Antenna & Propagation

“Propagation Media”

Dr. Cahit Karakuş, February-2019

İçerik

- Atmosfer
- Elektromanyetik dalgaların atmosferde yayılması
- Propagation Modes
- Signal Propagation
- Doppler Shift

Transmission Media

Transmission media of electromagnetic waves include all routes between transmitter and receiver consisting of one or more of the following main paths:

- Free space
- Earth atmosphere
- Ground surface and surrounding medium
- Ocean and sea water
- Inside Earth
- Outside Earth

Media Characteristics

Radiowaves propagation in free space or air occurs with acceptable loss while they are attenuated rapidly in sea-water or inside lands, increasing with frequency. Every media is characterized by three parameters as mentioned below:

- Permittivity denoted by ϵ in Farad per meter (F/m)
- Permeability denoted by μ in Henry per meter (H/m)
- Conductivity denoted by σ in Siemens per meter (S/m).

In free space, values of the above parameters are:

$$\sigma = 0, \quad \epsilon_0 = 8.85 \times 10^{-12}(\mathrm{F/m}), \mu_0 = 4\pi \times 10^{-7}\ (\mathrm{H/m}).$$

Conductivity of the transmission medium can be evaluated. Good conductivity is equivalent to $\frac{\sigma}{\omega\epsilon} \gg 1$ while poor conductivity is equivalent to $\frac{\sigma}{\omega\epsilon} \ll 1$.

Example 2.1. Calculate the conductivity of a piece of land specified by $\sigma = 5$ mS/m, $\mu_r = 1$, and $\epsilon_r = 12$ for radiowaves of $f_1 = 10$ KHz and $f_2 = 10$ GHz.

***Solution*:** For $f_1 = 10$ KHz

$$\frac{\sigma}{\omega\epsilon_r\epsilon_0} = \frac{0.005}{2\pi \times 10^4 \times 8.85 \times 10^{-12} \times 12}$$
$$= 749.3 \gg 1.$$

Thus the land is of good conductivity at f_1, and for $f_2 = 10$ GHz. The conductivity index is:

$$\frac{\sigma}{\omega\epsilon_r\epsilon_0} = 7.5 \times 10^{-4} \ll 1.$$

Therefore the land is a good dielectric at f_2. ■

Fundamentals of Wireless Channels

– Frequency & Wavelength
– Classification & Use
– Modes of Propagation
– Propagation Mechanisms
– Atmospheric Attenuation
– Propagation Models
– Fading Channels
– Multipath
– Noise

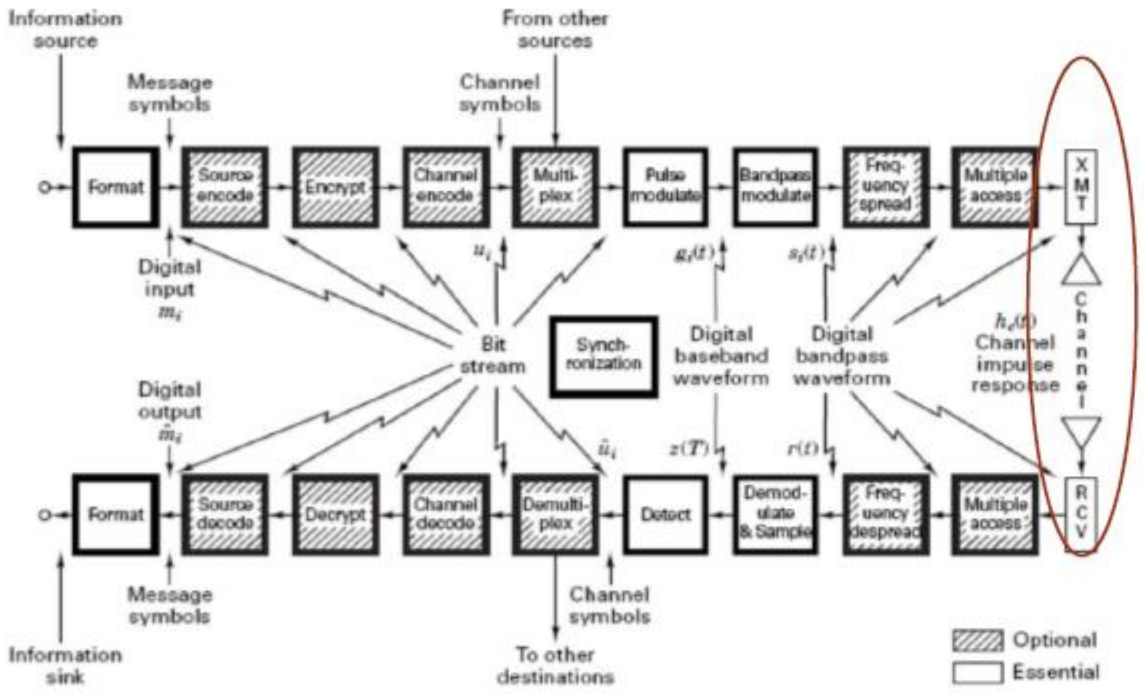
The Channel

- **Channel** is the propagating medium of electromagnetic path connecting the transmitter and the receiver.

- Physically a channel can be
  - For wired communications: Wire, coaxial cable, fiber optic cable,
  - For wireless (RF) communications: empty space, waveguide, the atmosphere, earth's surface, medium containing «buildings, trees, vehicles, etc…»

- **Free space**: A channel free of all impairments to RF propagation
  - Absorption, reflection, refraction, diffraction
  - Energy arriving at the receiver is only a function of the distance from the transmitter.

- We will consider the free space as the ideal channel!.



Error-Performance Degradation

- Main causes:
  - 1. **Noise**: thermal noise, impulsive noise, galactic noise, etc.
  - 2. **Interference**: Inter-Symbol Interference (ISI), Multi-User Interference (MUI), Other comm. signals, Man-made interference

  (Consider noise only for the time being.)

- Error performance depends on the received **Signal-to-Noise Ratio per bit** (SNR/bit), E_b/N_o, defined as

$$\frac{E_b}{N_o} = \frac{S}{N}\left(\frac{W}{R}\right)$$

Average signal power

Bandwidth

Bit energy

Noise PSD

Rate

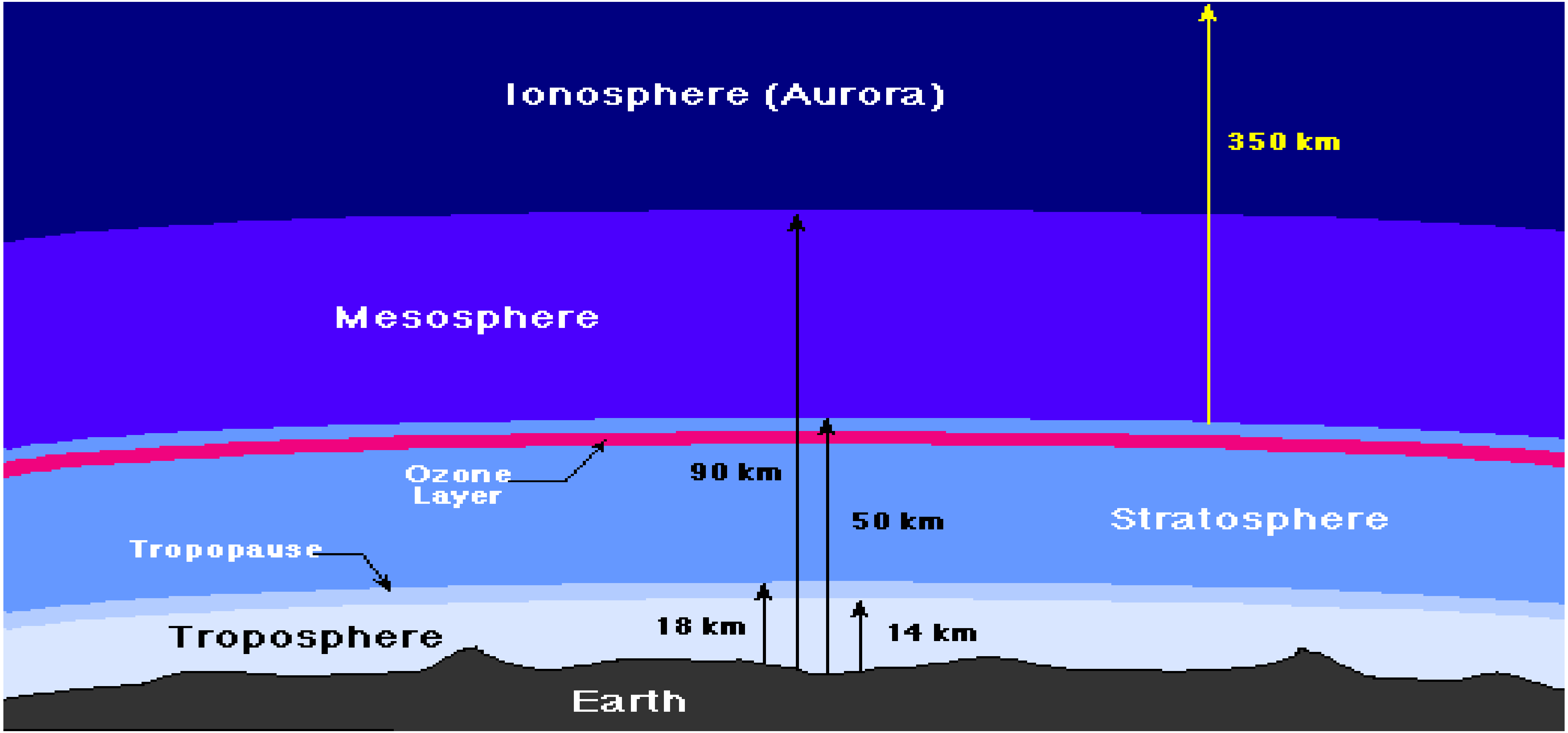
Average noise power

SNR

LOSS HAPPENS HERE ! (HOW ?)

