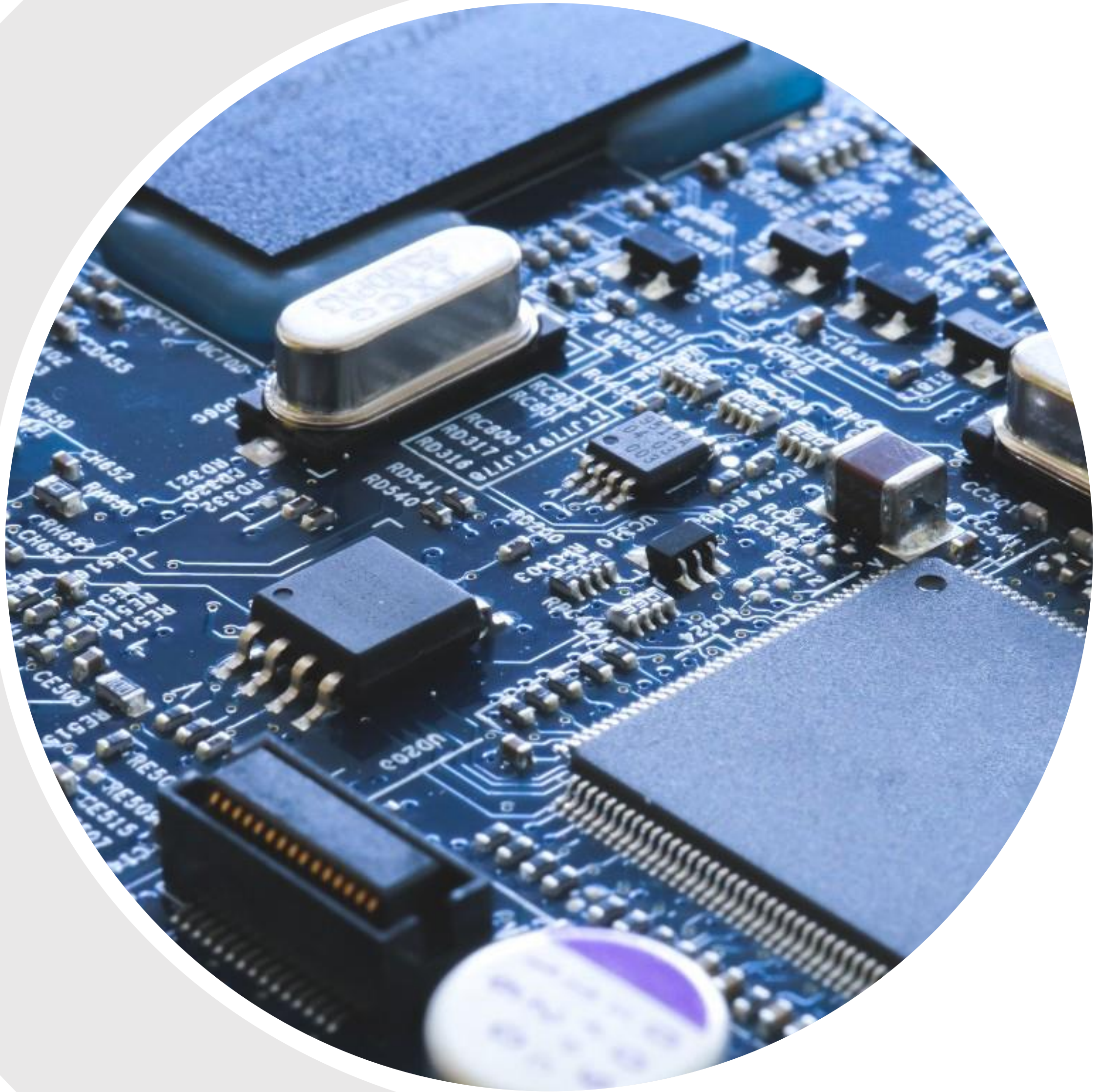

ANJUMAN
Institute of Technology
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BASIC ELECTRONICS & COMMUNICATION ENGINEERING

(21ELN14/21ELN24)

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Module 4

ANALOG & DIGITAL COMMUNICATION

SYLLABUS

Analog and Digital Communication

Modern Communication System Scheme, Information Source and Input Transducer, Transmitter, Channel or Medium – Hardwired and Softwired, Noise, Receiver, Multiplexing, Types of Communication Systems.

Types of Modulation (only concepts) – AM, FM, Phase Modulation, Pulse Modulation, PAM, PWM, PPM, PCM.

Concept of Radio Wave Propagation (Ground, Space, Sky).

Concepts of Sampling Theorem, Nyquist Rate, Digital Modulation Schemes – ASK, FSK, PSK.

Radio Signal Transmission

Multiple Access Techniques

Multipath and Fading

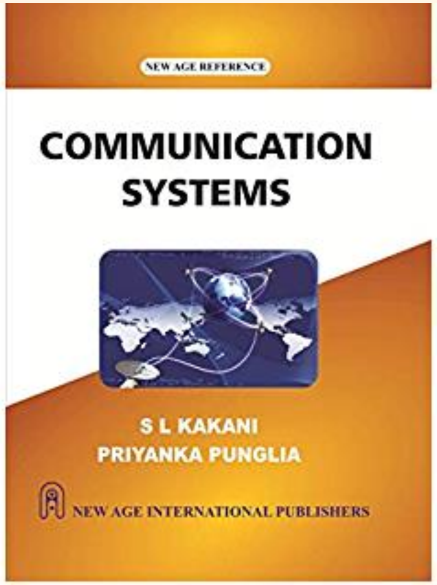
Error Management

Antenna, Types of Antennas – (only definition and antenna model, exclude radiation patterns).

Text Book

Communication Systems

S L Kakani and Priyanka Punglia
New Age International Publisher
2017



Introduction

What is Communication?

- Communication is the science and practice of transmitting information.
- *Communication Engineering* deals with the techniques of transmitting information.
- In brief, Communication Engineering means *Electrical Communication,* in which information is transmitted through electrical signals.

What is Communication? (continued)

- *Electrical Communication* is a process by which the information/message is transmitted from one point to another, from one person to another, or from one place to another in the form of electrical signals, through some communication link.

Modern Communication System Scheme

Modern Communication System Scheme

- A basic communication system provides a link between the information source and its destination.
- The process of electrical communication involves sending, receiving, and processing information in electrical form.
- The information to be transmitted passes through a number of stages of the communication system before it reaches its destination.
- Fig. 1.1 shows a block schematic diagram of the most general form of basic communication system.

Modern Communication System Scheme (continued)

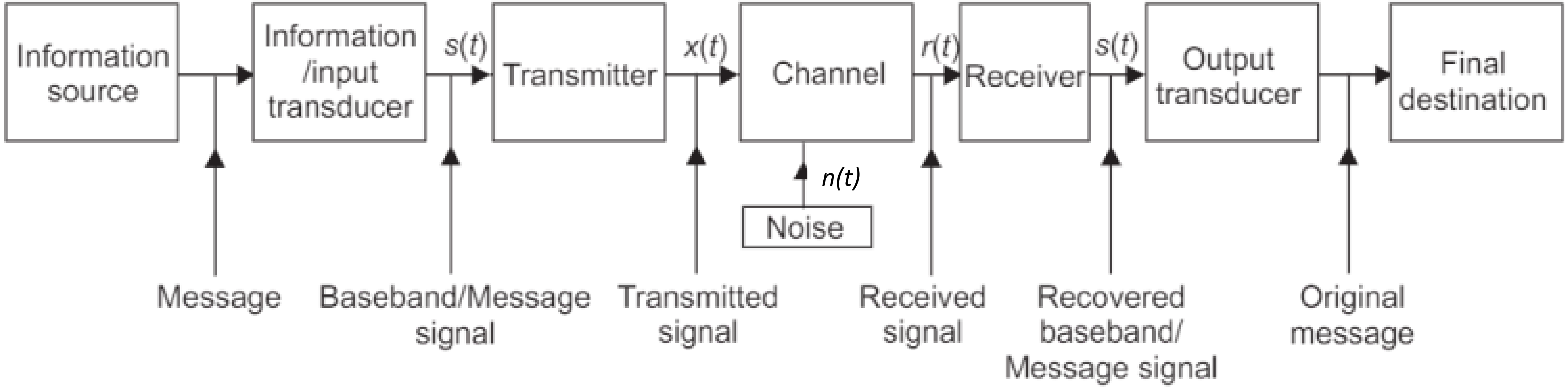


Fig. 1.1 Schematic block diagram of a basic communication system in most general form

Modern Communication System Scheme (continued)

- The main constituents of basic communication system are:

i. Information source and input transducer
ii. Transmitter
iii. Channel or medium
iv. Noise
v. Receiver
vi. Output transducer and final destination.

Information Source and Input Transducer

- A communication system transmits information from an information source to a destination.
  - Hence the first stage of a communication system is the *information source*.
- A communication system transmits information in the form of electrical signals.
  - If the information produced by the source is not in an electrical form, one will have to use a transducer to convert the information into electrical form.

Information Source and Input Transducer (continued)

- A transducer is a device that converts a non-electrical energy into its corresponding electrical energy called signal and vice versa.
  - An example of a transducer is a microphone.
    - Microphone converts sound signals into the corresponding electrical signals.
  - Similarly, a television (TV) picture tube converts electrical signals into its corresponding pictures.
  - Some other examples of transducers are movie cameras, Video Cassette Recorder (VCR) heads, tape recorder heads, and loudspeakers.

Information Source and Input Transducer (continued)

- The information produced by the information source is applied to the next stage, termed the *information or input transducer*.
- This in turn, produces an electrical signal corresponding to the information as output.
  - This electrical signal is called the *baseband signal*.
    - It is also called a message signal, an information signal, an intelligent signal, or an envelope.
- In the communication theory, the baseband signal is usually designated by $s(t)$.

Information Source and Input Transducer (continued)

- There are two types of signals:

  a) Analog signal

  b) Digital signal

Information Source and Input Transducer (continued)

a) Analog signal

- An analog signal is a function of time, and has a continuous range of values.
  - However, there is a definite function value of the analog signal at each point of time.
- Examples: a pure sine wave form, a voice signal.

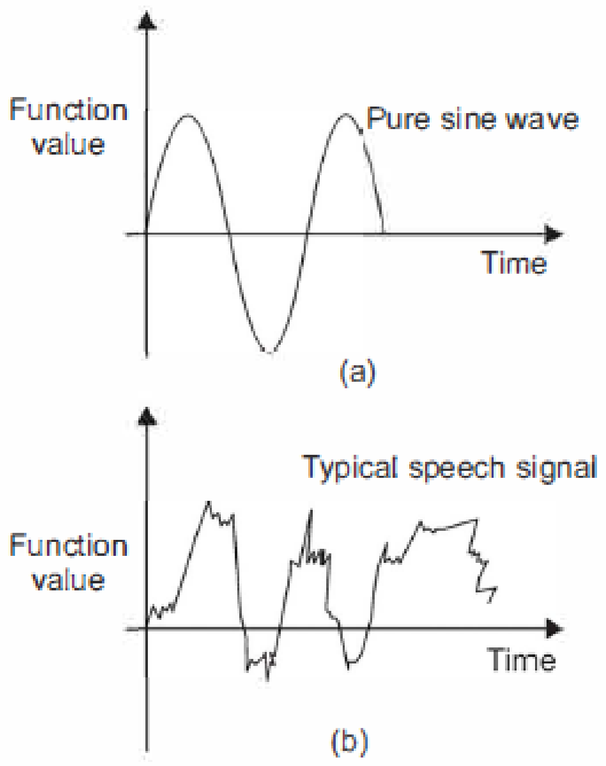


Fig. 1.2 Analog signals: (*a*) Pure sine wave, (*b*) Typical speech signal

Information Source and Input Transducer (continued)

b) Digital signal

- A digital signal does not have continuous function values on a time scale.
- It is discrete in nature, i.e., it has some values at discrete timings.
- In between two consecutive values, the signal values is either zero, or different value.
- Example: the sound signal produced by drumbeats.

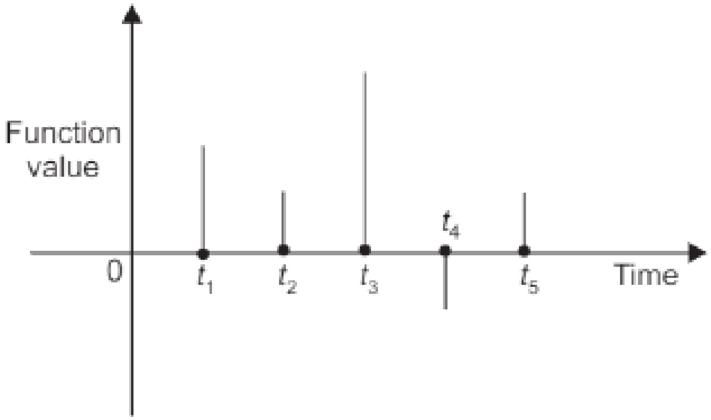


Fig. 1.3 Digital signal

Information Source and Input Transducer (continued)

- Digital signals correspond to a binary digital signal, where the discrete amplitude of the signal is coded into binary digits represented by ‘0' and '1’.
- The analog signal is converted to digital using Analog-to-Digital Converters (ADC).
  - ADC involves *Sampling* and *Quantization.*
    - Sampling – converts analog time to discrete time
    - Quantization – converts analog amplitude to discrete amplitude

Transmitter

- The transmitter is a collection of electronic components and circuits that converts the electrical signal into a signal suitable for transmission over a given medium.
- Transmitters are made up of oscillators, amplifiers, tuned circuits and filters, modulators, frequency mixers, frequency synthesizers and other circuits.

Transmitter (continued)

- The base band signal, which is the output of an input transducer, is input to the transmitter.
- The transmitter section processes the signal prior to transmission.
  - The nature of processing depends on the type of communication system.
- There are two options for processing signals prior to transmission:
  - Carrier communication system
    - The baseband signal, which lies in the low frequency spectrum, is translated to a higher frequency spectrum.
  - Baseband communication system
    - The baseband signal is transmitted without translating it to a higher frequency spectrum.

Transmitter (continued)

- In *baseband communication system*, baseband signal is transmitted without translating it to a higher frequency spectrum.
- However, some processing of the signal is required prior to its transmission.
  - e.g. a train of pulses that are to be transmitted can be replaced by a series of two sine waves of different frequencies prior to transmission.
  - One of these two frequencies represent a low and the other represents a high value of the digital pulse.
  - Therefore, the baseband signal is converted into a corresponding series of sine waves of two different frequencies prior to transmission.
- Fig. 1.4 illustrates this processing.

