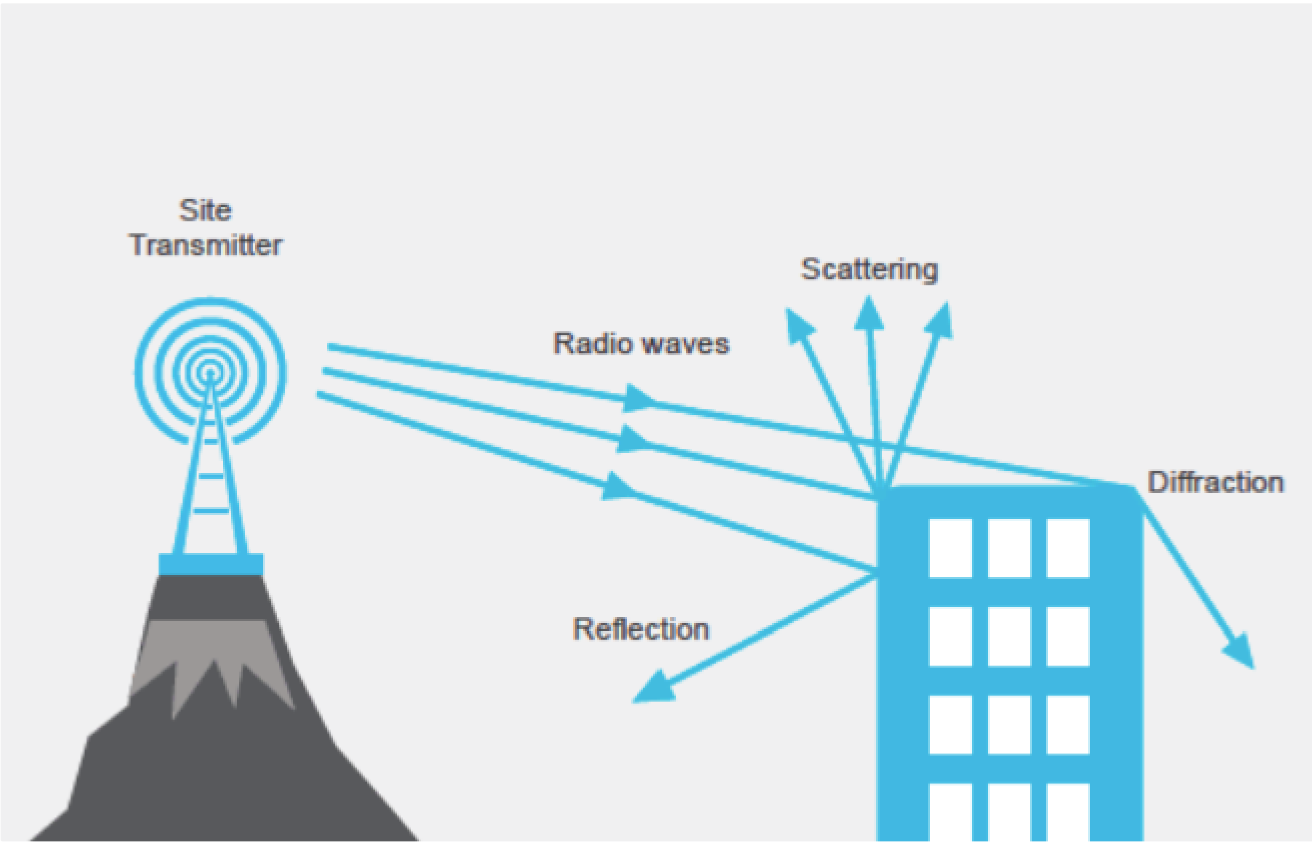
Wireless Propagation Characteristics

Basic Propagation Mechanisms

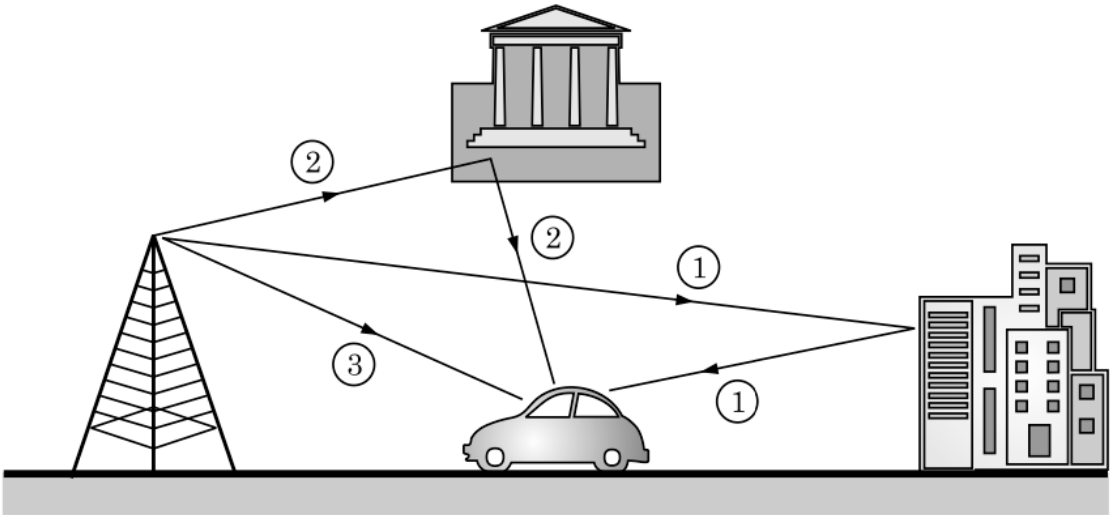
- **Reflection** — when an EM wave encounters a surface or obstacle and bounces back to its source. This causes loss of signal.
- **Diffraction** — Corners and sharp surfaces cause an EM wave just like the one thrown from a router to split into secondary smaller waves.
- **Scattering** — When the signal encounters a surface it dissipates into multiple reflected signals.



Multipath Propagation

- In multipath propagation, multiple signal paths are established between the base station and the user terminal (mobile phone).

- The fading due to multipath propagation is known as **Multipath fading** or Rayleigh fading.
- These indirect signals can add to or subtract from the direct signal arriving at the antenna.



Interference

Multipath interference is a phenomenon in the physics of waves whereby a wave from a source travels to a detector via two or more paths and the two (or more) components of the wave interfere constructively or destructively. Multipath interference is a common cause of "ghosting" in analog television broadcasts and of fading of radio waves.

