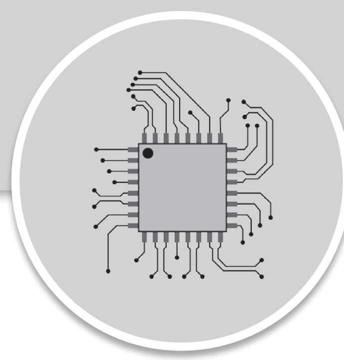
ELECTRONICS ENGINEERING

Advanced Communication



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with Solved Examples *and* Practice Questions

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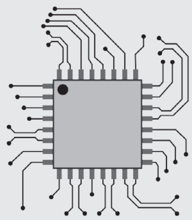

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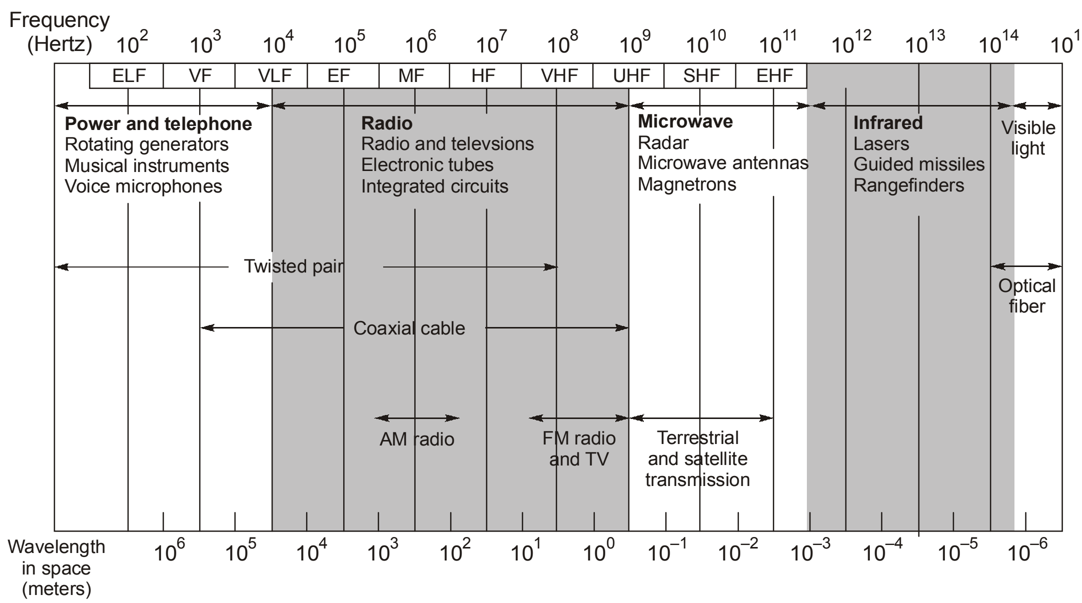
Advanced Communication : Part-II

Prelude to Advanced Communication-I

Every user in telecommunication is interested in higher and higher data rates and need for the high data rates is never ending. For higher data rates, we are going at higher and higher frequencies. The figure shown below shows the electromagnetic spectrum for the telecommunication.



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultra high frequency
SHF = Super high frequency
EHF = Extremely high frequency

***Figure:** Electromagnetic spectrum for telecommunication*

Microwave Line of Sight (LOS) includes both terrestrial and satellite communication. The communication media between the two users depends on the surrounding environment conditions. In the hilly areas, where the optical fibre cable is very difficult to lay down, the satellite communication is preferred over optical fibre.

While, the areas where optical fibre cable is easy to lay down, we prefer optical fibre to microwave LOS system. Also, from the above figure as we see the carrier frequencies of optical fibre is more as compared to that of terrestrial and satellite transmission system, so higher data rates are achievable with the help of optical fibre system.

We have divided this part of book into three parts. Chapter 1 deals with the microwave communication in which we study various types of communication mechanism at different frequencies we have also discussed various types of microwave communication systems.

In chapter 2, we are dealing with orbits of satellite and calculated various losses in satellite communication system alongwith link margin of satellite communication system.

In chapter 3, we have studied the transmission characteristics of optical fibre, different types of optical fibre, sources and detectors in optical fibre system and link margin of the system.

CHAPTER

1 Microwave Communication

Part-I

INTRODUCTION

- Microwave frequencies are used for wireless communication as they penetrate through ionosphere, but they get attenuated when used as ground waves as well as surface waves. Due to this reason the microwaves are mainly used for line of sight based communication.
- Microwave communication is further classified into **satellite system and terrestrial system.** Both of these require a transmitter and receiver. The transmitter system converts baseband signal to microwave signal.
- The receiver system converts the microwave signal to baseband signal. The baseband signal is a multiplexed signal which carries a number of individual low bandwidth signals such as voice, data and video.

1.1 BLOCK DIAGRAM OF TERRESTRIAL COMMUNICATION SYSTEM

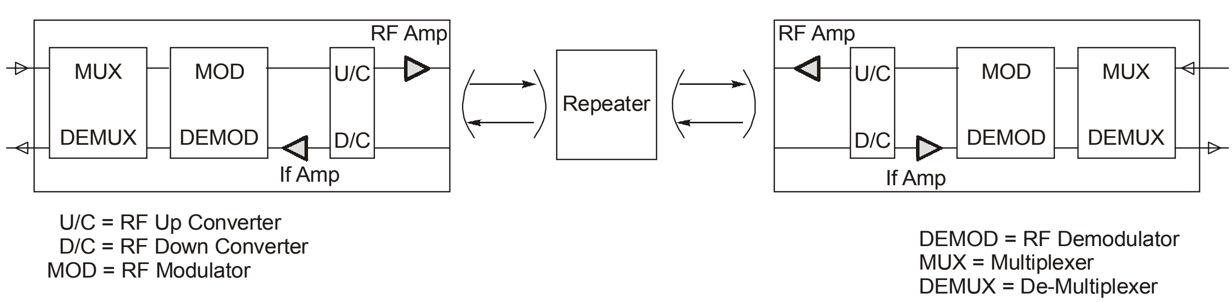


Figure: *Terrestrial communication system*

A terrestrial communication system, facilitating audio, video, data and any other type of communication within a local geographical area, and with an extremely large number of communication channels being made available simultaneously at a very low cost. It comprises at least two local terrestrial satellite (LTS), preferably located in a most or any other supporting structure, each LTS having high frequency communication equipment substantially corresponding to a conventional geostationary satellite for digital transmission of video, audio or data, arranged to transmit in the L Band (1-2 GHz) and S Band (2-4 GHz) or a high frequency band with a relatively low power output and having a preferably omnidirectional antenna installation for transmission in a substantially horizontal plane.