Transmitter (continued)

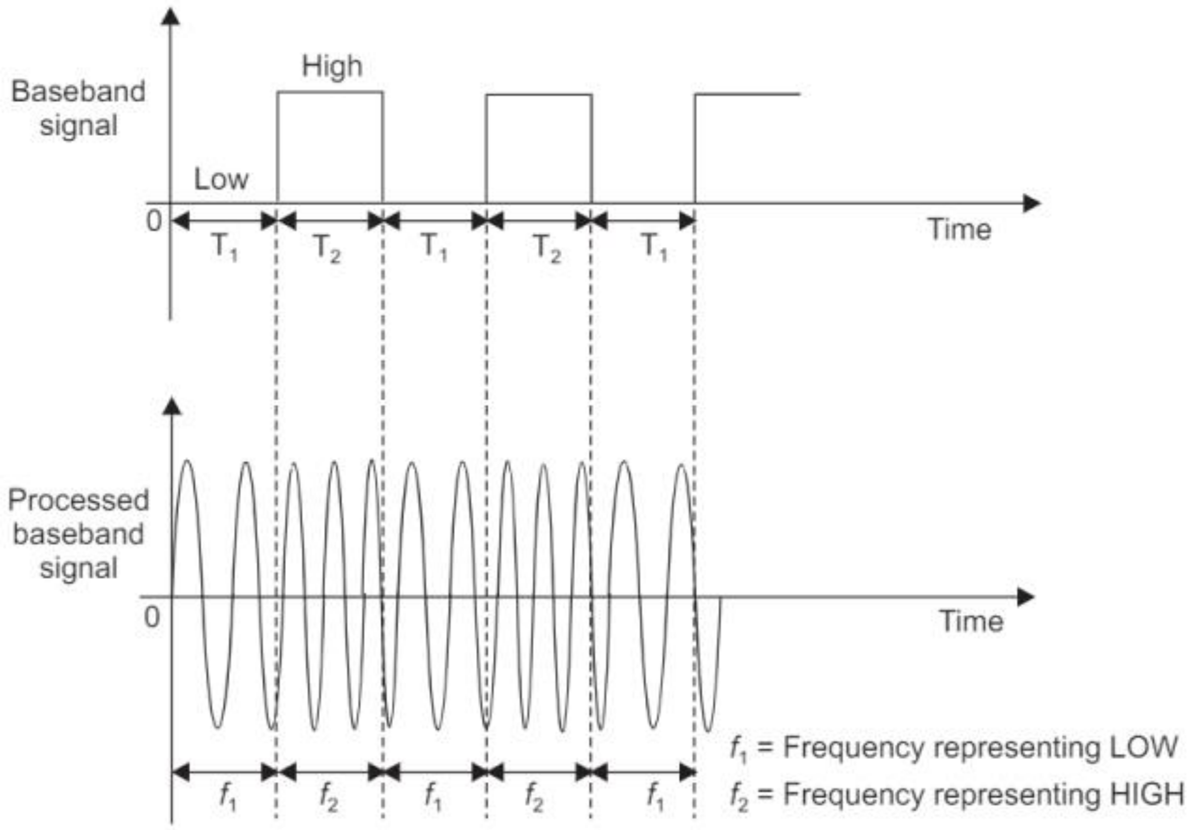


Fig. 1.4 The processing of a baseband signal

Transmitter (continued)

- In *carrier communication system*, the baseband signal is carried by a higher frequency signal, called the *carrier signal*.
- The carrier communication system is based on the principle of translating a low frequency baseband signal to higher frequency spectrum.
  - This process is termed as *modulation*.
- Now, if the baseband signal is a digital signal, the carrier communication system is called a digital communication system.
  - The digital modulation methods are employed for this.
- If the baseband signal is an analog signal, the carrier communication system is called as an analog communication system.
  - The analog modulation techniques are used for processing this.

Transmitter (continued)

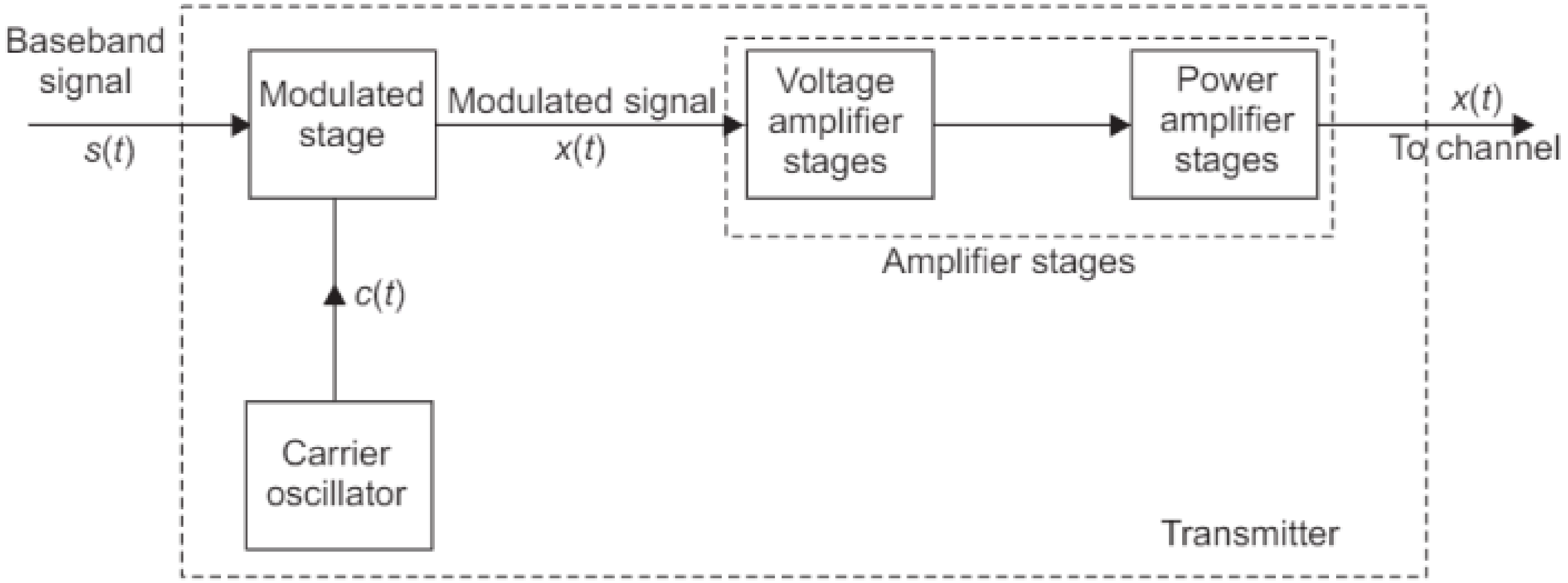


Fig. 1.5 Block diagram representing schematic of an analog transmitter section

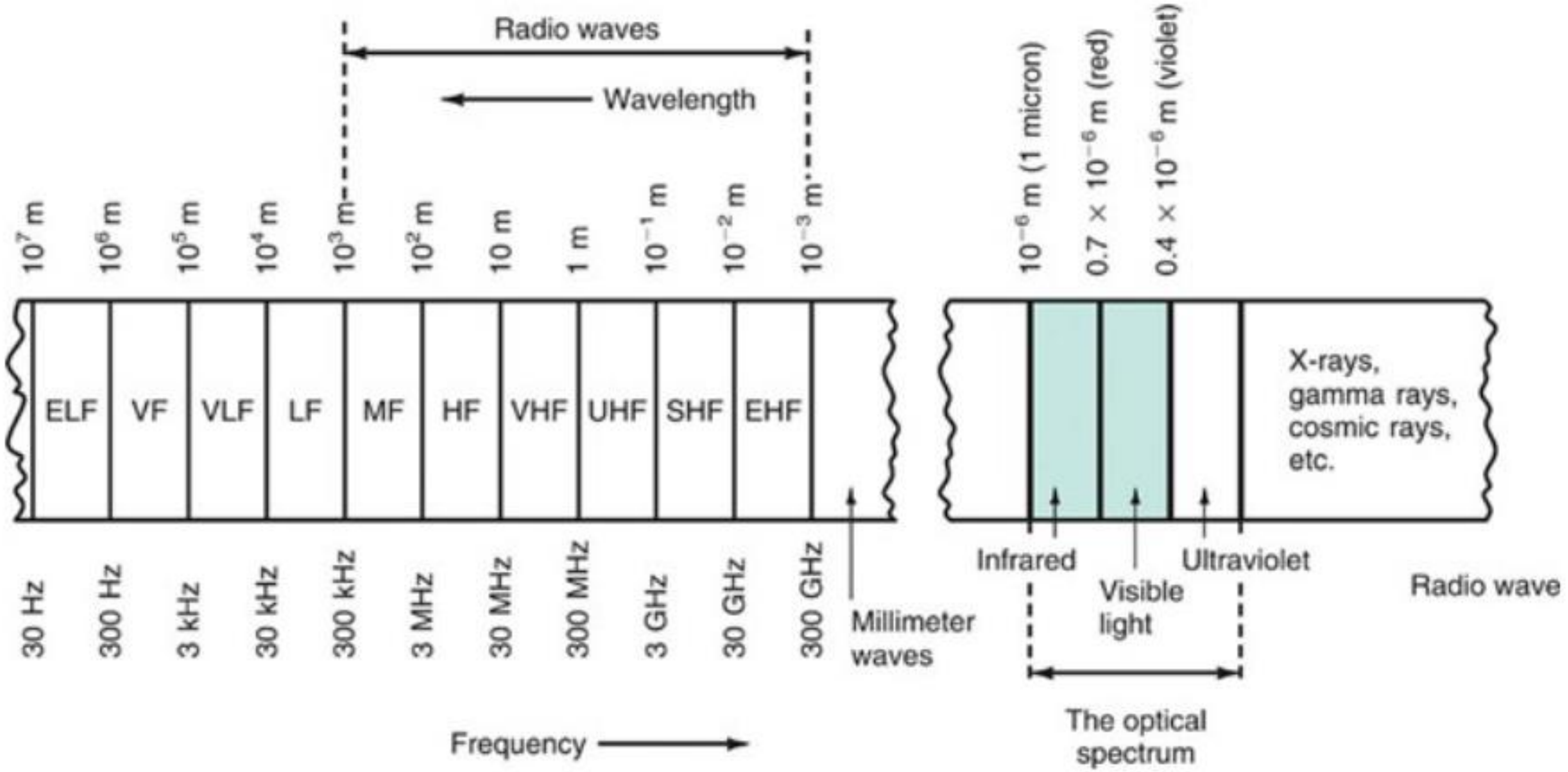
Transmitter (continued)

- Figure 1.5 shows the *baseband signal*, $s(t)$ applied to the modulated stage.
- This stage translates the baseband signal from its low frequency spectrum to high frequency spectrum.
- This stage also receives another input called the *carrier signal*, $c(t)$, which is generated by a high frequency carrier oscillator.
- Modulation takes place at this stage with the baseband and the carrier signals as two inputs after modulation, the baseband signal is translated to a high frequency spectrum and the carrier signal is said to be modulated by the baseband signal.
- The output of the modulated stage is called the *modulated signal*, and is designated as $x(t)$.

Transmitter (continued)

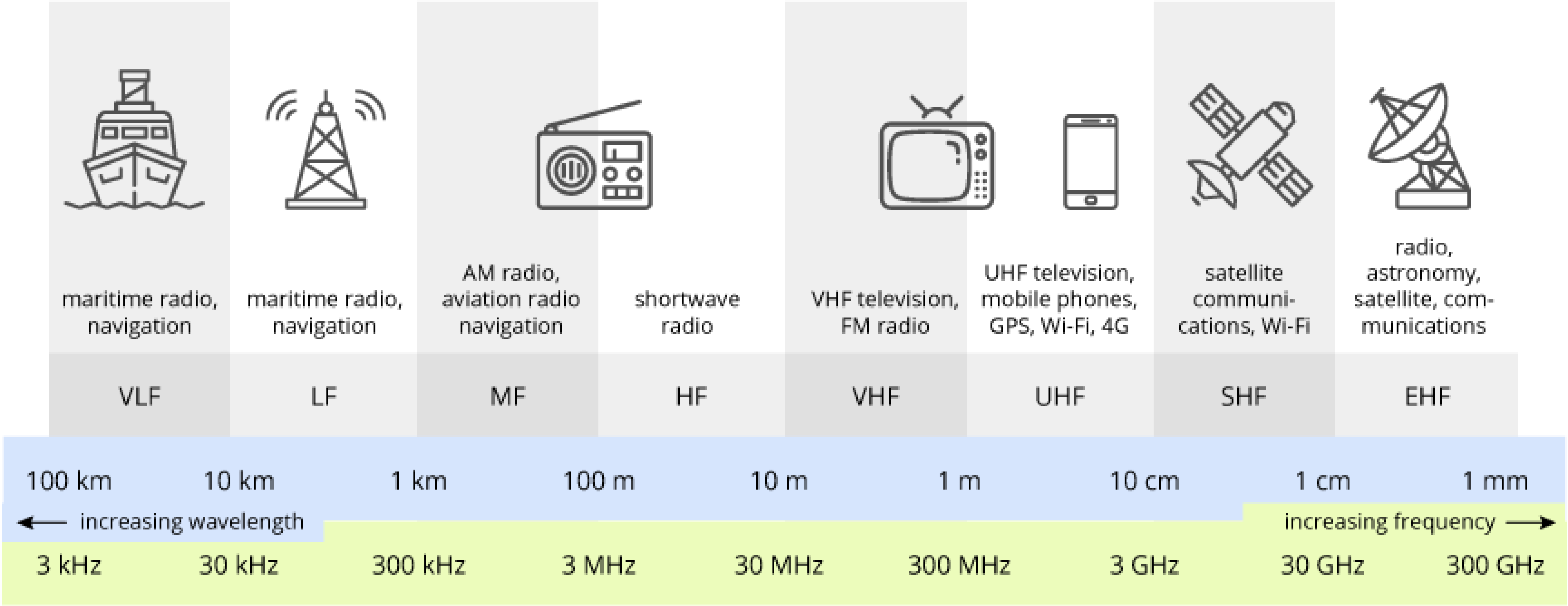
- *Radio signals* are transmitted through *electromagnetic (EM) waves*, also referred as *radio waves*, in a radio communication system.
- The radio waves have a wide frequency range starting from a few ten kilo Hertz (Hz) to several thousand Mega Hertz (MHz).
  - This wide range of frequencies is referred as *the radio frequency (RF) spectrum*.
- The RF spectrum is classified according to the applications of the spectrum in different service areas .
- Table 1.1 shows the classification of the RF spectrum along with the associated applications in communication systems.

Transmitter (continued)



Electromagnetic Spectrum

Transmitter (continued)



Radio Frequency Spectrum

Transmitter (continued)

Table 1.1: Classification of radio frequency (RF) spectrum alongwith the associated applications in communication systems.

Radio frequency range	Wavelength (meters)	Class	Applications
10–30 kHz	$3 \times 10^4 - 10^4$	Very Low Frequency (VLF)	Point-to-point communication (long distance)
30–300 kHz	$10^4 - 10^3$	Low Frequency (LF)	Point-to-point communication (long distance) and navigation
300–3000 kHz	$10^3 - 10^2$	Medium Frequency (MF)	Radio broadcasting
3–30 MHz	$10^2 - 10$	High Frequency (HF)	Overseas radio broadcasting, Point-to-point radio telegraphy, and telephony
30–300 MHz	$10 - 1.0$	Very High Frequency (VHF)	FM broadcast, television, and radar
300–3000 MHz	$1.0 - 0.1$	Ultra High Frequency (UHF)	Television and navigation
3000–30,000 MHz	$0.1 - 0.01$	Super High Frequency (SHF)	Radar navigation and radio relays

Channel or Medium

- The transmission medium between the transmitter and the receiver is called a *channel*.
- The channel is a very important part of a communication system.
- Its characteristics add many constraints to the design of the communication system.
- The transmitted signal should have adequate power to withstand the channel *noise*.
- The channel characteristics also impose constraints on the *bandwidth*.
- The channel characteristics are also taken into consideration as a *design parameter* while designing the transmitter and receiver.

Channel or Medium (continued)

- Depending on the physical implementations, channels are classified into two groups:
  - Hardwired channels
  - Softwired channels

Channel or Medium (continued)

Hardwired Channels (Hardware channels)

- These are manmade structures which can be used as transmission medium.
- There is always a physical link between the transmitter and receiver in hardware channels.
- A communication system that makes use of a hardware channel is called as a line communication system.
  - e.g. landline telephony and cable TV network.
- There are following three possible implementations of the hardware channels:
  - Transmission lines
  - Waveguides
  - Optical Fiber Cables (OFC)

Channel or Medium (continued)

- Transmission Lines
  - e.g. Twisted-pair cables used in landline telephony and coaxial cables used for cable TV transmission.
- Waveguides
  - They are hollow, circular, or rectangular metallic structures.
  - The signals enter the waveguide, are reflected at the metallic walls, and propagate towards the other end of the waveguide.
  - Waveguides are employed as medium to transmit signals at UHF range
- Optical Fiber Cables (OFC)
  - They are highly sophisticated transmission media, in the form of extremely thin circular pipes.
  - Signals are transmitted in the form of light energy in optical fiber cables.

