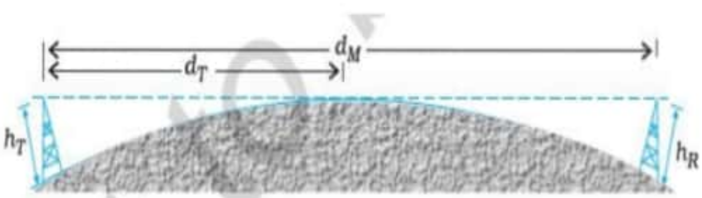
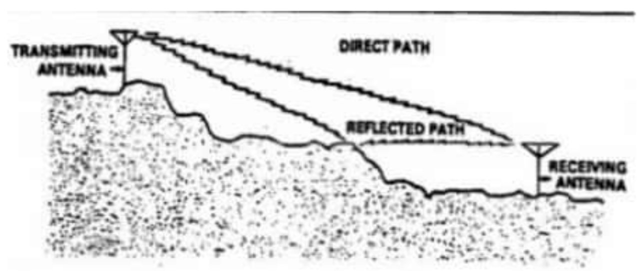
## 3. Space Wave Propagation

- Another mode of radio wave propagation is by *space waves*.
- The space wave follows two distinct paths from the transmitting antenna to the receiving antenna :
  - one through the air directly to the receiving antenna,
  - the other reflected from the ground to the receiving antenna.



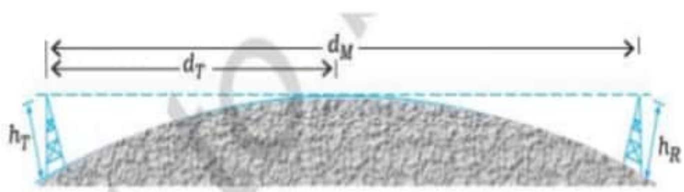



## Direct Wave Propagation

- The primary path of the space wave is directly from the transmitting antenna to the receiving antenna. So, the receiving antenna must be located within the radio horizon of the transmitting antenna.
- Because space waves are refracted slightly, even when propagated through the troposphere, the radio horizon is actually about one-third farther than the LOS or natural horizon.

## Direct Wave Propagation (Cont'd)

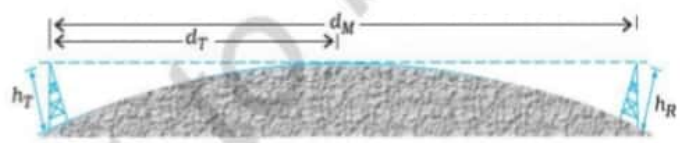
- At frequencies above 40 MHz, communication is essentially limited to LOS paths. At these frequencies, the antennas are relatively smaller and can be placed at heights of many wavelengths above the ground. Because of LOS nature of propagation, direct waves get blocked at some point by the curvature of the earth as illustrated in Fig.
- If the signal is to be received beyond the horizon then the receiving antenna must be high enough to intercept the LOS waves.



# Direct Wave Propagation (Cont'd)

- If the transmitting antenna is at a height $h_T$, then the distance to the horizon $d_T$ is given as

$$d_T = 2Rh_T$$




where $R$ is the radius of the Earth (approximately 6400 km).

$d_T$ is also called the radio horizon of the transmitting antenna.

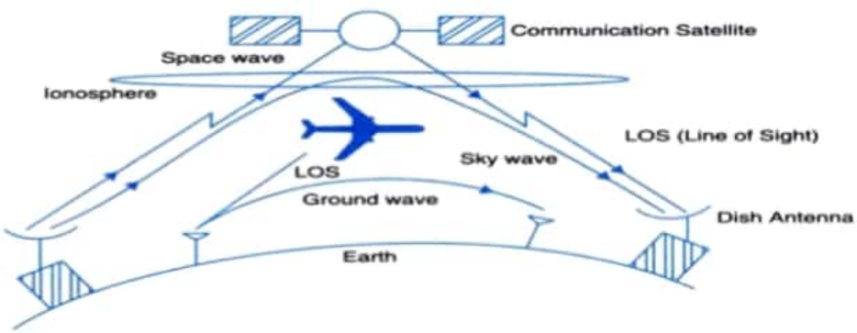
- The maximum LOS distance $d_M$ between the two antennas having heights $h_T$ and $h_R$ above the earth is given by

$$d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$

where $h_R$ is the height of receiving antenna.