- Microwave signals are attenuated due to geographical locations, atmospheric conditions like rain, dust etc., hence the range is limited. Thus to increase the range of microwave signal, we use repeaters at a certain distance. Repeaters are placed at a distance of about 30 to 80 km, typical value of repeater spacing is 50 km.
- Terrestrial system uses both analog and digital modulation. In analog systems, data information signals are frequency division multiplexed (FDM) and then converted for transmission by RF antenna.
- In digital systems, the information is time division multiplexed (TDM) to form baseband signals. Then it is modulated using either ASK or PSK and up converted for transmission using RF antennas.

1.2 ADVANTAGES OF MICROWAVE SYSTEM

Microwave communication has following advantages:

1. It has high bandwidth availability because of high carrier frequency. Microwave frequency ranges from 1 GHz to 1000 GHz.
2. Microwave systems are highly directive because wavelength is small which leads to designing of high gain antennas.
3. Power requirement of transmitter and receiver is low because gain is high.
4. Microwaves have transparency properties i.e. microwave signal can penetrate through ionosphere thus satellite communication is possible.
5. A large amount of information can be transmitted using it.
6. Microwave spectrum is divided into a different channel as per application.

1.3 PROPERTIES OF MICROWAVE SYSTEM

- Microwave systems are mainly point to point systems and generally used for line of sight (LOS) communication system.
- Also, at high frequency conventional tubes do not work satisfactorily due to various reasons like lead inductance effects, transit time limitations etc. Thus, at microwave frequencies devices like Magnetrons, Reflex Klystrons, Gunn diode, Tunnel diode and Avalanche Transit Time devices as oscillator are used.
- At microwave frequency, the design of the component plays a very important role, a small change in length of device leads to huge phase change which is given by:

$$\text{Phase difference} = \frac{2\pi}{\lambda}(\text{Path difference})$$

- Microwave systems are frequency selective devices i.e. they are designed to work at a specific frequency.

- At microwave frequency, the various circuit parameters like *z*-parameters, *y*-parameters cannot be directly measured, we are using **scattering parameters (s-parameters)** to represent any component.
- Microwave communication involves line of sight systems and over the horizon communication systems.
- Microwave frequency bands are classified as

Band	Frequency range	Applications
L	1 to 2 GHz	Satellite, navigation (GPS etc.), cellular
S	2 to 4 GHz	Satellite, sirusxm radio, unlicensed (wi-fi), Bluetooth etc.) cellular phones
C	4 to 8 GHz	Satellite and microwave relay
X	8 to 12 GHz	Radar
K_u	12 to 18 GHz	Satellite TV, Police Radar
K	18 to 26.5 GHz	Microwave backhaul
K_a	26.5 to 40 GHz	Microwave backhaul
Q	30 to 50 GHz	Microwave backhaul
U	40 to 60 GHz	Experimental, Radar
V	50 to 75 GHz	New WLAN, 802.11 ad/Wi Gig
E	60 to 90 GHz	Microwave backhaul
W	75 to 110 GHz	Automative Radar
F	90 to 140 GHz	Experimental, Radar
D	110 to 170 GHz	Experimental, Radar

Frequency spectrum can be classified as:

1. ELF = Extremely low frequency = 3 Hz - 30 Hz.
2. SLF = Super low frequency= 30 Hz - 300 Hz
3. ULF = Ultra low frequency = 300 Hz - 3 kHz
4. VLF = Very low frequency = 3 kHz - 30 kHz
5. LF = Low frequency = 30 kHz - 300 kHz
6. MF = Medium frequency = 300 kHz - 3 MHz
7. HF = High frequency = 3 MHz - 30 MHz
8. VHF = Very high frequency = 30 MHz - 300 MHz
9. UHF = Ultra high frequency = 300 MHz - 3 GHz
10. SHF = Super high frequency = 3 GHz - 30 GHz
11. EHF = Extremely high frequency = 30 GHz - 300 GHz
12. THF = Tremendously high frequency = 300 GHz - 3000 GHz

Now, we will study various propagation mechanisms of wave and can classify different wave mechanisms as

(i) Ground wave propagation (30 kHz - 2 MHz).
(ii) Sky wave propagation (2 MHz - 30 MHz).
(iii) Space wave propagation (Above 30 MHz).
(iv) Duct wave propagation (Above 100 MHz).

1.4 GROUND WAVE PROPAGATION OR SURFACE WAVE PROPAGATION

- Ground wave is a wave that is guided along the surface of the earth as an electromagnetic wave is guided by a waveguide or transmission line.
- Ground wave permits the propagation along the curvature of earth. This mode of propagation exists when the transmitting and receiving antennas are close to the surface of earth.
- Ground wave is produced by vertically polarized antennas. Any horizontal component of electric field with earth is short circuited by the earth.
- The ground wave propagation along the surface of the wave induces charges in the earth, which travels with the wave and hence constitute a current.
- When the ground wave moves over the earth, the energy of surface wave decreases due to absorption and earth attenuation.
- **Attenuation of earth increases as the frequency increases** and hence the mode of propagation is suitable for low and medium frequency i.e. **upto 2 MHz only.** It is also known as medium wave propagation and is used for local broadcasting.

- Surface waves are also attenuated due to diffraction and tilt in the wavefront.