Channel or Medium (continued)

Softwired Channels (Software channels)

- There are certain natural resources which can be used as the transmission medium for signals.
- Such transmission media are called software channels.
  - e.g. air or open space and sea water.
- There is no physical link between the transmitter and the receiver.
- The signals are transmitted in the form of *electromagnetic (EM) waves*, also called *radio waves*.

Channel or Medium (continued)

- Radio waves travel through open space at a speed equal to that of light ($c = 3 \times 10^8\, ms^{-1}$).
- The transmitter section converts the electrical signal into EM waves or radiation by using a transmitting antenna.
  - These waves are radiated into the open space by the transmitting antenna.
- At the receiver side, the receiving antenna picks up these radio waves and converts them into corresponding electrical signals.
- Systems that use radio waves to transmit signals through open space are called *radio communication systems*.
  - e.g. radio broad cast, television transmission, satellite communication, and cellular mobile communication.

Noise

- Noise is defined as unwanted electrical energy of random and unpredictable nature present in the system due to any cause.
- Noise is an electrical disturbance, which does not contain any useful information.
- Thus, noise is a highly undesirable part of a communication system, and have to be minimized.
- When noise is mixed with the transmitted signal, it rides over it and deteriorates its waveform.
  - This results in the alteration of the original information so that wrong information is received.

Noise (continued)

- External noise or extraneous noise
  - The noise introduced by the transmission medium
- Internal noise
  - The thermal agitation of atoms and electrons of electronic components used in the equipment

Noise (continued)

Signal to Noise Ratio (SNR)

- SNR is the ratio of the signal power to the noise power.
- It is the measure of the signal power delivered to the noise power at a particular point in the circuit.
- If P_s is the signal power and P_n is the noise power, then SNR is given as

$$\frac{S}{N} = \frac{P_s}{P_n}$$

Noise (continued)

- If $P_s = V_s^2/R$ and $P_n = V_n^2/R$, then

$$\frac{S}{N} = \frac{V_s^2 R}{V_n^2 R}$$

$$\frac{S}{N} = \frac{V_s^2}{V_n^2}$$

where V_s is signal voltage and V_n is noise voltage

Noise (continued)

- SNR can be expressed in terms of decibels (dB) as

$$\left(\frac{S}{N}\right)_{dB} = 10\log_{10}\left(\frac{V_s^2}{V_n^2}\right)$$

$$\left(\frac{S}{N}\right)_{dB} = 10\log_{10}\left(\frac{V_s}{V_n}\right)^2$$

$$\left(\frac{S}{N}\right)_{dB} = 20\log_{10}\left(\frac{V_s}{V_n}\right)$$

Noise (continued)

Example:

If, at a particular point in a circuit, the signal and noise voltages are given as 3.5 mV and 0.75 mV respectively, calculate SNR in dB.

Solution:

- Given, $V_s = 3.5\,mV$ and $V_n = 0.75\,mV$

SNR in dB is given by

$$\left(\frac{S}{N}\right)_{dB} = 20\log_{10}\left(\frac{V_s}{V_n}\right)$$

Noise (continued)

$$\left(\frac{S}{N}\right)_{dB} = 20\log_{10}\left(\frac{V_s}{V_n}\right)$$

$$\left(\frac{S}{N}\right)_{dB} = 20\log_{10}\left(\frac{3.5}{0.75}\right)$$

$$\left(\frac{S}{N}\right)_{dB} = 20\log_{10}(4.67)$$

That is

$$SNR = 13.38\ dB$$

Noise (continued)

Noise Figure (F)

- The noise figure is defined as ratio of the signal-to-noise power at the input of the circuit and the signal-to-noise power at the output of the circuit.
- The noise figure (F) is the measure of the noise introduced by the circuit and can be expressed as

$$F = \frac{\frac{S}{N}\, Power\ at\ the\ input\ terminals\ of\ the\ circuit}{\frac{S}{N}\, Power\ at\ the\ output\ terminals\ of\ the\ circuit}$$

- We can see that if F is unity, the noise power introduced by the circuit is zero, as both the input and output S/N powers are the same.

Receiver

- A receiver is a collection of electronic components and circuits that accepts the transmitted message from the channel and converts it back into its original form.
- The task of the receiver is to provide the original information to the user.
- This information is altered due to the processing at the transmitter side.
- The receiver system receives the transmitted signal and performs some processing on it to recover the original baseband signal.

Receiver (continued)

- The signal received by the receiver is *r(t)*, which contains both the transmitted signal *x(t)*, and the noise *n(t)*, added to it during transmission.
- The function of the receiver section is to separate the noise from the received signal, and then recover the original baseband signal by performing some processing on it.
- The detailed block diagram of a typical receiver section is shown in Fig. 1.7.

Receiver (continued)

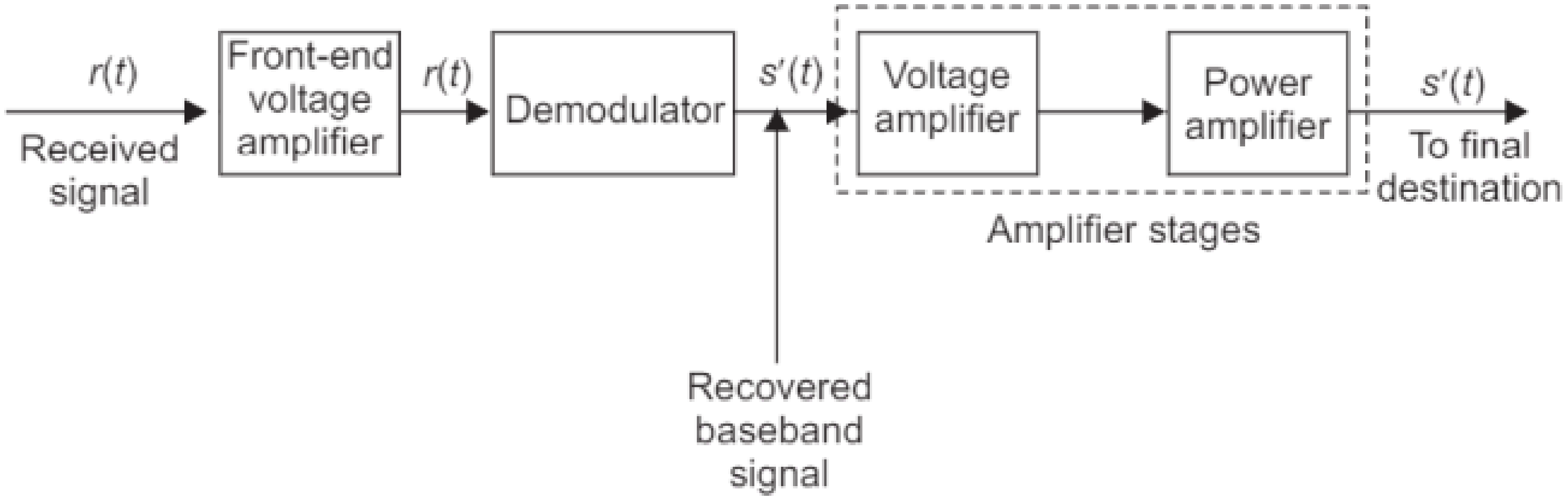


Fig. 1.7 Detailed block diagram of a typical receiver section

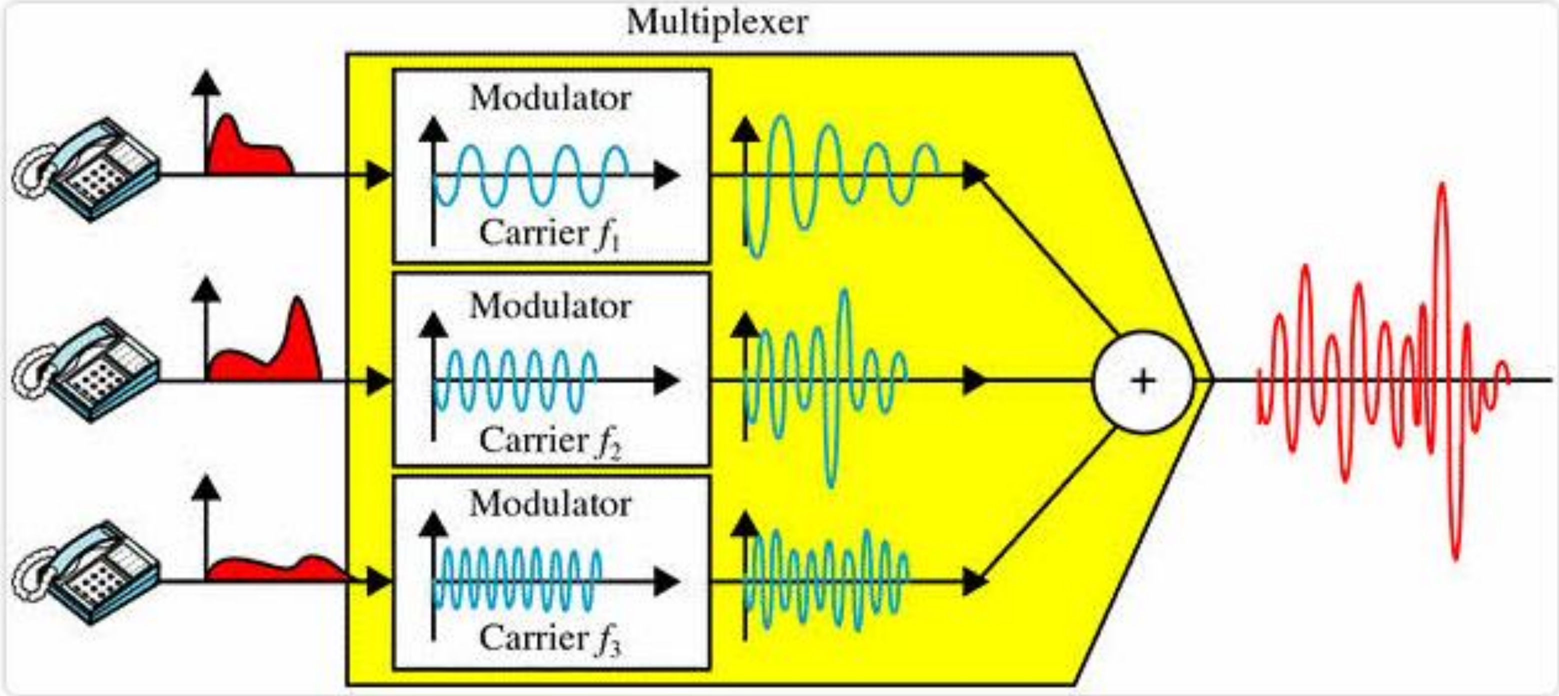
Receiver (continued)

- The received signal, r(t), is first amplified by the front-end voltage amplifier.
  - This is done to strengthen the received signal, which is weak and to facilitate easy processing.
- Next, this signal is given to the demodulator, which in turn, demodulates the received signal to recover the original baseband signal.
  - Demodulation is the process which brings the baseband signal from the higher frequency spectrum to its original low-frequency spectrum.
  - The type of demodulation is based on the type of modulation employed at the transmitter.
- After recovering the original baseband signal, its voltage and power is amplified prior to sending it to final destination block.

Multiplexing

- *Multiplexing* is a technique which allows more than one signal to be transmitted through a single channel.
- Multiplexing facilitates the simultaneous transmission of multiple messages over a single transmission channel.
- Multiplexing allows the maximum possible utilization of the available bandwidth of the system.
- The use of multiplexing also makes the communication system economical because more than one signal can be transmitted through a single channel.
- Multiplexing is possible in communication system only through *modulation*.

Multiplexing (continued)



Multiplexing (continued)

- Each signal is translated to a different frequency spectrum, such that every signal differs in its transmitted frequency.
  - This is done through modulation.
- At the transmitter they can be mixed and transmitted.
- At the receiver, the different signals can be easily separated because they are at different frequencies, and these can be delivered to the next stages of the receiver for further processing.

Types of Communication Systems

- Communication systems can be categorised based on their *physical infrastructure* and the *specifications of the signals they transmit*.
  - The physical infrastructure pertains to the type of the channel used and the hardware design of the transmitting and receiving equipment.
  - The signal specifications signify the nature and type of the transmitted signal.

Types of Communication Systems (continued)

Communication Systems based on Physical Infrastructure

- There are two types of communication systems based on the physical infrastructure:

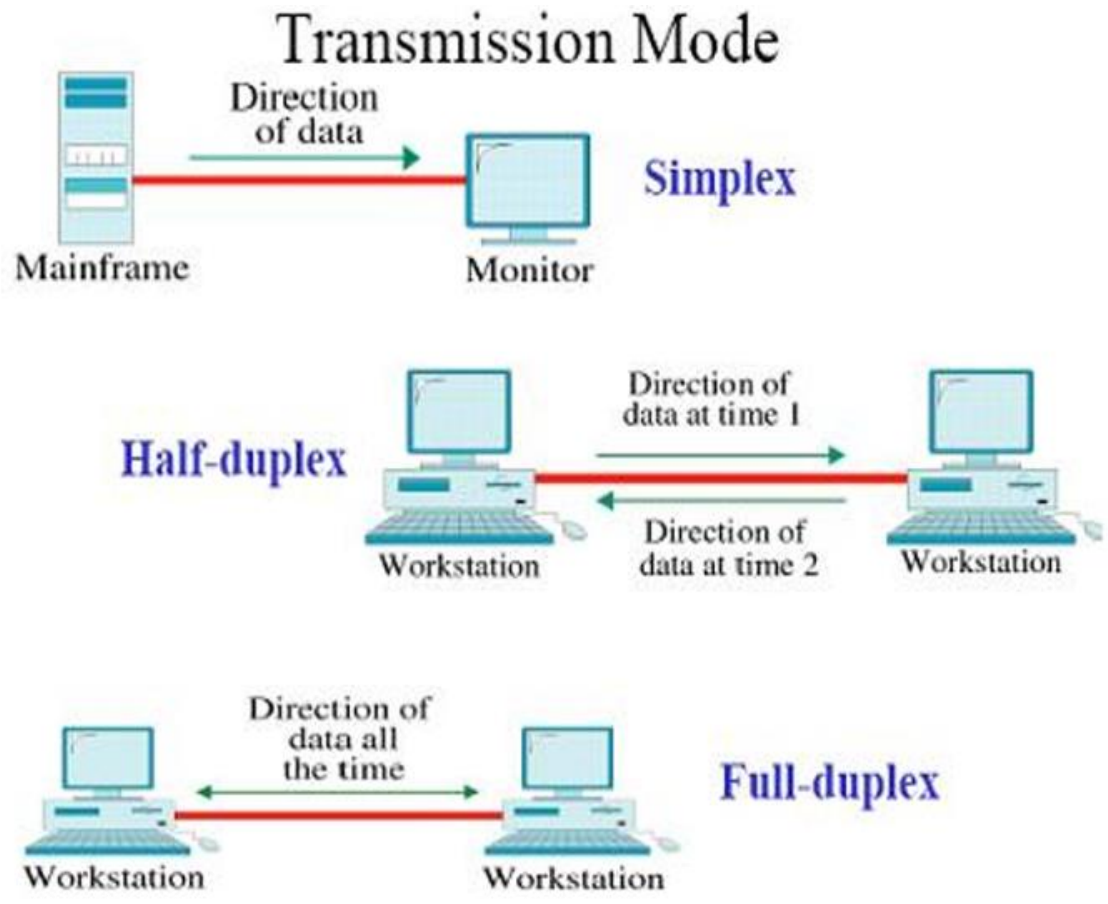
i. Line Communication System
  - There is a physical link, called the hardware channel, between the transmitter and the receiver.
  - e.g. landline telephony

ii. Radio communication system
  - There is no physical link between the transmitter and the receiver and natural resources, such as space and water are used as softwire channels.
  - e.g. radio broadcast

Types of Communication Systems (continued)

- There are two types of communication systems based on one-way or two-way transmission feature:
  i. Simplex Communication System
     - The single can be transmitted only in one direction (one-way transmission).
     - e.g. TV transmission
  ii. Duplex communication system
     - Signals can be sent and received from a point. (two-way transmission)
     - Half-duplex – two-way transmission is carried out, but not simultaneously
     - Full-duplex – two-way transmission is carried out simultaneously
     - e.g. telephony

Types of Communication Systems (continued)



Types of Communication Systems (continued)

Communication Systems based on Signal Specifications

- There are two types of communication systems based on the nature of *baseband* signal:

  i. Analog Communication System
     - e.g. TV transmission

  ii. Digital communication system
     - e.g. HDTV, Internet

Types of Communication Systems (continued)

- There are two types of communication systems based on the nature of *transmitted* signal:

  i. Baseband Communication System
     - e.g. landline telephony, fax

  ii. Carrier communication system
     - e.g. TV transmission, radio broadcast, cable TV

Modulation

What is Modulation?

