SNS COLLEGE OF ENGINEERINGz

Kurumbapalayam (Po), Coimbatore – 641 107

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

Subject Code: 19EC502

Subject: Transmission Lines and Antennas

Unit-V

Topic: Wave Propagation

Introduction

- The signals transmitted by a transmitter will travel through the channel to the receiver.
- In wireless radio communication, this channel is nothing but free space.
- The process of signal travel from transmitter to receiver can be divided as:
  - Radiation
  - Propagation

Introduction

Radiation

- Whenever a HF current flows through a conductor, the power measured on both sides of conductor is not same.
- A part of power is dissipated in the resistance and a part of it 'escapes' into the free space.
- This 'escape' is radiation.

Propagation

- This radiated power then propagates in space in the form of electromagnetic waves
- The radiation and propagation of radio waves cannot be seen.

Wave

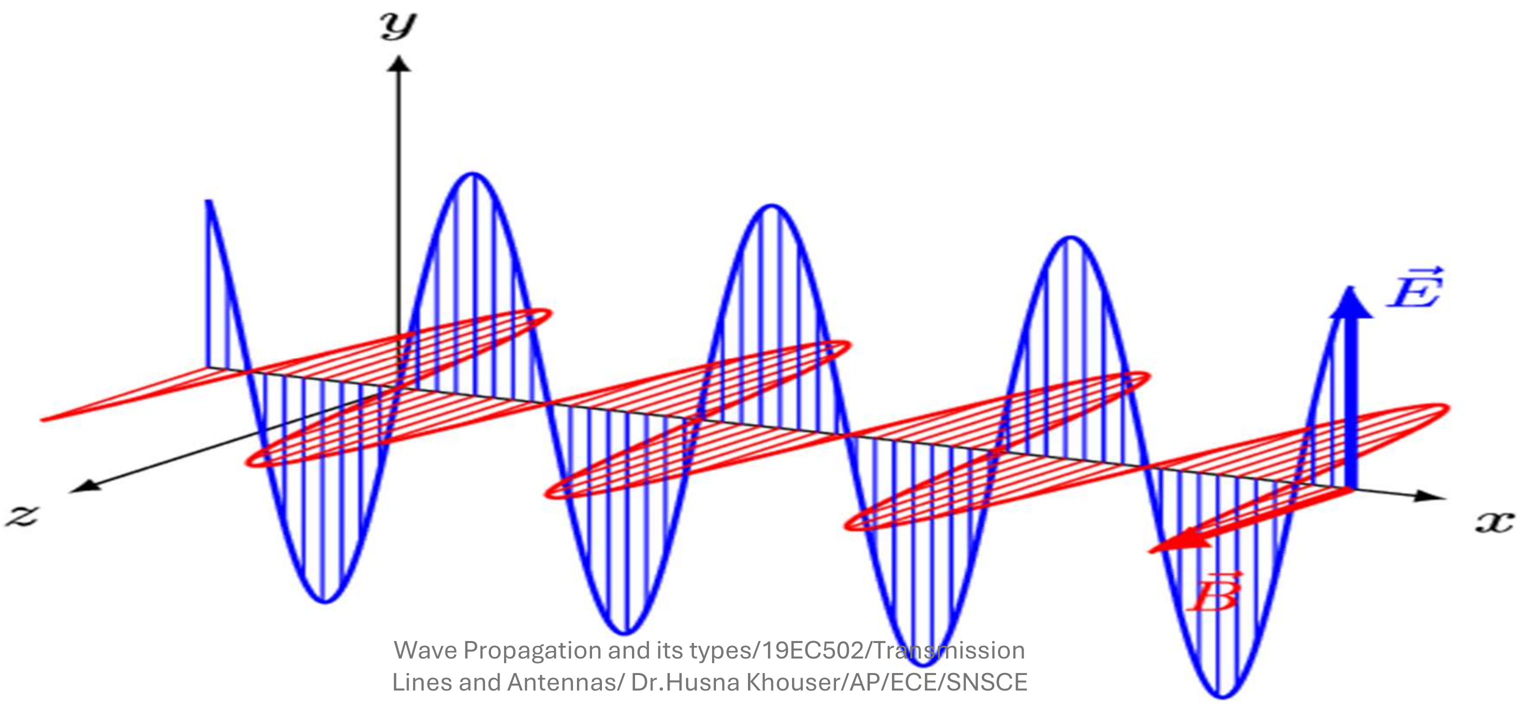
- Wave is a mode of transfer of energy
    - Transverse waves
    - Longitudinal waves

Transverse Waves

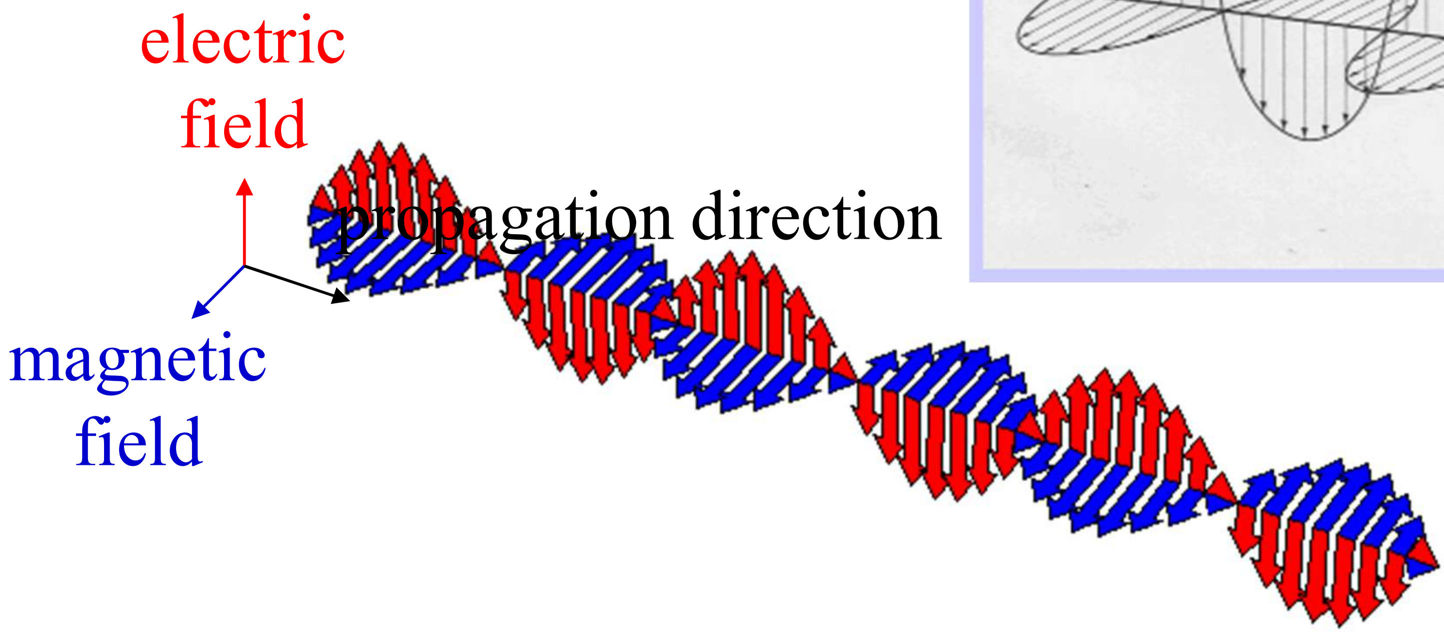
- Transverse waves are those whose direction of propagation is perpendicular to both the electrical field and the magnetic field The electrical field and the magnetic fields lie in planes that are perpendicular to each other. (x and y planes)
- Thus the direction of propagation will be in the z plane or third dimension

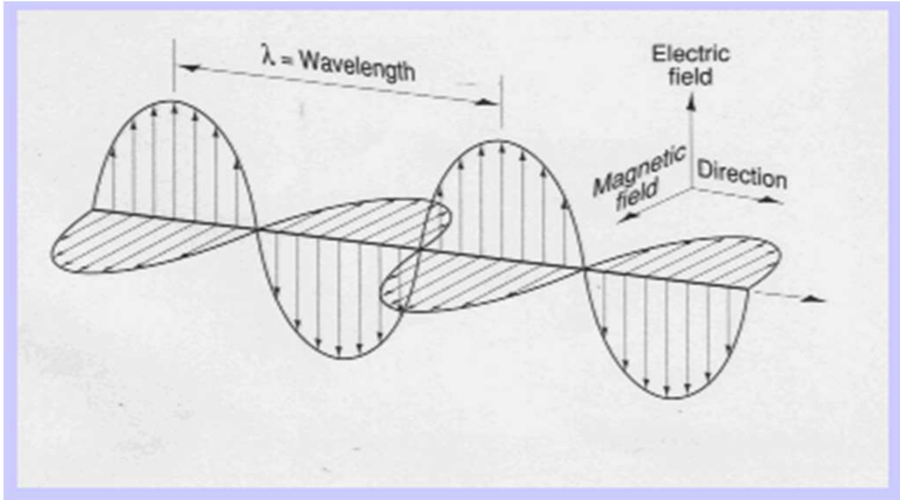
Electromagnetic Waves

- Consist of
  - Magnetic wave
  - Electrical wave
- Most of the energy is returned to the circuit.
- If it isn't, then some it must be "set free" or radiated. Radiated energy is not desirable.
- But if such power is "escaped on purpose" then it is said to be radiated



Wave Propagation Example





Properties of radio waves

1. Reflection

- Analogous to Bouncing

2. Refraction

- Analogous to Bending

3. Diffraction

- Analogous to Scattering

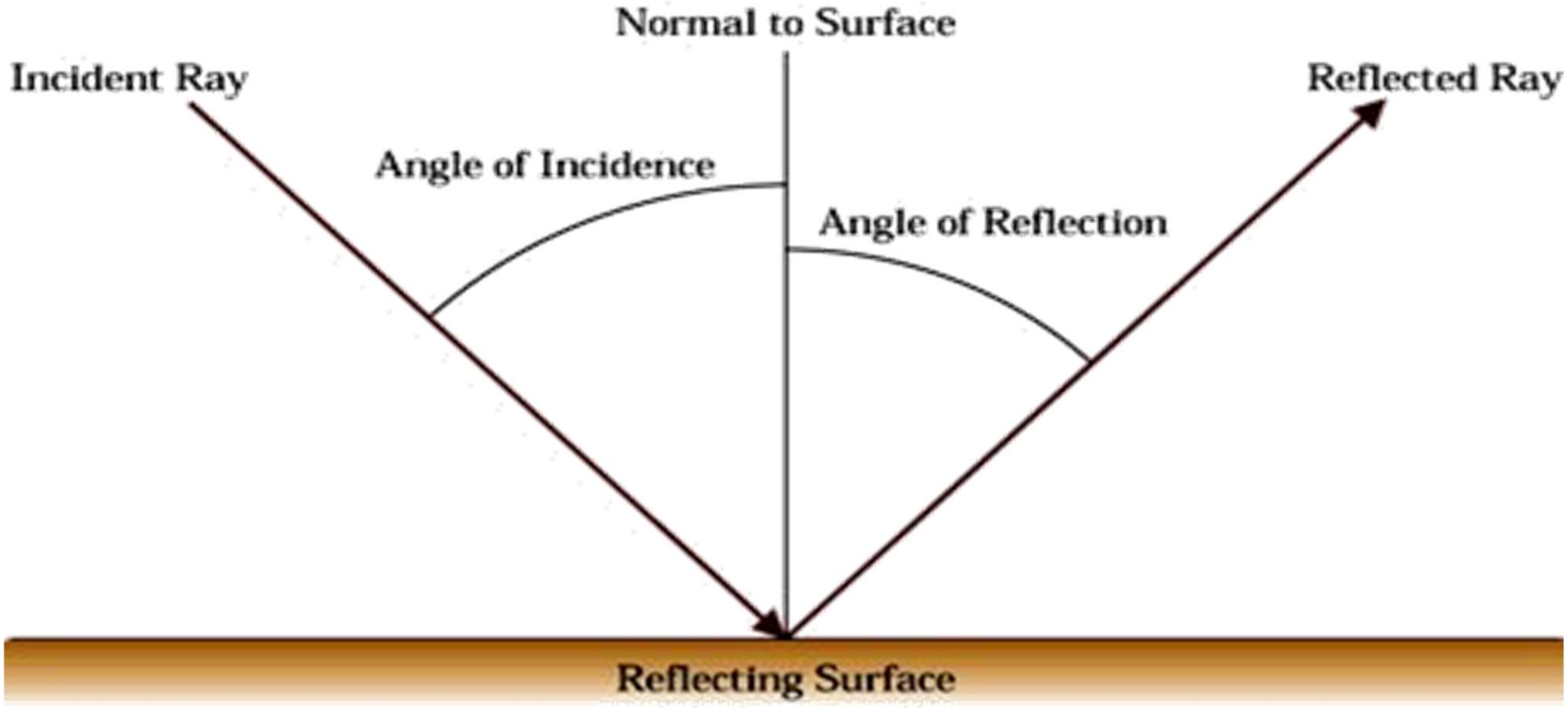
4. Interference

- Analogous to Colliding

Properties of radio waves

1. Reflection

- Reflection of waves from a smooth surface (*specular reflection*) results in the **angle of reflection being equal to the angle of incidence**



Properties of radio waves

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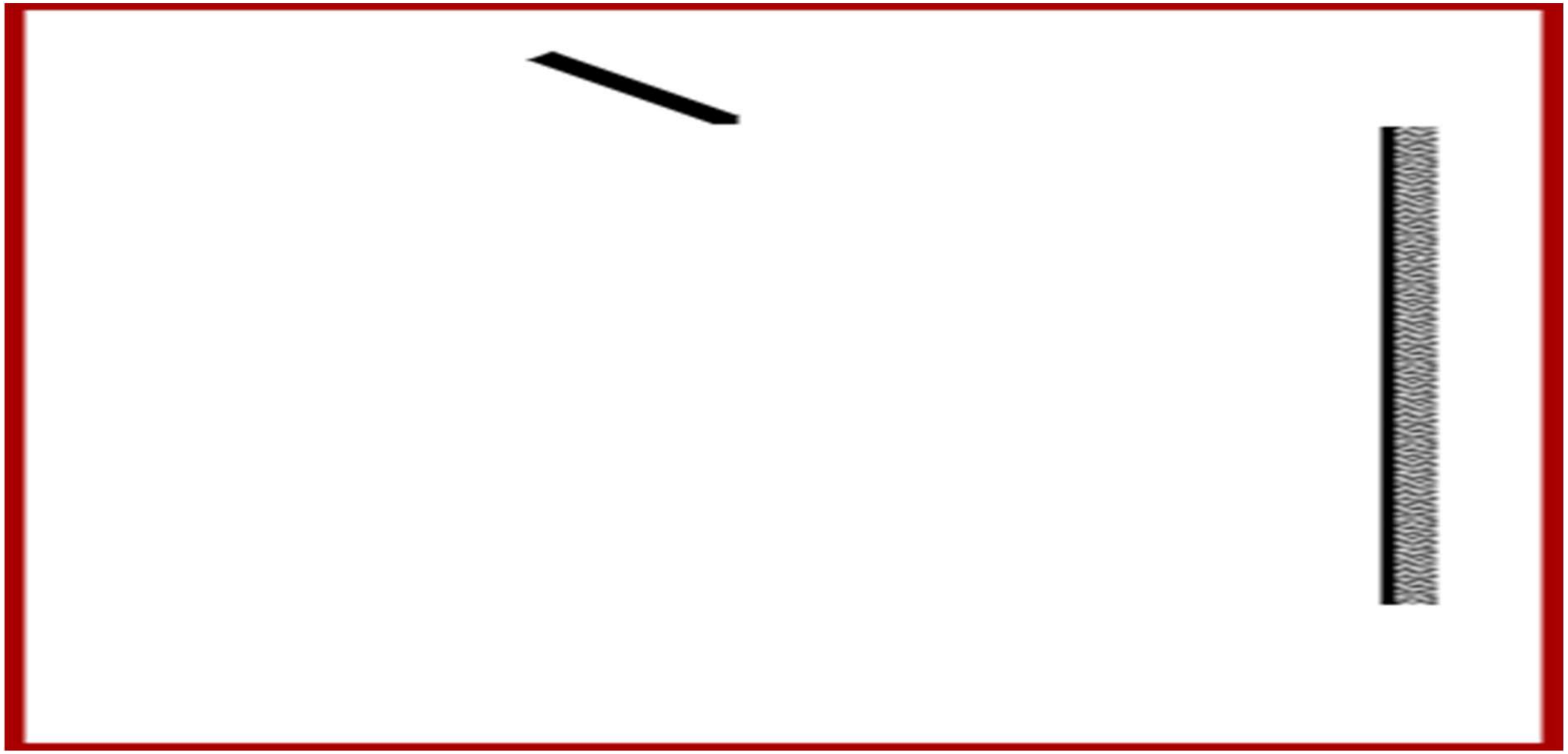
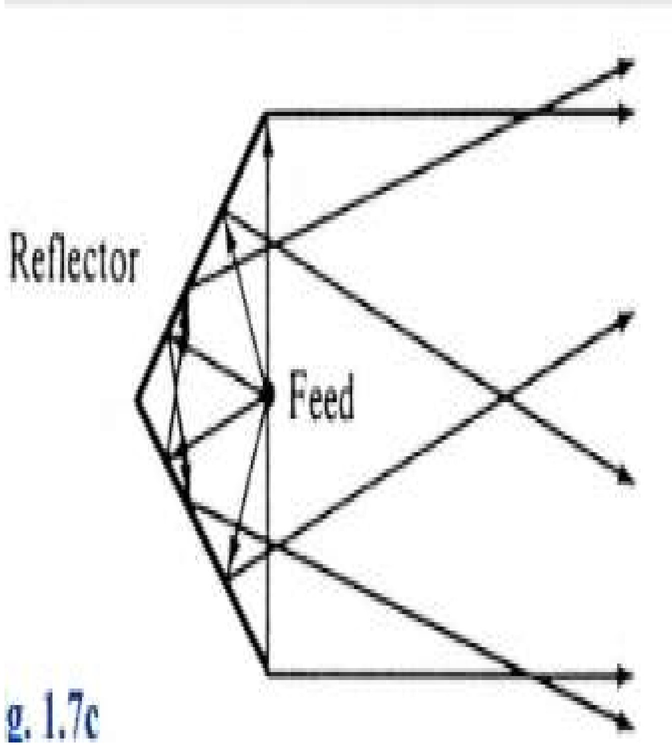


