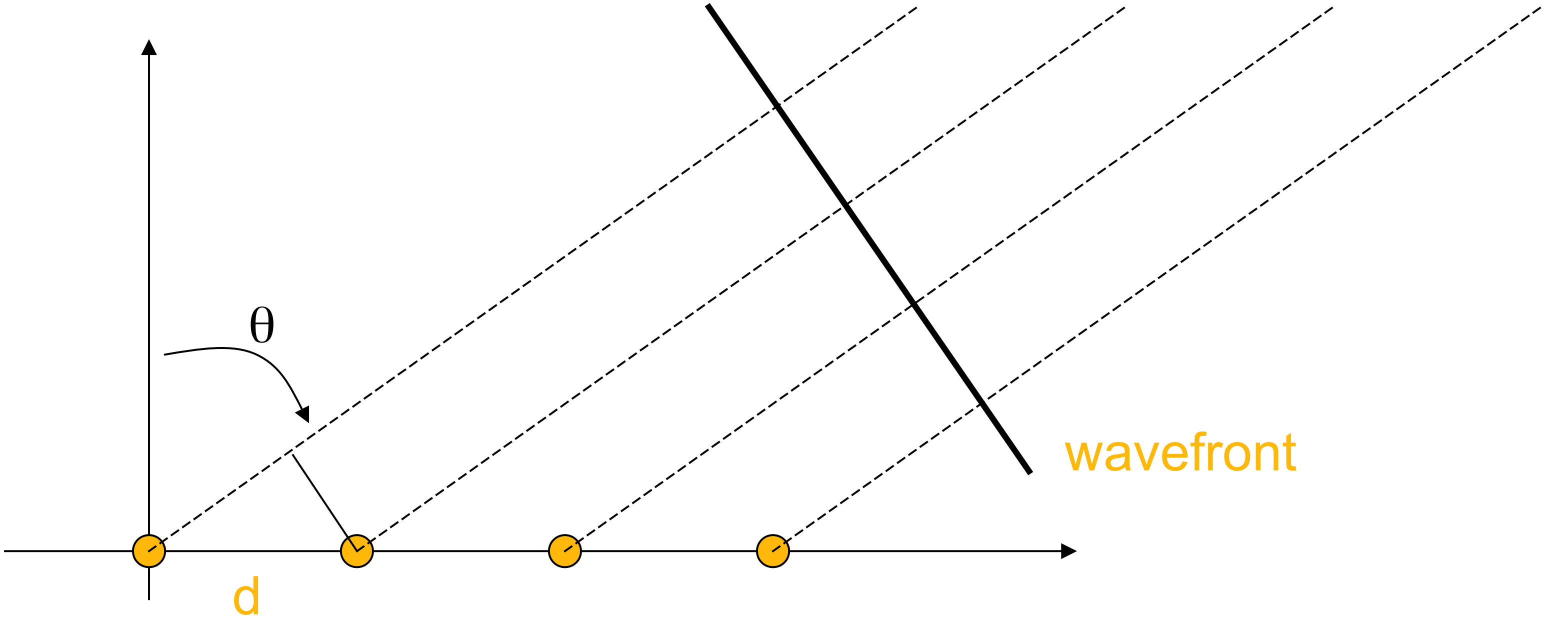
Ex array of patch antennas:



WEIGHTING

It may further choose the principle of combination of the laws of the radiating elements in phase and amplitude to change the array factor.

➡ Electronic steering

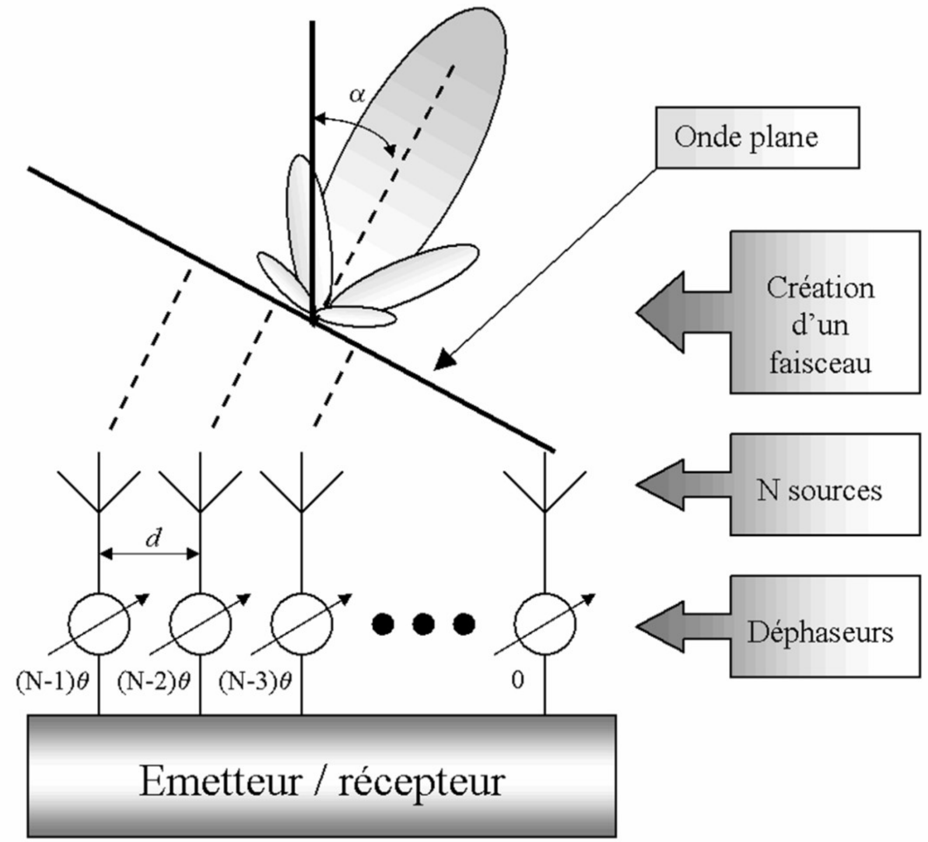


BEAMFORMING

To create the necessary laws of amplitudes and phases, we may use an array of fixed or reconfigurable distribution.

➡

Multibeam antennas
Adaptive or smart ante



YAGI-UDA ANTENNA

INTRODUCTION

- In the 1926, dr. shintaro uda and dr. hidetsugu yagi of the tohoku imperial university invented a directional antenna system consisting of an array of coupled parallel dipoles.this is commonly known as yagi-uda or simply yagi antenna.

- Yagi-uda antenna is familiar as the commonest kind of terrestrial tv antenna to be found on the rooftops of houses.it is usually used at frequencies between 30mhz and 3ghz and covers 40 to 60 km.

principle

- Yagi-uda antenna is an electromagnetic device that collects radio waves. an antenna tuned to a particular frequency will resonate to a radio signal of the same frequency.

construction

- The yagi-uda antenna consists of 2 parts:

  - The antenna elements
  - The antenna boom

- There are three types of elements:

  - The reflector (refl)
  - The driven element (de)
  - The directors (dir)

Working

- Reflector here derives it's main Power from a driver , it reduces the signal strength in it's own direction and thus reflects the radiation towards the driver and directors.

- The driven element is where the signal is intercepted by the receiving equipment and has the cable attached that takes the received signal to the receiver

- The radiator and driver can be placed more closer to increase the radiation length towards the directors.

FIVE ELEMENT YAGI-UDA

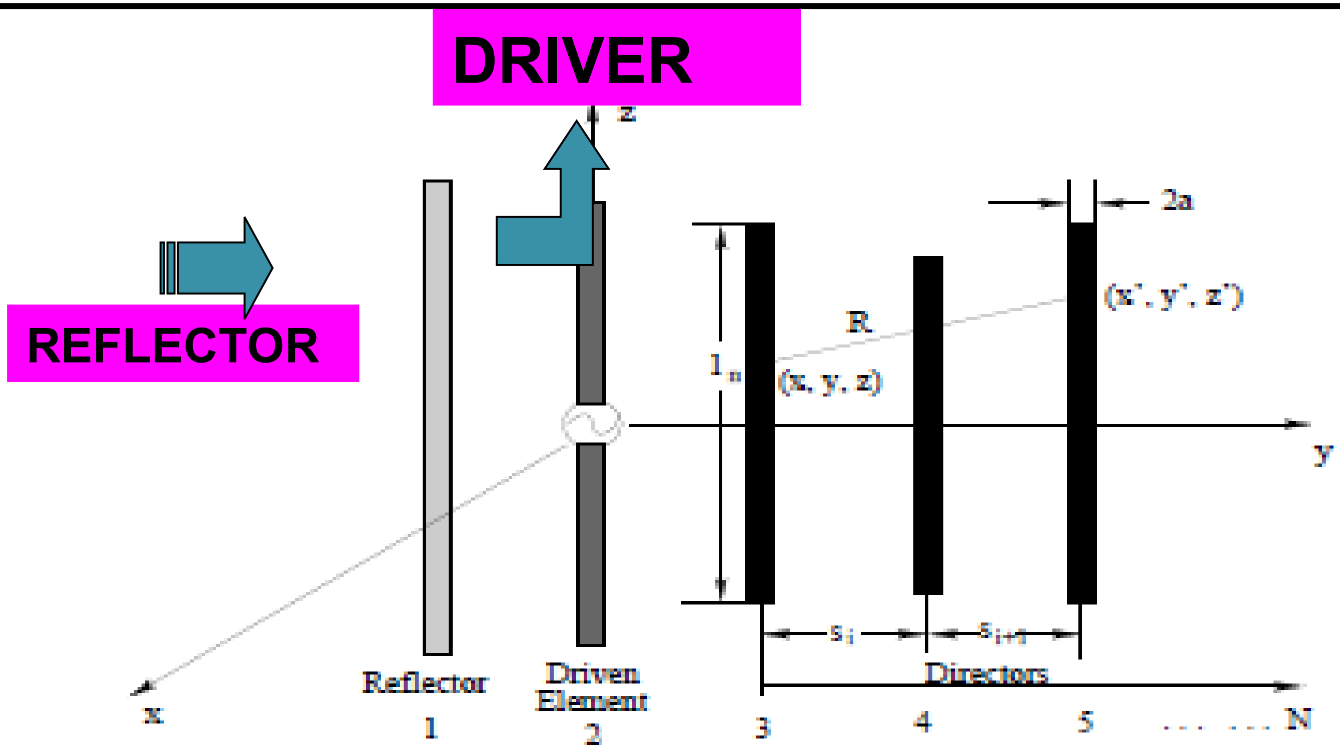


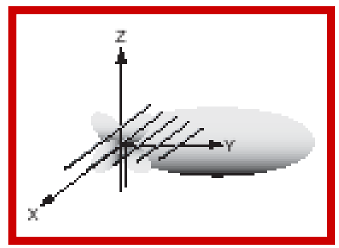
Figure 1.1: Geometry of Yagi-Uda array

- **WAVELENGTH = 3*10^8 / FERQUENCY(MHz)**

- To determine the wave-length of a radio station with a frequency of 92.1 mhz , SIMPLY DIVIDE THE SPEED OF LIGHT (300,000,000 METERS PER SECOND) BY 92,100,000 CYCLES PER SECOND.

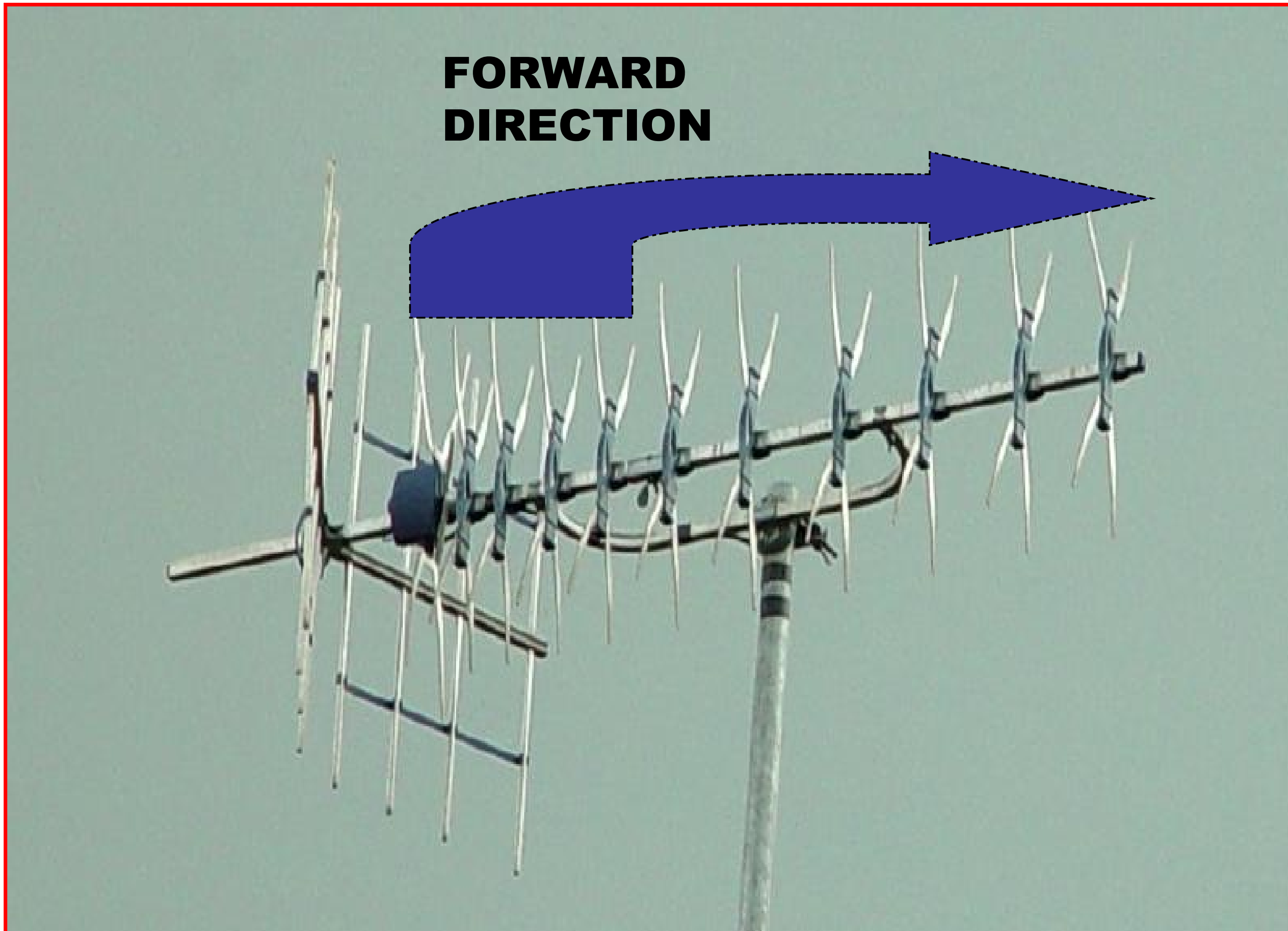
  The seconds cancels out in the formula with the wave-length ending up at 3.26 meters. In other words the waves passing you buy right now from a radio station transmitting at 92.1 mhz ARE 3.26 meters long.

Radiation pattern formed BY the directional antenna



jack

PICTURE OF ANTENNA



ELEVEN ELEMENT'S OF YAGI-UDA ANTENNA

ADVANTAGES

- It has a moderate gain of about 7 (db).
- It is a directional antenna.
- Can be used at high frequency.
- Adjustable from to back ratio.

DISADVANTAGES

- The gain is not very high.
- Needs a large number of elements to be used.

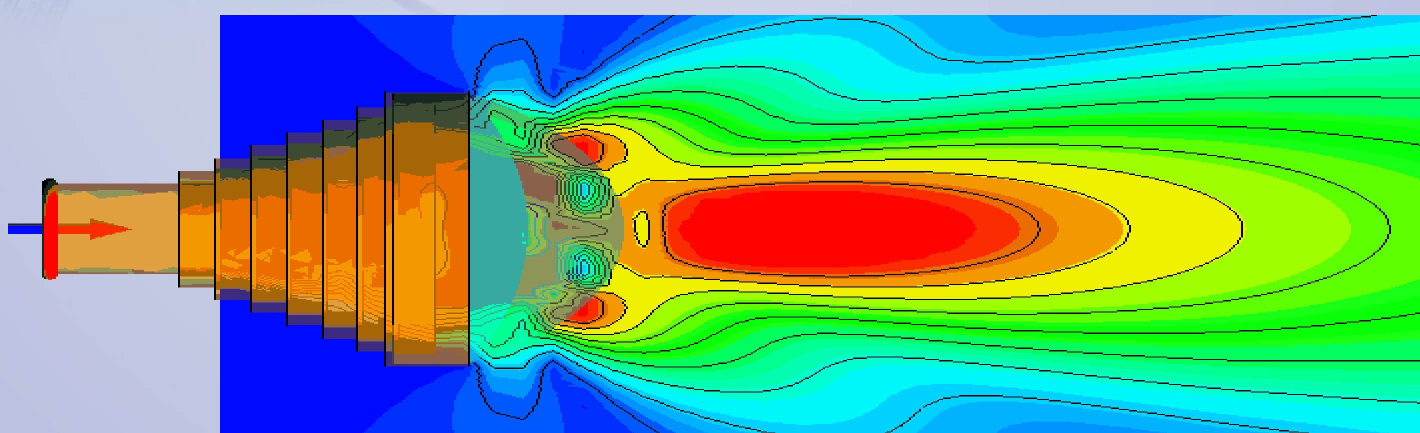
APPLICATIONS

Television receivers.

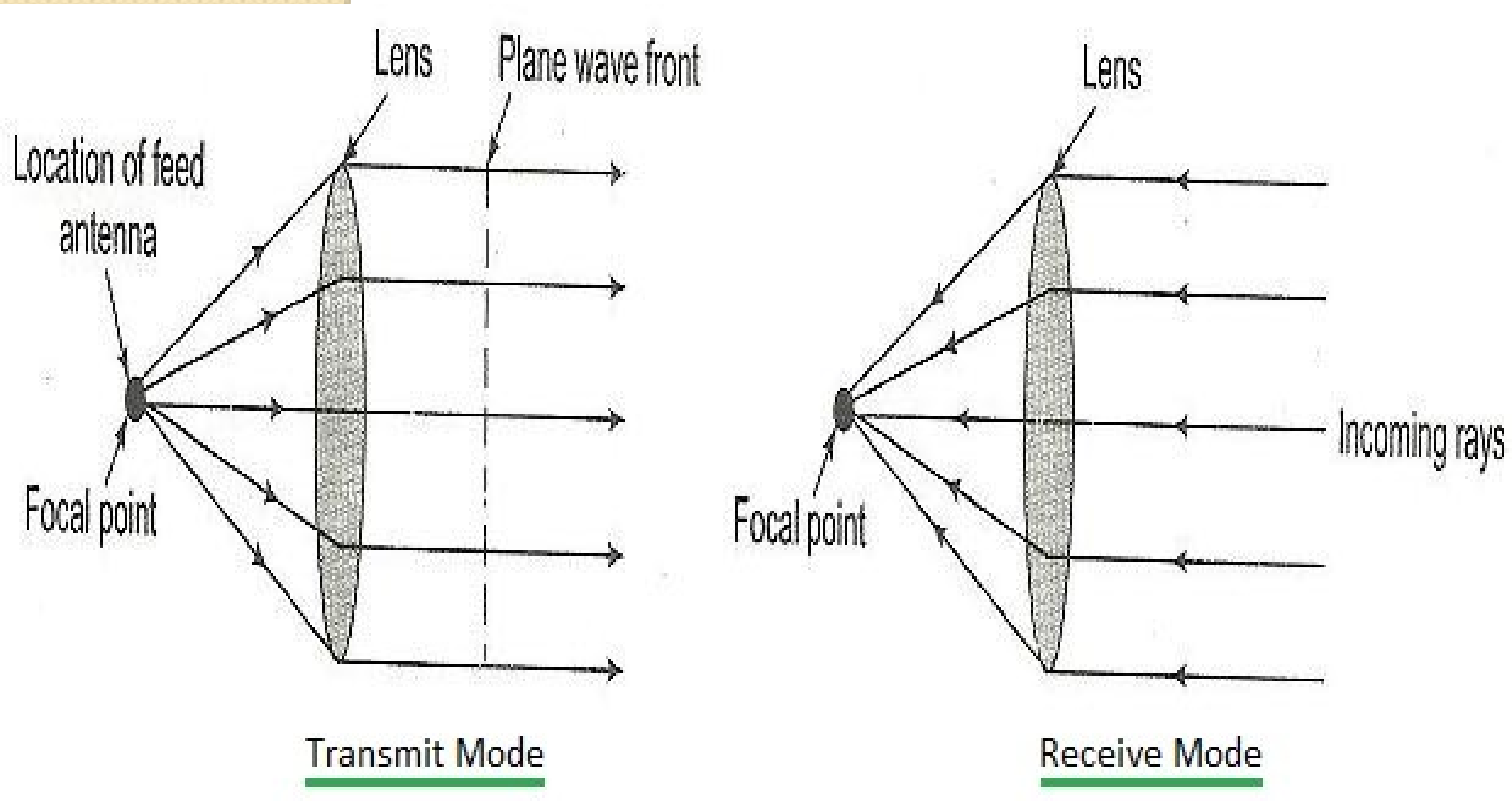
- It is also the antenna windly used with
- Used at hf at vhf a t.V receiving antenna.
- A stack of yagi antenna can be used as a super gain.

UNIT-IV
VHF, UHF and Microwave Antennas – II

LENS ANTENNA :-



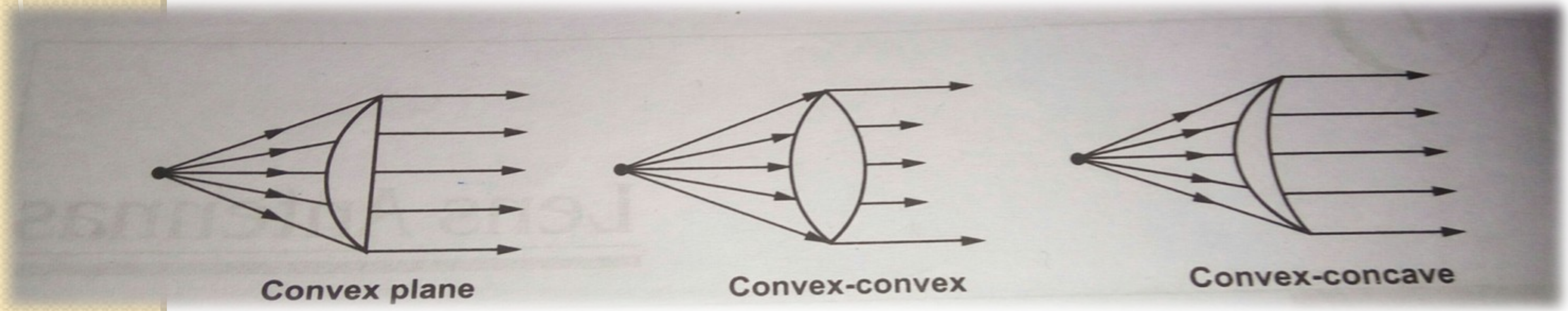
- TRANSMITTING MODE
- RECEVING MODE



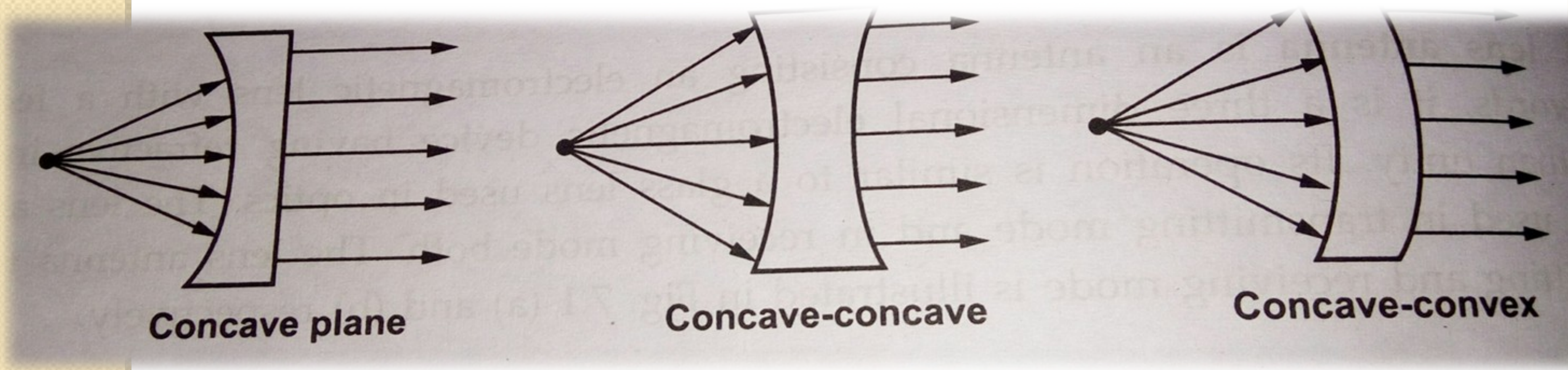
FUNCTIONS OF LENS ANTENNA

- It controls the illumination of aperture.
- It collimates the electromagnetic rays.
- It provides directional characteristics.
- In receiving mode ,it converges the incoming wave front at its focal point.
- It produces plane wave front form a spherical wave front.