In this illustration, an object (in this case an aircraft) pollutes the system by adding a second path. The signal arrives at receiver (RX) by means of two different paths which have different lengths. The main path is the direct path, while the second is due to a reflection from the plane.

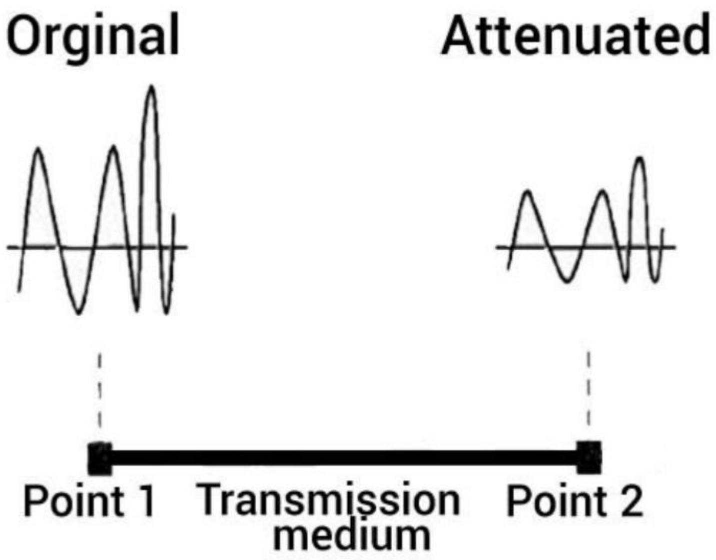
> 💡 The condition necessary is that the components of the wave remain coherent throughout the whole extent of their travel.

The interference will arise owing to the two (or more) components of the wave having, in general, travelled a different length (as measured by optical path length – geometric length and refraction (differing optical speed)), and thus arriving at the detector out of phase with each other.

The signal due to indirect paths interferes with the required signal in amplitude as well as phase which is called multipath fading.

Attenuation

Attenuation refers to the loss of signal strength with distance over any transmission medium.



