DEPARTMENT OF

ELECTRONICS AND COMMUNICATION ENGINEERING

EC 306

ANTENNA & WAVE PROPAGATION

COURSE MATERIAL

JAWAHARLAL COLLEGE OF ENGINEERING & TECHNOLOGY

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EFFECTIVE LENGTH/HEIGHT OF THE ANTENNA:

When a receiving antenna intercepts incident electromagnetic waves, a voltage is induced across the antenna terminals. The effective length $\boldsymbol{h_e}$ of a receiving antenna is defined as the ratio of the open circuit terminal voltage to the incident electric field strength in the direction of antennas polarization.

$$he = \frac{Voc}{E} \qquad meters$$

where V_{OC} = open circuit voltage

E = electric field strength

Effective length he is also referred to as effective height.

DUAL CHARACTERISTICS OF AN ANTENNA

The duality of an antenna specifies a circuit device on one hand and a space device on the other hand. Figure shows the schematic diagram of basic antenna parameters, illustrating dual characteristics of an antenna.

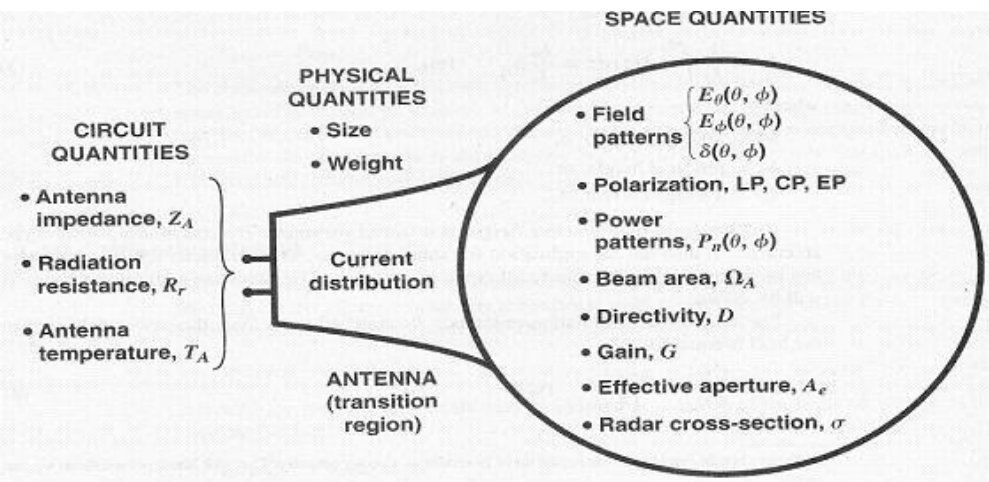


Fig:- Schematic diagram of basic parameters

RECIPROCITY

It is the ability to use the same antenna for both transmitting and receiving. The electrical characteristics of an antenna apply equally, regardless of whether you use the antenna for transmitting or receiving. The more efficient an antenna is for transmitting a certain frequency, the more efficient it will be as a receiving antenna for the same frequency. This is illustrated by figure , view A. When the antenna is used for transmitting, maximum radiation occurs at right angles to its axis. When the same antenna is used for receiving (view B), its best reception is along the same path; that is, at right angles to the axis of the antenna.

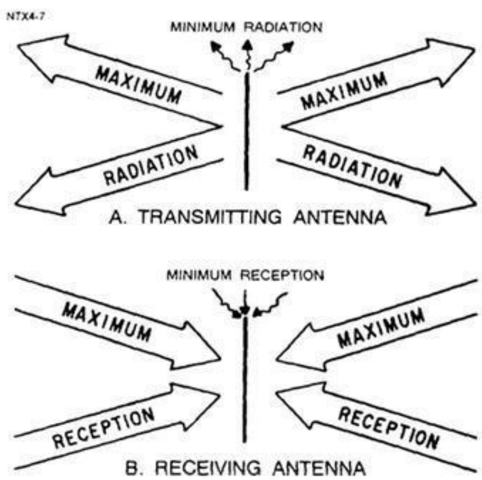


Fig: Reciprocity of Antenna

POLARIZATION

Polarization of an electromagnetic wave refers to the orientation of the electric field component of the wave. For a linearly polarized wave, the orientation stays the same as the wave moves through space. If we choose our axis system such that the electric field is vertical, we say that the wave is vertically polarized. If our transmitting antenna is vertically oriented, the electromagnetic wave radiated is vertically polarized since, as we saw before, the electric field is in the direction of the current in the antenna.

The convention is to refer to polarization with reference to the surface of the earth. Precise orientation is less problematic than one might think, since waves bounce of the ground and other objects so do not maintain their original orientation anyway. In space, horizontal and vertical lose their meaning, so alignment of linearly polarized sending and receiving antennas is more difficult to achieve. These difficulties are somewhat circumvented by circular polarization of waves. With circular polarization, the tip of the electric field vector traces out a circle when viewed in the direction of propagation.

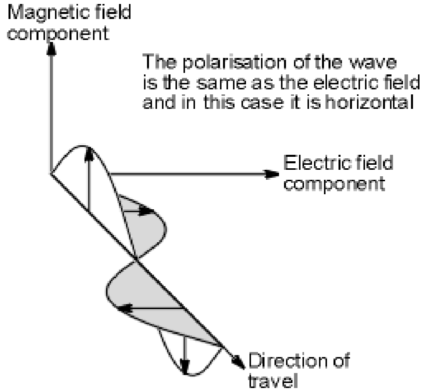


Fig: Polarisation

Polarization categories

Vertical and horizontal are the simplest forms of polarization and they both fall into a category known as linear polarization. However it is also possible to use circular polarization. This has a number of benefits for areas such as satellite applications where it helps overcome the effects of propagation anomalies, ground reflections and the effects of the spin that occur on many satellites. Circular polarization is a little more difficult to visualize than linear polarization. However it can be imagined by visualizing a signal propagating from an antenna that is rotating. The tip of the electric field vector will then be seen to trace out a helix or corkscrew as it travels away from the antenna. Circular polarization can be seen to be either right or left handed dependent upon the direction of rotation as seen from the transmitter.
Another form of polarization is known as elliptical polarization. It occurs when there is a mix of linear and circular polarization. This can be visualized as before by the tip of the electric field vector tracing out an elliptically shaped corkscrew.
However it is possible for linearly polarized antennas to receive circularly polarized signals and vice versa. The strength will be equal whether the linearly polarized antenna is mounted vertically, horizontally or in any other plane but directed towards the arriving signal. There will be some degradation because the signal level will be 3 dB less than if a circularly polarized antenna of the same sense was used. The same situation exists when a circularly polarized antenna receives a linearly polarized signal.

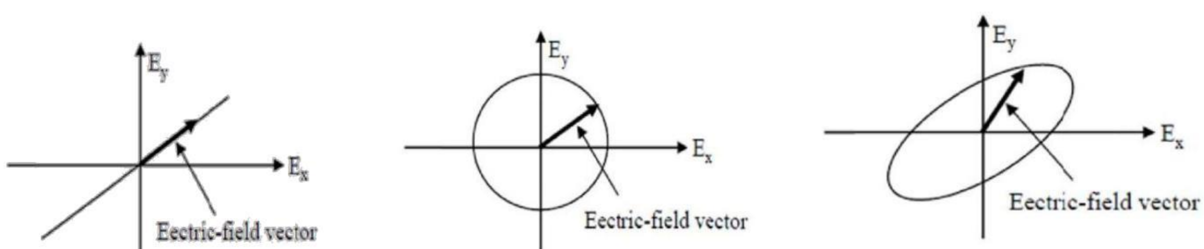
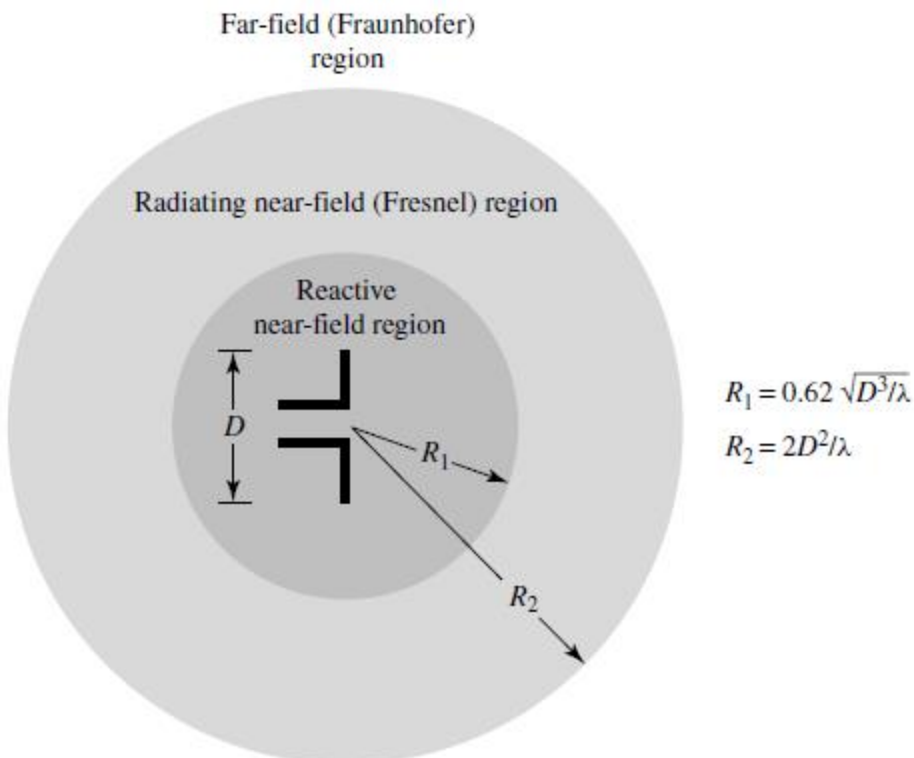


Figure: (a) Linear polarization (b) Circular polarization (c) Elliptical polarization

ANTENNA FIELD ZONES

The space surrounding an antenna is usually subdivided into three regions: (a) reactive near-field, (b) radiating near-field (Fresnel) and (c) far-field (Fraunhofer) regions as shown in Figure.



Reactive near-field *region* is defined as "that portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates." For most antennas, the outer boundary of this region is commonly taken to exist at a distance $R < 0.62\sqrt{\frac{D^3}{\lambda}}$ from the antenna surface, where λ is the wavelength and D is the largest dimension of the antenna.

Radiating near-field (Fresnel) *region* is defined as "that region of the field of an antenna between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon the distance from the antenna. The inner boundary is taken to be the distance $R \geq 0.62\sqrt{\frac{D^3}{\lambda}}$ and the outer boundary the distance $R < 2D^2/\lambda$ where D is the largest∗ dimension of the antenna.

Far-field (Fraunhofer) *region* is defined as "that region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. If the antenna has a maximum∗ overall dimension D, the far-field region is commonly taken to exist at distances greater than $2D^2/\lambda$ from the antenna, λ being the wavelength.

MODULE II

ANTENNA MEASUREMENTS

2.1 REQUIRED EQUIPMENT IN ANTENNA MEASUREMENTS

For antenna test equipment, we will attempt to illuminate the test antenna (often called an Antenna-Under-Test) with a plane wave. This will be approximated by using a source (transmitting) antenna with known radiation pattern and characteristics, in such a way that the fields incident upon the test antenna are approximately plane waves. The required equipment for antenna measurements include:

- ***A source antenna and transmitter*** - This antenna will have a known pattern that can be used to illuminate the test antenna
- ***A receiver system*** - This determines how much power is received by the test antenna
- ***A positioning system*** - This system is used to rotate the test antenna relative to the source antenna, to measure the radiation pattern as a function of angle.

A block diagram of the above equipment is shown in Figure 1.

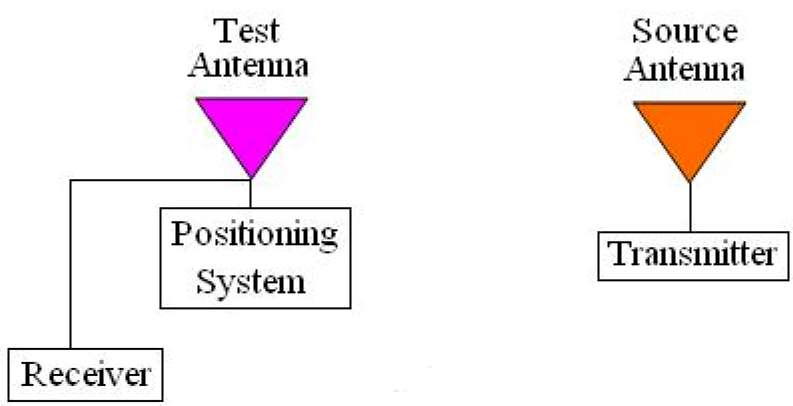


Figure 1. Diagram of required antenna measurement equipment.

The **Source Antenna** should of course radiate well at the desired test frequency. It must have the desired polarization and a suitable beamwidth for the given antenna test range. Source antennas are often horn antennas, or a dipole antenna with a parabolic reflector.

The **Transmitting System** should be capable of outputting a stable known power. The output frequency should also be tunable (selectable), and reasonably stable (stable means that the frequency you get from the transmitter is close to the frequency you want).

The **Receiving System** simply needs to determine how much power is received from the test antenna. This can be done via a simple bolometer, which is a device for measuring the energy of incident electromagnetic waves. The receiving system can be more complex, with high quality amplifiers for low power measurements and more accurate detection devices.

The **Positioning System** controls the orientation of the test antenna. Since we want to measure the radiation pattern of the test antenna as a function of angle (typically in spherical coordinates), we need to rotate the test antenna so that the source antenna illuminates the test antenna from different angles. The positioning system is used for this purpose.

Once we have all the equipment we need (and an antenna we want to test), we'll need to place the equipment and perform the test in an antenna range.

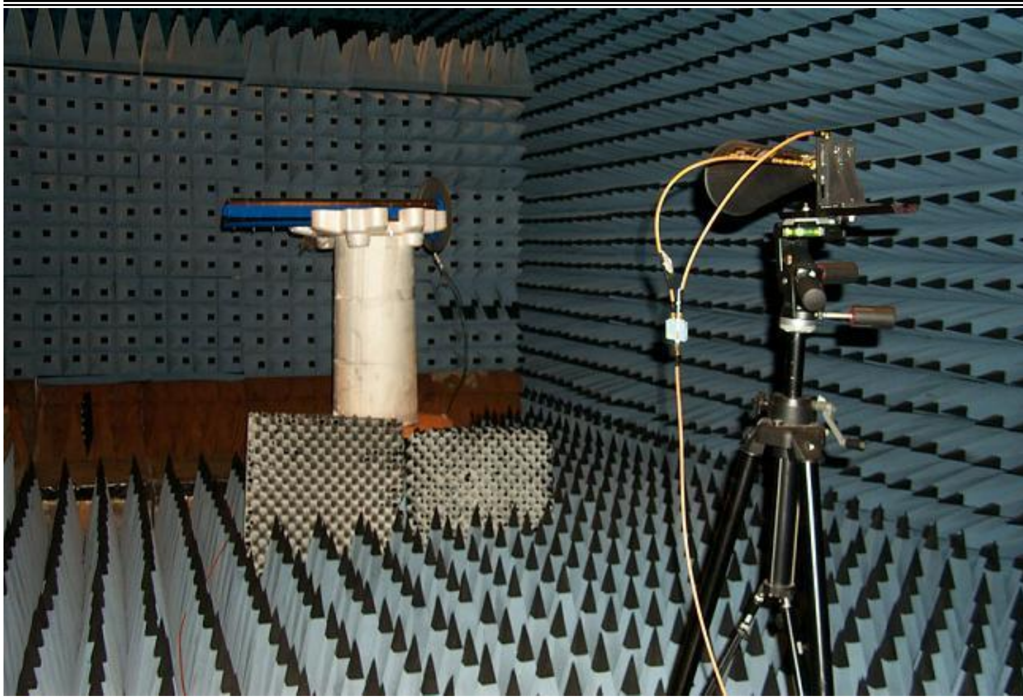
The first thing we need to do an antenna measurement is a place to perform the measurement. Maybe you would like to do this in your garage, but the reflections from the walls, ceilings and floor would make your measurements inaccurate. The ideal location to perform antenna measurements is somewhere in outer space, where no reflections can occur. However, because space travel is currently prohibitively expensive, we will focus on measurement places that are on the surface of the Earth. There are two main types of ranges, ***Free Space Ranges*** **and** ***Reflection Ranges***. Reflection ranges are designed such that reflections add together in the test region to support a roughly planar wave. We will focus on the more common free space ranges.

2.1.1 Free Space Ranges

Free space ranges are antenna measurement locations designed to simulate measurements that would be performed in space. That is, all reflected waves from nearby objects and the ground (which are undesirable) are suppressed as much as possible. The most popular free space ranges are anechoic chambers, elevated ranges, and the compact range.

2.1.2 Anechoic Chambers

Anechoic chambers are indoor antenna ranges. The walls, ceilings and floor are lined with special electromagnetic wave absorbing material. Indoor ranges are desirable because the test conditions can be much more tightly controlled than that of outdoor ranges. The material is often jagged in shape as well, making these chambers quite interesting to see. The jagged triangle shapes are designed so that what is reflected from them tends to spread in random directions, and what is added together from all the random reflections tends to add incoherently and is thus suppressed further. A picture of an anechoic chamber is shown in the following picture, along with some test equipment:



The drawback to anechoic chambers is that they often need to be quite large. Often antennas need to be several wavelengths away from each other at a minimum to simulate far-field conditions. Hence, it is desired to have anechoic chambers as large as possible, but cost and practical constraints often limit their size. Some defense contracting companies that measure the Radar Cross Section of large airplanes or other objects are known to have anechoic chambers the size of basketball courts, although this is not ordinary. Universities with anechoic chambers typically have chambers that are 3-5 meters in length, width and height. Because of the size constraint, and because RF absorbing material typically works best at UHF and higher, anechoic chambers are most often used for frequencies above 300 MHz. Finally, the chamber should also be large enough that the source antenna's main lobe is not in view of the side walls, ceiling or floor.

2.1.3 Elevated Ranges

Elevated Ranges are outdoor ranges. In this setup, the source and antenna under test are mounted above the ground. These antennas can be on mountains, towers, buildings, or wherever one finds that is suitable. This is often done for very large antennas or at low frequencies (VHF and below, <100 MHz) where indoor measurements would be intractable. The basic diagram of an elevated range is shown in Figure 2.

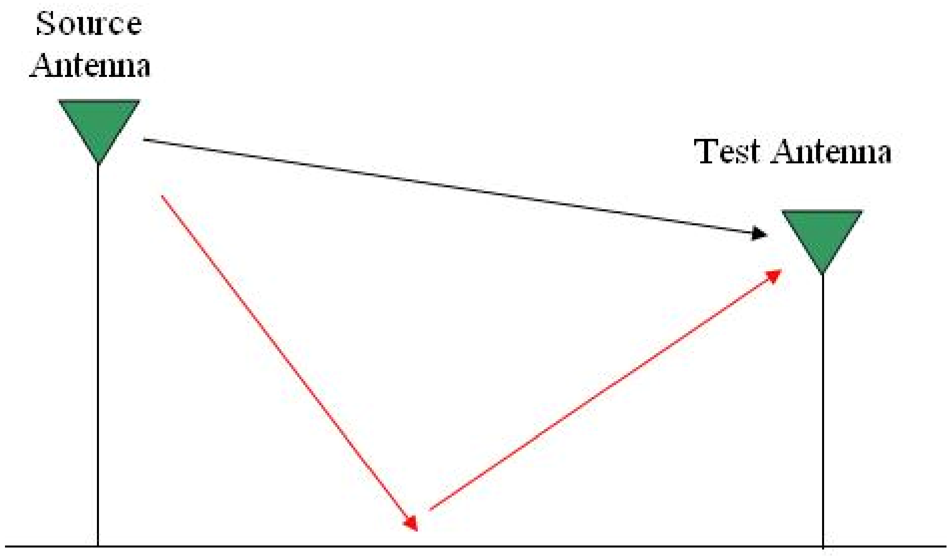


Figure 2. Illustration of elevated range.

The source antenna is not necessarily at a higher elevation than the test antenna, I just showed it that way here. The line of sight (LOS) between the two antennas (illustrated by the black ray in Figure 2) must be unobstructed. All other reflections (such as the red ray reflected from the ground) are undesirable. For elevated ranges, once a source and test antenna location are determined, the test operators then determine where the significant reflections will occur, and attempt to minimize the reflections from these surfaces. Often rf absorbing material is used for this purpose, or other material that deflects the rays away from the test antenna.

2.1.4 Compact Ranges

The source antenna must be placed in the far field of the test antenna. The reason is that the wave received by the test antenna should be a plane wave for maximum accuracy. Since antennas radiate spherical waves, the antenna needs to be sufficiently far such that the wave radiated from the source antenna is approximately a plane wave - see Figure 3.

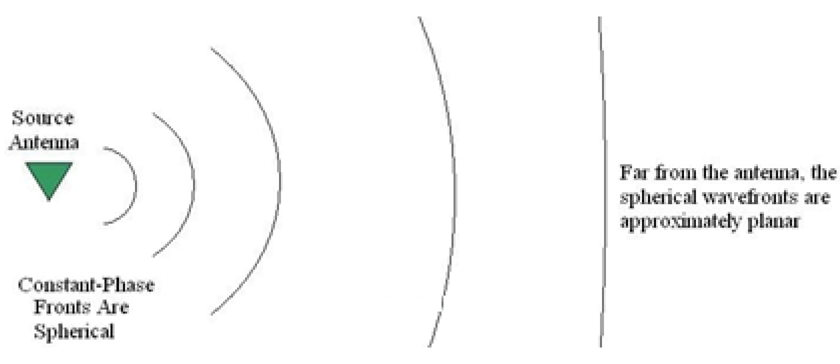


Figure 3. A source antenna radiates a wave with a spherical wavefront.

However, for indoor chambers there is often not enough separation to achieve this. One method to fix this problem is via a compact range. In this method, a source antenna is oriented towards a reflector, whose shape is designed to reflect the spherical wave in an approximately planar manner. This is very similar to the principle upon which a dish antenna operates. The basic operation is shown in Figure 4.

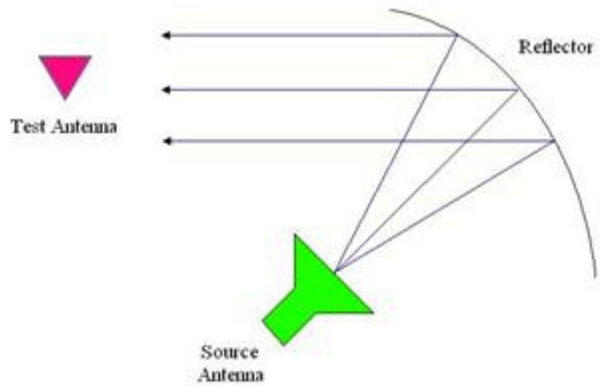


Figure 4. Compact Range - the spherical waves from the source antenna are reflected to be planar (collimated).

The length of the parabolic reflector is typically desired to be several times as large as the test antenna. The source antenna in Figure 4 is offset from the reflector so that it is not in the way of the reflected rays. Care must also be exercised in order to keep any direct radiation (mutual coupling) from the source antenna to the test antenna.

2.2 MEASURING RADIATION PATTERN

Now that we have our measurement equipment and an antenna range, we can perform some antenna measurements. We will use the source antenna to illuminate the antenna under test with a plane wave from a specific direction. The polarization and antenna gain (for the fields radiated toward the test antenna) of the source antenna should be known.

Due to reciprocity, the radiation pattern from the test antenna is the same for both the receive and transmit modes. Consequently, we can measure the radiation pattern in the receive or transmit mode for the test antenna. We will describe the receive case for the antenna under test.

The test antenna is rotated using the test antenna's positioning system. The received power is recorded at each position. In this manner, the magnitude of the radiation pattern of the test antenna can be determined. The coordinate system of choice for the radiation pattern is spherical coordinates.