Layers of the Atmosphere

Atmosfer Katmanları



Atmosfer Katmanları

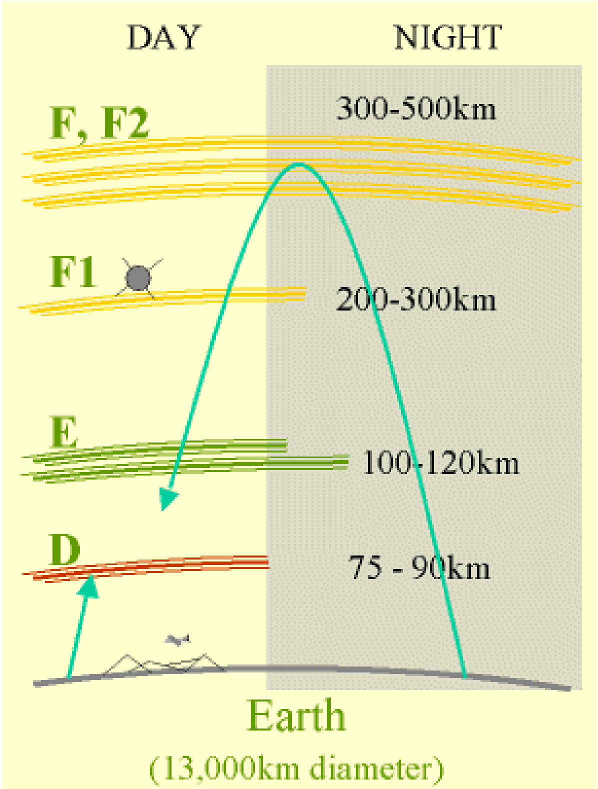
- Troposfer: En yoğun. Tüm hava burada gerçekleşir. Çoğu radyo dalgası kırılır. Kısa dalga boyu emilir.
- Stratosfer: Kuru, ultraviyole radyasyonu (UV) emer. Ozon tabakası burada, Ozon (O3) çok fazla UV C ve UV B dalgaları emer.
- Mezosfer: En soğuk. Birçok meteorlar burada yanıyor
- İyonosfer: Yüklü iyonların bölgesi (pozitif) ve elektronlar. Elektronlar, atomları kısa dalga boylarında güneş ışığı ile parçalamaktadır. Elektronlar kolayca birleşemezler çünkü moleküller arasındaki mesafe yüksek irtifalarda büyüktür ve çarpışmalar sık değildir. İyonosfer Yansımaya Neden Olabilir. İyonosferin iyonları ve serbest elektronları nedeniyle çoğu radyo dalgasını yansıttığı bilinmektedir.

Troposphere

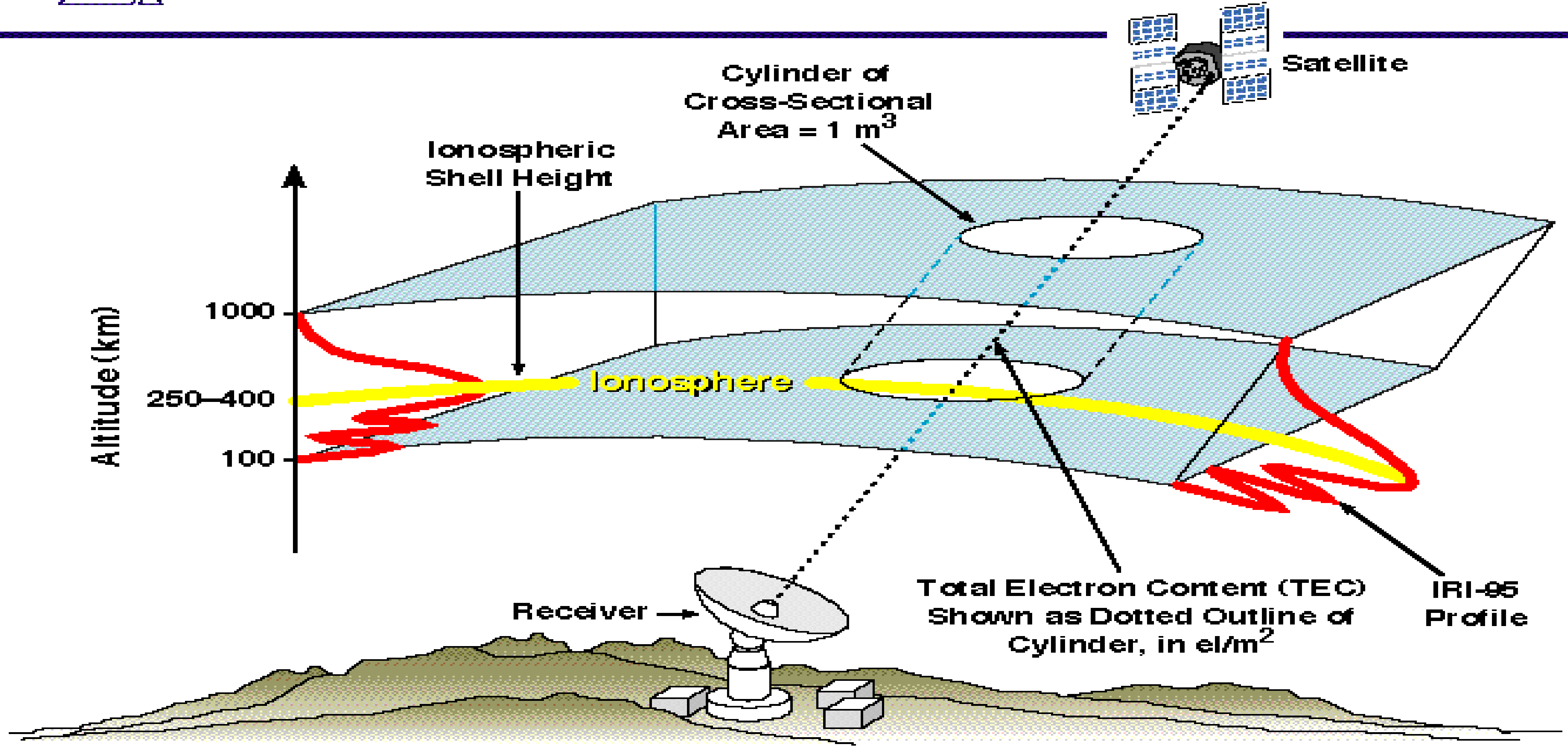
- Attenuation by the troposphere:All wavelengths >25cm pass through. O2, H2O, and weather (rain, fog, etc) cause attenuation
- Refraction in the troposphere: nair= 1.00029 when T=0°C and P=760mm of Hg. “n” differs for light and radio waves only due to presence of water vapor which increases dielectric constant

Ionosphere

- Ionosphere Can Cause Reflection.
- The ionosphere is known to reflect most radio waves because of its ions and free electrons.
- Penetration and refraction- dependent on electron density and wave frequency
- The ionosphere refracts radio waves of certain frequencies (3-30MHz or short waves).
- This refraction makes worldwide radio communication possible without using satellites.



Ionospheric Refraction

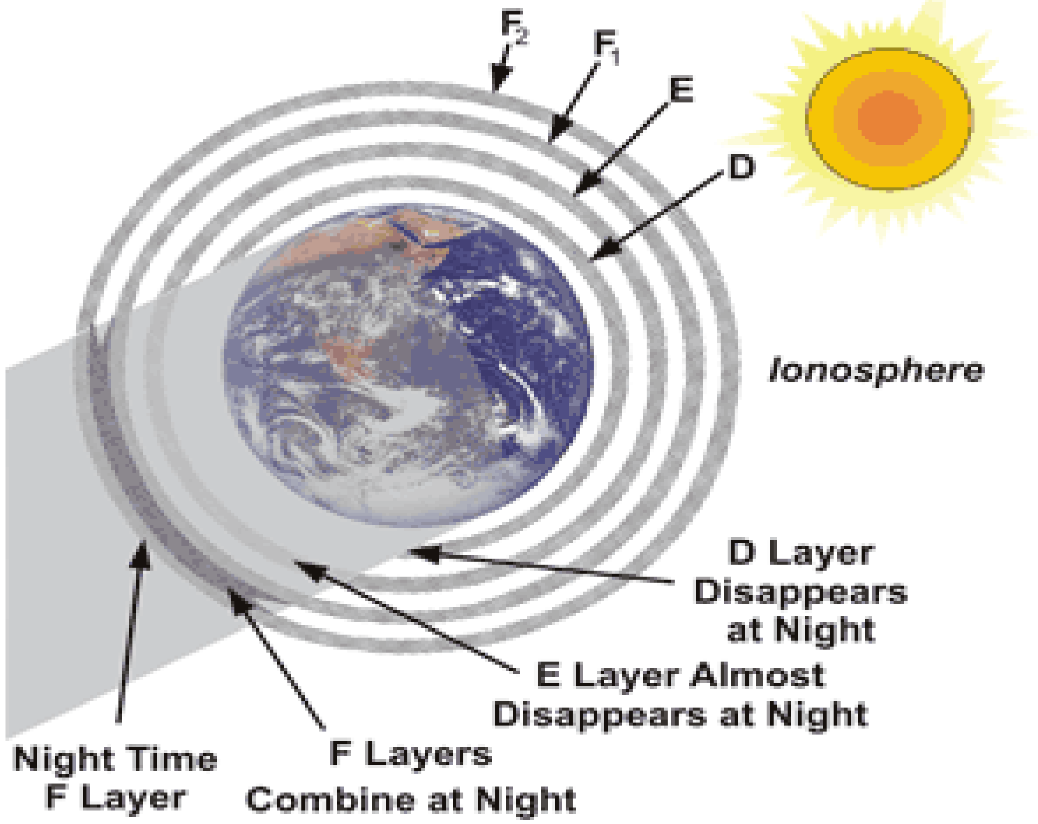


Attenuation by the Ionosphere

- Ionization varies with latitude, season, solar time, and phase of sunspot cycle
- 2 regions- E and F where penetration take place
- Region D- absorption
- Divergence occurs at angles of incidence<30° and intensity on ground is reduced
- Absorption loss increases with air density-greatest in lower ionosphere