Causes

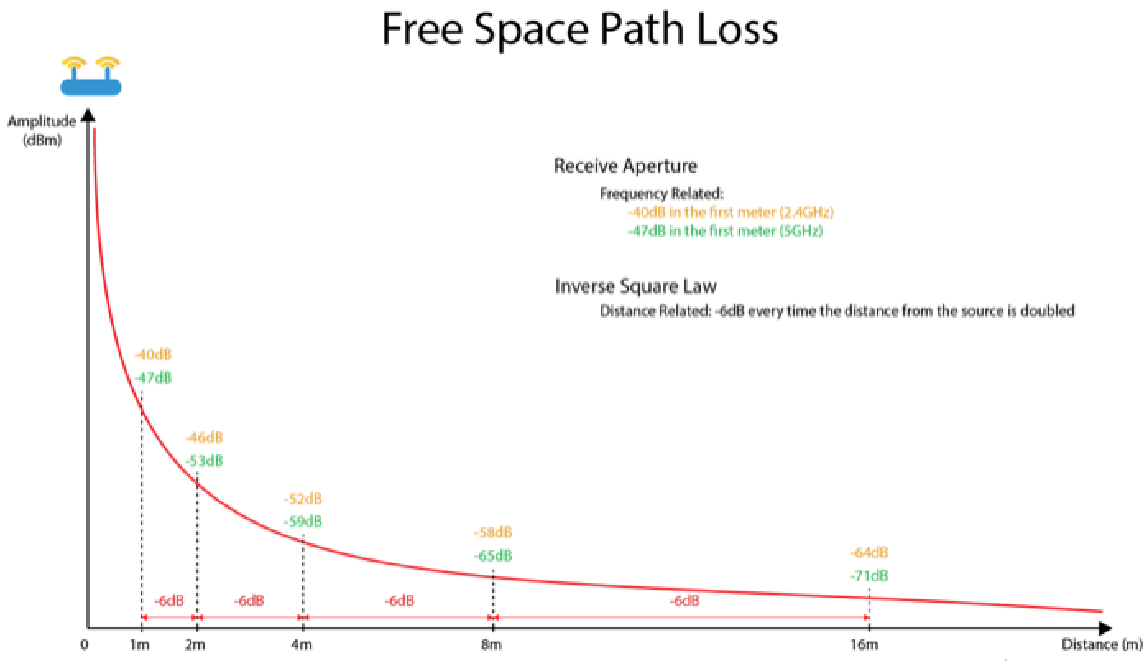
Other than distance, there are a few causes of signal attenuation:

- **Long cabling** – Over a long distance, transmitted signals slowly lose strength.
- **Wire size** – Thin wires experience more attenuation than thicker wires because they are more vulnerable to external interferences.
- **Noise** – Adjacent wires can cause electromagnetic interferences. The higher the noise, the higher the attenuation.
- **Defective connectors and conductors** – Poorly installed connectors and conductors lead to attenuation.

Path Loss

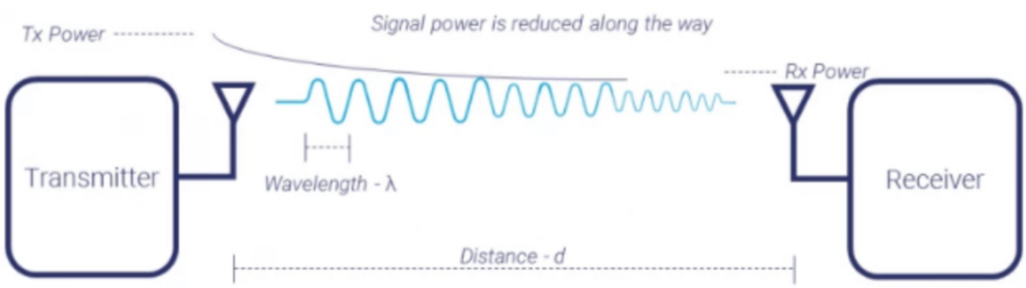
- Path Loss refers to the loss or attenuation a propagating electromagnetic signal or wave encounters along its path from the transmitter to the receiver.
- Also expressed as the ratio of transmitted power to received power

$$P_L = \frac{P_t}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2$$



In decibels, path loss can be expressed as

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



Causes

Path loss normally includes *propagation losses* caused by the natural expansion of the radio wave front in free space (which usually takes the shape of an ever-increasing sphere), *absorption losses* (sometimes called penetration losses), when the signal passes through media not transparent to electromagnetic waves, *diffraction losses* when part of the radio-wave front is obstructed by an opaque obstacle, and losses caused by other phenomena.

The signal radiated by a transmitter may also travel along many and different paths to a receiver simultaneously; this effect is called multipath. Multipath waves combine at the receiver antenna, resulting in a received signal that may vary widely, depending on the distribution of the intensity and relative propagation time of the waves and bandwidth of the transmitted signal. The total power of interfering waves in a Rayleigh fading scenario varies quickly as a function of space (which is known as *small scale fading*). Small-scale fading refers to the rapid changes in radio signal amplitude in a short period of time or distance of travel.

