Uma Charan Patnaik Engineering School, Berhampur

Department of Electronics and Telecommunication Engineering

Lecture Note

Course Name: Wave Propagation and Broadband Communication Engineering (Th4)

SEM: 5

Branch: ETC

Prepared By: Kshirabdhee Tanaya Dora, Guest Faculty, Electronics

Th.4 WAVE PROPAGATION & BROADBAND COMMUNICATION ENGINEERING

Theory : 4 Periods per week	I.A. : 20 Marks
Total Periods : 60 Periods	Term End Exam : 80 Marks

Sl.No.	Topics	Periods
1.	WAVE PROPAGATION & ANTENNA	12
2.	TRANSMISSION LINES	10
3.	TELEVISION ENGINEERING	13
4.	MICROWAVE ENGINEERING	15
5.	BROADBAND COMMUNICATION	10
	TOTAL	60

Detailed Syllabus

Unit-1: WAVE PROPAGATION & ANTENNA

1.1 Effects of environments such as reflection, refraction, interference, diffraction, absorption and attenuation (Definition only)
1.2 Classification based on Modes of Propagation-Ground wave, Ionosphere ,Sky wave propagation, Space wave propagation
1.3 Definition – critical frequency, max. useable frequency, skip distance, fading, Duct propagation & Troposphere scatter propagation actual height and virtual height
1.4 Radiation mechanism of an antenna-Maxwell equation.
1.5 Definition - Antenna gains, Directive gain, Directivity, effective aperture, polarization, input impedance, efficiency, Radiator resistance, Bandwidth, Beam width, Radiation pattern
1.6 Antenna -types of antenna: Mono pole and dipole antenna and omni directional antenna
1.7 Operation of following antenna with advantage & applications.
a) Directional high frequency antenna : , Yagi & Rohmbus only
b) UHF &Microwave antenna.: Dish antenna (with parabolic reflector) & Horn antenna
1.8 Basic Concepts of Smart Antennas- Concept and benefits of smart antennas

Unit-2: TRANSMISSION LINES.

2.1 Fundamentals of transmission line.

2.2 Equivalent circuit of transmission line & RF equivalent circuit
2.3 Characteristics impedance, methods of calculations & simple numerical.
2.4 Losses in transmission line.
2.5 Standing wave – SWR, VSWR, Reflection coefficient, simple numerical.
2.6 Quarter wave & half wavelength line
2.7 Impedance matching & Stubs – single & double
2.8 Primary & secondary constant of X-mission line.

Unit-3: TELEVISION ENGINEERING.

3.1 Define-Aspect ratio, Rectangular Switching. Flicker, Horizontal Resolution, Video bandwidth, Interlaced
scanning, Composite video signal, Synchronization pulses
3.2 TV Transmitter – Block diagram & function of each block.
3.3 Monochrome TV Receiver -Block diagram & function of each block.
3.4 Colour TV signals (Luminance Signal & Chrominance Signal,(I & Q,U & V Signals).
3.5 Types of Televisions by Technology- cathode-ray tube TVs, Plasma Display Panels, Digital Light Processing (DLP),Liquid Crystal Display (LCD),Organic Light-Emitting Diode (OLED) Display, Quantum Light-Emitting Diode (QLED) – **only Comparison based on application**
3.6 Discuss the principle of operation - LCD display, Large Screen Display.
3.7 CATV systems & Types & networks
3.8 Digital TV Technology-Digital TV Signals, Transmission of digital TV signals & Digital TV receiver Video programme processor unit.

Unit-4: MICROWAVE ENGINEERING.

4.1 Define Microwave Wave Guides.
4.2 Operation of rectangular wave gives and its advantage.
4.3 Propagation of EM wave through wave guide with TE & TM modes.
4.4 Circular wave guide.
4.5 Operational Cavity resonator.
4.6 Working of Directional coupler, Isolators & Circulator.
4.7 Microwave tubes-Principle of operational of two Cavity Klystron.
4.8 Principle of Operations of Travelling Wave Tubes
4.9 Principle of Operations of Cyclotron
4.10 Principle of Operations of Tunnel Diode & Gunn diode

Unit-5: Broadband communication

5.1 Broadband communication system-Fundamental of Components and Network architecture
5.2 Cable broadband data network- architecture, importance & future of broadband telecommunication internet based network.
5.3 SONET(Synchronous Optical Network)-Signal frame components topologies advantages applications, and disadvantages
5.4 ISDN - ISDN Devices interfaces, services, Architecture, applications,
5.5 BISDN -interfaces & Terminals, protocol architecture applications

[Coverage of Syllabus upto Internal Exams:Chapter 1,2,3,4]

Books Recommended:

1. Electronics Communication by G. Kennedy- MGH
2. Television & Video Engineering by A.M.Dhake, Tata McGraw Hill.
3. Broadband Communication System by AKUJUOBI & SADIKU (PHI)
4. Antennas and wave Propogation by John D Kraus,Ronald J Marhefka, Ahmad S Khan,TMG
5. Microwave & Radio Engg. By M.Kulkani-Ummesh Publication.
6. Microwave Engineering by Monojil Mitra – Dhanpat Rai& Co
7. Broadband Communication by Balaji Kumar (Reference)
8. Introduction to Broadband Communication Sysyem by Chapman & Hall (Reference)
9. Microwave Engineering by G.S.N. Raju,IKI (Reference)

CHAPTER - 1
WAVE PROPAGATION & ANTENNA

1.1 Effects of environments such as reflection, refraction, interference, diffraction, absorption and attenuation (Definition only)

Electromagnetic waves on the road are exposed to various environmental influences causing phenomena such reflection, refraction, interference, diffraction, absorption and attenuation. Note: Due to these environmental effects, the quality of information transmission is not satisfactory and a radio-relay link is not reliable.

Introduction to Electro Magnetic Waves: When the power is radiated into the free space is governed by the characteristics of free space. If such power escapes on purpose it is said to have been radiated, then it propagates in space in the particular shape is known as Electromagnetic wave. Free space is the space that does not interfere with the normal radiation and propagation of radio waves.

- EM waves are energy travel through free medium at the velocity of light, which is approximately 3×105 kilometer/second.
- Electromagnetic waves are similar to propagation of out ward travel of water wave on a river after a stone has been thrown into it with the only difference is that water waves are longitudinal & EM waves are transverse.
- The velocity of EM wave decreases when it travels into a medium.
- Electromagnetic waves can be related to the term „power density‟ and the direction of electric field.
- The magnetic field and Electric field propagation are mutually perpendicular in electromagnetic waves.
- In case of free space electromagnetic waves is spread uniformly in all direction form a point source. So the wave front is just like spherical.

Effects of environment:
When propagation near the earth is occurs the factors which are not available in free space must be considered. These propagated waves will be reflected by the ground, mountains and buildings. They will be refracted as they pass through layers of the atmosphere which have different degree of attenuation. The EM wave may diffracted around tall, massive objects. They also interface with each other, when two waves from same source meet after having travelled by different paths.

Reflection of waves :

• Reflection will occur due to presence of building mountains, ground when the EM wave is travelling in free space.

• In case of reflection the bright ness of EM wave is progressively reduced due to reflection the EM wave losses some energy on reflected surface.

• In case of reflection the EM wave of vector is perpendicular to conducting surface.

• If the reflecting surface is rough reflection will be much same as smooth surface.

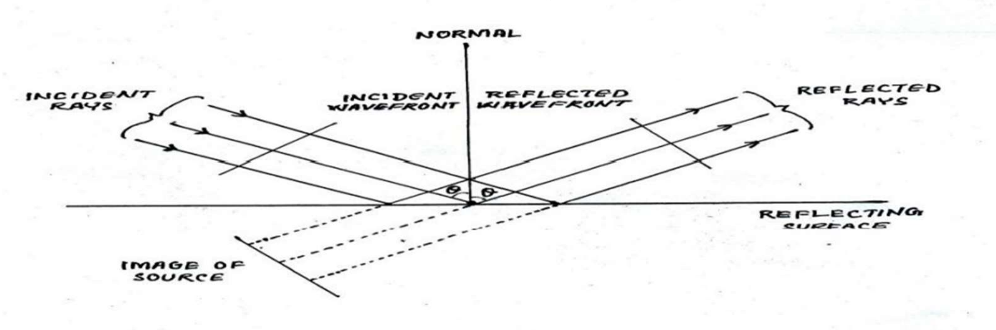


Fig: Reflection of electromagnetic waves.