## Space wave propagation (Satellite)

- Space satellite communication and very high-frequency waves use this propagation method.
- For very large distances, the height of the tower used for transmission is high enough to prevent waves from touching the earth curvature thus preventing attenuation and loss of signal strength.

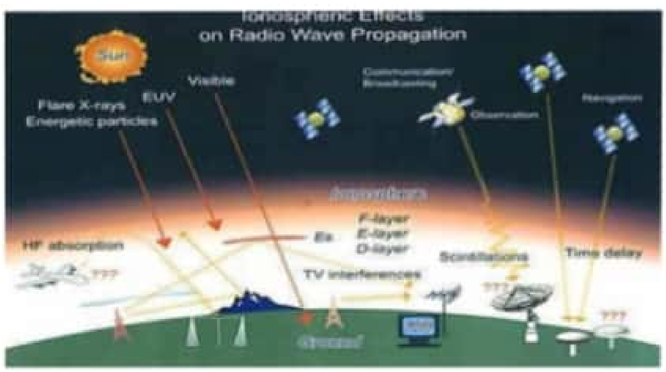


## Properties of Space Wave Propagation

- Space waves are used for LOS communication as well as satellite communication.
- Space satellite communication and very high-frequency waves use this propagation method.

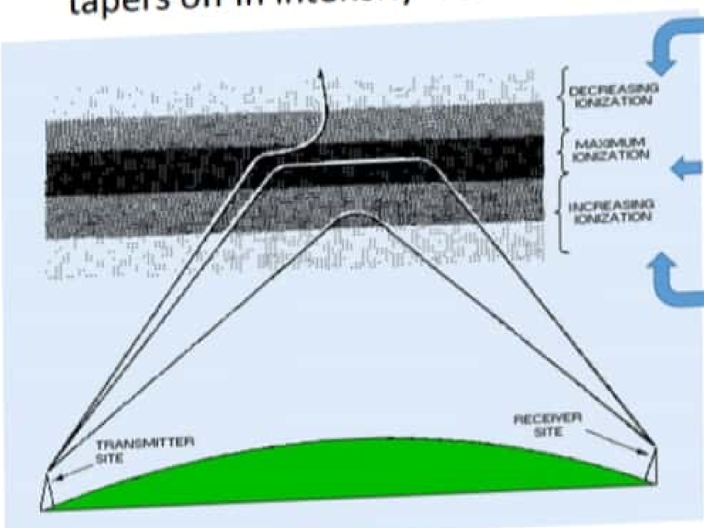
## Structure of Ionosphere

- In radio communication, **skywave** or **skip** refers to the propagation of radio waves reflected or refracted back toward Earth from the ionosphere, an electrically charged layer of the upper atmosphere.
- The ionosphere is a region of the upper atmosphere, from about 80 km to 1000 km in altitude, where neutral air is ionized by solar photons and cosmic rays.
- Ionization occurs due to the absorption of the ultraviolet and other high-energy radiation coming from the sun by air molecules.



# Ionospheric Effects on Radio Wave Propagation

- Each ionized layer has a central region of relatively dense ionization, which tapers off in intensity both above and below the maximum region.




As the wave enters into the upper part of the layer of **DECREASING IONIZATION**, the velocity of the radio wave decreases, and the wave is bent away from the Earth.

As the wave is in the highly dense centre portion of the layer, however, refraction occurs more slowly because the **DENSITY OF IONIZATION IS ALMOST UNIFORM.**

As a radio wave enters a region of **INCREASING IONIZATION**, the increase in velocity of the upper part of the wave causes it to be bent back towards the Earth.

