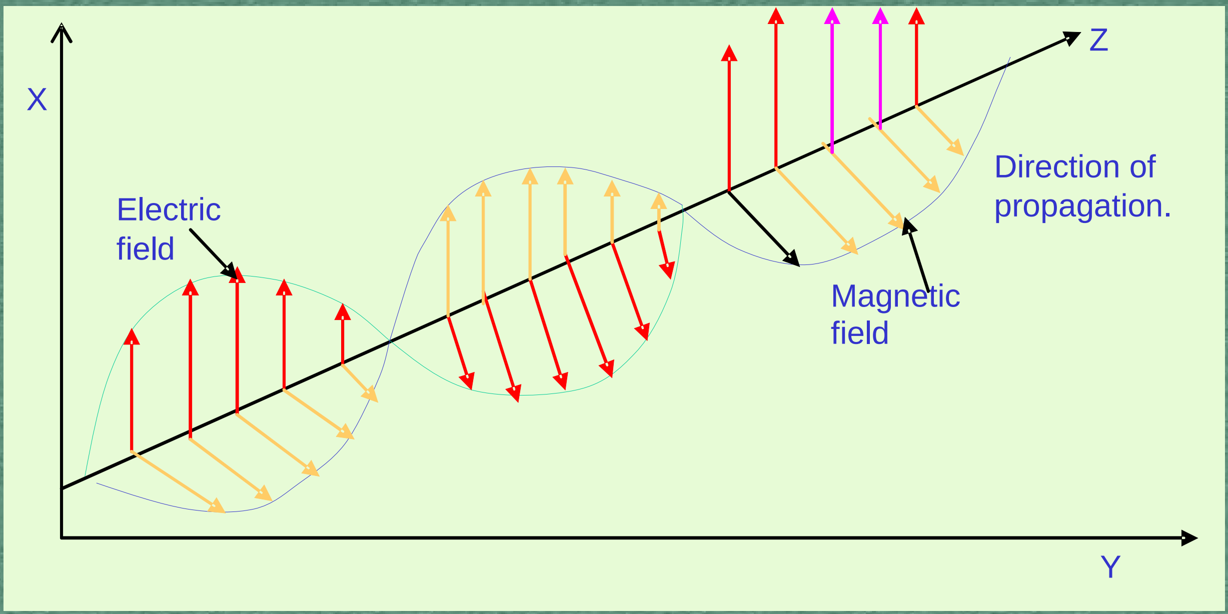
इरिसेट IRISET

# TB5

# RADIO PROPOGATION




Indian Railways Institute of
Signal Engineering and Telecommunications
SECUNDERABAD - 500 017

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INDIAN RAILWAYS INSTITUTE OF SIGNAL ENGINEERING & TELECOMMUNICATIONS, SECUNDERABAD - 500 017

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# TB5

# RADIO PROPAGATION

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# CHAPTER 1

# RADIO WAVE PROPAGATION

**1.0. Introduction:** Radio propagation is the behavior of radio waves when they are transmitted, or propagated from one point on the Earth to another, or into various parts of the atmosphere. The transfer of energy through space by electromagnetic radiation at radio frequencies.

## 1.1. ELECTROMAGNETIC WAVES

An electromagnetic wave consists of two fields, an electric field (**E)** and a magnetic field (**M**). Both of these fields have a direction and a strength (or amplitude). Within the electromagnetic wave the two fields (electric and magnetic) are oriented at precisely 90° to one another. The fields move (by definition at the speed of light 3 x $10^{8}$ m/sec. or 186.000 miles/sec) in a direction at 90° to both of them. These are transverse waves (oscillations Perpendicular to direction of propagation). In three dimensions consider the electric field to be oriented on the y-axis, and the magnetic field on the x-axis. Direction of travel would then be along the z-direction.

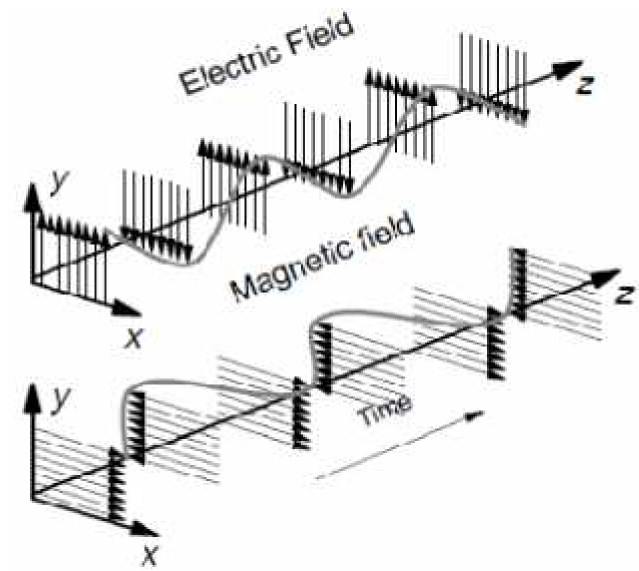



**Fig. 1. The Structure of an Electromagnetic Wave**

Electric and magnetic fields are actually superimposed over the top of one another but are illustrated separately for clarity in illustration. The z-direction can be considered to be either a representation in space or the passing of time at a single point.

As the electromagnetic wave moves the fields oscillate in direction and in strength. Figure **1** shows the electric and magnetic fields separately but they occupy the same space. They should be over layed on one another and are only drawn this way for clarity. We could consider the z-direction in the figure to represent passing time or it could represent a wave travelling in space at a single instant in time.

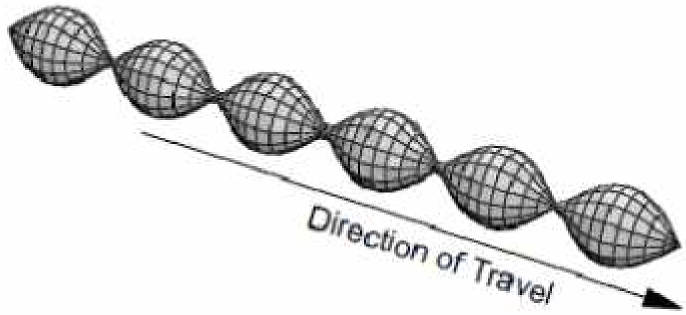



**Fig. 2. Amplitude Fluctuation in an Electromagnetic Wave**

Looking at the electric field from fig.1. that at the start the field is oriented from bottom to top (increasing values of y). Sometime later the field direction has reversed. At a still later time the field direction has reversed again and it has now reverted back to its original direction.

The curved line is intended to represent field strength. The field might start at a maximum in one direction, decay to a zero and then build up in the other direction until it reaches a maximum in that other direction. The field strength changes sinusoidally.

The key here is that we have two fields and they oscillate in phase. That is the electric and magnetic fields reach their peaks and their nulls at exactly the same time and place as shown in Fig.2. The rate of oscillation is the frequency of the wave. The distance travelled during one period of oscillation is the wavelength. Electromagnetic waves spread uniformly in all Directions in free space from a point Source.

**Electromagnetic radiation**: Power escaping into space is said to be radiated and is governed by the characteristics of free space.

**1.2. Free space:** Space that does not interfere with the normal radiation and propagation of radio waves. It does not have magnetic or gravitational Fields, solid bodies or ionized particles.

The important features of free space are:

1) Uniform everywhere
2) Contains no electrical charge
3) Carries no current
4) Infinite extent in all dimensions

Radio waves are predicted to propagate in free space by electromagnetic theory; they are a solution to Maxwell's Equations.

$$\nabla \bullet \varepsilon \mathbf{E} = \rho$$
$$\nabla \bullet \mu \mathbf{H} = 0$$
$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t}$$

**E** = Electric vector field represents the direction a charge will move

**H** = Magnetic vector field the represents directions a magnet would align

**ρ** = charge enclosed; **J** = current density; μ = permeability

**ε**=permittivity;

▪ =divergence, dot product; X=curl, vector product $\nabla$ =Vector operator (nabla)

## 1.3. Radio Frequency Spectrum

| | | |
|---|---|---|
| **VLF** | Very Low Frequencies | 3- 30 KHz |
| **LF** | Low Frequencies | 30-300 KHz |
| **MF** | Medium Frequencies | 300 - 3000 KHz. |
| **HF** | High Frequencies | 3MHz –30 MHz |
| **VHF** | Very High Frequencies | 30 MHz –300 MHz |
| **UHF** | Ultra High Frequencies | 300 MHz –3 GHz |
| **SHF** | Super High Frequencies | 3 GHz –30 GHz |
| **EHF** | Extra High Frequencies | 30 GHz –300 GHz |

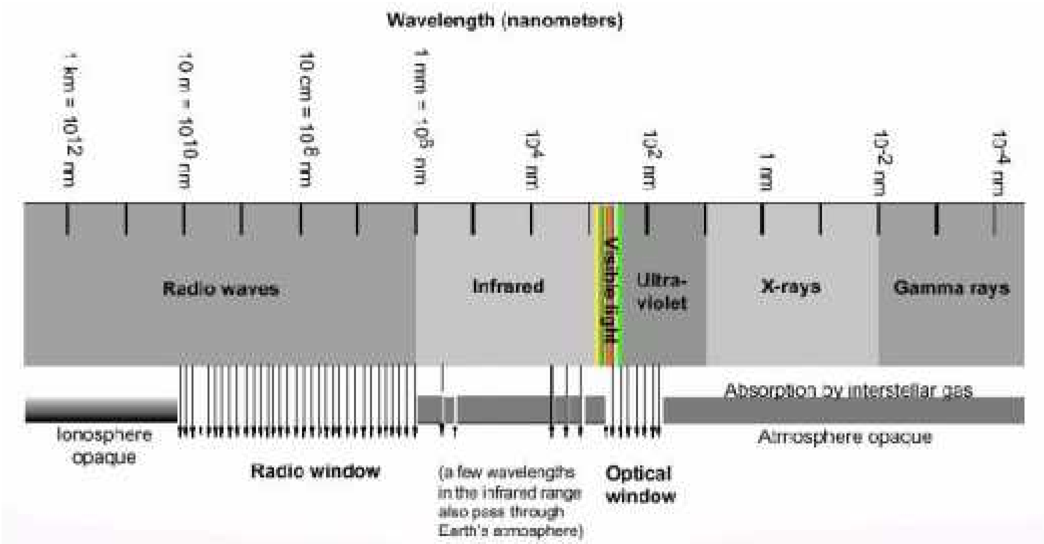



**FIG.3. Atmospheric Windows to Electromagnetic Radiation**

## 1.4. PROPAGATION CHARACTERISTICS OF EM WAVES:

The wave propagation characteristics between transmitter and receiver are controlled by

1) Transmitting & receiving antenna
2) Operating frequencies
3) Media between TX and RX

There are a number of mechanisms by which radio waves may travel from a transmitting to a Receiving antenna. The more important of these are the ground wave, the sky wave and the space (or troposphere) waves.

The **ground wave** (also surface) wave can exist when the transmitting and receiving antennas are close to the surface of the earth and are vertically polarized. This wave, supported at its lower edge by the presence of the ground, is of practical importance at broadcast (i.e., medium wave) and lower frequencies. The ground wave is vertically polarized, because any horizontal component of the electric field in contact with earth is short-circuited by the earth. As the ground wave passes over the surface of the earth, it is weakened as a result of energy absorbed by the earth in the earth's resistance. The field strength of the ground wave is inversely proportional to the square of the distance and the frequency. As a result the range for ground wave is very limited at frequencies above 3 MHz.

The **sky wave**s represent energy reaching the receiving antenna as a result of the reflection due to bending of the wave path by the ionized region, termed as the ions here, which begins at about 50 Kms above earth's surface. It accounts for practically all-very long distance HP radio communication. Frequencies above 30 MHz are not capable of being reflected back by the ionosphere even at low angles of take off and as such this method of communication is of importance for frequencies below 30 MHz

**Line of Sight Propagation (LOS)** The simplest form of propagation is line of site. All frequencies will function in this form. Distance between the transmitter and receiver is dependent on the frequency / wavelength of the signal. Line of site propagation is very useful at VHF and UHF Frequencies.

**1.4.1 Ground-wave propagation:** 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.

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.

### 1.4.1.1 Effect of frequency on ground wave propagation:

As the wave front 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.

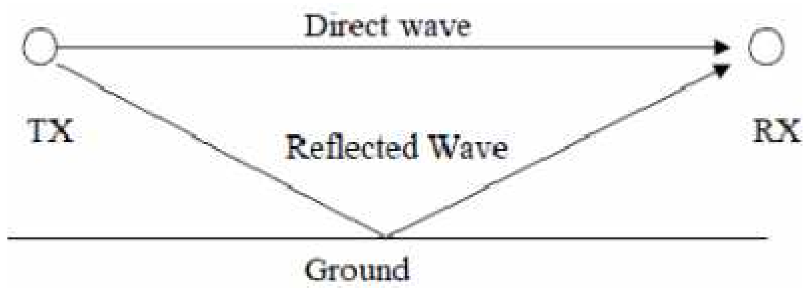



**FIG.4.ground wave**

Ground Wave = Direct Wave + Reflected Wave + Surface Wave. At MF and in the lower HF bands, aerials tend to be close to the ground (in terms of wavelength). Hence the direct wave and reflected wave tend to cancel each other out (there is a 180 degree phase shift on reflection). This means that only the surface wave remains. A surface wave travels along the surface of the earth by virtue of inducing currents in the earth. The imperfectly conducting earth leads to some of its characteristics. Its range depends upon: Frequency, Polarization, Location and Ground Conductivity. The surface waves dies more quickly as the frequency increases;

$$Range(km) = \frac{200}{\sqrt{f(MHz)}}$$

## 1.4.2. Sky waves or Ionospheric waves:

It is the upper portion of the atmosphere (between approx.50km and 400km above the Earth). In this region, gases get ionized by absorbing large quantities of radiation and form different layers. Ionization increases with altitude. Variation is not linear, but tends to be the amount of ionization depends upon the rate of formation of the ions and the rate of recombination. At lower altitudes since the atmospheric pressure is large the rate of combination is large so that ionization is small. At higher altitudes since the atmospheric pressure is low the rate of re-combination is small so that ionization so that ionization is large.

### 1.4.2.1. Ionospheric propagation*:*

Here the radio signals are modified and influenced by the action of the free electrons in the upper reaches of the earth's atmosphere called the ionosphere. This form of radio propagation is used by stations on the short wave bands for their signals to be heard around the globe.

As electromagnetic waves, and in this case, radio signals travel, they interact with objects and the media in which they travel. As they do this the radio signals can be reflected, refracted or diffracted. These interactions cause the radio signals to change direction, and to reach areas which would not be possible if the radio signals travelled in a direct line.

HF radio communications is dependent for most of its applications on the use of the ionosphere. This region in the atmosphere enables radio communications signals to be reflected, or more correctly refracted back to earth so that they can travel over great distances around the globe. Ionospheric propagation is normally as an HF propagation mode, although, it use can extend above and below the HF portion of the spectrum on many occasions.