Measurement Example

An example should make the process reasonably clear. Suppose the radiation pattern of a microstrip antenna is to be obtained. As is usual, lets let the direction the patch faces ('normal' to the surface of the patch) be towards the z-axis. Suppose the source antenna illuminates the test antenna from +y-direction, as shown in Figure 1.

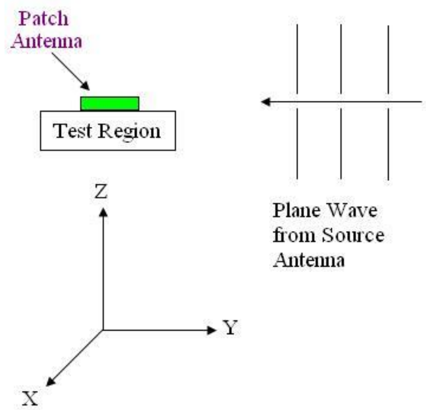


Figure 1. A patch antenna oriented towards the z-axis with a Source illumination from the +y-direction.

In Figure 1, the received power for this case represents the power from the angle:$(\theta, \emptyset) = (90^o, 90^o)$. We record this power, change the position and record again. Recall that we only rotate the test antenna, hence it is at the same distance from the source antenna. The source power again comes from the same direction. Suppose we want to measure the radiation pattern normal to the patch's surface (straight above the patch). Then the measurement would look as shown in Figure 2.

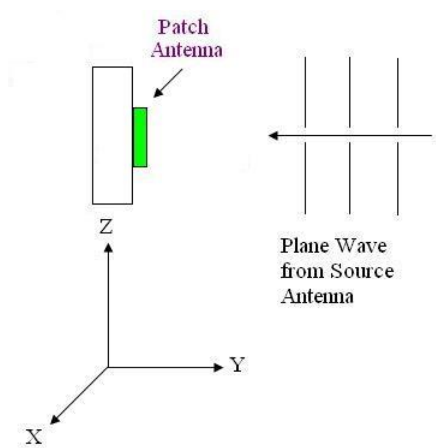


Figure 2. A patch antenna rotated to measure the radiation power at normal incidence.

In Figure 2, the positioning system rotating the antenna such that it faces the source of illumination. In this case, the received power comes from direction $(\theta, \emptyset) = (0^o, 0^o)$.. So by rotating the antenna, we can obtain "cuts" of the radiation pattern - for instance the E-plane cut or the H-plane cut. A "great circle" cut is when θ =0 and $\emptyset$ is allowed to vary from 0 to 360 degrees. Another common radiation pattern cut (a cut is a 2d 'slice' of a 3d radiation pattern) is when $\emptyset$ is fixed and θ varies from 0 to 180 degrees. By measuring the radiation pattern along certain slices or cuts, the 3d radiation pattern can be determined.

It must be stressed that the resulting radiation pattern is correct for a given polarization of the source antenna. For instance, if the source is horizontally polarized (see polarization of plane waves), and the test antenna is vertically polarized, the resulting radiation pattern will be zero everywhere. Hence, the radiation patterns are sometimes classified as H-pol (horizontal polarization) or V-pol (vertical polarization). See also cross-polarization.

In addition, the radiation pattern is a function of frequency. As a result, the measured radiation pattern is only valid at the frequency the source antenna is transmitting at. To obtain broadband measurements, the frequency transmitted must be varied to obtain this information.

2.3 GAIN MEASUREMENTS

On the previous page on measuring radiation patterns, we saw how the radiation pattern of an antenna can be measured. This is actually the "relative" radiation pattern, in that we don't know what the peak value of the gain actually is (we're just measuring the received power, so in a sense can figure out how directive an antenna is and the shape of the radiation pattern). In this page, we will focus on measuring the peak gain of an antenna - this information tells us how much power we can hope to receive from a given plane wave.

We can measure the peak gain using the Friis Transmission Equation and a "gain standard" antenna. A gain standard antenna is a test antenna with an accurately known gain and polarization (typically linear). The most popular types of gain standard antennas are the thin half-wave dipole antenna (peak gain of 2.15 dB) and the pyramidal horn antenna (where the peak gain can be accurately calculated and is typically in the range of 15-25 dB). Consider the test setup shown in Figure 1. In this scenario, a gain standard antenna is used in the place of the test antenna, with the source antenna transmitting a fixed amount of power (PT). The gains of both of these antennas are accurately known.

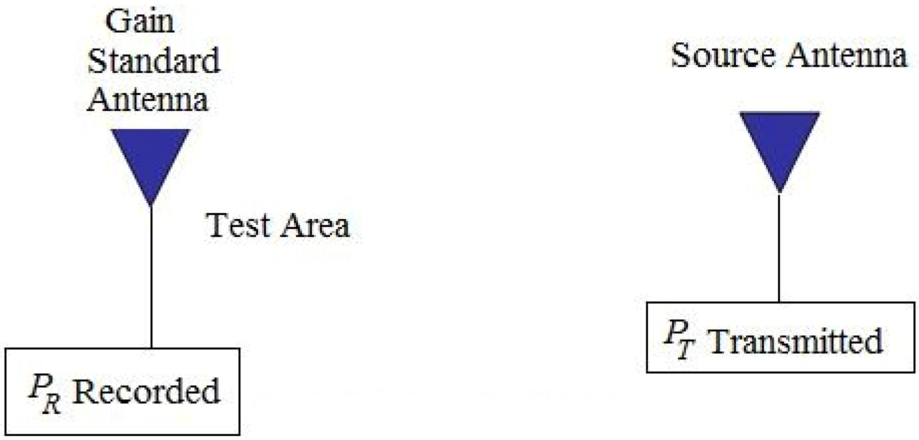


Figure 1. Record the received power from a gain standard antenna.

From the Friis transmission equation, we know that the power received (*PR*) is given by:

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

If we replace the gain standard antenna with our test antenna (as shown in Figure 2), then the only thing that changes in the above equation is *GR* - the gain of the receive antenna. The separation between the source and test antennas is fixed, and the frequency will be held constant as well.

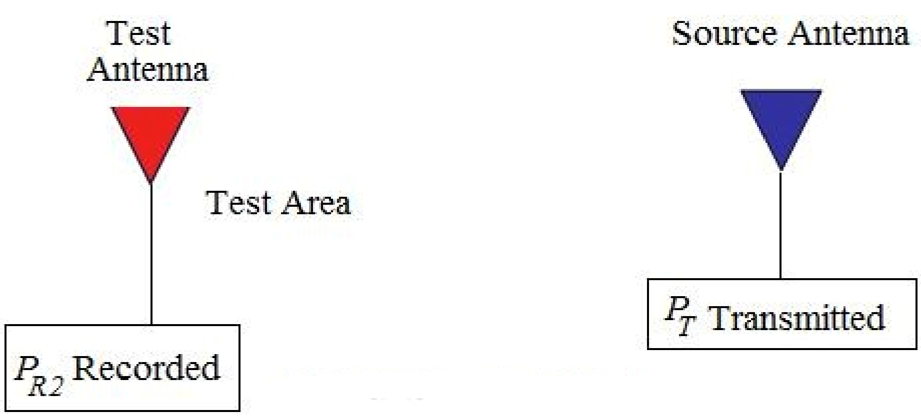


Figure 2. Record the received power with the test antenna (same source antenna).

Let the received power from the test antenna be *PR2*. If the gain of the test antenna is higher than the gain of the "gain standard" antenna, then the received power will increase. Using our measurements, we can easily calculate the gain of the test antenna. Let *Gg* be the gain of the "gain standard" antenna, *PR* be the power received with the gain antenna under test, and *PR2* be the power received with the test antenna. Then the gain of the test antenna (*GT*) is (in linear units):

$$G_T = G_G \frac{P_{R2}}{P_R}$$

The above equation uses linear units (non-dB). If the gain is to be specified in decibels, (power received still in Watts), then the equation becomes:

$$[G_T]_{dB} = [G_G]_{dB} + 10\log_{10}\left(\frac{P_{R2}}{P_R}\right)$$

And that is all that needs done to determine the gain for an antenna in a particular direction.

Efficiency and Directivity

Recall that the directivity can be calculated from the measured radiation pattern without regard to what the gain is. Typically this can be performed by approximated the integral as a finite sum, which is pretty simple.

Recall that the efficiency of an antenna is simply the ratio of the peak gain to the peak directivity:

$$\varepsilon = \frac{G}{D}$$

Hence, once we have measured the radiation pattern and the gain, the efficiency follows directly from these.

2.4 IMPEDANCE MEASUREMENTS

In this section, we'll be concerned with measuring the impedance of an antenna. As stated previously, the impedance is fundamental to an antenna that operates at RF frequencies (high frequency). If the impedance of an antenna is not "close" to that of the transmission line, then very little power will be transmitted by the antenna (if the antenna is used in the transmit mode), or very little power will be received by the antenna (if used in the receive mode). Hence, without proper impedance (or an impedance matching network), out antenna will not work properly.

Before we begin, I'd like to point out that object placed around the antenna will alter its radiation pattern. As a result, its input impedance will be influenced by what is around it - i.e. the environment in which the antenna is tested. Consequently, for the best accuracy the impedance should be measured in an environment that will most closely resemble where it is intended to operate. For instance, if a blade antenna (which is basically a dipole shaped like a paddle) is to be utilized on the top of a fuselage of an airplane, the test measurement should be performed on top of a cylinder type metallic object for maximum accuracy. The term driving point impedance is the input impedance measured in a particular environment, and self-impedance is the impedance of an antenna in free space, with no objects around to alter its radiation pattern.

2.4.1 Impedance Measurements Using Vector Network Analyzer (VNA).

Fortunately, impedance measurements are pretty easy if you have the right equipment. In this case, the right equipment is a Vector Network Analyzer (VNA). This is a measuring tool that can be used to measure the input impedance as a function of frequency. Alternatively, it can plot S11 (return loss), and the VSWR, both of which are frequency-dependent functions of the antenna impedance. The Agilent 8510 Vector Network Analyzer is shown in Figure 1.

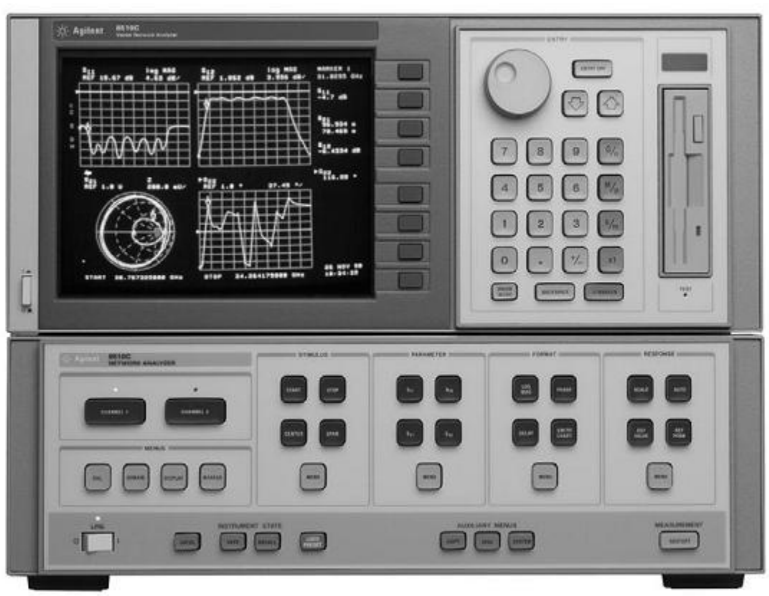


Figure 1. The popular Agilent (HP) 8510 VNA.

Let's say we want to perform an impedance measurement from 400-500 MHz. Step 1 is to make sure that our VNA is specified to work over this frequency range. Network Analyzers work over specified frequency ranges, which go into the low MHz range (30 MHz or so) and up into the high GigaHertz range (110 GHz or so, depending on how expensive it is). Once we know our network analyzer is suitable, we can move on.

Next, we need to calibrate the VNA. This is much simpler than it sounds. We will take the cables that we are using for probes (that connect the VNA to the antenna) and follow a simple procedure so that the effect of the cables (which act as transmission lines) is calibrated out. To do this, typically your VNA will be supplied with a "cal kit" which contains a matched load (50 Ohms), an open circuit load and a short circuit load. We look on our VNA and scroll through the menus till we find a calibration button, and then do what it says. It will ask you to apply the supplied loads to the end of your cables, and it will record data so that it knows what to expect with your cables. You will apply the 3 loads as it tells you, and then your done. Its pretty simple, you don't even need to know what you're doing, just follow the VNA's instructions, and it will handle all the calculations.

Now, connect the VNA to the antenna under test. Set the frequency range you are interested in on the VNA. If you don't know how, just mess around with it till you figure it out, there are only so many buttons and you can't really screw anything up.

If you request output as an S-parameter (S11), then you are measuring the return loss. In this case, the VNA transmits a small amount of power to your antenna and measures how much power is reflected back to the VNA. A sample result (from the slotted waveguides page) might look something like:

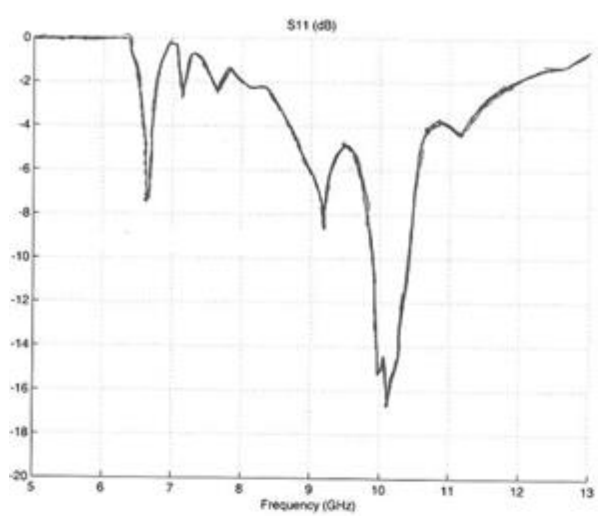


Figure 2. Example S11 measurement.

Note that the S-parameter is basically the magnitude of the reflection coefficient, which depends on the antenna impedance as well as the impedance of the VNA, which is typically 50 Ohms. So this measurement typically measures how close to 50 Ohms the antenna impedance is.

2.4.2 Impedance Measurements Using a Smith Chart

Another popular output is for the impedance to be measured on a Smith Chart. A Smith Chart is basically a graphical way of viewing input impedance (or reflection coefficient) that is easy to read. The center of the Smith Chart represented zero reflection coefficient, so that the antenna is perfectly matched to the VNA. The perimeter of the Smith Chart represents a reflection coefficient with a magnitude of 1 (all power reflected), indicating that the antenna is very poorly matched to the VNA. The magnitude of the reflection coefficient (which should be small for an antenna to receive or transmit properly) depends on how far from the center of the Smith Chart you are. As an example, consider Figure 3. The reflection coefficient is measured across a frequency range and plotted on a Smith Chart.

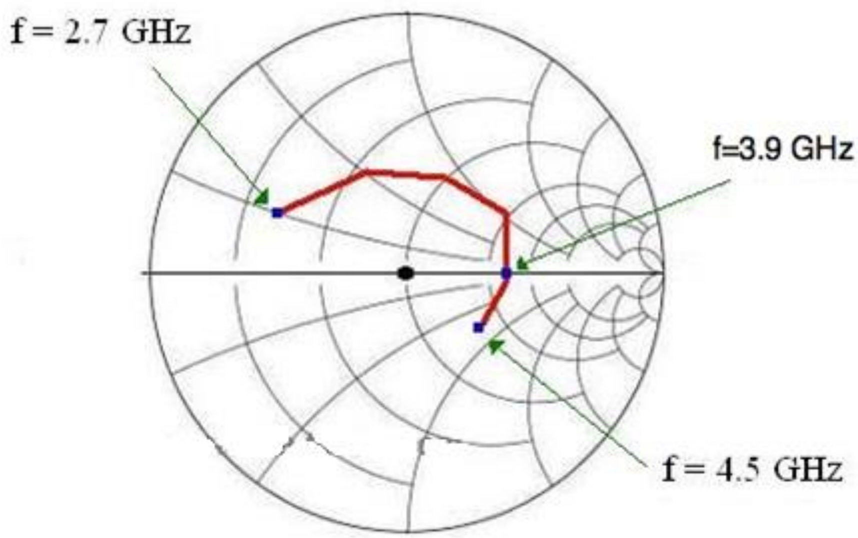


Figure 3. Smith Chart Graph of Impedance Measurement versus Frequency.

In Figure 3, the black circular graph is the Smith Chart. The black dot at the center of the Smith Chart is the point at which there would be zero reflection coefficient, so that the antenna's impedance is perfectly matched to the generator or receiver. The red curved line is the measurement. This is the impedance of the antenna, as the frequency is scanned from 2.7 GHz to 4.5 GHz. Each point on the line represents the impedance at a particular frequency. Points above the equator of the Smith Chart represent impedances that are inductive - they have a positive reactance (imaginary part). Points below the equator of the Smith Chart represent impedances that are capacitive - they have a negative reactance (for instance, the impedance would be something like Z = R - jX).

To further explain Figure 3, the blue dot below the equator in Figure 3 represents the impedance at f=4.5 GHz. The distance from the origin is the reflection coefficient, which can be estimated to have a magnitude of about 0.25 since the dot is 25% of the way from the origin to the outer perimeter.

As the frequency is decreased, the impedance changes. At f = 3.9 GHz, we have the second blue dot on the impedance measurement. At this point, the antenna is resonant, which means the impedance is entirely real. The frequency is scanned down until f=2.7 GHz, producing the locus of points (the red curve) that represents the antenna impedance over the frequency range. At f = 2.7 GHz, the impedance is inductive, and the reflection coefficient is about 0.65, since it is closer to the perimeter of the Smith Chart than to the center.

In summary, the Smith Chart is a useful tool for viewing impedance over a frequency range in a concise, clear form.

Finally, the magnitude of the impedance could also be measured by measuring the VSWR (Voltage Standing Wave Ratio). The VSWR is a function of the magnitude of the reflection coefficient, so no phase information is obtained about the impedance (relative value of reactance divided by resistance). However, VSWR gives a quick way of estimated how much power is reflected by an antenna. Consequently, in antenna data sheets, VSWR is often specified, as in "VSWR: < 3:1 from 100-200 MHz". Using the formula for the VSWR, you can figure out that this menas that less than half the power is reflected from the antenna over the specified frequency range.

In summary, there are a bunch of ways to measure impedance, and a lot are a function of reflected power from the antenna. We care about the impedance of an antenna so that we can properly transfer the power to the antenna.

2.5 DIRECTIVITY MEASUREMENT

The directivity measurements are directly related to the pattern measurements. Once the pattern is found over a sphere, the directivity can be determined using the definition:

$$Do = 4\pi \frac{F_{max}(\theta,\emptyset)}{\int_0^{2\pi}\int_0^{\pi} F_{max}(\theta,\emptyset)\sin\theta\, d\theta\, d\emptyset}$$

where $F_{max}(\theta,\emptyset)$is the power pattern of the test antenna and $(\theta,\emptyset)$is the direction of maximum radiation.

Generally, is measured by sampling the field over a sphere of constant radius R. The spacing between the sampling points depends on the directive properties of the antenna and on the desired accuracy. The integral

$$\pi = \int_0^{2\pi}\int_0^{\pi} F_{max}(\theta,\emptyset)\sin\theta\, d\theta\, d\emptyset$$

is computed numerically, e.g.,

$$\pi \approx \frac{\pi}{N}\frac{2\pi}{M}\sum_{j=1}^{M}\left[\sum_{i=1}^{N} F(\theta_i,\emptyset_j)\sin\theta i\right]$$

If the antenna is circularly or elliptically polarized, two measurements of the above type must be carried out in order to determine the partial directivities, D_θ and $D_\emptyset$. Then, the total directivity is calculated as

$$Do = D_\theta + D_\emptyset$$

where the partial directivities are defined as

$$D_\theta = 4\pi \frac{F_{\theta max}}{\pi_\theta + \pi_\emptyset}$$

$$D_\emptyset = 4\pi \frac{F_{\emptyset max}}{\pi_\theta + \pi_\emptyset}$$

MODULE IV

4.1 BEAM STEERING

Beam steering (also spelled beamsteering or beam-steering) is about changing the direction of the main lobe of a radiation pattern. In radio systems, beam steering may be accomplished by switching the antenna elements or by changing the relative phases of the RF signals driving the elements.

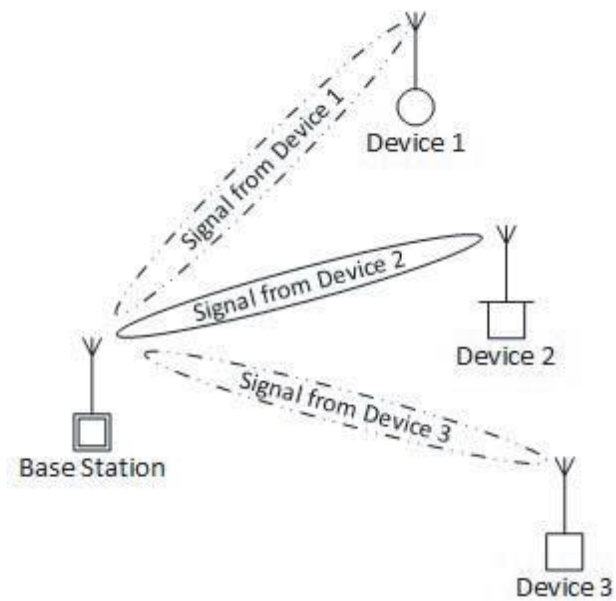


Figure 1. Illustrating beam steering.

4.1.1 BEAM STEERING TECHNIQUES

Lots of techniques have been used to steer an antenna's radiation pattern over the years, including:

(i) Mechanical steering.
(ii) Beamforming.
(iii) Reflectarray.
(iv) Parasitic steering.
(v) Integrated lens antennas (ILAs).
(vi) Switched beam antennas.
(vii) Traveling wave antennas.
(viii) Retrodirective antennas.
(ix) Metamaterial Antennas.

4.1.2 Mechanical Steering

This involves manually turning the antenna to face the direction of interest. Mechanical steering becomes undesirable and difficult when we consider factors such as antenna size, weight, and weather conditions. Mechanical steering is often performed by means of electric motors.

4.1.3 Beamforming

The term beamforming refers to the process of combining signals from an array of elements to form a highly directional beam of radiation. It is also used to precisely align the phases of an incoming signal from different parts of an array to form a well-defined beam in a specific direction. This is achieved by implementing a time delay on each element's signal. Beamforming techniques can be sub-classified as: RF/analogue, digital, or hybrid beamforming.

4.1.3.1. RF/Analogue Beamforming

From Fig. the signal from an element of the phased array is fed through a low noise amplifier after which the time delay is implemented by means of a phase shifter. The time delayed signals from each element are summed to produce the resultant beam by the beamformer. This method of beamforming is relatively cheap and low power when compared to digital beamforming.

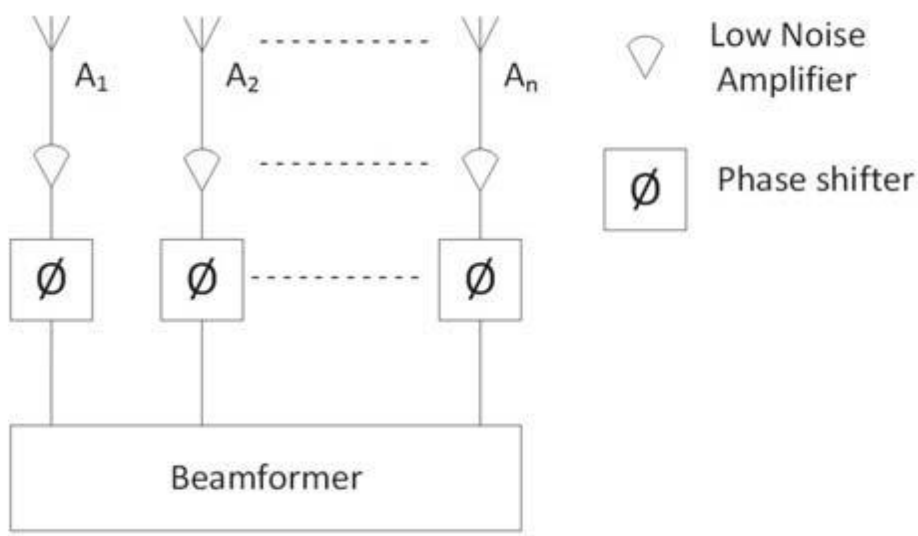


Figure 2. RF/analogue beamforming architecture.