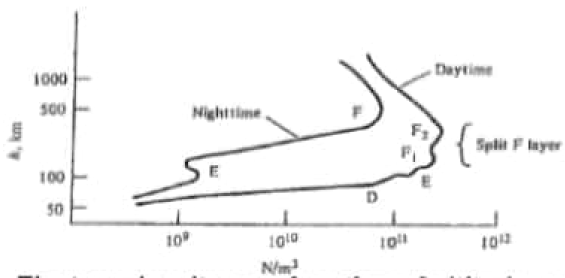
## Ionisation in the Ionospheric Layers

- The ionosphere is further subdivided into several layers, the details of which are given in Table.
- **Ionospheric Layers: C, D, E, F1, F2, Regions**

| RADIATION CAUSING IONISATION IN THE IONOSPHERIC LAYERS | |
|---|---|
| **LAYERS** | **PRIMARY IONISING RADIATION FORMS** |
| C | Cosmic |
| D | Lyman alpha, Hard X-Rays |
| E | Soft X-Rays and some Extreme Ultra-Violet |
| F1 | Extreme Ultra-violet, and some Ultra-Violet |
| F2 | Ultra-Violet |

## Electron density as a function of altitude

- Layers of high electrons densities : **D, E, and F layers**, as shown in Figure.
- During the day the F layer splits into two layers called the F1 and F2 layers.
- The D layer vanishes completely at night.



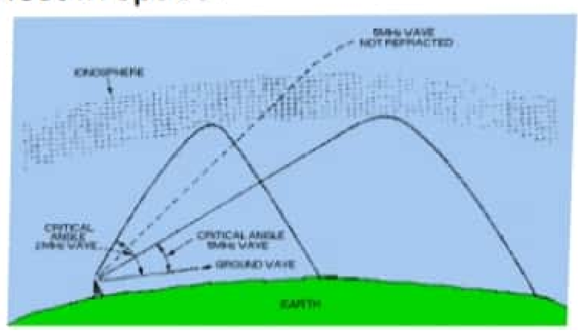

**Electron density as a function of altitude, and various ionospheric layers**

## Refraction by the Ionosphere

- When a radio wave is transmitted into an ionized layer, refraction, or bending of the wave, occurs.
- Refraction is caused by an abrupt change in the velocity of the upper part of a radio wave as it strikes or enters a new medium.
- The amount of refraction that occurs depends on three main factors:
  - ✓the density of ionization of the layer,
  - ✓the frequency of the radio wave, and
  - ✓the angle at which the wave enters the layer

## Reflection by the Ionosphere

- When **high-frequency signals** enter the ionosphere at a low angle they are bent back towards the earth by the ionized layer.
- When operating at **frequencies just below the MUF**, losses can be quite small, so the radio signal may effectively "bounce" or "skip" between the earth and ionosphere two or more times.
- If the **ionization is not great enough**, the wave only curves slightly downwards, and subsequently upwards as the ionization peak is passed so that it exits the top of the layer only slightly displaced. The wave then is lost in space.
- To prevent this a lower frequency must be chosen.



## Properties of Ionization

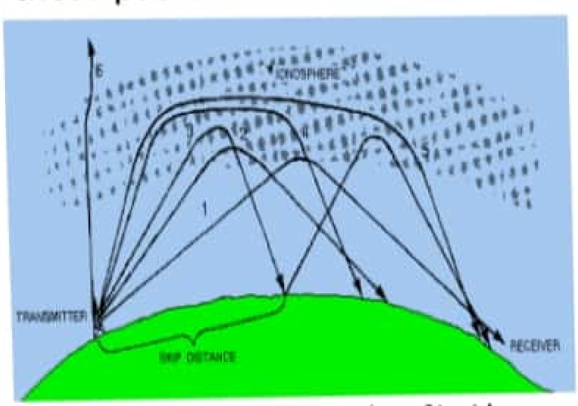
- The degree of ionization varies with the height. The density of atmosphere decreases with height.
- At great heights the solar radiation is intense but there are few molecules to be ionised.
- The ionospheric layer acts as a reflector for a certain range of frequencies (3 to 30 MHz). EM waves of frequencies higher than 30 MHz penetrate the ionosphere and escape.
- The phenomenon of bending of EM waves so that they are diverted towards the earth is similar to total internal reflection in optics.

