Principles of Communication Systems

- Mrs Rasika Naik

<table>
<tr><th rowspan="4">Subject Code</th><th rowspan="4">Subject Name</th><th colspan="8">Examination Scheme</th></tr>
<tr><th colspan="4">Theory Marks</th><th rowspan="3">Exam Duration (in Hrs.)</th><th rowspan="3">Term Work</th><th rowspan="3">Prac. & Oral</th><th rowspan="3">Total</th></tr>
<tr><th colspan="3">Internal assessment</th><th rowspan="2">End Sem. Exam</th></tr>
<tr><th>Test 1</th><th>Test 2</th><th>Avg. of Test 1 and Test 2</th></tr>
<tr><td>ECC405</td><td>Principles of Communication Engineering</td><td>20</td><td>20</td><td>20</td><td>80</td><td>03</td><td>--</td><td>--</td><td>100</td></tr>
</table>

<table>
<tr><th rowspan="4">Course Code</th><th rowspan="4">Course Name</th><th colspan="8">Examination Scheme</th></tr>
<tr><th colspan="5">Theory Marks</th><th rowspan="3">Term Work</th><th rowspan="3">Practical & Oral</th><th rowspan="3">Total</th></tr>
<tr><th colspan="3">Internal assessment</th><th rowspan="2">End Sem. Exam</th><th rowspan="2">Exam. Duration (in Hrs)</th></tr>
<tr><th>Test 1</th><th>Test 2</th><th>Avg. of Test 1 and Test 2</th></tr>
<tr><td>ECL403</td><td>Principles of Communication Engineering Lab</td><td>--</td><td>--</td><td>--</td><td>--</td><td>--</td><td>25</td><td>25</td><td>50</td></tr>
</table>

Course Pre-requisite:

1. ECC301 - Engineering Mathematics- III
2. ECC302 - Electronic Devices and Circuits

Course Objectives:

1. To illustrate the fundamentals of basic communication system.
2. To understand various analog modulation and demodulation techniques.
3. To focus on applications of analog modulation and demodulation techniques.
4. To explain the key concepts of analog and digital pulse modulation and demodulation techniques.

Course Outcomes:

After successful completion of the course student will be able to:

1. Understand the basic components and types of noises in communication system.
2. Analyze the concepts of amplitude modulation and demodulation.
3. Analyze the concepts of angle modulation and demodulation.
4. Compare the performance of AM and FM receivers.
5. Describe analog and digital pulse modulation techniques.
6. Illustrate the principles of multiplexing and demultiplexing techniques.

Module No.	Unit No.	Topics	Hours
1		**Basics of Communication System**	**04**
	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.	**02**
	1.2	Types of noise, signal to noise ratio, noise figure, noise temperature and Friss formula.	**02**
2		**Amplitude Modulation and Demodulation**	**11**
	2.1	Basic concepts, need for modulation, waveforms (time domain and frequency domain), modulation index, bandwidth, voltage distribution and power calculations.	**04**
	2.2	DSBFC: Principles, low-level and high-level transmitters, DSB suppressed carrier, Balanced modulators with diode (Ring modulator and FET) and SSB systems.	**04**
	2.3	Amplitude demodulation: Diode detector, practical diode detector, Comparison of different AM techniques, Applications of AM and use of VSB in broadcast television.	**03**

3		**Angle Modulation and Demodulation**	**09**
	3.1	Frequency and Phase modulation (FM and PM): Basic concepts, mathematical analysis, FM wave (time and frequency domain), sensitivity, phase and frequency deviation, modulation index, deviation ratio, bandwidth requirement of angle modulated waves, narrowband FM and wideband FM.	**03**
	3.2	Varactor diode modulator, FET reactance modulator, stabilized AFC, Direct FM transmitter, indirect FM Transmitter, noise triangle, pre- emphasis and de-emphasis	**03**
	3.3	FM demodulation: Balanced slope detector, Foster-Seely discriminator, Ratio detector, FM demodulator using Phase lock loop, amplitude limiting and thresholding, Applications of FM and PM.	**03**
4		**Radio Receivers**	**04**
	4.1	Characteristics of radio receivers, TRF, Super - heterodyne receiver block diagram, tracking and choice of IF, AGC and its types and Communication receiver.	**03**
	4.2	FM receiver block diagram, comparison with AM receiver.	**01**

5		**Analog and Digital Pulse Modulation & Demodulation**	**06**
	5.1	Sampling theorem for low pass signal, proof with spectrum, Nyquist criteria, Sampling techniques, aliasing error and aperture effect.	**03**
	5.2	PAM, PWM, PPM generation, detection and applications. Basics of PCM system and differential PCM system. Concepts of Delta modulation (DM) and Adaptive Delta Modulation (ADM).	**03**
6		**Multiplexing & De-multiplexing**	**02**
	6.1	Frequency Division Multiplexing transmitter & receiver block diagram and applications. Time Division Multiplexing transmitter & receiver block diagram and applications.	**02**
		Total	**36**

Textbooks:

1. Kennedy and Davis, "Electronics Communication System", Tata McGraw Hill, Fourth edition.
2. B.P. Lathi, Zhi Ding "Modern Digital and Analog Communication system", Oxford University Press, Fourth edition.
3. Wayne Tomasi, "Electronics Communication Systems", Pearson education, Fifth edition.

Reference Books:

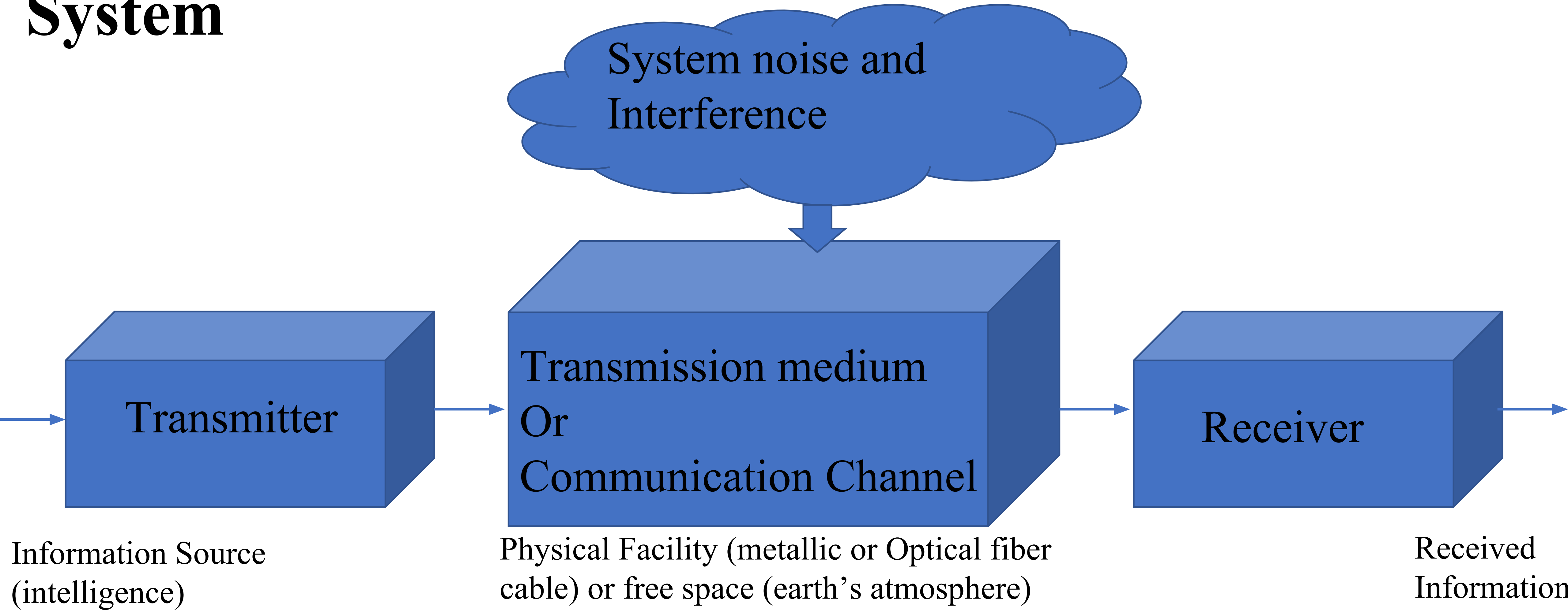
1. Taub, Schilling and Saha, "Taub's Principles of Communication systems", Tata McGraw Hill, Third edition.
2. P. Sing and S.D. Sapre, "Communication Systems: Analog and Digital”, Tata McGraw Hill, Third edition.
3. Simon Haykin, Michel Moher, "Introduction to Analog and Digital Communication", Wiley, Second edition.
4. Dennis Roddy and John Coolen, Electronic Communication, Pearson, 4/e, 2011.
5. Louis Frenzel, “Communication Electronics”, Tata McGraw Hill, Third Edition.

Chapter 1-
Basics of Communication System

Introduction

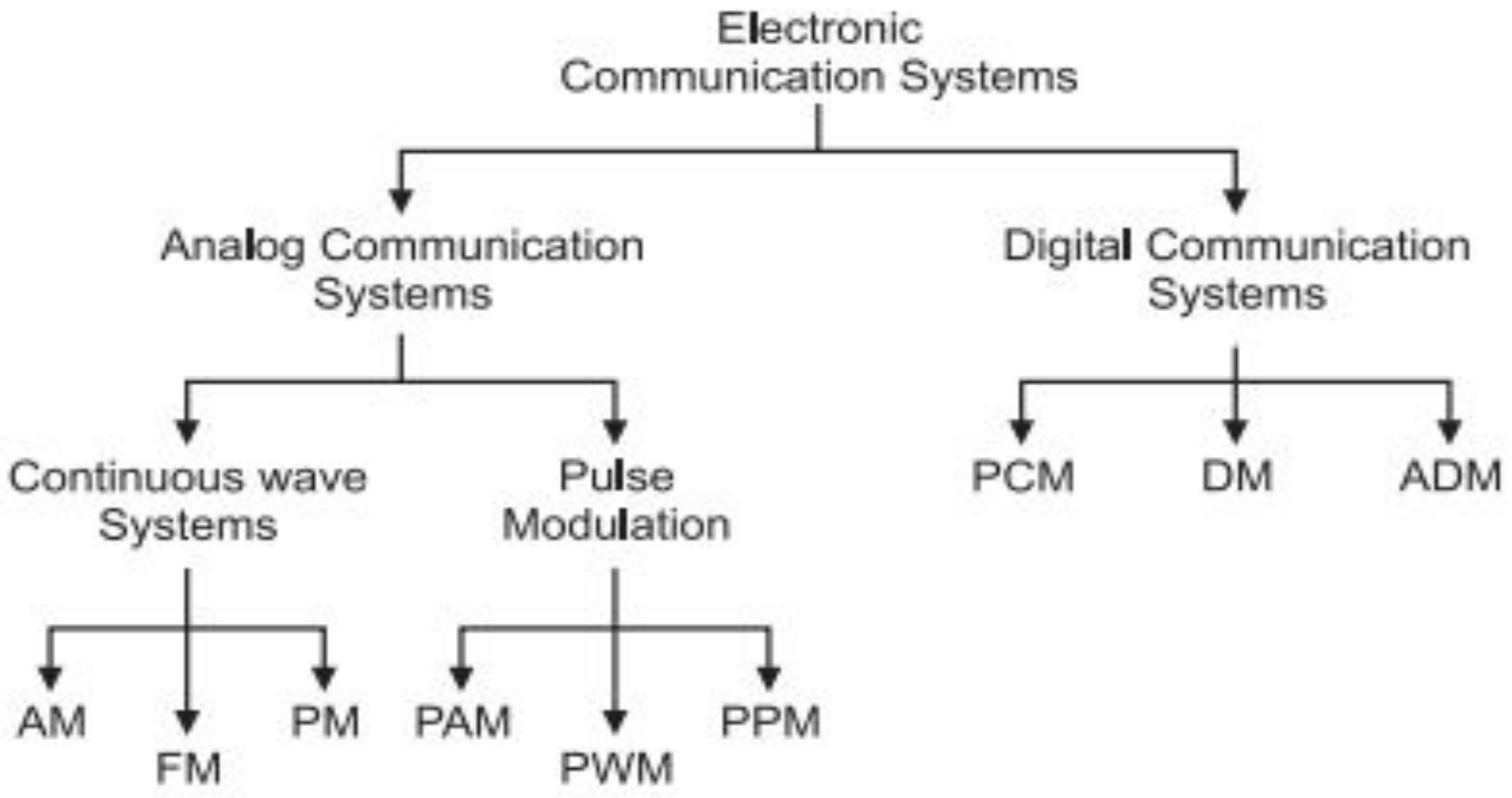
- The fundamental **purpose** of an Electronic communication system is **to transfer information** from one place to another.
- Electronics communication system is summarized as Transmission, reception and processing of information.
- A **Transmitter** is a collection of one or more electronic devices or circuits that converts original source information to a form more suitable for transmission over a particular transmission medium.
- Communication **channel** (or Transmission medium) provides a means of transporting signals between a transmitter and a receiver.
- A **Receiver** is a collection of electronic devices and circuits that accepts the transmitted signals from the transmission medium and then converts those signals back to their original form.

Block Diagram of an Electronic Communication System

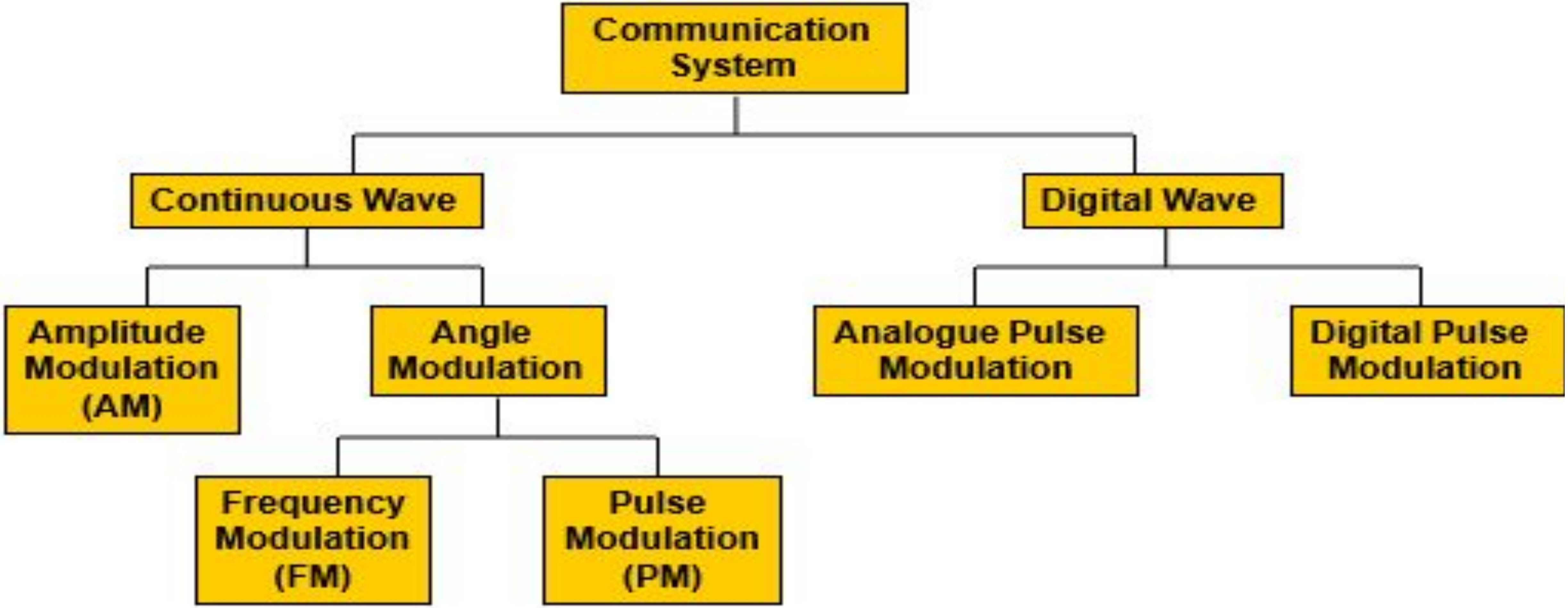


✔ System noise is any unwanted electrical signals that interfere with the information signal.