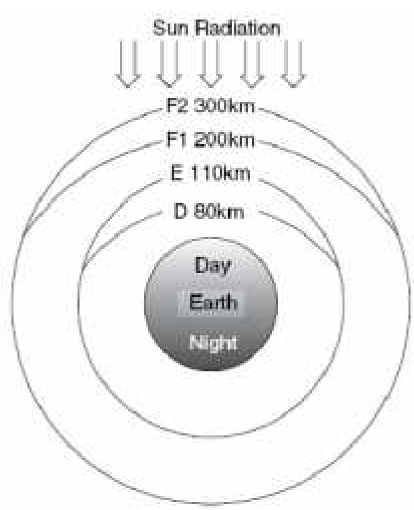
The fact that radio communications signals can travel all over the globe on the HF bands is widely used by many by broadcasters, news agencies, maritime, radio hams and many other users. Radio transmitters using relatively low powers can be used to communicate to the other side of the globe. Although radio propagation using the ionosphere may not be not as reliable as that provided by satellites, it nevertheless provides a very cost effective and efficient form of radio communication. To enable the most to be made of ionospheric propagation many radio users make extensive use of HF propagation programmes to predict the areas of the globe to which signals may travel, or the probability of them reaching a given area.

Radio communications signals in the medium and short wave bands travel by two basic means. The first is known as a ground wave (covered on a separate page in this section), and the second a sky wave using the ionosphere.

**Indirect or Obstructed Propagation**

The efficacy of indirect propagation depends upon the amount of margin in the communication link and the strength of the diffracted or reflected signals. The operating frequency has a significant impact on the viability of indirect propagation, with lower frequencies working the best.

**1.5. Ionosphere Regions** The part of the ionosphere that is primarily responsible for **"sky-wave"** exists in 3 to 4 layers depending on the time of day. These layers exist at differing altitudes.




D= layer-1

E = layer-2

F1 = layer-3

F2= layer-4

**FIG. 5 . Regions of space**

## 1.5.1. Description of the layers in the Ionosphere:

**D layer*:*** The D layer is the lowest of the layers of the ionosphere. It exists at altitudes around 60 to 90 km. It is present during the day when radiation is received from the sun. However the density of the air at this altitude means that ions and electrons recombine relatively quickly. This means that after sunset, electron levels fall and the layer effectively disappears. This layer is typically produced as the result of X-ray and cosmic ray ionization. It is found that this layer tends to attenuate signals that pass through it.

**E layer*:*** The next layer beyond the D layer is called the E layer. This exists at an altitude of between 100 and 125 km. Instead of acting chiefly as an attenuator, this layer reflects radio signals although they still undergo some attenuation.

In view of its altitude and the density of the air, electrons and positive ions recombine relatively quickly. This occurs at a rate of about four times that of the **F** layers that are higher up where the air is less dense. This means that after nightfall the layer virtually disappears although there is still some residual ionization.

**F layer*:*** The F layer is the most important region for long distance HF communications. During the day it splits into two separate layers. These are called the $F_1$ and $F_2$ layers, the $F_1$ layer being the lower of the two. At night these two layers merge to give one layer called the F layer. The altitudes of the layers vary considerably with the time of day, season and the state of the sun. Typically in summer the $F_1$ layer may be around 300 km with the $F_2$ layer at about 400 km or even higher. In winter these figures may be reduced to about 300 km and 200 km. Then at night the F layer is generally around 250 to 300 km. Like the D and E layers, the level of ionization falls at night, but in view of the much lower air density, the ions and electrons combine much more slowly and the F layer decays much less. Accordingly it is able to support radio communications, although changes are experienced because of the lessening of the ionization levels. The ionization of all the layers is maximum at day time and minimum at night.

### 1.6. Tropospheric Propagation

Consists the reflection or refraction of the RF waves from temperature and moisture layers in the atmosphere. Here the signals are influenced by the variations of refractive index in the troposphere just above the earth's surface. Tropospheric radio propagation is often the means by which signals at VHF and above are heard over extended distances. On frequencies above 30 MHz, it is found that the troposphere has an increasing effect on radio signals and radio communications systems. The radio signals are able to travel over greater distances than would be suggested by line of sight calculations. At times conditions change and radio signals may be detected over distances of 500 or even 1000 km and more. This is normally by a form of tropospheric enhancement, often called "tropo" for short. At times signals may even be trapped in an elevated duct in a form of radio signal propagation known as tropospheric ducting. This can disrupt many radio communications links (including two way radio communications links) because interference may be encountered that is not normally there. As a result when designing a radio communications link or network, this form of interference must be recognized so that steps can be taken to minimize its effects.

The way in which signals travel at frequencies of VHF and above is of great importance for those looking at radio coverage of systems such as cellular telecommunications, mobile radio communications and other wireless systems as well as other users including radio hams.

### 1.7. Propagation in the HF Bands:

Without ionization of the atmosphere due to the sun's energy, HF propagation would be limited to line of site.

### 1.8. Propagation on the VHF Bands

VHF propagation is principally line of site but much longer paths are possible with Ionization of the atmosphere's E-layer phenomena. Due to re-entry of meteors will also create a condition for VHF long distance propagation. One new method of long distance VHF communication results from bouncing VHF signals off high altitude commercial airliners.

### 1.9. Propagation on the UHF Bands

UHF propagation is basically line of site. Some long range propagation is possible with E-Layer phenomena. UHF is used mainly for local communication. Sometimes UHF can be part of a wide area repeater system allowing for interstate communication.

## 1.10. Radio Wave Behavior

Radio waves, like light waves, exhibit certain characteristics when coming into contact with objects. Here are some of the possible behaviors.

**1.10.1. Reflection:** Reflection occurs when a radio wave hits an object that has a dimension is larger than the wavelength of the radio wave. The radio wave is then reflected off the surface.

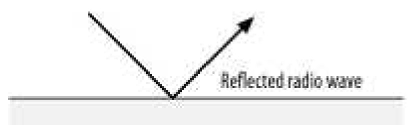



**Fig.6. Reflection of a radio wave**

Reflection occurs when signal encounters a surface that is large relative to the wavelength of the signal · Radio waves may be reflected from various substances or objects they meet during travel between the transmitting and receiving sites. The amount of reflection depends on the reflecting material. Smooth metal surfaces of good electrical conductivity are efficient reflectors of radio waves. The surface of the Earth itself is a fairly good reflector. The radio wave is not reflected from a single point on the reflector but rather from an area on its surface. The size of the area required for reflection to take place depends on the wavelength of the radio wave and the angle at which the wave strikes the reflecting substance. When radio waves are reflected from flat surfaces, a phase shift in the alternations of the wave occurs· The shifting in the phase relationships of reflected radio waves is one of the major reasons for fading.

### 1.10.2. Refraction

Refraction occurs when a radio wave hits an object of a higher density than its current medium. The radio wave now travels at a different angle. An example would be radio waves propagating through clouds. The bending, or change of direction, is always toward the medium that has the lower velocity of propagation.

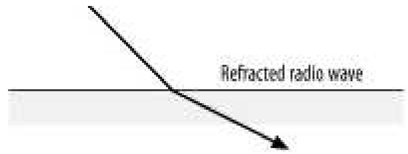



**Fig.7.Refraction of a radio wave**

### 1.10.3. Scattering

Scattering occurs when a radio wave hits an object of irregular shape, usually an object with a rough surface area and the radio wave bounces off in multiple directions.


**Fig.8.Scattering of a radio wave**

### 1.10.4. Absorption

Absorption occurs when a radio wave hits an object that does not cause it to be reflected, refracted, or scattered, so it is absorbed by the object. The radio wave is then lost.

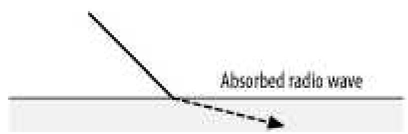



**Fig.9. Absorption of a radio wave**

Radio waves are subject to interference caused by objects and obstacles in the air. Such obstacles can be concrete walls, metal cabinets, or even raindrops. In general, transmissions made at higher frequencies are more subject to radio absorption (by the obstacles) and larger signal loss. Larger frequencies have smaller wavelengths, and hence signals with smaller wavelengths tend to be absorbed by the obstacles that they collide with. This causes high frequency devices to have a shorter operating range.

For devices that transmit data at high frequencies, much more power is needed in order for them to cover the same range as compared to lower frequency transmitting devices.

### 1.10.5. Diffraction

Diffraction is a phenomenon that takes place when the radio wave strikes a surface and changes its direction of propagation owing to the inability of the surface to absorb it. The loss due to diffraction depends upon the kind of obstruction in the path.

Sometimes a radio wave will be blocked by objects standing in its path. In this case, the radio wave is broken up and bends around the corners of the object. It is this property that allows radio waves to operate without a visual line of sight.

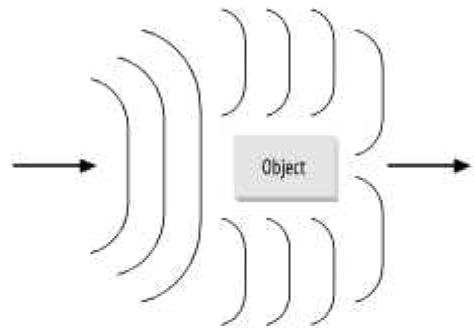



**Fig. 10. Diffraction of radio waves**

Diffraction is the name given to the mechanism by which waves enter into the shadow of an obstacle. Diffraction occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave. A radio wave that meets an obstacle has a natural tendency to bend around the obstacle. The bending, called diffraction, results in a change of direction of part of the wave energy from the normal line-of-sight path. This change makes it possible to receive energy around the edges of an obstacle.

The ratio of the signal strengths without and with the obstacle is referred to as the diffraction loss. The diffraction loss is affected by the path geometry and the frequency of operation. The signal strength will fall by 6 dB as the receiver approaches the shadow boundary, but before it enters into the shadow region. Deep in the shadow of an obstacle, the diffraction loss increases with 10*log (frequency). So, if double the frequency, deep in the shadow of an obstacle the loss will increase by 3 dB. This establishes a general truth, namely that radio waves of longer wavelength will penetrate more deeply into the shadow of an obstacle.

In practice, the mobile antenna is at a much lower height than the base station antenna, and there may be high buildings or hills in the area. Thus, the signal undergoes diffraction in reaching the mobile antenna. This phenomenon is also known as 'shadowing' because the mobile receiver is in the shadow of these structures.

### 1.10.6.Building and Vehicle Penetration

When the signal strikes the surface of a building, it may be diffracted or absorbed. If it is to some extent absorbed the signal strength is reduced. The amount of absorption is dependent on the type of building and its environment: the amount of solid structure and glass on the outside surface, the propagation characteristics near the building, orientation of the building with respect to the antenna orientation, etc. This is an important consideration in the coverage planning of a radio network.

Vehicle penetration loss is similar, except that the object in this case is a vehicle rather than a building.

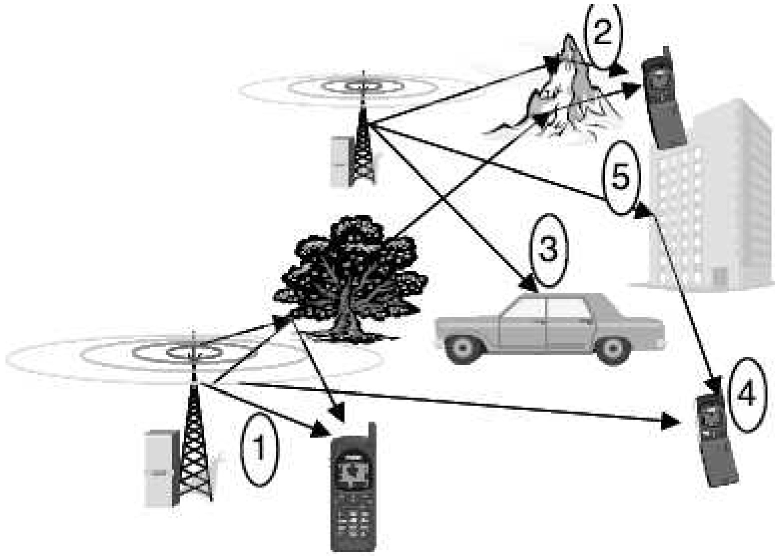



**Fig.11.Factors affecting wave propagation: (1) direct signal; (2) diffraction; (3) vehicle penetration; (4) interference; (5) building penetration**

## 1.11. Fresnel Zone

Radio waves diffracted by objects can affect the strength of the received signal. This happens even though the obstacle does not directly obscure the direct visual path. This area, known as the "Fresnel Zone", and must be kept clear of all obstructions

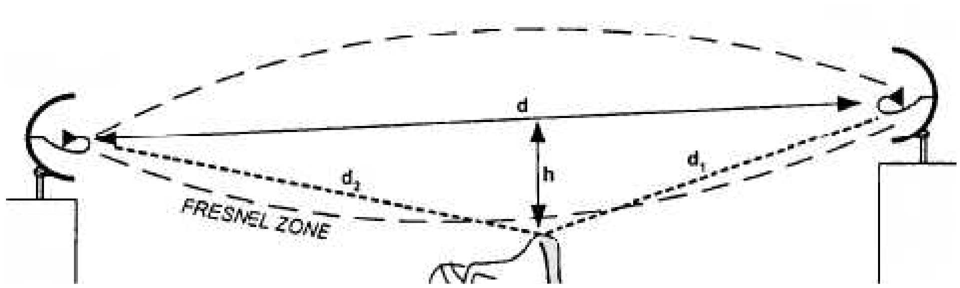



**Fig.12.Fresnel zone**

$$h = 17.3 \sqrt{\frac{d_1 d_2}{f(d_1 + d_2)}}$$

Where **d1** and **d2** = km, **f** = GHz, **h** = meters.

The 1st Fresnel zone is a spheroid space formed within the trajectory of the path when the path difference when radio wave energy reaches the receiver by the shortest distance, and when it gets there by another route, is within λ/2. Odd-numbered Fresnel zones have relatively intense field strengths, whereas even numbered Fresnel zones are nulls. When the radio signal pass from site A to site B, the lack of adequate Fresnel Zone clearance caused signal diffraction, and degradation of the radio signal. If the 1st Fresnel zone is not clear, then free-space loss does *not* apply and an adjustment term must be included.

To avoid this have to use an antenna with a narrower lobe pattern, usually a higher gain antenna will achieve this.Raise the antenna mounting point on Site A and/or Site B.

## 1.12 Multipath

Multipath is a term used to describe the multiple paths a radio wave may follow between transmitter and receiver. Such propagation paths include the ground wave, ionospheric refraction, and reradiation by the ionospheric layers, reflection from the Earth's surface or from more than one ionospheric layer, etc. If the two signals reach the receiver in-phase (both signals are at the same point in the wave cycle when they reach the receiver), then the signal is amplified. This is known as an "up fade." If the two waves reach the receiver out-of-phase (the two signals are at opposite points in the wave cycle when they reach the receiver), they weaken the overall received signal. If the two waves are 180º apart when they reach the receiver, they can completely cancel each other out so that a radio does not receive a signal at all. A location where a signal is canceled out by multipath is called a "null" or "down fade."

