

Module 4

Fundamentals of Communication

4.1 ELEMENTS OF AN ELECTRICAL COMMUNICATION SYSTEM

Communication is the transfer of information from one place to another place. Communication system is a system which describes the information exchange between two points. The major elements of communication are the transmitter of information, channel or medium of communication and receiver of information.

The information to be transmitted passes through several stages of the communication system prior it reaches its destination. Figure shows a block schematic diagram of the most general form of basic communication system.

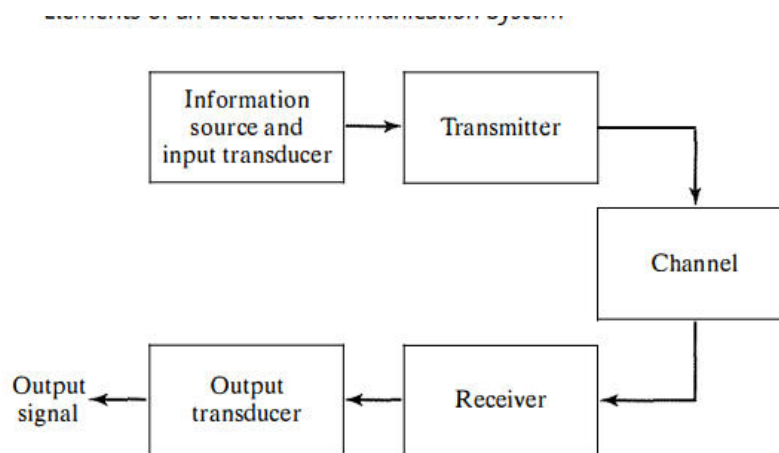


Figure 4.1. Functional diagram of a communication system.

The main constituents of basic communication system are:

- (i) Transmitter
- (ii) Channel or medium
- (iii) Receiver

(i) Transmitter.

- The transmitter converts the electrical signal into a form that is suitable for transmission through the physical channel or transmission medium.
- For example, in radio and TV broadcasts, the FCC specifies the frequency range for each transmitting station.
- Hence, the transmitter must translate the outgoing information signal into the appropriate frequency range that matches the frequency allocation assigned to the transmitter.
- Thus, signals transmitted by multiple radio stations do not interfere with one another. Similar functions are performed in telephone communication systems where the electrical speech signals from many users are transmitted over the same wire.

- In general, the transmitter matches the message signal to the channel via a process called modulation. Usually, modulation involves the use of the information signal to systematically vary either the amplitude or the frequency or the phase of a sinusoidal carrier.
- For example, in AM radio broadcast, the information signal that is transmitted is contained in the amplitude variations of the sinusoidal carrier, which is the center frequency in the frequency band allocated to the radio transmitting station.
- This is an example of amplitude modulation. In an FM radio broadcast, the information signal that is transmitted is contained in the frequency variations of the sinusoidal carrier. This is an example of frequency modulation.
- In general, carrier modulation such as AM, FM, and PM is performed at the transmitter, as previously indicated, to convert the information signal to a form that matches the characteristics of the channel.
- Thus, through the process of modulation, the information signal is translated in frequency to match the allocation of the channel.
- The choice of the type of modulation is based on several factors, such as the amount of bandwidth allocated, the types of noise and interference that the signal encounters in transmission over the channel, and the electronic devices that are available for signal amplification prior to transmission.
- In any case, the modulation process makes it possible to accommodate the transmission of multiple messages from many users over the same physical channel.
- In addition to modulation, other functions that are usually performed at the transmitter are filtering of the information-bearing signal, amplification of the modulated signal and, in the case of wireless transmission, radiation of the signal by means of a transmitting antenna.

(ii)Channel.

- The communication channel is the physical medium that is used to send the signal from the transmitter to the receiver. In wireless transmission, the channel is usually the atmosphere (free space).
- On the other hand, telephone channels usually employ a variety of physical media, including wirelines, fiber optic cables, and wireless (microwave radio).
- Whatever the physical medium for signal transmission, the essential feature is that the transmitted signal is corrupted in a random manner by a variety of possible mechanisms.
- The most common form of signal degradation comes in the form of additive noise, which is generated at the front end of the receiver, where signal amplification is performed.
- This noise is often called thermal noise. In wireless transmission, additional additive disturbances are man-made noise and atmospheric noise picked up by a receiving antenna.

- Automobile ignition noise is an example of man-made noise, and electrical lightning discharges from thunderstorms is an example of atmospheric noise.
- Interference from other users of the channel is another form of additive noise that often arises in both wireless and wireline communication systems.
- In some radio communication channels, such as the ionospheric channel that is used for long-range, short-wave radio transmission, another form of signal degradation is multipath propagation.
- Such signal distortion is characterized as a nonadditive signal disturbance that manifests itself as time variations in the signal amplitude, usually called fading.
- The effect of these signal distortions must be considered in the design of the communication system.
- In the design of a communication system, the system designer works with mathematical models that statistically characterize the signal distortion encountered on physical channels.
- Often, the statistical description that is used in a mathematical model is a result of actual empirical measurements obtained from experiments involving signal transmission over such channels.
- In such cases, there is a physical justification for the mathematical model used in the design of communication systems.

(iii) The Receiver.

- The function of the receiver is to recover the message signal contained in the received signal.
- If the message signal is transmitted by carrier modulation, the receiver performs carrier demodulation to extract the message from the sinusoidal carrier.
- Since the signal demodulation is performed in the presence of additive noise and possibly other signal distortions, the demodulated message signal is generally degraded to some extent by the presence of these distortions in the received signal.
- As we shall see, the fidelity of the received message signal is a function of the type of modulation and the strength of the additive noise.
- Besides performing the primary function of signal demodulation, the receiver also performs a number of peripheral functions, including signal filtering and noise suppression.