Refraction of waves:

• Refraction takes place when electromagnetic waves pass from one propagating medium to a medium having a different density.

• This situation caves the wave front to acquire new direction in second medium and is brought about by a change in wave velocity.

• In case of Refraction the first signal is being propagated in the free space in case of high wall medium.

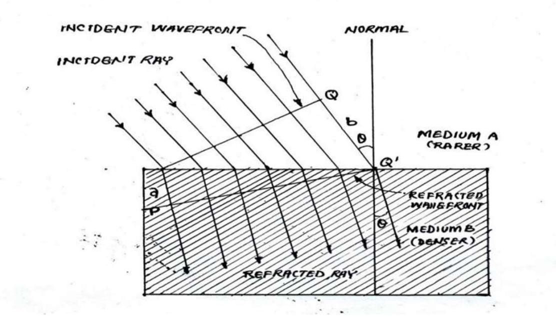


Fig: Refraction of electromagnetic waves

Interference of waves :

• When two waves traveled and left from one source but when they met each other Interference occurs.

• This happens very often in high frequency sky wave propagation and in Microwave space-wave propagation. • It also occurs when a microwave antenna is located near the ground, and wave Reach the receiving point not only directly but also after being reflected from the ground.
• At frequencies up to the very high frequency interference will not be significant because of the large wave lengths of such signals.
• The below figure occurs when a microwave antenna is located near the ground, and the waves reach the receiving point only directly after being reflected from the ground.

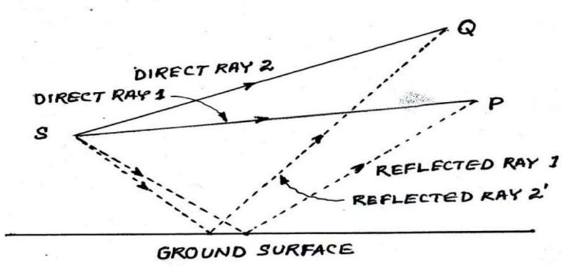


Fig. Interference of electromagnetic waves

Diffraction of waves:
• It is caused in electromagnetic wave when it is affected by the presence of small Slits in a conducting plane or share edges of obstacle.
• It involves change of direction of waves which are travel through a medium.
• Diffraction is depends on the wavelength of signal wave i.e. it increase with increase in wave length and decrease with decrease in wave length.
• Diffraction plays an important role in preventing the narrow pencil of radiation which is often desired, by generating unwanted side lobes

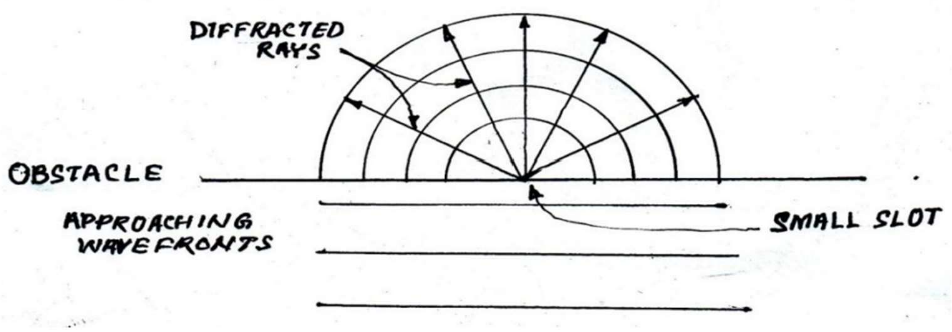


Fig. Diffraction of electromagnetic waves

1.2 Classification based on Modes of Propagation-Ground wave, Ionosphere ,Sky wave propagation, Space wave propagation

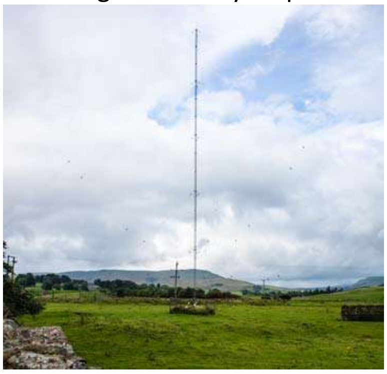
Ground Wave Propagation:

Ground wave propagation is a form of signal propagation where the signal travels over the surface of the ground, and as a result it is used to provide regional coverage on the long and medium wave bands.

Ground wave propagation is particularly important on the LF and MF portion of the radio spectrum. Ground wave radio propagation is used to provide relatively local radio communications coverage, especially by radio broadcast stations that require to cover a particular locality.

Ground wave radio signal propagation is ideal for relatively short distance propagation on these frequencies during the daytime. Sky-wave ionospheric propagation is not possible during the day because of the attenuation of the signals on these frequencies caused by the D region in the ionosphere. In view of this, radio communications stations need to rely on the ground-wave propagation to achieve their coverage.

A ground wave radio signal is made up from a number of constituents. If the antennas are in the line of sight then there will be a direct wave as well as a reflected signal. As the names suggest the direct signal is one that travels directly between the two antenna and is not affected by the locality. There will also be a reflected signal as the transmission will be reflected by a number of objects including the earth's surface and any hills, or large buildings. That may be present.

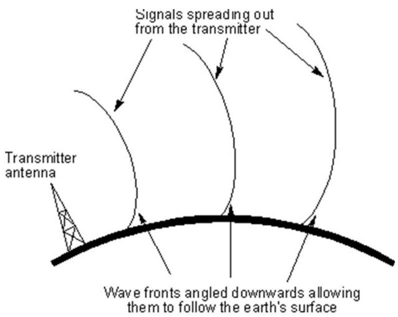


A medium wave broadcast transmitter antenna used for relatively local coverage using ground wave propagation In addition to this there is surface wave. This tends to follow the curvature of the Earth and enables coverage to be achieved beyond the horizon. It is the sum of all these components that is known as the ground wave.

Beyond the horizon the direct and reflected waves are blocked by the curvature of the Earth, and the signal is purely made up from the diffracted surface wave. It is for this reason that surface wave is commonly called ground wave propagation.

Surface wave

The radio signal spreads out from the transmitter along the surface of the Earth. Instead of just travelling in a straight line the radio signals tend to follow the curvature of the Earth. This is because currents are induced in the surface of the earth and this action slows down the wave-front in this region, causing the wave-front of the radio communications signal to tilt downwards towards the Earth. With the wave-front tilted in this direction it is able to curve around the Earth and be received well beyond the horizon.



Ground wave radio propagation

Effect of frequency on ground wave propagation

As the wavefront of the ground wave travels along the Earth's surface it is attenuated. The degree of attenuation is dependent upon a variety of factors. Frequency of the radio signal is one of the major determining factor as losses rise with increasing frequency. As a result it makes this form of propagation impracticable above the bottom end of the HF portion of the spectrum (3 MHz). Typically a signal at 3.0 MHz will suffer an attenuation that may be in the region of 20 to 60 dB more than one at 0.5 MHz dependent upon a variety of factors in the signal path including the distance. In view of this it can be seen why even high power HF radio broadcast stations may only be audible for a few miles from the transmitting site via the ground wave.

Effect of the ground

The surface wave is also very dependent upon the nature of the ground over which the signal travels. Ground conductivity, terrain roughness and the dielectric constant all affect the signal attenuation. In addition to this the ground penetration varies, becoming greater at lower frequencies, and this means that it is not just the surface conductivity that is of interest. At the higher frequencies this is not of great importance, but at lower frequencies penetration means that ground strata down to 100 metres may have an effect.

Despite all these variables, it is found that terrain with good conductivity gives the best result. Thus soil type and the moisture content are of importance. Salty sea water is the best, and rich agricultural, or marshy land is also good. Dry sandy terrain and city centres are by far the worst. This means sea paths are optimum, although even these are subject to variations due to the roughness of the sea, resulting on path losses being slightly dependent upon the weather! It should also be noted that in view of the fact that signal penetration has an effect, the water table may have an effect dependent upon the frequency in use.