Layers of the Ionosphere

- Lowest part: D layer has enough collisions to cause it to disappear after sunset
- Remaining ions and electrons recombine, without sunlight new ones are no longer produced
- Layer return at sunrise



D Layer and Radio Transmission

- Low frequencies (below 10MHz) absorbed - high frequencies pass through
- More ionized = more radio wave absorption
- Maximum usable frequency (highest frequency that can be refracted) : 16 MHz
- Optimal usable frequency: 13.6 MHz
- Most abundant molecule present: O_3

E Layer of Ionosphere

- Ionized gas
- Reflects medium frequency waves, causes radio waves to be propagated beyond horizon
- Day- solar wind presses this layer closer to the Earth limiting distance radio waves can be reflected
- Night - solar wind drags the ionosphere further away, increasing the range of radio waves
- Season and sunspot activity also influence reflection

E Layer and Radio Transmission

- Refracts radio signals and causes them to skip back to earth
- Weakest at night - radio signals pass right through
- Maximum usable frequency : 28 MHz
- Optimal usable frequency : 23.8 MHz
- Most abundant molecule: O_2
- Few seasonal or daily differences for transmission

F Layer of Ionosphere

- Most important in terms of high frequency communications
- During the day- 2 layers; combines into one layer at night
- Thickest
- Most reflective of radio on the side of the Earth facing the sun

F Layer and Radio Transmission

- Ionized all night
- Refracts higher frequencies by day, but passes them through at night
- Low frequencies (10-15MHz) are refracted back to earth at night
- Maximum usable frequency : 16 MHz
- Optimal usable frequency : 13.6 MHz
- Most abundant molecules present: Nitrogen in F1 sub layer and Oxygen in F2 sub layer.

Radio Waves Through the Atmosphere

- D layer disappears at night- low frequencies can now be used (AM vs. FM)
- E Layer weak at night
- F sublayers combine into one layer at night
- Sunspots can increase the ionosphere's ability to refract high frequency radio waves
- Solar flares can increase the amount of radio wave absorption, thus hurting radio communications

Space Weather

- What happens in the Sun and in space effects what happens here on Earth.

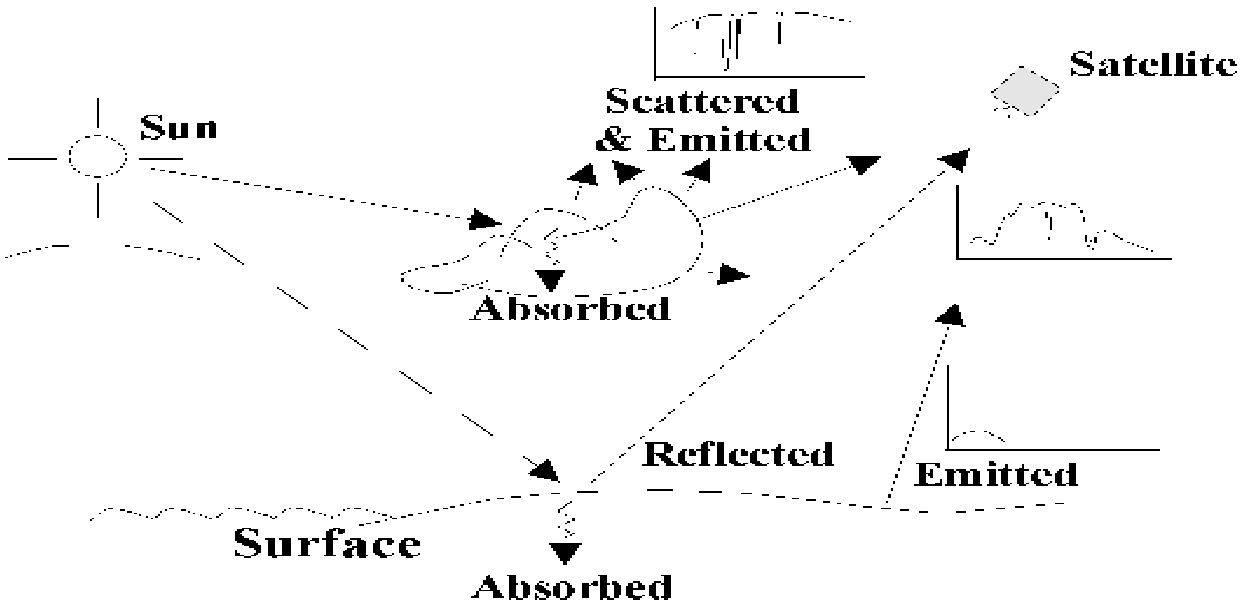
What Else Can the Sun Do?

- The Earth has a magnetic field that reaches into space
- The magnetic field of the Earth is surrounded in a region called the magnetosphere. The magnetosphere prevents most of the particles from the sun (solar wind) from hitting the Earth
- Some particles from the solar wind can enter the magnetosphere and cause auroras

Dünya Atmosferinin Yapısı ve Özellikleri

Dünya Atmosferinin Yapısı ve Özellikleri

- Dünyanın atmosferi, asılı sıvı ve katı parçacıklarıyla birlikte birçok gazın bir araya gelmesidir. Su buharı, ozon, kükürt dioksit ve toz gibi değişken bileşenler hariç, azot ve oksijen gazları hacmin yaklaşık yüzde 99'unu kaplar, argon ve karbondioksit ise en fazla bulunan iki gazdır. Dünyanın yüzeyinden yaklaşık 80 kilometre yüksekliğe kadar, atmosferin ısıyla çalışan hava akımlarının mekanik karışımı, atmosferin bileşenlerini eşit olarak dağıtır. Yaklaşık 80 kilometrede, karışım, ağırlıklarına bağlı olarak gazların tabakalaşma eğiliminde olduğu noktalarda azalır.



Propagation Mechanisms

- Düşük frekanslarda (uzun dalga boylarında) yayılan radyo dalgaları dünyanın yüzeyini takip etme eğilimindedir.
- Yüksek frekanslarda düz çizgiler halinde hareket etme eğilimindedirler.
- HF'de (3 - 30 MHz) radyo dalgaları iyonosfer tarafından yansıtılır:

Radio Propagation… 2

- Above 300 MHz propagation is by line of sight.
- Higher still, above 3 GHz say, atmospheric gases (mainly oxygen), water vapour and precipitation (rain!) absorb and scatter radio waves.
  - 23 GHz – water vapour resonance
  - 62 GHz – oxygen absorption
- Care needed in design of microwave links and ground to satellite links.

REFRACTION BY THE LOWER ATMOSPHERE

Refraction by the lower atmosphere causes waves to be bent back towards the earth's surface. The ray trajectory is described by the equation: $n\,R_e \sin\theta = \text{CONSTANT}$

Two ways of expressing the index of refraction $n\ \left(=\sqrt{\varepsilon_r}\right)$ in the troposphere:

1. $n = 1 + \chi\rho/\rho_{SL}$ + HUMIDITY TERM

R_e = 6378 km = earth radius

$\chi \approx 0.00029$ = Gladstone-Dale constant

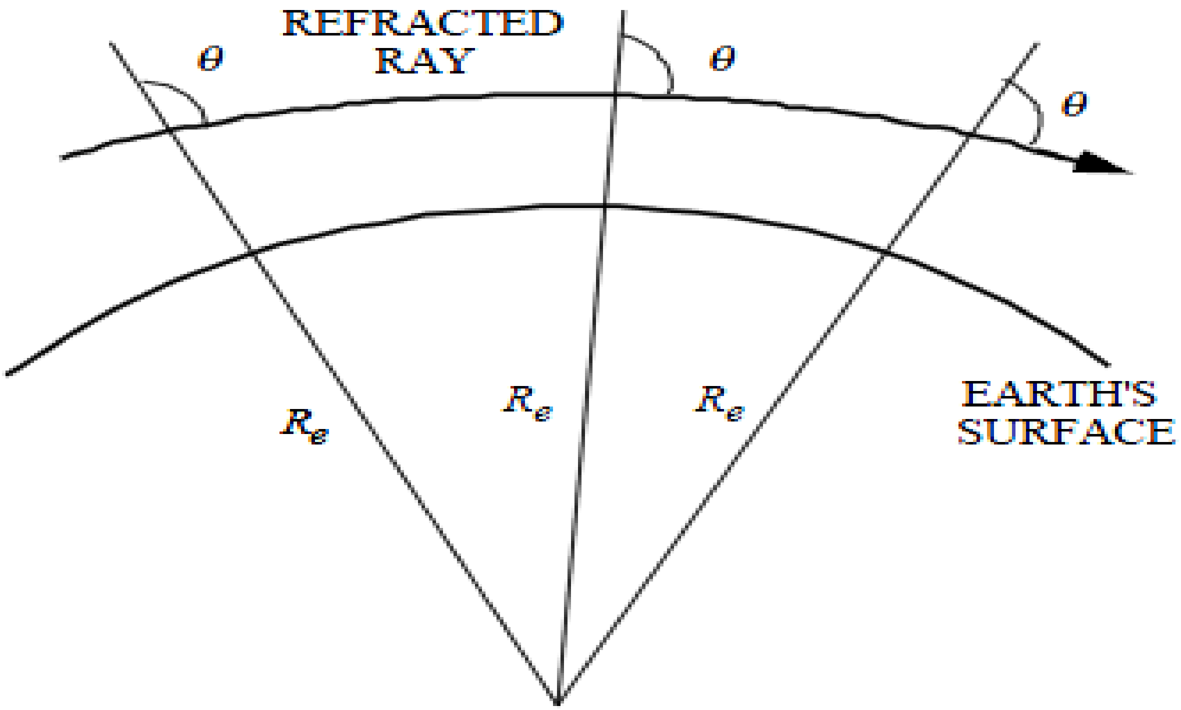
ρ, ρ_{SL} = mass densities at altitude and sea level

2. $n = \dfrac{77.6}{T}(p + 4{,}810\,e/T)10^{-6} - 1$

p = air pressure (millibars)