ANTENNA CONFIGURATIONS



Lens antenna with refractive index n>1

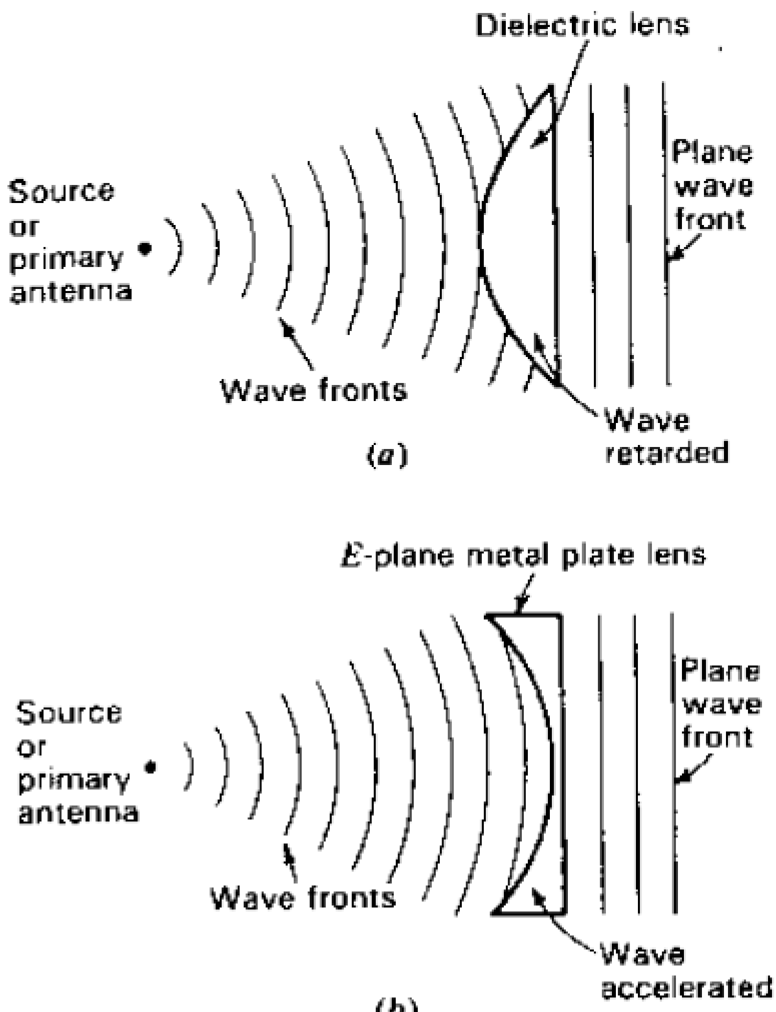


Lens antenna with refractive index n<1

LENS ANTENNAS CLASSIFIED AS

- DEALY LENS
- FAST LENS

Dielectric Lens



- There are two types of lens antenna
  - Delay lances (electrical path length increased by lens medium)

    Ex. Dielectric lances, H plane metal-plate lenses
  - Fast lances (electrical path length decreased by lens medium)

    Ex. E plane metal-plate lenses

Dielectric Lens

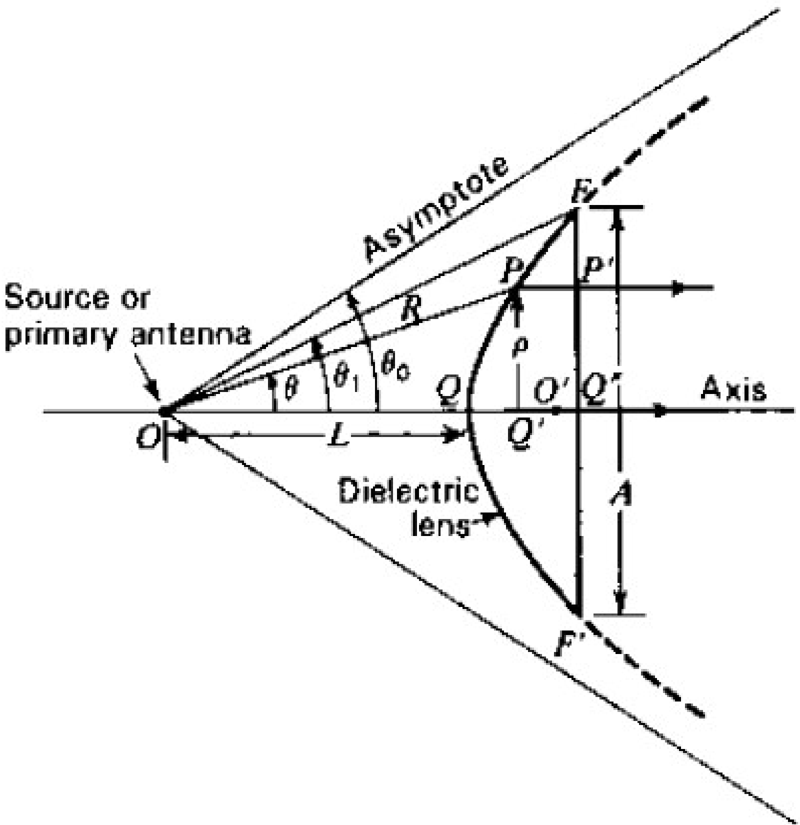
- There are two types of dielectric lenses
  - Non Metallic
  - Metallic/artificial

- Non Metallic Dielectric lens
  - This types is similar to optical lens
  - It may designed by ray analysis methods of geometrical optics.

  - Metallic or Artificial Dielectric lens
  - This types is less heavy compare to nonmetallic lens
  - It consist of discrete metal particles of macroscopic size.

Non Metallic Dielectric lens (Fermat's Principle)

$$\frac{R}{\lambda_0} = \frac{L}{\lambda_0} + \frac{R\cos\theta - L}{\lambda_d}$$



where λ_0 = wavelength in free space (air or vacuum)
λ_d = wavelength in the lens

Multiplying (1) by λ_0,

$$R = L + n(R\cos\theta - L)$$

where $n = \lambda_0/\lambda_d$ = index of refraction

In general,

$$n = \frac{\lambda_0}{\lambda_d} = \frac{f\lambda_0}{f\lambda_d} = \frac{v_0}{v_d} = \frac{\sqrt{\mu\varepsilon}}{\sqrt{\mu_0\varepsilon_0}}$$

where f = frequency, Hz
v_0 = velocity in free space, m s^{-1}
v_d = velocity in dielectric, m s^{-1}
μ = permeability of the dielectric medium, H m^{-1}
ε = permittivity of the dielectric medium, F m^{-1}
μ_0 = permeability of free space = $4\pi \times 10^{-7}$, H m^{-1}
ε_0 = permittivity of free space = 8.85×10^{-12}, F m^{-1}

Non Metallic Dielectric lens (Fermat's Principle)

However,

$$\mu = \mu_0 \mu_r$$

and

$$\varepsilon = \varepsilon_0 \varepsilon_r$$

where $\mu_r = \dfrac{\mu}{\mu_0}$ = relative permeability of dielectric medium

$\varepsilon_r = \dfrac{\varepsilon}{\varepsilon_0}$ = relative permittivity of dielectric medium

Thus,

$$n = \sqrt{\mu_r \varepsilon_r}$$

For nonmagnetic materials μ_r is very nearly unity so that

$$R = \frac{(n-1)L}{n\cos\theta - 1} \qquad \theta_0 = \arccos\frac{1}{n}$$

Non Metallic Dielectric lens

Reflection Coefficient

$$\rho = \frac{Z_0 - Z}{Z_0 + Z}$$

where Z_0 = intrinsic impedance of free space $= \sqrt{\mu_0/\varepsilon_0}$

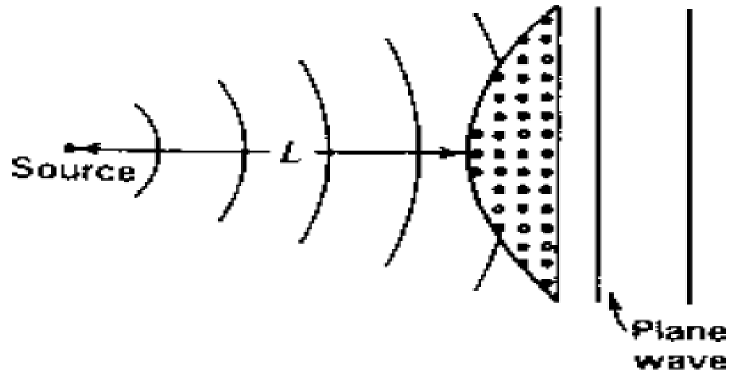
Z = intrinsic impedance of dielectric lens material $= \sqrt{\mu/\varepsilon}$

Thus,

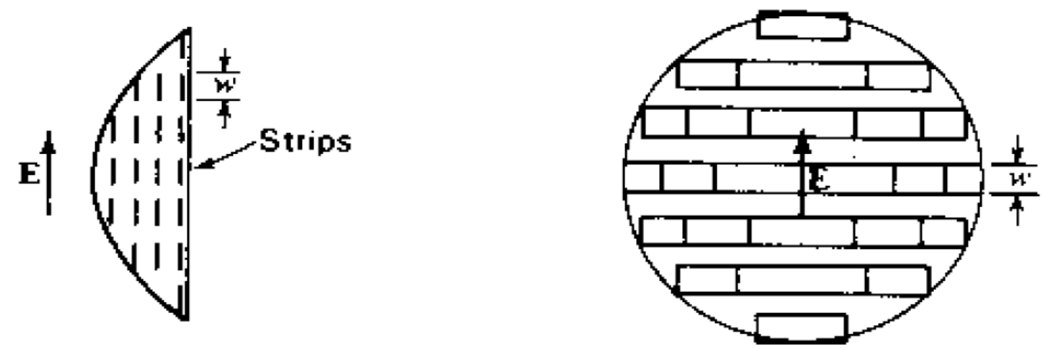
$$\rho = \frac{(Z_0/Z) - 1}{(Z_0/Z) + 1} = \frac{n - 1}{n + 1}$$

where n = the index of refraction of the dielectric lens material

Metallic/Artificial Dielectric lens



Artificial dielectric lens of metal spheres.



Cross section of lens

(a)

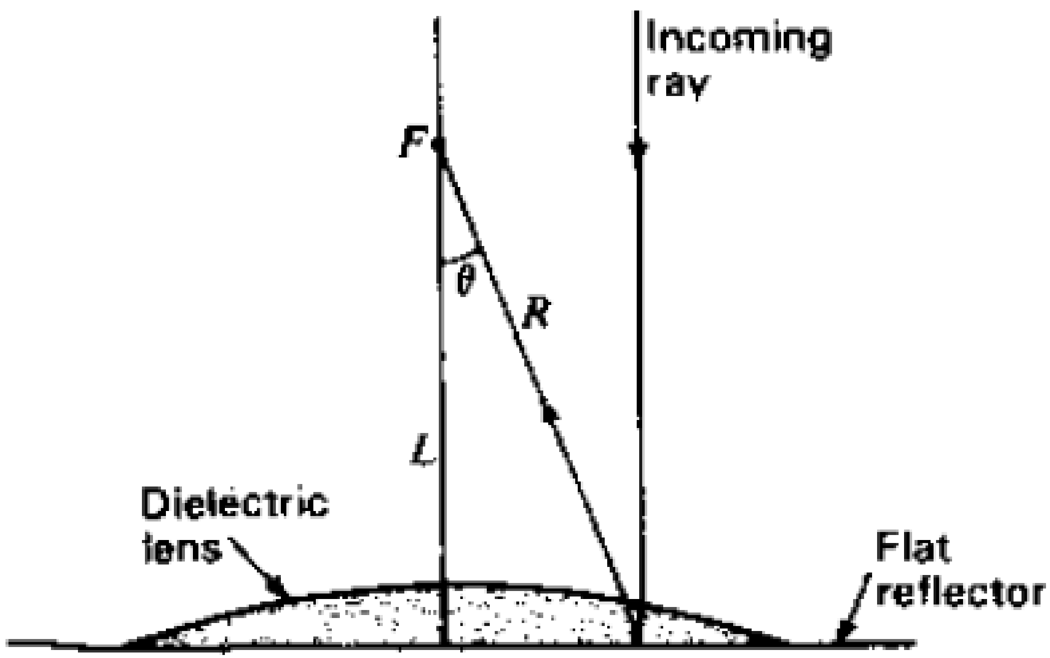
Convex side of lens

(b)

Artificial dielectric lens of flat metal strips of width w.

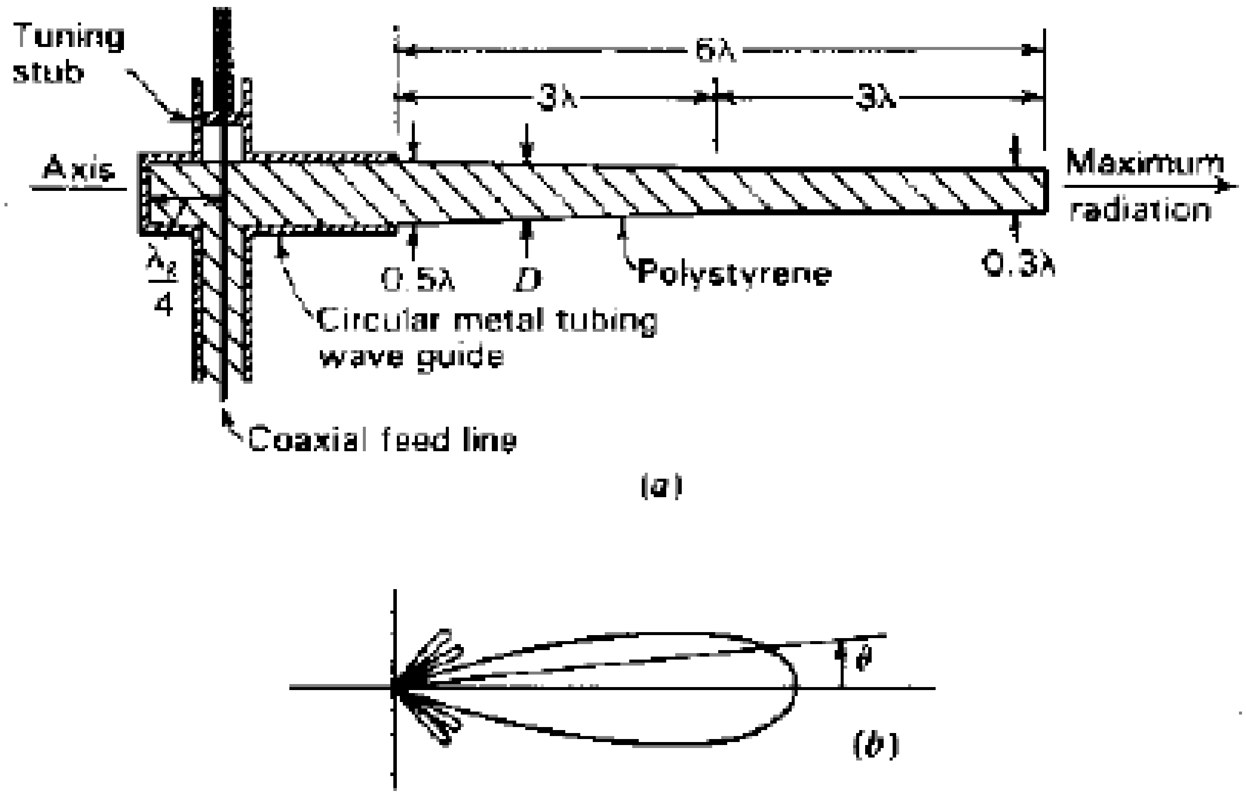
Reflector Lens Antenna

$$R = \frac{(n-1)2L}{(2n-1)\cos\theta - 1}$$

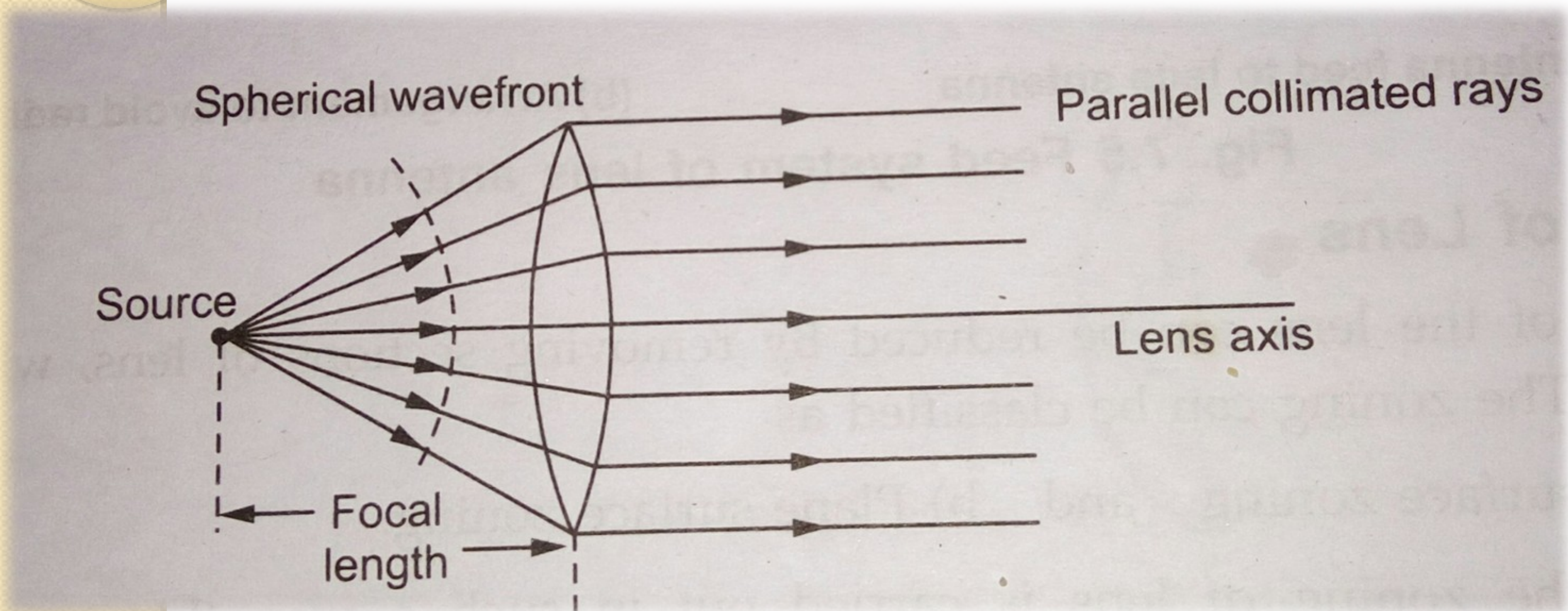


Polyrod

- A dielectric rod or wire can act as a guide for EM waves. This tendency to radiate is turned to advantage in the polyrod antenna. (made of Polystyrene)

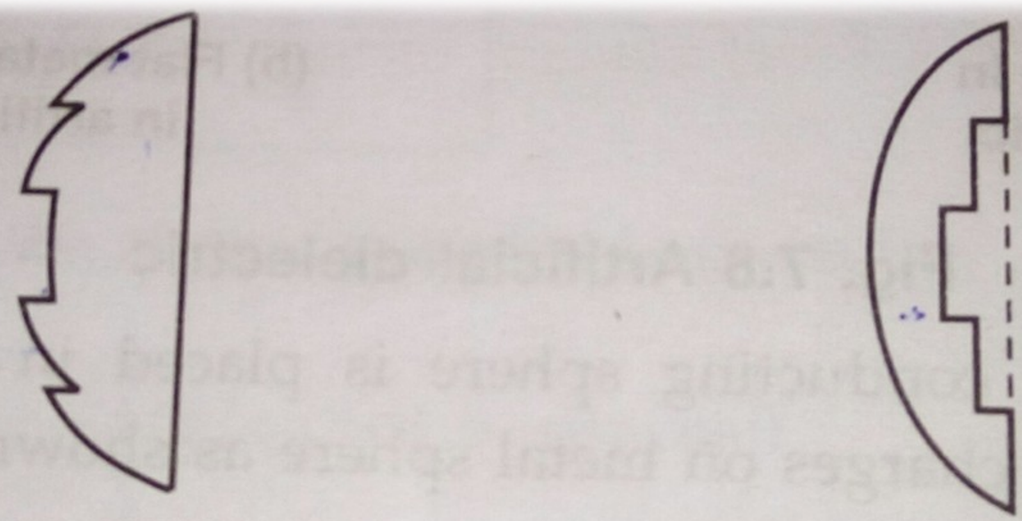


PRINCIPLE OF LENS ANTENNA



ZONING OF LENS(Z)

- Curved surface zoning
- Plane surface zoning



(a) Curved surface zoning (b) Plane surface zoning

Advantages of lens antenna

- Lens are bulkier
- Design of lens antenna is complicated
- Lens are expensive

Applications of lens antennas

- Lens antenna used as microwave antenna
- For large bandwidth requirements unstepped dielectric lens antennas are used
- For narrow bandwidth applications ,dielectric lens antennas are used

LUNEBURG LENS ANTENNA

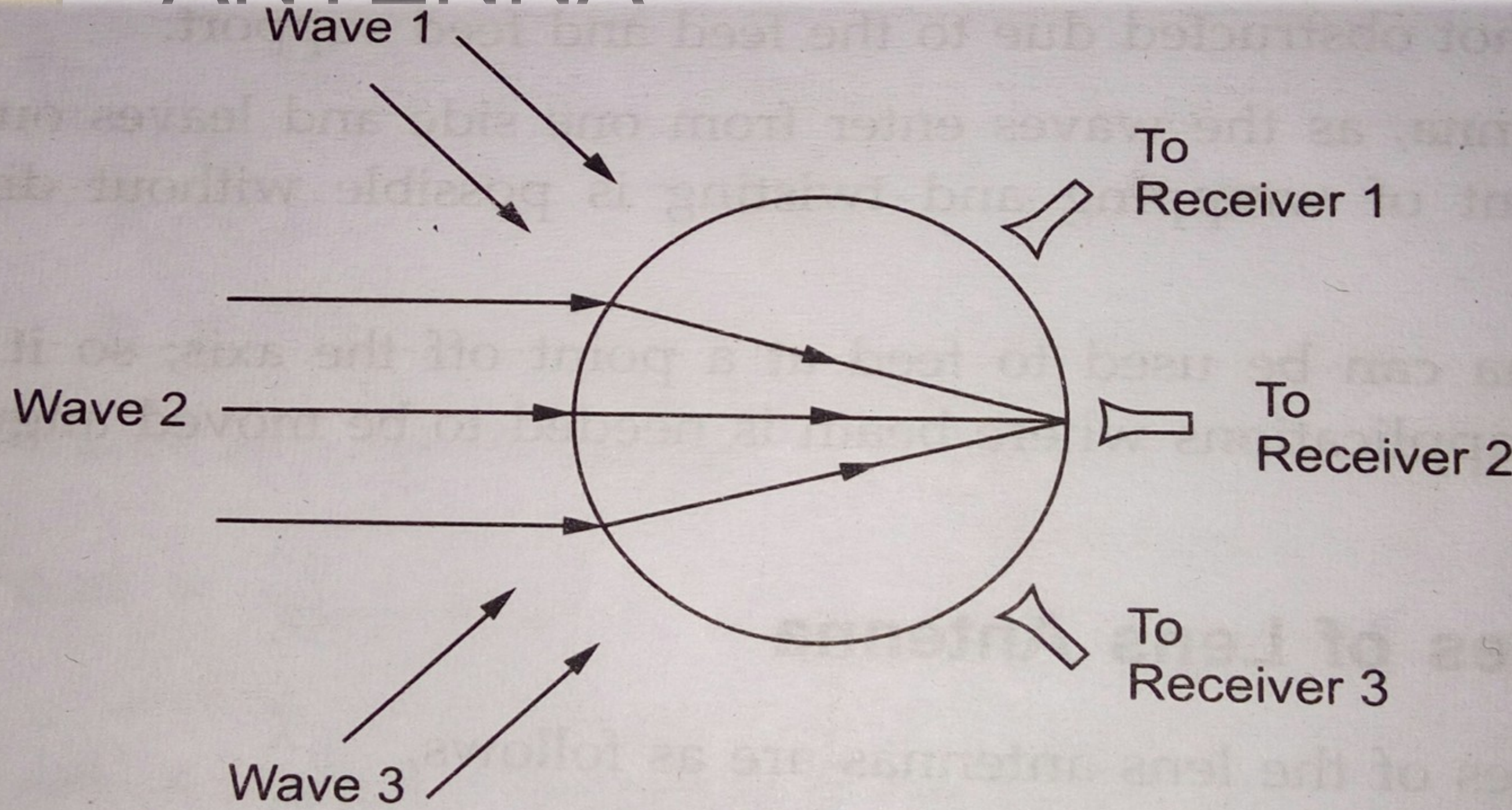


Fig. 7.16 Luneburg lens

EINSTEN'S GRAVITY LENS

The incident electromagnetic waves passing around stars are deflected through an angle which is proportional to mass of the star and then they brought into focus on the far side this is know as **Einsten's gravity lens**