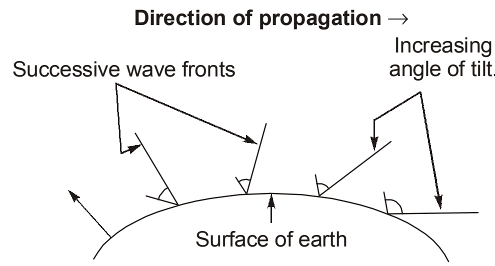


Figure : Tilting of ground waves

- The maximum range of transmission depends on: (a) Frequency (b) Power of transmitted wave.
- **Field strength at a distance:** Radiation from an antenna gives rise to a field strength at a distance 'd' which is given by

$$E = \frac{120\pi h_t I}{\lambda d} \text{ V/m}$$

If the receiving antenna is now placed at this point, the signal received 'V' in volts is

$$V = \frac{120\pi h_t h_r I}{\lambda d} \text{ Volts}$$

where, h_t = Effective height of transmitting antenna ; h_r = Effective height of receiving antenna
I = Antenna current ; d = Distance from transmitting antenna ; λ = Wavelength

- Ground wave will travel long distance on sea surface due to high conductivity of sea water.
- It is mainly used for **ship to ship communication and AM broadcasting.**

1.5 SKY WAVE PROPAGATION/IONOSPHERIC WAVE PROPAGATION

It is a type of radio wave communication in which the electromagnetic wave propagates due to the reflection mechanism of the ionospheric layer of the atmosphere. Due to propagation through the ionospheric, it is also known as ionospheric wave propagation.

The permissible frequency range in the case of sky wave propagation lies between 3 MHz to 30 MHz.

- Sky waves are of practical importance at medium and high frequencies for long distance radio communication.
- In this mode of propagation, electromagnetic waves reach the receiving point after reflection from ionized region in upper atmosphere called ionosphere lying between 100 km to 400 km above earth surface.

1.5.1 Structure of Atmosphere

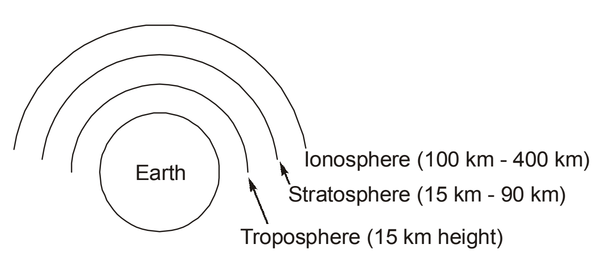


Figure : Layers of atmosphere

The atmosphere is divided into various regions and propagation of wave is affected by the wave characteristics.

1.5.2 Structure of Troposphere

- Troposphere is that portion which is extending upto a height of 8 km to 10 km at poles and upto 16 to 18 km at equator. On an average, the height of troposphere is considered as 15 km.

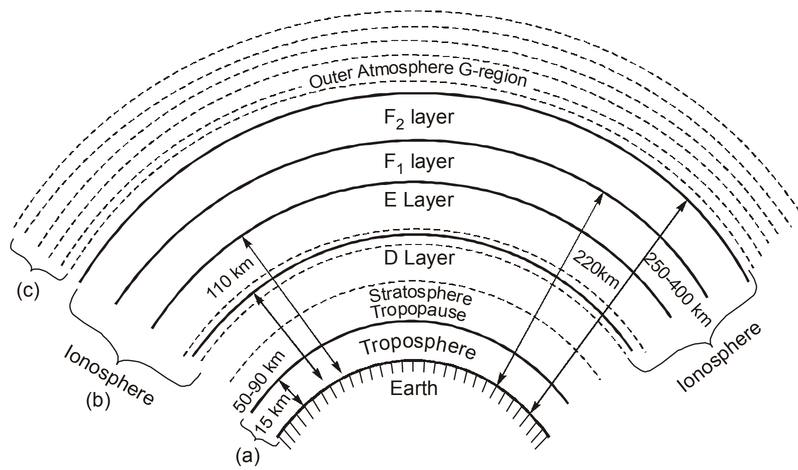


***Figure:** (a) Troposphere upto 15 km (b) Ionosphere 50-400 km (c) Outer atmosphere above 400 km*

- Above troposphere, tropopause starts and ends at the beginning of 'stratosphere' or region of calm.
- Above a certain height called tropopause the temperature remains uniform through the narrow belt and begins to increase afterwards.

EXAMPLE : 1.1 Derive an expression of refractive index of ionosphere.

Solution:

- The radio wave passing through the ionosphere is influenced by the electrons and the electric field of radio wave set electrons of the ionosphere in motion.
- These electrons then vibrate simultaneously along paths parallel to the electric field of the radio waves and the vibrating electrons give an AC current proportional to the velocity of vibration.
- Here the effect of earth's magnetic field on the vibrations of ionospheric electrons lags behind the electric field of wave, thus resulting electron current is inductive in nature.
- The actual current flowing through a volume of space consists of the components e.g. capacitive current which leads the voltage by 90° and the electron current which lags the voltage by 90° and hence subtracted from the capacitive current.
- Thus free electrons in the space decreases the current and dielectric constant of space is also be reduced. **The reduction in the dielectric constant due to presence of the electrons in the ionosphere causes the path of radio waves to bend towards earth i.e. from higher electron density to lower electron density.**

Let the electric field be $E = E_m \sin\omega t$ volts/metre is acting across a cubic metre of space in the ionosphere, where ω is the angular velocity and E_m, the maximum amplitude.

Force exerted by electric field on each electron is given by

$$F = -eE \quad \text{Newton}$$

Let us assume there is no collision, then the electron will have an instantaneous velocity v meters/sec.

$$\text{Force} = \text{Mass} \times \text{Acceleration}$$

$$-Ee = m\frac{dv}{dt}$$

where, m = Mass of electrons (in kg) ; $\frac{dv}{dt}$ = Acceleration

Integrating both sides, we have

$$\int dv = -\int \frac{eE}{m} dt \;;\; v = -\frac{e}{m}\int E_m \sin\omega t dt$$

$$v = \frac{eE_m \cos\omega t}{m\omega} = \left(\frac{e}{m\omega}\right)E_m \cos\omega t \quad \text{...(i)}$$

- If N be the number of electrons per cubic metre, then instantaneous electric current constituted by these N electrons moving with instantaneous velocity v is

$$i_e = -Nev \text{ amp/m}^2 = -Ne\left(\frac{e}{m\omega}\right)E_m \cos\omega t$$

From equation (i), $$i_e = -\left(\frac{Ne^2}{m\omega}\right)E_m \cos\omega t = \left(\frac{Ne^2}{m\omega}\right)E_m \sin(\omega t - 90°) \quad \text{...(ii)}$$

which shows current i_e lags behind the electric field E by 90°.