Polarisation & ground wave propagation:

The type of antenna and its polarisation has a major effect on ground wave propagation. Vertical polarisation is subject to considerably less attenuation than horizontally polarised signals. In some cases the difference can amount to several tens of decibels. It is for this reason that medium wave broadcast stations use vertical antennas, even if they have to be made physically short by adding inductive loading. Ships making use of the MF marine bands often use inverted L antennas as these are able to radiate a significant proportion of the signal that is vertically polarised.

At distances that are typically towards the edge of the ground wave coverage area, some sky-wave signal may also be present, especially at night when the D layer attenuation is reduced. This may serve to reinforce or cancel the overall signal resulting in figures that will differ from those that may be expected.

Ref: https://www.electronics-notes.com/articles/antennas-propagation/ground-wave/basics-tutorial.php

Sky Wave Propagation:

Definition: A type of radio wave communication in which the electromagnetic wave propagates due to the reflection mechanism of the ionospheric layer of the atmosphere is known as sky wave propagation. Due to propagation through the ionosphere, it is also known as ionospheric wave propagation.

The permissible frequency range in the case of sky wave propagation lies between 3 MHz to 30 MHz. Basically the electromagnetic waves in the range of 3 to 30 MHz get reflected by the ionosphere. However, the signals with frequency beyond 30 MHz despite undergoing reflection get penetrated. So, due to this reason, *sky wave propagation is suitable only for this particular range of frequency*.

Need Of Sky Wave Propagation:

In the previous article, we have discussed ground wave propagation in which the electromagnetic wave propagates through the surface of the earth. We know that ground wave propagation is usually suitable for the transmission of low-frequency electromagnetic signals (usually up to 2 or 3 MHz).

Also, another major disadvantage associated with ground wave propagation is that it is suitable only for short-range operation. This is so because the induced wave in ground wave propagation causes attenuation of the propagated signal. Therefore, in order to transmit the signal with the least attenuation, it is preferred that the signal is transmitted only to short ranges, in the case of ground wave propagation.

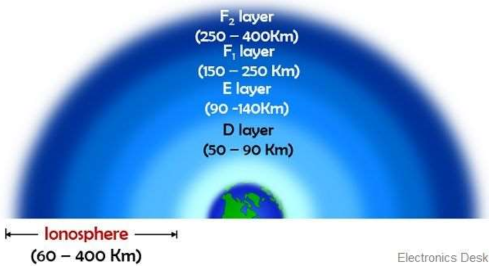
So, these two factors: low-frequency signal transmission and short distance propagation are the two major disadvantages associated with ground wave propagation. And in order to overcome these two disadvantages, sky wave propagation is used.

It allows the propagation of electromagnetic waves of higher frequency from one end to another at a larger distance than ground wave propagation. And it does so by reflections of the wave from the ionosphere. Thus sometimes referred to as ionospheric wave propagation.

Structure of Ionosphere:

We know that the ionosphere is present in the upper atmospheric region and is composed of ionized layers. Generally, the ionosphere consists of 4 different layers namely D, E, F_1, and F_2. These layers are present at different heights from the surface of the earth. Basically the ionosphere is said to be extended from 60 to 400 Km from the surface of the earth.

The figure below represents the structure of the ionosphere:



Each layer has a different concentration of atoms in a way that the ionized layer which is present nearer to the surface of the earth has the highest number of neutral atoms. While the middle layer has moderate concentration and the outermost layer consists of a very less number of neutral atoms.

It is clearly shown in the above figure that the D layer is present at around 50 to 90 km above the surface of the earth. While E, F_1, and F_2 are present at 90 to 140 km, 150 to 250 km, and 250 to 400 km respectively above the surface of the earth.

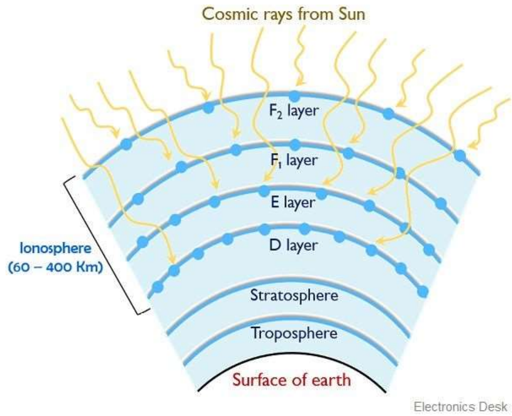
What is Sky Wave Propagation?

Till now we have discussed that electromagnetic waves propagate through the ionospheric region in order to get transmitted over larger distances. Let us now understand, how sky wave propagation takes place.

We have recently discussed that the ionosphere is composed of 4 different layers and each layer consists of a different number of atoms. The outmost layer has the lowest number of atoms while the innermost layer of the ionosphere is highly dense. The reason behind this is that the atmosphere of earth is denser towards its surface and becomes rarer on proceeding upwards.

We are already aware of the fact that the sun emits powerful cosmic rays. So, due to less number of neutral atoms in the outermost layer, most of the cosmic rays penetrate the inner surface of the atmosphere without even interacting with the atoms present there. However, as the inner layer is slightly denser than the outer one so here interaction between cosmic rays and atoms takes place.

Moreover, this interaction between cosmic rays and the atoms increases tremendously in the E layer of the ionosphere, as this layer has a greater number of atoms. But on penetrating to such a level inside the earth's atmosphere, the intensity of the cosmic rays reduces to a large extent. Hence very few cosmic rays interact with the innermost layer of the ionosphere although this layer is denser than other layers. This is clearly shown in the figure given below:



So, when cosmic rays interact with the atoms present in the ionospheric layers then electrons are emitted from the valence shell of the atom. Thus *ionization takes place*. And as interaction is higher in the case of middle layers of the atmosphere, therefore, ionization will be higher in that layer itself. Thus it holds the maximum number of charged particles.

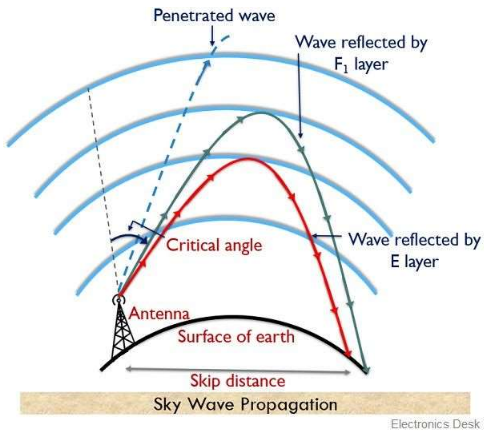
- Now, whenever an electromagnetic signal is transmitted from an antenna then it suffers reflection from the ionospheric layer and comes back to the surface of the earth and is received by the receiving antenna.

We know that electromagnetic waves are composed of *electric and magnetic fields*. Also, the charged particles present in the layers of the ionosphere have their own electric field. So, when EMW is allowed to be propagated through the earth's atmosphere then the field of the EMW and the charged particles interact with each other. And this leads to *cause reflection of the electromagnetic wave* by the atmosphere.

More simply we can say this as TIR taking place in the atmosphere.

- We know that when light propagates from a denser to a rarer medium with an angle equal to or greater than a critical angle then it gets reflected back towards the same medium. This is referred as Total Internal Reflection.

In a similar way when the transmitting antenna transmits the electromagnetic wave with a certain angle (equal or greater than critical angle) then due to ionization on the earth's atmosphere it gets reflected back towards the surface of the earth. This causes the reception of the reflected signals by the receiving antenna.



It is to be noted here that the field in the atmospheric layer must be sufficiently large so that it can allow reflection of the electromagnetic waves through it. This is so because it may be possible that a high-frequency wave may not be reflected by the lower region of the ionosphere.
However, with upward movement, even the high-frequency wave will get reflected due to a higher degree of ionization.

- So, we can say this as a low-frequency wave is reflected by the lower layer and the high-frequency wave is reflected by the upper layer. But beyond a certain permissible frequency (generally 30 MHz) the wave despite getting reflected penetrates the atmospheric region and is lost.

Hence sky wave propagation is suitable for the frequency range from 3MHz to 30 MHz. But for signal frequency greater than 30 MHz, space wave propagation is used. The critical frequency in the case of sky wave propagation is given as:

$$f_c = 9\sqrt{N_{max}}$$

We know that frequency and wavelength are inversely proportional to each other and the higher the frequency lower will be the wavelength. Also, we are aware of the fact that a signal of a lower wavelength propagates a higher distance. Thus in sky wave propagation signal can be transmitted to a larger distance. In this way, sky wave propagation eliminates the disadvantages associated with ground wave propagation.

