Module 1

Basics of Communication System

Module 1 contents

- **1.1** Block diagram, electromagnetic spectrum, signal bandwidth and power, types of communication channels, Introduction to time and frequency domain. Basic concepts of wave propagation.

- **1.2** Types of noise, signal to noise ratio, noise figure, noise temperature and Friss formula.

Historical Background

Telegraph

Radio

Telephone

Electronics

Television

Digital Communications

Computer Networks

Satellite Communications

Optical Communications

Let us discuss….

- What is Communication?

The word communication arises from the Latin word commūnicāre, which means "to share". Communication is the basic step for exchange of information.

- What is Electronic Communication?

Electronic communication uses electronic circuits to transmit, process, and receive information between two or more locations.

The basic components of an Electronic communication system include a transmitter, a communication medium or channel, a receiver and noise.

Information is transmitted into the system in analog or digital form, it is then processed and decoded by the receiver.

Terminologies in communication systems

- **Terminology is** a general **word** for the group of specialized words or meanings relating to a particular field, and also the study of such **terms** and their use, this also known as **terminology** science.

- Basic terminology used in electronic communication systems:

Signal: Conveying an information by some means such as gestures, sounds, actions, etc., can be termed as **signaling**

- A **signal** carries information and contains energy.

- function that conveys information about a phenomenon.

- In electronics and telecommunications, it refers to any time varying voltage, current or electromagnetic wave that carries information.

- A **signal** may also be defined as an observable change in a quality such as quantity

- Signals are classified into the following categories:

Continuous Time and Discrete Time Signals

Deterministic and Non-deterministic Signals

Even and Odd Signals

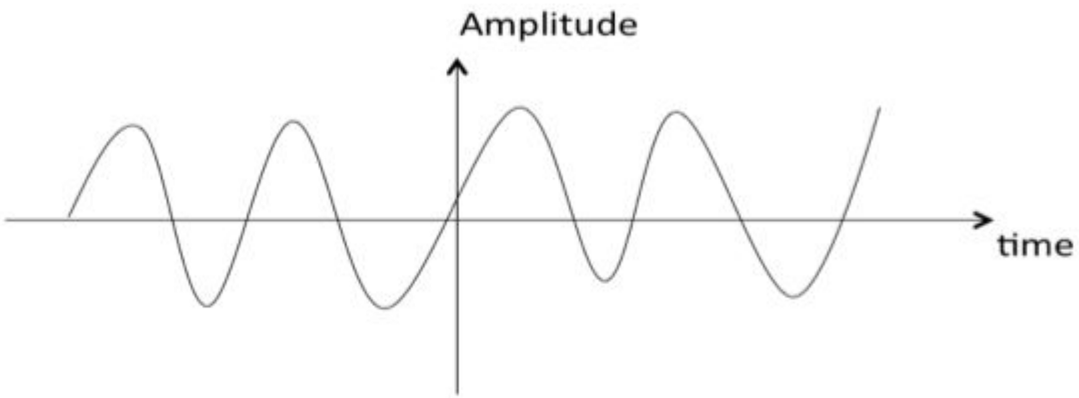
Periodic and Aperiodic Signals

Energy and Power Signals

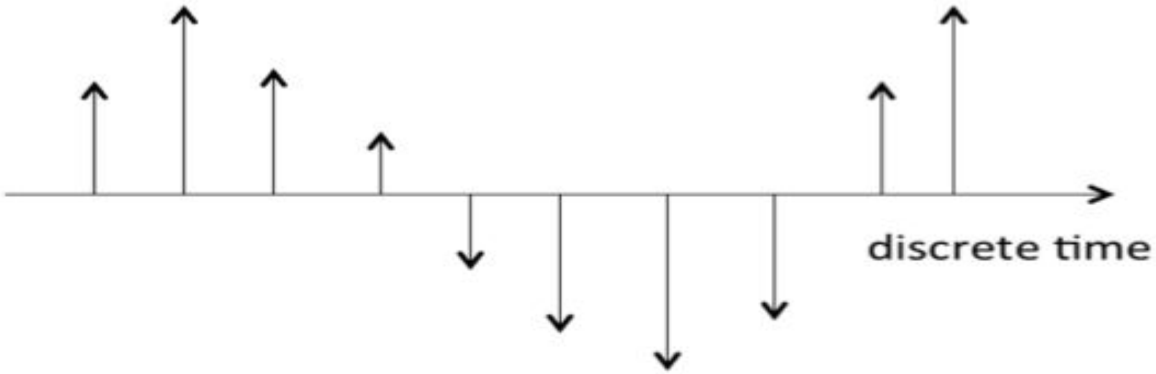
Real and Imaginary Signals

- Continuous Time and Discrete Time Signals

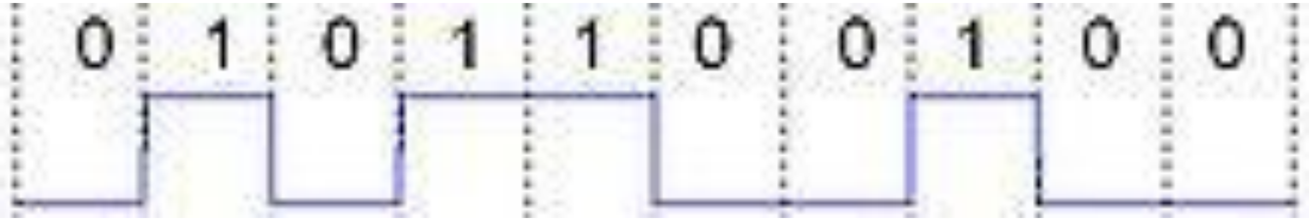
A signal is said to be continuous when it is defined for all instants of time.

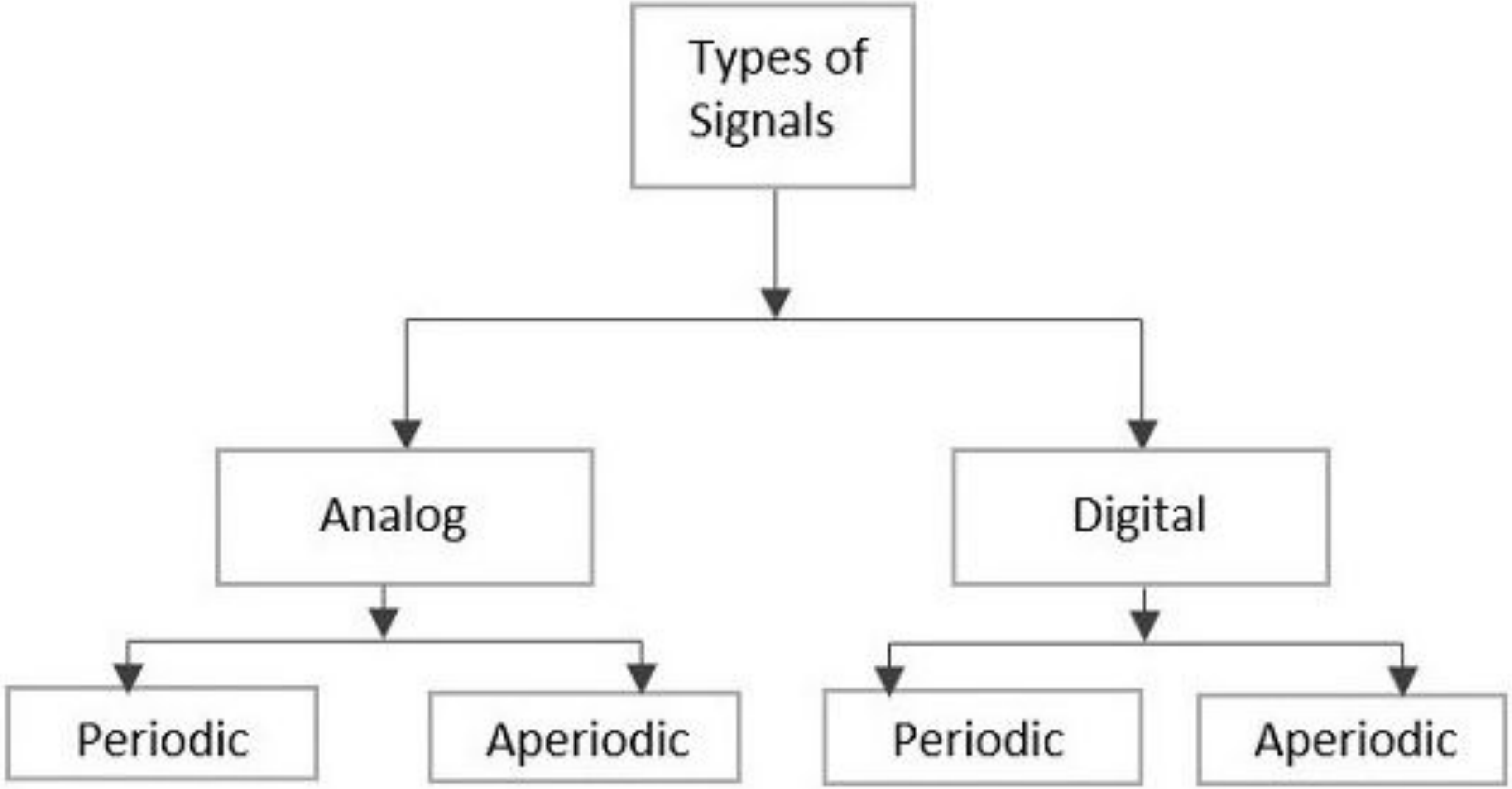


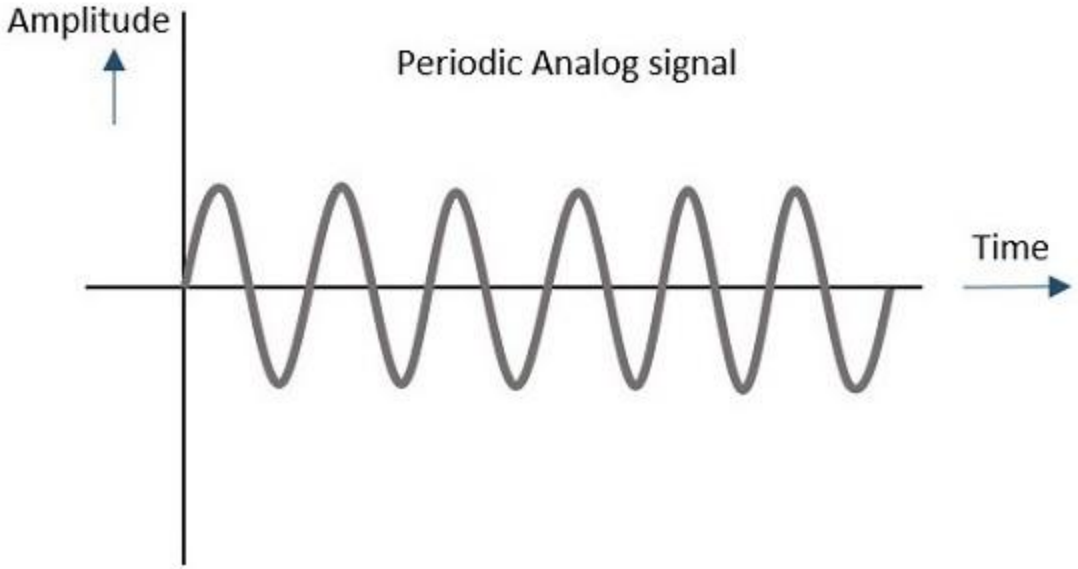
- A signal is said to be discrete when it is defined at only discrete instants of time

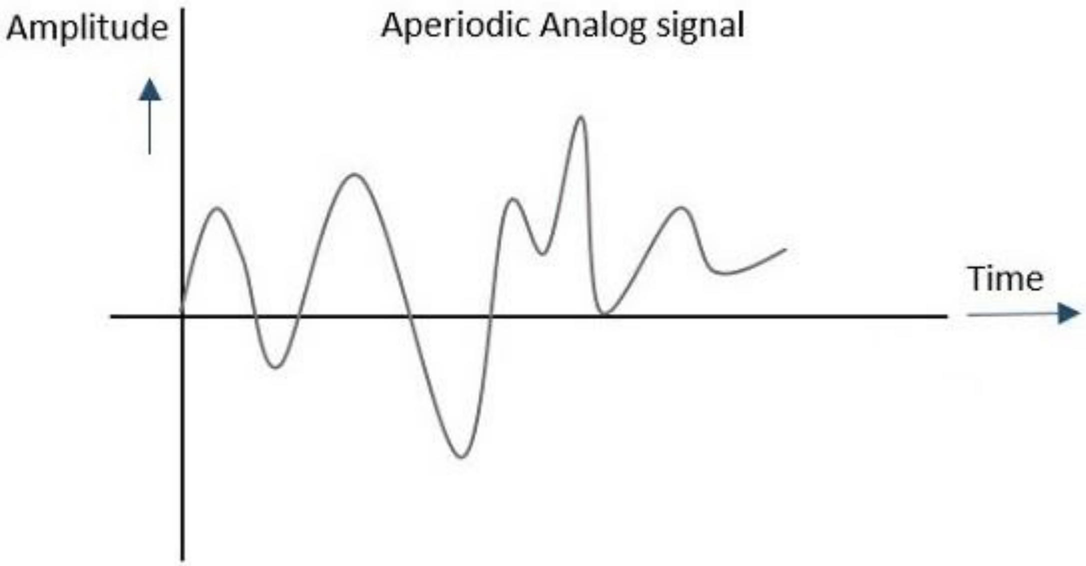


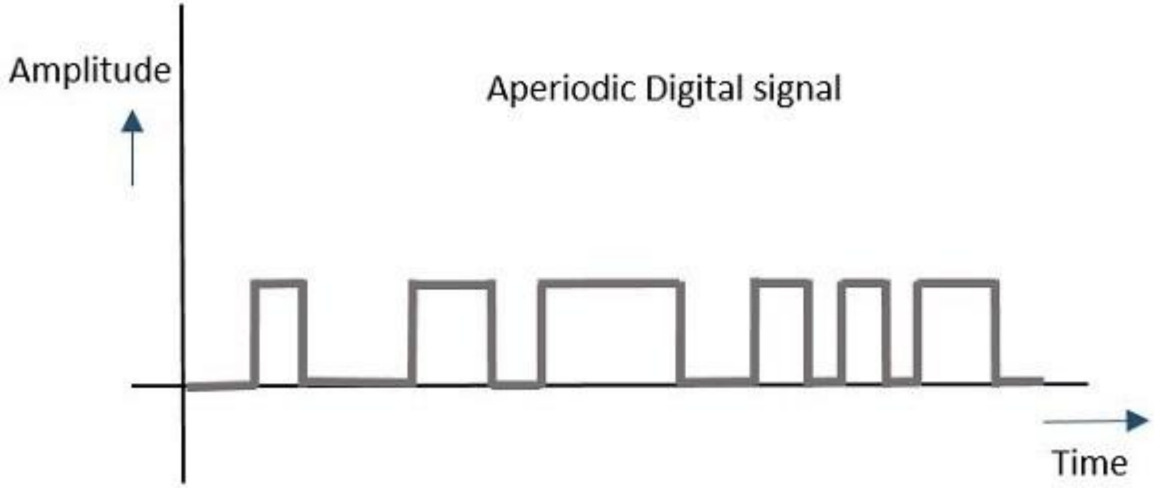
- A digital signal is a signal that is constructed from a discrete set of waveform of a physical quantity so as to represent a sequence of discrete values




Types of Signals
Analog
Digital
Periodic
Aperiodic
Periodic
Aperiodic


Amplitude
Periodic Analog signal
Time


Amplitude
Aperiodic Analog signal
Time


Amplitude
Aperiodic Digital signal
Time

Transducer

- The transducer is a device that converts one form of energy into another form of energy.

- In electronic communication, Transducer is mainly a device that converts one form of physical variables such as temperature, pressure and force etc. into a corresponding electrical signal and provides it as an output.

- Transducer converts the mechanical input into electrical energy.

- The simplest example of a Transducer is the receiver of our phone. A mechanical input, our voice in the form of sound waves, is provided to the phone which in turn converts it into an electrical signal and transmits it.
- Other common examples include loud-speakers and antennas.

- **Communication Channel:**

This is the medium by which a signal can be transmitted from the sender to the receiver. It can be a simple copper wire or a satellite system.

Transmission channel may be **analog** or **digital**

- **Receiver**

A receiver is a device that receives the signals sent/ transmitted by the senders and decodes them into a form that is understandable by the humans.

A common example of a receiver is the television.

- Data Transfer Rate

The speed of data transferred or received over transmission channel, measured per unit time, is called data transfer rate. The smallest unit of measurement is bits per second (bps). 1 bps means 1 bit (0 or 1) of data is transferred in 1 second.

1 Bps = 1 Byte per second = 8 bits per second

1 kbps = 1 kilobit per second = 1024 bits per second

1 Mbps = 1 Megabit per second = 1024 Kbps

1 Gbps = 1 Gigabit per second = 1024 Mbps

- **Attenuation**

Attenuation refers to the reduction in the strength of the analog or digital signal as it is transmitted over a communication medium or channel. Attenuation often occurs when signals are transmitted over long distances.

- **Amplitude**

An amplitude of the signal refers to the strength of the signal.

- **Amplification**

Sometimes when the distance between the sender of the signal and the receiver of the signal is too large, the amplitude of the signals drop significantly. To remedy the problem of weak signals, amplification of the signals is carried out to rejuvenate their strength.

Amplification is the process to strengthening the amplitude of the signals using an electronic circuit.

- **Bandwidth**

Bandwidth describes the range of frequency over which a signal has been transmitted.

Modern day networks provide bandwidth in Kbps, Mbps and Gbps.

Some of the factors affecting a network's bandwidth include.

Network devices used

Protocols used

Number of users connected

Network overheads like collision, errors, etc.

- Range:

It is the largest distance between a source and a destination up to which the signal is received with sufficient strength.

- **Modulation**

Modulation refers to the act of adding information to an electronic or optical waveform. The information may be added by altering the frequency, phase of the waveform and, its amplitude.

• Need of Modulation

1) Modulation is needed because most of the time information is generated and transmitted via signals having low frequencies.

A low-frequency signal is highly susceptible to attenuation and therefore it cannot be transferred to long distant locations.

In order to rectify this problem, the original carrier wave having a low frequency is superimposed upon a high-frequency carrier wave. This process is known as modulation.

AM and FM are both examples of Modulation.

2) Height of Antenna

For efficient transmission & reception, the antenna height should be at least one-fourth the signal wavelength ($\lambda/4$).

To transmit a signal of $f = 10kHz$, Minimum antenna height = $\lambda/4 = c/(4f) = 7500$ m □

This is practically impossible !!

Consider a modulated signal at $f = 1$ MHz , Minimum antenna height = $\lambda/4 = c/(4f) = 75$ m □ This can be installed practically.

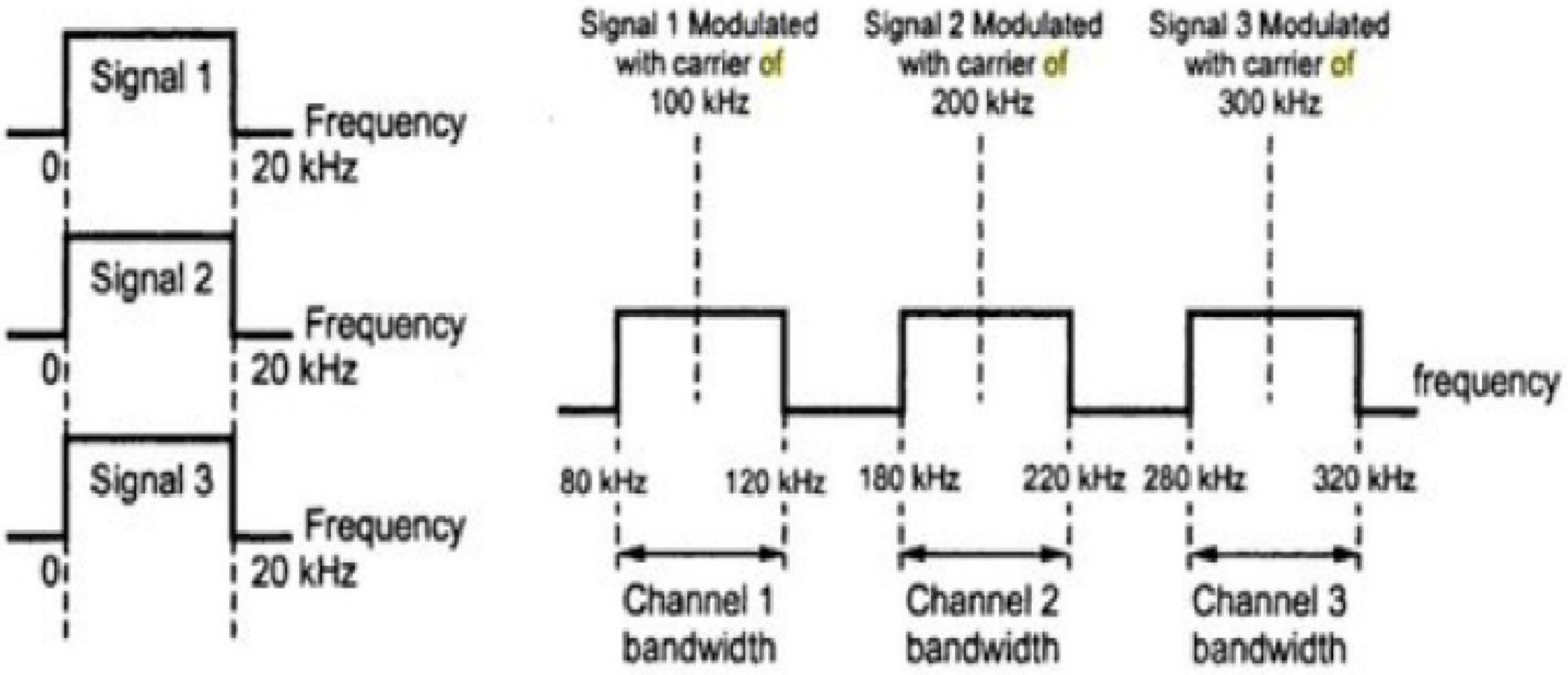
- 3) Avoids mixing of signals

All sound is concentrated within the range from 20 Hz to 20 kHz.

If no modulation is used, all the signals would get mixed up.

The receiver would not be able to separate them from each other.

If each baseband signal is used to modulate a different carrier, then they will occupy different slots in the frequency domain.



- 4) Allows Multiplexing

Multiplexing – Two or more signals can be transmitted over the same channel simultaneously.

Multiplexing allows the same channel to be used by many signals.

Therefore, many TV channels can use the same frequency range without getting mixed up with each other.

5) Increases Range of communication

- Low frequency signal – low energy – travels low distances
- High frequency signal – high energy –travels longer distances

- **Demodulation**

Demodulation reverses modulation. It takes a

signal and extracts the original message out of it.

- **Repeater**

The job of the repeater is to extend the range of the communication systems by amplifying the signals.

The repeaters act as both the sender and the receiver in the communication system.

A weak signal is received at the repeater which is then amplified and retransmitted.

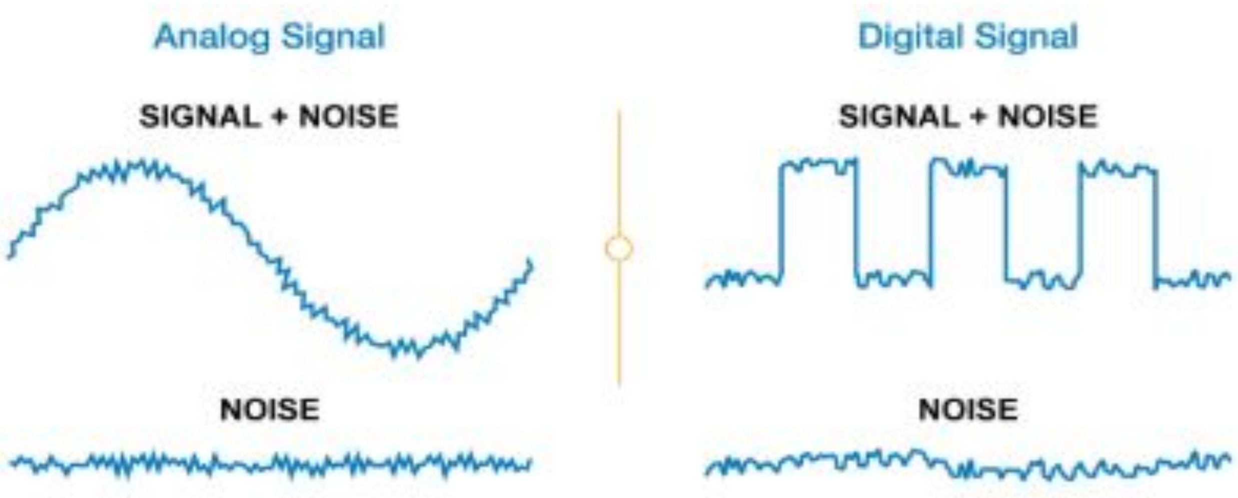
• Noise

Any electrical signal that interferes with the information signal is known as noise

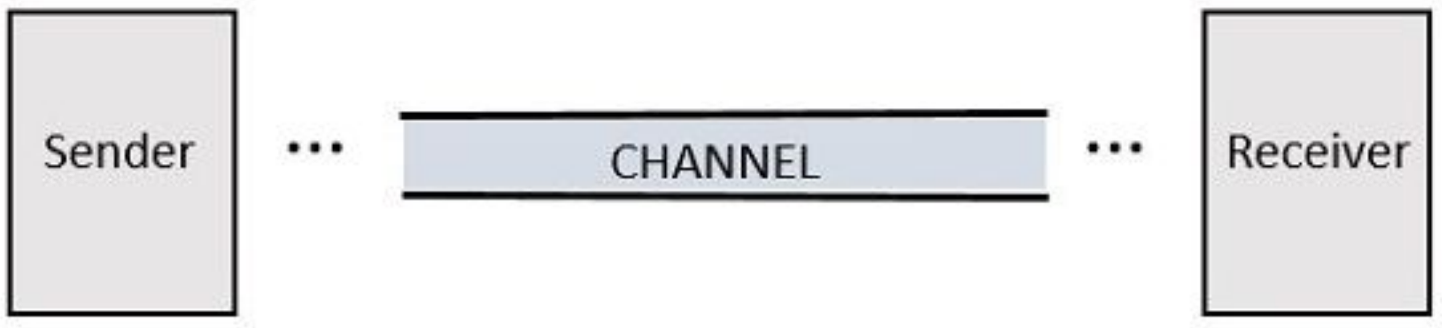
It can come from a variety of sources in the environment such as the rain, hailstorms or thunderstorms etc.

Noise is always present in the system, it can be diminished but it can never be completely eliminated.

In some instances, noise may even be generated by the receiver and hinder the demodulation process.