- Besides this inductive current, there is a capacitive current (**or displacement current exists in an unionized air**).

The capacitive or displacement current through the capacitance is

$$i_c = \frac{d}{dt}\vec{D} = \frac{d}{dt}(\epsilon_0 E) = \epsilon_0 \frac{d}{dt}(E_m \sin\omega t)$$

$$i_c = \epsilon_0 E_m \omega\cos\omega t \quad \text{...(iii)}$$

Thus, total current i that flows through a cubic metre of ionized medium is

$$i = i_c + i_e = \epsilon_0 E_m \omega \cos\omega t - \frac{Ne^2}{m\omega}E_m \cos\omega t$$

$$i = E_m \omega\cos\omega t\left[\epsilon_0 - \frac{Ne^2}{m\omega^2}\right] \quad \text{...(iv)}$$

From equation (iii) and (iv), the effective dielectric constant of the ionosphere (i.e. ionized space).

$$\epsilon = \epsilon_0 - \frac{Ne^2}{m\omega^2} = \epsilon_0\left[1 - \frac{Ne^2}{m\omega^2 \epsilon_0}\right]$$

Hence, the relative dielectric constant w.r.t. air

$$\epsilon_r = \frac{\epsilon}{\epsilon_0} = 1 - \frac{Ne^2}{m\omega^2 \epsilon_0}$$

Thus, refractive index (μ) of the ionosphere w.r.t. vacuum or air is given by

$$\mu = \sqrt{\epsilon_r} = \sqrt{\frac{\epsilon}{\epsilon_0}} = \sqrt{1 - \frac{Ne^2}{m\omega^2 \epsilon_0}}$$

Putting, $m = 9.107 \times 10^{-31}$ kg; $e = 1.602 \times 10^{-19}$ Coulombs

$$\epsilon_0 = 8.854 \times 10^{-12} \text{ F/m}$$

So, we get, $$\boxed{\mu = \sqrt{1 - \frac{81N}{f^2}}} \quad \text{...(v)}$$

where, N = Number of electrons per cubic meter or ionic density

f = Frequency in Hz

NOTE

- If N is in cubic cm, then frequency is kHz.
- From equation (v), we can see refractive index of ionosphere is less than one whereas that of unionized medium is one.

1.5.3 Reflection and Refraction of Sky Waves by Ionosphere

- In radio communication, sky wave refers to propagation of radio waves reflected/refracted back towards earth from the ionosphere, an electrically charged layer of upper atmosphere.
- The ionosphere is divided into various layers.

  (i) D-layer (ii) E-layer

  (iii) F_1-layer (iv) F_2-layer
- In night time, D and E layer will disappear and F_1 and F_2 layers will combine into single layer.
- From Snell's law, we can represent

$$\mu = \frac{\sin\theta_i}{\sin\theta_r} = \sqrt{1 - \frac{81N}{f^2}}$$

Since $\mu < 1$ for ionosphere, so $\sin\theta_i < \sin\theta_r$ i.e. angle of refraction will go on deviating from the normal as the wave will encounter rarer medium of atmosphere as shown below:

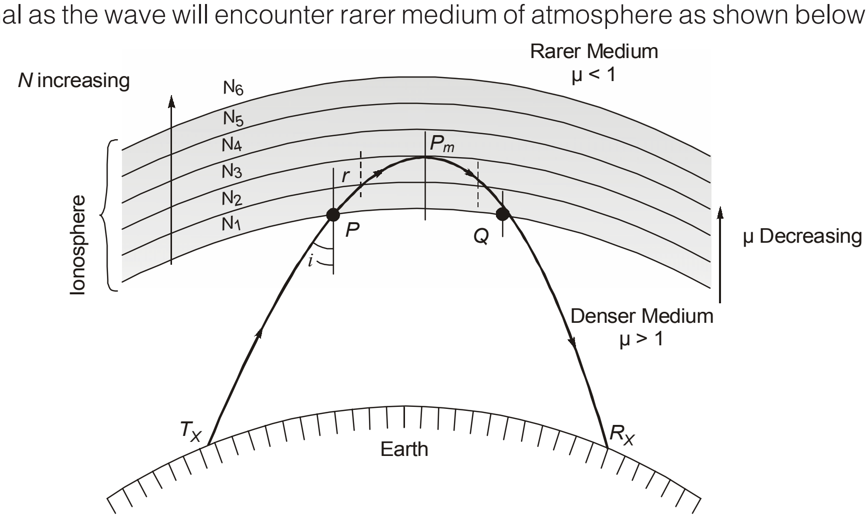


Figure: *Refraction of the radio wave in the atmosphere*

If successive layers of ionosphere are of electron density i.e. $N_6 > N_5 > N_4 > N_3 > N_2 > N_1$ then from expression of μ, refractive index will be decreasing and decreasing

$$\mu_1 > \mu_2 > \mu_3 > \mu_4 > \mu_5 > \mu_6$$

- Thus a wave enters a point P where it will deviate more, and more a point will reach where it travels parallel to earth (at P_m).

- Here the angle of refraction is 90° and the point P_m is the highest point in the atmosphere reached by radio wave.
- So, we can simplify from value of μ by substitution $\theta_r = 90°$ when $\theta_i = \theta_c$

We have, $$\sin\theta_c = \sqrt{1-\frac{81}{f^2}}$$

Critical frequency: It is the maximum frequency that can be reflected by an ionosphere for vertical incident.