Phased arrays have been the conventional way of steering beams electronically to different directions within the range of the element pattern. By changing the phases of each element in the array with phase shifters, the combined beam of the array is steered. It has the advantage of high directivity, multiple beamforming (one at a time in different directions), fast scanning when compared to mechanical steering due to its electronic circuitry, and spatial filtering.

4.1.3.2. Digital Beamforming

In digital beamforming, the signals from each antenna element are sampled by an ADC. The sampled signals are then down converted to a lower frequency by mixing the output of the ADC with a complex sinusoid to yield a baseband signal. The baseband signals are then split into different channels by using channelisers. The resulting channels are then fed into a beamformer. The beamformer applies steering and correction coefficients to each channel before summing the channels to produce a radiated beam.

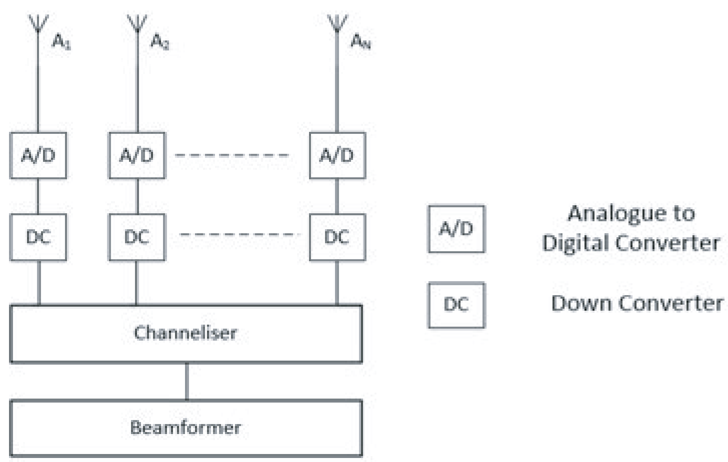


Figure 3. Digital beamforming architecture

In digital beamforming, the signals from each antenna element are sampled by an ADC. The sampled signals are then down converted to a lower frequency by mixing the output of the ADC with a complex sinusoid to yield a baseband signal. The baseband signals are then split into different channels by using channelisers. The resulting channels are then fed into a beamformer. The beamformer applies steering and correction coefficients to each channel before summing the channels to produce a radiated beam.

4.1.3.3. Hybrid Beamforming

hybrid beamforming simply involves attaching digital beamforming architecture to the end of the RF/analogue beamformer. The RF/analogue beamforming section controls the phase of the signal at each element while the digital beamforming section applies baseband signal processing to enhance the performance of the multiple data channels

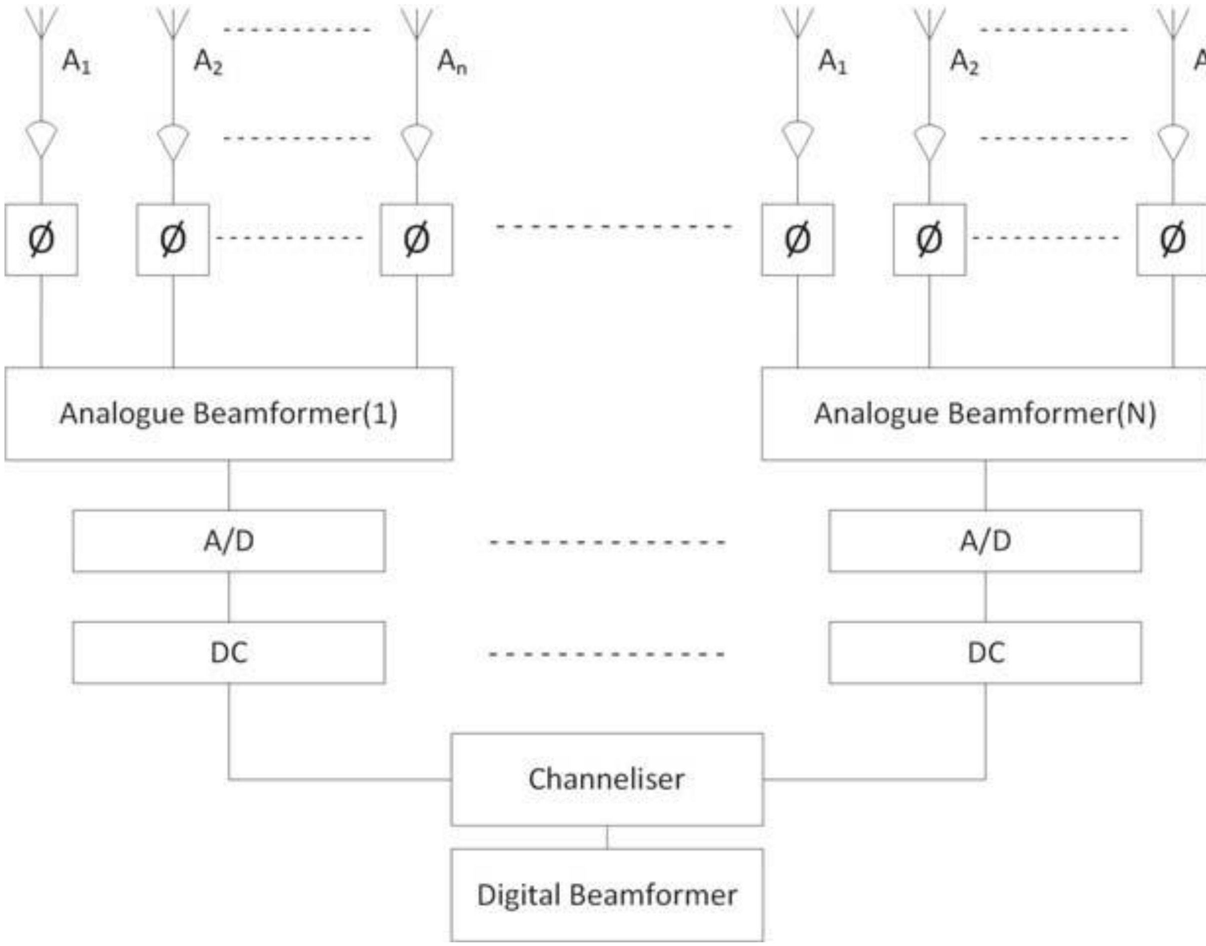


Figure 4. Hybrid architecture.

To find the optimum beam steering technique, the following properties are vital:

(i) **Insertion loss (IL):** This is the loss that arises as a result of inserting a device in a transmission line. It is mathematically the difference between the power that goes in and the power that comes out of the device expressed in dB

$$\text{Insertion loss (dB)} = 10\log\frac{P_{in}}{P_{out}}$$

(ii) **Steering range:** The maximum angle away from the bore sight direction to which the beam can be steered. The steering range depends on the radiating element.

For example, a phased array made up of microstrip patch antennas cannot be steered over 360◦ by means of phase shifters due to the limitation of the element. While a monopole can be steered over 360◦ due to its omnidirectional radiation pattern. Hence, the steering range of techniques will be classified as either full range (based on the element) or a specific angle based on literature.

(iii) **Steering resolution (S-Res):** This is the step increment that can be achieved while covering the steering range. It could be continuous, predefined or fine. Continuous signifying that it achieves any steering angle needed. Predefined signifying large angles greater than 20◦ and fine signifying angle steps of 2◦ or less.

(iv) **Steering speed:** This is how fast the beam steering can be performed. The speed of steering determines the sensitivity of the technique and hence will determine if it is suitable for dynamic or static environment. The steering speed for a mobile user driving along the road will be different from that of a backhaul antenna that needs to switch its beam to a different node in the network.

(v) **Complexity:** This takes into account the ease of implementing a technique. This also has a direct effect on the cost of implementing the technique. It will be rated as either high, moderate or low.

(vi) **Bandwidth phase deviation (BPD):** This term refers to the uniformity of beam steering, as a function of frequency, across the operating bandwidth of the antenna.

(vii) **Size**: The size of the manufactured device will determine the application that will make use of it. If it becomes very bulky, applications such as smartphones and tablets will not be able to accommodate it.

(viii) **Cost:** On a sales perspective, the cost of implementing a technique will influence the cost of the device.

4.2 TRAVELLING WAVE ANTENNAS

A traveling-wave antenna is a class of antenna that uses a traveling wave on a guiding structure as the main radiating mechanism. Their distinguishing feature is that the radio-frequency current that generates the radio waves travels through the antenna in one direction.

4.2.1.RHOMBIC ANTENNA

The Rhombic Antenna is an equilateral parallelogram shaped antenna. Generally, it has two opposite acute angles. The tilt angle, θ is approximately equal to 90° minus the angle of major lobe. Rhombic antenna works under the principle of travelling wave radiator. It is arranged in the form of a rhombus or diamond shape and suspended horizontally above the surface of the earth.

4.2.1.1Frequency Range

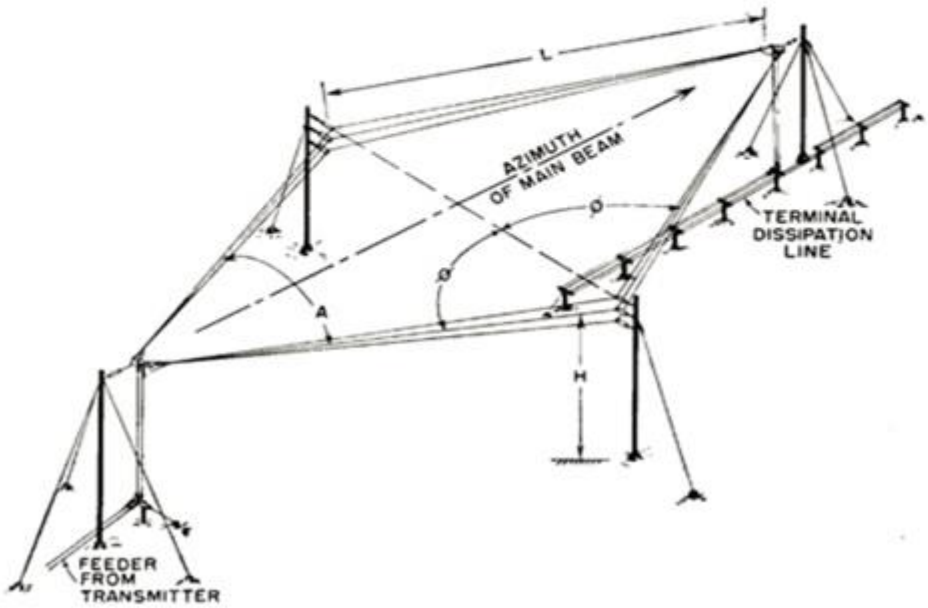
The frequency range of operation of a Rhombic antenna is around 3MHz to 300MHz. This antenna works in HF and VHF ranges.

4.2.1.2.Construction of Rhombic Antenna

Rhombic antenna can be regarded as two V-shaped antennas connected end-to-end to form obtuse angles. Due to its simplicity and ease of construction, it has many uses −

- In HF transmission and reception
- Commercial point-to-point communication

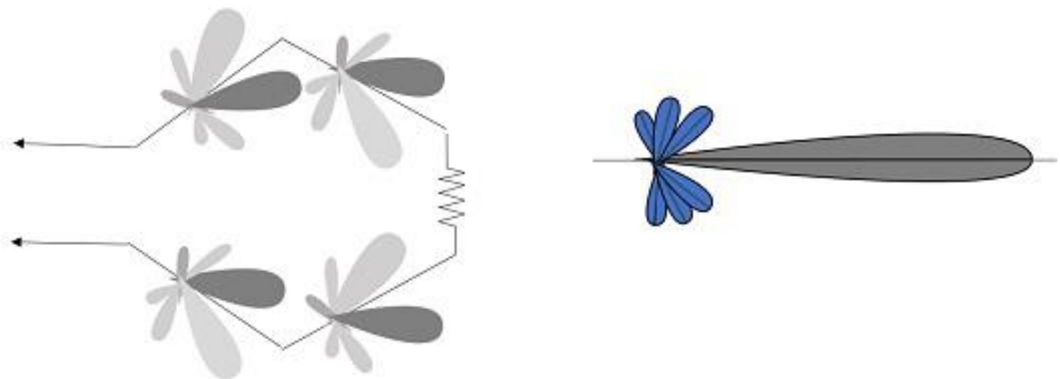
The construction of the rhombic antenna is in the form a rhombus, as shown in the figure.



The two sides of rhombus are considered as the conductors of a two-wire transmission line. When this system is properly designed, there is a concentration of radiation along the main axis of radiation. In practice, half of the power is dissipated in the terminating resistance of the antenna. The rest of the power is radiated. The wasted power contributes to the minor lobes. The maximum gain from a rhombic antenna is along the direction of the main axis, which passes through the feed point to terminate in free space. The polarization obtained from a horizontal rhombic antenna is in the plane of rhombus, which is horizontal.

4.2.1.3 Radiation Pattern

The radiation pattern of the rhombic antenna is shown in the following figure. The resultant pattern is the cumulative effect of the radiation at all four legs of the antenna. This pattern is uni-directional, while it can be made bi-directional by removing the terminating resistance.



INDIVIDUAL RADIATION PATTERNS RESULTANT RADIATION PATTERNS

The main disadvantage of rhombic antenna is that the portions of the radiation, which do not combine with the main lobe, result in considerable side lobes having both horizontal and vertical polarization.

4.2.1.4 Advantages

The following are the advantages of Rhombic antenna −

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

4.2.1.5 Disadvantages

The following are the disadvantages of Rhombic antenna −

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

4.2.1.6 Applications

The following are the applications of Rhombic antenna −

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

- Used in point-to-point communications
-

4.2.2 V-ANTENNA

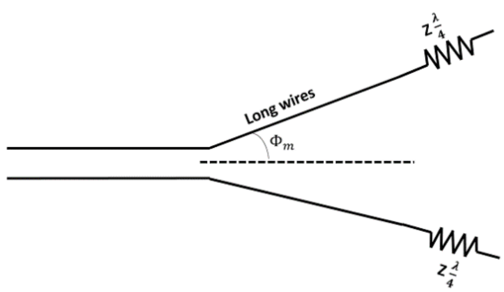
V-Antenna is formed by arranging the long wire in a V-shaped pattern. The end wires are called as legs. This antenna is a bi-directional resonant antenna.

4.2.2.1 Frequency Range

The frequency range of operation of V-antenna is around 3 to 30 MHz. This antenna works in high frequency range.

4.2.2.2.Construction & Working of V-Antennas

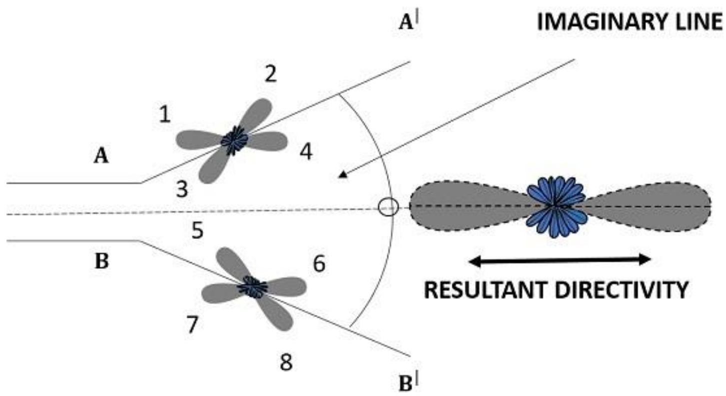
Two long wires are connected in the shape of V to make a V-antenna. The two long wires are excited with 180° out of phase. As the length of these wires increases, the gain and directivity also increases.
The following figure shows a V-antenna with the transmission line impedance z and the lengh of the wire λ/2, making an angle Φm with the axis, which is called as apex angle.



The gain achieved by V-antenna is higher than normal single long wire antenna. The gain in this V-formation is nearly twice compared to the single long wire antenna, which has a length equal to the legs of V-antenna. If wide range of radiation is to be achieved, the apex angle should have an average value between higher and lower frequencies in terms of the number of λ/2 in each leg.

4.2.2.3 Radiation Pattern

The radiation pattern of a V-antenna is bi-directional. The radiation obtained on each transmission line is added to obtain the resultant radiation pattern. This is well explained in the following figure –



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

4.2.2.4. Advantages

The following are the advantages of V-antenna −
Construction is simple
High gain
Low manufacturing cost

4.2.2.5 Disadvantages

The following are the disadvantages of V-antenna −

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

4.2.2.6 Applications

The following are the applications of V-antenna −

- Used for commercial purposes
- Used in radio communications

4.3 HORN ANTENNAS

Horn antennas are very popular at UHF (300 MHz-3 GHz) and higher frequencies. Horn antennas often have a directional radiation pattern with a high antenna gain, which can range up to 25 dB in some cases, with 10-20 dB being typical. Horn antennas have a wide impedance bandwidth, implying that the input impedance is slowly varying over a wide frequency range (which also implies low values for S11 or VSWR). The bandwidth for practical horn antennas can be on the order of 20:1 (for instance, operating from 1 GHz-20 GHz), with a 10:1 bandwidth not being uncommon.

The gain of horn antennas often increases (and the beamwidth decreases) as the frequency of operation is increased. This is because the size of the horn aperture is always measured in wavelengths; at higher frequencies the horn antenna is "electrically larger"; this is because a higher frequency has a smaller wavelength. Since the horn antenna has a fixed physical size (say a square aperture of 20 cm across, for instance), the aperture is more wavelengths across at higher frequencies. And, a recurring theme in antenna theory is that larger antennas (in terms of wavelengths in size) have higher directivities.

Horn antennas have very little loss, so the directivity of a horn is roughly equal to its gain.

Horn antennas are somewhat intuitive and relatively simple to manufacture. In addition, acoustic horn antennas are also used in transmitting sound waves (for example, with a megaphone). Horn antennas are also often used to feed a dish antenna, or as a "standard gain" antenna in measurements.

Popular versions of the horn antenna include the E-plane horn, shown in Figure 1. This horn antenna is flared in the E-plane, giving the name. The horizontal dimension is constant at **w**.

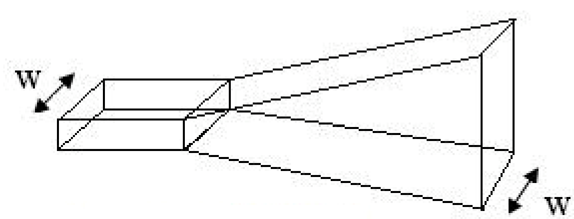


Figure 1. E-plane horn antenna.

Another example of a horn antenna is the H-plane horn, shown in Figure 2. This horn is flared in the H-plane, with a constant height for the waveguide and horn of *h*.

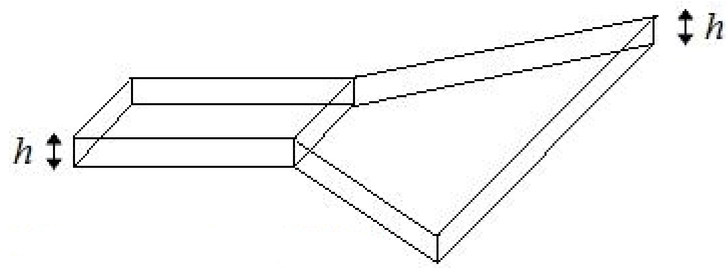


Figure 2. H-Plane horn antenna.

The most popular horn antenna is flared in both planes as shown in Figure 3. This is a pyramidal horn, and has a width *B* and height *A* at the end of the horn.

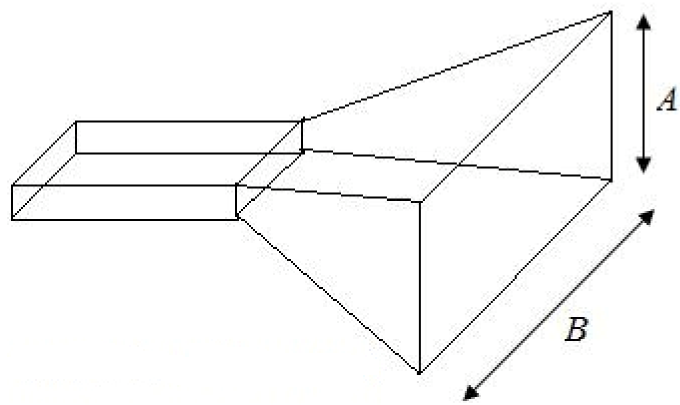


Figure 3. Pyramidal horn antenna.

Horn antennas are typically fed by a section of a waveguide, as shown in Figure 4. The waveguide itself is often fed with a short dipole, which is shown in red in Figure 4. A waveguide is simply a hollow, metal cavity (see the waveguide tutorial). Waveguides are used to guide electromagnetic energy from one place to another. The waveguide in Figure 4 is a rectangular waveguide of width b and height a, with $b>a$. The E-field distribution for the dominant mode is shown in the lower part of Figure 1.

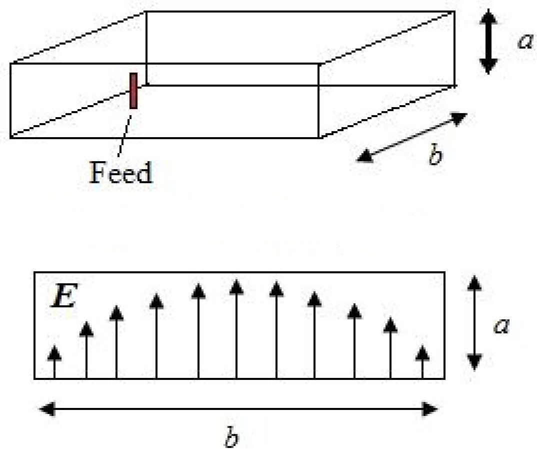


Figure 4. Waveguide used as a feed to horn antennas.

FIELDS AND GEOMETRICAL PARAMETERS FOR HORN ANTENNAS

Antenna texts typically derive very complicated functions for the radiation patterns of horn antennas. To do this, first the E-field across the aperture of the horn antenna is assumed to be known, and the far-field radiation pattern is calculated using the radiation equations. While this is conceptually straight forward, the resulting field functions end up being extremely complex, and personally I don't feel add a whole lot of value. If you would like to see these derivations, pick up any antenna textbook that has a section on horn antennas.

Instead of the traditional academic derivation approach, I'll state some results for the horn antenna and show some typical radiation patterns, and attempt to provide a feel for the design parameters of horn antennas. Since the pyramidal horn antenna is the most popular, we'll analyze that. The E-field distribution across the aperture of the horn antenna is what is responsible for the radiation.

The radiation pattern of a horn antenna will depend on B and A (the dimensions of the horn at the opening) and R (the length of the horn, which also affects the flare angles of the horn), along with b and a (the dimensions of the waveguide). These parameters are optimized in order to taylor the performance of the horn antenna, and are illustrated in the following Figures.

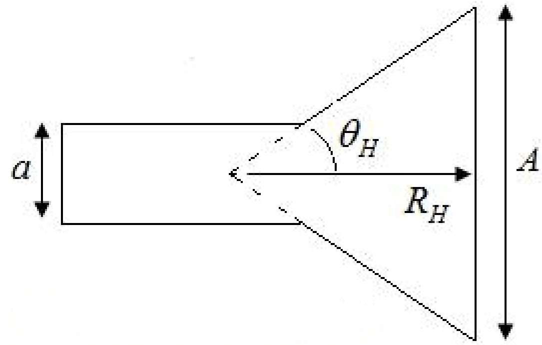


Figure 5. Cross section of waveguide, cut in the H-plane.