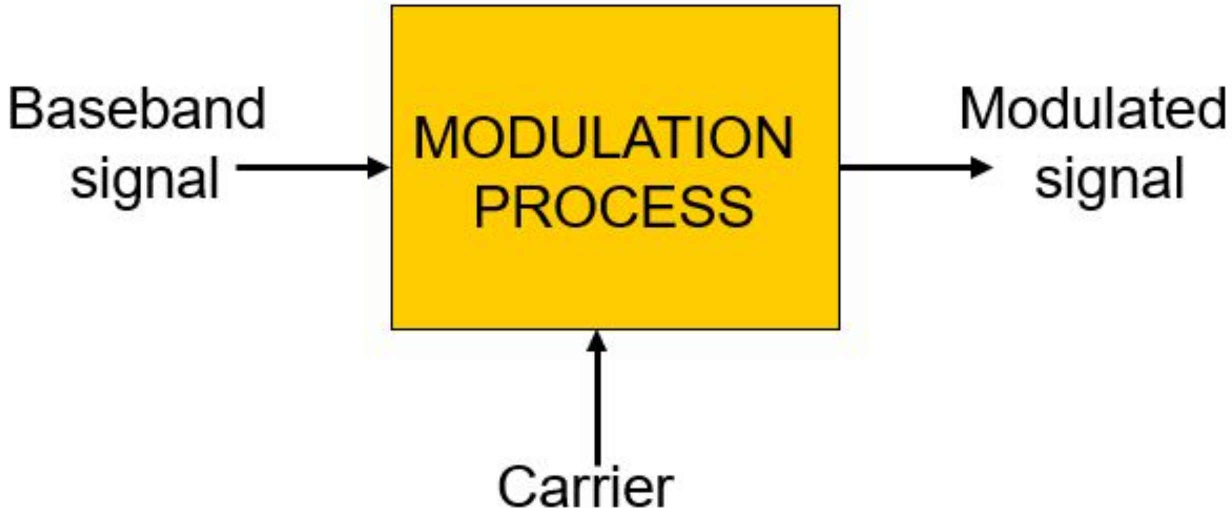
Types of Electronic Communication Systems



Classification of Communication System



Modulation Process



- **Modulation**

Modulation is the process of changing one or more properties of the analog carrier in proportion with the information signal.

- **Modulated Signal**

Modulated signal is baseband signal which its original frequency is **shifted to higher frequency** to facilitate transmission purposes

- **Baseband Signal**

Baseband signal is the modulating signal/**original information** signal either in a digital or analog form (intelligent/message) in communication system Example: voice signal (300Hz – 3400Hz)Transmission of original information whether analog or digital, directly into transmission medium is called **baseband transmission.**

Need of Modulation

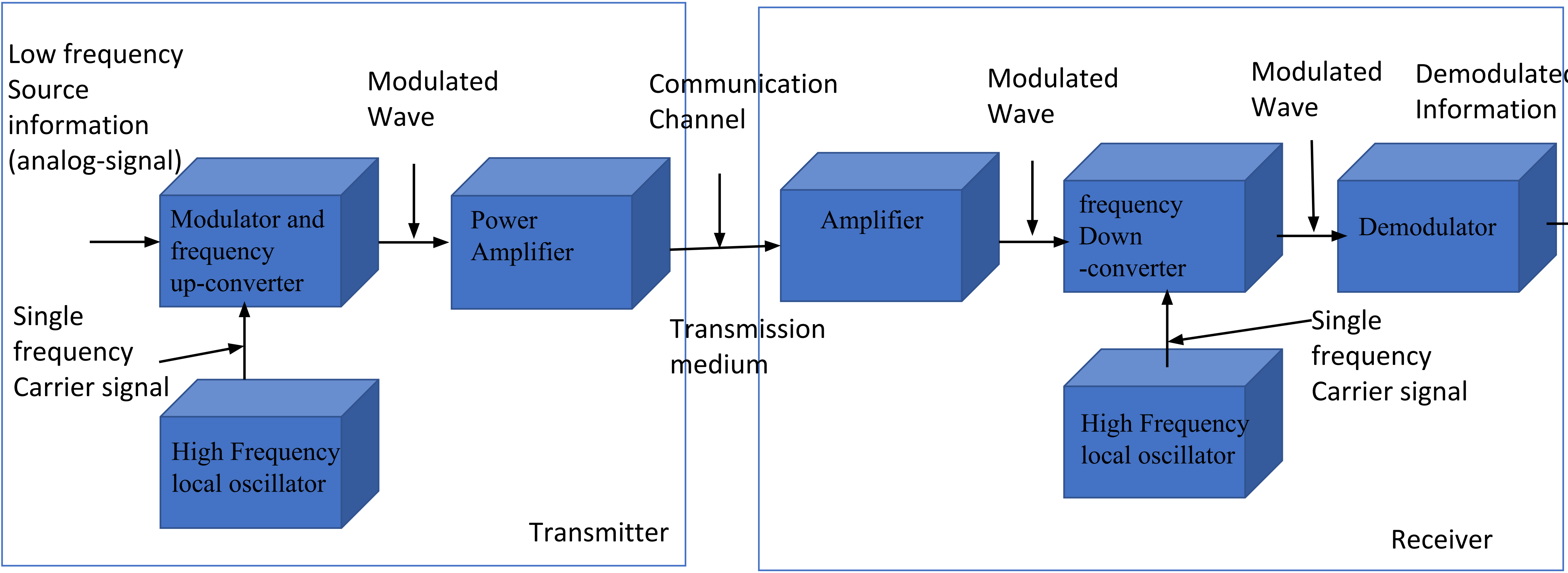
Two reasons why modulation is necessary in electronic Communications:

1. It is extremely difficult to radiate low frequency signals from an antenna in the form of electromagnetic energy.
2. Information Signals often occupy the same frequency band and if signals from two or more sources are transmitted at the same time.

- **Process of modulation**
  - Frequency translation such as AM, FM, PM etc
  - Sampling and coding such as PAM, PCM etc
  - Keying such as ASK, FSK, PSK etc

Demodulation – is the reverse process of modulation and converts the modulated carrier back to the original information. It is performed in a receiver by a circuit called as demodulator.

Simplified block diagram of an analog communication system



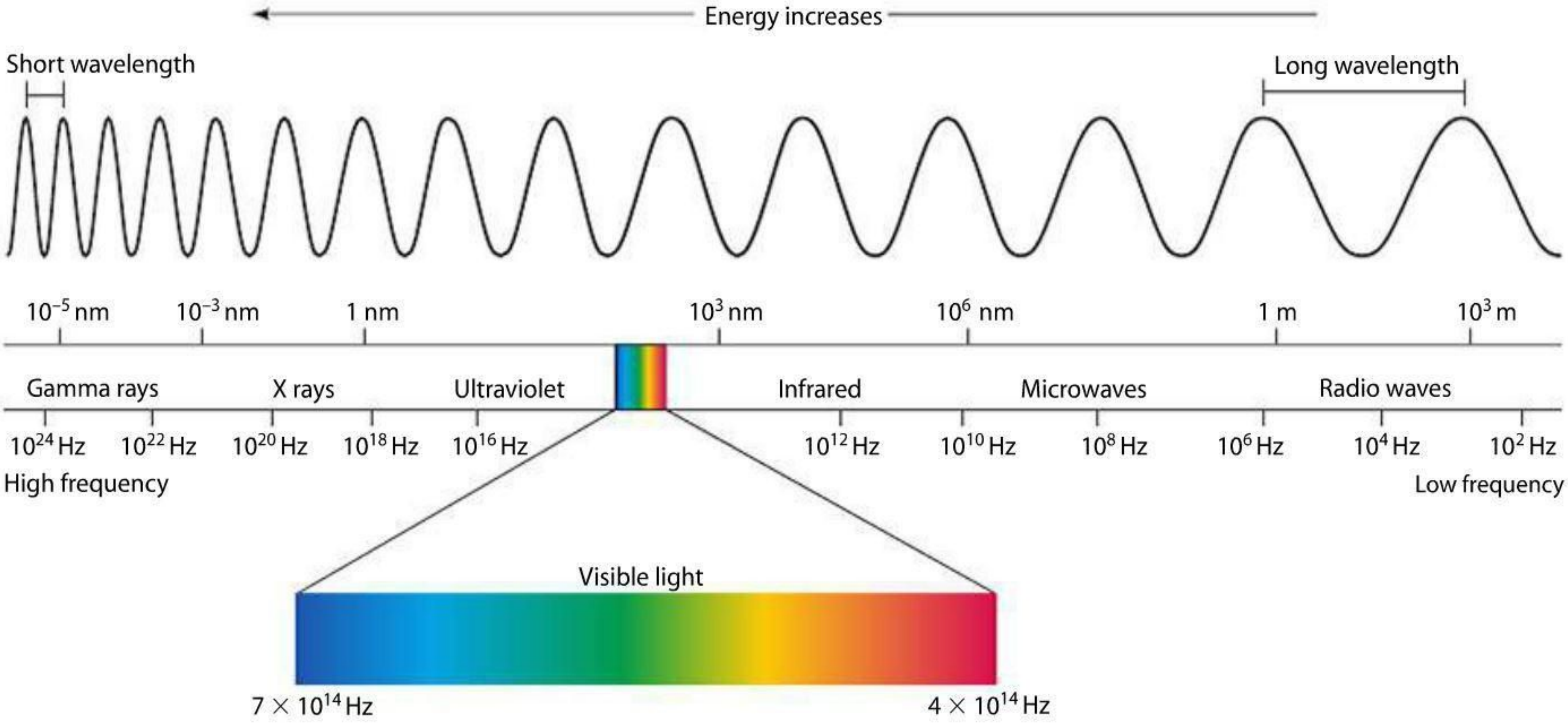
Simplified block diagram of an analog communication system

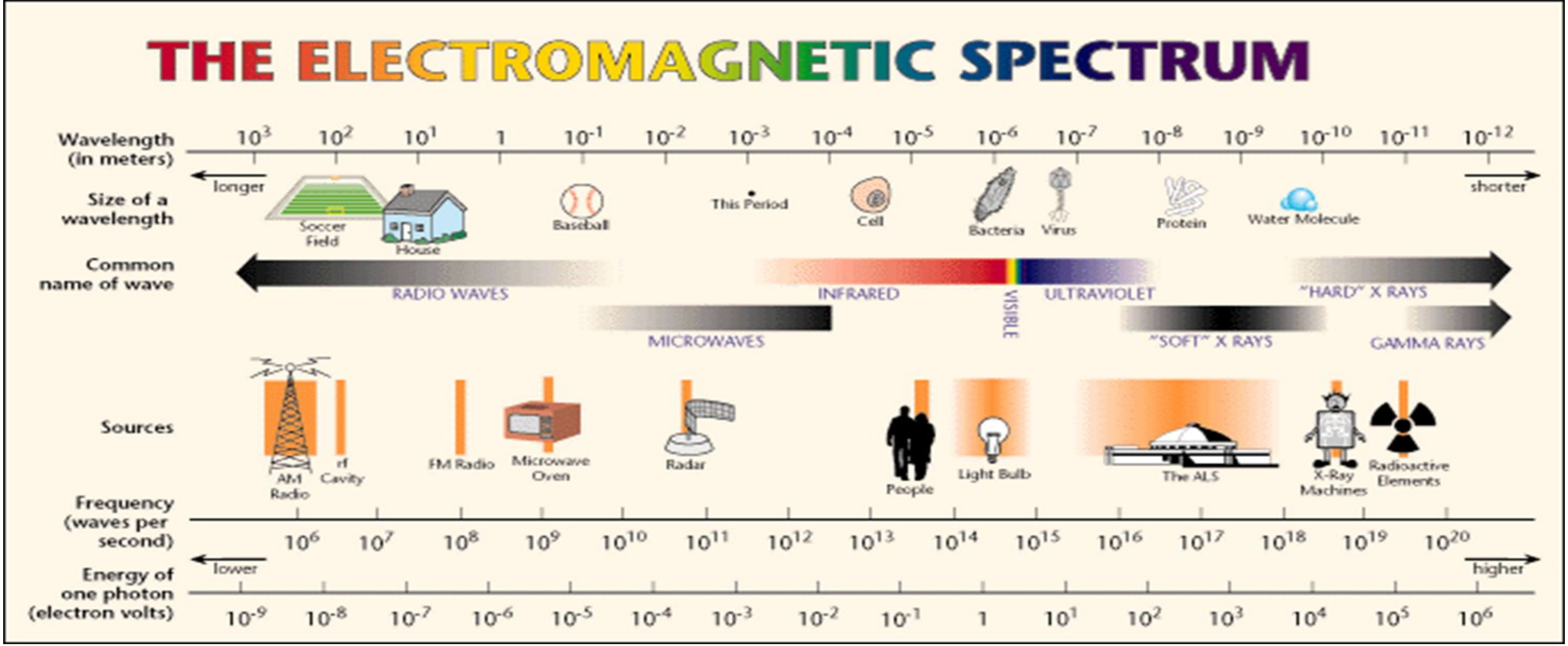
- The information signal (sometimes called intelligence signal) combines with the carrier in the modulator to produce modulated wave.
- The information can be in analog or digital form and modulator can perform analog or digital modulation.
- Information signals are up-converted from low frequencies to high frequencies in the transmitter and down-converted from high frequencies to low frequencies in the receiver.
- The process of converting frequency or band of frequencies to another location in the total frequency spectrum is called Frequency translation.
- The modulated signal is amplified, down converted in frequency and then demoudulated to reproduce the original source information.

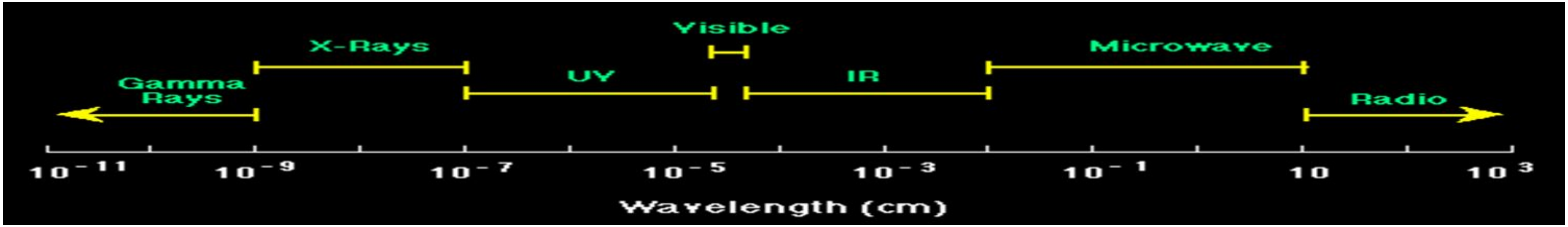
The Electromagnetic Frequency Spectrum

- The purpose of an electromagnetic communication system is to communicate information between two or more locations called Stations.
- This is done by converting the original information into electromagnetic energy and then transmitting it to one or more receive stations where it is converted back to its original form.
- Electromagnetic energy can propagate as a voltage or current along a metallic wire as emitted radio waves through free space or as light waves down an optical fiber.
- Electromagnetic energy is distributed throughout an almost infinite range of frequencies.
- The electromagnetic frequency spectrum is divided into subsections or bands with each band having a different name and boundary.
- The international Telecommunication Union (ITU) is an international agency in control of allocating frequencies and services within the overall frequency spectrum.

Electromagnetic Frequency spectrum




THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
lower
higher
Energy of one photon (electron volts)
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^1 10^2 10^3 10^4 10^5 10^6


Visible
X-Rays
Microwave
UV
IR
Gamma Rays
Radio
10^{-11} 10^{-9} 10^{-7} 10^{-5} 10^{-3} 10^{-1} 10 10^3
Wavelength (cm)

Federal Communications Commission (FCC) Emission Classifications

Frequency Bands	Letter Designation	
1.0 – 2.0 GHz	L	
2.0 – 4.0 GHz	S	
4.0 – 8.0 GHz	C	
8.0 – 12.0 GHz	X	
12.0 – 18.0 GHz	Ku	
18.0 – 27.0 GHz	K	
27.0 – 40.0 GHz	Ka	
26.5 – 40.0 GHz	R	
33.0 – 50 GHz	Q	Radar/satellite comm
40.0 – 75.0 GHz	V	Radar/satellite comm
75.0 – 110 GHz	W	Radar/satellite comm
10^3 – 10^7GHz	Infrared, visible light and ultra violet	Optical communication

International Telecommunications Union (ITU) Band Designation

3 – 30 kHz	VLF	(very low freq)	Ground wave
30 – 300 kHz	LF	(low freq)	Ground wave
300 – 3000 kHz	MF	(medium freq)	Ground wave/sky wave
3-30 MHz	HF (High Freq)		Sky Wave
30 – 300 MHz	VHF (very high freq)		Space wave (LOS)
300 – 3000 MHz	UHF (ultrahigh freq)		Space wave (LOS)
3 – 30 GHz	SHF (superhigh freq)		LOS/Satellite
30 – 300 GHz	EHF (Extremely high freq)		LOS/Satellite

Electromagnetic Frequency spectrum

$$f = \frac{c}{\lambda}$$

where: f = frequency
c = speed of wave
λ = wavelength of wave

- Wavelength is the length that one cycle of an electromagnetic wave occupies in space (ie the distance between similar points in a repetitive wave.)
- Wavelength inversely proportional to the frequency of the wave and directly proportional to the velocity of propagation.

History Development

Year	Events
1975	First digital telephone switch
1975	Wideband communication system (cable TV etc)
1980	Compact disc is developed by Philip & Sony
1981	FCC adopts rules for commercial cellular telephone
1982	Internet is used to replace ARPANET
1985	Fax machines widely available in offices
1989	First SONET standard optical fiber products released
1990	WWW becomes part of the internet
1990-2000	Digital communication system (ISDN, BISDN, HDTV, handheld computers, digital cellular etc Global telecom system

History Development

Year	Events
1844	Telegraph
1876	Telephone
1904	AM Radio
1923	Television
1936	FM Radio
1962	Satellite
1966	Optical links using laser and fiber optics
1972	Cellular Telephone

Bandwidth and Information Capacity

- Two most important limitations on the performance of a communication system are NOISE and BANDWIDTH.
- Then Bandwidth of an information signal is the difference between the highest and lowest frequencies contained in the information.
- e.g Voice frequencies contain signals between 300Hz and 3000Hz. therefore Bandwidth of voice frequency channel is 3000Hz - 300Hz = 2700Hz

★ Information Theory is a highly theoretical study of the efficient use of bandwidth to propagate information through electronic communication systems.
★ Information theory can be used to determine INFORMATION CAPACITY of a data communication system.
★ INFORMATION CAPACITY is a measure of how much information can be propagated through a communication system.
★ It is a function of bandwidth and transmission time.