- An important factor of ionospheric wave propagation is – skip distance. And skip distance is defined as the minimum distance on the surface of the earth from where the signal is transmitted and the reflected signal from the ionosphere has been received.

It is given by:

$$D_{skip} = 2h\sqrt{\frac{f_{MUF}^{2}}{f_c} - 1}$$ where,

- h denotes the height where reflection occurred,
- f_{MUF} represents the maximum usable frequency,
- f_c denotes the critical frequency,
- D_{skip} is the skip distance.

Advantages of sky wave propagation

1. It supports *large distance propagation*.
2. The *frequency range* of operation is considerably *high*.
3. *Attenuation* due to atmospheric conditions is *less*.

Disadvantages of sky wave propagation

1. Long-distance propagation requires *large-sized antennas*.
2. Due to the presence of the ionosphere near and far during night and day respectively there exist *variation in signal transmission in day and night*.

Applications

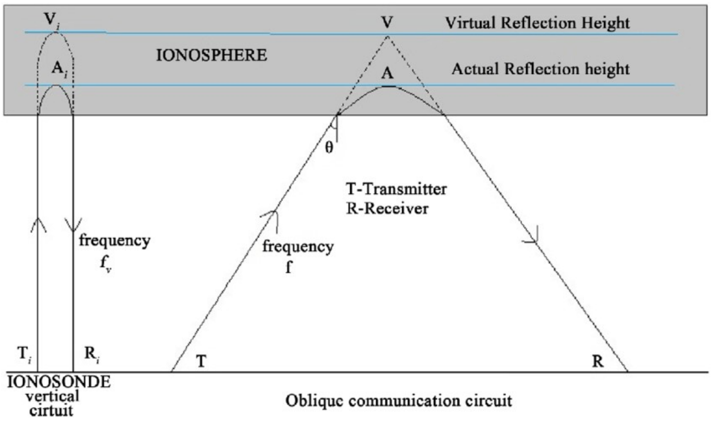
Sky wave propagation is widely used in mobile and satellite communications as it needs suitable atmospheric conditions.

Ref: https://electronicsdesk.com/sky-wave-propagation.html

Space Wave Propagation:

Space Wave Propagation refers to the transmission of radio waves within the troposphere layer of the Earth's atmosphere, or within 20 kilometers of the atmosphere. As the radio waves involved can go directly to the troposphere layer, space wave propagation is also known as tropospheric propagation. When radio waves from a broadcasting antenna travel into space around the Earth to reach a receiving antenna, this is known as space wave propagation. Radio waves can propagate in the troposphere either directly or after reflection from the ground. In this article, we will understand space wave propagation, its components, and its applications.

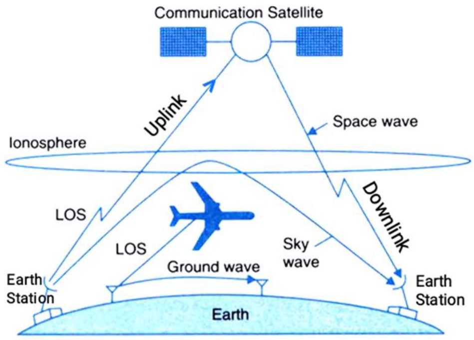
Radio Wave Propagation
Radio wave propagation is the process through which radio waves travel from one location to another. Radio wave propagation not only defines the behavior of waves as they move from one point to another, but it also shows how radio waves are impacted by the medium through which they travel, and in particular, how they travel through different portions of the atmosphere.



Radio Wave Propagation
Different types of radio wave propagation in free space and the atmosphere can be categorized into three categories:

- Skywave Propagation- When a wave must travel a longer distance, skywave propagation is preferred.
- Ground wave Propagation- The propagation of a ground wave follows the earth's contour. A direct wave is a name given to such a wave. Due to the Earth's magnetic field, the wave might bend and be reflected back to the receiver.
- Free space Propagation- The transmission of electromagnetic radiation across a straight-line channel in a vacuum or ideal atmosphere, sufficiently far from all objects that could affect the wave in any manner, is known as free space propagation.

The propagation of radio waves within the troposphere layer of the Earth's atmosphere, or within 20 kilometers of the atmosphere, is referred to as space wave propagation. There are both direct and reflected waves in it. Direct waves are those that travel directly from the source antenna to the receiving antenna at the destination without being interrupted or obstructed. After being reflected off of the ground and barriers like buildings, reflected waves eventually reach the receiving antenna at the destination. Space waves are radio waves that have an extraordinarily high frequency.



Space Wave Propagation

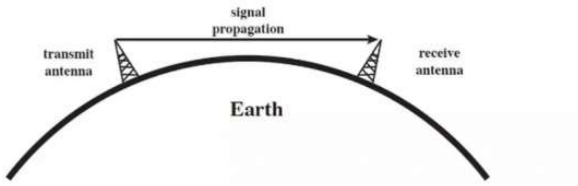
Such waves can travel across the troposphere. There are two other names for it:

- Tropospheric propagation- In general, the troposphere extends up to 10 to 20 kilometers above the earth's surface. As a result, space wave propagation occurs in the atmospheric zone around 20 km. Because the radio waves involved can go directly to the troposphere layer of the atmosphere, space wave propagation is also known as tropospheric propagation.
- Line-of-sight propagation- The wave traverses a minimal distance of sight in line-of-sight communication. That is, it travels up to the distance that the naked eye can see. If there is a barrier in the transmission path, line-of-sight propagation will be disrupted. This mode is utilized for infrared or microwave communications because the signal can only travel a short distance in this mode.

Components of Space Wave Propagation:

The three components on which space wave propagation depends are:

- Tropospheric Wave- After reflection from the troposphere, radio signals reach the receiving antenna.
- Direct Waves- The radio waves that are directly received by the receiving antenna after being broadcast from the sending antenna.
- Ground Reflected Waves- After being reflected by the ground, radio waves reach the receiving antenna



Line-of-sight (LOS) propagation (above 30 MHz)

Space wave propagation, or line-of-sight propagation, is not necessarily smooth, as seen in the diagram. It signifies that this method of transmission may encounter impediments that cause signal attenuation or loss. To avoid these problems, the height of both the transmitting and receiving antennas, as well as the distance between them, must be adjusted. In this case, the formula below appears to be useful:

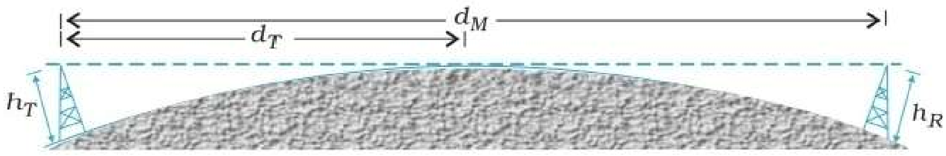
$DM = (2RhT)^{-½} + (2RhR)^{-½}$

where DM is the distance measured between the two antennas,

R is the radius of the earth,

h_T is the height of the transmitting antenna, and

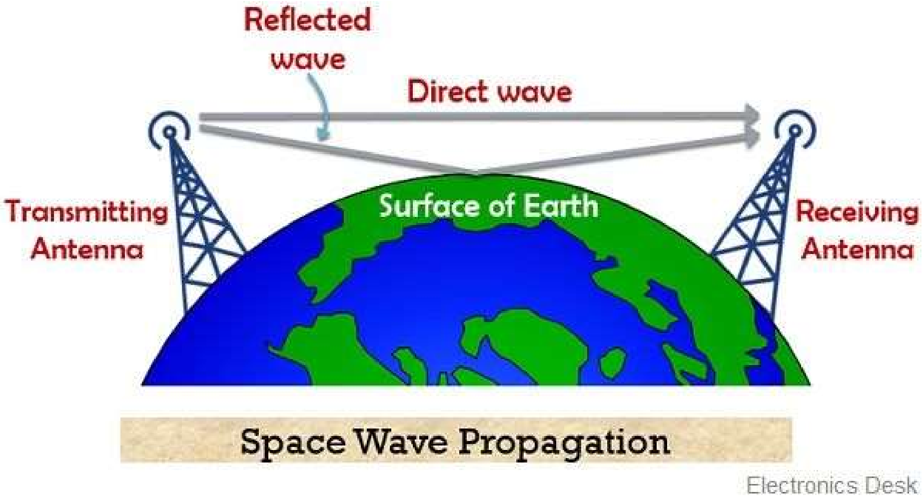
h_R is the height of the receiving antenna.