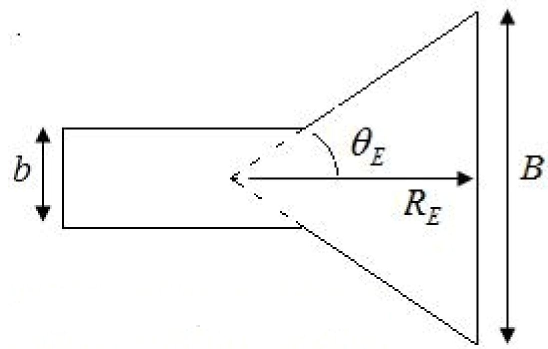


Figure 6. Cross section of waveguide, cut in the E-plane.

Observe that the flare angles (θ_E and θ_H) depend on the height, width and length of the horn antenna.

Given the coordinate system of Figure 6 (which is centered at the opening of the horn), the radiation will be maximum in the +z-direction (out of the screen).

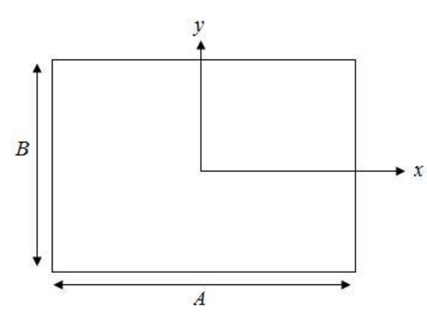


Figure 7. Coordinate system used, centered on the horn antenna opening.

The E-field distribution across the opening of the horn antenna can be approximated by:

$$\mathbf{E}_A = \hat{\mathbf{y}} E_0 \cos\left(\frac{\pi x}{A}\right) e^{-j\frac{k}{2}\left(\frac{x^2}{R_H} + \frac{y^2}{R_E}\right)}$$

The E-field in the far-field will be linearly polarized, and the magnitude will be given by:

$$|\mathbf{E}| = \frac{k}{4\pi r}(1+\cos\theta)\int_{-B/2}^{B/2}\int_{-A/2}^{A/2} E_A(x,y)\, e^{jk(x\sin\theta\cos\phi + y\sin\theta\sin\phi)}\, dx dy$$

The above equation states that the far-fields of the horn antenna is the Fourier Transform of the fields at the opening of the horn.

4.4 THE PARABOLIC REFLECTOR ANTENNA (SATELLITE DISH)

The most well-known reflector antenna is the **parabolic reflector antenna**, commonly known as a **satellite dish antenna.** Parabolic reflectors typically have a very high gain (30-40 dB is common) and low cross polarization. They also have a reasonable bandwidth, with the fractional bandwidth being at least 5% on commercially available models, and can be very wideband in the case of huge dishes (like the Stanford "big dish" above, which can operate from 150 MHz to 1.5 GHz).

The smaller dish antennas typically operate somewhere between 2 and 28 GHz. The large dishes can operate in the VHF region (30-300 MHz), but typically need to be extremely large at this operating band.

The basic structure of a parabolic dish antenna is shown in Figure 3. It consists of a feed antenna pointed towards a parabolic reflector. The feed antenna is often a horn antenna with a circular aperture.

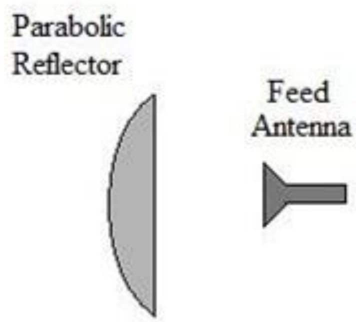


Figure 3. Components of a dish antenna.

Unlike resonant antennas like the dipole antenna which are typically approximately a half-wavelength long at the frequency of operation, the reflecting dish must be much larger than a wavelength in size. The dish is at least several wavelengths in diameter, but the diameter can be on the order of 100 wavelengths for very high gain dishes (>50 dB gain). The distance between the feed antenna and the reflector is typically several wavelenghts as well. This is in contrast to the corner reflector, where the antenna is roughly a half-wavelength from the reflector.

Geometry of Parabolic Dish Antenna

Now we'll try to explain why a paraboloid makes a great reflector. To start, let the equation of a parabola with focal length *F* can be written in the (*x,z*) plane as:

$$x^2 = 4F(F-z), \quad |x| \leq \frac{D}{2}$$

This is plotted in Figure 4.

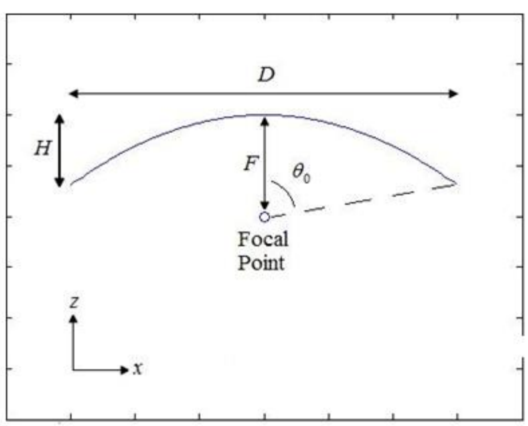


Figure 4. Illustration of parabola with defining parameters.

The parabola is completely described by two parameters, the diameter D and the focal length F. We also define two auxilliary parameters, the vertical height of the reflector (H) and the max angle between the focal point and the edge of the dish (θ_0). These parameters are related to each other by the following equations:

$$\frac{F}{D} = \frac{1}{4\tan(\theta_0/2)}$$

$$F = \frac{D^2}{16H}$$

To analyze the reflector, we will use approximations from geometric optics. Since the reflector is large relative to a wavelength, this assumption is reasonable though not precisely accurate. We will analyze the structure via straight line rays from the focal point, with each ray acting as a plane wave. Consider two transmitted rays from the focal point, arriving from two distinct angles as shown in Figure 5. The reflector is assumed to be perfectly conducting, so that the rays are completely reflected.

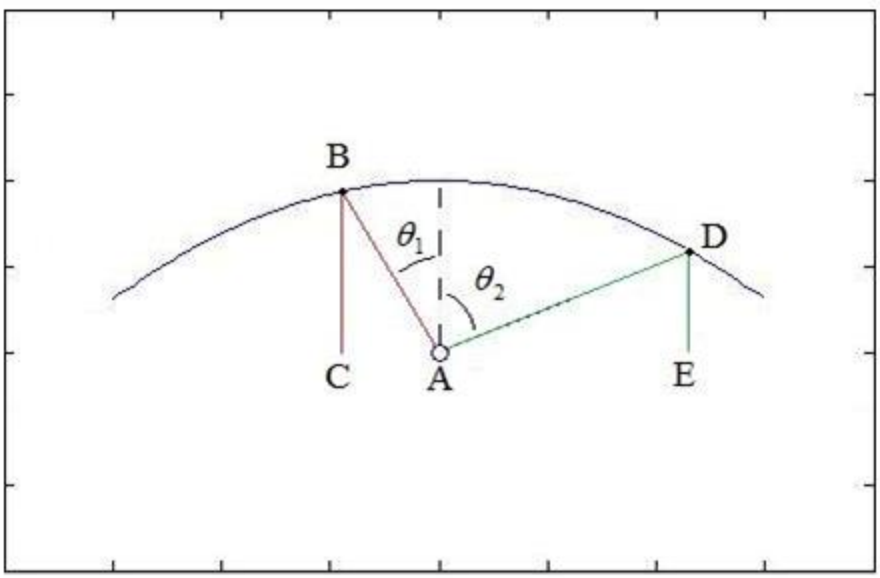


Figure 5. Two rays leaving the focal point and reflected from the parabolic reflector.

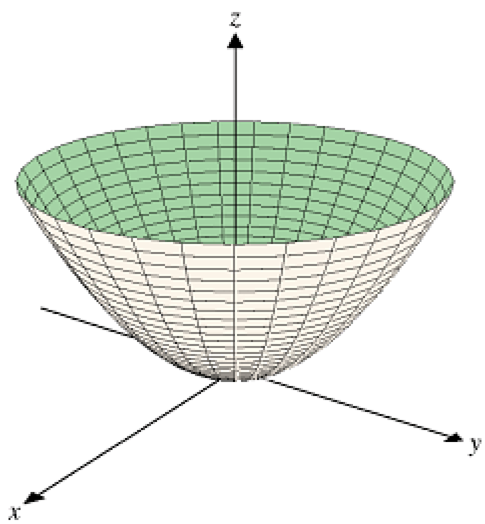
There are two observations that can be made from Figure 5. The first is that both rays end up travelling in the downward direction (which can be determined because the incident and reflected angles relative to the normal of the surface must be equal).

The rays are said to be *collimated*. The second important observation is that the path lengths ADE and ABC are equal. This can be proved with a little bit of geometry, which I won't reproduce here. These facts can be proved for any set of angles chosen. Hence, it follows that:

- All rays emanating from the focal point (the source or feed antenna) will be reflected towards the same direction.
- The distance each ray travels from the focal point to the reflector and then to the focal plane is constant.

As a result of these observations, it follows the distribution of the field on the focal plane will be in phase and travelling in the same direction. This gives rise to the parabolic dish antennas highly directional radiation pattern. This is why the shape of the dish is parabolic.

Finally, by revolving the parabola about the z-axis, a paraboloid is obtained, as shown below.



For design, the value of the diameter *D* should be increased to increase the gain of the antenna. The focal length *F* is then the only free parameter; typical values are commonly given as the ratio *F/D*, which usually range between 0.3 and 1.0. Factors affecting the choice of this ratio will be given in the following sections.
The fields across the aperture of the parabolic reflector is responsible for this antenna's radiation. The maximum possible antenna gain can be expressed in terms of the physical area of the aperture:

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

The actual gain is in terms of the effective aperture, which is related to the physical area by the efficiency term (ε). This efficiency term will often be on the order of 0.6-0.7 for a well designed dish antenna:

$$G = \varepsilon \frac{4\pi}{\lambda^2} A = \varepsilon \frac{(\pi D)^2}{\lambda^2}$$

Understanding this efficiency will also aid in understanding the trade-offs involved in the design of a parabolic reflector. The antenna efficiency can be written as the product of a series of terms:

$$\varepsilon = \varepsilon_r \varepsilon_{AT} \varepsilon_S \varepsilon_O$$

We'll walk through each of these terms.

Radiation Efficiency

The radiation efficiency ε_r is the usual efficiency that deals with ohmic losses, as discussed on the efficiency page. Since horn antennas are often used as feeds, and these have very little loss, and because the parabolic reflector is typically metallic with a very high conductivity, this efficiency is typically close to 1 and can be neglected.

Aperture Taper Efficiency

The aperture radiation efficiency ε_{AT} is a measure of how uniform the E-field is across the antenna's aperture. In general, an antenna will have the maximum gain if the E-field is uniform in amplitude and phase across the aperture (the far-field is roughly the Fourier Transform of the aperture fields). However, the aperture fields will tend to diminish away from the main axis of the reflector, which leads to lower gain, and this loss is captured within this parameter.

This efficiency can be improved by increasing the *F/D* ratio, which also lowers the cross-polarization of the radiated fields. However, as with all things in engineering, there is a tradeoff: increasing the *F/D* ratio reduces the spillover efficiency, discussed next.

Spillover Efficiency

The spillover efficiency ε_S is simple to understand. This measures the amount of radiation from the feed antenna that is reflected by the reflector. Due to the finite size of the reflector, some of the radiation from the feed antenna will travel away from the main axis at an angle greater than θ_0, thus not being reflected. This efficiency can be improved by moving the feed closer to the reflector, or by increasing the size of the reflector.

FACTORS AFFECTING PARABOLIC REFLECTOR ANTENNA GAIN

There are a number of factors that affect the parabolic antenna gain. These factors include the following:

- ***Diameter of reflecting surface*** The larger the diameter of the reflecting surface of the antenna the higher the parabolic reflector gain will be.
- ***Antenna efficiency:*** The efficiency of the antenna has a significant effect on the overall parabolic reflector gain. Typical figures are between 50 and 70%. Further details are given below.
- ***Operational wavelength:*** The parabolic reflector antenna gain is dependent upon the reflector size in terms of wavelengths. Therefore if the same reflector is used on two different frequencies, the gain will be different and inversely proportional to the wavelength.

PARABOLIC REFLECTOR ANTENNA GAIN

The parabolic antenna gain can easily be calculated from a knowledge of the diameter of the reflecting surface, the wavelength of the signal, and a knowledge or estimate of the efficiency of the antenna.

The parabolic reflector antenna gain is calculated as the gain over an isotropic source, i.e. relative to a source that radiates equally in all directions. This is a theoretical source that is used as the benchmark against which most antennas are compared. The gain is quoted in this manner is denoted as dBi.

The standard formula for the parabolic reflector antenna gain is:

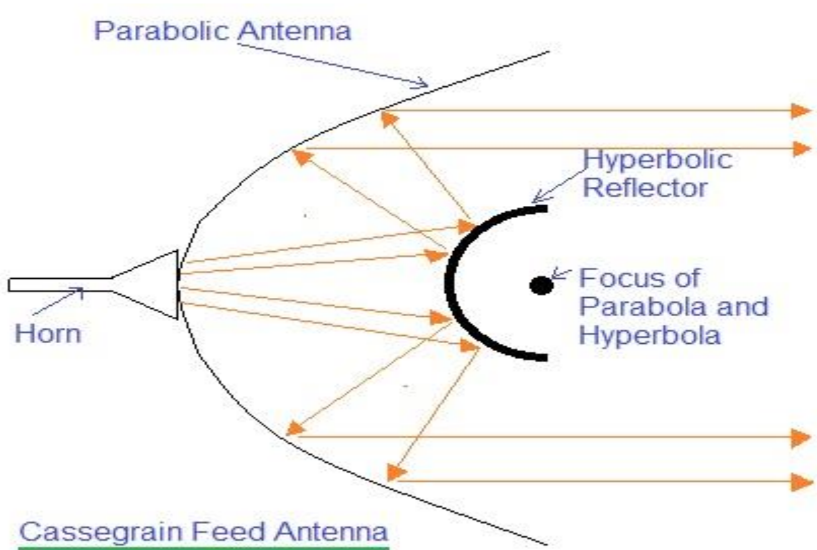
$$\text{Gain } G = 10 \log_{10} k \left(\frac{\pi D}{\lambda}\right)^2$$

Where:

G is the gain over an isotropic source in dB
k is the efficiency factor which is generally around 50% to 60%, i.e. 0.5 to 0.6
D is the diameter of the parabolic reflector in metres
λ is the wavelength of the signal in metres

4.5 CASSEGRAIN ANTENNA

A **Cassegrain antenna** is a parabolic antenna in which the feed antenna is mounted at or behind the surface of the concave main parabolic reflector dish and is aimed at a smaller convex secondary reflector suspended in front of the primary reflector. The beam of radio waves from the feed illuminates the secondary reflector, which reflects it back to the main reflector dish, which reflects it forward again to form the desired beam. The Cassegrain design is widely used in parabolic antennas, particularly in large antennas such as those in satellite ground stations, radio telescopes, and communication satellites.



During transmission, EM radiation from the horn transmitted towards small reflector first. The smaller reflector reflects energy towards larger dish. The large dish radiates signal in the parallel beams. This arrangement is referred as cassegrain feed.

Advantages of Cassegrain feed

Following are advantages of Cassegrain feed:

- Waveguide line is short.
- Radial bends in the waveguide are no longer needed.
- Due to above the Cassegrain arrangement leads to less attenuation and improvement in the noise figure.

The larger Earth station antenna use the cassegrain feed type of arrangement.

MODULE V

5.1 PRINCIPLE OF LOG PERIODIC ANTENNA ARRAY

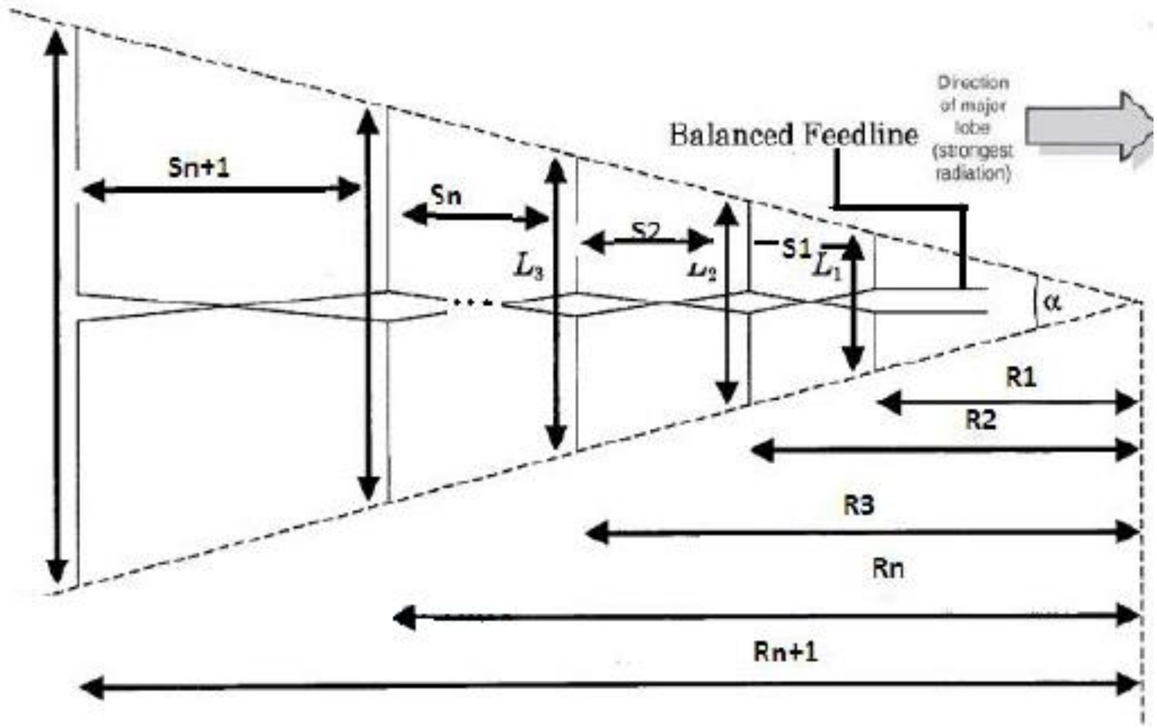
- A Log-periodic antenna is that whose impedance or electrical performance is a logarithmically periodic function of frequency. these antennas are *called* logarithmically periodic *or simply* LP *antennas .*

5.1.1 LPDA

- LPDA normally consists of a series of dipoles known as "elements" positioned along a support beam lying along the antenna axis.
- It provides the capability to operate on many different frequencies.
- The antenna is frequency independent
- The length of the elements corresponds to resonance at different frequencies within the antenna's overall bandwidth. This leads to a series of ever-shorter dipoles towards the "front" of the antenna. ie the dipole length increases along the antenna such that included angle remains constant. The relationship between the lengths is a function known as *tau*.
- The ever-decreasing lengths makes the LPDA look, when viewed from the top, like a triangle or arrow with the tip pointed in the direction of the peak radiation pattern.
- *Sigma* and *tau* are the key design elements of the LPDA design.
- The array consists of dipoles of different lengths and spacing, which are fed from a two-wire transmission line. This line is transposed between each adjacent pair of dipoles.
- Every element in the LPDA design is "active", that is, connected electrically to the feed line along with the other elements

5.1.2 FREQUENCY RANGE

The frequency range, in which the log-periodic antennas operate is around **30 MHz to 3GHz** which belong to the **VHF** and **UHF** bands.



5.1.3 PARAMETERS OF LPDA

1. SCALE FACTOR/DESIGN RATIO/GEOMETRIC RATIO

$$\tau = \frac{L_1}{L_2} = \frac{L_2}{L_3} = \frac{L_3}{L_4} = \cdots \ldots \ldots \ldots \ldots . \frac{L_n}{L_{n+1}}$$

$$\tau = \frac{R_1}{R_2} = \frac{R_2}{R_3} = \frac{R_3}{R_4} = \cdots \ldots \ldots \ldots \ldots . \frac{R_n}{R_{n+1}}$$

$$\tau = \frac{S_1}{S_2} = \frac{S_2}{S_3} = \frac{S_3}{S_4} = \cdots \ldots \ldots \ldots \ldots . \frac{S_n}{S_{n+1}}$$

$$\tau = \frac{L_n}{L_{n+1}} = \frac{R_n}{R_{n+1}} = \frac{S_n}{S_{n+1}}$$

2. SPACING FACTOR σ

$$\sigma = \frac{R_{n+1} - R_n}{2L_n} = \frac{S_n}{2L_n}$$

- Typical values of $\alpha = 30$ & $\tau = 0.7$
- Characteristic of frequency independent antenna is defined in terms of angle

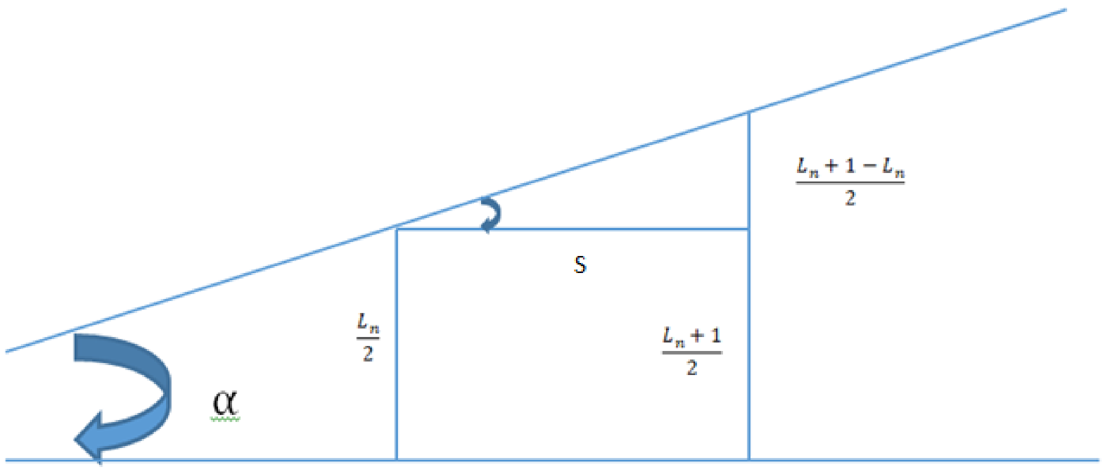
$$\log\frac{f_2}{f_1} = \log\frac{1}{\tau} \quad or \quad \frac{f_2}{f_1} = \frac{1}{\tau}$$

$$f_1 = \tau f_2 \quad f_2 > f_1$$

- Properties at frequency f will be repeated at frequency $\tau^n f$ or $\frac{f}{\tau^n}$

  - R is the distance between the feed and the dipole
  - L is the length of the dipole.
  - α included angle

5.1.4 DESIGN EQUATIONS



$$tan\frac{\alpha}{2} = \frac{L_{n+1} - L_n}{2S}$$

$$= \frac{L_{n+1} - \frac{L_{n+1}}{k}}{2S} = \frac{L_{n+1}\left(1 - \frac{1}{k}\right)}{2S}$$

$$= \frac{\lambda/_2\left(1 - \frac{1}{k}\right)}{2S}$$

$$tan\frac{\alpha}{2} = \frac{\left(1 - \frac{1}{k}\right)}{4S/_\lambda}$$

$$Where\ \alpha = Apex\ Angle\ ,\ \frac{S}{\lambda} = Spacing$$

$$\frac{L_{n+1}}{L_n} = k^n = F$$

F=Frequency Ratio

$$\sigma = \frac{S}{\lambda} = \frac{(1-\tau)}{4tan\frac{\alpha}{2}}$$

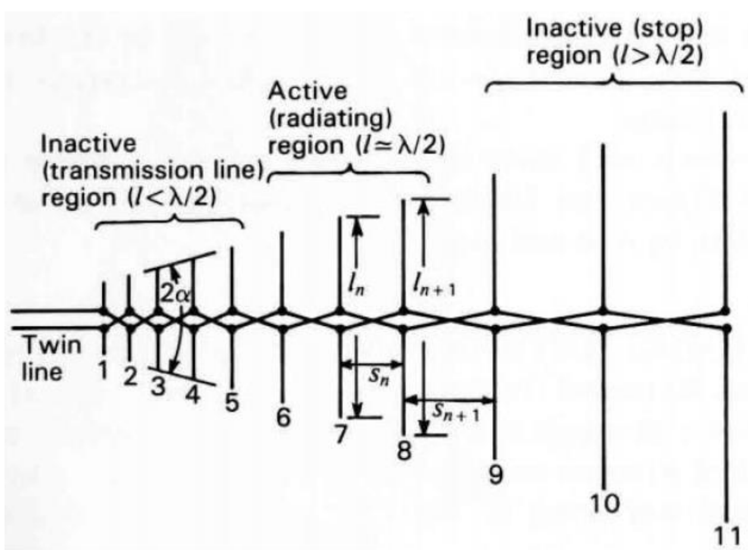
$$\alpha = 2tan^{-1}\left(\frac{1-\tau}{4\sigma}\right)$$

5.1.5 CONSTRUCTION & WORKING OF LOG-PERIODIC ANTENNA

- The main advantage of this antenna is that it exhibits constant characteristics over a desired frequency range of operation. It has the same radiation resistance and therefore the same SWR. The gain and front-to-back ratio are also the same.
- With the change in operation frequency, the active region shifts among the elements and hence all the elements will not be active only on a single frequency. This is its **special characteristic**.
- There are several type of log-periodic antennas such as the planar, trapezoidal, zig-zag, V-type, slot and the dipole. The mostly used one is log-periodic dipole array, in short, LPDA.
- The physical structure and electrical characteristics, when observed, are repetitive in nature. The directive gains obtained are low to moderate. The radiation patterns may be **Unidirectional or Bi-directional**.