4.1.1 Digital Communication System

- Analog signals can be transmitted directly over the communication channel via carrier modulation and demodulated accordingly at the receiver. We call such a communication system an analog communication system.
- Alternatively, an analog source output may be converted into a digital form, and the message can be transmitted via digital modulation and demodulated as a digital signal at the receiver.

- There are some potential advantages to transmitting an analog signal by means of digital modulation.
- The most important reason is that signal fidelity is better controlled through digital transmission than through analog transmission. In particular, digital transmission allows us to regenerate the digital signal in long-distance transmission, thus eliminating effects of noise at each regeneration point.
- In contrast, the noise added in analog transmission is amplified along with the signal when amplifiers are periodically used to boost the signal level in long-distance transmission.
- Another reason for choosing digital transmission over analog is that the analog message signal may be highly redundant. With digital processing, redundancy may be removed prior to modulation, thus conserving channel bandwidth.
- Figure 4.2 illustrates the functional diagram and the basic elements of a digital communication system.

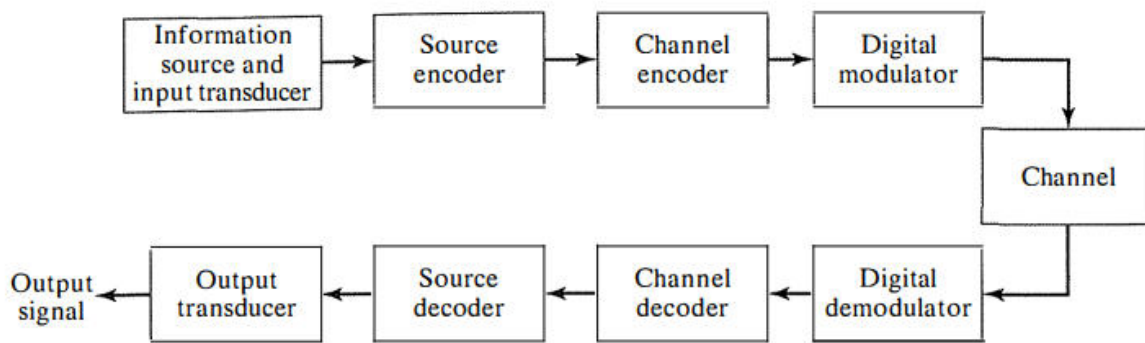


Figure 4.2. Digital Communication System

- The source output may be either an analog signal, such as an audio or video signal, or a digital signal, such as computer output, which is discrete in time and has a finite number of output characters.
- In a digital communication system, the messages produced by the source are usually converted into a sequence of binary digits. Ideally, we would like to represent the source output (message) with as few binary digits as possible.
- In other words, we seek an efficient representation of the source output that results in little or no redundancy.
- The process of efficiently converting the output of either an analog or a digital source into a sequence of binary digits is called source encoding or data compression.
- The source encoder outputs a sequence of binary digits, which we call the information sequence; this is passed to the channel encoder.
- The purpose of the channel encoder is to introduce, in a controlled manner, some redundancy in the binary information sequence that can be used at the receiver to overcome the effects of noise and interference encountered in the transmission of the signal through the channel.

- The binary sequence at the output of the channel encoder is passed to the digital modulator, which serves as the interface to the communication channel.
- Since nearly all of the communication channels encountered in practice are capable of transmitting electrical signals (waveforms), the primary purpose of the digital modulator is to map the binary information sequence into signal waveforms.

4.2 COMMUNICATION CHANNELS AND THEIR CHARACTERISTICS

- As indicated in the previous lecture, the communication channel provides the connection between the transmitter and the receiver. Communication channels can be either:
 - **Wirelines** that carry the electrical signal,
 - **Optical fiber** that carries the information on a modulated light beam,
 - **Free space** over which the signal is radiated in the form of **electromagnetic waves** by use of an antenna,
 - **Underwater ocean channel** that transmits information acoustically.
- Other media that can be characterized as communication channels are data storage media, such as magnetic tape, magnetic disks, and optical disks.
- Next, we describe some of the important characteristics of these communication channels.

Wireline Channels

- Signals transmitted through wireline channels are distorted in both **amplitude** and **phase**, and they are further corrupted by **additive noise**.
- **Twisted-pair wirelines** and **coaxial cable** are basically **guided electromagnetic channels** that provide relatively **modest bandwidths**.
 - **Twisted-pair cables (1–128 Mbps)** are generally used to connect a customer to a central office. They consist of strands of insulated copper wires, with each pair twisted around each other to reduce **crosstalk interference** generated by the electrical fields of physically adjacent channels. Example: **telephone lines**.
 - **Coaxial cables (up to 200 Mbps)** consist of insulated thick copper wire wrapped in a metal shield, then an external plastic cover. They are used for communications of **higher bandwidth** than twisted-pair. Example: **TV cable**.