- *Modulation* is a process in which some characteristic or property of a high frequency signal called carrier signal is varied in accordance with the instantaneous amplitude of the message signal.
- The carrier signal is a sinusoidal signal that can be represented as

$$\boldsymbol{v_c(t) = V_c \sin(\omega_c t + \theta)}$$

- The characteristic of the carrier wave that is modified may be amplitude V_c, frequency f_c or phase angle θ.
- Accordingly, we have three types of modulation:
  - Amplitude Modulation
  - Frequency Modulation
  - Phase Modulation

Need for Modulation

- Improves Quality of reception
- Reduces Height of antenna
- Allows Multiplexing
- Extends the Bandwidth
- Increases Range of Communication
- Reduces noise and interference

Amplitude Modulation

- *Amplitude Modulation (AM)* is a modulation technique in which the instantaneous amplitude of the carrier signal is varied in accordance with the instantaneous amplitude of the analog modulating signal to be transmitted.
- The modulating signal is an analog baseband signal which is random and has a low frequency, while the carrier signal is always a sinusoidal wave with high frequency.
- The variations in amplitude of carrier signal represent the information carried.

Amplitude Modulation (continued)

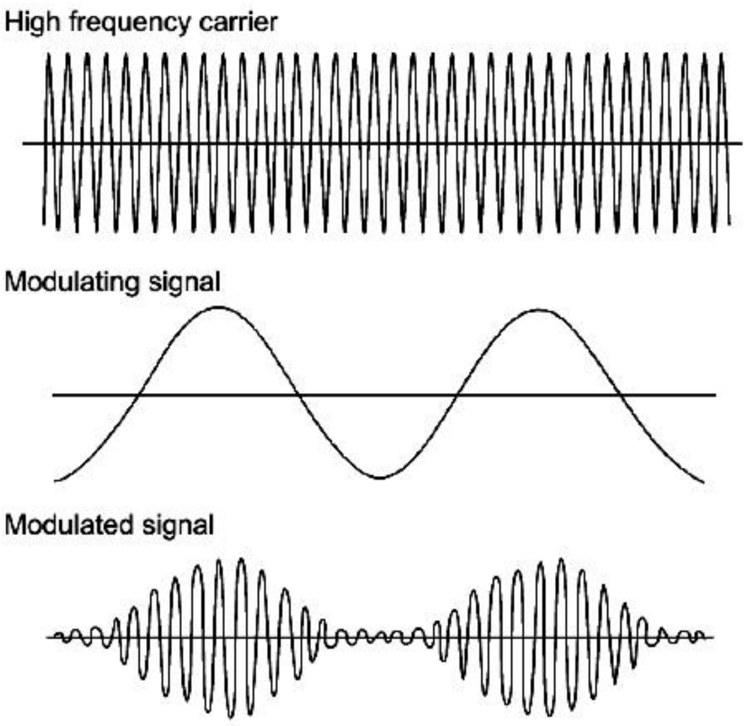
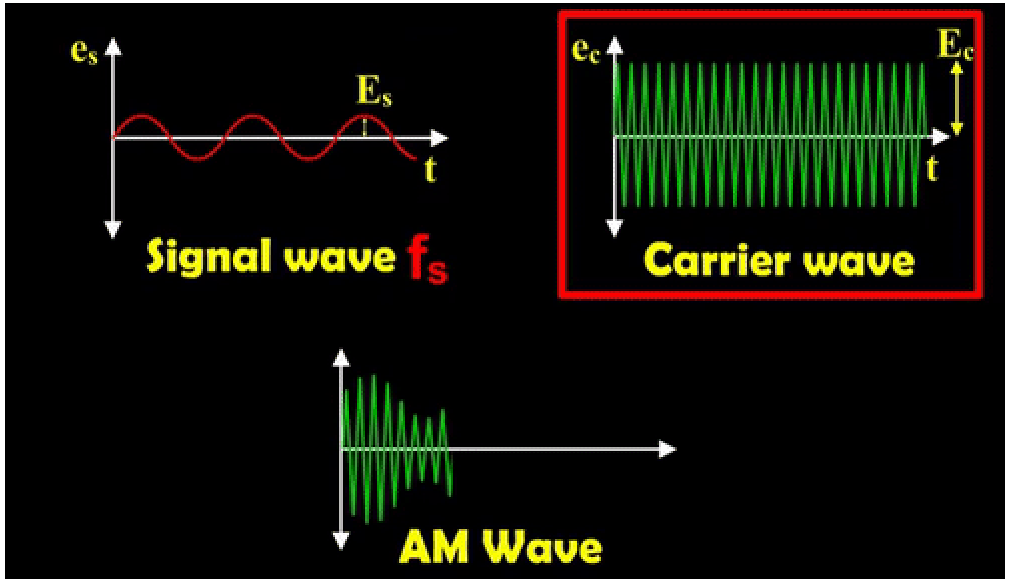


Fig. 2.1 Waveforms related to amplitude modulation

- The amplitude of the carrier wave is varied in accordance with the modulating signal while the frequency and phase of the carrier signal remains unchanged.
- The modulating signal seems to be superimposed on the carrier signal.
- The amplitude variations in the peak values of the carrier signal exactly replicate the modulating signal at different points of time which is known as an *envelope*.
- Modulation Index is given by $\mu = A_m/A_c$

Amplitude Modulation (continued)



Frequency Modulation

- *Frequency Modulation (FM)* is a modulation technique in which the frequency of the carrier signal is varied in accordance with the instantaneous amplitude of the analog modulating signal to be transmitted.
- Only the frequency of the carrier signal is varied while the amplitude and phase of the carrier are kept constant.
- The original frequency of the carrier signal is called the centre or resting frequency and denoted as f_c.
- The amount by which the frequency of the carrier wave changes or shifts above or below the resting frequency is called frequency deviation Δf. This means $\Delta f \propto m(t)$.

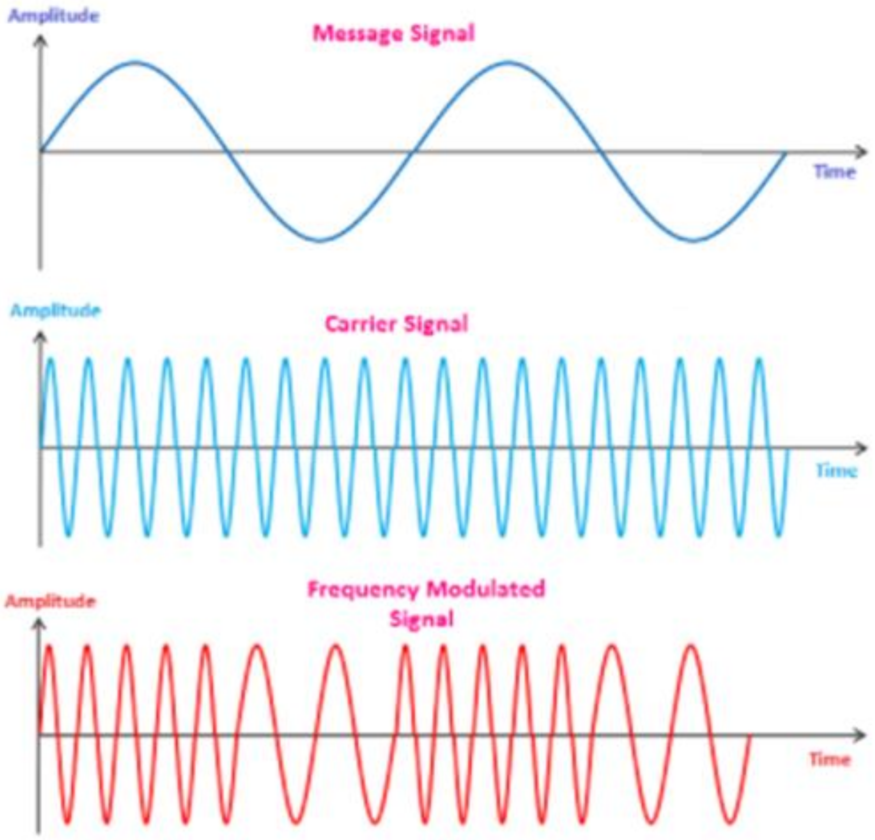
Frequency Modulation (continued)

- The total variation of frequency of FM wave from the lowest to highest is termed as carrier swing (CS),

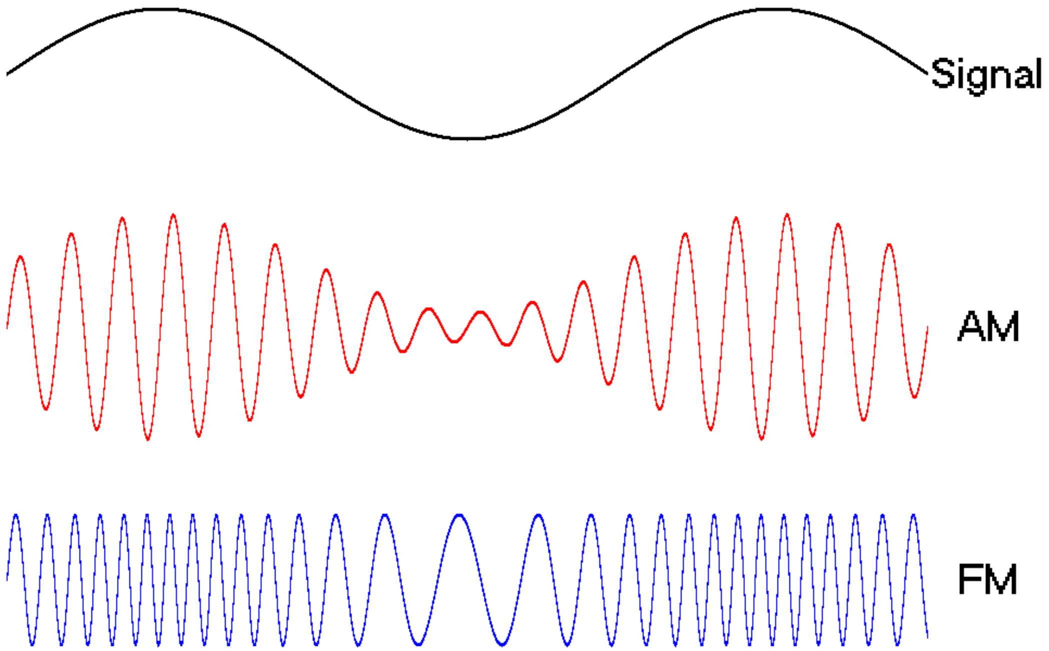
$$CS = 2\,\Delta f$$

- Modulation Index

$$\mu_f = \frac{Frequency\ deviation}{Modulating\ frequency} = \frac{\Delta f}{f_m}$$



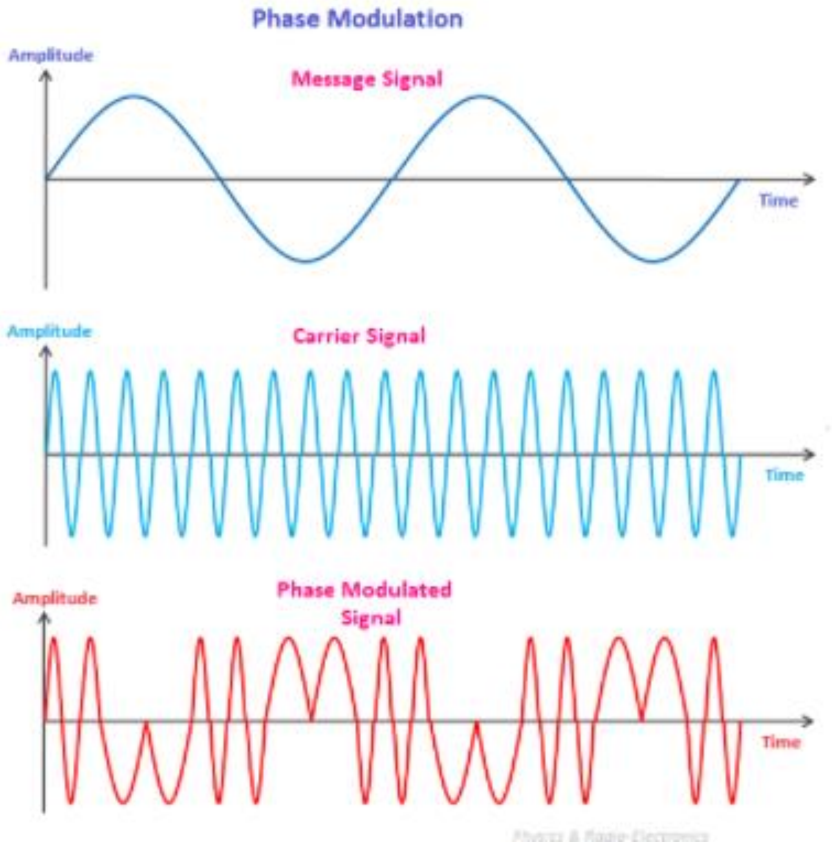
Amplitude and Frequency Modulation



Phase Modulation

- *Phase Modulation (PM)* is a modulation technique in which the phase of the carrier signal is varied in accordance with the instantaneous amplitude of the analog modulating signal to be transmitted.
- After phase modulation, amplitude and frequency of the carrier signal remain unaltered.
- The modulating signal is mapped to the carrier signal in the form of variations in the instantaneous phase of the carrier signal.
- Phase modulation and frequency modulation are closely related to each other.
  - In both the cases, the total phase angle ϕ of the modulated signal varies.

Phase Modulation (continued)



Pulse Modulation

- Pulse Modulation may be used to transmit analog information such as continuous speech or data.
  - Continuous waveforms are sampled at regular intervals.
- It has the advantage of ability to use constant amplitude pulses.
- Pulse modulation may be subdivided into two categories, *analog* and *digital*.
  - In *analog*, the indication of sample amplitude may be indefinitely variable.
  - In *digital*, a code which indicates the sample amplitude to the nearest predetermined level is sent.
  - Pulse-amplitude and pulse-time modulation are both analog, while the pulse code and delta modulation systems are both digital.

