Module VI - Radiation and Propagation of Waves

Lecture 1

- Electromagnetic radiation fundamentals
  - Attenuation and Absorption
  - Effect of Environment
- Wave propagation and its types

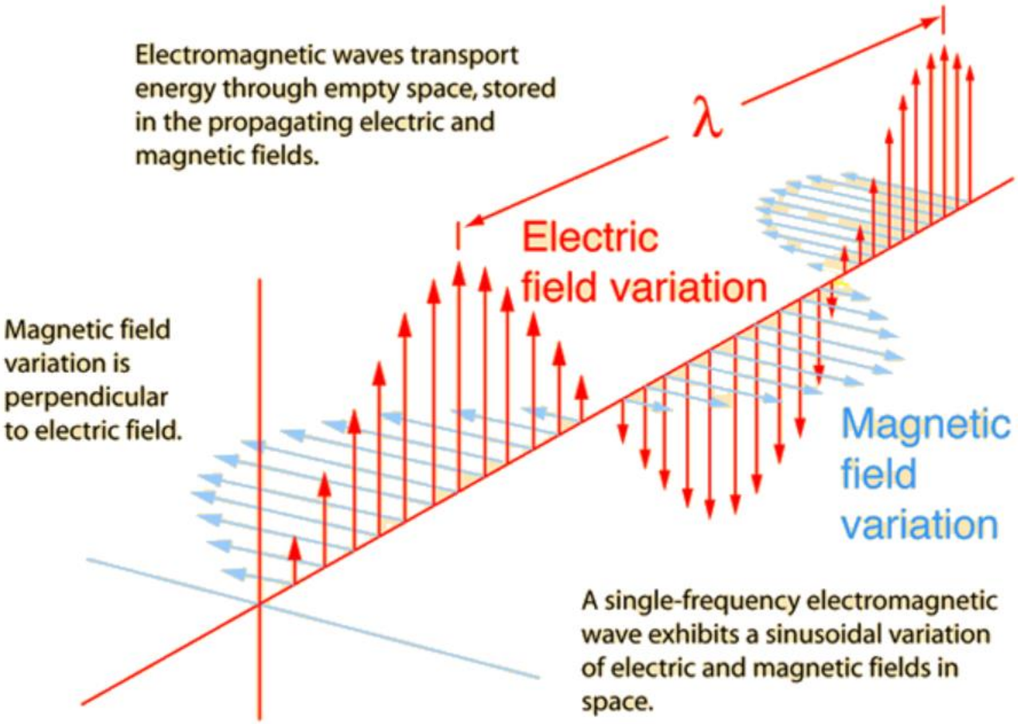
Radiation and Propagation

- Signals generated and processed by transmitter are conveyed over the **CHANNEL** to receiver
- Channel → Physical space between Tx and Rx antenna

- This module deals with…
  - Behavior of these signals in the channel
  - Two concepts -
    - **Electromagnetic Radiation**
    - **Method of Propagation**

- **Electromagnetic Radiation**
- Deals with …
  - Nature of waves as well as the phenomenon of attenuation and absorption they may undergo
  - Effect of environment on waves in terms of phenomenon like reflection, refraction, interference and diffraction
- **Method of propagation**
- Depends on the frequency
- Three main methods of propagation -
  - Around the curvature of the earth – Ground waves
  - By reflection from ionized part of atmosphere – Sky waves
  - In straight line – Space waves
  - Another aspect of microwave propagation is Tropospheric Scatter propagation

Electromagnetic Wave



- When electric power is allowed to escape in free space via use of antenna … it is said to be **radiated**
- Propagates in the form of electromagnetic waves
- Its nature governed by frequency of the wave
- Theory of electromagnetic radiation was propounded by British physicist James Clerk Maxwell

- Basic source of electromagnetic wave is accelerated charge which produces changing electric and magnetic field
- Travels with a velocity of 3×10^8 m/s

http://hyperphysics.phy-astr.gsu.edu/hbase/Waves/emwavecon.html

Concept of Radiation

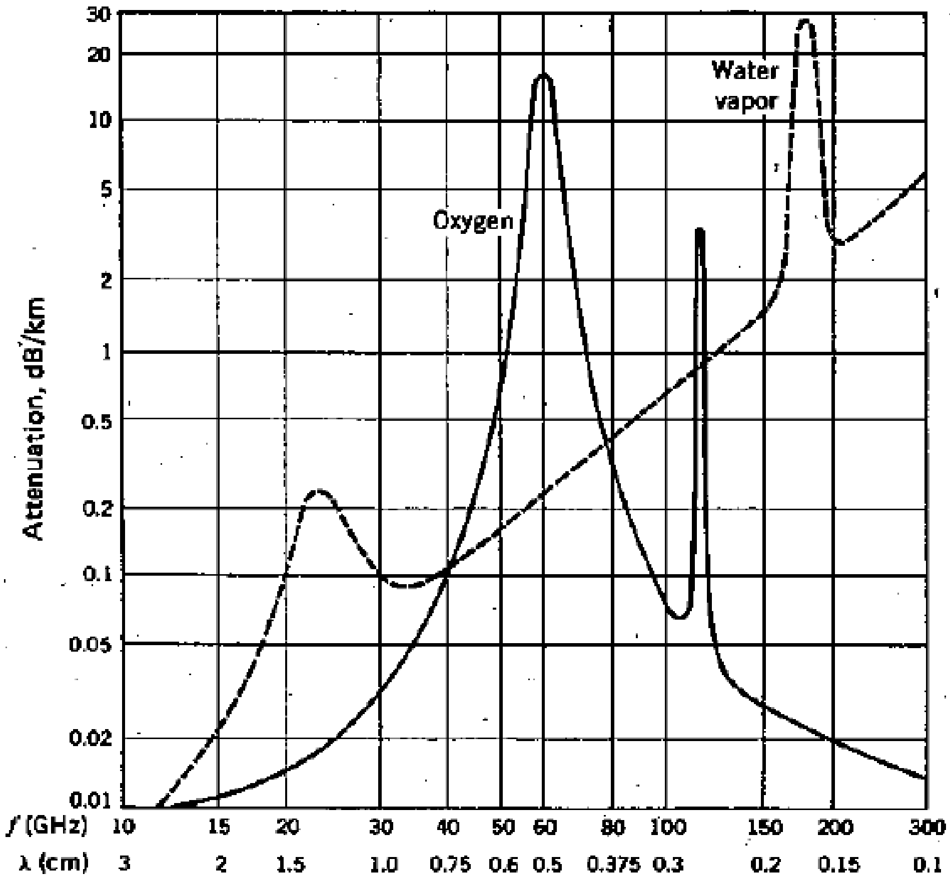
- Antenna radiates em waves as a result of electron flow in a suitable conductor
- Current flowing in a wire is accompanied by a magnetic field around it
- As magnetic field changes as it does with alternating current electric field will be present too
- Part of this electric and magnetic field is capable of leaving the current carrying wire
- How much of it leaves the conductor depends on the relation to its length to wavelength of current
- On the same principle… Reception takes place…