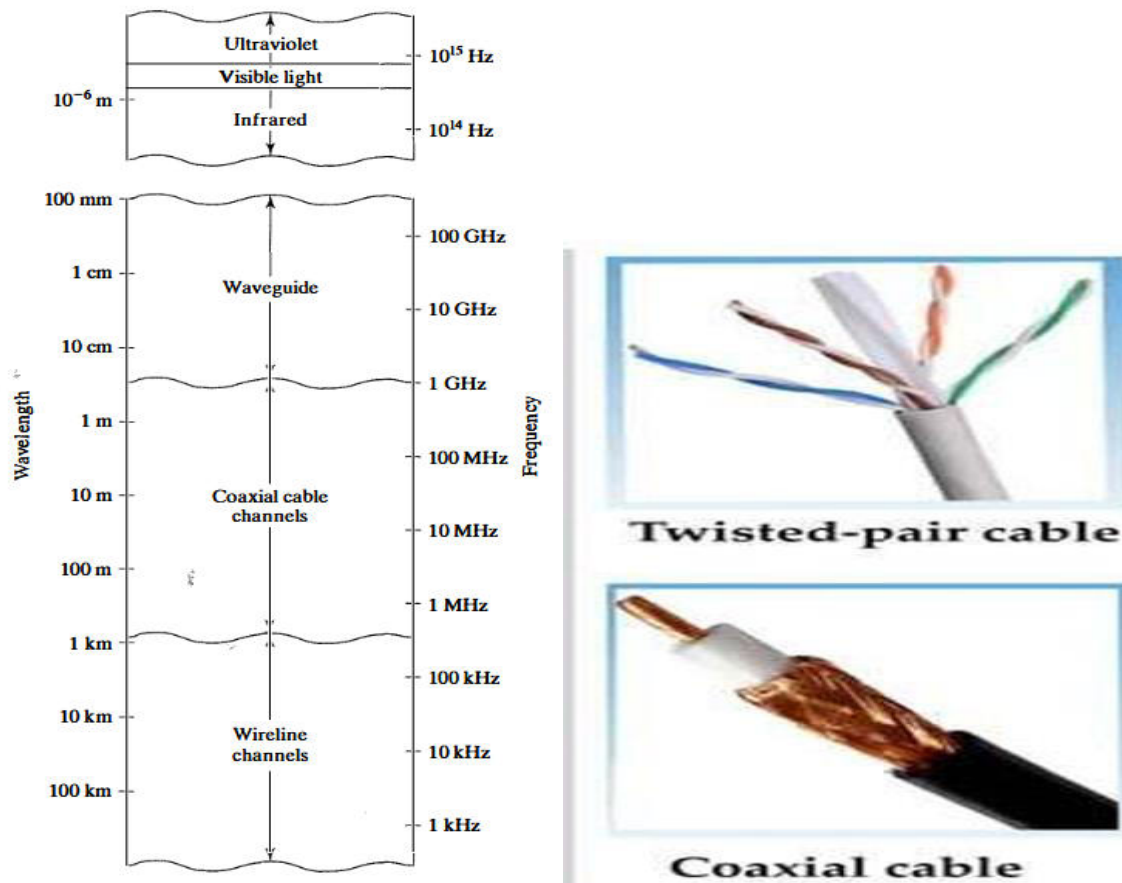
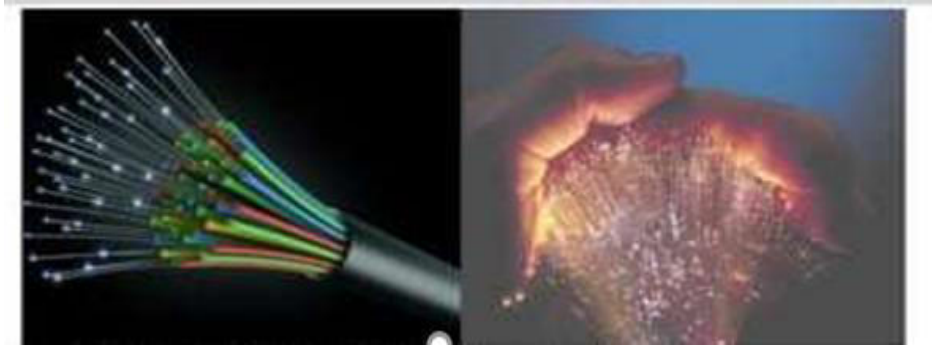


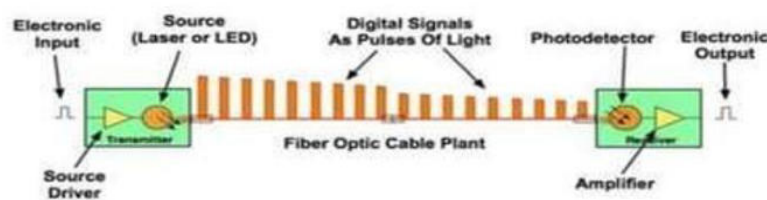
Figure 4.3 Frequency range for guided wireline channels.

Fiber Optic Channels

- **Optical fiber cables (100 Mbps – 10 Gbps)** consist of hundreds of thin strands of glass/plastic fiber that transmit data through pulses of **light** instead of electric signals, which eliminates the need for electrical interference.
- Optical fiber cables have a relatively **low signal attenuation** and highly **reliable photonic devices**, which improve signal generation and signal detection.
- Each fiber strand is as thin as a **human hair**, and it can transmit up to **10 billion pulses per second (2 Gbps)**.
- Optical fiber cables can be found in **domestic telecommunication systems**, mainly in the **Internet backbone**, as well as in **transatlantic and transpacific communications**.



- The transmitter or modulator in a fiber-optic communication system is a **light source**, either a **light-emitting diode (LED)** or a **laser**, such that information is transmitted by varying (**modulating**) the **intensity of the light source** with the message signal.
- The light propagates through the fiber as a **light wave** and is **amplified periodically** along the transmission path to compensate for **signal attenuation**.
- At the receiver, the **light intensity** is detected by a **photodiode**, whose output is an **electrical signal**.