Pulse Modulation (continued)

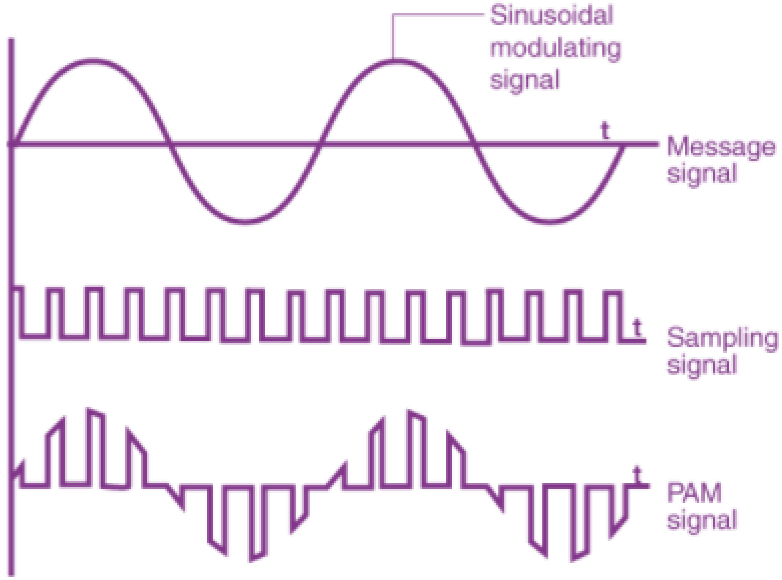
- Two types of pulse modulation schemes:
  - Pulse Amplitude Modulation (PAM)
  - Pulse Time Modulation (PTM)
    - Pulse Width Modulation (PWM)
    - Pulse Position Modulation (PPM)

Pulse Amplitude Modulation

- *Pulse Amplitude Modulation (PAM)* is the simplest form of pulse modulation.
- The signal is sampled at regular intervals and each sample is made proportional to the amplitude of the signal at the instant of sampling.
- Disadvantage - PAM does not use constant-amplitude pulses.
  - Hence it is not used frequently.

Pulse Amplitude Modulation (continued)

- In PAM, the amplitude of the pulses of the carrier pulse train is varied in accordance with the modulating signal



Pulse Amplitude Modulation (continued)

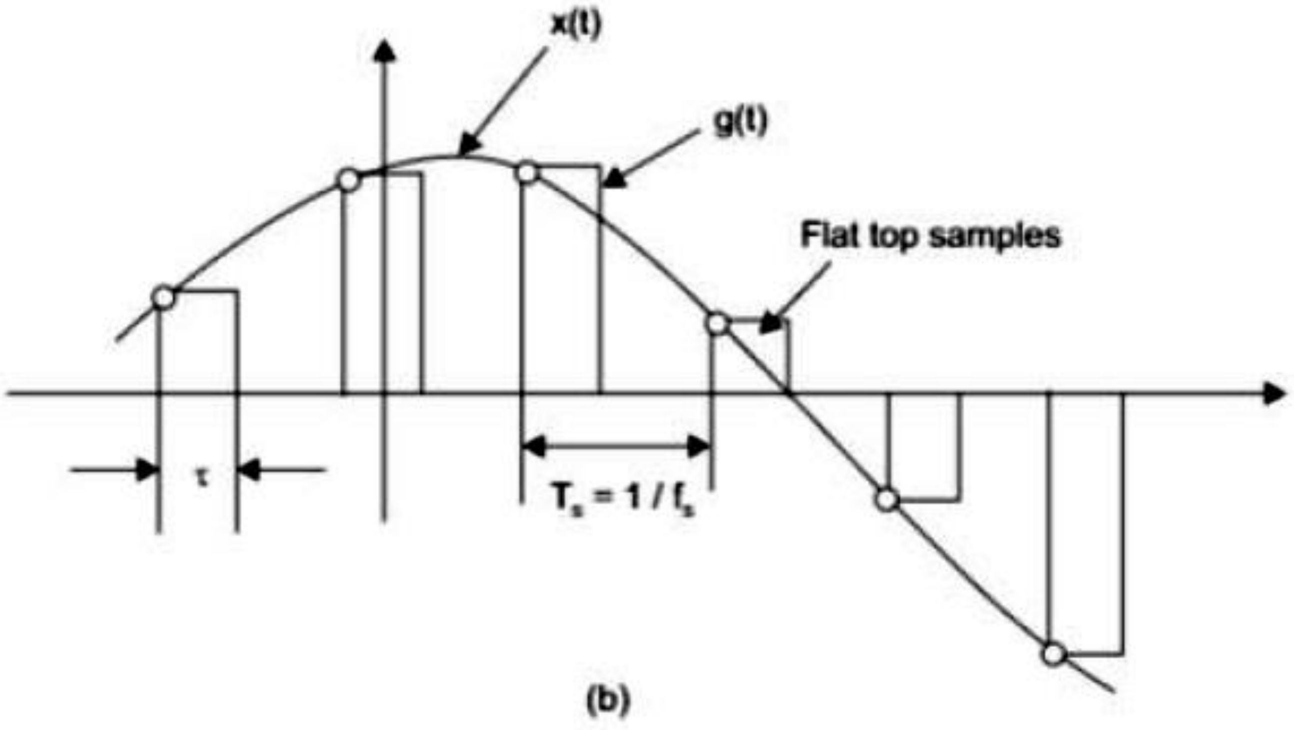
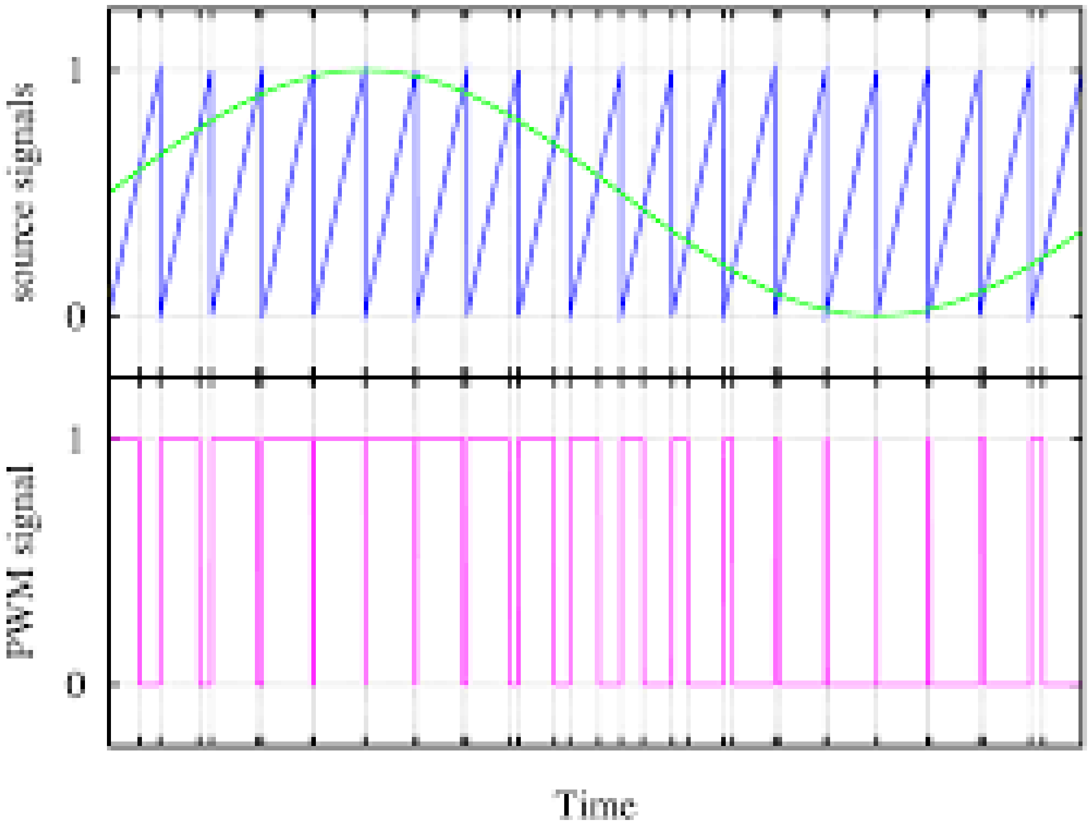


Fig. 6.5 (*a*) Sample and hold circuit to generate PAM (*b*) Waveform of PAM

Pulse Width Modulation or Pulse Duration Modulation

- *Pulse Width Modulation (PWM),* also called *Pulse Duration Modulation (PDM)* is a system in which the width or duration of each pulse is made proportional to the instantaneous value of analog signal.
- The starting time and amplitude of each pulse are constant.
- Disadvantage - Pulses are of varying width and hence of varying power content.
  - The transmitter must be powerful enough to handle the maximum-width pulses

Pulse Width Modulation or Pulse Duration Modulation (continued)



Pulse Width Modulation or Pulse Duration Modulation (continued)

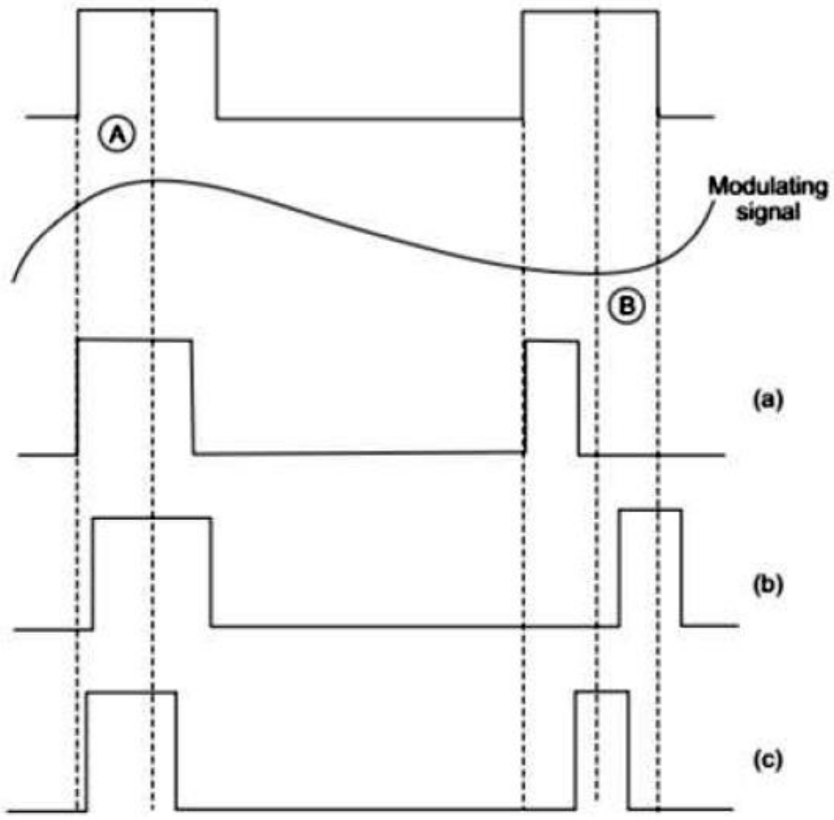
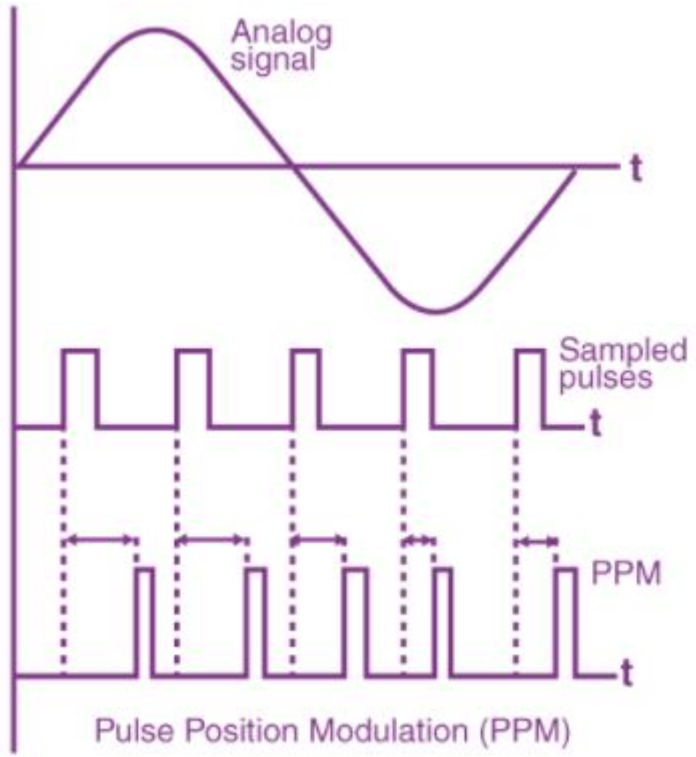


Fig. 6.8 PWM waveforms

Pulse Position Modulation

- *Pulse Position Modulation (PPM),* is a system in the position of each pulse in relation to the position of a recurrent reference pulse is varied according to the instantaneous sampled value of the modulating signal.
- The amplitude and width of the pulses are constant.
- Advantage over PWM – Requires constant transmitter power output
- Disadvantage – Dependence of transmitter-receiver synchronization

Pulse Position Modulation (continued)

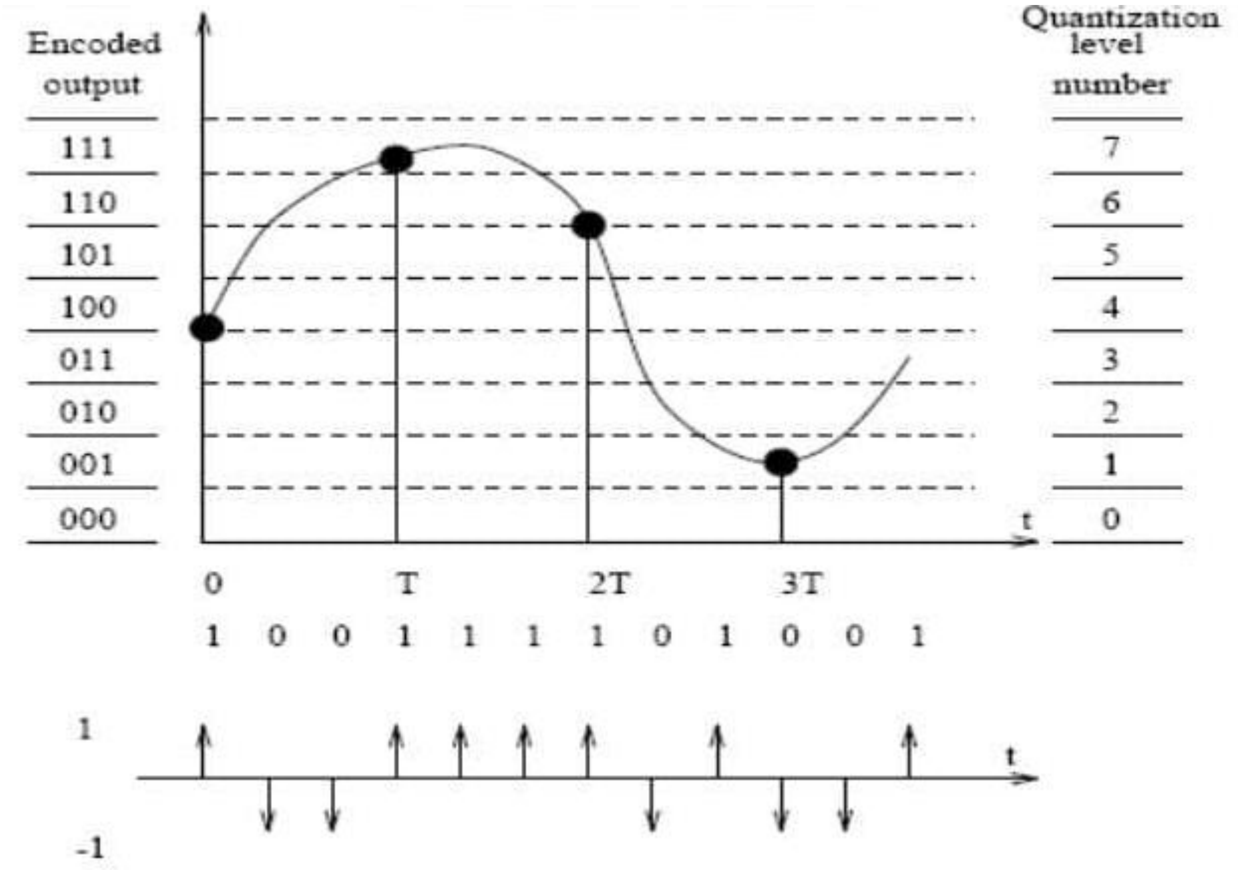


Pulse Position Modulation (PPM)