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Fading

Fading refers to the fluctuations in signal strength when received at the receiver. These are basically unwanted variations introduced at the time when the signal propagates from an end to another by taking multiple paths. Fading can be classified into two types:

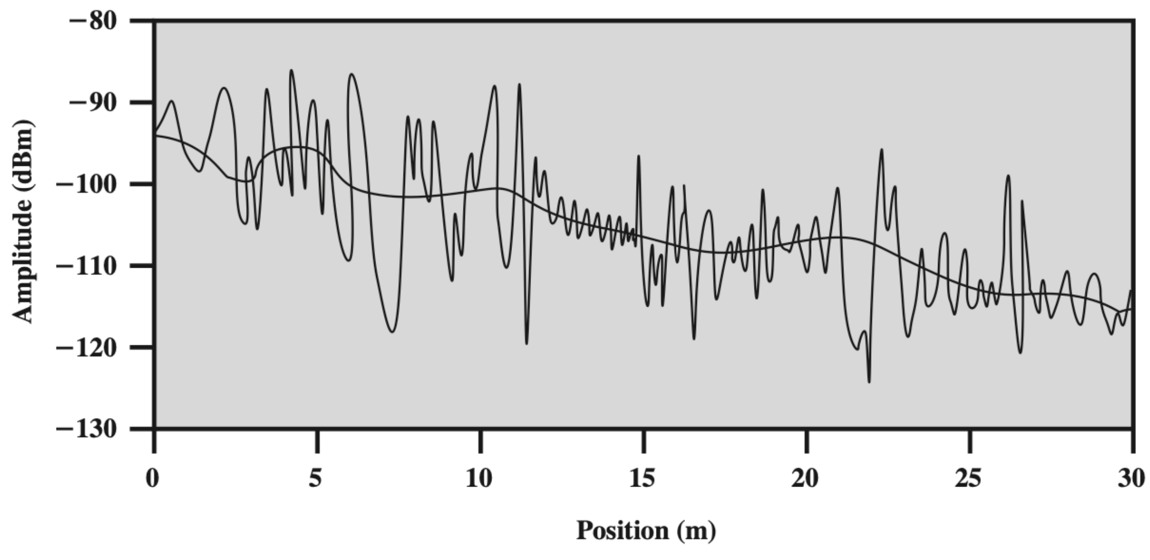
1. Fast Fading
2. Slow Fading

Fast Fading

- Fast Fading refers to the rapid fluctuations in the amplitude, phase or multi path delays of the received signals, due to the interference between multiple versions of the same transmitted signal arriving at the receiver at slightly different times.
- The multiple signal paths may sometimes add constructively or sometimes destructively at the receiver causing a variation in the power level of the received signal.

Slow Fading

- The name Slow Fading itself implies that the signal fades away slowly.
- Slow fading occurs when objects that partially absorb the transmission lie between the transmitter and receiver.
- Slow fading is also referred to as **shadow fading** since the objects that cause the fade, which may be large buildings or other structures, block the direct transmission path from the transmitter to the receiver.



Selective fading

It is also known as frequency selective fading. Basically when waves propagate through different paths by being reflected from various man-made entities then the different frequencies get affected to different degrees.

This will lead to cause variation in the amplitude and phase of the signals to a different extent while propagating in the channel.

It is to be noted that even if the path length through which the signal is propagating is same, then also the signals will possess different wavelengths. This causes variation in the phase of the signal across the overall bandwidth.

Selective fading can occur over a quite large range of frequencies. Suppose signals are utilizing ground wave propagation and sky wave propagation, then in such case the phase of the signals will change with time as the two are using two different medium of propagation.

Thus combinely when the signals are received at the receiving antenna then there will be changes in the received signal from the actually transmitted one.

So, as this type of fading is frequency selective, thus at the time of propagation, even adjacent parts of the signal fade independently even if their frequency of separation is small.

Hence we can say, this causes **severe distortion** of the modulated signal.

As it severely affects high-frequency signals thus is more dangerous in case of sky wave propagation. The amplitude modulated signals are generally more prone to such distortions rather than SSB signals.