Basic Parts of a Communication System

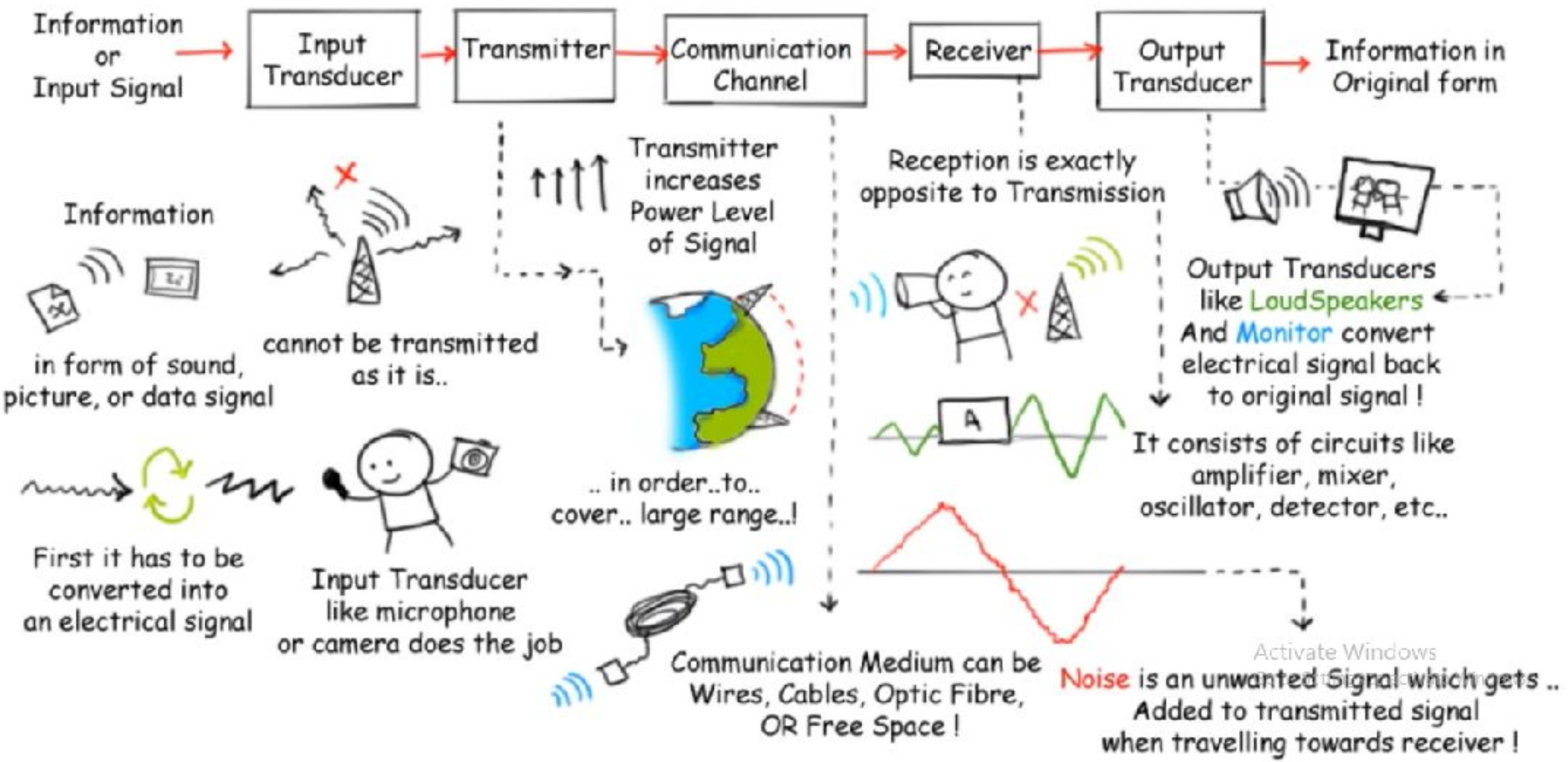


- **Sender** is the person who sends a message. It could be a transmitting station from where the signal is transmitted.

- **Channel** is the medium through which the message signals travel to reach the destination.

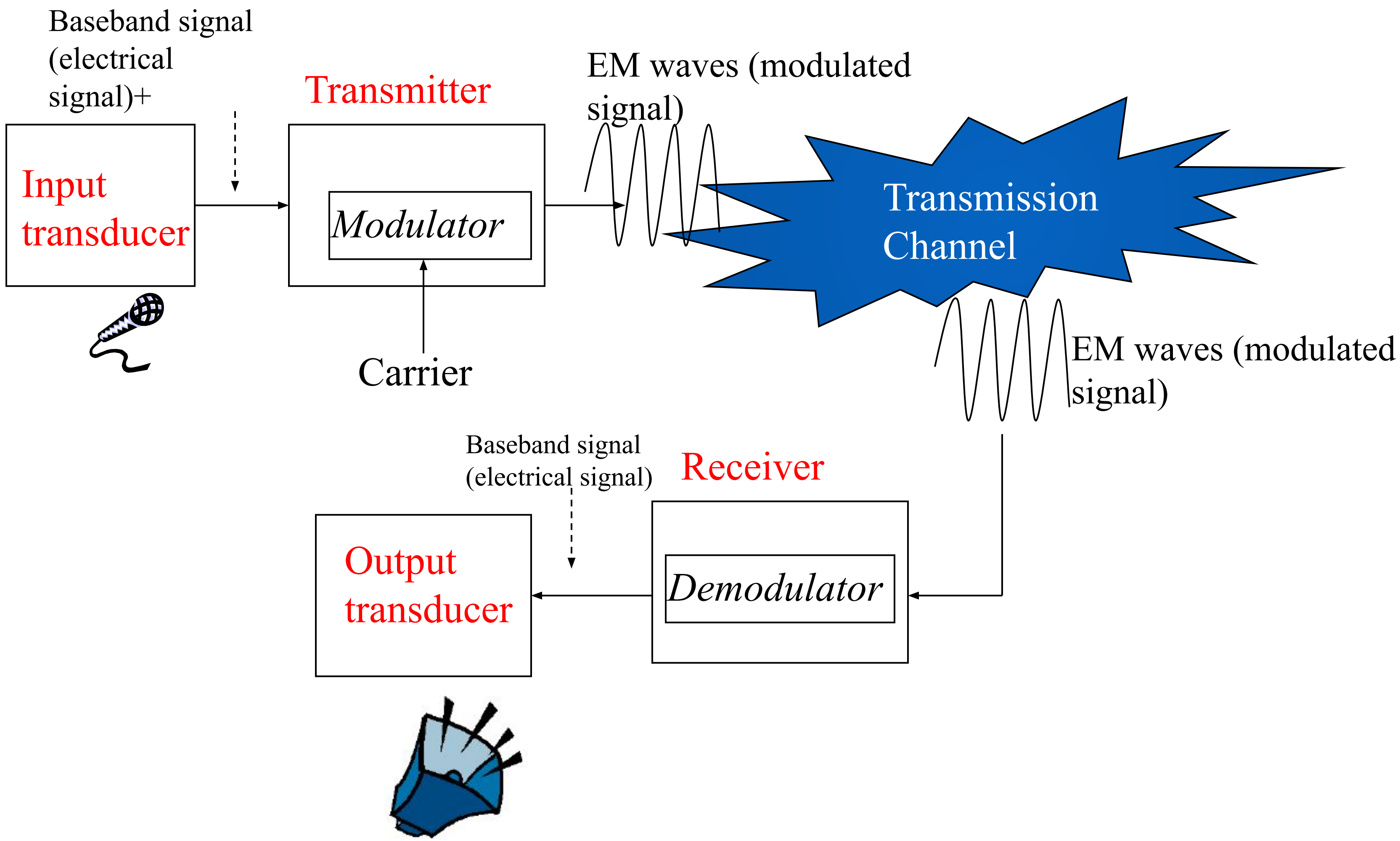
- **Receiver** is the person who receives the message. It could be a receiving station where the transmitted signal is being received.

BASICS OF COMMUNICATION SYSTEM



Activate Windows

Basic analog communications system



Electromagnetic spectrum and Applications

- **What is the Electromagnetic Spectrum?**

The Electromagnetic Spectrum refers to the full range of all possible Electromagnetic Field energy frequencies. This energy traveling through space is called radiation.

Radiation is a process by which **energy particles or waves travel though space**.

Radiant Energy is made up of small packets of particles, called **photons**.

Photons can travel alone or move around together in synchrony.

When photons move together, they do so in waves.

These waves are all categorized by least powerful to most powerful, depending on their

Energy (E),

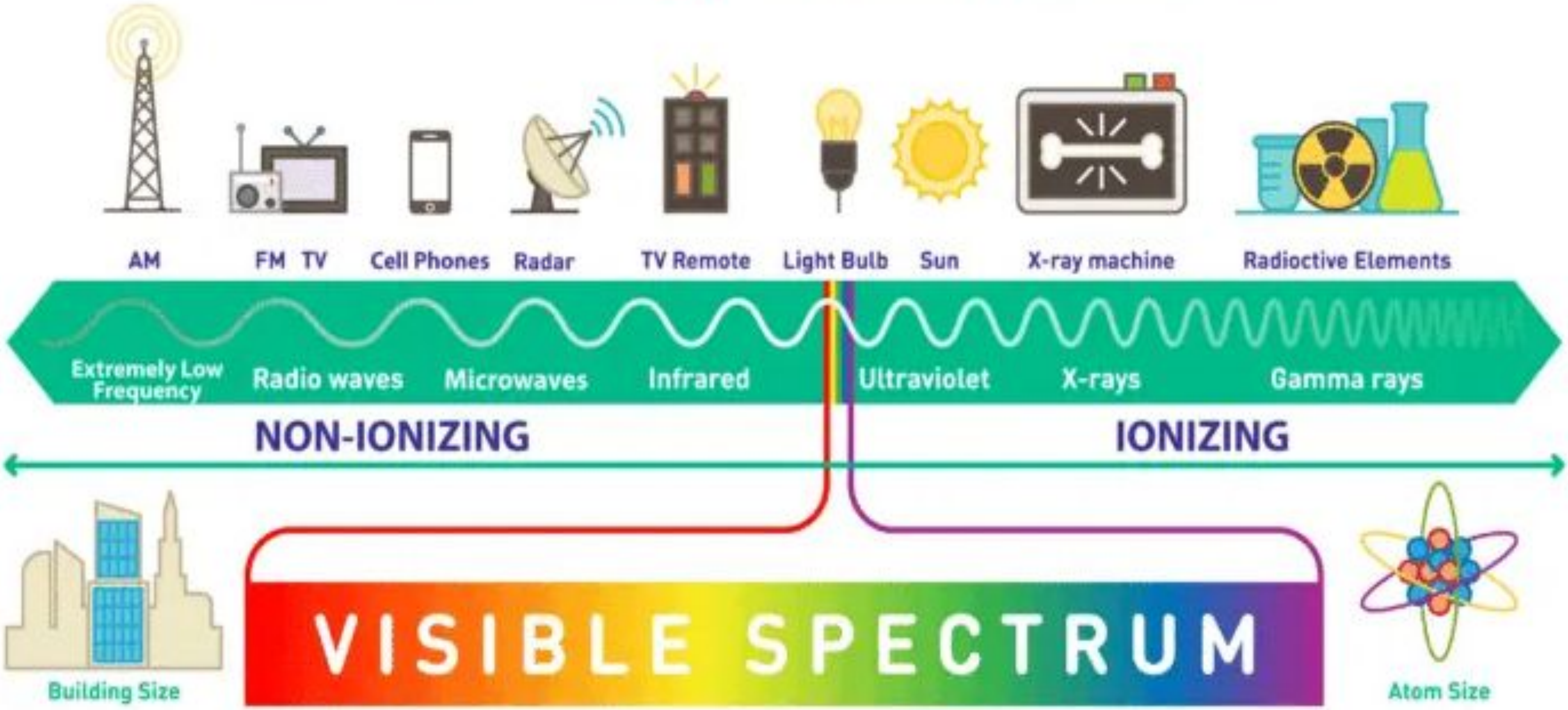
Wavelength (λ), and

Frequency (f).

- Energy is how much “juice” it carries.
- The frequency of a wave is the number of waves per second.
- The wavelength is the distance from the peak of one wave to the next one.

To visualize these different spans of waves, scientists came up with the **Electromagnetic Spectrum**.

Electromagnetic Spectrum



- **visible energy** or the light energy we see with our eyeballs lands in the middle of the spectrum.
- Visible light energy is generally not harmful. It’s considered a safe zone.
- To the right, you have high energy ionizing radiation, which is bad for you.
- **Ultraviolet light** is famous for wrinkling skin, mutating skin cells and causing melanoma.
- Even further out, **X-rays** or **Gamma rays** are capable of annihilating atomic structure.

Frequencies on the Electromagnetic Spectrum

- The Frequency (F) spectrum starts close to zero (0) and can extend to infinity. The Wavelength (W) spectrum also starts around zero and extends to infinity, in reverse.

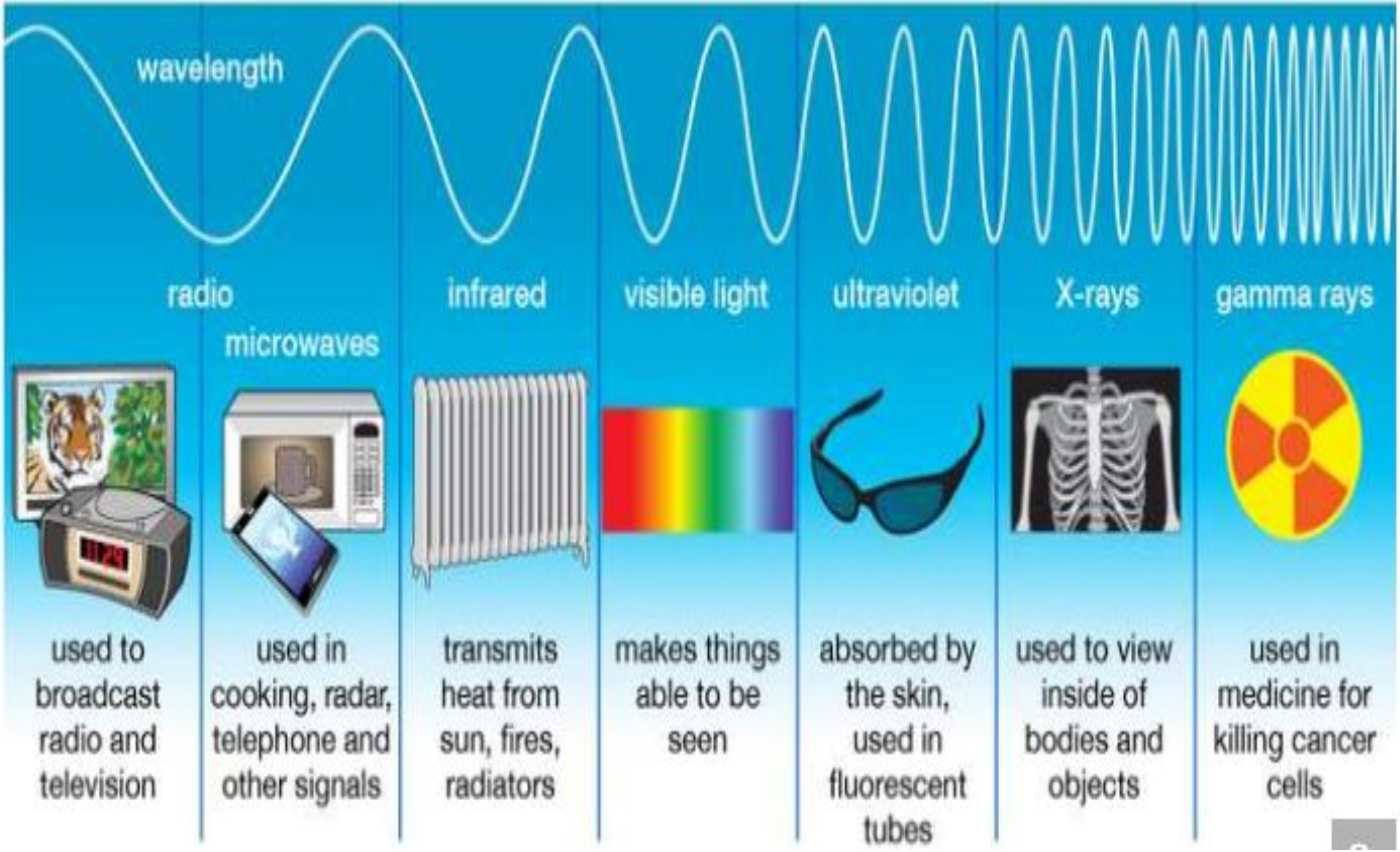
The following identifies frequency band designations, nominal frequency ranges, nominal wavelengths, and application uses.

Band Designation	Frequency (Hz)	Wavelength	Applications
Extremely Low Frequency (ELF) Radio	30 Hz - 300 Hz	10,000 km - 1,000 km	Electronics, Submarine Communications

Band Designation	Frequency (Hz)	Wavelength	Applications
Audible	20 Hz - 20 kHz	>100 km	Acoustics
Extremely Low Frequency (ELF) Radio	30 Hz - 300 Hz	10,000 km - 1,000 km	Electronics, Submarine Communications
Infralow Frequency (ILF)	300 Hz – 3 kHz	1,000 km - 100 km	Not Applicable
Very Low Frequency (VLF) Radio	3 kHz - 30 kHz	100 km - 10 km	Navigation, Weather
Low Frequency (LF) Radio	30 kHz - 300 kHz	10 km - 1 km	Navigation, Maritime Communications, Information and Weather Systems, Time Systems
Medium Frequency (MF) Radio	300 kHz - 3 MHz	1 km – 100 m	Navigation, AM Radio, Mobile Radio

High Frequency (HF) Radio	3 MHz – 30 MHz	100 – 10 m	Citizens Band (CB) Radio (aka Shortwave Radio), Mobile Radio, Maritime Radio
Very High Frequency (VHF) Radio	30 MHz -300 MHz	10 m - 1 m	Amateur (Ham) Radio, VHF TV, FM Radio, Mobile Satellite, Mobile Radio, Fixed Radio
Ultra High Frequency (UHF) Radio	300 MHz - 3 GHz	1 m - 10 cm	Microwave, Satellite, UHF TV, Paging, Cordless Telephone, Cellular and PCS Telephony, Wireless LAN (e.g., WiFi)
Super High Frequency (SHF) Radio	3 GHz - 30 GHz	10 cm – 1 cm	Microwave, Satellite, Wireless LAN (e.g., WiFi)
Extremely High Frequency	30 GHz - 300 GHz	1 cm - 1 mm	Microwave, Satellite,

Extremely High Frequency (EHF) Radio	30 GHz - 300 GHz	1 cm - 1 mm	Microwave, Satellite, Radiolocation
Infrared Light (IR)	300 GHz – 400 THz	1 mm - 750 nm	Wireless LAN Bridges, Wireless LANs, Fiber Optics
Visible Light	400 THz – 1 PHz	750 nm - 380 nm	Not Applicable
Ultraviolet Light (UV)	1 PHz – 30 PHz	380 nm -10 nm	Not Applicable
X-Rays	30 PHz - 30 EHz	10 nm - .01 nm	Not Applicable
Gamma and Cosmic Rays	>3 EHz	<.1 nm	Not Applicable

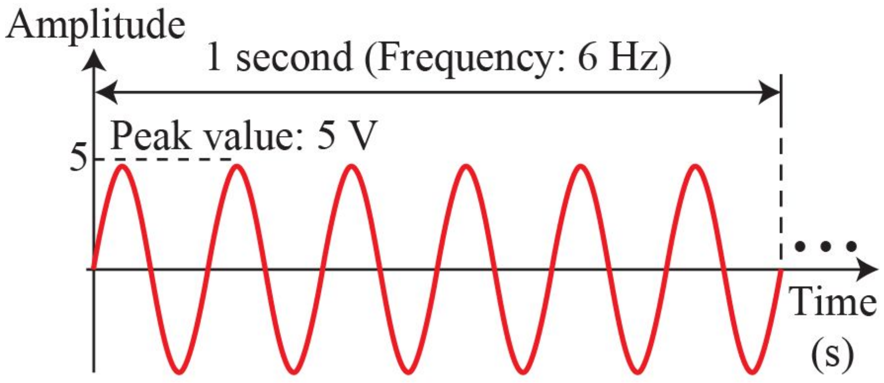


wavelength
radio
microwaves
infrared
visible light
ultraviolet
X-rays
gamma rays
used to broadcast radio and television
used in cooking, radar, telephone and other signals
transmits heat from sun, fires, radiators
makes things able to be seen
absorbed by the skin, used in fluorescent tubes
used to view inside of bodies and objects
used in medicine for killing cancer cells

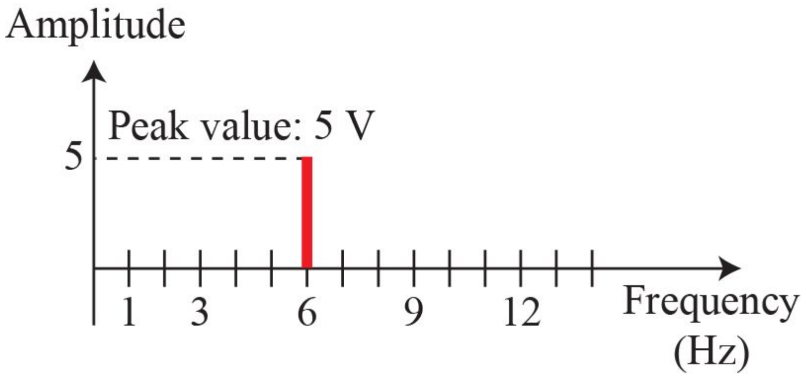
3.2.4 Time and Frequency Domains

A sine wave is comprehensively defined by its amplitude, frequency, and phase. We have been showing a sine wave by using what is called a time domain plot. The time-domain plot shows changes in signal amplitude with respect to time (it is an amplitude-versus-time plot). Phase is not explicitly shown on a time-domain plot.

Figure 3.8: The time and frequency-domain plots of a sine wave



a. A sine wave in the time domain

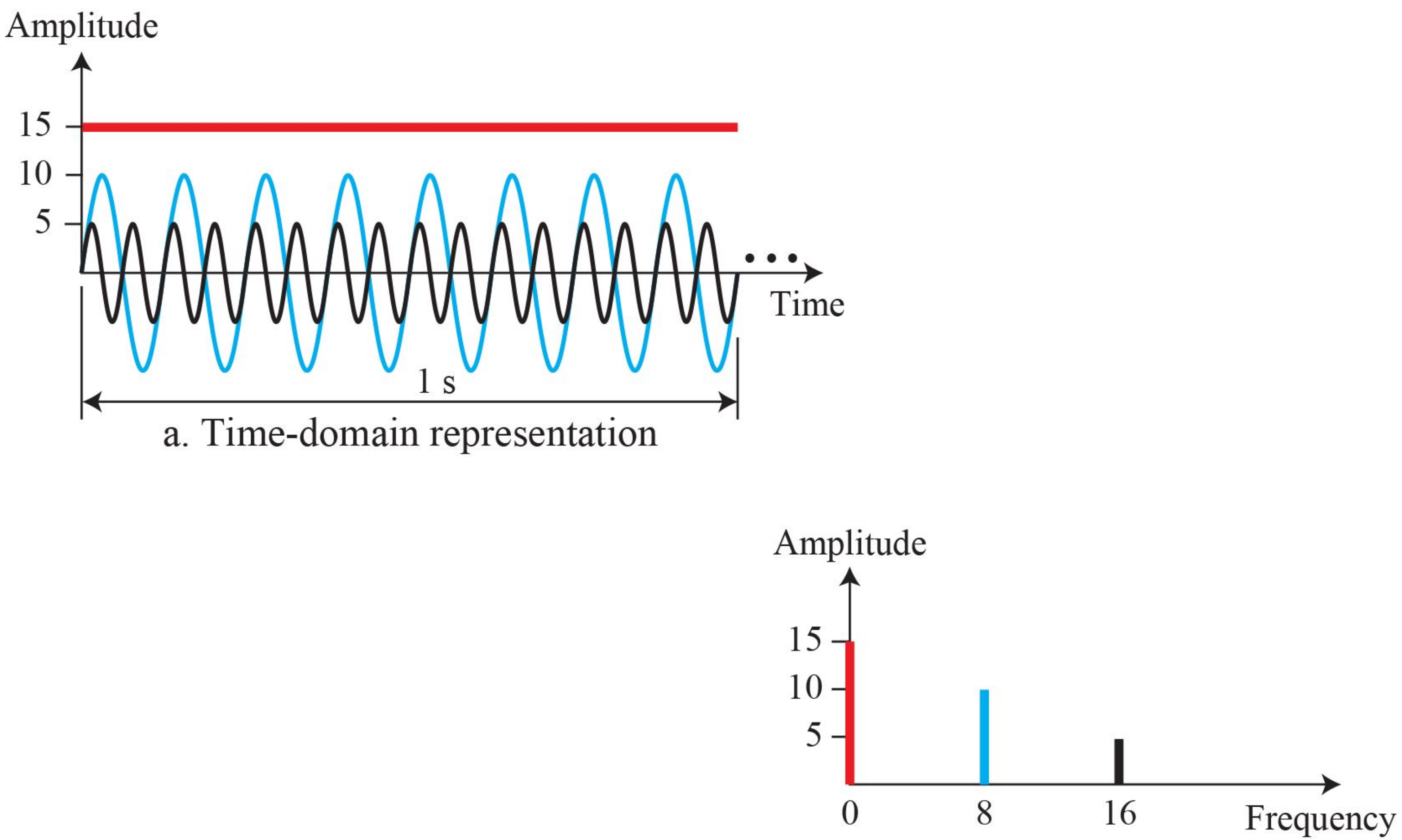


b. The same sine wave in the frequency domain

Example 3.7

The frequency domain is more compact and useful when we are dealing with more than one sine wave. For example, Figure 3.9 shows three sine waves, each with different amplitude and frequency. All can be represented by three spikes in the frequency domain.

Figure 3.9: The time and frequency domain of three sine waves



a. Time-domain representation

b. Frequency-domain representation

3.2.5 Composite Signals

So far, we have focused on simple sine waves. Simple sine waves have many applications in daily life. We can send a single sine wave to carry electric energy from one place to another. For example, the power company sends a single sine wave with a frequency of 60 Hz to distribute electric energy to houses and businesses. As another example, we can use a single sine wave to send an alarm to a security center when a burglar opens a door or window in the house. In the first case, the sine wave is carrying energy; in the second, the sine wave is a signal of danger.

Example 3.8

Figure 3.10 shows a periodic composite signal with frequency f. This type of signal is not typical of those found in data communications. We can consider it to be three alarm systems, each with a different frequency. The analysis of this signal can give us a good understanding of how to decompose signals. It is very difficult to manually decompose this signal into a series of simple sine waves. However, there are tools, both hardware and software, that can help us do the job. We are not concerned about how it is done; we are only interested in the result. Figure 3.11 shows the result of decomposing the above signal in both the time and frequency domains.