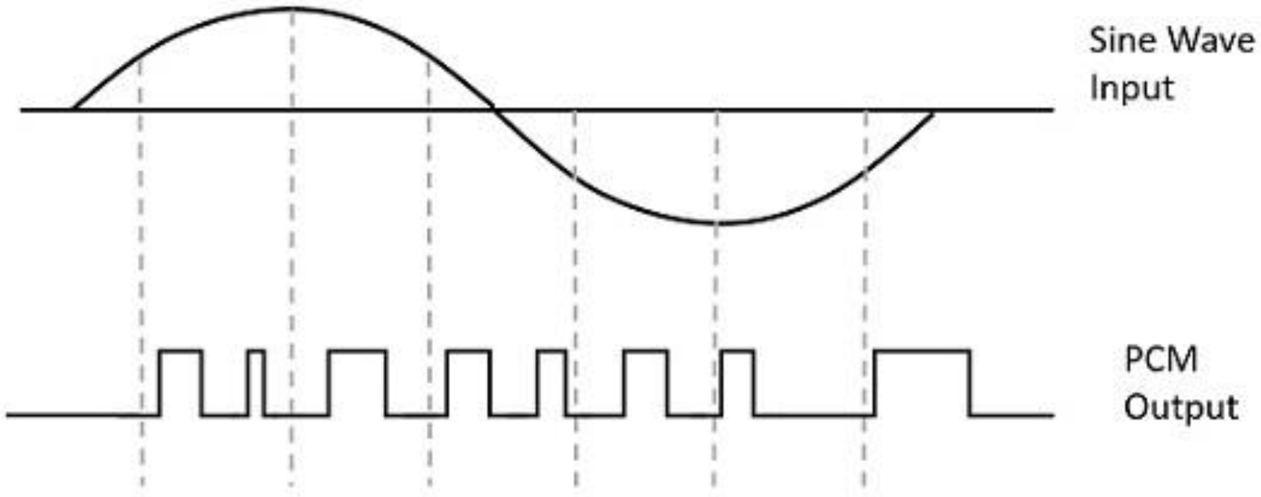
Pulse Code Modulation

- *Pulse Code Modulation (PCM),* is a digital process in which the message is sampled and rounded off to the nearest value of a finite set of allowable values.
  - The rounded values are coded.
- PCM generator produces a series of numbers or digits.
- Each one of these digits, in binary code, represents the amplitude of the signal sample at that instant.
- Signals are transmitted as binary code.

Pulse Code Modulation (continued)



Pulse Code Modulation (continued)



Digital Modulation Schemes

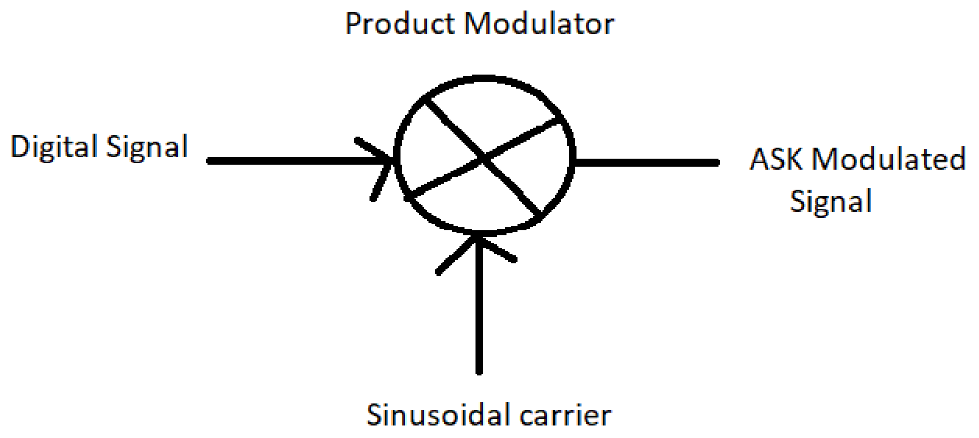
- In digital communications, the modulating signal consists of binary data or M-ary version of it.
- When it is required to transmit digital signals, the amplitude, frequency or phase of the sinusoidal carrier is varied in accordance with the incoming digital data.
- Since, the digital data is in discrete steps, the modulation of the bandpass sinusoidal carrier is also done in discrete steps.
  - Due to this reason, this type of modulation is known as *digital modulation*.

Digital Modulation Schemes (continued)

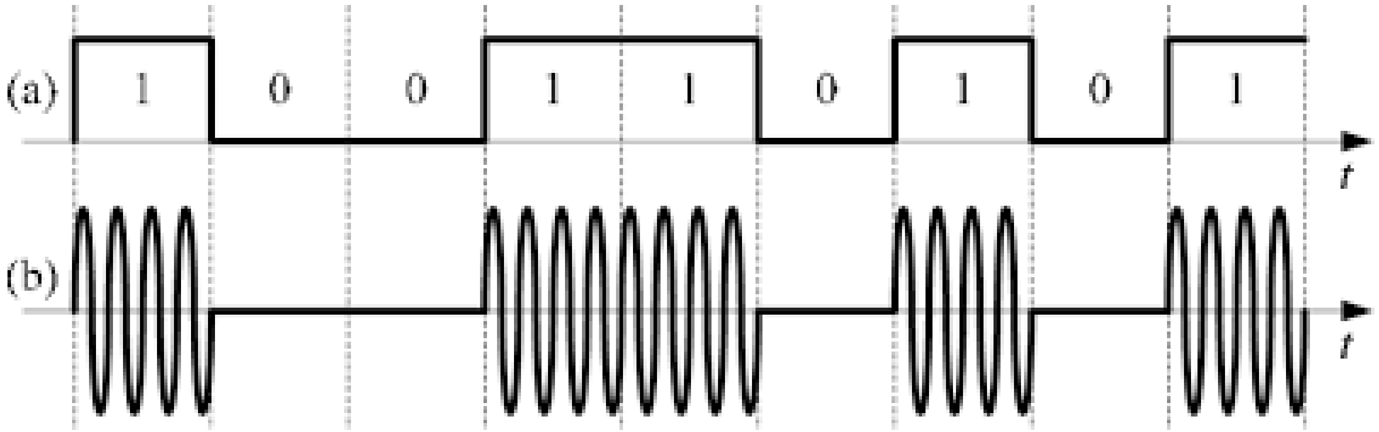
- Digital modulation schemes are classified as
  - Amplitude Shift Keying (ASK)
  - Frequency Shift Keying (FSK)
  - Phase Shift Keying (PSK)

Amplitude Shift Keying

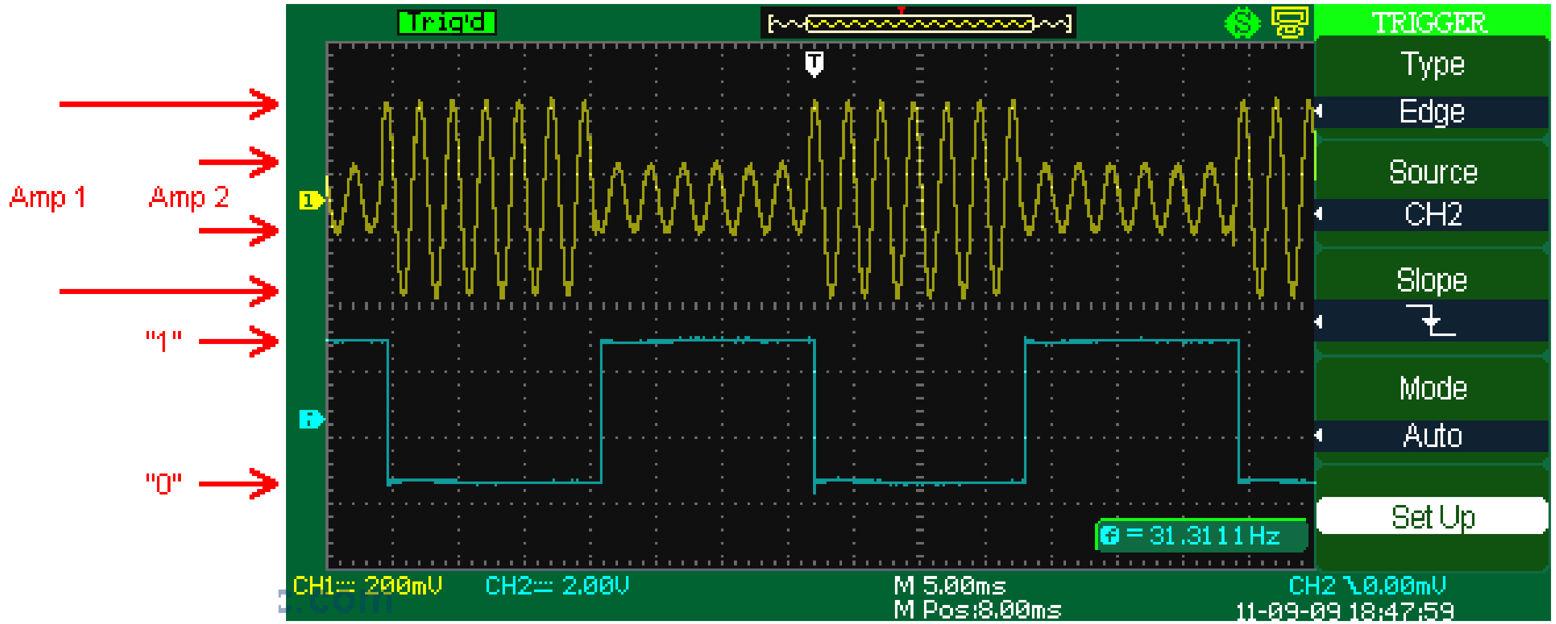
- *Amplitude Shift Keying (ASK)* represents digital data as variations in the amplitude of a carrier wave.
- ASK signal may be generated by simply applying the incoming binary data and the sinusoidal carrier to the two inputs of a product modulator.



Amplitude Shift Keying (continued)



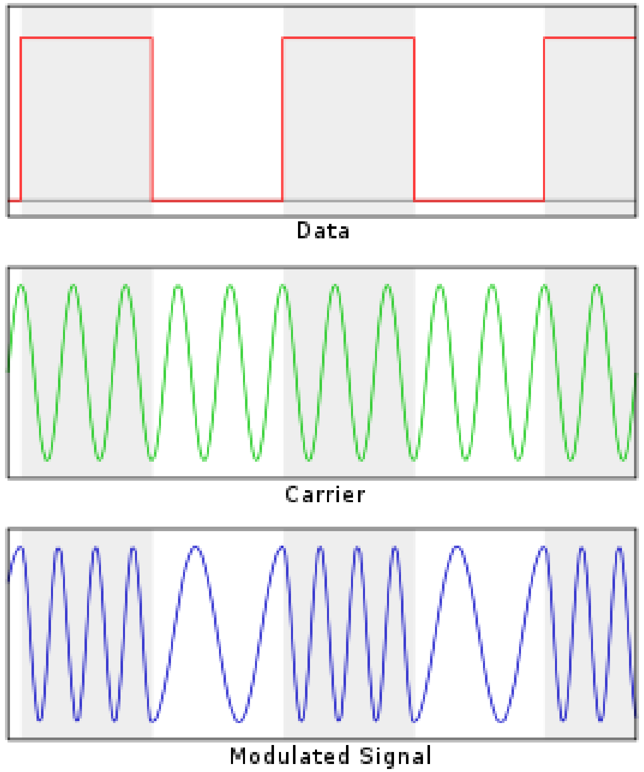
Amplitude Shift Keying (continued)



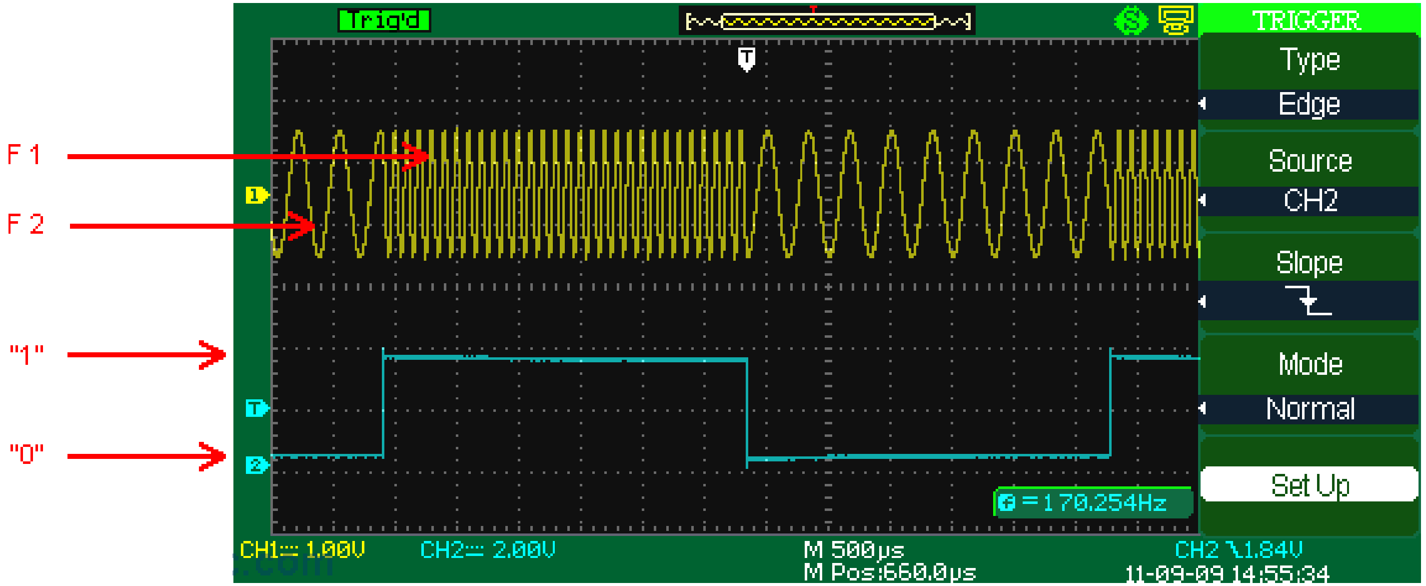
Frequency Shift Keying

- In *Frequency Shift Keying (FSK),* the digital information is transmitted through discrete frequency changes of a carrier signal.
- The simplest FSK is binary FSK (BFSK).
- BFSK uses a pair of discrete frequencies to transmit binary information (0s and 1s).