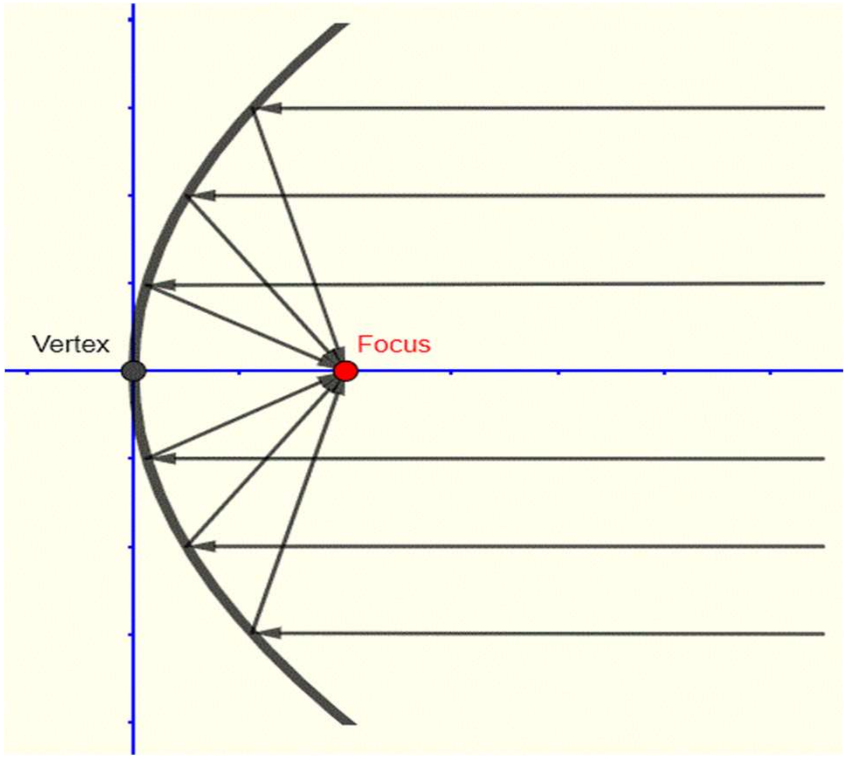
Properties of radio waves

1. Reflection

Other Types of Reflection



Corner reflector

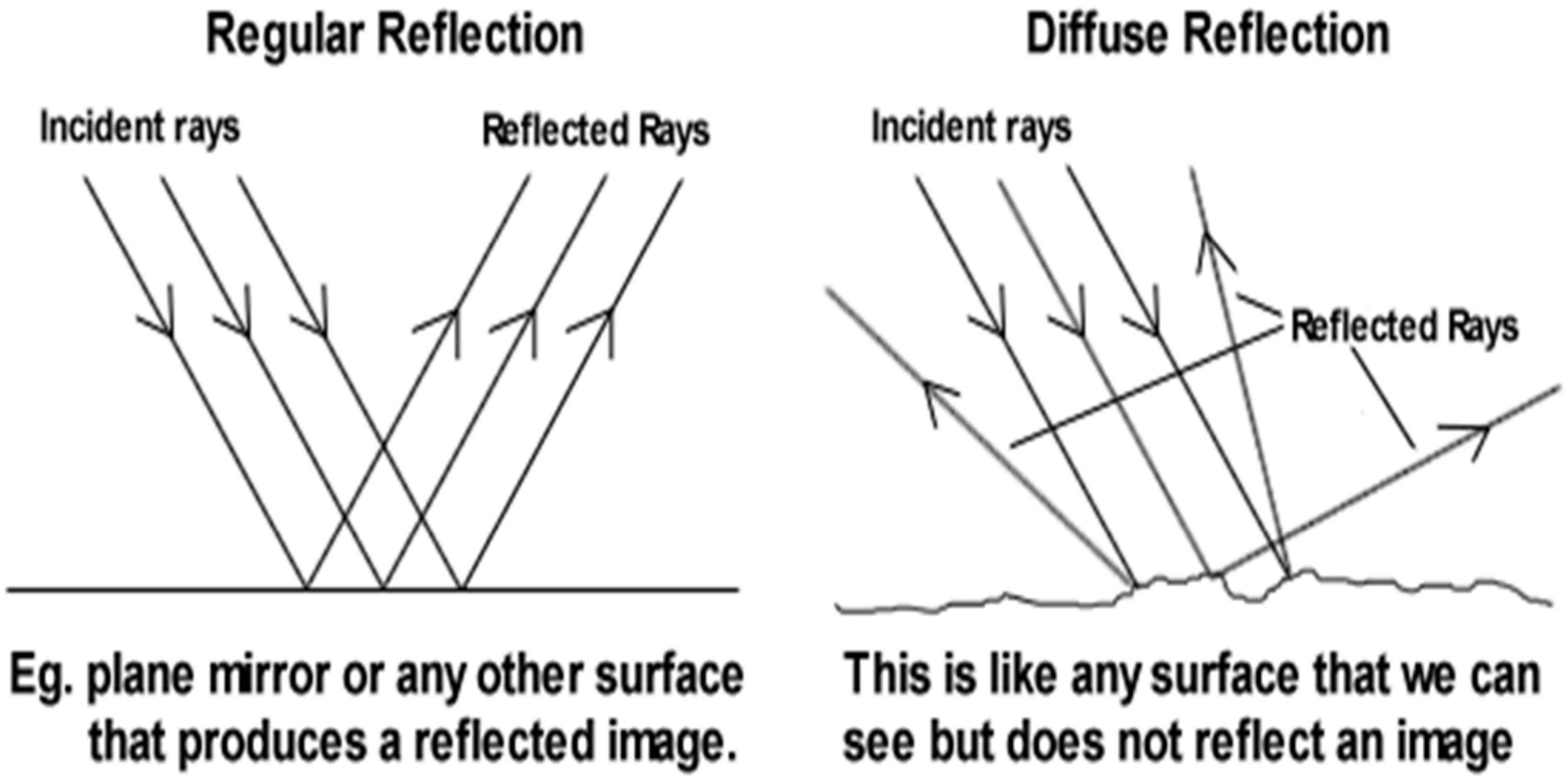


Parabolic reflector

Properties of radio waves

1. Reflection

Other Types of Reflection



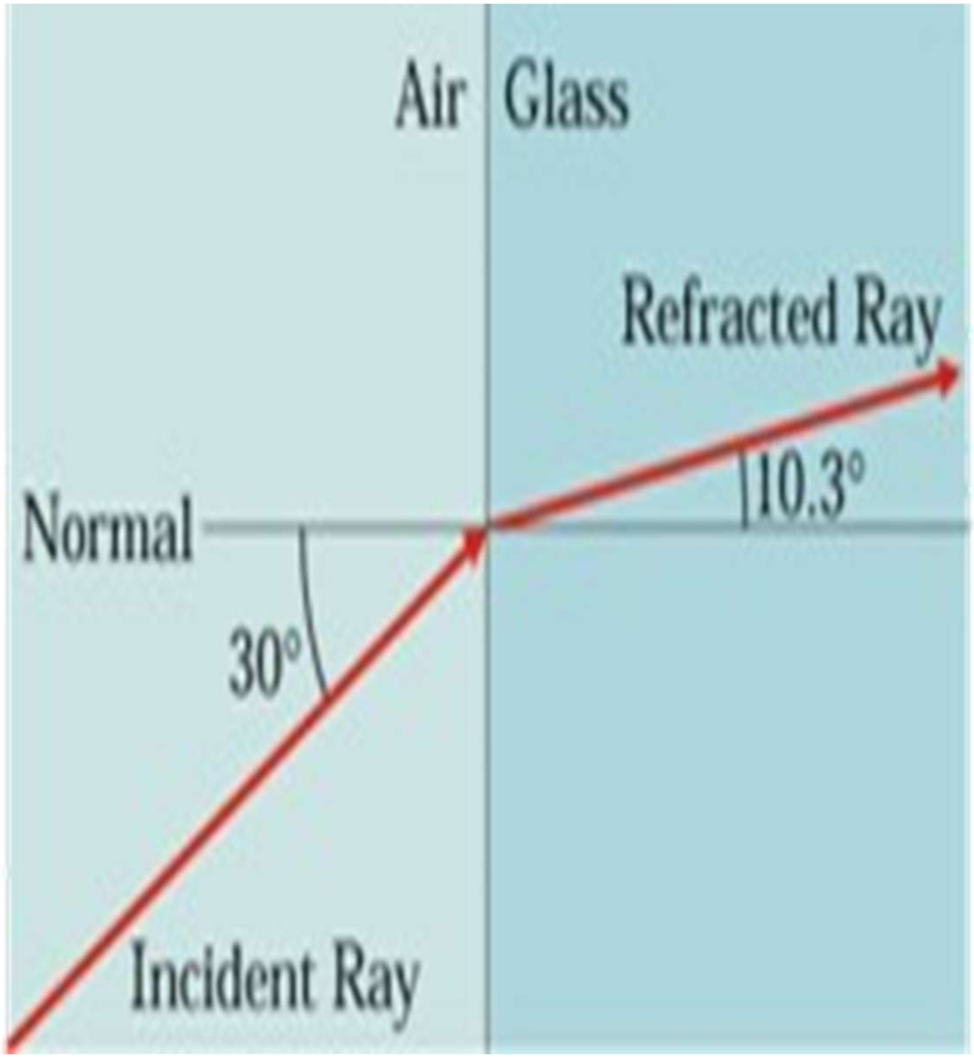
Diffused Reflection

Properties of radio waves

2. Refraction

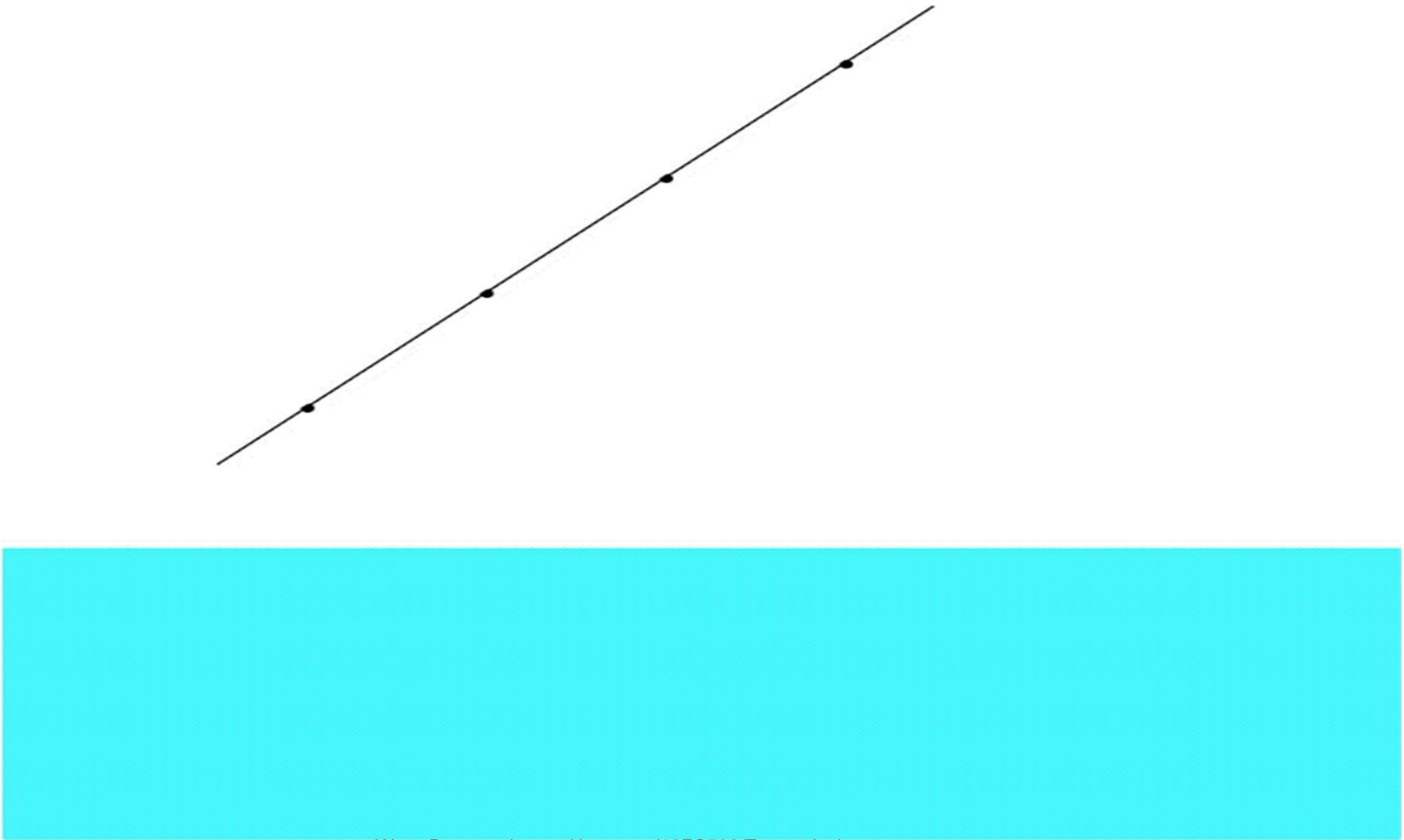
- A transition from one medium to another results in the bending of radio waves, just as it does with light
- Snell's Law governs the behavior of electromagnetic waves being refracted:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



Properties of radio waves

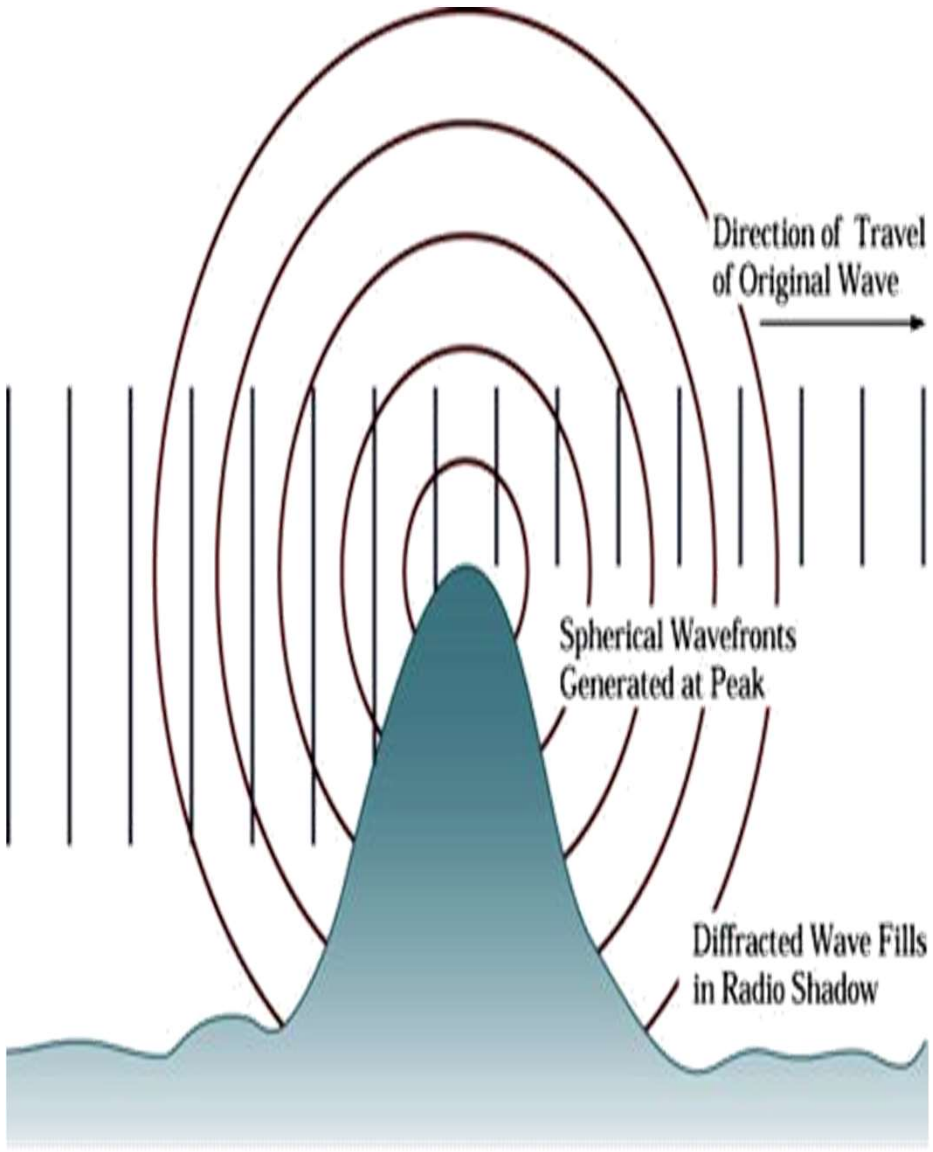
2. Refraction



Properties of radio waves

3. Diffraction

- As a result of diffraction, electromagnetic waves can appear to "go around corners"
- Diffraction is more apparent when the object has sharp edges, that is when the dimensions are small in comparison to the wavelength



Properties of radio waves

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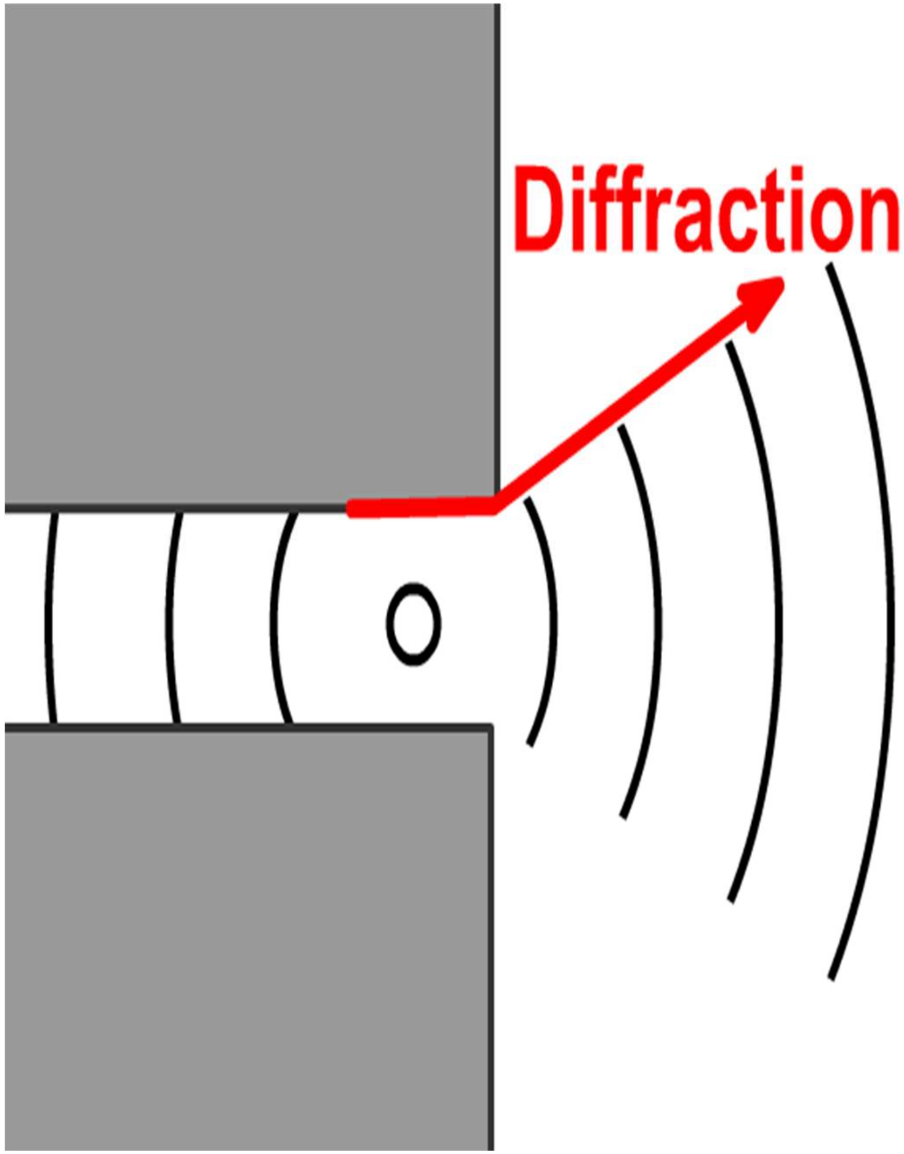
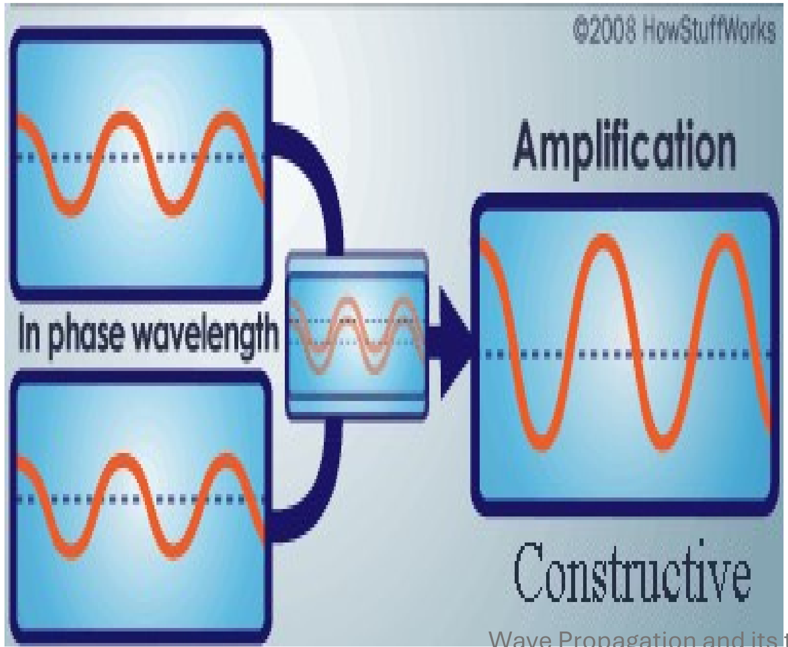