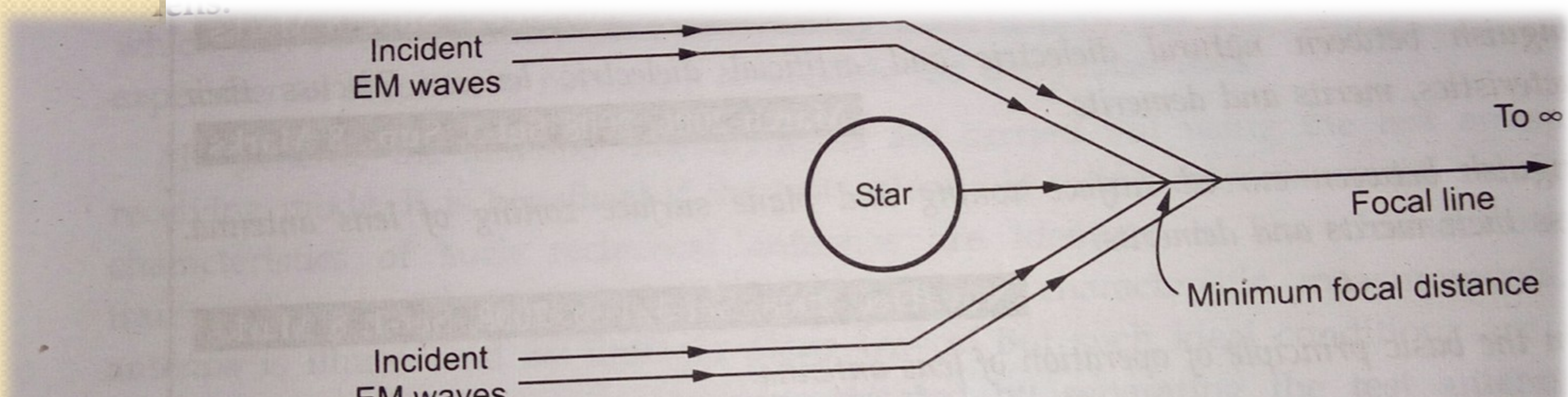
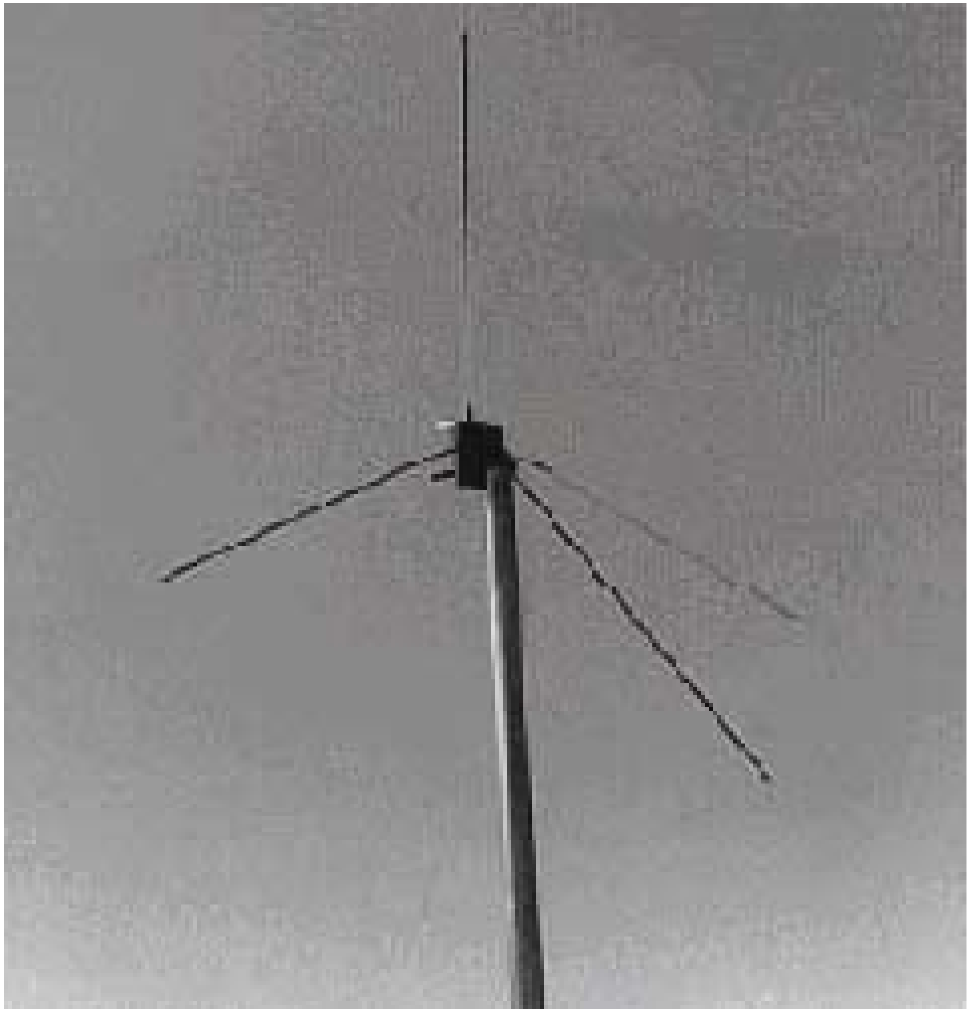


Fig. 7.17 Einstein's gravity lens

Antenna Arrays & Measurements

Assignment



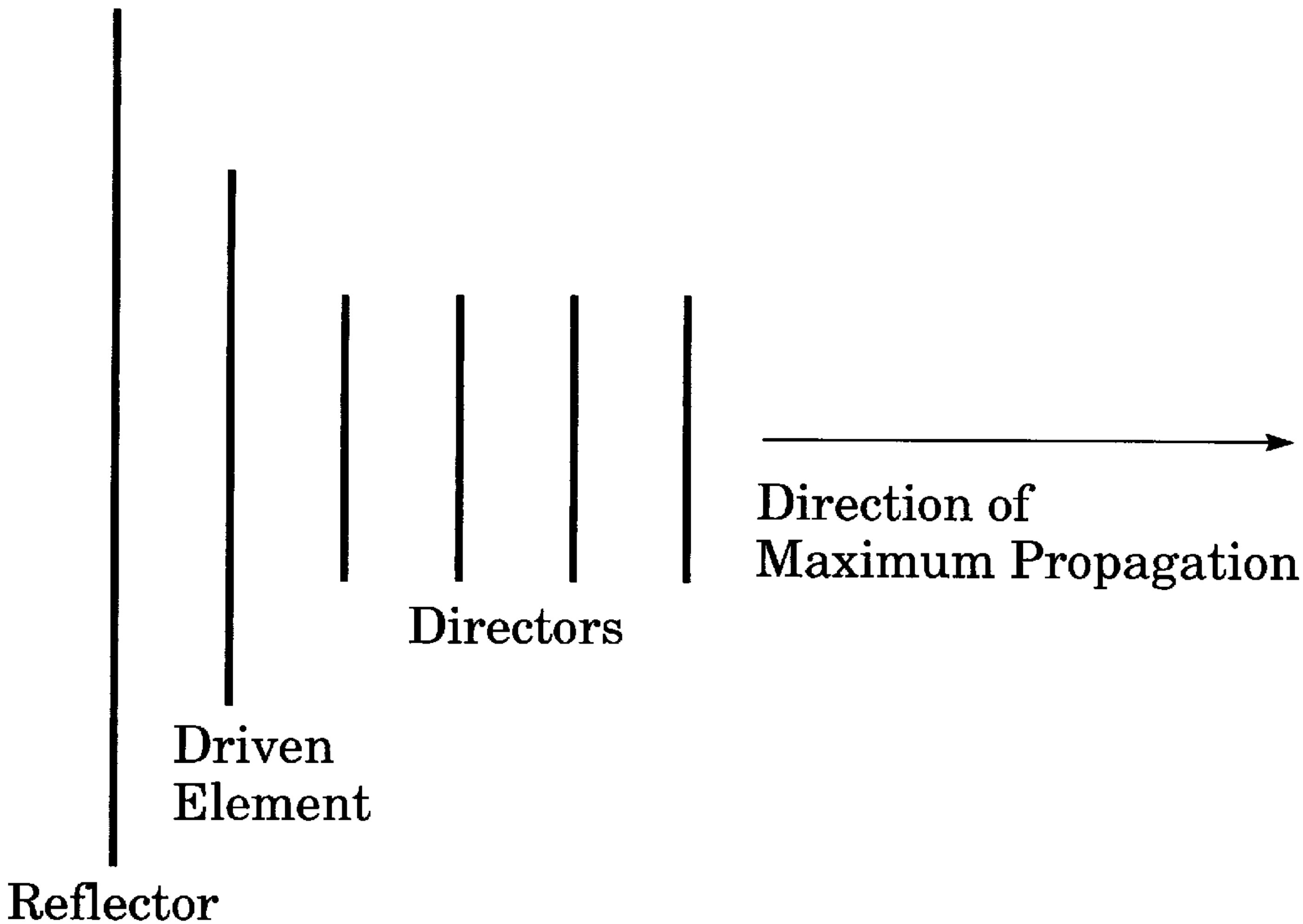
Broadside Array

- Bidirectional Array
- Uses Dipoles fed in phase and separated by 1/2 wavelength

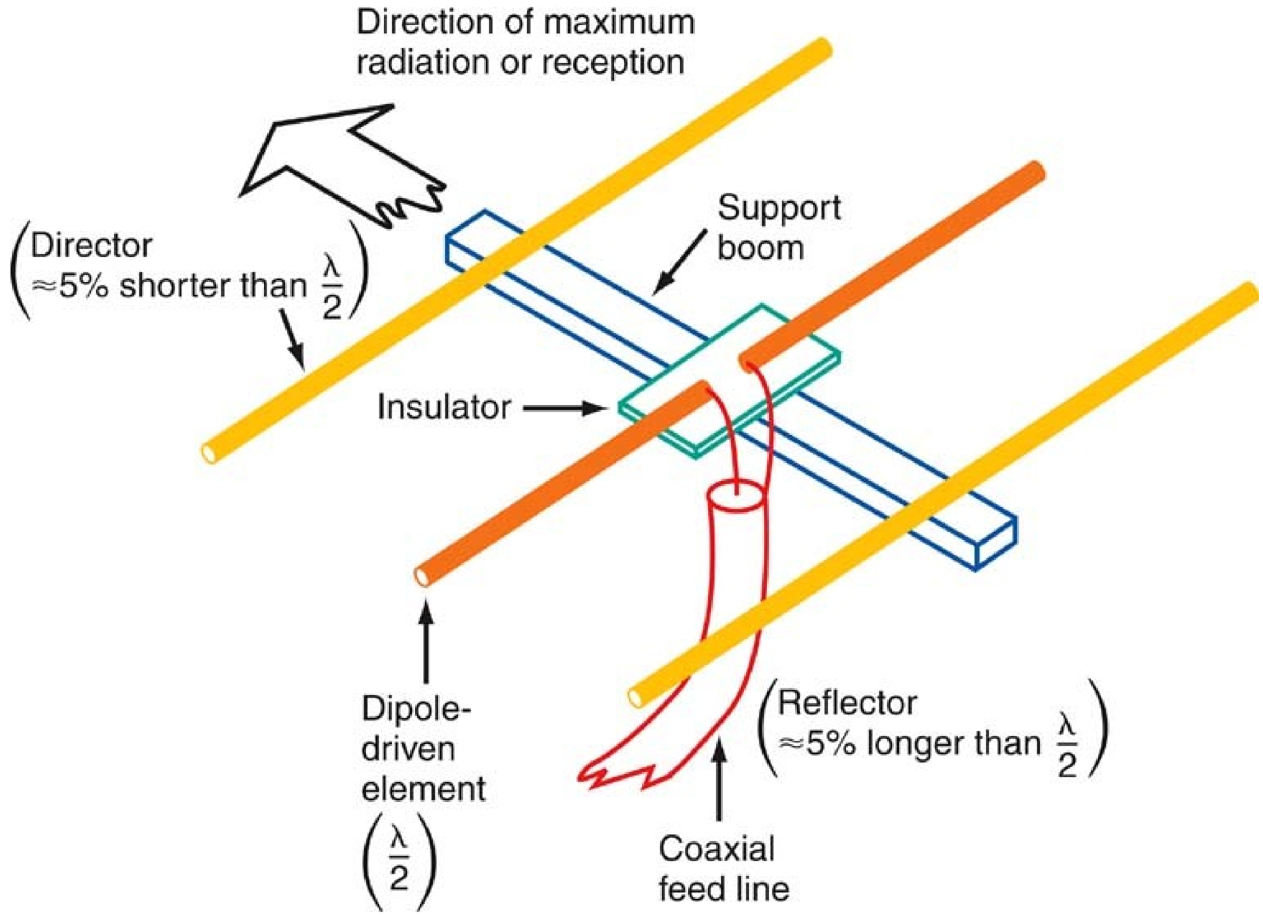
Broadside Antenna

- A **broadside array** is a stacked collinear antenna consisting of half-wave dipoles spaced from one another by one-half wavelengths.
- This antenna produces a highly directional radiation pattern that is broadside or perpendicular to the plane of the array.
- The broadside antenna is bidirectional in radiation, but the radiation pattern has a very narrow beam width and high gain.

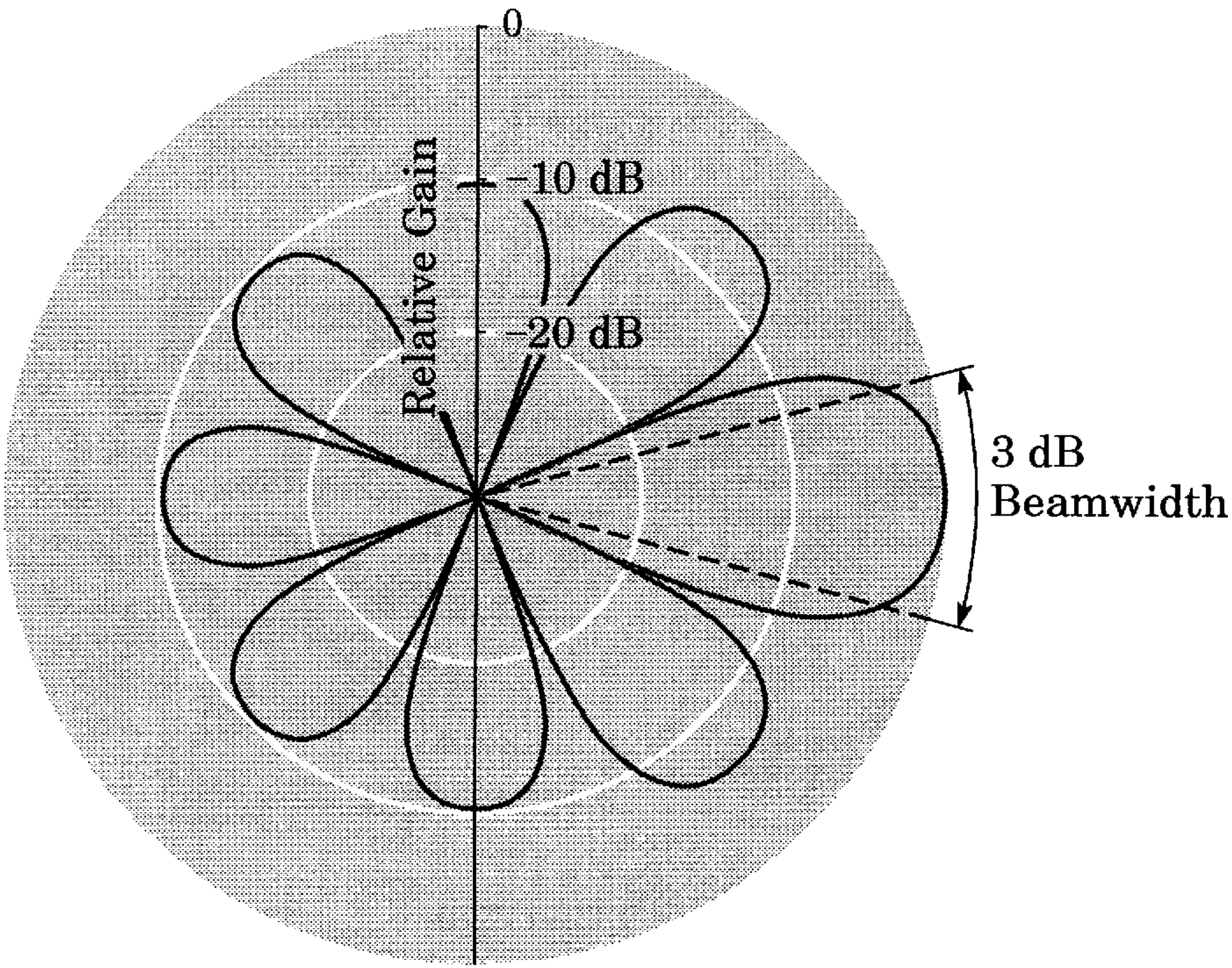
Yagi Array



Transparency 236 (Figure 18.25)


Direction of maximum radiation or reception
Director
≈5% shorter than $\frac{\lambda}{2}$
Support boom
Insulator
Dipole-driven element
$\left(\frac{\lambda}{2}\right)$
Reflector
≈5% longer than $\frac{\lambda}{2}$
Coaxial feed line

Radiation Pattern for Eight-Element Yagi



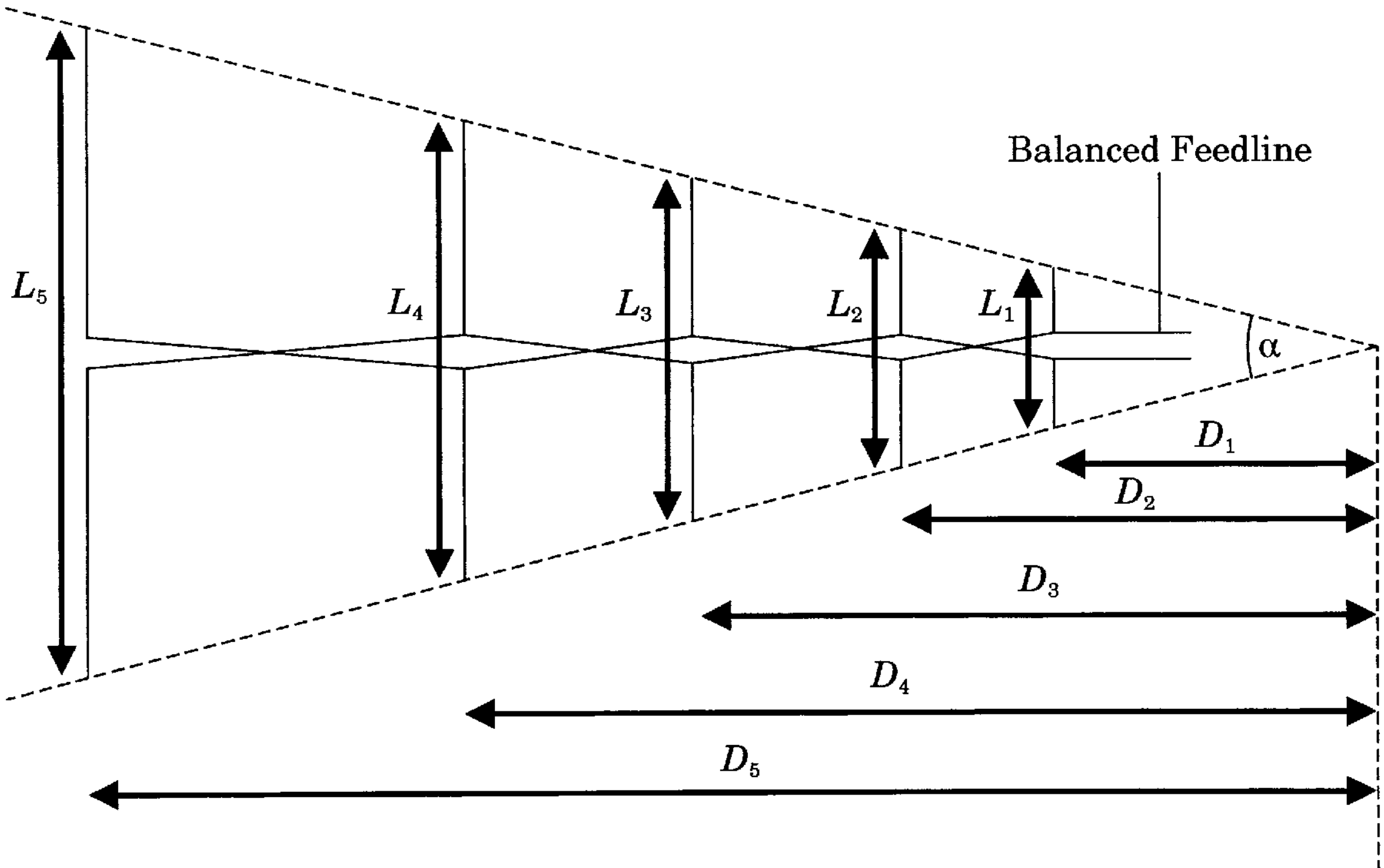
Transparency 237 (Figure 18.26)

UHF-TV Antenna: Yagi with Corner Reflector

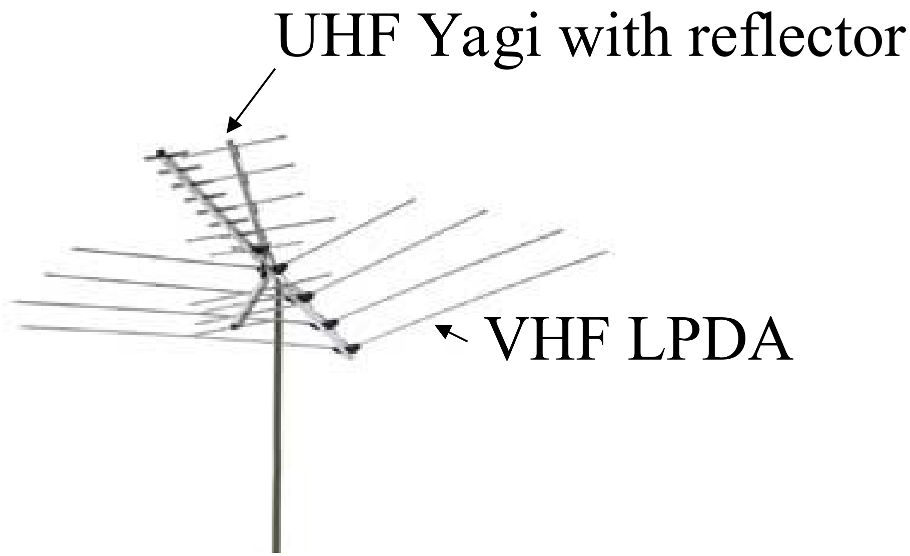
Log-Periodic Dipole Array

- Multiple driven elements (dipoles) of varying lengths
- Phased array
- Unidirectional end-fire
- Noted for wide bandwidth
- Often used for TV antennas

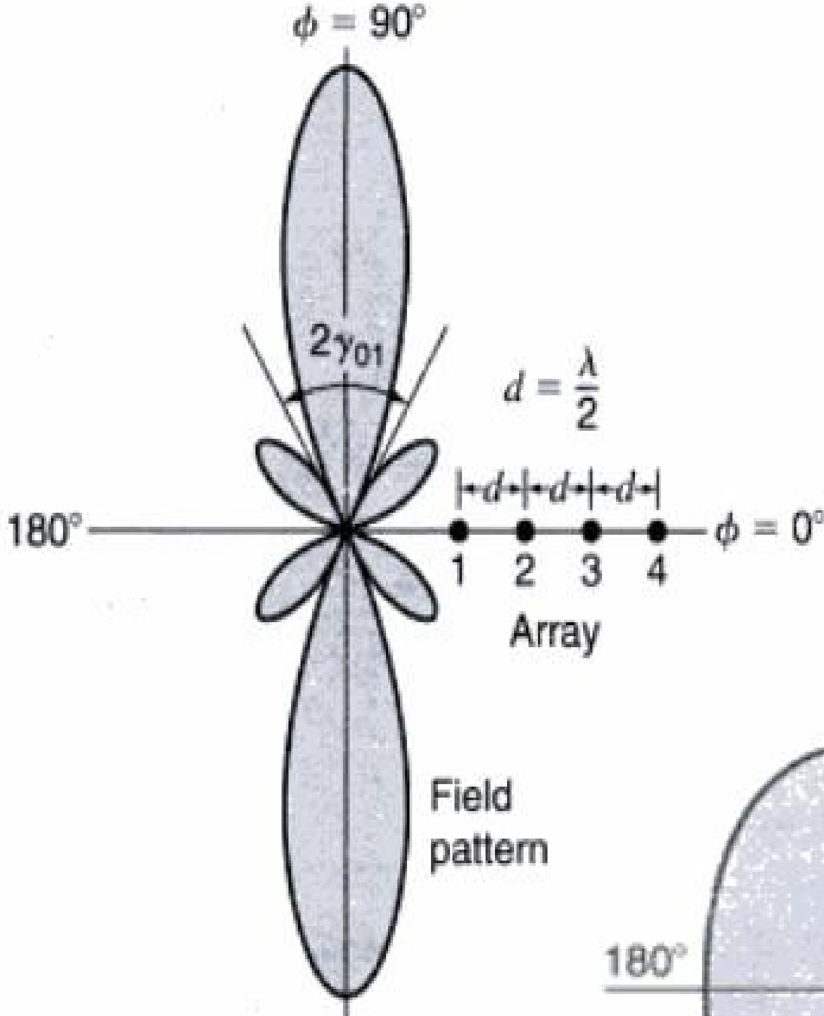
Log-Periodic Dipole Array



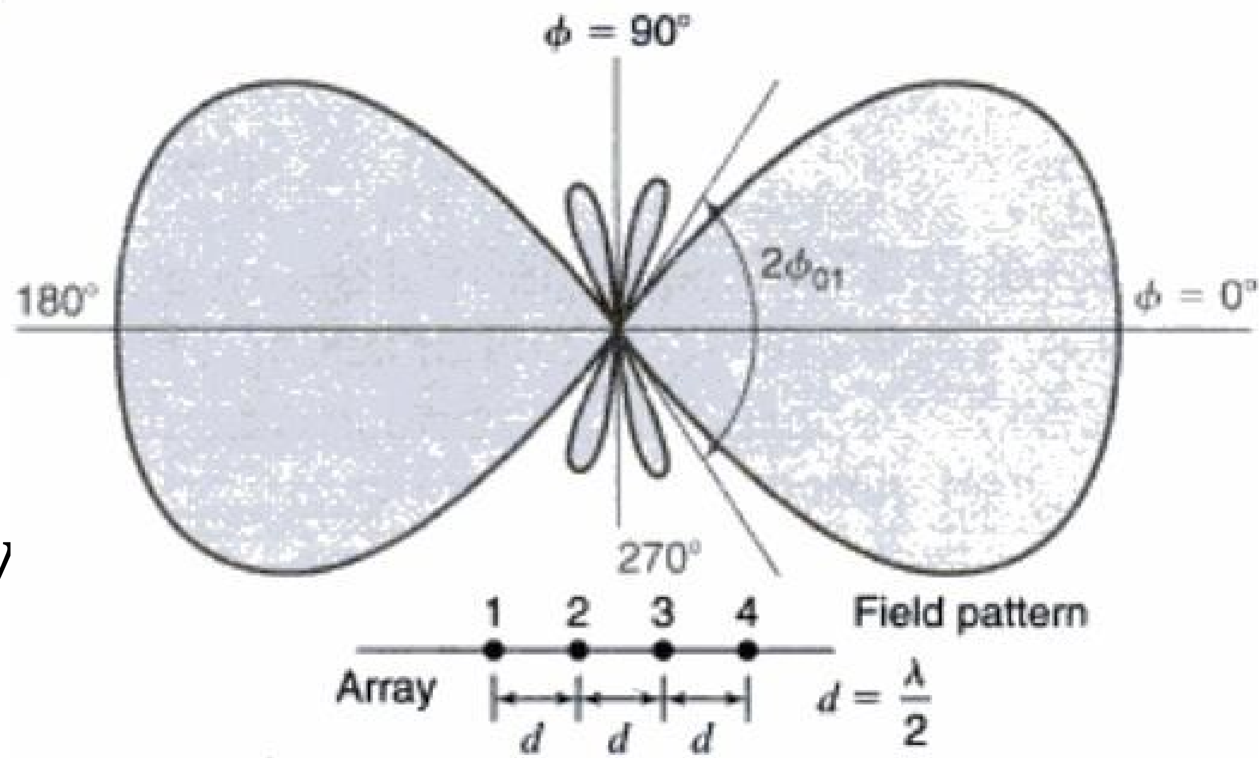
Transparency 238 (Figure 18.27)