Information Capacity

Hartley's Law

$$I \propto B \times t$$

Where

I = information capacity (bps)

B = bandwidth (Hz)

t = transmission time (s)

From the equation, Information capacity is a linear function of bandwidth and transmission time and directly proportional to both.

- Information Capacity represents the number of independent symbols that can be carried through a system in a given unit of time.
- The most basic digital symbol used to represent information is the Binary digit or bit.
- So information capacity of a system is expressed as a bit rate.
- Bit Rate is simply the number of bits transmitted during one second and is expressed in bits per second (bps)

Power Measurements (dB, dBm, AND Bel)

- The decibel (dB) is a logarithmic unit that can be used to measure ratios of virtually anything.
- dB is a transmission- measuring unit used to express relative gains and losses of electronic devices and circuits
- It also describes relationships between signals and noise.
- Decibel compares one signal level to another.
- The dB is used for calculating power relationships and performing power measurements in electronic communications systems.

$$\textbf{Decibels (dB)} = 10 \log(P2/P1)$$

where p2= power level at output

p1 = power level at input

- A positive **(+) dB** value indicates that the output is greater than the input power which indicate **AMPLIFICATION.**
- A negative **(-) dB** value indicates that output power is less than the input power which indicate **LOSS.**

Power Measurements (dB, dBm, AND Bel)

- A dBm is a unit of measurement used to indicate the ratio of a power level with respect to a fixed reference level 1mW.
- dBm means decibel relative to 1miliwatt.
- 1 mW was chosen for the reference because it equals the average power produced by a telephone transmitter.

dbm = 10 log P1/1mw = 10 log P1/0.001w

where 0.001 is the reference power of 1mW

P is any power in Watts.

Examples

1. Convert the absolute power ratio of 200 to a power gain in dB

Solution:

$$\text{Power gain, } A_p\,(\text{dB}) = 10 \log_{10} [200]$$
$$= 10(2.3)$$
$$= 23 \text{ dB}$$

2. Convert the power gain $A_p = 23$ dB to an absolute power ratio

Solution

$$\text{Power gain, } A_p\,(\text{dB}) = 10 \log_{10} [\text{Pout/Pin}]$$
$$2.3 = \log_{10} [\text{Pout/Pin}]$$

Examples

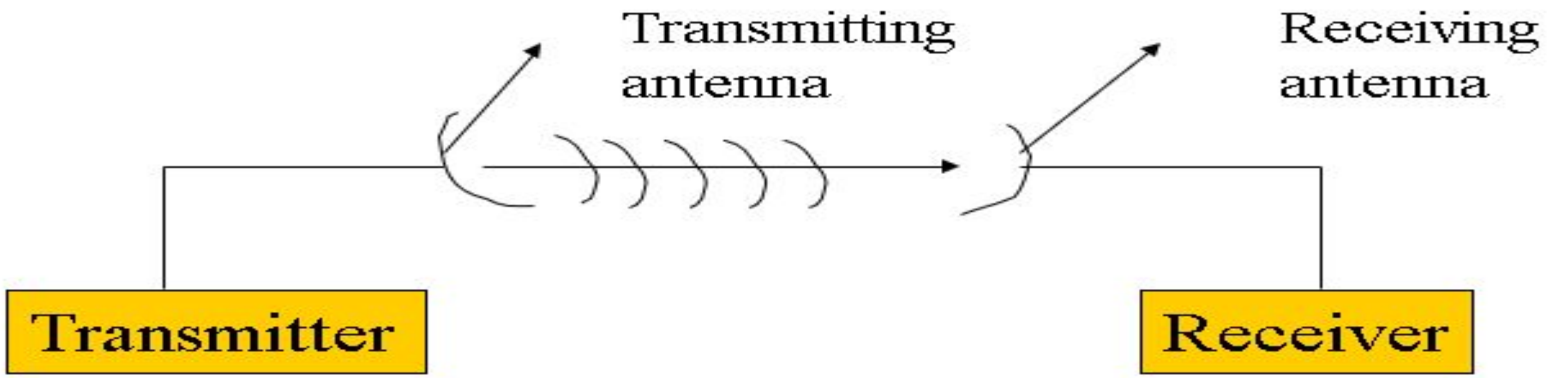
3. Convert a power level of 200mW to dBm

Solutuion:

$$dBm = 10 \log_{10} [200mW/1mW]$$
$$= 10(200)$$
$$= 23 \text{ dBm}$$

Radio Communication System

- It is wireless communication system
- The information is being carried by the electromagnetic waves, which is propagated in free space
- Electromagnetic waves are waves that travel at the speed of light and made up of an electrical field and magnetic field at right angles to one another and to the direction of propagation



Block diagram of a radio communication system

Propagation Waves

There are three main type of propagations:

➢ **Ground wave propagation**

- Dominants mode for frequencies **below 2 MHz**
- The movement tend to follow the contour of the earth with large antenna size

➢ **Sky-wave propagation**

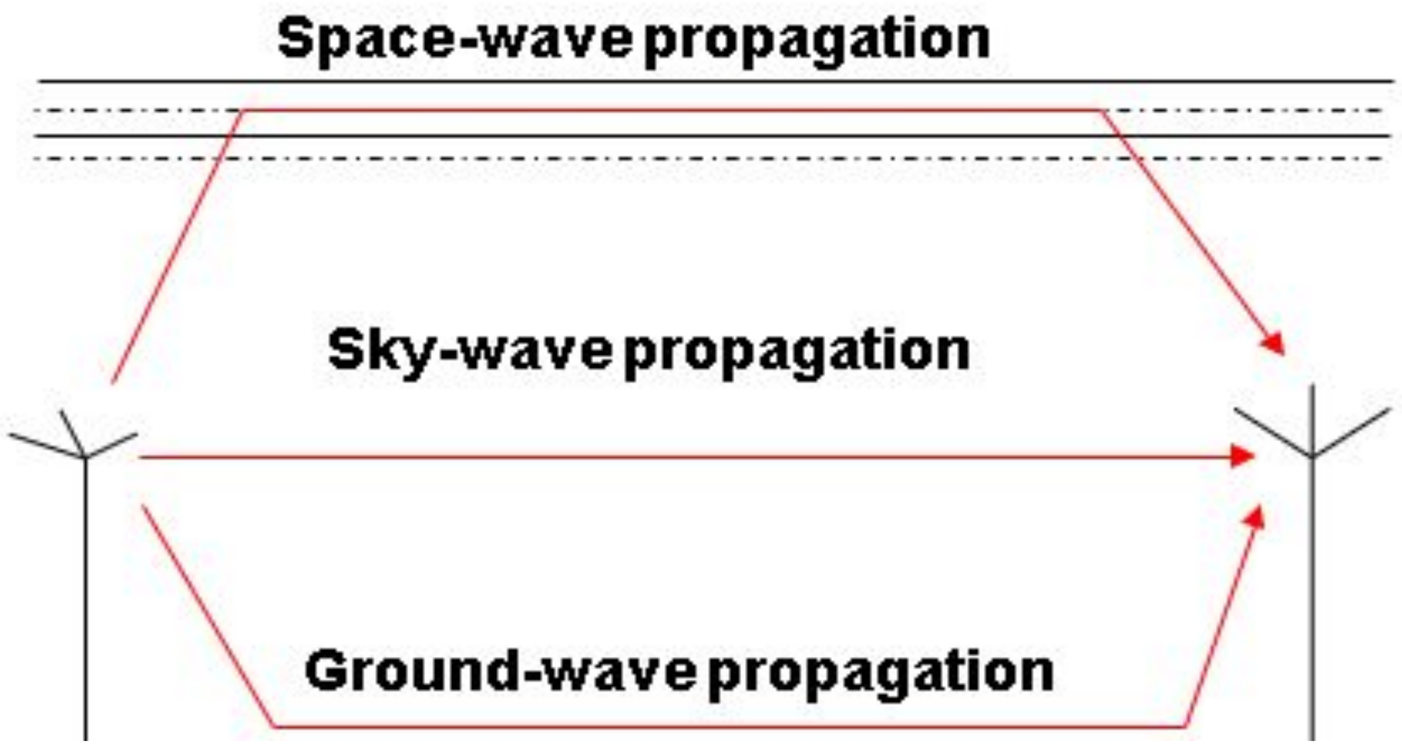
- Dominants mode for frequencies between 2 – 30 MHz range
- Coverage is obtained by reflection the wave at ionosphere and at the earth boundaries
- This is because the index **refractions of the ionosphere** varies with the altitude as the ionization density changes
- There are areas of **no coverage along the earth surface** between transmitting and receiving antenna
- The angle of reflection and the loss of signal depend on the **frequency, time, season, activities** of the sun etc

➢ **Space wave propagation (LOS)**

- Dominants mode for frequencies above **30 MHz** where in propagates in straight line
- No refraction and can almost propagates through ionosphere

Propagation Waves

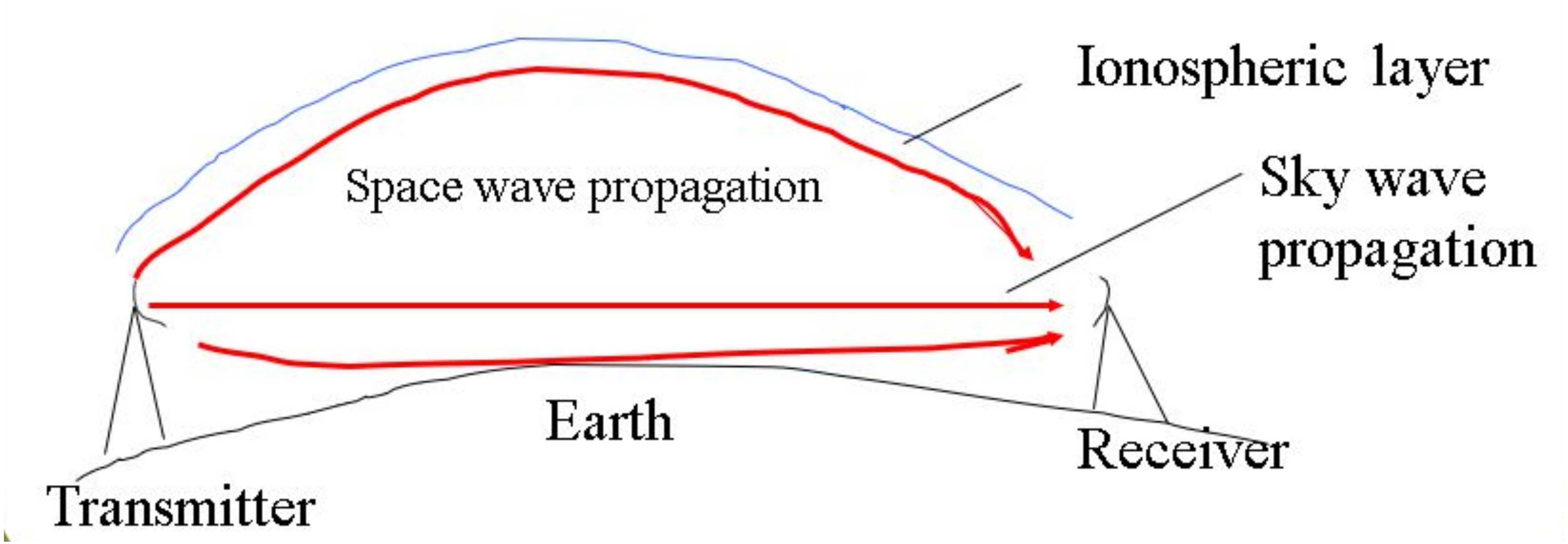
- But the signal path has to be above horizon to avoid blocking leading antenna to be placed on tall towers
- The distance to radio horizon is $d = \sqrt{2h}$ miles



Radio Wave Propagation Methods

The three methods of Radio waves propagation

- ★ Ground wave propagation
- ★ Sky wave propagation
- ★ Space wave propagation



Radio Wave Propagation Methods

- **Ground (surface) wave**
- Wave that progress along the surface the earth
- It follows the curvature of the earth
- **Sky wave propagation**
- Sky waves are those waves that radiated towards ionosphere. By a process of refraction and reflection, the receiver on the earth will receive the signal. The various layers of the ionosphere have specific effects on the propagation of radio waves
- Space wave
- The wave is propagated in a straight line
- space wave is limited in their propagation by the curvature of the earth sometimes it is called direct wave or line-of-sight (LOS)
- The radio horizon of the antenna is the distance between the transmitter and receiver and is denoted by d, where

$$d \approx d_t + d_r \quad \text{in km}$$

$$\text{and} \quad d_t = 4\sqrt{h_t} \quad \text{and} \quad d_r = 4\sqrt{h_r}$$

Line of sight propagation

d_t = radio horizon of the transmitting antenna, in km

h_t = height of transmitting antenna, in m

d_r = radio horizon of the receiving antenna, in km

h_r = height of receiver antenna, in m

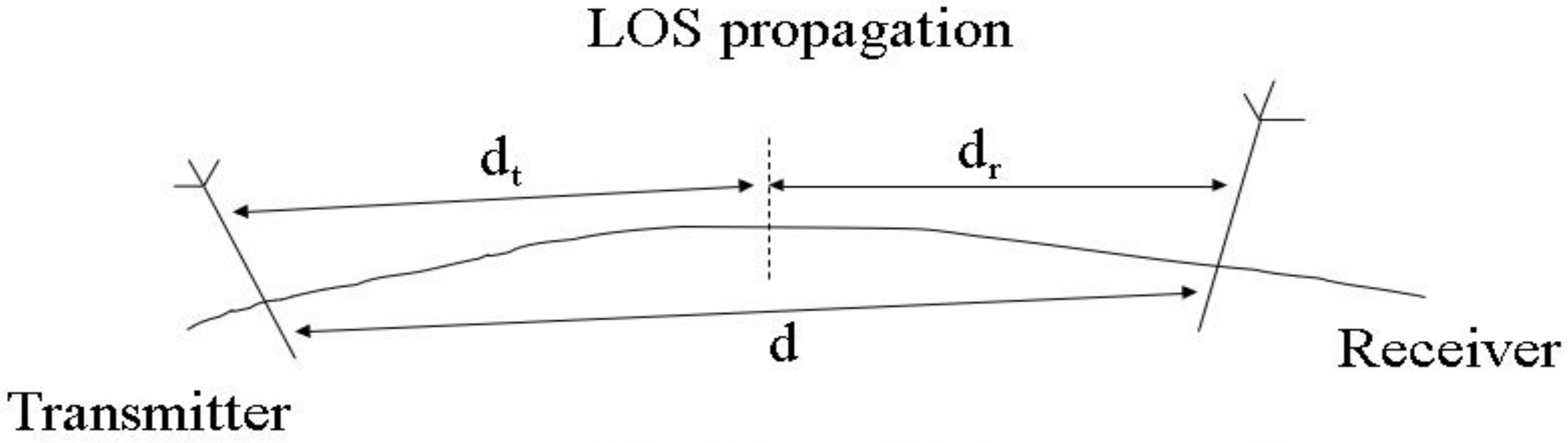
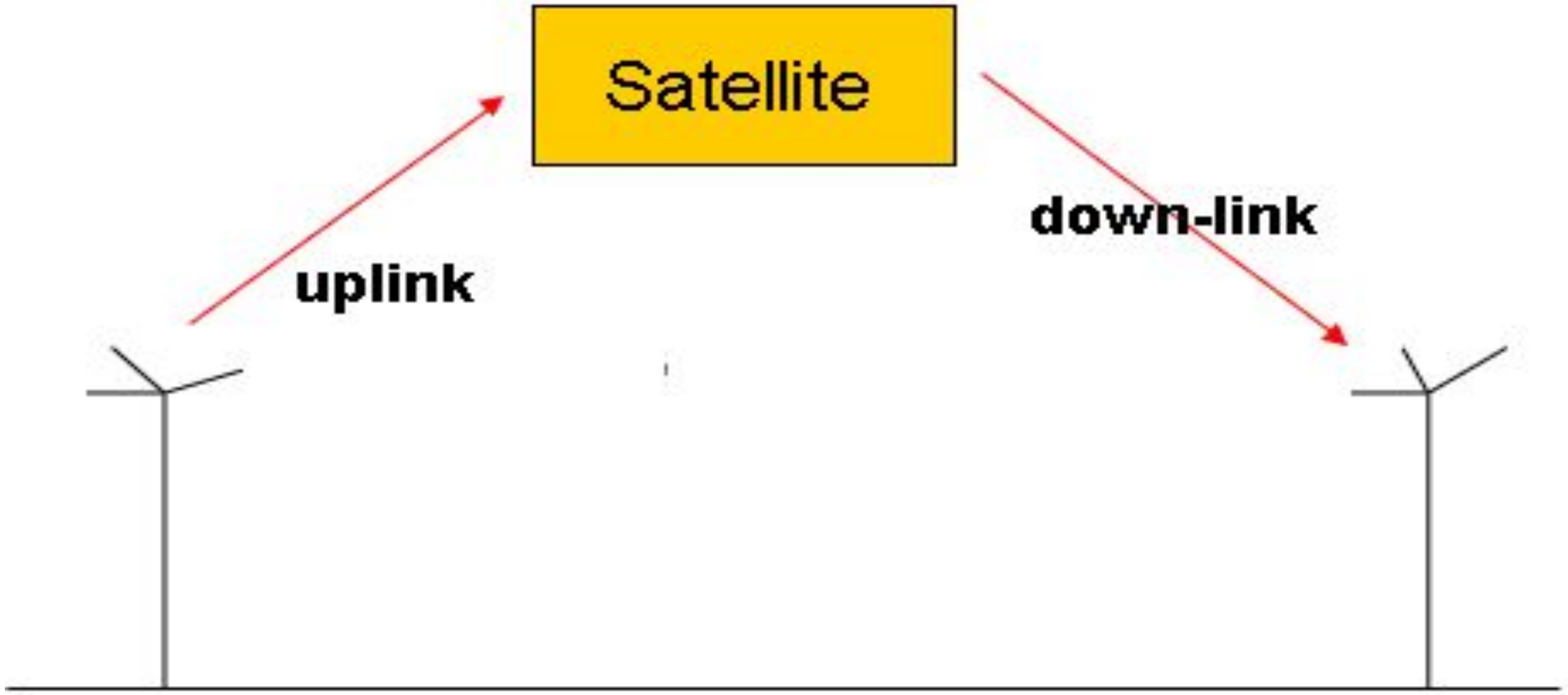


