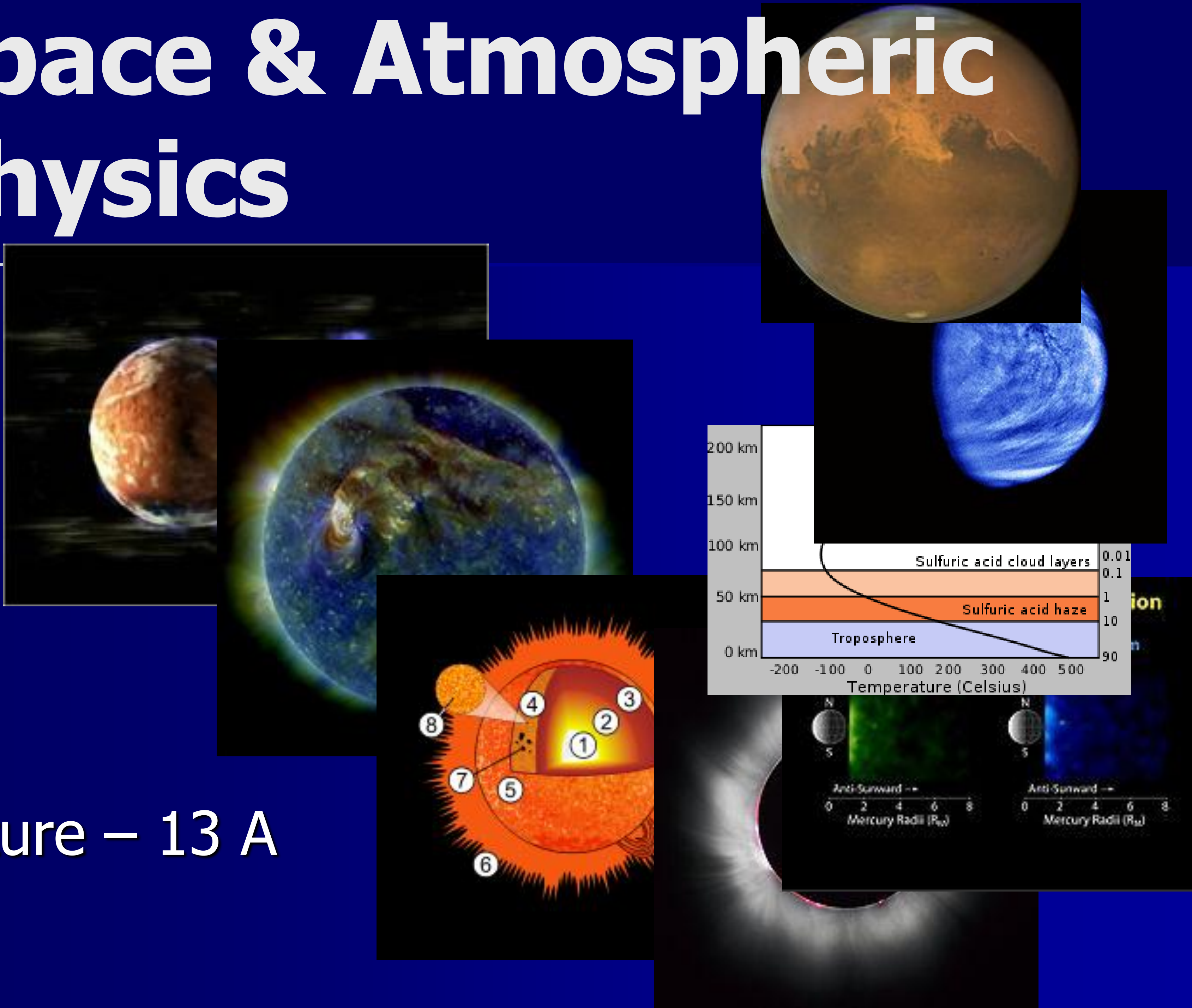
# Space Physics

# Space & Atmospheric Physics

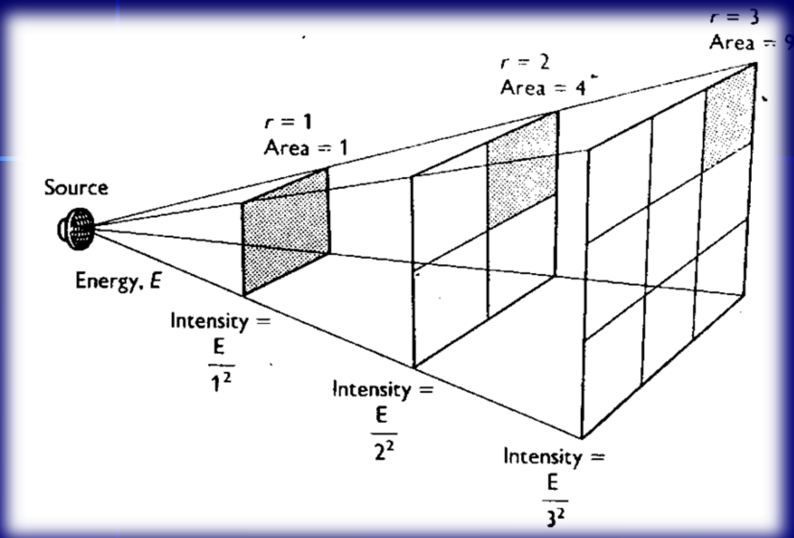



Lecture – 13 A

# Radio Wave Communication

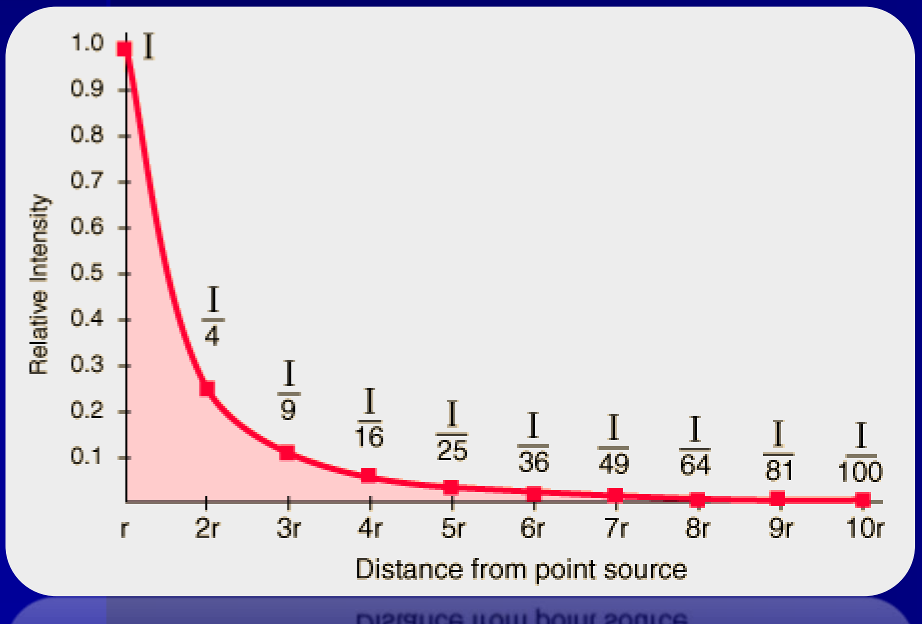
Radio waves
Radio Communication
Reflection of Radio Waves
Absorption of Radio Waves
Complex Refractive Index
Reflection Heights
Deviating Region Absorption, Non-Deviating Region Absorption
Ordinary/Extra Ordinary Waves
Ionosphere – Sounding Techniques
Pulse Reflection Methods

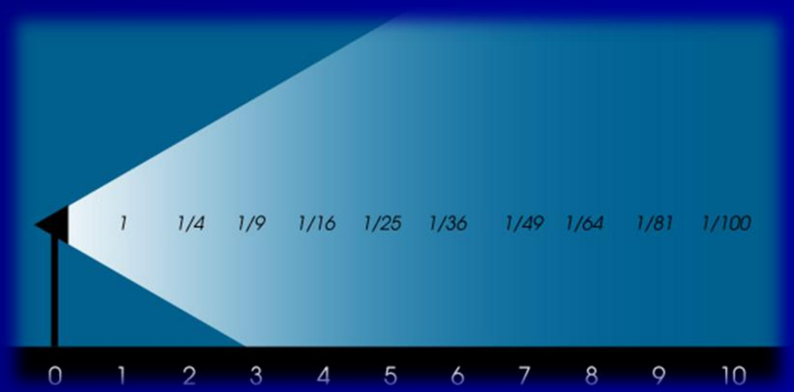
# Free Space Propagation




In free space all EM waves obey the **Inverse Square law** which states that the **power density of an EM wave** is proportional to the **inverse of the square of the distance from the Source**.

$$\rho_p \quad \alpha \quad \frac{1}{r^2}$$

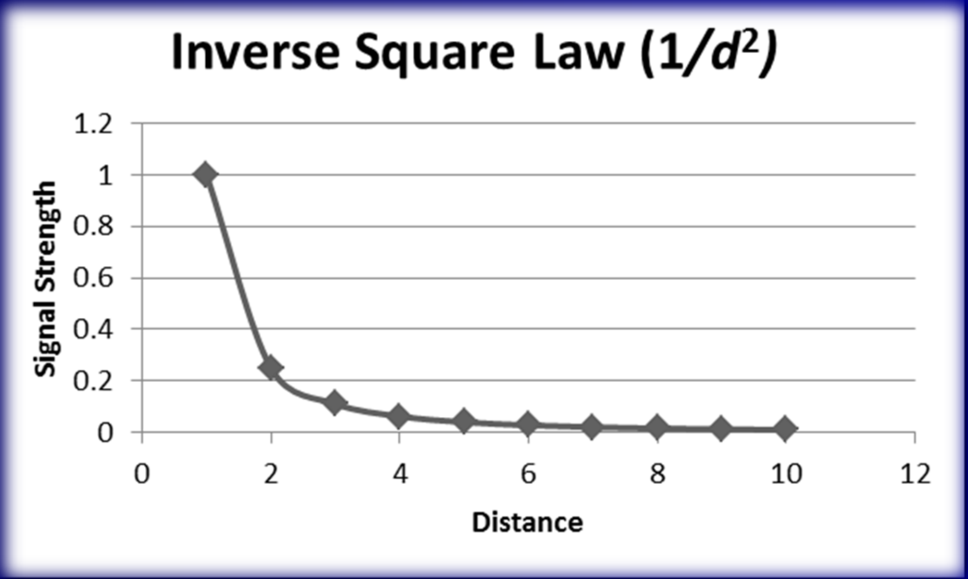


# Free Space Propagation

Doubling the distance from a transmitter means that the power density of the radiated wave at that new location is reduced to one quarter of its previous value !

The power density per surface unit is proportional to the product of the electric and magnetic field strengths. Thus, **doubling the propagation path distance from the transmitter reduces each of their received field strengths over a free-space path by one half.**



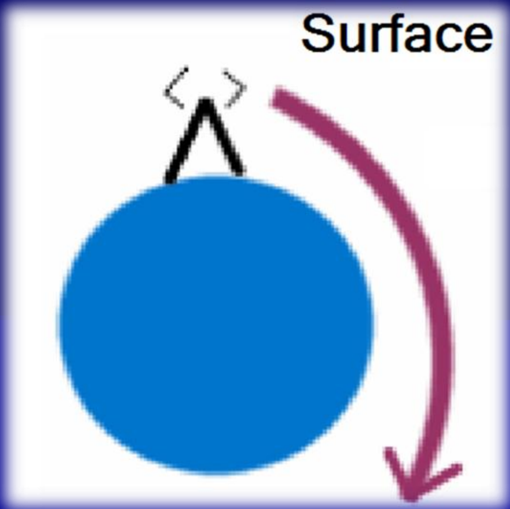
# Modes

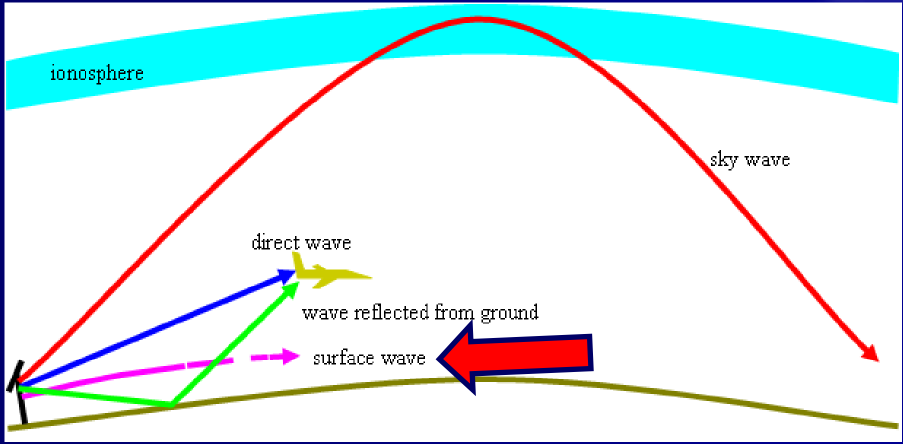
| Band | | Frequency | Wavelength | Propagation via |
|---|---|---|---|---|
| VLF | Very Low Frequency | 3–30 kHz | 100–10 km | Guided between the earth and the ionosphere. |
| LF | Low Frequency | 30–300 kHz | 10–1 km | Guided between the earth and the D layer of the ionosphere. Surface Waves. |
| MF | Medium Frequency | 300–3000 kHz | 1000–100 m | Surface waves.<br>E, F layer ionospheric refraction at night, when D layer absorption weakens. |
| HF | High Frequency (Short Wave) | 3–30 MHz | 100–10 m | E layer ionospheric refraction.<br>F1, F2 layer ionospheric refraction. |
| VHF | Very High Frequency | 30–300 MHz | 10–1 m | Infrequent E ionospheric refraction. Extremely rare F1, F2 layer ionospheric refraction during high sunspot activity up to 80 MHz. Generally direct wave. Sometimes tropospheric ducting. |
| UHF | Ultra High Frequency | 300–3000 MHz | 100–10 cm | Direct wave. Sometimes tropospheric ducting. |
| SHF | Super High Frequency | 3–30 GHz | 10–1 cm | Direct wave. |
| EHF | Extremely High Frequency | 30–300 GHz | 10–1 mm | Direct wave limited by absorption. |

# Propagation Modes

Surface Modes :

Lower frequencies (between 30 kHz – 3000 kHz) have the property of the curvature of the Earth via ground wave propagation in the majority of occurrences.



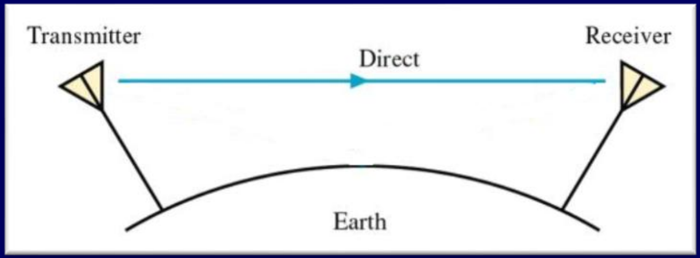




Ground waves are attenuated rapidly as they follow the Earth's surface. Attenuation is proportional to the frequency making this mode mainly useful for LF and VLF frequencies.

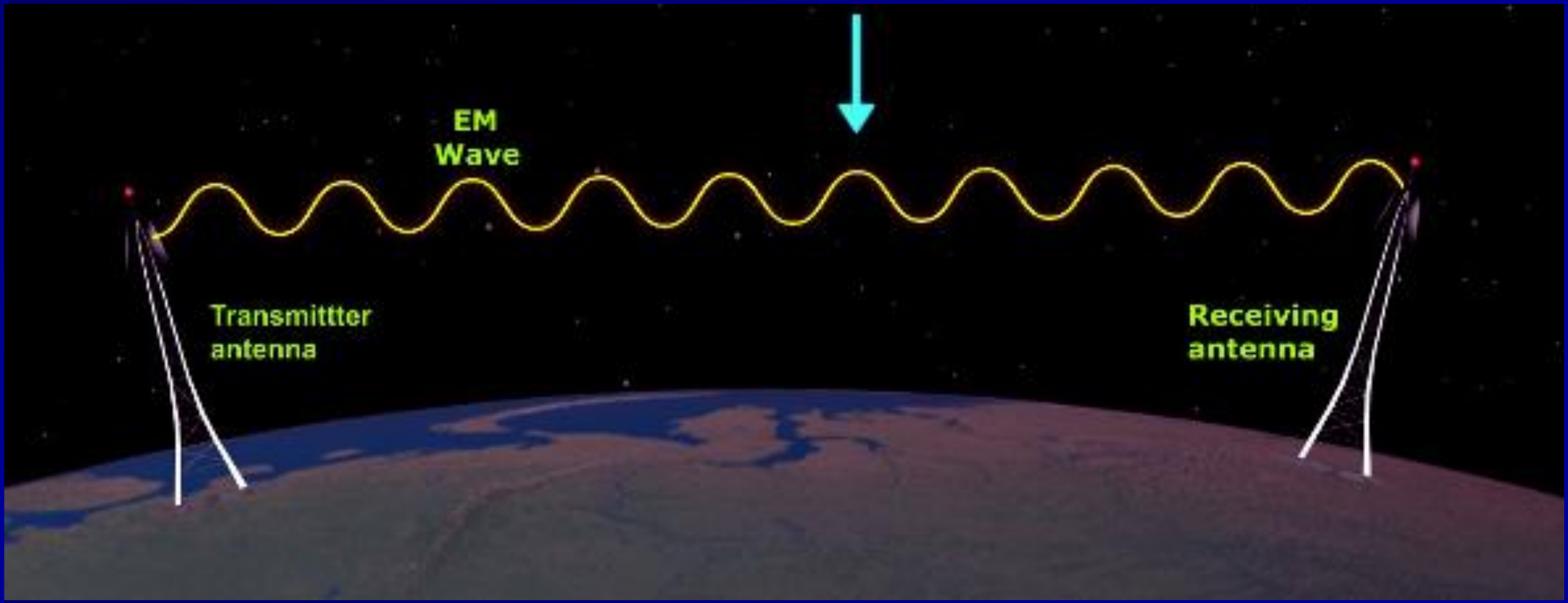
$$Attenuation \quad \alpha \quad f$$

# Propagation Modes

Direct Modes : (line-of-sight)



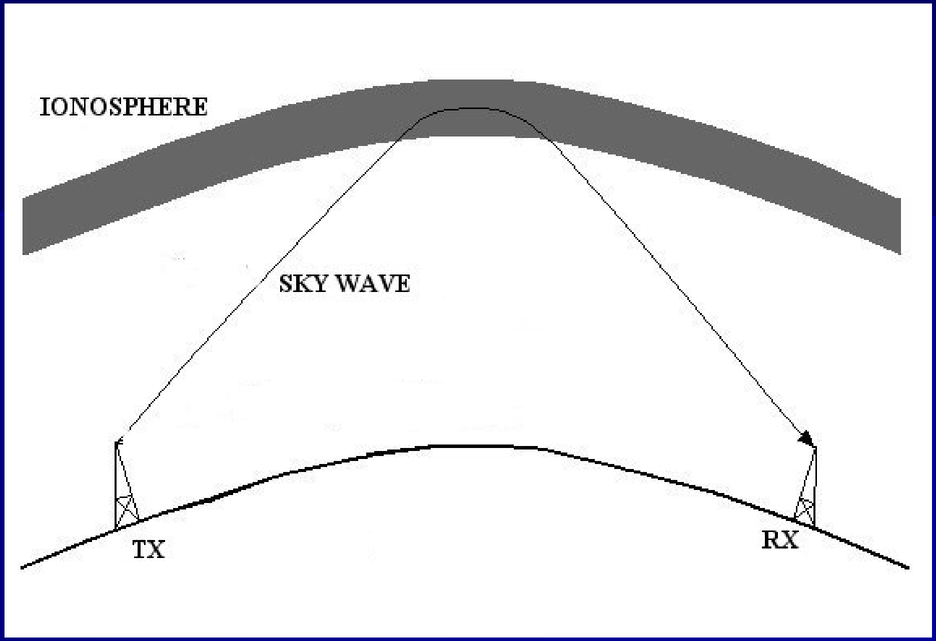

Line of sight is the **direct propagation of radio waves between antennas** that are visible to each other. This is probably the most common of the radio propagation modes **at VHF and higher frequencies**



# Propagation Modes

Ionospheric Modes :

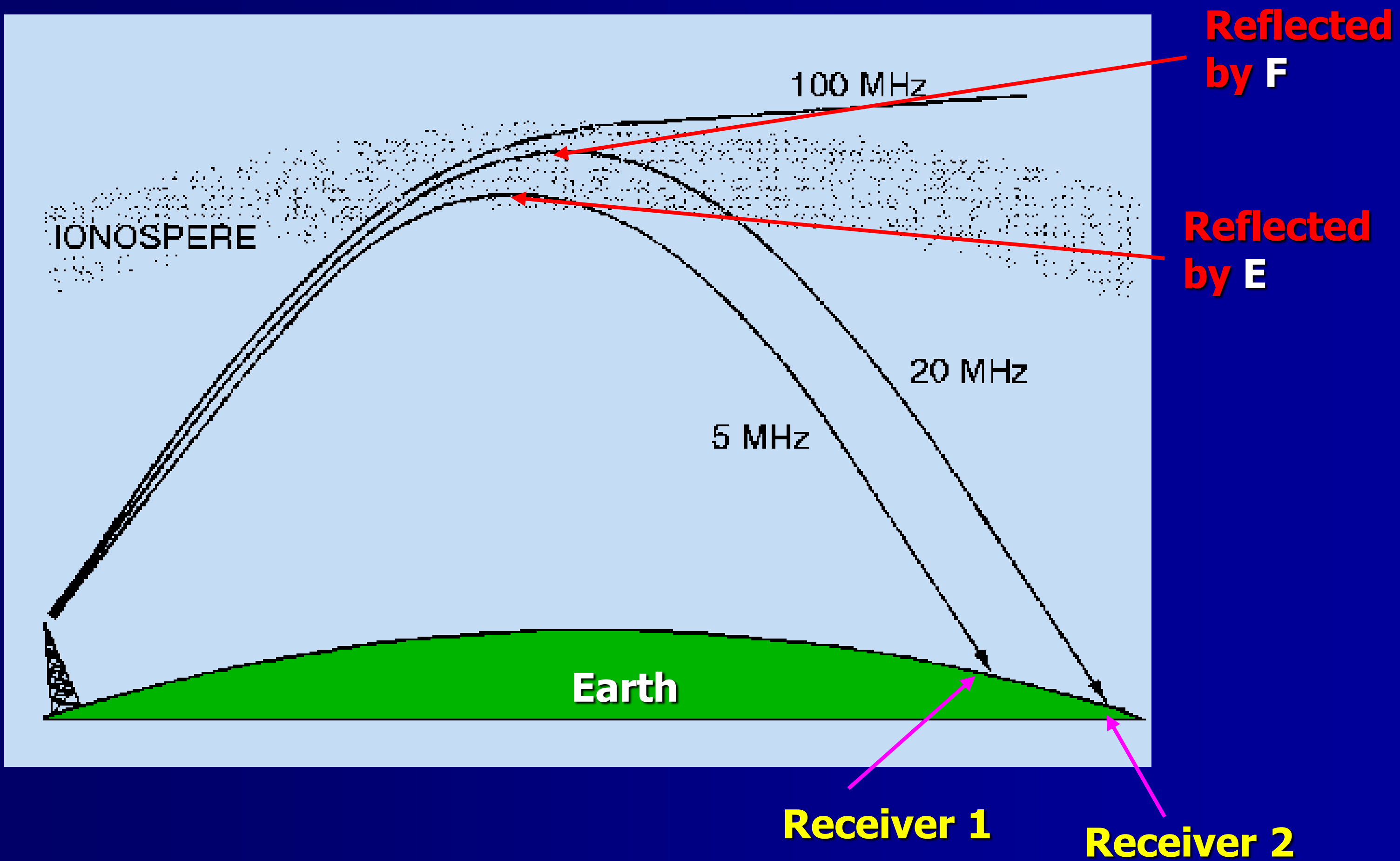
Sky wave propagation, also referred to as skip, is any of the modes that rely on **refraction** of radio waves in the **ionosphere**, which is made up of one or more ionized layers in the upper atmosphere




**$F_2$ layer** is the most important ionospheric layer for **HF** propagation, through **$F_1$**, **E** and **D** layers also play some role. These layers are directly affected by the Sun on a daily cycle, the reasons and the **11-year sunspot cycle** determines the utility of these modes. During **solar maxima**, the whole **HF range** up to **30 MHz** can be used and **$F_2$** propagation up to **50MHz** are observed frequently depending upon daily solar flux values. During **solar maxima**, **propagation of higher frequencies is generally worse**.