## 1.13. Fading

As the signal travels from the transmitting antenna to the receiving antenna, it loses strength. This may be due to the phenomenon of path loss or it may be due to the **Rayleigh** effect. Rayleigh fading is due to the fast variation of the signal level both in terms of amplitude and phase between the transmitting and receiving antennas when there is no line-of-sight. Rayleigh fading can be divided into two kinds: multipath fading and frequency-selective fading.

Reduction in received signal strength due to fluctuations in radio path caused by non-homogenous and time varying atmospheric parameters is called Fading. Arrival of the same signal from different paths at different times and its combination at the receiver causes the signal to fade. This phenomenon is multipath fading and is a direct result of multipath propagation. Multipath fading can cause fast fluctuations in the signal level. This kind of fading is independent of the downlink or uplink if the bandwidths used are different from each other in both directions.

Frequency-selective fading takes place owing to variation in atmospheric conditions. Atmospheric conditions may cause the signal of a particular frequency to fade. When the mobile station moves from one location to another, the phase relationship between the various components arriving at the mobile antenna changes, thus changing the resultant signal level. Doppler shift in frequency takes place owing to the movement of the mobile with respect to the receiving frequencies.

### 1.13.1. Types of Fading

**1.13.1.1. Fast fading** - occurs when the coherence time of the channel is small relative to the delay constraint of the channel. Fast fading causes rapid fluctuations in phase and amplitude of a signal if a transmitter or receiver is moving or there are changes in the radio environment (e.g. car passing by). If a transmitter or receiver is moving, the fluctuations occur within a few wave lengths. Because of its short distance fast fading is considered as small-scale fading.

**Coherence time:** For an electromagnetic wave, the time over which a propagating wave may be considered coherent. In long-distance transmission systems, the coherence time may be reduced by propagation factors such as dispersion, scattering, and diffraction.

**1.13.1.2. Slow fading** - arises when the coherence time of the channel is large relative to the delay constraint of the channel. Slow fading occurs due to the geometry of the path profile. This leads to the situation in which the signal gradually gets weaker or stronger.

**1.13.1.3. Flat fading** – Occurs when the coherence bandwidth of the channel is larger than the bandwidth of the signal. The coherence bandwidth of a wireless channel is the range of frequencies that are allowed to pass through the channel without distortion.

Coherence bandwidth is a statistical measurement of the range of frequencies over which the channel can be considered "flat", or in other words the approximate maximum bandwidth or frequency interval over which two frequencies of a signal are likely to experience comparable or correlated amplitude fading. If the multipath time delay spread equals *D* seconds, then the coherence bandwidth $W_c$ in rad/s is given approximately by the equation:

$$W_c \approx \frac{2\pi}{D}$$

Also coherence bandwidth $B_c$ in Hz is given approximately by the equation:

$$B_c \approx \frac{1}{D}$$

It can be reasonably assumed that the channel is flat if the coherence bandwidth is greater than the data signal bandwidth. The coherence bandwidth varies over cellular or PCS communications paths because the multipath spread *D* varies from path to path.

Frequencies within a coherence bandwidth of one another tend to all fade in a similar or correlated fashion. One reason for designing the spread spectrum (CDMA IS-95) waveform with a bandwidth of approximately 1.25 MHz is because in many urban signaling environments the coherence bandwidth $W_c$ is significantly less than 1.25 MHz. Therefore, when fading occurs it occurs only over a relatively small fraction of the total CDMA signal bandwidth. The portion of the signal bandwidth over which fading does not occur typically contains enough signal power to sustain reliable communications. This is the bandwidth over which the channel transfer function remains virtually constant.

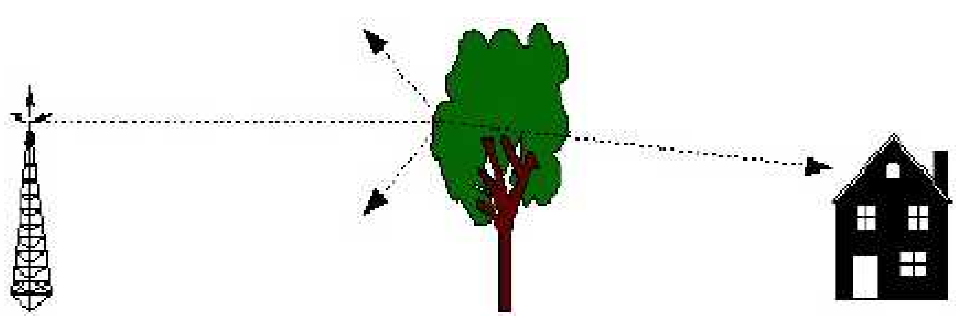


**Fig. 13. Flat fading**

Flat Fading is caused by absorbers between the two antennae and is countered by antenna placement and transmit power level.

**1.13.1.4. Selective fading** – occurs when the coherence bandwidth of the channel is smaller than the bandwidth of the signal.

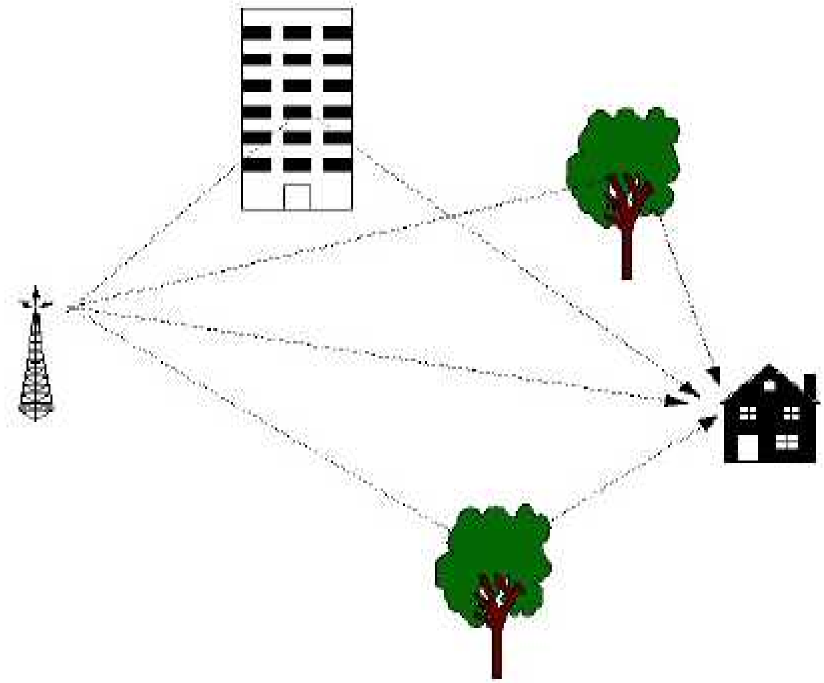


**Fig. 14.Selective fading**

Frequency selective fading is caused by reflectors between the transmitter and receiver creating multi-path effects.

**Effects of Frequency Selective Fading**

1. The dips or fades in the response due to reflection cause cancellation of certain frequencies at the Receiver.
2. Reflections off near-by objects (e.g. ground, buildings, trees, etc) can lead to multi-path signals of similar signal power to the direct signal.
3. This can result in deep nulls in the received signal power due to destructive interference.

**1.13.1.5. Rayleigh fading** – Rayleigh fading is the name given to the form of fading that is often experienced in an environment where there is a large number of reflections present. The Rayleigh fading model uses a statistical approach to analyse the propagation, and can be used in a number of environments.

The Rayleigh fading model is normally viewed as a suitable approach to take when analysing radio wave propagation performance for areas such as cellular communications in a well built up urban environment where there are many reflections from buildings, etc.. HF ionospheric radio wave propagation where reflections (or more exactly refractions) occur at many points within the ionosphere is also another area where Rayleigh fading model applies. It is also appropriate to use the Rayleigh fading model for tropospheric radio propagation because, again there are many reflection points and the signal may follow a variety of different paths. Assume that the magnitude of a signal that has passed through a communications channel will vary randomly.

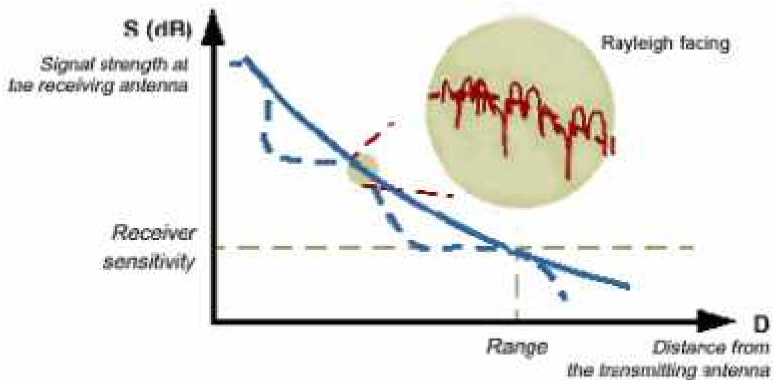



**Fig.15. Rayleigh fading**

**1.13.1.6. Multipath (Nakagami) fading** - occurs for multipath scattering with relatively larger time delay spreads, with different clusters of reflected waves.

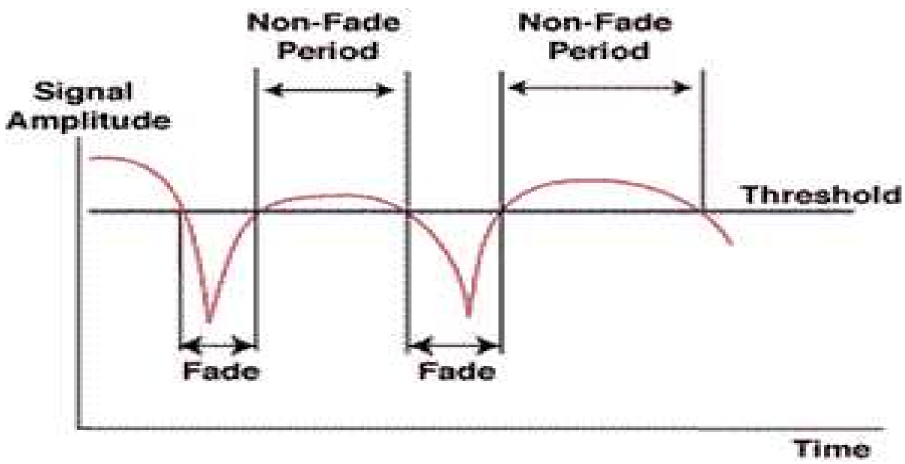



**Fig.16. Multi-path fading**

When the waves of multi-path signals are out of phase, reduction of the signal strength at the receiver can occur. Multi-path can also cause inter-symbol interference.

### 1.13.2. Fade Margin

Fade margin is the difference between the unfaded receive signal level and the receiver sensitivity threshold. Each link must have sufficient fade margin to protect against path fading that weakens the radio signals.

A design allowance in radio link budget, that provides sufficient system gain or sensitivity to accommodate expected fading, for the purpose of ensuring that the required quality of service is maintained. The amount by which a received signal level may be reduced without causing system performance to fall below a specified threshold value.

Number of decibels of attenuation which may be added to a specified radio-frequency propagation path before the signal-to-noise ratio of a specified channel falls below a specified minimum in order to avoid fading.

Network engineers need to know link performance factors to design wireless networks that meet performance expectations in the given environment. Link budget calculations are used to determine the placement of network elements. Link budget is the difference between transmit power and receiver sensitivity and indicates the amount of attenuation while still supporting communication. Fade margin is a design cushion allowance for fluctuations of the received signal's strength. These fluctuations are caused by:

1. Interference in the operating band
2. Movement of the transmitter or the receiver
3. Reflections or scattering due to the objects in the vicinity

### 1.13.2.1. Factors that affect the Link Budget

Path loss is the energy that is lost between the transmitter and the receiver. Many factors can cause signals to lose energy. Network architects need to understand transmission losses attributed to:

a. Obstructions such as trees or buildings
b. Reflections from buildings or bodies of water
c. Insufficient antenna height
d. Environmental conditions such as humidity, precipitation or ice

Adequate allowance for fading is essential to ensure that an RF link is available at all times. Allowing for more fade margin will increase link reliability, but will also reduce the distance between modules

### 1.13.2.1. Radio Link

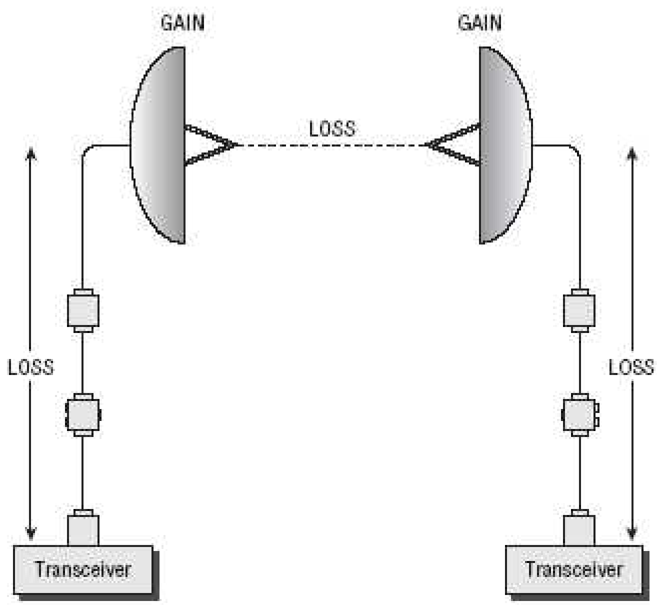



**FIG 17.Radio link**

The formulas below can be used to calculate if the radio link has an acceptable fade margin or, if not, how much antenna gain that needs to be added or if repeaters have to be used.