Attenuation and Absorption

- **Attenuation**
- As signal travel, its power density decreases (attenuates) as it travels away from the source
- Decrease in power density (and hence attenuation) is inversely proportional to square of distance from the source

$$P_r = \frac{P_t}{4\pi r^2}$$

- ## Absorption
- When em wave travels in atmosphere, atoms and molecules in atmosphere to absorb some energy which causes them to vibrate
- Very insignificant for frequency < 10 GHz
- Absorption mainly by oxygen and water vapor in atmosphere
- It is a function of humidity…
- Therefore…increases with rain, fog, snow



Atmospheric absorption of electromagnetic waves.

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Effects of Environment

- Effect of environment cannot be neglected…
- It may cause –
  - **Reflection** by ground, mountains and buildings
  - **Refraction** as waves pass through layers of atmosphere that has varying densities
  - **Diffraction** around tall massive objects
- These can then interfere with each other as may reach at different times because they travelled by different paths

Propagation of Waves

- Radiated from an isotropic transmitter, em wave travels through different paths to reach the receiver
- The path taken by the wave to travel from the transmitter and reach the receiver is known as **Wave Propagation**
- Wave propagation path is affected by the atmosphere and Earth
- Dependent on frequency…
  - Frequencies > HF travel in straight line (Space waves) in the troposphere (portion of atmosphere closest to ground)
  - Frequencies < HF travel around curvature of Earth (Ground waves) due to combination of diffraction and a type of waveguide effect using earth's surface and lowest ionized layer of the atmosphere resulting in beyond the horizon propagation
  - Frequencies in HF are reflected by ionized layers of the atmosphere (Sky waves). These waves are beamed into the sky and come down by reflection returning to the Earth well beyond horizon
  - Another beyond the horizon propagation mechanism (UHF) is Tropospheric scatter propagation

Frequency Band		Frequency Range	Characteristics
Extremely low	ELF	< 300 Hz	Ground wave
Infra low	ILF	300 Hz - 3 kHz	
Very low	VLF	3 kHz - 30 kHz	
Low	LF	30 kHz - 300 kHz	
Medium	MF	300 kHz - 3 MHz	Ground/Sky wave
High	HF	3 MHz - 30 MHz	Sky wave
Very high	VHF	30 MHz - 300 MHz	Space wave
Ultra high	UHF	300 MHz - 3 GHz	
Super high	SHF	3 GHz - 30 GHz	
Extremely high	EHF	30 GHz - 300 GHz	
Tremendously high	THF	300 GHz - 3000 GHz	

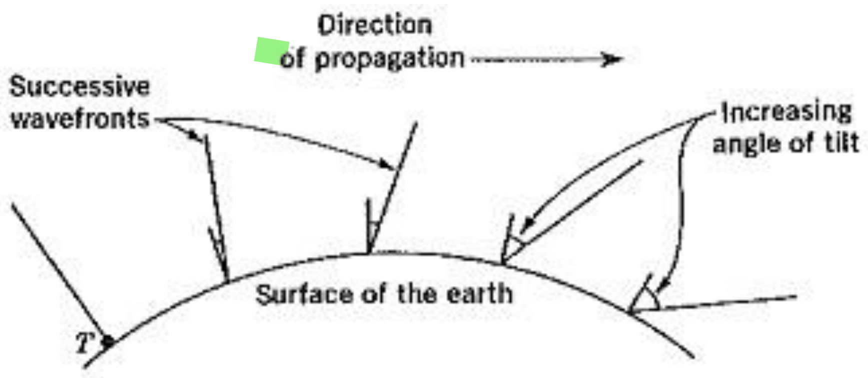
Module VI - Radiation and Propagation of Waves

Lecture 2

- Types of propagation
  - Ground wave propagation
  - Sky wave propagation
  - Space wave propagation
  - Tropospheric scatter propagation

Ground Wave Propagation

- Propagation of radio waves along the surface of the Earth, following the curvature of the Earth



- Earth has one refractive index and the atmosphere has another, thus constituting an interface that supports the surface wave transmission
- Ground waves propagate in vertical, with their magnetic field horizontal and electric field (close to) vertical… Any horizontal component of electric field would be shorted out by the ground.
- So… vertical antenna used
- Waves of long wavelengths more strongly diffracted around obstacles allowing them to follow the Earth's curvature