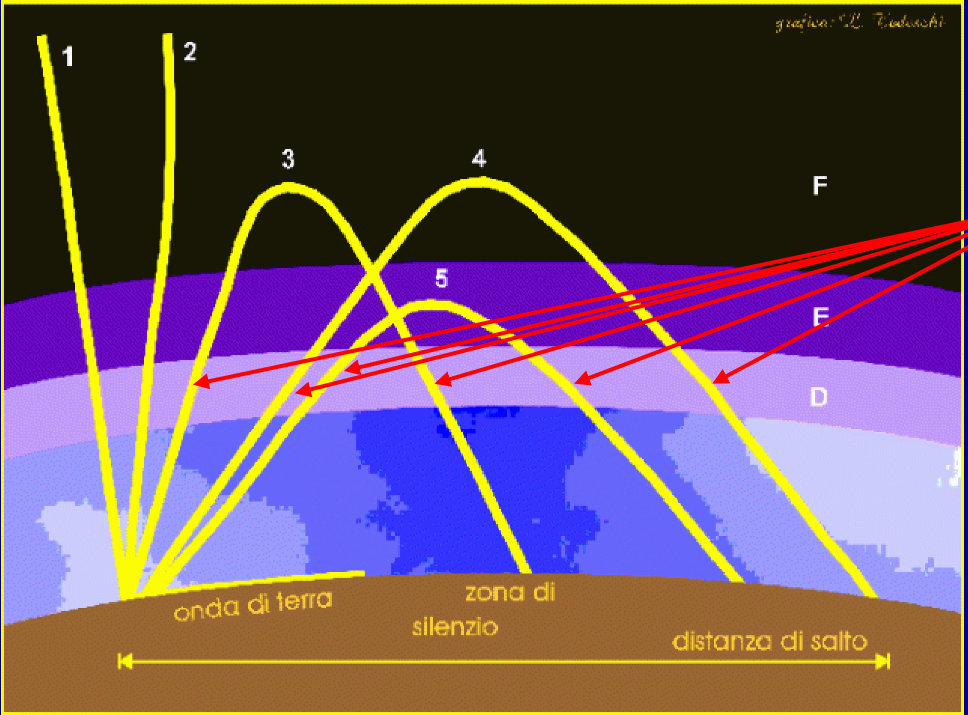
# Reflection of Radio Waves

Generally, radio waves reflected by E and F regions, because that ionosphere E and F have more electron densities compared to the region D.



# Reflection of Radio Waves

- Always radio waves **absorbed by the region D** in the ionosphere. That is a main problem of the radio communication.

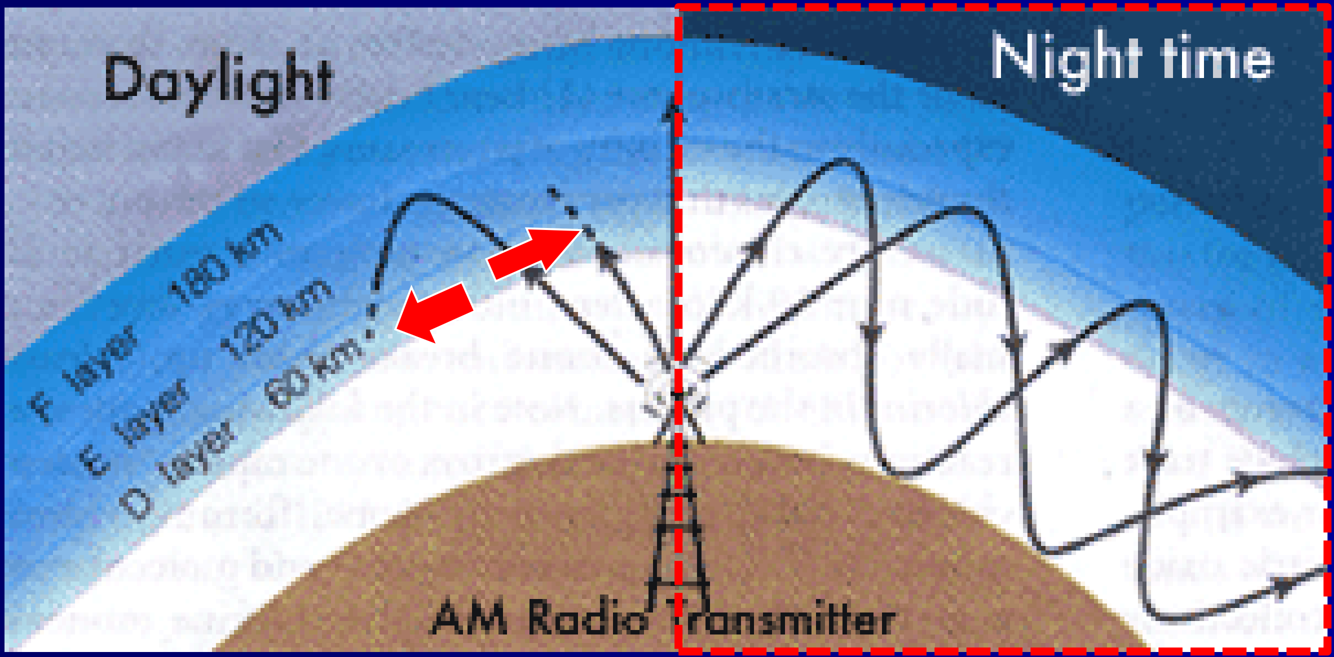



Absorbed by **D**

Because in the day time, radio waves reflected from the region E and F. But always the waves are going through the region D twice. (incident beam and reflected beam)

# Reflection of Radio Waves

- In the Night time region **D** of the ionosphere vanishing suddenly, because the Sun goes down. But **E** and **F** regions are not destroying suddenly, specially the region **F** ($F_2$)




**As a result SW radio broadcasting lines can listen very clearly at the night.**

Eg: BBC Sandeshaya

BBC NEWS සිංහල

මුල් පිටුව ශ්‍රී ලංකා ලෝකය විශේෂාංග

**ශ්‍රී ලංකාවේ වේලාවෙන් දිනපතාම රාත්‍රී 9:15 ට කෙටි තරංග 19 (15690 kHz), කෙටි තරංග 22 (13630 kHz) සහ කෙටි තරංග 41 (7435 kHz) ඔස්සේ බීබීසී සිංහල සේවයේ සංදේශය වැඩසටහන ගුවන්ගත වේ.**

බ්‍රිතාන්‍යයේ දී 16:45 GMT

# ජාතික ජන බලවේගයේ විරෝධතාව අතරතුර තුවාල ලබා රෝහල්ගත කර සිටි පුද්ගලයෙක් මිය යයි

NPP|FACEBOOK

26 පෙබරවාරි 2023
යාවත්කාලීනවී ඇත පැය 4 කට පෙර

පළාත් පාලන මැතිවරණය පවත්වන්නැයි ඉල්ලා ජාතික ජනබලවේගය කොළඹ දී පැවැත්වූ විරෝධතාව අතරතුර කොළඹ ජාතික රෝහලට ඇතුලත් කර සිටි පුද්ගලයෙකු අද (පෙබරවාරි 27 වැනිදා) මිය ගියේය.

මෙලෙස මිය ගොස් ඇත්තේ, ජාතික ජනබලවේගයේ නිවිතිගල ප්‍රාදේශීය සභා අපේක්ෂක නිමල් අමරසිරිය.

මිය යන විට ඔහු 61 වැනි වියේ පසුවිය.

ජාතික ජනබලවේගය පෙබරවාරි 26 වැනිදා පැවැත්වූ විරෝධතාව විසුරුවා හැරීමට පොලීසිය කඳුළු ගෑස් සහ ජල ප්‍රහාර එල්ල කරනු ලැබිය.

ජාතික ජන බලවේගයේ

# ශ්‍රී ලංකා මානව හිමිකම් කොමිසම පැය 24ක් ඇතුළත පූර්ණ වාර්තාවක් කැඳවයි..

ජාතික ජනබලවේගයේ විරෝධතාවට එල්ල වූ ජල හා කඳුළු ගෑස් ප්‍රහාරවලින් පුද්ගලයින් පිරිසක් තුවාල ලැබීමේ සිද්ධිය පිළිබඳව පැය 24ක් ඇතුළත පූර්ණ වාර්තාවක් ලබා දෙන්නැයි, ශ්‍රී ලංකා මානව හිමිකම් කොමිසම පොලිස්පතිට දැනුම්දී තිබේ.

මානව හිමිකම් කොමිෂන් සභාව නිවේදනයක් නිකුත් කරමින් පවසන්නේ, ශ්‍රී ලංකා මානව හිමිකම් කොමිෂන් සභාව ද මේ සම්බන්ධයෙන් කඩිනම් පරීක්ෂණයක් ආරම්භ කර ඇති බවයි.

වාර්තාවේ කරුණු පදනම් කර ගෙන ඉදිරි පරීක්ෂණ සිදු කරන බව ද එහි දැක්වෙයි.

Human Rights Commission of Sri Lanka

මාධ්‍ය නිවේදන අංක: HRC/P/i/S/27/02/23

**මාධ්‍ය නිවේදනය**

ජාතික ජන බලවේගය 2023 පෙබරවාරි මස 26 වන දින ක්‍රියාත්මක කරන ලද විරෝධතා පා ගමන කොළඹ කොම්පඤ්ඤවීදිය පොලිස් බල ප්‍රදේශයේ යූනියන් පෙදෙස ප්‍රදේශයේ ක්‍රියාත්මක වන අවස්ථාවේදී, එම ප්‍රදේශය විරෝධතා පා ගමන් පැවැත්වීම තහනම් කරමින් අධිකරණ නියෝග නිකුත් කර නොතිබූ තත්වයක් තුළ ජල හා කඳුළු ගෑස් ප්‍රහාර එල්ලවීමත් සහ එම අවස්ථාවේ දී පුද්ගලයින් 28 දෙනෙකු පමණ තුවාල ලැබීම සම්බන්ධයෙන් ශ්‍රී ලංකා මානව හිමිකම් කොමිෂන් සභාව අවධානය යොමු කර ඇත.

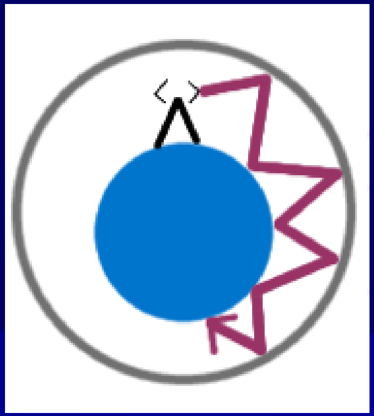
ඒ අනුව මෙම සිද්ධිය සම්බන්ධයෙන් ශ්‍රී ලංකා මානව හිමිකම් කොමිෂන් සභාව විසින් කඩිනම් පරීක්ෂණයක් ආරම්භ කර ඇති අතර, උක්ත සිදුවීම සම්බන්ධයෙන් 2023 පෙබරවාරි මස 28 (එනම් පැය 24ක කාලයක් ඇතුළත) වන දින පූර්ණ වාර්තාවක් ශ්‍රී ලංකා මානව හිමිකම් කොමිෂන් සභාව වෙත ලබාදෙන ලෙස පොලිස්පතිවරයා වෙත දන්වා යවා ඇත. එම වාර්තාවේ කරුණු පදනම් කරගෙන ඉදිරි පරීක්ෂණ කටයුතු සිදුකරනු ලැබේ.

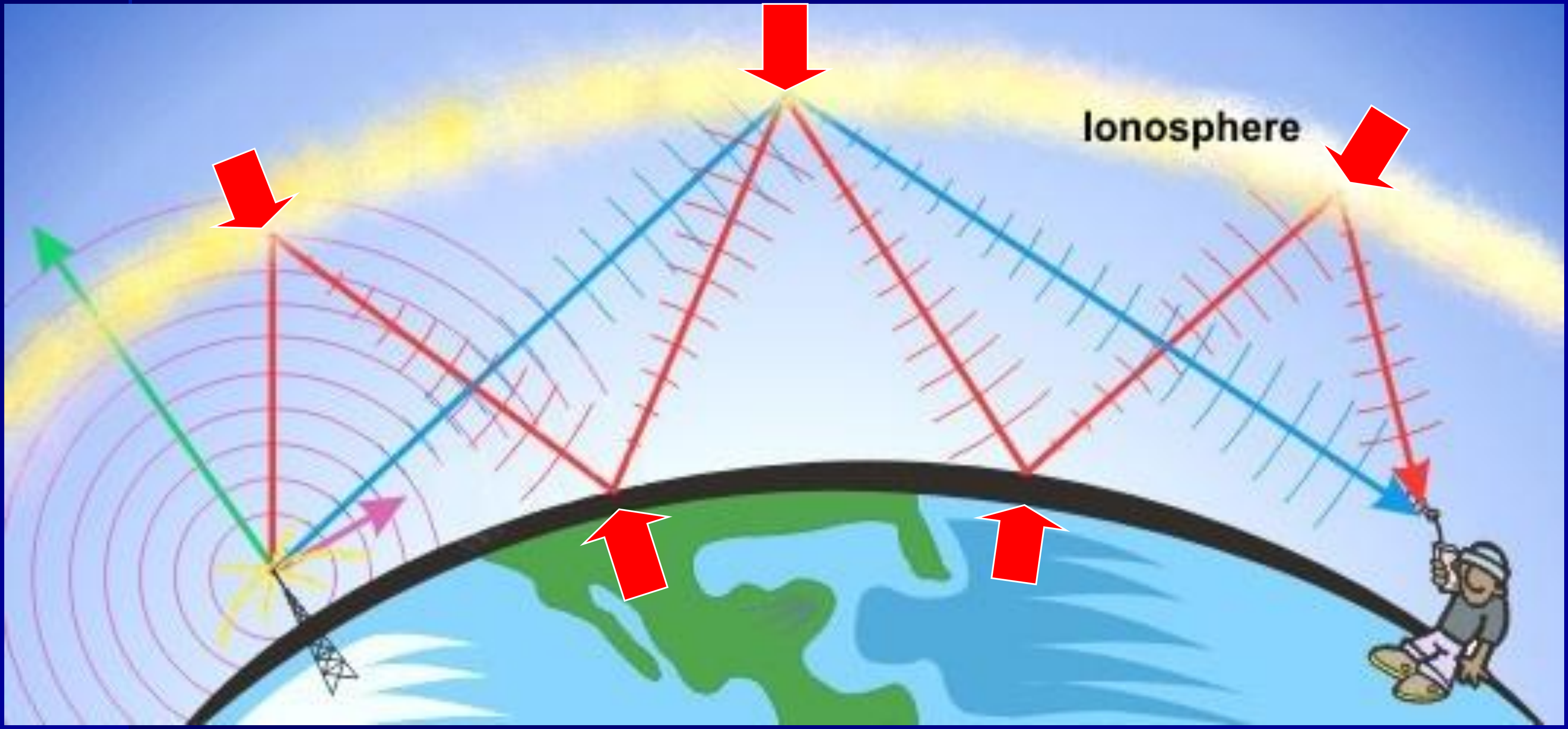
මාධ්‍ය ප්‍රකාශක
ශ්‍රී ලංකා මානව හිමිකම් කොමිෂන් සභාව

2023.02.27

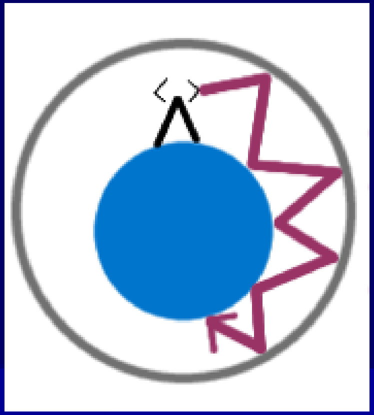
# Multi - Reflection

- In the Night there are high possibilities for multi reflection too.





# Multi - Reflection



Then the Sun is rising in the morning, all communications reflected from F-region going to weak. Because again D-region is creating !

**In the night MW (medium waves) also reflected from the region F. As a result, we can listen some MW channels from India.**

**For long distance communication it is very useful SW reflection broadcast method.** (But the problem is D-region in the day)

We can not use surface waves communication for long distance communications. There are two reasons:

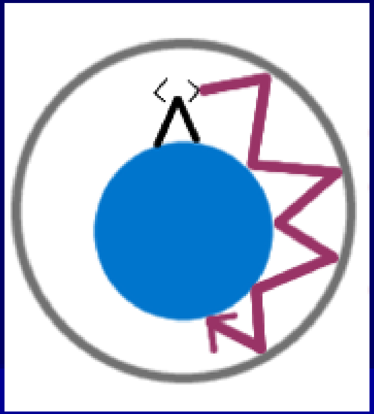
01. The problem from the curvature of the earth.

02. The surface waves dies more quickly as the frequency increases;

$$Range\ (km) = \frac{200}{\sqrt{Frequency\ (MHz)}}$$

# Multi - Reflection

$$Range\ (km) = \frac{200}{\sqrt{Frequency\ (MHz)}}$$



If **f** increases the range of the propagation, **R** decreases rapidly. But **f** is decreases the range of the propagation, **R** increases.

Eg: A 100 kHz low frequency radio wave use for the surface propagation to long distance. Find the maximum range of the propagation of the wave.

f = 100 kHz → f = 0.1 MHz

Using, $R\ (km) = \frac{200}{\sqrt{f\ (MHz)}}$ → $R\ (km) = \frac{200}{\sqrt{0.1}}$

→ $R = 632.456 km$

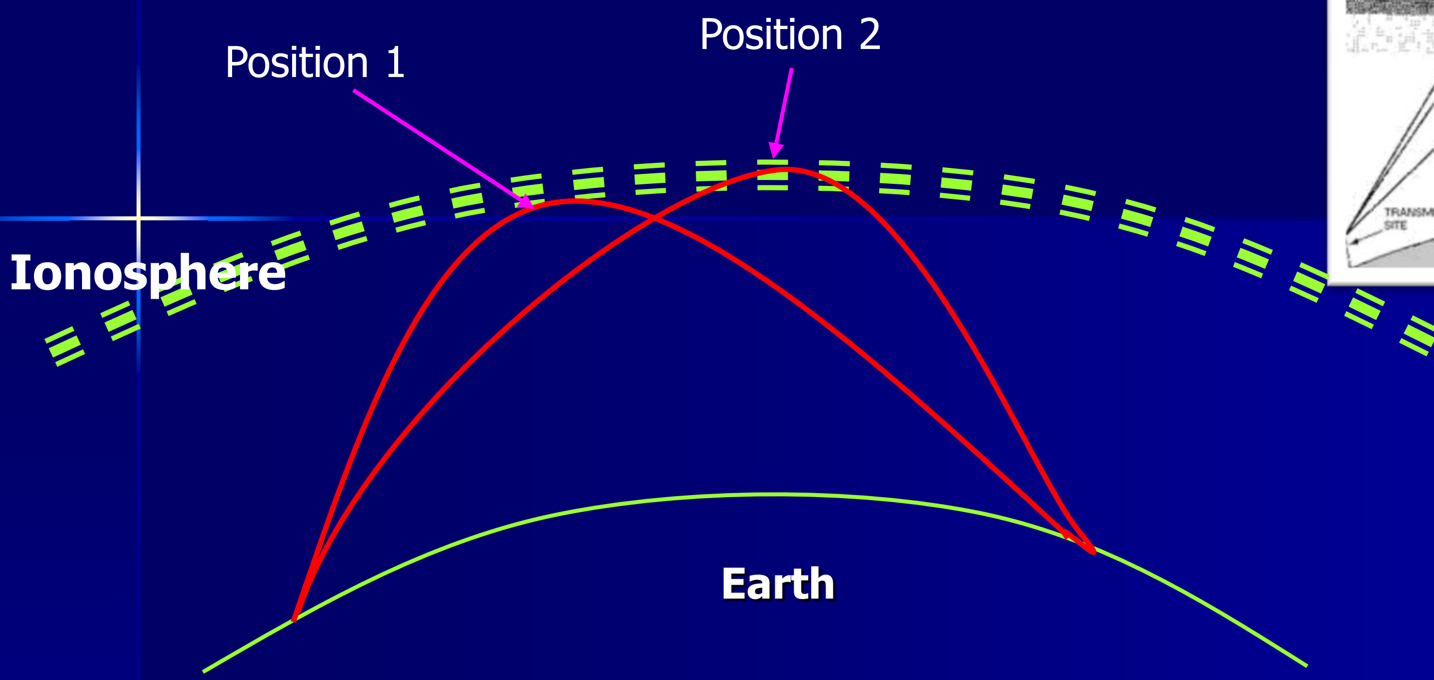
→ $R \approx 600 km$

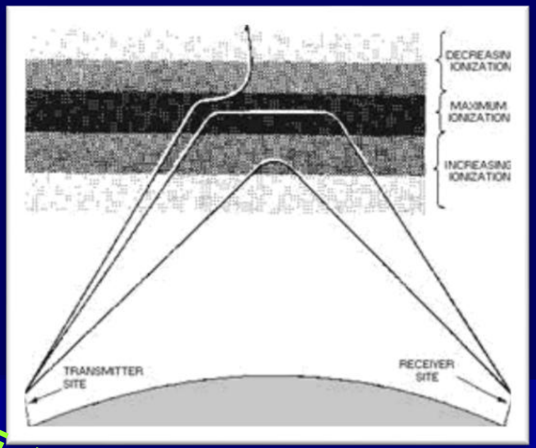
**After that range it is dying more quickly !**

# Properties of Reflection of Radio Waves

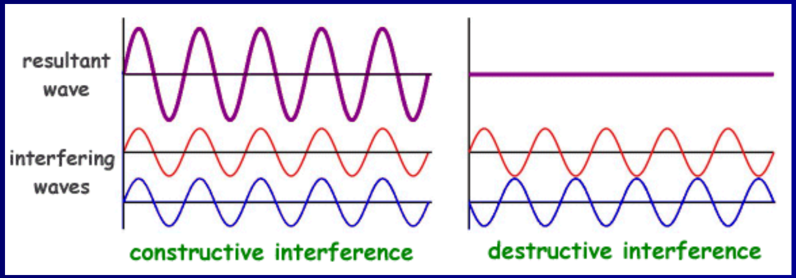
- Signal reflected from ionized layer of the ionosphere back down to Earth
- Reflection effect caused by refraction
- Reflection occurs when signal encounters a surface that is large relative to the wavelength of the signal.
- The radio wave is not reflected from a single point on the reflector but rather from an area on its surface. The size of the area required for reflection to take place depends reflecting substance.
- Radio wave may be reflected from various substances or objects they meet during travel between the transmitting and receiving sites.
- When the radio waves are reflected from flat surfaces, a phase shift in the alternations of the wave occurs.
- The shifting the phase relationship of reflected radio waves is one of the major reasons for fading.