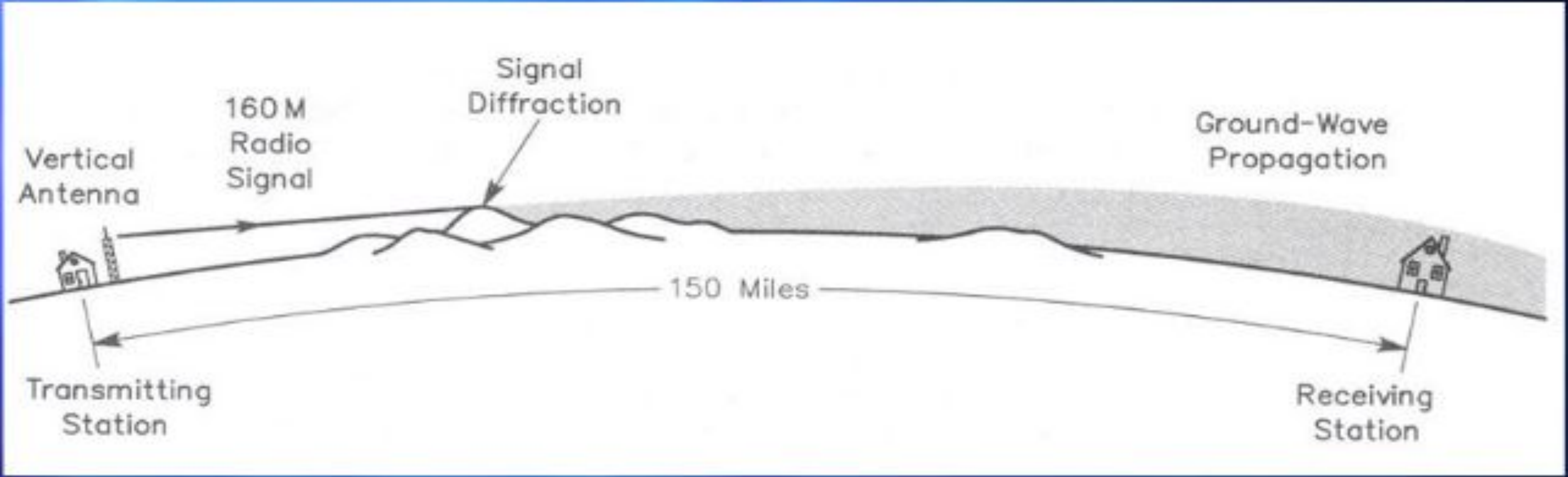
Fig: Line of sight propagation

Satellite Communication

- Satellite employs LOS radio transmission over very long distance
- It offers brad coverage even across the ocean and can handle bulk of very long distance telecommunication



Ground-Wave Propagation



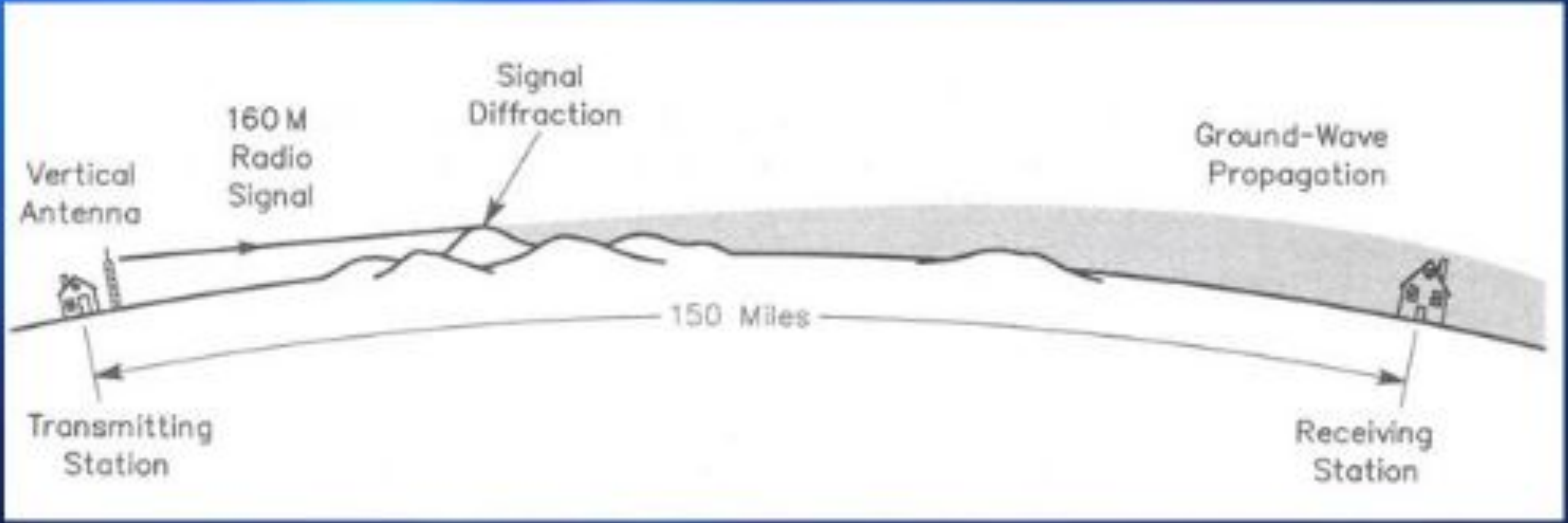
The curved surface of the Earth horizon can diffract long-wavelength (low frequency) radio waves. The waves can follow the curvature of the Earth for as much as several hundred miles.

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:

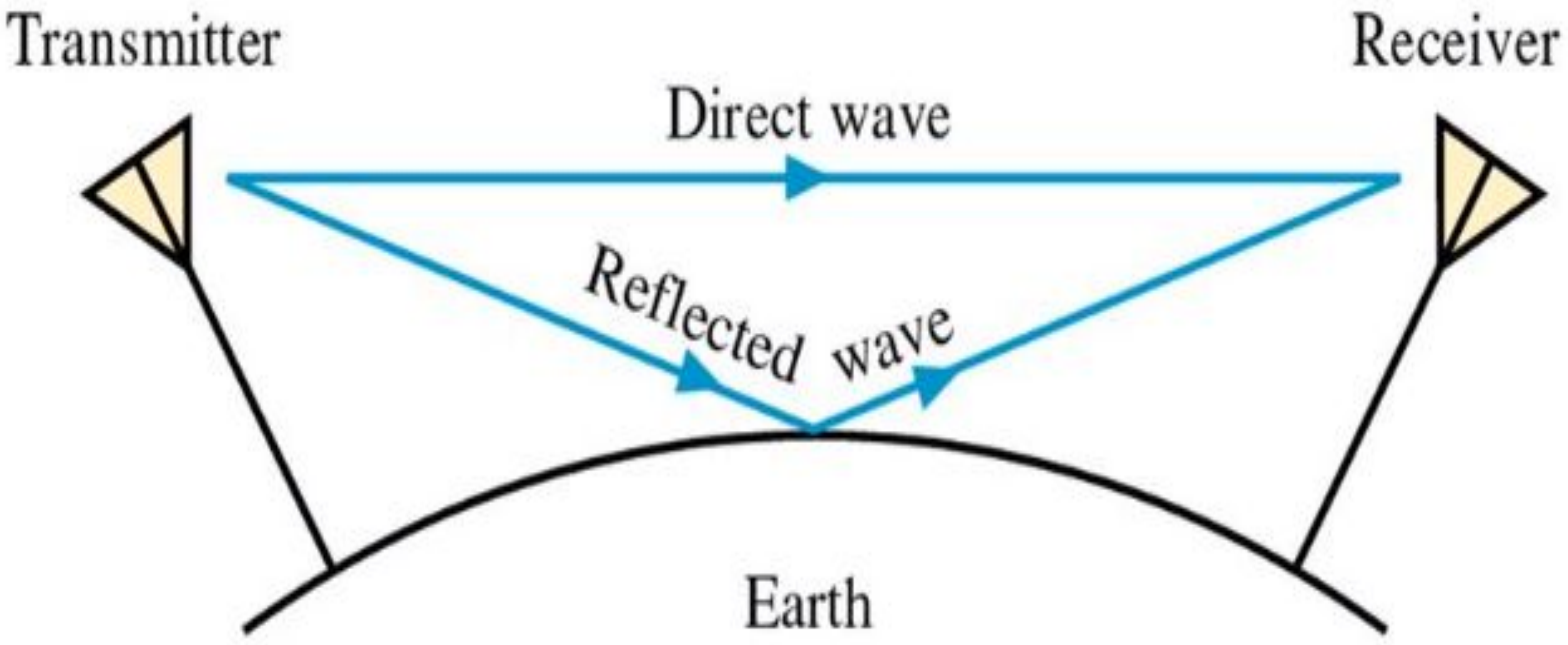
$$d \cong \sqrt{2h_t} + \sqrt{2h_r}$$

Where:

d = radio horizon (mi)

h_t = transmitting antenna height (ft)

h_r = receiving antenna height (ft)



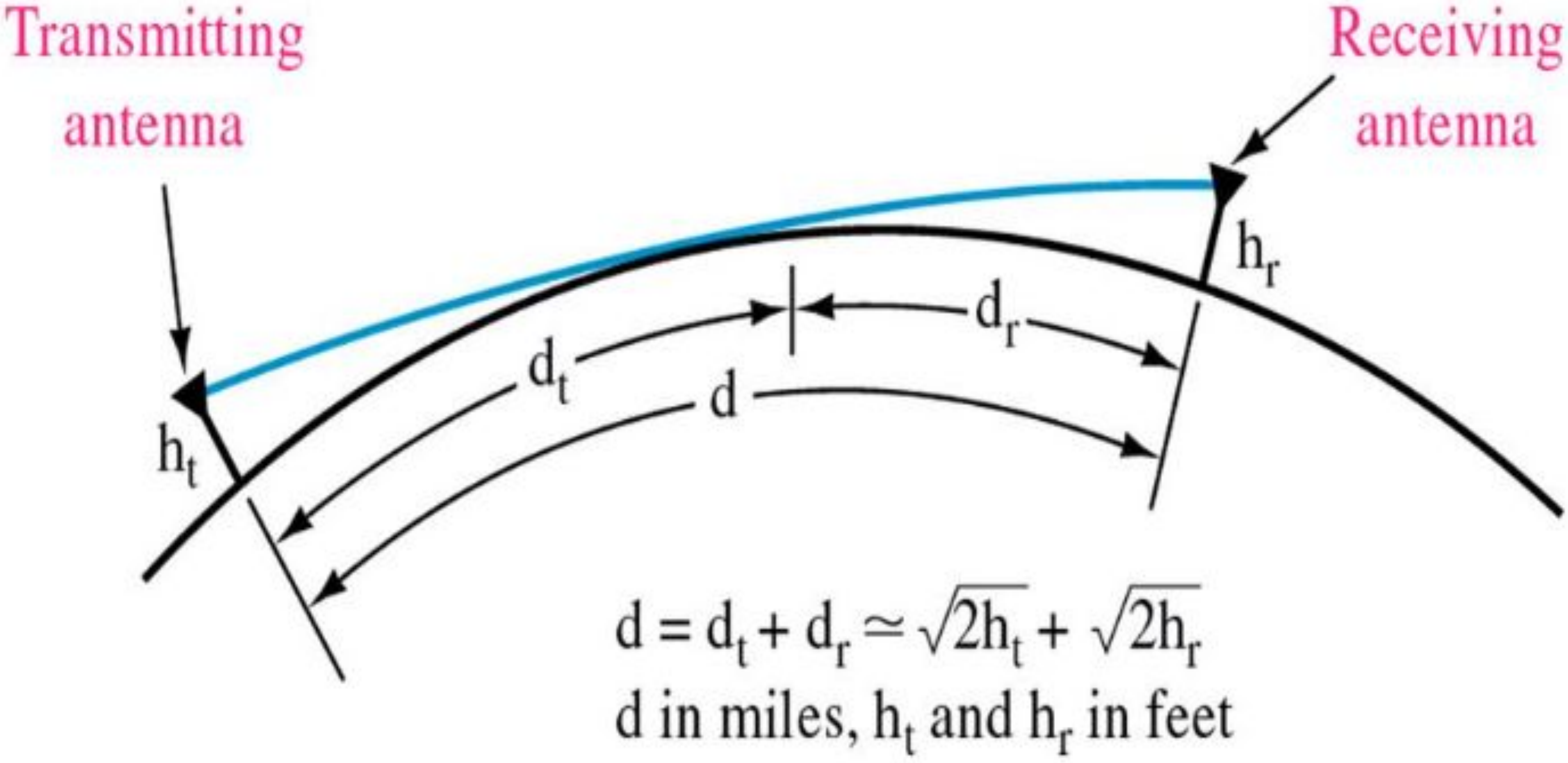
Transmitter
Receiver
Direct wave
Reflected wave
Earth

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.