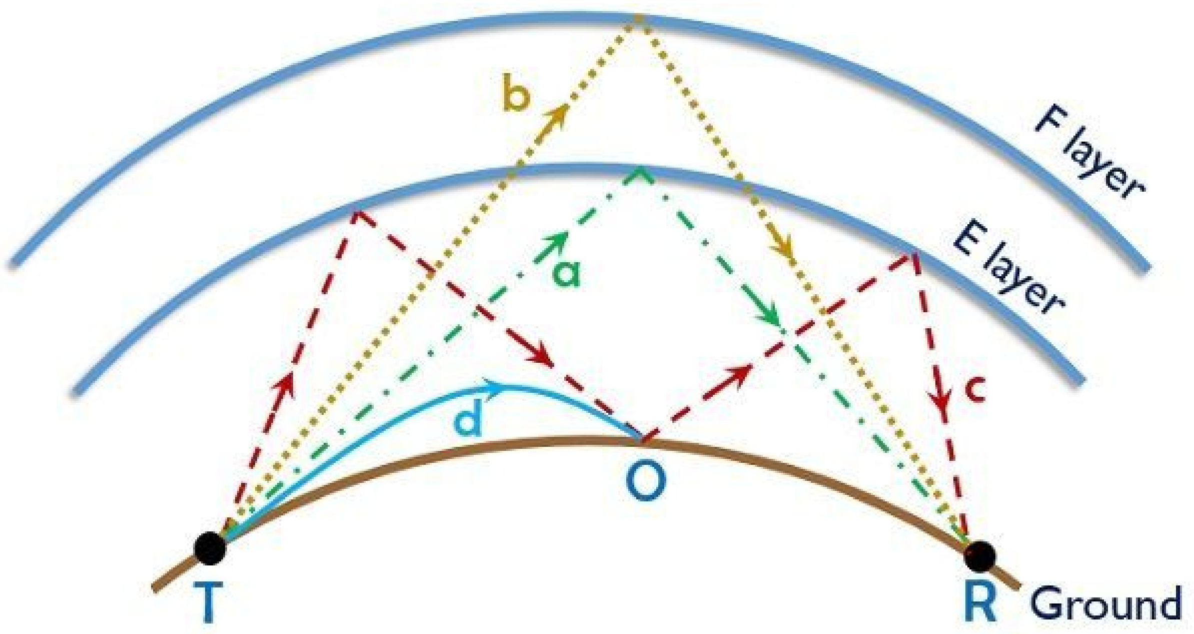
Thus one can use SSB systems to reduce selective fading.

Interference fading

Interference fading is also a result of the multipath propagation of signals transmitted from the antenna. It occurs when waves interfere at the channel while propagating from an end to another.

Suppose a signal is propagated through sky wave propagation, then the waves travel by getting reflected from the upper and lower regions of the ionosphere. Sometimes the waves propagate through single or multiple hops also, in case of low-frequency signals. Thereby leading to cause interference of signals in the channel.

The figure below represents interference fading caused due to the propagation of rays through multiple paths:



Interference fading due to various rays in the atmosphere

- Here ray 'a' is reflected from E layer,
- ray 'b' is reflected from F layer,
- ray 'c' is multihop propagation and
- ray 'd' is groundwave.

It is noteworthy here that sometimes it occurs even due to variation in the ionization density. Basically with the variation in path length, there is random variation in the phase and thus amplitude changes continually thus cause interference of waves.

Absorption fading

We know that when the signal propagates from an end to another then there are losses that are introduced by the transmission medium. Generally, when the signal is propagated through any medium, then the medium possesses some amount of signal absorption.

However, the amount of signal being absorbed by the medium is not constant as this depends on various factors. Thus it will be wrong to say that every transmitted signal suffers an equal amount of absorption while propagating through the same medium.

So, due to the absorption of the signal by the transmission medium, the strength of the signal varies and this deteriorates the received signal.

Polarization fading

Polarization fading is the result of variation in the polarization of the waves reaching the surface of the earth.

In sky wave propagation when wave reflects back to the surface of earth then its polarization changes. The change in polarization of the reflected wave is the result of the superposition of other waves (ordinary and extraordinary) with opposite polarization that are having different amplitudes and phases.

This leads to cause change in polarization of the wave continually with the antenna. Hence the amplitude of the signal received at the receiver also varies.

Thus is known as **polarization fading**.

Skip fading

Here the name itself is indicating that this type of fading is associated with skip distance of radio wave propagation.

It generally occurs near the skip distance region. This type of fading is an outcome of variation in the height and ionization density of the ionospheric region.