By definition, at vertical incidence

$$\theta_i = 0\;; \qquad \mu = \frac{\sin\theta_i}{\sin\theta_r} = \sqrt{1-\frac{81N}{f^2}} = 0$$

$$\sqrt{1-\frac{81N_{max}}{f^2}} = 0 \qquad \text{So,} \quad \boxed{f_c = \sqrt{81N_{max}} = 9\sqrt{N_{max}}}$$

From above expression, it is clear that critical frequency is directly related to square root of ionization density. As the ionization density depends on the sun, so ionization density is maximum in F_2 layer and minimum in D layer.

NOTE Critical frequency is the maximum frequency that can be reflected for vertical incidence. For any other angle, this is not the highest frequency which will get reflected. The frequency that can be reflected from a layer for angle of incidence (θ_i) is called maximum usable frequency (MUF).

1.5.4 Maximum Usable Frequency

It is the maximum frequency that can be used to provide communication between two points on earth by given ionosphere layer.

$0 < \theta_i < 90°$, $\qquad \theta_r = 90°\;;\; N = N_{max}$

$$\frac{\sin\theta_i}{\sin\theta_r} = \sqrt{1-\frac{81N}{f^2}} \quad\Rightarrow\quad \frac{\sin\theta_i}{\sin 90°} = \sqrt{1-\frac{81N_{max}}{f_{MUF}^2}}$$

$$\sin^2\theta_i = 1-\frac{81N_{max}}{f_{MUF}^2} \quad\Rightarrow\quad \frac{81N_{max}}{f_{MUF}^2} = \cos^2\theta_i$$

$$f_{MUF} = \frac{\sqrt{81N_{max}}}{\cos\theta_i} = \frac{f_c}{\cos\theta_i} \qquad \boxed{f_{MUF} = f_c\sec\theta_i} \cdots \text{Secant law}$$

Thus $f_{MUF} > f_c$

From above expression, we can say that the maximum usable frequency is greater than critical frequency. The relationship between f_c and f_{MUF} is given by secant law.

1.5.5 Calculation of MUF for Flat Earth Surface

- For short distance (upto 500 km) the earth can be assumed to be flat.
- The ionized layer is assumed to be a thin layer with sharp ionization density gradient, which gives mirror like reflection as shown below in Figure.

- The distance between the transmitter and receiver is D and height of ionosphere be h.

$$\cos\theta_i = \frac{AC}{AB} = \frac{h}{\sqrt{\left(\frac{D}{2}\right)^2 + h^2}}$$

$$\cos^2\theta_i = \frac{h^2}{h^2 + \left(\frac{D}{2}\right)^2} = \frac{1}{1+\left(\frac{D}{2h}\right)^2}$$

Also, we know $\cos^2\theta_i = \frac{f_c^2}{f_{MUF}^2}$

$$\Rightarrow \boxed{f_{MUF} = f_c\sqrt{1+\left(\frac{D}{2h}\right)^2}}$$

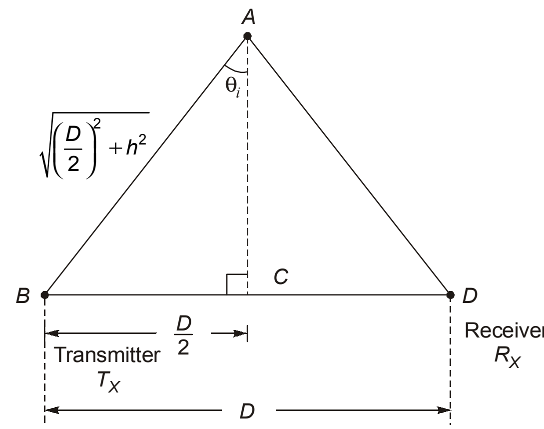


Figure: *Flat earth surface with transmit and receive antenna*

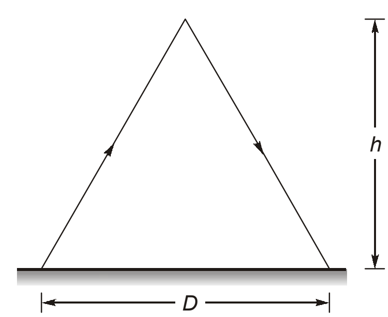
D is the propagation distance and h is height of layer.

EXAMPLE : 1.2

A high frequency radio link has to be established between two points at a distance of 2500 km on the earth's surface. Considering ionospheric height to be 200 km and its critical frequency 5 MHz, calculate the maximum usable frequency for the given path.

Solution:

Given:
D = 2500 km
h = 200 km
f_c = 5 MHz



Maximum Usable frequency is,

$$f_{muf} = f_c\sqrt{1+\left(\frac{D}{2h}\right)^2}$$

$$\Rightarrow f_{muf} = 5\sqrt{1+\left(\frac{2500}{2\times 200}\right)^2} = 31.65 \text{ MHz}$$

1.5.6 Skip Distance

- Radio wave radiated horizontally from transmitter near the earth's surface is quickly absorbed causing ground losses and hence only short distance communication is possible through ground wave propagation.
- Radio wave radiated at high angle may not be bent sufficiently at the ionospheric layers to return to earth at all and hence penetrates in the layer.
- Thus, the distance at which surface wave becomes negligible and distance at which first wave returns to earth from the ionospheric layer, there is a zone which is not covered by any wave. This is called as **skip zone**.

The skip distance is the stretch of space from the point at which an electromagnetic wave is transmitted and the point of reception after reaching the ionosphere and then reflected towards the surface. The signals are emitted by the transmitter and move further away from it until they reach the ionosphere.

- At high frequency, skip distance is higher. For a frequency less than critical frequency, skip distance is zero.