Space Wave Propagation Applications:
The propagation mode of space waves is used in a variety of communication systems, including:

- Satellite communication
- Line-of-sight communication
- Radar communication
- Microwave Linking
- Television Broadcasting

Very high-frequency bands ranging from 30 MHz to 300 MHz, ultra-high frequency (UHF) bands, and microwaves all utilize space waves. Because both skywave and ground wave propagation fail at such high frequencies, this is the case.
These frequencies have smaller antennas that can be installed at heights of several wavelengths above the ground. The curvature of the earth blocks the waves here due to the line-of-sight aspect of this propagation. As a result, if one wishes to receive a signal from beyond the horizon, one must guarantee that the receiving antenna is tall enough to intercept line-of-sight waves.
The line of sight distance, which is defined as the distance between the transmitting and receiving antennas at which both can see one another, is the limit of space wave propagation. It's also known as the communication range, and it can be enhanced by raising the antennas' heights. Furthermore, the curvature of the globe has an impact on the propagation of space waves.



Limitations of Space Wave Propagation:
The limitations of space wave propagation are:

- These waves are influenced by the earth's curvature.
- The propagation of these waves occurs along the line of sight distance, which is defined as the distance between the transmitting antenna and the receiving antenna and is also known as the range of communication.

Things to Remember

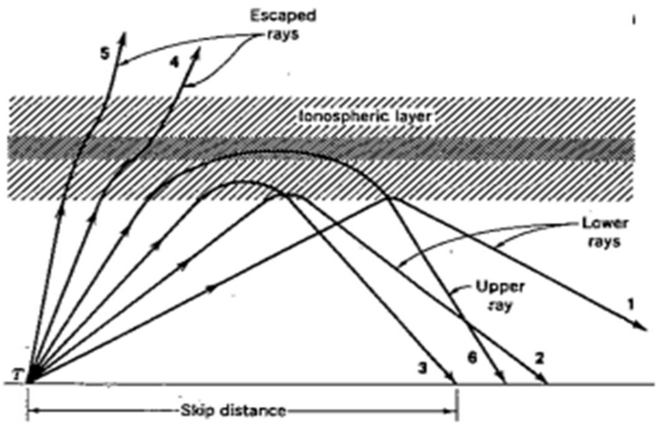
- The behavior of radio waves as they spread from one location to another or into different areas of the atmosphere is known as radio wave propagation.
- Space wave propagation refers to radio waves that occur within 20 kilometers of the troposphere and includes both direct and reflected waves.
- When radio waves from a broadcasting antenna travel into space around the Earth to reach a receiving antenna, this is known as space wave propagation.
- Waves can propagate directly from the earth's surface to the troposphere's surface in tropospheric propagation.
- The waves travel in a straight line and cover the shortest distance possible in line-of-sight propagation. It indicates that the waves propagate to a point where they can be seen with the naked eye.
- The curvature of the earth and the straight path traveling nature of the space waves affect the space wave propagation.
- Line-of-sight communication, television broadcasting, and microwave connecting are all examples of applications that involve space wave propagation.

Ref: https://collegedunia.com/exams/space-wave-propagation-applications-and-limitations-physics-articleid-2634

1.3 Definition – critical frequency, max. usable frequency, skip distance, fading, Duct propagation & Troposphere scatter propagation actual height and virtual height

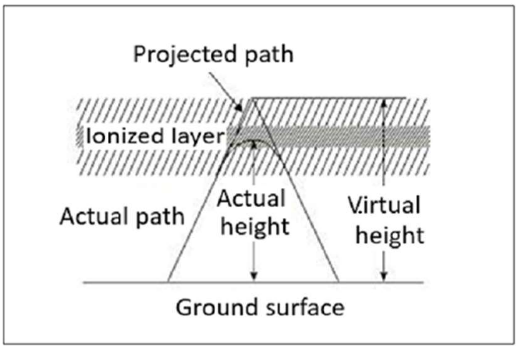
Critical frequency(F_c): It is the maximum frequency which can be reflected to earth by ionosphere at vertical projection of the ray.

Maximum Usable Frequency(MUF): It is the maximum frequency which can be reflected to earth by ionosphere when the ray is projected in a certain angle.



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 will be returned to earth.

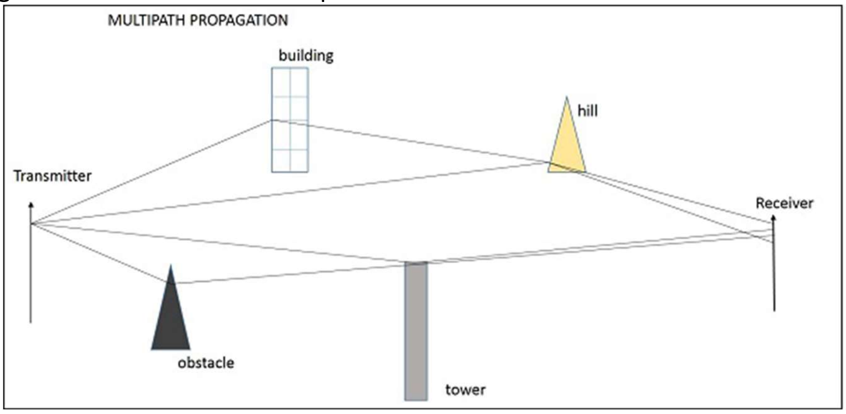
<u>Virtual Height:</u> When a wave is refracted, it is bent down gradually, but not sharply. However, the path of incident wave and reflected wave are same if it is reflected from a surface located at a greater height of this layer. Such a greater height is termed as virtual height.



The figure clearly distinguishes the virtual height (height of wave, supposed to be reflected) and actual height (the refracted height). If the virtual height is known, the angle of incidence can be found.

Multi-path

For the frequencies above 30 MHz, the sky wave propagation exists. Signal multipath is the common problem for the propagation of electromagnetic waves going through Sky wave. The wave, which is reflected from the ionosphere, can be called as a hop or skip. There can be a number of hops for the signal as it may move back and forth from the ionosphere and earth surface many times. Such a movement of signal can be termed as multipath.

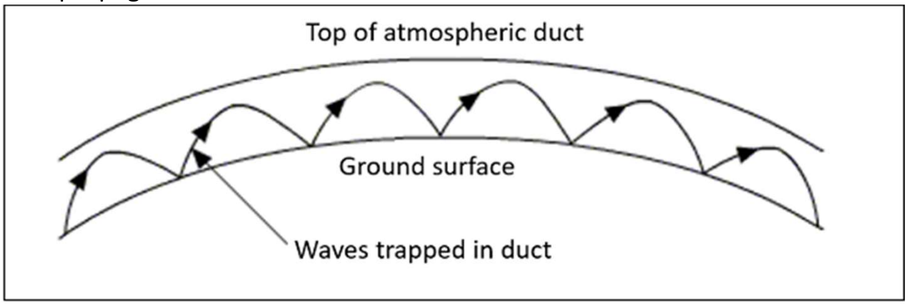


The above figure shows an example of multi-path propagation. Multipath propagation is a term, which describes the multiple paths a signal travels to reach the destination. These paths include a number of hops. The paths may be the results of reflection, refraction or even diffraction. Finally, when the signal from such different paths gets to the receiver, it carries propagation delay, additional noise, phase differences etc., which decrease the quality of the received output.

Fading : The decrease in the quality of the signal can be termed as fading. This happens because of atmospheric effects or reflections due to multipath.

Fading refers to the variation of the signal strength with respect to time/distance. It is widely prevalent in wireless transmissions. The most common causes of fading in the wireless environment are multipath propagation and mobility (of objects as well as the communicating devices).

Duct Propagation: At a height of around 50 mts from the troposphere, a phenomenon exists; the temperature increases with the height. In this region of troposphere, the higher frequencies or microwave frequencies tend to refract back into the Earth's atmosphere, instead of shooting into ionosphere, to reflect. These waves propagate around the curvature of the earth even up to a distance of 1000km.
This refraction goes on continuing in this region of troposphere. This can be termed as Super refraction or Duct propagation.