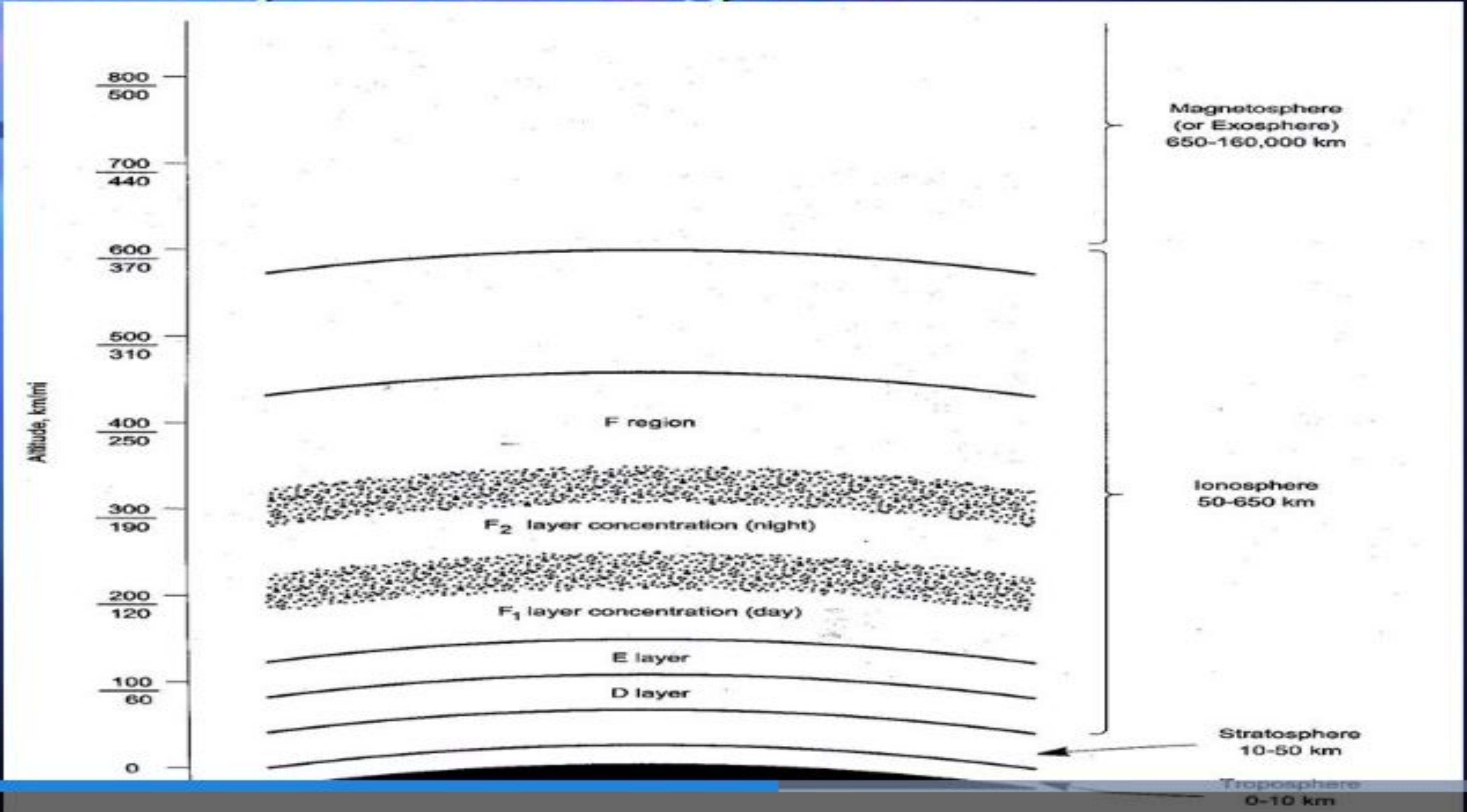

Transmitting antenna
Receiving antenna
h_t
h_r
d_t
d_r
d
$d = d_t + d_r \simeq \sqrt{2h_t} + \sqrt{2h_r}$
d in miles, h_t and h_r in feet

Sky Wave Propagation

Atmospheric Regions

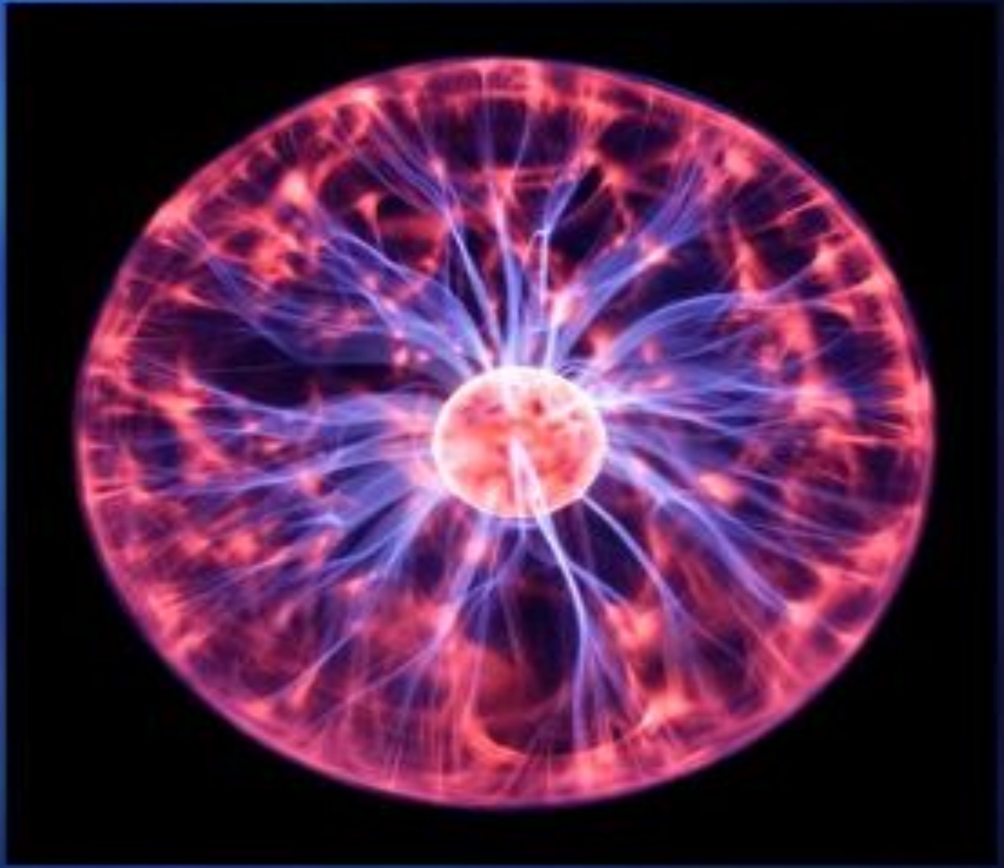
Region	Height	Notes
Troposphere	7 miles	Region where all weather occurs
Stratosphere	6 to 30 miles	Region where atmospheric gases "spread out" horizontally. The high speed jet stream travels in the stratosphere.
Ionosphere	30 to 400 miles	Region where solar radiation from the sun creates ions. **Major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

Atmospheric Regions



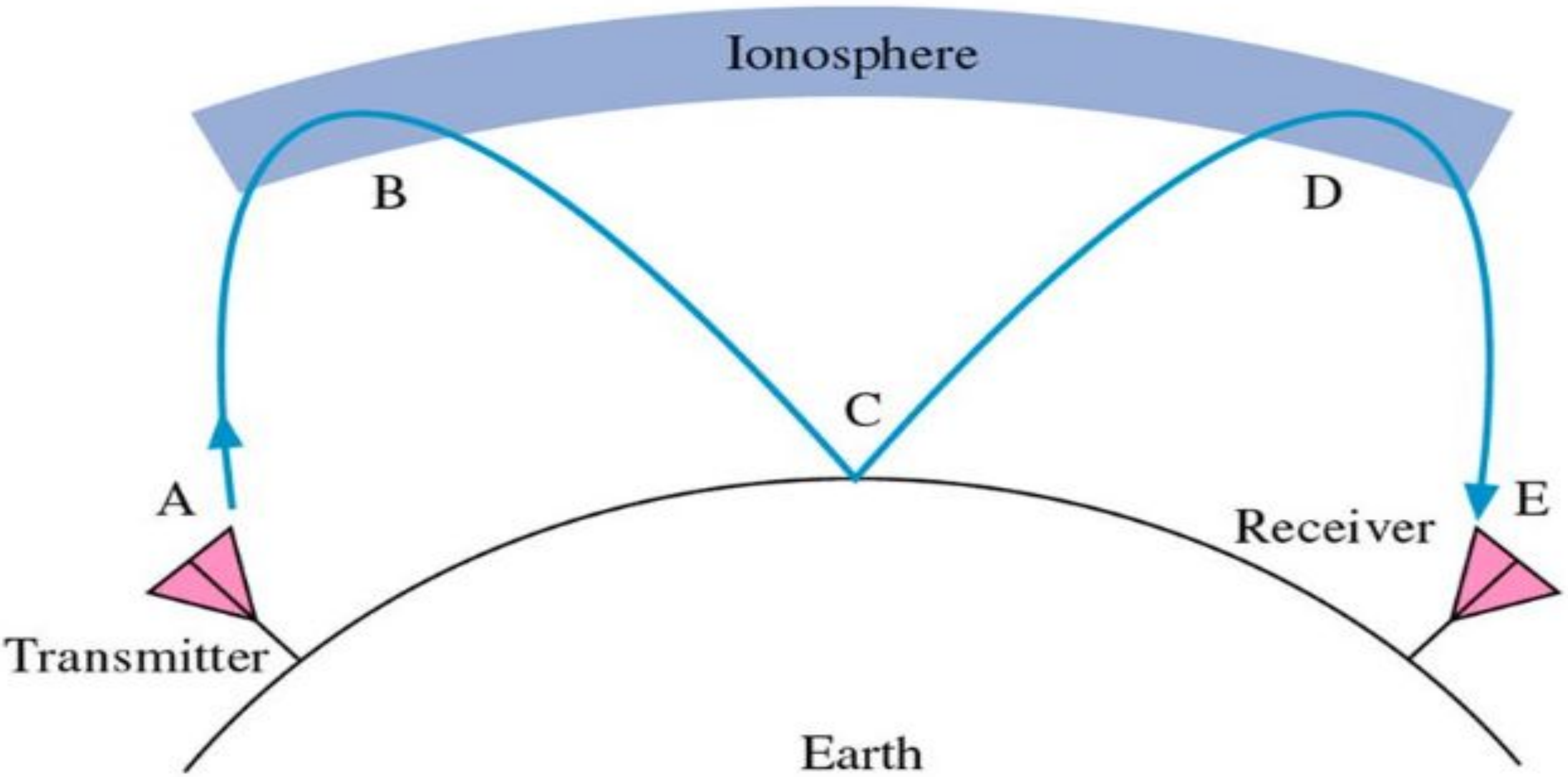
What is the ionosphere?

- 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

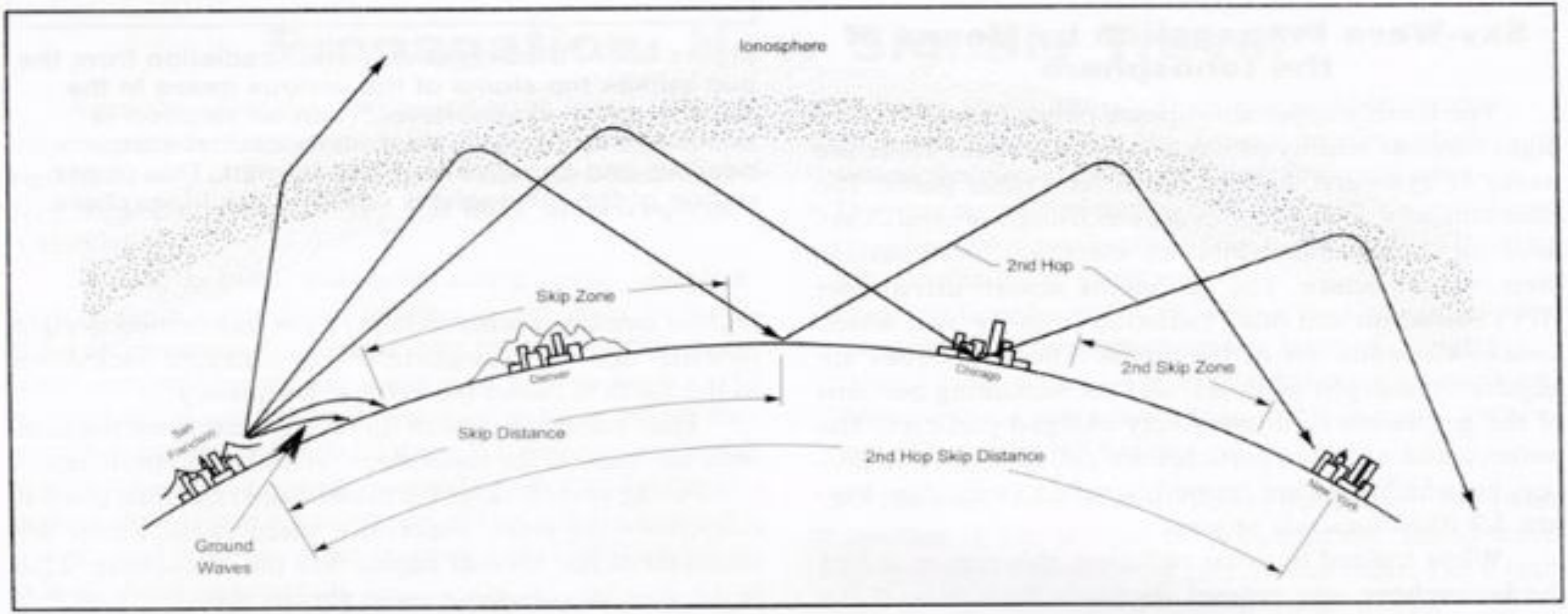
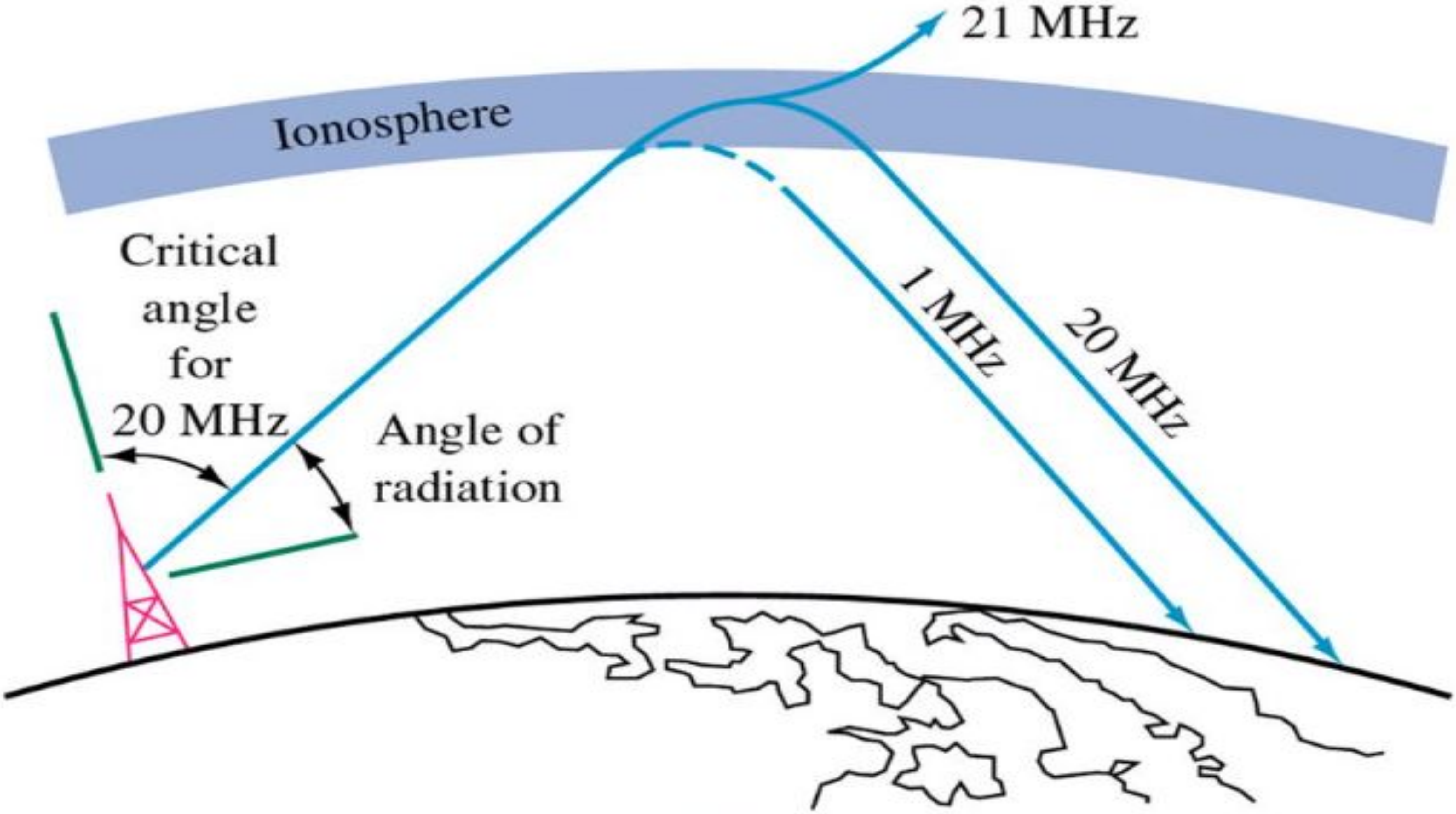
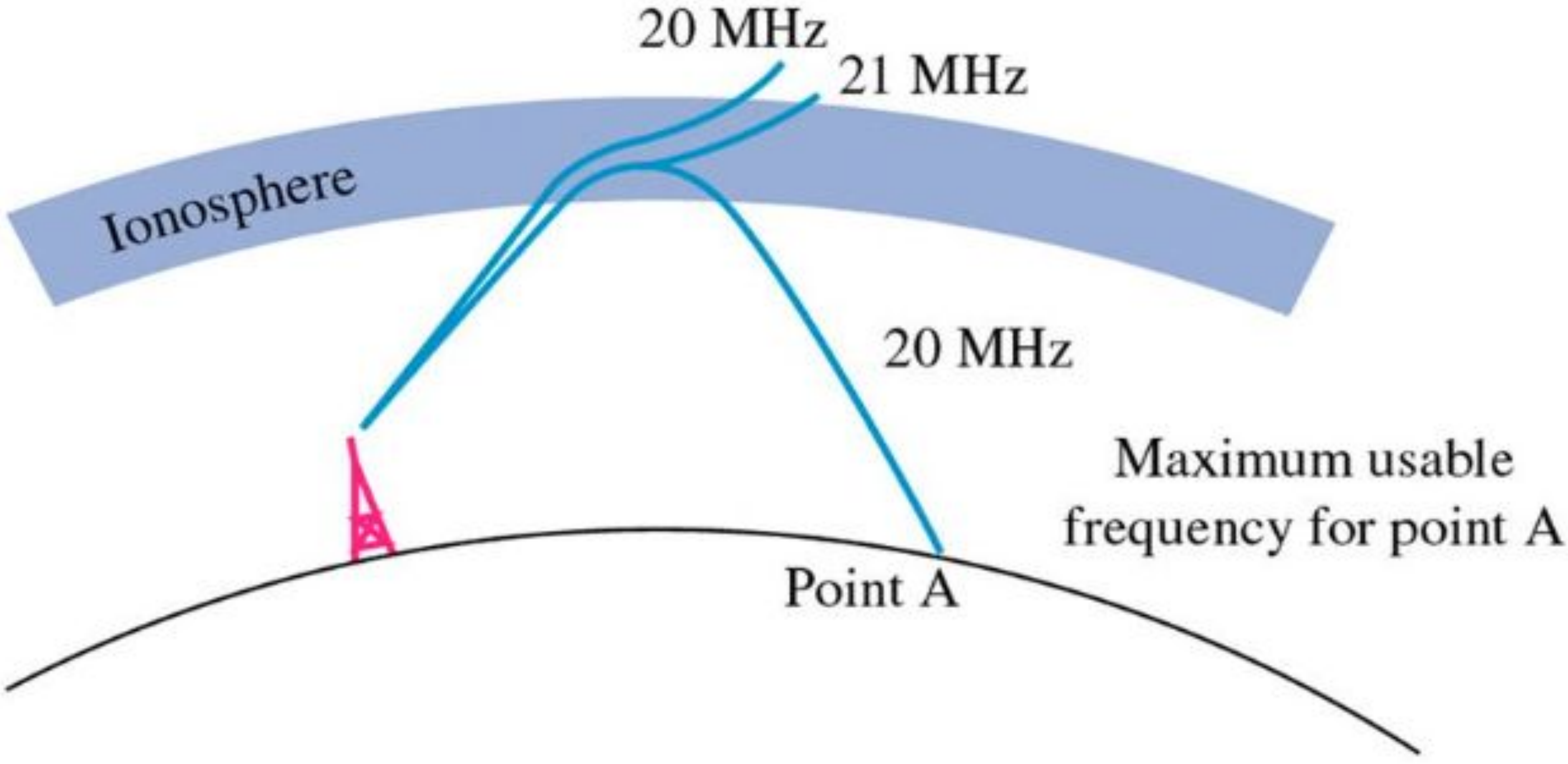


Figure 3.4 — This drawing illustrates how radio waves travel into the ionosphere and are bent back to Earth. Ground waves, skip distance and skip zone are all shown on the drawing.