Figure 3.10: A composite periodic signal

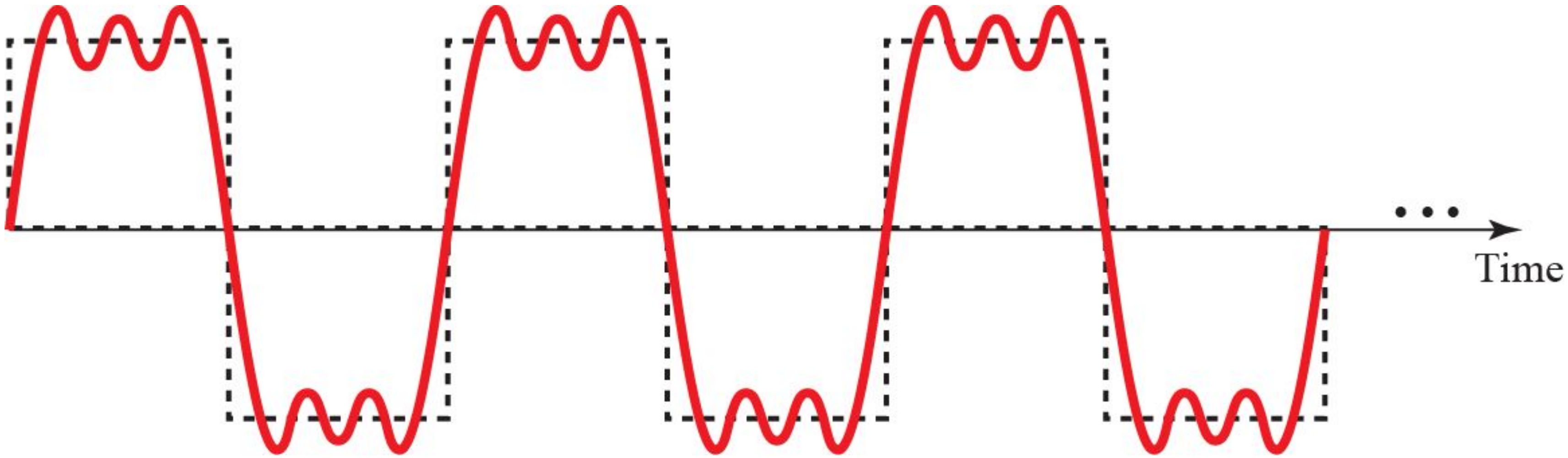
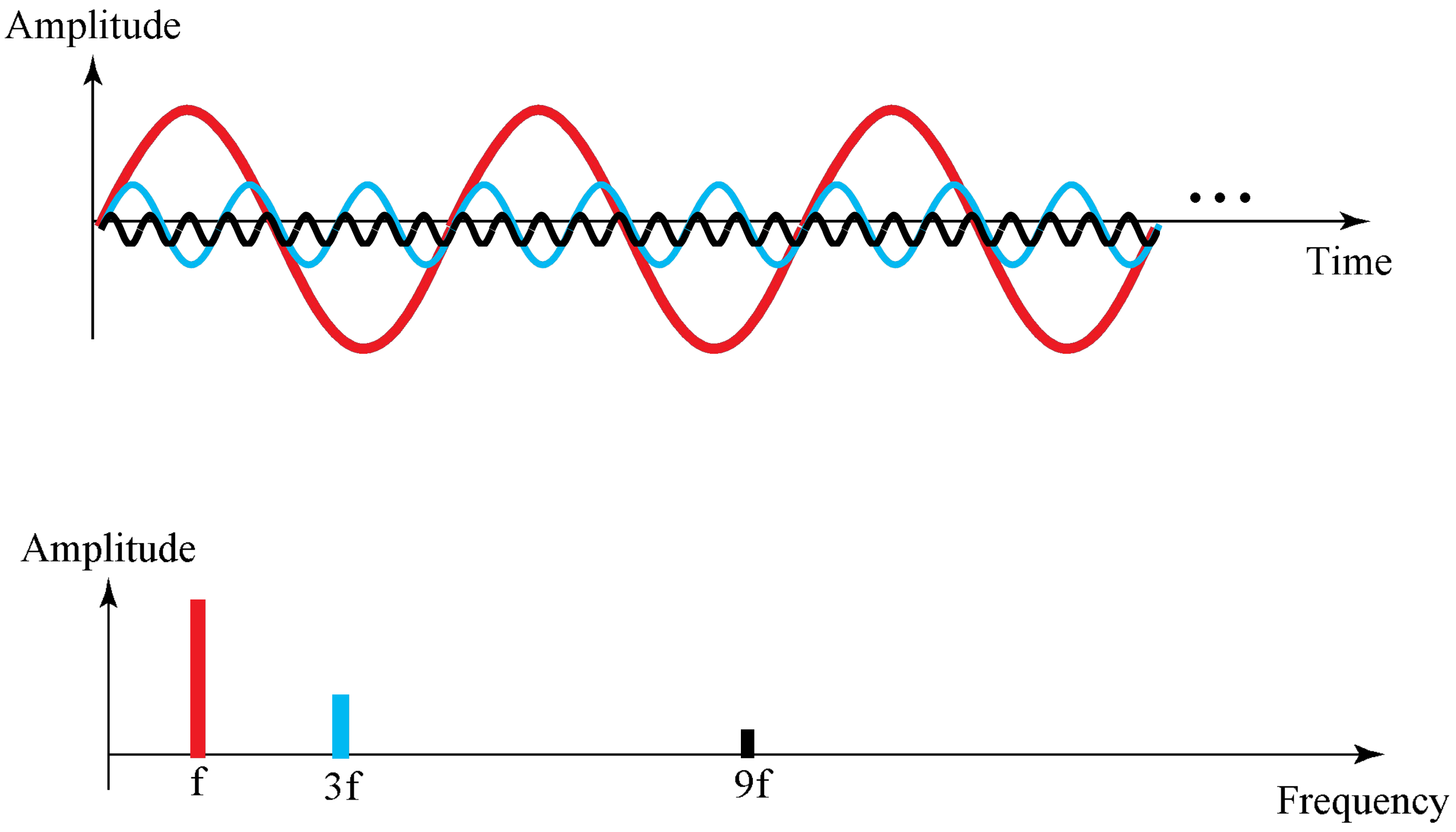


Figure 3.11: Decomposition of a composite periodic signal

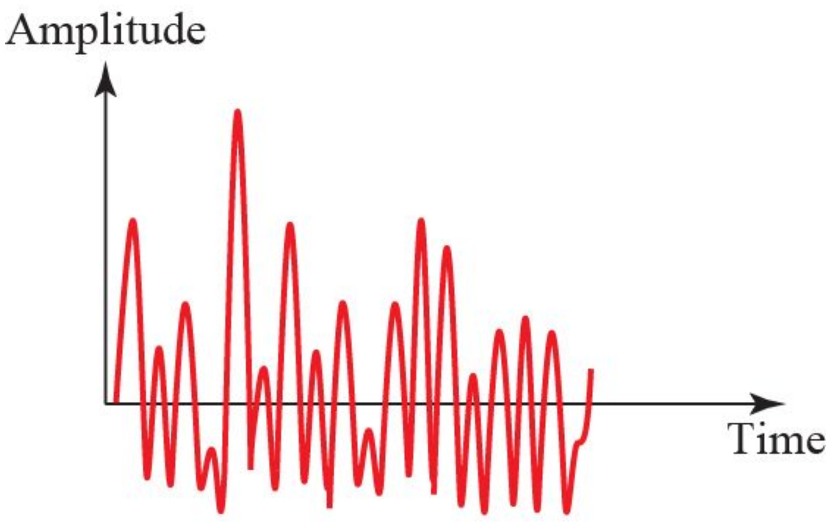


b. Frequency-domain decomposition of the composite signal

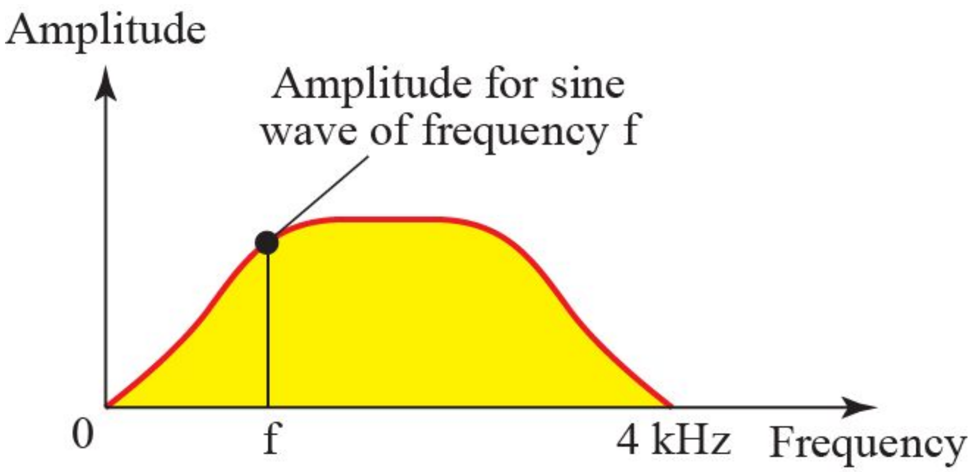
Example 3.9

Figure 3.12 shows a nonperiodic composite signal. It can be the signal created by a microphone or a telephone set when a word or two is pronounced. In this case, the composite signal cannot be periodic, because that implies that we are not repeating the same word or words with exactly the same tone.

Figure 3.12: Time and frequency domain of a non-periodic signal



a. Time domain

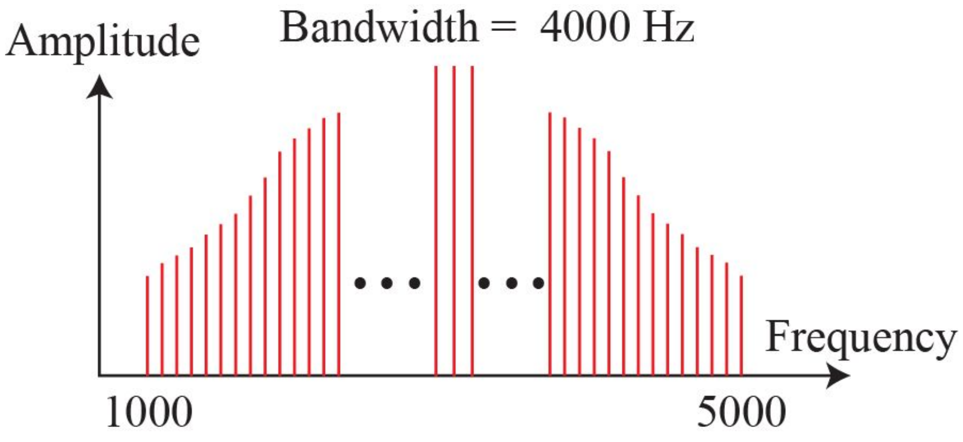


b. Frequency domain

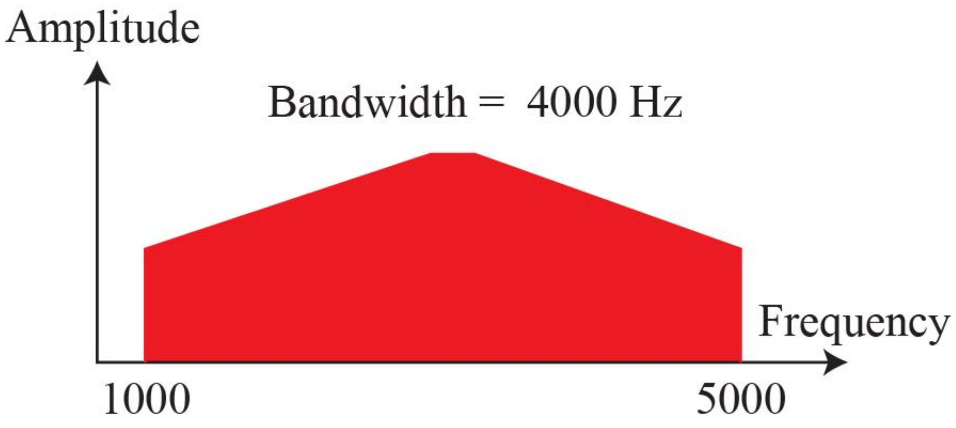
3.2.6 Bandwidth

The range of frequencies contained in a composite signal is its bandwidth. The bandwidth is normally a difference between two numbers. For example, if a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000 − 1000, or 4000.

Figure 3.13: The bandwidth of periodic and nonperiodic composite signals



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

Example 3.10

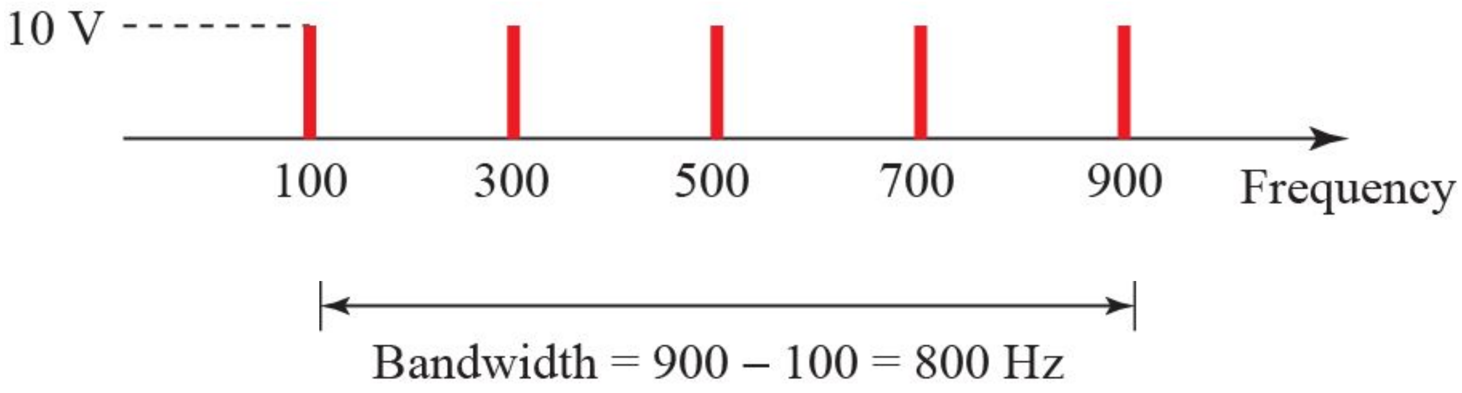
If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l = 900 - 100 = 800 \text{ Hz}$$

Figure 3.14:* *The bandwidth for example 3.10



Example 3.11

A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

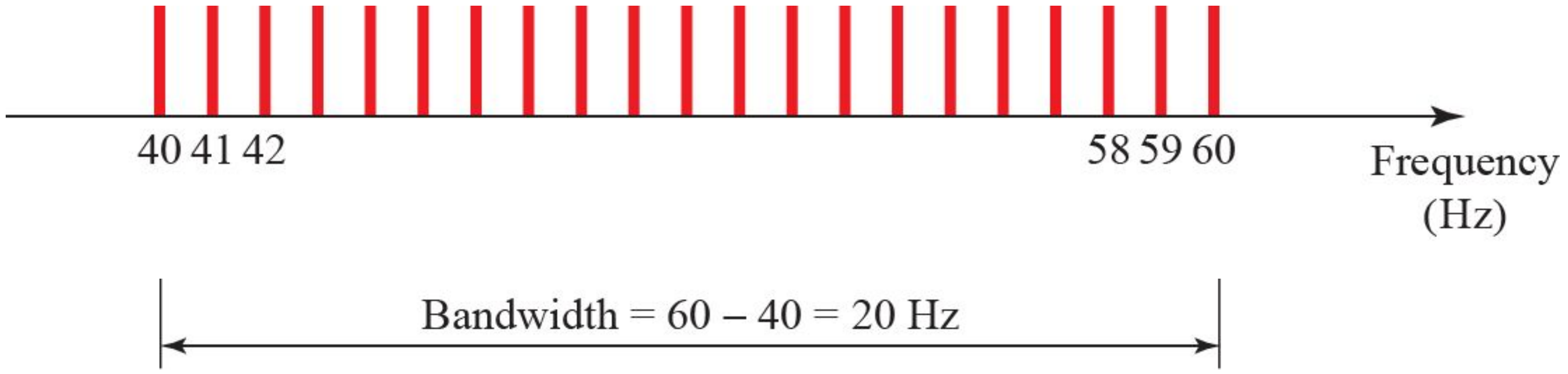
Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l \longrightarrow 20 = 60 - f_l \longrightarrow f_l = 60 - 20 = 40 \text{ Hz}$$

The spectrum contains all integer frequencies. We show this by a series of spikes (see Figure 3.15).

Figure 3.15: The bandwidth for example 3.11



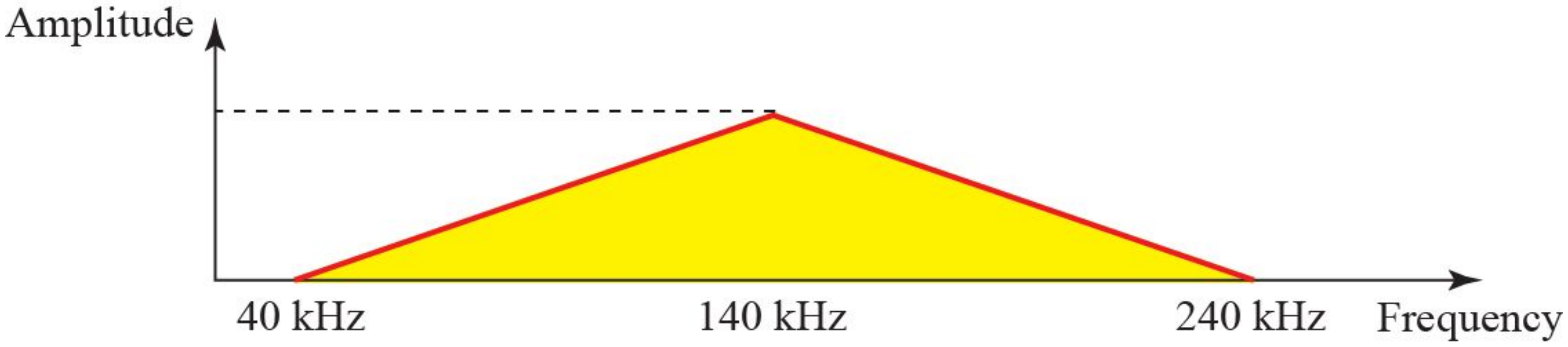
Example 3.12

A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure 3.16 shows the frequency domain and the bandwidth.

Figure 3.16: The bandwidth for example 3.12



Example 3.15

Another example of a nonperiodic composite signal is the signal received by an old-fashioned analog black-and-white TV. A TV screen is made up of pixels (picture elements) with each pixel being either white or black. The screen is scanned 30 times per second. If we assume a resolution of 525 × 700 (525 vertical lines and 700 horizontal lines), which is a ratio of 3:4, we have 367,500 pixels per screen. If we scan the screen 30 times per second, this is 367,500 × 30 = 11,025,000 pixels per second. The worst-case scenario is alternating black and white pixels. In this case, we need to represent one color by the minimum amplitude and the other color by the maximum amplitude. We can send 2 pixels per cycle.

Example 3.15 (continued)

Therefore, we need 11,025,000 / 2 = 5,512,500 cycles per second, or Hz. The bandwidth needed is 5.5124 MHz. This worst-case scenario has such a low probability of occurrence that the assumption is that we need only 70 percent of this bandwidth, which is 3.85 MHz. Since audio and synchronization signals are also needed, a 4-MHz bandwidth has been set aside for each black and white TV channel. An analog color TV channel has a 6-MHz bandwidth.

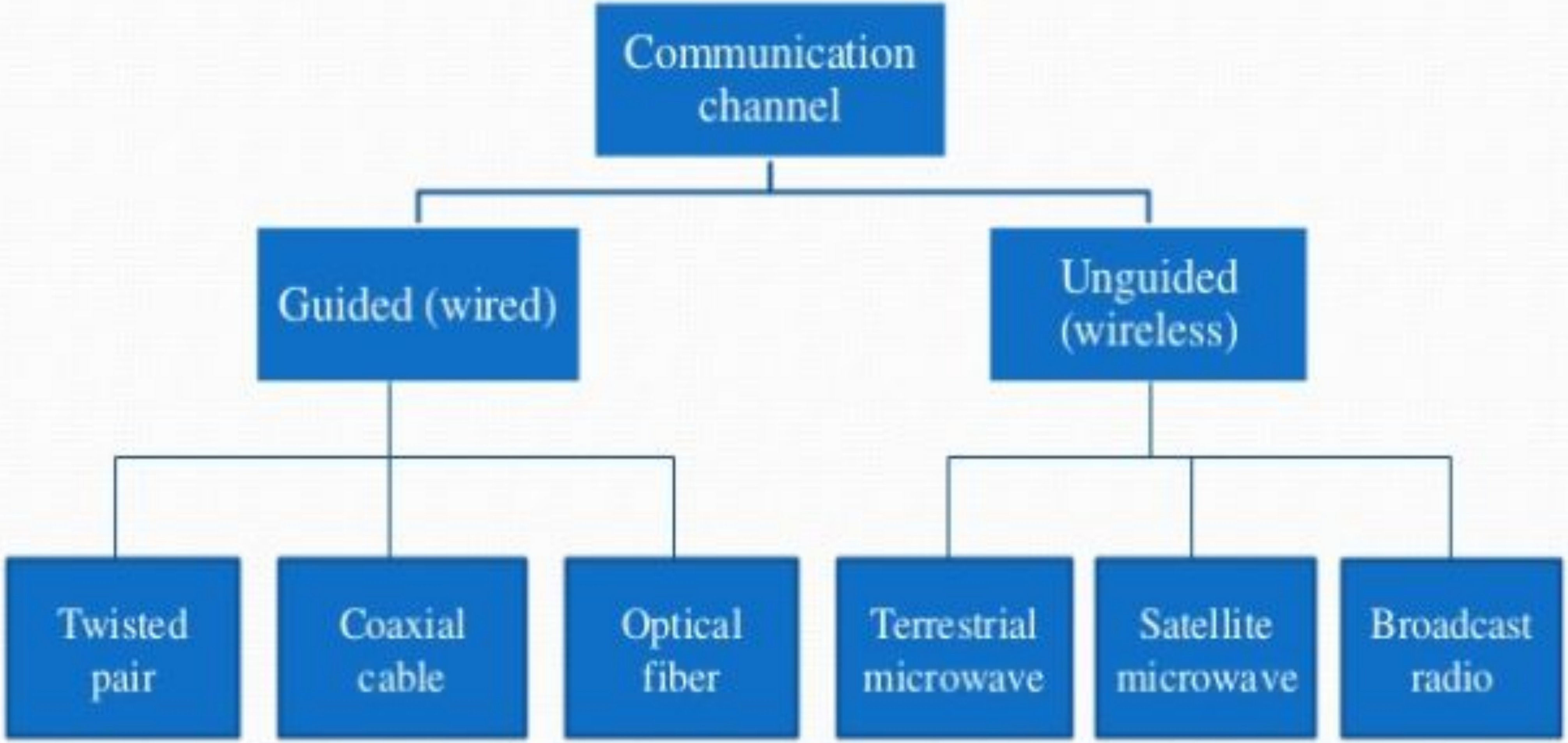
Types of Communication channels.

- Communication channel is a connection between transmitter and receiver through which Data can be transmitted.
- Communication channel also called as communication media or transmission media

Design Factors

- Bandwidth
  - Higher bandwidth gives higher data rate
- Transmission impairments
  - eg. attenuation
- Interference
- Number of receivers in guided media
  - More receivers introduces more attenuation

Types of Communication channel



- Other types are Under Water Acoustic Channels, Storage Channels like magnetic tapes, magnetic disks etc.

- **1. Guided Media**:
  It is also referred to as Wired or Bounded transmission media. Signals being transmitted are directed and confined in a narrow pathway by using physical links.
- Features:

High Speed

Secure

Used for comparatively shorter distances

There are 3 major types of Guided Media:

Twisted-pair cable

- One of the wires carries signal, the other is used only as a ground reference.
- Number of twists per unit length determines the quality of the cable.

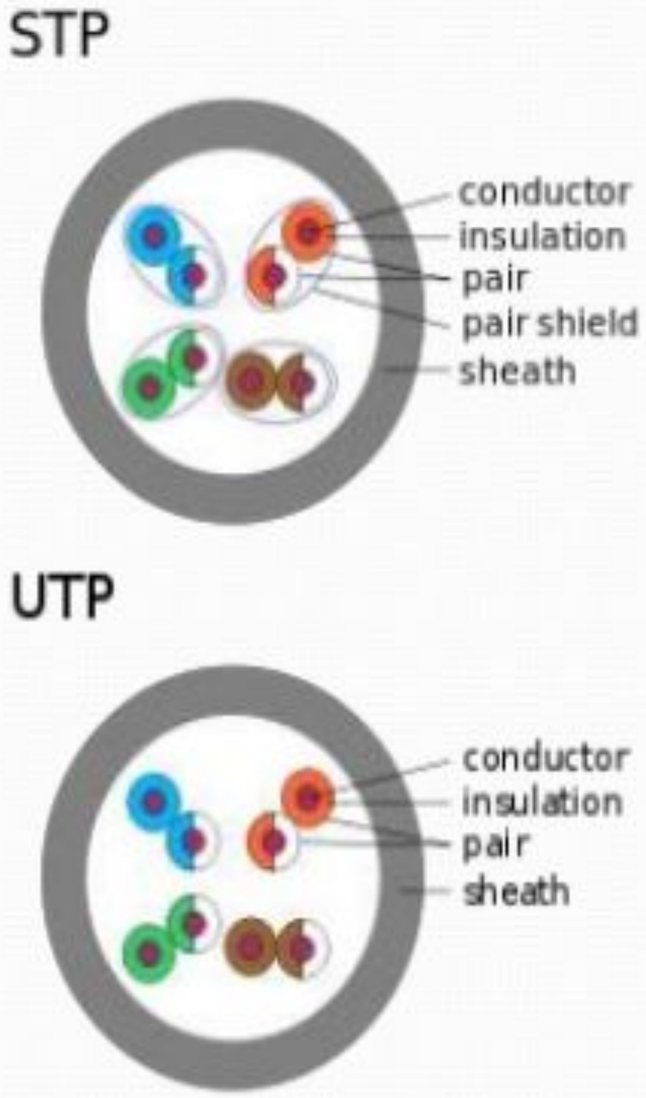
It consists of 2 separately insulated conductor wires wound about each other.

Generally, several such pairs are bundled together in a protective sheath.

They are the most widely used Transmission Media. Twisted Pair is of two types:

Types in twisted pair cables

- Shielded twisted-pair cable
- Unshielded twisted-pair cable
- Categories of Twisted-Pair Cables
  - Category 1- 0.1 Mbps
  - Category 2- 2 Mbps
  - Category 3- 10 Mbps
  - Category 4- 20 Mbps
  - Category 5- 100 Mbps
  - Category 6- 200 Mbps
  - Category 7- 600 Mbps



- **Unshielded Twisted Pair (UTP):**

This type of cable has the ability to block interference and does not depend on a physical shield for this purpose.

It is used for telephonic applications.

Advantages:

- Least expensive
- Easy to install
- High speed capacity

- Disadvantages:
  - Susceptible to external interference
  - Lower capacity and performance in comparison to STP
  - Short distance transmission due to attenuation

- **Shielded Twisted Pair (STP):**

This type of cable consists of a special jacket to block external interference. It is used in fast-data-rate Ethernet and in voice and data channels of telephone lines.

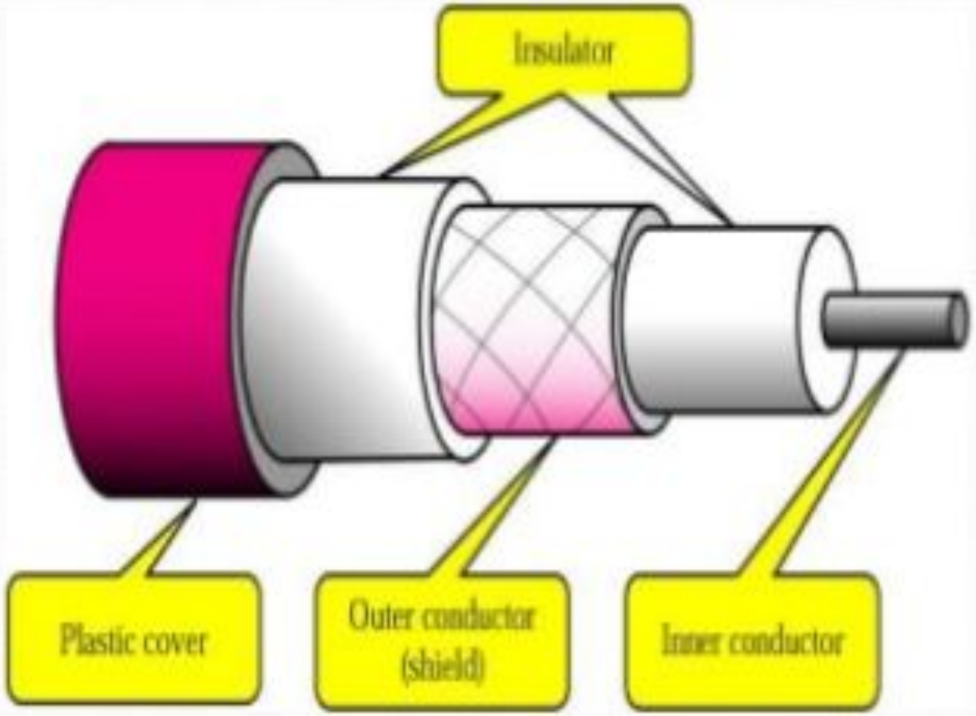
Advantages:

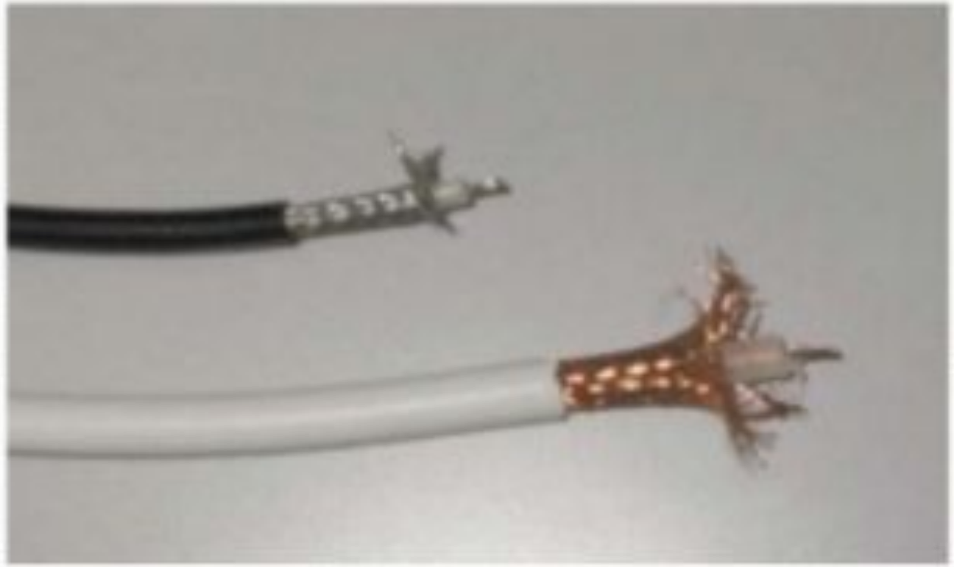
- Better performance at a higher data rate in comparison to UTP
- Eliminates crosstalk
- Comparatively faster

- Disadvantages:
  - Comparatively difficult to install and manufacture
  - More expensive
  - Bulky

Coaxial cable

- Used for both analog and digital signals
- Effectively used at higher data rate and higher bandwidth
- For analog signals need amplifiers every few km
- For digital signals requires repeater every 1km





It has an outer plastic covering containing 2 parallel conductors each having a separate insulated protection cover.
Coaxial cable transmits information in two modes:
Baseband mode(dedicated cable bandwidth) and
Broadband mode(cable bandwidth is split into separate ranges).
Cable TVs and analog television networks widely use Coaxial cables.