Comparison of Wirelines vs. Optical Fiber Channels

Twisted pair cable	Co-axial cable	Optical fiber
1. Transmission of signals takes place in the electrical form over the metallic conducting wires.	1. Transmission of signals takes place in the electrical form over the inner conductor of the cable.	1. Signal transmission takes place in an optical form over a glass fiber.
2. In this medium the noise immunity is low.	2. Coaxial having higher noise immunity than twisted pair cable.	2. Optical fiber has highest noise immunity as the light rays are unaffected by the electrical noise.
3. Twisted pair cable can be affected due to external magnetic field.	3. Coaxial cable is less affected due to external magnetic field.	3. Not affected by the external magnetic field.
4. Cheapest medium.	4. Moderate Expensive.	4. Expensive
5. Low Bandwidth.	5. Moderately high bandwidth.	5. Very high bandwidth
6. Attenuation is very high.	6. Attenuation is low.	6. Attenuation is very low.
7. Installation is easy.	7. Installation is fairly easy.	7. Installation is difficult.

Wireless Electromagnetic (EM) Channels

- **Wireless Electromagnetic (EM) Channels** are communication channels that can be used to transmit data through **free space**.
Examples are **Infrared, Bluetooth, Satellite, Broadcast radio, and Microwave**.
- **Figure 4.4** illustrates the **frequency range** and **use** of the available wireless EM channels.

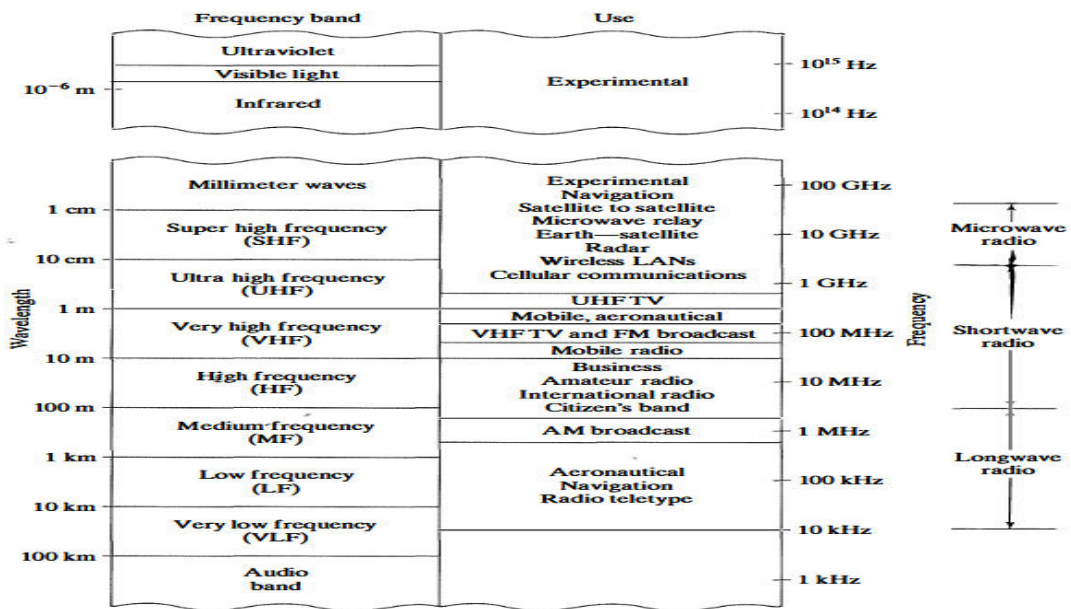


Figure 4.4 Frequency range for wireless electromagnetic channels.

- The mode of propagation of electromagnetic waves in the atmosphere and in free space may be subdivided into three categories, namely, ground-wave propagation, sky-wave propagation, and line-of-sight (LOS) propagation.
- In the very low frequency (VLF) and extremely low frequency bands where the wavelengths exceed 10 kilometers, the earth and the ionosphere act as a waveguide for electromagnetic wave propagation.
- In these frequency ranges, communication signals practically propagate around the globe.
- For this reason, these frequency bands are primarily used to provide navigational aids from shore to ships around the world. The channel bandwidths available in these frequency bands are relatively small (usually 1 %-10% of the center frequency);
- hence, the information that is transmitted through these channels is relatively of slow speed and generally confined to digital transmission.
- A dominant type of noise at these frequencies is generated from thunderstorm activity around the globe, especially in tropical regions. Interference results from the many users of these frequency bands.

- The mode of propagation of EM waves in the atmosphere and in free space may be subdivided into **three categories**:
 1. **Ground-wave propagation**
 2. **Sky-wave propagation**
 3. **Line-of-sight (LOS) propagation**

1. Ground-wave Propagation

- In **Very Low Frequency (VLF)** and below, where wavelengths exceed **10 km**, the **earth and ionosphere act as a waveguide** for EM wave propagation, and communication signals propagate around the globe.
- Channel bandwidths available in these frequency bands are **relatively very small**. Hence, they are primarily used to provide **navigational aids from shore to ships** around the world.
- **Noise** is mainly due to **thunderstorms** and **interference from many users**.
- **Ground-wave propagation**, illustrated in **Figure 4.5**, is the **dominant mode of propagation** for frequencies in the **medium frequency (MF) band (0.3–3 MHz)**.
- This is the frequency band used for **AM broadcasting** and **maritime radio broadcasting**.
- In **AM broadcast**, ground-wave propagation limits the range of even the most powerful radio stations to about **100 miles**.
- **Atmospheric noise**, **man-made noise**, and **thermal noise** from electronic components at the receiver are dominant disturbances for signal transmission at **MF**.



Figure 4.5 Illustration of Ground-wave propagation.