VHF/UHF TV Antenna



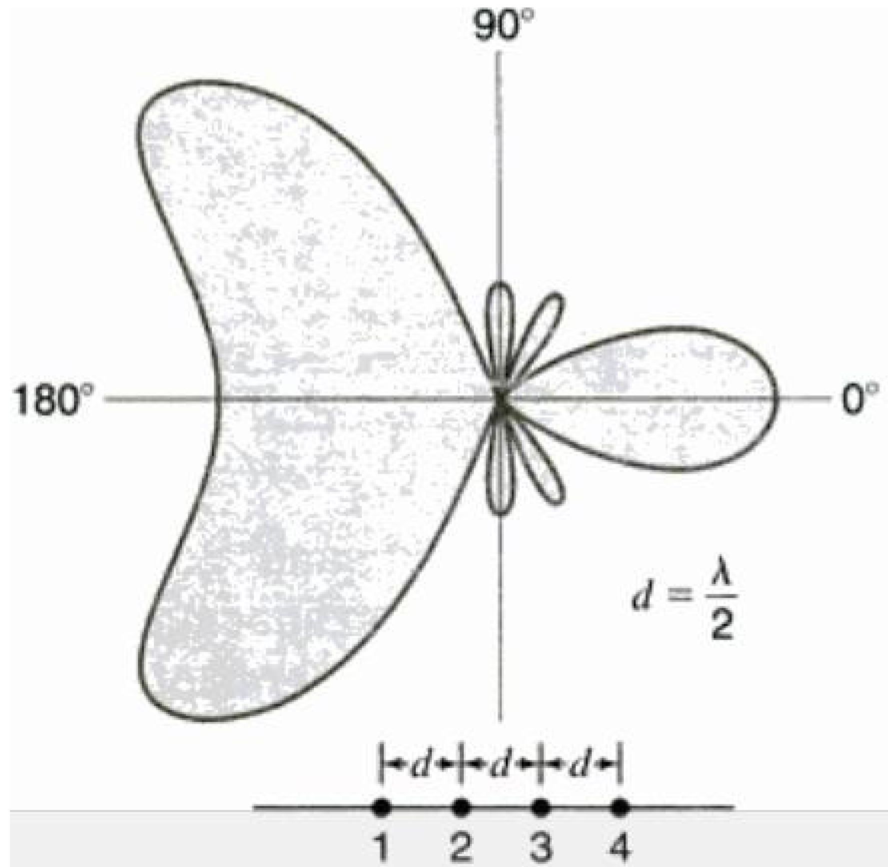
Broad side type of array



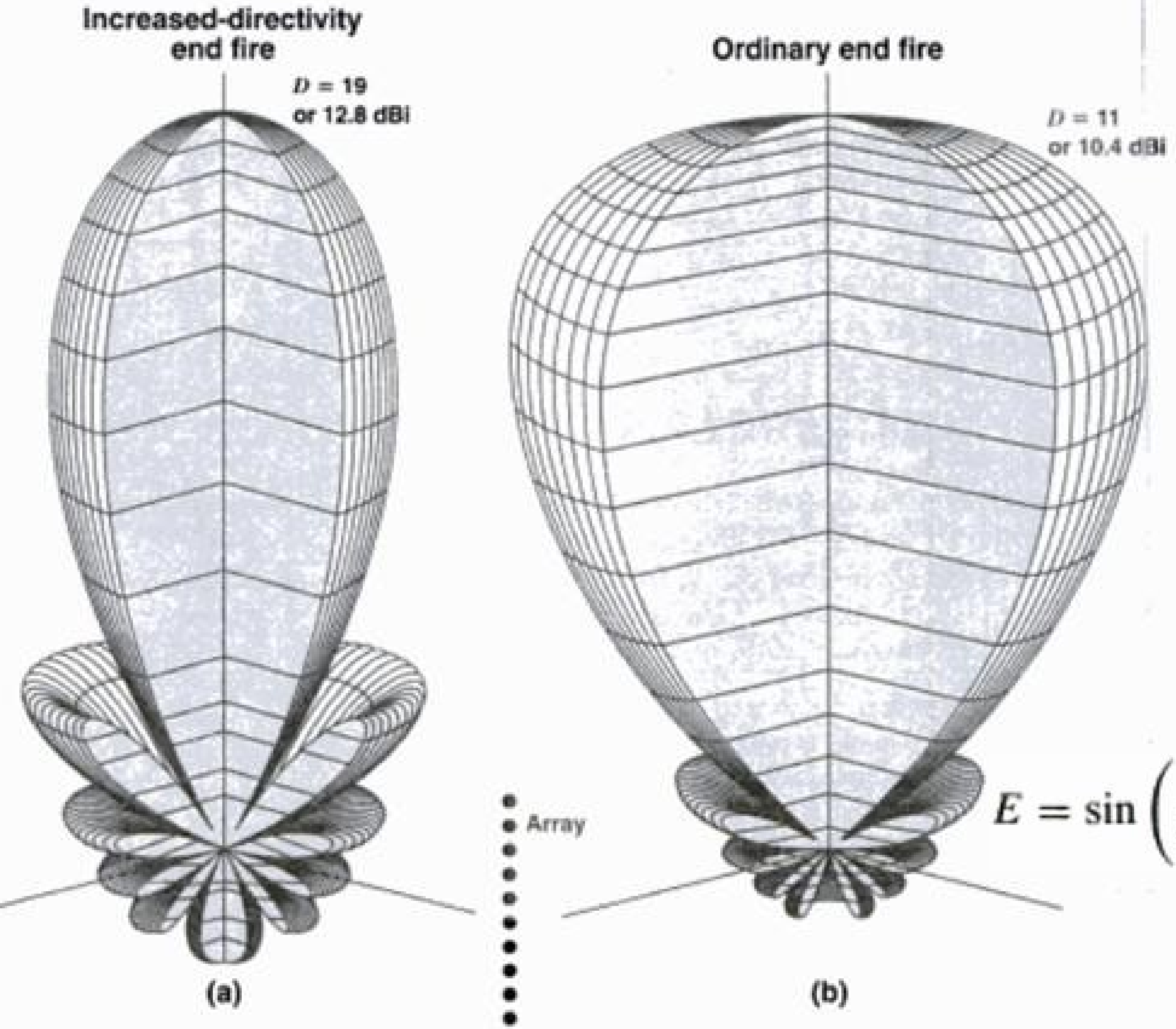
- Endfire

Type of array

- Endfire with increased directivity



Phase shift 180° (0.6π) versus 90° (0.5π)



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

End-Fire Array

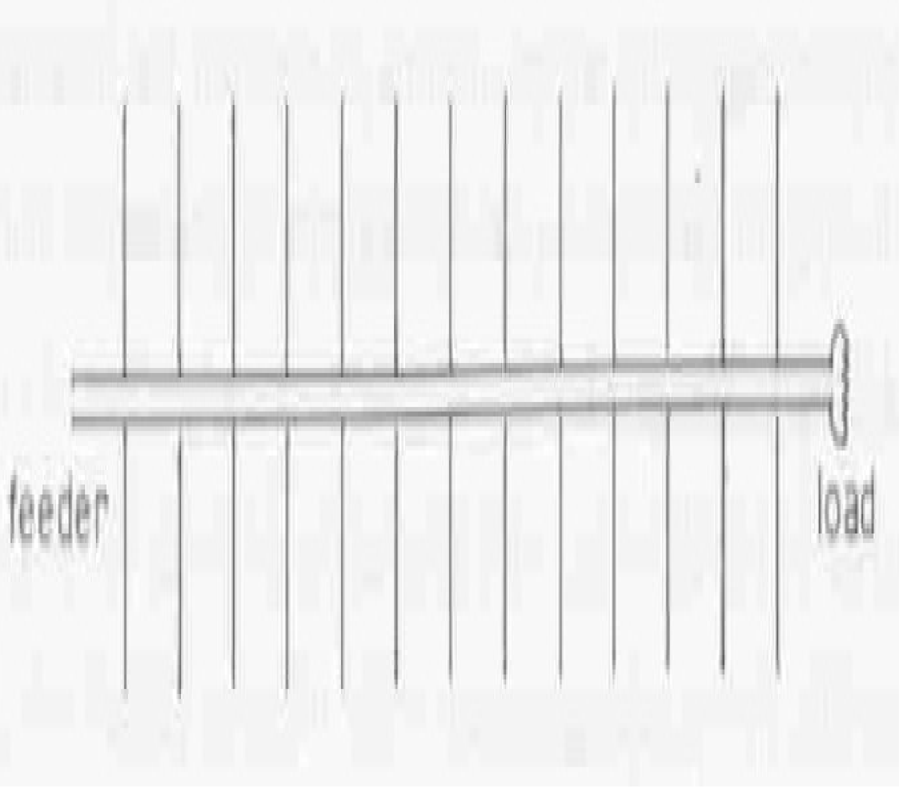
- Similar to broadside array except dipoles are fed 180 degrees out of phase
- Radiation max. off the ends

End-Fire Antenna

- The **end-fire array** uses two half-wave dipoles spaced one-half wavelength apart.
- The end-fire array has a bidirectional radiation pattern, but with narrower beam widths and lower gain.
- The radiation is in the plane of the driven elements.
- A highly unidirectional antenna can be created by careful selection of the optimal number of elements with the appropriately related spacing.

End-fire Arrays

- Higher directivity.
- Provide increased direct
  elevation and azimuth pl
- Generally used for recep
- Impedance match difficu
  high power transmission
- Variants are:
  - Horizontal Array of Di
  - RCA Fishborne Anten
  - Series Phase Array



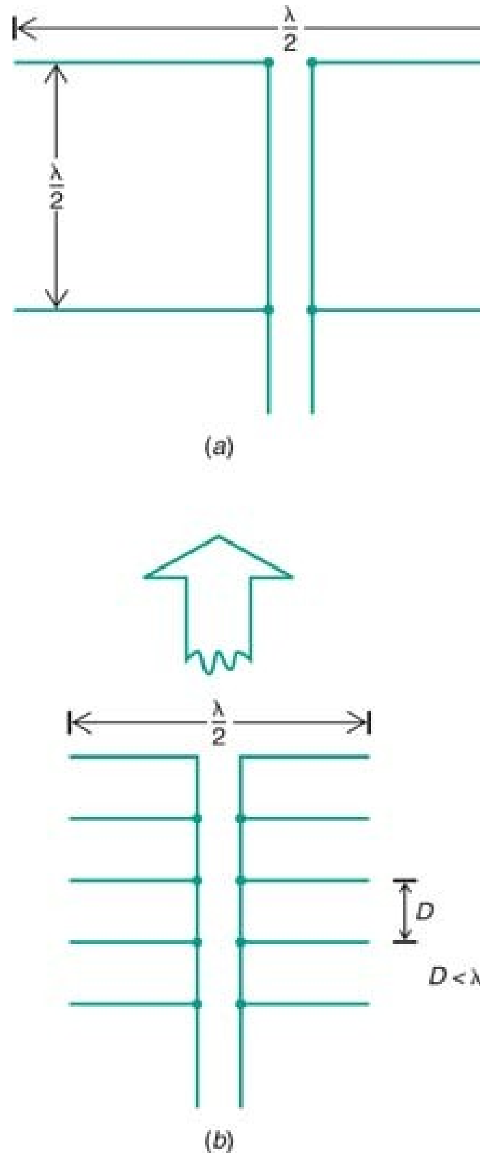
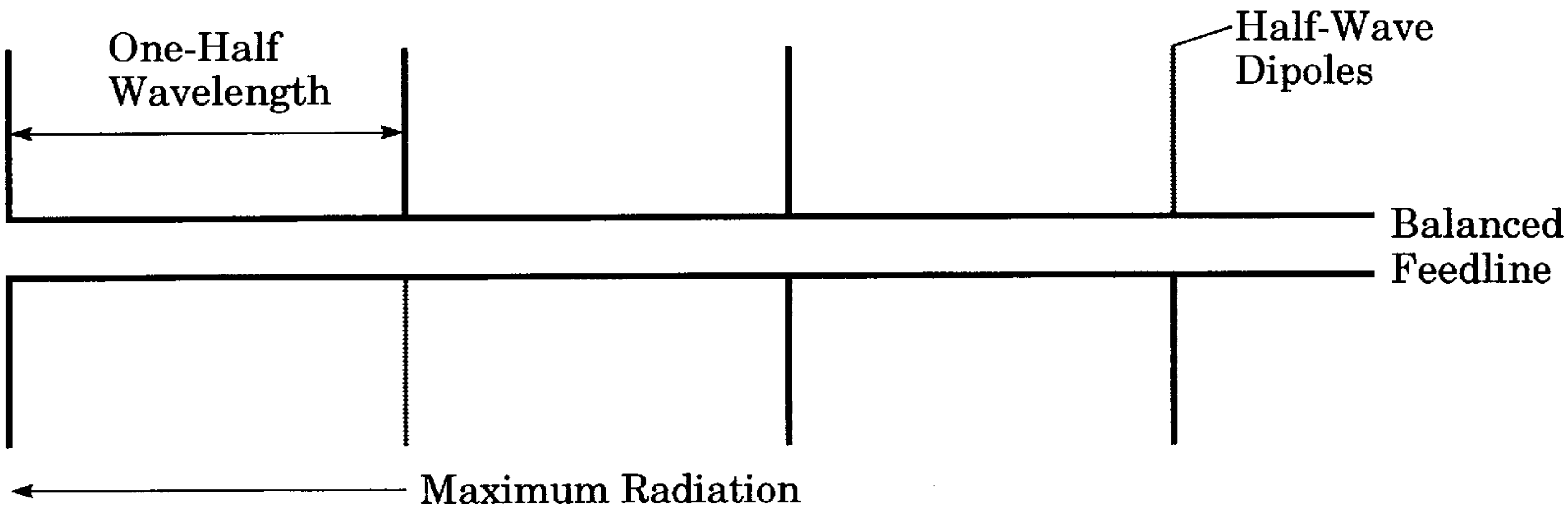


Figure : End-fire antennas. (*a*) Bidirectional. (*b*) Unidirectional.

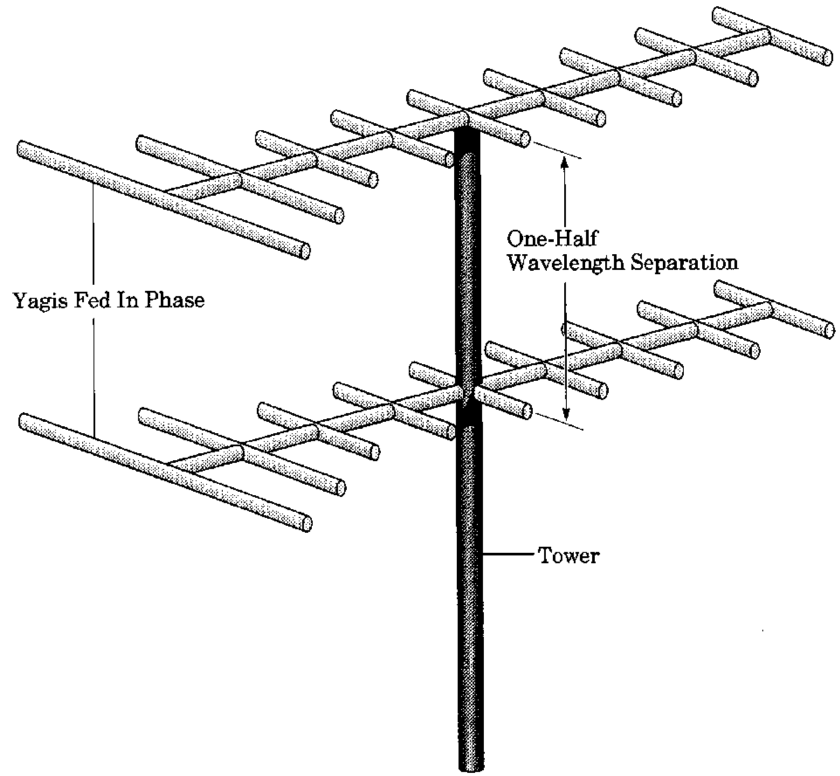
End-Fire Array



Stacked Yagis

- Stacking in-phase Yagis with half-wavelength vertical spacing
- Reduces radiation above and below horizon
- Increases gain in plane of the antenna

Stacked Yagis

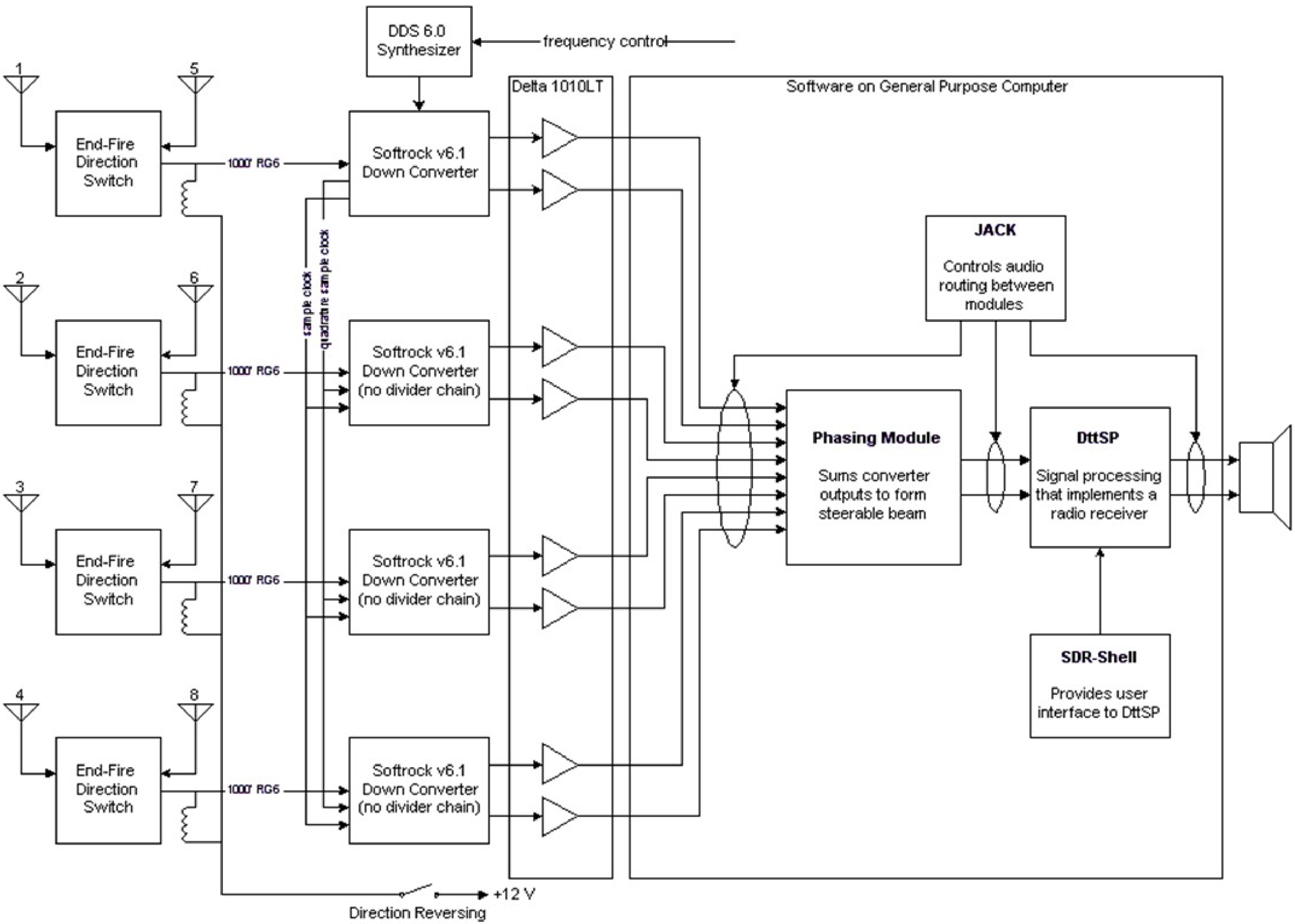


Transparency 246 (Figure 18.36)

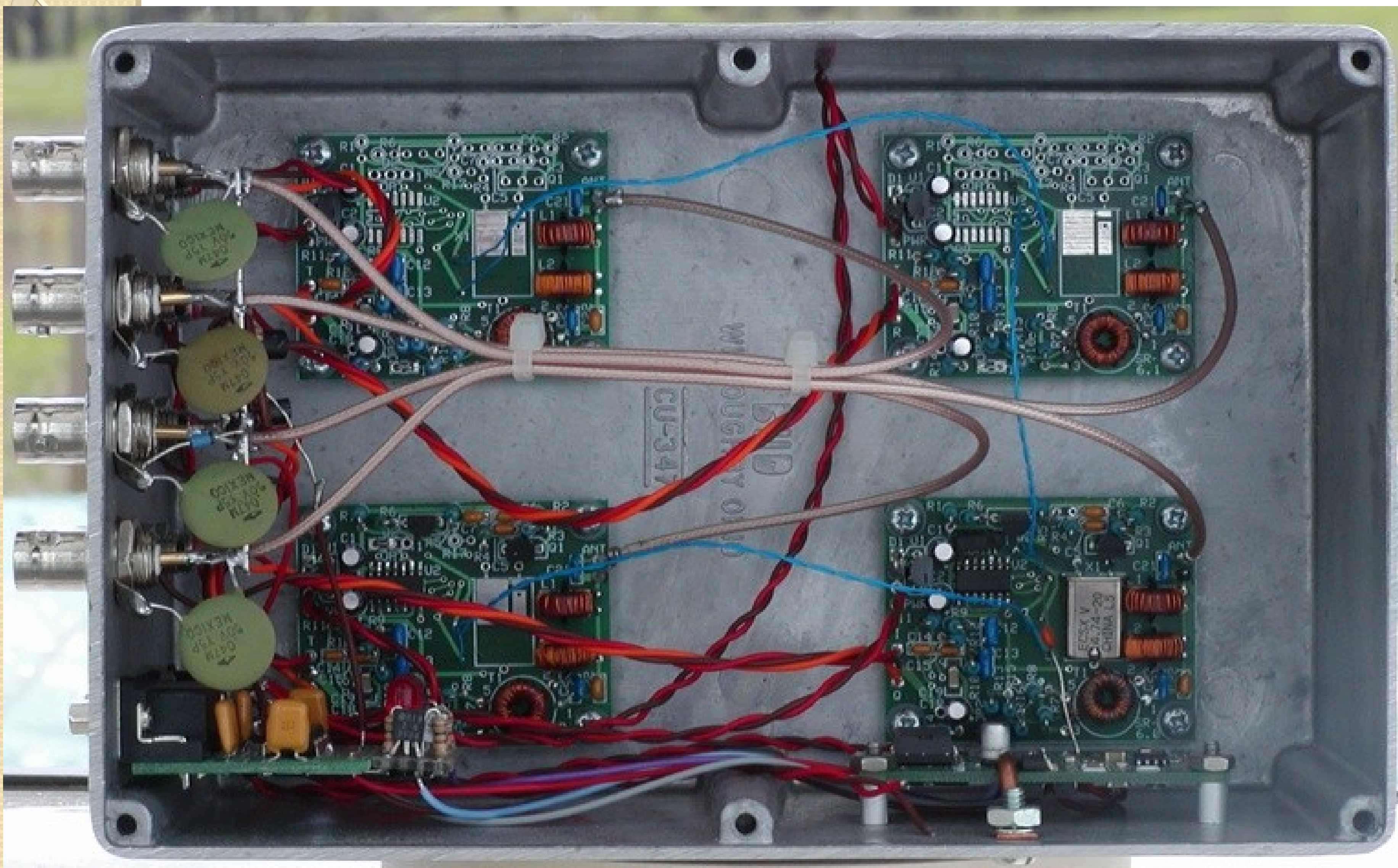
End-Fire Reversing Switch

- Decouples relay power from feedline
- First transformer inverts signal from east vertical
- Second transformer converts 37Ω to 75Ω
- Phasing specs from ON4UN’s book