## Key factors within ionospheric High Frequency (HF) radio communication link

- Ray path
- Critical frequency
- Maximum Usable Frequency (MUF)
- Lowest Usable Frequency (LUF )
- Optimum Frequency (OF)
- Virtual Height and
- Skip distance

## Ray Path/Propagation Path

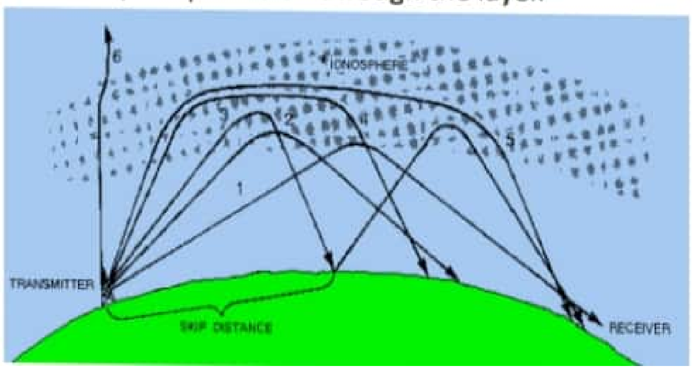
- The path that a refracted wave follows to the receiver depends on the angle at which the wave strikes the ionosphere.
- It may also, reach the receiving antenna over a path involving more than one layer, by multiple **hops/skip** between the ionosphere and Earth, or by any combination of these paths.




Ray paths with varying angles of incidence.

The various angles at which RF waves strikes the layer are represented by dark lines and designated as rays 1 through 6.

- **Ray 1** -- the propagation path is long.
- **Ray 2 and Ray 3**-- the rays penetrate deeper into the layer but the range of these rays decreases.
- When a certain angle is reached (**Ray 3**), the refraction of the ray is first returned to Earth , its second refraction from the ionospheric layer.
- **Ray 4 and Ray 5**--the RF energy penetrates the central area of maximum ionization of the layer. These rays are refracted rather slowly and are eventually returned to Earth at great distances.
- **Ray 6--** the ray is not returned at all, but passes on through the layer.



## Frequency Selection Considerations

Selection of a suitable operating frequency (within the bounds of frequency allocations and availability) is of prime importance for successful communications between any two specified locations at any given time of the day:

- Critical frequency (CF)
- Maximum usable frequency(MUF),
- Lowest usable frequency(LUF),
- Optimum working frequency(OWF) that can be used.

## Critical frequency

- The critical frequency is an important figure that gives an indication of the state of the ionosphere and the resulting HF propagation.
- It is obtained by sending a signal pulse directly upwards.
- Critical frequency is defined as the maximum frequency at which the **total internal reflection(TIR)** takes place from the ionosphere.

The mathematical representation is given as:

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

Where,

$f_c$ is the critical frequency in Hz

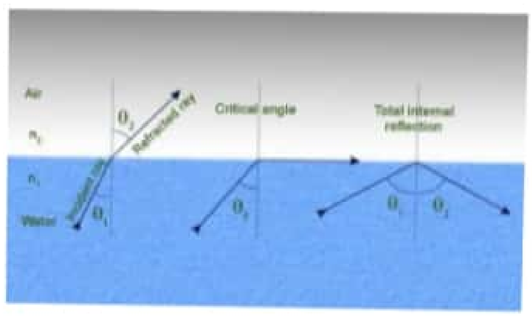
$N_{max}$ is the maximum electron density /ionization density **(electrons per cubic meter)**

Critical frequency varies depending upon atmospheric conditions, time of the day and the angle of incidence of the radio waves by the antenna.