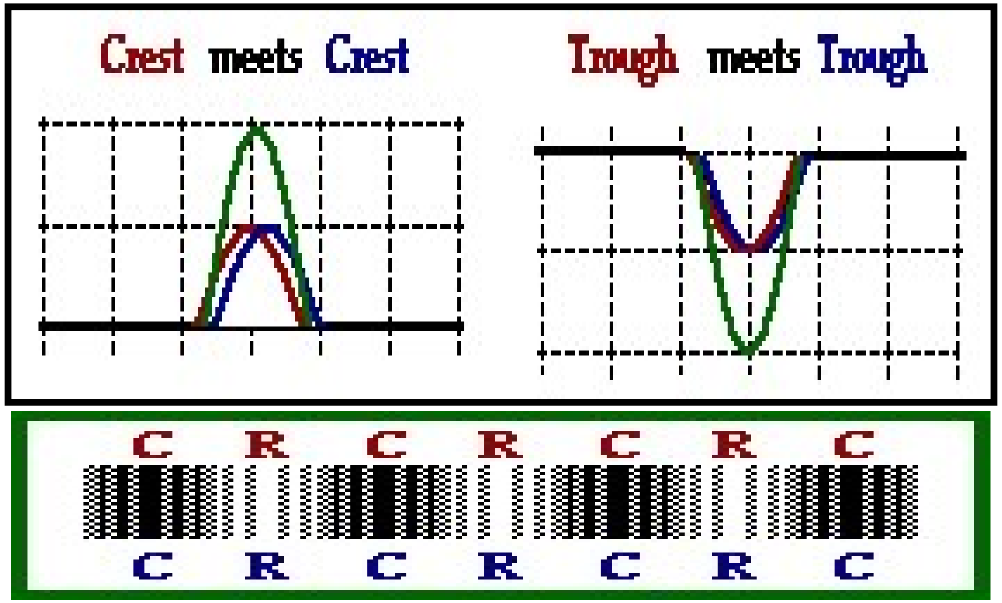
Properties of radio waves

4. Interference

- **Interference – occurs when 2 or more waves overlap**
  - <u>constructive interference</u> ⇒ 2 or more waves combine to produce a wave with larger displacement

Constructive - louder

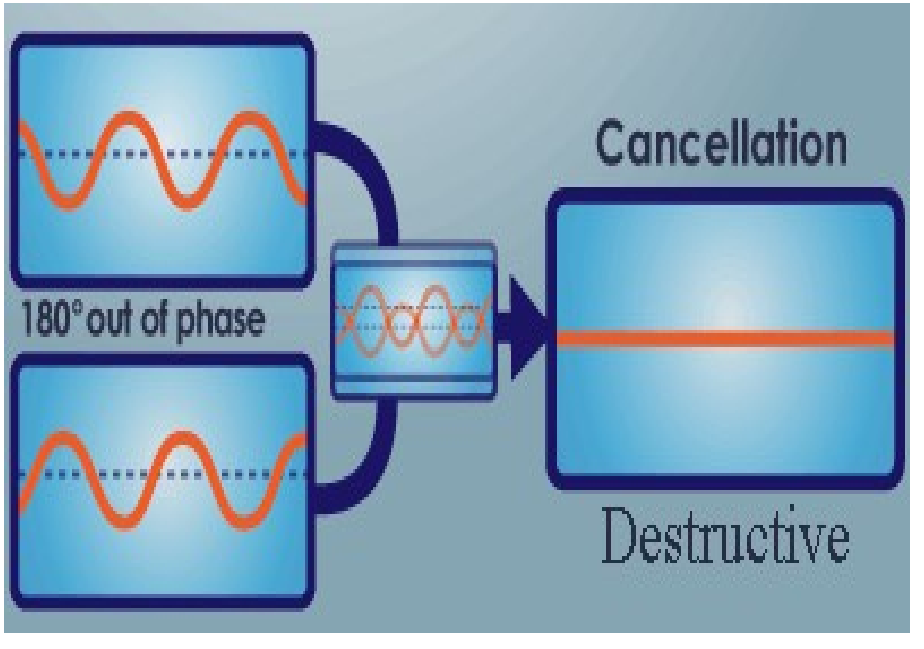




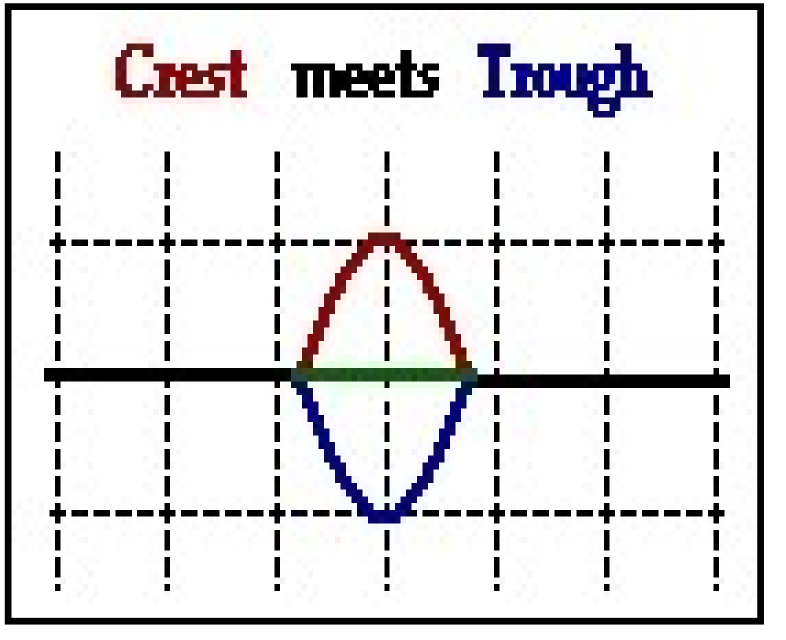
Properties of radio waves

4. Interference

- Destructive interference ⇒ 2 or more waves combine to produce a wave with smaller displacement

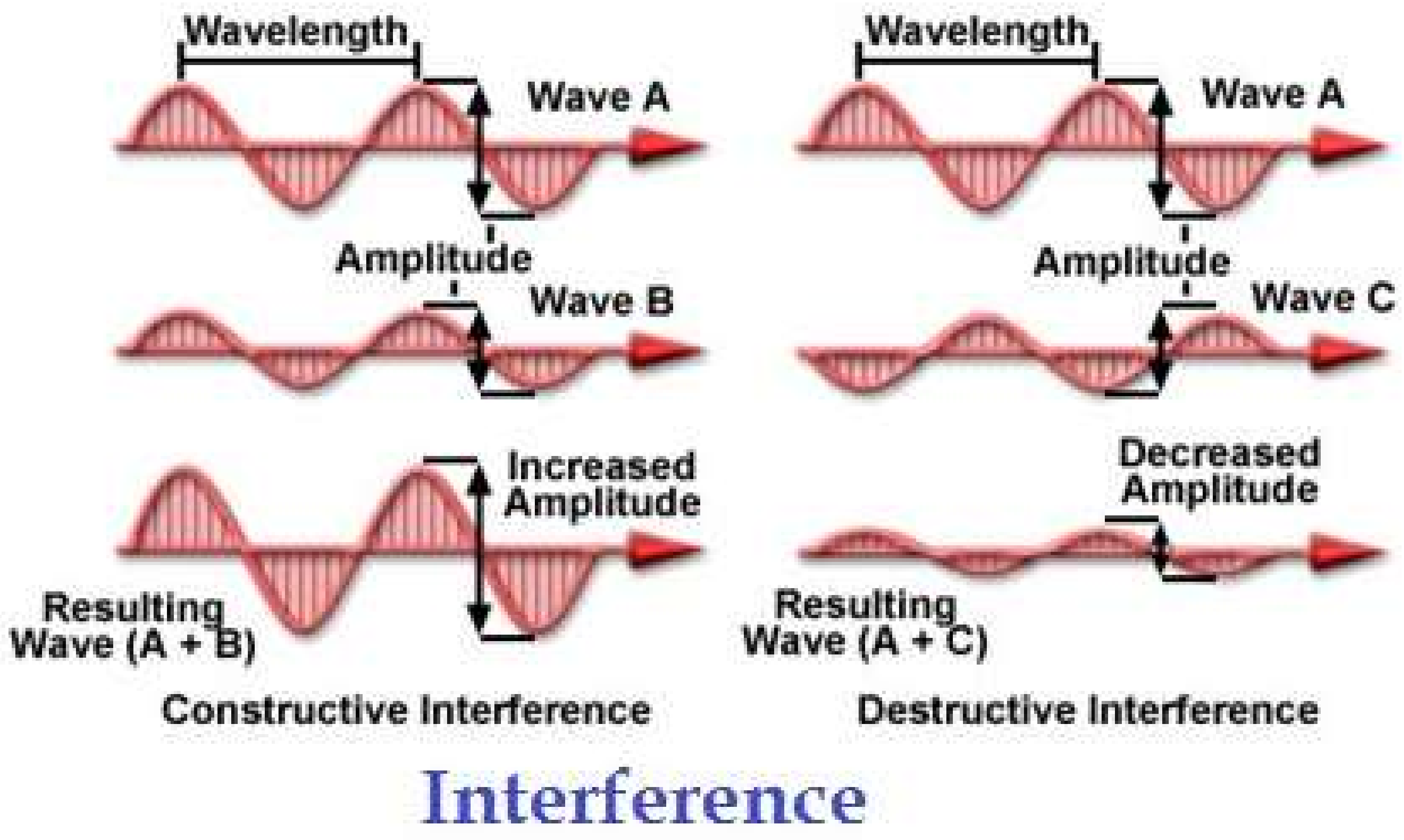


Destructive - softer



Properties of radio waves

4. Interference



Propagation of EM waves

- Once the signal leaves the antenna, (i.e., radiated) it can take any of the three paths

Frequency	Propagation	Use
above 30 MHz	Space wave or Line of Sight Propagation	(TV or FM transmission)
3 MHz – 30 MHz	Sky Wave Propagation	(SW band in radio broadcasting)
30 KHz – 3 MHz	Ground Wave Propagation	(MW band in radio)

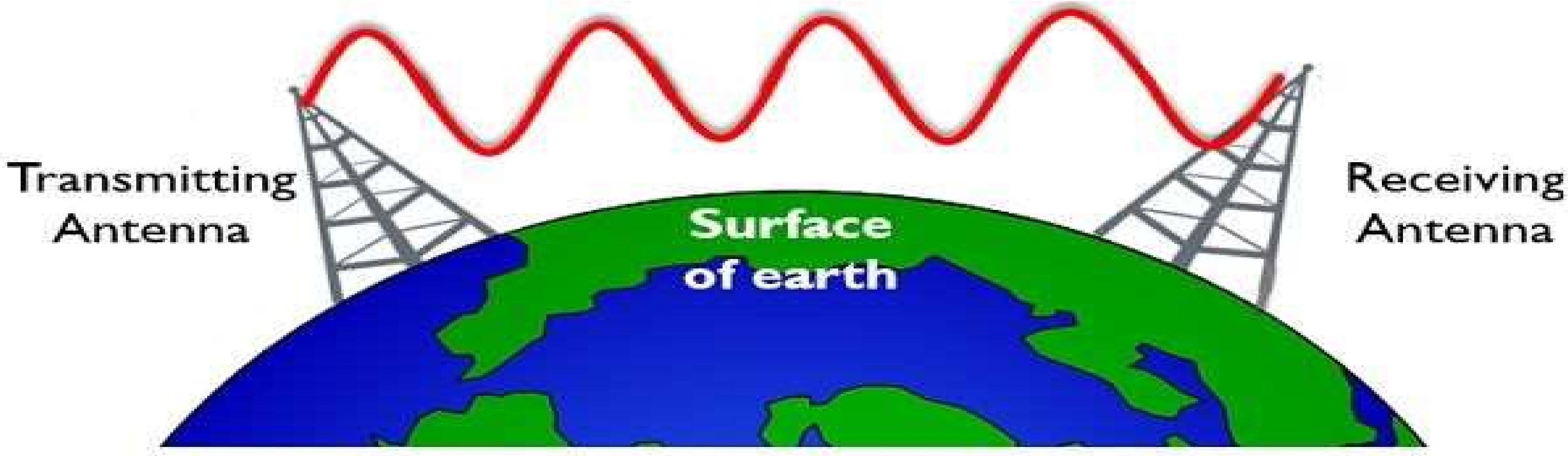
Propagation of EM waves

- Three basic paths that a radio signal can take
  - Ground wave propagation — Along the surface of Earth
  - Sky wave Propagation — Up to the ionosphere and back
  - Space wave Propagation — From the transmitter to receiver in a straight line

Path taken by radio signal depends on

- Frequency of signal
- Atmospheric conditions
- Time of the day

1. Ground wave propagation



Ground Wave Propagation

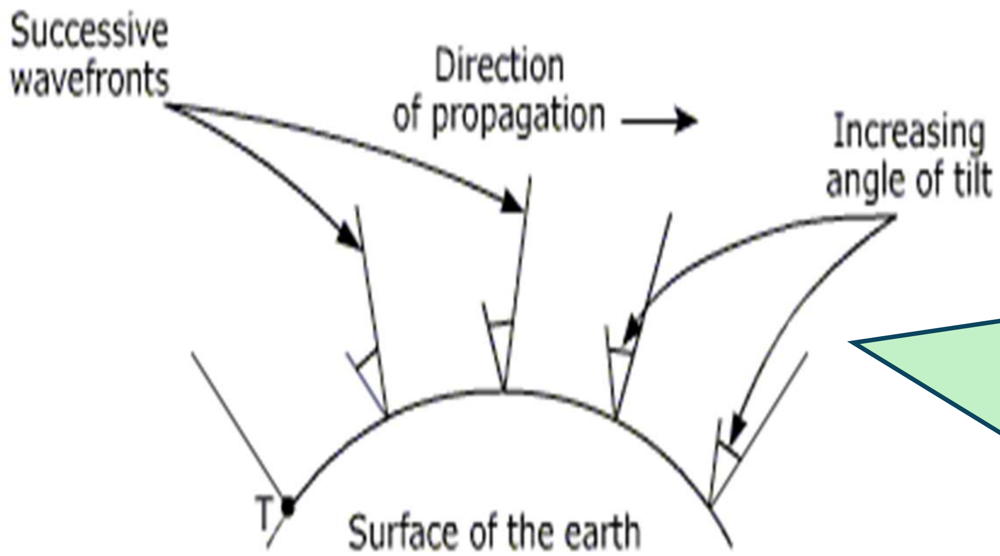
The ground or surface wave leaves the antenna and remains close to the earth. The ground wave will actually follow the curvature of the earth and therefore can travel a distance beyond the horizon.

It is the strongest at the low and medium frequency ranges. The ground waves is the path chosen by the signal when the frequency is between 30 KHz and 3 MHz.

The ground waves must be vertically polarized to prevent short circuiting of the electric field component. The EM waves are said to be vertically polarized if all its electric intensity vectors are vertical.

1. Ground wave propagation

Attenuation of the Ground Waves:



Due to diffraction, the wavefronts will gradually tilt over as shown.
The angle of tilt goes on increasing as the ground waves progress over the surface of the earth.
Eventually, the wave lies down and dies.

- While passing over the earth surface, the ground waves induce some current into it. Thus they lose some energy due to absorption.
- **The tilt angle increases with increase in frequency, hence puts a limitation on the range of transmission** if the transmission takes place near the top of the medium frequency range (near 3 MHz).

1. Ground wave propagation

Advantages

- If transmitted power is large enough, then ground wave propagation can be used to communicate between any two parts of the world.
- The atmospheric conditions do not affect the ground wave propagation too much.

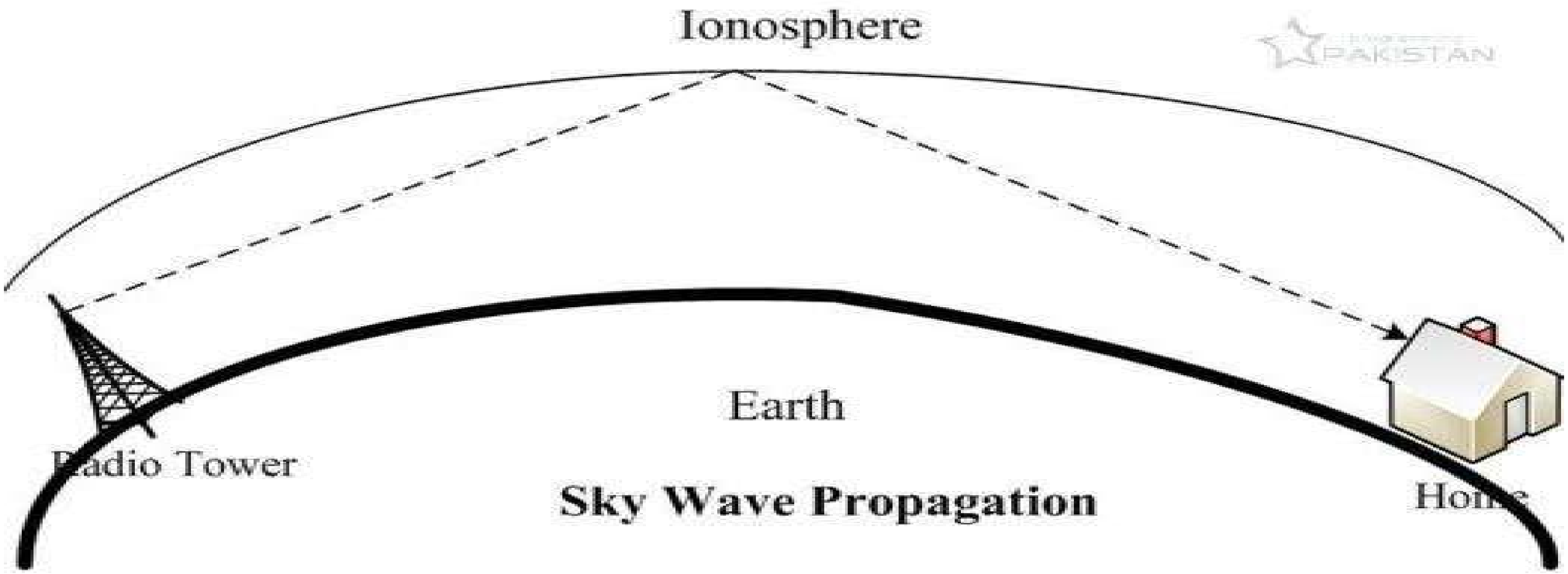
Disadvantages

- Limited range for higher operating frequencies.
- At low operating frequencies, very tall antennas should be used.
- High transmission power is necessary to cover the adequate range..