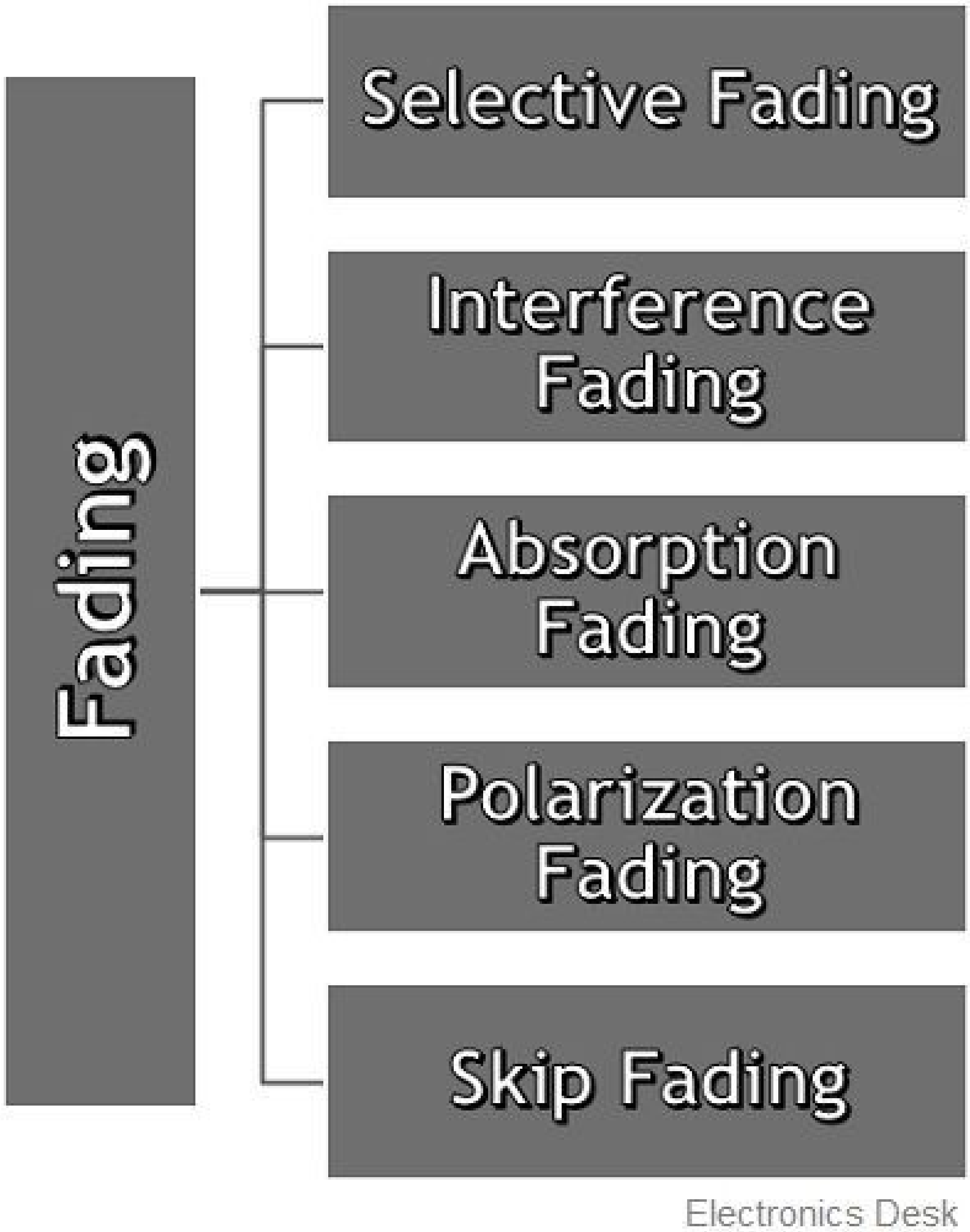
We are aware of the fact that skip distance is the region between transmitting and receiving point where the signal is received after getting reflected from the ionosphere.

So, the variation in the ionization density will undoubtedly alter the skip zone. This variation can be a point either in or out of the skip zone.

Now the question arises on how to deal with fading?

So, generally, a method commonly used to reduce fading is to use automatic voltage control at the receiving section. But this does not act as a complete solution because it does not show usefulness when the signal level reduces below the noise level.

As in such a case, the amplification will not be of any use. Also, this method does not support selective fading. Thus a diversity reception system is used to reduce the fading of the signal.



Fading
Selective Fading
Interference Fading
Absorption Fading
Polarization Fading
Skip Fading
Electronics Desk