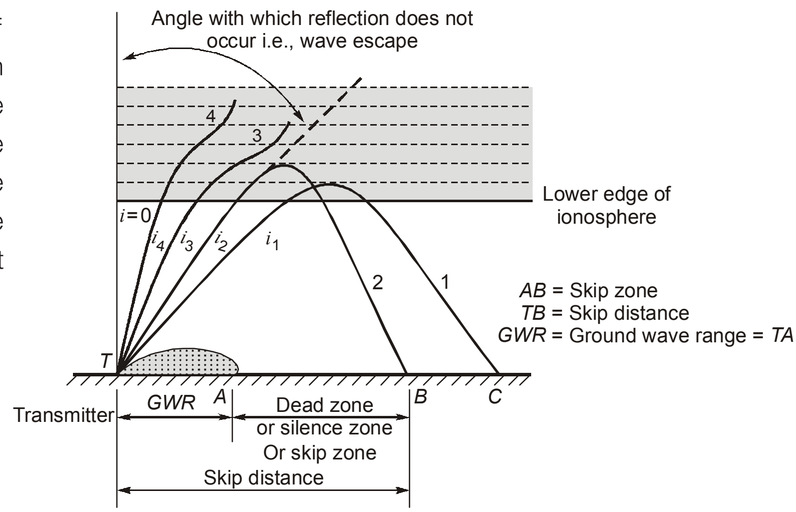


Figure: *Skip distance explanation*

- As the frequency of a wave exceeds the critical frequency, the effect of ionosphere depends upon the angle of incidence as shown in the above Figure.
- It is noted that the **frequency which makes a given distance corresponds to the skip distance is the maximum usable frequency for the two point.**
- For a given frequency of propagation $f = f_{MUF}$ the skip distance can be calculated as

$$f_{MUF} = f_c\sqrt{1+\left(\frac{D_{skip}}{2h}\right)^2} \quad \Rightarrow \left(\frac{f_{MUF}}{f_c}\right)^2 - 1 = \left(\frac{D_{skip}}{2h}\right)^2$$

$$\Rightarrow \quad \boxed{D_{skip} = 2h\sqrt{\left(\frac{f_{MUF}}{f_c}\right)^2 - 1}}$$

REMEMBER
- Higher the maximum usable frequency, higher is the skip distance.
- Skip distance is zero for a frequency below critical frequency of a given layer.
- During night time, F_1 and F_2 layers combines and form one *F*-layer and *D*-layer gets vanished. Thus in night time only we have *E* and *F*-layer. So, there is better high frequency reception during night time and skip distance is increased.

1.5.7 Virtual Height

The height that a brief energy pulse travelling at the speed of light along a vertical axis would reach in the same amount of time as the wave's first reflection from the ionosphere.

- The distance of point *D* from the earth surface that is created by projection of the actual path of forward and reflected wave.
- The actual path of the wave in the ionized layer is a curve due to refraction of the wave.

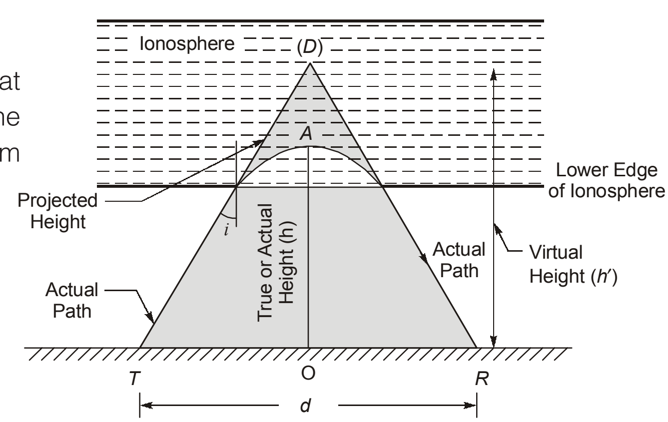


Figure: *Virtual and actual heights of an ionized layer*

- It is convenient to think that the wave being reflected rather than refracted therefore path can be assumed to straight lines TD and RD as shown in Figure. This assumption is made for measurement of the height of a layer, this height is known as virtual height.
- The height differs from the point where the wave is actually reflected.
  From diagram, it is clear that

$$\text{Virtual height (OD)} > \text{Actual height (OA)}$$

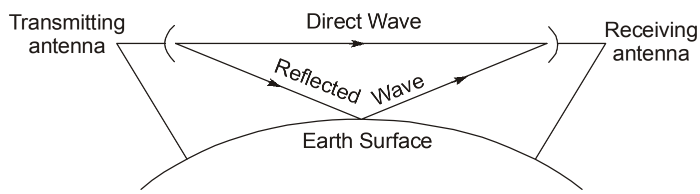
- For calculation of height (h), let the wave travel to point of refraction and then come back to earth in a total time of t (round trip time) then

$$2h = C \times t\ ; \quad h = \frac{Ct}{2}$$

  Thus we can calculate the actual height.

1.6 SPACE WAVE PROPAGATION

- In this mode of propagation, electromagnetic waves from the transmitting antenna reach the receiving antenna either directly or after reflections from ground in earth's troposphere region.
- Although the wave leaves the transmitting antenna at the same time but may reach the receiving antenna either in phase or out of phase, because the two waves travel different path length.



- The strength of the resultant wave thus at the receiving point may be stronger or weaker than the direct path alone depending upon whether the two waves are adding or opposing in phase.
- Space wave is mainly used for frequencies above 30 MHz i.e. VHF. At such frequencies sky wave and ground wave fails.
- Space wave propagation also known as **line of sight (LOS) propagation and is limited by the curvature of earth.**
- In LOS, the transmitting and receiving antennas must see each other. **Range of each LOS can be increased by increasing the height of transmit and receive antenna and power of transmitting signal.**

1.6.1 Limitations of Space Wave Propagation

1. These waves are limited by earth's curvature.
2. These waves have line of sight propagation only.
3. It suffers multi path fading because of reception of multiple waves.
4. Large height antennas are to be used.

1.6.2 Applications

1. TV signals (80 MHz to 200 MHz) uses LOS propagation as these signals are not reflected by earth's ionosphere.
2. Radar communication including both general communication by radio waves or transmission at specific channels and frequencies.

EXAMPLE : 1.3 Derive an expression for LOS distance in space wave expression?