- Advantages:

High Bandwidth

Better noise Immunity

Easy to install and expand

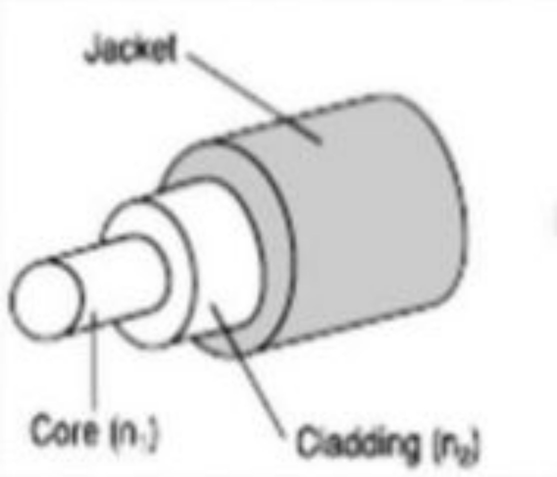
Inexpensive

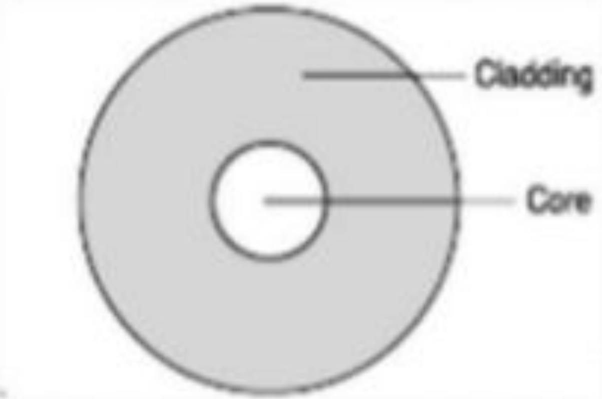
- Disadvantages:

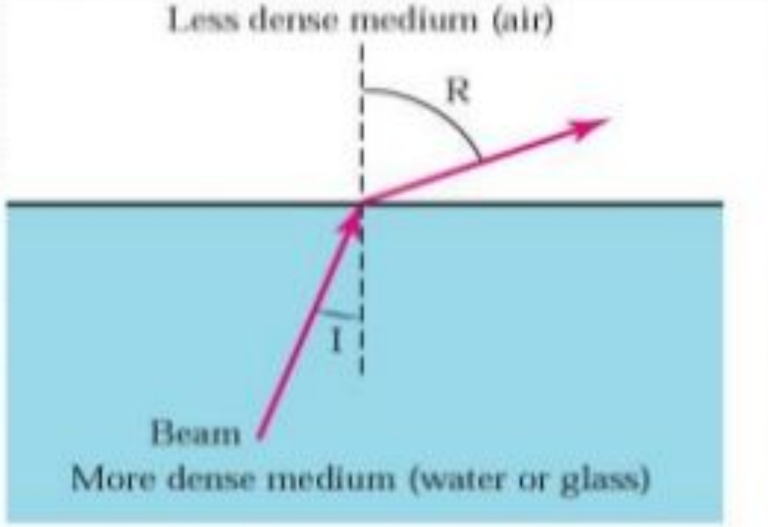
Single cable failure can disrupt the entire network

Optical fiber

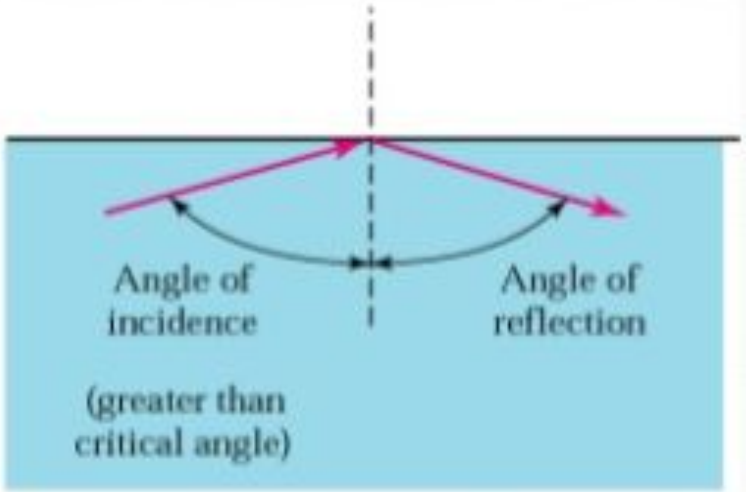
Refraction and reflection





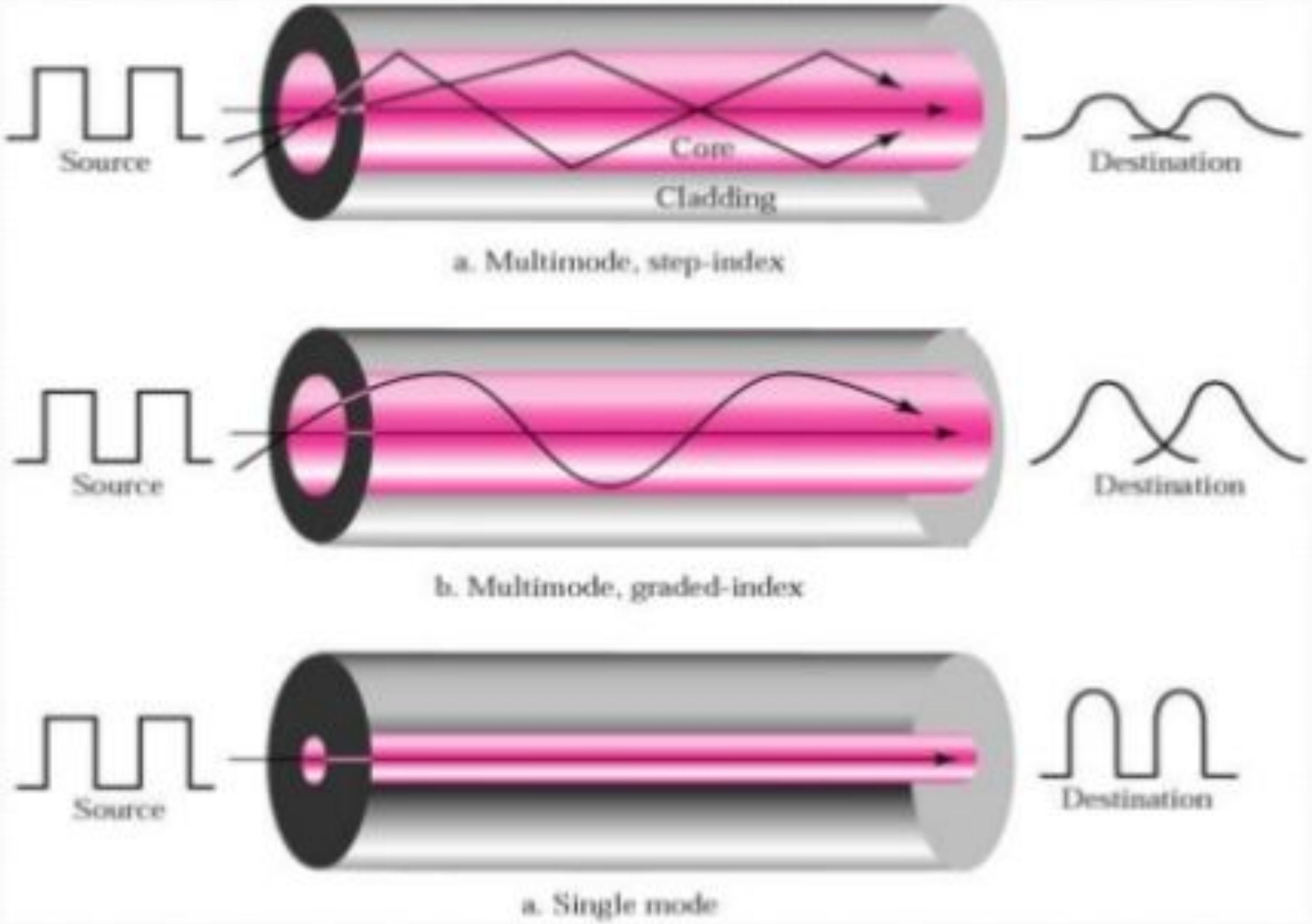


a. Refraction



b. Reflection

Propagation modes



- It uses the concept of reflection of light through a core made up of glass or plastic. The core is surrounded by a less dense glass or plastic covering called the cladding. It is used for transmission of large volumes of data.
- Advantages:

Increased capacity and bandwidth

Light weight

Less signal attenuation

Immunity to electromagnetic interference

Resistance to corrosive materials

- Disadvantages:

Difficult to install and maintain

High cost

Fragile

unidirectional, ie, will need another fibre, if we need bidirectional communication

- **Unguided Media:**

It is also referred to as Wireless or Unbounded transmission media. No physical medium is required for the transmission of electromagnetic signals.

- Features:

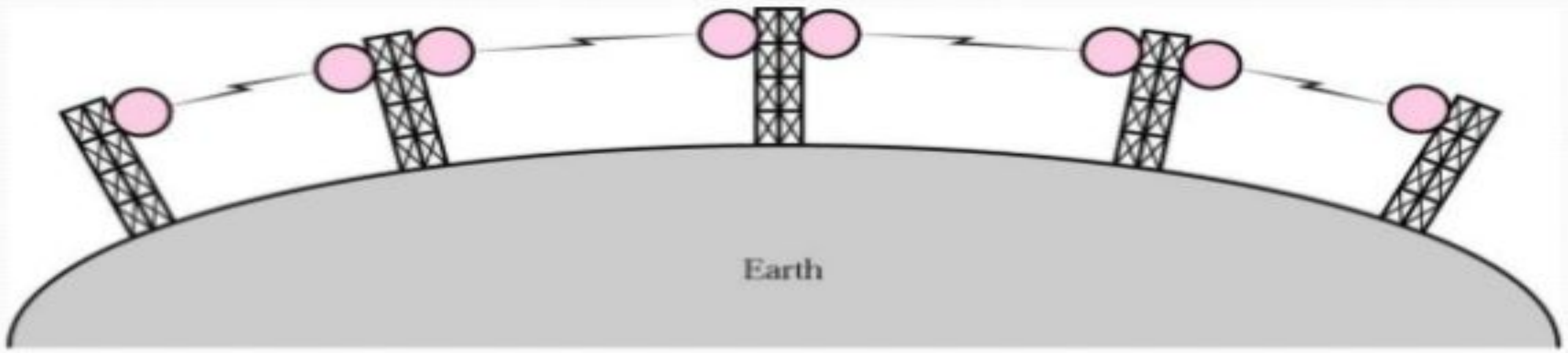
Signal is broadcasted through air

Less Secure

Used for larger distances

Terrestrial microwave

- Requires fewer repeaters
- Use a parabolic dish to focus a narrow beam.
- 1-40GHz frequencies



It is a line of sight transmission i.e. the sending and receiving antennas need to be properly aligned with each other. The distance covered by the signal is directly proportional to the height of the antenna. Frequency Range:1GHz – 300GHz. These are majorly used for mobile phone communication and television distribution.

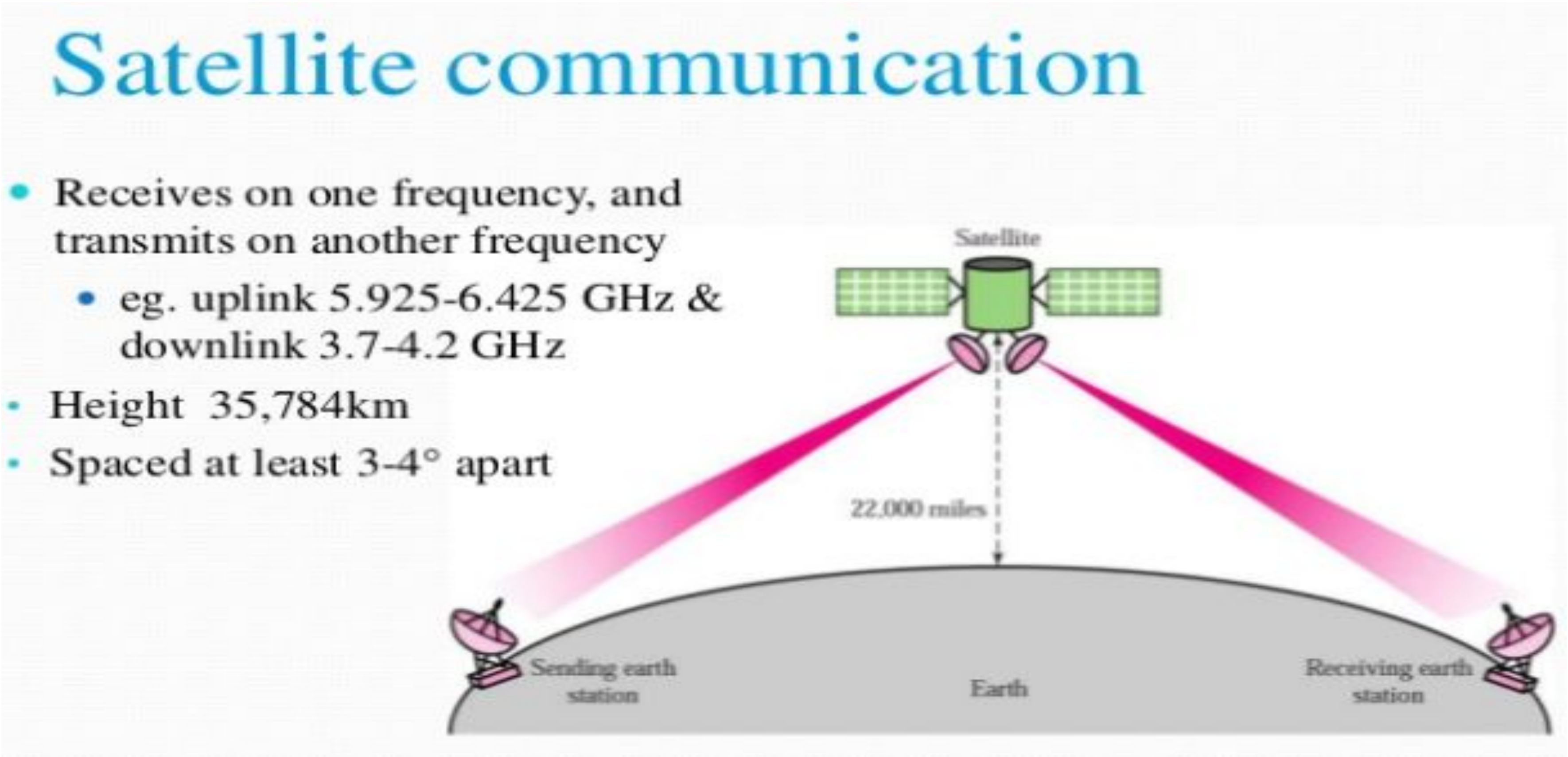
Broadcast Radio

- Radio frequency range is 3kHz to 300GHz
- Use broadcast radio of 30MHz - 1GHz, for:
  - FM radio
  - UHF and VHF television
- Is a unidirectional
- Suffers from multipath interference
  - Reflections from land, water, other objects
- Are used for multicasts communications, such as radio and television, and paging system.

•Radio waves

These are easy to generate and can penetrate through buildings. The sending and receiving antennas need not be aligned. AM and FM radios and cordless phones use Radio waves for transmission.

- Further Categorized as (i) Terrestrial and (ii) Satellite.



- Communication channel is essential for communication systems. The transmission characteristics are important in selecting channel because they directly affect the communication quality.
- Different types of communication channels have different transmission characteristics and costs, they are used in different applications.

Wave propagation

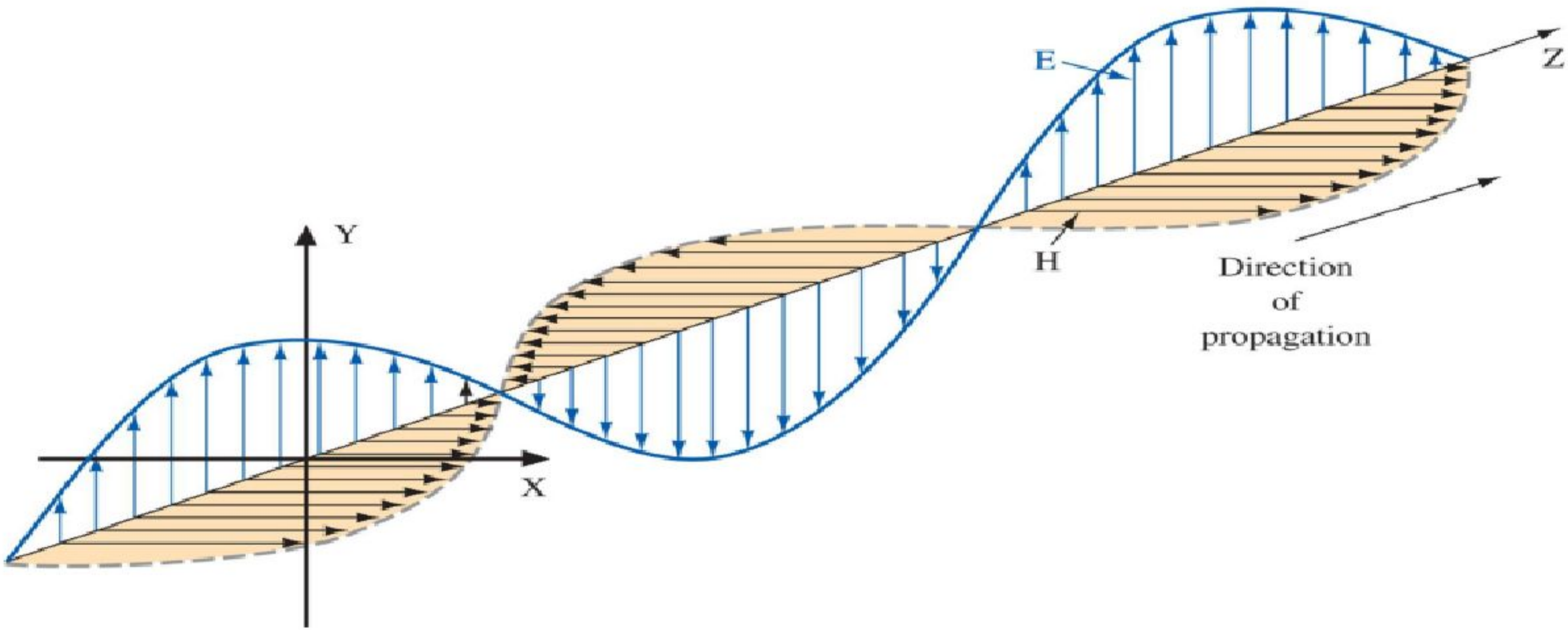
Electrical to Electromagnetic Conversion

- Since the atmosphere is not a conductor of electrons (instead a good insulator), electrical energy must be converted into another form of energy for transmission
- It is converted into electromagnetic energy by a transmitting antenna and back into electrical energy by a receiving antenna
  - Technically speaking an antenna is a transducer
  - Usable radio wave are at ~1.5×10^4 Hz up to 3×10^{11} Hz
  - A light bulb also converts electrical energy into electromagnetic energy: light at ~5×10^{14} Hz

Electromagnetic Waves

- In free space, an oscillating electric field creates and oscillating magnetic field, which creates an oscillating electric field, and so on.
- These two fields contain energy:
  - In circuits the energy is returned to the circuit when the fields collapse
  - In a radio transmitter the antenna is designed not to allow the energy to collapse back into the circuit, but instead to be radiated (or set free) into the form of an *electromagnetic (EM) wave* (aka radio wave)
- An EM wave electric field, magnetic field and direction of propagation are mutually orthogonal (see Fig 13-1)

Figure 13-1 Electromagnetic wave.



Wavefronts

- An *isotropic point source* is a point in space that radiates electromagnetic radiation in all directions
- A *wavefront* is a surface joining all points of equal phase in an electromagnetic wave (see Fig 13-2)
- The power density at a waveform is given by:

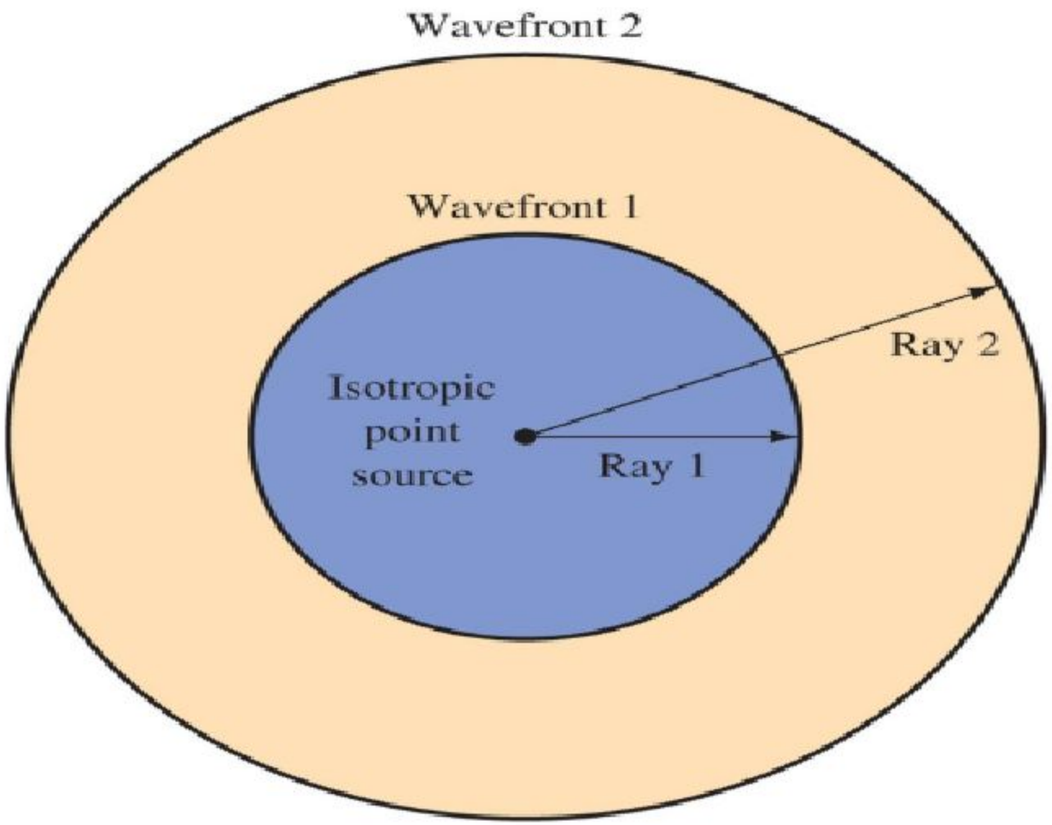
$$\mathcal{P} = \frac{P_t}{4\pi r^2}$$

Where:

P_t = transmitted power (Watts)

r = distance from source (meters)

Figure 13-2 Antenna wavefronts.



Waves not in Free Space

- *Reflection* occurs when a radio wave bounces off an object or a surface of a different medium
  - Similar to light waves reflected in a mirror
  - Angle of incidence equals angle of reflection (see Fig13-3)
- *Refraction* occurs when radio waves pass from a medium of one to another of different density
  - See illustration on Fig 12-4
  - The angle of incidence (θ_1) and the angle of refraction (θ_2) are related by the <u>Snell's Law</u>:

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

    Where:

    n_x: refractive index for medium x (water: 1.33, glass: 1.5)

Figure 13-3 Reflection of a wavefront.