8 Element Electronic Beam Steering Phased Array Antenna



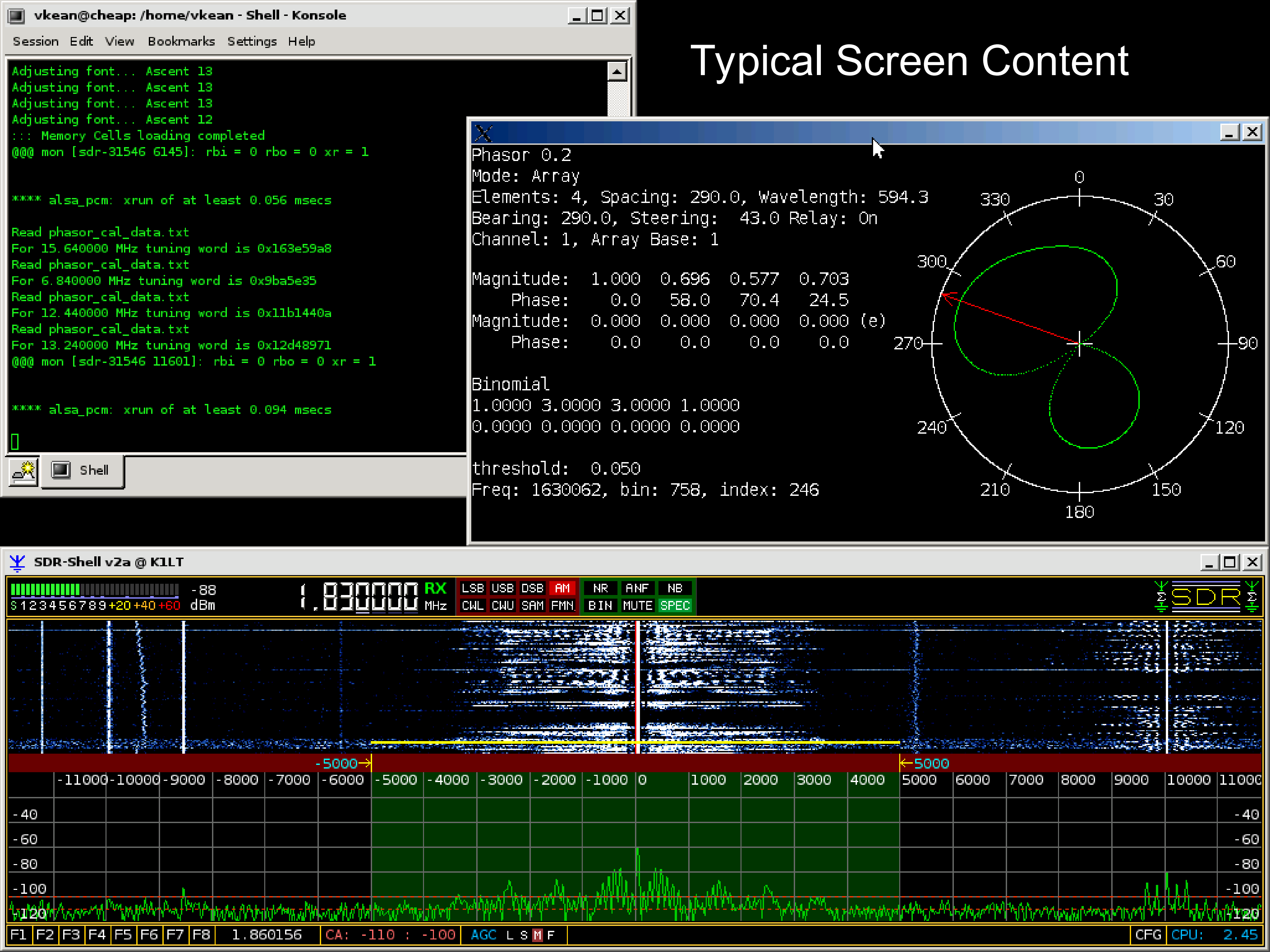
Softrock v6 Receivers & DDS 6.0 VFO



Calibration is Annoying

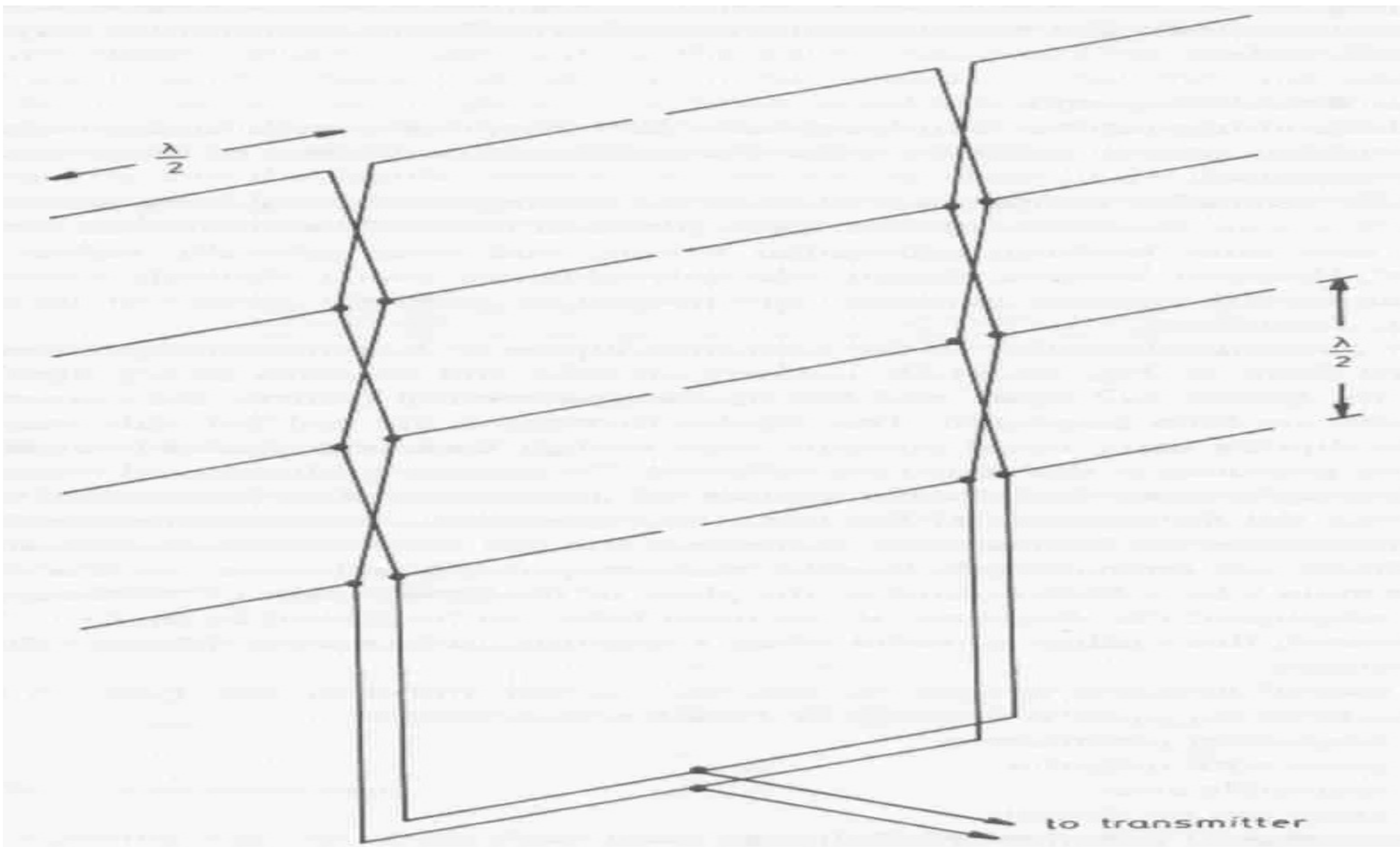
- Softrock input filter very inconsistent
- Antennas vary despite careful tuning
- Calibration accommodates inconsistency
- Use of off-site signal best calibration strategy
- In-shack calibration source seems almost good enough

Typical Screen Content



Broadside Arrays

Beam steering by phase variation is possible.



Transmission impairments

14-3: Radio-Wave Propagation

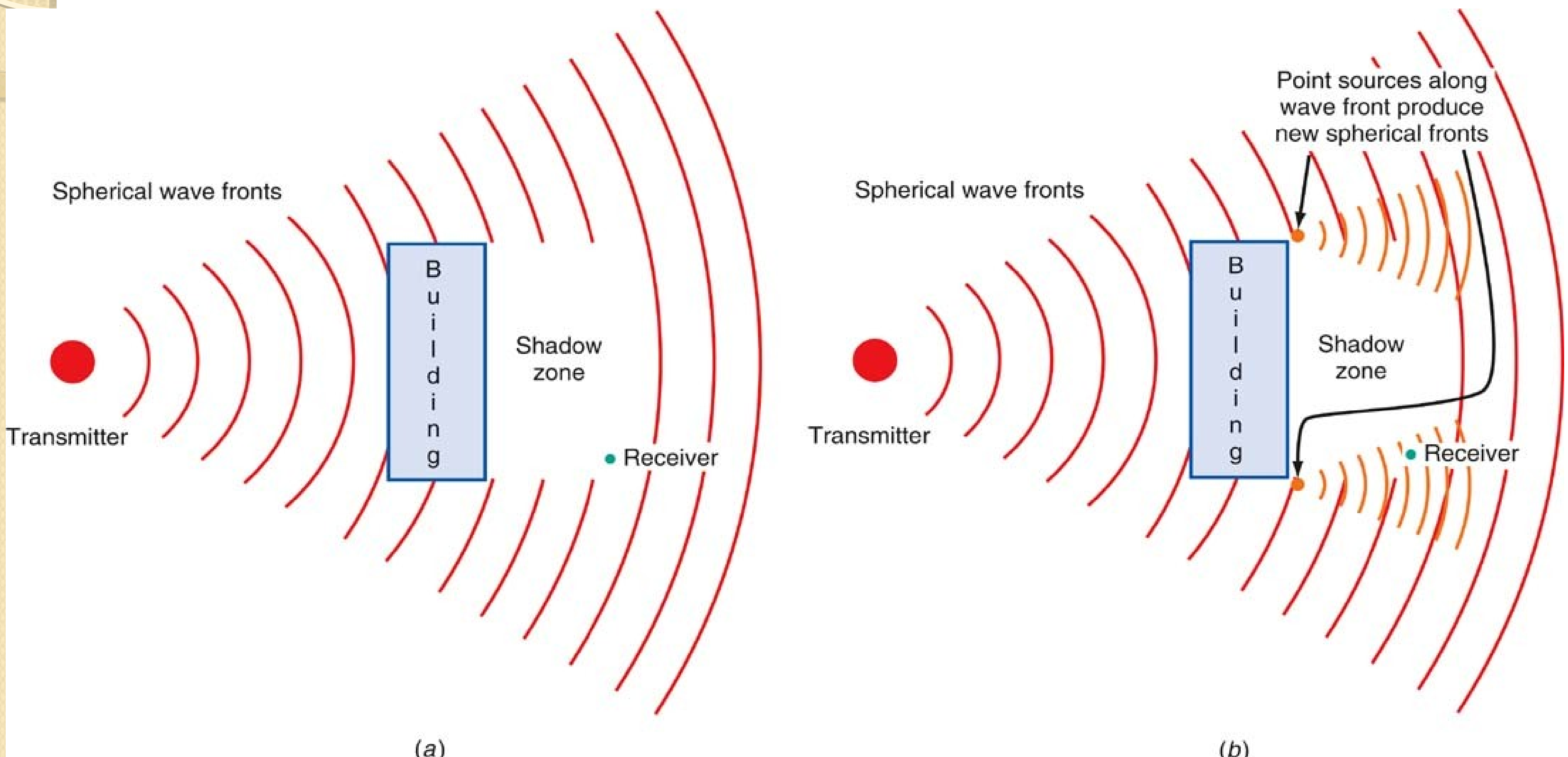
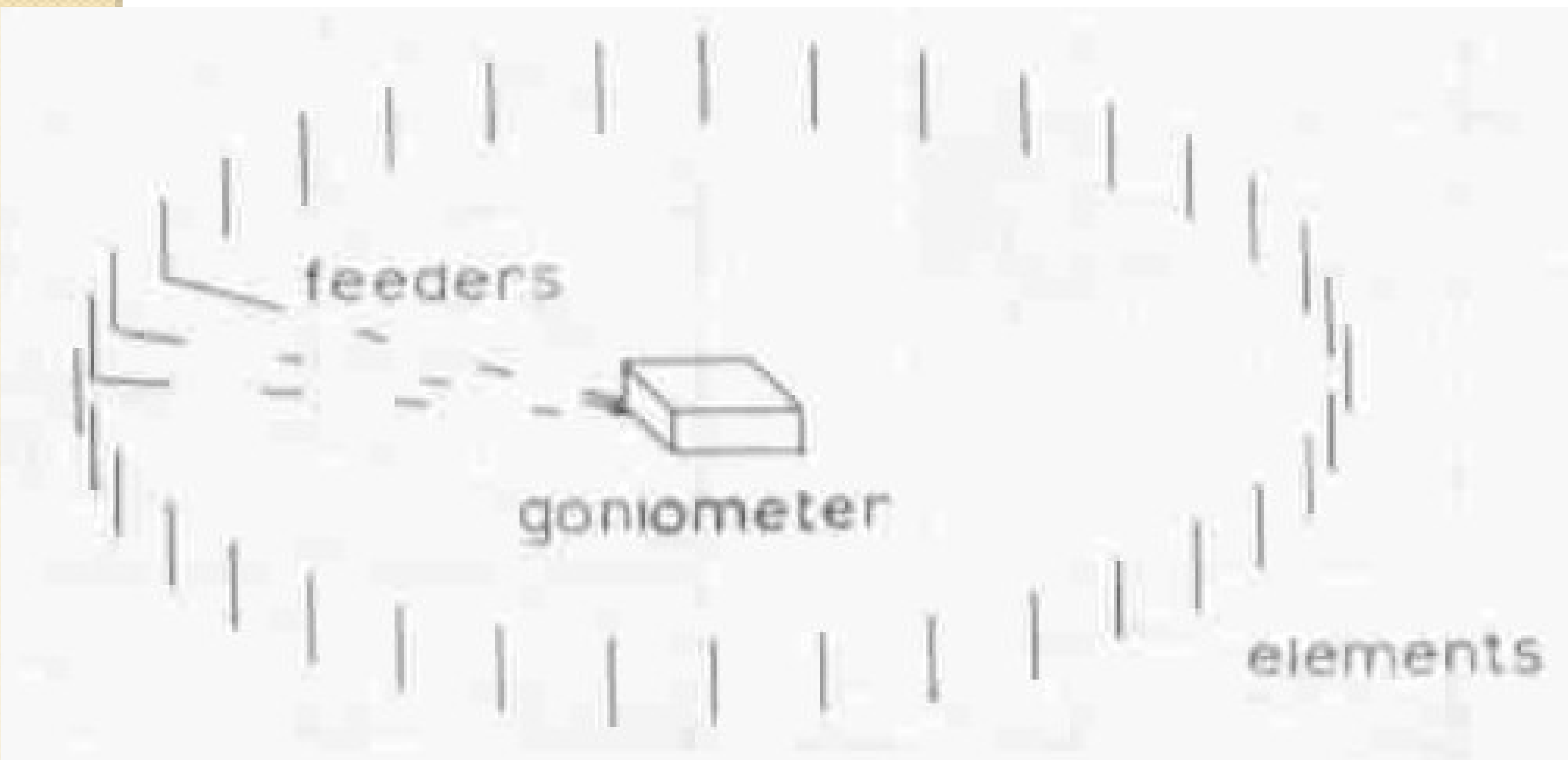


Figure : Diffraction causes waves to bend around obstacles.

Circular Arrays

- Used for direction finding.
- Consists of 30 – 100 elements, with equi-spaced and fed from a central source – goniometer.
- Band-width seperation is possible:



UNIT-V
Wave Propagation

The Ionosphere

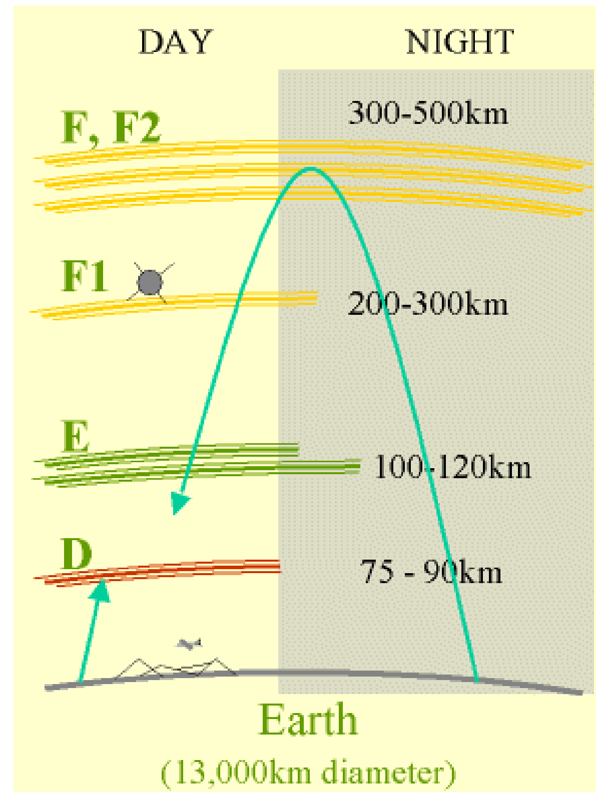
- Regions
  - Ionosphere
    - The region of the atmosphere extending from 30 miles to 300 miles above the surface of the earth
    - Solar radiation causes atoms in the ionosphere to become ionized
      - Electrons freed up, resulting in weak conduction

The Ionosphere

- Regions
  - Ionosphere
    - The ionosphere organizes itself into regions or "layers"
      - Varies with amount of ionization
        - D-region disappears at night
        - E-region is like D and disappears at night
        - F-region composed of F_1 and F_2 regions during the day; re-combines at night

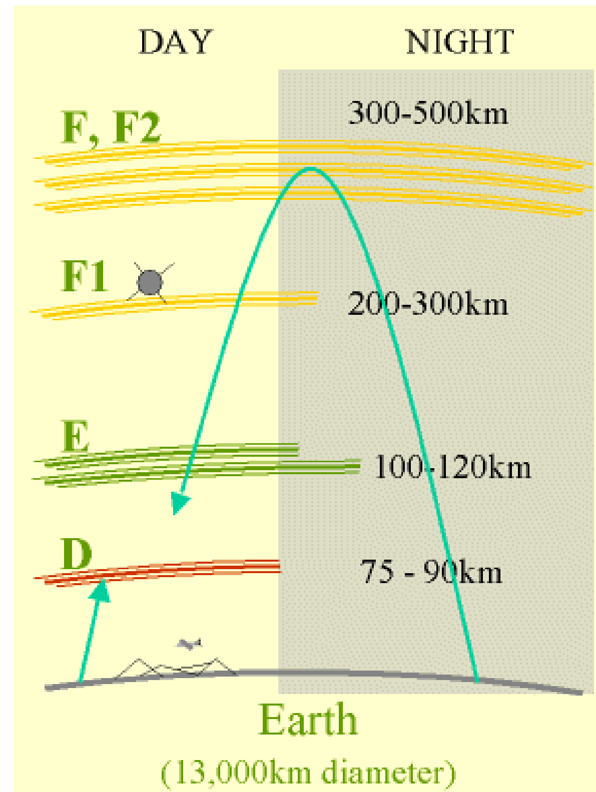
The Ionosphere

- Regions
  - D-Layer
    - 30-60 miles altitude
    - Rapidly disappears at Sunset
    - Rapidly re-forms at Sunrise
    - Absorbs long wavelength radio waves
      - 160m, 80m, and 40m generally unuseable during the day



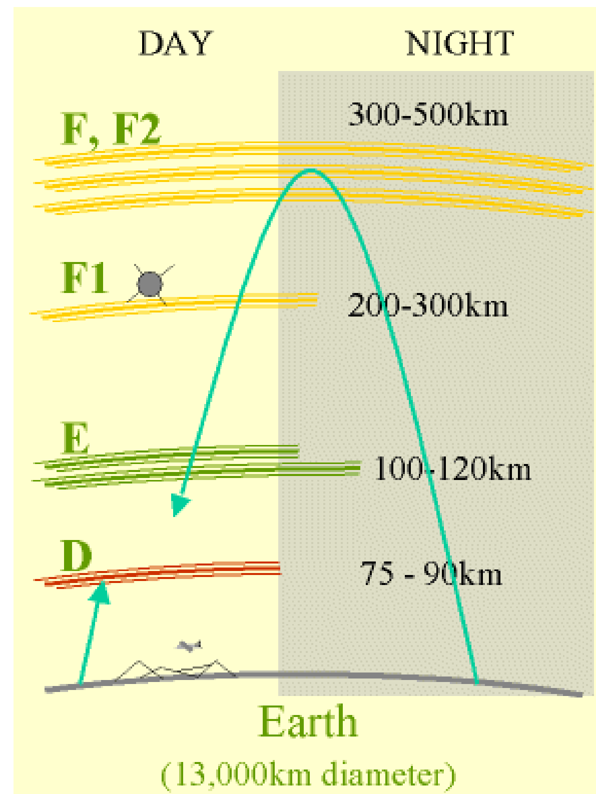
The Ionosphere

- Regions
  - E-Layer
    - 60-70 miles altitude
      - One hop up to 1,200 miles
    - Acts similar to D-layer
      - Lasts longer into the night
      - Less absorption during the day
    - Enables auroral propagation at northern latitudes
    - Sporadic-E skip
      - 10m, 6m, and 2m



The Ionosphere

- Regions
  - F-Layer
    - 100-300 miles altitude
      - One-hop up to 2,500 miles
    - Can remain partially ionized at night
    - Splits into F1 and F2 layer during the day
      - F1 layer = 100-140 miles.
      - F2 layer = 200-300 miles.
    - Long-range HF propagation

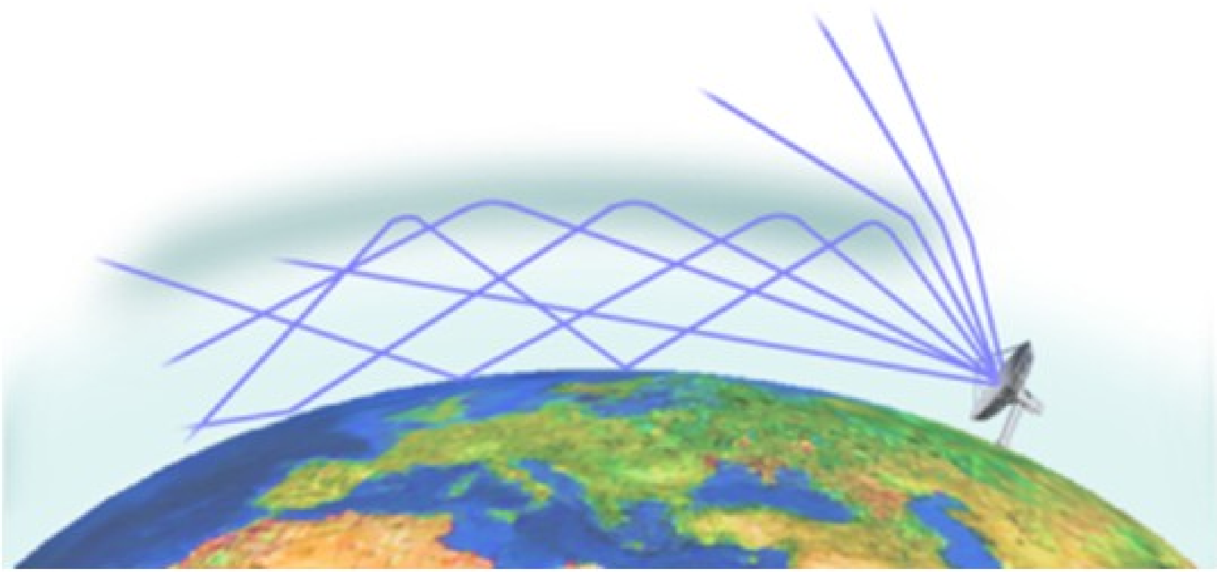


The Ionosphere

- Diffraction, Refraction, Reflection, Absorption
  - Diffract: To alter the direction of a wave as it passes by the edges of obstructions
  - Reflect: Bouncing of a wave after contact with a surface
  - Refract: Bending of wave as it travels through materials having different properties (e.g., densities)
  - Absorption: Dissipation of energy of a wave as it travel through a medium

The Ionosphere

- Refraction
  - Radio waves are refracted (bent) by the ionosphere



The Ionosphere

- Refraction
  - Radio waves are refracted (bent) in the ionosphere
    - The stronger the ionization, the more the waves will be bent
    - The higher the frequency (shorter wavelength), the less the waves will be bent
    - VHF and UHF are only slightly bent and almost never enough to return Earth

The Ionosphere

- Refraction
  - Critical angle
    - Maximum angle at which radio waves are bent enough to return to earth for a given frequency
    - Critical angle decreases with increasing frequency
    - One reason why a low angle of radiation is important for working DX

The Ionosphere

- Refraction
  - Critical frequency
    - The highest frequency at which radio waves sent straight up are bent enough to return to earth
    - Higher frequencies “escape”

The Ionosphere

- Absorption
  - Atmosphere is denser at lower altitudes, causing part of the RF energy to be absorbed
    - The lower the frequency (longer wavelength), the higher the absorption

The Ionosphere

- Absorption
  - D-region
    - Almost no refraction (bending) of radio waves
    - Region almost completely absorbs radio waves below 10 MHz
  - E-region
    - More refraction than D-region
    - Less absorption than D-region

The Ionosphere

- Sky Wave and Ground Wave Propagation
  - Sky Wave
    - Refracting radio waves back to earth using the ionosphere, i.e., skip
    - Each trip from Earth to ionosphere and back to Earth is a “hop”
    - Multiple hops are common
    - The higher the region used, the longer the hop

The Ionosphere

- Sky-Wave and Ground-Wave Propagation
  - Sky-Wave
    - Maximum distance of a single hop depends on altitude of the region where refraction takes place
      - E-region: Single hop can be up to 1,200 miles
      - F-region: Single hop can be up to 2,500 miles

The Ionosphere

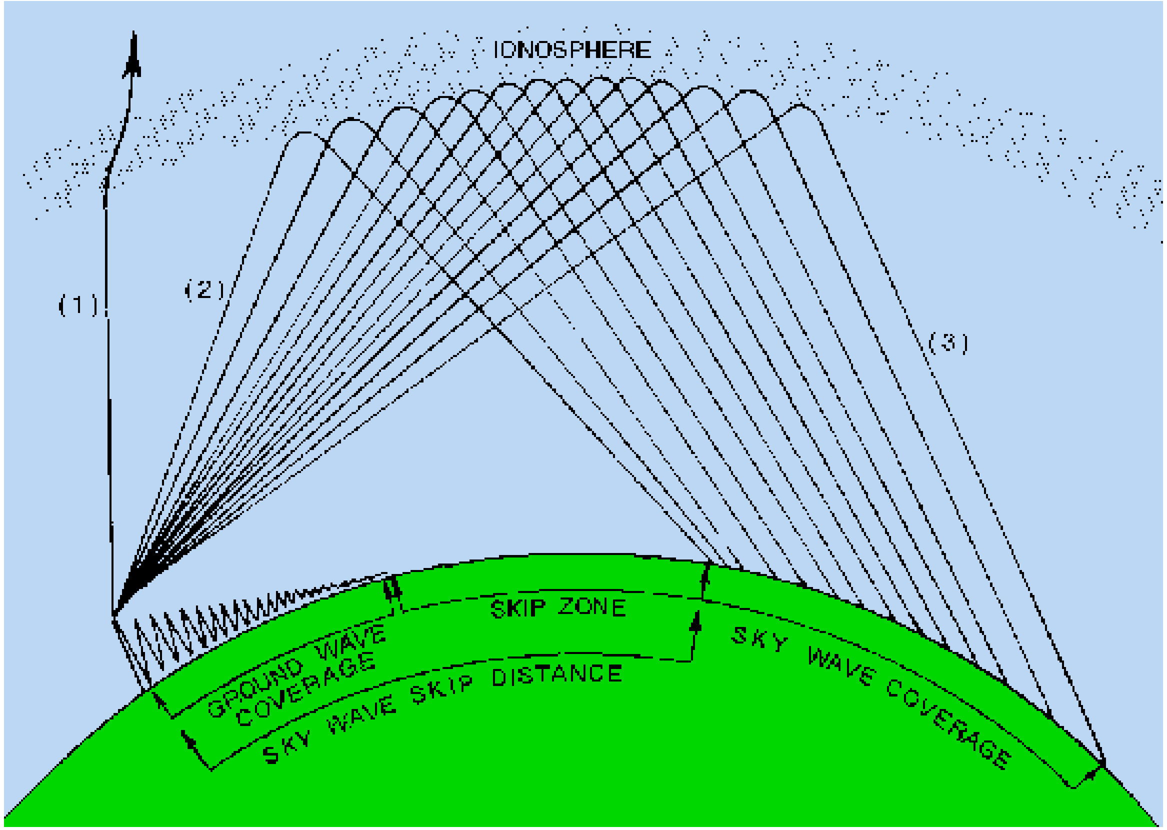
- Sky-Wave and Ground-Wave Propagation
  - Ground-Wave
    - Radio waves can travel along the surface of the earth
      - Primarily vertically polarized
      - Losses due to Earth’s surface cause rapid decrease of signal strength as distance from antenna increases
        - The higher frequency, the greater the loss