# Multi – Position Reflection

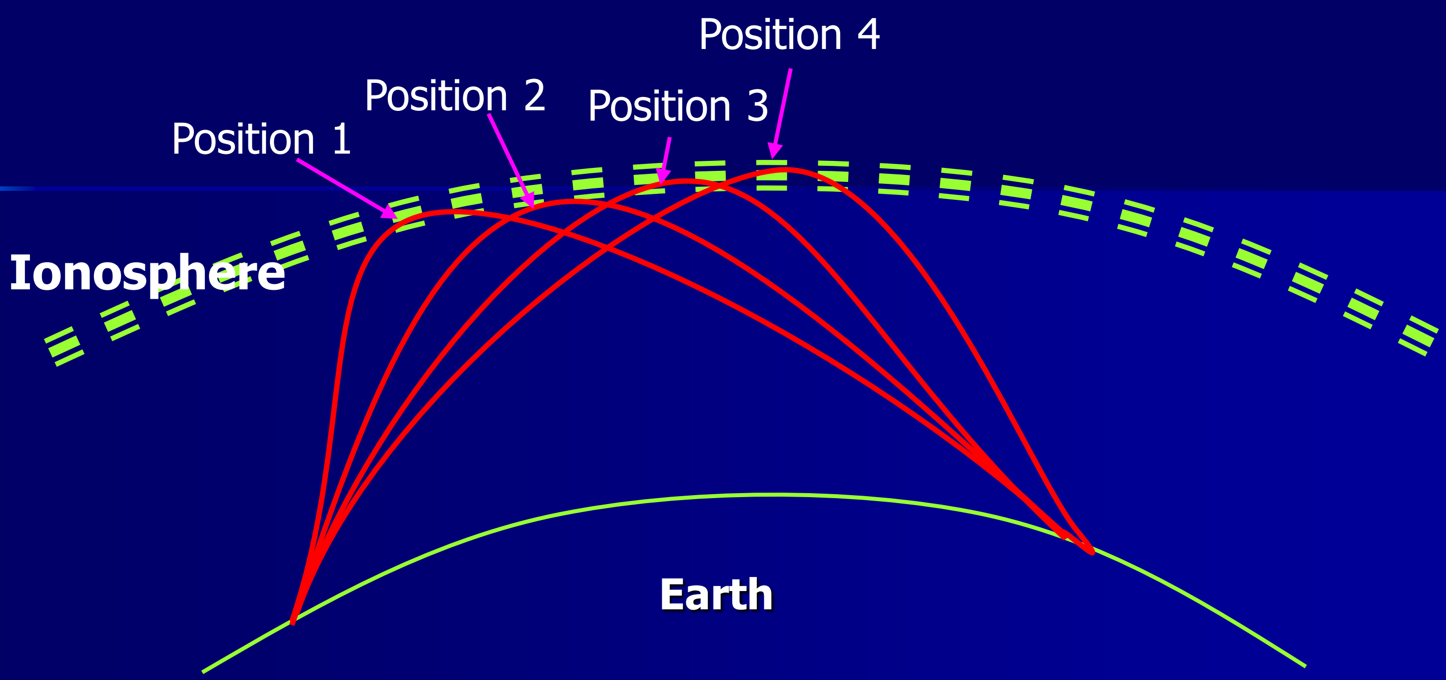



This is a possible situation. That means multi position of the ionosphere is supported to reflected the radio wave to the same receiver. **As a result the strength of the signal may be very strong**. But sometimes it may be very weak, because the **result of interference** final wave may be cancelled.



# Multi – Position Reflection

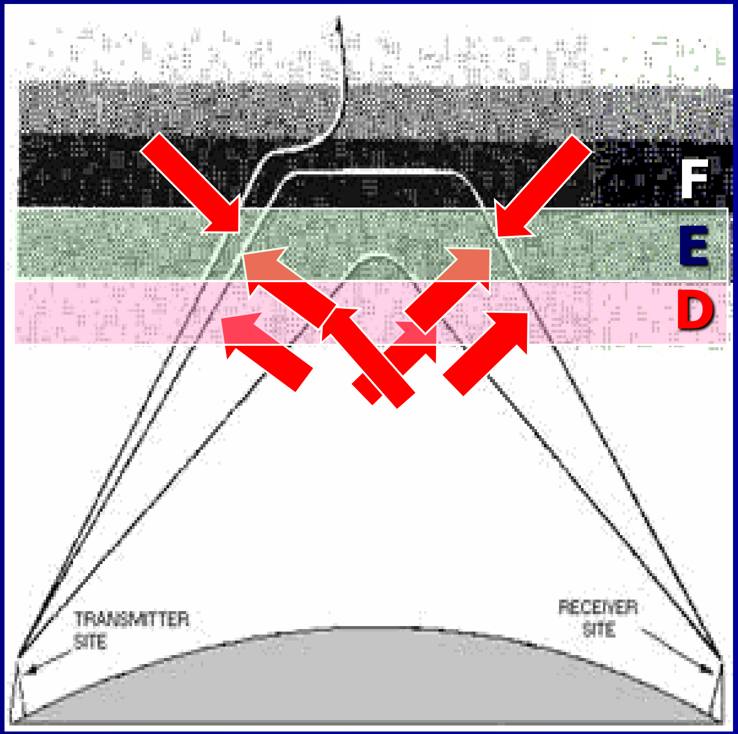



As **a result of reflection of multi position final wave may be destroyed**, because of the **attenuation of the carrier wave** of the radio signal. OR **final wave may be destroyed, because of anti-phase situation** (destructive interference)

# Absorption of Radio Waves

Normally ions (electrons and positive ions) in the ionosphere interact with radio waves (EM waves). As a result, ions in the ionosphere are oscillating due to absorption energy from the radio waves. That means energy of the ions increases. Because, electric field of the radio wave transfer energy to ions. The temperature of the ionosphere is increases.

If we want to cancel this phenomena **we should use High Power radio waves** for this purpose. In the day time this phenomena is happening well, because, molecular density of the ionosphere is very high. Normally ions in the D-region are participated for this incident.



# Absorption of Radio Waves

**Oscillation frequency** is the most important fact to absorb radio waves from the D-region. (**Oscillation frequency is no of oscillation per second of the electrons or positive ions** )
If **the radio wave frequency is equal to the oscillation frequency** of the D-region; the **wave is absorbed from the D-region**. Therefore, this oscillation frequency is the most important factor for the Radio Wave Propagation.

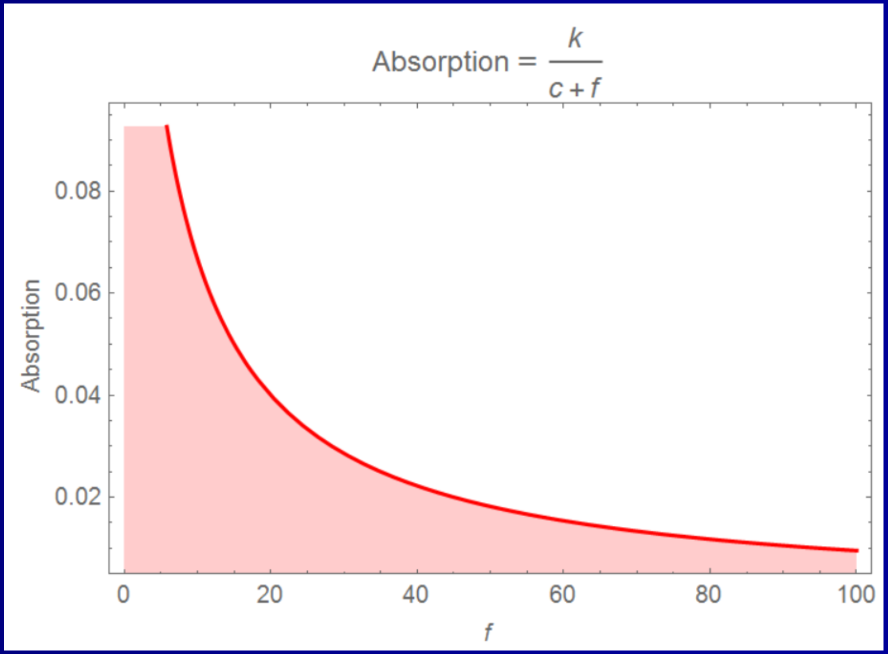
**Normally, absorption is directly depend on the frequency of the Radio Wave.**

$$Absorption \quad \alpha \quad \frac{1}{c + Frequncy\ of\ the\ wave}$$

Where, c is a constant.

$$Ab = \frac{k}{c + f}$$

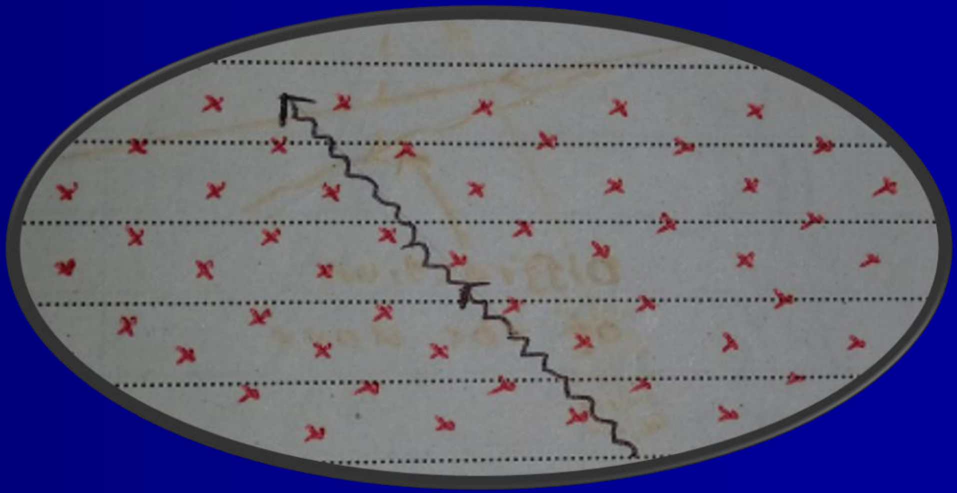
Where, k is proportional constant.

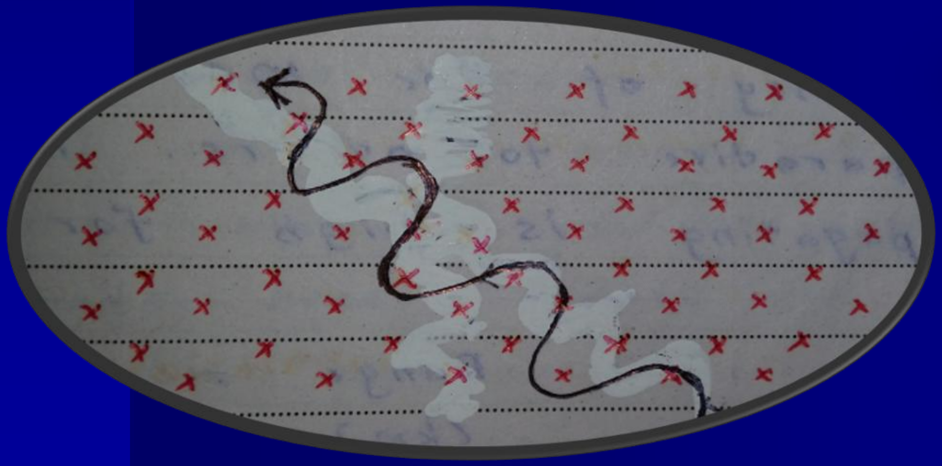


# Absorption of Radio Waves

$$Absorption \quad \alpha \quad \frac{1}{c + Frequncy\ of\ the\ wave}$$

If **f** ↑ then **ab** ↓

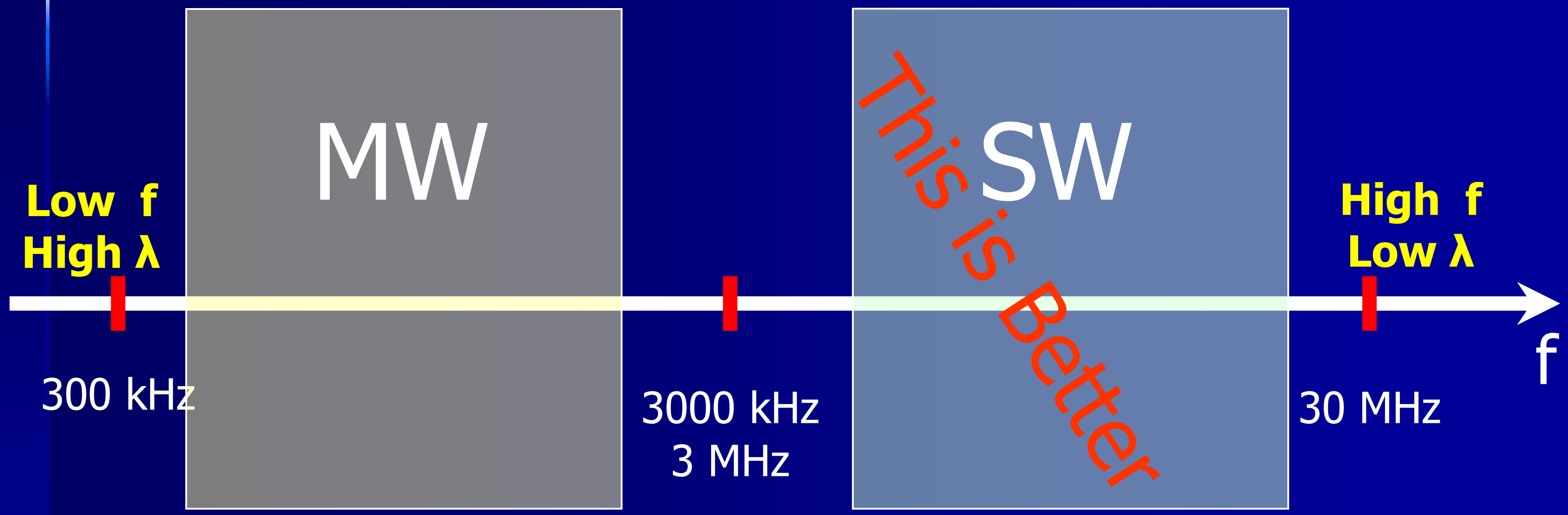




If **f** ↓ **(λ ↑)** then **ab** ↑

# Absorption of Radio Waves

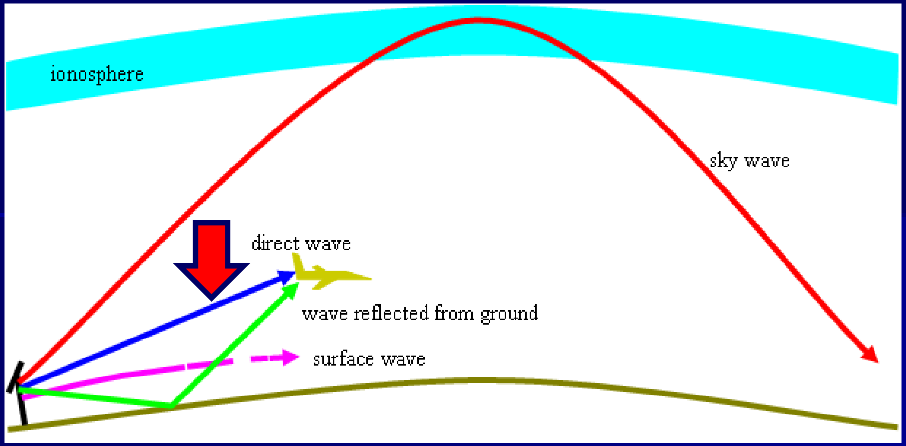
**Generally, Short Waves (SW) are not much absorbed from the D-Region of the ionosphere. But, Medium Waves (MW) are normally absorbed from the ionosphere**




**In the day time, MW is almost absorbed from the D-Region of the ionosphere. But SW are not absorbed.**

**Therefore, we can use MW to direct communication without reflection from the ionosphere.** That direct communication means use to communicate by direct ground waves.

# Absorption of Radio Waves




But direct ground waves also face some practical problems due to **diffraction**. Because the wave is bending due to diffraction. **Therefore, we can not use ground waves to communicate too far**.

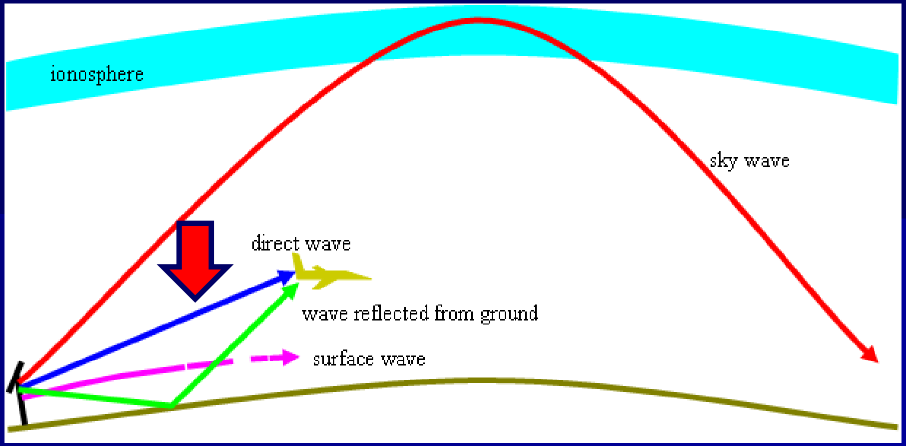
**Frequency** of the **MW** signal **very low** with comparative to others. As a result **range of propagating** is **high** for low frequency signals.

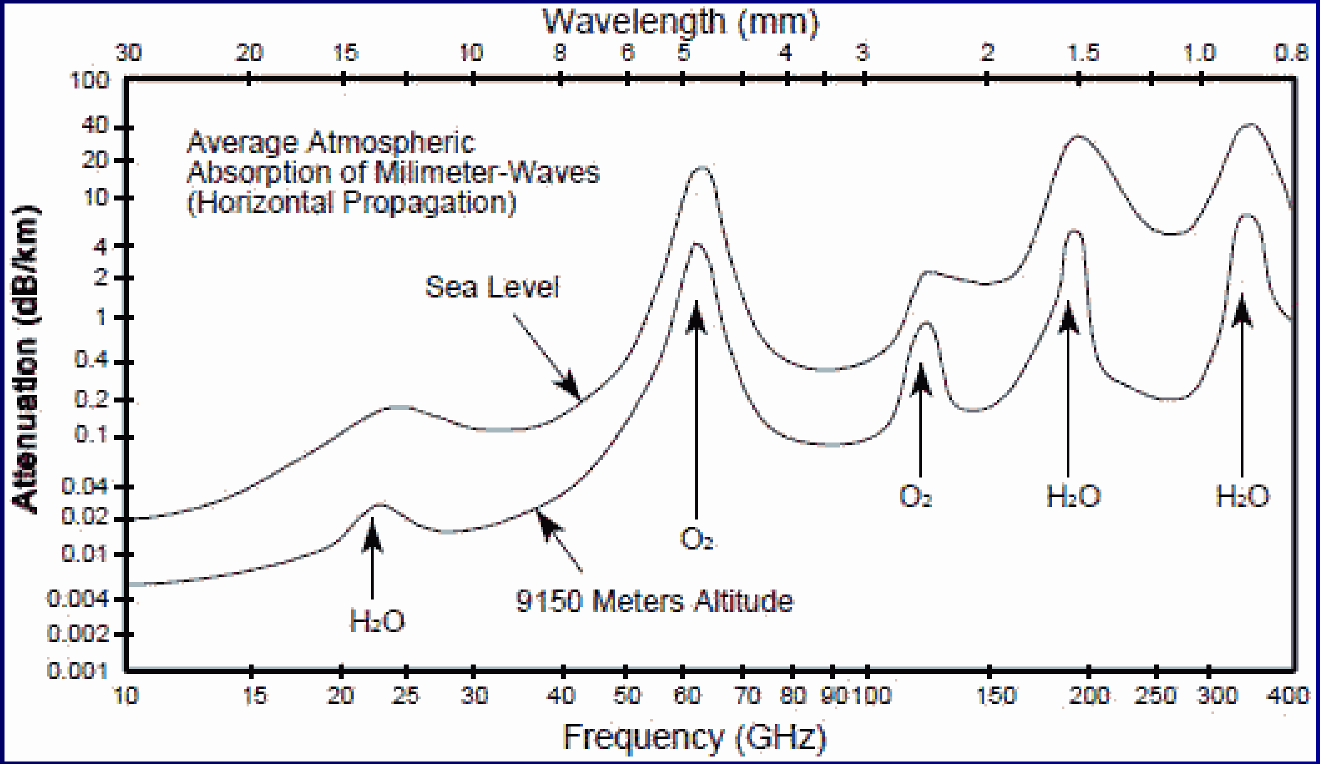
$$\because \; Range\,(km) = \frac{200}{\sqrt{f\ (MHz)}}$$

But the problem is **diffraction of the wave**.

# Absorption and attenuation of Radio Waves

**Direct ground waves face another problem due to many different gasses**, water (**water vapor**) and **particles contained the atmosphere**. That is **attenuation of the wave by atmosphere of the Earth**.