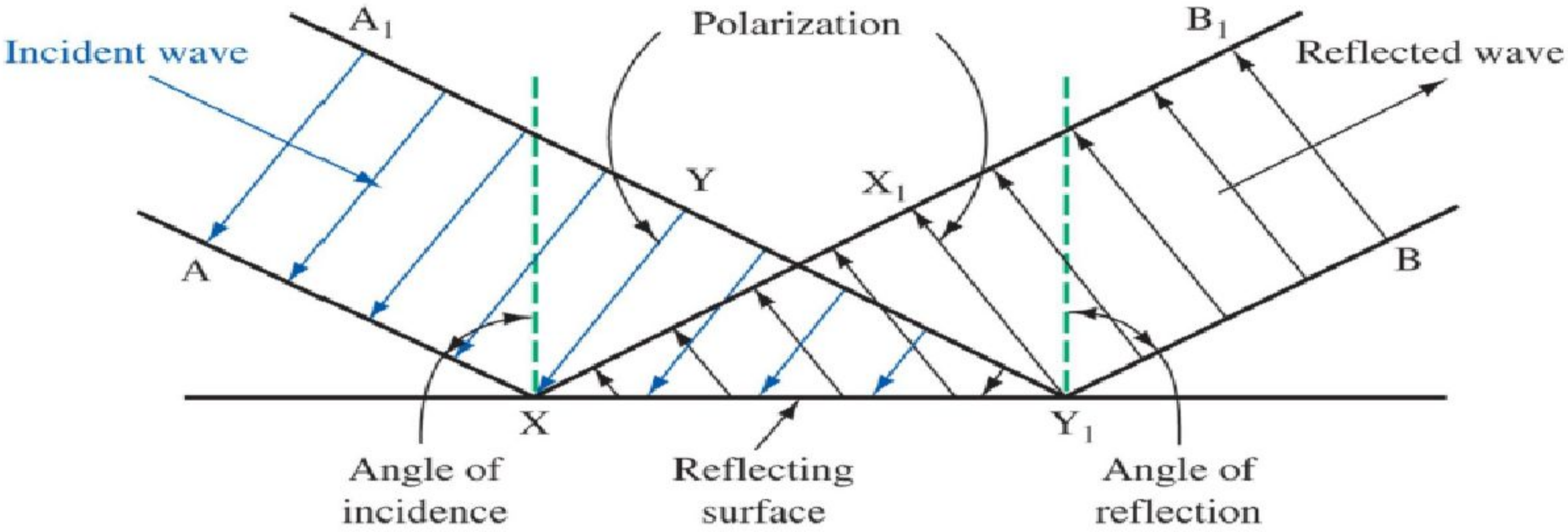
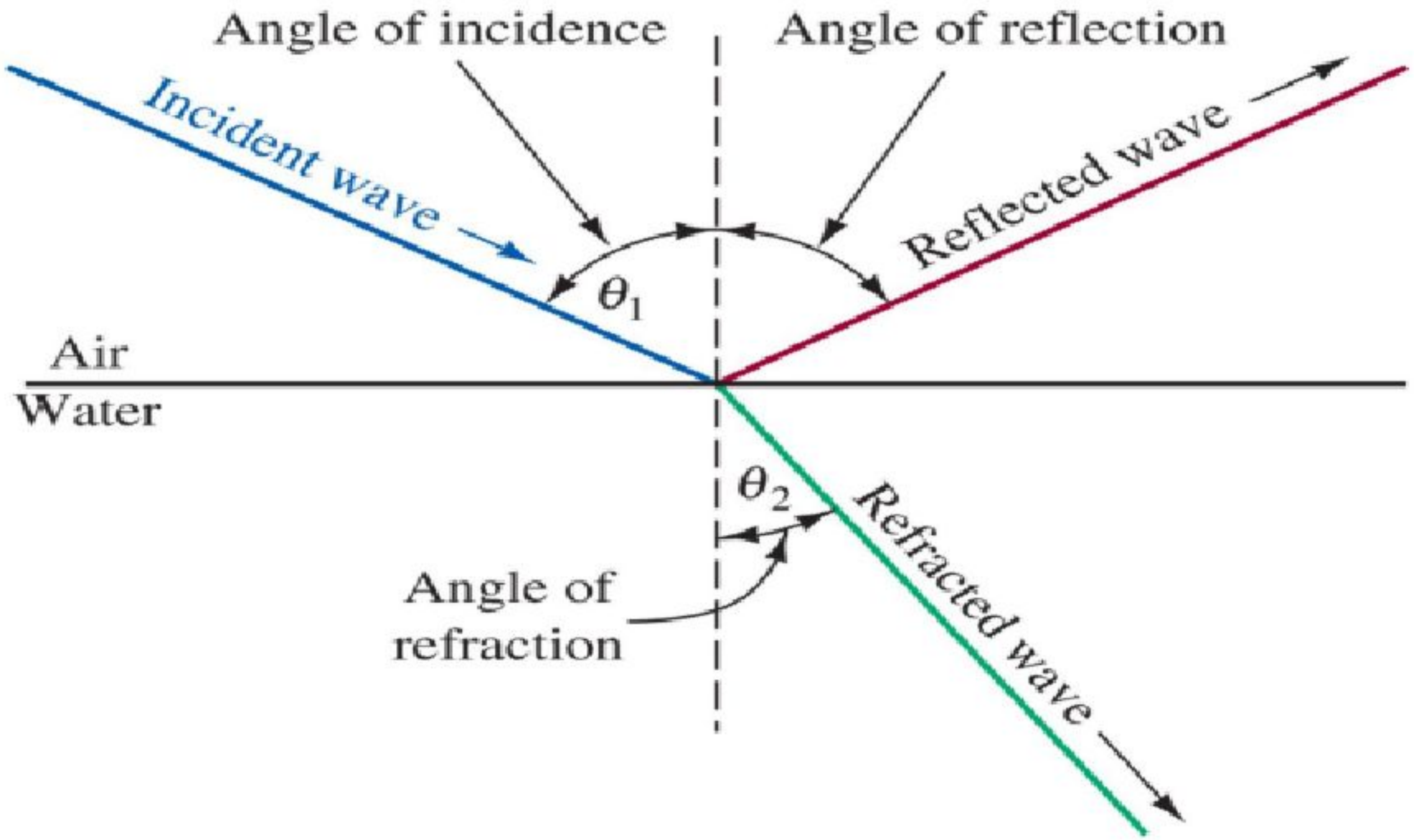


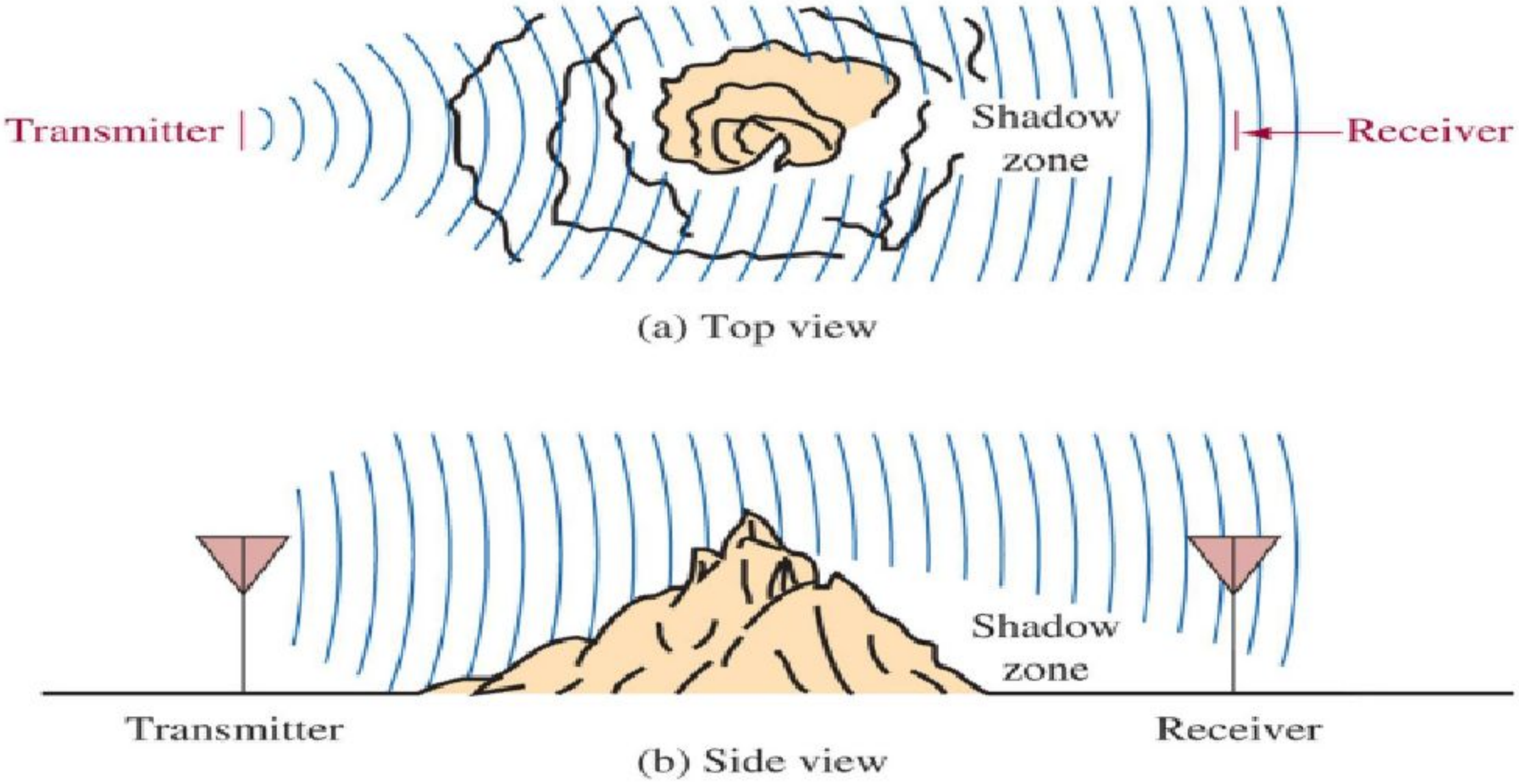
Figure 13-4 Wave refraction and reflection.



Waves not in Free Space – Cont'd

- *Diffraction* is the phenomenon whereby radio waves traveling in straight paths "bend" around an obstacle (see Fig. 13-5)
  - Result of Huyges's principle: each point in a wavefront may be considered as the source of a secondary spherical wavefront
  - Explains radio reception behind a mountain or tall building
  - Lower frequencies tend to bend more, higher frequencies tend to bend less, they're more directional (that's why a subwoofer can be anywhere, while tweeters must be aimed at listener)

Figure 13-5 Diffraction around an object.



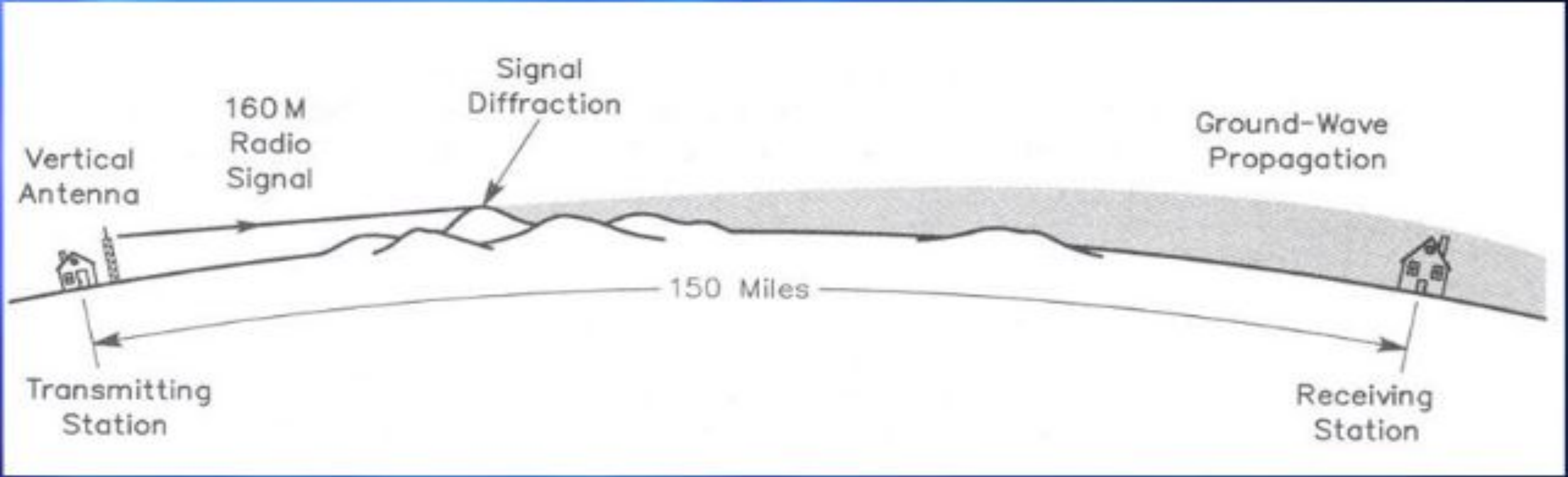
Ground And Space Propagation

- There are four basic modes of getting a radio wave from the transmitting to a receiving antenna:
  - Ground Wave
  - Space Wave
  - Sky Wave
  - Satellite Communication (SATCOM)
- The frequency of the radio wave is of primary importance in considering the performance of each type of propagation

Ground-Wave Propagation

- A *Ground Wave* (aka Surface Wave) is a radio wave that travels along earth's surface due to diffraction
- It travels better traveling over a conductive surface such as sea water
- Losses increase with increasing frequency - not very effective above 2 MHz
- Only way to communicate with submarines
  - Extremely Low Frequencies (ELF) propagation is used
  - ELF range from 30 to 300 Hz

Ground-Wave Propagation



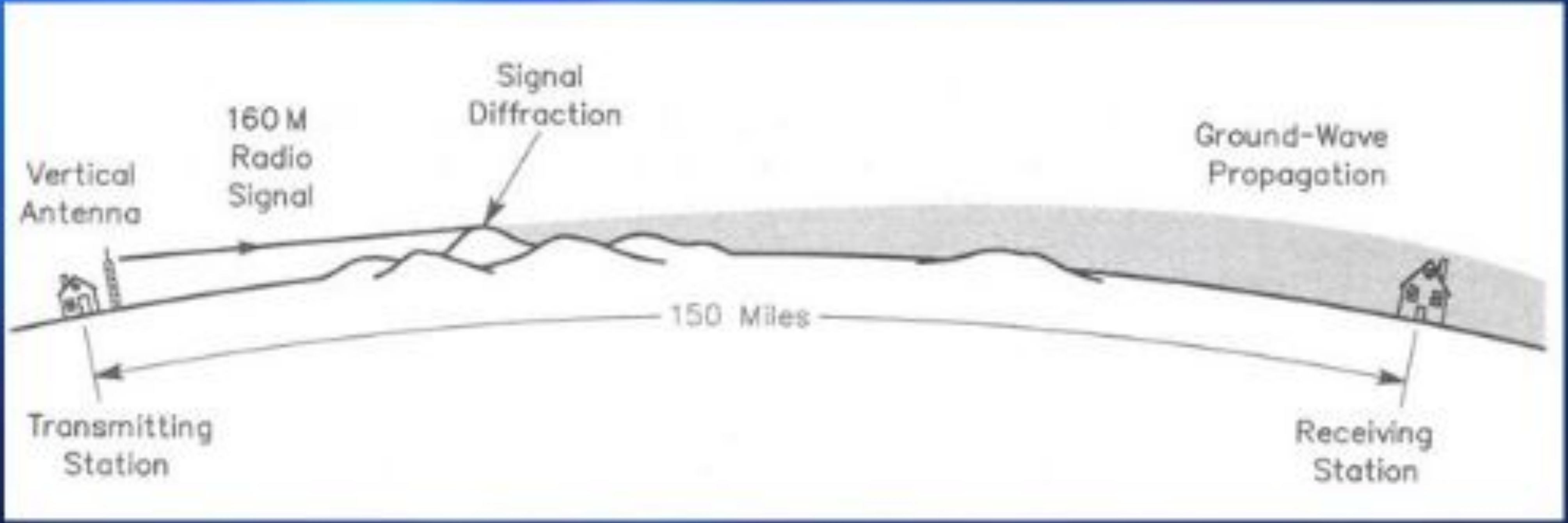
The curved surface of the Earth horizon can diffract long-wavelength (low frequency) radio waves. The waves can follow the curvature of the Earth for as much as several hundred miles.

Ground-Wave Propagation

- Results from a radio wave diffraction along the Earth's surface.
- Primarily affects longer wavelength radio waves that have vertical polarization (electric field is oriented vertically).
- Most noticeable on AM broadcast band and the 160 meter and 80 meter amateur bands.
- Communication distances often extend to 120 miles or more.
- Most useful during the day at 1.8 MHz and 3.5 MHz when the D-Region absorption makes sky-wave propagation impossible.

- Attenuation related to frequency
  - Loses increase with increase in frequency
  - Not very effective at frequencies above 2Mhz
  - Very reliable communication link
  - Reception is not affected by daily or seasonal weather changes

- Used to communicate with submarines
- ELF (30 to 300 Hz) propagation is utilized



Space Wave

- Two types
  - Direct
  - Ground reflected

Space-Wave Propagation

- A *Space Wave* can be classified as a direct wave (line-of-sight) or ground reflected wave (Fig 13-6)
- Because of diffraction, a direct space wave can travel ~ 4/3 greater than line-of-sight. This distance is known as the *radio horizon* (see Fig 13-7) and can be approximated as:

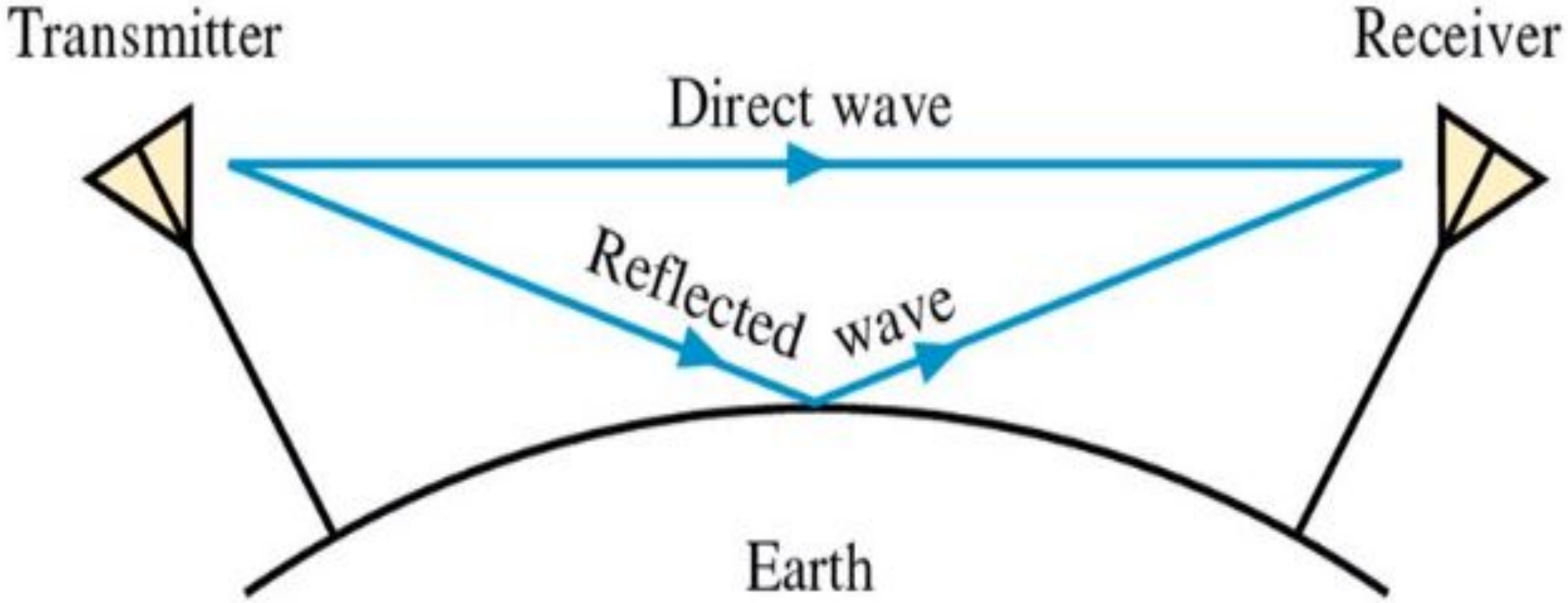
$$d \cong \sqrt{2h_t} + \sqrt{2h_r}$$

Where:

d = radio horizon (mi)

h_t = transmitting antenna height (ft)

h_r = receiving antenna height (ft)



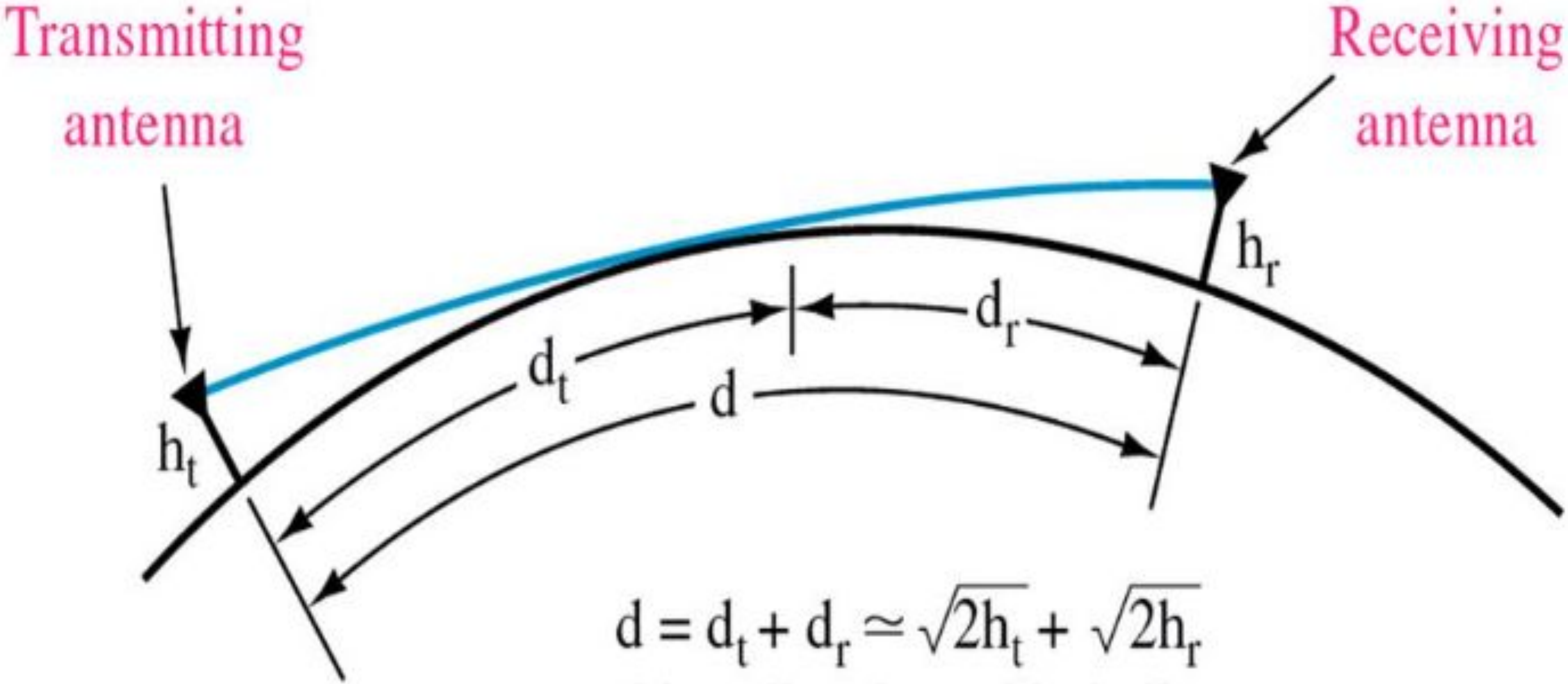
Transmitter
Receiver
Direct wave
Reflected wave
Earth

Direct

- Limited to “line-of sight” transmission distances
- Antenna height and curvature of earth are limiting factors
- Radio horizon is about 80% greater than line of sight because of diffraction effects

Line-Of-Sight Propagation

- Radio signals travel in a straight line from a transmitting antenna to the receiving antenna.
- Provides VHF/UHF communications within a 100 miles or so.
- Signals can be reflected by buildings, hills, airplanes, etc.



$$d = d_t + d_r \simeq \sqrt{2h_t} + \sqrt{2h_r}$$

d in miles, h_t and h_r in feet

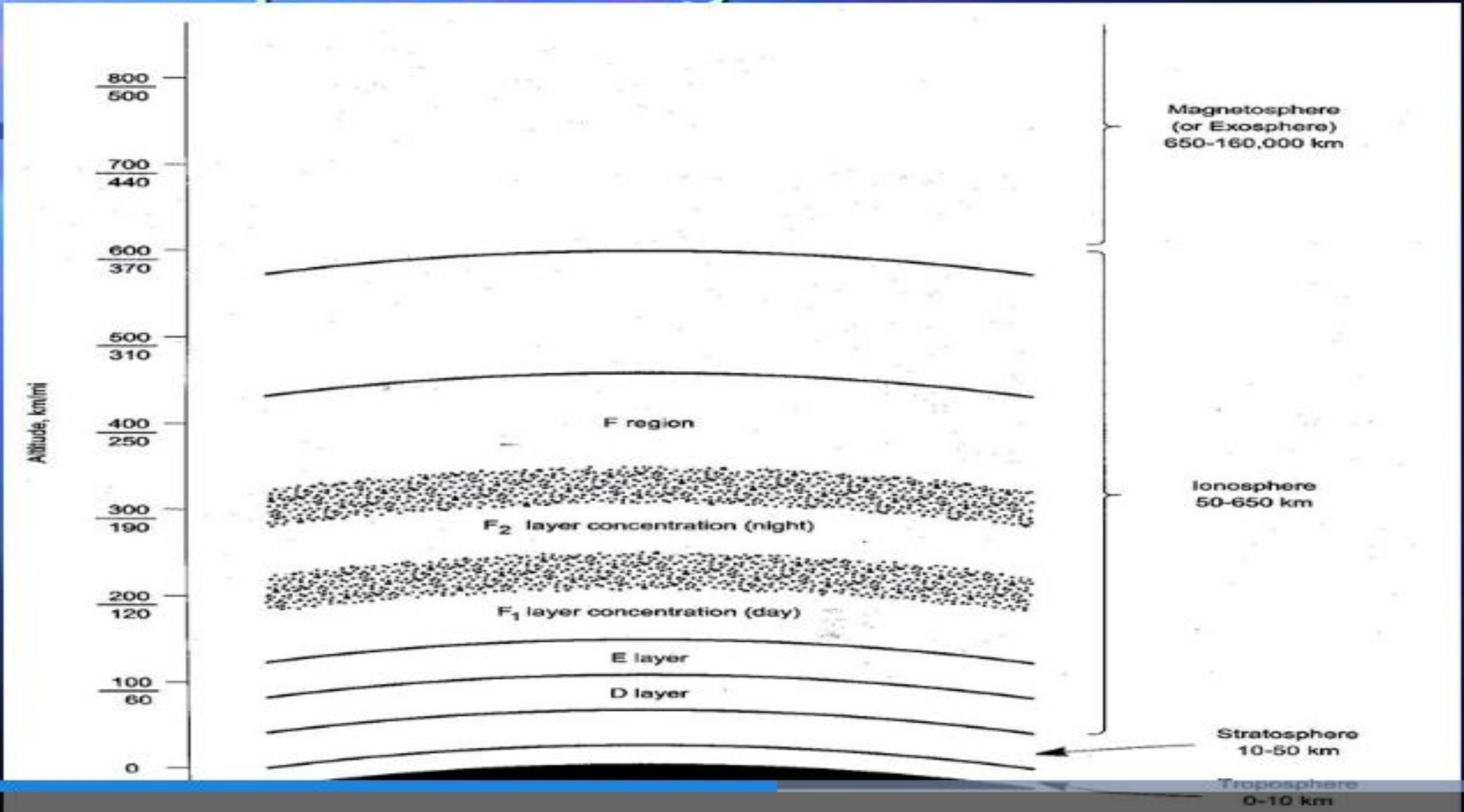
Sky Wave Propagation

Atmospheric Regions

Region	Height	Notes
Troposphere	7 miles	Region where all weather occurs
Stratosphere	6 to 30 miles	Region where atmospheric gases "spread out" horizontally. The high speed jet stream travels in the stratosphere.
Ionosphere	30 to 400 miles	Region where solar radiation from the sun creates ions. **Major influence on HF radio wave propagation.**