The known factors are often:

1. The distance between two sites
2. The (possible) height of the antennas
3. The transmit power of the radio
4. The receiver sensitivity of the radio
5. The antenna gain

This is a calculation with all the possible losses in the system and subtracting the losses from the line of sight to give an estimated value of your likely link performance

$$\mathbf{FM = S_{rx} + P_{tx} + G_{tx} + FSL + G_{rx} – CL}$$

| | | |
|---|---|---|
| **FM** | = | Fade Margin |
| **$S_{rx}$** | = | Sensitivity of the receiver (dBm) (using +dBm instead of –dBm) |
| **$P_{tx}$** | = | Transmitter RF output power (dBm) |
| **$G_{tx}$** | = | TX Antenna Gain (dB) |
| **FSL** | = | Free Space Loss (dB) = 32.4 + 20 Log f + 20 log d |
| **$G_{rx}$** | = | Receiver (RX) Antenna Gain (dB) |
| **CL** | = | Cable/Connector Loss (dB) |

**Calculation of fade margin FM (A typical example):**

| | | |
|---|---|---|
| Distance | = | 5 kilometers |
| Antenna height 1 | = | 20 meters |
| Antenna height 2 | = | 5 meters |
| Radio Tx Power | = | 33 dBm (2 W) |
| Radio Rx Sensitivity | = | -110 dBm |
| Frequency | = | 456.000 MHz |
| Antenna Gain 1 | = | 3 dBd |
| Antenna Gain 2 | = | 6 dBd |
| Cable / Connector losses | = | 4 dB total |
| FM | = | ? |
| FSL | = | 129 dB (frequency & distance dependant value) |
| FSL | = | 32.44+ 20 log F + 20 Log D |

Where F is in MHz and D is in Kms

FM = Srx + Ptx + Gtx - FSL+ Grx – Cl

FM = 110 dBm + 33 dBm + 3 dBd – 129 dB + 6 dBd – 4 dB = 19 dB

The fade margin is 19 dB, which is an acceptable level. The radio link should be possible.

## 1.14. Diversity Techniques

**Diversity:** It is the technique used to compensate for fading channel impairments. It is implemented by using two or more receiving antennas. Diversity is usually employed to reduce the depth and duration of the fades experienced by a receiver in a flat fading channel.

Fade margin on the transmitter path is not an efficient solution at all, and one alternate solution is to take the advantage of the statistical behavior of the fading channel. This is the basic concept of Diversity, where two or more inputs at the receiver are used to get uncorrelated signals.

**1.14.1. Frequency Diversity:** The same information signal is transmitted and received simultaneously on two or more independent fading carrier frequencies. Different frequencies mean different wavelengths. The hop when using frequency diversity (Separation of carriers) is that the same physical multipath routes will not produce simultaneous deep fades at two separate wavelengths.

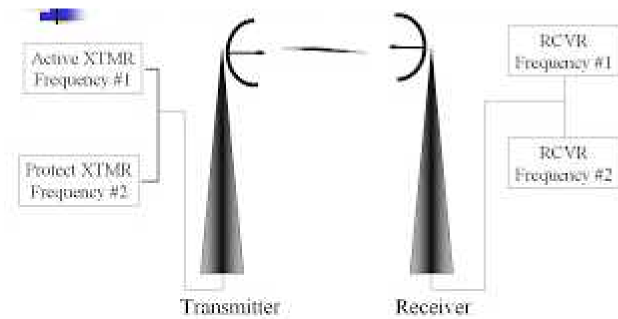



**Fig.18. Frequency Diversity**

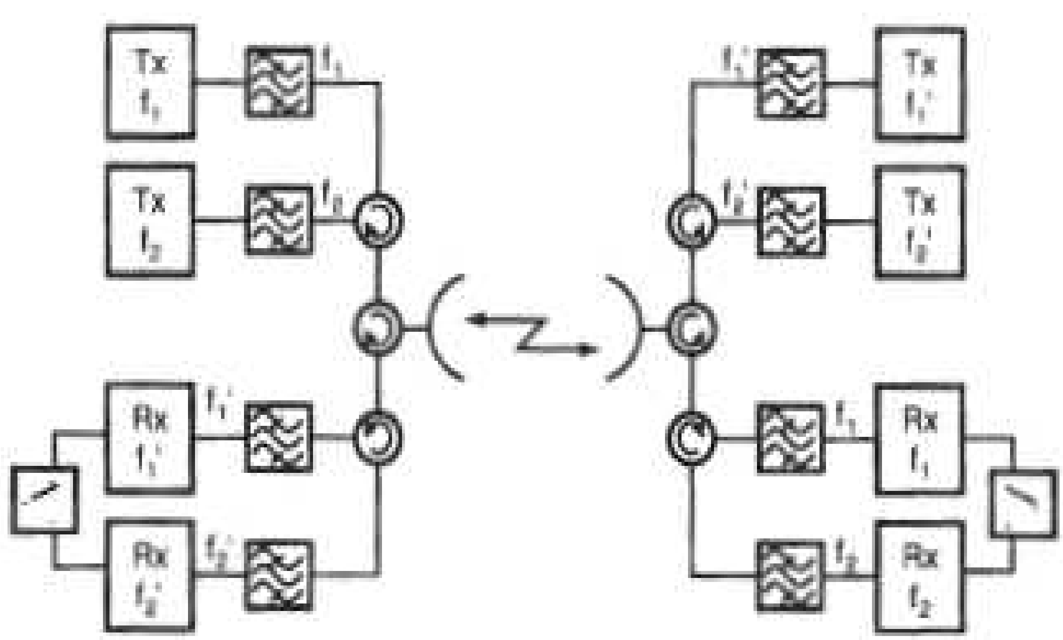



**Fig.19.Block diagram of Frequency Diversity**

## ADVANTAGES

1. Reliability is more
2. Equivalent to 100% hot standby, hence no need of providing stand by TX or RX.

## DISADVANTAGES

1. Two frequencies are needed
2. Improvement by diversity is not much, since 5% separation of frequency is rarely achieved.

### 1.14.2. Space Diversity

A method of transmission or reception, or both, in which the effects of fading are minimized by the simultaneous use of two or more physically separated antennas, ideally separated by one half or more wavelengths. Deep multipath fade have unlucky occurrence when the receiving antenna is in exactly in the 'wrong' place. One method of reducing the likelihood of multipath fading is by using two receive antennas (Separation of antennas) and using a switch to select the better signal. If these are physically separated then the probability of a deep fade occurring simultaneously at both of these antennas is significantly reduced.

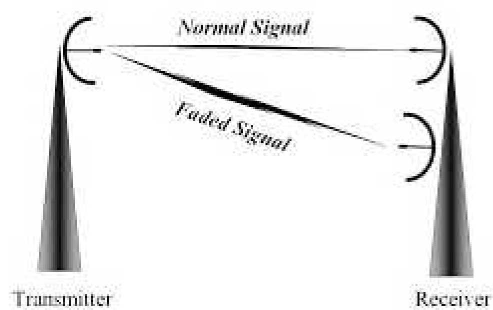



**Fig.19. Space Diversity**

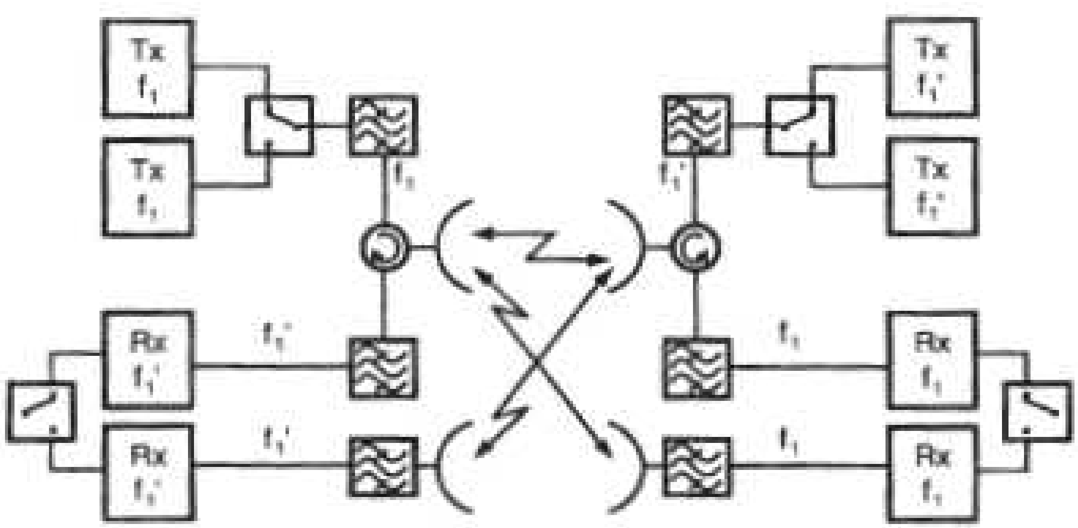



**Fig.20.Block diagram of space Diversity**

**ADVANTAGES**

1. One frequency is used.
2. Propagation reliability is improved.
3. For more vertical separation of antennas, improvement factor can be more.

**DISADVANTAGES**

1. The two antennas are kept on the same tower.The lower antenna should be in Line of Sight with the TX antenna. Hence length of tower may increase beyond 100m.
2. Costly
3. Good tower foundation necessary, since wind pressure will be large.
4. Equipment reliability decreased, hence stand by required

### 1.14.3. Angle Diversity

Angle diversity reception in which several antennas are used pointing in different directions with generally a small angular separation. In this case the receiving antennas are co-located but have different principal directions.

### 1.14.4. Polarization Diversity

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

### 1.14.5. Time Diversity

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

## 1.15. Effects of Rain, Snow and Fog

The loss of LOS paths may sometimes be affected by weather conditions. Rain and fog (clouds) become a significant source of attenuation only when we get well into the microwave region. Attenuation from fog only becomes noticeable (i.e., attenuation of the order of 1 dB or more) above about 30 GHz. Snow is in this category as well. Rain attenuation becomes significant at around 10 GHz, where a heavy rainfall may cause additional path loss of the order of 1 dB/km.

### Propagation of a Signal over Water

Propagation over water is a big concern for radio planners. The reason is that the radio signal might create interference with the frequencies of other cells. Moreover, as the water surface is a very good reflector of radio waves, there is a possibility of the signal causing interference to the antenna radiation patterns of other cells.

### 1.15.1. Essential Features of Rain Scatter the received signal strength is proportional to

1. transmitted power (obviously)
2. the common volume (this is the antenna beam intersection),
3. the particle density (for example how hard it is raining)
4. the scattering function $So^2$ (how well the particles scatter

**And inversely proportional to:**

1. the 4th power of range
2. the 4th power of the wavelength

Of course, the rain also attenuates the energy in the radio wave, so the scattered power at the receiver will be reduced.

## 1.16. Propagation of a Signal over Vegetation (Foliage Loss)

Foliage loss is caused by propagation of the radio signal over vegetation, principally forests. The variation in signal strength depends upon many factors, such as the type of trees, trunks, leaves, branches, their densities, and their heights relative to the antenna heights. Foliage loss depends on the signal frequency and varies according to the season.

Trees can be a significant source of path loss, and there are a number of variables involved, such as the specific type of tree, whether it is wet or dry, and in the case of deciduous trees, whether the leaves are present or not. Isolated trees are not usually a major problem, but a dense forest is another story.

The attenuation depends on the distance the signal must penetrate through the forest, and it increases with frequency. According to a CCIR report, the attenuation is of the order of 0.05 dB/m at 200 MHz, 0.1 dB/m at 500 MHz, 0.2 dB/m at 1 GHz, 0.3 dB/m at 2 GHz and 0.4 dB/m at 3 GHz.

At lower frequencies, the attenuation is somewhat lower for horizontal polarization than for vertical, but the difference disappears above about 1 GHz. This adds up to a *lot* of excess path loss if your signal must penetrate several hundred meters of forest! Fortunately, there is also significant propagation by diffraction over the treetops, especially if you can get your antennas up near treetop level or keep them a good distance from the edge of the forest, so all is not lost if you live near a forest.

# CHAPTER 2

# ANTENNA

## 2.0. Introduction

By definition, an antenna is a device used to transform an RF signal, traveling on a conductor, into an electromagnetic wave in free space. Antennas demonstrate a property known as reciprocity, which means that an antenna will maintain the same characteristics regardless if it is transmitting or receiving. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band of the radio system to which it is connected; otherwise the reception and the transmission will be impaired. When a signal is fed into an antenna, the antenna will emit radiation distributed in space in a certain way. A graphical representation of the relative distribution of the radiated power in space is called a radiation pattern.

**2.1. Antenna Glossary:** A few common terms that related to antenna are defined and explained below:

### 2.1.1. Input Impedance

For an efficient transfer of energy, the impedance of the radio, of the antenna and of the transmission cable connecting them must be the same. Transceivers and their transmission lines are typically designed for 50Ω impedance. If the antenna has impedance different from 50Ω, then there is a mismatch and an impedance matching circuit is required.

### 2.1.2. Return loss

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. The relationship between SWR and return loss is the following:

$$\text{Return Loss (in dB)} = 20 \log_{10} \frac{SWR}{SWR - 1}$$

### 2.1.3. Bandwidth

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1. The bandwidth can also be described in terms of percentage of the center frequency of the band.

$$BW = 100 \times \frac{F_H - F_L}{F_C}$$

Where $F_H$ is the highest frequency in the band, $F_L$ is the lowest frequency in the band, and $F_C$ is the center frequency in the band. In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations.

### 2.1.4. Directivity and Gain

**Directivity** is the ability of an antenna to focus energy in a particular direction when transmitting, or to receive energy better from a particular direction when receiving. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. However in a dynamic system where the transceiver is not fixed, the antenna should radiate equally in all directions, and this is known as an omni-directional antenna.

**Gain** is not a quantity which can be defined in terms of a physical quantity such as the Watt or the Ohm, but it is a dimensionless ratio. Gain is given in reference to a standard antenna. The two most common reference antennas are the isotropic antenna and the resonant half-wave dipole antenna. The isotropic antenna radiates equally well in all directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. Any real antenna will radiate more energy in some directions than in others. Since it cannot create energy, the total power radiated is the same as an isotropic antenna, so in other directions it must radiate less energy.

The gain of an antenna in a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power. Usually we are only interested in the maximum gain, which is the gain in the direction in which the antenna is radiating most of the power. An antenna gain of 3 dB compared to an isotropic antenna would be written as 3 dBi. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires a number of dipoles of different lengths. An antenna gain of 3 dB compared to a dipole antenna would be written as 3 dBd.

The method of measuring gain by comparing the antenna under test against a known standard antenna, which has a calibrated gain, is technically known as a gain transfer technique. Another method for measuring gain is the 3 antennas method, where the transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance.

### 2.1.5. Radiation Pattern

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but usually the measured radiation patterns are a two dimensional slice of the three-dimensional pattern, in the horizontal or vertical planes. These pattern measurements are presented in either a *rectangular* or a *polar* format. The following figure shows a rectangular plot presentation of a typical 10 element Yagi. The detail is good but it is difficult to visualize the antenna behavior at different directions.

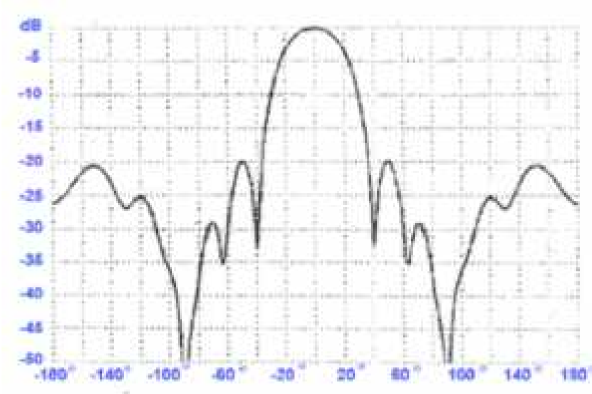



**Fig-1.Radiation Pattern**

Polar coordinate systems are used almost universally. In the polar coordinate graph, points are located by projection along a rotating axis (radius) to an intersection with one of several concentric circles. Following is a polar plot of the same 10 element Yagi antenna.