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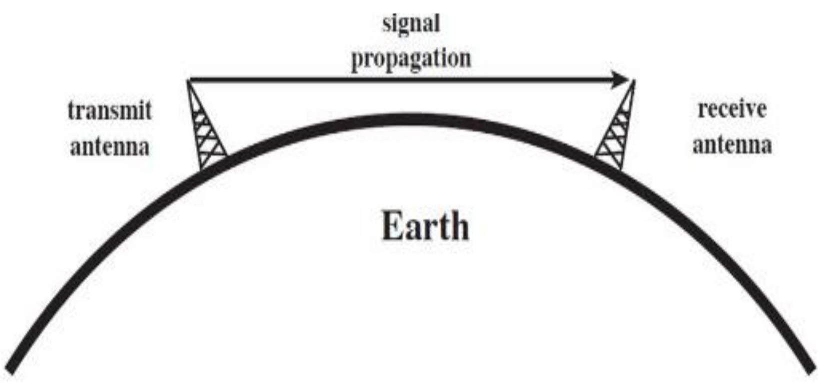
- Energy is lost in propagation and attenuated as it passes over the surface
  - Wave induces current in the ground over which it passes and thus loses some energy by absorption
  - Also wave gets attenuated because of diffraction, the wave gradually tilts over
    - Tilt increases as wave propagates leading to greater short circuiting of electric field component
    - Eventually the lies down and dies
- As ground waves pass over the surface of the earth they are also called the **Surface wave**

- Maximum range of ground wave propagation not only depends on the frequency but also on the power of the transmitter
- When propagation is over a good conductor, like sea water particularly at frequency below 100 kHz, surface absorption is small and so is attenuation due to atmosphere
- Then… only tilt is the determining factor in long distance propagation of this wave
- Degree of tilt depends on the distance from the antenna in wavelengths
    - For HF propagation → wavelength small → tilt higher → wave dies early
    - VLF → has large wavelength → waves able to travel long distances before disappearing (can travel around the globe if sufficient power transmitted)

- Very useful to propagate at low frequencies below about 2 MHz
- Remarkably steady upto 1000 km
- Used in Long distance VLF transmission for applications like
  - Ship communication (10-110 kHz) - Radio navigation and Maritime mobile communication
  - Time and frequency transmission (16 kHz and 17.8 kHz)
- Typically … high powers (1 MW) and tallest possible masts (tallest reported 387 m) used

Space Waves (Line of Sight Propagation)

- Limited in their propagation by curvature of Earth
- Used for microwave transmissions - frequency between 30 MHz to 300 MHz
- Wavelengths are too short for reflection from ionosphere and ground wave disappears very close to transmitter owing to tilt
- Wave reaches receiving antenna directly from transmitter or after reflection from troposphere which is present at about 16 km above the earth surface (ie. space wave mode consists of two components - Direct wave and Indirect wave)



Line-of-sight (LOS) propagation

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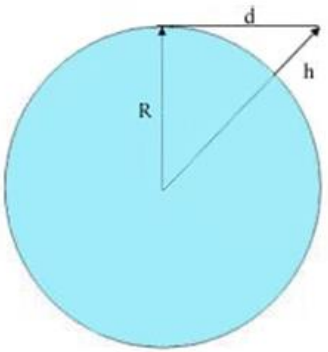
- **Optical horizon**

$$d_o = 3.57\sqrt{h}$$

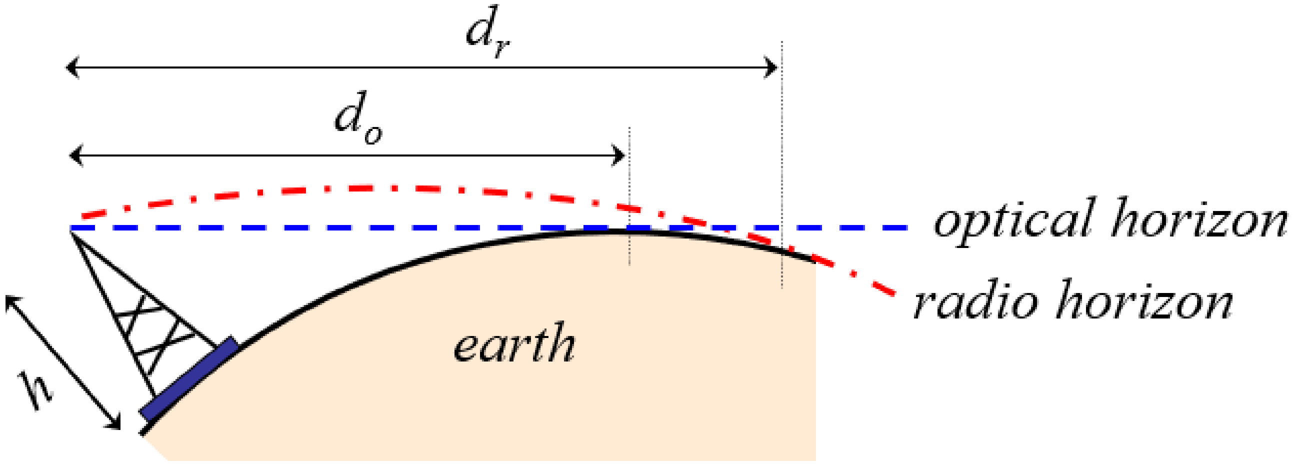
  - d_o is distance from transmitting antenna in km
  - h is height of transmitting antenna in m