5.1.6 LPDA -3 REGIONS

- 1 Transmission line region (inactive region L < λ/2)
- 2 Active region (L= λ/2)
- 3 Reflection region (inactive region L> λ/2)



*** Inactive Transmission line region (L < λ/2)***

- Antenna elements are electrically shorter than resonant length Present capacitive impedance to the transmission line .
- Since the smaller element current leads the supply voltage by 90 degree
- Since the current-is small this region present a small radiation

Active Region (L = λ/2)

- Antenna elements having near resonant length .
- Impedance offered by dipole elements of this region is resistive in nature
- Element current is large and in-phase with supply voltage
- Thus will radiate a strong beam

Inactive reflective region (L > λ/2)

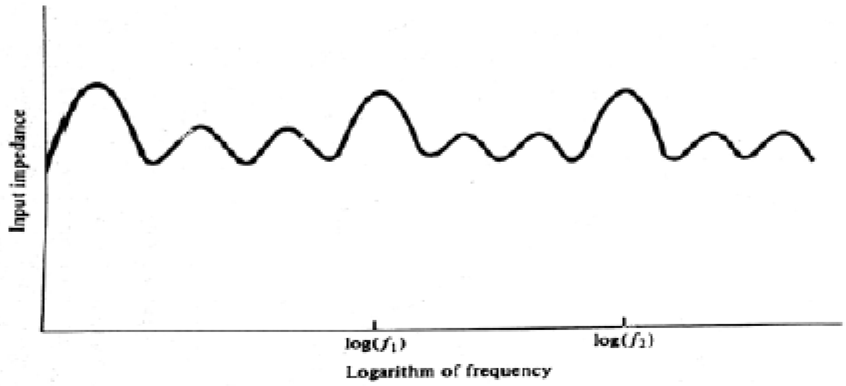
- Element length is longer than resonant length .
- Current lag base voltage.
- Impedance becomes inductive
- Radiate small beam
- The cutoff frequencies of LPDA can be determined by electrical lengths of longest and shortest elements of the structure
- The higher cutoff is when shortest element is near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

5.1.7 WORKING OF LPDA

- At wavelength nearer to middle of operating range radiation occurs primarily from the central region of the antenna as shown in figure, known as active region
- The elements on right side of active region have larger electrical dimension (order of 1λ) and they carry smaller current and present more inductive reactance thus weak radiation. '
- Elements on left side of active region have dimension less than λ/2 present a large capacitive reactance to the line hence current is small and radiation is weak. .
- When the wavelength increases the radiation zone moves to the right when the wavelength is decreased it moves to the left with maximum radiation toward the apex or feed point of the array
- At any given frequency only a fraction of the antenna is used, where the dipoles are about λ/2 long.

5.1.8 PERIODICITY OF LPDA

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



Advantages

- The antenna design is compact.
- Gain and radiation pattern are varied according to the requirements.

Disadvantages

- External mount
- Installation cost is high.

Applications

- Used for HF Communications
- Used for particular sort of TV receptions
- Used for all monitoring in higher frequency bands

5.2 HELICAL ANTENNA

- **Helical antenna** is an example of wire antenna and itself forms the shape of a helix. This is a broadband VHF and UHF antenna.
- The frequency range of operation of helical antenna is around **30MHz to 3GHz**. This antenna works in **VHF** and **UHF** ranges.
- The most popular helical antenna (helix) is a travelling wave antenna in the shape of a corkscrew that produces radiation along the axis of the helix antenna. These helix antennas are referred to as axial-mode helical antennas. The benefits of this helix antenna is it has a wide bandwidth, is easily constructed, has a real input impedance, and can produce circularly polarized fields. The basic geometry of the helix antenna shown in Figure 5

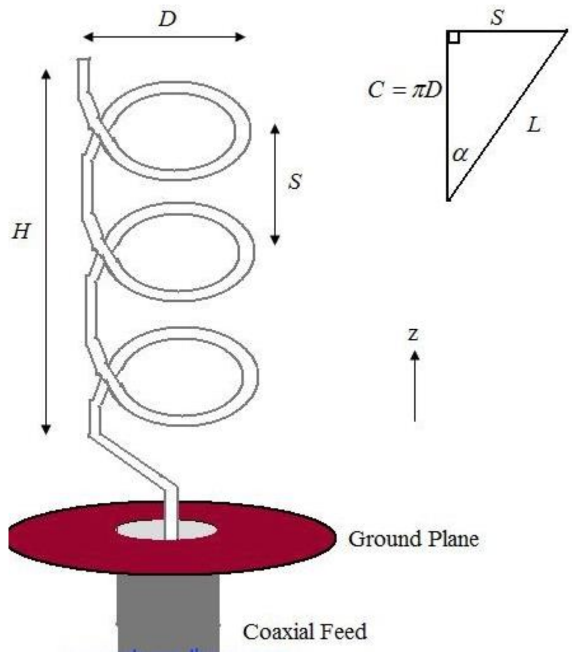


Fig 5 : Geometry of Helical antenna

6.2.1 THE PARAMETERS OF THE HELIX

The parameters of the helix antenna are defined below.

- D - Diameter of a turn on the helix antenna.
- C - Circumference of a turn on the helix antenna (C=pi*D).
- S - Vertical separation between turns for helical antenna.
- α - pitch angle, which controls how far the helix antenna grows in the z-direction per turn, and is given by $\alpha = tan^{-1}\left(\frac{S}{C}\right)$
- N - Number of turns on the helix antenna.
- H - Total height of helix antenna, $H=NS$.
- L = length of one turn = $\sqrt{S^2 + (\pi D)^2}$

The antenna in Figure 5 is a left handed helix antenna, because if you curl your fingers on your left hand around the helix your thumb would point up (also, the waves emitted from this helix antenna are Left Hand Circularly Polarized). If the helix antenna was wound the other way, it would be a right handed helical antenna.

The radiation pattern will be maximum in the +z direction (along the helical axis in Figure 5). The design of helical antennas is primarily based on empirical results, and the fundamental equations will be presented here.

Helix antennas of at least 3 turns will have close to circular polarization in the +z direction when the circumference C is close to a wavelength:

$$\frac{3\lambda}{4} \leq C \leq \frac{4\lambda}{3}$$

Once the circumference C is chosen, the inequalites above roughly determine the operating bandwidth of the helix antenna. For instance, if C=19.68 inches (0.5 meters), then the highest frequency of operation will be given by the smallest wavelength that fits into the above equation, or $\frac{3\lambda}{4}$=0.75C=0.375 meters, which corresponds to a frequency of 800 MHz. The lowest frequency of operation will be given by the largest wavelength that fits into the above equation, or $\frac{4\lambda}{3}$=1.333C=0.667 meters, which corresponds to a frequency of 450 MHz. Hence, the Fractional BW ($FBW = \frac{f_2-f_1}{f_c}$)is 56%, which is true of axial helical antennas in general.

The helix antenna is a travelling wave antenna and the input impedance is primarily real and can be approximated in Ohms by:

$$Z_{in} = 140\frac{C}{\lambda}$$

The helix antenna functions well for pitch angles (α) between 12 and 14 degrees. Typically, the pitch angle is taken as 13 degrees.

6.2.2 MODES OF OPERATION

- Normal mode of radiation
- Axial mode of radiation.

1. **Normal mode (perpendicular mode) of radiation**

- Normal mode of radiation characteristics is obtained when dimensions of helical antenna are very small compared to the operating wavelength.
- Here, the radiation field is maximum in the direction normal to the helical axis.
- In normal mode, bandwidth and efficiency are very low. The above factors can be increased, by increasing the antenna size.
- The radiation fields of helical antenna are similar to the loops and short dipoles. So, helical antenna is equivalent to the small loops and short dipoles connected in series. The far field of small loop is given by

$$E_\phi = j\frac{120\pi^2[I]\sin\theta}{r} \times \frac{A}{\lambda^2}$$

Where

I=Retarded Current

r=Distance

A= Area of the loop = $\frac{\pi D^2}{4}$

Far field of a short dipole is given by

$$E_\theta = j\frac{60\pi^2[I]\sin\theta}{r}\times\frac{S}{\lambda}$$

Where S=dL = Length of dipole

The performance of helical antenna is measured in terms of Axial Ratio *(AR).* Axial ratio is defined as the ratio of far fields of short dipole to the small loop.

$$A.R = \frac{|E_\theta|}{|E_\phi|} = \frac{j\frac{60\pi^2[I]\sin\theta}{r}\times\frac{S}{\lambda}}{j\frac{120\pi^2[I]\sin\theta}{r}\times\frac{A}{\lambda^2}}$$

$$A.R = \frac{S\lambda}{2\pi A}$$

Substitute the A=$\frac{\pi D^2}{4}$

Then

$$A.R = \frac{2S\lambda}{\pi^2 D^2}$$

- When (EØ)=0 AR=0, leading to linearly horizontal polarization ie helix act as loop
- When (EΦ)=0 , AR=infinity leading to a linear vertical polarization ie helix act as a vertical dipole
- when AR = 1 polarization becomes circular polarization

$$A.R = 1 = \frac{|E_\theta|}{|E_\phi|} = \frac{2S\lambda}{\pi^2 D^2}$$

$$E_\theta = E_\phi = 2S\lambda = \pi^2 D^2$$

$$S = \frac{\pi^2 D^2}{2\lambda} = \frac{C^2}{2\lambda}$$

$$C = Circumference = \pi D$$

2. **Axial mode of radiation**

- Helical antenna is operated in axial mode when circumference C and spacing S are in the order of one wavelength.
- Here, maximum radiation field is along the helical axis and polarization is circular.
- In axial mode, pitch angle lies between 12° to 18° and beam width and antenna gain depends upon helix length NS.

General expression for terminal impedance is,

$$R = 140C/\lambda \text{ ohms}$$

Where, R = Terminal impedance C = Circumference.

- In normal mode, beam width and radiation efficiency is very small. The above factors increased by using axial mode of radiation.
- Axial Ratio,

$$A.R = 1 + \frac{1}{2N}$$

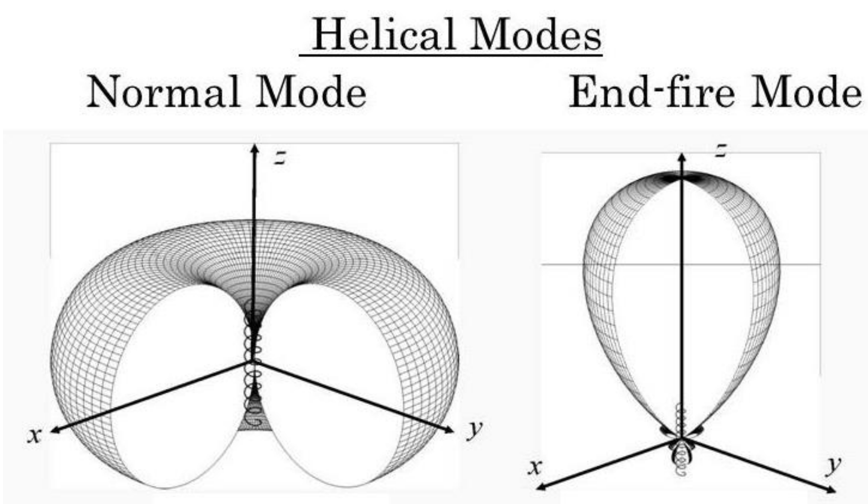


Fig 6.a Fig 6.b

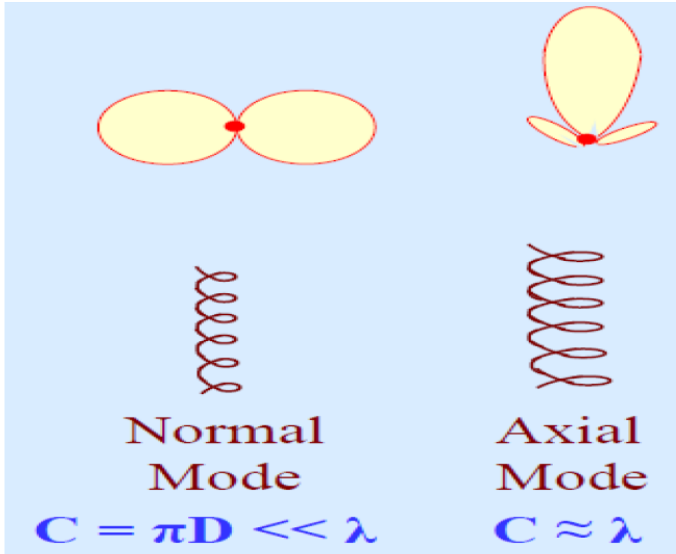


Fig 6.c Fig 6.d

5.3 ANTENNAS FOR MOBILE BASE STATION AND HANDSETS.

The revolution of mobile communication systems has led to the use of novel antennas for base stations (BS) and mobile station/ handset (MS)

- For terrestrial mobile communication the frequencies ranges from 200 MHz to 60 GHz
- In Cellular mobile communication frequency ranges from 800-1000 MHz and 1700-2200 MHz
- In WLAN around 2.4-2.5, 5.1-5.8 and 17 GHz
- In *mobile communication the BS antennas must be highly directive and handset antennas must be compact*

5.3.1 BASE STATION ANTENNAS

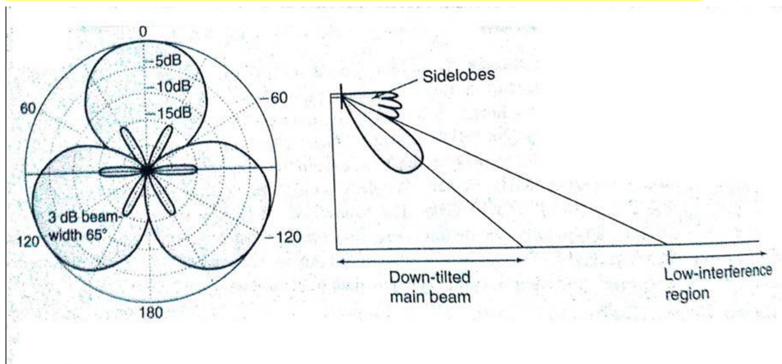
- The BS antennas should direct the signals to the wanted coverage area as effectively as possible
- But the distribution of power must be restricted accurately in order to minimize the frequency reuse distance in the system

Base station antennas can be classified into **adaptive base station antenna and non adaptive base station antenna**

- In non adaptive BS antennas the antenna performance is fixed and won't change according to the instantaneous requirements of the system
- But the adaptive BS antenna Changes its parameters to improve Signal-to-Interference and noise ratio (SINR)

1. **Non Adaptive BS antennas**

   - Typical values of gain is 5 to 17 dB
   - The horizontal plane beam width varies between 50 degrees and 360 degrees
   - Vertical beam width varies between 10 degree and 70 degree
   - For making the coverage area high, the horizontal beam width is increased(Horizontal directivity is reduced) at the expense of vertical beam width
   - The beam of BS antennas maybe tilted down (typically less than 15 degrees) to reduce the interference level in neighbouring cells.



Typical beam patterns for base station antennas: (*a*) horizontal plane pattern for a 3-sector base station site, (*b*) vertical plane pattern.

   - Common aspects of BS antennas are Weight, wind load, size, appearance, radiation characteristics and bandwidth
   - Common types are dipoles, corner reflectors, patch antenna arrays and horn antennas
   - In indoor environments leaky lines can be employed as BS antenna
   - A leaky line is a coaxial cable with leaky outer conductor
   - To reduce the multipath effects diversity techniques are employed in BS receivers
   - Antenna diversity is a prominent diversity technique employed in wireless receivers.
   - Several receiving antennas are employed to obtain independent samples of the incoming field

2. **Adaptive BS antennas**

Adaptive BS antenna will improve SINR of single connection to maximize the coupling between the BS and the wanted user while minimizing the coupling with other user .This is accomplished in both uplink and downlink. But In downlink the optimization is more critical since the MS cannot detect the channel fully

- Advantages
  - Increased capacity due to Increased SINR
  - Increased coverage due to higher gain
  - Reduced output power

Types

- **Switched beam antenna:**

- The adaption in changing MS distribution is done using a BS antenna with several selectable beams
- Fairly simple RF signal processing is required
- Limited adaptivity

➢ **Adaptive Array:**

- Here an adaptive array is employed in which each array element is connected to a separate transceiver and a DSP Unit is used to control signal weigths

➢ **Beam forming:**

- Adaption is done using beam forming in which form pattern maxima to wanted directions and nullls to unwanted directions

5.3.2 TYPES OF ANTENNAS IN CELLULAR HANDSETS

Since the volume of Cellular Handset is very smaller the antenna volume should be very smaller for a compact Phone.

- This smaller size makes it difficult to achieve system bandwidths 10% without inducing currents on entire handset chassis.
- For overcoming the situation earlier handsets make use of retractable antennas which can provide large bandwidth with comparatively smaller effective volume

5.3.2.1 Antennas for mobile handsets

Following are some of the antennas used in cellular phones:

❖ External Antennas
  - Retractable whip antennas
  - Helical antennas

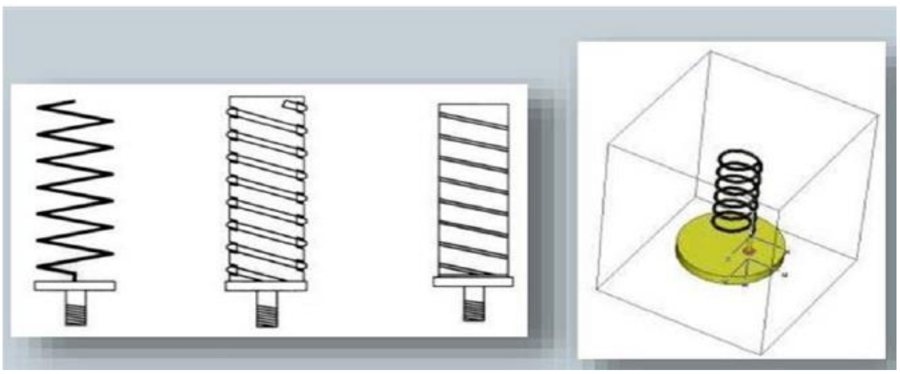
❖ Internal Antennas
  - Planar antennas
  - Chip antennas

1. EXTERNAL ANTENNAS

Retractable Monopole Antenna

- An antenna that we can retract.
- Retractable whip antenna can be considered as a monopole with phone chassis as the ground plane or an unsymmetrical dipole whose other half is the phone chassis
- Typical length of whip is $\lambda/4$ or $3\lambda/8$, these lengths are chosen such that the current maxima should be farther away from the user and to reduce current in phone chassis.

Normal Mode Helical Antenna



- A normal mode helical antenna can be used for circular polarization
- Dual band operation is obtained by using 2 different pitch angles .It is convenient for users

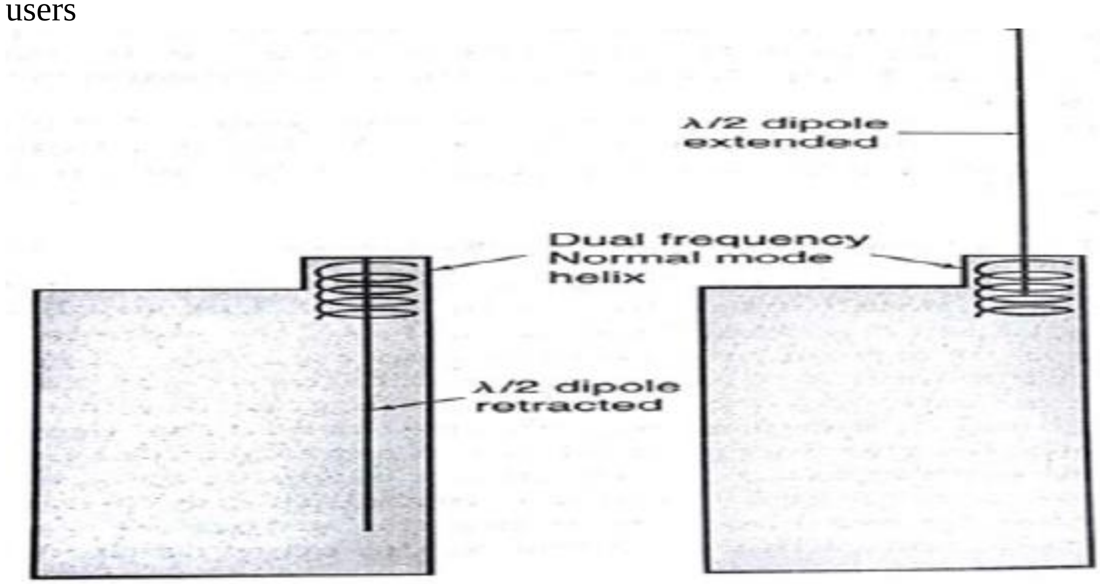


Fig: Handset with dual frequency normal-mode helix and λ/2 dipole extended

2. INTERNAL ANTENNAS

- **Planar antenna** is usually a λ/4 micro strip mounted on the conducting chassis of the handset.

  One example is Planar Inverted F Antennas (PIFA).

- **Chip antennas** are very small and mounted on circuit board of phone.

  Internal antennas reduce the size of the phone by sacrificing the performance, especially when hand is over the antenna or the unit is close to the head.

PIFA - PLANAR INVERTED-F ANTENNA

The Planar Inverted-F antenna (PIFA) is increasingly used in the mobile phone market. The antenna is resonant at a quarter-wavelength (thus reducing the required space needed on the phone), and also typically has good SAR properties. This antenna resembles an inverted F, which explains the PIFA name. The Planar Inverted-F Antenna is popular because it has a low profile and an omnidirectional pattern.

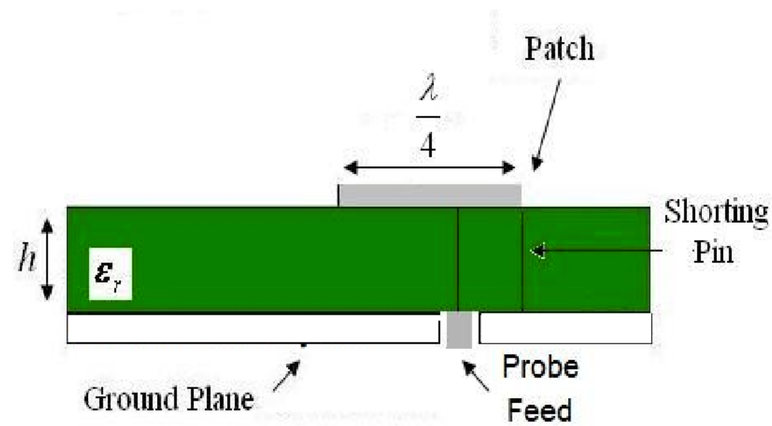


Figure . The Planar Inverted-F Antenna (PIFA).