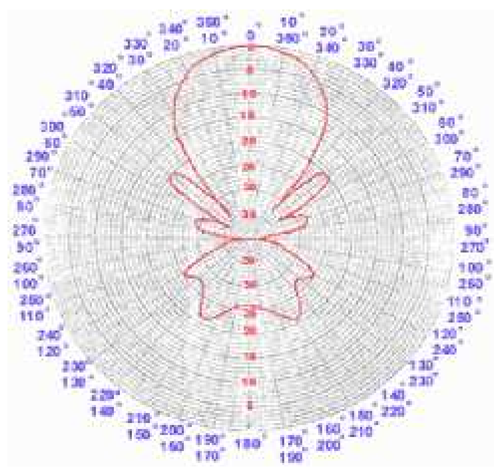


**Fig.2. Polar plot of Yagi antenna**

Polar coordinate systems may be divided generally in two classes: linear and logarithmic. In the linear coordinate system, the concentric circles are equally spaced, and are graduated. Such a grid may be used to prepare a linear plot of the power contained in the signal. For ease of comparison, the equally spaced concentric circles may be replaced with appropriately placed circles representing the decibel response, referenced to 0 dB at the outer edge of the plot. In this kind of plot the minor lobes are suppressed. Lobes with peaks more than 15 dB or so below the main lobe disappear because of their small size. This grid enhances plots in which the antenna has a high directivity and small minor lobes. The voltage of the signal, rather than the power, can also be plotted on a linear coordinate system. In this case, too, the directivity is enhanced and the minor lobes suppressed, but not in the same degree as in the linear power grid.

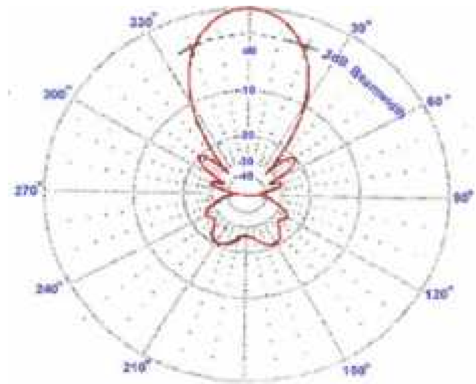



**Fig.3. Shape of the beam**

A modified logarithmic scale emphasizes the shape of the major beam while compressing very low-level (>30 dB) side lobes towards the center of the pattern. There are two kinds of radiation pattern: absolute and relative. Absolute radiation patterns are presented in absolute units of field strength or power. Relative radiation patterns are referenced in relative units of field strength or power. Most radiation pattern measurements are relative to the isotropic antenna, and then the gain transfer method is then used to establish the absolute gain of the antenna.

The radiation pattern in the region close to the antenna is not the same as the pattern at large distances. The term near-field refers to the field pattern that exists close to the antenna, while the term far-field refers to the field pattern at large distances. The far-field is also called the radiation field, and is what is most commonly of interest. Ordinarily, it is the radiated power that is of interest, and so antenna patterns are usually measured in the far-field region. For pattern measurement it is important to choose a distance sufficiently large to be in the far-field, well out of the near-field. The minimum permissible distance depends on the dimensions of the antenna in relation to the wavelength. The accepted formula for this distance is:

$$\mathbf{r_{min} = 2d^2/}ª$$

Where $\mathbf{r_{min}}$ is the minimum distance from the antenna, **d** is the largest dimension of the antenna, and is ª the wavelength.

### 2.1.6. Beam width

An antenna's beam width is usually understood to mean the half-power beam width. The peak radiation intensity is found and then the points on either side of the peak which represent half the power of the peak intensity are located. The angular distance between the half power points is defined as the beam width. Half the power expressed in decibels is —3dB, so the half power beam width is sometimes referred to as the 3dB beam width. Both horizontal and vertical beam widths are usually considered.

Assuming that most of the radiated power is not divided into side lobes, then the directive gain is inversely proportional to the beam width: as the beam width decreases, the directive gains increases.

### 2.1.7. Nulls

In an antenna radiation pattern, a **null** is a zone in which the effective radiated power is at a minimum. A null often has a narrow directivity angle compared to that of the main beam. Thus, the null is useful for several purposes, such as suppression of interfering signals in a given direction.

### 2.1.8. Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is in general described by an ellipse. Two special cases of elliptical polarization are linear polarization and circular polarization. The initial polarization of a radio wave is determined by the antenna.

With linear polarization the electric field vector stays in the same plane all the time. Vertically polarized radiation is somewhat less affected by reflections over the transmission path. Omni directional antennas always have vertical polarization. With horizontal polarization, such reflections cause variations in received signal strength. Horizontal antennas are less likely to pick up man-made interference, which ordinarily is vertically polarized.

In circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. This rotation may be right hand or left hand. Choice of polarization is one of the design choices available to the RF system designer.

### 2.1.9. Polarization Mismatch

In order to transfer maximum power between a trans and a receive antenna, both antennas must have the same spatial orientation, the same polarization sense and the same axial ratio.

When the antennas are not aligned or do not have the same polarization, there will be a reduction in power transfer between the two antennas. This reduction in power transfer will reduce the overall system efficiency and performance.

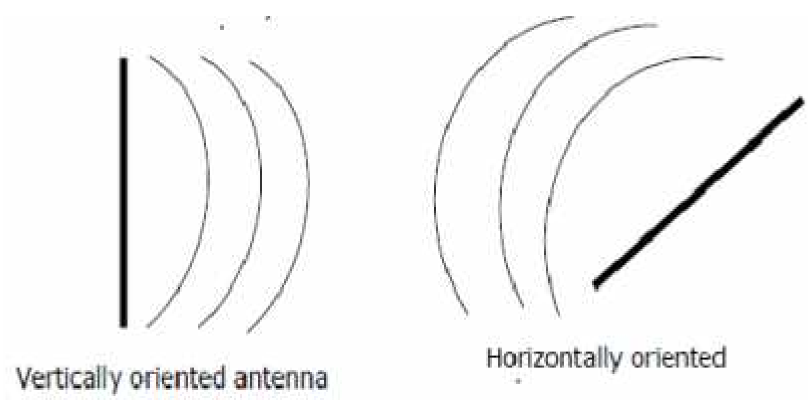



**FIG.4. Polarity mismatched**

When the transmit and receive antennas are both linearly polarized, physical antenna misalignment will result in a polarization mismatch loss which can be determined using the following formula

**Polarization Mismatch Loss (dB) = 20 log (cosϑ)**

Where ϑ is the misalignment angle between the two antennas. For 15° we have a loss of 0.3 dB, for 30° we have 1.25 dB, for 45° we have 3 dB and for 90° we have an infinite loss.

The actual mismatch loss between a circularly polarized antenna and a linearly polarized antenna will vary depending upon the axial ratio of the circularly polarized antenna.

If polarizations are coincident no attenuation occurs due to coupling mismatch between field and antenna, while if they are not, then the communication can't even take place.

### 2.1.10. Front-to-back ratio

The front-to-back ratio is the ratio of the maximum directivity of an antenna to its directivity in the rearward direction. For example, when the principal plane pattern is plotted on a relative dB scale, the front-to-back ratio is the difference in dB between the level of the maximum radiation, and the level of radiation in direction 180 degrees.

## 2.2. Types of Antennas

A classification of antennas can be based on:

### 2.2.1. Frequency and size

Antennas used for HF are different from the ones used for VHF, which in turn are different from antennas for microwave. The wavelength is different at different frequencies, so the antennas must be different in size to radiate signals at the correct wavelength.

### 2.2.2. Directivity

Antennas can be Omni directional, sectorial or directive. Omni directional antennas radiate the same pattern all around the antenna in a complete 360 degrees pattern. The most popular types of omnidirectional antennas are the Dipole-Type and the Ground Plane. Sectorial antennas radiate primarily in a specific area. The beam can be as wide as 180 degrees, or as narrow as 60 degrees. Directive antennas are antennas in which the beam width is much narrower than in sectorial antennas. They have the highest gain and are therefore used for long distance links. Types of directive antennas are the Yagi, the biquad, the horn, the helicoidal, the patch antenna, the Parabolic Dish and many others.

## 2.3. Isotropic antenna

Any signal that is transmitted by an antenna will suffer attenuation during its journey in free space. The amount of power received at any given point in space will be inversely proportional to the distance covered by the signal. This can be understood by using the concept of an isotropic antenna. An isotropic antenna is an imaginary antenna that radiates power equally in all directions. As the power is radiated uniformly, we can assume that a 'sphere' of power is formed, as shown in Figure 5

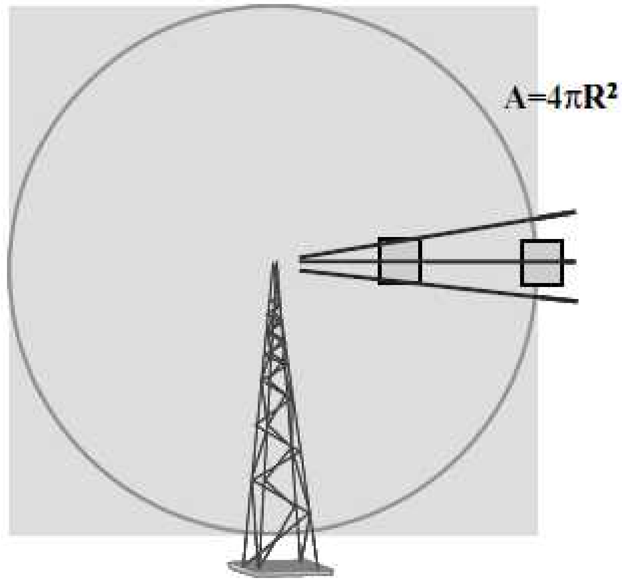



**Fig.5.Isotropic antenna**

The surface area of this power sphere is:

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

The power density *S* at any point at a distance *R* from the antenna can be expressed as:

$$S = P*G/A$$

Where **P** is the power transmitted by the antenna, and **G** is the antenna gain. Thus, the received power **Pr** at a distance **R** is:

$$Pr = P * G_t * G r (\lambda/4\pi R)^2$$

Where **Gt** and **Gr** are the gain of the transmitting and receiving antennas and ª is the wavelength respectively. On converting this to decibels we have:

$$Pr(dB) = P(dB) + Gt(dB) + Gr(dB) + 20\log(\lambda/4\pi) - 20\log d.$$

Last two terms are together called the path loss in free space, or the free space loss (**FSL)**. The first two terms **(P and Gt)** combined are called the effective isotropic radiated power (**EIRP)**.

Thus:

Free-space loss (dB) = **EIRP + Gr(dB) − Pr(dB).**

The free-space loss can then be given as:

$$L\ dB = 32.4 + 20\log f + 20\log d$$

Where **f** is the frequency in GHz and **d** is the distance in km.

## Free Space Loss

As signals spread out from a radiating source, the energy is spread out over a larger surface area and the strength of that signal gets weaker. Free space loss (FSL), measured in dB, specifies how much the signal has weakened over a given distance.


**Fig.6.FSL in a radio link**

### Effective Isotropic Radiated Power

Effective isotropic radiated power (EIRP) is the actual RF power as measured in the main lobe (or focal point) of an antenna. It is equal to the sum of the transmit power into the antenna (in dBm) added to the dBi gain of the antenna. Since it is a power level, the result is measured in dBm.

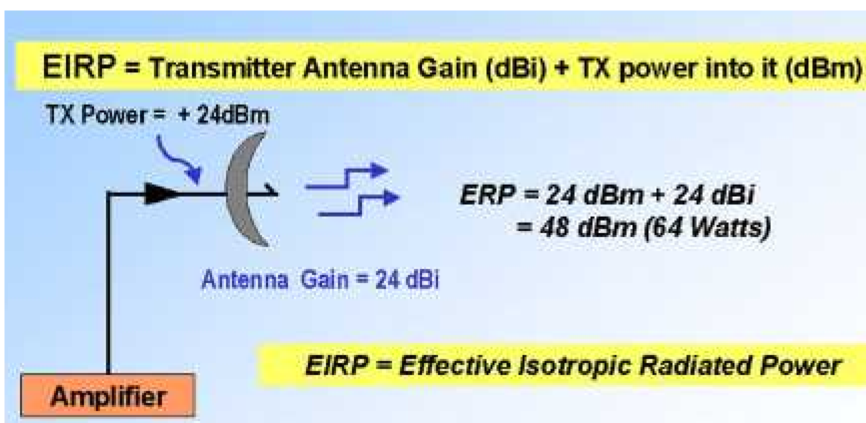



**Fig.6.EIRP of a radio**

## 2.4. Ground-plane antenna

A ground-plane antenna is a designed for use with an unbalanced feed line such as coaxial cable. This antenna is designed to transmit a vertically polarized signal. It consists of a 1⁄4 wave element as half-dipole and three or four 1⁄4 wavelength ground elements bent 30 to 45 degrees down. This set of elements, called radials, is known as a ground plane. This is a simple and effective antenna that can capture a signal equally from all directions.

The main element can be any length, but it must be adjusted to function at and near a specific frequency. This adjustment is done using a tuning coil. The radials are connected to the outer conductor or shield of the feed line cable; the main element is connected to the center conductor.

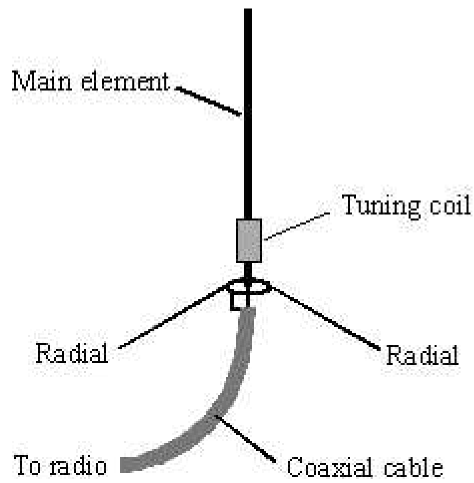



**Fig.6.GP antenna**

The main element of a ground-plane antenna is almost always oriented vertically. This results in transmission of, and optimum response to, vertically polarized wireless signals. When the base of the antenna is placed at least 1/4 wavelength above the ground or other conducting surface, the radials behave as a near-perfect ground system for an electromagnetic field, and the antenna is highly efficient. It works equally well in all horizontal directions. Ground-plane antennas are favored at frequencies above approximately 10 MHz. This type of antenna is used for base radio VHF equipment.