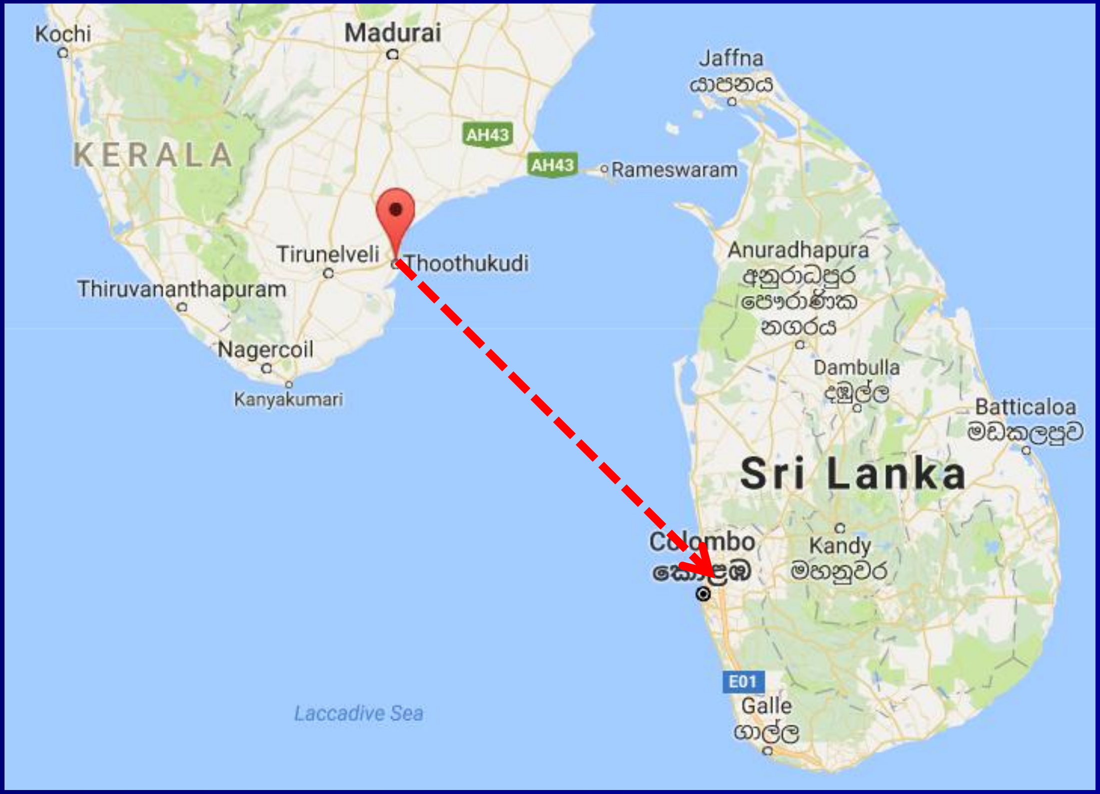


# Absorption and attenuation of Radio Waves

A significant atmosphere effect is that of **attenuation due to rain**. **Below about 10 GHz, rain fading is not very significant**, but at **higher microwave frequencies, it becomes the major factor limiting path length**, particularly in areas that experience high level of rainfall (eg: **Watawala town in Sri Lanka**). In addition to attenuation of EM waves, rain and other precipitation (dew,...) tend to cause depolarization of the wave.

There is a ULF (Ultra Low Frequency) radio frequency channel from **Thoothukudi** in India whose frequency range is **1020 Hz – 1070 Hz**. **We can listen to that channel in Sri Lanka** because they are using **Very High Power Transmitter** !



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## AIR Tuticorin

**Language:** All India Radio / Tamil

5(1)

AIR Tuticorin (Thoothukudi)is part of All India Radio broadcasting live from Tuticorin(Thoothukudi) Tamilnadu broadcasting at 100.5 MHZ.All India Radio Tuticorin plays Akashvani news,Talk programmes,Current Affairs,World news and plays Tamil songs and Tamil talk programmes.Listen to Akashvani Tuticorin FM radio station online.



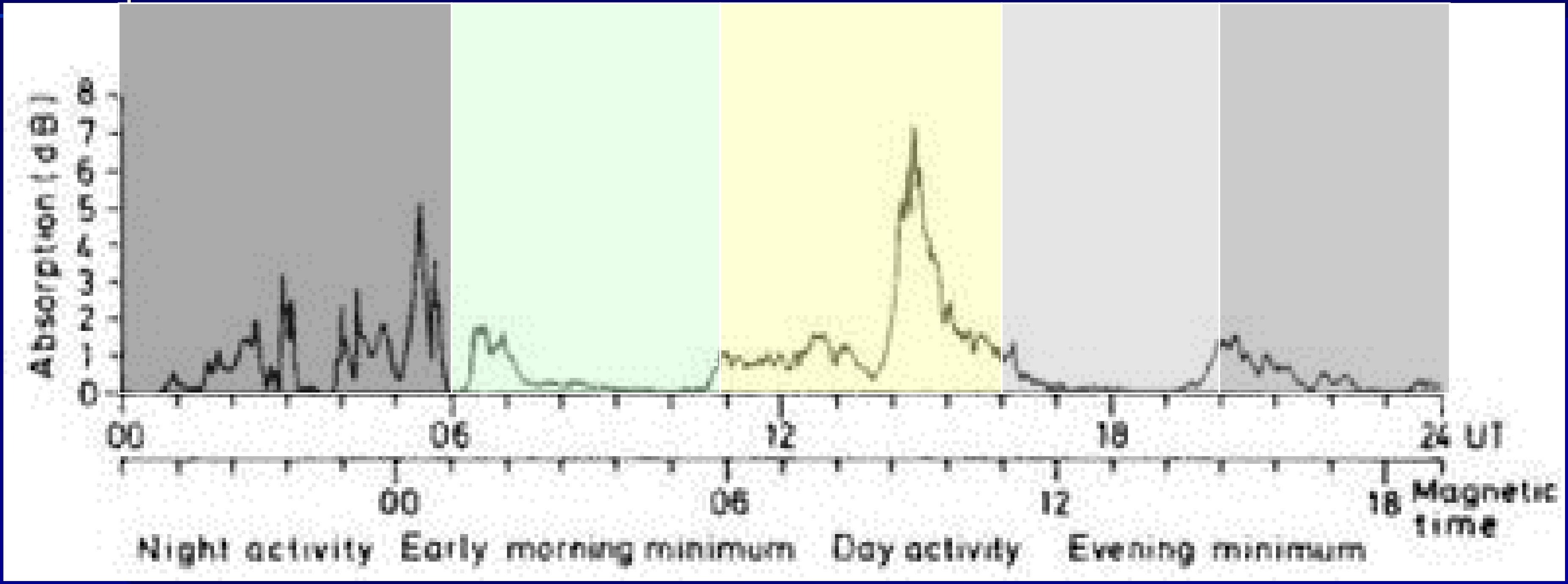
### How useful was the programs in this Radio?

Select a star to rate it!

Average rating 5 / 5. Vote count: 1

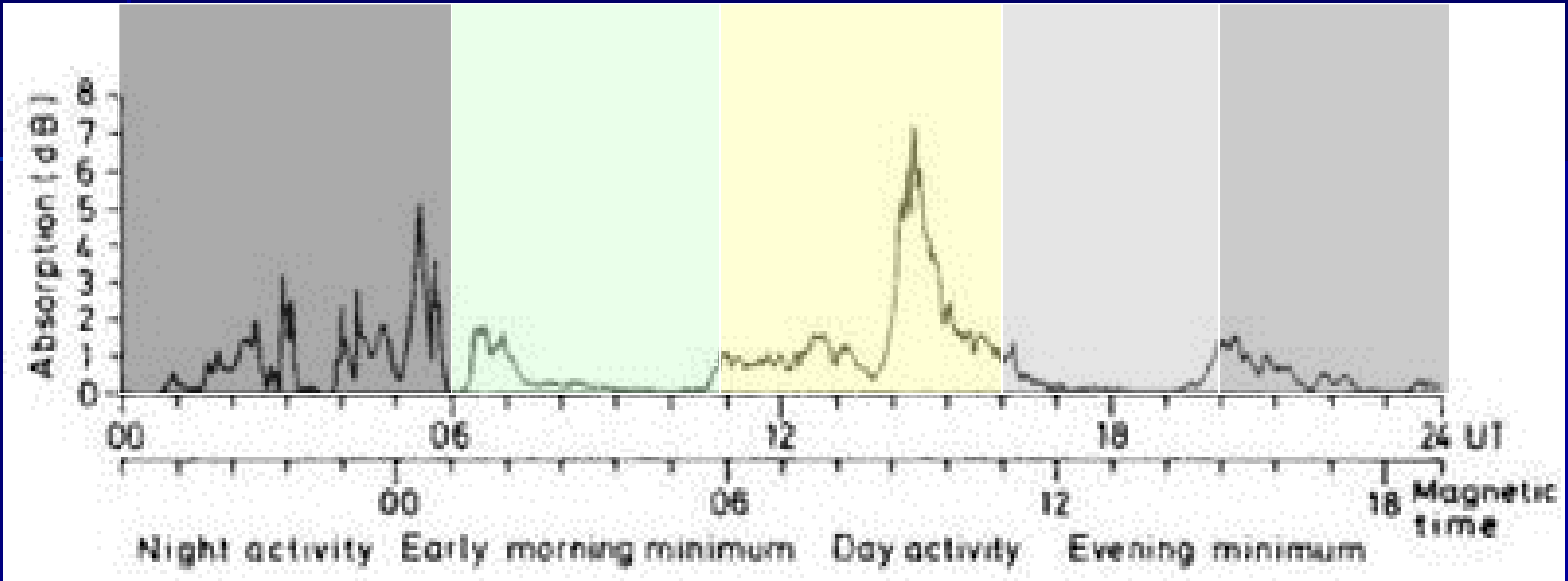
# Chart of Attenuation

Carrier radio wave frequency should be change with time ! Because absorption rate of radio waves changing with time in the following diagram.




Ionosphere absorption (or ISAB) is only a factor in the period of the day where radio signals travel through the portion of the ionosphere facing the **Sun**. The solar wind and radiation cause the ionosphere to become charged with electrons in the first place.

# Chart of Attenuation



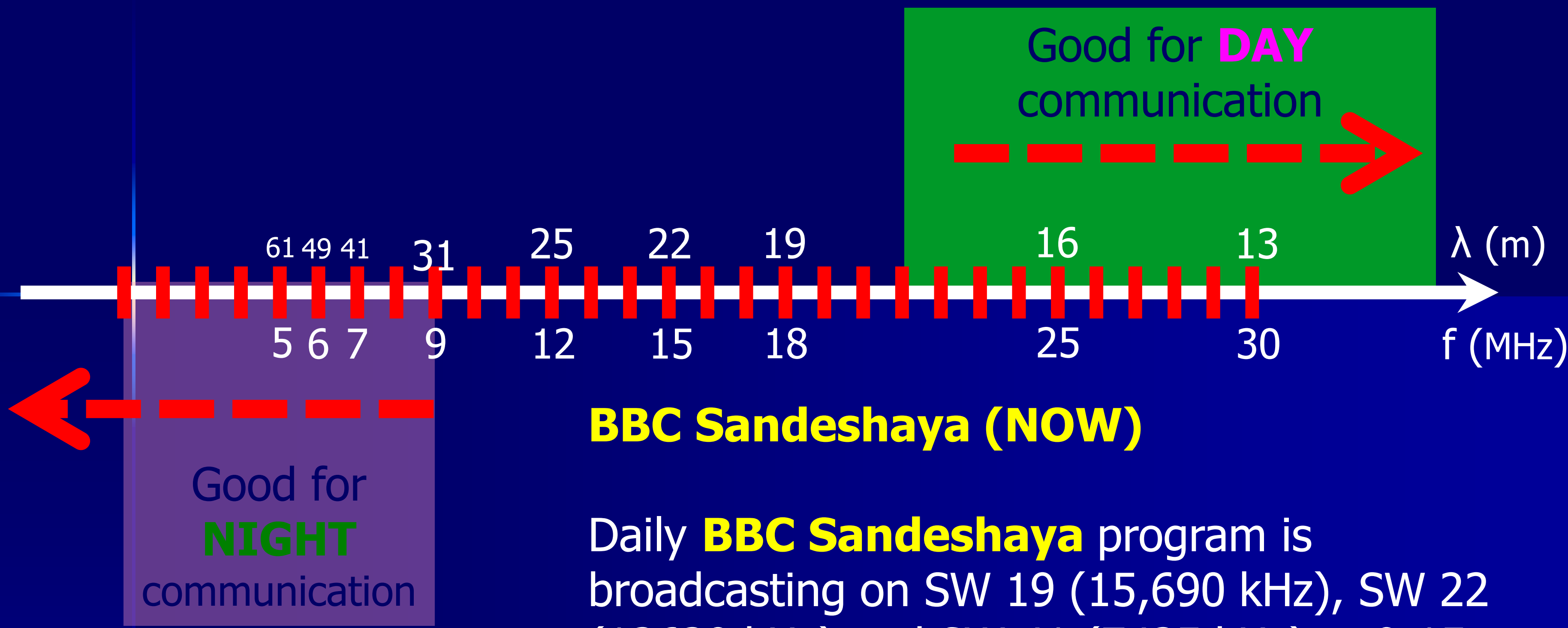

At **night, the atmosphere become drained (fall) of its charge**, and radio signals can go much further with less loss of signal. In particular, low wavelength signals that would be attenuated to nothing during the day will be received much further away at night.

The specific amount of attenuation can be derived as a function of the inverse square law. The lower the frequency, the greater the attenuation.


In radio wave communication, the **Radio Broadcasting Center** should be change their carrier frequencies in the day and the night like the above diagram. Also this frequencies depend on the no of sunspots and activity of the Sun.

Eg: **BBC Sandeshaya**

( They used the transmission frequency **250 kHz** for the communication during the **DAY** and transmission frequency **100 kHz** for the **NIGHT** )




**BBC Sandeshaya (NOW)**

Daily **BBC Sandeshaya** program is broadcasting on SW 19 (15,690 kHz), SW 22 (13630 kHz) and SW 41 (7435 kHz) at 9:15 pm (night) on Sri Lankan time !

http://www.bbc.com/sinhala

**Generally India using SW communication to broadcast their radio channels for all over the country !**

# Radio Wave Communication

Radio waves
Radio Communication
Reflection of Radio Waves
Absorption of Radio Waves
Complex Refractive Index
Reflection Heights
Deviating Region Absorption, Non-Deviating Region Absorption
Ordinary/Extra Ordinary Waves
Ionosphere – Sounding Techniques
Pulse Reflection Methods

# Complex Refractive Index

If the radio wave going through the ionosphere, **refractive index n is always a complex number**. (As we discussed in the ionosphere chapter) That means **n = α + i β** and n is complex. Therefore, we can use **n → n***. i.e.;

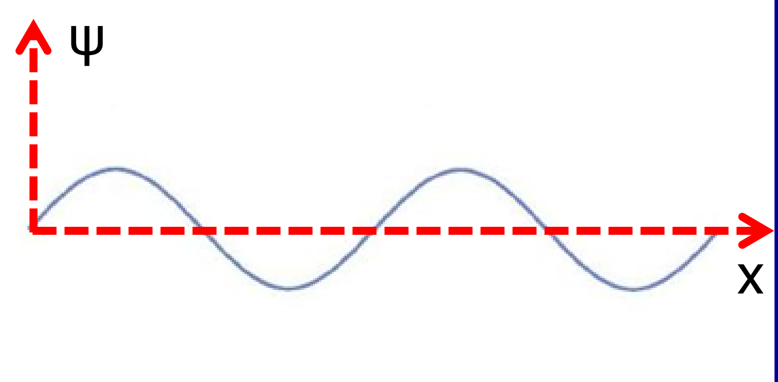
$$n^* = \alpha + i\,\beta$$

Where **α** and **β** are positive constants. And $i = \sqrt{-1}$

.: Equation of the motion of the radio wave can be express as the following form;

$$\psi = \psi_o e^{i\,n\,x}$$

$\beta \rightarrow small$



# Complex Refractive Index

$$\psi = \psi_o e^{inx}$$

Now we can substitute, **n = n*= α + i β** to the above equation.

$$\therefore \psi = \psi_o e^{i(\alpha + i\beta)x}$$

$$\Rightarrow \psi = \psi_o e^{i\alpha x} e^{-\beta x}$$

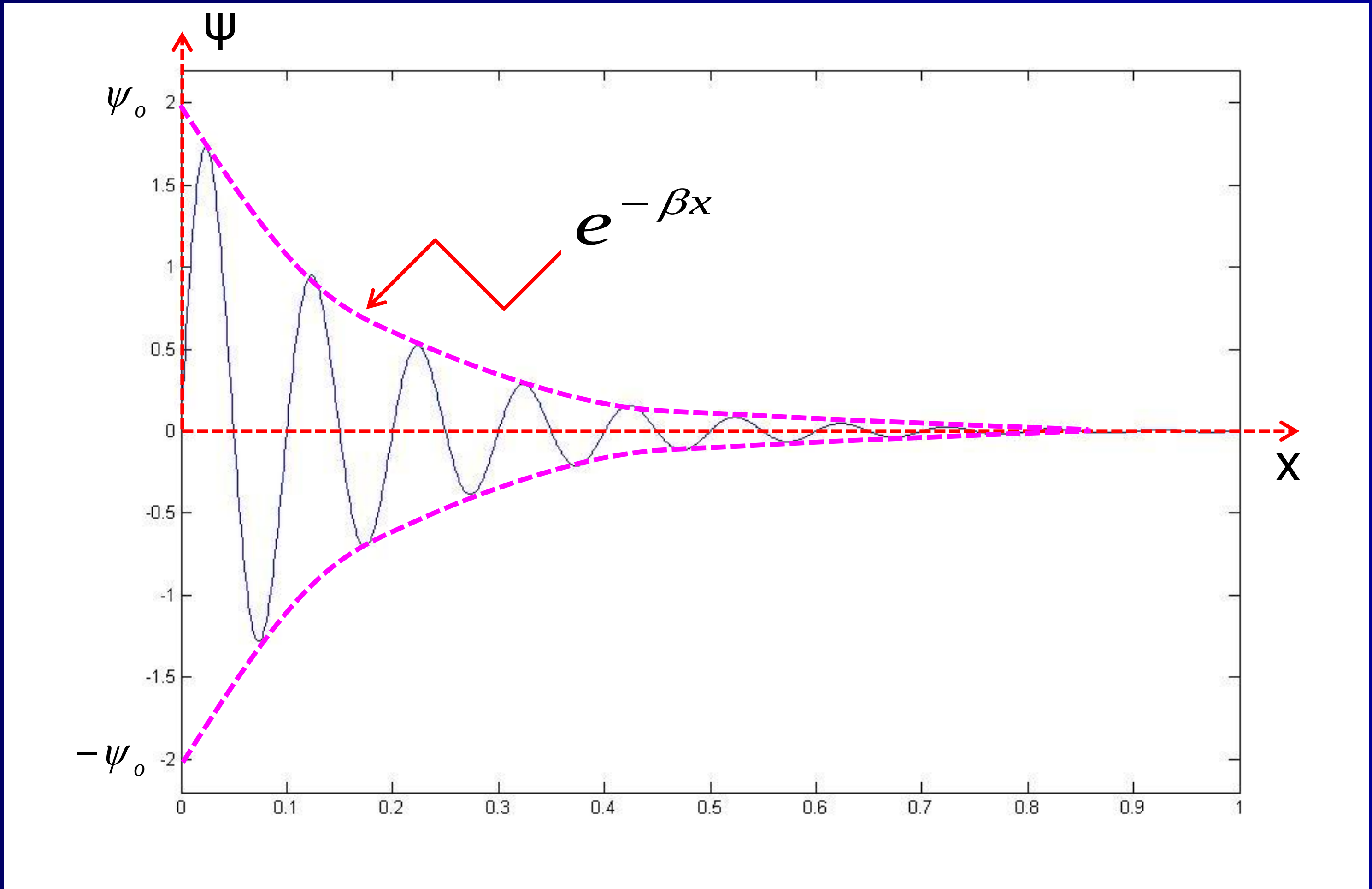
$$\Rightarrow \psi = \left(\psi_o e^{-\beta x}\right) e^{i\alpha x}$$

$$\Rightarrow \psi = \psi_o^1 \, e^{i\alpha x}$$ and $$\psi_o^1 = \psi_o e^{-\beta x}$$

Where $\psi_o^1 = \psi_o e^{-\beta x}$ is the new amplitude of the Radio Wave.

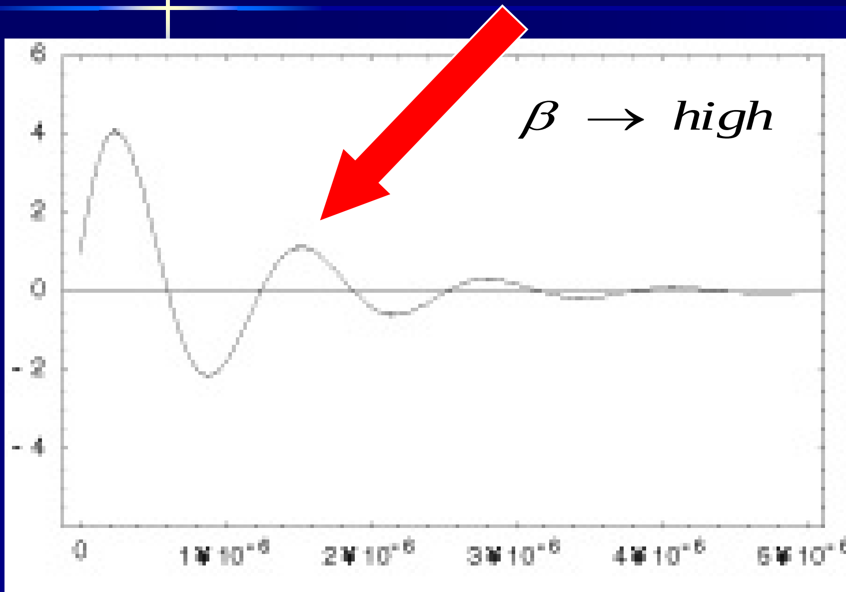
# Complex Refractive Index

$\psi_o^1 = \psi_o e^{-\beta x}$ means that the new amplitude is attenuated from the ionosphere.