The above image shows the process of Duct Propagation. The main requirement for the duct formation is the temperature inversion. The increase of temperature with height, rather than the decrease in the temperature is known as the phenomenon of temperature inversion.
We have discussed the important parameters, which we come across in wave propagation. The waves of higher frequencies are transmitted and received using this wave propagation technique.
Tropospheric Scatter Propagation is a means of beyond-the-horizon propagation for UHF signals.
Tropospheric Scatter Propagation uses certain properties of the troposphere, the nearest portion of the atmosphere (within about 15 km of the ground).
Properties of Tropospheric Scatter Propagation:
As shown in Figure 8-20, two directional antennas are pointed so that their beams intersect midway between them, above the horizon. If one of these is a UHF transmitting antenna, and the other a UHF receiving one, sufficient radio energy will be directed toward the receiving antenna to make this a useful communication system. The reasons for the scattering are not fully understood, but there are two theories. One suggests reflections from "blobs" in the atmosphere, similar to the scattering of a searchlight beam by dust particles, and the other postulates reflection from atmospheric layers. Either way, this is a permanent state of affairs, not a sporadic phenomenon.

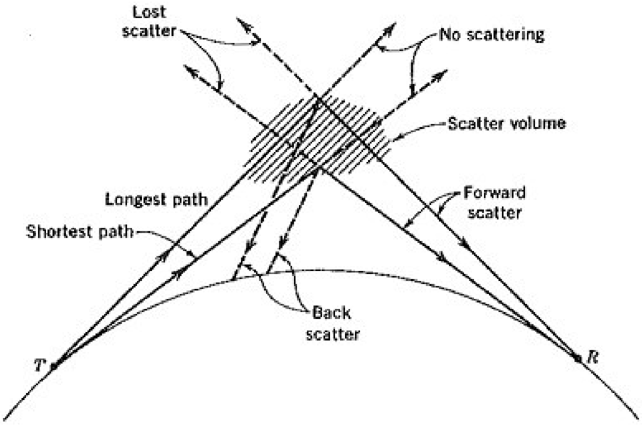


FIGURE 8-20 Tropospheric scatter propagation.

The best frequencies, which are also the most often used, are centered on 900, 2000 and 5000 MHz. Even here the actual proportion of forward scatter to signals incident on the scatter volume is very tiny

between 60 and 90 dB, or one-millionth to one-billionth of the incident power. High transmitting powers are obviously needed.
Practical considerations:
Although forward scatter is subject to fading, with little signal scattered forward, it nevertheless forms a very reliable method of over-the-horizon communication. It is not affected by the abnormal phenomena that afflict HF sky-wave propagation. Accordingly, this method of propagation is often used to provide long-distance telephone and other communications links, as an alternative to microwave links or coaxial cables over rough or inaccessible terrain. Path links are typically 300 to 500 km long.
Tropospheric scatter propagation is subject to two forms of fading. The first is fast, occurring several times per minute at its worst, with maximum signal strength variations in excess of 20 dB. It is often called Rayleigh fading and is caused by multi path propagation.
As Figure 8-20 shows, scattering is from a volume, not a point, so that several paths for propagation exist within the scatter volume. The second form of fading is very much slower and is caused by variations in atmospheric conditions along the path.

Ref:
https://www.tutorialspoint.com/antenna_theory/antenna_theory_terms_in_wave_propagation.htm#:~:text=Such%20a%20greater%20height%20is,of%20incidence%20can%20be%20found.

1.4 Radiation mechanism of an antenna-Maxwell equation

Maxwell's Equations are a set of four vector-differential equations that govern all of electromagnetics (except at the quantum level, in which case we as antenna people don't care so much). They were first presented in a complete form by James Clerk Maxwell back in the 1800s. He didn't come up with them all on his own, but did add the displacement current term to Ampere's law which made them complete. The four equations (written only in terms of E and H, the electric field and the magnetic field), are given below.

$$\nabla \cdot \mathbf{E} = \frac{\rho_v}{\varepsilon} \qquad \text{(Gauss' Law)}$$

$$\nabla \cdot \mathbf{H} = 0 \qquad \text{(Gauss' Law for Magnetism)}$$

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \qquad \text{(Faraday's Law)}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t} \qquad \text{(Ampere's Law)}$$

In Gauss' law, ρ_v is the volume electric charge density, J is the electric current density (in Amps/meter-squared), ε is the permittivity and μ is the permeability.
The good news about this is that all of electromagnetics is summed up in these 4 equations. The bad news is that no matter how good at math you are, these can only be solved with an analytical solution in extremely simple cases. Antennas don't present a very simple case, so these equations aren't used a whole lot in antenna theory (except for numerical methods, which numerically solve these approximately using a whole lot of computer power).

The last two equations (Faraday's law and Ampere's law) are responsible for electromagnetic radiation. The curl operator represents the spatial variation of the fields, which are coupled to the time variation. When the E-field travels, it is altered in space, which gives rise to a time-varying magnetic field. A time-varying magnetic field then varies as a function of location (space), which gives rise to a time varying electric field. These equations wrap around each other in a sense, and give rise to a wave equation. These equations predict electromagnetic radiation as we understand it.

1.5 Definition - Antenna gains, Directive gain, Directivity, effective aperture, polarization, input impedance, efficiency, Radiator resistance, Bandwidth, Beam width, Radiation pattern

Directive gain: ***Directive gain*** is defined as the ratio of the power density in a particular direction of one antenna to the power density that would be radiated by an omnidirectional antenna (isotropic antenna). The power density of both types of antenna is measured at a specified distance, and a comparative ratio is established.

The gain of a Hertzian dipole with respect to an isotropic antenna = 1.5: 1 power (1.5 (10 log 10) = 1.76 dB).
The gain of a half-wave dipole compared to the isotropic antenna= 1.64: 1 power (1.64 (10 log 10) = 2.15 dB)

Directivity and power gain (ERP) *:* Power gain is a comparison of the *output* power of an antenna in a certain direction to that of an *isotropic* antenna. The gain of an antenna is an antenna in a certain direction to that of an isotropic antenna. The gain of an antenna is a power ratio comparison between an isotropic and unidirectional radiator. This ratio can be expressed as:

$$A(dB) = 10\, log_{10} \frac{P_2}{P_1}$$

Where A(dB)=Antenna gain in decibels
P_1 = power of unidirectional antenna
P_2 = power of reference antenna

Radiation Resistance: *Radiation resistance is the ratio of the power radiated by the antenna to the square of the current at the feed point.*

Antenna losses and efficiency: Antenna losses can be caused by ground resistance, corona effects, imperfect dialectric near the antenna, energy loss due to eddy currents induced into nearby metallic objects, and I^2R losses in the antenna itself. We can combine these losses and represent them as shown in Equation below.

$$Pin = Pd + Prad$$

where P_{in} = power delivered to the feed point=I^2R_{in}
P_d = power lost= I^2R_d
P_{rad} = power actually radiated= I^2R_{rad}

hence the above equation can be written as:

$$I^2R_{in}= I^2R_d+ I^2R_{rad}$$

$$R_{in}= R_d+ R_{rad}$$

From this expression we can now develop an equation for calculating antenna efficiency (η)

$$\eta= \frac{R_{rad}}{R_{rad}+R_d}$$

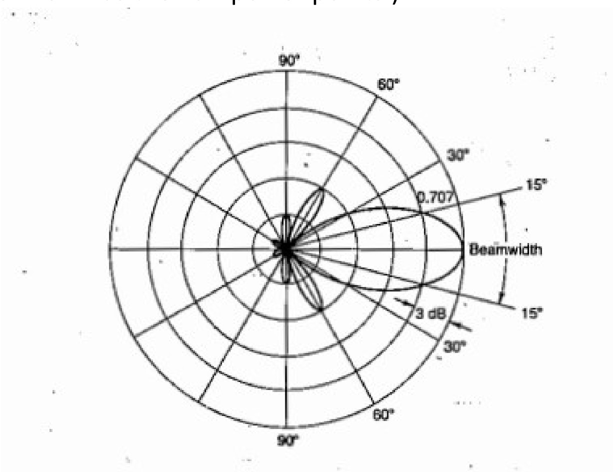
where R_{rad}= Antenna Radiation Resistance

R_d=Antenna resistance

Bandwidth, beamwidth, **and** ***polarization*** are three important terms dealing respectively with the operatingfrequency range, the degree of concentration of the radiation pattern, and the space orientation of the radiated waves.