Solution:

In general, space wave communication is possible only upto or slightly beyond line of sight distance and this distance is determined mainly by the heights of transmitting and receiving antenna.

Let d be the distance between transmitter and receiver antenna and height of the transmitting and receiving antenna be h_t and h_r (in metre) respectively above ground. So, line of sight distance

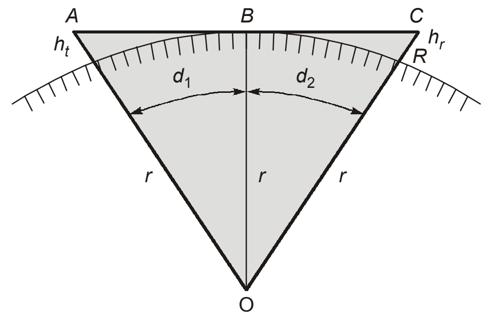


Figure : *Optical range of sight (LOS) propagation*

$$d = d_1 + d_2 \qquad \text{...(i)}$$

If r be the radius of earth (equal to 6370 km) then from ΔABO and ΔCBO

$$d_1 = \sqrt{(h_t + r)^2 - r^2} = \sqrt{h_t^2 + r^2 + 2h_t \cdot r - r^2} \simeq \sqrt{2rh_t} \text{ metre} \quad \left[\because h_t^2 << 2rh_t\right] \qquad \text{...(ii)}$$

Similarly,

$$d_2 = \sqrt{(h_r + r)^2 - r^2} = \sqrt{h_r^2 + r^2 + 2h_r r - r^2} = \sqrt{2rh_r} \text{ metres} \quad [\because h_r^2 << 2rh_r] \qquad \text{...(iii)}$$

Putting value of equation (ii) and (iii) in equation (i)

$$d = \left[\sqrt{2rh_t} + \sqrt{2rh_r}\right] \text{meters} = \sqrt{2r}\left[\sqrt{h_t} + \sqrt{h_r}\right] \text{meters} \qquad \text{...(iv)}$$

$$d = 3.57(\sqrt{h_t} + \sqrt{h_r}) \text{ km} ; \text{ where } h_t \text{ and } h_r \text{ are expressed in meters}$$

This is known as **optical horizon**.

When a radio wave travels horizontally, it follows a slightly downwards curvature path due to refraction. This curvature of path overcome the loss of signal due to curvature of earth and direct ray to reach point slightly beyond the horizon as found by straight line.

Thus in the calculation, the effective earth radius has to be taken and the effective earth radius is given by

$$\boxed{R_E = \frac{4}{3}R} \qquad \text{...(v)}$$

where, R_E = Effective earth radius

R = Radius of earth (6370 km)

Substituting equation (v) and equation (iv)

$$d = \sqrt{2 \times \frac{4}{3} \times 637 \times 10^3}\left[\sqrt{h_t} + \sqrt{h_r}\right]\text{m} = 4.123 \times 10^3 \left[\sqrt{h_t} + \sqrt{h_r}\right]\text{m}$$

$$\boxed{d = 4.123\left[\sqrt{h_t} + \sqrt{h_r}\right]\text{km}} \qquad \text{...(vi)}$$

where, h_t = Height of transmit antenna (in metre) and h_r = Height of receiving antenna (in metre)

The equation (iv) corresponds to radio horizon. From equation (iv) and (vi) we can see, radio horizon is greater than optical horizon due to effective earth radius.

OBJECTIVE BRAIN TEASERS

Q.1 For an aperture antenna of aperture dimension D and wavelength of radiation from the antenna λ, the far field distance is greater than

(a) $\frac{D^2}{2\lambda}$ (b) $\frac{2D^2}{\lambda}$

(c) $\frac{D^2}{\lambda}$ (d) $\frac{(2D)^2}{\lambda}$

Q.2 Match **List-I** (medium) with **List-II** (Type of radio waves) and select the correct answer using the code given below the lists:

List-I	List-II
A. Microstrip	**1.** Surface wave
B. Earth crust	**2.** Guided wave
C. Troposphere	**3.** Sky wave
D. Ionosphere	**4.** Space wave

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	1	2	4	3
(c)	2	1	3	4
(d)	2	1	4	3

Q.3 In free space line of sight propagation case, the transmission losses between transmitter and receiver increases with frequency (f) as

(a) f (b) f^2

(c) f^4 (d) $f^{1/2}$

Q.4 Consider the following statements:
In the case of space wave propagation, the signal strength at the receiver is

1. Directly proportional to transmitter and receiver heights.
2. Inversely proportional to distance between transmitter and receiver.
3. Directly proportional to frequency.

Which of the above statement(s) is/are correct?

(a) 1 and 2 (b) 1 and 3

(c) 2 and 3 (d) 3 only

Q.5 Two microwave signals travelling in the free space have a path length difference of 3 cm when operating at 10 GHz. What is relative phase difference of the signals?

(a) 2π (b) π

(c) 3π (d) 4π

Q.6 In an LOS communication system, the ground below the direct path is the first Fresnel zone and is smooth reflecting. The phase difference between direct and reflected waves at the receiving antenna will be

(a) 180° (b) 360°

(c) 270° (d) 450°

Q.7 The skip distance is

(a) same for each layer
(b) independent of frequency
(c) independent of state of ionization
(d) independent of transmitted power

Q.8 In troposcatter links, diversity system is used to

(a) increase the bandwidth
(b) increase the directivity of the antenna
(c) prevent noise effects
(d) detect signal in presence of fading

Q.9 In terrestrial microwave links, the number of 'fades' per unit increases as

(a) Both the transmission frequency and the distance between the antennas are increased
(b) The transmission frequency is increased but the distance between the antennas is decreased
(c) The transmission frequency is decreased but the distance between the antennas is increased
(d) Both the transmission frequency and the distance between the antennas are decreased

Q.10 A radio cab company with its antenna at a height of 15 m communicates with a cab having its antenna 1.5 m. The maximum communication distance without obstacles is roughly

(a) 10 km (b) 20 km

(c) 28 km (d) 36 km

Q.11 In microwave communication systems, sometime the same frequency is used by separation of signals through vertical and horizontal polarization. This technique is called

(a) steady frequency multiplexing
(b) variable frequency modulation technique
(c) frequency reconditioning technique
(d) frequency reuse technique

ANSWERS KEY

1. (b)	2. (d)	3. (b)	4. (b)	5. (a)
6. (a)	7. (d)	8. (d)	9. (c)	10. (b)
11. (d)				

HINTS & EXPLANATIONS

1. (b)

For an aperture antenna of aperture dimension D and wavelength of radiation from the antenna λ, the far field distance is greater than $\frac{2D^2}{\lambda}$.