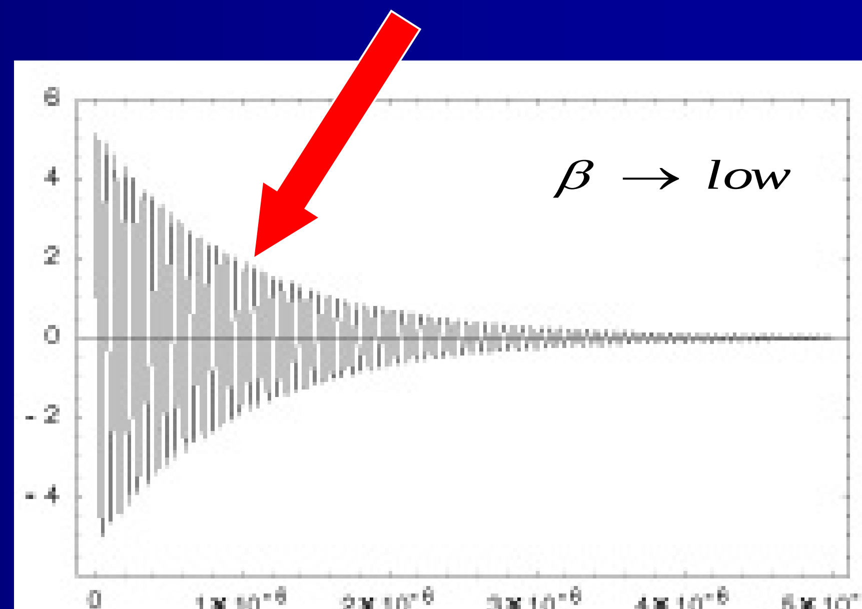


# Complex Refractive Index

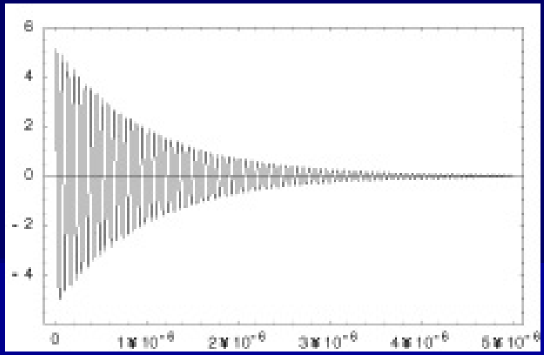
$$n = \alpha + i\,\beta$$




Attenuation



# Complex Refractive Index




The wave is attenuated. That means the wave is decaying. Because, the wave is absorbed from the ionosphere.

$$Ab \ \alpha \ \frac{1}{c + f}$$

- If the **frequency of the radio wave is very high**, **the absorption from the ionosphere is very low**. That means the **attenuation of the radio wave is small**. That means **Exp[-βx]** is **approximately equal to one**.

$$e^{-\beta x} \approx 1$$

$$\beta \to 0$$

That means complex part of the refractive index ( $n^* = \alpha + i\beta$ ) is negligible. It is going through the ionosphere.

# Complex Refractive Index

- If the **frequency of the radio wave is very small, the absorption from the ionosphere is very high**. That means the **attenuation of the radio wave is high**. That means **Exp[-βx]** is **going to zero**.

$$e^{-\beta x} \approx 0$$

→ **β is very large !**

That means complex part of the refractive index ( $n^* = \alpha + i\beta$ ) is very large. It is reflected back from the ionosphere to the Earth surface.

Plasma frequency of the ionosphere: $f_p = 8.97 \times N^{1/2}$

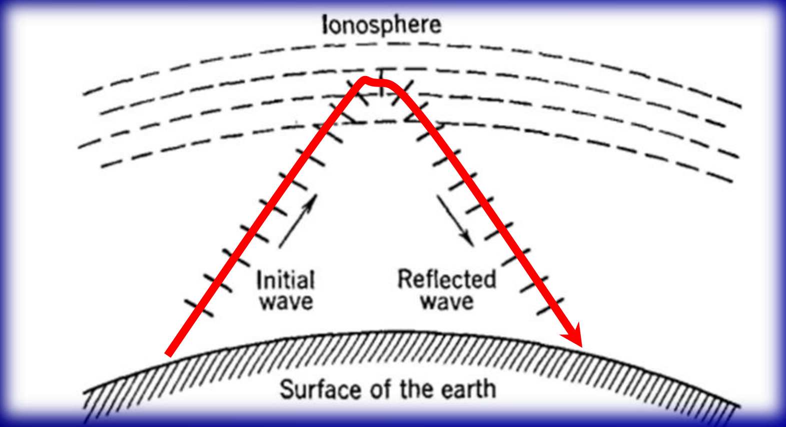
If the electron density of the ionosphere is $10^{12}$ $e^n/cm^3$,

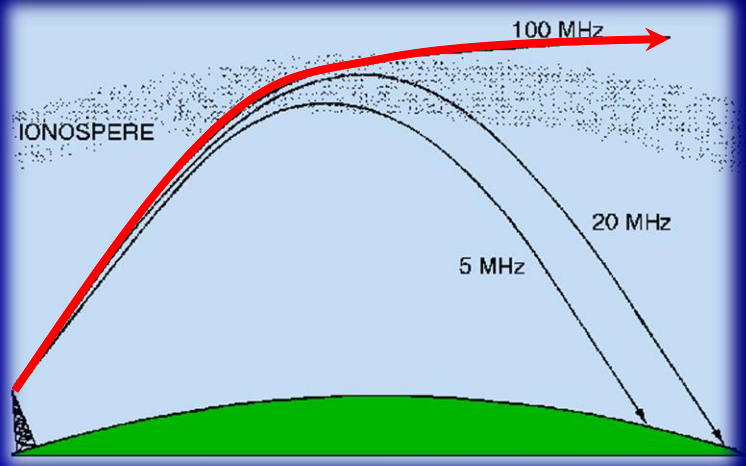
$$f_p = 8.97 \times \left(10^{12}\right)^{1/2}$$ → $$f_p \approx 9 MHz$$

# Complex Refractive Index

- That means, if we send a **Radio Wave** to the ionosphere with frequency **9 MHz** (or lower value), it is **reflected from the region of the ionosphere** whose electron density is $10^{12}$ $e^n/cm^3$.

That means **VLF** (3-30 kHz), **LF** (30-300 kHz), **MF** (300-3000 kHz), and **HF** (some short waves in the region 3 MHz - **9** MHz) are **reflected from the ionosphere** !




But, if we send **UHF** (>30 MHz) and **VHF** (>300 MHz) signal to the ionosphere, both signals are **going through ionosphere** to the space without reflection back!

# Complex Refractive Index

Complex index of refraction is **n = n*= α + i β**, in looking in detail at the **polarization of dielectrics**, we switched from a simple di-electric constant **$\varepsilon_r$** to a **Complex di-electric function** $\varepsilon_r(\omega) = \varepsilon_1 + i\,\varepsilon_2$.

i.e.; $$\varepsilon_r(\omega) = \varepsilon_1 + i\varepsilon_2$$

Also we know; $$n^* = \alpha + i\beta$$

With the di-electric constant $\varepsilon_r$ and refraction index constant n* , we had the basic relation;

$$n^2 = \varepsilon_r \;\rightarrow\; n^{*2} = \varepsilon_r \;\rightarrow\; (\alpha + i\beta)^2 = \varepsilon_1 + i\varepsilon_2$$

That means, $\alpha = \alpha(\omega)$ and, $\beta = \beta(\omega)$

$$\rightarrow\; (\alpha + i\beta)^2 = \varepsilon_1 + i\varepsilon_2 \;\rightarrow\; \alpha^2 - \beta^2 + 2(\alpha\beta)i = \varepsilon_1 + i\varepsilon_2$$

# Complex Refractive Index

$$\alpha^2 - \beta^2 + 2(\alpha\beta)i = \varepsilon_1 + i\varepsilon_2$$

$$\alpha^2 - \beta^2 = \varepsilon_1 \quad \text{and,} \quad 2\alpha\beta = \varepsilon_2$$

……..

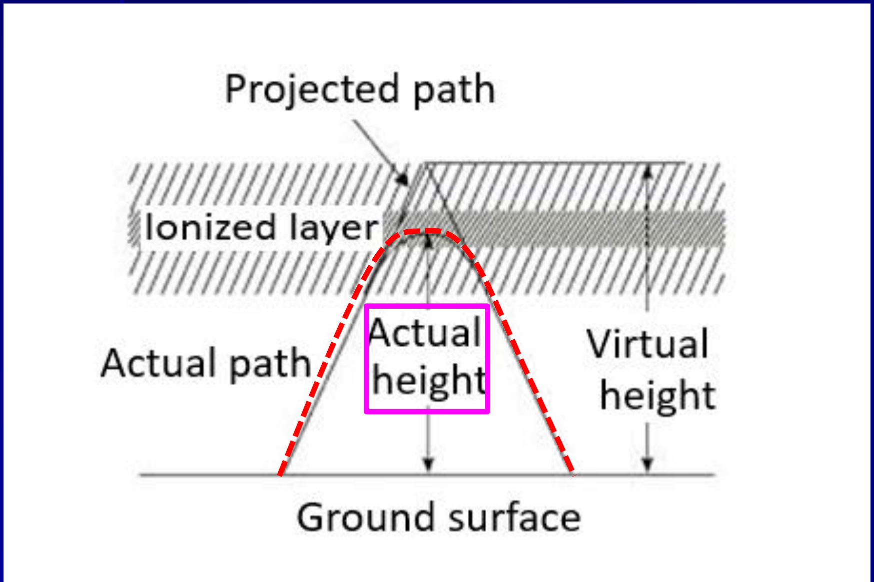
$$\alpha^2 = \frac{1}{2}\left[\left(\varepsilon_1^2 + \varepsilon_2^2\right)^{1/2} + \varepsilon_1\right] \quad \text{and,} \quad \beta^2 = \frac{1}{2}\left[\left(\varepsilon_1^2 + \varepsilon_2^2\right)^{1/2} - \varepsilon_1\right]$$

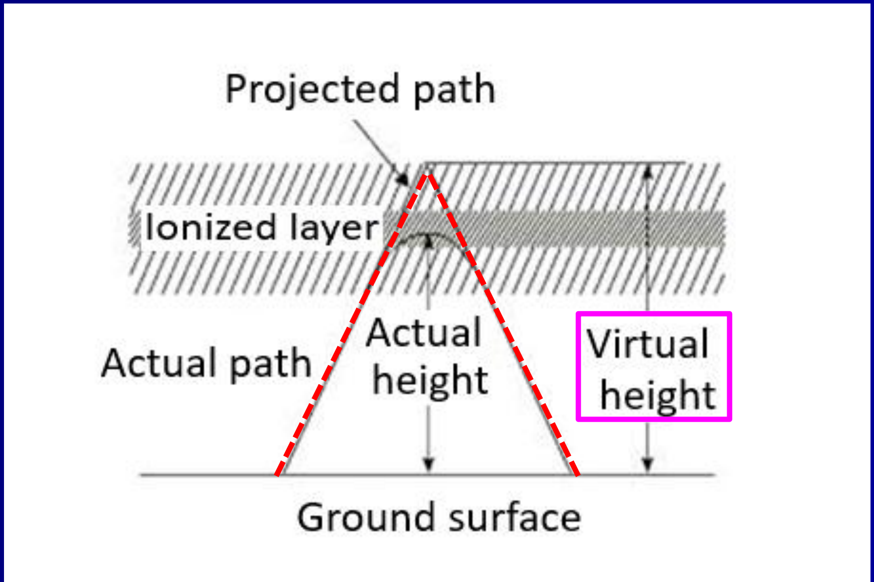
Using above equations we can find the values of **α** and **β** when **$\varepsilon_1$** and **$\varepsilon_2$** are already known.

- If **β** $\rightarrow 0$ then **$\varepsilon_2$** $\rightarrow 0$
  that means **$\varepsilon_r(\omega) = \varepsilon_1$**. (Real)
- If **β** $\rightarrow \infty$ (very large) then **$\varepsilon_2$** $\rightarrow \infty$ (very large)
  that means **$\varepsilon_r(\omega) = i\,\varepsilon_2$**. (complex)

# Reflection Heights

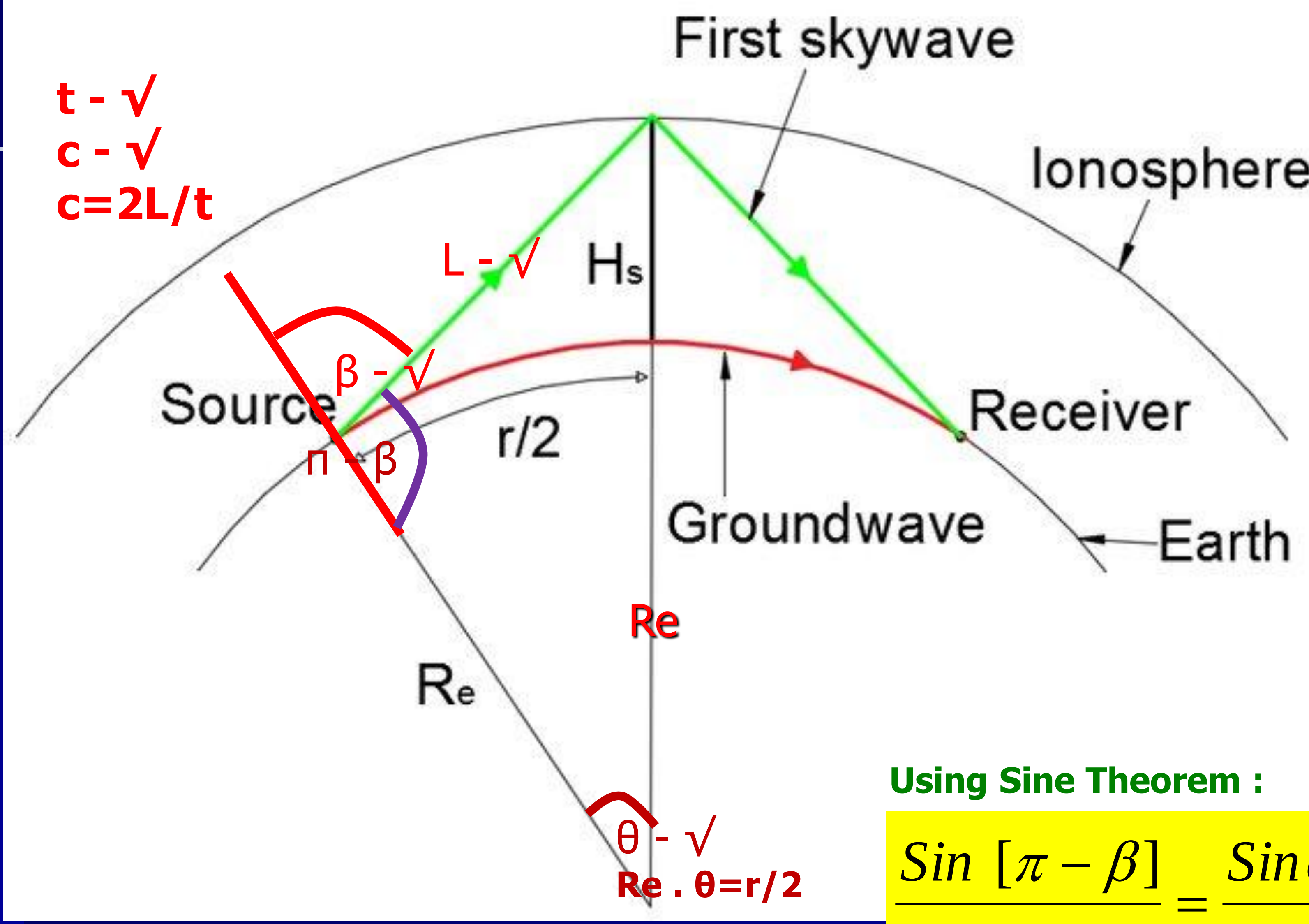
A radio wave transmitted towards the ionosphere is subject to be reflected. The process of this reflection shows an exciting feature which is, that the position it reflects from the ionosphere is varying with corresponding to the frequency of a particular radio wave. This particular position of reflection is expressed in terms of heights and it is known as **reflection height** for the particular radio wave.



# Reflection Heights

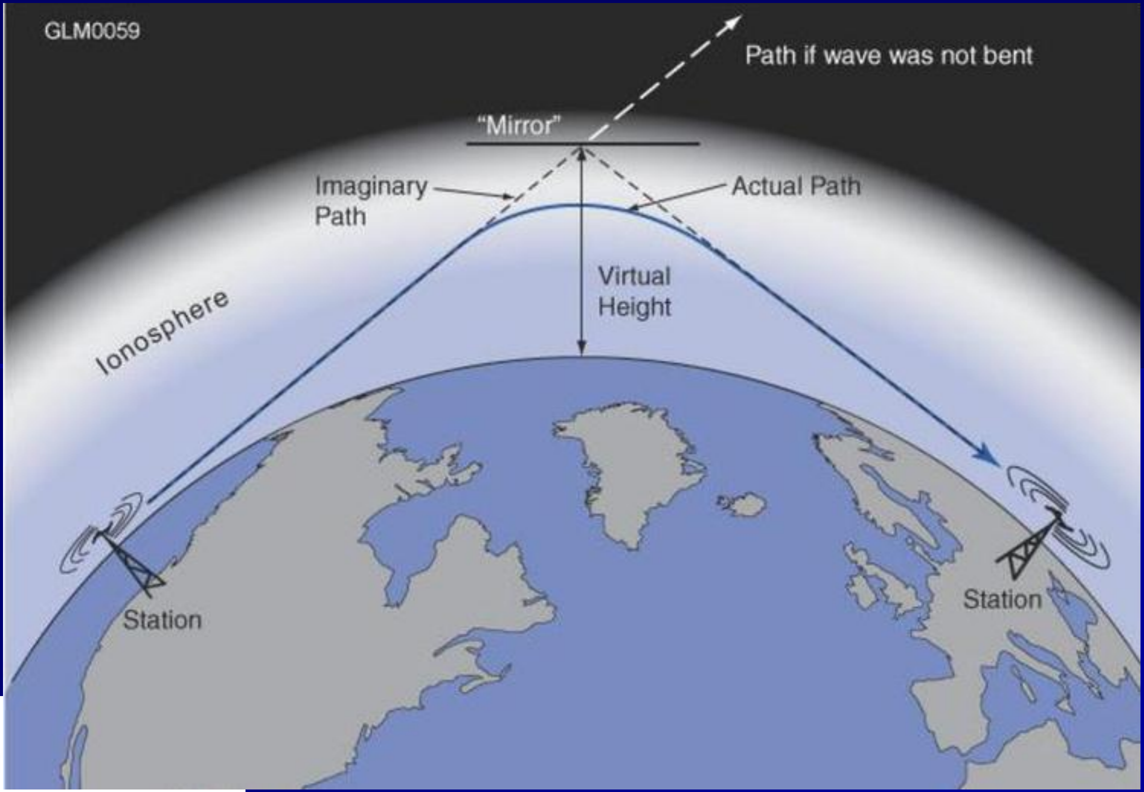
Incident angle - √

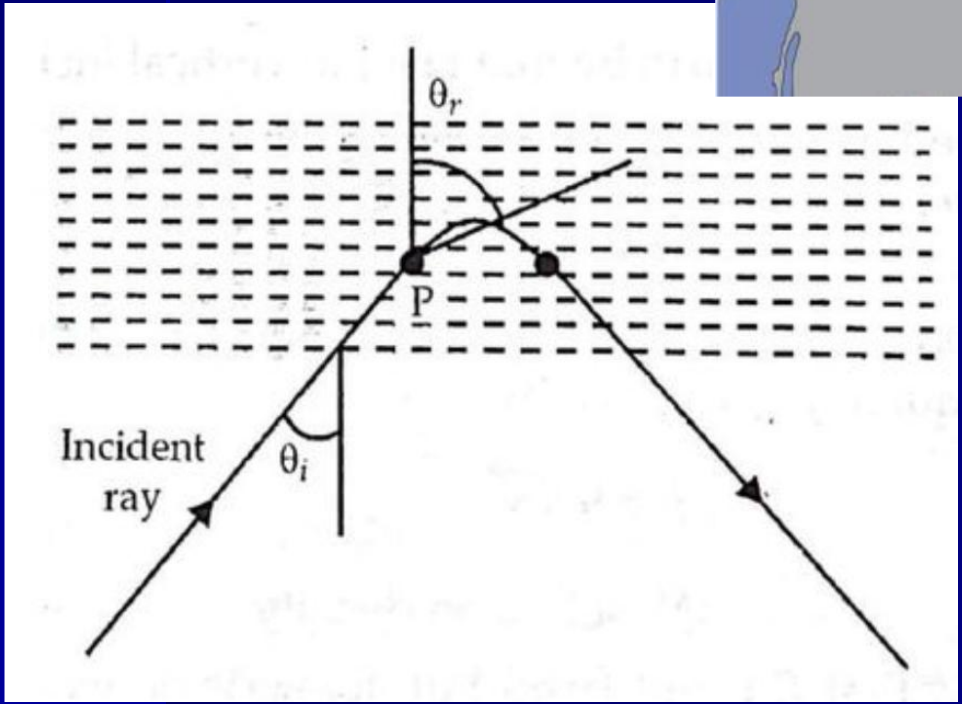



Using Sine Theorem :

$$\frac{Sin\ [\pi - \beta]}{\mathrm{Re}\ + Hs} = \frac{Sin\,\theta}{L}$$

# Reflection Heights




Snell's Law of refraction in the ionosphere.

$$n = \frac{\sin \theta_i}{\sin \theta_r}$$

n- is refractive index

$\theta_i$- is angle of incident

$\theta_r$- is angle of refraction

$$H(r,\theta)=\frac{\mu_o}{4\pi}\cdot\frac{M}{r^3}\cdot\left(1+3\cos^2\theta\right)^{1/2}$$

# Reflection Heights

We know $n = \sqrt{1 - \frac{81\,N}{f^2}}$

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

Angle of incident $\theta_i = 0$

when $\theta_i = 0$, $N = N_{max}$ and $f = f_C$

Therefore, $0 = \sqrt{1 - \frac{81\,N_{max}}{f_C^2}}$

$$f_C = \sqrt{81\,N_{max}} = 9\sqrt{N_{max}}$$

$$f_C = \sqrt{81\,N_{max}}$$

$$f_C^2 = 81\,N_{max}$$

$$\frac{81\,N_{max}}{f_C^2} = 1$$

$$1 - \frac{81\,N_{max}}{f_C^2} = 0 \Rightarrow n = \sqrt{\varepsilon_r} = \sqrt{1 - \frac{81\,N}{f^2}}$$

# Reflection Heights

Now, the condition for the wave to be reflected back is given by

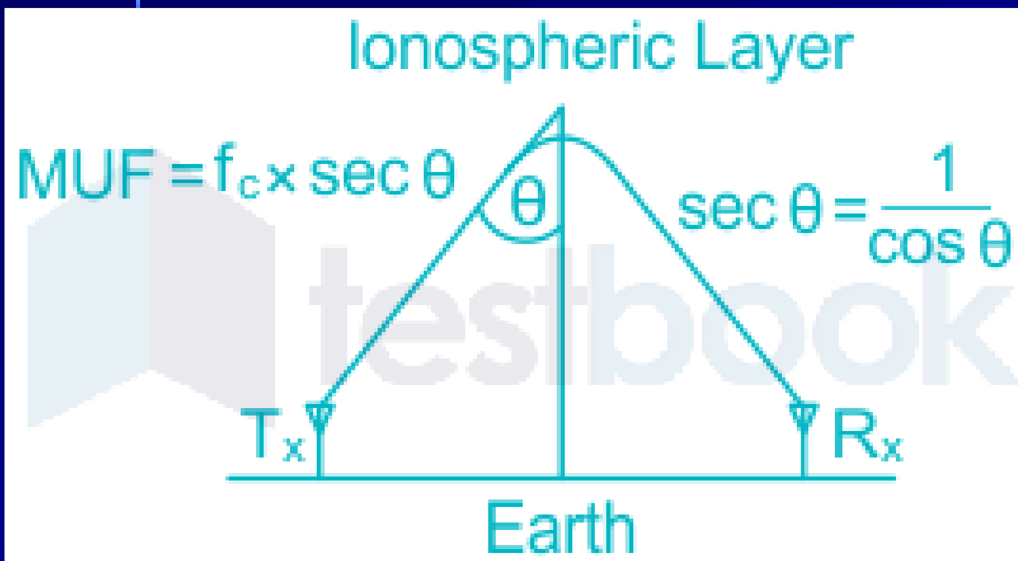
$$\sin\theta_i > \sqrt{1 - \frac{81\,N_{max}}{f^2}}$$

But $f_C = \sqrt{81\,N_{max}}$

$$\therefore \quad \sin\theta_i > \sqrt{1 - \left(\frac{f_C}{f}\right)^2}$$

# Maximum usable frequency (MUF) :

MUF (Maximum Usable Frequency) is the maximum frequency which can be reflected for given distance of transmission. MUF is usually 3 to 4 times of critical frequency.