$$d^2 = (R+h)^2 - R^2$$
$$= 2 \cdot R \cdot h + h^2$$

Since the altitude of the station is much less than the radius of the Earth,

$$d \approx \sqrt{2 \cdot R \cdot h}$$
$$\approx 3.57 \cdot \sqrt{h}$$

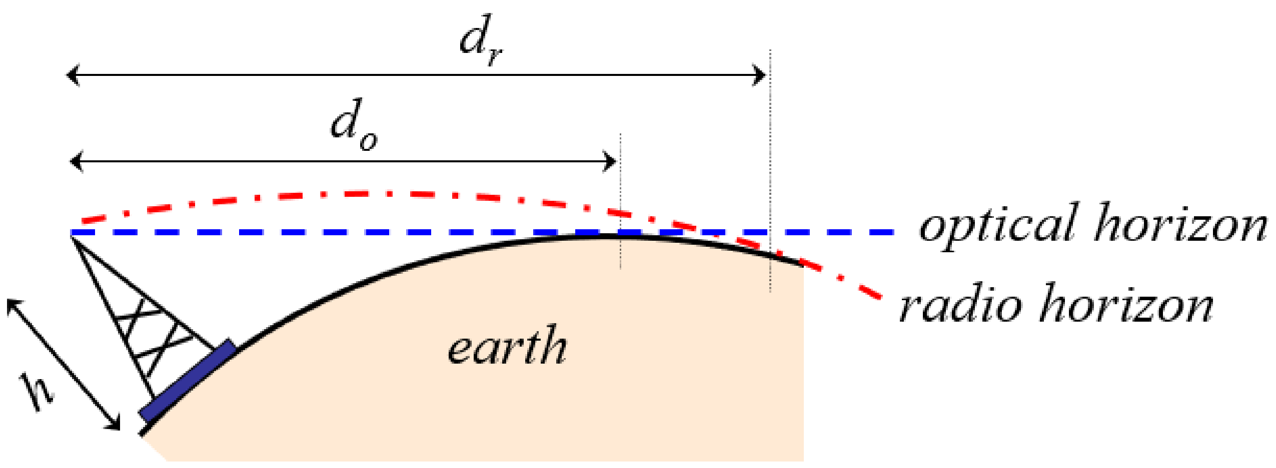


https://en.wikipedia.org/wiki/Line-of-sight_propagation , http://eent3.sbu.ac.uk/staff/baoyb/acs

- **Radio horizon** is caused by varying density of atmosphere and because of diffraction around curvature of Earth
- Radio horizon given by

$$d_r = 3.57\sqrt{Kh}$$

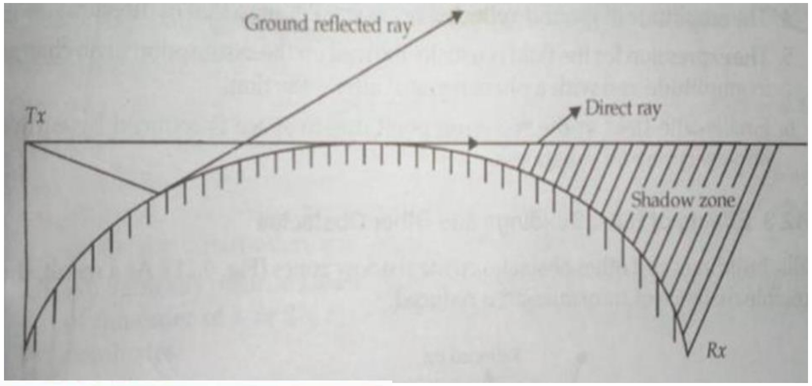
  - K = adjustment factor for refraction, K = 4/3

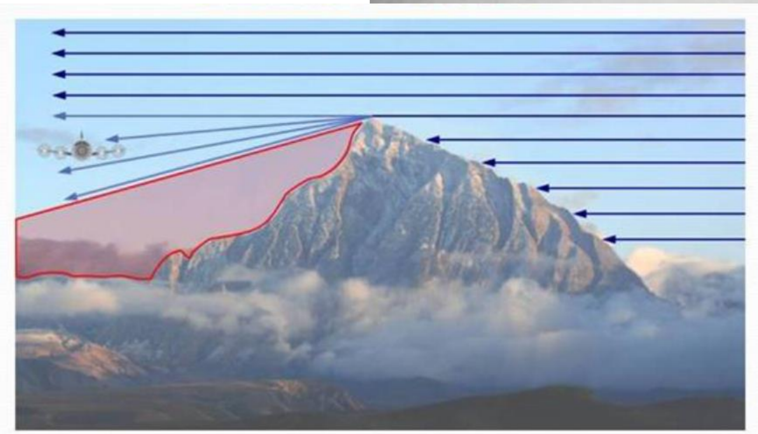


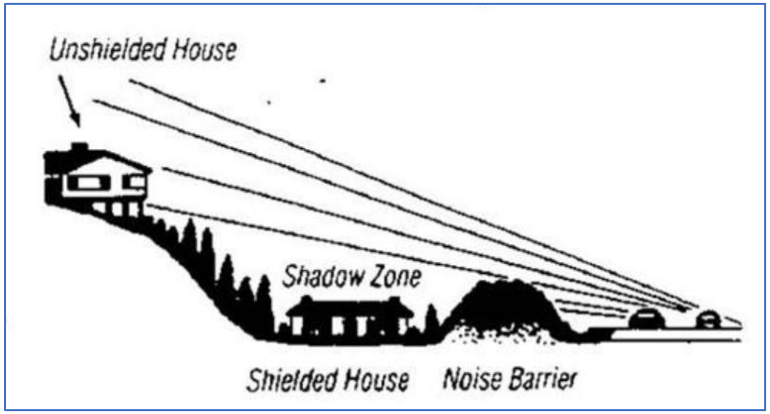
- Distance of communication can be increased by increasing height of antenna
- Links longer than 100 km not generally used

http://eent3.sbu.ac.uk/staff/baoyb/acs

- The curvature of the Earth and tall structures like trees, buildings, hills and mountains impair space wave propagation
- Result in creation of **shadow zones**







http://www.authorstream.com/Presentation/rajofraj01-1347783-antenna-ppt/

- Space waves used in
  - Cell phones
  - Cordless phones
  - Walkie-talkies
  - Wireless networks
  - Point-to-point microwave radio relay links
  - FM and television broadcasting
  - Radar
  - Satellite communication uses longer line-of-sight paths
    - Home satellite dishes receive signals from communication satellites 22,000 miles (35,000 km) above the Earth
    - Ground stations can communicate with spacecraft billions of miles from Earth