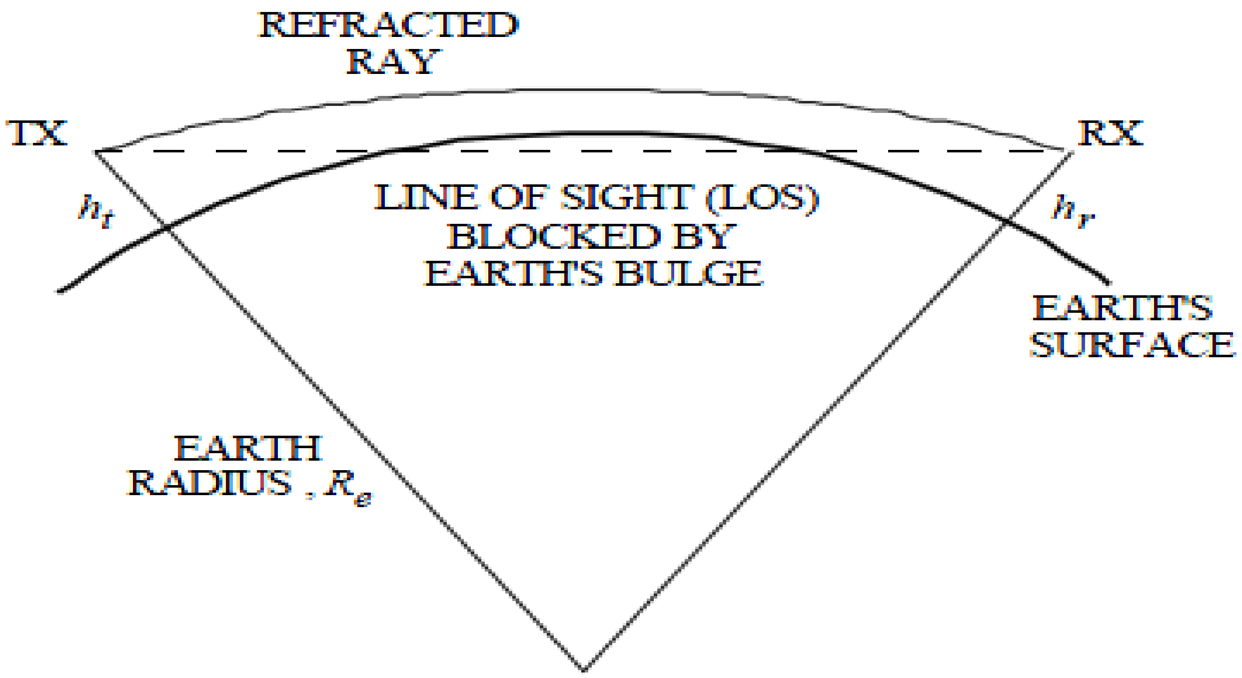
T = temperature (K)

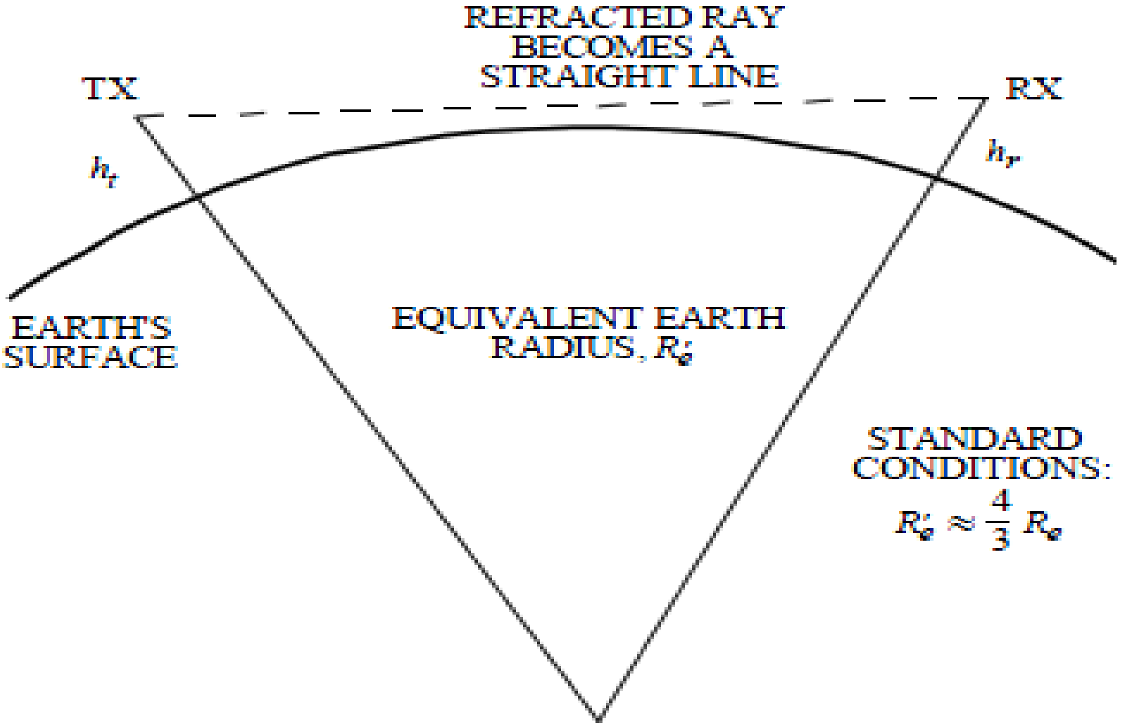
e = partial pressure of water vapor (millibars)



EQUIVALENT EARTH RADIUS

Refraction of a wave can provide a significant level of transmission over the horizon. A bent refracted ray can be represented by a straight ray if an equivalent earth radius R_e' is used. For most atmospheric conditions $R_e' = 4R_e / 3 = 8500$ km



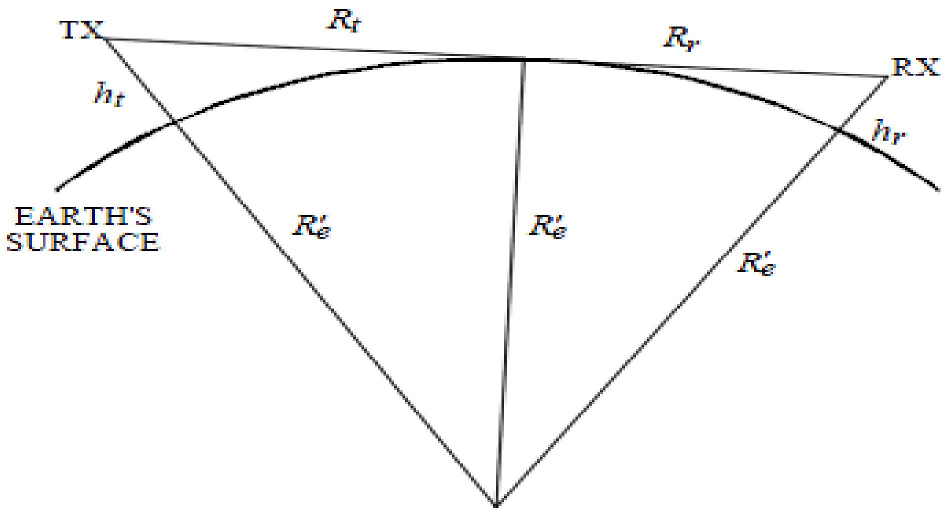


DISTANCE FROM Rx ANTENNA

Distance from the transmit antenna to the horizon is $R_t = \sqrt{(R'_e + h_t)^2 - (R'_e)^2}$ but $R'_e >> h_t$ so that $R_t \approx \sqrt{2R'_e h_t}$. Similarly $R_r \approx \sqrt{2R'_e h_r}$. The radar horizon is the sum

$$R_{RH} \approx \sqrt{2R'_e h_t} + \sqrt{2R'_e h_r}$$

Example: A missile is flying 15 m above the ocean towards a ground based radar. What is the approximate range that the missile can be detected assuming standard atmospheric conditions?



Using $h_t = 0$ and $h_r = 15$ gives a radar horizon of

$$\begin{aligned} R_{RH} &\approx \sqrt{2R'_e h_r} \\ &\approx \sqrt{(2)(8500 \times 10^3)(15)} \\ &\approx 16 \text{ km} \end{aligned}$$

The Refractive Index

The refractive index, n, of the atmosphere differs only slightly from unity, so that it is customary to define refractivity, N, as the amount by which the refractive index is greater than one, expressed in parts per million, *i.e.*, [*ITU-R, 1999c*],

$$N = 10^6 (n - 1.0)$$

At radio frequencies, the refractivity may be derived from the expression

$$N = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right)$$

where:

P = Atmospheric pressure (hPa)

e = Water vapour pressure (hPa)

T = Absolute temperature (K).

The contribution to the total refractivity due to dry atmospheric gases alone is:

$$N_{dry} = 77.6\frac{P}{T}$$

The contribution to the total refractivity due to water vapour is:

$$N_{wet} = 3.733 \times 10^5 \frac{e}{T^2}$$

Radio Refractivity, refractivity gradient and k-factor.

The refractivity, N is related to the refractive index, n of air as; [1, 2]

$$N = (n-1)\times 10^{6} = 77.6\frac{p}{T} + 3.73\times 10^{5}\frac{e}{T^{2}}$$

where: p = atmospheric pressure (hPa), e = water vapour pressure (hPa) and T = absolute temperature (K).

The water vapour pressure e is calculated from the relative humidity, and saturated water vapour, using the expression:

$$e = H \times \frac{6.1121\exp\left(\frac{17.502t}{t+240.97}\right)}{100}$$

where: H = relative humidity (%), t = temperature in degree Celsius (°C) and e_s = saturation vapour pressure (hPa).

The effective earth radius factor k can be used to characterise refractive conditions as **normal refraction or standard atmosphere, sub-refraction, super-refraction and ducting** respectively.

Thus, k may be expressed in terms of refractivity gradient, dN/dh as [3, 4]

$$k \simeq \frac{1}{1 + \left(\frac{dN}{dh}\right)/157}$$

Near the earth's surface, dN/dh is about -39N/km which gives an effective earth radius factor, k = 4/3. This is referred to as normal refraction or standard atmosphere. Here, radio signals travel on a straight line path along the earth's surface and go out to space unobstructed.