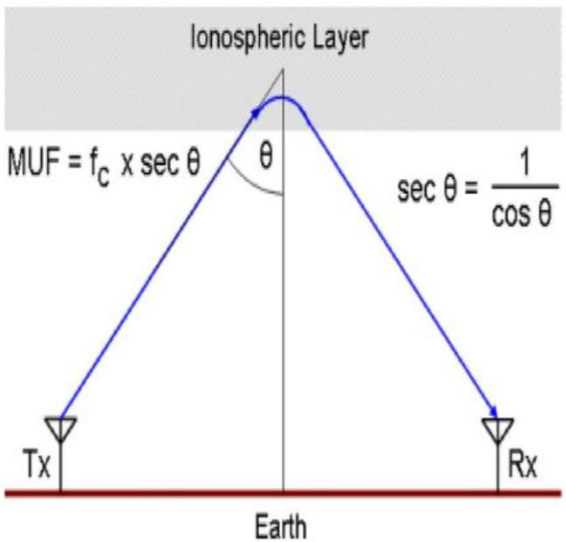

$$MUF = \frac{\text{critical frequency}}{\cos\theta}$$

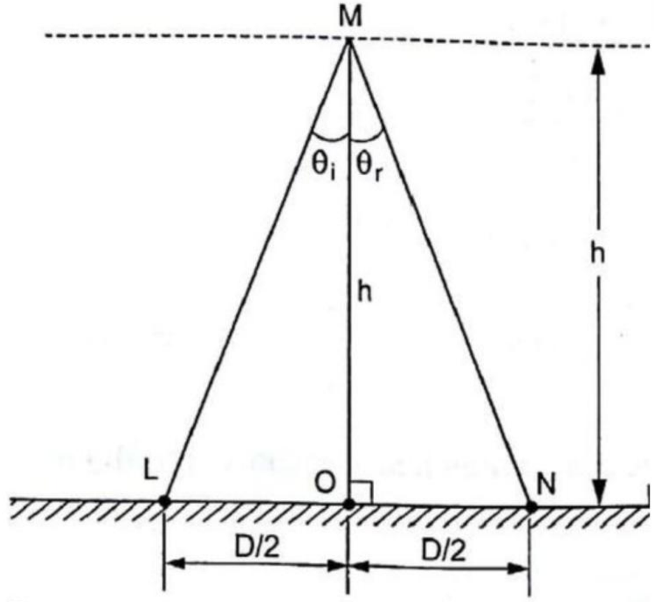
Where,

MUF = Maximum Usable Frequency

$\theta$ = Angle of Incidence

# Reflection Heights




Considering Δ LOM in Fig.

$$\cos\theta_i = \frac{h}{LM}$$

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

$$\Rightarrow \cos\theta_i = \frac{2h}{\sqrt{D^2 + 4h^2}} \longrightarrow 1$$

# Reflection Heights

We know

$$\therefore \quad n = \sin\theta_i = \sqrt{1 - \frac{81\, N_{max}}{f_{MUF}^2}}$$

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

$$\cos^2\theta_i = \frac{81\, N_{max}}{f_{MUF}^2}$$

We know $f_C = \sqrt{81\, N_{max}}$

$$\therefore \quad \cos^2\theta_i = \frac{f_C^2}{f_{MUF}^2}$$

$$\therefore \quad \boxed{\cos\theta_i = \frac{f_C}{f_{MUF}}} \longrightarrow 2$$

Comparing Equ. 1 & 2.

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

$$f_{MUF} = f_C \left[ \frac{\sqrt{D^2 + 4h^2}}{2h} \right]$$

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

$$\boxed{f_{MUF} > f_C}$$

# Reflection Heights

- The Skip distance, $d_s$ is

$$d_s = \frac{2h}{\tan \theta_c}$$

h – height of the layer

$\theta_c$ – Critical angle

A **skip distance** is **the distance a radio wave travels, usually including a hop in the ionosphere**. A skip distance is a distance on the Earth's surface between the two points where radio waves from a transmitter, refracted downwards by different layers of the ionosphere, fall.

We know

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

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

$$\left(\frac{f_{MUF}}{f_C}\right)^2 = 1 + \left(\frac{D_{skip}}{2h}\right)^2$$

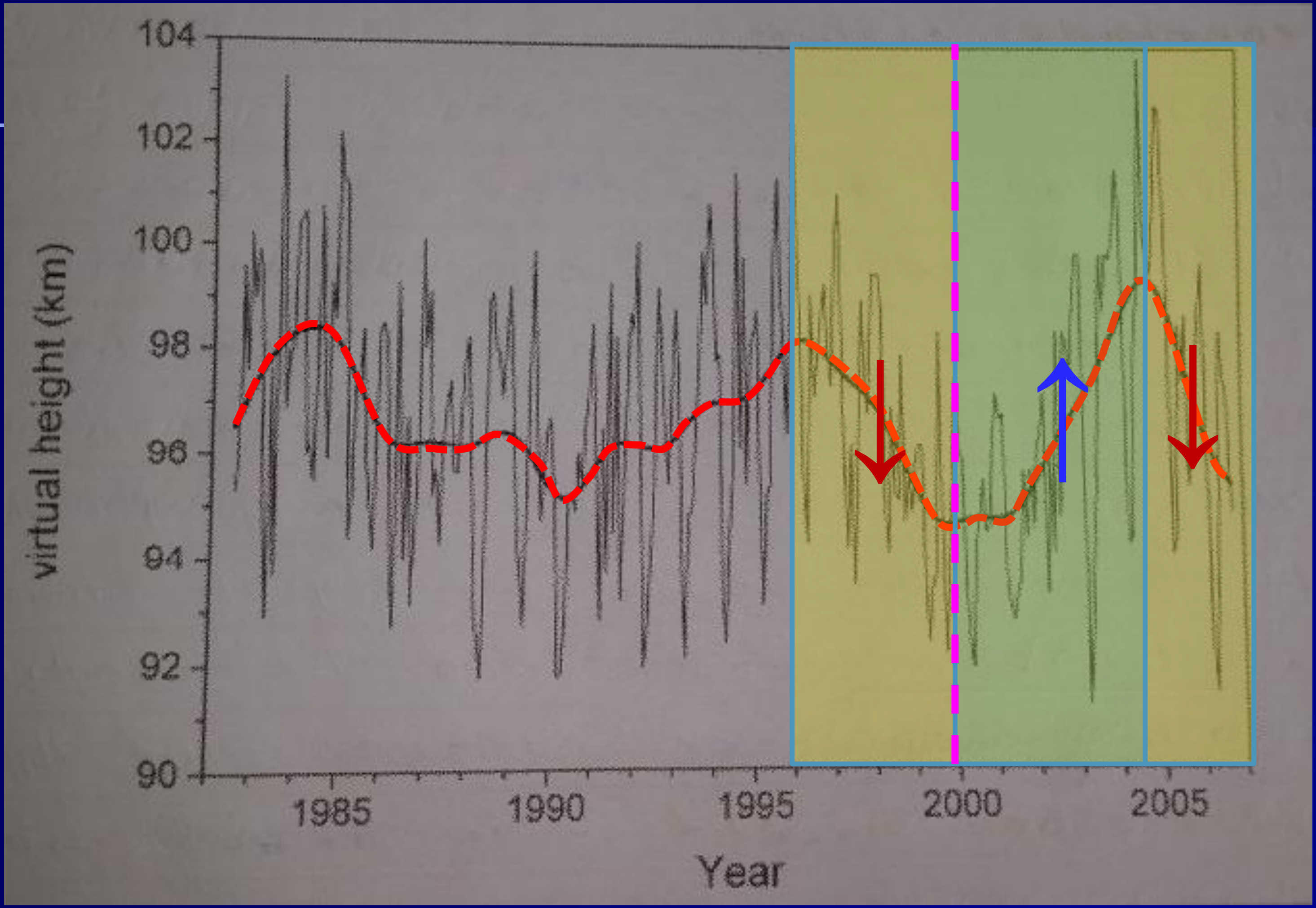
$$D_{skip} = 2h\sqrt{\left(\frac{f_{MUF}}{f_C}\right)^2 - 1}$$

# Reflection Heights

**Trends in low frequency radio wave reflection heights and lower E-region drifts over Collm** (a city), **Germany.**

Lower E-region low frequency measurements using commercial radio broadcasting stations have been used to indirectly measure mesospheric temperature variability via change of the radio wave reflection height. Recent analyses have shown that the temperature decrease is obviously not linear, but ceases (stops) during the last decade. Collm (a city in Germany) measurements of reflection heights on **177 kHz**, referring to a reflection point at **(52.1ºN,13.2ºE)** are shown in the following figure. These virtual heights are about 5 km too high compared with the real ones. **Until about year 2000**, **the reflection height decreases**, but after that time the lower E-region heights remain at a similar level.

# Reflection Heights




Collm measurements of reflection heights on **177 kHz**, referring to a reflection point at **(52.1ºN,13.2ºE)** are shown in the above figure.

# Reflection Heights

Low frequency measurements are also used to analyze E-region drifts can be interpreted as neutral winds at about 90 km altitude. Analyses of long-term trends have **revealed** possible long-term trends in some parameters, generally through to be in **connection with middle atmosphere changes**. Semi-diurnal (half daily) tidal amplitude have decreased, possibly in connection with stratospheric ozone decrease. **Meridional** (southern) **winds have decreased** due to stratospheric cooling, decrease of mesospheric wind jets and a resulting weaker gravity wave filtering which leads to reduced Brewer-Dobson circulation.

Generally, there is an increase of the zonal prevailing wind, a decrease of Meridional wind, which means a positive trends in summer (negative northerly winds) and a negative trend in winter (southerly weak wind). The trends are not linear. The strongest trends visible in the early 1990's while before and after that time trends are weak, and during recent years, even seem to reverse. The Meridional winds have decreased. In particular the summer trend weakens. The semi-diurnal tidal amplitudes show a complicated behavior, there are large values in the early 1990's, possibly connected with the **11 year solar cycle**.

# Reflection Heights

To **conclude**, the long-term wind and reflection height time series show trends during the last 3 decades. But there seem to be changes of these trends after the 1990’s. This is clearly visible in the prevailing winds and also in temperatures. It is generally through that middle atmosphere climate change is responsible for at least part of the lower E-region changes. This means, that in addition to the continuing $CO_2$ cooling other influences act on the upper middle atmosphere. One candidate is Ozone, which has decreased strongly since 1980’s, but had remained at a constant level or even recovered after the mid 1990’s.

# Radio Wave Communication

- Radio waves
- Radio Communication
- Reflection of Radio Waves
- Absorption of Radio Waves
- Complex Refractive Index
- Reflection Heights
- Deviating Region Absorption, Non-Deviating Region Absorption
- Ordinary/Extra Ordinary Waves
- Ionosphere – Sounding Techniques
- Pulse Reflection Methods

# Deviation Region Absorption & Non-Deviation Region Absorption

There are many different type of phenomena that attenuate or reduce the signal strength of propagating radio waves. Those phenomena types extract energy from the radio wave by converting its energy to **heat** and **electro-magnetic noise** and are associated with the term absorption.

When referring to the actual propagation of a radio wave through the ionosphere, we have **principally two types of ionospheric absorption**.

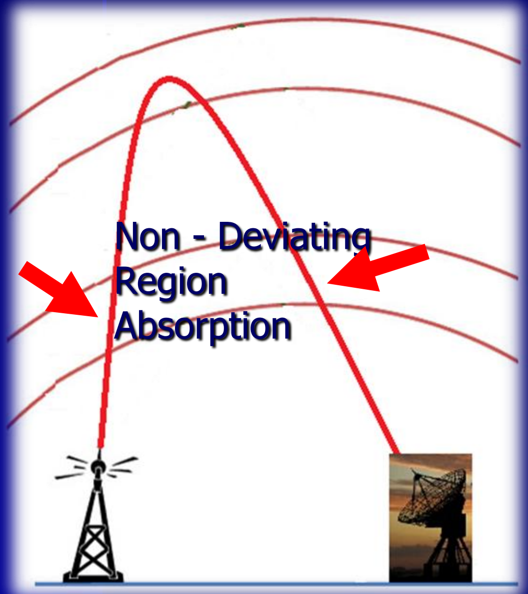
01. Deviating Absorption

02. Non - Deviating Absorption

During the day the ionospheric electron density is much increased but recombine also at a quick rate with the ever-present high densities of ions and neutral particles, especially in the lower ionosphere where the gasses are denser than at the higher more verified regions. **This produces stronger levels of ionospheric non-deviating absorption**.

# Deviation Region Absorption & Non-Deviation Region Absorption

In contrast, during the night, when the electron densities are substantially lower, the non-deviating absorption decreases. The following equation summarizes empirically the **non-deviating absorption**:




*Non-Dev Region*
***Absorption Coefficient***

$$\kappa = 1.15 \times 10^{-3} \frac{N \nu}{f}$$

***Ele; Density** in the Lower Ionosphere*

***Collision Frequency** of ele; with neutral particles*

***Freq; of the Radio wave***

# Deviation Region Absorption & Non-Deviation Region Absorption

$$\kappa = 1.15 \times 10^{-3} \frac{N \nu}{f}$$

From the above equation, we can see that; if the electron density **N** or the collision frequency **ν** is increased, while the radio frequency **f** stays constant, then the absorption level **κ** will increase,

If **N** ↑ or **ν** ↑ → **κ** ↑ (when **f** constant)

However, if the radio frequency (**f**) is increased then the effect of non-deviating absorption (**κ**) decreases.

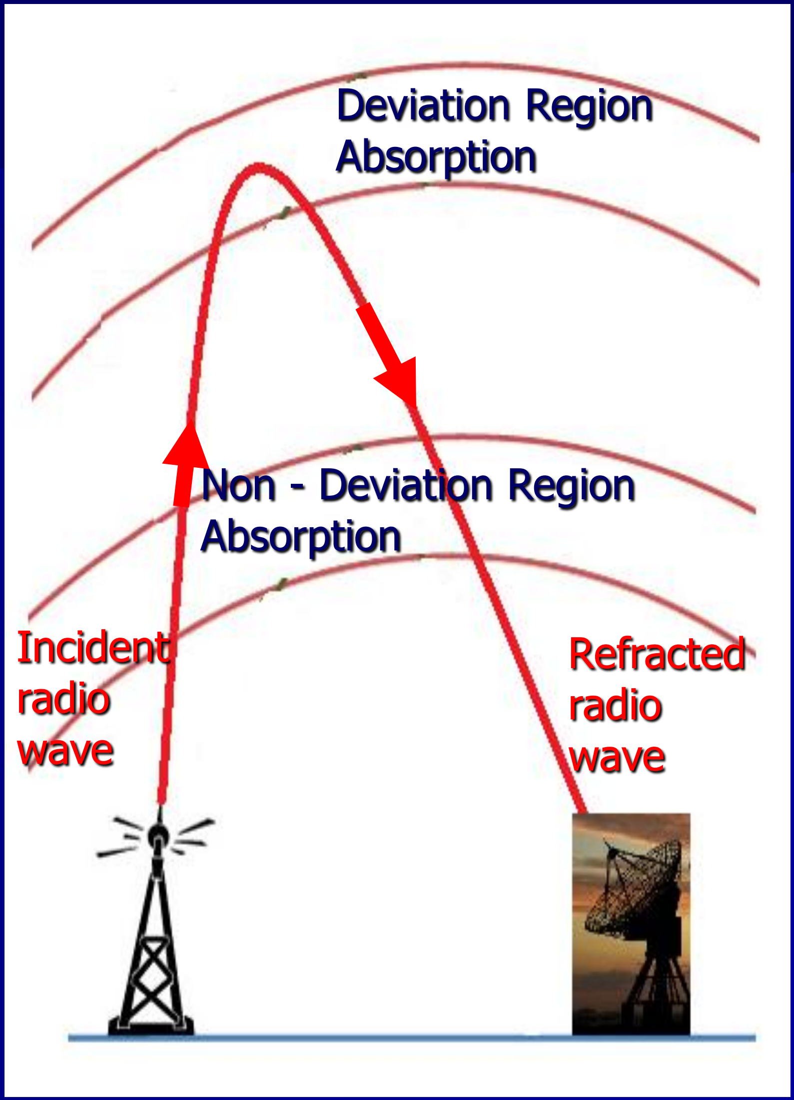
If **f** ↑ → **κ** ↓

**Lower frequencies have a greater or larger wave front than higher frequencies (even when the amplitude is equal) !**

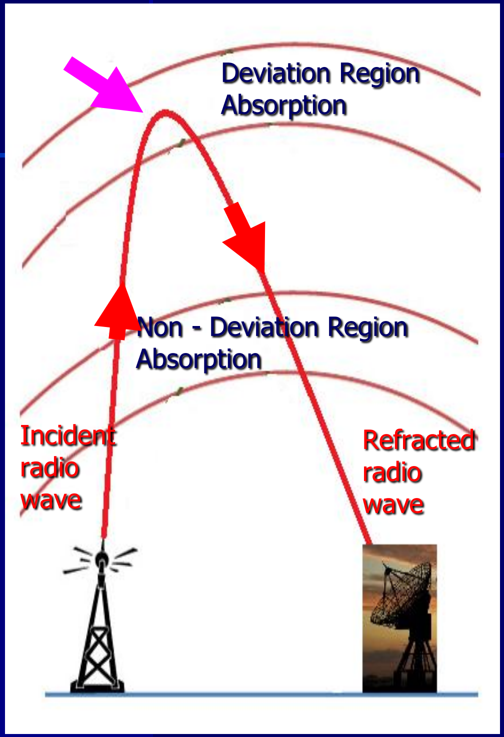
# Deviation Region Absorption & Non-Deviation Region Absorption

**A greater wave front will collides much more with ions and neutral particles and therefore be more attenuated**. If we send a wave to the ionosphere, the **wave is spending the additional time interval in the ionosphere due to more collisions with ions and neutral particles.**

That extra spending time interval is large, that means, the wave meet Deviation Region or not. If we analyzed the **time interval** of the incident and reflected waves, we can conclude the wave meet a peak (deviating region) or not.



# Deviation Region Absorption & Non-Deviation Region Absorption




Sometimes **electron density** of the ionosphere is having a **very large values** when **huge solar activity**, **VHF** (30 MHz – 300 MHz) and **UHF** (300 MHz – 3 GHz) **also may be** reflected from the ionosphere.

**Deviative Absorption** is a type of absorption that occurs when the signal spends a **longer period** of time within the absorbing medium and meanwhile is refracting. The derivative absorption coefficient depends heavily upon the **refractive index of the signal** and frequency of the electron collisions with neutral particles.

*Deviation Region Absorption Coefficient*

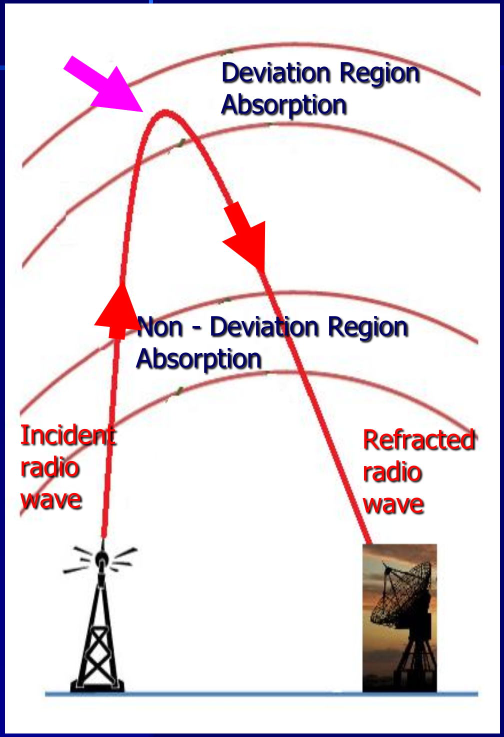
$$\kappa^1 = \kappa^1(n,\ f)$$

*Refractive Index of the Signal*

*Collision Frequency of ele; with neutral particles*

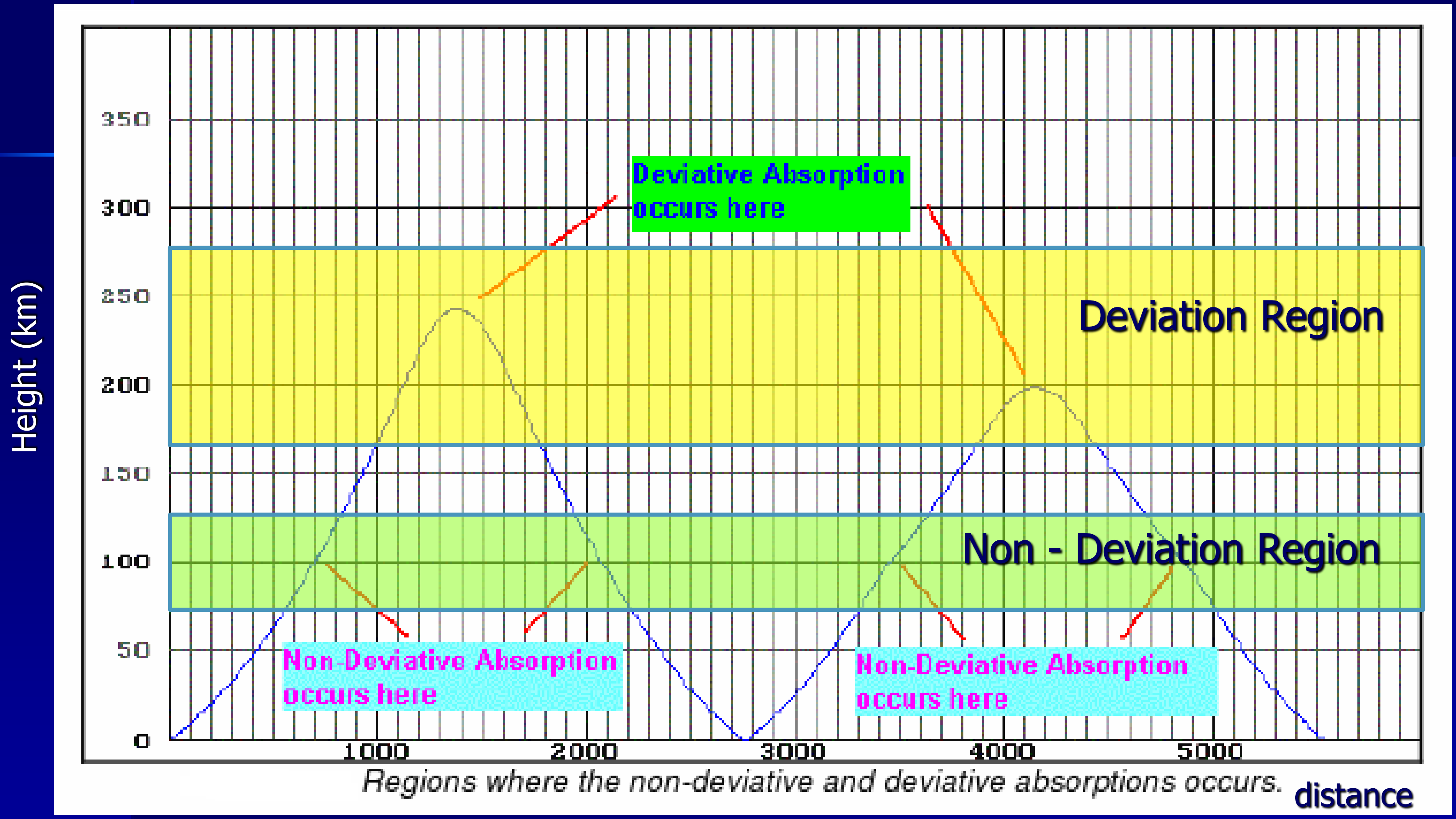
# Deviation Region Absorption & Non-Deviation Region Absorption

$$\kappa^1 = \kappa^1(n,\ f)$$




Each time a signal is refracted in the ionosphere, deviating absorption occurs. Refraction in the lower ionospheric regions, where the electron collision frequency is rather high, experience greater absorption and can be rather high, particularly the frequencies in the lower **HF** spectrum. If the Sun also illuminates (very active) the communication circuit, then the effects of non-deviating absorption will take an additional toll on (badly damaged) the signal strength.