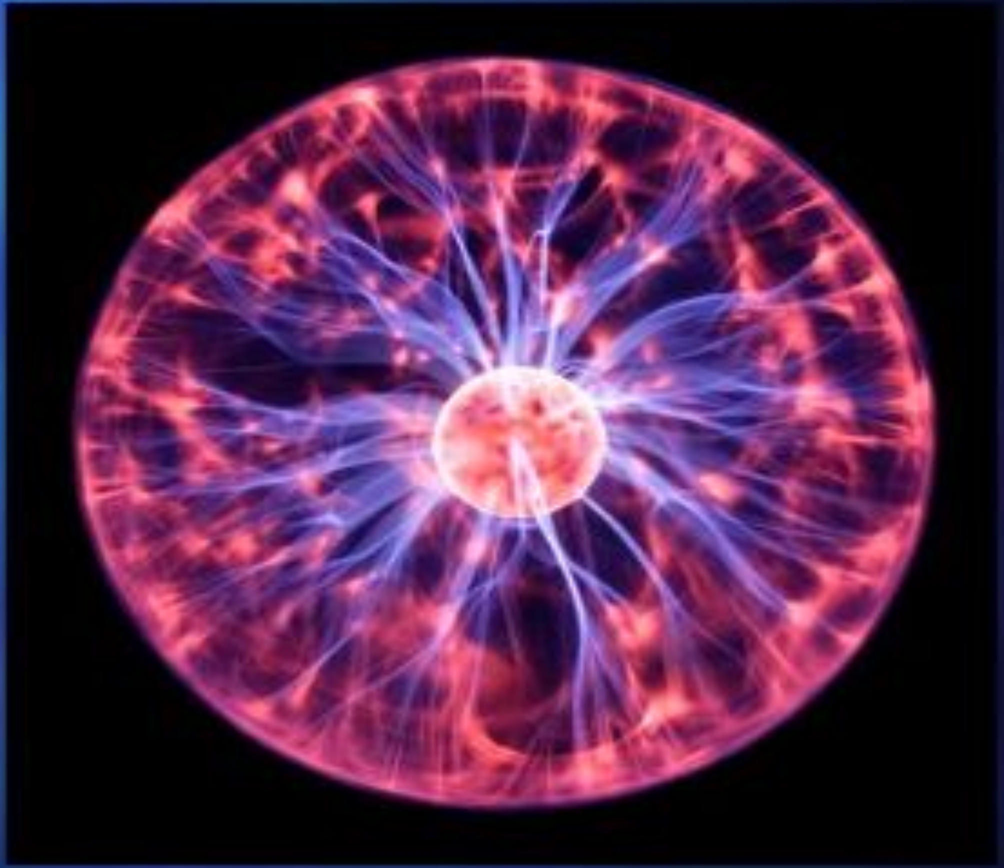
Slide

Atmospheric Regions



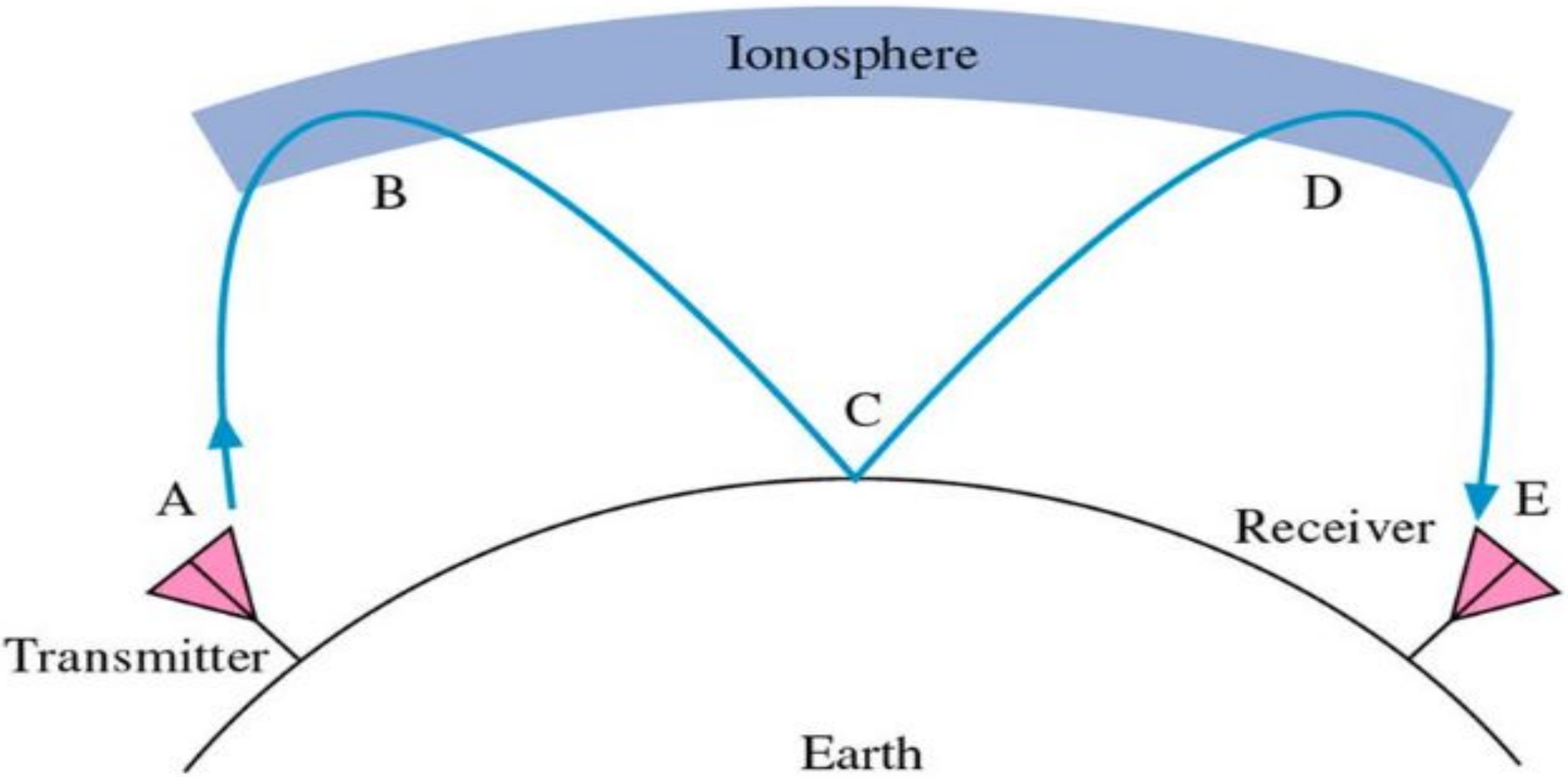
What is the ionosphere?

- The *ionosphere* is the uppermost part of the atmosphere, distinguished because it is *ionized* by solar radiation.
- At heights above 80 km (50 miles), the atmosphere is so thin that free electrons can exist for short periods of time before they are captured by nearby ions.
- This part of the atmosphere is ionized and contains a *plasma*.
- In a plasma, negative free electrons and positive ions are attached by the electromagnetic force, but they are too energetic to stay fixed together in neutral molecules.



Sky-wave Propagation

- Ionization levels in the Earth's ionosphere can refract (bend) radio waves to return to the surface.
  - Ions in the Earth's upper atmosphere are formed when ultraviolet (UV) radiation and other radiation from the sun knocks electrons from gas atoms.
  - The ionization regions in the Earth's ionosphere is affected the sunspots on the sun's surface


Ionosphere
B
D
C
A
E
Receiver
Transmitter
Earth

Sky Wave Propagation

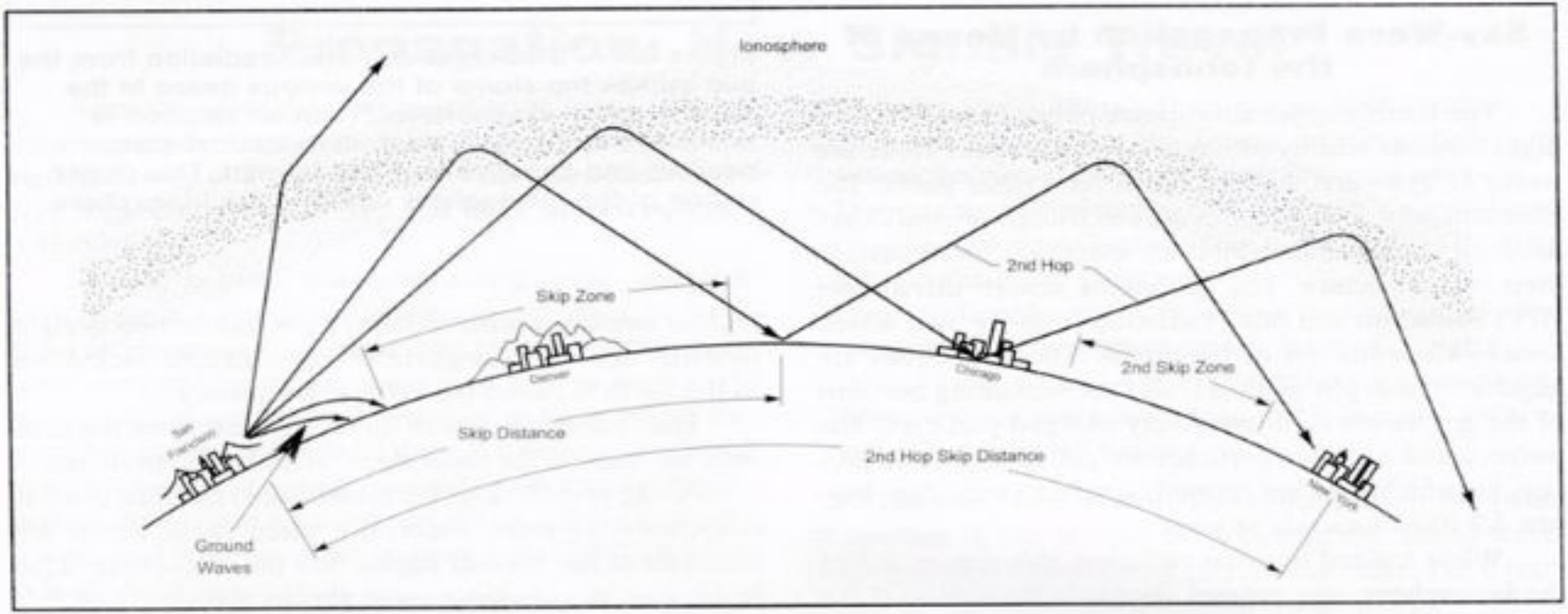
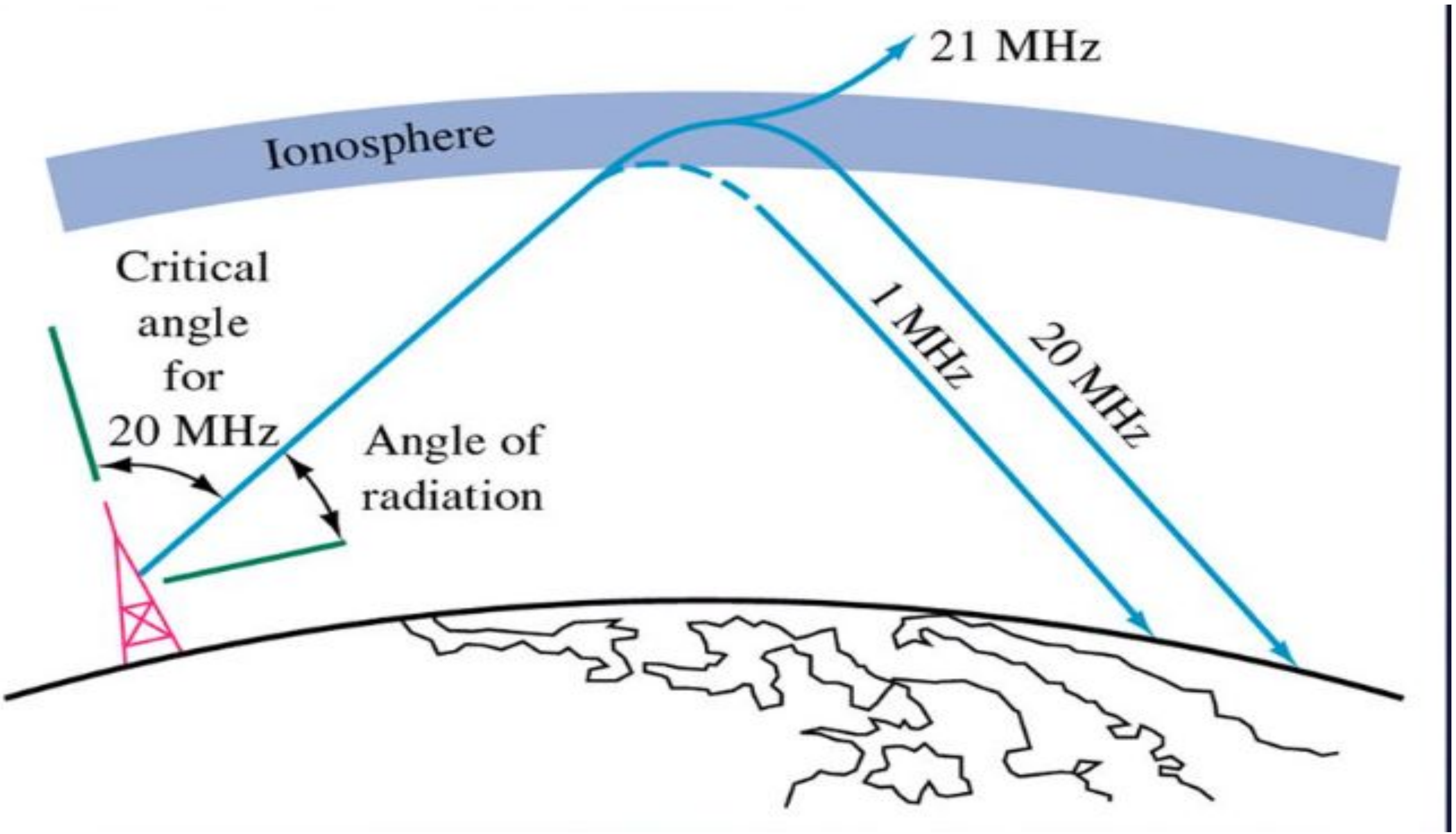
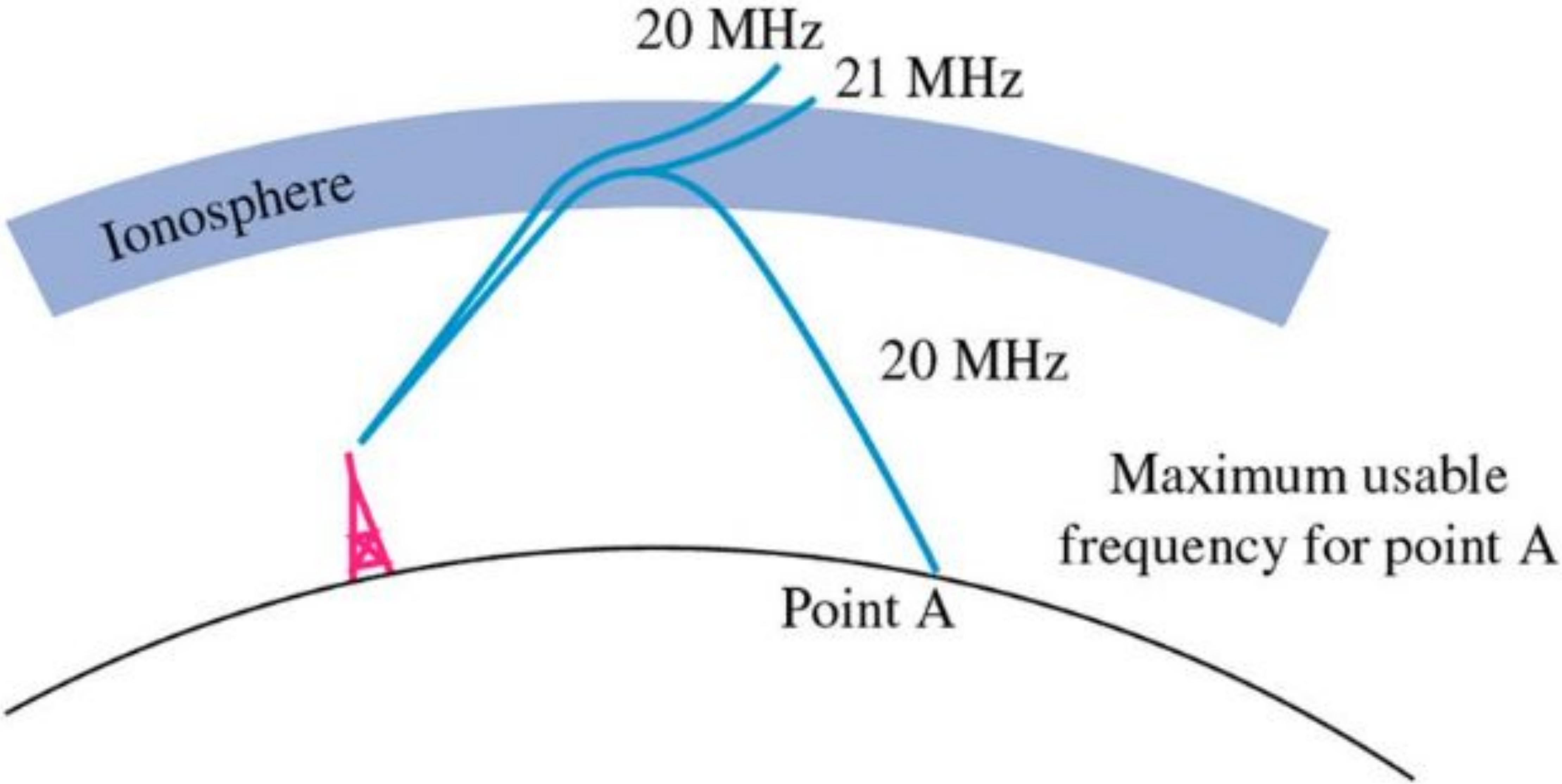


Figure 3.4 — This drawing illustrates how radio waves travel into the ionosphere and are bent back to Earth. Ground waves, skip distance and skip zone are all shown on the drawing.

- Radio waves radiated from the transmitting antenna in a direction toward the ionosphere
- Long distance transmissions
- Sky wave strike the ionosphere, is refracted back to ground, strike the ground, reflected back toward the ionosphere, etc until it reaches the receiving antenna
- Skipping is the refraction and reflection of sky waves



21 MHz
Ionosphere
Critical angle for 20 MHz
Angle of radiation
1 MHz
20 MHz


20 MHz
21 MHz
Ionosphere
20 MHz
Maximum usable frequency for point A
Point A

Terms

- Critical Frequency:
  - The highest frequency that will be returned to the earth when transmitted vertically under given ionospheric conditions
- Critical Angle:
  - The highest angle with respect to a vertical line at which a radio wave of a specified frequency can be propagated and still be returned to the earth from the ionosphere

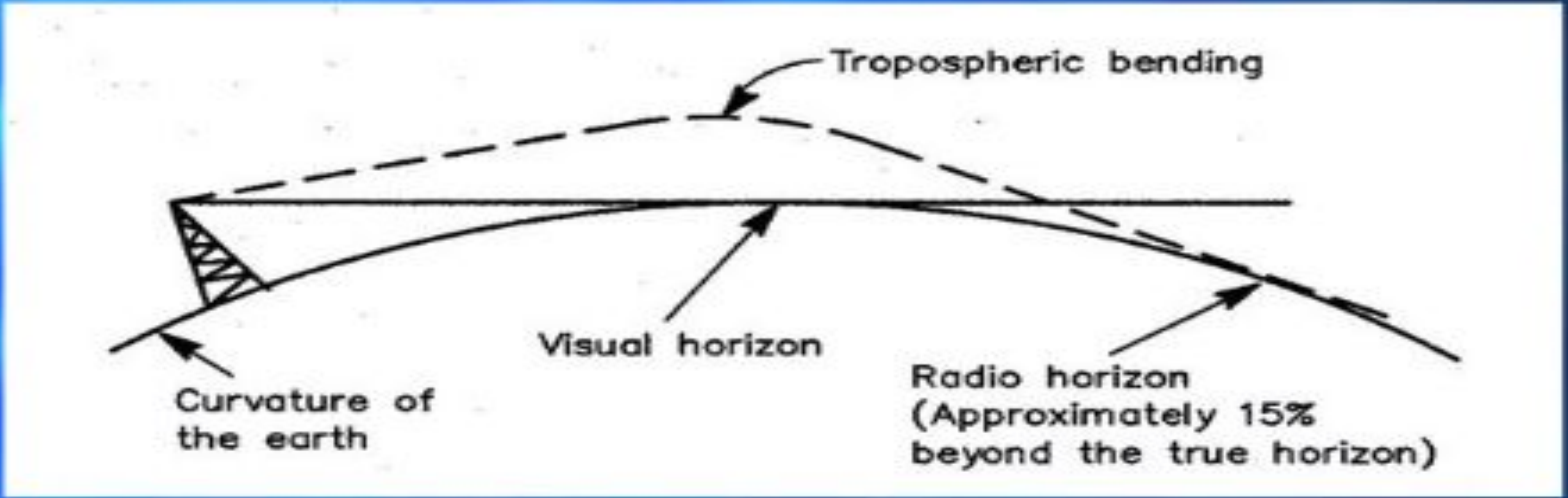
- Maximum usable frequency (MUF)
  - The highest frequency that is returned to the earth from the ionosphere between two specific points on earth
- Optimum Working frequency:
  - The frequency that provides for the most consistent communication path via sky waves

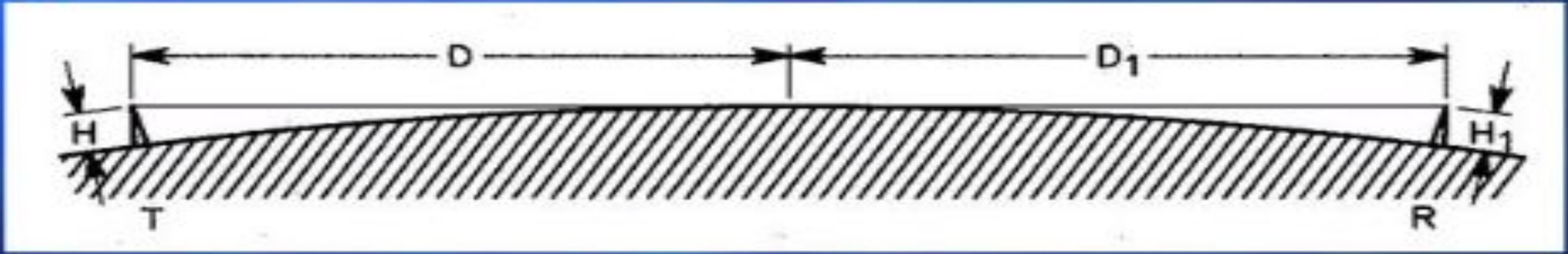
- Quiet Zone or Skip Zone:
  - The space between the point where the ground wave is completely dissipated and the point where the first sky wave is received
- Fading:
  - Variations in signal strength that may occur at the receiver over a period of time.

Tropospheric scattering

- Tropospheric Scattering
  - Signals are aimed at the troposphere rather than the ionosphere
  - 350 Mhz to 10GHz for paths up to 400 mi
  - Received signal = 10^{-6} th of the transmitted power
  - Fading a problem

Radio Path Horizon





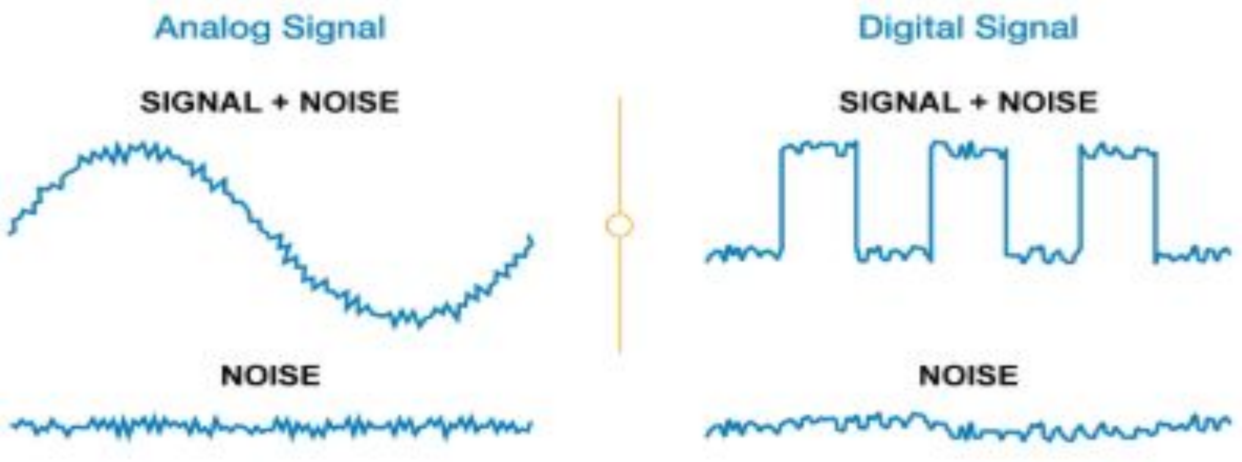
The distance D to the radio horizon is greater from a higher antenna. The maximum distance over which two stations may communicate by space wave is equal to the sum of their distances to the horizon.

Noise

- Noise is an **unwanted signal** which interferes with the original message signal and corrupts the parameters of the message signal.
- This alteration in the communication process, leads to the message getting altered.
- It is most likely to be entered at the channel or the receiver.
- Hence, it is understood that noise is some signal which has

no pattern and no constant frequency or amplitude.

- It is quite random and unpredictable.
- Measures are usually taken to reduce it, though it can't be completely eliminated.
- Most common examples of noise are –
- **Hiss** sound in radio receivers
- **Buzz** sound amidst of telephone conversations
- **Flicker** in television receivers, etc.



Effects of Noise

- Noise limits the operating range of the systems
- Noise indirectly places a limit on the weakest signal that can be amplified by an amplifier. The oscillator in the mixer circuit may limit its frequency because of noise. A system's operation depends on the operation of its circuits. Noise limits the smallest signal that a receiver is capable of processing.
- Noise affects the sensitivity of receivers
- Sensitivity is the minimum amount of input signal necessary to obtain the specified quality output.
- Noise affects the sensitivity of a receiver system, which eventually affects the output.

Types of NOISE

EXTERNAL NOISE

- Atmospheric Noise
- Extraterrestrial Noise
  - Solar Noise
  - Cosmic Noise
- Industrial Noise/ man-made

INTERNAL NOISE

- Thermal Agitation Noise (White/Johnson)
- Shot Noise
- Transit-Time Noise

EXTERNAL NOISE

External noise is defined as the type of Noise which is generated externally due to communication system.

Atmospheric Noise

- ✔ Atmospheric noise is to listen to shortwaves on a receiver which is not well equipped to receive them.
- ✔ The majority of these radio waves come from natural sources of disturbance ….They represent atmospheric noise, generally called static noise.
- ✔ Static is caused by lightning discharges in thunderstorms and other natural electric disturbances occurring in the atmosphere
- ✔ The static is likely to be more severe but less frequent if the storm is local…

EXTERNAL NOISE

- Static field strength is inversely proportional to frequency, so that this noise will interfere more with the reception of radio than that of television

- **Characteristics of atmospheric noise…**

- Atmospheric noise becomes less severe at frequencies above about 30 MHz

  Two separate factors.

1. The higher frequencies are limited to line-of-sight propagation i.e., less than 80 kilometers or so.

2. Nature of the mechanism generating this noise is such that very little of it is created in the VHF range and above.

EXTERNAL NOISE

Extra-terrestrial Noise

There are almost as many types of space noise as there are sources !!!
We divide into two sub groups

1. **Solar : Surface temperature is over 6000 degree Celsius..**

Two Types:

- In normal " quiet'' conditions It radiates over a very broad frequency spectrum which includes the frequencies we use for communication.

- Undergoes cycles of peak activity from which electrical disturbances erupt, such as solar flares and sunspots

2. Cosmic (Thermal/black-body): Due to distance stars radiates RF noise like sun!

Characteristic : It is distributed fairly uniformly over the entire sky..

SPACE NOISE FREQUENCIES

- Space noise is observable at frequencies in the range from about 8 MHz to somewhat above 1.43 gigahertz (1.43 GHz)

- Man-made noise it is the strongest component over the range of about 20 to 120 MHz

EXTERNAL NOISE

Industrial Noise: Sources of Industrial noise are auto-mobiles, aircraft, ignition of electric motors and switching gear.

The main cause of Industrial noise is High voltage wires. These noises is generally produced by the discharge present in the operations.

Lies between the frequencies of 1 to 600 MHz (in urban, suburban and other industrial areas)

Characteristic: This noise obey the general principle **that received noise increases as the receiver bandwidth is increased**

** The intensity of noise made by humans easily outstrips that created by any other source*

INTERNAL NOISE

Internal Noise are the type of Noise which are generated internally or within the Communication System or in the receiver. They may be treated qualitatively and can also be reduced or minimized by the proper designing of the system

- Noise created by any of the active or passive devices found in receivers.