Bandwidth: The term bandwidth refers to the range of frequencies the antenna will radiate effectively; i.e., the antenna will perform satisfactorily throughout this range of frequencies. When the antenna power drops to 1/2 (3 dB), the upper and lower extremities of these frequencies have been reached and the antel)na no longer performs satisfactorily. Antennas that operate over a wide frequency. range and still maintain satisfactory performance must have compensating circuits switched into the system to maintain impedance matching, thus ensuring no deterioration of the transmitted signals.

Beamwidth: The *beamwidth* of an antenna is described as the angles created by comparing the half-power points (3 dB) on the main radiation lobe to its maximum power point. In Figure 9-9, as an example, the *beam angle* is 30°, which is the sum of the two angles created at the points where the *field strength* drops to 0.707 (field strength is measured in *·µJVIm)* of. the maximum voltage at the center of the lobe. (These points are known as the half-power points.)



Polarization: Polarization of an antenna refers to the direction in space of the *E* field (electric vector) portion of the electromagnetic wave being radiated (Figure below) by the transmitting system.

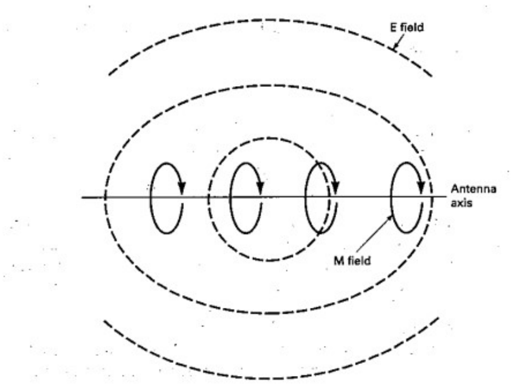


Figure: Polarization of the antenna showing *E* and *M* fields

YAGI-UDA ANTENNA

The Yagi antenna sometimes called the Yagi-Uda RF antenna is widely used where specified gain and directivity are required.

INTRODUCTION: The Yagi-Uda antenna is one of the most successful RF antenna designs for directive antenna applications. This antenna is used in a wide variety of applications where an RF antenna design with gain and directivity is required. It has become particularly popular for television reception, but it is also used in many other domestic and commercial applications where an RF antenna is needed that has gain and directivity.

Not only is the gain of the Yagi-Uda antenna important as it enables better levels of signal to noise ratio to be achieved, but also the directivity can be used to reduce interference levels by focusing the transmitted power on areas where it is needed, or receiving signals best from where the source is present.

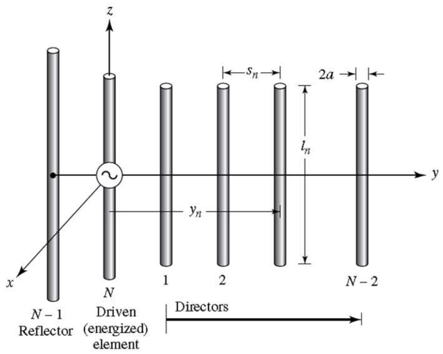
ANTENNA BASICS

The Yagi antenna design has a dipole as the main radiating or driven element. Further 'parasitic' elements are added which are not directly connected to the driven element. These parasitic elements pick up power from the dipole and re-radiate it. The phase is in such a manner that it affects the properties of the RF antenna as a whole, causing power to be focused in one particular direction and removed from others.

The parasitic elements of the Yagi antenna operate by re-radiating their signals in a slightly different phase to that of the driven element. In this way the signal is reinforced in some directions and cancelled out in others. It is found that the amplitude and phase of the current that is induced in the parasitic elements is dependent upon their length and the spacing between them and the dipole or driven element.

snFig 1: Yagi-Uda antenna showing
element types.

There are three types of element within a Yagi antenna:



(i) Driven element: The driven element is the Yagi antenna element to which power is applied. It is normally a half wave dipole or often a folded dipole.

(ii) Reflector : The Yagi antenna will generally only have one reflector. This is behind the main driven element, i.e. the side away from the direction of maximum sensitivity. Further reflectors behind the first one add little to the performance. However many designs use reflectors consisting of a reflecting plate, or a series of parallel rods simulating a reflecting plate. This gives a slight improvement in performance, reducing the level of radiation or pick-up from behind the antenna, i.e. in the backwards direction. Typically a reflector will add around 4 or 5 dB of gain in the forward direction.

(iii) Director: The director or directors are placed in front of the driven element, i.e. in the direction of maximum sensitivity. Typically each director will add around 1 dB of gain in the forward direction, although this level reduces as the number of directors increases.

The antenna exhibits a directional pattern consisting of a main forward lobe and a number of spurious side lobes. The main one of these is the reverse lobe caused by radiation in the direction of the reflector. The antenna can be optimized to either reduce this or produce the maximum level of forward gain. Unfortunately, these two do not coincide exactly, and a compromise on the performance has to be made depending upon the application.

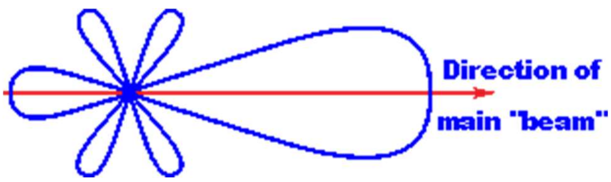


Fig 3: Yagi-Uda antenna radiation pattern.

MERITS AND DEMERITS:

The Yagi-Uda antenna offers many advantages for its use in a number of applications:

- It has high gain allowing lower strength signals to be received.
- It has high directivity enabling interference levels to be minimized.
- This antenna allows all constructional elements to be made from rods simplifying construction.
- The construction enables the antenna to be mounted easily on vertical and other poles with standard mechanical fixings.
- The Yagi antenna is particularly useful in applications where an RF antenna design is required to provide required gain and directivity. In this way the optimum transmission and reception conditions can be obtained.

The Yagi antenna also has a number of disadvantages that need to be considered.

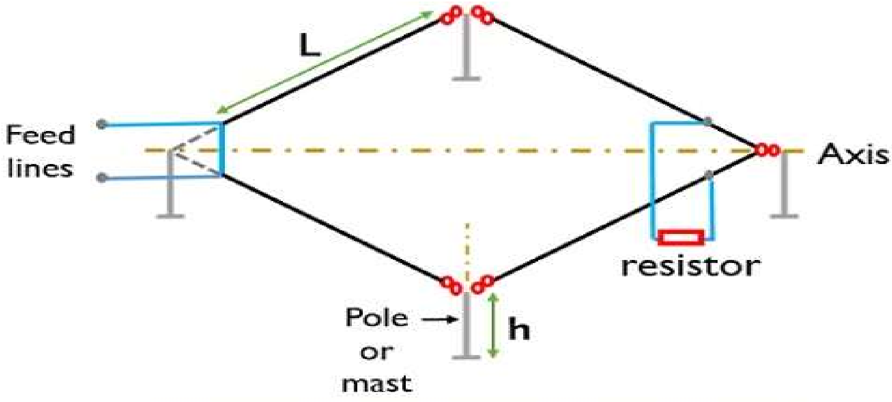
- For high gain levels the antenna becomes very long.
- Gain limited to around 20dB or so for a single antenna.

Rhombic Antenna

Definition: The type of antenna which is formed by connecting long wires in the orientation of a rhombus is known as a rhombic antenna. Its basis of operation is similar to the traveling wave radiator. It is also known as a *diamond antenna*. These are highly directional broadband antenna that radiates maximal power along the axis.

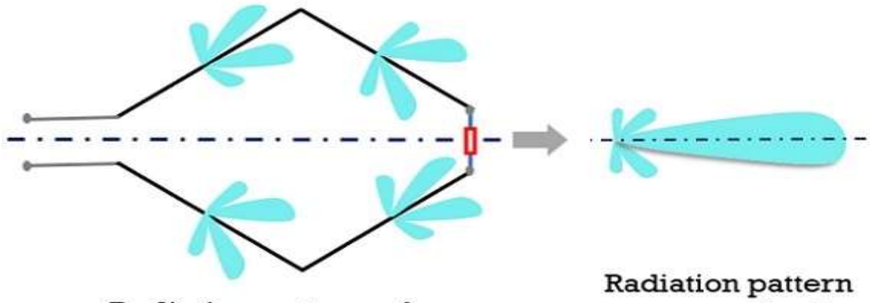
Rhombic antenna generally operates on high frequency and very high-frequency ranges. The operating range exists between 30 MHz to 300 MHz.