Frequency Shift Keying (continued)



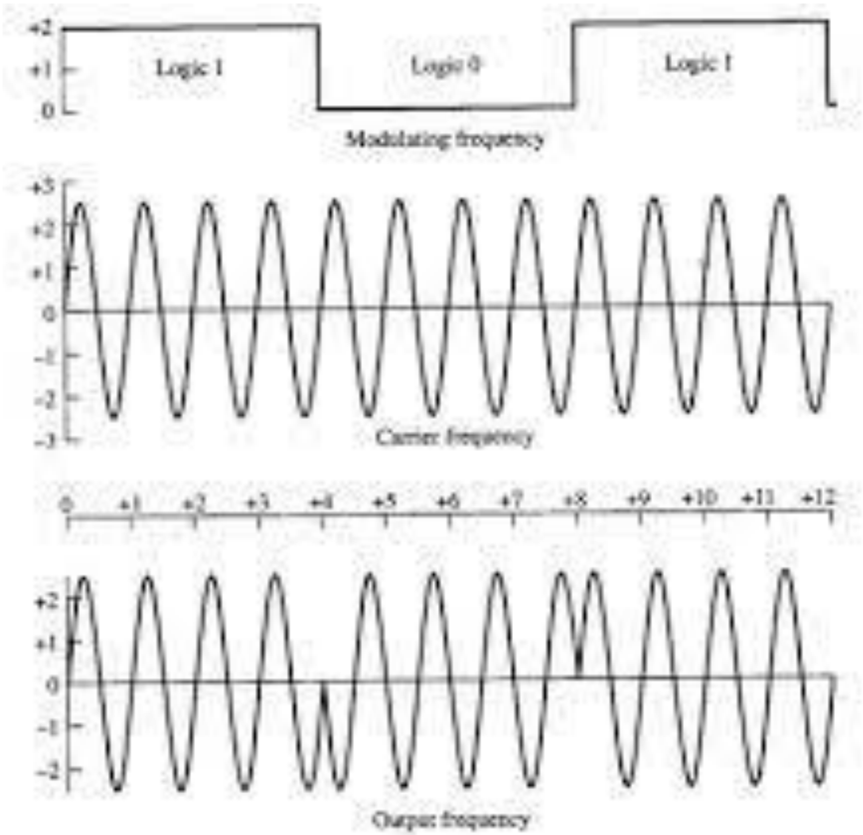
Frequency Shift Keying (continued)



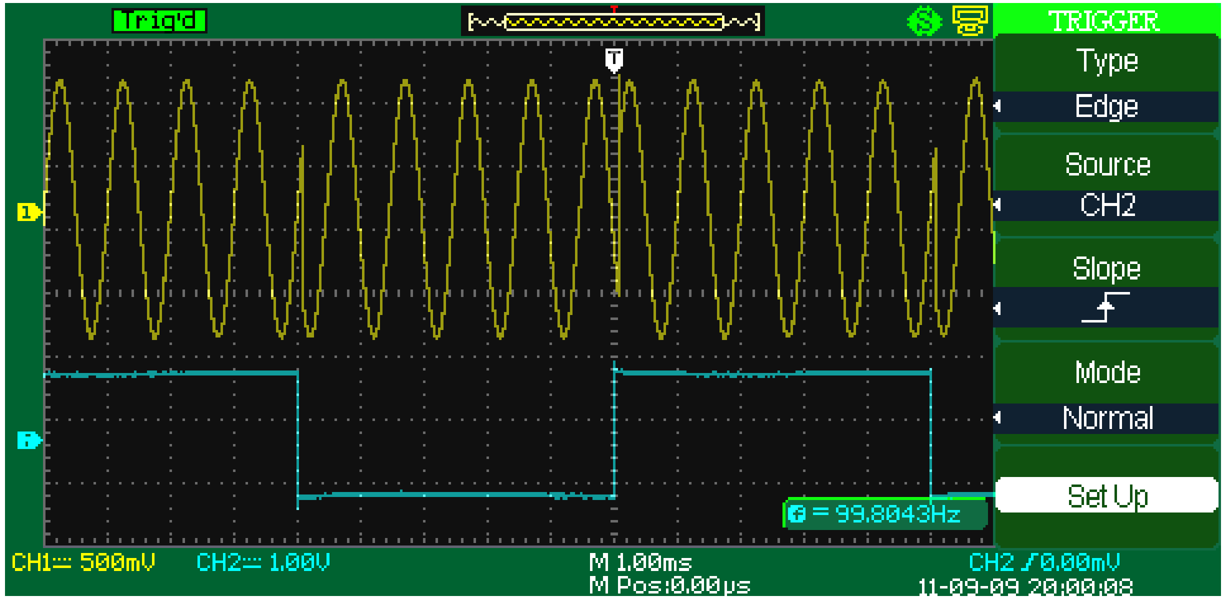
Phase Shift Keying

- *Phase Shift Keying (PSK)* conveys data by changing (modulating) the phase of constant frequency carrier.
- Each symbol (pattern of bits) is represented by a particular phase.
- The simplest form of PSK is Binary PSK (BPSK).
  - It uses phases $0°$ and $180°$.
- It is widely used for wireless LANs, RFID and Bluetooth Communication.

Phase Shift Keying (continued)



Phase Shift Keying (continued)



Why FSK and PSK are preferred over ASK?

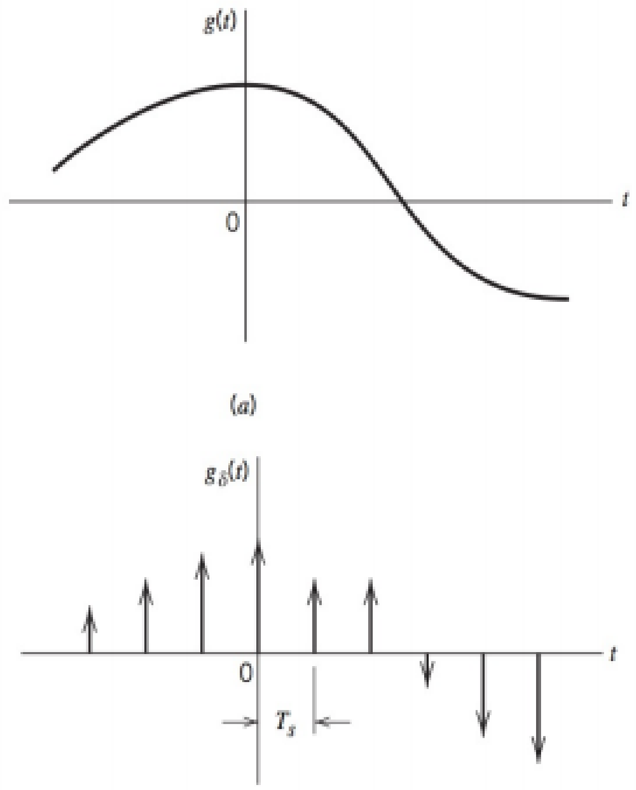
- Because of the constant amplitude of FSK or PSK, the effect of non-linearities, noise and interference is minimum on signal detection.
- These effects are more pronounced in ASK.

Coherent Digital Modulation Techniques

- Coherent digital modulation techniques are those techniques which employ *coherent detection*.
- In coherent detection, the local carrier generated at the receiver is phase locked with the carrier at the transmitter.
- Thus, the detection is done by correlating the received noisy signal and locally generated carrier.
- The coherent detection is also called *synchronous detection*.

Sampling Theorem and Nyquist Rate

- It is necessary that we choose the sampling rate properly
- Sequence of samples uniquely defines the original analog signal
- The sampling theorem governs the conversion of continuous-time signal into discrete-time signal.



Sampling Theorem and Nyquist Rate (continued)

- The sampling theorem states that

Any continuous time signal can be completely represented in its samples and recovered back if the sampling frequency is greater than or equal to twice the highest frequency component of base band signal, that is, sampling frequency, $f_s > 2f_m$.

where f_m *is the highest frequency in base band continuous time signal.*

- When the sampling rate becomes exactly equal to $2f_m$ samples per second, then it is called Nyquist rate.
  - Nyquist rate is the minimum sampling rate.

Sampling Theorem and Nyquist Rate (continued)

- A low pass filter is used to recover the original signal from its samples.
- The process of reconstructing the continuous-time signal from its samples is known as *interpolation*.
- When the sampling frequency is less than the Nyquist rate, *aliasing* problem is said to occur.
- *Aliasing* is the phenomenon in which a high frequency component in the frequency spectrum of the signal takes the identity of a lower frequency component in the spectrum of the sampled signal.

Sampling Theorem and Nyquist Rate (continued)

- To avoid aliasing:
  - Prealias filter must be used to limit the band of frequencies of the signal to f_m Hz.
  - Sampling frequency must be selected such that $f_s \geq 2f_m$.

Radio Wave Propagation

Radio Wave Propagation

- Based on the nature of the communication channel, the communication can be broadly classified the into following three categories:
  a) Line communication,
  b) Optical communication and
  c) Space communication
- In *space communication,* electromagnetic waves of different frequencies are used to carry information through the physical space acting as the transmission medium.
- Electromagnetic waves with frequencies extending from about 10 kHz to 300 GHz are classified as *radio waves*.

Radio Wave Propagation (continued)

- Depending on the frequency, a radio wave travels from the transmitting to the receiving antenna in several ways.
- On the basis of the mode of propagation, radio waves can be broadly classified as:
  1. ground or surface wave
  2. space or tropospheric wave
  3. sky wave
- Accordingly, we have three types of propagation.

Radio Wave Propagation (continued)

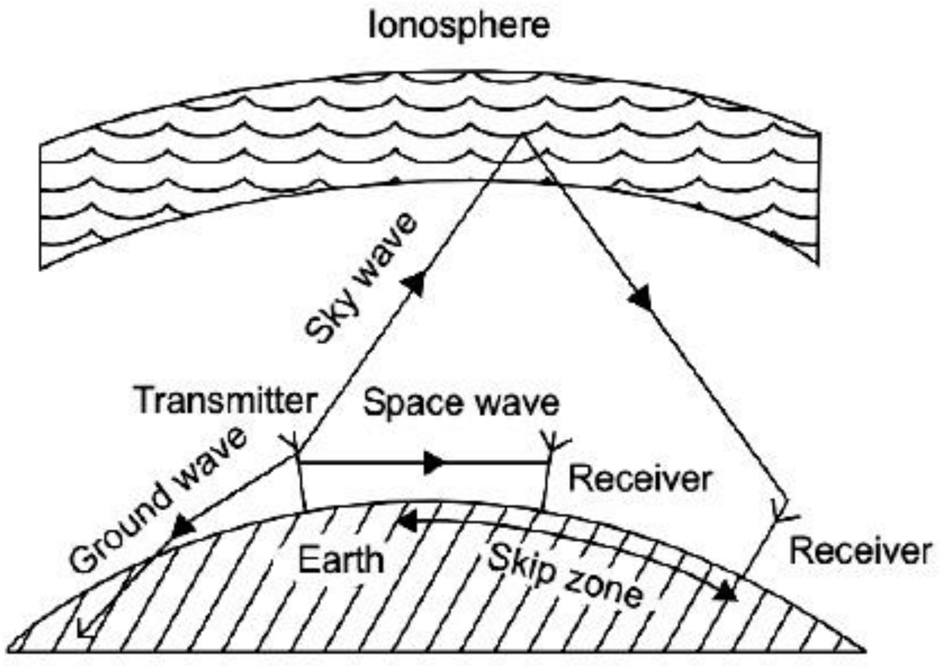


Fig. 1.28

Ground Wave Propagation

- Radio waves are guided by the earth and move along its curved surface from the transmitter to the receiver.
  - They are strongly influenced by the electrical properties of the ground.
- This is useful only at low frequencies as high frequency waves are strongly absorbed by ground.
- Below 500 kHz, ground waves can be used for communication within distances of about 1500 km from the transmitter.
- AM radio broadcast in the medium frequency band cover local areas and take place primarily by the ground wave.
- Ground wave transmission is very reliable whatever the atmospheric conditions be.

Space or Tropospheric Wave Propagation

- Radio wave transmitted from an antenna, travels in a straight line and directly reaches the receiving antenna.
- In space wave or line of sight propagation, radio waves move in the earth's troposphere within about 15 km over the surface of the earth.
- The space wave is made up of two components:
  a) *a direct or line-of- sight wave* from the transmitting to the receiving antenna
  b) *the ground-reflected wave* traversing form the transmitting antenna to ground and reflected to the receiving antenna
- Television frequencies in the range 100-220 MHz are transmitted through this mode.

Sky Wave Propagation

- Radio waves transmitted from the transmitting antenna reach the receiving antenna after reflection from the ionosphere, i.e. the ionized layers lying in the earth's upper atmosphere.
- Short wave transmission around the globe is possible through sky wave via successive reflections at the ionosphere and the earth's surface.
- *Ionosphere* - The ionized region of the earth's upper atmosphere extending from about 40 km to the height of a few earth radii above the earth.
  - The ionosphere is made up of electrons, and positive and negative ions in the background of neutral particles of the atmosphere.
- The propagation of radio wave through the ionosphere is affected by the electrons and ions in the ionosphere.
  - The effect of the electrons on the propagation is much greater than that of the ions since the electronic mass is much less than the ionic mass.

Radio Signal Transmission

Radio Signal Transmission

- Figure 6A.1 shows the most important components of a wireless transmission system.

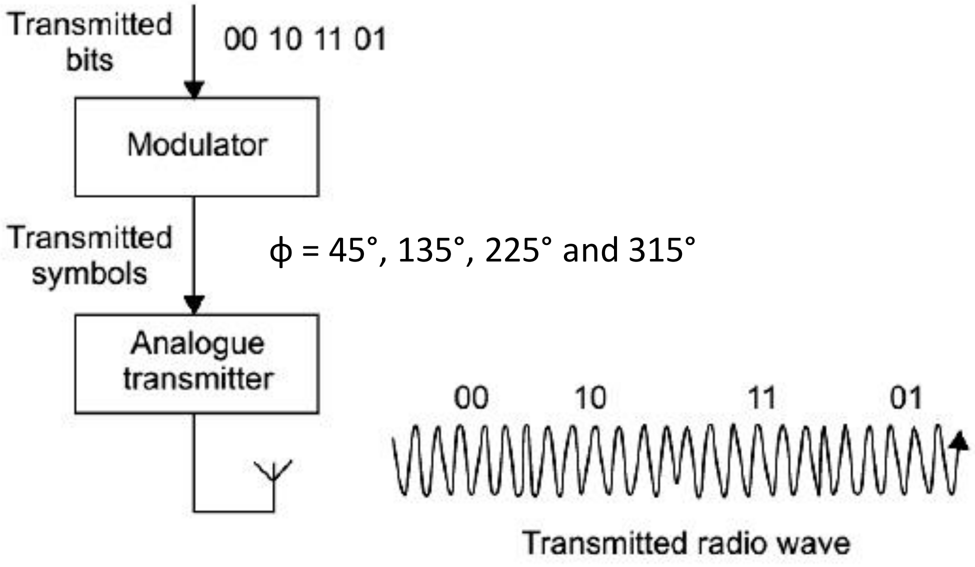


Fig. 6A.1 Architecture of a wireless communication transmitter

Radio Signal Transmission (continued)

- The transmitter accepts a stream of bits from the application software.
- It then encodes these bits onto a radio wave, known as a *carrier*, by adjusting parameters of the wave such as its amplitude or phase.
- The transmitter usually processes the information in two stages.
  - Modulator – accepts the incoming bits, and computes *symbols* that represent the amplitude and phase of the outgoing wave.
  - Analogue transmitter – generates the radio wave

Radio Signal Transmission (continued)

- The modulation scheme used in Fig. 6A.1 is known as *Quadrature Phase Shift Keying (QPSK)*.
- A QPSK modulator takes the incoming bits two at a time and transmits them using a radio wave that can have four different states.
- These have phases of 45°, 135°, 225° and 315°, which correspond to bit combinations of 00, 10, 11 and 01 respectively.
- We can represent the four states of QPSK using the constellation diagram shown in Fig. 6A.2b.