Applications

1. AM radio broadcasting operating in MW band.
2. VLF transmission is used for ship communications such as radio navigation and marine mobile communications.

2. Sky wave propagation



A type of radio wave communication in which the electromagnetic wave propagates **due to the reflection mechanism of the ionospheric layer** of the atmosphere is known as sky wave propagation.

Due to propagation through the ionosphere, it is also known as **ionospheric wave propagation**.

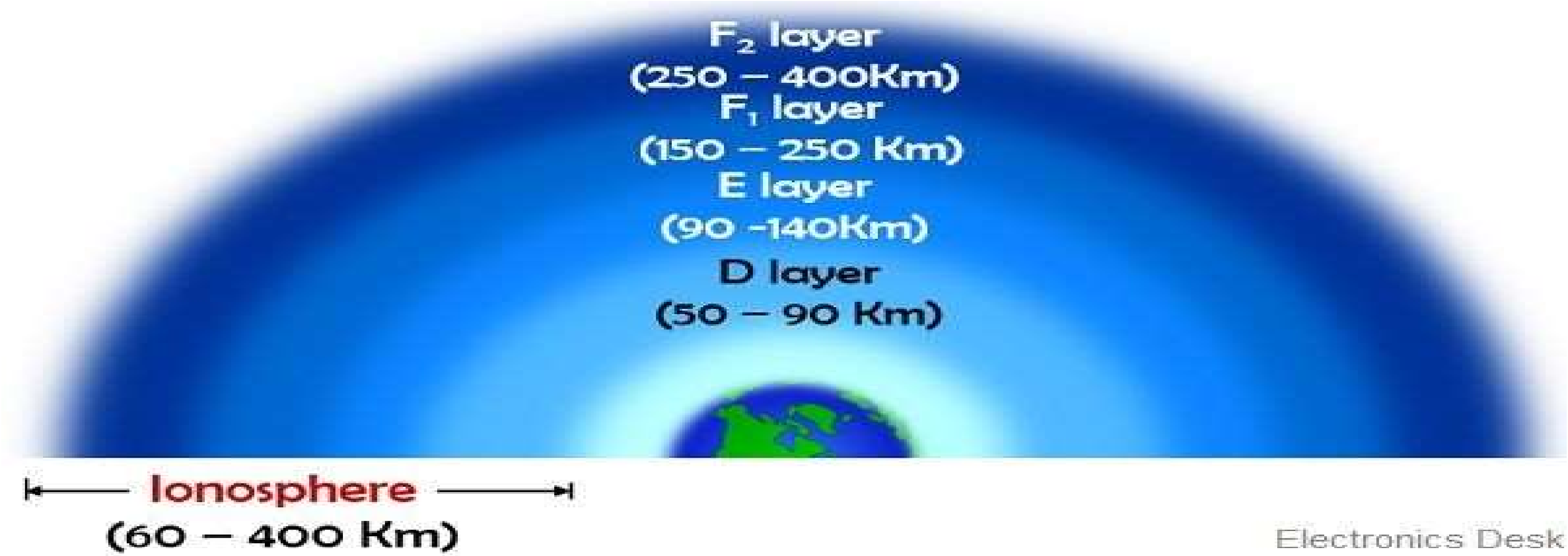
2. Sky wave propagation

Need

1. Ground wave propagation is usually suitable for the transmission of low-frequency electromagnetic signals (usually up to **2 or 3 MHz**).
2. Another major disadvantage associated with ground wave propagation is that it is suitable only for short-range operation. This is so because the induced wave in ground wave propagation causes attenuation of the propagated signal.

2. Sky wave propagation

Ionosphere



Ionosphere is present in the upper atmospheric region and is composed of **ionized layers**.

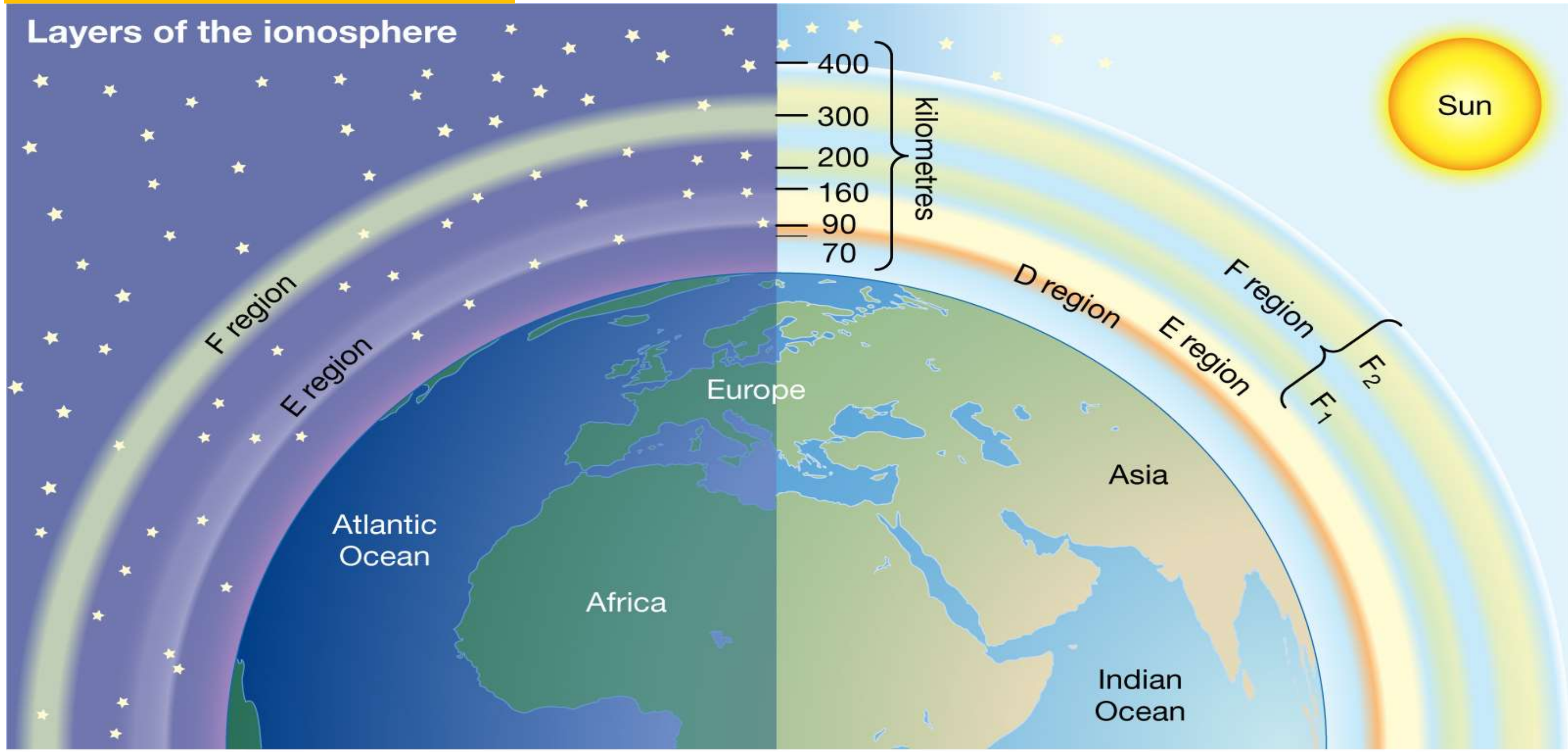
Generally, the ionosphere consists of 4 different layers namely D, E, $F_{1,}$ and F_2.

These layers are present at different heights from the surface of the earth.

Basically the ionosphere is said to be extended from **60 to 400 Km** from the surface of the earth.

2. Sky wave propagation

Ionosphere



Each layer has a different concentration of atoms in a way that the ionized layer which is present nearer to the surface of the earth has the highest number of neutral atoms.

While the middle layer has moderate concentration and the outermost layer consists of a very less number of neutral atoms.

2. Sky wave propagation

Ionosphere – The D - Layer

- Average height 70km
- Average thickness 10km
- Its exists only in day time.
- It is not useful layer for HF communication
- It reflects some VLF and LF waves
- Its electron density N=400 electrons/cc
- f_c=180kHz
- Almost no refraction (bending) of radio waves.
- Its virtual height is 60 to 80km.

2. Sky wave propagation

Ionosphere – The E - Layer

- Average height 100km
- Average thickness 25km
- Its exists only in day time
- It reflects some HF waves
- Its electron density $N=5 \times 10^5$ electrons/cc
- f_c=4MHz
- Its virtual height is 110km
- Maximum single hop range 2,350km

2. Sky wave propagation

Ionosphere – The E_s - Layer

- Its exists in both day and night
- It is a thin layer
- Its height normally 90 to 130km
- Its electron density is high
- It is difficult to know where and when it will occur and how long it will persist.

2. Sky wave propagation

Ionosphere – The F_1 - Layer

- Average height 180km
- Average thickness 20km
- It combines with F_2 layer at night
- f_c=5MHz
- Its virtual height is 180km
- Maximum single hop range 3,000km
- Although some HF waves get reflected from it, most of them pass through it
- It affect HF waves by providing more absorption.

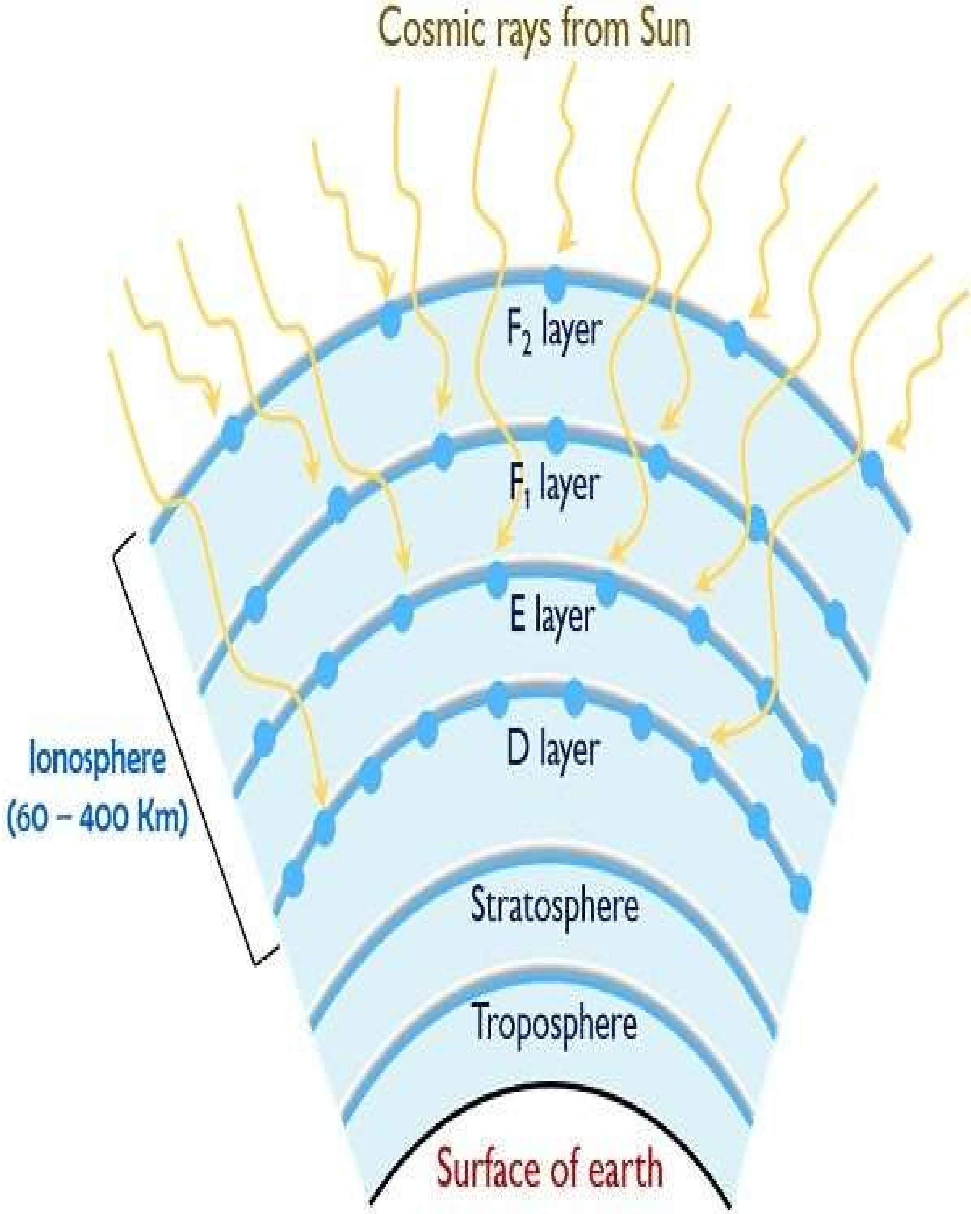
2. Sky wave propagation

Ionosphere – The F_2 - Layer

- Average height 325km in day time
- Thickness is about 200km
- It falls to a height of 300km at nights as it combines with F1 layer
- It offers better HF reflection
- Its electron density $N=8\times10^{11}$ electrons/m^3
- f_c=8MHz in day & f_c=6MHz in night
- Its virtual height is 300km
- Maximum single hop range 4,000km

2. Sky wave propagation

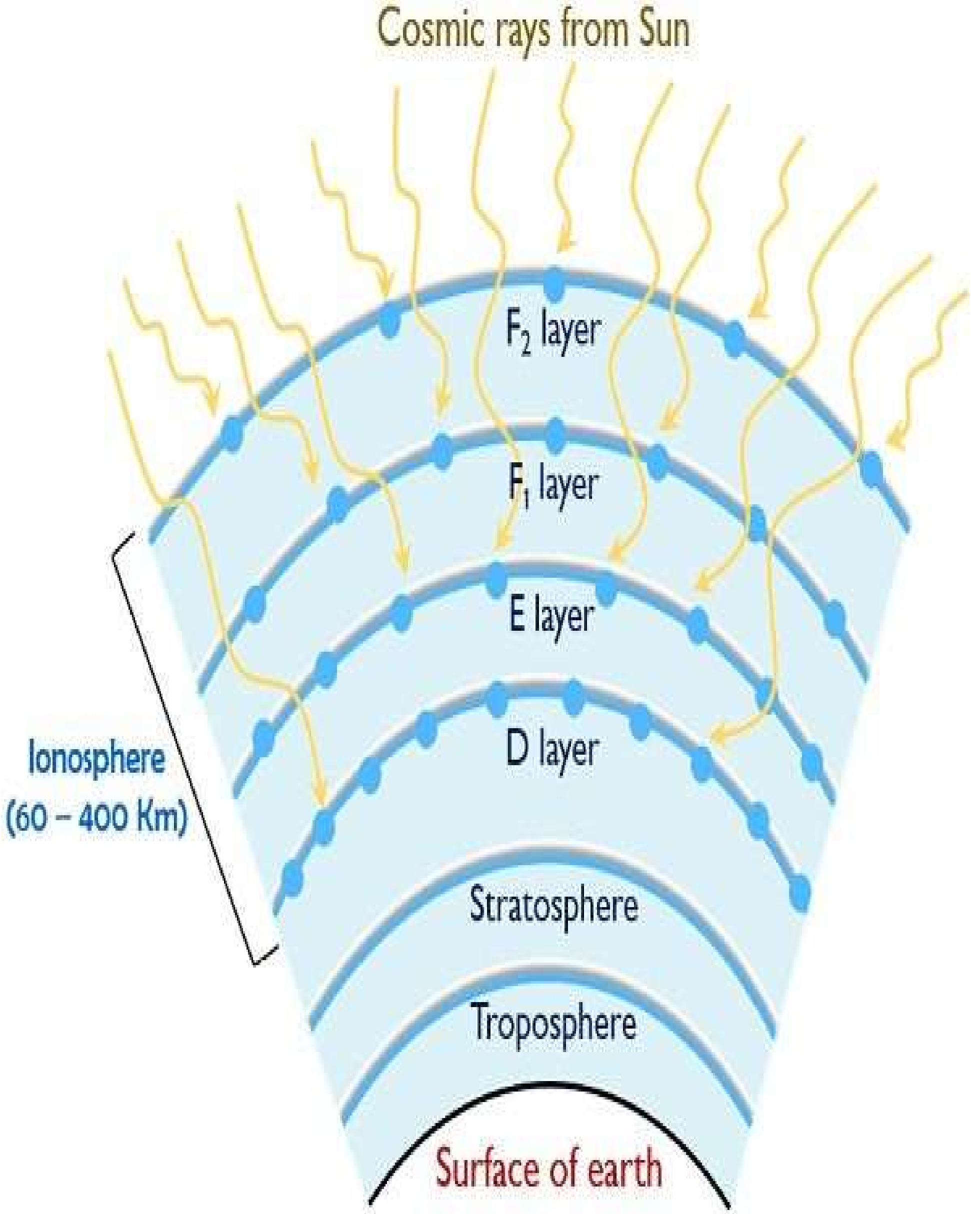
How does it take place??



- The ionosphere is composed of 4 different layers and each layer consists of a different number of atoms.
- The atmosphere of earth is denser towards its surface and becomes rarer on proceeding upwards.
- The sun emits powerful **cosmic rays**. So, due to less number of neutral atoms in the outermost layer, most of the cosmic rays penetrate the inner surface of the atmosphere without even interacting with the atoms present there.
- However, **as the inner layer is slightly denser than the outer one so here interaction between cosmic rays and atoms takes place.**

2. Sky wave propagation

How does it take place??

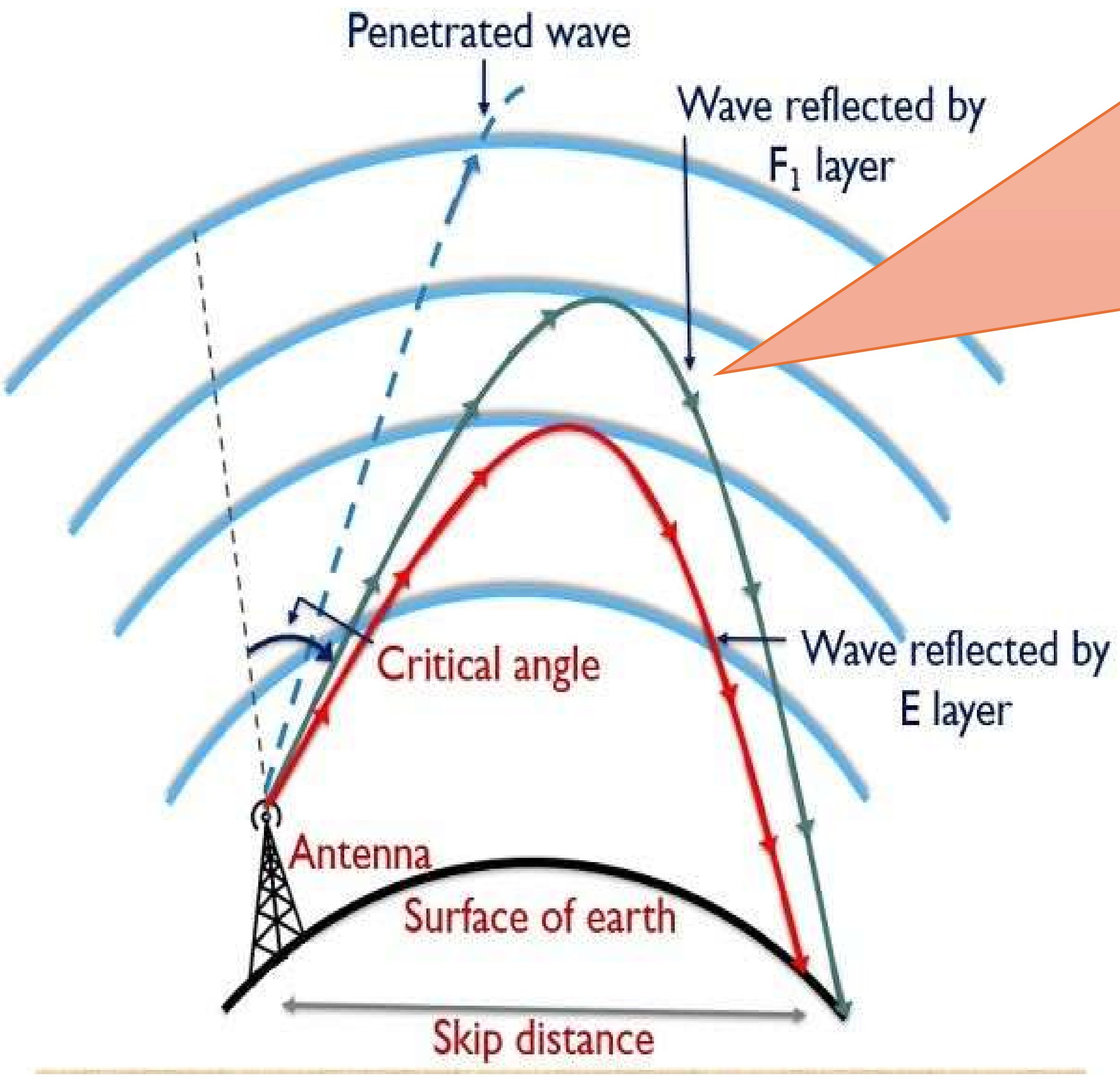


So, when cosmic rays interact with the atoms present in the ionospheric layers then electrons are emitted from the valence shell of the atom. Thus *ionization takes place*.