If $\frac{4}{3} > k > 0$

Sub-refraction occurs, meaning that radio waves propagate abnormally away from the earth's surface.

When $\infty > k > \frac{4}{3}$

In this case, super-refraction occurs and radio waves propagate abnormally towards the earth's surface thus extending the radio horizon.

Subsequently, if $-\infty < k < 0$

ducting occurs and the waves bend downwards with a curvature greater than that of the earth.

EFFECTIVE EARTH RADIUS

where, a=6375 km is the actual earth radius; then we calculate the effective earth radius, ρ, from the formula [1,3]:

$$\rho = \left(\frac{a}{\left(1 - 0.04665 e^{0.005577 N_s}\right)} \right) \quad (10)$$

where N_S is the surface refractivity. This is the refractivity at the altitude of the LOS microwave sight that was selected, or the average refractivity of the path.

If N_o is known then the surface refractivity can be obtained as [5]:

$$N_S = N_o e^{-0.1057 h_s} \quad (11)$$

ANTENNA PATTERN FACTOR

The propagation loss including antenna patterns, is equivalent to

$$L = L_{fs} - 20\log_{10}(F).$$

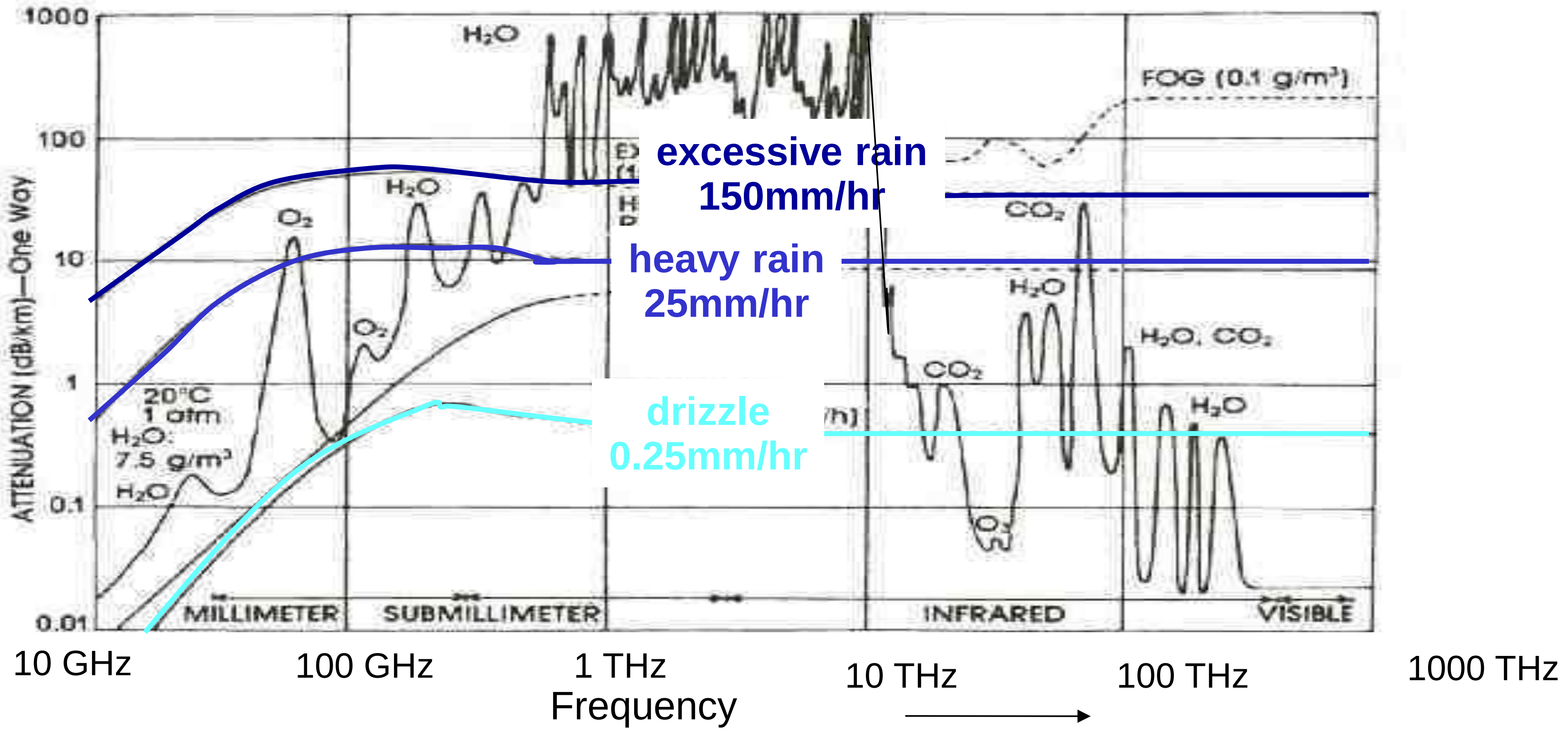
Antenna Pattern Factors

The remaining terms in equation 13, $f(\varepsilon_i)$, the normalized antenna pattern factors, are determined as a function of the antenna pattern type, beamwidth, and pointing angle. Five different antenna types are used in EREPS: omnidirectional, $\sin(x)/x$, cosecant-squared, generic height-finder, and Gaussian beam. The first and simplest case is that of the omnidirectional antenna which, as its name implies, has a gain of unity in all directions. That is, $f(\mu)=1$ for all angles μ.

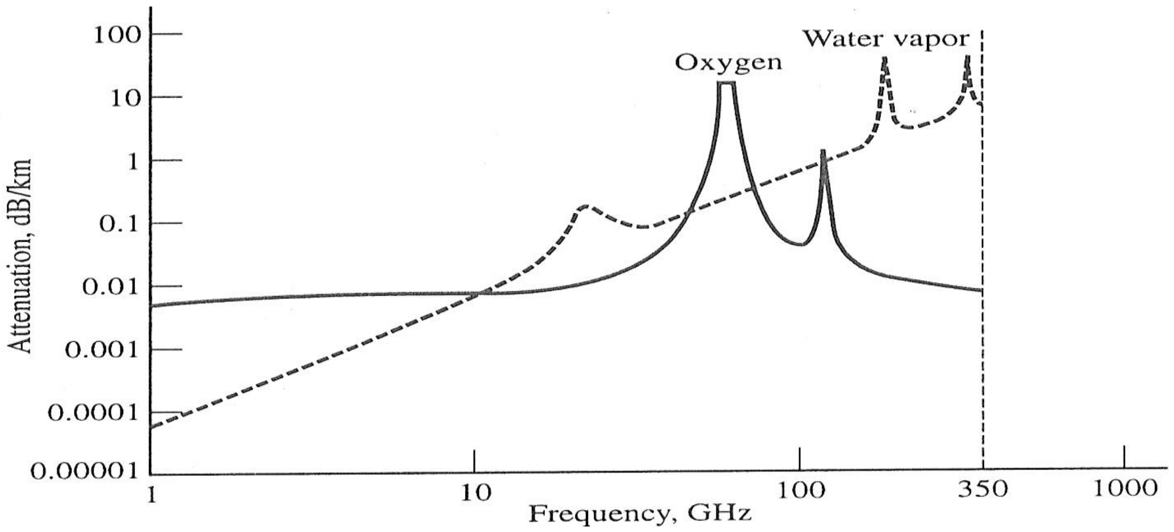
The second case is the $\sin(x)/x$ antenna type. The radiation pattern of this antenna is symmetric about the elevation (pointing) angle of the antenna. The pattern factor for this antenna is given by Blake (1970) as

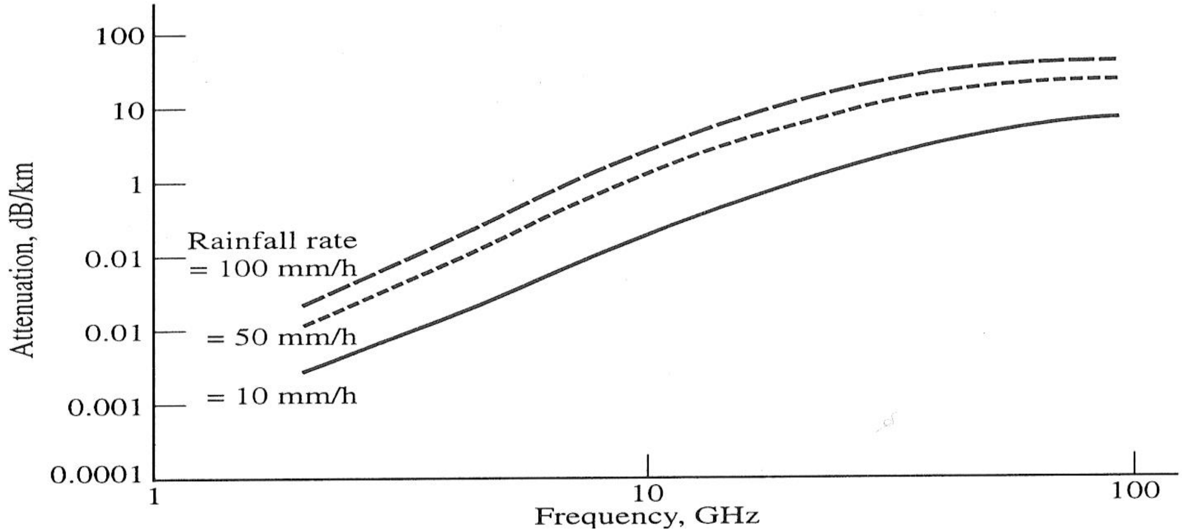
ATTENUATION BY ATMOSPHERIC GASES, RAIN AN FOG

- Masking or 'self-screening' effect of atmospheric attenuation
- Reduced RF power density at remote sites
  - low probability of exploitation (LPE) / minimal EMI/EMC problems
- Covert operation
  low propagation "overshoot"/ low probability of intercept (LPI)