Characteristics:

- Are described statistically
- Random noise power is proportional to the bandwidth over which it is measured.

INTERNAL NOISE: THERMAL AGITATION NOISE

- Thermal Agitation Noise :

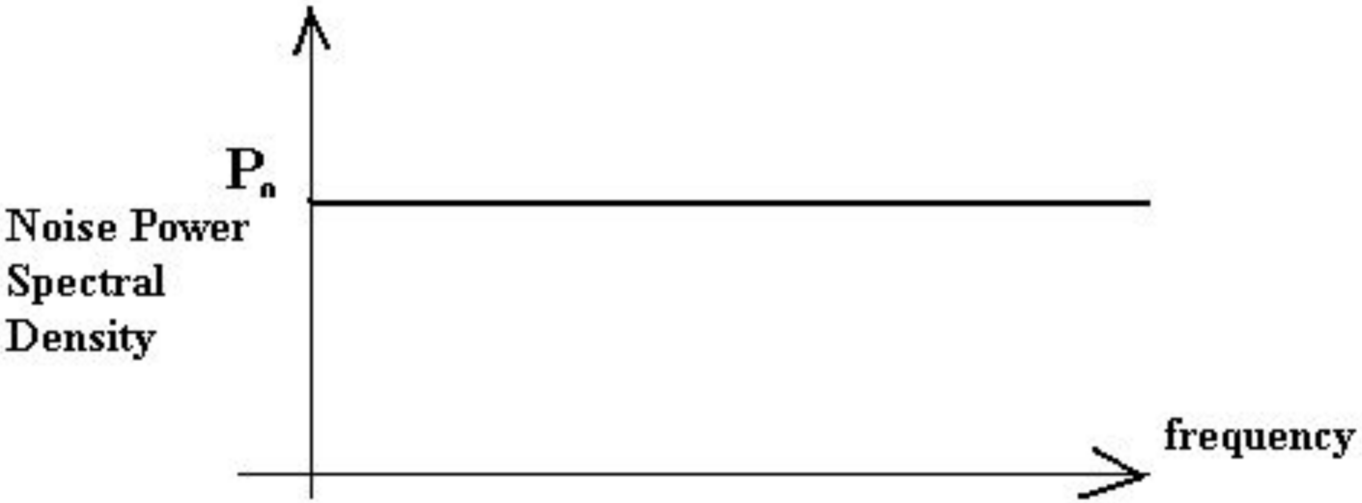
  - The noise generated in a resistance or the resistive component is random and is referred to as thermal,
  - White or Johnson noise is due to the rapid and random motion of the molecules (atoms and electrons) inside the component itself.
  - The kinetic energy of these particles becomes approximately zero {i.e., their motion ceases) at the temperature of absolute zero, which is 0 degree K and is very nearly equals - 273°C.

2. Thermal Noise (Johnson Noise) (Cont'd)

The law relating noise power, N, to the temperature and bandwidth is

N = k TB watts

Thermal noise is often referred to as 'white noise' because it has a uniform 'spectral density'.



Uniform Noise Power Spectral Density

INTERNAL NOISE

Therefore

$$P_n \propto T\,\Delta f = kT\,\Delta f \qquad \text{- - - - - - - - - - -} \qquad (15)$$

where k, = Boltzmann's constant = 1.38×10^{-23} J(joules)/K the appropriate proportionality constant in this case

T = absolute temperature, K = 273 + °C

Δf = bandwidth of interest

P_n = maximum noise power output of a resistor

$\propto$ = varies directly

THERMAL NOISE PROBLEM (Internal Noise)

If the resistor is operating at 27°C and the bandwidth of interest is 2 MHz, then what is the maximum noise power output of a resistor?

K=1.380 649. 10^-23 J / K
Boltzmann constant

Solution

$$P_n = k.T.\Delta f = 1.38 \times 10^{-23} \times 300 \times 2 \times 10^6$$

$$P_n \simeq 1.38 \times 10^{-17} \times 600 = 0.138 \times 0.6 \times 10^{-12}$$

$$P_n = 0.0828 \times 10^{-12} \text{ Watts}$$

INTERNAL NOISE (rms noise voltage associated with a resistor)

If an ordinary resistor at the standard temperature of 17°C (290 K) is connected to any voltage source, there may even be quite a large voltage across it.

Since it is random and therefore has a finite rms value but no dc component, only the alternating current (ac) meter will register a reading.

This noise voltage is caused by the random movement of electrons within the resistor, which constitutes a current.

INTERNAL NOISE (rms noise voltage associated with a resistor)

$$P_n = \frac{V^2}{R_L} = \frac{V_n^2}{4R}$$

PL=Vn^2{RL/(R+RL)^2}

$$V_n^2 = 4RP_n = 4RkT\,\Delta f$$

$$V_n = \sqrt{4kT\,\Delta f\,R}$$

- . - . - . - . - . - (16)

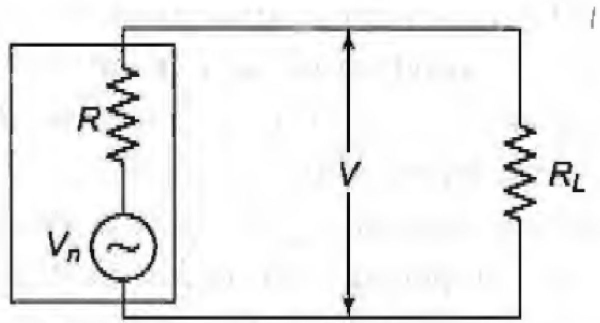


Fig. 2.1 *Resistance noise generator.*

INTERNAL NOISE (rms noise voltage associated with a resistor)

An amplifier operating over the frequency range from 18 to 20 MHz has a 10-kilohm (10-kΩ) input resistor. What is the rms noise voltage at the input to this amplifier if the ambient temperature is 27°C?

Solution

$$
\begin{aligned}
V_n &= \sqrt{4kT\Delta f R} \\
&= \sqrt{4 \times 1.38 \times 10^{-23} \times (27 + 273) \times (20 - 18) \times 10^6 \times 10^4} \\
&= \sqrt{4 \times 1.38 \times 3 \times 2 \times 10^{-11}} = 1.82 \times 10^{-5} \\
&= 18.2 \text{ microvolts } (18.2\,\mu\text{V})
\end{aligned}
$$

As we can see from this example, it would be futile to expect this amplifier to handle signals unless they were considerably larger than 18.2 μV. A low voltage fed to this amplifier would be masked by the noise and lost.

INTERNAL NOISE : Shot Noise

- Shot noise occurs in all amplifying devices and virtually in all active devices.

- It is caused by random variations in the arrival of electrons (or holes) at the output electrode of an amplifying device and appears as a randomly varying noise current superimposed on the output.

- When amplified, it is supposed to sound as though a shower of lead shot were falling on a metal sheet. Hence the name shot noise.

- Shot noise behaves in a similar manner to thermal agitation noise, apart from the fact that it has a different source.

3. Shot Noise

- Shot noise was originally used to describe noise due to random fluctuations in electron emission from cathodes in vacuum tubes (called shot noise by analogy with lead shot).
- Shot noise also occurs in semiconductors due to the liberation of charge carriers.
- For *pn* junctions the mean square shot noise current is

$$I_n^2 = 2\left(I_{DC} + 2I_o\right)q_e B \qquad (amps)^2$$

Where

is the direct current as the *pn* junction (amps)
is the reverse saturation current (amps)
is the electron charge = 1.6 x 10-19 coulombs
B is the effective noise bandwidth (Hz)

- Shot noise is found to have a uniform spectral density as for thermal noise

INTERNAL NOISE: Transit-Time Noise (Active Device)

- If the time taken by an electron to travel from the emitter to the collector of a transistor becomes significant to the period of the signal being amplified, i.e., at frequencies in the upper VHF (30-300 MHz) range and beyond, the so-called transit-time effect takes place….

- The minute currents induced in the input of the device by random fluctuations in the output current become of great importance at VHF and above frequencies and create random noise (frequency distortion).

INTERNAL NOISE: Transit-Time Noise (Active Device)

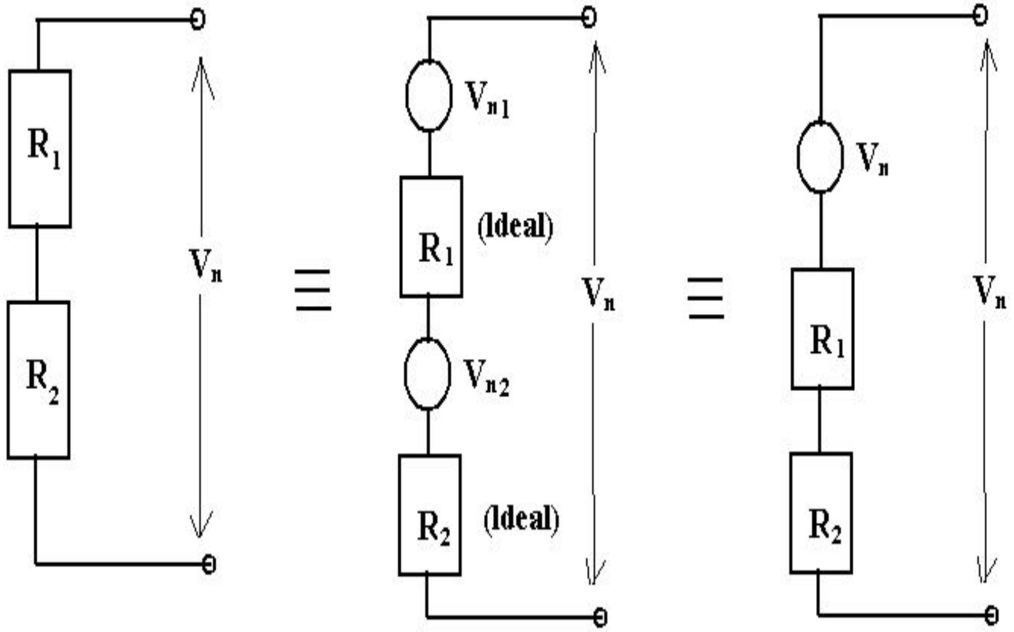
- Once this high-frequency noise makes its presence felt, it goes on increasing with frequency at a rate that soon approaches 6 decibels (6 dB) per octave

- The result of all this is that it **is preferable to measure noise at such high frequencies, instead of trying to calculate an input equivalent noise resistance for it.**

Analysis of Noise In Communication Systems

Resistors in Series

Assume that R_1 at temperature T_1 and R_2 at temperature $T_{2,}$ then



$$\overline{V_n^{\,2}} = \overline{V_{n1}}^{\,2} + \overline{V_{n2}}^{\,2}$$

$$\overline{V_{n1}^{\,2}} = 4kT_1BR_1$$

$$\overline{V_{n2}^{\,2}} = 4kT_2BR_2$$

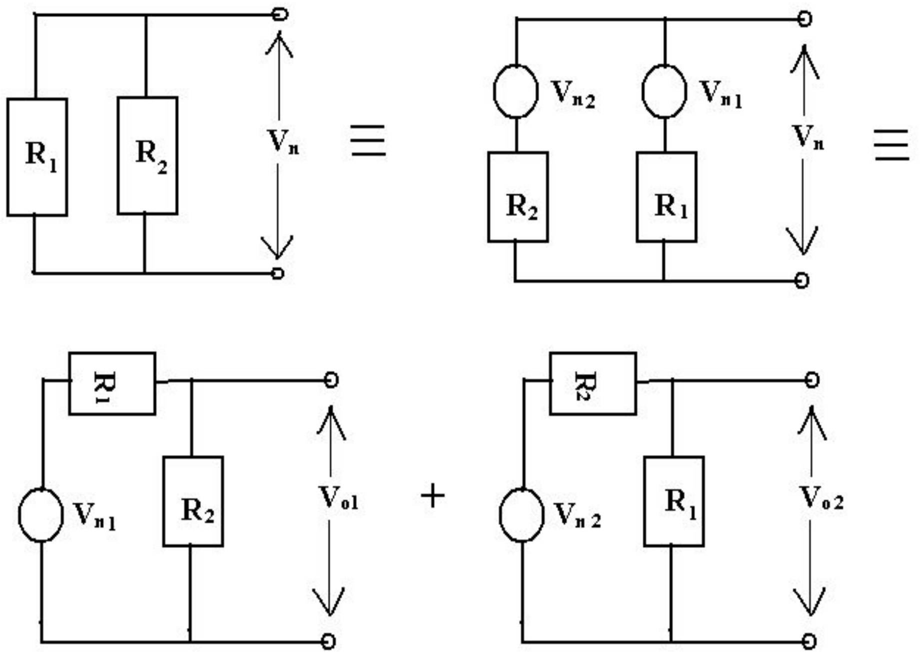
$$\therefore \quad \overline{V_n^{\,2}} = 4kB(T_1R_1 + T_2R_2)$$

$$\overline{V_n^{\,2}} = 4kTB(R_1 + R_2)$$

i.e. The resistor in series at same temperature behave as a single resistor

Analysis of Noise In Communication Systems (Cont'd)

Resistance in Parallel



$$V_{o1} = V_{n1}\frac{R_2}{R_1+R_2} \qquad V_{o2} = V_{n2}\frac{R_1}{R_1+R_2}$$

$$\overline{V_n^{\,2}} = \overline{V_{o1}^{\,2}} + \overline{V_{o2}^{\,2}}$$

$$\overline{V_n^{\,2}} = \frac{4kB}{(R_1+R_2)^2}\left[R_2^2\,T_1R_1 + R_1^2\,T_2R_2\right] \times \left(\frac{R_1R_2}{R_1R_2}\right)$$

$$\overline{V_n^{\,2}} = \frac{4kB\,R_1R_2(T_1R_1+T_2R_2)}{(R_1+R_2)^2}$$

$$\overline{V_n^{\,2}} = 4kTB\left(\frac{R_1R_2}{R_1+R_2}\right)$$

NOISE CALCULATIONS :Addition of Noise due to Several Sources

Calculate the noise voltage at the input of a television RF amplifier, using a device that has a 200-ohm (200-Ω) equivalent noise resistance and a 300-Ω input resistor. The bandwidth of the amplifier is 6 MHz, and the temperature is 17°C.

Solution

$$
\begin{aligned}
V_{n,\text{tot}} &= \sqrt{4kT\,\Delta f\,R_{\text{tot}}} \\
&= \sqrt{4 \times 1.38 \times 10^{-23} \times (17 + 273) \times 6 \times 10^{6} \times (300 + 200)} \\
&= \sqrt{4 \times 1.38 \times 2.9 \times 6 \times 5 \times 10^{-13}} = \sqrt{48 \times 10^{-12}} \\
&= 6.93 \times 10^{-6} = 6.93\,\mu\text{V}
\end{aligned}
$$

To calculate the noise voltage due to several resistors in parallel, find the total resistance by standard methods, and then substitute this resistance into Equation (2.3) as before. This means that the total noise voltage is less than that due to any of the individual resistors, but, as shown in Equation (2.1), the noise power remains constant.

Addition of Noise due to Several Amplifiers in Cascade

Figure below shows a number of amplifying stages in cascade, each having a resistance at its input and output.

The first such stage is very often an RF amplifier, while the second is a mixer. The problem is to find their combined effect on the receiver noise

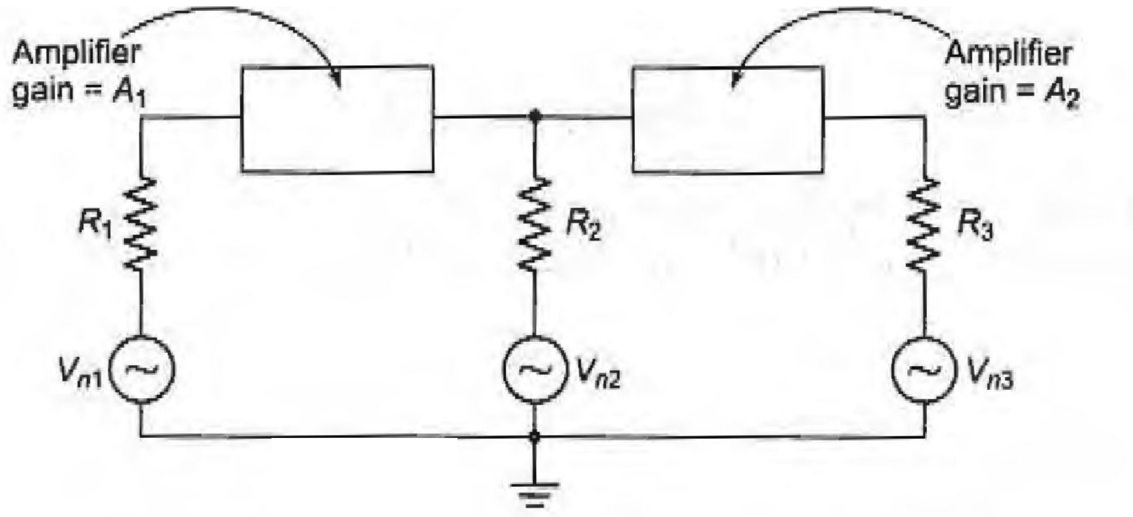


Fig. 2.2 *Noise of several amplifying stages in cascade.*

$$R_{eq} = R_1 + \frac{R_2}{A_1^2} + \frac{R_3}{A_1^2 A_2^2}$$

Consider the two-stage amplifier of Figure 2-2. The gain of the first stage is A_1, and that of the second is A_2. The first stage has a total input-noise resistance R_1, the second R_2 and the output resistance is R_3. The rms noise voltage at the output due to R_3 is

$$V_{n3} = \sqrt{4kT\,\delta f\,R_3}$$

The same noise voltage would be present at the output if there were no R_3 there. Instead R_3' was present at the input of stage 2, such that

$$V_{n3}' = \frac{V_{n3}}{A_2} = \frac{\sqrt{4kT\,\delta f\,R_3}}{A_2} = \sqrt{4kT\,\delta f\,R_3'}$$

where R_3' is the resistance which if placed at the input of the second stage would produce the same noise voltage at the output as does R_3. Therefore

$$R_3' = \frac{R_3}{A_2^2} \tag{2-6}$$

Equation (2-6) shows that when a noise resistance is "transferred" from the output of a stage to its input, it must be divided by the square of the voltage gain of the stage. Now the noise resistance actually present at the input of the second stage is R_2, so that the equivalent noise resistance at the input of the second stage, due to the second stage and the output resistance, is

$$R'_{eq} = R_2 + R'_3 = R_2 + \frac{R_3}{A_2^2}$$

Similarly, a resistor R'_2 may be placed at the input of the first stage to replace R'_{eq}, both naturally producing the same noise voltage at the output. Using Equation (2-6) and its conclusion, we have

$$R'_2 = \frac{R'_{eq}}{A_1^2} = \frac{R_2 + R_3/A_2^2}{A_1^2} = \frac{R_2}{A_1^2} + \frac{R_3}{A_1^2\,A_2^2}$$

The noise resistance actually present at the input of the first stage is R_1, so that the equivalent noise resistance of the whole cascaded amplifier, at the input of the first stage, will be

$$\begin{aligned} R_{eq} &= R_1 + R'_2 \\ &= R_1 + \frac{R_2}{A_1^2} + \frac{R_3}{A_1^2\,A_2^2} \end{aligned} \tag{2-7}$$

It is possible to extend Equation (2-7) by induction to apply to an n-stage cascaded amplifier, but this is not normally necessary. As Example 2-3 will show, the noise resistance located at the input of the first stage is by far the greatest contributor to the total noise, and only in broadband, i.e., low-gain amplifiers is it necessary to consider a resistor past the output of the second stage.

Addition of Noise due to Several Amplifiers in Cascade

The first stage of a two-stage amplifier has a voltage gain of 10, a 600-Ω input resistor, a 1600-Ω noise resistance and a 27-kΩ output resistor. For the second stage, these values are 25, 81 kΩ, 1 megaohm (1 MΩ), respectively. Calculate the equivalent input-noise resistance of this two-stage

Solution

$$R_1 = 600 + 1600 = 2200\ \Omega$$

$$R_2 = \frac{27 \times 81}{27 + 81} + 10 = 20.2 + 10 = 30.2\ \text{k}\Omega$$

$$R_3 = 1\ \text{M}\Omega \qquad \text{(as given)}$$

$$R_{eq} = 2200 + \frac{30.200}{10^2} + \frac{1{,}000{,}000}{10^2 \times 25^2} = 2200 + 302 + 16$$

$$= 2518\ \Omega$$

Note that the 1-MΩ output resistor has the same noise effect as a 16-Ω resistor at the input.

Signal-to-Noise Ratio

The calculation of the equivalent noise resistance of an amplifier, receiver or device may have one of two purposes or sometimes both.

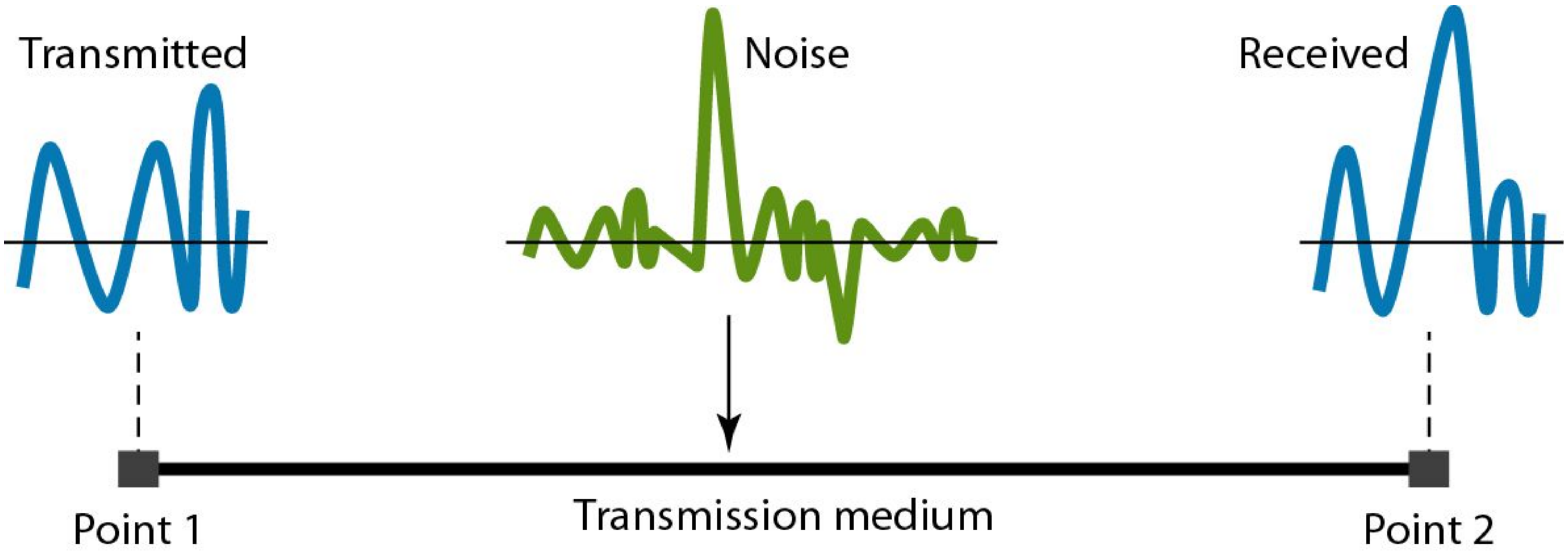
- The first purpose is comparison of two kinds of equipment in evaluating their performance.

- The second is comparison of noise and signal at the same point to ensure that the noise is not excessive.

In the second instance, and also when equivalent noise resistance is difficult to obtain, the signal-to-noise ratio (SIN) is very often used.

It is defined as the ratio of signal power to noise power at the same point. ….

- To measure the quality of a system the SNR is often used. It indicates the strength of the signal wrt the noise power in the system.
- It is the ratio between two powers.
- It is usually given in dB and referred to as $SNR_{dB.}$



Signal to Noise

The signal to noise ratio is given by

$$\frac{S}{N} = \frac{Signal\ Power}{Noise\ Power}$$

The signal to noise in dB is expressed by

$$\left(\frac{S}{N}\right)_{dB} = 10\log_{10}\left(\frac{S}{N}\right)$$

$$\left(\frac{S}{N}\right)_{dB} = S_{dBm} - N_{dBm}$$ for S and N measured in mW.

$$\frac{S}{N} = \frac{X_s}{X_n} = \frac{V_s^2/R}{V_n^2/R} = \left(\frac{V_s}{V_n}\right)^2$$

S = signal power

N = noise power

Example

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB} ?

Solution

The values of SNR and SNRdB can be calculated as follows:

$$SNR = \frac{10{,}000\ \mu W}{1\ mW} = 10{,}000$$

$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

Example 3.32

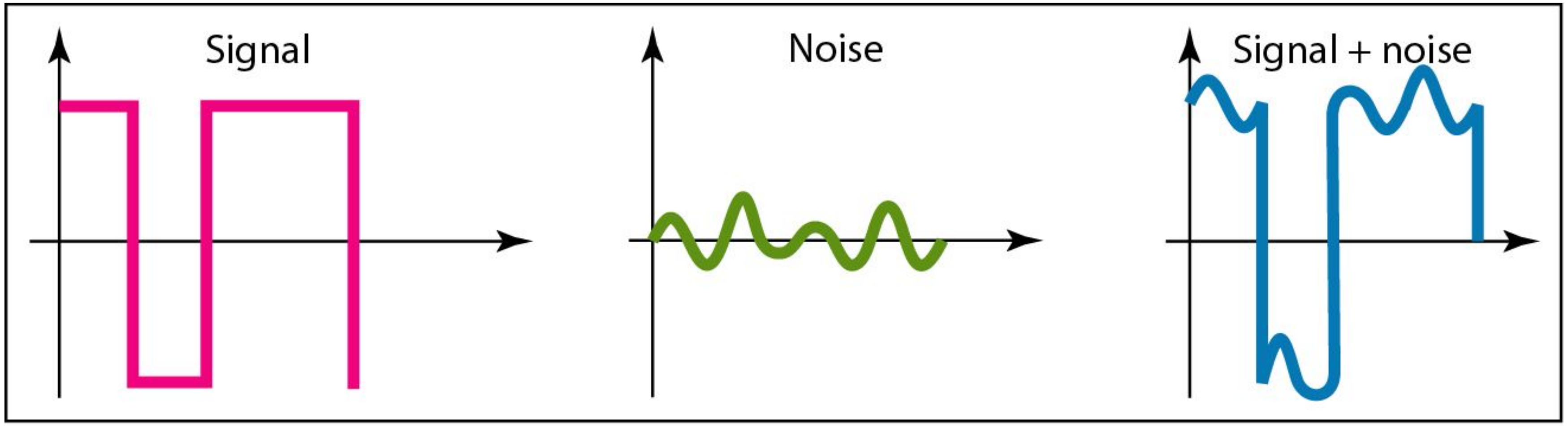
The values of SNR and SNRdB for a noiseless channel are

$$\text{SNR} = \frac{\text{signal power}}{0} = \infty$$

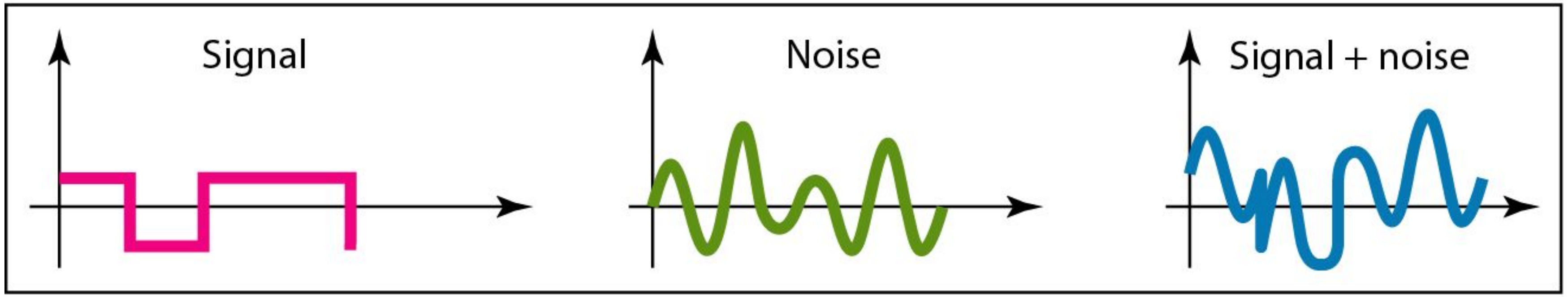
$$\text{SNR}_{\text{dB}} = 10 \log_{10} \infty = \infty$$

We can never achieve this ratio in real life; it is an ideal.