- interaction is higher in the case of middle layers of the atmosphere, therefore, ionization will be higher in that layer itself.
- Thus it holds the maximum number of charged particles.
- **Whenever an electromagnetic signal is transmitted from an antenna then it suffers reflection from the ionospheric layer and comes back to the surface of the earth and is received by the receiving antenna.**

2. Sky wave propagation

How does it take place??



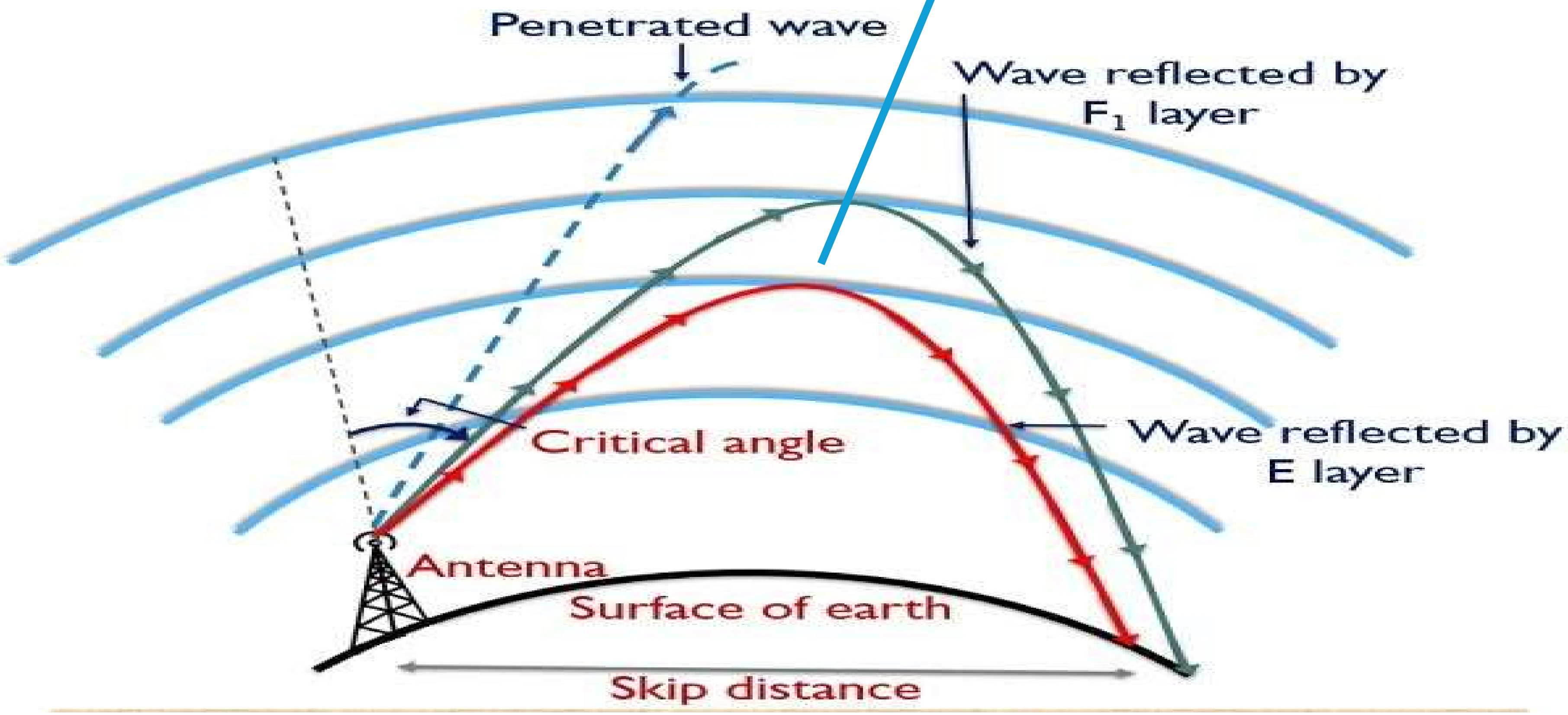
When the transmitting antenna transmits the electromagnetic wave with a certain angle (equal or greater than critical angle) then due to ionization on the earth's atmosphere it gets reflected back towards the surface of the earth.

This causes the reception of the reflected signals by the receiving antenna.

2. Sky wave propagation

How does it take place??

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



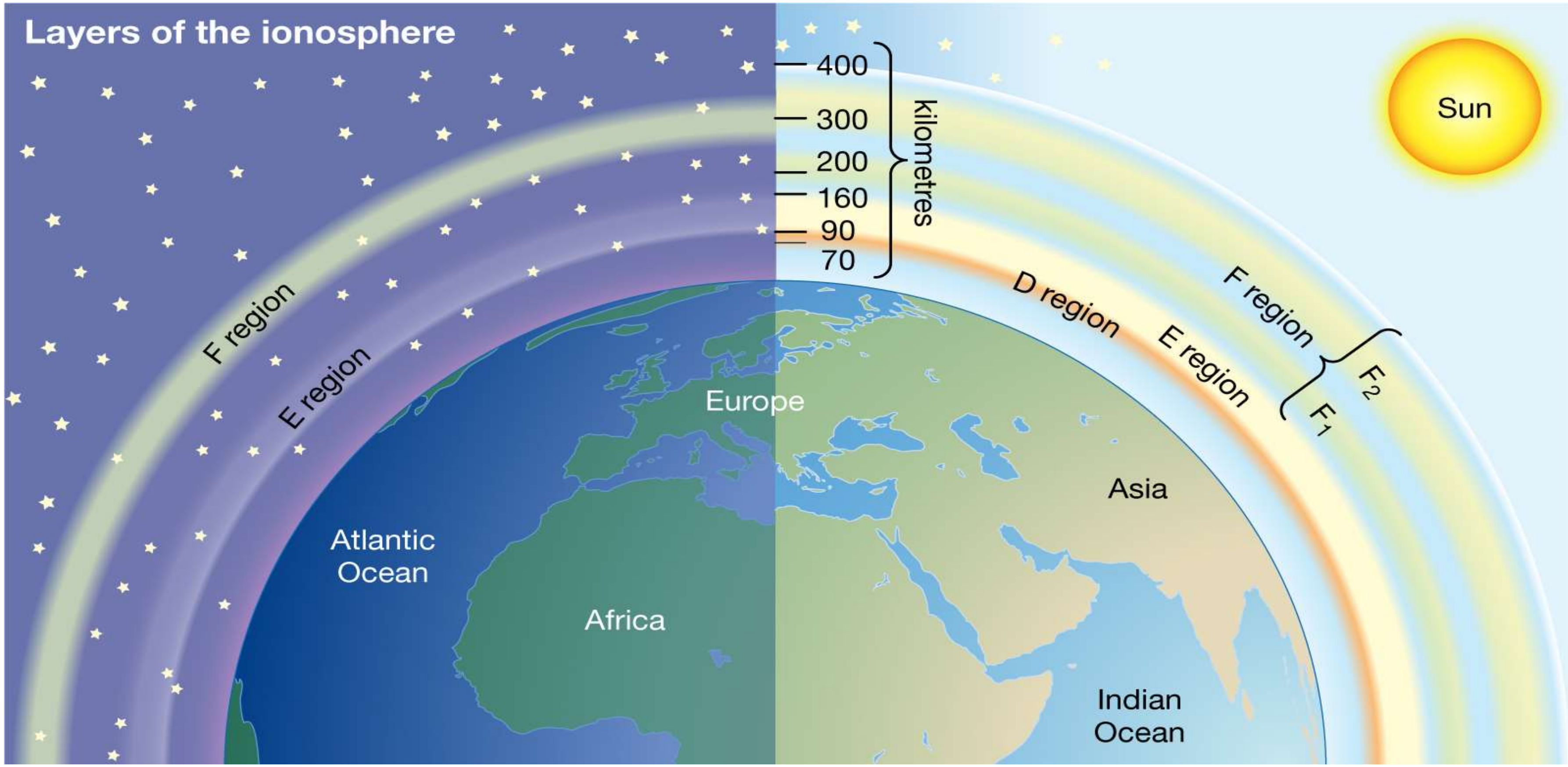
2. Sky wave propagation

How does it take place??

- Electromagnetic waves are composed of *electric and magnetic fields*.Also, the charged particles present in the layers of the ionosphere have their own electric field. So, when EMW is allowed to be propagated through the earth's atmosphere then the field of the EMW and the charged particles interact with each other. And this leads to *cause reflection of the electromagnetic wave* by the atmosphere.
- More simply we can say this as TIR taking place in the atmosphere.
- However, with upward movement, even the high-frequency wave will get reflected due to a higher degree of ionization.
- So, we can say this as a low-frequency wave is reflected by the lower layer and the high-frequency wave is reflected by the upper layer. **But beyond a certain permissible frequency (generally 30 MHz) the wave despite getting reflected penetrates the atmospheric region and is lost.**
- Hence sky wave propagation is suitable for the frequency range from **3MHz to 30 MHz**. But for signal frequency greater than 30 MHz, space wave propagation is used.

2. Sky wave propagation

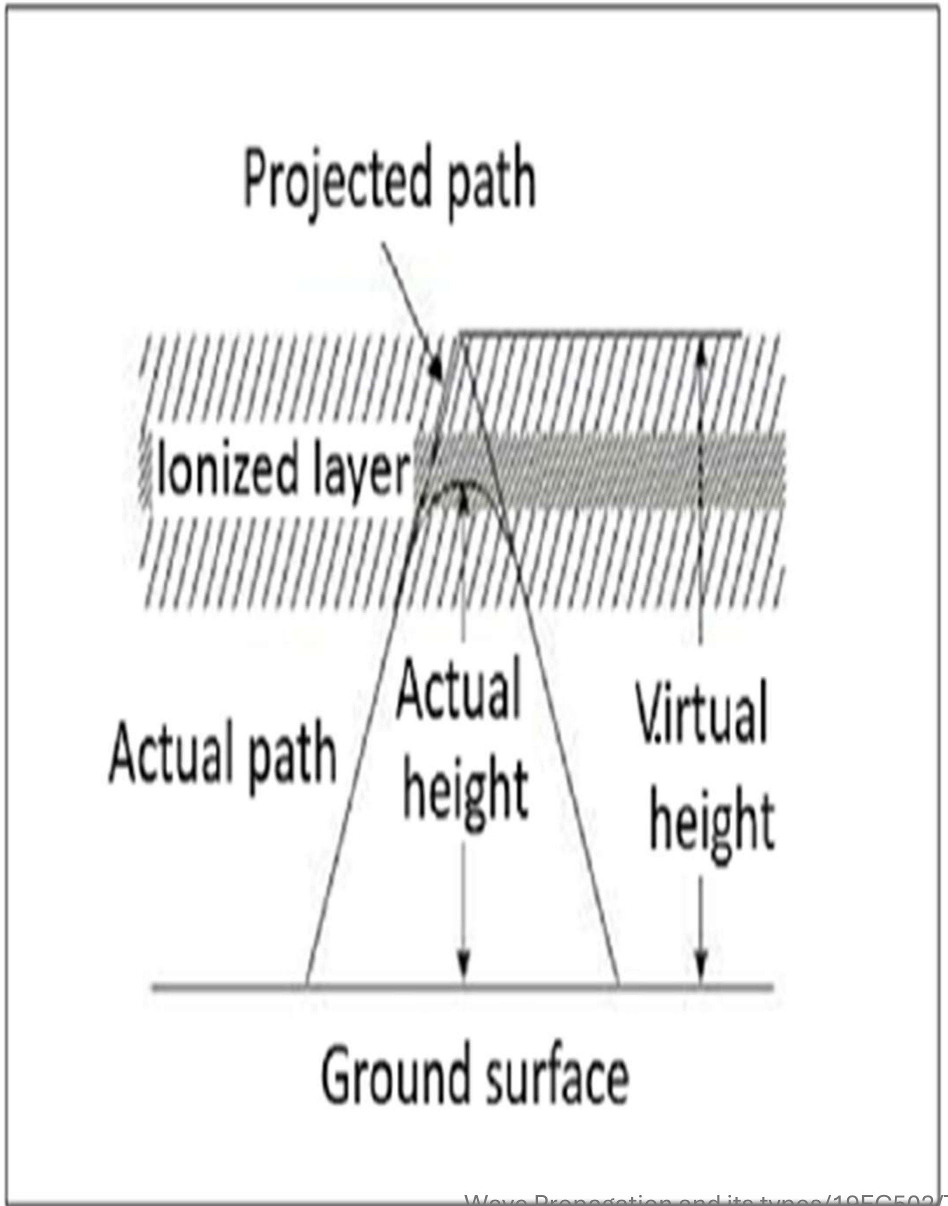
Why do we get better reception at night?



- At night, F1 and F2 layers combine to form one layer and the lower two layers D and E disappear.
- As the lower layers are absent, the absorption of the signal does not take place, which was taking place during the day time.
- This improves the strength of reflected signal and hence the quality of reception at night.

2. Sky wave propagation

Important Terms



1. Virtual Height

As the wave is refracted, it is bent down gradually rather than sharply.

However, below the ionized layer, the incident and refracted rays follow paths that are exactly the same as they would have been if reflection had taken place from a surface located at a greater height, called the virtual height of this layer.

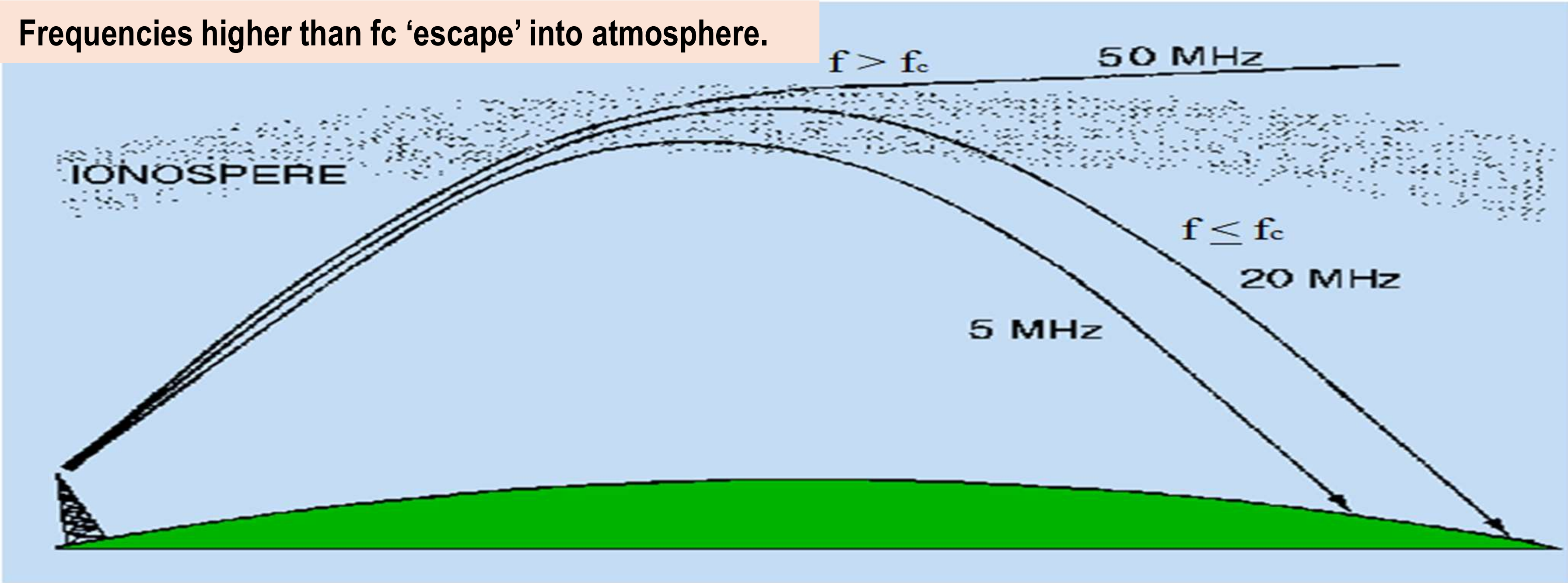
It is the height from which the radio wave appears to be reflecting.