Atmospheric Attenuation





– a) attenuation caused by atmospheric gases
  - note molecular resonance peaks
– b) attenuation caused by rain
  - can increase path loss by an order of magnitude (10 x)

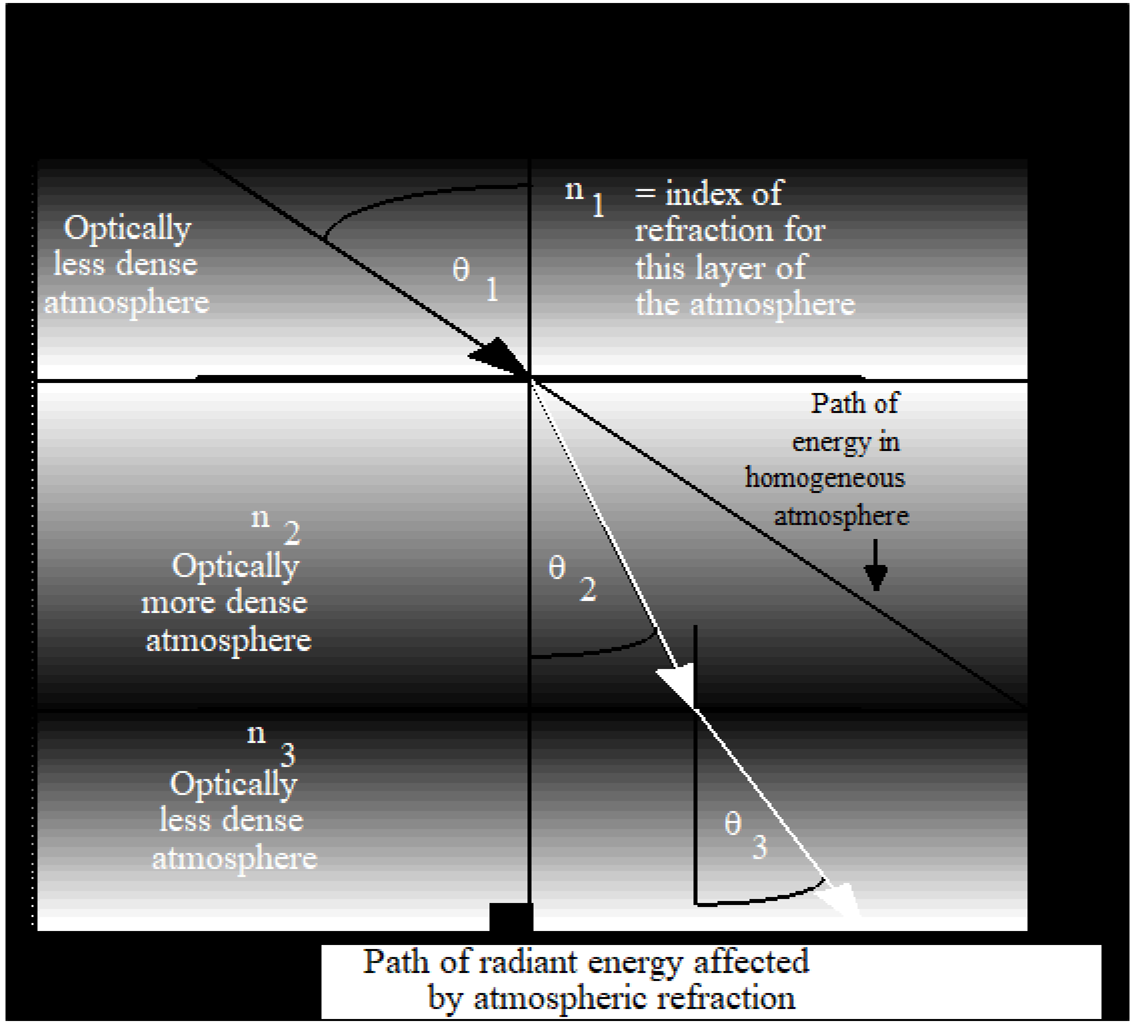
Atmospheric Refraction

The Speed of Light in a Vacuum and in the Atmosphere

- The speed of light c is 3 x 10^8 m s^{-1} (same as Electromagnetic Radiation EMR)
- When encounters substances of different density (air and water), refraction may take place
- Refraction: bending of light when it passes from one medium to another
  - Refraction occurs because the media are of differing densities and the speed of EMR is different in each
- The index of refraction, n: measure of the optical density of a substance
  - This index is the ratio of c, to the speed of light in the substance, c_n:

$$n = \frac{c}{c_n}$$

Index of Refraction and Snell's Law



Snell's law

- for a given frequency of light, the product of the index of refraction and the sine of the angle between the ray and a line normal to the interface is constant

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

Atmospheric Scattering

The type of scattering is a function of:

- The wavelength of the incident radiant energy
- The size of the gas molecule, dust particle, or water droplet encountered

Color of the Sky

- Why is the sky blue?
- A clear cloudless day-time sky is blue because molecules in the air scatter blue light from the sun more than they scatter red light
- When the air is clear the sunset will appear yellow
- When we look towards the sun at sunset, we see red and orange colors because the blue light has been scattered out and away from the line of sight

Atmospheric Absorption

- Absorption is the process by which radiant energy is absorbed and converted into other forms of energy
- An absorption band is a range of wavelengths (or frequencies) in the electromagnetic spectrum within which radiant energy is absorbed by substances such as water (H_2O), carbon dioxide (CO_2), oxygen (O_2), ozone (O_3), and nitrous oxide (N_2O)
- The cumulative effect of the absorption by the various constituents can cause the atmosphere to close down in certain regions of the spectrum
- This is bad for remote sensing because no energy is available to be sensed

Summary

1. Electromagnetic energy interactions: interaction with atmosphere, earth, atmosphere, sensor system components (camera, film, emulsion, etc.)
2. Electromagnetic radiation models (wave/particle): three energy transfer ways (conduction, convection & radiation), two EM models (wave ($c=v.\lambda$), particle ($Q=h.v$), $Q\sim\lambda$), S. B. law (total emitted radiance) & Wien's law (peak-wavelength),
3. Atmospheric refraction: $n1.\sin\theta 1= n2.\sin\theta 2= n3.\sin\theta 3$
4. Atmospheric scattering: Rayleigh ($d<<\lambda$), Mie ($d\sim\lambda$), non-selective ($d>>\lambda$), blue sky phenomenon at noon, yellow/radish phenomenon at sunrise/set
5. Atmospheric absorption ("atmospheric windows"): 'close down' regions, 'atmospheric windows'
6. Radiometric quantities and reflectance:1=refectance+absorption+transmittance, three type reflectances (specular, diffuse & lambertian)
7. Radiance and atmospheric transfer/correction: irradiance, exitance and radiance, atmospheric transfer (path radiance, total radiance, etc.)

Propagation Models

Propagation of electromagnetic waves in the atmosphere

Speed of light in a vacuum: $c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$

Speed of light in air: $v = \frac{1}{\sqrt{\varepsilon_1 \mu_1}}$

Refractive index: $n = \frac{c}{v} = \frac{\sqrt{\varepsilon_0 \mu_0}}{\sqrt{\varepsilon_1 \mu_1}}$

At sea level: n = 1.0003
In space: n = 1.0000

Radio refractivity: $N = (n-1) \times 10^6$

At sea level: N = 300
In space: N = 0

Diagram demonstrating the Earth's curvature, standard refraction, and non-standard refraction.

Non-standard refraction
- Sub-refraction
- Super-refraction

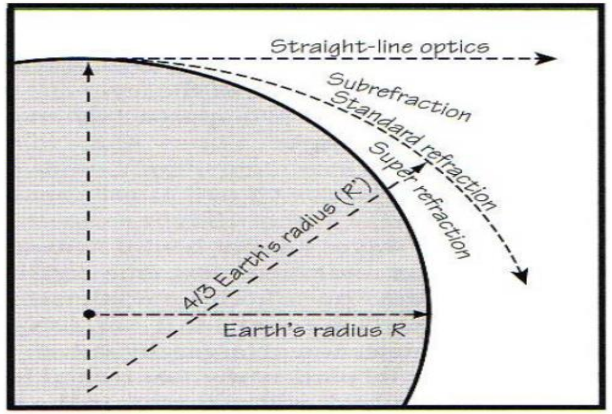


Figure 3.6 Earth's curvature showing the earth (gray circle), earth's radius, 4/3 earth's radius, standard refraction, super refraction, subrefraction and straight-line optics. Subrefraction would also be above the straight-line optics line.

Rinehart (2004)

4 cases of refraction (dN/dZ):

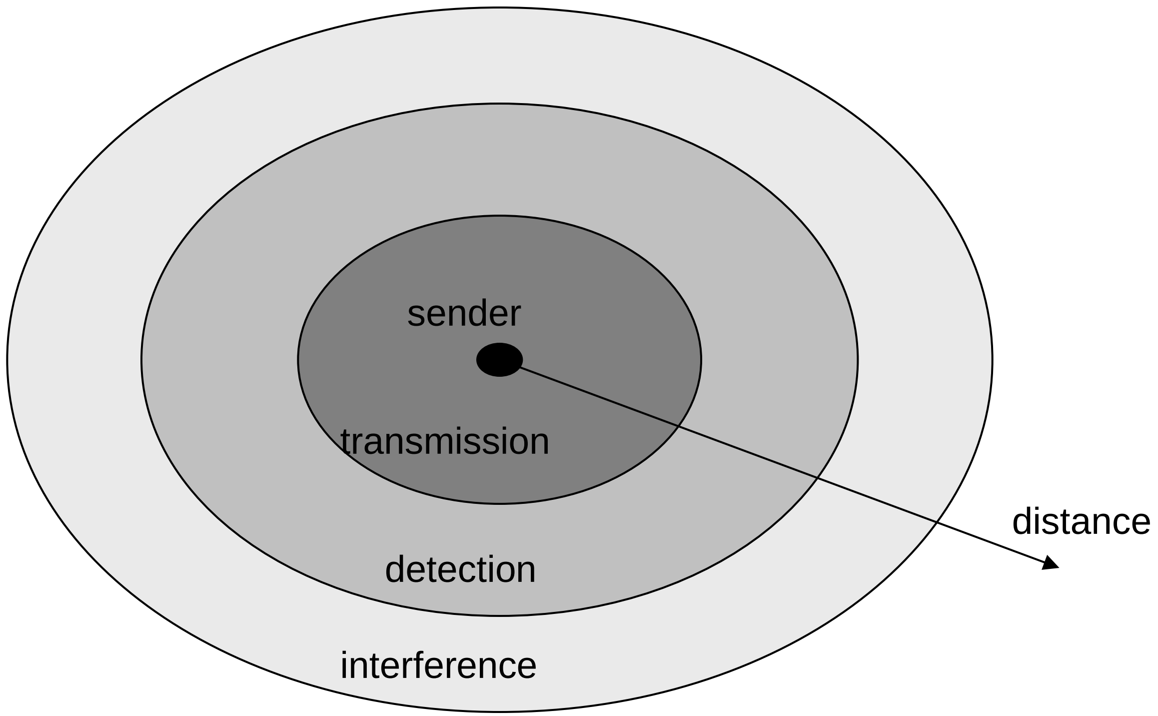
Standard:	dN/dZ ~ 0 and -40 km^{-1}
Super:	dN/dZ < -79 km^{-1} and > -158 km^{-1}
Sub:	dN/dZ > 0
Ducting:	dN/dZ < -158 km^{-1} (dn/dh = -1/R)