The Ionosphere

- Sky-Wave and Ground-Wave Propagation
  - Skip distance
    - Distance from transmitter where refracted radio wave first returns to earth
  - Skip zone
    - Zone between the end of the ground wave and where the sky-wave returns to earth

The Ionosphere

- Sky-Wave and Ground-Wave Propagation



The Ionosphere

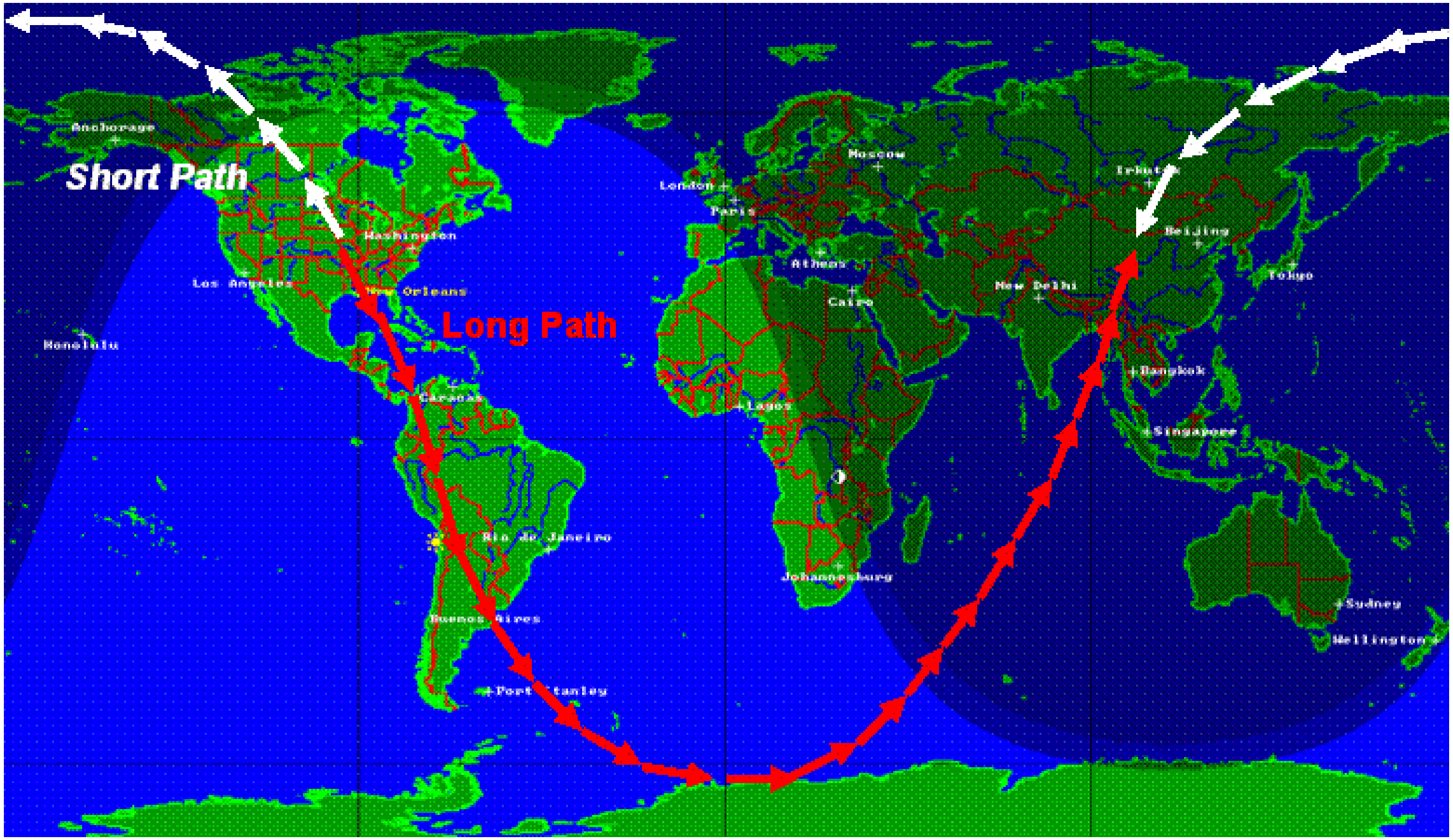
- Long Path and Short Path
  - Short path
    - Direct route between stations
    - Shortest distance
    - More common path
  - Long path
    - 180° back azimuth from short path
    - Longer distance

The Ionosphere

- Long Path and Short Path
  - Conditions may not support short path, but long path may be possible
  - Echo indicates both short and long paths are “open”

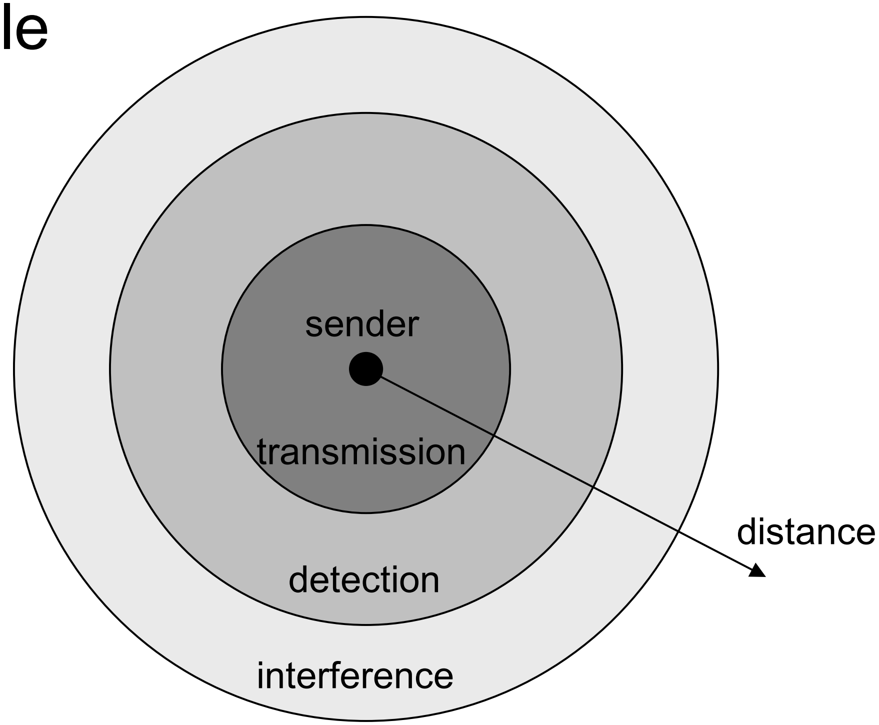
The Ionosphere

- Long Path and Short Path



Signal Propagation Ranges

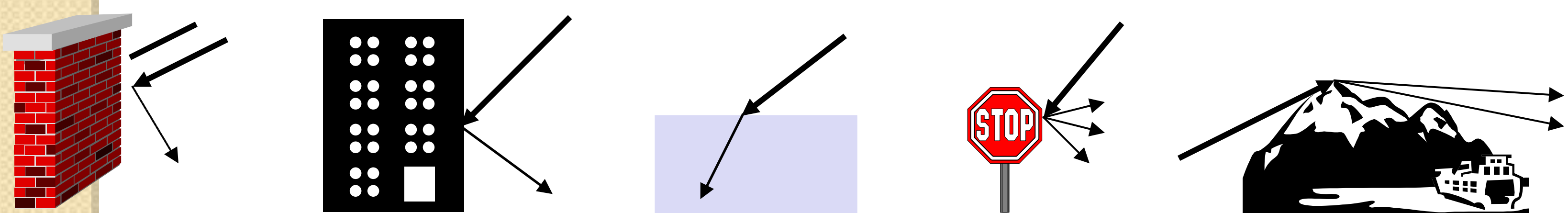
- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - communication not possible
- Interference range
  - signals may not be detected
  - signals add to the background noise



Note: These are **not** perfect spheres in real life!

Signal Propagation

- Propagation in free space is always like light (straight line).
- Receiving power proportional to **$1/d^2$** in vacuum – much more in real environments (**d** = distance between sender and receiver)
- Receiving power additionally influenced by
  - fading (frequency dependent)
  - Shadowing (blocking)
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges

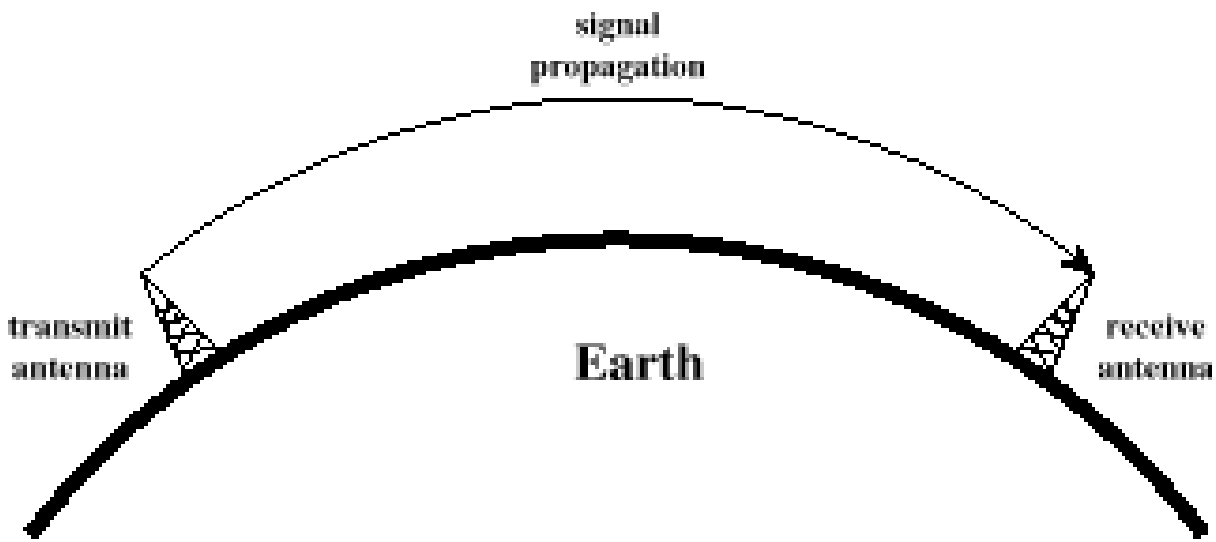


shadowing reflection refraction scattering diffraction

Propagation Modes

- Ground-wave (< 2MHz) propagation
- Sky-wave (2 – 30 MHz) propagation
- Line-of-sight (> 30 MHz) propagation

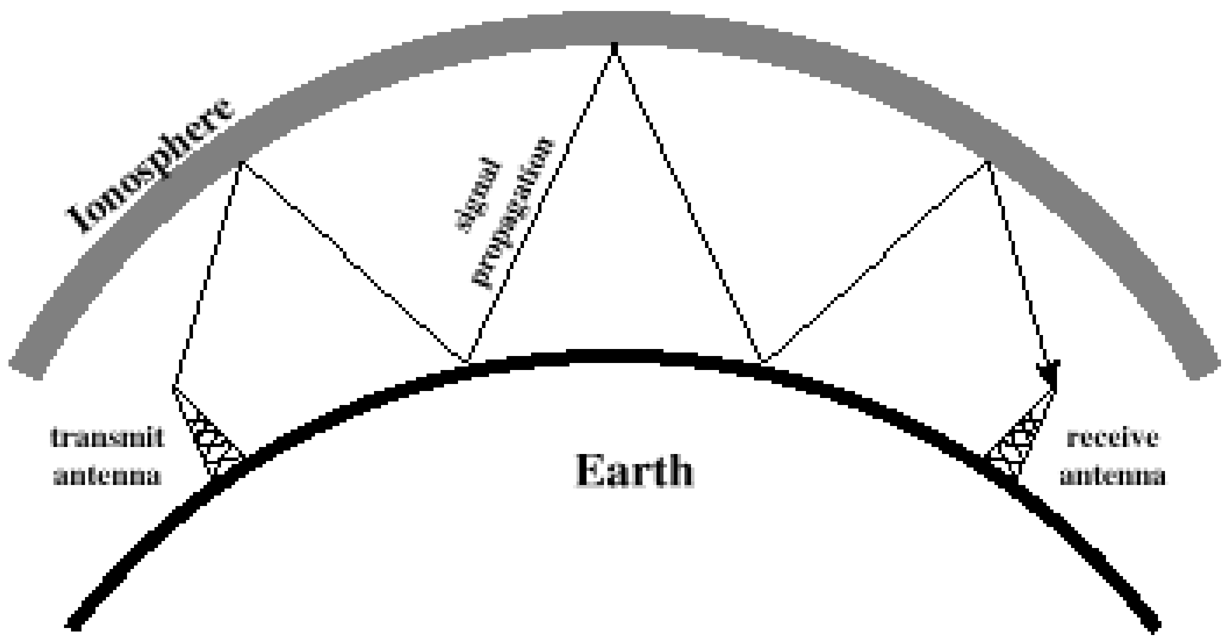
Ground Wave Propagation



Ground Wave Propagation

- Follows the contour of the earth
- Can propagate considerable distances
- Frequencies up to 2 MHz
- Example
  - AM radio
  - submarine communication (long waves)

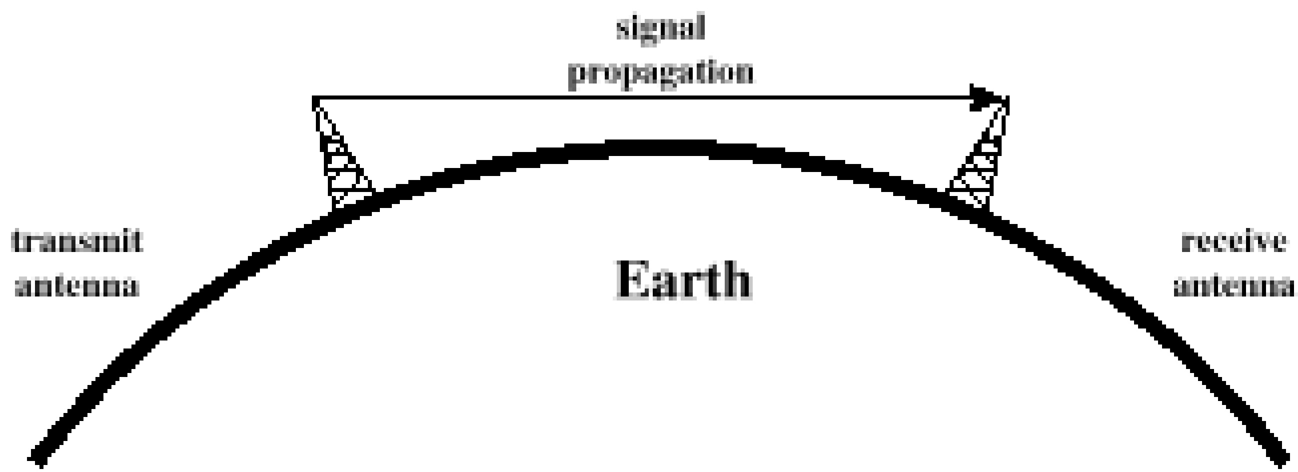
Sky Wave Propagation



Sky Wave Propagation

- Signal reflected from ionized layer of atmosphere back down to earth
- Signal can travel a number of hops, back and forth between ionosphere and the earth surface
- Reflection effect caused by refraction
- Examples
    - amateur radio
    - International broadcasts

Line-of-Sight Propagation



Line-of-Sight Propagation

- Transmitting and receiving antennas must be within line of sight
  - Satellite communication – signal above 30 MHz not reflected by ionosphere
  - Ground communication – antennas within *effective* line of sight due to refraction
- Refraction – bending of microwaves by the atmosphere
  - Velocity of an electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between mediums
- Mobile phone systems, satellite systems, cordless phones, etc.

Line-of-Sight Equations

- Optical line of sight

$$d = 3.57\sqrt{h}$$

- Effective, or radio, line of sight

$$d = 3.57\sqrt{\mathrm{K}h}$$

  - *d* = distance between antenna and horizon (km)
  - *h* = antenna height (m) (altitude relative to a receiver at the sea level)
  - K = adjustment factor to account for refraction caused by atmospherics layers; rule of thumb K = 4/3

Line-of-Sight Equations

- Maximum distance between two antennas for LOS propagation:

$$3.57\left(\sqrt{\mathrm{K}h_1} + \sqrt{\mathrm{K}h_2}\right)$$

  - h_1 = height of antenna one
  - h_2 = height of antenna two

LOS Wireless Transmission Impairments

- Attenuation and attenuation distortion
- Free space loss
- Atmospheric absorption
- Multipath (diffraction, reflection, refraction…)
- Noise
- Thermal noise

Attenuation

- Strength of signal falls off with distance over transmission medium
- Attenuation factors for unguided media:
  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Attenuation is greater at higher frequencies, causing distortion (attenuation distortion)

Free Space Path Loss

- Free space path loss, ideal isotropic antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

  - P_t = signal power at transmitting antenna
  - P_r = signal power at receiving antenna
  - λ = carrier wavelength
  - d = propagation distance between antennas
  - c = speed of light ($\approx 3 \times 10$ 8 m/s)

where d and λ are in the same units (e.g., meters)

Free Space Path Loss in dB

- Free space path loss equation can be recast (decibel version):

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

$$= -20\log(\lambda) + 20\log(d) + 21.98\ \mathrm{dB}$$

$$= 20\log\left(\frac{4\pi f d}{c}\right) = 20\log(f) + 20\log(d) - 147.56\ \mathrm{dB}$$

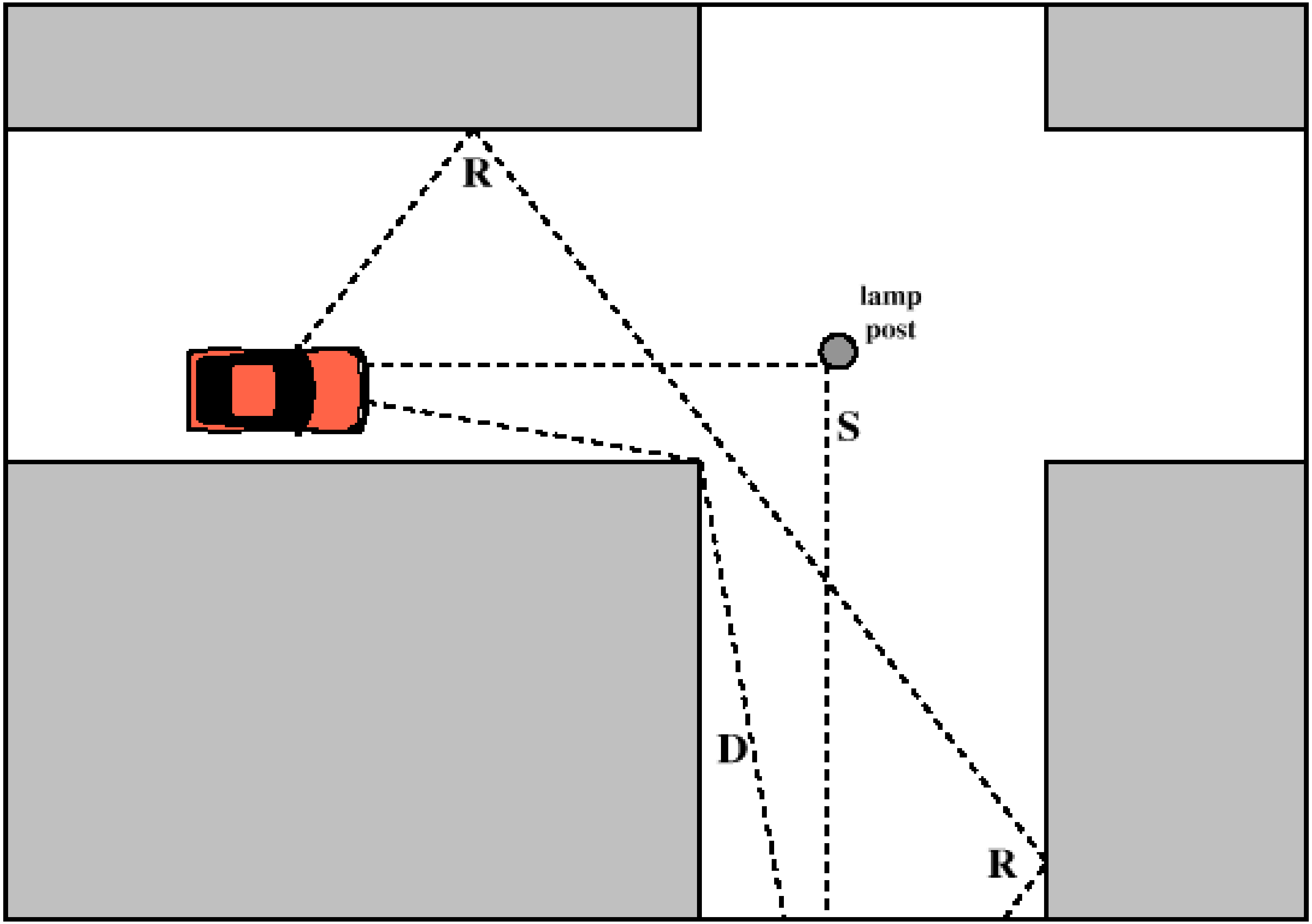
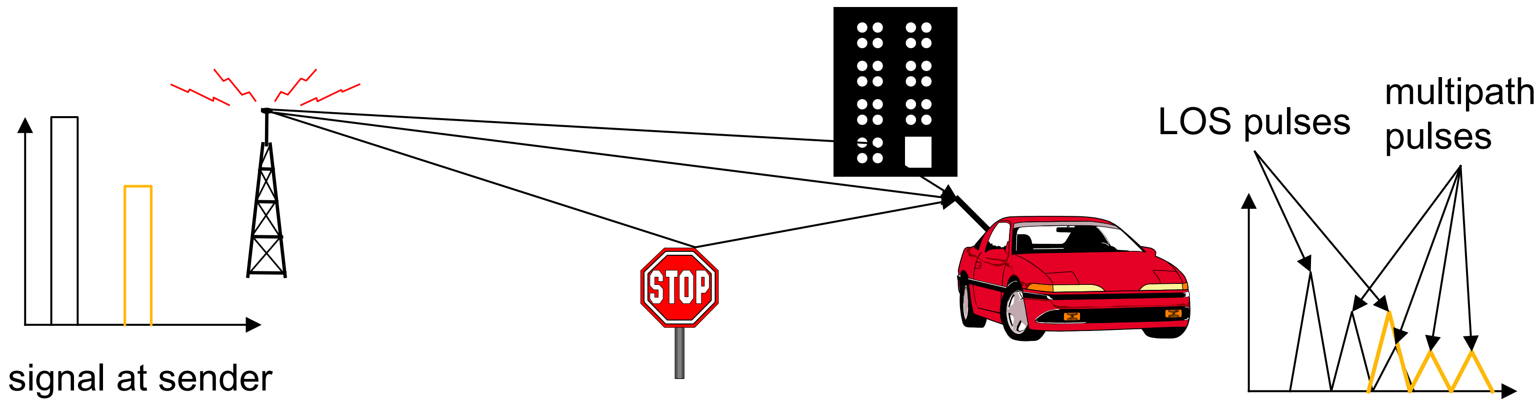


Figure 5.10 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D) [ANDE95]

Multi-path Propagation

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



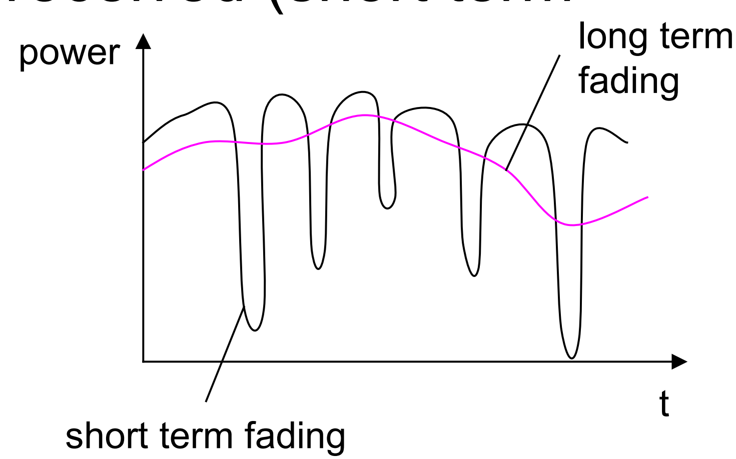
- Time dispersion: signal is dispersed over time
  - interference with “ neighbor” symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
  - distorted signal depending on the phases of the different parts

Atmospheric Absorption

- Water vapor and oxygen contribute most
- Water vapor: peak attenuation near 22GHz, low below 15Ghz
- Oxygen: absorption peak near 60GHz, lower below 30 GHz.
- Rain and fog may scatter (thus attenuate) radio waves.
- Low frequency band usage helps.