2. Sky-wave propagation,

- Illustrated in **Figure 4.6**, results from transmitted signals being **reflected (bent or refracted)** from the **ionosphere**.
- The **ionosphere** consists of several layers of charged particles ranging in altitude from **30 to 250 miles** above the surface of the earth.
- During the **daytime hours**, the heating of the lower atmosphere by the sun causes the formation of the **lower layers** at altitudes below **75 miles**, which **absorb frequencies below 2 MHz**; thus, they severely limit sky-wave propagation of **AM radio broadcasts**.
- During the **nighttime hours**, the electron density in the lower layers of the ionosphere **drops sharply**, and the frequency absorption that occurs during the day is **significantly reduced**.
- **Powerful AM radio broadcast stations** can propagate over **large distances via sky-wave** over the ionosphere, ranging from **90 miles to 250 miles** above the surface of the earth.

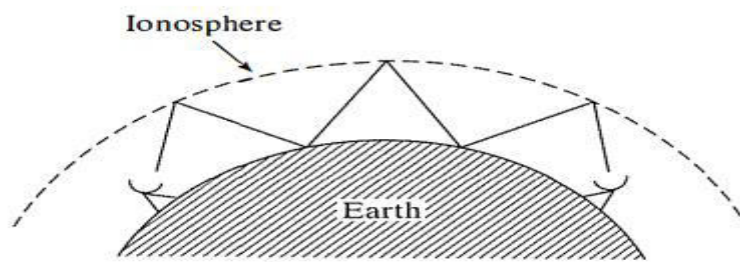


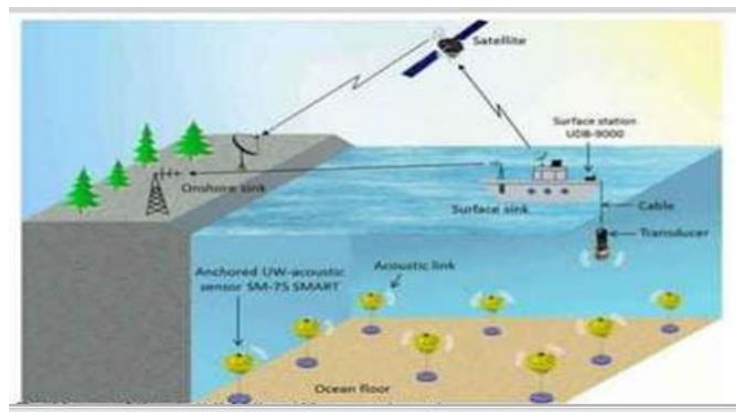
Figure 4.6 Illustration of sky-wave propagation

- In **sky-wave propagation**, a common problem with electromagnetic wave propagation in the **high frequency (HF) range** is **signal multipath**, which occurs when the transmitted signal arrives at the receiver via **multiple propagation paths** at different delays.
- Signal multipath generally results in an **inter-symbol interference** problem.
- Also, the signal components arriving via different propagation paths may add **destructively**, resulting in a phenomenon called **signal fading**.
- Most people have experienced this phenomenon when listening to a **distant radio station at night**, when sky-wave is the dominant propagation mode.
- **Additive noise** at HF is a combination of **atmospheric noise** and **thermal noise**.

- **Sky-wave ionospheric propagation** ceases to exist at frequencies above approximately **30 MHz**, which is the end of the **HF band**.

3. Underwater Acoustic Channels

- For **ocean exploration activities**, there is a need to transmit data collected by **underwater sensors** to the **surface of the ocean**. From there, it is possible to relay the data via a **satellite** to a **data collection center**.
- **Electromagnetic (EM) waves** do **not propagate over long distances underwater**, except at **extremely low frequencies**. However, transmitting signals at such low frequencies is **prohibitively expensive** because of the **large and powerful transmitters** required.



- Electromagnetic waves do not propagate over long distances underwater, except at extremely low frequencies.
- However, the transmission of signals at such low frequencies is prohibitively expensive because of the large and powerful transmitters required.
- The attenuation of electromagnetic waves in water can be expressed in terms of the skin depth, which is the distance a signal is attenuated by $1/e$.
- For seawater, the skin depth $\delta = 250/\sqrt{f}$, where f is expressed in Hertz and δ is in meters. For example, at 10 kHz, the skin depth is 2.5 meters. In contrast, acoustic signals propagate over distances of tens and even hundreds of kilometers.
- A shallow-water acoustic channel is characterized as a multipath channel due to signal reflections from the surface and the bottom of the sea. Due to wave motion, the signal multipath components undergo time-varying propagation delays that result in signal fading.
- In addition, there is frequency-dependent attenuation, which is approximately proportional to the square of the signal frequency. Ambient ocean acoustic noise is caused by shrimp, fish, and various mammals.

- Additionally, man-made acoustic noise exists near harbors. In spite of this hostile environment, it is possible to design and implement efficient and highly reliable underwater acoustic communication systems for transmitting digital signals over large distances.

Storage Channels

- **Information storage and retrieval systems** constitute a significant part of our **data-handling activities** on a daily basis.
- Following are examples of data storage systems that can be characterized as **communication channels**:
 - **Magnetic tapes** – including digital audio tape and video tape.
 - **Magnetic disks** – used for storing large amounts of computer data.
 - **Optical disks** – used for computer data storage, music, and video.



- The process of **storing data** on a **magnetic tape**, **magnetic disk**, or **optical disk** is equivalent to **transmitting a signal** over a **telephone** or a **radio channel**.
- The **read-back process** and the **signal processing** used to recover the stored information are equivalent to the functions performed by a **telephone receiver** or **radio communication system** to recover the transmitted information.
- **Additive noise** generated by the electronic components and **interference from adjacent tracks** is generally present in the readback signal of a storage system.
- The amount of data that can be stored is generally limited by:
 - the **size of the disk or tape**, and
 - the **density** (number of bits stored per square inch) achievable by the **write/read electronic systems and heads**.
- **Channel coding** and **modulation** are essential components of a well-designed **digital magnetic or optical storage system**.