- 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

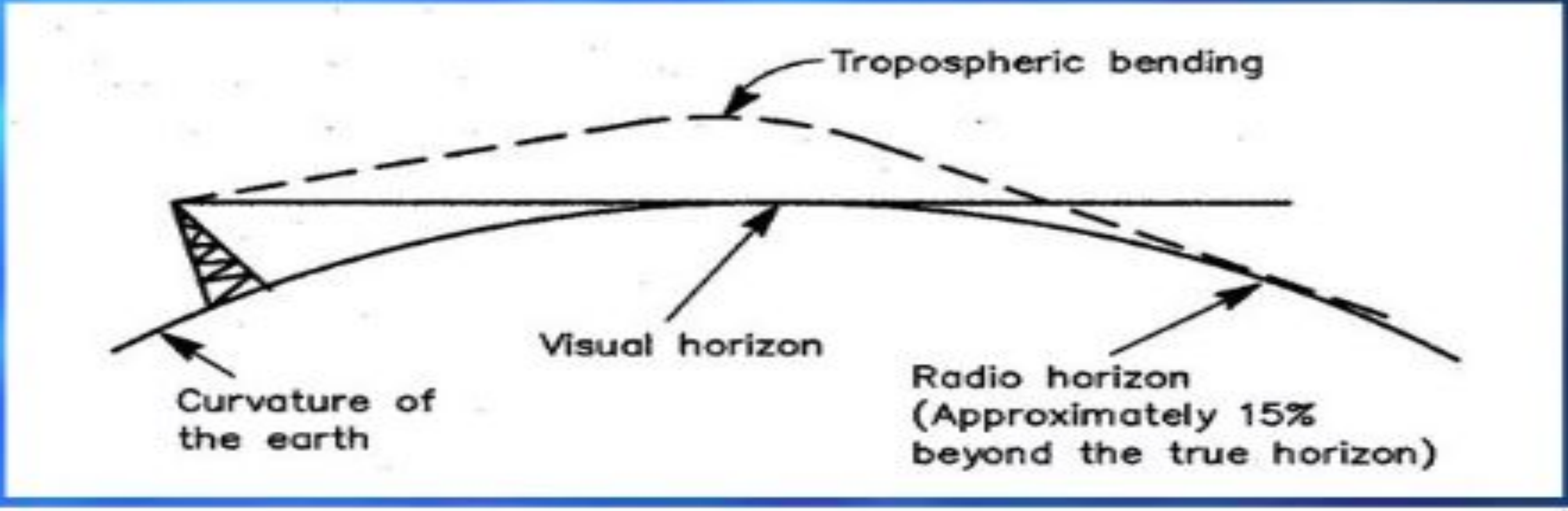
- Maximum usable frequency (MUF)
  - The highest frequency that is returned to the earth from the ionosphere between two specific points on earth
- Optimum Working frequency:
  - The frequency that provides for the most consistent communication path via sky waves

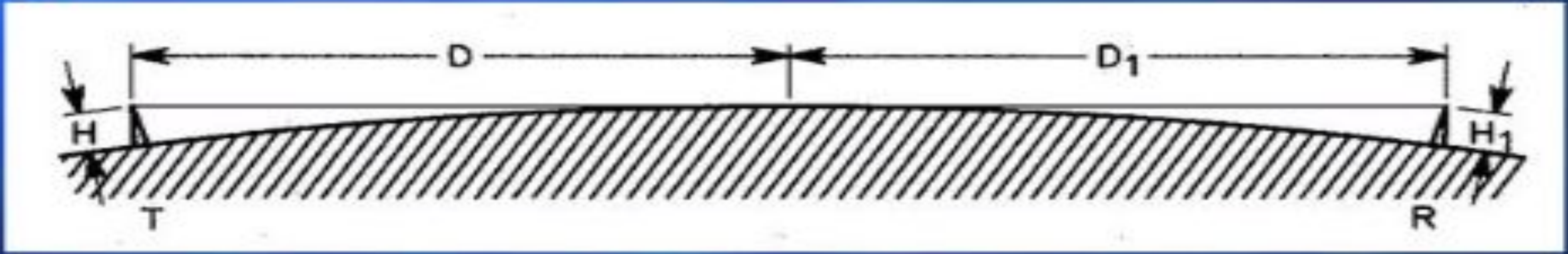
- Quiet Zone or Skip Zone:
  - The space between the point where the ground wave is completely dissipated and the point where the first sky wave is received
- Fading:
  - Variations in signal strength that may occur at the receiver over a period of time.

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

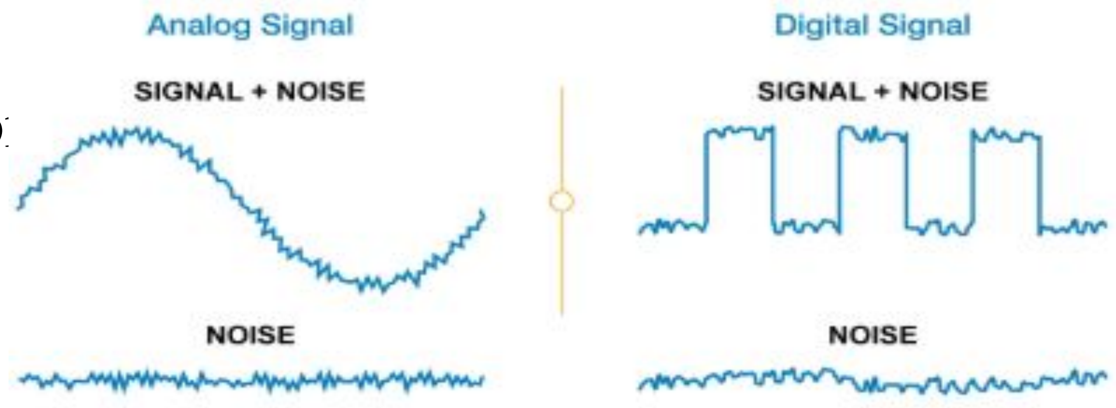




The distance D to the radio horizon is greater from a higher antenna. The maximum distance over which two stations may communicate by space wave is equal to the sum of their distances to the horizon.

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 conversatio
- **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
- Extra-terrestrial 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 system due to communication

1. 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

2. 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

3. 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

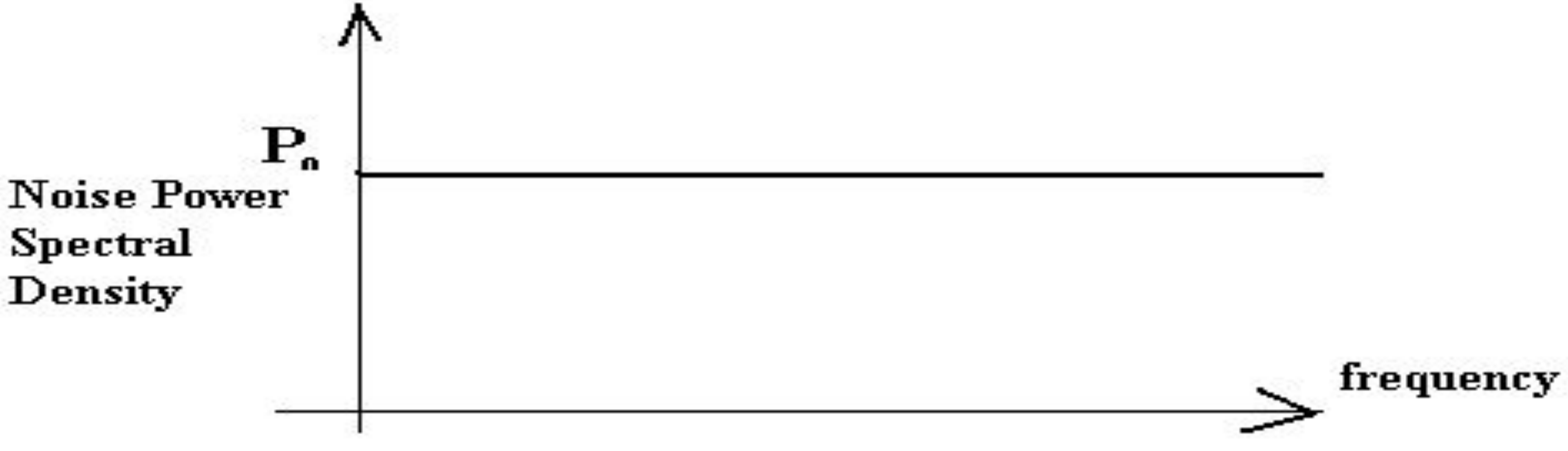
1. **Thermal Agitation Noise :**
   - The noise generated in a resistance or the resistive component is random and is referred to as thermal,
   - White or Johnson noise is due to the rapid and random motion of the molecules (atoms and electrons) inside the component itself.
   - The kinetic energy of 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.

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

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

$$N = k\,TB \text{ watts}$$

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



Uniform Noise Power Spectral Density

INTERNAL NOISE

Therefore

$$P_n \propto T\,\Delta f = kT\,\Delta f$$

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?

Solution

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

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

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

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

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)

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

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

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

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

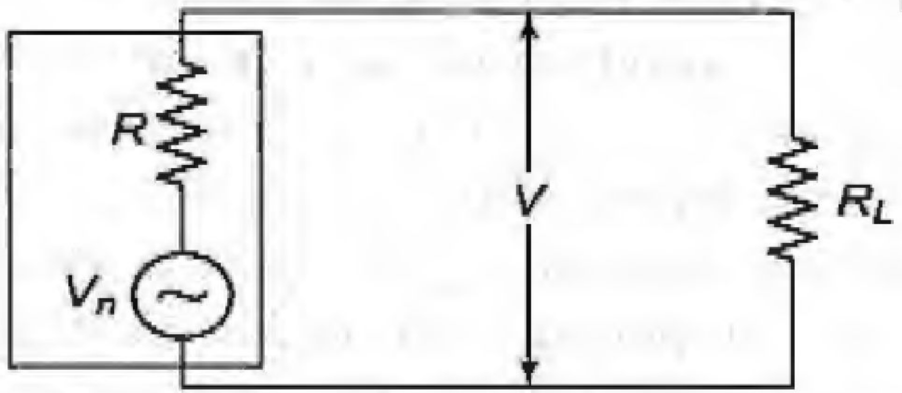


Fig. 2.1 *Resistance noise generator.*

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

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

$$= \sqrt{4 \times 1.38 \times 10^{-23} \times (27 + 273) \times (20 - 18) \times 10^6 \times 10^4}$$

$$= \sqrt{4 \times 1.38 \times 3 \times 2 \times 10^{-11}} = 1.82 \times 10^{-5}$$

$$= 18.2 \text{ microvolts } (18.2\,\mu\text{V})$$

INTERNAL NOISE :

2. **Shot Noise**

- Shot noise occurs in all amplifying devices and virtually **in all active devices** (Diode, Transistor, SCR, ICs, DC generator, Current & Voltage sources etc.)
- 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.

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

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

Where

I_{DC} is the direct current as the *pn* junction (amps)

I_o is the reverse saturation current (amps)

q_e is the electron charge = 1.6×10^{-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

3. 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)

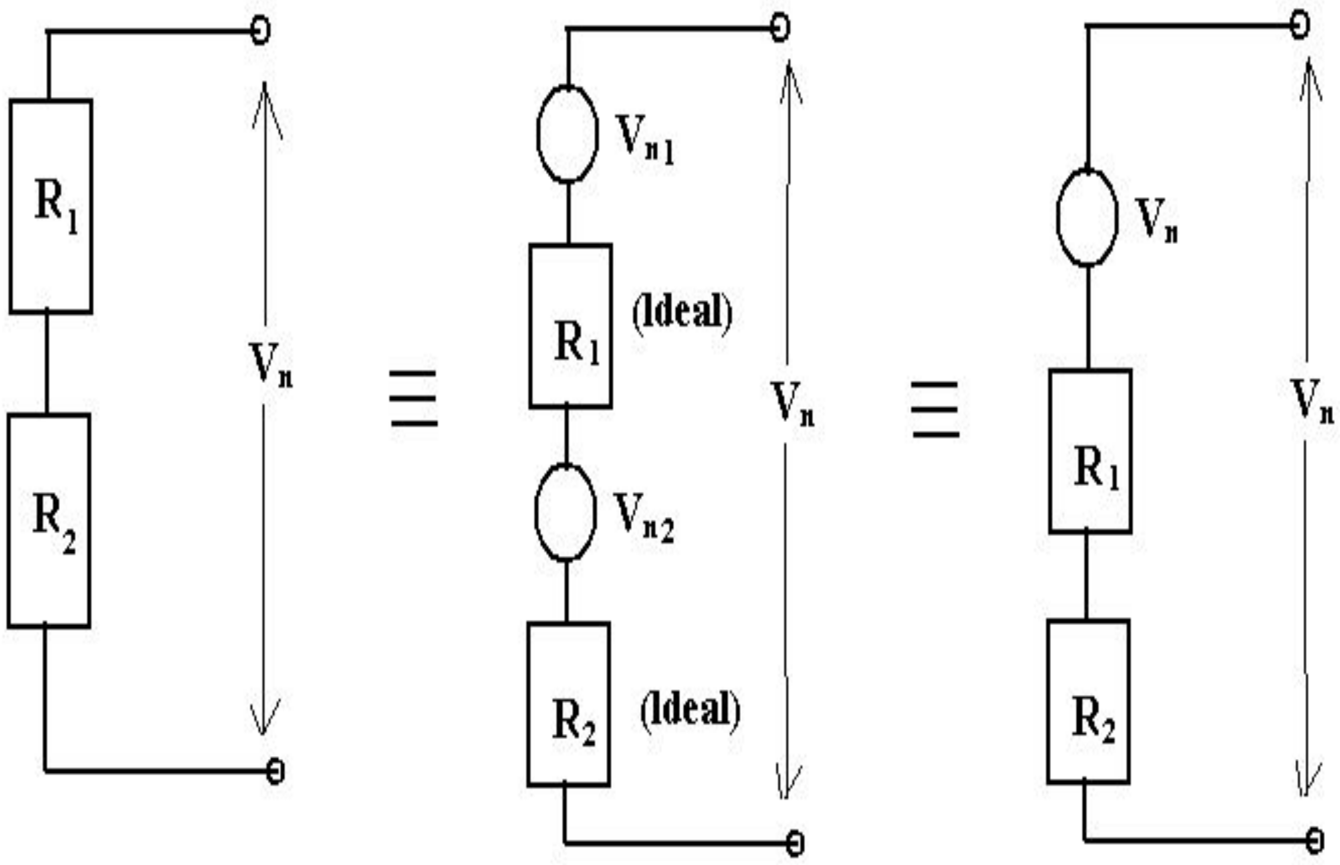
- Once this high-frequency noise makes its presence felt, it goes on increasing with frequency at a rate that soon approaches 6 decibels (6 dB) per octave