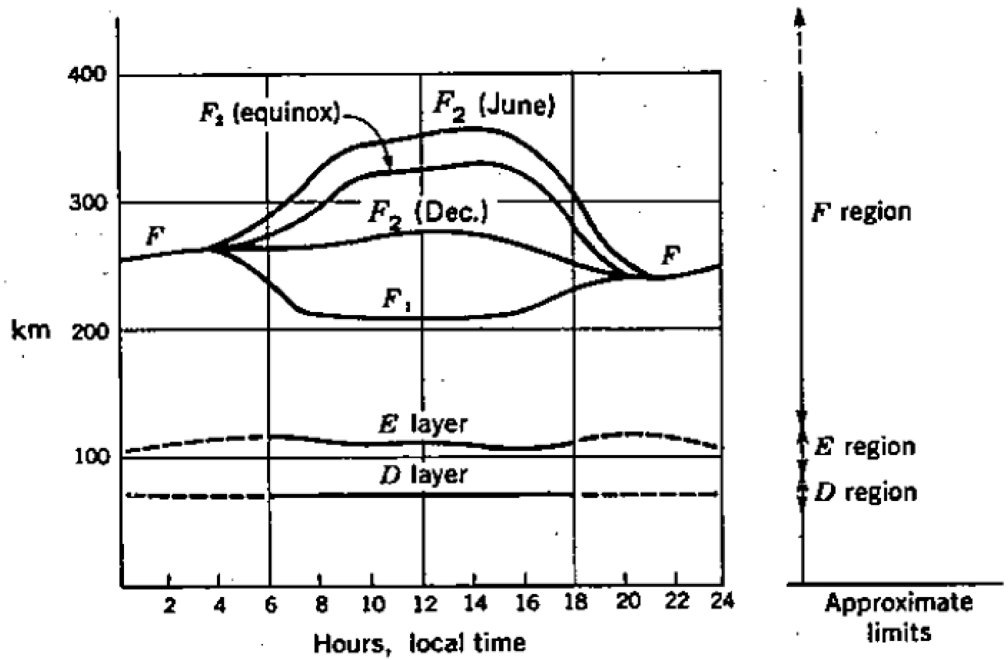
Sky waves

- Medium and high frequencies are conducted using sky wave propagation
- Reflection of EM waves from the ionized region in the upper part of the atmosphere of the earth is used for transmission of waves to longer distances
- This part of the atmosphere is called **ionosphere** which is at about **70-400 km height**. Ionosphere reflects back the EM waves if the frequency is between **2 to 30 MHz**
- Hence, this mode of propagation is also called as Short wave propagation
- Using sky wave propagation point to point communication over long distances is possible
- Typically used for MW and SW radio and amateur radio

- Ionosphere is the upper portion of the atmosphere which absorbs radiant energy from the sun becoming heated and its molecules split into positive and negative ions
- They remain ionized for long periods of time
- There are several layers of ionization at differing heights which reflect back hf waves that would otherwise escape into space
- The physical properties such as temperature density and composition varies and with radiations received, the ionosphere tend to be stratified

- Ionosphere has four layers D, E, F1 and F2
- F1 and F2 combine at night to form a single layer

- **D layer** is the lowest layer existing at a height of 70 km with average thickness of 10 km
- Degree of ionization depends on altitude of sun above the horizon and thus it disappears at night
- Not very significant for HF propagation
- Reflects some VLF and LF waves and absorbs MF



Ionospheric layers and their regular variations

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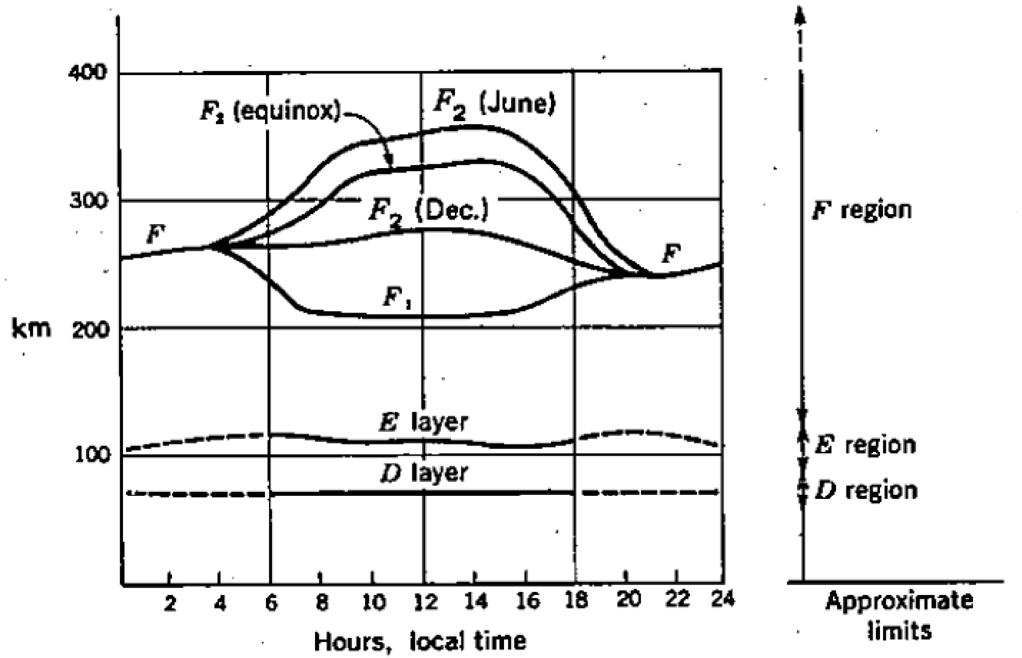
- **E layer** is next at a height of about 100km with a thickness of 25 km
- Disappears at night due to recombination of ions into molecules
- Aids MF surface wave transmission and reflect HF waves in daytime