The PIFA is resonant at a quarter-wavelength due to the shorting pin at the end. The feed is placed between the open and shorted end, and the position controls the input impedance

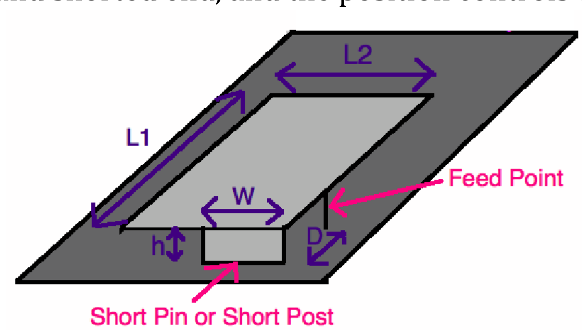


Figure . The Planar Inverted-F Antenna (PIFA), with a shorting Plane.

In Figure , we have a PIFA of length *L1*, of width *L2*. The shorting pin (or shorting post) is of width *W*, and begins at one edge of the PIFA as shown in Figure 5. The feed point is along the same edge as shown. The feed is a distance *D* from the shorting pin. The PIFA is at a height *h* from the ground plane. The PIFA sits on top of a dielectric with permittivity ε_r as with the patch antenna.

The impedance of the PIFA can be controlled via the distance of the feed to the short pin (*D*). The closer the feed is to the shorting pin, the impedance will decrease; the impedance can be increased by moving it farther from the short edge. The PIFA can have it's impedance tuned with this parameter.

$$L + W = \frac{\lambda}{4\sqrt{\varepsilon_r}}$$

The main advantages of using PIFA antenna

- Due to the small size of PIFA antenna it gives the availability to insert the antenna inside the cellular phone.
- PIFA has availability to get high gain for both polarization states vertically and horizontally there for it can receive the reflection wave easily from different directions.
- The backward radiation of the PIFA has be reduced that's mean the electromagnetic waves power has reduced which lead us to get a good deal to less damage of the human health.
- The design and the material of the PIFA are not costly on top of that it has a very high efficiency also It is easy to fabricate.

FRACTAL ANTENNA

Modern telecommunication systems require antennas with wider bandwidths and smaller dimensions as compared to the conventional antennas. Fractal shaped antenna elements was one of them. Some of these geometries have been particularly useful in reducing the size of the antenna, while others exhibit multi-band characteristics. These are low profile antennas with moderate gain and can be made operative at multiple frequency bands and hence are multi-functional.

The term fractal was coined by Benoit Mandelbrot, a French mathematician about 20 years ago in his book "The fractal geometry of Nature". Nathan Cohen, professor at Boston University built the first known fractal antenna in 1988. Cohen's efforts were first published the first scientific publication about fractal antennas in 1995.

One of the properties of fractals geometry is that it can have an infinite length while fitting in a finite volume. The radiation characteristic of any electromagnetic radiator depends on electrical length of the structure. Using the property of fractal geometry, we may increase the electrical length of an antenna, keeping the volume of antenna same. There are an infinite number of possible geometries that are available to try as a design of fractal antenna.

- Fractals are those fun shapes that if you zoom in or zoom out, the structure is always the same.
- Fractals have self-similarity in their geometry, which is a feature where a section of the fractal appears the same regardless of how many times the section is zoomed in upon.
- A fractal is a geometric object that is similar to itself on all scales. If you zoom in on a fractal object it will look similar or exactly like the original shape. This property is called self-similarity. Examples of a self-similar objects are the Sierpinski triangle & carpet are show below.

- Self-similarity in the geometry creates effective antennas of different scales. This can lead to multiband characteristics in antennas, which is displayed when an antenna operates with a similar performance at various frequencies.
- Since fractals show up in the real world of nature (snail shells, leaves on a tree, pine cones), ***why not see if they perform well as antennas?*** It turns out that if you make antennas with fractal shapes, they will radiate, and often have multiband properties.

Advantages of fractal antenna technologie are:

- minituratization.
- better input impedance matching wideband/multiband (use one antenna instead of many).
- frequency independent (consistent performance over huge frequency range)
- reduced mutual coupling in fractal array antennas.

Disadvantages of fractal antenna technologie are:

- gain loss.
- complexity.
- numerical limitations.
- the benefits begin to diminish after first few iterations.

FACTORS TO BE CONCIDERED WHILE DESIGNING MOBILE PHONE ANTENNA

- Antenna Operating Frequency
- VSWR & Return Loss (Input impedance)
- Bandwidth

- Gain & Directivity
- Diversity
- Size of Chassis (In terms of Wavelength)
- Specific Absorption Rate (SAR) of Antenna

Specific Absorption Rate (or **SAR**) is a measure of how transmitted RF energy is absorbed by human tissue.

Phones emitting the most radiation SAR (Specific Absorption Rate) in watts per kilogram	
Xiaomi Mi A1	1.75
OnePlus 5T	1.68
Xiaomi Mi Max 3	1.58
OnePlus 6T	1.55
HTC U12 Elite	1.48
Xiaomi Mi Mix 3	1.45
Google Pixel 3XL	1.39
OnePlus 5	1.39
iPhone 7	1.38
Sony Xperia X21 Compact	1.36
HTC Design 12/12 Plus	1.34
Google Pixel 3	1.33
OnePlus 6	1.33
iPhone 8	1.32
Xiaomi Redmi Note 5	1.29
ZTE AXON 7 mini	1.29

5.4 SMART ANTENNA TECHNOLOGY

A smart antenna consists of several antenna elements, whose signal is processed adaptively in order to exploit the spatial domain of the mobile radio channel.

In actual, antennas are not Smart Antenna, systems are smart. Generally co-located with a base station, a smart antenna system combines an antenna array with a digital signal-processing capability to transmit and receive in an adaptive, spatially sensitive manner. In other words, such a system can automatically change the directionality of its radiation patterns in response to its signal environment.

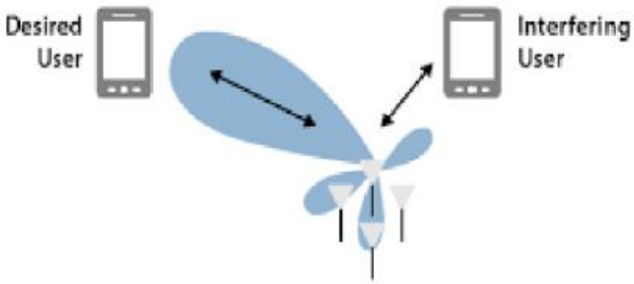
This is a new and promising technology in the field of wireless and mobile communications in which capacity and performance are usually limited by two major impairments multipath and co-channel interference. Multipath is a condition that arises when a transmitted signal undergoes reflection from various obstacles in the environment. This gives rise to multiple signals arriving from different directions at the receiver. Smart antennas (also known as adaptive array antennas and multiple antennas) are antenna arrays with smart signal processing algorithms to identify spatial signal signature such as the **Direction of arrival (DOA)** of the signal and use it to calculate beam forming vectors, to track and locate the antenna beam on the mobile targets.

A smart antenna enables a higher capacity in wireless networks by effectively reducing multipath and co-channel interference.

5.4.1. SMART ANTENNA FUNCTIONS

While the main purposes of standard antennas are to effectively transmit and receive radio signals, there are two additional functions that smart antennas or adaptive antennas need to fulfil:

- ***Direction of arrival estimation:*** In order for the smart antenna to be able provide the required functionality and optimization of the transmission and reception, they need to be able to detect the direction of arrival of the required incoming signal. The information received by the antenna array is passed to the signal processor within the antenna and this provides the required analysis.
- ***Beam steering:*** With the direction of arrival of the required and any interfering signals analysed, the control circuitry within the antenna is able to optimize the directional beam pattern of the adaptive antenna array to provide the required performance.
- Smart antenna forms a radiation pattern towards the desired user and nullifying the interferers



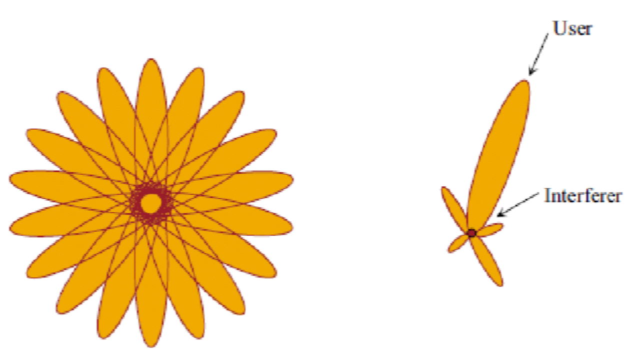
5.4.2 BASIC WORKING MECHANISM

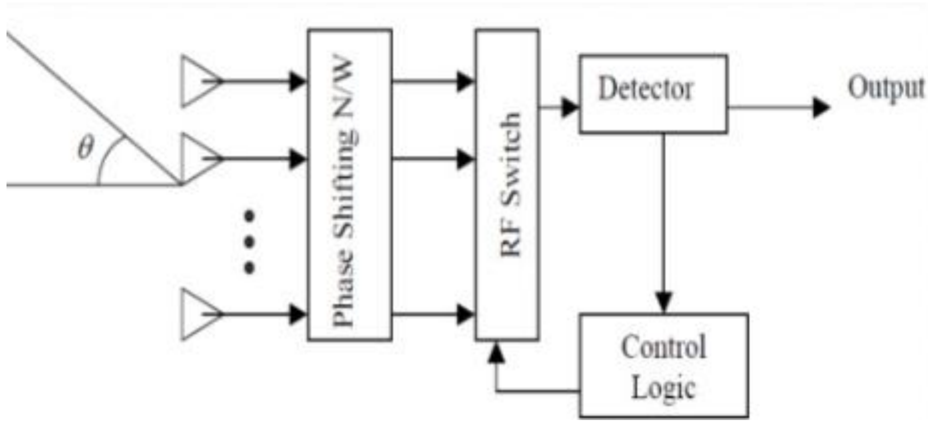
A smart antenna system can perform the following functions:-

- First, the direction of arrival of all the incoming signals including the interfering signals and the multipath signals are estimated using the Direction of Arrival algorithms.
- Secondly, the desired user signal is identified and separated from the rest of the unwanted incoming signals.
- Lastly, a beam is steered in the direction of the desired signal and the user is tracked as he moves while placing nulls at interfering signal directions by constantly updating the complex weights.

5.4.3 TYPES OF SMART ANTENNA SYSTEMS

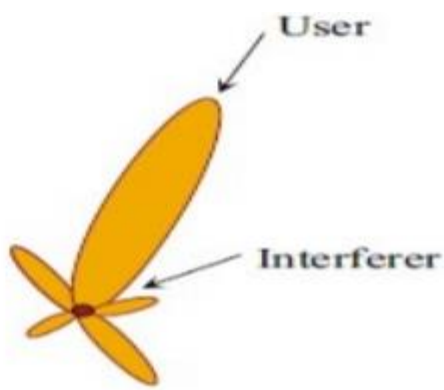
- **Switched Beam Antennas.** Switched beam antenna systems form multiple fixed beams with heightened sensitivity in particular directions. These antenna systems detect signal strength, choose from one of several predetermined, fixed beams and switch from one beam to another as the mobile moves throughout the sector. Instead of shaping the directional antenna pattern with the metallic properties and physical design of a single element, switched beam systems combine the outputs of multiple antennas in such a way as to form finely directional beams with more spatial selectivity than can be achieved with conventional, single-element approaches.

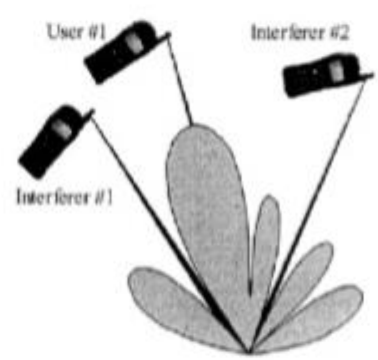




- PSN(Phase Shift Network), Which forms multiple beams looking in certain directions.
- RF Switch actuate; the right beam in the desired direction
- The selection of right beam is made by control logic which is governed by an algorithm.
- The algorithm which scans all the beams and selects the one strongest receiving signal based on a measurement made by the detector.
- The overall goal of the switched-beam system is to increase the gain according to the location of the user.

❖ **Adaptive Array Antennas.** Adaptive antenna technology represents the most advanced smart antenna approach as on date. Using a variety of new signal-processing algorithms, the adaptive system takes advantage of its ability to effectively locate and track various types of signals to dynamically minimize interference and maximize intended signal reception. Both systems attempt to increase gain according to the location of the user, however, only the adaptive system provides optimal gain while simultaneously identifying, tracking and minimizing interfering signals.





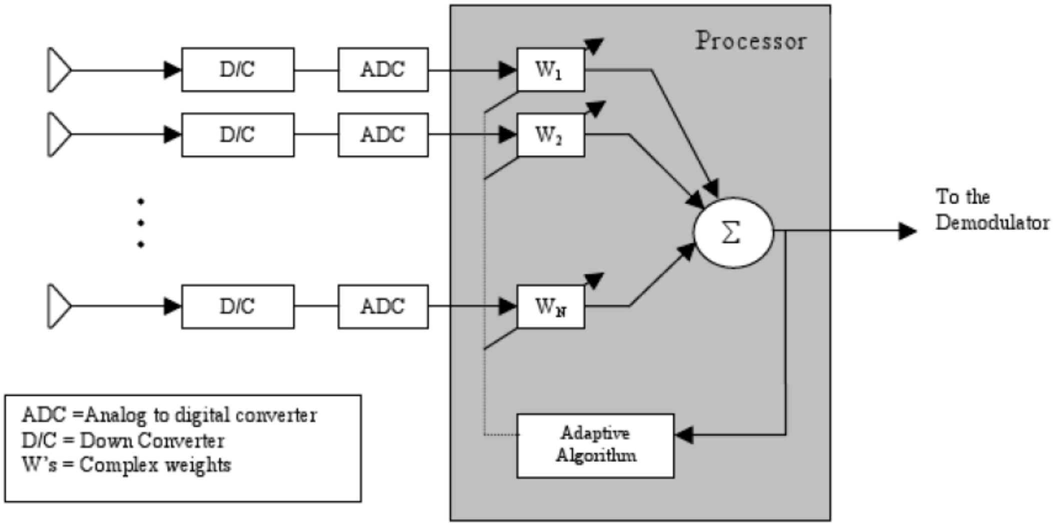


Fig: Block diagram of Adaptive array systems

5.4.4 COMPARISON BETWEEN SWITCHED BEAM AND ADAPTIVE ARRAY SYSTEMS

1. **Switched Beam System.**
   - It uses multiple fixed directional beams with narrow beam widths.
   - The required phase shifts are provided by simple fixed phase shifting networks like the butler matrix.
   - They do not require complex algorithms; simple algorithms are used for beam selection.
   - It requires only moderate interaction between mobile unit and base station as compared to adaptive array system.
   - Since low technology is used, it has lesser cost and complexity.
   - Integration into existing cellular system is easy and cheap.
   - It provides significant increase in coverage and capacity compared to conventional antenna based systems.
   - Since, multiple narrow beams are used, frequent intra-cell hand-offs between beams have to be handled as mobile moves from one beam to another.
   - It cannot distinguish between direct signal and interfering and/or multipath signals, this leads to undesired enhancement of the interfering signal more than the desired signal.
   - Since, there is no null steering involved, switched beam systems offer limited co-channel interference suppression as compared to the adaptive array systems.
2. **Adaptive Array System.**
   - A complete adaptive system; steers the beam towards desired signal of interest and places nulls at the interfering signal directions.
   - It requires implementation of DSP technology.
   - It requires complicated adaptive algorithms to steer the beam and the nulls.

- It has better interference rejection capability compared to Switched beam systems.
- It is not easy to implement in existing systems i.e. up-gradation is difficult and expensive.
- Since, continuous steering of the beam is required as the mobile moves; high interaction between mobile unit and base station is required.
- Since, the beam continuously follows the user; intra-cell hand-offs are less.
- It provides better coverage and increased capacity because of improved interference rejection as compared to the Switched beam systems.
- It can either reject multipath components or add them by correcting the delays to enhance

5.4.5 BENEFITS OF SMART ANTENNA TECHNOLOGY

There are large number of benefits of Smart Antennas, some of them are enumerated below as:

- **Reduction in Co-Channel Interference.** Smart antennas have a property of spatial filtering to focus radiated energy in the form of narrow beams only in the direction of the desired mobile user and no other direction. In addition, they also have nulls in their radiation pattern in the direction of other mobile users in the vicinity. Therefore, there is often negligible co-channel interference.

- **Range Improvement.** Since, smart antennas employs collection of individual elements in the form of an array they give rise to narrow beam with increased gain when compared to conventional antennas using the same power. The increase in gain leads to increase in range and the coverage of the system. Therefore, fewer base stations are required to cover a given area.

- **Increase in Capacity.** Smart antennas enable reduction in co-channel interference which leads to increase in the frequency reuse factor means smart antennas allow more users to use the same frequency spectrum at the same time bringing about tremendous increase in capacity.

- **Reduction in Transmitted Power.** Ordinary antennas radiate energy in all directions leading to a waste of power. Comparatively, smart antennas radiate energy only in the desired direction. Therefore, less power is required for radiation at the base station. Reduction in transmitted power also implies reduction in interference towards other users.

- **Reduction in Handoff.** To improve the capacity in a crowded cellular network, congested cells are further broken into micro cells to enable increase in the frequency reuse factor. This results in frequent handoffs as the cell size is smaller. Using smart antennas at the base station, there is no need to split the cells as the capacity is increased by using independent spot beams.

MODULE VI
RADIO WAVE PROPAGATION

MODES OF PROPAGATION

Electromagnetic waves may travel from transmitting antenna to the receiving antenna in a number of ways. Different propagations of electromagnetic waves are as follows,

(i) Ground wave propagation
(ii) Sky wave propagation
(iii) Space wave propagation
(iv) Tropospheric scatter propagation.

This classification is based upon the frequency range, distance and several other factors.

1. Ground Wave Propagation

Ground wave propagation is also known as surface wave propagation. This propagation is practically important at frequencies up to 2 MHz. Ground wave propagation exists when transmitting and receiving antenna are very close to the earth's curvature.

Ground wave propagation suffers attenuation while propagating along the surface of the earth.

Applications

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

2. Sky Wave Propagation

Sky wave propagation is practically important at frequencies between 2 to 30 MHz Here the electromagnetic waves reach the receiving point after reflection from an atmospheric layer known as ionosphere. Hence, sky wave propagation is also known as 'ionospheric wave propagation'.

It can provide communication over long distances.

Hence, it is also known as point-to-point propagation or point-to-point communication.

Disadvantage

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

APPLICATION

Global communication is possible.

3. Space Wave Propagation

Space wave propagation is practically important at frequencies above 30 MHz It is also known as tropospheric wave propagation because the waves reach the receiving point through tropospheric region.

In space wave propagation, signal at the receiving point is a combination of direct and indirect rays. It provides communication over long distances with VHF .UHF and microwave frequencies. Space wave propagation is also known as "line of sight propagation".

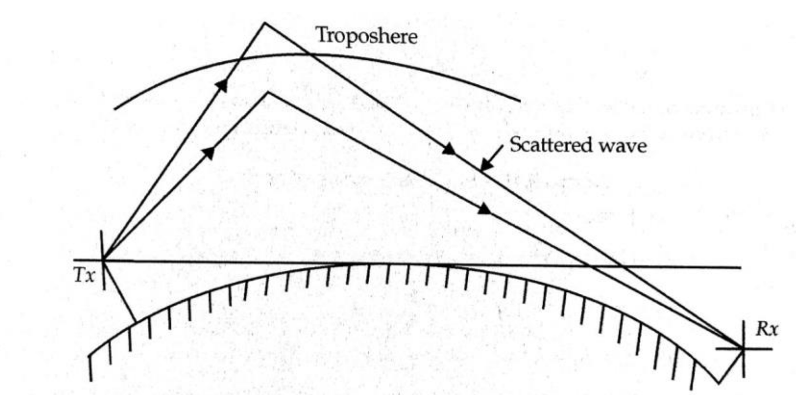
Applications

1. Space wave propagation is used in RADAR Application.
2. It is used in FM and TV broadcasting.

(iv) Troposcatter Propagation

This is a mechanism by which propagation is possible by the scattered and diffracted rays. The scattering takes place due to tropospheric region. Troposcatter propagation is also known as forward 1 scatter propagation, it is practically important at frequency range from 160MHz onwards. This mechanism helps to get unexpectedly large field strengths at receivers even when they are in shadow zone.

The EM waves are generated by high powered transmitters with high gain directive antennas to reach the upper layer of troposphere. Scattering of waves takes place due to considerable variation of refractive index. The scattered wave reaching the receiver is shown in figure.



This propagation covers long distances in the range of 160 to 1600 km.

SKY WAVE PROPAGATION/ IONOSPHERE WAVE PROPAGATION

It is also called as Ionosphere wave propagation. The ionosphere acts like a reflecting surface and is able to reflect back the electromagnetic waves of frequencies between 2 MHz to 30MHz .Since, long distance point to point communication is possible with sky propagation, it is also called as point to point propagation. This mode of propagation is also known as short wave propagation.

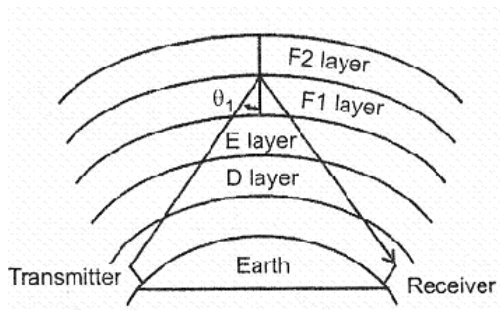


fig 1.1 Sky Wave Propagation

STRUCTURE OF ATMOSPHERE

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

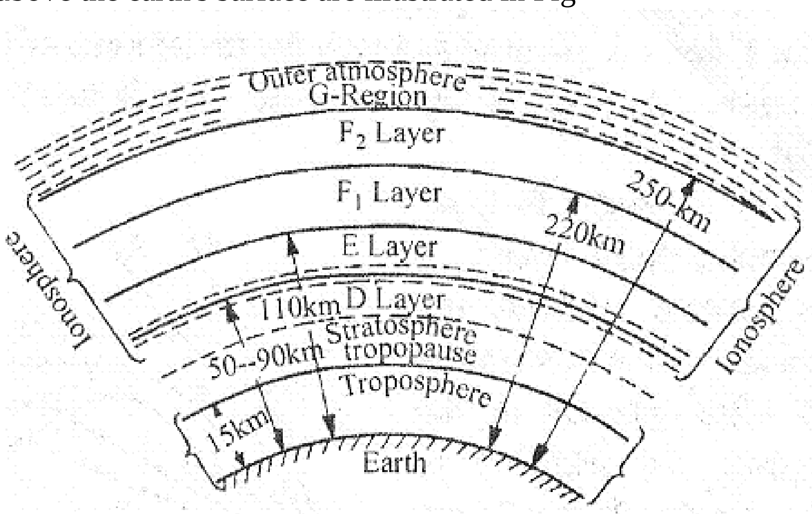


fig 2.1 Structure of ionosphere

The portion of the atmosphere, extending up to a height *(average of 15 Km)* of about 16 to 18 Kms from the earth's surface, at the equator is termed as troposphere or region of change.

Tropopause starts at the top of the *troposphere* and ends at the beginning of or region of calm.