Figure 3.30 Two cases of SNR: a high SNR and a low SNR



a. Large SNR



b. Small SNR

Noise Factor- Noise Figure (Cont'd)

- The amount of noise added by the network is embodied in the Noise Factor F, which is defined by

$$\text{Noise factor F} = \frac{\left(S/N\right)_{IN}}{\left(S/N\right)_{OU}}$$

- F equals to 1 for noiseless network and in general F > 1. The noise figure in the noise factor quoted in dB
  i.e. Noise Figure F dB = 10 log10 F   F ≥ 0 dB

- The noise figure / factor is the measure of how much a network degrades the (S/N)IN, the lower the value of F, the better the network.

Calculation of noise figure

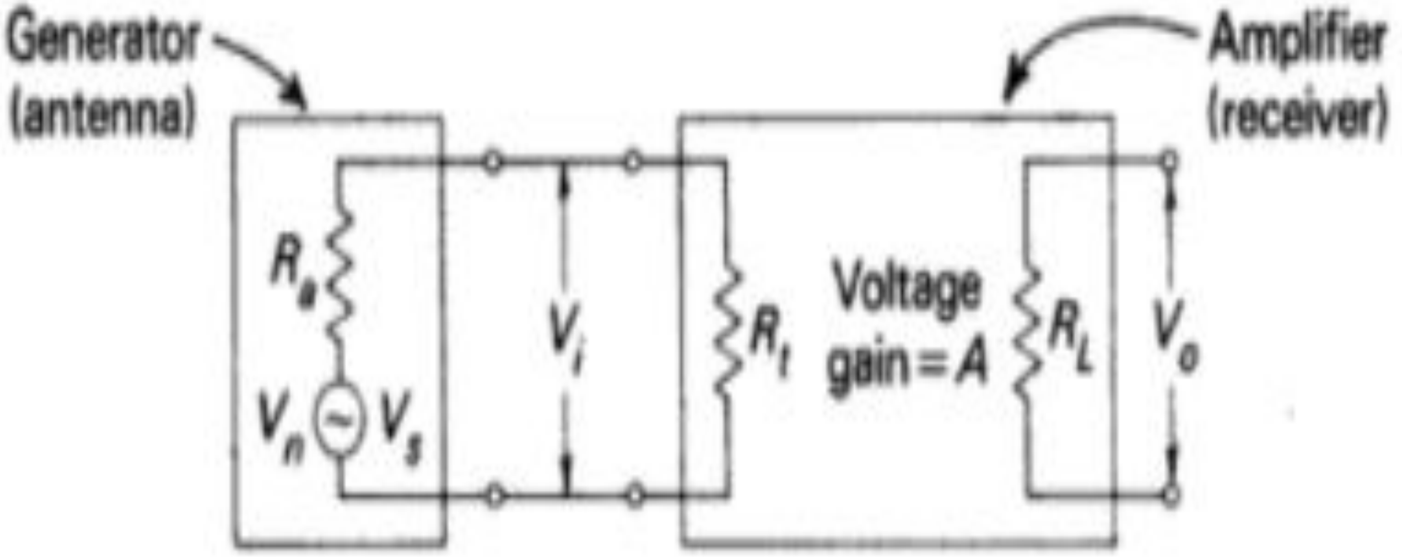


FIGURE 2-4 Block diagram for noise figure calculation.

The calculation procedure may be broken down into a number of general steps. Each is now shown, followed by the number of the corresponding equation(s) to follow:

1. Determine the signal input power P_{si} (2-12, 2-13).
2. Determine the noise input power P_{ni} (2-14, 2-15).
3. Calculate the input signal-to-noise ratio S/N_i from the ratio of P_{si} and P_{ni} (2-16).
4. Determine the signal output power P_{so} (2-17).
5. Write P_{no} for the noise output power to be determined later (2-18).
6. Calculate the output signal-to-noise ratio S/N_o from the ratio of P_{so} and P_{no} (2-19).
7. Calculate the generalized form of noise figure from steps 3 and 6 (2-20).
8. Calculate P_{no} from R_{eq} if possible (2-21, 2-22), and substitute into the general equation for F to obtain the actual formula (2-23, 2-24), *or* determine P_{no} from measurement (2-3, 2-25, 2-26), and substitute to obtain the formula for F (2-27, 2-28, 2-29).

It is seen from Figure 2-4 that the signal input voltage and power will be

$$V_{si} = \frac{V_s R_t}{R_a + R_t} \tag{2-12}$$

$$V_{si} = \frac{V_{si}^2}{R_t} = \left(\frac{V_s R_t}{R_a + R_t}\right)^2 \frac{1}{R_t} = \frac{V_s^2 R_t}{(R_a + R_t)^2} \tag{2-13}$$

Similarly, the noise input voltage and power will be

$$V_{ni}^2 = 4kT\,\delta f \frac{R_a R_t}{R_a + R_t} \tag{2-14}$$

$$P_{ni} = \frac{V_{ni}^2}{T_t} = 4kT\,\delta f \frac{R_a R_t}{R_a + R_t} \frac{1}{R_t} = \frac{4kT\,\delta f\, R_a}{R_a + R_t} \tag{2-15}$$

The input signal-to-noise ratio will be

$$\frac{\mathrm{S}}{\mathrm{N}_i} = \frac{P_{si}}{P_{ni}} = \frac{V_s^2 R_t}{(R_a + R_t)^2} \div \frac{4kT\,\delta f\, R_a}{R_a + R_t} = \frac{V_s^2 R_t}{4kT\,\delta f\, R_a (R_a + R_t)} \tag{2-16}$$

The output signal power will be

$$P_{so} = \frac{V_{so}^2}{R_L} = \frac{(AV_{si})^2}{R_L}$$

$$= \left(\frac{AV_s R_t}{R_a + R_t}\right)^2 \frac{1}{R_L} = \frac{A^2 V_s^2 R_t^2}{(R_a + R_t)^2 R_L} \tag{2-17}$$

The noise output power may be difficult to calculate. For the time being, it may simply be written as

$$P_{no} = \text{noise output power} \tag{2-18}$$

The output signal-to-noise ratio will be

$$\frac{\mathrm{S}}{\mathrm{N}_o} = \frac{P_{so}}{P_{no}} = \frac{A^2 V_s^2 R_t^2}{(R_a + R_t)^2 R_L P_{no}} \tag{2-19}$$

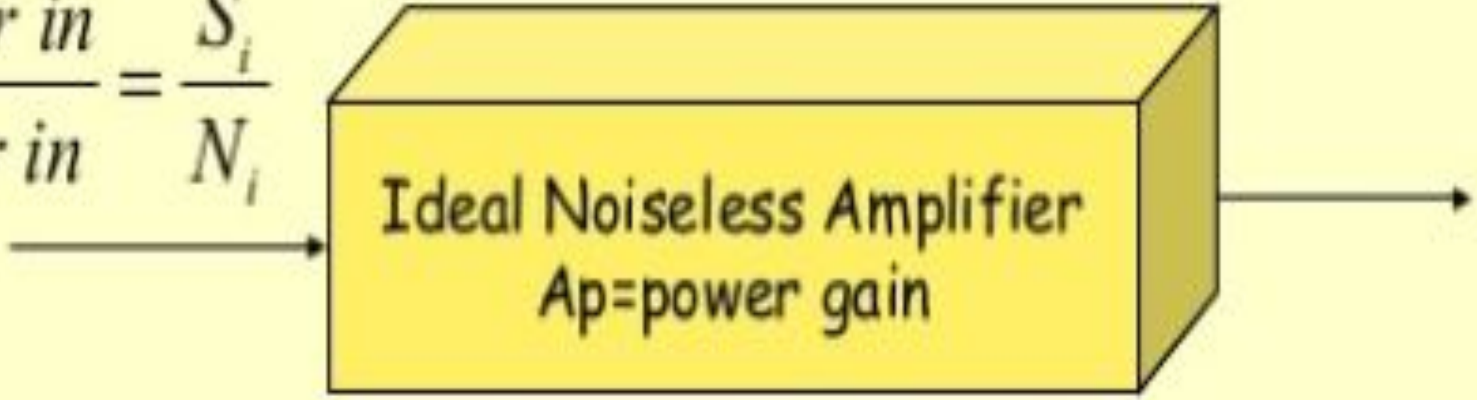
Finally, the general expression for the noise figure is

$$F = \frac{\mathrm{S/N}_i}{\mathrm{S/N}_o} = \frac{V_s^2 R_t}{4kT\,\delta f\, R_a(R_a + R_t)} \div \frac{A^2 V_s^2 R_t^2}{(R_a + R_t)^2 R_L P_{no}}$$

$$= \frac{R_L P_{no}(R_a + R_t)}{4kT\,\delta f\, A^2 R_a R_t} \tag{2-20}$$

Ideal Noiseless Amplifier

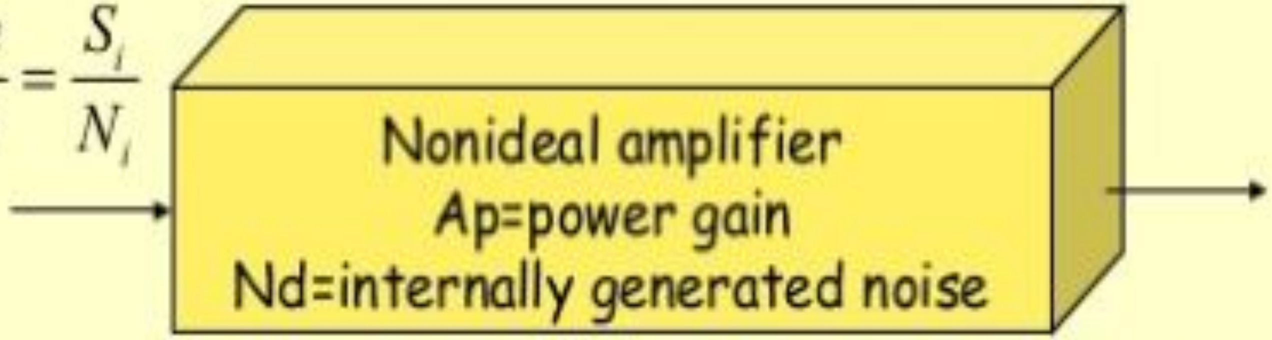
$$\frac{Signal\ \ power\ in}{Noise\ \ power\ in} = \frac{S_i}{N_i}$$



$$\frac{Signal\ \ power\ out}{Signal\ \ power\ in} = \frac{A_p S_i}{A_p N_i} = \frac{S_i}{N_i}$$

Non ideal amplifier

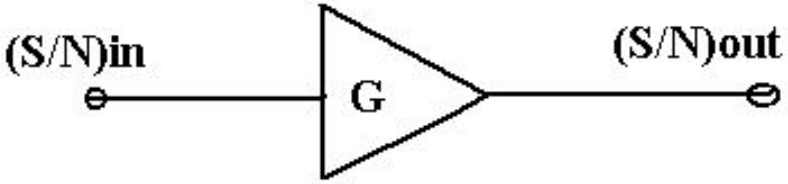
$$\frac{Signal\ power\ in}{Noise\ power\ in} = \frac{S_i}{N_i}$$



$$\frac{Signal\ power\ out}{Signal\ power\ in} = \frac{A_p S_i}{A_p N_i + N_d} = \frac{S_i}{N_i + {N_d}/{A_p}}$$

Noise Figure – Noise Factor for Active Elements

For active elements with power gain G>1, we have



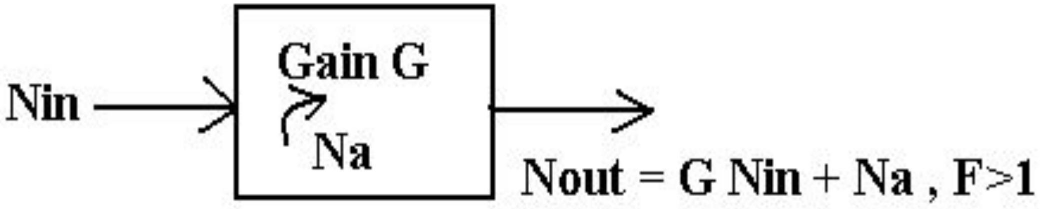
$$F = \frac{(S/N)_{IN}}{(S/N)_{OUT}} = \frac{S_{IN}}{N_{IN}}\frac{N_{OUT}}{S_{OUT}}$$

But $S_{OUT} = G\,S_{IN}$

Therefore

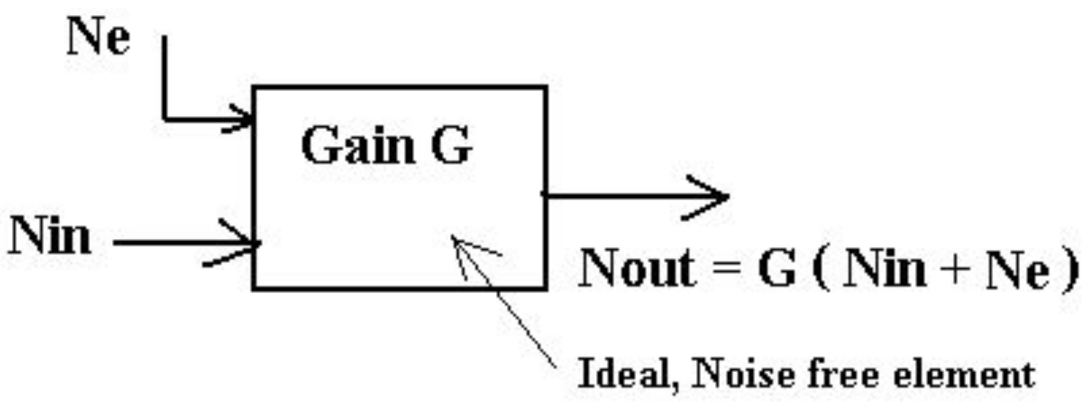
$$F = \frac{S_{IN}}{N_{IN}}\frac{N_{OUT}}{G\,S_{IN}} = \frac{N_{OUT}}{G\,N_{IN}}$$

Since in general F v> 1 , then N_{OUT} is increased by noise due to the active element i.e.



Na represents 'added' noise measured at the output. This added noise may be referred to the input as extra noise, i.e. as equivalent diagram is

Noise Figure – Noise Factor for Active Elements (Cont’d)



Ne is extra noise due to active elements referred to the input; the element is thus effectively noiseless.

$$\text{Hence } F = \frac{N_{OUT}}{G\,N_{IN}} = F = \frac{G(N_{IN} + N_e)}{G\,N_{IN}}$$

Rearranging gives,

$$N_e = (F - 1)\,N_{IN}$$

Noise Figure – Noise Factor for Passive Elements

Since $F = \frac{S_{IN}}{N_{IN}} \frac{N_{OUT}}{S_{OUT}}$ and $N_{OUT} = N_{IN}$.

$$F = \frac{S_{IN}}{G\,S_{IN}} = \frac{1}{G}$$

If we let L denote the insertion loss (ratio) of the network i.e. insertion loss

$$L_{dB} = 10 \log L$$

Then

$$L = \frac{1}{G} \text{ and hence for passive network}$$

$$F = L$$

Also, since $T_e = (F\text{-}1) T_S$

Then for passive network

$$T_e = (L\text{-}1) T_S$$

Where T_e is the equivalent noise temperature of a passive device referred to its input.

Equivalent Noise Temperature (T_e)

- Hypothetical value that cannot be directly measured.
- To indicates the reduction in the SNR a signal undergoes as it propagates through a receiver.
- The lower Te is the better quality of a receiver.

$$T_e = T(F-1) \qquad F = 1 + \frac{T_e}{T}$$

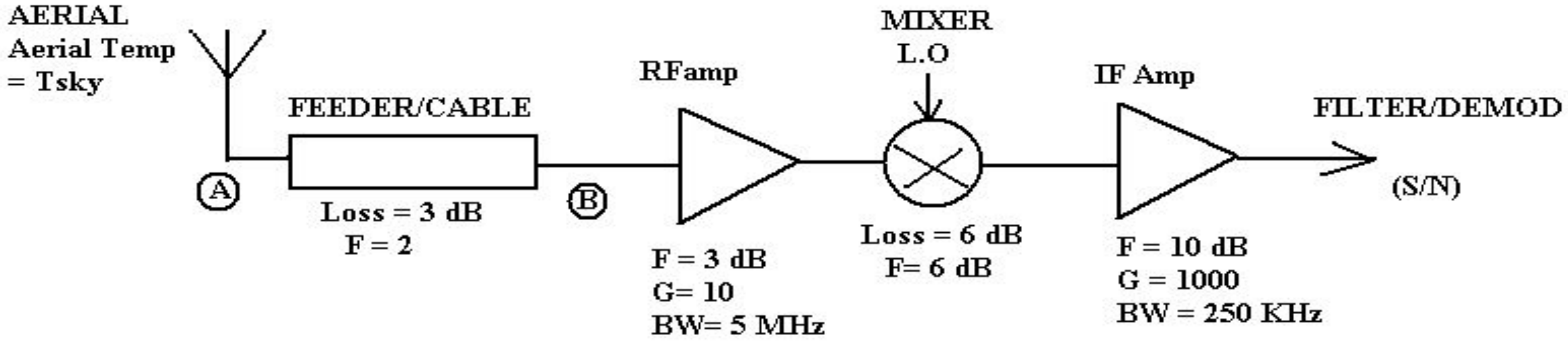
Review of Noise Factor – Noise Figure –Temperature

Typical values of noise temperature, noise figure and gain for various amplifiers and attenuators are given below:

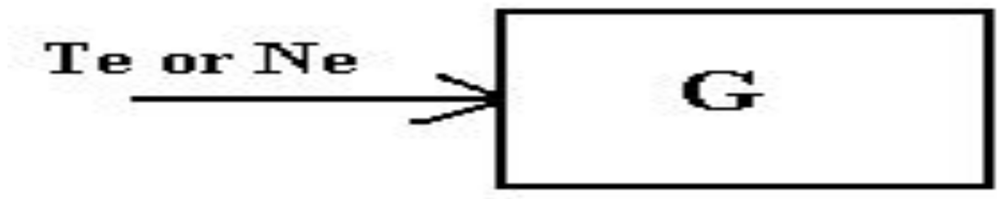
Device	**Frequency**	T_e **(K)**	F_{dB} **(dB)**	**Gain (dB)**
Maser Amplifier	9 GHz	4	0.06	20
Ga As Fet amp	9 GHz	330	303	6
Ga As Fet amp	1 GHz	110	1.4	12
Silicon Transistor	400 MHz	420	3.9	13
L C Amp	10 MHz	1160	7.0	50
Type N cable	1 GHz		2.0	2.0

Cascaded Network

A receiver systems usually consists of a number of passive or active elements connected in series. A typical receiver block diagram is shown below, with example



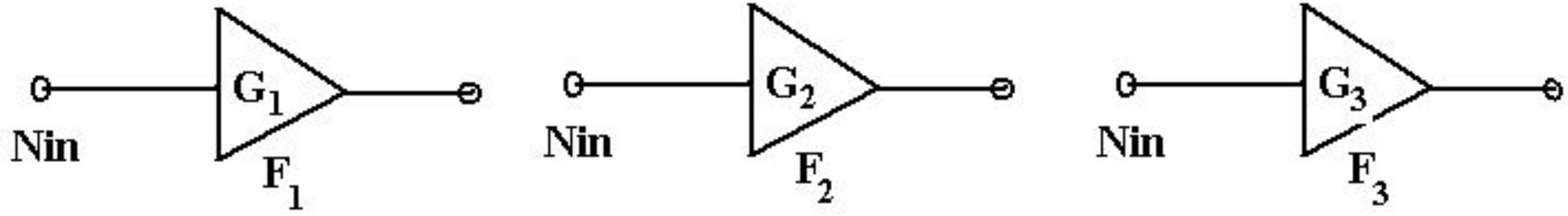
In order to determine the (S/N) at the input, the overall receiver noise figure or noise temperature must be determined. In order to do this all the noise must be referred to the same point in the receiver, for example to A, the feeder input or B, the input to the first amplifier.



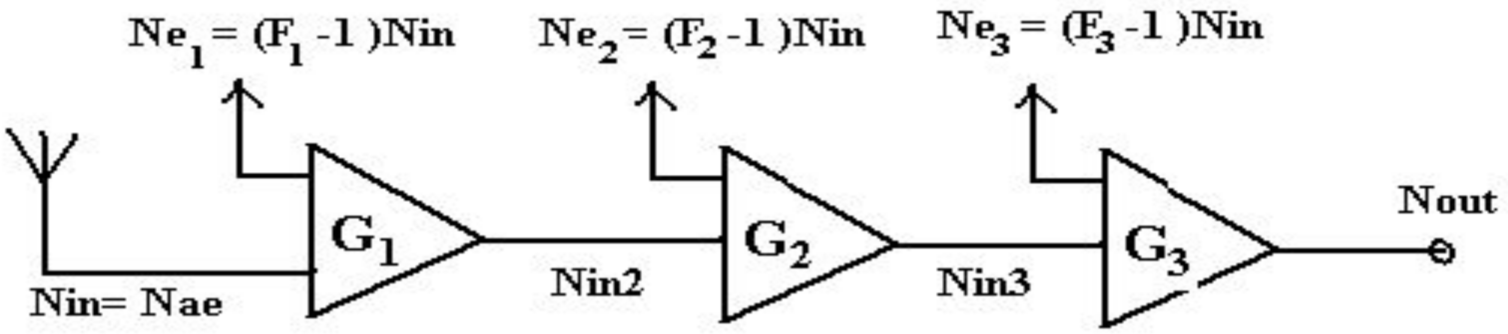
T_e or N_e is the noise referred to the input.

System Noise Figure

Assume that a system comprises the elements shown below,



Assume that these are now cascaded and connected to an aerial at the input, with $N_{IN} = N_{ae}$ from the aerial



Now,

$$N_{OUT} = G_3\left(N_{IN3} + N_{e3}\right)$$

$$= G_3\left(N_{IN3} + \left(F_3 - 1\right)N_{IN}\right)$$

Since

$$N_{IN3} = G_2\left(N_{IN2} + N_{e2}\right) = G_2\left(N_{IN2} + \left(F_2 - 1\right)N_{IN}\right)$$ similarly $$N_{IN2} = G_1\left(N_{ae} + \left(F_1 - 1\right)N_{IN}\right)$$

system Noise Figure (Cont'd)

$$N_{OUT} = G_3\left[G_2\left[G_1 N_{ae} + G_1\left(F_1 - 1\right)N_{IN}\right] + G_2\left(F_2 - 1\right)N_{IN}\right] + G_3\left(F_3 - 1\right)N_{IN}$$

The overall system Noise Factor is

$$F_{sys} = \frac{N_{OUT}}{GN_{IN}} = \frac{N_{OUT}}{G_1 G_2 G_3 N_{ae}}$$

$$= 1 + \left(F_1 - 1\right)\frac{N_{IN}}{N_{ae}} + \frac{\left(F_2 - 1\right)}{G_1}\frac{N_{IN}}{N_{ae}} + \frac{\left(F_3 - 1\right)}{G_1 G_2}\frac{N_{IN}}{N_{ae}}$$

If we assume N_{ae} is $\approx N_{IN}$, i.e. we would measure and specify F_{sys} under similar conditions as F_1, F_2 etc (i.e. at 290 K), then for n elements in cascade.

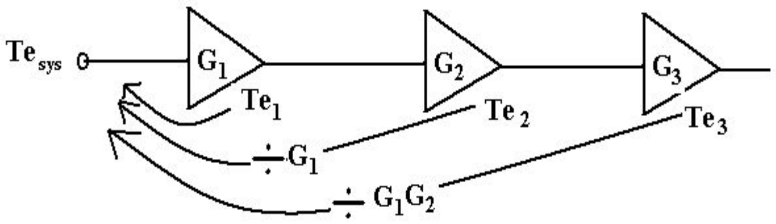
$$F_{sys} = F_1 + \frac{\left(F_2 - 1\right)}{G_1} + \frac{\left(F_3 - 1\right)}{G_1 G_2} + \frac{\left(F_4 - 1\right)}{G_1 G_2 G_3} + \ldots\ldots\ldots\ldots + \frac{\left(F_n - 1\right)}{G_1 G_2 \ldots\ldots\ldots\ldots G_{n-1}}$$

The equation is called FRIIS Formula.

System Noise Temperature

Since $T_e = (\text{L-1})T_S$, i.e. $F = 1 + \dfrac{T_e}{T_s}$

Then



$$F_{sys} = 1 + \frac{T_{e\,sys}}{T_s} \qquad \begin{cases} where\, T_{e\ sys}\ is\, the\, equivalent\, Noise\ temperature\ \ of\ \ the\, system \\ and\, T_s\ is\, the\, noise\, temperature\ \ of\ \ the\, source \end{cases}$$

and

$$\left(1 + \frac{T_{e\,sys}}{T_s}\right) = \left(1 + \frac{T_{e\,1}}{T_s}\right) + \frac{\left(1 + \dfrac{T_{e\,2}}{T_s} - 1\right)}{G_1} + \ldots etc$$

$$i.e.\ \ from\, F_{sys} = F_1 + \frac{(F_2 - 1)}{G_1} + \ldots\ldots etc$$

$$which\, gives$$

$$T_{e\,sys} = T_{e1} + \frac{T_{e\,2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \frac{T_{e4}}{G_1 G_2 G_3} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Example 1

Convert the following temperatures to kelvin:

a) 100°C

b) 0°C

c) -10°C

$T = a°C + 273°C$

Example 2

Calculate the thermal noise power available from any resistor at room temperature (290K) for a bandwidth of 1 MHz. Calculate also the corresponding noise voltage, given that $R = 50\Omega$.

Example 3

For an electronic device operating at a temperature of 17°C with a bandwidth of 10 kHz, determine

a) Thermal noise power in watts and dBm

b) rms noise noise voltage for a 100 Ω internal resistance and 100 Ω load resistance.

Example 4

Two resistor of 20k Ω and 50 kΩ are at room temperature (290K). For a bandwidth of 100kHz, calculate the thermal noise voltage generated by

1. each resistor
2. the two resistor in series
3. the two resistor in parallel

Example 7

What is the gain of an amplifier that produces an output of 750 mV for 30 μV input?

Example 8

The power output of an amplifier is 6 W. The power gain is 80. What is the input power?

Example 9

Three cascade amplifier have power gains of 5,2, and 17. The input power is 40 mW. What is the output power?

Example 10

1. For an amplifier with an output signal power of 10W and an output noise power of 0.01W, determine the SNR.
2. For an amplifier with an output signal voltage of 4V, an output noise voltage of 0.005V and an input and output resistance of 50Ω, determine the SNR.

Example 11

- For a nonlinear amplifier and the following parameter, determine:
  a) Input SNR(dB)
  b) Output SNR(dB)
  c) Noise Factor and Noise Figure

  Input signal power=2×10^{-10}W
  Input Noise power=2×10^{-18}W
  Power gain=1,000,000
  Internal noise (Nd)=6×10^{-12}W

Example 13

Determine:

a) Noise Figure for an equivalent noise temperature of 75K.

b) Equivalent noise temperature for a noise figure of 6dB.

Example 14

- FOR THREE CASCADED AMPLIFIER STAGES, EACH WITH NOISE FIGURE OF 3 DB AND POWER GAIN OF 10 DB. DETERMINE THE TOTAL NOISE FIGURE?