- 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



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

$$\overline{V_{n1}^{\,2}} = 4kT_1 B R_1$$

$$\overline{V_{n2}^{\,2}} = 4kT_2 B R_2$$

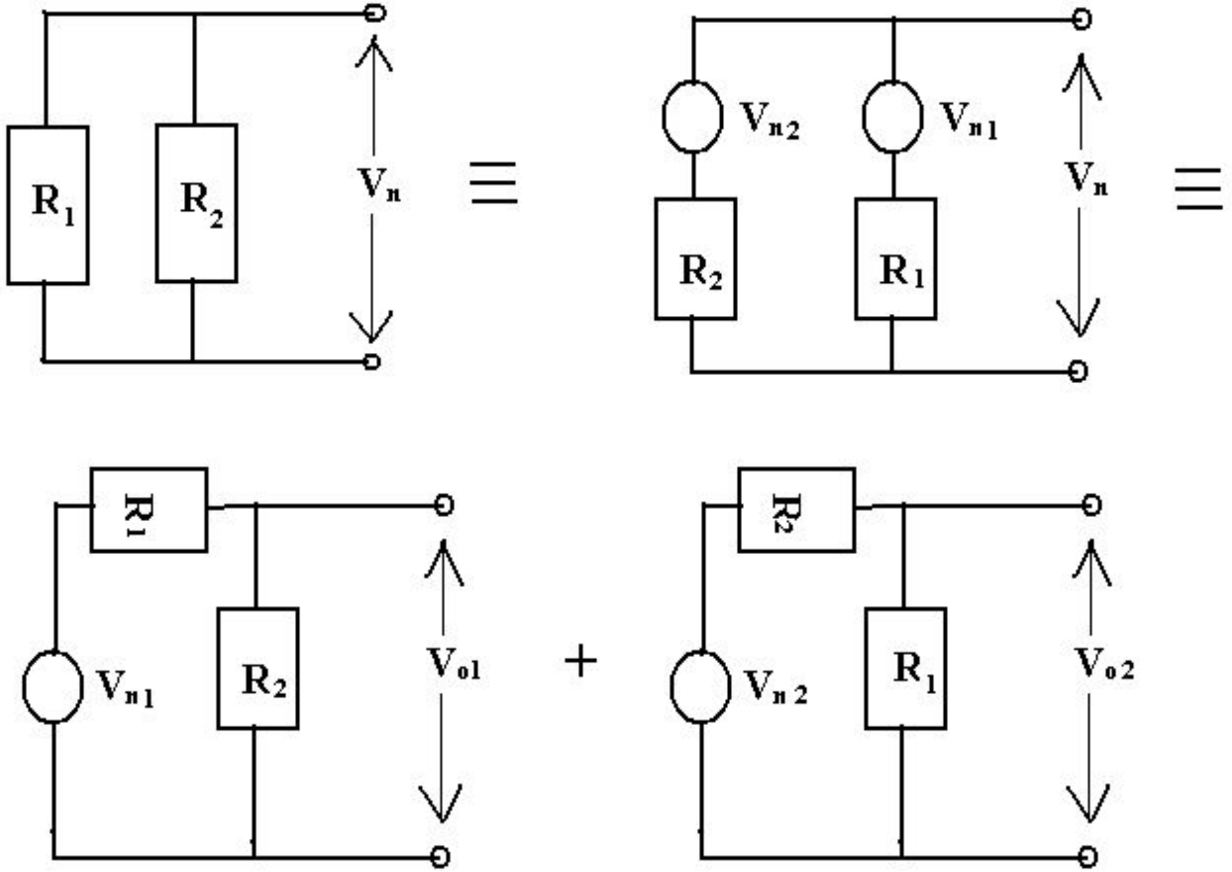
$$\therefore \ \overline{V_n^{\,2}} = 4kB(T_1R_1 + T_2 R_2)$$

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

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

$$V_{n,\text{tot}} = \sqrt{4kT\,\Delta f\,R_{\text{tot}}}$$

$$= \sqrt{4 \times 1.38 \times 10^{-23} \times (17 + 273) \times 6 \times 10^{6} \times (300 + 200)}$$

$$= \sqrt{4 \times 1.38 \times 2.9 \times 6 \times 5 \times 10^{-13}} = \sqrt{48 \times 10^{-12}}$$

$$= 6.93 \times 10^{-6} = 6.93\,\mu\text{V}$$

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

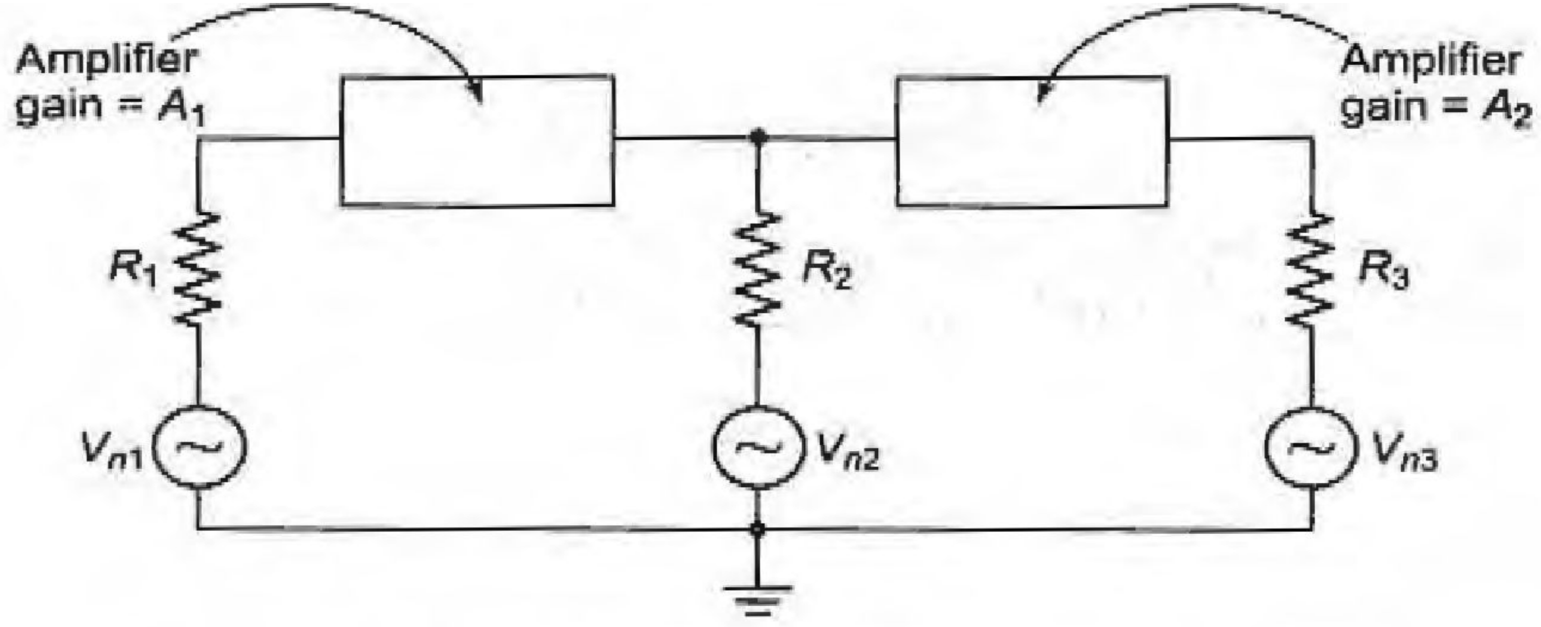


Fig. 2.2 *Noise of several amplifying stages in cascade.*

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

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

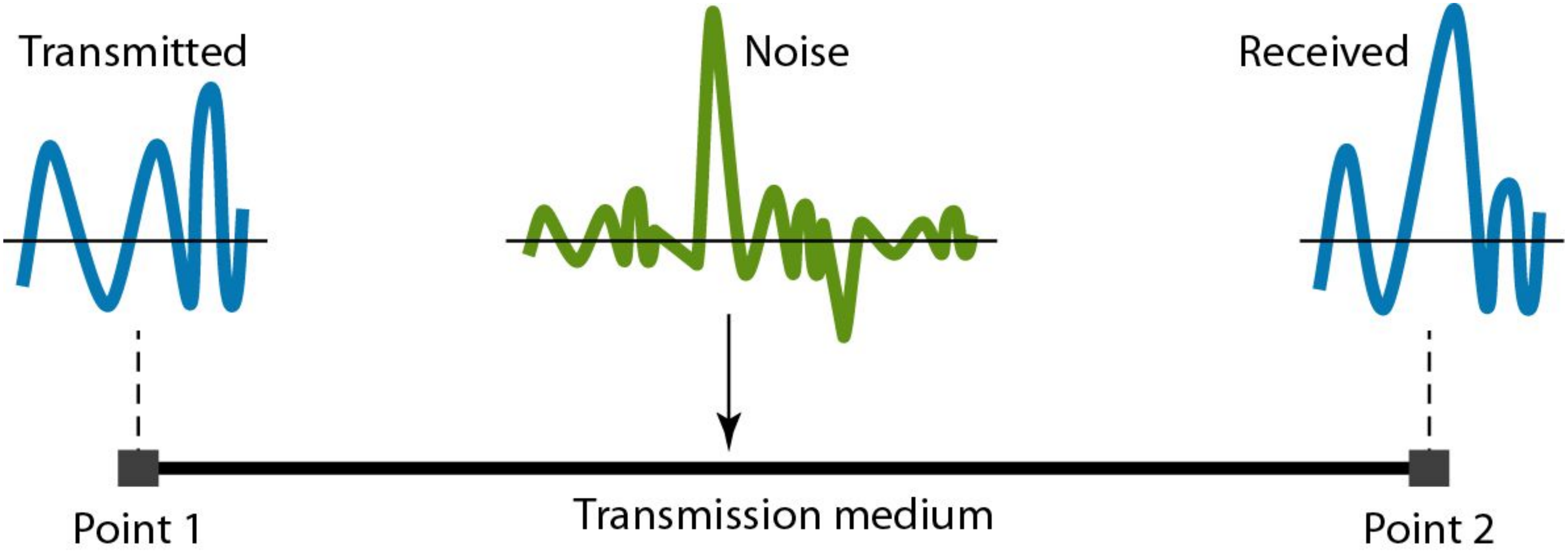
The calculation of the equivalent noise resistance of an amplifier, receiver or device may have one of **two purposes** or sometimes both.

- 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

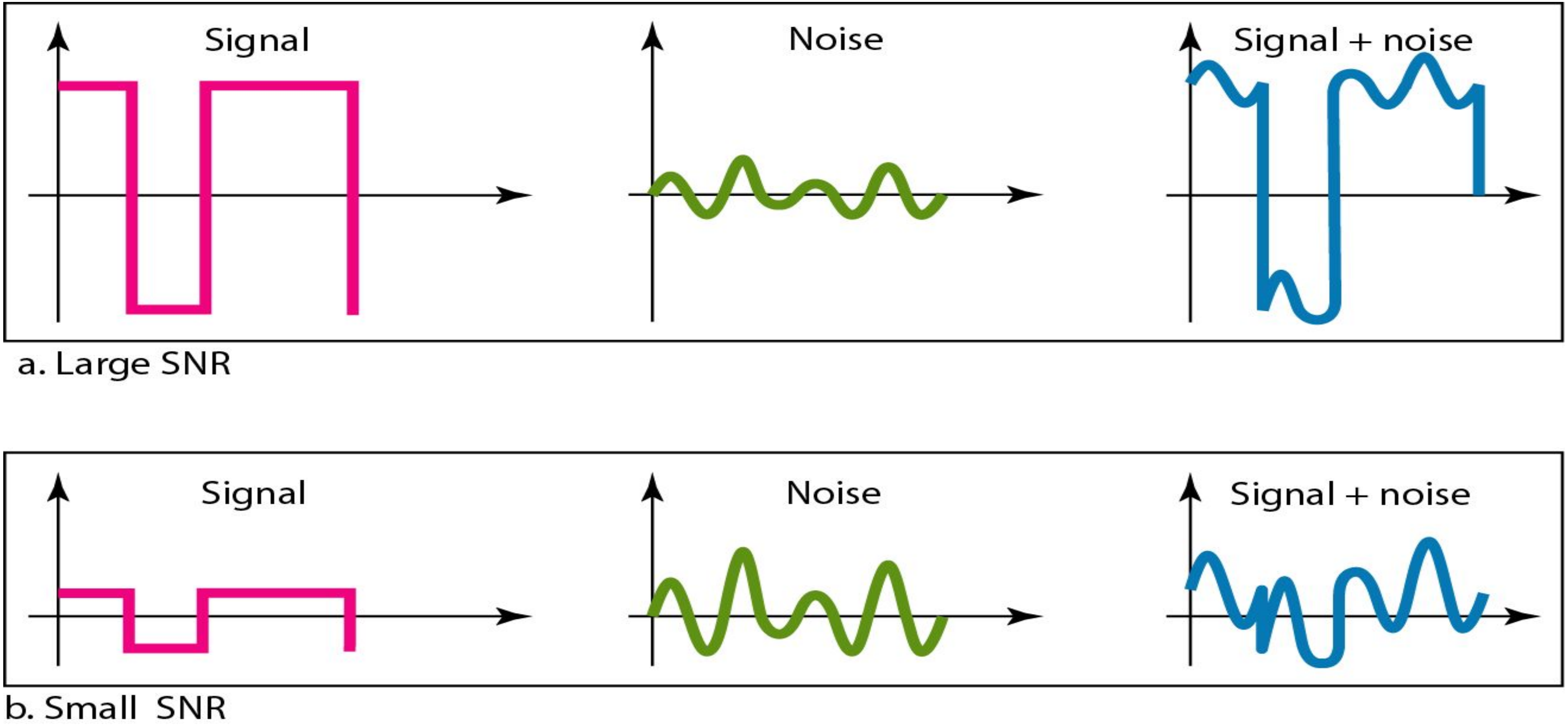
The values of SNR and SNRdB for a noiseless channel are

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

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

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

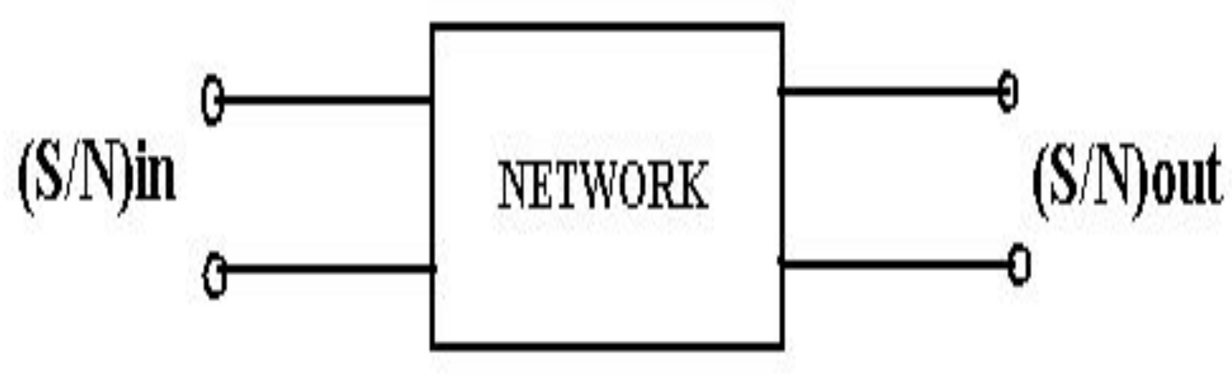
Figure Two cases of SNR: a high SNR and a low SNR



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

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



- 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 $F \geq 0$ 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

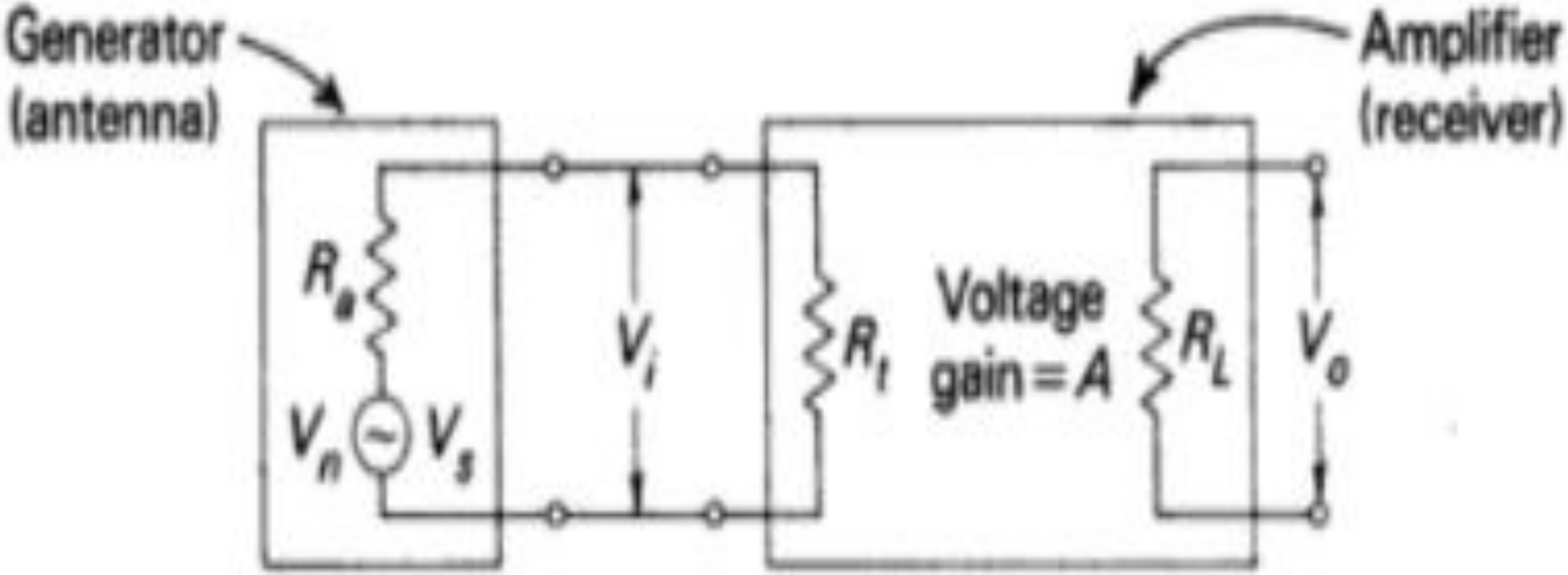


FIGURE 2-4 Block diagram for noise figure calculation.