Above the stratosphere, the upper *stratosphere* parts of the earth's atmosphere absorb large quantities of radiant energy from the sun. This not only heats up the atmosphere, but also produces some ionization in the form of free electrons, positive and negative ions. This part of the atmosphere where the ionization is appreciable, is known as the *ionosphere.* The most important ionizing agents are ultraviolet UV radiation, ά , β and cosmic rays and meteors. The ionization tends to be stratified due to the differences in the physical properties of the atmosphere at different heights and also because various kinds of radiation are involved.

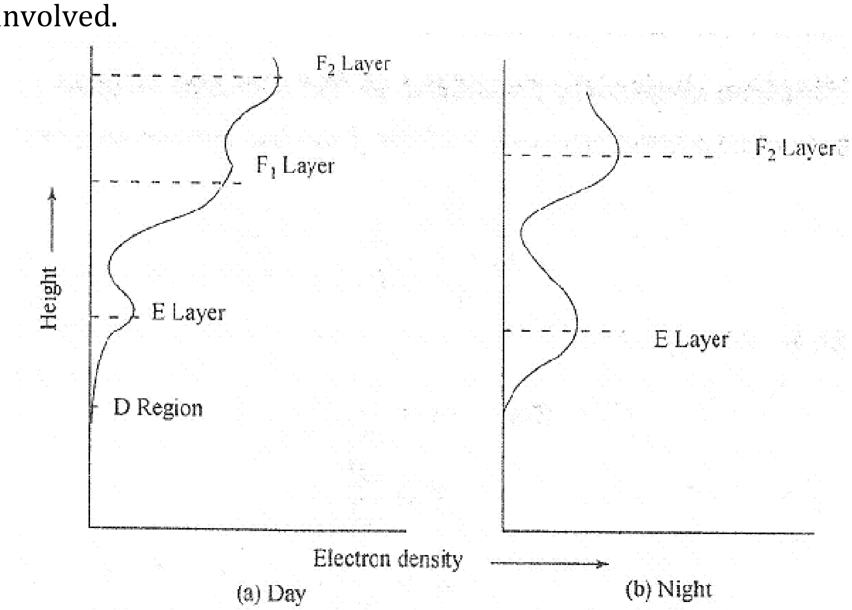


fig 2.2 Electron density of ionosphere layers

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

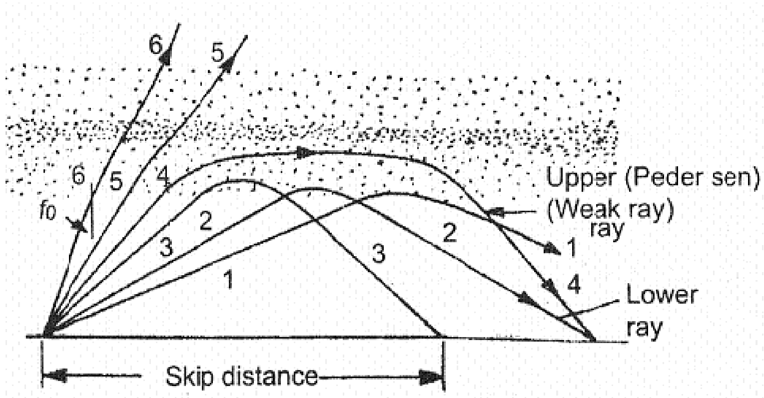


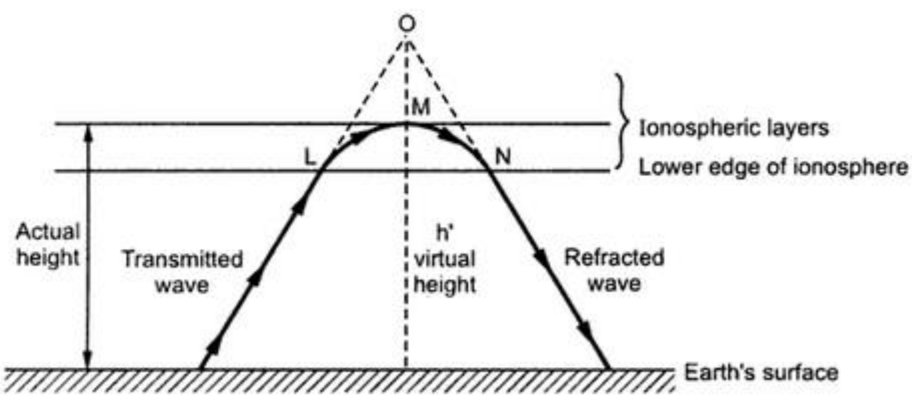
fig 2.3 Effect of ionosphere on rays

At night **F1** and **F2** layers combine to form a single night time **F2** layer. The **E** layer is governed closely by the amount of UV light from the sun and at night tends to decay uniformly with time. The **D** layer ionization is largely absent during night.

A sporadic **E** layer is not a thick layer. It is formed without any cause. The ionization is often present in the region, in addition to the regular **E** ionization. Sporadic **E** exhibits the characteristics of a very thin layer appearing at a height of about 90 to 130 Kms. Often, it occurs in the form of clouds, varying in size from 1 Km to several 100 Kms across and its occurrence is quite unpredictable. It may be observed both day and night and its cause is still uncertain.

VIRTUAL HEIGHT

The height at a point above the surface at which the wave bends down to earth is called Actual height or true height. How ever below the ionized layer, the incident and refracted waves follow the same paths which are exactly the same if a reflection takes place along path at a height above the earths surface, which is greater than the actual height. Such height is called Virtual height and is denoted by **h'.**



Virtual height is useful to find the angle of incidence required for the wave to return to earth at a specified point.

CRITICAL FREQUENCY *fc*

fc for a given layer is defied as the height frequency that will be reflected to earth by that layer at vertical incidence.
It is also defined as the limiting frequency below which a wave is reflected and above which it penetrates through ionospheric layer,when the waves are incident on the layer normally.

$fc = 9\sqrt{N}$ *N= electron density*

MAXIMUM USABLE FREQUENCY (MUF)

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

The maximum, frequency that can be reflected back for a given distance of transmission is called the maximum usable frequency (MUF) for that distance.

$$MUF = fc \times \sec\theta_i$$

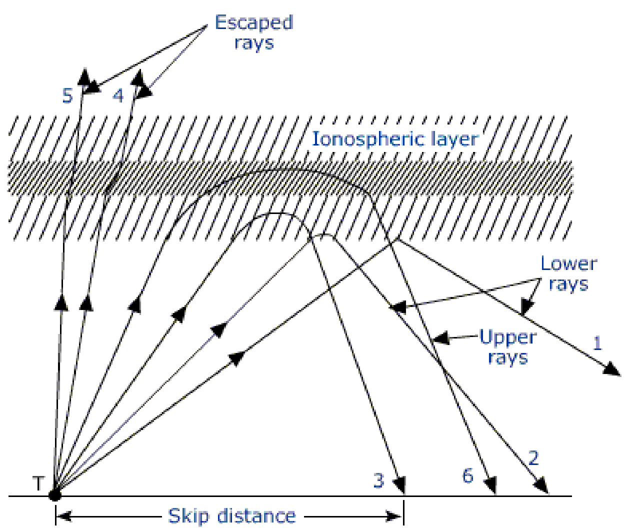
Where $\theta_i = angle\ of\ incidance\ between\ incident\ ray\ and\ normal$

Refractive index $\mu = \sqrt{1 - \frac{81N}{f_c}}$

SKIP DISTANCE

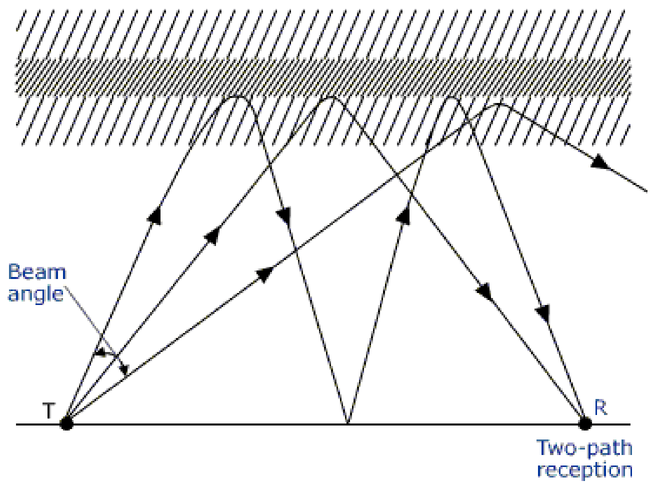
The skip distance is the shortest distance from a transmitter, measured along the surface of the Earth, at which a sky wave of fixed frequency (more than f_c) will be returned to Earth.

When the angle of incidence is made quite large, as for ray 1 of the below figure, the sky wave returns to ground at a long distance from the transmitter. As this angle is slowly reduced, naturally the wave returns closer and closer to the transmitter, as shown by rays 2 and 3. If the angle of incidence is now made significantly less than that of ray 3, the ray will be too close to the normal to be returned to Earth. It may be bent noticeably, as for ray 4, or only slightly, as for ray 5. In either case the bending will be insufficient to return the wave, unless the frequency being used for communication is less than the critical frequency {which is most unlikely}; in that case everything is returned to Earth. Finally, if the angle of incidence is only just smaller than that of ray 3, the wave may be returned, but at a distance farther than the return point of ray 3; a ray such as this ray 6 of below figure. This upper ray is bent back very gradually, because ion density is changing very slowly at this angle. It thus returns to Earth at a considerable distance from the transmitter and is weakened by its passage.



Effects of ionosphere on rays of varying incidence

If the frequency used is low enough, it is possible to receive lower rays by two different paths after either one or two hops, as shown in the below figure.



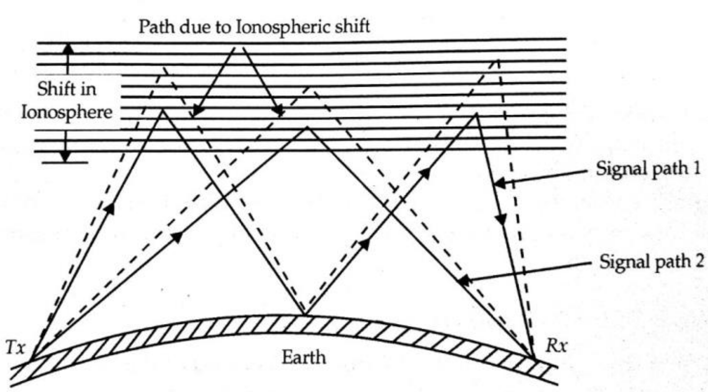
Multipath sky-wave propagation

FADING

Fading is the change in signal strength at receiver.

The main causes of fading are

1. Variation sin ionospheric conditions
2. Multipath reception



As the ionosphere is not stable and electron density changes, signal path length changes and hence there will be a change in phase. This causes received signal strength to change.

Types of fading are

1. Selective fading

2. Interference fading
3. Absorption fading
4. Polarization fading
5. Skip fading

Selective fading :

it produces serious distortion in the modulated signal. It is more prominent at high frequencies and fading is large with AM signal with high modulation index. Selective fading can be reduced by the use of SSB system

Interference Fading :

It is produced by the interference between rays & by the interference between the waves received at the receiver through different paths. It occurs due to the fluctuations in the layer height at a fixed frequency. Interference fading can be reduced by using different Diversity techniques

Absorption Fading:

This takes place due to absorption of waves by ionosphere.

Polarization fading:

This takes place due to change in polarization of EM wave. When polarization changes , the signal amplitude changes at receiver. This can be minimized by using polarization diversity.

Skip Fading

This occurs near the skip distance. The variation of height & density of layer cause skip fading. This can be minimized by using AGC at receiver.

DIVERSITY TECHNIQUES

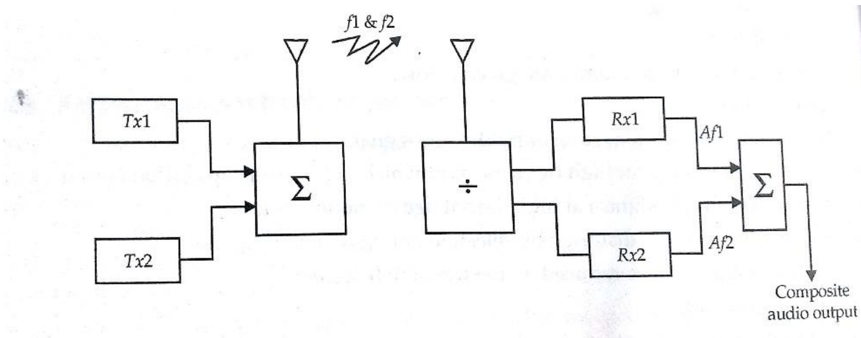
Fading can be reduced by using diversity techniques

Diversity technique can be

1. Frequency Diversity
2. Space Diversity
3. Polarity Diversity
4. Time Diversity

Frequency Diversity:

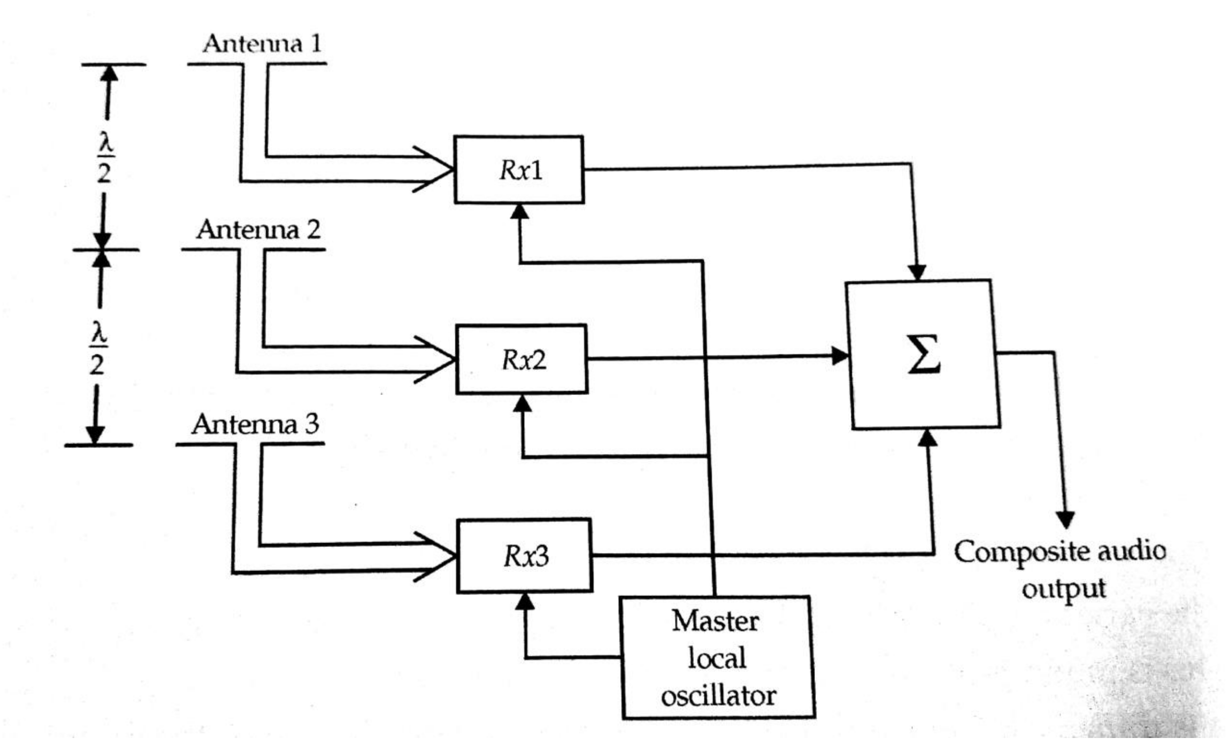
Here Transmitter will send two or more frequency simultaneously with the same modulating information. As different frequencies will fade differently one will be strong always.



Frequency Diversity to reduce fading

Space Diversity

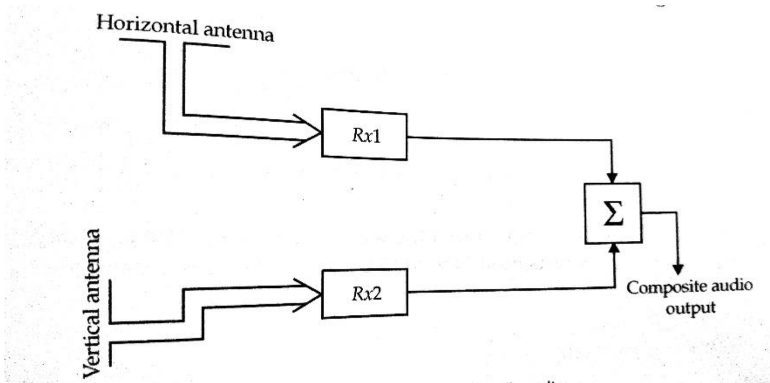
Here a single Transmitter is used. At the receiving site, two or more receiving antennas spaced at one-half wave length apart are used. The signal will fade at one antenna while it increases at another antenna.



Space diversity

Polarization Diversity

Here Vertical and horizontal polarized antennas are used to receive the signal. The two receivers are combined to produce constant output.



Polarization Diversity

Time Diversity:

Here same signals are transmitted at different times. As fading is time-dependent ,some signals may be strong and fading is less.

EFFECT OF EARTH'S MAGNETIC FIELD

The average magnetic field of earth is 40 A/m. This makes the ionosphere to behave like an anisotropic medium, ie, permittivity varies in different directions.

The earth's magnetic field causes the electrons to trace complicated trajectories with Gyro-frequency fc = 1.4 MHz at H= 40A/m.

Gyro-Frequency is defined as the lowest natural frequency at which charged particles spiral in a fixed magnetic field.

It is a vector quantity and is defined mathematically as

$$f_g = \frac{Q_e B}{2\pi \times m}$$

Where Qe = Charge of electron; B = Magnetic flex density; m=mass of electrons

- Earth's magnetic field exerts a deflecting force on the moving electrons.This force is given by

$$F = Q_e(V \times B)$$

$Where\ F = force\ on\ electron; V = velocity\ of\ electron;$

$B = magnetic\ flux\ density = \mu_0 H\ ; H = magnetic\ field\ intensity\ of\ earth$

The Direction of force is perpendicular to velocity of electron and magnetic field

- The magnetic field component of earth which is perpendicular to electric field of incident wave makes vibrating electrons to follow elliptical paths
- The electrons of the ionosphere absorb some energy from EM wave. This absorbed energy is re-radiated with a polarization that is 90^o out of phase with incident wave. This wave also differs the phase of incident wave. So the plane polarized wave changes to elliptically polarized wave.
- The average velocity of electron in inversely proportional to frequency , the effect of earth's magnetic field is more pronounced at low frequencies
- At high frequencies electron vibrate in narrow spiral paths under the influence of earth's magnetic field.
- When the frequency is decreased to gyro-frequency 1.4MHz, electrons follow a spiral path along with increased velocity.

IONOSPHERIC ABNORMALITIES

The electrical characteristics of ionosphere depends on solar radiation and hence they vary continuously. The variations in ionosphere are classified as

1. NORMAL:

   These occur due to

   - Dinural
   - Seasonal
   - Thickness & Height variations of the ionosphere

2. ABNORMAL:

   These occurs mainly due to changes in solar activity

   1. Ionospheric storms
   2. Sudden ionospheric disturbances
   3. Sunspot cycle

4. Whistlers
5. Tides & winds

Ionospheric storms:

These are due to the high absorption of sky waves and abnormal changes in critical frequencies of E and F_2 layers. These storms usually persist for few days.

Sudden ionospheric disturbances (SID)

The sudden solar flares causes SIDs. Solar flares occurs during solar peak activity. SIDs block out the signals completely. They persist for few minutes to an hour. SID causes complete fading of signal and is called Dellinger fade-out. Ultra violet radiation is intensive due to solar flares in D layer and is not found in E, F_1 and F_2 layers.

Sunspot cycle

Sunspot cycle is a eleven years cycle during which radiation varies drastically. The variation due to ultraviolet rays, flares, particle radiation and sunspots in very high. During sunspot maxima ,the critical frequencies are height and they are lowest during sunspot minima. To reduce the effect of sunspot cycle, the operating frequencies are carefully chosen.

Whistlers

These are transient electromagnetic disturbances which occurs naturally. Whistlers consists of EM pulses of audio frequency radiation along the direction of earth's magnetic field between conjugate points in the northern and southern hemispheres.

Tides & winds

Tides and winds are common in atmosphere. Solar tide effects are more pronounced. The winds in the ionosphere are caused by the tides. The presence of ionospheric winds are due to the motion of turbulence in F2 layer.

Table 9.1 Ionospheric layer heights and their electron densities

Layer	Approximate height above earth	Electron density (electrons/cc)	Day	Night
D	70 km	400	Exists	Absent
E	100 km	5×10^5	Exists	Absent
F_1	180 km	—	Exists	Merges with F_2
F_2	325 km	—	Exists	Exists
F	300 km	2×10^6	Exists	Exists

SPACE WAVE OR TROPOSPHERIC WAVE PROPAGATION

The EM wave propagates from transmitter to receiver in the earth's troposphere is called space wave or tropospheric wave .

Troposphere is the region of atmosphere within 16 Km above the surface of earth.

In space wave propagation , the field strength at receiver is contributed by

1. Direct ray from transmitter
2. Ground reflected ray
3. Reflected and refracted rays from troposphere
4. Diffracted rays around the curvature of earth, hills and so on

Contribution of first two rays are predominant

Space wave propagation is useful at frequencies above 30MHz. It is useful for FM,TV and Radar Applications.