### 2.5. Yagi antenna

A basic Yagi consists of a certain number of straight elements, each measuring approximately half wavelength. The driven or active element of a Yagi is the equivalent of a center-fed, half-wave dipole antenna. Parallel to the driven element, and approximately 0.2 to 0.5 wavelengths on either side of it, are straight rods or wires called reflectors and directors, or passive elements altogether. A reflector is placed behind the driven element and is slightly longer than half wavelength; a director is placed in front of the driven element and is slightly shorter than half wavelength. A typical Yagi has one reflector and one or more directors. The antenna propagates electromagnetic field energy in the direction running from the driven element toward the directors, and is most sensitive to incoming electromagnetic field energy in this same direction. The more directors a Yagi has, the greater the gain. As more directors are added to a Yagi, however, it becomes longer. Following is the photo of a Yagi antenna with 6 directors and one reflector.

**Fig. 7. Yagi antenna**

Yagi antennas are used primarily for Point-to-Point links, have a gain from 10 to 20 dBi and a horizontal beam width of 10 to 20 degrees.

## 2.6. Horn

The horn antenna derives its name from the characteristic flared appearance. The flared portion can be square, rectangular, cylindrical or conical. The direction of maximum radiation corresponds with the axis of the horn.

**Fig.8. Horn antenna**

## 2.7. Parabolic Dish

Antennas based on parabolic reflectors are the most common type of directive antennas when a high gain is required. The main advantage is that they can be made to have gain and directivity as large as required.

The main disadvantage is that big dishes are difficult to mount and are likely to have a large wind age. The basic property of a perfect parabolic reflector is that it converts a spherical wave irradiating from a point source placed at the focus into a plane wave. Conversely, all the energy received by the dish from a distant source is reflected to a single point at the focus of the dish.

The position of the focus, or focal length, is given by:

$$f = \frac{D^2}{16 \times c}$$

Where D is the dish diameter and c is the depth of the parabola at its center. The size of the dish is the most important factor since it determines the maximum gain that can be achieved at the given frequency and the resulting beam width. The gain and beam width obtained are given by:

$$G = \frac{(\pi \times D)^2}{\lambda^2} \times n$$

$$BW = \frac{70\lambda}{D}$$

Where D is the dish diameter and n is the efficiency. The efficiency is determined mainly by the effectiveness of illumination of the dish by the feed, but also by other factors. Each time the diameter of a dish is doubled, the gain is four times, or 6 dB, greater. If both stations double the size of their dishes, signal strength can be increased of 12 dB, a very substantial gain. An efficiency of 50% can be assumed when hand-building the antenna.

The ratio f/D (focal length/diameter of the dish) is the fundamental factor governing the design of the feed for a dish. The ratio is directly related to the beam width of the feed necessary to illuminate the dish effectively. Two dishes of the same diameter but different focal lengths require different design of feed if both are to be illuminated efficiently. The value of 0.25 corresponds to the common focal-plane dish in which the focus is in the same plane as the rim of the dish.

Dishes up to one meter are usually made from solid material. Aluminum is frequently used for its weight advantage, its durability and good electrical characteristics. Windage increases rapidly with dish size and soon becomes a severe problem. Dishes which have a reflecting surface that uses an open mesh are frequently used. These have a poorer front-to-back ratio, but are safer to use and easier to build. Copper, aluminum, brass, galvanized steel and iron are suitable mesh materials.

## 2.8. Other Antennas

Many other types of antennas exist and new ones are created following the advances in technology.

**2.8.1 Sector or Sectorial antennas**: they are widely used in cellular telephony infrastructure and are usually built adding a reflective plate to one or more phased dipoles. Their horizontal beam width can be as wide as 180 degrees, or as narrow as 60 degrees, while the vertical is usually much narrower. Composite antennas can be built with many Sectors to cover a wider horizontal range (multisectorial *antenna*).

A **sector antenna** is a type of directional microwave antenna with a sector-shaped radiation pattern. The word "sector" is used in the geometric sense; some portion of the circumference of a circle measured in degrees of arc. 60°, 90° and 120° designs are typical, often with a few degrees ’extra’ to ensure overlap and mounted in multiples when wider or full-circle coverage is required.

A 60 degree sector antenna covers 60 degrees (1/6) of a 360 degree circle, while a 90 degree sector antenna covers a fourth of that same circle. The radiation areas don't end abruptly at 60, 90, or 120 degrees; these have a few degrees of overlap so you could, for example, use three 120 degree sector antennas for full coverage of a circle

The largest use of these antennas is for cell phone base-station sites. They are used for limited-range distances of around 4 to 5 km.

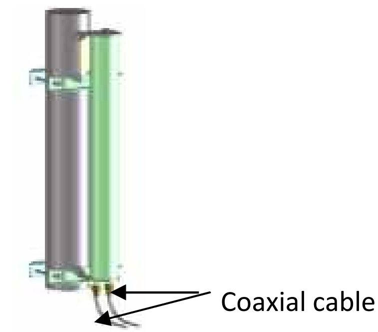



**Fig . 9 . Sector antenna**

A typical sector antenna is depicted in the figure 9. At the bottom, there are RF connectors for coaxial cable (feed line), and adjustment mechanisms. For its outdoor placement, the main reflector screen is produced from aluminum, and all internal parts are housed into a fiberglass radome enclosure to keep its operation stable regardless of weather conditions.

The antenna's long narrow form gives it a fan-shaped radiation pattern, wide in the horizontal direction and relatively narrow in the vertical direction. According to the radiation patterns depicted, typical antennas used in a three-sector base station has 66° of horizontal beam width. This means that the maximum gain is achieved at 0° and its value is slightly low at the ±33° directions. At the ±60° directions, it is suggested to be a border of a sector and antenna gain is negligible there.

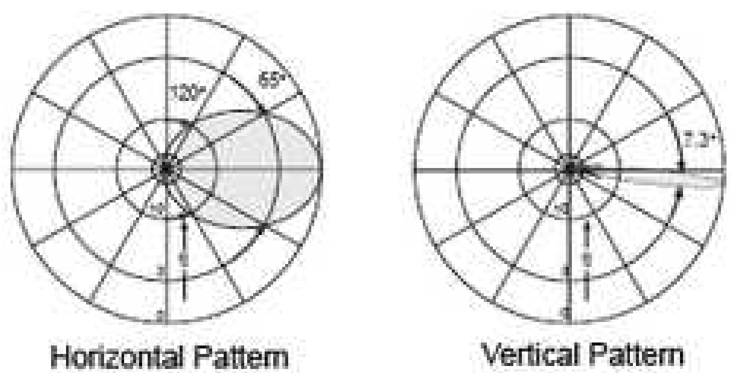



**Fig.10 .Field pattern**

Vertical beam width is not wider than 15°, meaning 7.5° in each direction. Which must achieve line-of-sight over many miles or kilometers, there is usually a downward beam tilt or down tilt so that the base station can more effectively cover its immediate area and not cause RF interference to distant cells.

The coverage area which is equal to the square of the sector's projection to the ground can be adjusted by changing electrical or mechanical down tilts. Electrical tilt is set by using a special control unit which usually is built into the antenna case and Mechanical down tilt is set manually by adjusting an antenna fastener

Grounding is very important for an outdoor antenna so all metal parts are DC-grounded.

### 2.8.2. Whip antenna

A **whip antenna** is an antenna consisting of a single straight flexible wire or rod. The bottom end of the whip is connected to the radio receiver or transmitter. They are designed to be flexible so that they won't break off, and the name is derived from their whip-like motion when disturbed. Often whip antennas for portable radios are made of a series of interlocking telescoping metal tubes, so they can be retracted when not in use. Longer ones made for fixed mounting on vehicles or structures are made of a flexible fiberglass rod surrounding a wire core, and can be up to 35 ft (10 m) long. Whips are the most common type of monopole antenna. These antennas are widely used for hand-held radios such as cell phones, cordless phones, walkie-talkies, FM radios, boom boxes, Wifi enabled devices, and GPS receivers, and also attached to vehicles as the antennas for car radios and two way radios for police, fire and aircraft attached to vehicles as the antennas for car radios and two way radios for police, fire and aircraft.

**FIG.11 .Whip antenna used for VHF sets**

Multi-band operation is possible with coils at about one-half or one-third and two-thirds that do not affect the aerial much at the lowest band but create the effect of stacked dipoles at a higher band (usually x2 or x3 frequency).

### 2.9. Smart Antenna

A smart antenna is a digital wireless communications antenna system that takes advantage of diversity effect at the source (transmitter), the destination (receiver), or both. Diversity effect involves the transmission and/or reception of multiple radio frequency (RF) waves to increase data speed and reduce the error rate.

In conventional wireless communications, a single antenna is used at the source, and another single antenna is used at the destination. This is called SISO (single input, single output). Such systems are vulnerable to problems caused by multipath effects. When an electromagnetic field (EM field) is met with obstructions such as hills, canyons, buildings, and utility wires, the wave fronts are scattered, and thus they take many paths to reach the destination. The late arrival of scattered portions of the signal causes problems such as fading, cut-out (cliff effect), and intermittent reception (picket fencing). In a digital communications system like the Internet, it can cause a reduction in data speed and an increase in the number of errors. The use of smart antennas can reduce or eliminate the trouble caused by multipath wave propagation.

Smart antennas fall into three major categories: SIMO (single input, multiple output), MISO (multiple input, single output), and MIMO (multiple input, multiple output).

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.

### 2.9.1. Smart Antenna – Functions

#### 2.9.1. 1. Estimation of Direction of arrival (DOA)

In smart antennas various techniques like MUSIC (Multiple Signal Classification) and estimation of signal parameters via rotational invariance techniques algorithms are used to find the DOA of a signal. This method requires a lot of computations and algorithms.

#### 2.9.1. 2. Beam forming Method

The mobiles or targets at which the signals are to be sent are first sought out and then a radiation pattern of the antenna array is created by adding the signal phases. At the same time the mobiles which will not need the signal will be out of pattern. Though this method may seem a little too complicated, it can be done easily with the help of a FIR (Finite Impulse Response) tapped delay line filter. According to the signal used the weight of the FIR filter can also be changed accordingly. The filters will also be helpful in providing optical beam forming so as to decrease the MMSE (Minimum Mean Squared Error) between the actual and wanted beam pattern that is formed

### 2.9.2.Types of Smart Antennas

The classification of Smart Antennas depends on the type of environment and the requirements of the system. There are mainly two types of Smart Antennas. They are

1. Phased Array/Beam Smart/Multi-beam Antenna
2. Adaptive Array Antenna

#### 2.9.2.1 Phased Array/Beam Smart/Multi-beam Antenna

In this type of array, there will be numerous amount of fixed beams amongst which one beam will turn on or will be steered towards the wanted signal. This can be done only with the help of adjustment in the phase.

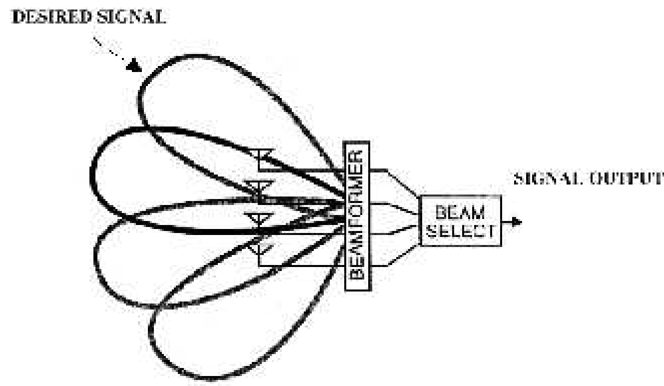



**Fig.12. Phased Array Antenna**

### 2.9.2.2 Adaptive Array Antenna

In this type of antenna, there will be a change in the beam pattern according to the movement of the wanted user and the movement of the interference. The signals that are received will be weighted and later combined to increase the wanted signal to interference in addition to the noise and power ratio [S/N]. Thus, the direction of interference will be balanced as the wanted signal will be in the direction of the main beam.

The antenna can easily steer the main beam to any direction, while at the same time nullifying the interfering signal. The direction of the beam can be calculated using the DOA method. The figure of an adaptive array antenna is shown below

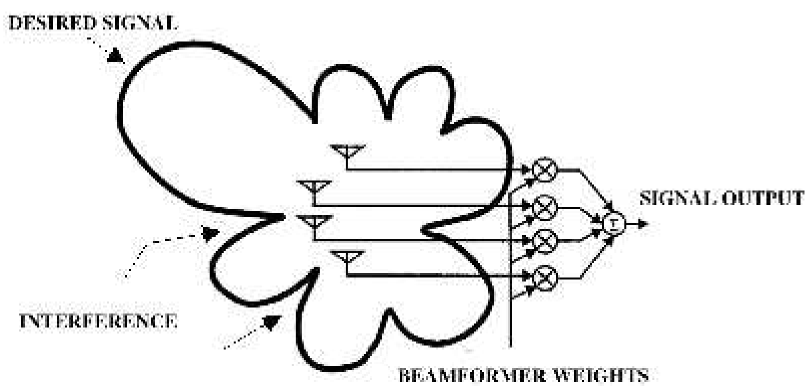



**Fig.13. Adaptive Array Antennas**

### 2.9.2.3. Advantages

Both beam smart and adaptive arrays provide high efficiency and thus high power for the desired signal. When a large number of antenna elements are used at a higher frequency, Beam Smart antennas use narrow pencil beams. Thus high efficiency is obtained in the direction of the desired signal. If a fixed number of antenna elements are used the same amount times the power gain will be produced with the help of adaptive array antennas.

Another advantage is in the amount of interference that is suppressed. Beam smart antennas suppress it with the narrow beam and adaptive array antennas suppress the interference by adjusting the beam pattern.

### 2.9.2.4 Disadvantages

The main disadvantages are

**1. Cost:** The cost of such a device will be more, not only in the electronics section, but also in the power. That is the device is way too expensive [especially if MIMO methods are used.], and will also decrease the life of battery of mobiles. The receiver chains that are used must be reduced in order to reduce the cost. Also the costs rise up due to the RF electronics and A/D converter used for each antenna.

**2. Size:** For this method to be efficient large base stations are needed. This will increase the size. Apart from this multiple external antennas are needed on each terminal. This is not practical. But companies re trying methods like dual polarization to reduce the size.

**3. Diversity:** When multiple mitigation is needed, diversity becomes a big problem. The terminals and base stations must have multiple antennas. There are mainly three types of diversities. They are spatial, polarization, and angle.

Spatial separation of the antennas that are used is practically impossible when it is applied on mobile phones. It is also difficult to be achieved in point-to-point systems where a near line-of-sight exists between the transmitter and receiver. By using polarized diversity, the above problem can be avoided to a certain point. Dual polarization can be easily instigated without the use of spatial separation.

Angular diversity is the most commonly used method nowadays. The signals which have the maximum signal power are selected from multiple beams and are used to maintain diversity. But the gain depends on the angular spread. That is, if the spread is small, the diversity will also be small.