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

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

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

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

$$\frac{\mathrm{S}}{\mathrm{N}_o} = \frac{P_{so}}{P_{no}} = \frac{A^2V_2^2R_t^2}{(R_a + R_t)^2R_LP_{no}} \tag{2-19}$$

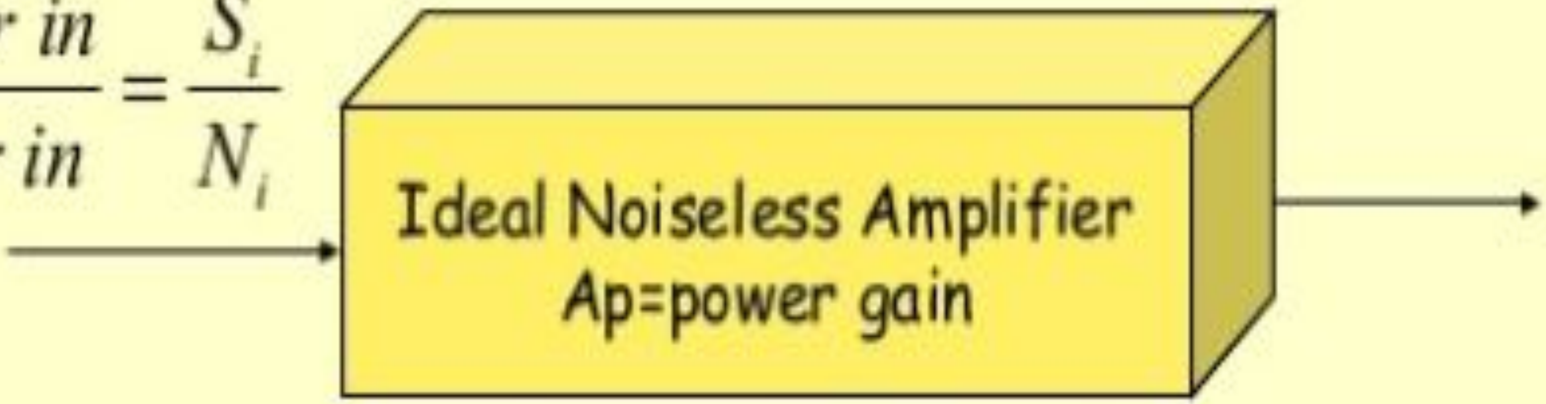
Finally, the general expression for the noise figure is

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

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

Ideal Noiseless Amplifier

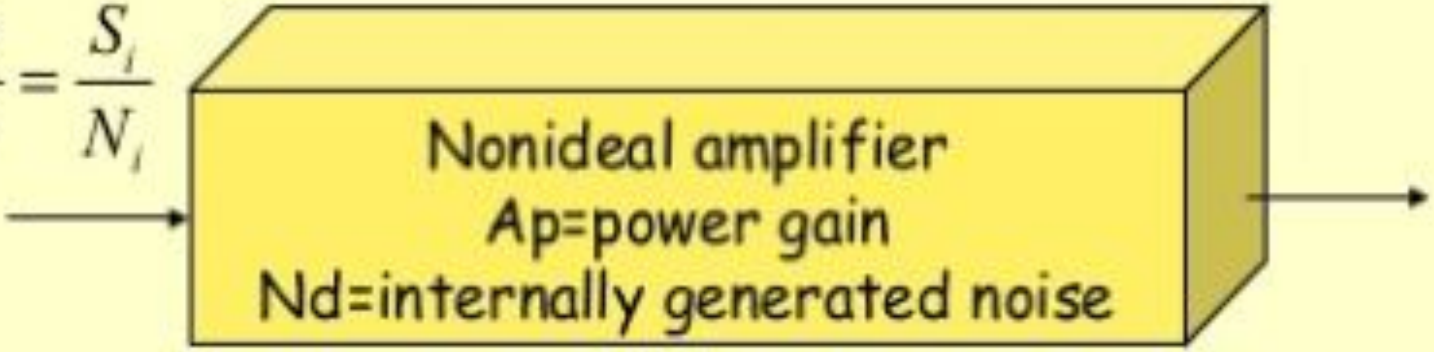
$$\frac{Signal\ \ power\ in}{Noise\ \ power\ in}=\frac{S_i}{N_i}$$



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

Non ideal amplifier

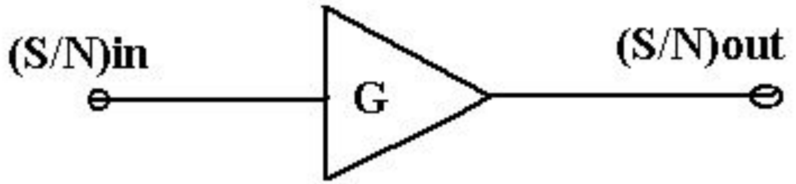
$$\frac{Signal\ power\ in}{Noise\ power\ in} = \frac{S_i}{N_i}$$



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

Noise Figure – Noise Factor for Active Elements

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



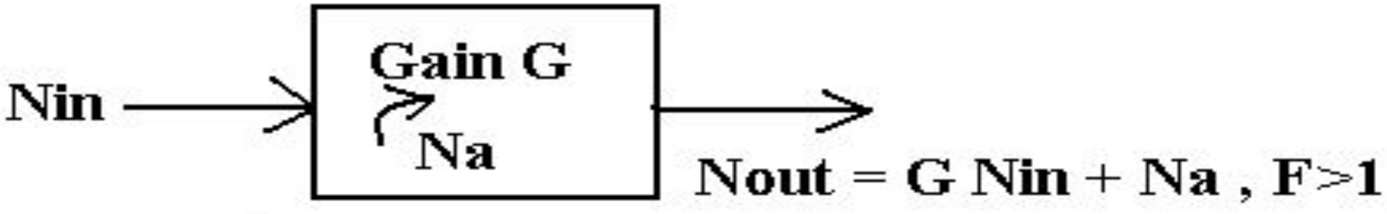
$$F = \frac{\left(S/N\right)_{IN}}{\left(S/N\right)_{OUT}} = \frac{S_{IN}}{N_{IN}}\frac{N_{OUT}}{S_{OUT}}$$

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

Therefore

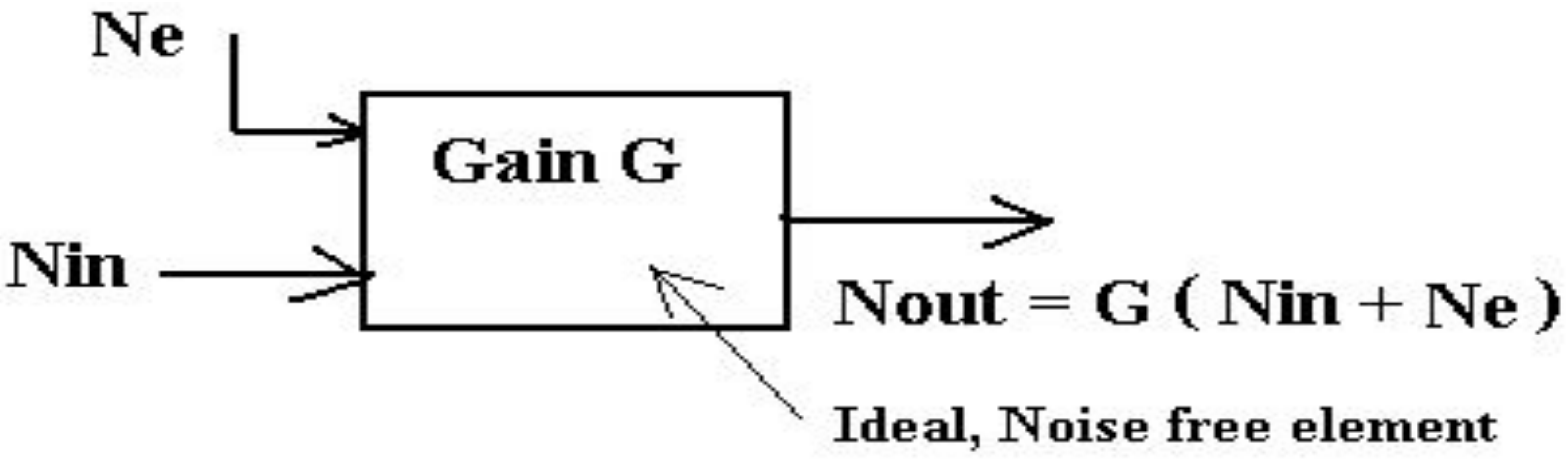
$$F = \frac{S_{IN}}{N_{IN}}\frac{N_{OUT}}{G\,S_{IN}} = \frac{N_{OUT}}{G\,N_{IN}}$$

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.

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

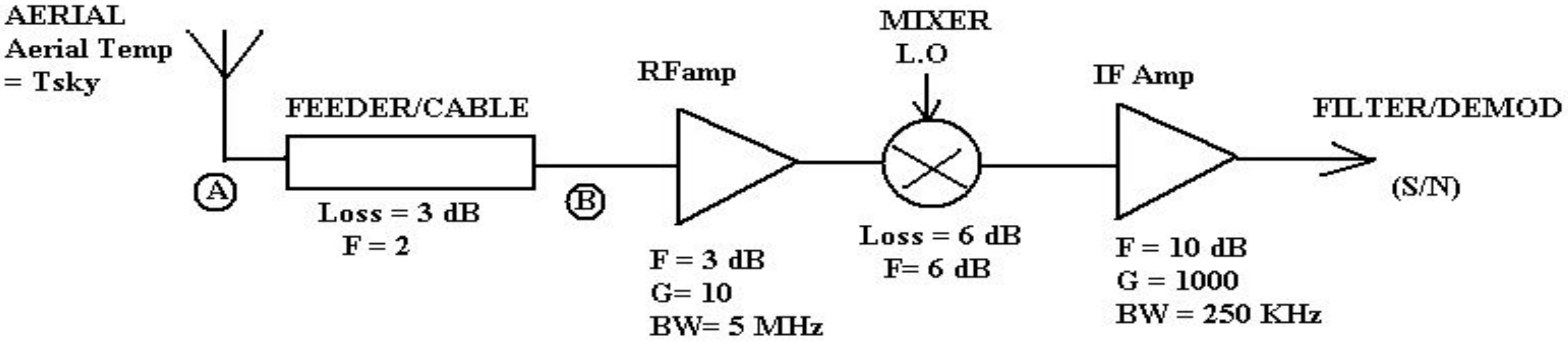
Review of Noise Factor – Noise Figure –Temperature

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

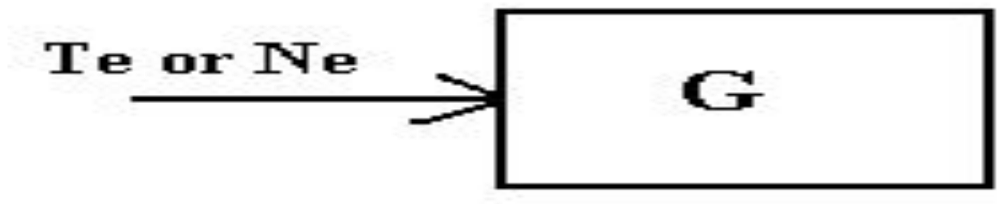
Device	**Frequency**	T_e **(K)**	$\mathbf{F_{dB}}$ **(dB)**	**Gain (dB)**
Maser Amplifier	9 GHz	4	0.06	20
Ga As Fet amp	9 GHz	330	303	6
Ga As Fet amp	1 GHz	110	1.4	12
Silicon Transistor	400 MHz	420	3.9	13
L C Amp	10 MHz	1160	7.0	50
Type N cable	1 GHz		2.0	2.0

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



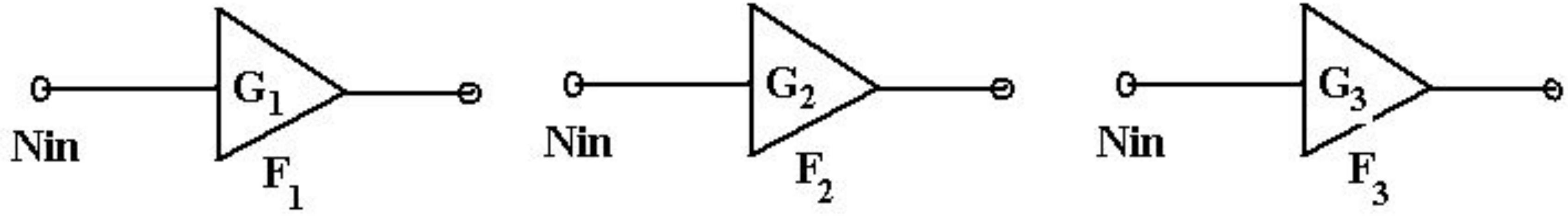
In order to determine the (S/N) at the input, the overall receiver noise figure or noise temperature must be determined. In order to do this all the noise must be referred to the same point in the receiver, for example to A, the feeder input or B, the input to the first amplifier.



T_e or N_e is the noise referred to the input.

System Noise Figure

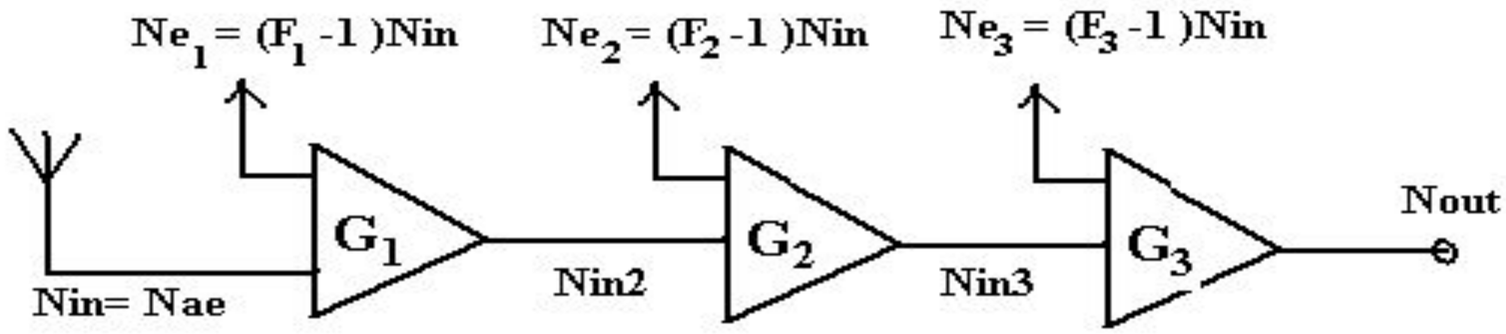
Assume that a system comprises the elements shown below,



$$N_{IN} = N_{ae}$$

Assume that these are now cascaded and connected to an aerial at the input, with

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.

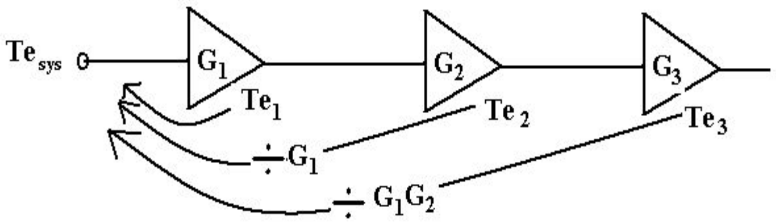
$$F_{sys} = F_1 + \frac{\left(F_2 - 1\right)}{G_1} + \frac{\left(F_3 - 1\right)}{G_1 G_2} + \frac{\left(F_4 - 1\right)}{G_1 G_2 G_3} + \ldots\ldots\ldots\ldots + \frac{\left(F_n - 1\right)}{G_1 G_2 \ldots\ldots\ldots\ldots G_{n-1}}$$

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

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

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

$$which\ gives$$

$$T_{e\ sys} = T_{e1} + \frac{T_{e\,2}}{G_1} + \frac{T_{e3}}{G_1G_2} + \frac{T_{e4}}{G_1G_2G_3} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

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 $= 2\times10^{-10}$ W
  Input Noise power $= 2\times10^{-18}$ W
  Power gain $= 1{,}000{,}000$
  Internal noise $(N_d) = 6\times10^{-12}$ 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?