Ionospheric layers and their regular variations

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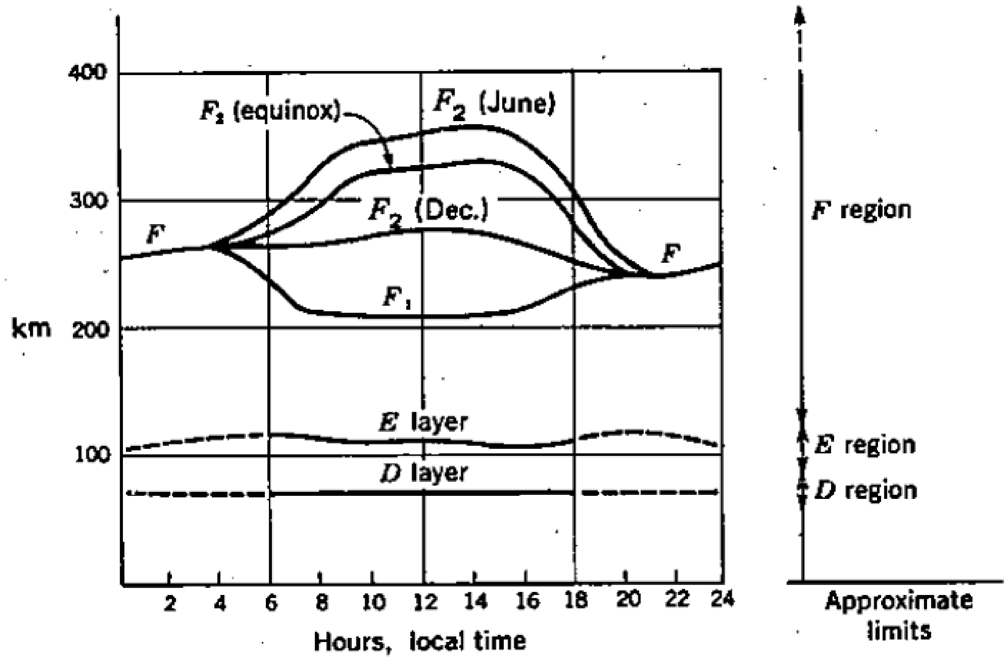
- **F1 layer** exists at a height of 180 km in daytime and combines with F2 layer at night
- Daytime thickness is about 20 km
- Some HF waves do reflect but most pass through F1 to be reflected by F2 layer
- Main effect of F1 is to provide more absorption for HF waves



Ionospheric layers and their regular variations

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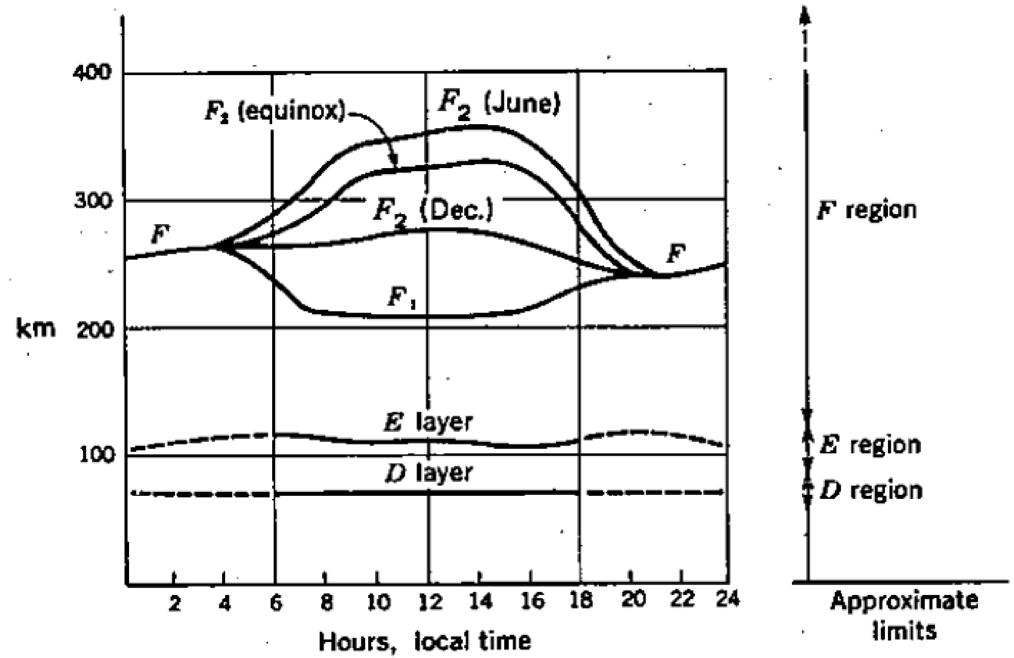
- **F2 layer** is the most important reflecting medium for HF waves
- Approximate thickness can be 200 km and its height ranges from 250-400 km in daytime
- At night it falls to a height of 300 km where it combines with F1 layer
- Its height and ionization density vary depending on time of the day, average ambient temperature and sun-spot cycle



Ionospheric layers and their regular variations

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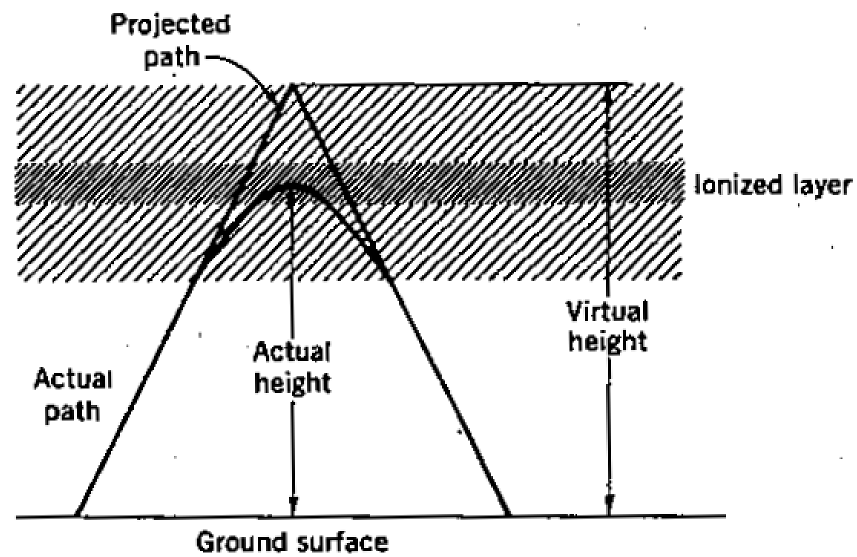
- **Reflection Mechanism**
- Electromagnetic waves returned to earth by one of the layers of the ionosphere and appear to have been reflected
- Actually, the mechanism involved is refraction
- As the ionization density increases for a wave approaching the given layer at an angle, so the refractive index of the layer is reduced.
- Hence the incident wave is gradually bent farther and farther away from the normal
- If the rate of change of refractive index is sufficient, the refracted ray will eventually become parallel to the layer
- It will then be bent downward, finally emerging from the ionized layer at an angle equal to the angle of incidence
- Some absorption has taken place, but the wave has been returned by the ionosphere (well over the horizon if an appropriate angle of incidence was used)