# ANNEXURE

## FREQUENCY ALLOCATIONS AND FREQUENCY PLAN

Indian Railways have been allotted a frequency band of 7125 MHz to 7425 MHz (4.21 cms - 4.04 cms wavelengths) in the Xc band. (The band of frequency from 7250 - 7300 MHz is restricted in view of satellite to earth allotment). The spot frequencies permitted in the band for operation of a transmitter (and Receiver) are governed by CCIR Recommendation 385 - 1 which inter - alia stipulates as follows: -

$fo$ = Center frequency = 7275 MHz
$f_n$ = Channel frequency in MHz in lower half of the band
$f^1{}_n$ = Channel frequency in MHz in Upper half of the band.

Then the frequencies (MHz) of the individual channels are expressed by the following relationships:-

Lower half of band $fn = fo - 154 + 7n$
Upper half of band $f^1{}_n = fo + 7 + 7n$

Where n = 1, 2, 3, etc., .upto 20.

e.g., $f1 = (7275 – 154 + 7x1) = 7128$ MHz & $f^1{}_1 = (7275 + 7 + 7x1) = 7289$ MHz
$f_2 = 7135$ MHz & $f'_2 = 7296$ MHz and so on.

In section over which the international conduction is arranged all the 'go' channels should be in one half of the band and all the 'return' channels in the other half of the band.

When systems with 300 telephone channels are operated in a radio frequency band, channel combination, which result in differences between channel frequencies of less than 14 MHz, should in general be avoided. If sufficient antenna discrimination is available, this precaution may be disregarded.

### Frequency Plan

There are two distinct patterns of frequency plans employed on the Railways. They are the 'Four Frequency' and the 'Two Frequency' plans.

**Characteristics of a four-frequency plan:** Allocation of frequencies in a four frequency plan is as shown in the **Fig.1.**

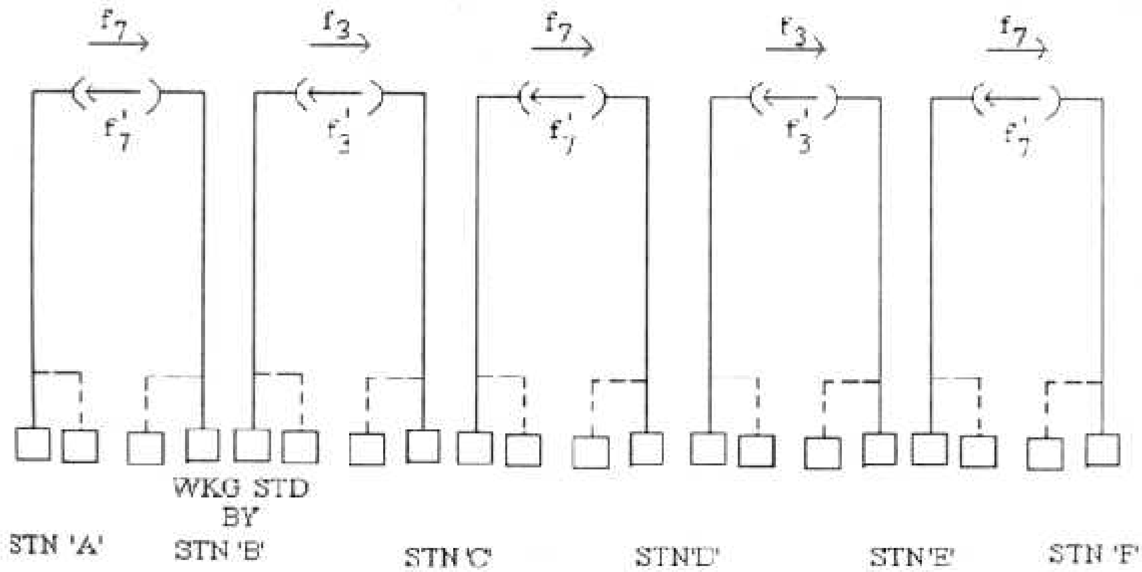



**FIG.1. Four Frequency Plan (100% Standby Equipment)**

The transmit frequencies from A towards B and from B towards C are different so that there is no chance of interference caused by radiation from A to B reaching Station C (or vice versa i.e. C to B reading A). The signal from A meant for B and reaching C would be attenuated primarily by Band Pass filter in the receiver at C and thus interference noise shall be effectively curtailed.

Similarly, signal from Station B towards C (frequency f3) going in the backward direction (i.e., towards A) is effectively attenuated by band pass filter in receiver at A which permits only f’7 to pass in the rectifier section. It is possible therefore, to employ a standard performance antenna with an F/B ratio of up to 45 dB. The four-frequency plan is, therefore, superior in as much as the interference caused in the system is effectively controlled due to judicious use of different frequencies. The price one pays for such improved performance is the use of more frequency pairs. In the third hop, however, (i.e. transmission from C to D) the frequency f7 is repeated (to conserve the frequency spectrum usage). No discussion on the four-frequency plan can be complete without ref. to the ’radio equipment standby’ vis-à-vis the frequency plan. Let us take the case of Station B. The transmitter at B for direction BC is tuned for frequency f3 and for direction BA is tuned to frequency f’7. The corresponding receivers are tuned for frequencies f’3 and f’7 and provide standby radio equipment at any Station to cater for improved system reliability even in the face of component failure causing an equipment (a transmitter or a receiver in this case) to fail. It should be obvious in this case that a separate transmitter tuned to radiate on f3 for direction BC and a separate one of f’7 for direction BA shall be required as standby transmitters. Similarly, separate receivers operating on f’3 and f’7 are required. Two standby transmitter/receivers will thus be required for two working transreceivers.

A four-frequency plan thus needs 100% standby radio equipment. In a nutshell, it can be said that a four-frequency plan causes less interference, permits standard antennae, but requires 100% radio equipment standby and of course necessitates larger pairs of frequencies.

**Characteristics of a two-frequency plan are: -**

1) F/B interference is likely to be sizeable unless antenna of better F/B ratio (High performance antenna with 65 dB F/B ratios) is employed. F/B interference refers to signal transmitted from B in the direction of C that goes in the backward direction to A as noise.

2) Better utilization of frequencies achieved.

3) Standby radio equipment to the tune of only 50% is sufficient meaning thereby that one transreceiver can be used as a standby for both the working transreceivers because the transmit frequencies in both directions (e.g., B to C & B to A) are identical. Receive frequencies from both directions (e.g. A to B and D to B) are also identical.

In the event of any component failure in transreceivers the standby transreceivers is automatically switched over by the supervisory equipment that monitors the functioning of the radio equipment.

The trade - off of the 'two frequency plan' is economy in radio equipment costs and better usage of limited number of frequencies made feasible against the higher price to be paid for better types of Antennae.

On India Railways a majority of the systems installed earlier employees a two-frequency plan whereas recently there is a trend in favour of the four frequency plans.

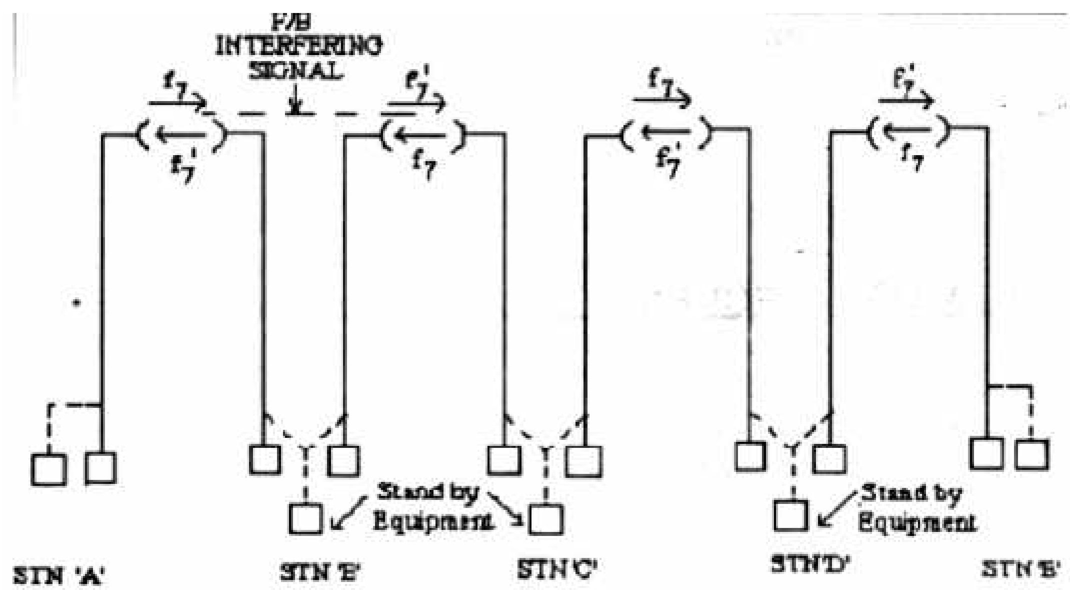



**FIG.2. Two-frequency plan (50% Stand by equipment)**

Frequency plan recommended for use on Indian Railways is as given below (RDSO's Lr.No.STT/MW/Inv. of 12-8-75).

| Frequency Combination | Normal (MHz) | | | |
|---|---|---|---|---|
| | Transmit | Receive | Transmit | Receive |
| A | $f_5$ 7156 (V) | $f'_5$ 7315 (V) | $f'_{12}$ 7366 (V) | $f_{12}$ 7205 (V) |
| B | $f_7$ 7170 (H) | $f'_7$ 7331 (H) | $f'_{14}$ 7380 (H) | $f_{14}$ 7219 (H) |
| C | $f_9$ 7184(H) | $f'_9$ 7345 (H) | $f'_{16}$ 7394 (H) | $f_{16}$ 7233 (H) |
| D | $f_3$ 7142 (V) | $f'_3$ 7303 (V) | $f'_{18}$ 7408 (V) | $f'_{18}$ 7247 (V) |

**Note: -**

1) Frequencies are in Mega Hertz and the subscript within bracket represents the type of polarization (whether vertical or horizontal).
2) Combination B and D to be used for main microwave route.
3) Combination A to be used for first spur taking off from the main route.
4) Combination C to be used for second spur taking off from the main route.
5) High performance antenna to be used when interference is expected at the time of designing the system with reference to Para 6 of CCIR's Recommendation No.385-1 (Refer Para 2.5).
6) Polarisation has been indicated as H or V tentatively, but shall be decided for each location depending upon the directions and heights separating the antennae.

In systems not employing frequency diversity the standby radio equipment would operate on the same frequency as the main radio equipment. In systems where over reach interference is anticipated to be heavy, the polarization plan may have to be altered so that polarization is altered for adjacent pairs of hops as shown below: -

| | | | | | |
|---|---|---|---|---|---|
| HOP: | AB | BC | CD | DE | EF |
| POLARIZATION | V | V | H | H | V |

Such an arrangement gives added discrimination against interfering over - reach signal due to cross polarization discrimination of 25 dB obtainable with standard parabolic antenna. Such a plan, however, has reduced protection from F/B or Adjacent channel. Interference, which can be kept low by employing H.P. Antenna.

### The K Factors

The amount and direction of bending undergone by the microwave beam is defined either by the refractive index gradient dN/dh or, more often by the effective earth's radius factor, k. The effective earth's radius factor, 'k' is a factor which when multiplied by the actual earth's radius gives the value of the modified earth's radius employed in profile chart to make the microwave beam a straight line. Use of k for profile chart preparation helps in checking up the clearance of Fresnel zone for a particular configuration. Any change in the amount of refraction caused by atmospheric conditions can then be expressed as a change in K.

## The Atmosphere

Blackout fading results from the formation of unusually steep, negative atmospheric density gradients, a dramatic drop in humidity, or an increase in temperature with height, for example. As the microwave beam is propagated through a blackout atmosphere, the lower part of the wave front is allowed by the dense air with respect to the upper part, causing a tilting of the wave front towards the ground or water. The amount of tilt is very small, but over a 20 mils distance the amount of accumulated bending could refract the propagated beam into the ground before it reaches the receive antenna. The beam may then be absorbed by foliage or crops, or scattered by rough terrain, but in most often specularly reflected by smooth terrain, or water (in which case it will re-appear again at greater distance).

Atmospheric density and refractive indexes are important in determining k factors for establishing path clearances. The density of the atmosphere, in terms of its refractive properties, is a function of pressure, temperature and humidity in the following approximate relationship.

$$N = 77.6 / T (P + 48 \log10 e/T) \text{ Rec 453 CCIR.}$$

Where N = Atmospheric refractive index (N-Units)
P = Pressure, millibars
T = Temperature, K (273 + C) 0
e = Saturation vapour pressure, millibars

Further K is given by, K = 157/(157 + dN/dh.)

During standard atmospheric conditions, the range of k is from 1.2 in dry elevated areas and 4/3 in typical inland areas, to 2 or 3 in humid coastal area. The earth appears to become increasingly flat as the value of k increases (). When k equals infinity the earth appears to a microwave beam to be perfectly flat since the beam curves at exactly the same rate as the earth. If the value of k becomes less than one, the beam curves upwards or opposite to the curvature of the earth; to the microwave beam, the earth appears to "bulge". The effect of earth's bulge may be to partially obstruct the transmission path, causing an obstruction or diffraction.

| K, effective earth's radius factor | dN/dh Units/Km. | Atmospheric condition | Microwave Propagation |
|---|---|---|---|
| 5/12 to 1 | +220 to 0 | Sub-refractive | Inverse bending (earth's bulge) |
| 1 to 1.6 | 0 to –58 | Dry-Standard | Moderate refraction |
| 1.6 to 3 | -58 to –157 | Super refractive | Flat Earth (at k =∞) |
| ∞ to -0.5 | -157 to –470 | Extreme gradient | Black out and Duct Type. |