Propagation Models

- Optical Interference Region
- Optical Path Length Difference
- Reflection Coefficients
- Antenna Pattern Factors
- Diffraction
- Troposcatter
- Water Vapor Absorption
- Sea Clutter
- Raytracing
- Evaporation Duct Height
- Wind

Signal propagation ranges

- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible
- Interference range
  - signal may not be detected
  - signal adds to the background noise



Types of Radio Link Waves

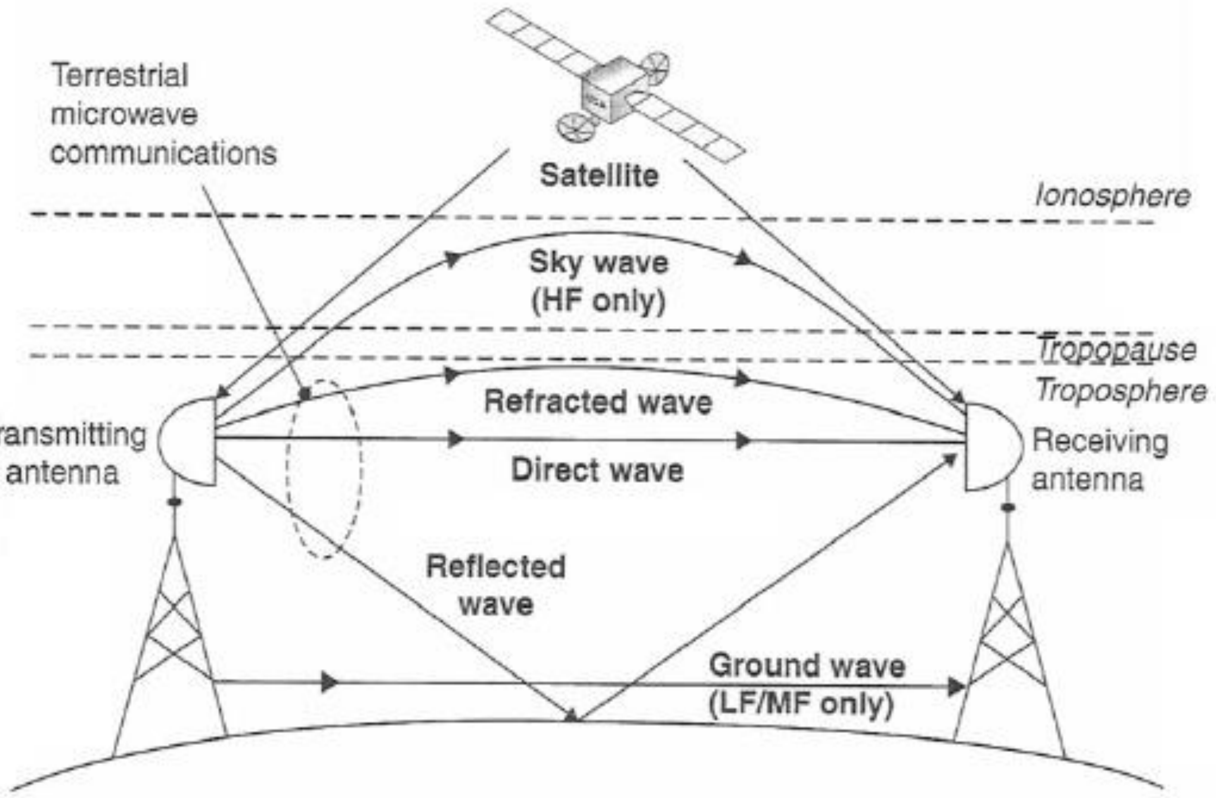
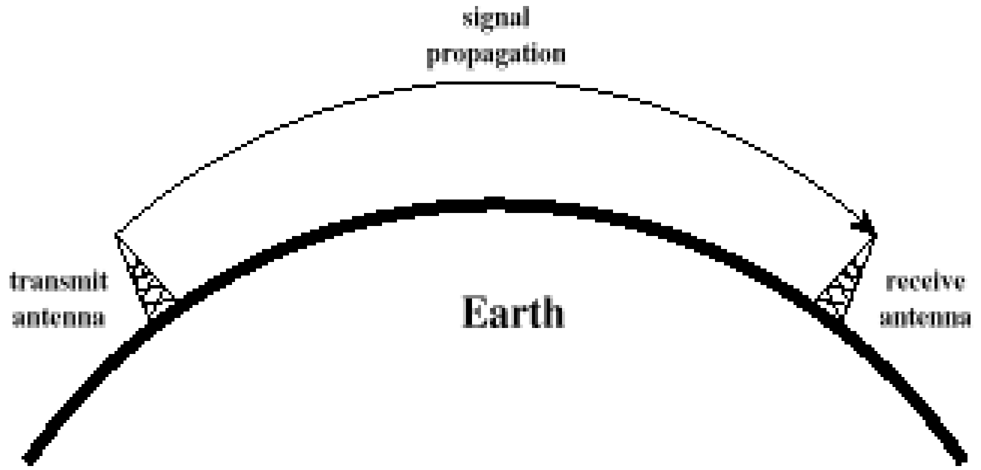


Figure 2.2 Radio wave propagation

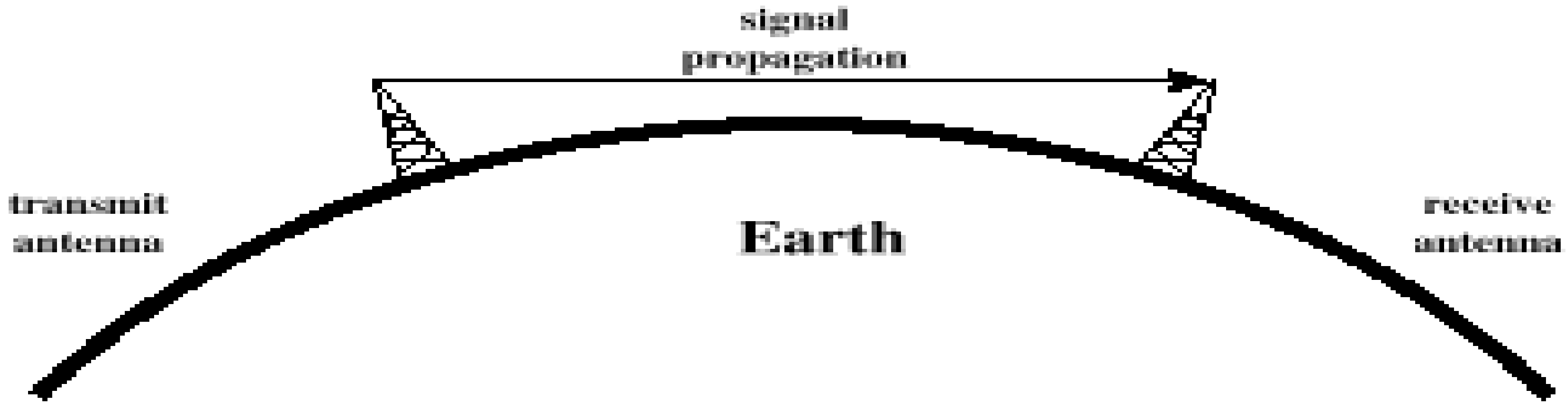
Source: Lehpamer, H., *Microwave Transmission Networks: Planning, Design, and Deployment (Second Edition)*, McGraw-Hill, 2010.