INTRODUCTION TO ANALOG MODULATION TYPES

Modulation

Modulation is the process in which some characteristic of high frequency carrier signal is varied in accordance with the instantaneous value of the message/baseband signal.

The message signal is called as baseband or modulating signal. After modulation, the resultant signal is called modulated signal and the baseband signal of low frequency is transferred to the high frequency modulated signal. The carrier signal can be represented as

$$e_c = E_c \sin(\omega_c t + \phi)$$

where e_c = instantaneous amplitude of carrier

E_c = amplitude of carrier

ω_c = angular frequency of carrier which is equal to $2\pi f_c$ where f_c is carrier frequency

ϕ = initial phase of carrier

After modulation, any one of the said three parameters of carrier signal namely amplitude, frequency, phase is varied keeping the remaining two parameters constant.

Why modulation is required? /Need for modulation

If modulation is not employed the system designer encounter the following problems-

1. Antenna height
2. Narrow bending
3. Poor radiation and penetration
4. Diffraction angle
5. Multiplexing

Types Of Modulation: Continuous-wave Modulation and Pulse modulation

Continuous wave modulation types are-Amplitude Modulation and Angle Modulation. Angle Modulation are of two types-Frequency Modulation and Phase Modulation

Amplitude modulation (AM)

AM is defined as the modulation technique in which the amplitude of the carrier signal is varied in accordance with the instantaneous value of the analog modulating signal keeping frequency and phase of the carrier signal constant.

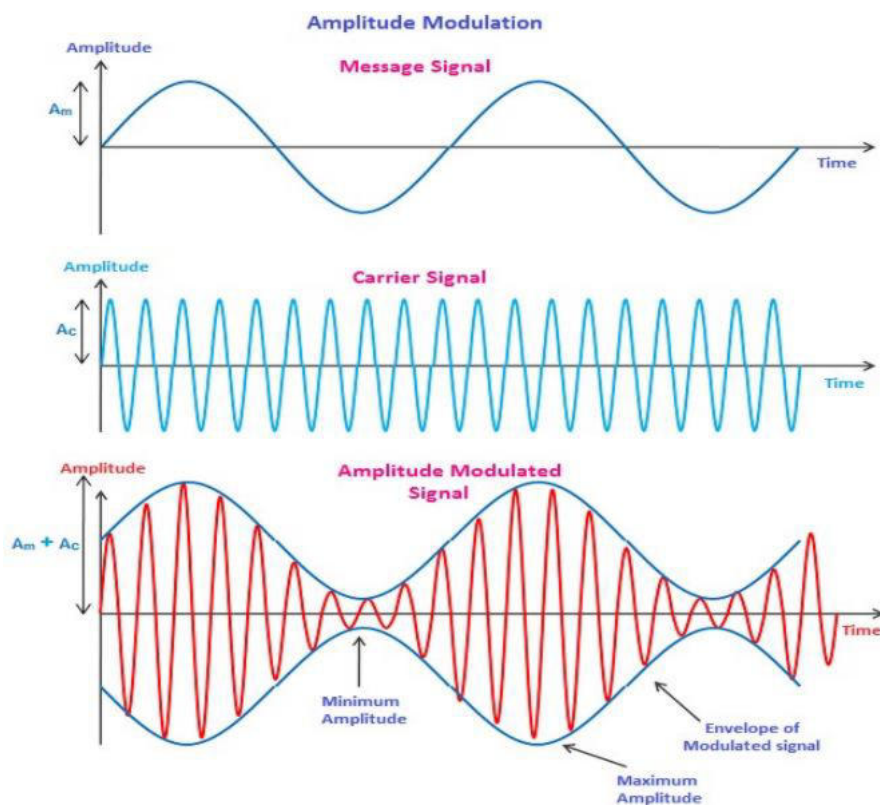
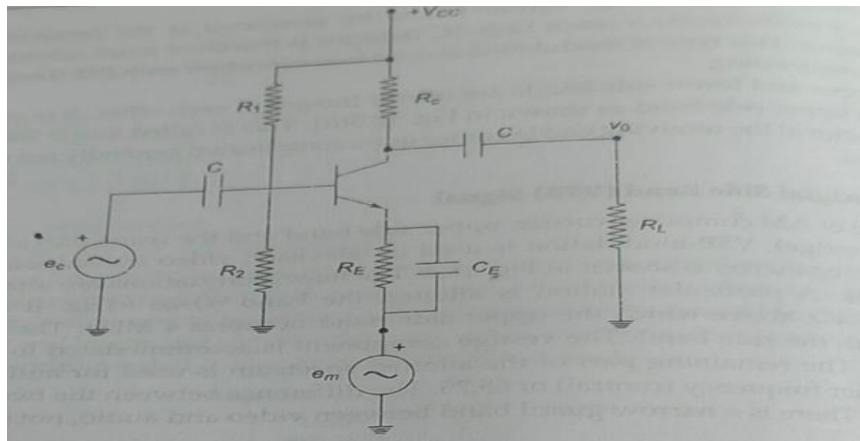
Figure shows the high frequency carrier signal, modulating signal and the modulated signal. The modulating signal is superimposed on the carrier signal. The amplitude variations in the peak values of the carrier signal exactly replicate the modulating signal at different points in time which is known as an envelope.