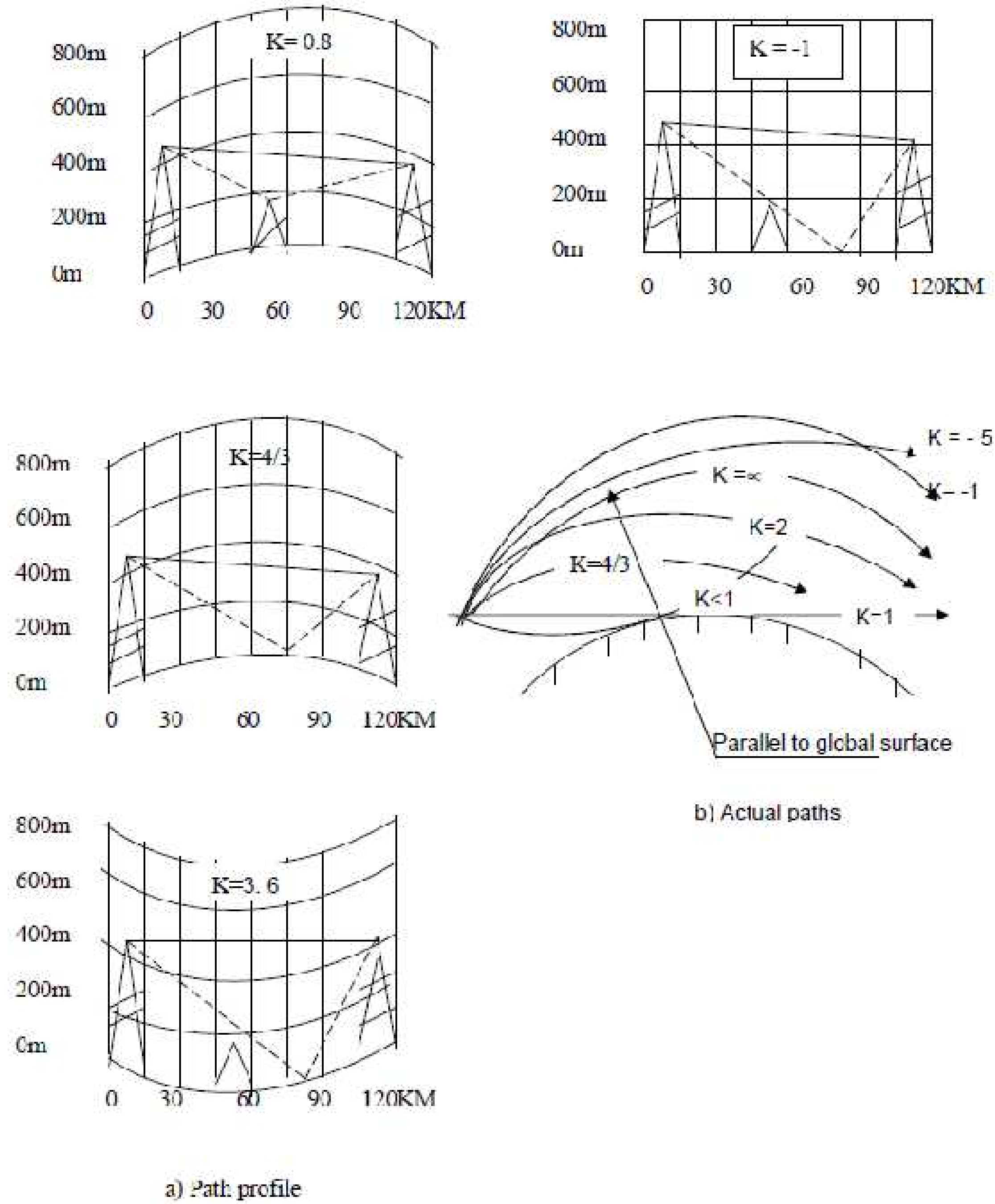



**FIG.3. Relation between K and microwave propagations**

The curvature for various values of k can be calculated from the relationship: -

$$h = d1\ d2/12.75\ k.$$

Where *h = the change in vertical distance from a horizontal reference line in meters.*

*d1= the distance from a point to one end of the path in Kms.*

*d2= the distance from the same point as above to the other end of the path, in Kms., and*

*k = the effective earth's radius factor.*

Exempting multipath fading (easily overcome with diversity techniques), changes in k from 1 to infinity have little influence upon the received signal level of a properly engineered microwave path. Anomalous propagation occurs outside of this ’normal’ range of k. With k less than 1, the path could become obstructed and vulnerable to extreme multipath fading. When negative values of k occur, the path may become trapped and susceptible to blackout fading

### Super standard Refraction

Super standard refraction (also called super-refraction), results from such meteorological conditions as a rise in temperature with increasing height (temperature inversion) or a marked decrease in total moisture content in the air with increasing height, either of which will cause a reduction in the atmospheric density with height. Under these circumstances, k increases, resulting in a flattening of the effective earth’s curvature.

One of the conditions that may cause this type of abnormal refraction is the passage of cool air over warm body of water. Evaporation of the water will cause an increase in humidity and the low temperature near the surface is a sign of a temperature inversion. Low temperature near the surface is a sign of a temperature inversion. Low temperatures and high humidity greatly increase the atmospheric density near the surface, causing an abnormally high do wire bending of the wave-front. In moderate instances of super-refraction, k approaches infinity and a microwave beam which is propagated parallel to the earth will remain parallel until obstructed or otherwise attenuated. An extreme case of super refraction will bend the wave front downward with a radius smaller than that of the earth (negative k), causing a blackout fade if the receiver is beyond the point at which the wave front refracts into the ground (the radio horizon).

### Sub-standard Refraction

Substandard or less than standard refraction occurs with certain meteorological conditions which causes the atmospheric density to actually increase with height. This conditions, described earlier as Earth’s bulge or inverse than bending, causes an upward curvature of the microwave beam, where k = 1/2. A sub-standard atmospheric condition may occur through the formation of fog created with the passage of warm air over a cool air or a moist surface. This will cause the atmospheric density to be lower near the ground than at higher elevations, causing an upward bending of the beam.

### M Profiles

The discussion of atmospheric irregularities is often aided by the use of another term or symbol, M, which is called the ’modified’ index of refraction. It is defined in terms of the radio refractive index and the mean sea level elevation. The following formula is applicable: -

$$M = (n - 1) \times 106 + 15.75h \quad \text{... V.3}$$

Where *n = the radio refractive index.*
*h = the height above sea level in hundreds of meters*.

In the normal atmosphere (where K = 4/3), M increases at a linear rate of about a 11.8 units per hundred meters increase in altitudes. When height is plotted as ordinate against M as abscissa, the plot is called an M profile. The slop of the M profile determines the degree of bending of the microwave beam in relation to the earth.

For discussion purposes it might be somewhat easier to follow a simplified equation for M. The term N, which is the variable fraction of the refractive index, then becomes the parameter against which the modified index M and its profile are compared.

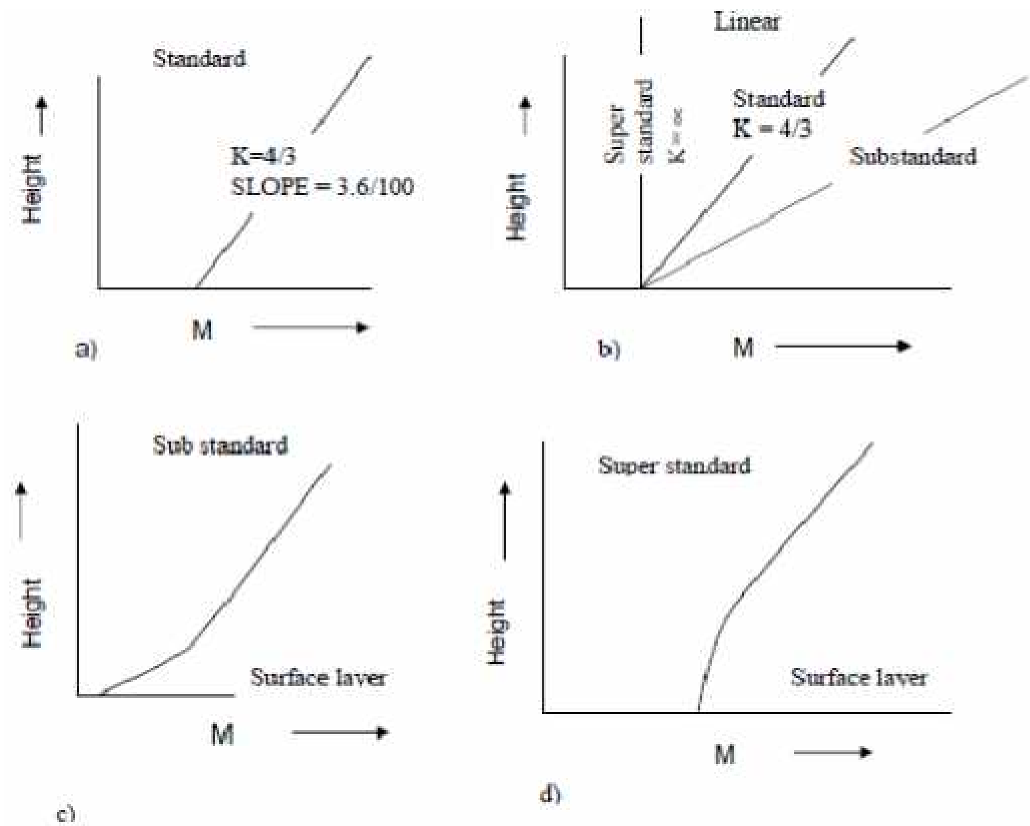
The new equation becomes: $M = N + 15.75h$ ... v.3

**Illustrations of Refraction as Related to the M Profile**

Figure 4 illustrates the M profile representing the "standard" condition, where K = 4/3 and the slope of the profile is constant at3.6units per hundred meters.

Fig. 4 is a group of M profiles representing specific conditions that will be discussed in the following paragraphs.

If N decreases more rapidly than normal increasing altitude, the slope of the M curve is steeper, the value is greater than 4/3, and the microwave beam follows the curvature of the earth more closely. If the value of M becomes constant with change in altitude, the microwave beam follows curvature of the earth exactly, and K is equal to infinity.



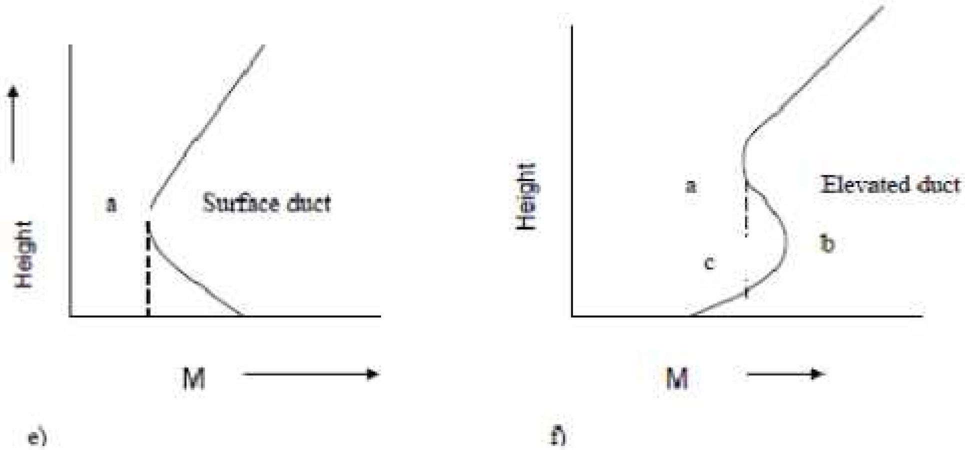



**FIG.4. M profiles**

This condition is represented graphically by a vertical M profile as shown for super-standard in **Fig. 4**. It would be represented on a path profile by a flat earth and a straight-line microwave beam. If conditions become even more extreme, the M profile will have a negative slope, corresponding to a negative K, or a "concave earth" condition. An example of this condition is the rare instance when an overreach interference signal is recorded at a station, and yet the over reach path is obstructed by several hundred meters when the path profile is plotted on flat earth.

When the slope of the M profile is greater than normal, the refractive, condition is referred to as super-standard or earth flattening, since the radio horizon distance is increased. When the slope of the M profile is less than normal, the refractive condition is known as sub-standard or earth building. This condition is reflected in **Fig. 4(b).**

In practice, linear profiles do not usually occur except near the standard profile, because whether factors usually change the shape of the M profile as well as its slope.

The effect of an abnormally high surface temperature, or increasing water vapour content with altitude, is shown in the M profile of **Fig.4(c)**. Such a sub-standard surface condition will result in curving the beam away from the earth and this is called inverse beam bending or earth bulging. The effect is similar to that from a linear M profile with a slope less than normal (earth bulging) except that it is concentrated near the surface of the earth.

A rise in temperature with increasing height, or a decrease in water vapour content, or both, will produce the effect shown in **Fig. 4 (d)**. This is a slightly super-standard condition that will cause the beam to follow the curvature of the earth more closely (earth flattening).

When the changes in refractive index are most severe near the surface, the condition will be as shown in **Fig. 4(e)**. This condition is known as a surface duct, because the beam will tend to stay within the surface and the elevation limits; depending on the slope of the M profile near the surface. When the beam enters the duct at a small angle, it is bent until it is horizontal and then turned downward by further bending.

**Fig. 4(f)** is the M profile of an elevated duct, the upper limit of which is formed by the upper limit of the super-standard or inversion layer from a to b, and the lower limit by the sub-standard layer from b to c. Under these conditions, the beam will tend to remain within the duct limits from a to c, due to the bending toward the centre of the duct. Concentration of radio energy within a duct will cause an increase in received signal when both the transmitting and receiving antennas are within the duct. Obviously, this effect cannot be relied on for satisfactory propagation, because the conditions producing it are subject to change. The terms trapping, super-refraction and guided propagation are also employed to describe duct phenomena.

M profiles that are essentially linear are significant primarily because of their effect on path clearance. The non-linear profiles, in addition to affecting path clearances, also give rise to conditions leading to an atmospheric multipath effect.

Figs No. 3 show the profile charts drawn for values of k = 0.8 k = 1.33, k = 3.6 and k = 1. A look at these graphs would indicate that for a given choice of antenna heights at station 'A' and Station 'B', the existing obstructions in the path are likely to obstruct the microwave path when the value of k is low which corresponds to sub refractive conditions. From this point of view, it is important that the path is engineered in such a fashion, that at the lowest value of k for which the system should function satisfactorily two-thirds of the first fresnel zone should be clear. As for Indian Railways, Tc-10 specification stipulates that at k = 4/3, the full fresnel zone should be clear at a low value k = 1 at least 2/3 of the fresnel zone is clear. It would thus to appreciate that path engineering has to ensure that at low value of k the terrain and the profile chart examined from the point of view of obstruction.

It would be observed that the obstruction in the intermediate terrain zone to be less important at higher values of k. As a matter of fact, as K increases in magnitude the clearance available at intermediate point tends to be higher and no serious cognizance is required to be taken from the point of view of obstruction of the radiation and stability of adequate fresnel zone clearance. At higher values of k, there exists greater probability of the reflected ray reaching the antenna after reflection at an intermediate point. In the event of the terrain near the point of reflection being highly reflective, e.g., river, marshy land, lake or irrigated land, the reflected ray can be strong and can cause fading of the receiving signal. In view of this at higher values of k, the system engineer has to evaluate the point of reflection, locate the point of reflection in the field, and check up the reflection co-efficient that is likely to be prevalent in that area. In the event of reflected ray being strong, the antenna heights should be modified to ensure that the reflected ray does not reach the receiving antenna even up to the highest values of k at which we want the path to be engineered. Such a situation can be maneuvered by judicious choice of antenna height wherein one of the rays that in the event of being reflected is successfully obstructed by natural obstruction. It would, therefore, be apparent that one of the important aspects in path engineering considerations involves checking up of the path from the point of view of obstruction and availability of adequate fresnel zone clearance at the low values of 'k' and checking of the conditions of reflection and its being successfully obstructed by an obstruction at higher values of 'k'.