- # Terms and Definitions
- ## Virtual height
- As the wave is refracted, it is bent down gradually rather than sharply
- However, the path of incident wave and reflected wave are same if it is reflected from a surface located at a greater height of this layer.
- Such a greater height is termed as virtual height.
- If the virtual height is known, the angle of incidence can be found.



Actual and virtual heights of an ionized layer

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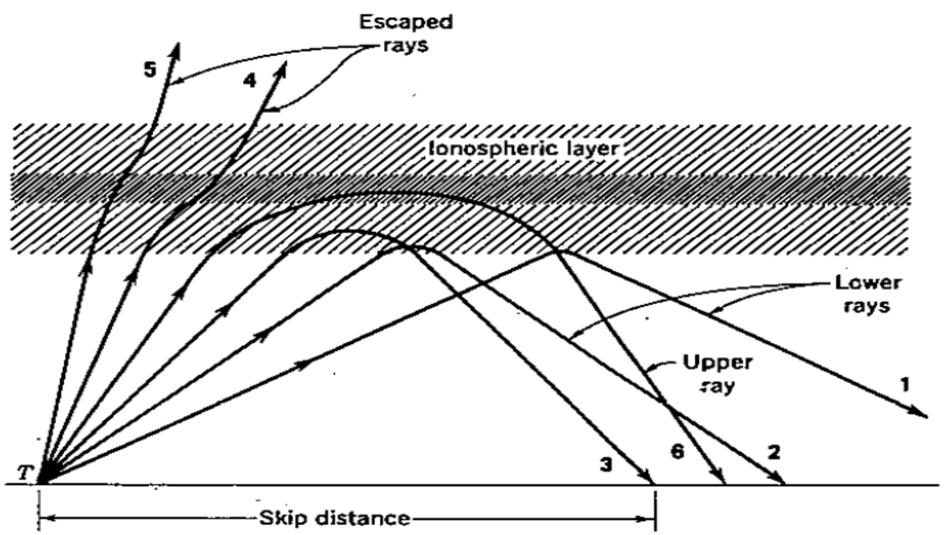
- **Critical frequency (f_c) –**
- For a given layer, it is the highest frequency that will be returned down to earth by that layer after having been beamed straight up at it
- This maximum value exists under a given set of conditions
- In practice, its value ranges from 5 to 12 MHz for the F2 layer



Effects of ionosphere on rays of varying incidence

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- **Maximum usable frequency (MUF)**
- Also called as limiting frequency, but this time for some specific angle of incidence other than the normal
- If the angle of incidence (between the incident ray and the normal) is θ, it follows that

$$MUF = \frac{critical\ frequency}{\cos\theta} = f_c \sec\theta$$

- This is the so-called secant law and it is very useful in making preliminary calculations for a specific MUF
- It is alternatively defined at the highest frequency that can be used for sky-wave communication between two given points on earth
- There is a different value of MUF for each pair of points on the globe
- Normal values of MUF may range from 8 to 35 MHz

- **Skip distance**
- It is the shortest distance from a transmitter, measured along the surface of the earth, at which a sky wave of fixed frequency (more than f_c) will be returned to earth
- It is seen that the frequency which makes a given distance correspond to the skip distance is the MUF for that pair of points