Effects of Mobility

- Channel characteristics change over time and location
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts
  - ➔ quick changes in the power received (short term fading)



- Additional changes in
  - distance to sender
  - obstacles further away
  - ➔ slow changes in the average power received (long term fading)

Fading Channels

- Fading: Time variation of received signal power
- Mobility makes the problem of modeling fading difficult
- Multipath propagation is a key reason
- Most challenging technical problem for mobile communications

Types of Fading

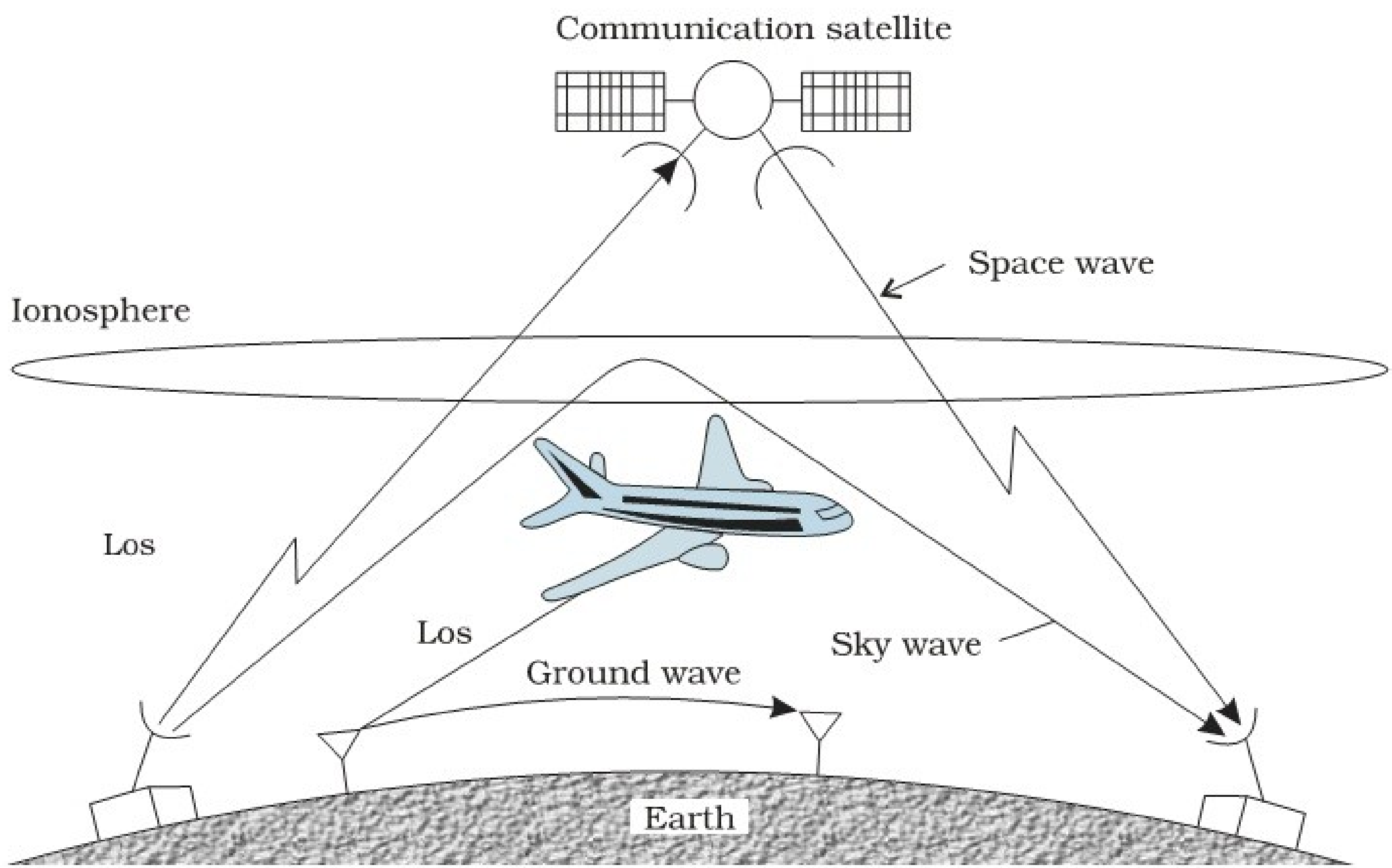
- Short term (fast) fading
- Long term (slow) fading
- Flat fading – across all frequencies
- Selective fading – only in some frequencies
- Rayleigh fading – no LOS path, many other paths
- Rician fading – LOS path plus many other paths

What is Space Wave Propagation?

- These waves occur within the lower 20 km of the atmosphere, and are comprised of a direct and reflected wave.
- The radio waves having high frequencies are basically called as space waves. These waves have the ability to propagate through atmosphere, from transmitter antenna to receiver antenna.
- These waves can travel directly or can travel after reflecting from earth’s surface to the troposphere surface of earth. So, it is also called as Tropospherical Propagation.

- . Basically the technique of space wave propagation is used in bands having very high frequencies. E.g. V.H.F. band, U.H.F band etc. At such higher frequencies the other wave propagation techniques like sky wave propagation, ground wave propagation can’t work. Only space wave propagation is left which can handle frequency waves of higher frequencies. The other name of space wave propagation is line of sight propagation.

Principle used in space wave propagation



Various propagation modes for em waves.

Sky wave propagation.

- The space wave follows two distinct paths from the transmitting antenna to the receiving antenna - one through the air directly to the receiving antenna, the other reflected from the ground to the receiving antenna.
- The primary path of the space wave is directly from the transmitting antenna to the receiving antenna. So, the receiving antenna must be located within the radio horizon of the transmitting antenna.
- Because space waves are refracted slightly, even when propagated through the troposphere, the radio horizon is actually about one-third farther than the line-of-sight or natural horizon.

- Although space waves suffer little ground attenuation, they nevertheless are susceptible to fading. This is because space waves actually follow two paths of different lengths (direct path and ground reflected path) to the receiving site and, therefore, may arrive in or out of phase.
- If these two component waves are received in phase, the result is a reinforced or stronger signal. Likewise, if they are received out of phase, they tend to cancel one another, which results in a weak or fading signal.

Limitations of space waves

As a form of electromagnetic radiation, like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization, and scattering.

There are some limitations of space wave propagation:

- These waves are limited to the curvature of the earth.
- These waves have line of sight propagation, means their propagation is along the line of sight distance.

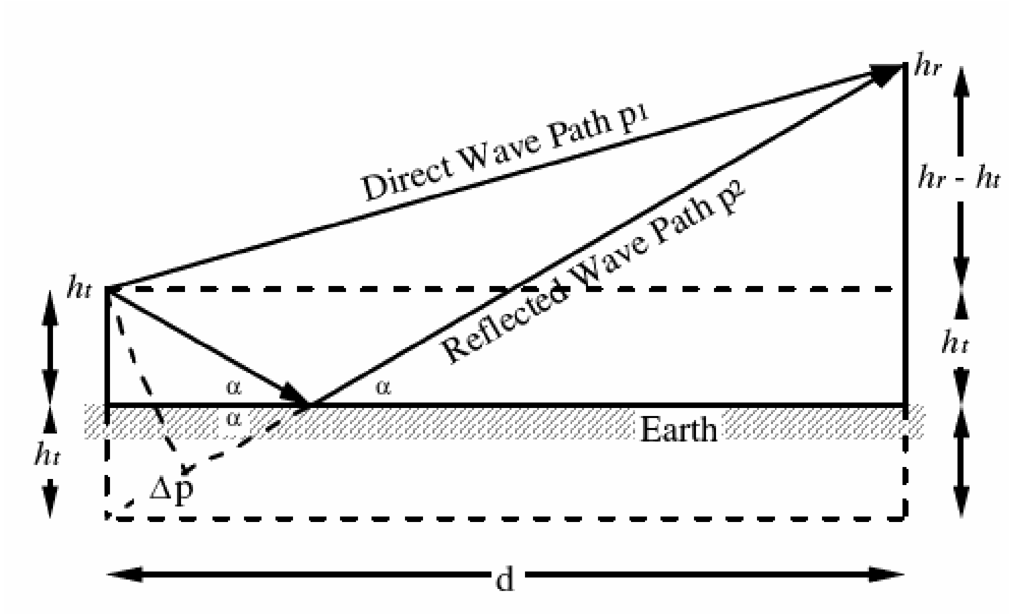
Effect of curvature of earth

- Effect of curvature of earth When the distance between the transmitting and receiving antennas is large, curvature of earth has considerable effect on SWP.
- The field strength at the receiver becomes small as the direct ray may not be able to reach the receiving antenna.
- The earth reflected rays diverge after their incidence on the earth. The curvature of earth creates shadow zones.

Effect of imperfection of earth

- Earth is basically imperfect and electrically rough.
- When a wave is reflected from perfect earth, its phase change is 180°.
- But actual earth makes the phase change different from 180°. The amplitude of ground reflected ray is smaller than that of direct ray.
- The field at the receiving point due to space is reduced by earth's imperfection and roughness

Effect of interference zone



The resultant received signal is the sum of the two components

- The line of sight distance is that exact distance at which both the sender and receiver antenna are in sight of each other. So, from the above line it is clear that if we want to increase the transmission distance then this can be done by simply extending the heights of both the sender as well as the receiver antenna.
- This type of propagation is used basically in radar and television communication.
- The frequency range for television signals is nearly 80 to 200MHz. These waves are not reflected by the ionosphere of the earth. The property of following the earth's curvature is also missing in these waves. So, for the propagation of television signal, geostationary satellites are used.
- The satellites complete the task of reflecting television signals towards earth. If we need greater transmission then we have to build extremely tall antennas.

Shadowing effect of hills and buildings

- At VHF and above, serious disturbances in space wave propagation are caused by trees, buildings, hills and mountains.
- These obstacles cause reflection, diffraction and absorption. Losses caused by absorption and scattering increase with the increase of frequency until f exceeds 3 GHz.
- Beyond this frequency building walls and wood become opaque to the waves. At higher frequencies the received signal strength is considerably reduced at position on the shadow side of any hill.
- Shadowing effect of hills and building is illustrated. In view of Fig.18(a) the reduction in R2 can be seen It is not only the reduction in R2 the obstructive object also scatter the energy.

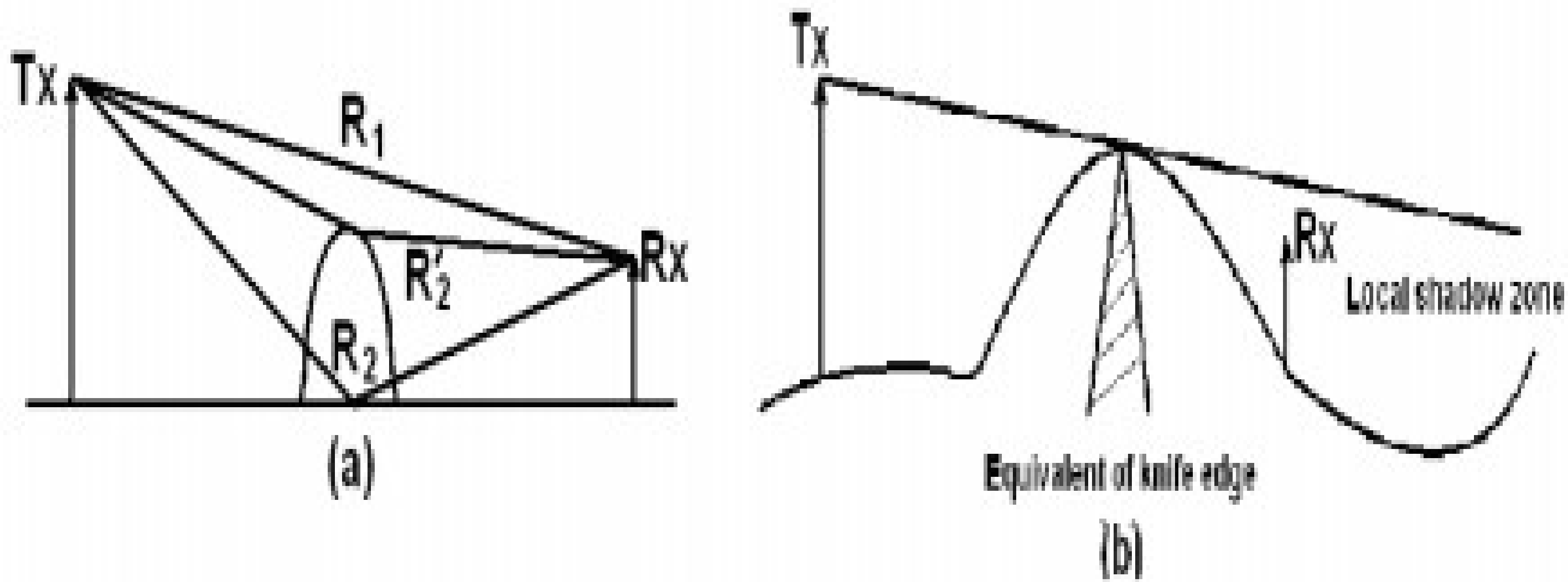


Fig.18 Shadowing effect and its equivalent

Super-refraction:

- In cold, rough weather lower temperature of atmosphere is usually well mixed and n is more or less standard.
- When day is warm, land and air both become warm. After sunset if sky is clear, land radiates its heat and its temperature falls rapidly.
- As a result earth and lower layer of atmosphere cool down but upper layer remains unchanged.
- It results in temperature inversion. If this inversion is sufficiently intense it results in super refraction.
- Though this effect is common over deserts, it can also occur anywhere if sky is clear and land is dry.
- It maximizes in early morning and disappears after sun rise.
- Such conditions frequently exist over sea particularly near coasts where air close to sea tends to be damp and cool while upper layer is dry and warm.

Scattering phenomena

- Reception far beyond optical horizon in VHF and UHF range is possible due to scatter propagation.
- Both troposphere and ionosphere are in continual state of turbulence. This gives rise to local variation in 'n' of the atmosphere.
- Waves passing through such turbulent region get scattered.
- When λ is large compared to the size of the turbulent eddies, waves scatter in all the directions.
- When λ is small compared to these irregularities then most of the scattering takes place within a narrow cone surrounding the forward direction of propagation of the incident radiation.
- To receive scattered signal at a point well beyond horizon Txg and Rxg antennas must be of high gain.

- Also these must be so oriented that their beams overlap in region where forward scattering is taking place.
- The scattering angle should also be as small as possible.
- This process is shown in Fig.24. Since scattering process is of random nature, scattered signals
- continuously fluctuate in amplitude and phase over a wide range. The scattering is of significant practical utility in
- the following regions:

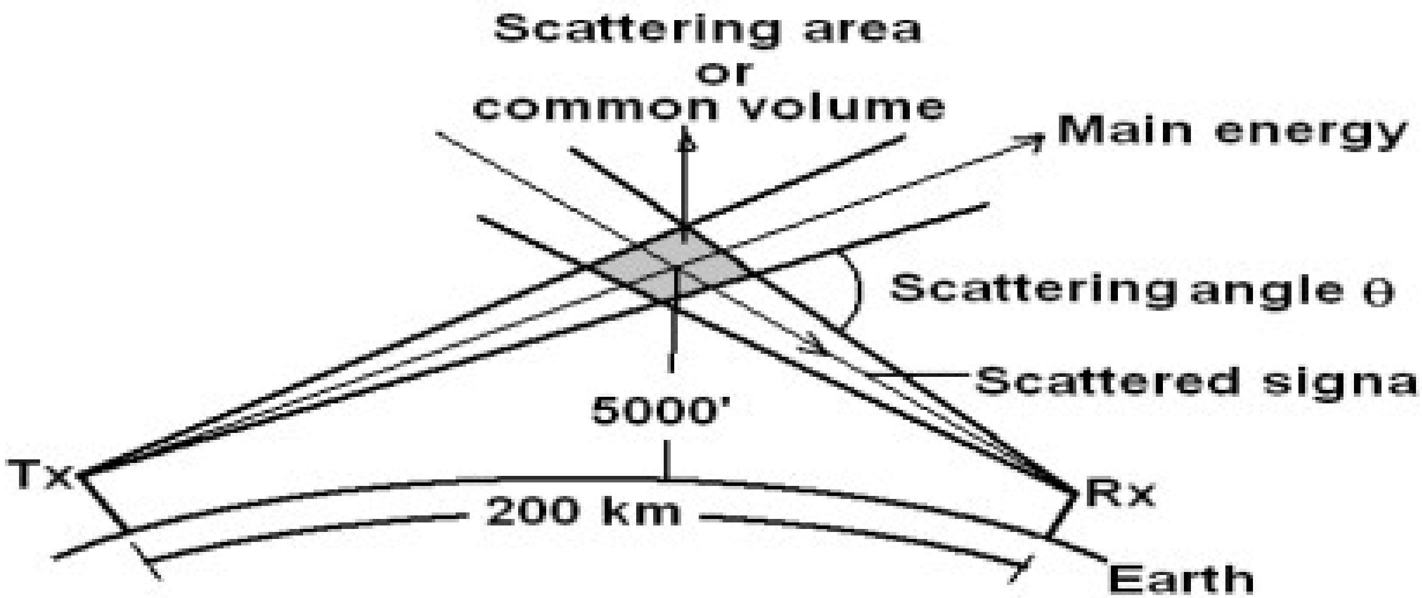


Fig.24 Illustration of the scattering process

FADING:

- It is a phenomenon of reduction of signals due to variation in refractive index - attributed to sudden changes in T, P and w. It is normally of Rayleigh nature.
- It can be classified as: fast or slow / single path or multi-path / short term or long term. For fast or multi-path fading - duration is about 0.01 sec
- For long term fading – average variation of signal is of the order of 10 dB.
- Summer signals are about 10 dB stronger than winter signals. Morning and evening signals are nearly 5 dB more than afternoon signal.
- Fading occasionally results in sudden disruption of communication.

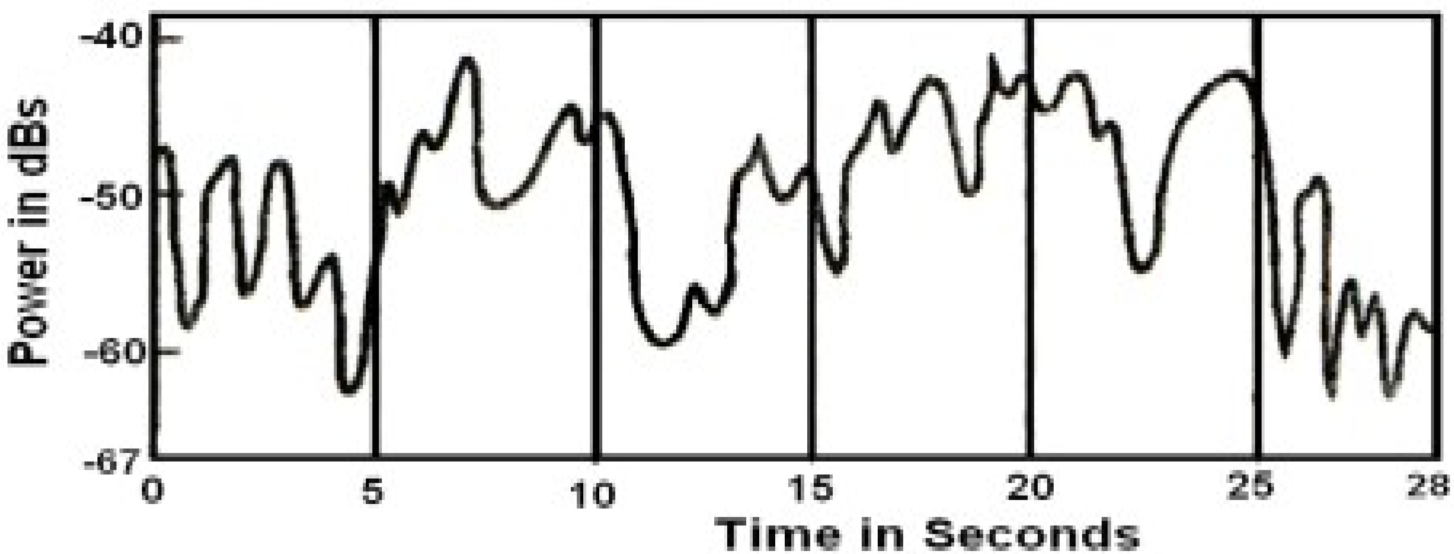


Fig.26

FADING

G2D06 -- How is a directional antenna pointed when making a “long-path” contact with another station?

A. Toward the rising Sun
B. Along the gray line
C. 180 degrees from its short-path heading
D. Toward the north

G2D06 -- How is a directional antenna pointed when making a “long-path” contact with another station?

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B. Along the gray line
C. **180 degrees from its short-path heading**
D. Toward the north

G3B01 -- How might a sky-wave signal sound if it arrives at your receiver by both short path and long path propagation?

A. Periodic fading approximately every 10 seconds

B. Signal strength increased by 3 dB

C. The signal might be cancelled causing severe attenuation

D. A well-defined echo might be heard

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C. The signal might be cancelled causing severe attenuation
D. **A well-defined echo might be heard**

G3B02 -- Which of the following is a good indicator of the possibility of sky-wave propagation on the 6 meter band?

A. Short skip sky-wave propagation on the 10 meter band
B. Long skip sky-wave propagation on the 10 meter band
C. Severe attenuation of signals on the 10 meter band
D. Long delayed echoes on the 10 meter band

G3B02 -- Which of the following is a good indicator of the possibility of sky-wave propagation on the 6 meter band?

A. **Short skip sky-wave propagation on the 10 meter band**
B. Long skip sky-wave propagation on the 10 meter band
C. Severe attenuation of signals on the 10 meter band
D. Long delayed echoes on the 10 meter band

G3B05 -- What usually happens to radio waves with frequencies below the Maximum Usable Frequency (MUF) and above the Lowest Usable Frequency (LUF) when they are sent into the ionosphere?

A. They are bent back to the Earth
B. They pass through the ionosphere
C. They are amplified by interaction with the ionosphere
D. They are bent and trapped in the ionosphere to circle the Earth

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C. They are amplified by interaction with the ionosphere
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G3B09 -- What is the approximate maximum distance along the Earth's surface that is normally covered in one hop using the F2 region?

A. 180 miles
B. 1,200 miles
C. 2,500 miles
D. 12,000 miles

G3B09 -- What is the approximate maximum distance along the Earth's surface that is normally covered in one hop using the F2 region?

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B. 1,200 miles
C. **2,500 miles**
D. 12,000 miles

G3B10 -- What is the approximate maximum distance along the Earth's surface that is normally covered in one hop using the E region?

A. 180 miles
B. 1,200 miles
C. 2,500 miles
D. 12,000 miles

G3B10 -- What is the approximate maximum distance along the Earth's surface that is normally covered in one hop using the E region?

A. 180 miles
B. **1,200 miles**
C. 2,500 miles
D. 12,000 miles

G3C01 -- Which of the following ionospheric layers is closest to the surface of the Earth?

A. The D layer
B. The E layer
C. The F1 layer
D. The F2 layer

G3C01 -- Which of the following ionospheric layers is closest to the surface of the Earth?

A. **The D layer**
B. The E layer
C. The F1 layer
D. The F2 layer

G3C02 -- Where on the Earth do ionospheric layers reach their maximum height?

A. Where the Sun is overhead
B. Where the Sun is on the opposite side of the Earth
C. Where the Sun is rising
D. Where the Sun has just set

G3C03 -- Why is the F2 region mainly responsible for the longest distance radio wave propagation?

A. Because it is the densest ionospheric layer
B. Because it does not absorb radio waves as much as other ionospheric regions
C. Because it is the highest ionospheric region
D. All of these choices are correct

G3C03 -- Why is the F2 region mainly responsible for the longest distance radio wave propagation?

A. Because it is the densest ionospheric layer
B. Because it does not absorb radio waves as much as other ionospheric regions
C. **Because it is the highest ionospheric region**
D. All of these choices are correct

G3C04 -- What does the term “critical angle” mean as used in radio wave propagation?

A. The long path azimuth of a distant station
B. The short path azimuth of a distant station
C. The lowest takeoff angle that will return a radio wave to the Earth under specific ionospheric conditions
D. The highest takeoff angle that will return a radio wave to the Earth under specific ionospheric conditions

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B. The short path azimuth of a distant station
C. The lowest takeoff angle that will return a radio wave to the Earth under specific ionospheric conditions
D. **The highest takeoff angle that will return a radio wave to the Earth under specific ionospheric conditions**

G3C05 -- Why is long distance communication on the 40, 60, 80 and 160 meter bands more difficult during the day?

A. The F layer absorbs signals at these frequencies during daylight hours
B. The F layer is unstable during daylight hours
C. The D layer absorbs signals at these frequencies during daylight hours
D. The E layer is unstable during daylight hours

G3C05 -- Why is long distance communication on the 40, 60, 80 and 160 meter bands more difficult during the day?

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B. The F layer is unstable during daylight hours
C. **The D layer absorbs signals at these frequencies during daylight hours**
D. The E layer is unstable during daylight hours

G3C12 -- Which ionospheric layer is the most absorbent of long skip signals during daylight hours on frequencies below 10 MHz?

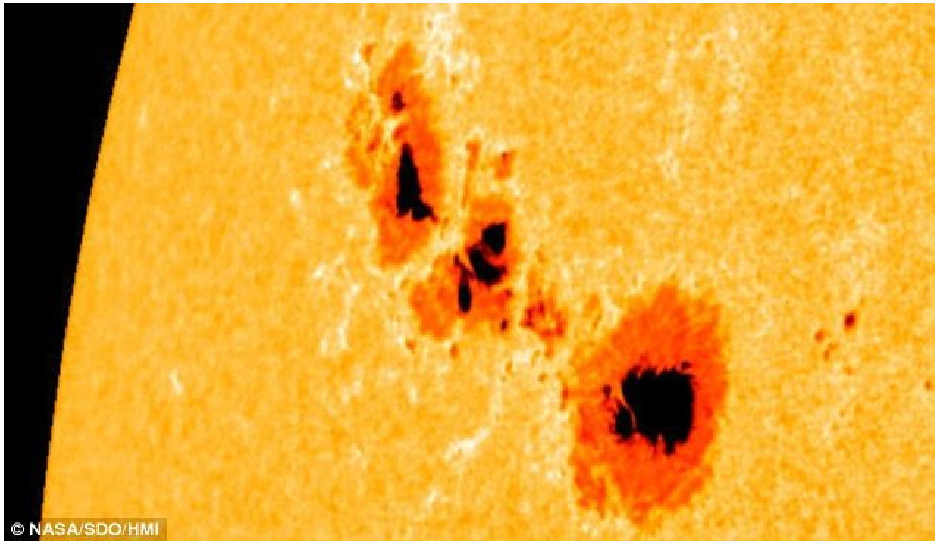
A. The F2 layer
B. The F1 layer
C. The E layer
D. The D layer

G3C12 -- Which ionospheric layer is the most absorbent of long skip signals during daylight hours on frequencies below 10 MHz?