Virtual height > Actual height

2. Sky wave propagation

Important Terms

2. Critical frequency (f_c)

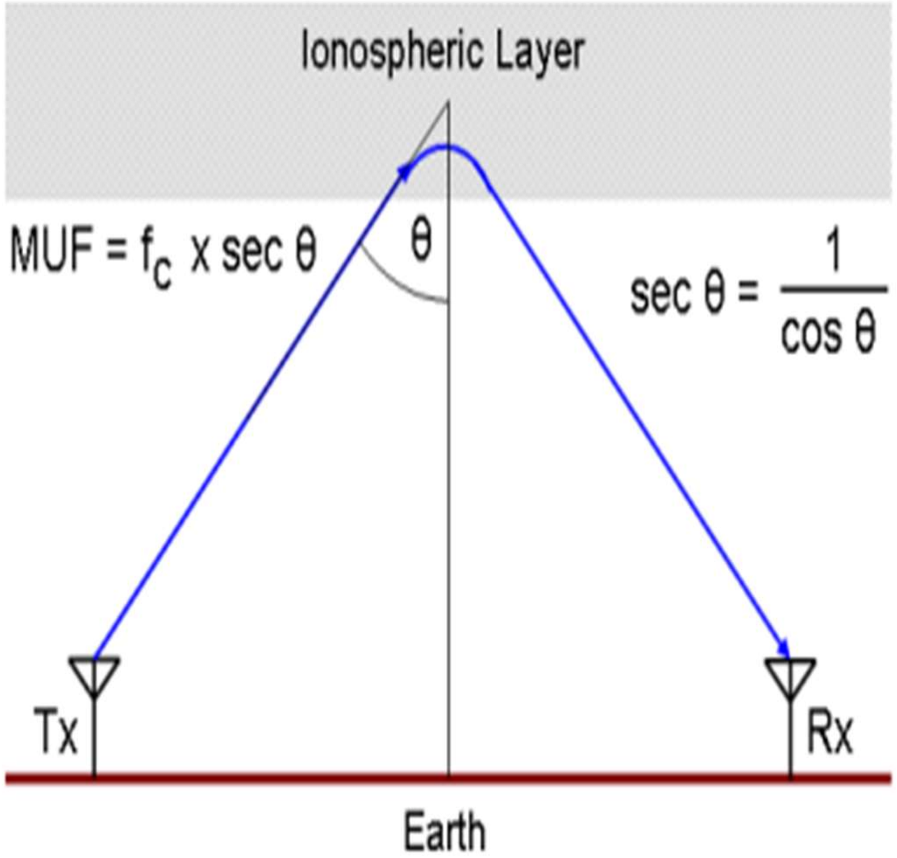


- The critical frequency is obtained by sending a signal pulse directly upwards. This is reflected back and can be received by a receiver on the same site as the transmitter. The pulse may be reflected back to earth, and the time measured to give an indication of the height of the layer.
- **As the frequency is increased a point is reached where the signal will pass right through the layer, and on to the next one, or into outer space.** ***The frequency at which this occurs is called the critical frequency.***

2. Sky wave propagation

Important Terms

3. Maximum Usable Frequency (MUF)



$$MUF = \frac{CF}{\cos\theta}$$

Where:

MUF = Maximum Usable Frequency

CF = critical frequency

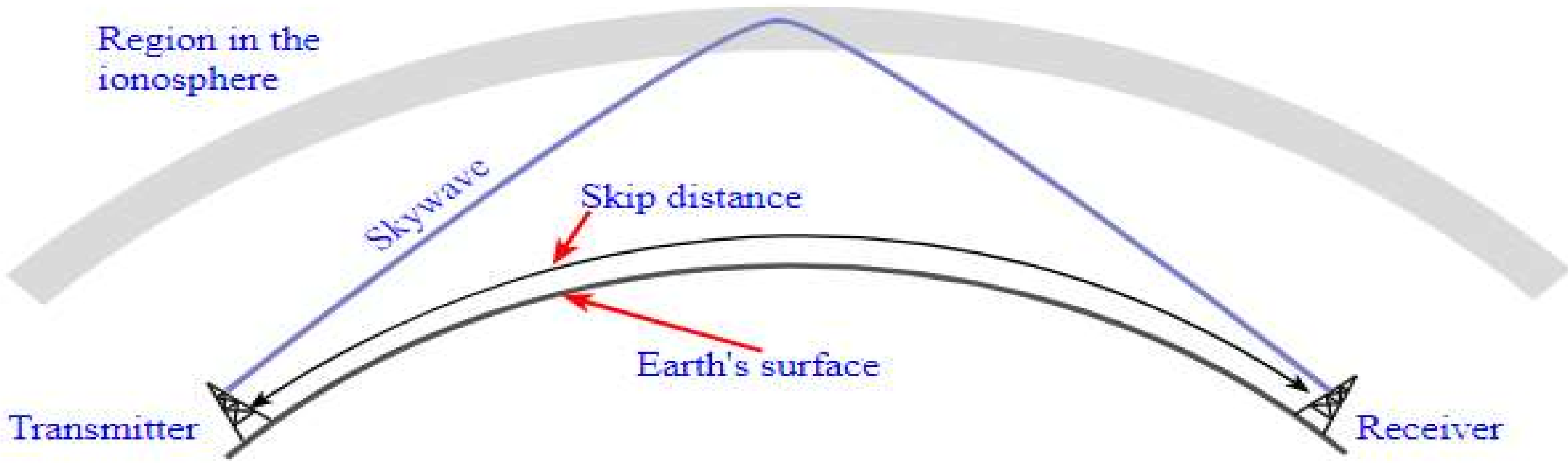
θ = the angle of incidence.

- When a signal is transmitted using HF propagation, over a given path there is a maximum frequency that can be used. This results from the fact that as the signal frequency increases it will pass through more layers and eventually travelling into outer space. As it passes through one layer it may be that communication is lost because the signal then propagates over a greater distance than is required. Also when the signal passes through all the layers communication will be lost.
- **The frequency at which radio communications just starts to fail is known as the Maximum Usable Frequency (MUF).**
- **As a rule of thumb it is generally three to five times the critical frequency.**

2. Sky wave propagation

Important Terms

4. Skip Distance



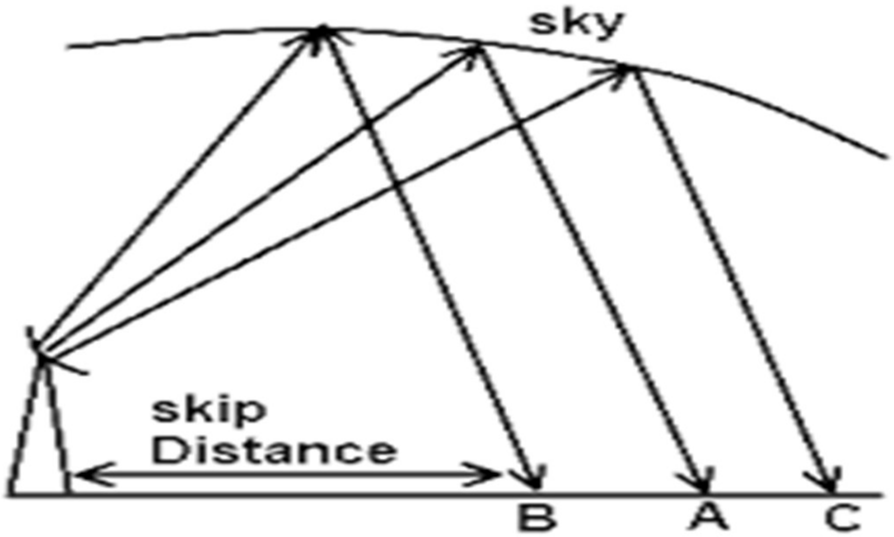
Skip distance

The skip distance is the distance over the Earth's surface between the point where a radio signal is transmitted, and the point where it is received having travelled to the ionosphere, and been refracted back by the ionosphere.

The signals leave the antenna and travel away from it, eventually reaching the ionosphere. Normally they will leave the earth at an angle called the angle of radiation. Whether it is low, i.e. almost parallel to the Earth, or high, i.e. at a high angle upwards, they will reach the ionosphere at some point.

2. Sky wave propagation

Important Terms | **4. Skip Distance**



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

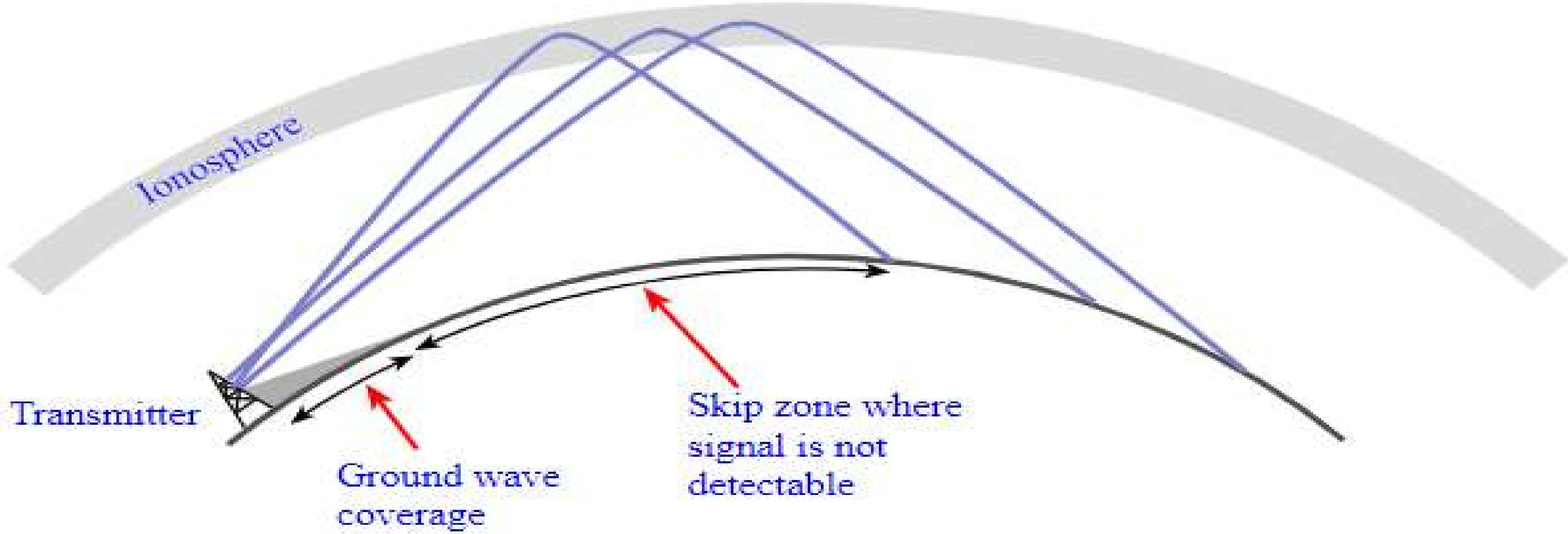
where,
h - the height where reflection occurred,
f_{MUF} - the maximum usable frequency,
f_c - critical frequency,
D_{skip} - skip distance.

- **The SKIP DISTANCE is the distance from the transmitter to the point where the sky wave is first returned to Earth.**
- The size of the skip distance depends on the frequency, angle of incidence and ionization.
- The minimum distance from the transmitter, along the surface of the earth, at which a wave above the critical frequency will be returned to earth.

2. Sky wave propagation

Important Terms

5. Skip Zone



- The **skip zone**, which may also be called a silent zone or dead zone, is a region **where radio transmission can not be received.**
- The skip zone is the region between the **point where the ground wave signals can no longer be heard and the point where the skywave first returns to Earth.**

2. Sky wave propagation

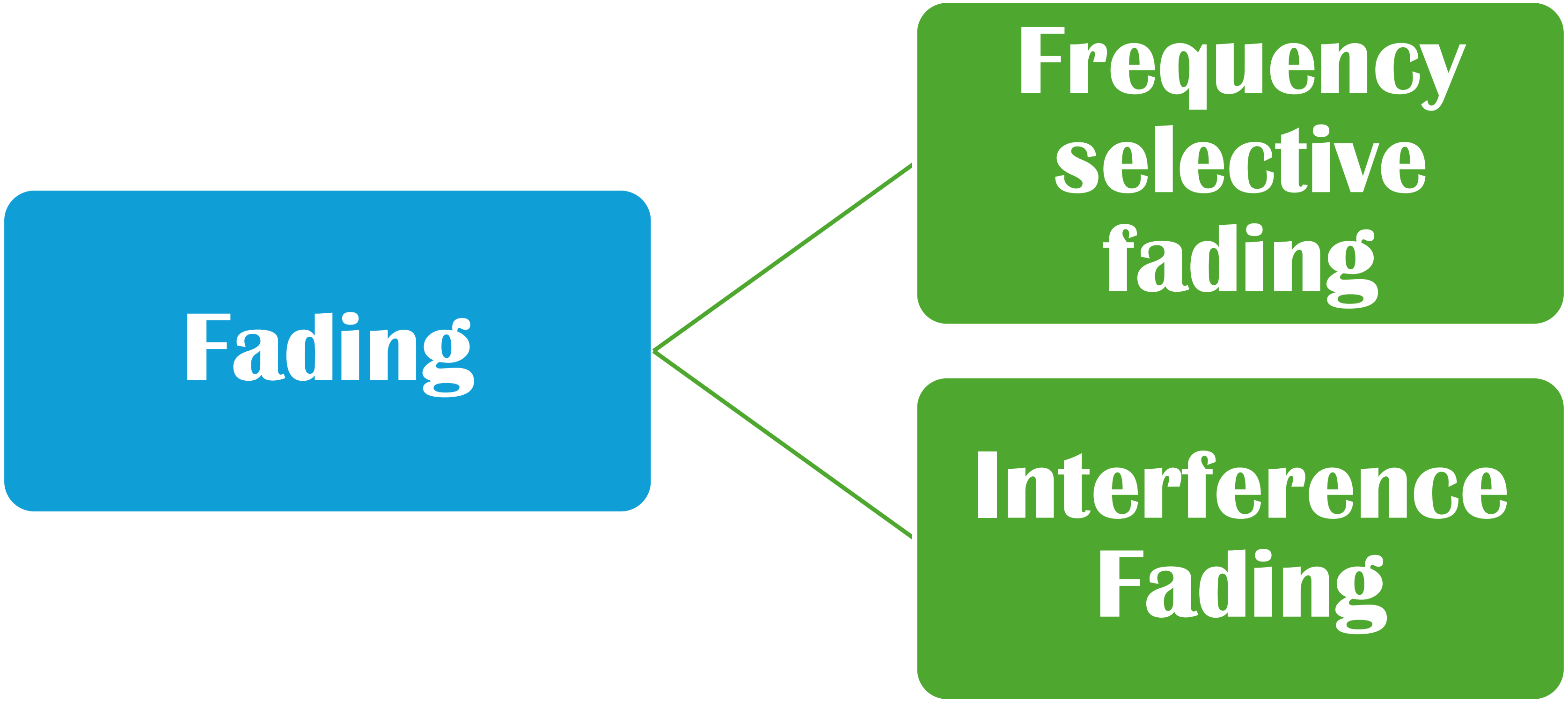
Fading

- Fading is defined as the fluctuation in the strength of the signal 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 is a gradual phenomenon and signal can be recovered.
- However, the fade-out is a phenomenon which is a condition of sudden ionospheric disturbance or ionospheric storms in sunspot cycles, etc. that leads to complete fading of the signal.

2. Sky wave propagation

Fading



2. Sky wave propagation

1. 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.

2. Sky wave propagation

1. Frequency selective Fading

- 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.

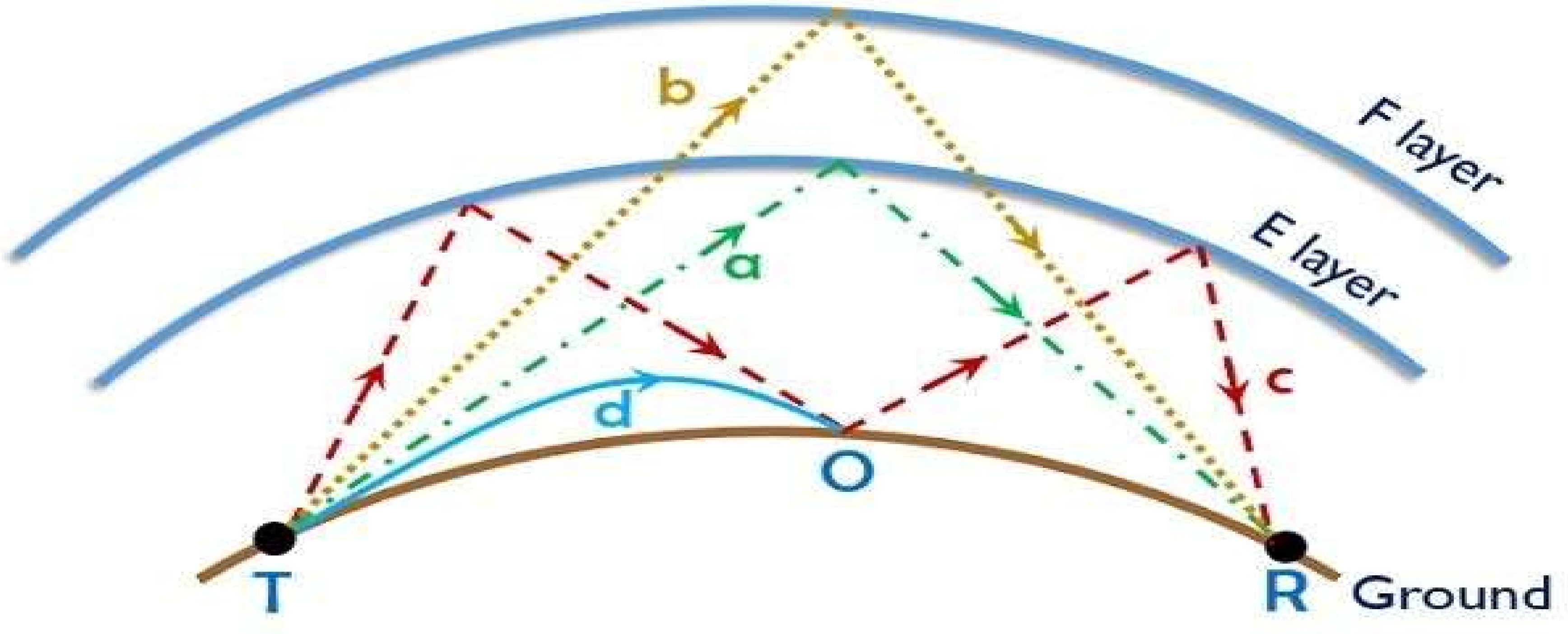
2. Sky wave propagation

2. 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.

2. Sky wave propagation

2. Interference Fading



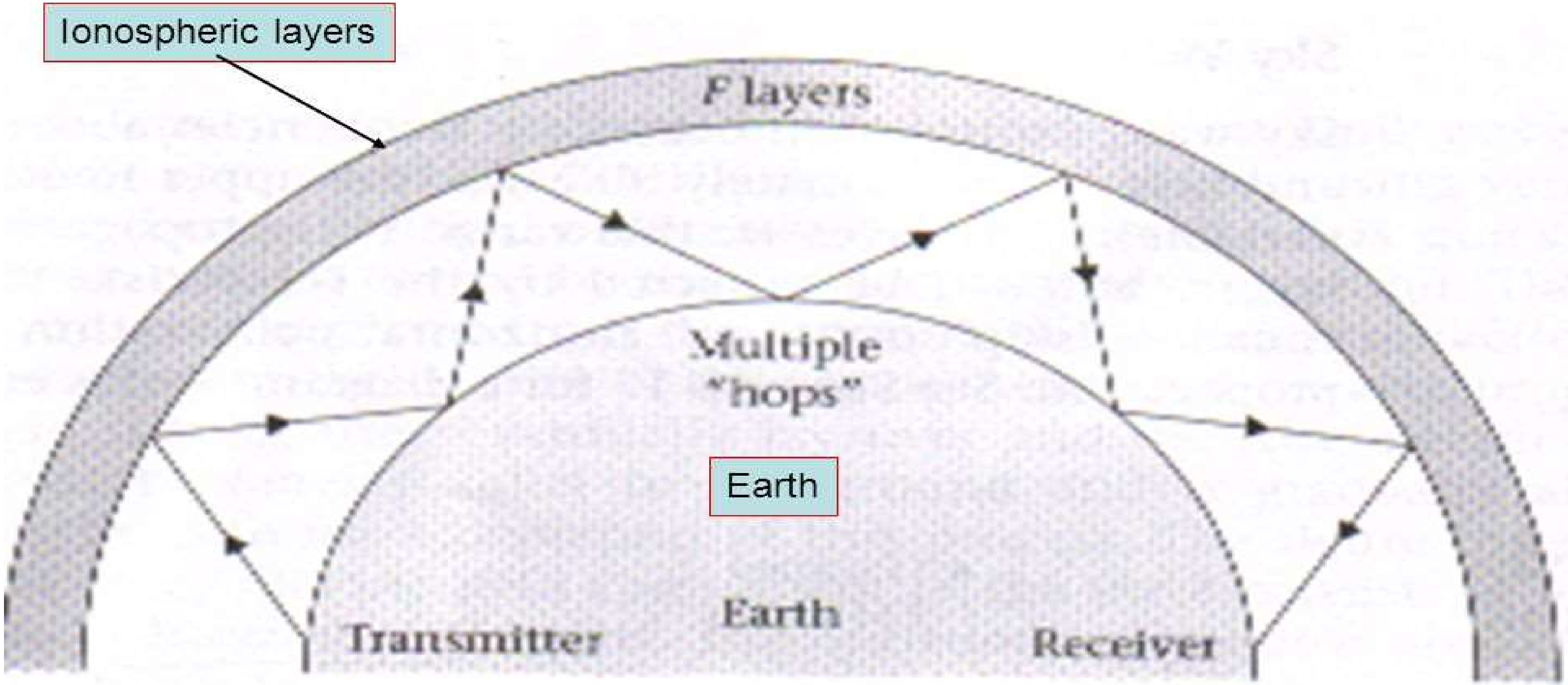
Interference fading due to various rays in the atmosphere

- Here ray ‘a’ is reflected from E layer,
- ray ‘b’ is reflected from F layer,
- ray ‘c’ is multihop propagation and
- ray ‘d’ is ground wave.