# Deviation Region Absorption & Non-Deviation Region Absorption




Deviating absorption is usually not as strong as Non-Deviating absorption !

# Radio Wave Communication

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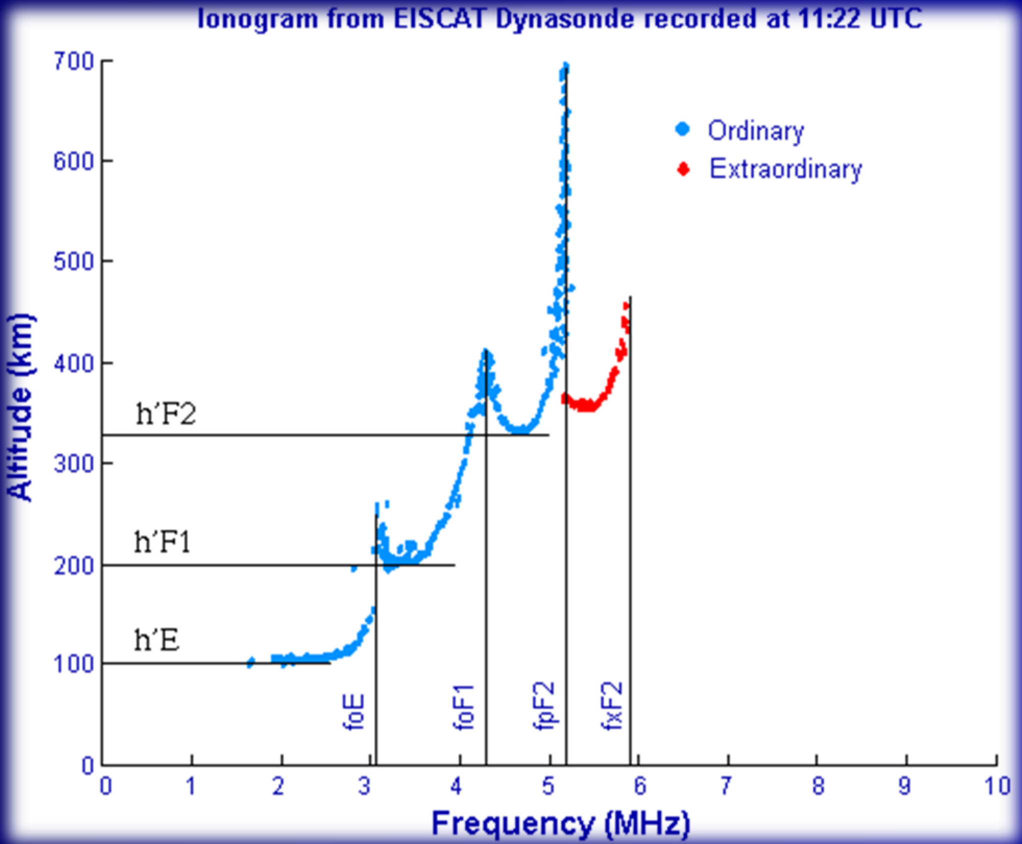
- Ionosphere – Sounding Techniques
- Pulse Reflection Methods

# Ordinary & Extraordinary WAVES

As soon as transmitted radio signals begins to penetrate the ionosphere, **it splits up into two characteristic components due to the Earth's Magnetic Field**. These two components are known as the **ordinary** and **extraordinary** waves.



# Ordinary & Extraordinary WAVES

For the **ordinary wave**, the E-field accelerates electrons **parallel** to the magnetic field. This means that the electric field has no influence, because a magnetic field only imposes a force on charged particles moving perpendicular to the Field !

For the **extraordinary wave**, the E-field of the incident radiation accelerates the free electrons **normal** to the magnetic field. This means that the exerts a force on the electrons and therefore modifies the motion. This causes the refractive index of the extraordinary wave to be different from the ordinary wave.

The different refractive indices of the two component waves, meaning different velocities, also cause a **progressive phase shift** between the two components. If the **phase shift becomes 90°**, then the initial **100% circular polarized wave**. For **smaller different phase shifts** will the wave becomes **elliptically polarized**.

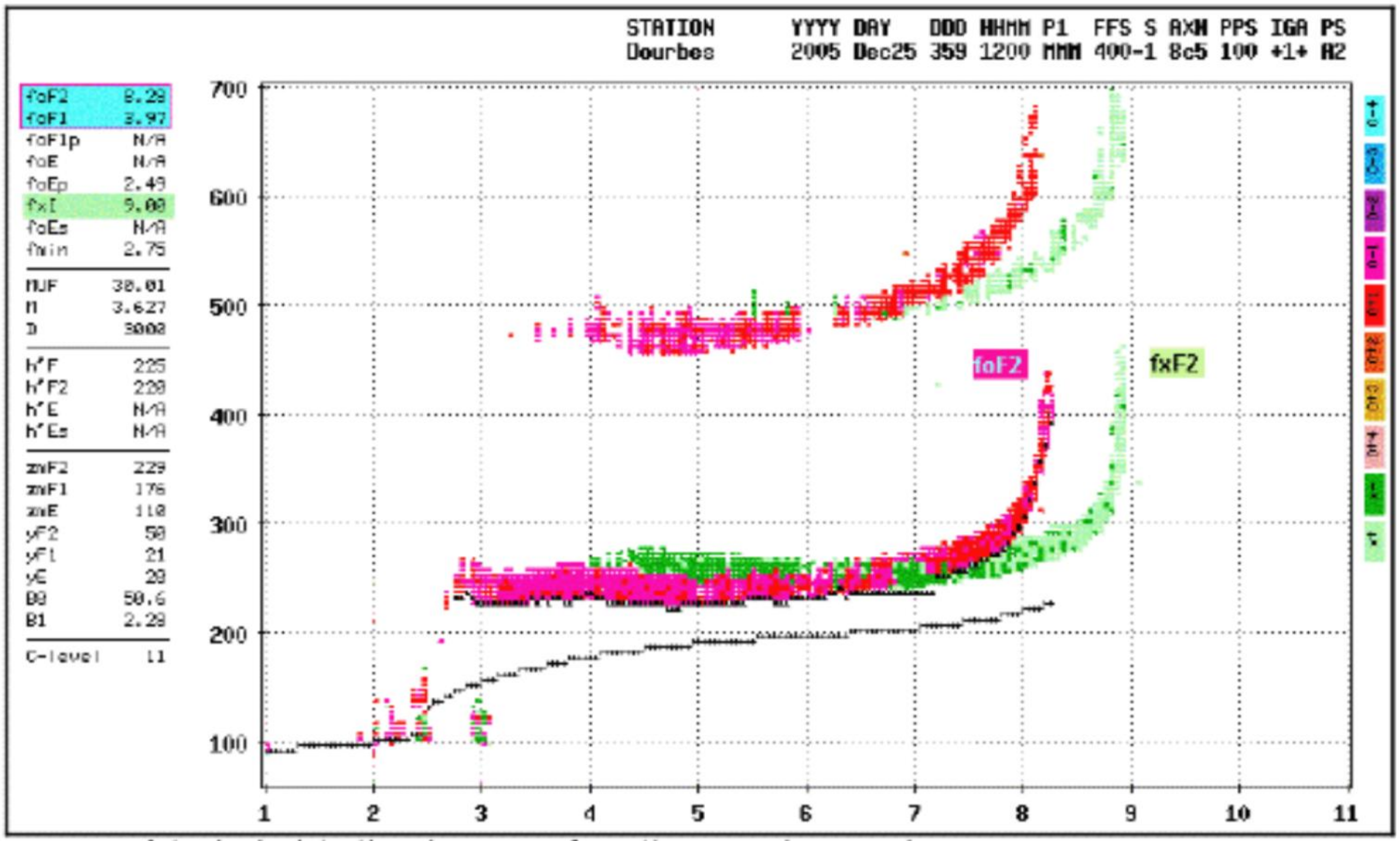
# Ordinary & Extraordinary WAVES

Each of these waves, the ordinary and the extraordinary identified as the o-wave or the x-wave, travels a completely independent path through the ionosphere. The single radio signal travels as simultaneously transmitted but independent transmissions. Each propagating signal component contributes to a different mixture of power level, which totals together the power the signal before it enters the ionosphere. **The individual power level depends upon some complicated relationships between the o-wave and x-wave at the base of the ionosphere**, but the x-wave is the weaker of the two.

- At **higher frequencies** the o-wave and x-wave often follow very simple path.
- At **lower frequencies** the o-wave and x-wave will diverge more considerably.

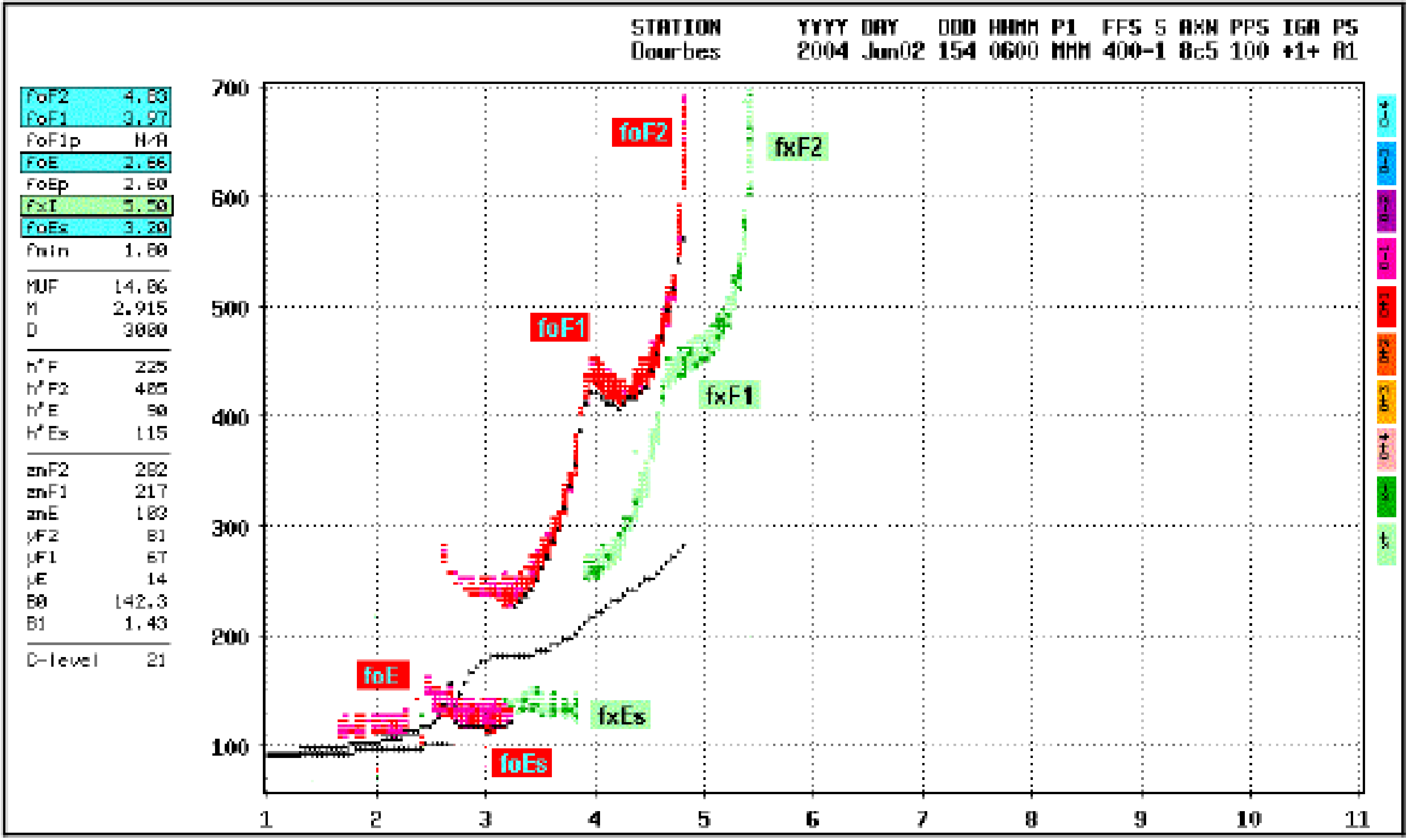
# Ordinary & Extraordinary WAVES

The existence of the ordinary waves and extraordinary waves and the gyro-frequency (cyclotron frequency) is also clearly noticeable and sounded in ionograms, in the following figure.




*A typical wintertime ionogram from the same ionosonde.*

# Ordinary & Extraordinary WAVES



# Ordinary & Extraordinary WAVES

Both waves have different critical frequencies for the different respective ionospheric layers. For example, we find the **$F_2$ layer**, respectively $f_oE_2$ and $f_xF_2$. The difference between the gyro-frequency as,

$$f_H = 2\left(f_x - f_o\right)$$

OR

$$f_x - f_o = \frac{1}{2} f_H$$

The critical frequency of the extraordinary wave (1/2) $f_H$ higher than the critical frequency of the ordinary wave [ $f_x = f_o + (1/2) f_H$ ]. It is obvious that both waves also have their own **MUF** (maximum usable frequency) values as well. The extraordinary wave MUF will always be higher.

$$MUF = \frac{f_c}{\sin\alpha}$$

Where, **alpha** is angle of incidence and **$f_c$** is the critical frequency, either **$f_o$** or **$f_x$** of the considered layer.

# Ordinary & Extraordinary WAVES

Electromagnetic waves propagate through a magneto-ionic medium in the (so-called) free space mode as long as $n^2>0$; where $n$ is the refractive index. When $n=0$ then reflection occurs (refracting downward). So we can use the **Appleton Equation** for a vertically propagating signal including the Earth' magnetic field and set the refractive index $n$ to zero and solve for **X**.

## Δ The Appleton - Hartee Equation

The Appleton – Hartee equation describes the complex index of refraction of the ionosphere in terms of the free motion of the electrons under the influence of thermal motion, geomagnetic fields and ionic collisions. It is successful application to the behavior of radio reflection demonstrated that free electrons in the ionosphere's F-layer in fact cause reflection.

$$n^2 = 1 - \frac{2X(1-X)}{2(1-X) - Y^2 \pm \left[Y^4 + 4(1-X)^2 Y^2\right]^{1/2}}$$

# Ordinary & Extraordinary WAVES

## The Appleton - Hartee Equation

$$n^2 = 1 - \frac{2X(1-X)}{2(1-X) - Y^2 \pm \left[Y^4 + 4(1-X)^2 Y^2\right]^{1/2}}$$

X = 1 : The ordinary wave ( o – wave )
X = 1 - Y : The extraordinary wave ( x – wave )
X = 1 + Y : The **z – wave**

Where, $X = \frac{f_p}{f}$ , $Y = \frac{f_H}{f}$ and $f_p = \left(\frac{Ne^2}{m\varepsilon_o}\right)^{1/2}$ , $f_H = \frac{eB}{2\pi m}$

N - number densities of the electrons, e - charge of the electrons, m - mass of the electrons, $\varepsilon_o$ - free space permittivity, B - the Earth's Magnetic Field, $f_p$ - plasma frequency, $f_H$ - gyro-frequency.

The o and z modes have left hand and the x mode right hand polarization with respect to the magnetic field direction. Except at high latitudes the z mode is rarely observed in ionograms. The two prevailing modes o and x can be identified by the sense of rotation of the E-Field vector.

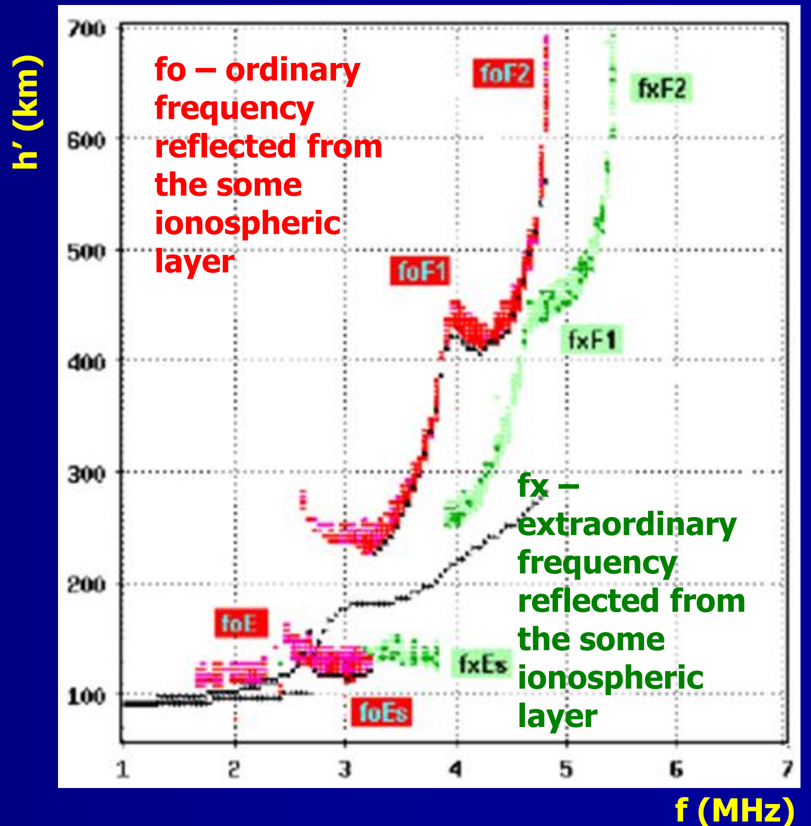
# Ordinary & Extraordinary WAVES

## Δ The deviation from great circle path

The illustration of the following figure help to display another important property of ordinary and extraordinary waves. The influence of the Earth's Magnetic Field causes them to split but also to divergence away from the great-circle path. The **ordinary wave** diverges toward the **magnetic pole** while the **extraordinary wave** diverges toward the (magnetic) **equator**.

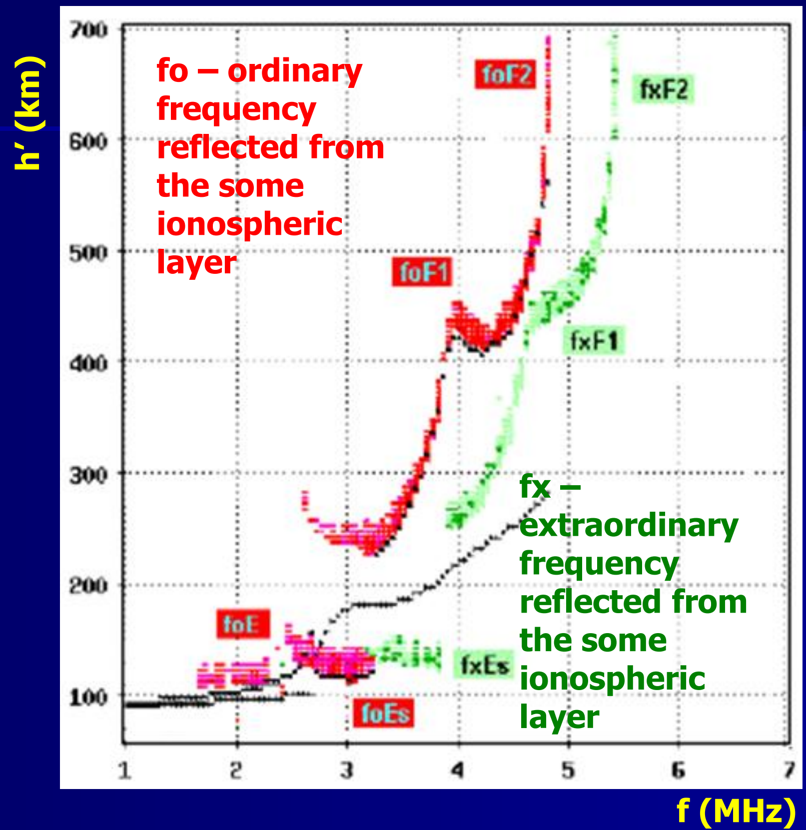
This can be observed in the ground track plots of these two signal components. NOTE: The divergence can also be cause additionally by ionospheric tilts (slope).

A typical ionogram showing the ordinary and extraordinary traces from the different ionospheric layers. This horizontal axis of the ionospheric sounder, and the vertical axis is the equivalent height.



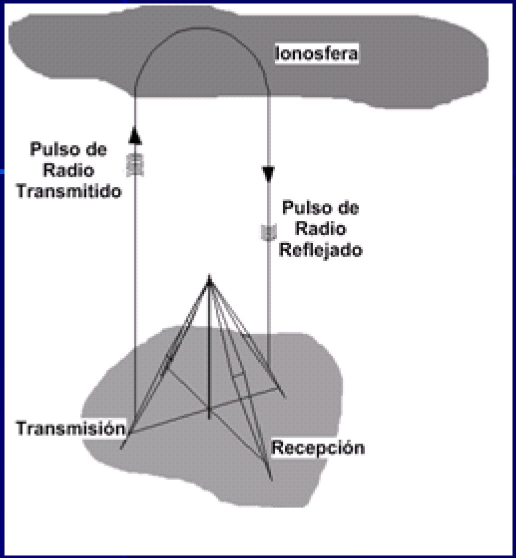
# Ordinary & Extraordinary WAVES

## Δ The deviation from great circle path




At frequencies lower than the peak plasma frequency (critical frequency) the ordinary wave deviates more pole-ward than the extraordinary wave equator-ward defection (removal) does. The most deviation of the ordinary wave occurs also at or near the point of reflection.