FIELD STRENGTH DUE TO SPACE WAVE

Field strength of space wave $E = \frac{2E_0}{d} \sin\frac{2\pi h_t h_r}{\lambda\, d}$

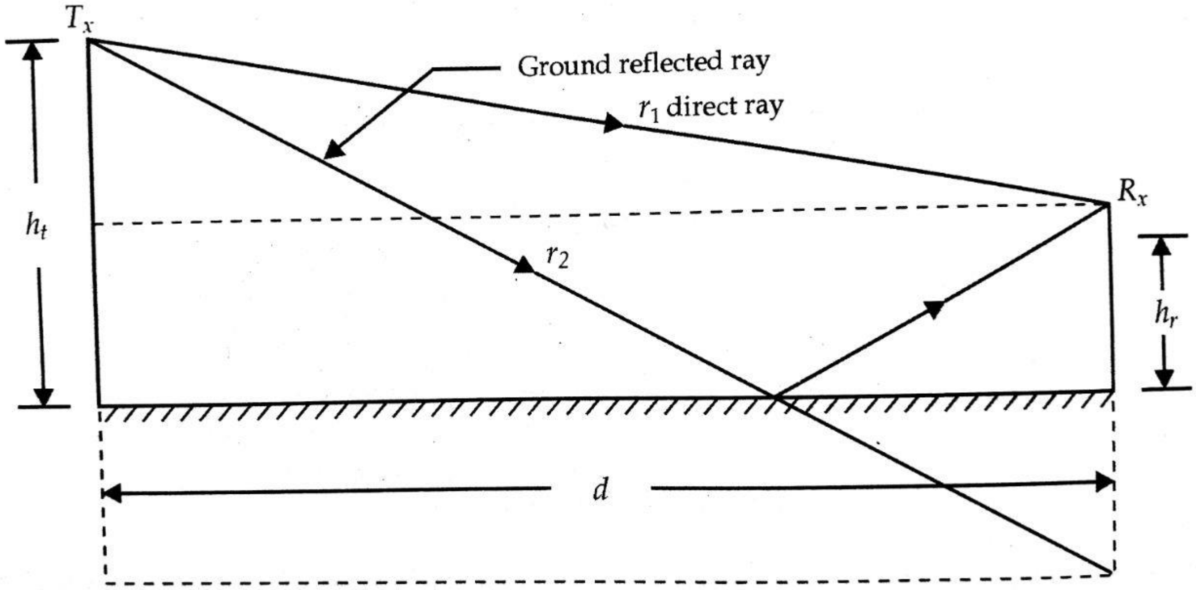
$$E \approx \frac{4\pi h_t h_r}{\lambda\, d^2}$$

Where Eo= Field strength due to direct ray at unit distance ht= Height of transmitting antenna

hr= Height of transmitting antenna

d = Distance between antennas

The field strength at receiver is mostly contributed by direct and ground reflected rays



From figure

$$r_1^2 = (h_t - h_r)^2 + d^2$$

$$r_1 = d\sqrt{1 + \left(\frac{(h_t - h_r)}{d}\right)^2}$$

From binomial series we have

$$(1 \pm x)^2 = 1 \pm \frac{1}{2}x - \frac{1}{2.4}x^2 + \cdots$$

If x is small , the higher order terms can be neglected.

$$(1 \pm x)^2 \approx 1 \pm \frac{1}{2}x$$

Therefore

$$r_1 = d\left[1 + \left(\frac{(h_t - h_r)}{d}\right)^2\right]^{1/2}$$

$$\approx d + \frac{(h_t - h_r)^2}{2d}$$

$$Similerly$$

$$r_2^2 = (h_t + h_r)^2 + d^2$$

$$r_2 \approx d + \frac{(h_t+h_r)^2}{2d}$$

Now the path difference between two rays

$$r_2 - r_1 = d + \frac{(h_t + h_r)^2}{2d} - d - \frac{(h_t - h_r)^2}{2d}$$

$$= \frac{h_t^2 + h_r^2 + 2h_t h_r}{2d} - \frac{h_t^2 + h_r^2 - 2h_t h_r}{2d}$$

$$r_2 - r_1 = \frac{4h_t h_r}{2d} = \frac{2h_t h_r}{d}$$

The phase difference due to path difference ,α is

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

$$\alpha = \frac{2h_t h_r}{d} \times \frac{2\pi}{\lambda}$$

Let Ed be the field due to direct ray and Er be due to reflected ray. Then the resultant field E_R at receiver is given by

$$E_R = \{E_d + E_r e^{-j\psi}\}$$

When the wave is incident on earth , it is reflected with same amplitude but with phase reversal. Therefore total phase shift

$\psi = 180^0$+α

Where α is phase difference due to path difference and

$$E_d = E_r = E_s$$

$$E_R = E_s\{1 + e^{-j(180+\alpha)}\}$$

$$= E_s[1 + \cos(180 + \alpha) - j\sin(180 + \alpha)]$$

$$= E_s[1 + \cos\theta + j\sin\theta] \qquad \text{where } \theta = 180 + \alpha$$

$$|E_R| = E_s\sqrt{(1+\cos\theta)^2 + (\sin\theta)^2} = Es\sqrt{1 + 2\cos\theta + cos^2\theta + sin^2\theta}$$

$$= Es\sqrt{2 + 2\cos\theta} = Es\sqrt{2 + 2\left[2\,cos^2\tfrac{\theta}{2} - 1\right]} = Es\sqrt{4\,cos^2\tfrac{\theta}{2}}$$

$$|E_R| = 2Es\,cos\,\tfrac{\theta}{2}$$

$$|E_R| = 2Es\,cos\left\{\frac{180+\alpha}{2}\right\}$$

$$|E_R| = 2Es\,sin\frac{\alpha}{2}$$

$$|E_R| = 2Es\,sin\frac{4\pi h_t h_r}{2\lambda d}$$

$$since\ d \gg ht\ or\ hr\ ; \quad sin\frac{4\pi h_t h_r}{2\lambda d} \approx \frac{4\pi h_t h_r}{2\lambda d}$$

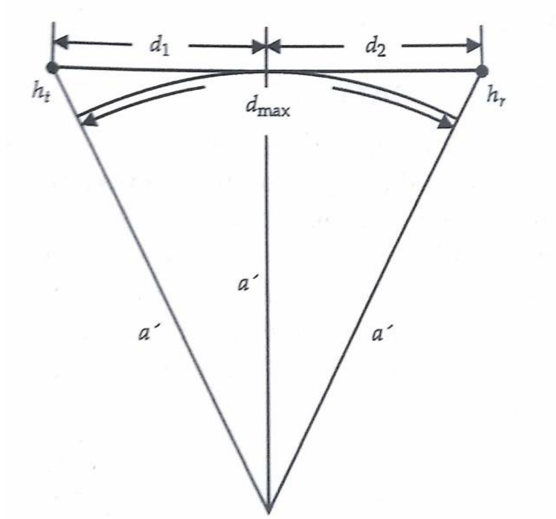
$$|E_R| = 2Es\,\frac{4\pi h_t h_r}{2\lambda d}$$

$$Es = \frac{Eo}{d}$$

Therefore

$$|E_R| = Eo\,\frac{4\pi h_t h_r}{\lambda d^2}$$

RANGE OF SPACE WAVE PROPAGATION (L.O.S RANGE)



Range Of Space Wave Propagation (Line of Sight Range)

If D is the distance between transmitter & receiver.

$$ht\ \&\ hr = height\ of\ transmitter\ \&\ receiver$$

$$D = d1 + d2$$

$$a = radious\ of\ earth$$

$$d_1 = \sqrt{(h_t + a)^2 - a^2} = \sqrt{ht^2 + a^2 + 2h_t a - a^2}$$

$$since\ h_t \ll 2h_t a$$

$$d_1 \approx \sqrt{2h_t a}$$

Similarly

$$d_2 = \sqrt{(h_r + a)^2 - a^2} \approx \sqrt{2h_r a}$$

$$D = d1 + d2 = \sqrt{2h_t a} + \sqrt{2h_r a}$$

$$= \sqrt{2a}\left\{\sqrt{h_t} + \sqrt{h_r}\right\}$$ But a , radius of earth = 6370 Km

$$D = 3.57\left\{\sqrt{h_t} + \sqrt{h_r}\right\}\ Km$$

The above analysis does not consider the effect of atmosphere on the propagation path of RF signals. In fact, RF signals don't propagate in straight lines: Because of the refractive effects of atmospheric layers, the propagation paths are somewhat curved. Thus, the maximum service range of the station is not equal to the line of sight (geometric) distance. Usually, a factor k is used in the equation above, modified to be

$$d_2 = \approx \sqrt{2kh_r a} \quad d_1 = \approx \sqrt{2kh_t a}$$

k is usually chosen to be $^4/_3$. That means that the maximum service range increases by 15%

$$D = 4.12\{\sqrt{h_t} + \sqrt{h_r}\} \quad Km$$

DUCT PROPAGATION

The higher frequencies or microwaves are continuously reflected in the duct and reflected by the ground. So that they propagate around the curvature for beyond the line of sight. This special refraction of electromagnetic waves is called super refraction and the process is called duct propagation. Duct propagation is also known as super refraction. Consider the figure,

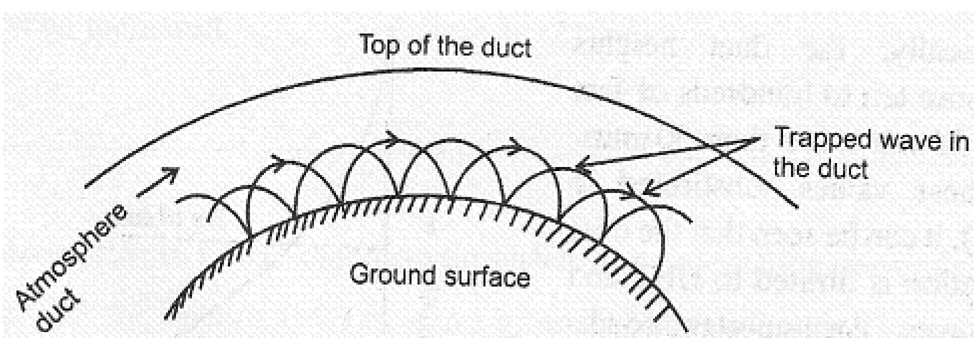


Fig 8.8.1 Duct Propagation

Here, two boundary surfaces between layers of air form a duct or a sort of wave guide which guides the electromagnetic waves between the walls. Temperature inversion is one of the important factor for the formation of duct. For proper value of curvature, the refractive index (n) must be replaced by a new refractive index *(N).*

$$N = n + \frac{h}{r}$$

The term modified index of refractive modules (m) is related to N as

$$(N - 1) = n - 1 + \frac{h}{r}$$

$$(N-1)\times 10^6 = \left[n-1+\frac{h}{r}\right]\times 10^6$$

$$Where\ (N-1)\times 10^6 = m$$

Therefore

$$m = \left[n-1+\frac{h}{r}\right]\times 10^6$$

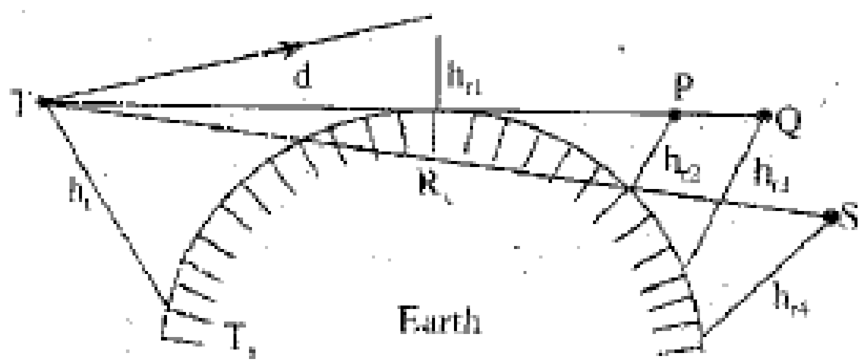
Where,
n = Refractive index
h = Height above ground
r = Radius of the earth = 6370 km

Duct can be used at VHF, UHF and microwave frequencies. Because, these waves are neither
reflected nor propagated along earth surface. So, the only possible way to transmit such signal is to utilize the phenomenon of refraction in the troposphere.

LINE OF SIGHT PROPAGATION (LOS)

Line of sight propagation is also known as space wave propagation. It is very important at higher frequency such as VHF, UHF and micro wave frequencies, i.e., 30 MHz to 300 MHz Consider two antennas, height of transmitting antennas is h_t and receiving antennas is h_r . The energy received at the receiving antenna can take two paths, one is direct from transmitting antenna to the receiving antenna and another is via ground.

Direct and indirect waves leave the transmitting antenna at the same time, but reach the receiving antenna at different times. The signal strength at receiving point is vector sum of direct and indirect waves. The field strength is greater, or less depending upon the two wave s which are combining or opposing in phase.



H ere the signal travels from the transmitting antenna to the receiving antenna through earth's tropospheric region, therefore, it is called as "Tropospheric propagation". At higher frequency, space wave propagation is limited to the line of sight distance and earth curvature, so that line of sight propagation is useful at VHF and UH F. Sky wave and ground wave propagations are failing at these frequencies.

In figure the height of transmit ting antenna is h_t and receiving antenna is h_r, and the distance between the two antennas is *d.* The signal path directly from transmitter to the receiver is denoted by ***TR***. As the receiving antenna is moved from point ***R*** to ***P,*** the line of sight path from ***R*** to ***P*** crosses the surface of the earth.

Here,

TR = Direct path

TP = Line of sig ht distance

The line of sight distance can increased to ***TQ*** by increasing the height of the antenna to h_{r3}.

L.O.S Range = D= $4.12\left\{\sqrt{h_t} + \sqrt{h_r}\right\}\ \ Km$

MODULE I

1. Calculate ***D(θ, ϕ)***,the directivity for three unidirectional sources with following power patterns.

   (a) $\Phi = \phi_m \sin\theta \sin^2\phi$ (b) $\Phi = \phi_m \sin\theta \sin^3\phi$ (c) $\Phi = \phi_m \sin^2\theta \sin^3\phi$

   Where θ & Φ lies between $\mathbf{0 \leq \theta \leq \pi}$ and $\mathbf{0 \leq \phi \leq \pi}$

   Hint:

$$D = \frac{4\pi \times \emptyset(\theta, \emptyset)}{P_{red}}$$

$$P_{red} = \int_0^{\pi} \int_0^{\pi} \emptyset \, sin\theta \; d\theta \; d\emptyset$$

   Use Willi's formula to find integrals.

2. The maximum Radiation intensity of a 90% efficiency antenna is 200mW/unit solid angle. Find the directivity and power gain in dB when input power is 125.66mW and radiated power is 125.66mW.

   Hint:

$$D = \frac{4\pi \times \emptyset(\theta, \emptyset)}{P_{red}}$$

$$Power\ gain = \frac{4\pi \times U}{input\ power}$$

3. Estimate the directivity of an antenna with $\theta_{HP} = 2^0$ and $\emptyset_{HP} = 2^0$

   Hint : Use Kraus Formula ; $D_{Max} = \dfrac{41253}{\theta_{HP}\emptyset_{HP}}$

4. What is the Maximum effective aperture of a microwave antenna with Directivity of 900.

   Hint: $A_e = \frac{\lambda^2}{4\pi} \times D$

5. Find the maximum effective aperture of a Beam antenna having HPBW of 30^0 and 35^0 in perpendicular planes intersecting in beam axis.

   Hint: Use Kraus Formula ; $D_{Max} = \frac{41253}{\theta_{HP}\phi_{HP}}$ and

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

6. Find Q of an antenna if it has a band width of 600KHz and cutoff frequency of 30MHz.

   Hint: $\Delta f = \frac{f_r}{Q}$

7. An antenna is desired to operate in a frequency of 30MHz whose Q is 40.calculate band width.

   Hint: $\Delta f = \frac{f_r}{Q}$

8. Calculate Radiation resistance of an antenna which draws a current of 15A and radiating 5KW.

   Hint: $W = I_{rms}^2 \times R_r$

9. Calculate the FBR(front to back ratio) of an antenna in dB which radiates 3KW in most optimum direction and 500W in opposite direction.

   Hint : FBR $=\frac{Radiation\ in\ forward\ direction}{Radiation\ inbackward\ direction}$

   FBR in dB = 10 log FBR

10. The radiation resistance of an antenna is 72Ω whose loss resistance is 8Ω.What is the directivity in dB, if power gain is 16

    Hint:

$$\eta = \frac{R_r}{R_r + R_l}$$

Gain = Directivity × η

11. An antenna has loss resistance 10Ω, power gain 20 and directivity 22. Calculate its radiation resistance.

    Hint:

$$\eta = \frac{R_r}{R_r + R_l} = \frac{G_P}{G_d}$$

12. An antenna has $R_r = 72\Omega$, $R_l = 8\ \Omega$ $G_P = 12dB$. Determine η & $Directivity$.

Hint: $\eta = \frac{R_r}{R_r+R_l} = \frac{G_P}{G_d}$

$G_d = Directivity$

13. An isotropic antenna radiates equally in all direction. The total power delivered to radiator is 100KW.calculate the power density at a distance of 100m, 1000m, and 10000m.

    Hint: $Pr = \frac{W_{rad}}{4\pi r^2}$

14. A power gain test of a reference antenna and a test antenna resulted in following data.

    (a). input power to reference antenna (P2) = 400mW

    (b). Power to test antenna (P1) = 100mW

    Calculate power gain.

    Hint: $G_p = 10 \log \frac{P1}{P2}$

15. A receiving antenna picks up 50μV signal. The transmitting section switches toa nearby antenna which has 5dB gain over original antenna. How much is the new signal picked up by receiving section.

    Hint: $G_p\ in\ dB = 20 \log\ \frac{V_1}{V_2}$

16. The noise figure of an amplifier at room temperature (T= 290^{o}K) is dB. Find equivalent temperature.

    Hint: F in dB = 10 log F

    $T_e = (F-1)T_0$

MODULE II

17. Calculate the radiation Resistance of a $\frac{\lambda}{10}$ wire dipole in free space.

    Hint:

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

18. A thin dipole antenna is $\frac{\lambda}{15}$ long. If its loss resistance is 1.5Ω find radiation resistance & efficiency.

    Hint:

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

$$\eta = \frac{R_r}{R_r + R_l}$$

19. A short vertical grounded antenna is designed to radiate at 1MHz. Calculate the Radiation resistance , if the effective height of antenna if 30 Meters.

    Hint:

    For a Grounded short dipole antenna $Rr = \frac{160\pi^2 l_e^2}{\lambda^2}$

20. An antenna has an effective height of 100 meters and current at base is 450 Amperes(rms) at 40KHz.What is the power radiated? If the total resistance of antenna circuit is 1.12ohms,what is the efficiency of the antenna

    Hint:

$$\eta = \frac{R_r}{R_r + R_l}$$

$$W = I_{rms}^2 \times R_r$$

$$Rr = \frac{160\pi^2 l_e^2}{\lambda^2}$$

$$\lambda = \frac{300}{f(MHz)}$$

21. A transmitting antenna having effective height of 100 meters has a current at base 100A at a frequency of 300KHz.Calculete
    1. The field strength at a distance of 100m.
    2. Value of radiation resistance
    3. The power radiated.

Hint:

$$|E| = \frac{120\pi l_e I_{rms}}{\lambda \times r}$$ Where $l_e = effective\ length$; r = distance

$$W = I_{rms}^2 \times R_r$$

$$Rr = \frac{160\pi^2 l_e^2}{\lambda^2}$$

$$\lambda = \frac{300}{f(MHz)}$$

22. A grounded vertical antenna fed at the bottom with RF current of 32 Amperes at 1MHz,Produces afield strength of 9 millivolts/meter at a distance of 100 Km. Calculate the height of antenna in meters.

Hint; $E_{rms} = \frac{120\pi l_e I_{rms}}{\lambda \times r}$

23. A grounded vertical antenna of height 75 meters fed at bottom with a current of 10 Amperes rms at 1 MHz. Calculate the field strength at a distance of 100Km on the surface of the earth.

Hint: $$l_e = \frac{2}{\pi} \times Height\ of\ antenna$$

$$E_{rms} = \frac{120\pi l_e I_{rms}}{\lambda \times r}$$

24. A plane travelling wave in free space has an average poynting vector of 1 W/m^2.Find average energy density.

Hint: Poynting vector P =EH ; total energy density W= μH^2

$$\frac{P}{W} = \frac{EH}{\mu H^2} = \frac{E}{\mu H} = \frac{1}{\mu}\sqrt{\frac{\mu}{\varepsilon}} = \frac{1}{\sqrt{\mu\varepsilon}} = Velocity$$

$$Average\ energy\ density = \frac{Poynting\ vector}{Average\ velocity}$$

MODULE III

25. For an end-fire array consists of 7 half wave length long isotropic radiators is to have a directive gain of 30.Find the array length and width of major lobe(FNBW).What will be these values for a Broad side array

    Hint:

    For End fire array $D = \frac{4L}{\lambda}$ & $FNBW = 114.6\sqrt{\frac{2}{L/\lambda}}$

    For Broad side array $D = \frac{2L}{\lambda}$ & $FNBW = \frac{114.6}{L/\lambda}$

26. A four element Uniform linear array has element spacing 0.375λ and progressive phase shift 50^0. Find the radiation pattern and direction of maximum radiation.
27. For a broad side array of 3 elements, the null occurs in a direction 45^0 from the array axis. What are the array parameters?
28. Calculate the directivity of given linear end-fire array with improved directivity, Hansan-Woodyard array of 10 elements with a separation of λ/4 between the elements.
29. Calculate the direction of nulls for 8 element end-fire array having element spacing equal to 0.375λ
30. Calculate the directivity of broad side array having 10 elements with inter element spacing 0.3 λ. What is the length of array?
31. What is the directivity of end-fire array of 5 elements with spacing equal to 0.2 λ
32. Calculate the directivity of Hansan-Woodyard end-fire array of 12 elements with spacing equal to 0.2 λ
33. Design broad side array of 4 elements with spacing equal to 0.5 λ , and main lobe to side lobe ratio 19.1 dB(Use Dolph-Tchebyshev array method)

34. Design a 8 element broad side array of isotropic sources of $\lambda/2$ spacing between elements. The pattern is to be optimum with a side lobe level 26dB down from main lobe maximum.
35. Design a 7 element broad side array which has the optimum pattern for a side lobe level of -20dB. The spacing between the elements has to be $\lambda/2$
36. Determine the Dolph- Tchebyshev current distribution for the minimum of a linear inphase broad side array of 8 isotropic sources. The spacing between the elements is 3 $\lambda/4$ and the side-lobe level is to be 40dB down. What is the Half power bean width?

MODULE IV

37. Calculate the power gain of an optimum horn antenna approximately with a square aperture of 10λ on a side.

    Hint: $D = \frac{4.5\,A}{\lambda^2}$ where A = area

38. Find out the power gain in dB of a paraboloidal reflector of open mouth aperture 10λ

    Hint: $G_p = 6\left(\frac{D}{\lambda}\right)^2$ where D= diameter of aperture in λ

    Power gain in dB = 10 log Gp

39. Find out the beamwidth between first nulls and power gain of a 2m paraboloid reflector operating at 6000MHz.

    Hint: $FNBW = \frac{140\lambda}{D}$ and $G_p = 6\left(\frac{D}{\lambda}\right)^2$

40. Estimate the diameter and effective aperture of a paraboloid reflector antenna required to produce FNBW of 10^0 at 3GHz.

    Hint: $FNBW = \frac{140\lambda}{D}$

41. A paraboloid reflector is required to have a power gain of 1000 at 3GHz.Determine the mouth diameter and Beam width of antenna.

    Hint : $G_p = 6\left(\frac{D}{\lambda}\right)^2$; $D = \lambda\sqrt{\frac{G_p}{6}}$

    $FNBW = 140 \times \left(\frac{\lambda}{D}\right)$; $HPBW = 70 \times \left(\frac{\lambda}{D}\right)$

MODULE V

42. Calculate the directivity of a 20 turn helix in dB, having α= 12^0 , circumference equal to one wave length.

    Hint:

$$D = \frac{15NSC^2}{\lambda^3}$$

43. Design a Rectangular patch antenna which can be used for Wi-Fi. Assume FR-4 substrate with substrate height of 1.6mm.
44. Design a Rectangular patch antenna which resonate at 3.3GHz. Assume FR-4 substrate with substrate height of 1.6mm.

MODULE VI

45. Jalandhar Doordarshan transmitter antenna has a height of 200m and the receiving antenna has height of 16m.What is the maximum distance through which the TV signal could be reached by space propagation? Take effective radius into consideration.

    Hint: LOS equation $d = 4.12\left[\sqrt{h_t} + \sqrt{h_r}\right]$ in Km.
46. For a TV antenna placed at height 165m ,what should be the height of receiving antenna at a distance of 65Km?

    Hint: LOS equation $d = 4.12\left[\sqrt{h_t} + \sqrt{h_r}\right]$ in Km.
47. The critical frequency of an ionized layer is 1.5 MHz, find electron density of the layer.

    Hint: $f_c = 9\sqrt{N}$ $\quad Where\ N = electron\ density$
48. Determine the critical frequency of EM wave for D(N=400electrons/cc) ,E (5×10^5 electrons/cc), and F (2×10^6 electrons/cc) Layers.

    Hint: $f_c = 9\sqrt{N}$ $\quad Where\ N = electron\ density$
49. Find Critical Frequency if the maximum electron density is 1.3×10^6 electrons/cc.

    Hint: $f_c = 9\sqrt{N}$ $\quad Where\ N = electron\ density$

50. Find the relative permittivity of D,E and F layers of ionosphere for an EM wave frequency of 50MHz.

    Hint:

    For D layer N=400electrons/cc ,For E layer N= 5×10^5 electrons/cc, and F layer N= (2×10^6 electrons/cc)

    Refractive index $\mu = \sqrt{\varepsilon_r} = \sqrt{1 - \frac{81N}{f^2}}$ Where f in KHz

$$\varepsilon_r = \left[1 - \frac{81N}{f^2}\right]$$

51. Find the frequency of propagation of wave in F layer with refractive index 0.5

    Hint: For D layer N=400electrons/cc

    $\mu = \sqrt{\varepsilon_r} = \sqrt{1 - \frac{81N}{f^2}}$ Find f

52. A HF radio communication is to be established between two points on earth's surface. The points are at a distance of 2600Km.The height of ionosphere is 200Km and critical frequency is 4MHz.Find MUF.

    Hint:

    $MUF = f_c\sqrt{1 + \frac{d^2}{4h^2}}$ Where d = skip distance; h= height

MUF for F layer = 3.6 ***fc***

Skip Distance = *2h × tan i*