2. Sky wave propagation

Multiple Hop Sky wave Propagation

Multiple hop sky wave propagation: frequency range 3-30 MHz.



multiple reflections in the forward direction, called hopping, are due to reflection of em waves between earth and F ionospheric layers.

2. Sky wave propagation

Multiple Hop Sky wave Propagation

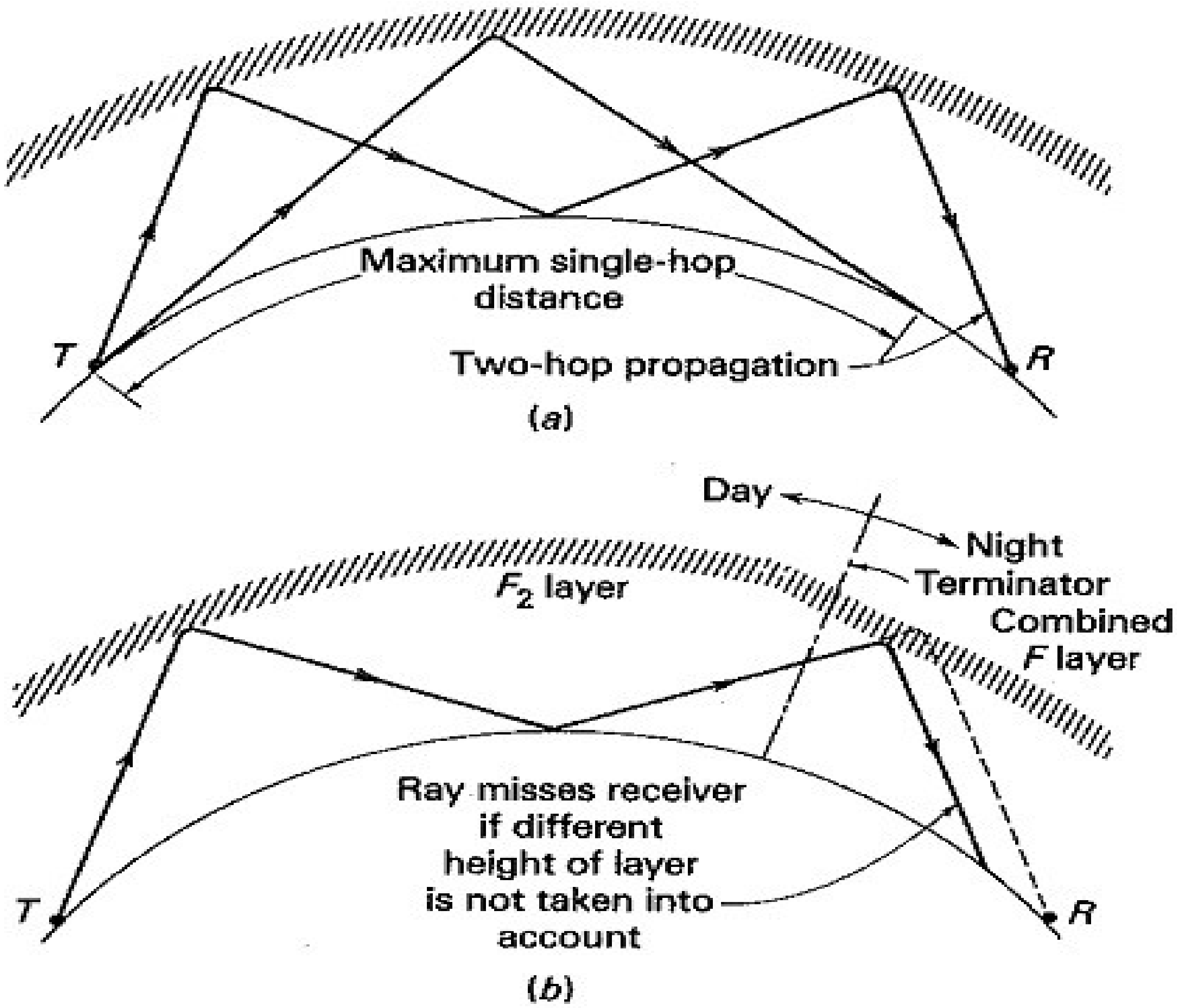
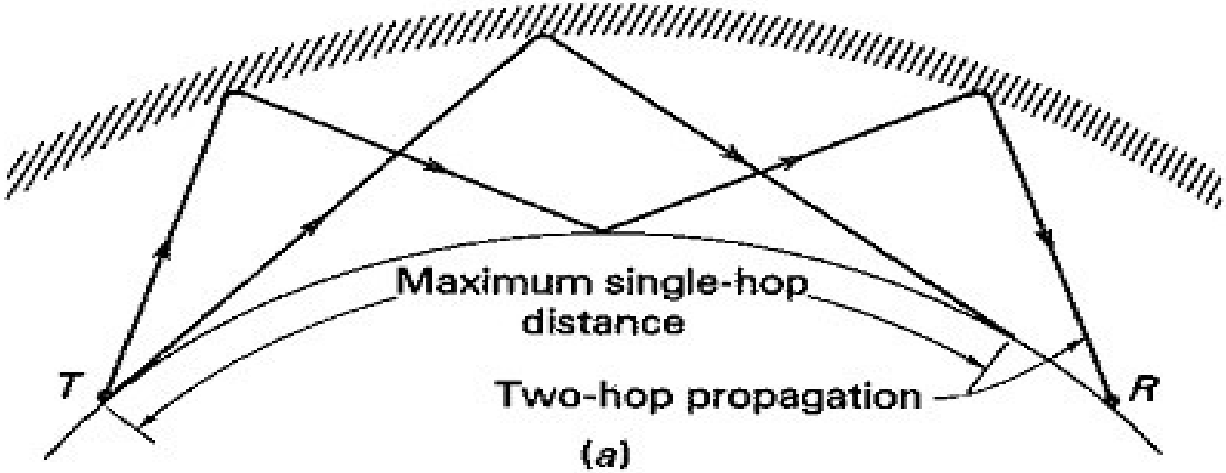


FIGURE 8-17 Long-distance sky-wave transmission paths. (*a*) North-south; (*b*) east-west.

2. Sky wave propagation

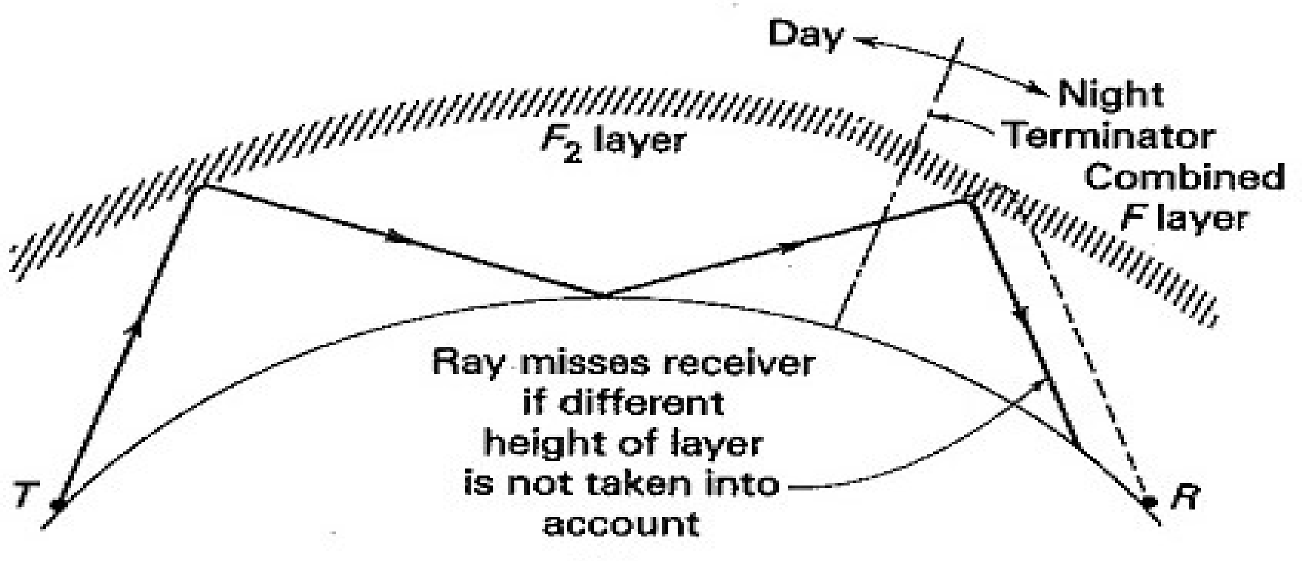
Multiple Hop Sky wave Propagation



- The transmission path is limited by the skip distance at one end and the curvature of the earth at the other.
- The longest single-hop distance is obtained when the ray is transmitted tangentially to the surface of the earth, as shown in Figure.
- For the F_2 layer, this corresponds to a maximum practical distance of about 4000 km. Since the semi circumference of the earth is just over 20,000 km, multiple-hop paths are often required.
- No unusual problems arise with multihop north-south paths.

2. Sky wave propagation

Multiple Hop Sky wave Propagation



(b)

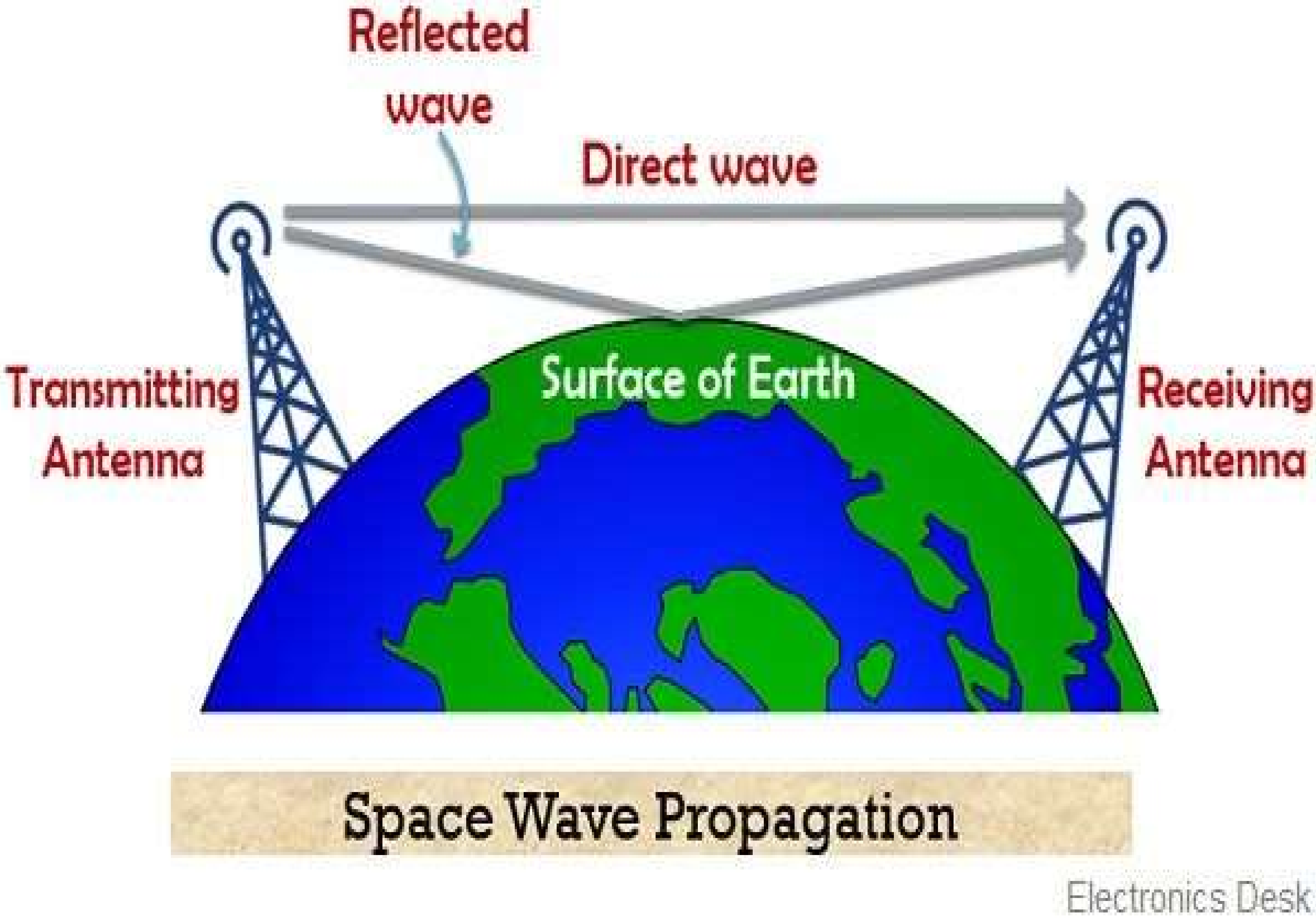
- However, care must be taken when planning long east-west paths to realise that although it is day "here," it is night "there," if "there" happens to be on the other side of the terminator.
- The result of not taking this into account is shown in Figure b.
- A path calculated on the basis of a constant height of the F_2 layer will, if it crosses the terminator, undershoot and miss the receiving area as shown the F layer over the target is lower than the F2 layer over the transmitter.

3. Space wave propagation

- Space wave propagation is the type of radio wave propagation in which the radio waves are propagated either directly from transmitting antenna to receiving antenna or by getting reflected from the ground.
- Basically in space wave propagation, direct transmission of the signal is achieved by line of sight communication.

- The transmission of a signal between transmitter and receiver is achieved in the tropospheric region of the atmosphere. Thus space wave propagation is sometimes referred as **tropospheric wave propagation**.
- This type of radio wave propagation allows the transmission of signals having a very large range of frequencies.
- Usually, it permits the transmission of signals having a **frequency greater than 30 MHz.**

3. Space wave propagation

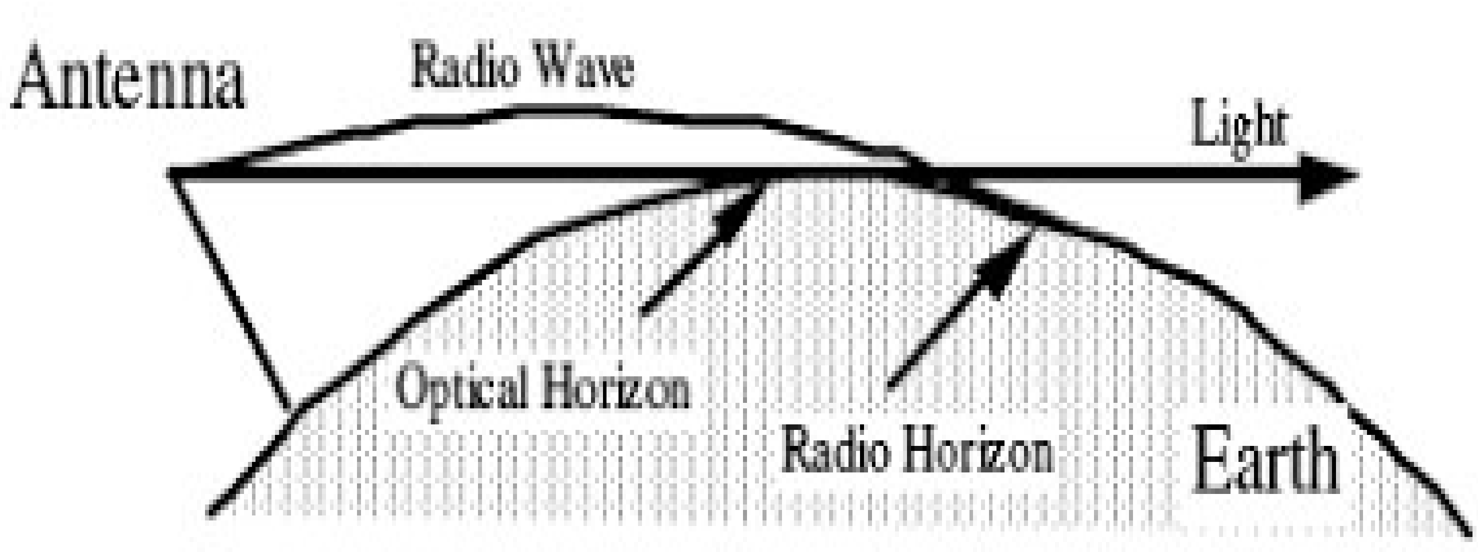


3. Space wave propagation

- In space wave propagation, the electromagnetic waves are propagated when a direct path of communication is present between the sender and receiver. Sometimes the waves are transmitted by getting reflected from the ground.
- The radio waves with extremely high frequencies are known as space waves. The troposphere allows the propagation of such waves.
- Generally, the troposphere is extended up to 10 to 20 km above the surface of the earth. Thus space wave propagation occurs at about 20 km region in the atmospheric zone.
- Sometimes called the **line of sight communication**. This is so because such high-frequency waves require a direct path for propagation.

3. Space wave propagation

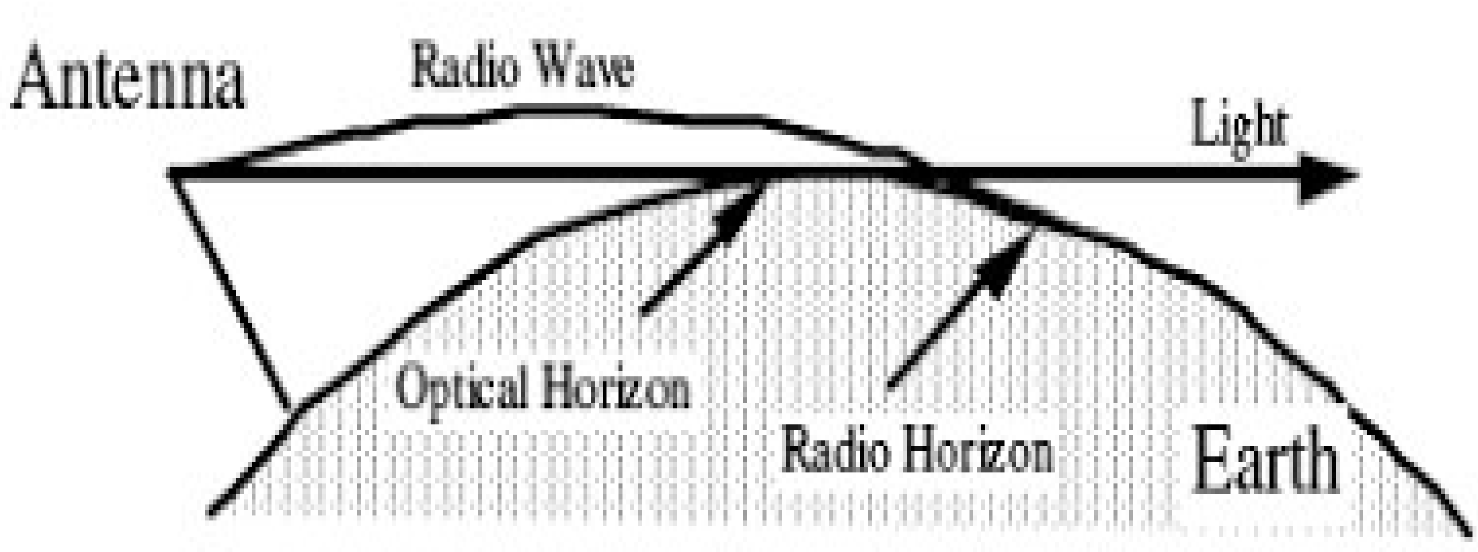
Optical Horizon



- **It is the farthest point that can be seen by the transmitting antenna.**
- If the space waves travel truly in a straight line then the maximum range of space wave communication would be limited to the optical horizon.