2. (d)

Microstrip supports Guided wave propagation.
Earth crust supports Surface wave propagation.
Troposphere supports Space wave propagation.
Ionosphere supports Sky wave propagation.

3. (b)

In free space LOS propagation case, the transmission losses between transmitter and receiver is given by

$$P_L = \left(\frac{4\pi df}{c}\right)^2$$

∴ transmission losses, $P_L \propto f^2$

4. (b)

In case of space wave propagation, the signal strength at the receiver is given by

$$|E| = \frac{240\pi I\, h_t h_r}{\lambda d^2}$$

where; h_t = height of transmitting antenna
h_r = height of receiving antenna

$$\lambda = \frac{c}{f}$$

$$\therefore \quad |E| \propto f;\ |E| \propto h_t;\ \ |E| \propto \frac{1}{d^2}$$
$$\propto h_t$$

5. (a)

We know that,

$$\text{phase difference} = \frac{2\pi}{\lambda}\ (\text{path difference})$$

$$\text{where,} \quad \lambda = \frac{c}{f} = \frac{3\times10^{10}}{10\times10^{9}} = 3\ \text{cm}$$

$$\text{phase difference} = \frac{2\pi}{3}(3) = 2\pi$$

10. (b)

Given, h_t = 15 m
h_r = 1.5 m

Maximum communication distance,

$$d = 4.12\left[\sqrt{h_t} + \sqrt{h_r}\right]\text{km}$$
$$= 4.12\left[\sqrt{15} + \sqrt{1.5}\right]\text{km}$$
$$= 21.0026\ \text{km}$$
$$\therefore \quad d \simeq 20\ \text{km}$$

CONVENTIONAL BRAIN TEASERS

Q.1 In a microwave communication link operating at 100 MHz, the respective heights of transmitting and receiving antennas are 49 m and 25 m respectively. If the transmitted power is 100 W, then determine:
(i) The line of sight (LOS) distance.
(ii) The electric field strength received at LOS distance.

1. (Sol.)

Given data: Operating frequency, f = 100 MHz ; Transmitted power, P_t = 100 W
Height of transmitting antenna ; h_t = 49 m ; Height of receiving antenna, h_r = 25 m

(i) **Calculating the LOS distance:**

$$\text{LOS distance} = 4.12\left(\sqrt{h_t} + \sqrt{h_r}\right) \text{ km}$$

Here, h_t and h_r must be represented in meters to get the value of LOS distance in kilometers.

So, $$\text{LOS distance} = 4.12\left(\sqrt{49} + \sqrt{25}\right) \text{ km} = 49.44 \text{ km}$$

(ii) **Calculating the electric field strength received at LOS distance:**

Electric field strength received (E_r) at a distance "d" from the transmitter can be given by,

$$E_r = \frac{88\sqrt{P_t}}{\lambda d^2} h_t h_r$$

Here, $$\lambda = \text{wavelength} = \frac{c}{f} = \frac{3\times10^8}{100\times10^6} \text{ m} = 3 \text{ m}$$

$$d = \text{LOS distance} = 49.44 \text{ km}$$

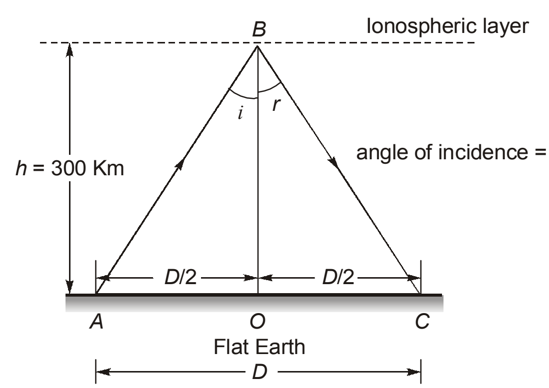
So, $$E_r = \frac{88\sqrt{100}}{(3)(49.44\times10^3)^2}(49\times25) \text{ V/m} = 147\ \mu\text{V/m}$$

Q.2 For an ionospheric layer at a height of 300 km, having electron concentration of 5×10^{11} per m^3. Find the maximum permissible frequency at an angle of incidence of 60°. Calculate the critical frequency and skip distances, under flat earth assumptions.

2. (Sol.)

Under Flat Earth assumptions we have,

From Δ AOB,



$$\cos i = \frac{BO}{AB} = \frac{h}{\sqrt{h^2 + D^2/4}}$$

$$= \frac{2h}{\sqrt{4h^2 + D^2}}$$

$$\Rightarrow \quad \cos 60° = \frac{2\times300}{\sqrt{4\times(300)^2 + D^2}}$$

$$\Rightarrow \quad 4\times(300)^2 + D^2 = (1200)^2$$

$$\Rightarrow \quad D^2 = 1080{,}000$$

$$\Rightarrow \quad D = \text{Propagation distance } AC = 1039.23 \text{ km}$$

Also, ionization density (electrons per cubic meter) = $N_{max} = 5 \times 10^{11} / m^3$

$\therefore$ $$f_{cr} = \text{Critical frequency for the layer}$$

$$= 9\sqrt{N_{max}} = 9\sqrt{5\times10^{11}} = 6{,}36{,}3961.03 \text{ Hz}$$

$$= 6.36 \times 10^6 \text{ Hz} = 6.36 \text{ MHz}$$

Now, maximum permissible frequency under flat earth assumptions is,

$$f_{muf} = f_c\sqrt{1+\left(\frac{D}{2h}\right)^2}$$