# Total Internal Reflection

- **Example: A ray of light passes from a medium of water to that of air.**
- Obviously, the light ray will be refracted at the junction separating the two media. Since it passes from a medium of a higher refractive index to that having a lower refractive index, the refracted light ray bends away from the normal.
- At a specific angle of incidence, the incident ray of light is refracted in such a way that it passes along the surface of the water.
- This particular angle of incidence is called the critical angle. Here the angle of refraction is 90 degrees.

**Definition** : The radio frequency at or below the wave gets reflected from the ionosphere and above this frequency waves penetrate through the ionospheric layer . This frequency is known as **Critical Frequency**



## Maximum usable frequency (MUF)

- When a signal is transmitted using HF propagation, over a given path there is a maximum frequency that can be used.
- **A maximum frequency that can be used for communications between two given locations**. This frequency is known as the **MUF**.
- Waves at frequencies above the MUF are normally refracted so slowly that they return to Earth beyond the desired location, or pass on through the ionosphere and are lost.
- However, that use of an established MUF certainly does not guarantee successful communications between a transmitting site and a receiving site. Variations in the ionosphere may occur at any time and consequently raise or lower the predetermined MUF.

## Maximum usable frequency (MUF)

The mathematical representation of critical frequency as a function of MUF is:

$$f_c = f_{MUF} / \sec\theta; \qquad f_{MUF} = f_C / \cos\theta$$

Where,

$f_c$ is the critical frequency in Hz

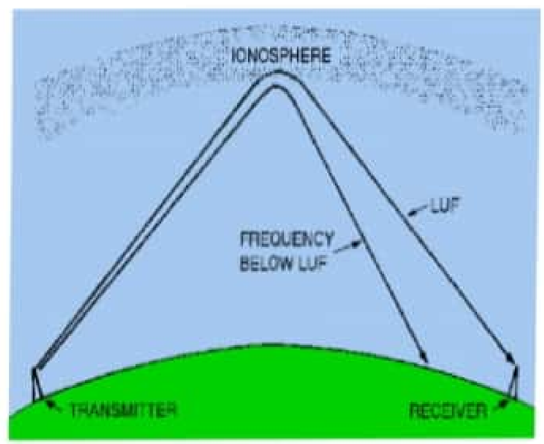
$f_{MUF}$ is the maximum usable frequency (3 to 4 times of $f_c$)

θ is the angle of incidence

The factor **sec θ** is called the MUF factor and it is a function of the path length if the height layer is known.

## Lowest Usable frequency (LUF)

- ✓ As there is a maximum operating frequency that can be used for communications between two points, there is also a minimum operating frequency. This is known as the LUF.
- ✓ As the frequency of a radio wave is lowered, the rate of refraction increases. So the wave whose frequency is below the established LUF is refracted back to Earth at a shorter distance than desired, as shown in Figure.
- ✓ The LUF is defined as the **frequency at below which the signal falls below the minimum strength required for satisfactory reception.**
- ✓ The LUF is the practical limit below which communication cannot be maintained between two particular radio communications stations.




**Refraction of frequency below the LUF**

## Optimum Working Frequency (OWF)

- Neither the MUF nor the LUF is a practical operating frequency.
- When the radio waves at the LUF can be refracted back to Earth at the desired location, **the signal-to-noise ratio is still much lower than at the higher frequencies, and the probability of multipath propagation is much greater.**
- Operating at or near the MUF can result **in frequent signal fading and dropouts when ionospheric variations** alter the length of the transmission path.
- The most practical operating frequency is one that you can rely on with the least amount of problems. It should be high enough to avoid the **problems of multipath, absorption, and noise encountered at the lower frequencies**; but not so high as to result in the adverse effects of rapid changes in the ionosphere.
- A frequency that meets the above criteria has been established and is known as the OWF

## OWF (Cont'd)

- The frequency, which is being used mostly for a particular transmission and which has been predicted to be used over a particular period of time, over a path, is termed as OWF.
- Estimates the maximum frequency that must be used for a given critical frequency and incident angle. It is the frequency chosen to avoid the irregularities of the atmosphere.

$$OWF = 0.85 f_{MUF} = 0.85 f_C / \cos\theta$$