3. Space wave propagation

Radio Horizon



- **It is the farthest point at which the radio wave can travel.**
- It is slightly greater than the optical horizon.
- It is greater due to the varying density of atmosphere and because of the diffraction around the curvature of the Earth.

3. Space wave propagation

Shadow Zones

(b) Side view

- Since the space waves travel very close to the ground, any tall or massive objects such as hills, buildings, trees etc will obstruct the space waves.
- These objects will absorb as well as scatter energy. Hence, shadow zones are formed.
- The signal strength is very low in these zones therefore the receiving antennas need to be taller to receive adequate amount of signal.

3. Space wave propagation

Applications

1. TV broadcasting
2. FM radio broadcasting
3. Microwave Links
4. Satellite Communication

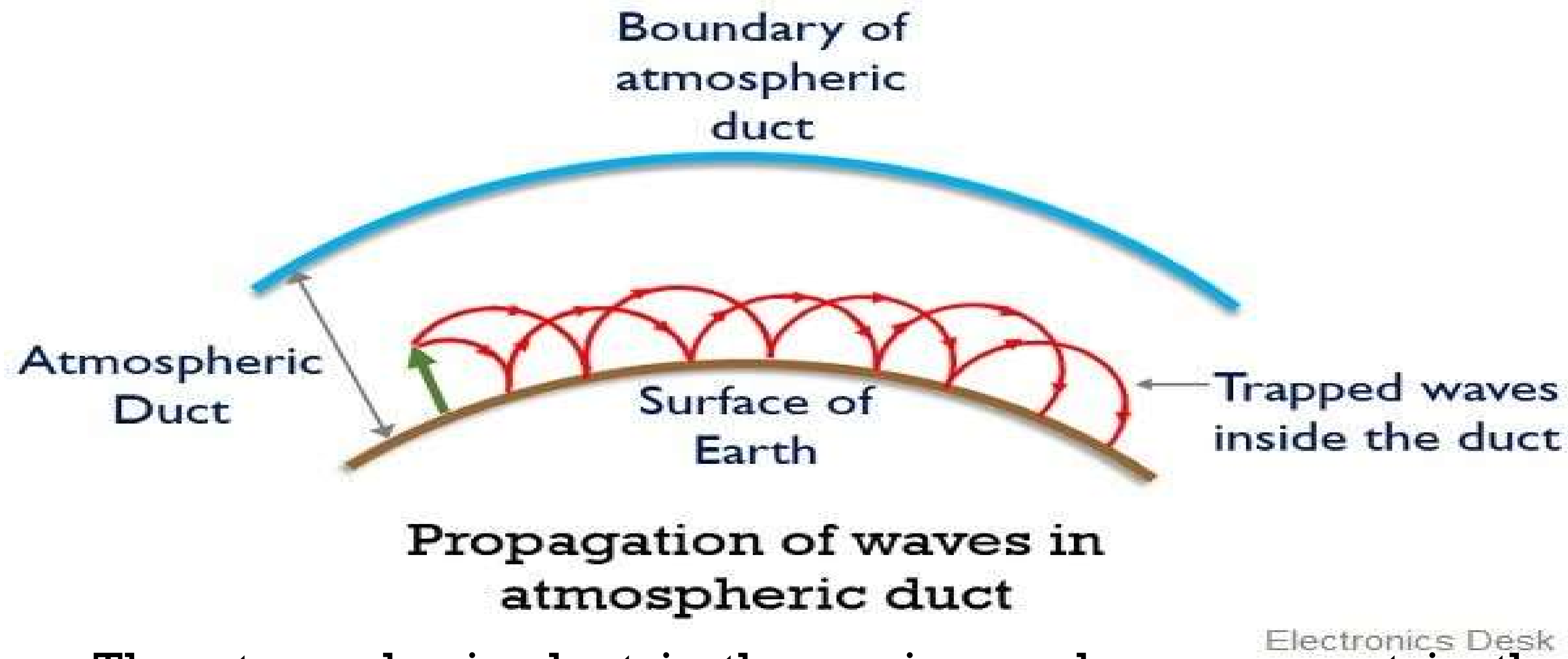
Duct propagation

Need

- Due to high frequency, the signals in the troposphere require an obstruction-free path as wavelengths of such high-frequency signals are short. Thus this mode of propagation limits the range for signal transmission.
- So, for UHF and VHF signal transmission to an even greater distance, the duct present in the tropospheric region of the atmosphere is utilized.
- This duct acts as a channel to guide the high-frequency wave to the other end by successive refraction. *Hence is referred as super refraction*.

Duct propagation

What is an atmospheric duct?



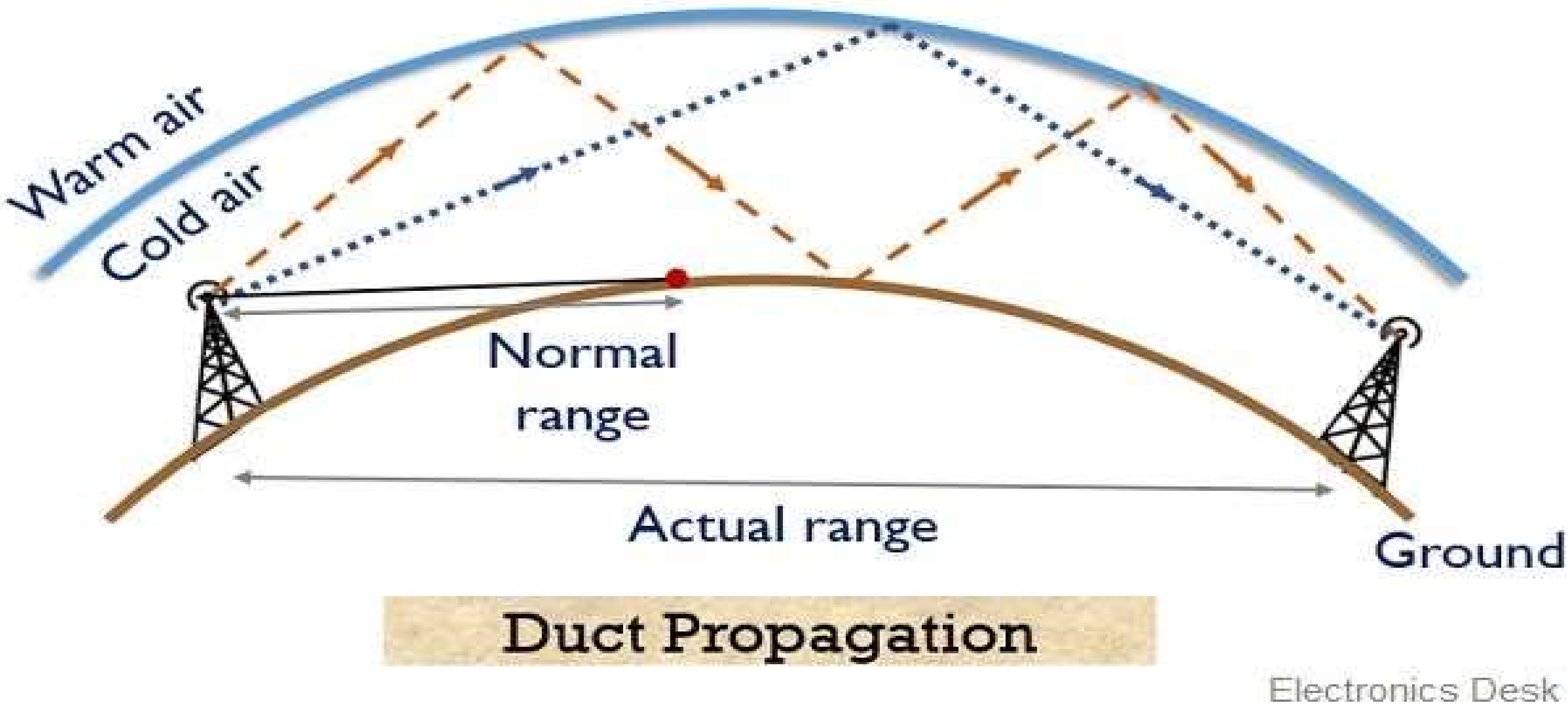
- The atmospheric duct is the region or layer present in the lower atmosphere, which is a result of **temperature inversion.**
- The duct behaves as a waveguide in the atmosphere and guides the radio waves along the curvature of the earth thereby allowing the spreading of wavefronts in a horizontal manner only.

Duct propagation

What is temperature inversion?

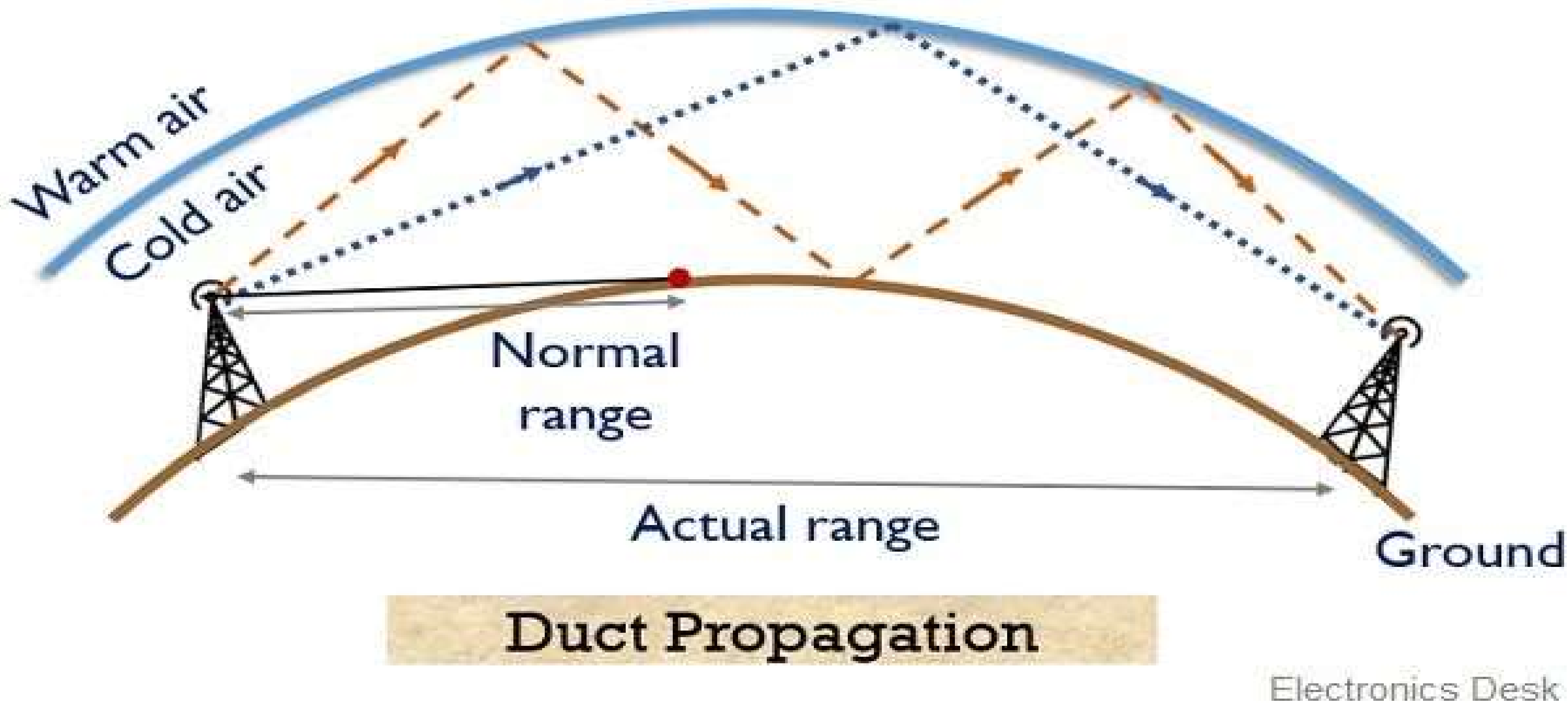
- We know that in a standard atmosphere, the temperature shows reduction with height. This means with the upward movement in the atmosphere the dielectric constant must decrease uniformly.
- So, this will lead to have unity dielectric constant in the region of zero air density. However, practically this standard atmospheric condition shows rare existence.
- The reason behind this is that the air is of turbulent nature, also there exist different layers of air. These multiple layers of air contain different water vapor contents thus different temperatures.
- So, the property of significantly having a decrease in temperature with height gets failed to be achieved.
- This leads to the development of an unusual situation in the atmosphere, where a layer of warm air exists above the cool air.
- This is known as **temperature inversion** and this gives rise to the phenomenon of super refraction in the atmosphere.

Duct propagation



- Duct propagation is the phenomenon of transmitting UHF and VHF signals to longer distances.
- The presence of a layer of cool air between warm air, generates a duct that guides the high-frequency signals inside it like a waveguide.

Duct propagation



- For duct propagation to take place, the two necessary conditions are as follows:
  1. The transmitting antenna must be extended up to the region of the duct in the atmosphere and
  2. The angle of incidence of radio waves should be less than the value of the critical angle.

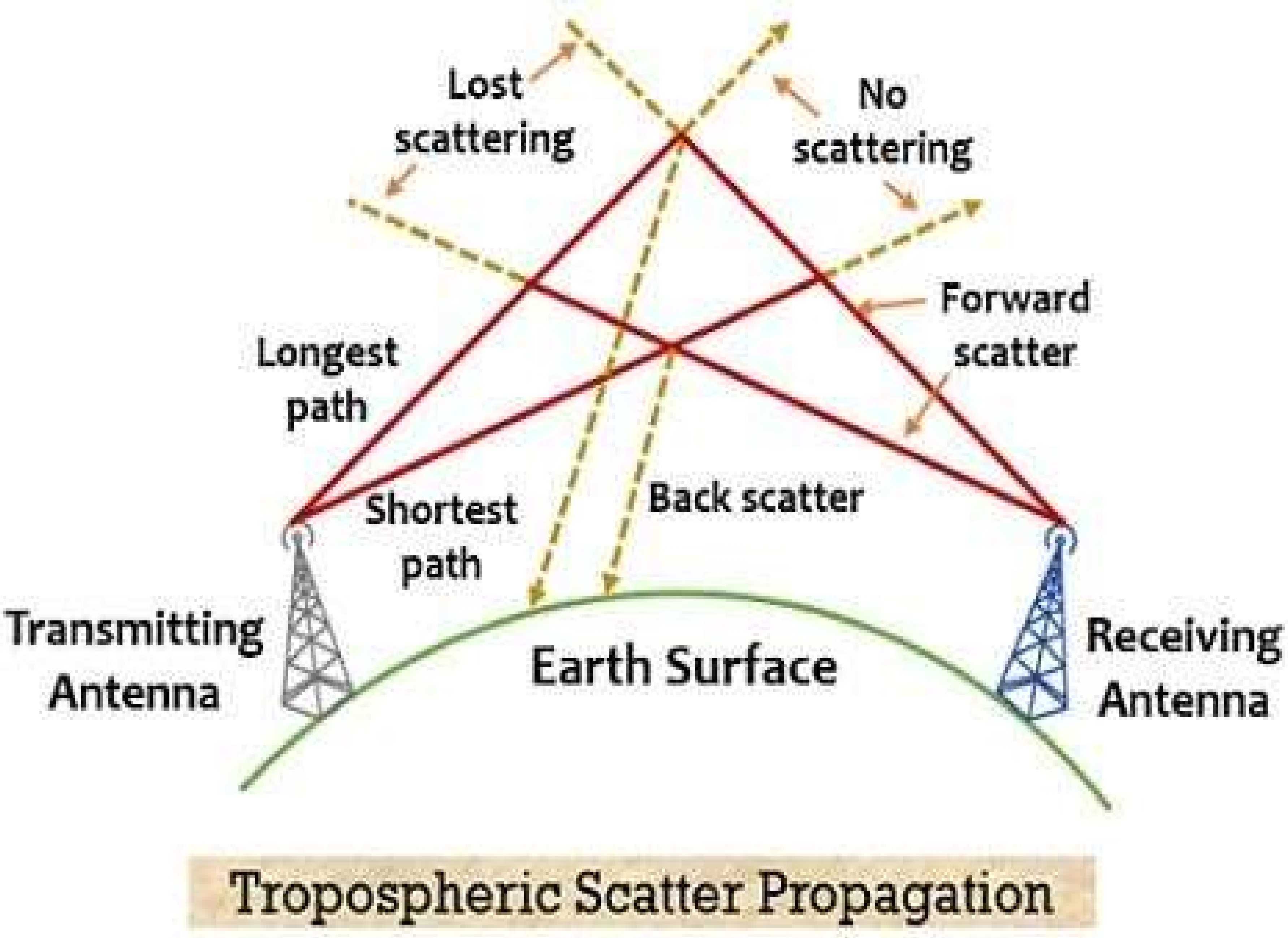
Duct propagation

- Warm and cool airs possess variation in the refractive index. This is due to the variation in their densities.
- So, when such high-frequency wave emitted from the transmitting antenna in the region of the duct (i.e., cool air) with a low angle of incidence, then on experiencing lower refractive index from the region of warm air due to lower density, the wave gets refracted back to the surface of the earth.
- The air above the surface of the earth has a higher temperature, thus the warm region is present lower next to the duct.
- So, the wave while propagating through the cool region (having higher refractive index) towards the ground again gets refracted when interacted with the medium of lower refractive index.
- This sudden variation in the refractive index of the medium is due to the change in the dielectric constant of the atmosphere.

Duct propagation

- Due to this reason, the wave undergoes multiple refractions and oscillates between the two boundaries of the duct and received by the receiving antenna.
- In this way, the transmitted signal gets achieved by the antenna at the opposite end with less attenuation.
- In this way, duct propagation allows the transmission of high-frequency signals to larger distances without the condition of line of sight propagation.
- Through duct propagation, these high-frequency signals can be transmitted up to a *distance of 1000 km* in the atmosphere.

Tropospheric Scatter propagation



Tropospheric Scatter propagation

- It is sometimes called forward scatter propagation or scatter propagation and is suitable for VHF, UHF and microwaves.
- **In this, the waves propagate through forward scattering due to the irregularities of the troposphere.**
- **This propagation technique uses the properties of the troposphere.** This mode offers reliable communication between 160 km to 1600 km.
- It is called so because in this case, the propagation occurs beyond the horizon i.e., the fine layers of the troposphere.
- This type of propagation sometimes leads to the production of unwanted noise or fading.

Tropospheric Scatter propagation

Advantages

- It is not affected by the abnormal phenomena that affect sky wave propagation.
- Hence it is very reliable.

Applications

- Long distance telephones
- Communication links in inaccessible areas.
- Alternative to microwave links or co-axial cables.