Construction: A rhombic antenna is a type of traveling wave antenna which utilizes the principle of traveling wave radiator.It consists of 4 conducting long wires connected in the form of a rhombus or diamond. The complete antenna structure is placed horizontally above the surface of the ground.A rhombic antenna may also be considered as a combination of 2 V antennas or inverted V antennas forming an obtuse angle. The figure below represents the rhombic antenna:



Structure of Rhombic Antenna

Radiation Pattern: The rhombic antenna provides the highest gain along its main axis joining the feed point and terminating end. And the horizontal rhombic antenna provides horizontal polarization. The figure below represents the radiation pattern:



Radiation pattern of rhombic antenna

Radiation pattern over a perfectly conducting plane

Here as all the major lobes get combined together thus we achieve a unidirectional radiation pattern in one direction only.

Advantages

1. The structure of the antenna is quite simple and it is cost affordable.
2. It provides high directivity by radiating most of the power along the main axis.
3. It provides efficient long-distance radio communication when installed in a large space.
4. The offered input impedance is quite large.
5. The radiation pattern and input impedance remain constant for a large range of frequencies.
6. These can be easily switched from one working frequency to another during operation.
7. It suits long-distance F-layer propagation due to low vertical radiation angle.

Disadvantages

1. The required area for the installation of the rhombic antenna is quite large.
2. The transmission efficiency is quite low as a large amount of power is wasted in terminating the load.

However, when multiple rhombic with definite spacing are placed on the same mast then this somewhat overcomes the disadvantage of lower efficiency to a large extent.

Applications

Rhombic antennas are used in high frequency and very high-frequency signal transmission. Generally, these are suitable for point to point communication in case of long-distance skywave propagation.

(Ref:https://electronicsdesk.com/rhombic-antenna.html)

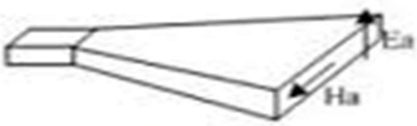
Horn Antenna

A horn antenna is formed by flaring a metal waveguide in the shape of a horn to direct radio waves in a beam. Horn antennas are widely used at UHF and Microwave frequencies. Above 300MHz. A horn antenna is used to transmit radio waves from a waveguide out into space, or to collect radio waves into a waveguide while reception.

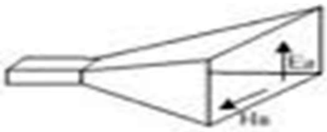
Horn antenna types:

There are several types of horn antenna:

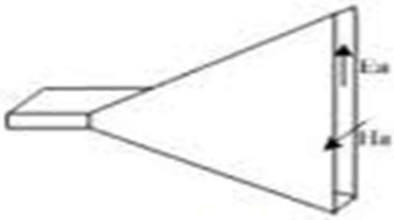
- *Pyramid horn antenna* As the name suggests, the pyramid horn antenna takes on a rectangular shape - the cross-section through the antenna is rectangular, as is the end of the antenna. It is normally used with a rectangular waveguide.
- *Sectoral horn antenna:* This form of horn antenna is one in which only one pair of sides flared whilst the other remains parallel. This form of configuration produces a fan-shaped beam, which is narrow in the plane of the flared sides, but wide in the plane of the narrow sides.
    - *E-plane horn antenna:* This form of antenna is one that is flared in the direction of the electric or E-field in the waveguide.
    - *H plan horn antenna:* This form of antenna is one that is flared in the direction of the electric or H-field in the waveguide.
- *Conical horn antenna* Again, as the name indicates, the conical horn antenna has a circular cross-section and end to it. It is normally used with a circular waveguide and is seen less frequently than the rectangular version.



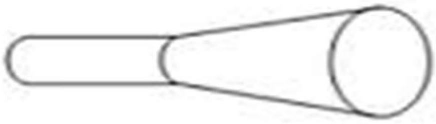
Sectoral Horn Flared in H Plane



Pyramid Horn



Sectoral Horn Flared in E Plane


Circular or Conical Horn

Advantages

The following are the advantages of Horn antenna −

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

Disadvantages

The following are the disadvantages of Horn antenna −

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

Applications

The following are the applications of Horn antenna −

- Used for astronomical studies
- Used in microwave applications

<u>Parabolica Reflector Antenna</u>

The parabolic dish antenna is the form most frequently used in the radar engineering

A parabolic reflector, dish, or mirror is a device that is used to collect or project electromagnetic waves. Alter incoming plane waves traveling along the same axis as the parabola into a wave that is spherical and they all meet at the focus of the reflector.

Figure 1 illustrates the parabolic antenna. A dish antenna consists of one circular parabolic reflector and a point source situated in the focal point of this reflector. This point source is called “primary feed” or “feed”. A horn antenna or a dipole antenna is placed in this focus point, which is also known as a feed.

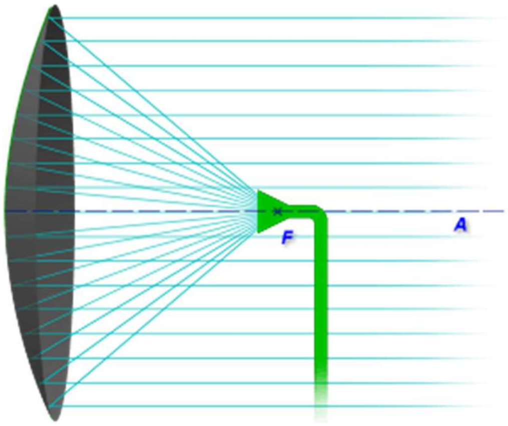


Figure 1. Parabolic Reflector Antenna

Advantages:
Some of the major advantages of the parabolic reflector antenna include the following:

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

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

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

Parabolic reflector antenna applications

- *Direct broadcast television:* Direct broadcast or satellite television has become a major form of distribution for television content. The wide and controllable coverage areas available combined with the much larger bandwidths enable more channels to be broadcast and this makes satellite television very attractive.

- *Microwave links:* Terrestrial microwave links are used for many applications. Often they are used for terrestrial telecommunications infrastructure links. One of the major areas where they are used these days is to provide the backhaul for mobile telecommunications systems.

- A variety of microwave parabolic reflector antennas mounted on a mobile phone tower
- *Satellite communications*
- *Radio astronomy*

(Ref:Parabolic Antenna - Radartutorial,
Parabolic Reflector Antenna - Dish Aerial » Electronics Notes)

Smart Antennas

An array of antennas operated by a signal processing unit in order to improve the radiation mechanism, to increase the data rates, and to reduce the error rate.A smart antenna is a multi-element antenna where the signals received at each antenna element are intelligently combined to improve the performance of the wireless system.

Smart antennas fall into three major categories: SIMO (single input, multiple outputs), MISO (multiple inputs, single output), and MIMO (multiple inputs, multiple outputs). In SIMO technology, one antenna is used at the source, and two or more antennas are used at the destination. In MISO technology, two or more antennas are used at the source, and one antenna is used at the destination. In MIMO technology, multiple antennas are employed at both the source and the destination. MIMO has attracted the most attention recently because it can not only eliminate the adverse effects of multipath propagation but in some cases can turn it into an advantage.

Applications of the smart antenna:

1. Simultaneous wireless information and power transfer (SWIPT)
2. Rotorcraft
3. High-Performance Radio Local Area Network/2 (HIPERLAN/2)
4. Wireless Mesh Networks (WMNs) technology
5. Wireless Ad Hoc Networks
6. In multibeam or adaptive antenna array
7. Macrocellular Base Stations
8. Wi-Fi a/b/g access points and clients
9. In-vehicle DBS entertainment systems (Mobile video, Mobile broadband/gaming)
10. Satellite/digital radio
11. GPS, 3G Wireless, WiMa, RFID and UWB
12. It will be used in 5G Network also