# Ionospheric Sounding Technique




In telecommunication and radio science, an ionospheric sounding is a technique that provides real-time data on high frequency ionospheric-dependent radio propagation, using a basic system consisting of a **synchronized transmitter** and a **receiver**.

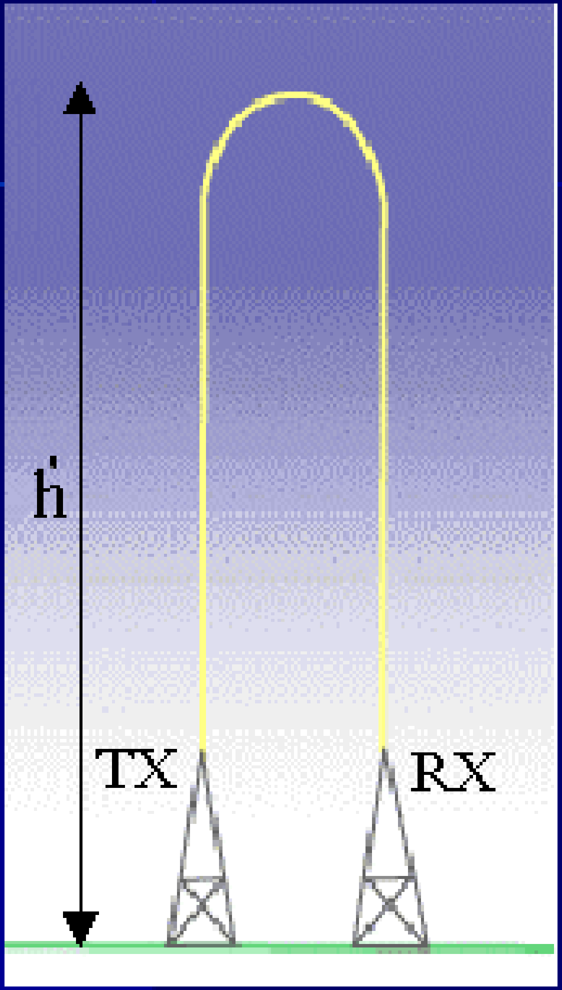
The time delay between transmission and reception is translated into effective ionospheric layer altitude. Vertical incident sounding uses a collocated (arrange) transmitter and receiver and involving directing a range of frequencies vertically to the ionosphere and measuring the values of the reflected returned signals to determine the effective ionospheric layer altitude. This technique is also used to determine the critical frequency.

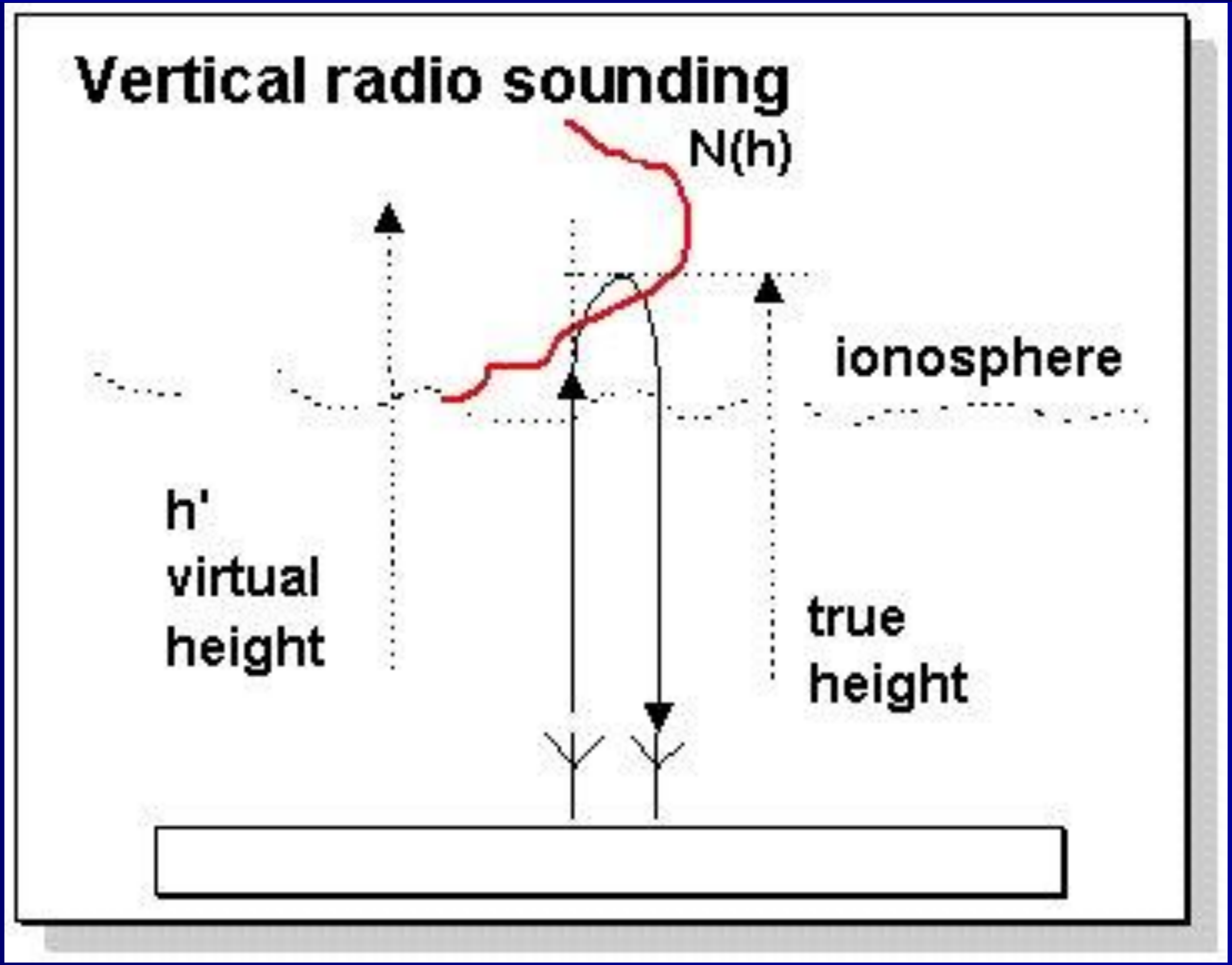
# Ionospheric Sounding Technique

Oblique (indirect) sounders use a transmitter at one end of a given propagation path, and a synchronized receiver, usually with an oscilloscope type display (ionogram), at the other end.

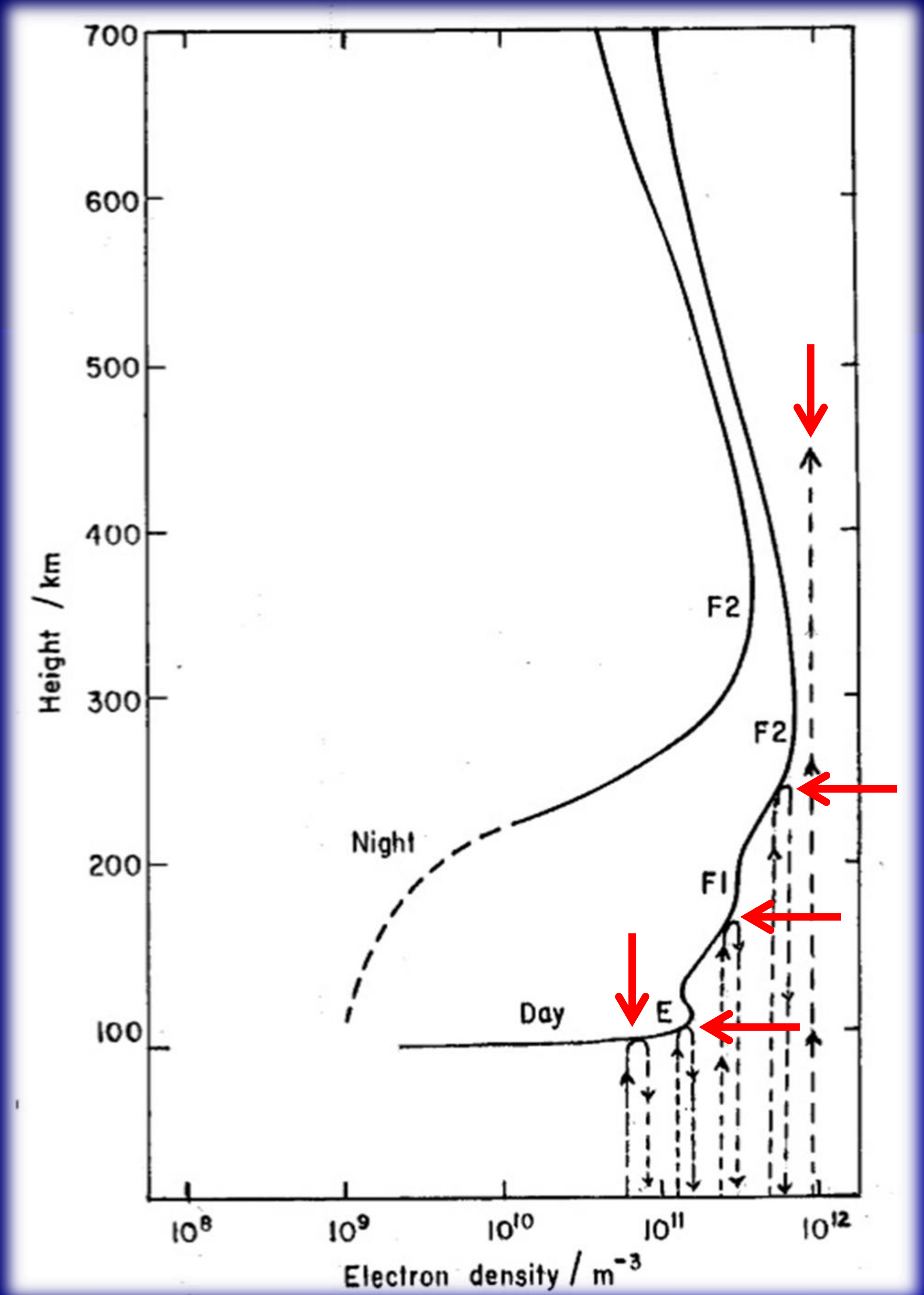
The transmitter emits a stepped (incident) or swept (sweep) frequency signal which is displayed or measured at the receiver. The measurement converts **time delay** to effective altitude of the ionospheric layer. The ionogram display shows the **effective altitude of the ionospheric layer** as a function of frequency.

# Ionospheric Sounding Technique



# Ionospheric Sounding Technique



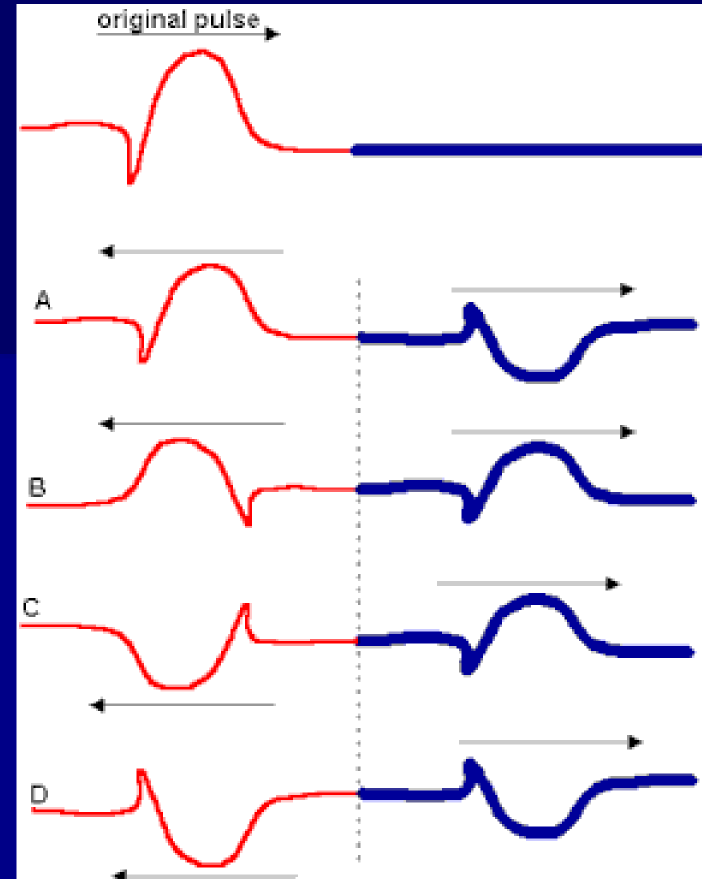
# Pulse Reflection Method

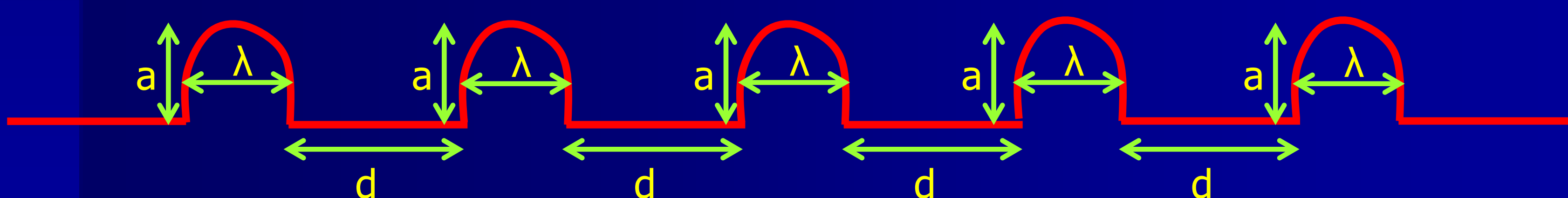
Pulse reflection method is widely used to study the characteristics of the upper atmosphere by sending pulses towards it. These pulses are sequential and having the,

1. **same gaps between each pulses**,
2. **same amplitude**

and

3. **same frequency**.



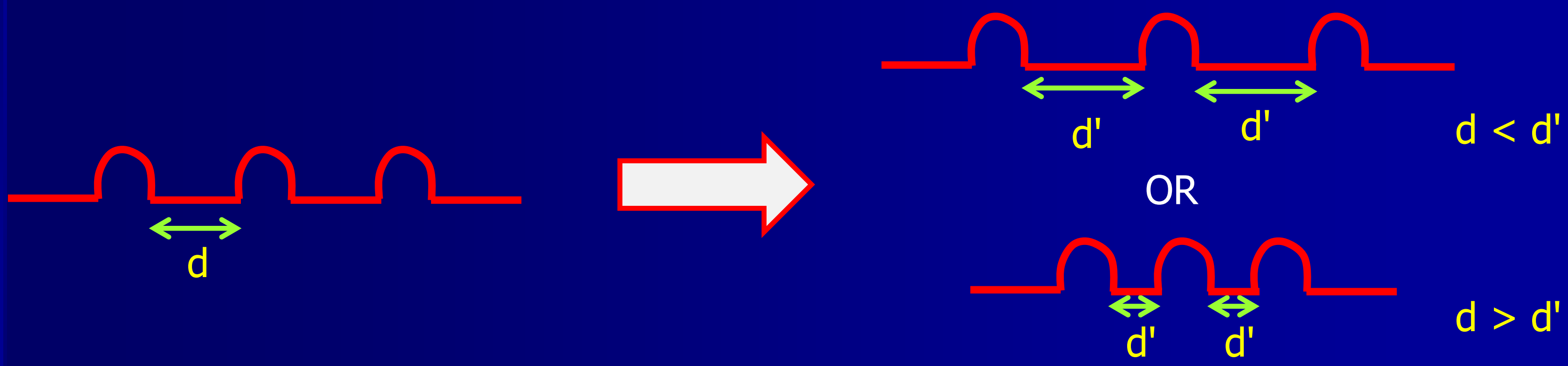

Where **$c = f\lambda$**

# Pulse Reflection Method

**Method :**

These pulses are send towards the upper layers of the atmosphere and by observing the changes they shows at the step of direction, then can be used to make conclusion regarding the characteristics of those layers. Such differences between the incident and reflected signals can be depict as follows.

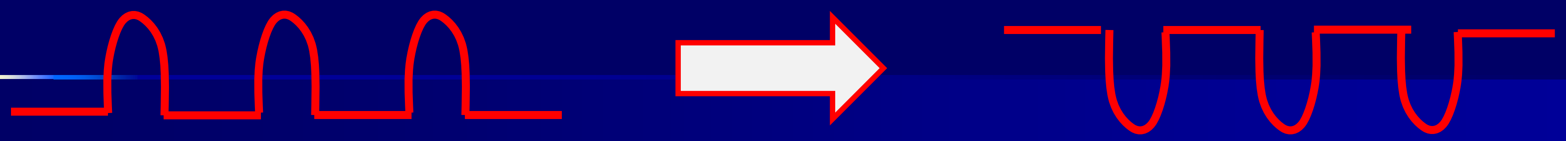
**01. A difference can be observed between two consecutive gaps**




Incident Signal Reflected Signal

# Pulse Reflection Method

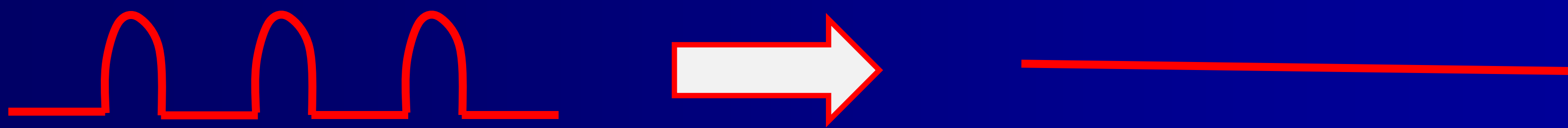
## 02. The wave form can be inverted during the step of reflection



Incident Signal

Reflected Signal

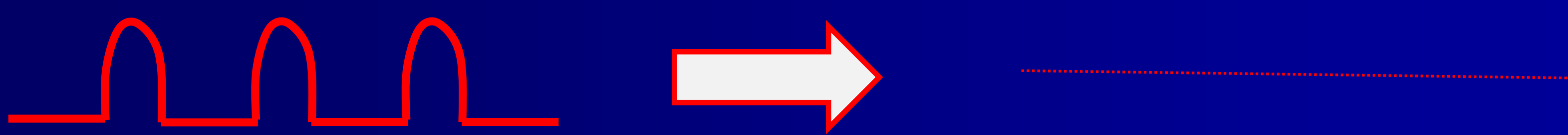
## 03. The wave form can be vanished during the step of reflection



Incident Signal

Reflected Signal

## 04. There is no reflected signal

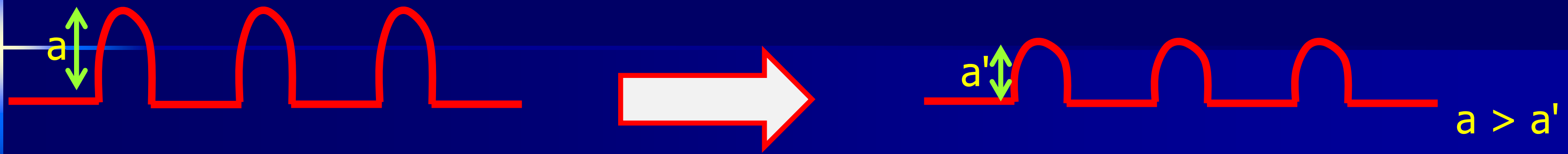


Incident Signal

NO Reflected Signal

# Pulse Reflection Method

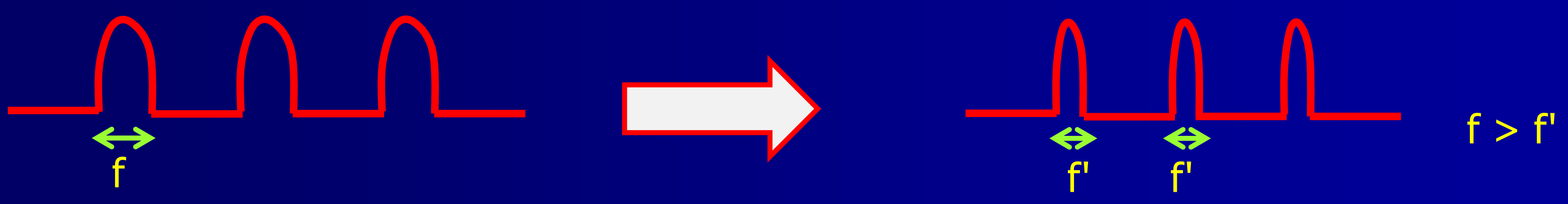
**05. Amplitude is tends to be reduced during the step of reflection**




Incident Signal

Reflected Signal

**06. Frequency of the reflected pulse can be observed to be vary according to the prevailing circumstances in the upper atmosphere**



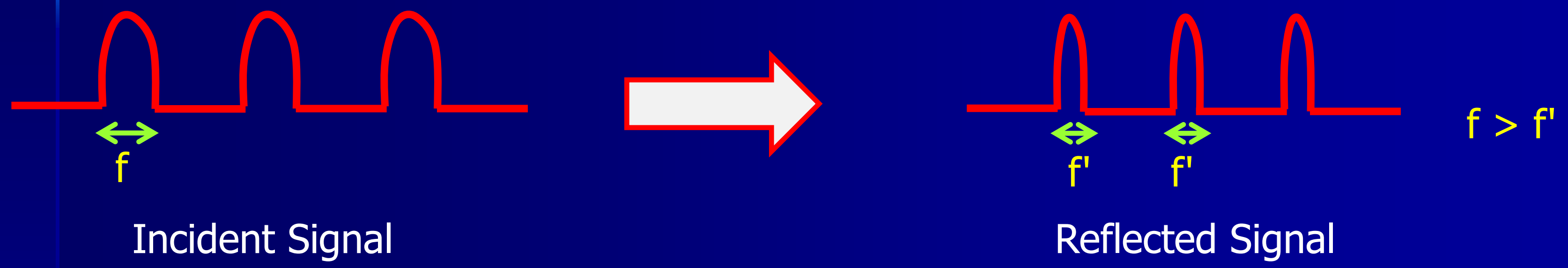

Incident Signal

Reflected Signal

Here the gap between two consecutive pulses wont get affected.

# Pulse Reflection Method

**06.** **Frequency of the reflected pulse can be observed to be vary according to the prevailing circumstances in the upper atmosphere**




Here the gap between two consecutive pulses wont get affected.

Time that would take to detect after the reflection can be use to study the regions where these pulses being reflected from. **As the time vary**, it indicate that the **pulses are reflecting from different sections of the upper atmosphere !**

# Thank You !