A. The F2 layer
B. The F1 layer
C. The E layer
D. **The D layer**

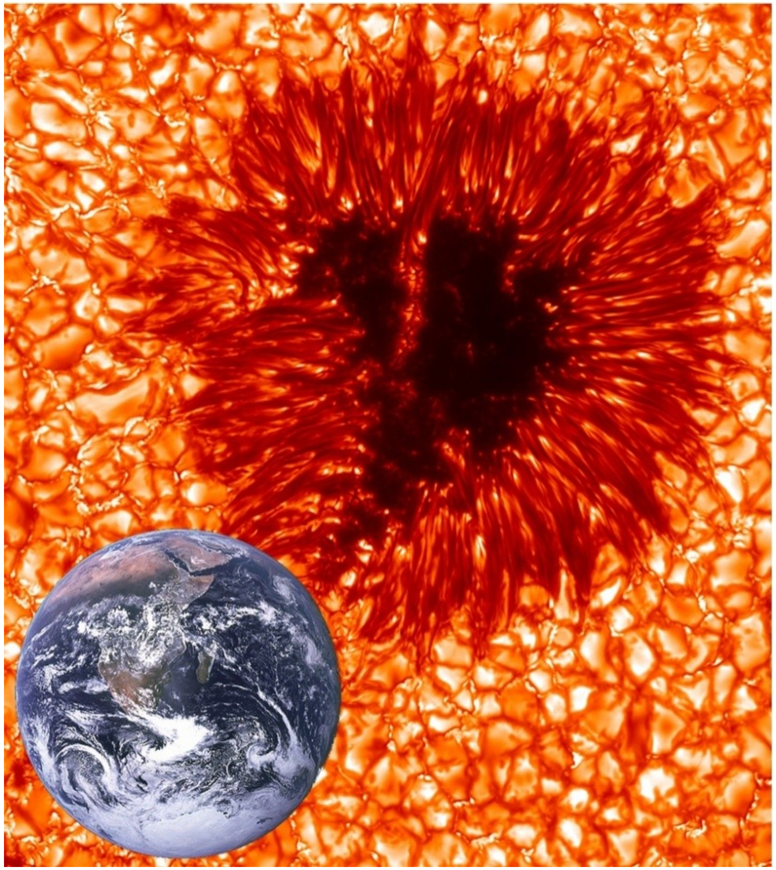
The Sun

- Sunspots and Cycles
  - Sunspots
    - Areas of intense magnetic activity on the surface (photosphere) of the Sun



The Sun

- Sunspots and Cycles
  - Sunspots
    - Up to 50,000 miles in diameter
    - Emit UV radiation which ionizes Earth's atmosphere
    - Earliest observation dates from 354 BC

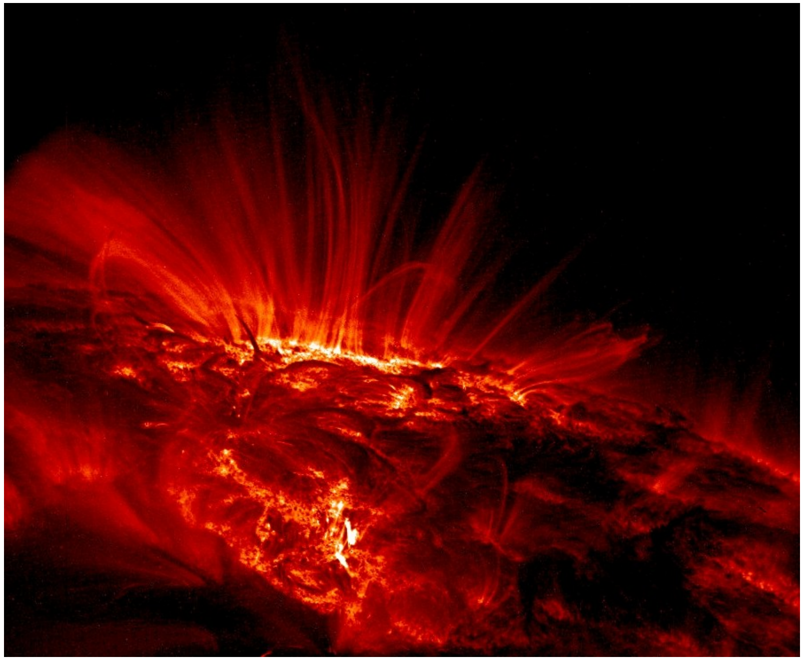


The Sun

- Sunspots and Cycles
  - Sunspots
    - Cooler in temperature (4,900°F to 7,600°F) than surrounding surface (10,000°F) so they appear darke

The Sun

- Sunspots and Cycles
  - Sunspots emit UV radiation which ionizes the Earth's atmosphere

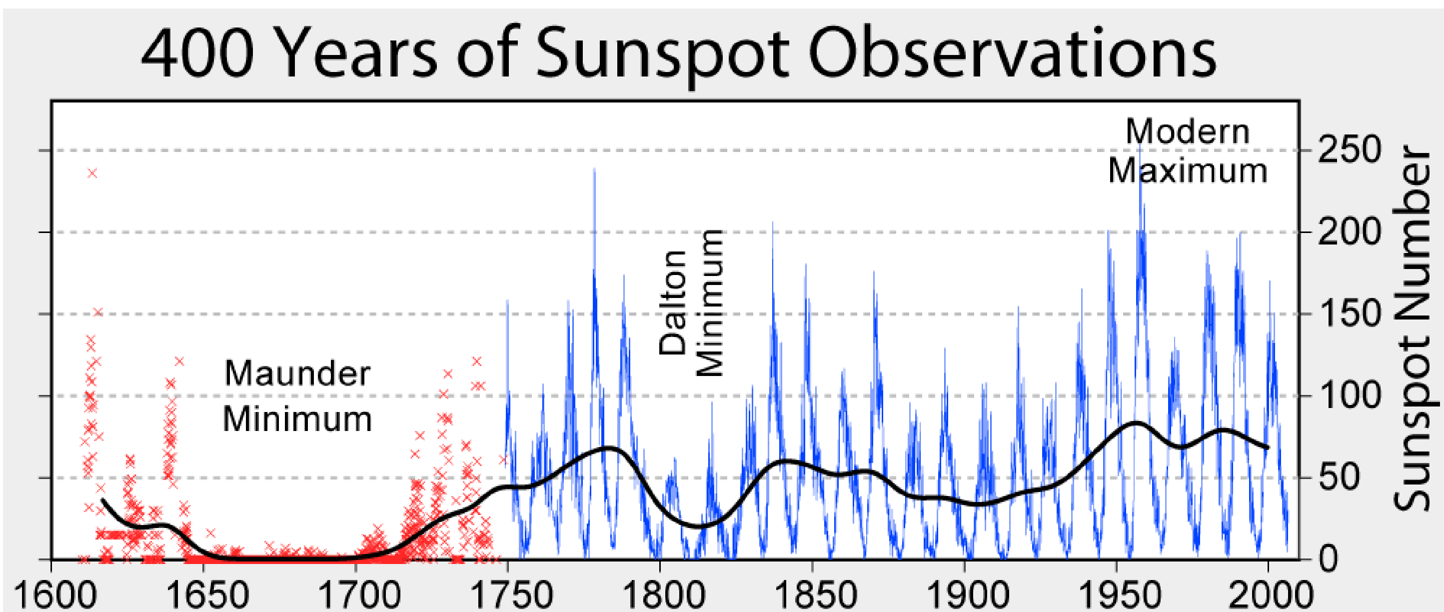


The Sun

- Sunspots and Cycles
  - Sunspots
    - Life span from less than a day to a few weeks
    - Stationary on Sun’s surface
    - Appear to move because of Sun’s rotation
      - Sunspots rotate back into view every 28 days

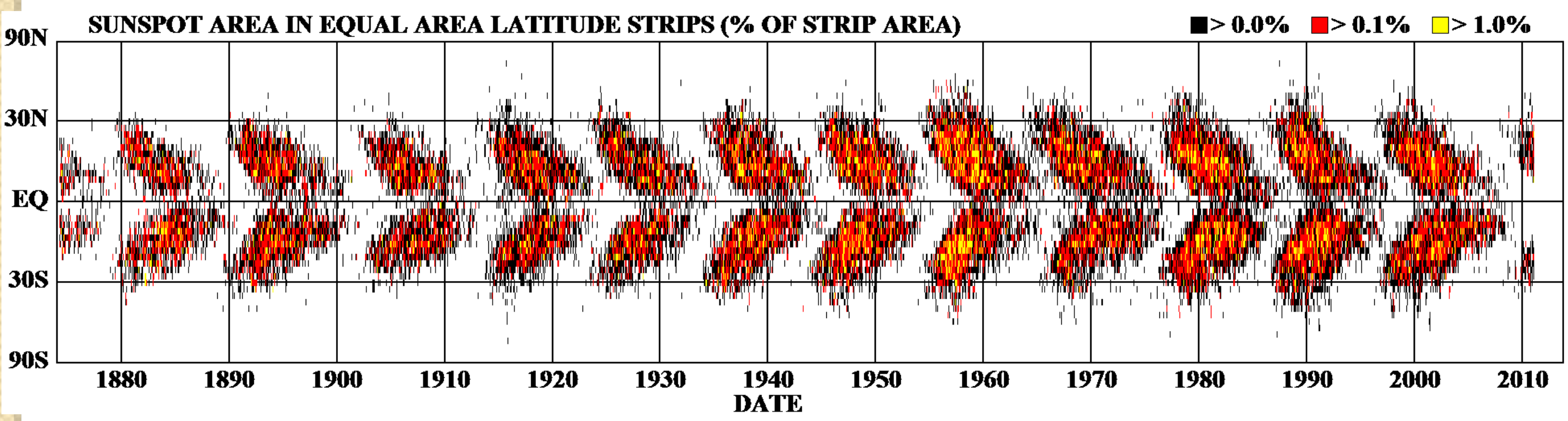
The Sun

- Sunspots and Cycles
  - Solar Cycles
    - Number of Sunspots varies in 11-year cycles



The Sun

- Sunspots and Cycles
  - Solar Cycles.
    - At beginning of cycle, Sunspots appear at mid latitudes and appear closer to equator as cycles progresses



The Sun

- Sunspots and Cycles
  - Solar Cycles
    - At peak of solar cycle, ionization level can be high enough that 10m stays open all night
    - At minimum of solar cycle, bands above 20m may not be open at all

The Sun

- Sunspots and Cycles
  - Solar Cycles
    - Strong seasonal and daily variations in propagation
      - Seasonal variations due to different levels of ionization between summer and winter
      - Seasonal variations on lower bands due to lower atmospheric noise during winter months
      - Daily variations due to different levels of ionization between day and night

The Sun

- Measuring Solar Activity
  - Sunspot number (SSN)
    - SSN = 10 x Nr of groups + Nr of Sunspots
    - Average of observations from many different locations
  - Solar flux index (SFI)
    - Measure of 10.7 cm (2.8 GHz) solar radiation
      - Indicator of UV radiation
    - Minimum value = 65, no maximum
- The higher the number, the higher the freq you use

The Sun

- Measuring Solar Activity
  - K-index (K_P)
    - Measure of short-term stability of earth's magnetic field
    - Minimum value = 0
    - Maximum value = 9
    - Updated every 3 hours
    - Higher values → Poorer HF propagation

K-Index	Meaning
0	Inactive
1	Very quiet
2	Quiet
3	Unsettled
4	Active
5	Minor storm
6	Major storm
7	Severe storm
8	Very severe storm
9	Extremely severe

The Sun

- Measuring Solar Activity
  - A-Index (A_P)
    - Measure of long-term stability of earth's magnetic field
    - Minimum value = 0 maximum value = 400
    - Calculated from previous 8 K-index value measurements
    - Higher values → Poorer HF propagation

A-Index	Meaning
0-7	Quiet
8-15	Unsettled
16-29	Active
30-49	Minor storm
50-99	Major storm
100-400	Severe storm

The Sun

- Assessing Propagation
  - Maximum Useable frequency (MUF)
    - Highest frequency that will allow communications between 2 points
      - Radio waves on frequencies below the MUF will be refracted back to earth
      - Radio waves on frequencies above the MUF will be lost into space
      - Use a frequency just below the MUF for the best results

The Sun

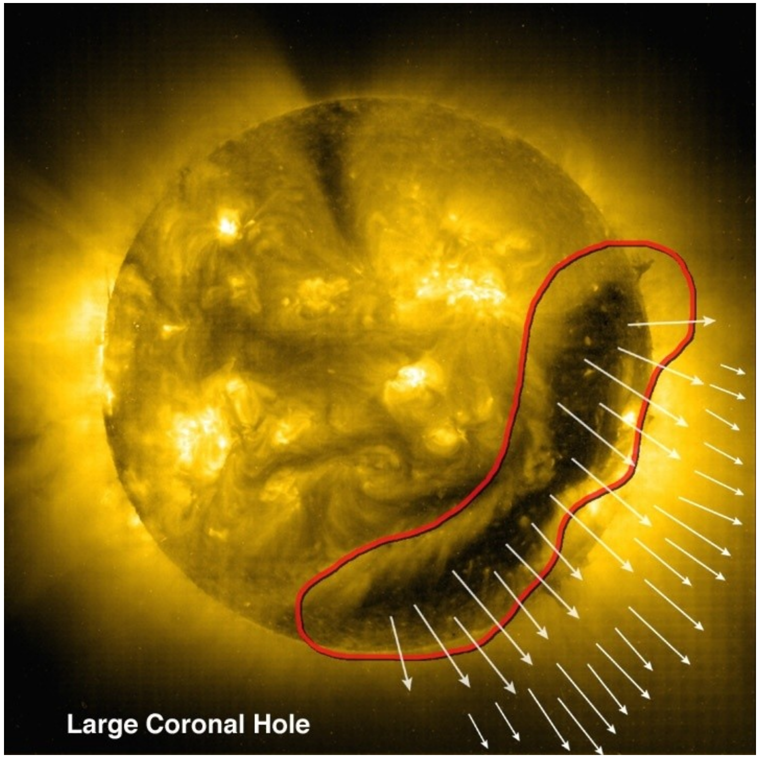
- Assessing Propagation
  - Lowest useable frequency (LUF)
    - Lowest frequency that will allow communications between 2 points
      - Radio waves on frequencies below the LUF will be absorbed by the D-region
      - If the MUF drops below the LUF, then sky-wave communications are not possible between those 2 points

The Sun

- Assessing Propagation
  - International beacons
    - Transmitters placed at 18 locations around the world.
      - Sponsored by the NCDXF and the IARU
    - 14.100 MHz, 18.110 MHz, 21.150 MHz, 24.930 MHz, and 28.200 MHz
    - Sends call sign at 22 wpm followed by four 1-second dashes
      - Call sign and 1st dash = 100 Watts
      - 2nd dash = 10 Watts
      - 3rd dash = 1 Watt
      - 4th dash = 0.1 Watt

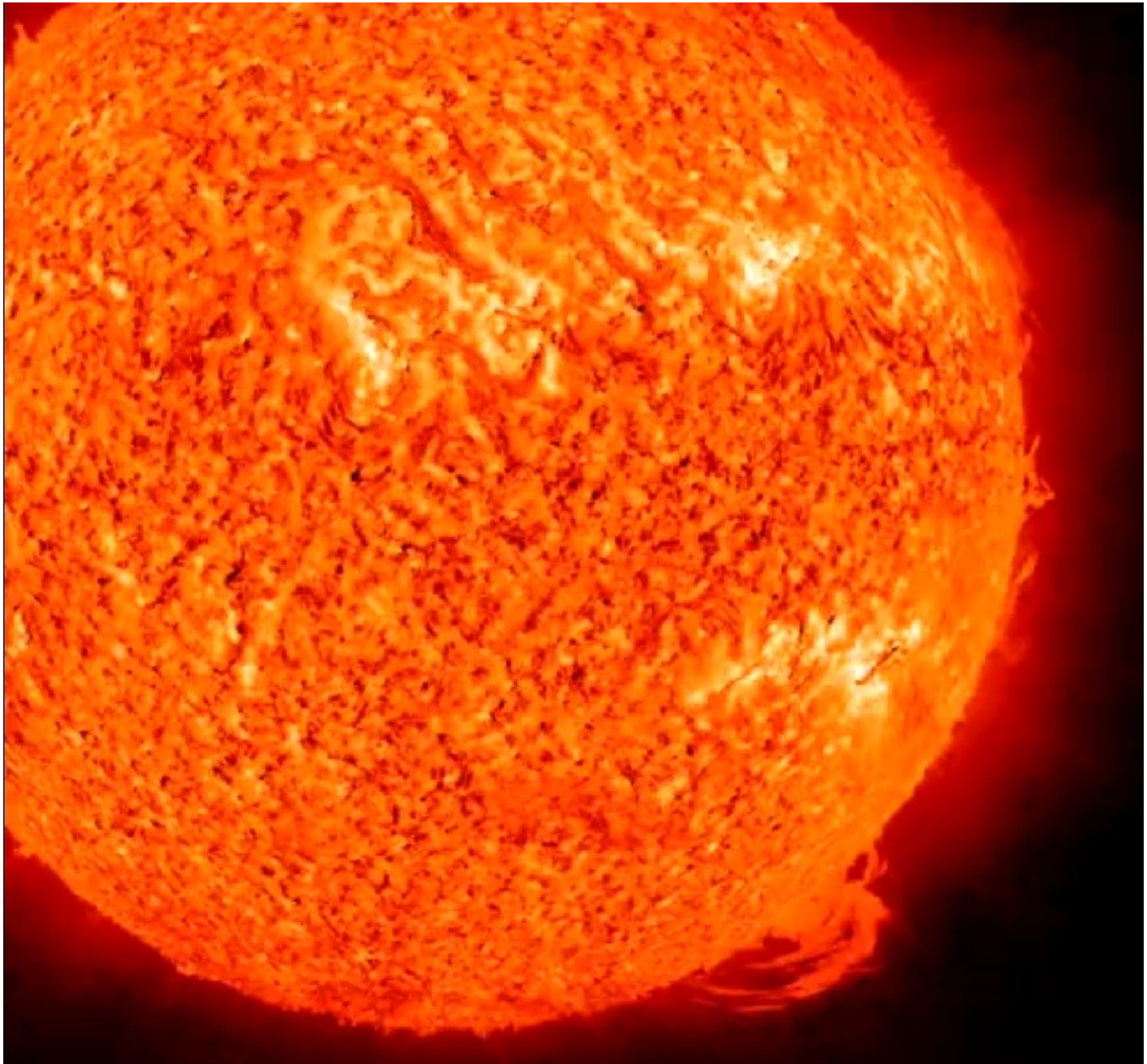
The Sun

- Solar Disturbances
  - Coronal hole
    - A weak area in the corona through which plasma can escape the Sun's magnetic field and stream through space at high velocity



The Sun

- Solar Disturbances
  - Coronal mass ejection (CME)
    - Ejection of a large amount of material from the corona
    - Narrow beam or wide area
    - Often associated with a large solar flare
    - Takes about 20-40 hours for particles to reach earth



The Sun

- Solar Disturbances
  - Sudden ionospheric disturbance (SID)
    - UV-rays and X-rays from a solar flare travel to earth at the speed of light (186,000 mi/sec).
      - Reach earth in about 8 minutes
    - Greatly increases ionization level of D-region
      - Lower frequencies more greatly affected
    - Can last from a few seconds to several hours
    - Only affects sunlit side of earth

The Sun

- Solar Disturbances
  - Geomagnetic disturbances
    - CME's greatly increase strength of solar wind
      - A continuous stream of charged particles
      - Reaches earth in about 20-40 hours
    - Particles become trapped in the magnetosphere near both poles increasing ionization of E-region and creating a geomagnetic storm

The Sun

- Solar Disturbances
  - Geomagnetic disturbances
    - High-latitude HF propagation greatly decreased
      - Can last several hours to a few days
    - Auroral activity greatly increased
      - Reflection possible on 15m and up
        - Strongest on 6m and 2m
      - Signals modulated with hiss or buzz
        - CW

The Sun

- Solar Disturbances

G3A01 -- What is the Sunspot number?

A. A measure of solar activity based on counting Sunspots and Sunspot groups
B. A 3 digit identifier which is used to track individual Sunspots
C. A measure of the radio flux from the Sun measured at 10.7 cm
D. A measure of the Sunspot count based on radio flux measurements

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G3A02 -- What effect does a Sudden Ionospheric Disturbance have on the daytime ionospheric propagation of HF radio waves?

A. It enhances propagation on all HF frequencies
B. It disrupts signals on lower frequencies more than those on higher frequencies
C. It disrupts communications via satellite more than direct communications
D. None, because only areas on the night side of the Earth are affected

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C. It disrupts communications via satellite more than direct communications
D. None, because only areas on the night side of the Earth are affected

G3A03 -- Approximately how long does it take the increased ultraviolet and X-ray radiation from solar flares to affect radio-wave propagation on the Earth?

A. 28 days
B. 1 to 2 hours
C. 8 minutes
D. 20 to 40 hours

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G3A04 -- Which of the following amateur radio HF frequencies are least reliable for long distance communications during periods of low solar activity?

A. 3.5 MHz and lower
B. 7 MHz
C. 10 MHz
D. 21 MHz and higher

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G3A05 -- What is the solar-flux index?

A. A measure of the highest frequency that is useful for ionospheric propagation between two points on the Earth
B. A count of Sunspots which is adjusted for solar emissions
C. Another name for the American Sunspot number
D. A measure of solar radiation at 10.7 cm

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G3A06 -- What is a geomagnetic storm?

A. A sudden drop in the solar-flux index
B. A thunderstorm which affects radio propagation
C. Ripples in the ionosphere
D. A temporary disturbance in the Earth's magnetosphere

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G3A07 -- At what point in the solar cycle does the 20 meter band usually support worldwide propagation during daylight hours?

A. At the summer solstice
B. Only at the maximum point of the solar cycle
C. Only at the minimum point of the solar cycle
D. At any point in the solar cycle

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G3A08 -- Which of the following effects can a geomagnetic storm have on radio-wave propagation?

A. Improved high-latitude HF propagation
B. Degraded high-latitude HF propagation
C. Improved ground-wave propagation
D. Improved chances of UHF ducting

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G3A09 -- What effect do high Sunspot numbers have on radio communications?

A. High-frequency radio signals become weak and distorted
B. Frequencies above 300 MHz become usable for long-distance communication
C. Long-distance communication in the upper HF and lower VHF range is enhanced
D. Microwave communications become unstable

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G3A10 -- What causes HF propagation conditions to vary periodically in a 28-day cycle?

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B. Cyclic variation in the Earth's radiation belts
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G3A11 -- Approximately how long is the typical Sunspot cycle?

A. 8 minutes
B. 40 hours
C. 28 days
D. 11 years

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G3A12 -- What does the K-index indicate?

A. The relative position of Sunspots on the surface of the Sun
B. The short term stability of the Earth’s magnetic field
C. The stability of the Sun's magnetic field
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G3A13 -- What does the A-index indicate?

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B. The amount of polarization of the Sun's electric field
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G3A14 -- How are radio communications usually affected by the charged particles that reach the Earth from solar coronal holes?

A. HF communications are improved
B. HF communications are disturbed
C. VHF/UHF ducting is improved
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G3A15 -- How long does it take charged particles from coronal mass ejections to affect radio-wave propagation on the Earth?

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B. 14 days
C. 4 to 8 minutes
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G3A16 -- What is a possible benefit to radio communications resulting from periods of high geomagnetic activity?

A. Aurora that can reflect VHF signals
B. Higher signal strength for HF signals passing through the polar regions
C. Improved HF long path propagation
D. Reduced long delayed echoes

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G3B03 -- Which of the following applies when selecting a frequency for lowest attenuation when transmitting on HF?

A. Select a frequency just below the MUF
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G3B04 -- What is a reliable way to determine if the Maximum Usable Frequency (MUF) is high enough to support skip propagation between your station and a distant location on frequencies between 14 and 30 MHz?

A. Listen for signals from an international beacon
B. Send a series of dots on the band and listen for echoes from your signal
C. Check the strength of TV signals from Western Europe
D. Check the strength of signals in the MF AM broadcast band

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G3B06 -- What usually happens to radio waves with frequencies below the Lowest Usable Frequency (LUF)?

A. They are bent back to the Earth
B. They pass through the ionosphere
C. They are completely absorbed by the ionosphere
D. They are bent and trapped in the ionosphere to circle the Earth

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G3B07 -- What does LUF stand for?

A. The Lowest Usable Frequency for communications between two points
B. The Longest Universal Function for communications between two points
C. The Lowest Usable Frequency during a 24 hour period
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G3B08 -- What does MUF stand for?

A. The Minimum Usable Frequency for communications between two points
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G3B11 -- What happens to HF propagation when the Lowest Usable Frequency (LUF) exceeds the Maximum Usable Frequency (MUF)?

A. No HF radio frequency will support ordinary skywave communications over the path
B. HF communications over the path are enhanced
C. Double hop propagation along the path is more common
D. Propagation over the path on all HF frequencies is enhanced

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G3B12 -- What factors affect the Maximum Usable Frequency (MUF)?

A. Path distance and location
B. Time of day and season
C. Solar radiation and ionospheric disturbances
D. All of these choices are correct

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Scatter Modes

- Scatter Characteristics
  - Localized areas in the ionosphere can reflect radio waves as well as refract them
    - Direction of reflection is unpredictable
    - Reflected signals MUCH weaker than refracted signals
    - Allows propagation above the MUF

Scatter Modes

- Scatter Characteristics
  - Backscatter
    - Signals can be reflected from uneven terrain at the far end of the path back towards the source

Scatter Modes

- Near Vertical Incidence Sky-wave (NVIS)
  - At frequencies below the critical frequency, signals arriving at any angle are reflected
    - Select a frequency below the critical frequency, but high enough that absorption in the D-region is not excessive
    - Use a horizontally-polarized antenna mounted 1/8λ to 1/4λ above the ground
    - Propagation up to 300 miles away

G3C06 -- What is a characteristic of HF scatter signals?

A. They have high intelligibility
B. They have a wavering sound
C. They have very large swings in signal strength
D. All of these choices are correct

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G3C07 -- What makes HF scatter signals often sound distorted?

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B. Ground waves are absorbing much of the signal
C. The E-region is not present
D. Energy is scattered into the skip zone through several different radio wave paths

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G3C08 -- Why are HF scatter signals in the skip zone usually weak?

A. Only a small part of the signal energy is scattered into the skip zone
B. Signals are scattered from the magnetosphere which is not a good reflector
C. Propagation is through ground waves which absorb most of the signal energy
D. Propagations is through ducts in F region which absorb most of the energy

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G3C09 -- What type of radio wave propagation allows a signal to be detected at a distance too far for ground wave propagation but too near for normal sky-wave propagation?

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G3C10 -- Which of the following might be an indication that signals heard on the HF bands are being received via scatter propagation?

A. The communication is during a Sunspot maximum
B. The communication is during a sudden ionospheric disturbance
C. The signal is heard on a frequency below the Maximum Usable Frequency
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G3C11 -- Which of the following antenna types will be most effective for skip communications on 40 meters during the day?

A. Vertical antennas
B. Horizontal dipoles placed between 1/8 and 1/4 wavelength above the ground
C. Left-hand circularly polarized antennas
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