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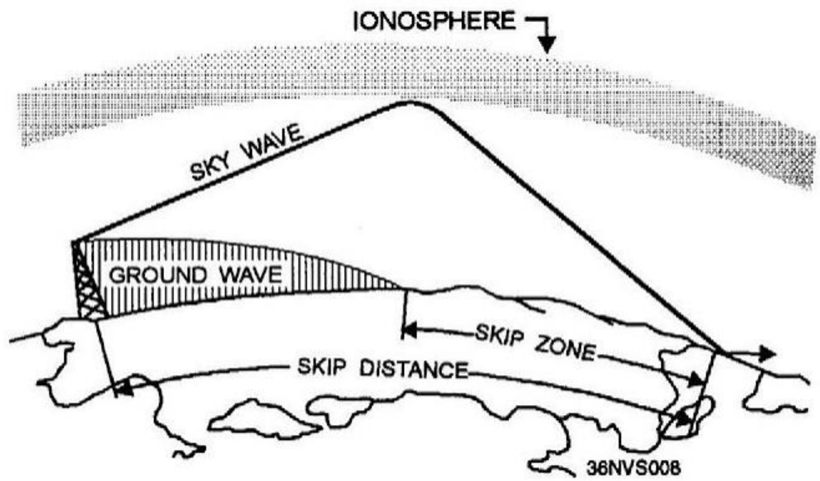
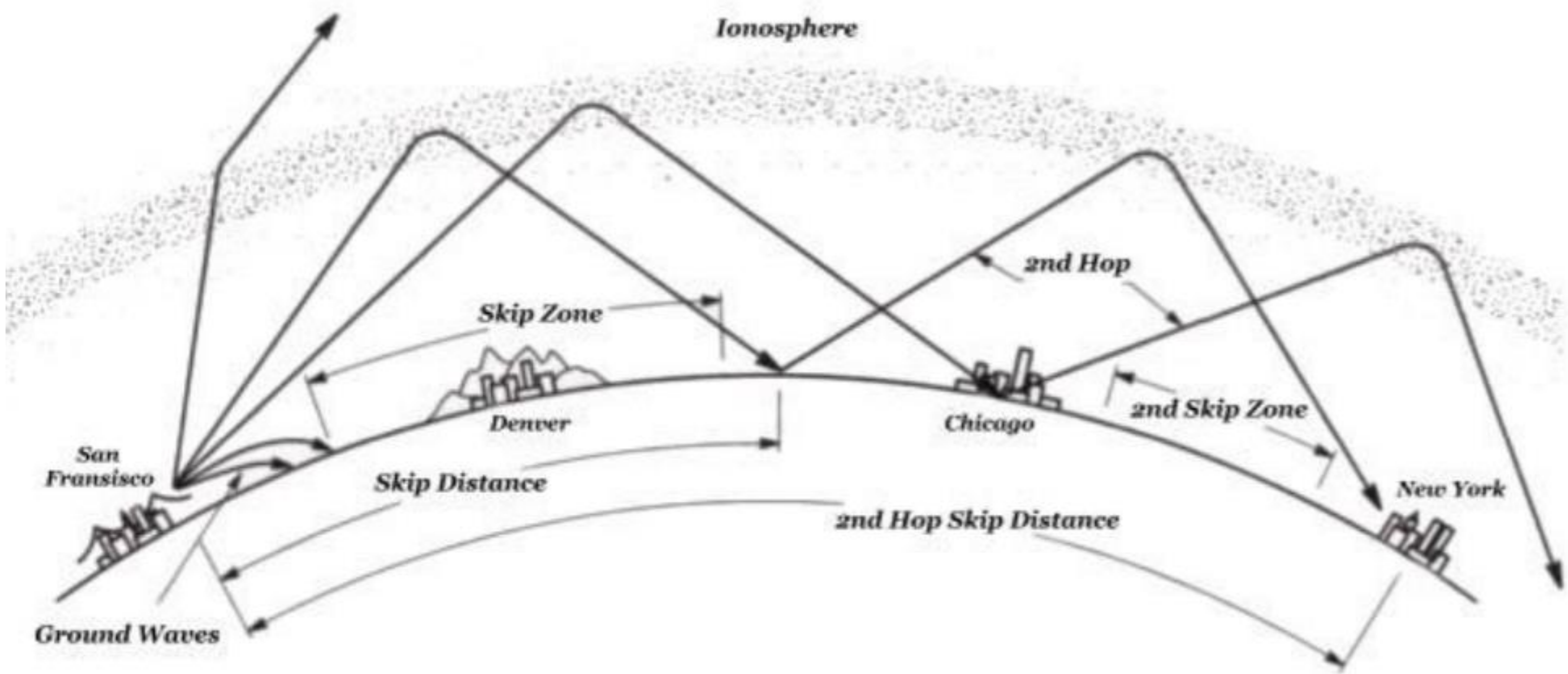
- **Skip zone**
- When using MF to HF, there are waves which travel both parallel to the ground, and towards the ionosphere, referred to as a ground wave and sky wave, respectively
- A skip zone is an annular region between the furthest points at which the ground wave can be received and the nearest point at which the refracted sky waves can be received
- No signal is heard in the Skip Zone



Relationship between skip zone, skip distance, and ground wave.

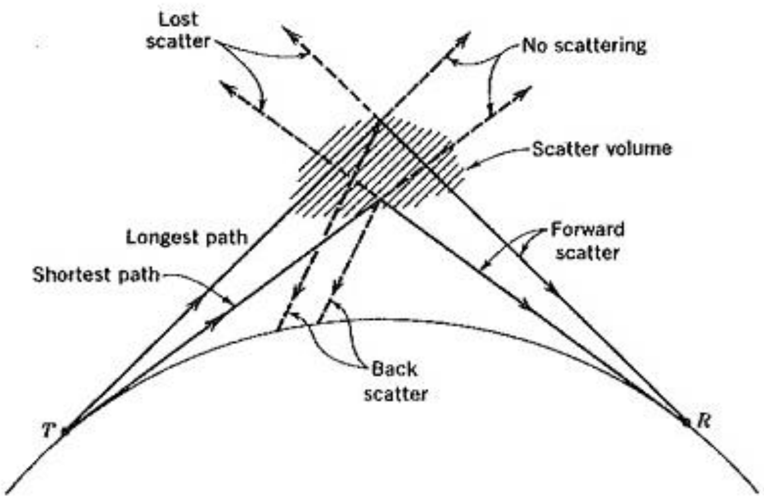
https://en.wikisource.org/wiki/Page:Electronics_Technician_-_Volume_7_-_Antennas_and_Wave_Propagation_-_NAVEDTRA_14092.pdf/15



https://www.bugoutbagbuilder.com/blog/understanding-radio-wave-propagation

Tropospheric Scatter Propagation

- Is a means for beyond the horizon propagation or beyond line-of-sight transmission for UHF signal
- Best frequencies – 200 MHz, 2000 MHz, 5000 MHz
- Uses properties of troposphere (within 15 km from surface of earth)
- A radio wave beamed slightly above the horizon can be scattered at altitudes up to several km, making over-the-horizon communication possible
- Largest communication range can be realized over flat land or over water
- Scattered waves are weak, so high-power transmitters and sensitive receivers are necessary



Tropospheric scatter propagation

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- Troposcatter relies on the fact that there are areas of slightly different dielectric constant in the atmosphere
- Two directional antennas are pointed so that their beams intersect midway between them above the horizon
- Two theories –
  - Reflection from blobs in atmosphere
  - Reflection from atmospheric layers
- Used for long distance telephone and other communication links as an alternative to microwave links or coaxial cables over rough or inaccessible terrain
- Path links typically 300-500 km long
- Typically, proportion of forward scatter to incident power is very less… therefore… high transmitting power needed