Amplitude Modulation Circuit

- Amplitude modulation is achieved by feeding the carrier to an amplifier whose gain varies in accordance with the modulating frequency.
- A BJT AM circuit is drawn in Figure in which the carrier signal e_c is fed to the base and the modulating signal e_m to the emitter.

$$r_e = \frac{v_{be}}{i_e} = \frac{r_\pi}{(1 + \beta)}$$

- The large modulating signal causes the emitter small-signal resistance r_e to vary accordingly as
- As we have seen, the amplifier gain depends on r_e . Change in r_e requires a large em signal but the carrier amplitude must meet the condition $m \leq 1$, where m is the modulation index.
- To avoid the problem caused by coupling and bypass capacitor, a dc amplifier modulator is employed; beyond the scope of this book.

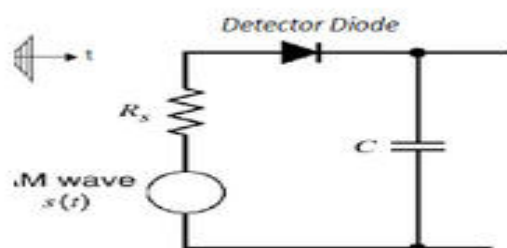


AM Detection (Envelope Detector)

- AM Detection (Envelope Detector) is a simple circuit, typically using a diode, resistor (R), and capacitor (C), that demodulates **an Amplitude Modulated signal** by extracting the original message signal (like audio) by following its "envelope," essentially stripping the high-frequency carrier wave to leave the baseband information.
- It works by rectifying the AM signal with a diode and using the RC filter to smooth out the carrier, charging the capacitor to the carrier's peak and slowly discharging it through the resistor, mimicking the message signal's variations.

Working:

- **Rectification (Diode):** The incoming AM signal (a high-frequency carrier whose amplitude varies with the message) hits the diode. The diode allows current to flow only during the positive half-cycles of the carrier, effectively chopping off the negative halves.
- **Charging (Capacitor):** The capacitor rapidly charges up to the peak voltage of each positive half-cycle of the AM wave.
- **Discharging (Resistor):** As the input AM signal voltage drops below the capacitor's voltage, the diode stops conducting. The capacitor then slowly discharges through the load resistor (R).
- **Envelope Following:** When the input signal rises again above the capacitor's voltage, the diode conducts, and the cycle repeats. The voltage across the resistor (and capacitor) thus traces the outline, or "envelope," of the original AM signal, which is the desired message.
- **Filtering (Low-Pass):** A final low-pass filter (often just the R in the RC network) removes the remaining high-frequency carrier ripple, leaving a smooth DC voltage that varies with the original audio.



Frequency Modulation (FM)

FM is defined as the modulation technique in which frequency of the carrier signal is varied in accordance with the instantaneous value of the analog modulating signal keeping amplitude and phase of the carrier signal constant.

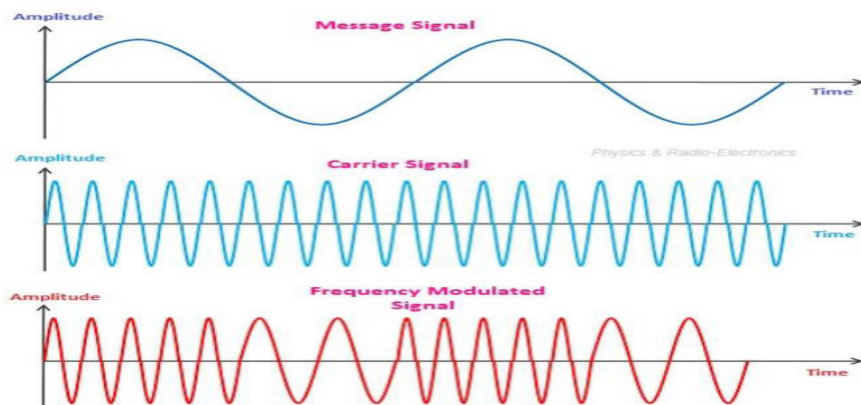
The original frequency of the carrier signal is called Centre or resting frequency and denoted by f_c . The amount by which the frequency of the carrier wave changes or shifts above or below the resting frequency is termed as frequency deviation (Δf). The total variation is frequency of F.M. wave from the lowest to the highest is termed as carrier swing (CS).

$$CS = 2 \cdot \Delta f$$

Modulation index in F.M. is the ratio of frequency deviation to the modulating frequency,

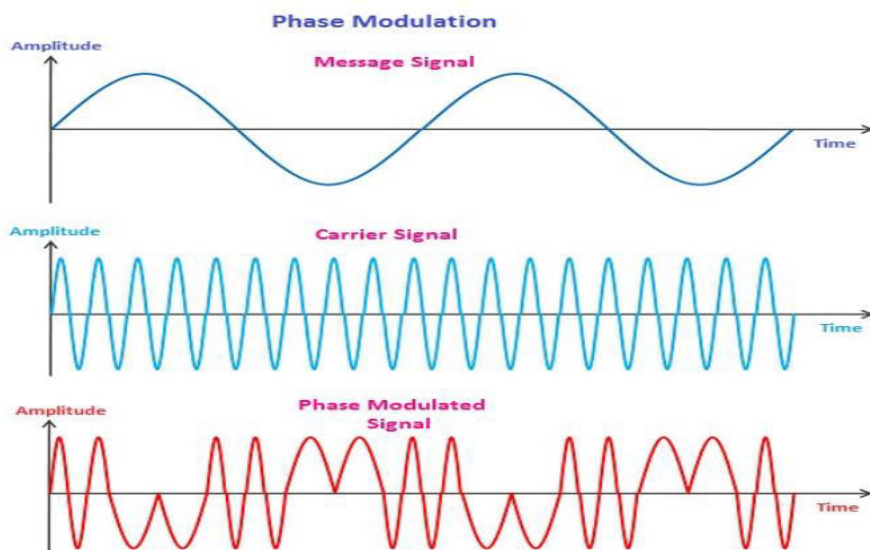
$$m_f = \frac{\Delta f}{f_m}$$

where f_m is frequency of the modulating signal



Phase modulation (PM)

PM is defined as the modulation technique in which phase of the carrier signal is varied in accordance with the instantaneous value of the analog modulating signal keeping amplitude and frequency of the carrier signal constant.