Ground Wave Propagation

- Happens at relatively low frequencies
  - up to about 2 MHz, Example: AM Radio
- Only works with vertically polarized waves
- Waves follow the curvature of earth
  - range varies from worldwide at 100 kHz and less to about 100 km at AM broadcast band frequencies (approx. 1 MHz)
- Follows contour of the earth
- Can Propagate considerable distances



Line-of-Sight Propagation



Line-of-Sight Propagation

- Transmitting and receiving antennas must be within line of sight
  - Satellite communication – signal above 30 MHz not reflected by ionosphere
  - Ground communication – antennas within *effective* line of site due to refraction
- Refraction – bending of microwaves by the atmosphere
  - Velocity of electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between mediums

- Maximum distance between two antennas for LOS propagation:
  - h_1 = height of antenna one
  - h_2 = height of antenna two

$$3.57\left(\sqrt{\mathrm{K}h_1} + \sqrt{\mathrm{K}h_2}\right)$$

- d = distance between antenna and horizon (km)
- h = antenna height (m)
- K = adjustment factor to account for refraction, rule of thumb K = 4/3

LOS Wireless Transmission Impairments

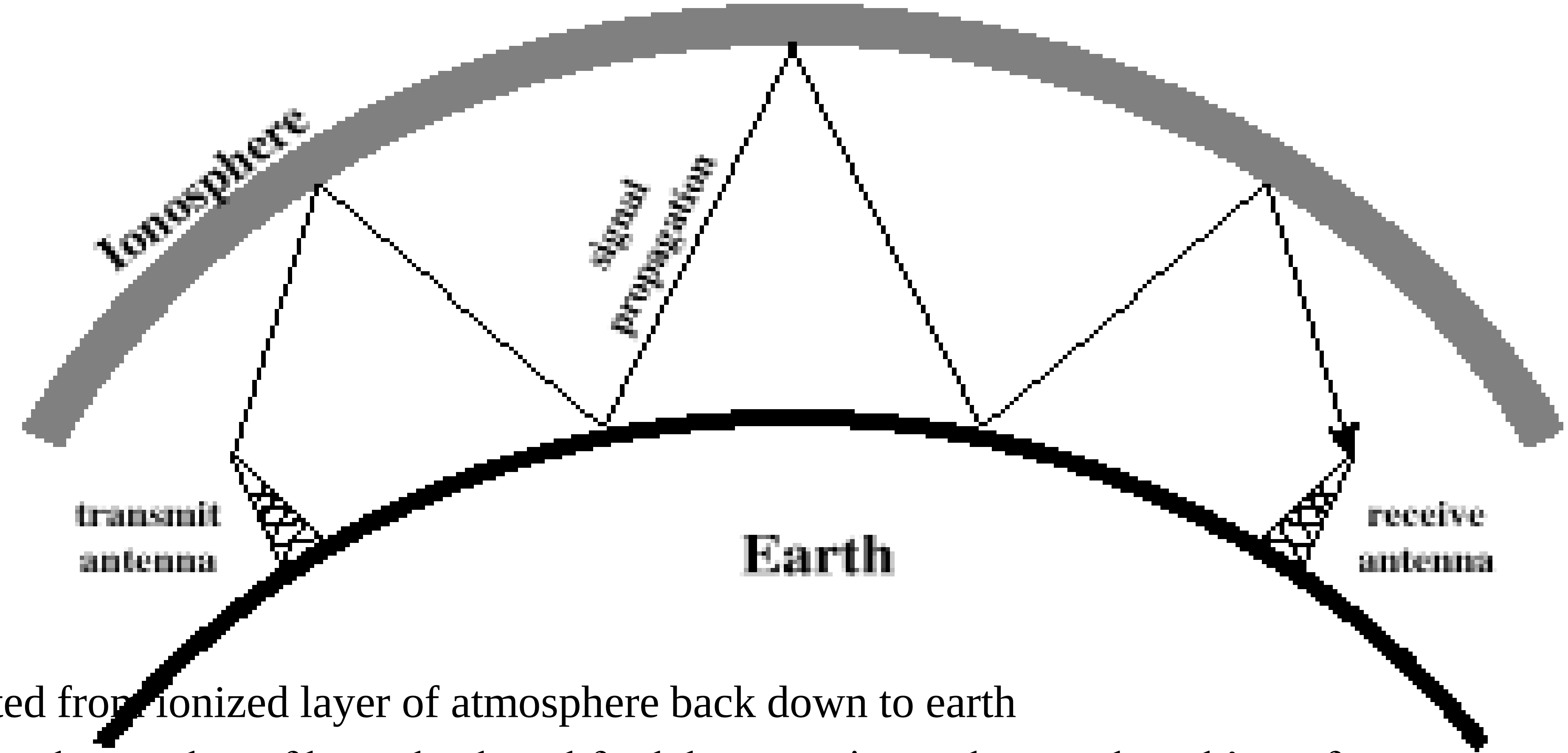
- Attenuation and attenuation distortion
- Free space loss
- Noise, Thermal Noise
- Atmospheric absorption
- Multipath; Refraction, Reflection, Scattering, Difraction

Difraksiyon: Yüzeyden kaynak gibi ışımaya devam eder.

Terrestrial Propagation

- Propagation over earth's surface
- Different from free-space propagation
  - Curvature of the earth
  - Effects of the ground
  - Obstacles in the path from transmitter to receiver
  - Effects of the atmosphere, especially the ionosphere

Sky Wave Propagation



- Signal reflected from ionized layer of atmosphere back down to earth
- Signal can travel a number of hops, back and forth between ionosphere and earth's surface
- Reflection effect caused by refraction
- Examples
  - Amateur radio
  - CB radio

Effects of the Ionosphere on the Sky wave

If we consider a wave of frequency , f incident on an ionospheric layer whose maximum density is N then the refractive index of the layer is given by

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

Critical Frequency

If the frequency of a wave transmitted vertically is increased, a point will be reached where the wave will not be refracted sufficiently to curve back to earth and if this frequency is high enough then the wave will penetrate the ionosphere and continue on to outer space. The highest frequency that will be returned to earth when transmitted vertically under given atmospheric conditions is called the *critical frequency*.

$$f_c = 9\sqrt{N}$$

Maximum Usable Frequency

There is a best frequency for communication between any two points under specific ionospheric conditions. The highest frequency that is returned to earth at a given distance is called the Maximum Usable Frequency (MUF).

$$f_{muf} = 9\sqrt{N}\sec\theta$$

Optimum Working Frequency

This is the frequency which provides the most consistent communication and is therefore the best to use. For transmission using the F2 layer it is defined as

$$f_{owf} = 0.85 \times 9\sqrt{N}\sec\theta$$

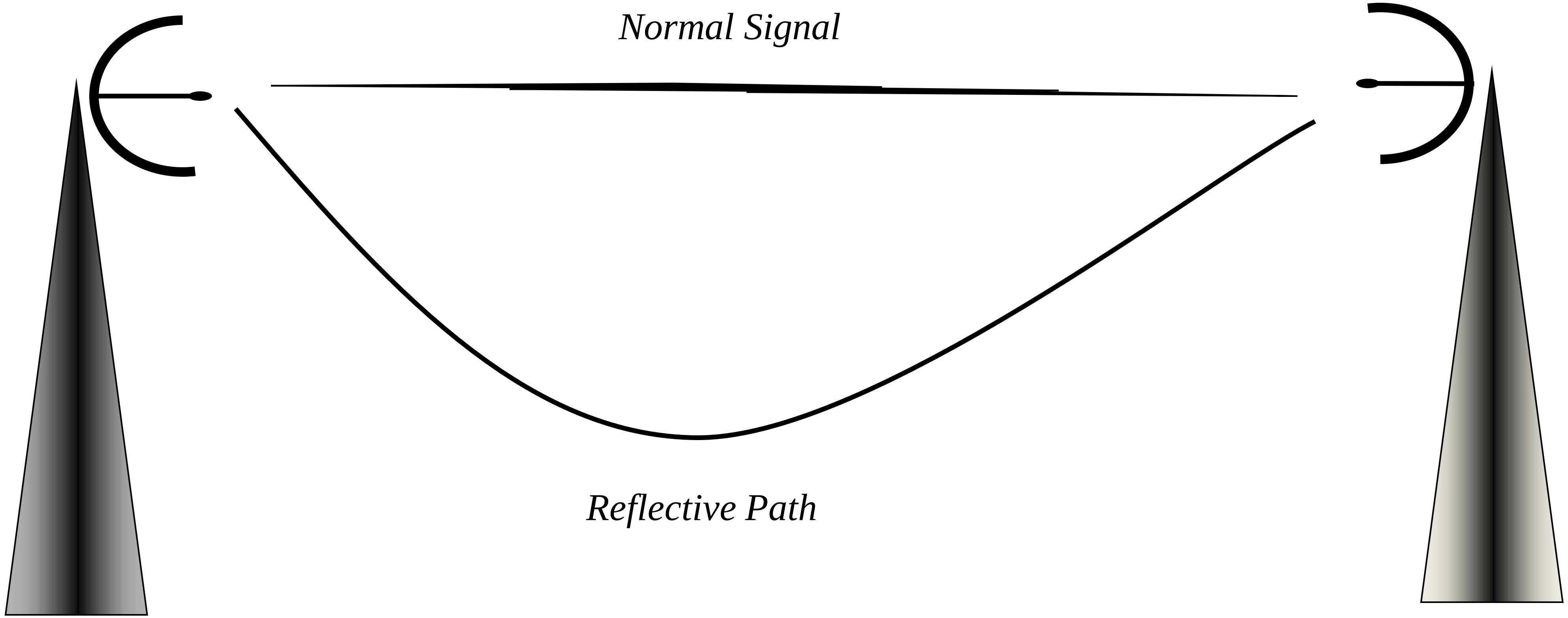
Skip Zone

- Region between maximum ground-wave distance and closest point where sky waves are returned from the ionosphere,

Skin Affect

- *Skin Affect* is the concept that high frequency energy travels only on the outside skin of a conductor and does not penetrate into it any great distance. *Skin Affect* determines the properties of microwave signals.

Microwave Fading



Caused by multi-path reflections and heavy rains

Types of Fading

- Fast fading
- Slow fading
- Flat fading
- Selective fading
- Rayleigh fading
- Rician fading

Range

- The distance a signal travels and its increase in frequency are inversely proportional
- Repeaters extend range
  - Back-to-back antennas
  - Reflectors

- High frequencies are repeated/received at or below one mile
- Lower frequencies can travel up to 100 miles but 25-30 miles is the typical placement for repeaters

Kaynaklar

- Antennas from Theory to Practice, Yi Huang, University of Liverpool UK, Kevin Boyle NXP Semiconductors UK, Wiley, 2008.
- Antenna Theory Analysis And Desıgn, Third Edition, Constantine A. Balanis, Wiley, 2005
- Antennas and Wave Propagation, By: Harish, A.R.; Sachidananda, M. Oxford University Press, 2007.
- Navy Electricity and Electronics Training Series Module 10—Introduction to Wave Propagation, Transmission Lines, and Antennas NAVEDTRA 14182, 1998 Edition Prepared by FCC(SW) R. Stephen Howard and CWO3 Harvey D. Vaughan.
- Lecture notes from internet.

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Sincerely,

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