Applications

AM RADIO BROADCASTING

Block Diagram of Superheterodyne AM Receiver

- AM broadcast system covers the frequency range from **535 kHz to 1605 kHz**. It consists of **106 channels** each with a **bandwidth of 10 kHz**.
- Therefore, all AM receivers must be sensitive enough, to select only one desired frequency from among the signals received.
- The signal received by the antenna is coupled into a tunable-circuit RF section.
- The RF amplifier selects the tuned frequency and rejects all others.
- The signal is then amplified by RF amplifier.
- In the mixer stage, mixing (heterodyning) of the received RF signal and the local oscillator signal occurs.

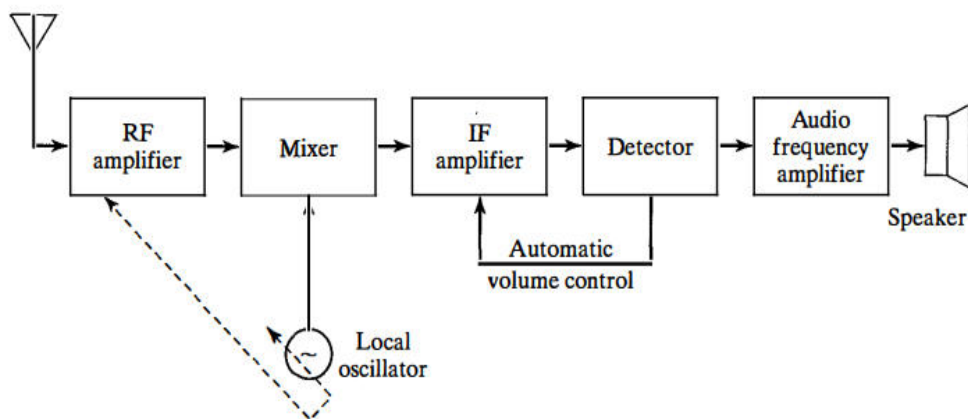


Figure 4.7 Superheterodyne AM Receiver

- The RF, mixer and local oscillator stages are ganged for simultaneous tuning.
- The output of the mixer stage is the difference frequency between the RF signal and the local oscillator signal frequencies.
- The difference frequency is a constant value which lies between the original RF carrier and AF modulating frequency.
- Therefore it is termed as intermediate frequency (IF).
- For AM, IF is fixed as 455 kHz. In the block diagram, since RF signal can vary between 535 to 1605 kHz, local oscillator frequency should be between $535+455$ to $1605+455=900$ to 2605 kHz.

- IF section is designed for optimum results at the single, fixed frequency. It can contain any number of amplifier circuits.
- The amplified IF signal is coupled to the detector where the original modulating information is recovered.
- The detected audio signal is coupled to suitable voltage and power amplifiers, and finally to the loudspeaker.

Superheterodyne FM Receiver

- Following is the block diagram for an FM superheterodyne receiver-

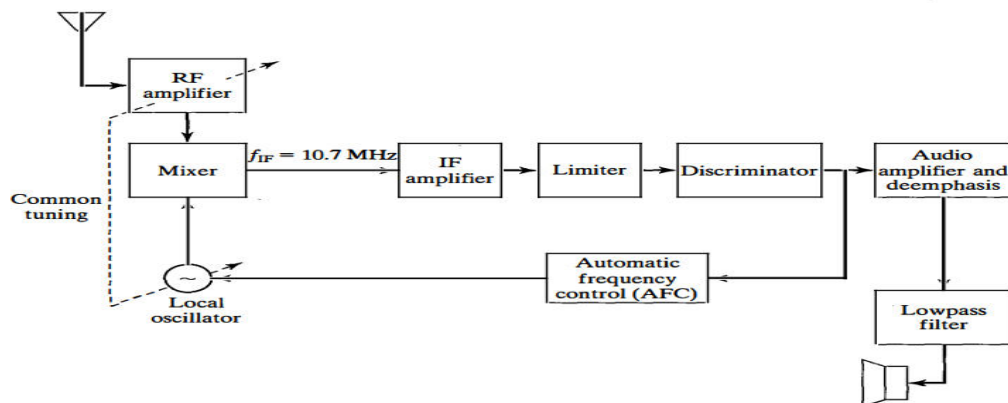


Figure 4.8 Superheterodyne FM Receiver

- The receiver first receives the signals from the antenna and is fed to the RF Amplifier. In the RF amplifier, they are also tuned in order to remove any unwanted signals from other frequencies.
- The tuned signals from the RF amplifier mix with the incoming local frequency signals which are generated from a local oscillator. This mixing process is done in the mixer and this mixing creates an intermediate frequency (IF).
- The intermediate frequency formed by the mixing is more convenient to process as compared to the original carrier frequency.
- The intermediate frequency is then amplified and filtered, this amplitude is maintained by using a limiter. During filtering, the signals of a particular channel can be selected. As compared to RF filtering, the IF filter can be tuned better than the RF filter because it can be designed for a fixed frequency.
- This signal is then applied to a demodulator which is an FM detector, this detector demodulates the output. It is also possible to switch between different demodulators to achieve the desired output form.
- This demodulated signal is then audio amplified using a loudspeaker where it converts to sound waves of the audible frequency.

Note: The speciality of a superheterodyne FM receiver is that it mixes the original incoming frequency from a source with a locally generated frequency, this allows the receiver to filter and select only the desired RF signals.