Radio Signal Transmission (continued)

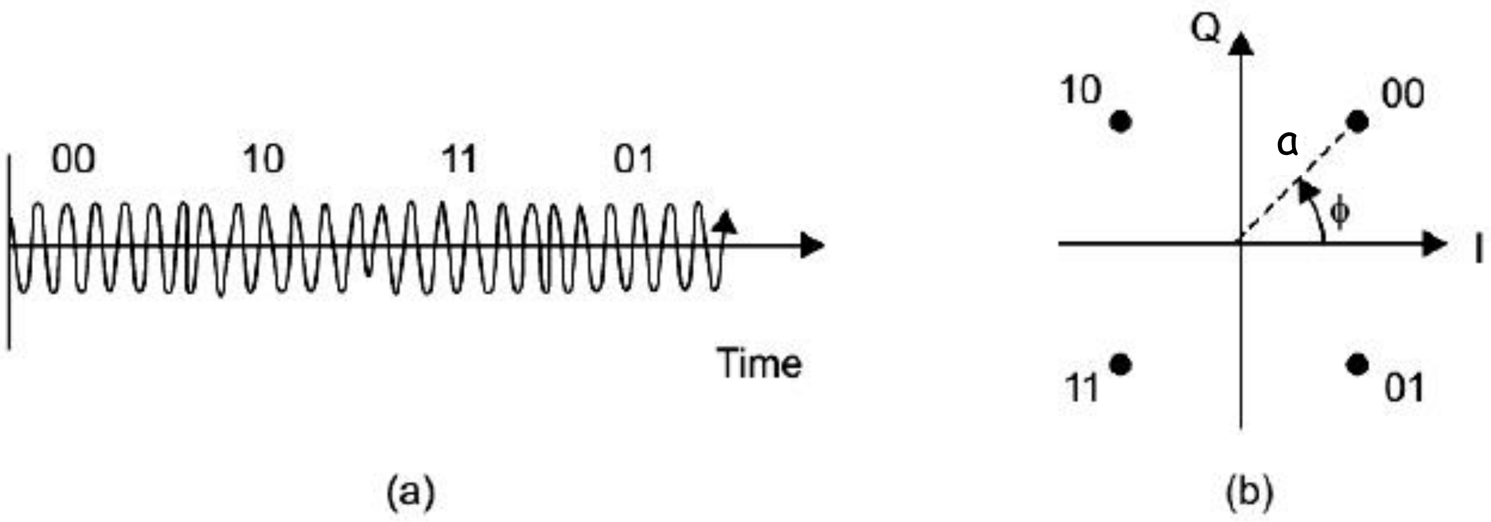


Fig. 6A.2 Quadrature phase shift keying. (*a*) Example QPSK waveform. (*b*) QPSK constellation diagram

Radio Signal Transmission (continued)

- In constellation diagram, the distance of each state from the origin represents the amplitude of the transmitted wave, while the angle (measured anti-clockwise from the x-axis) represents its phase.
- Usually, each symbol is represented using two other numbers, which are known as the in-phase (I) and quadrature (Q) components:

$$I = a\ \cos\phi$$
$$Q = a\sin\phi$$

where a is the amplitude of the transmitted wave and ϕ is its phase.

- The in-phase and quadrature components are the real and imaginary parts of a complex number respectively.

Radio Signal Transmission (continued)

- LTE (Long Term Evolution) uses four modulation schemes altogether.
  - **Binary Phase Shift Keying (BPSK)** – sends bits one at a time, using two states that can be interpreted as starting phases of 0° and 180°, or as signal amplitudes of $+1$ and -1.
  - **Quadrature Phase Shift Keying (QPSK)** – sends bits two at a time, using four states that can be interpreted as phases of 45°, 135°, 225° and 315° which correspond to bit combinations of 00, 10, 11 and 01 respectively.
  - **16-Quadrature Amplitude Modulation (16-QAM)** – sends bits four at a time, using 16 states that have different amplitudes and phases.
  - **64-Quadrature Amplitude Modulation (64-QAM)** – sends bits six at a time using 64 different states, so it has a data rate six times greater than that of BPSK.

Radio Signal Transmission (continued)

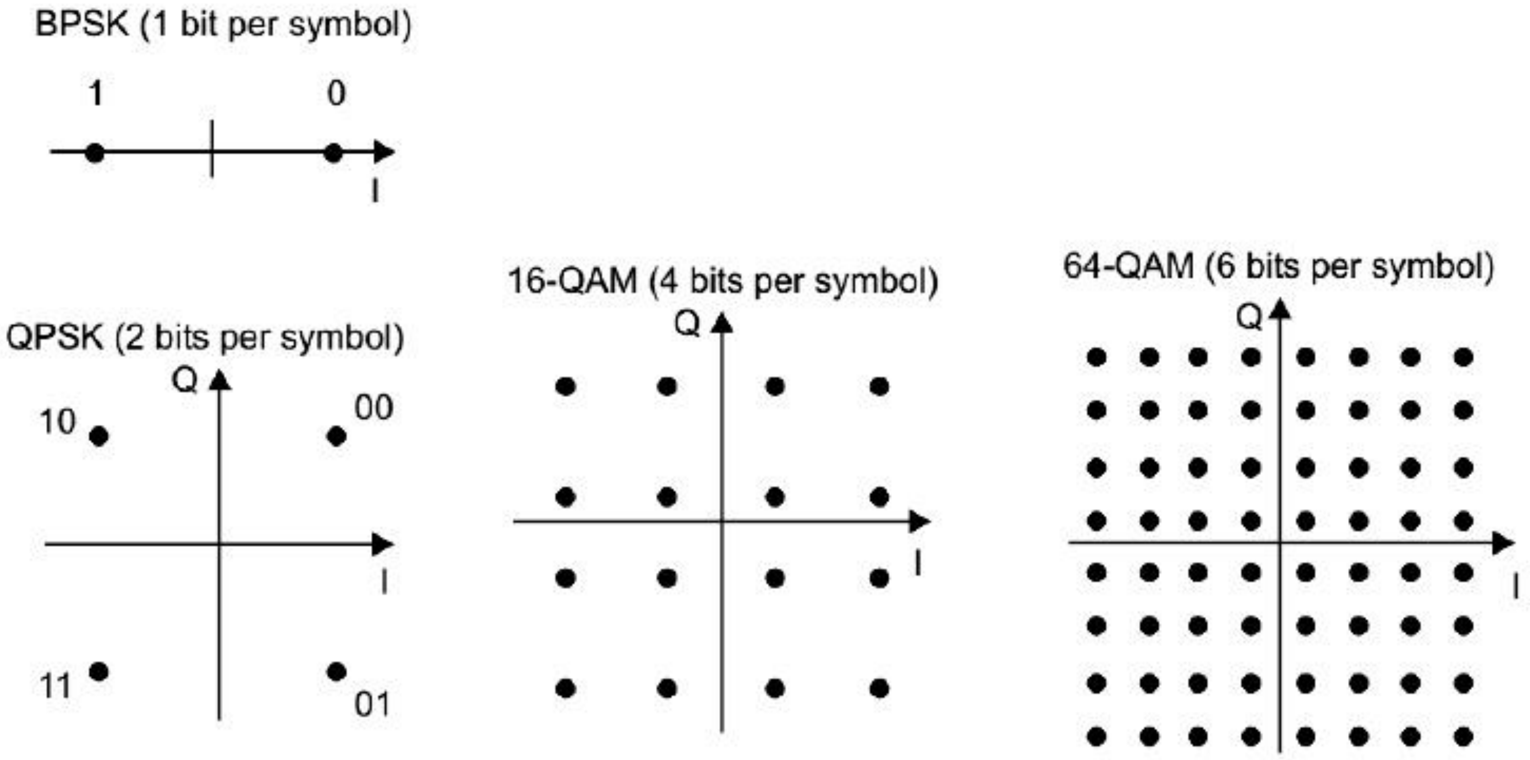


Fig. 6A.3 Modulation schemes used by LTE

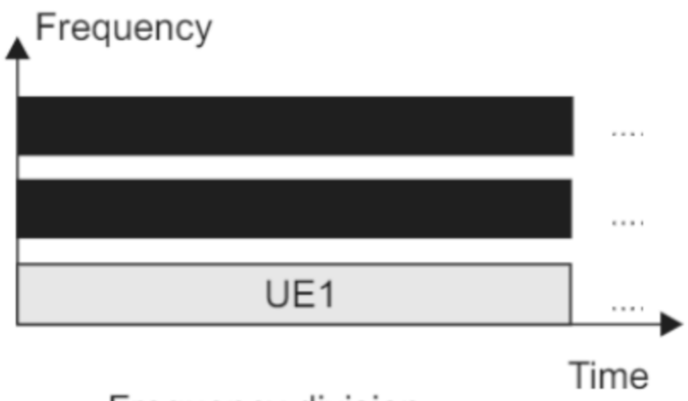
Multiple Access Techniques

Multiple Access Techniques

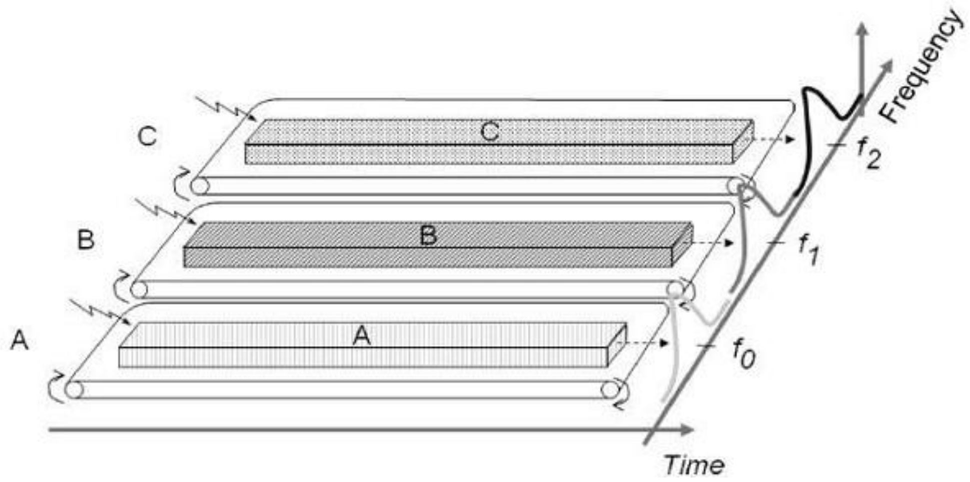
- In a cellular network, a base station has to transmit to many different mobiles at once.
- This is done by sharing the resources of the air interface using a technique known as *multiple access*.
- Mobile communication systems use different multiple access techniques:
  - Frequency Division Multiple Access (FDMA)
  - Time Division Multiple Access (TDMA)
  - Code Division Multiple Access (CDMA)

Frequency Division Multiple Access (FDMA)

- Each mobile receives signal on its own carrier frequency, which it distinguishes from the others using analogue filters.
- The carriers are separated by unused *guard bands* to minimize the interference between them.

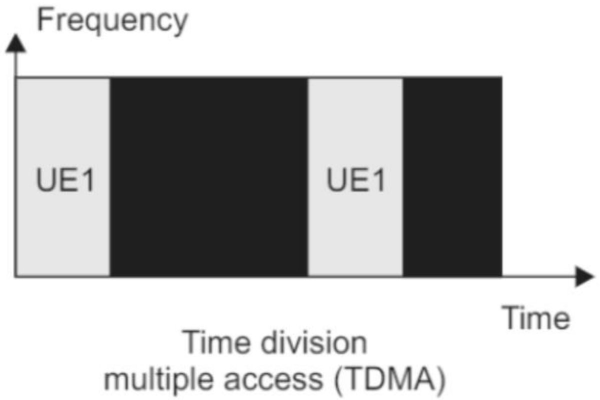


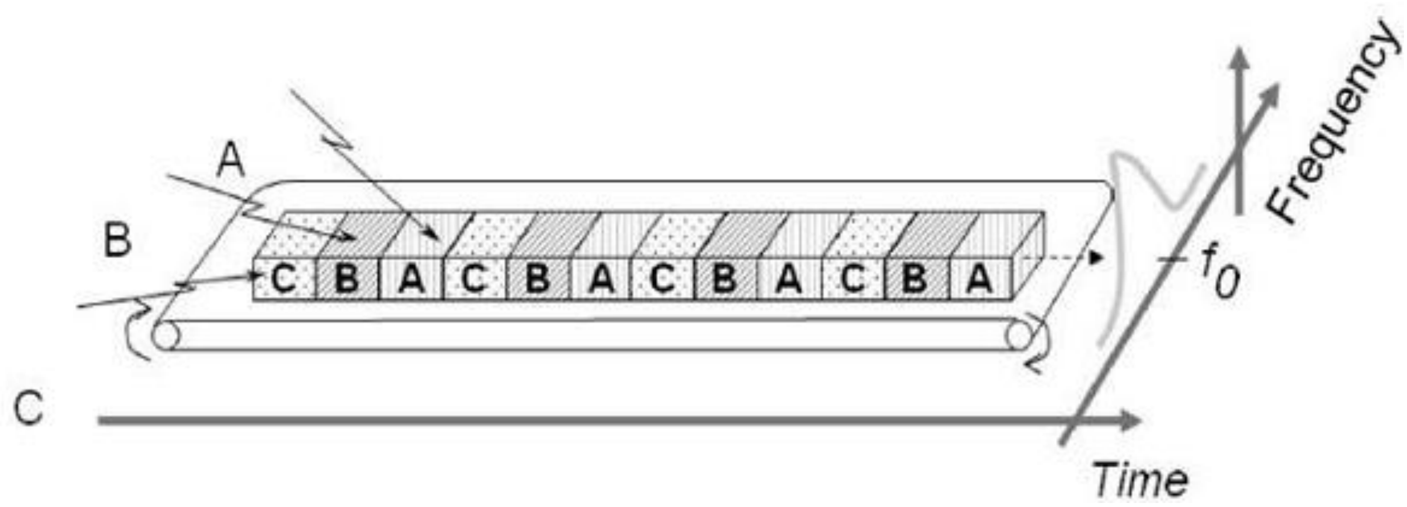
Frequency division multiple access (FDMA)



Time Division Multiple Access (TDMA)

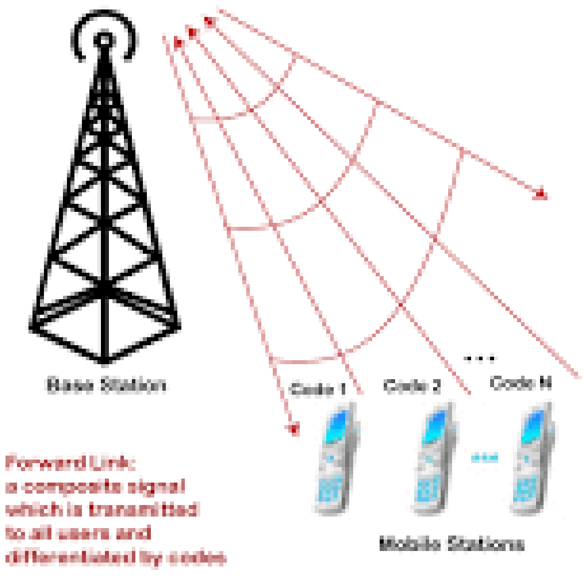
- Mobiles receive signals on the same carrier frequency, but at different times.

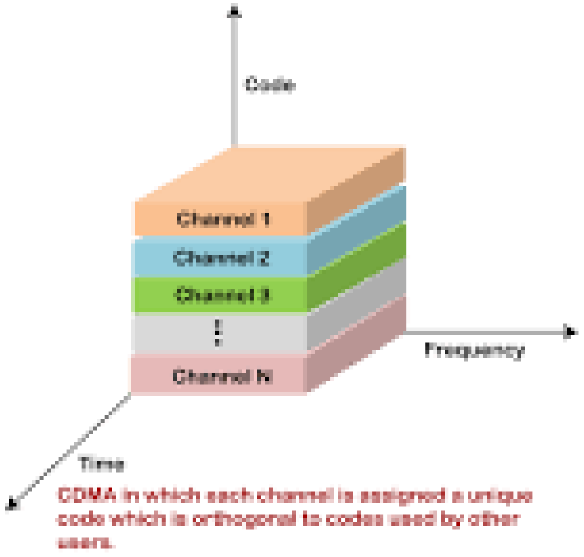




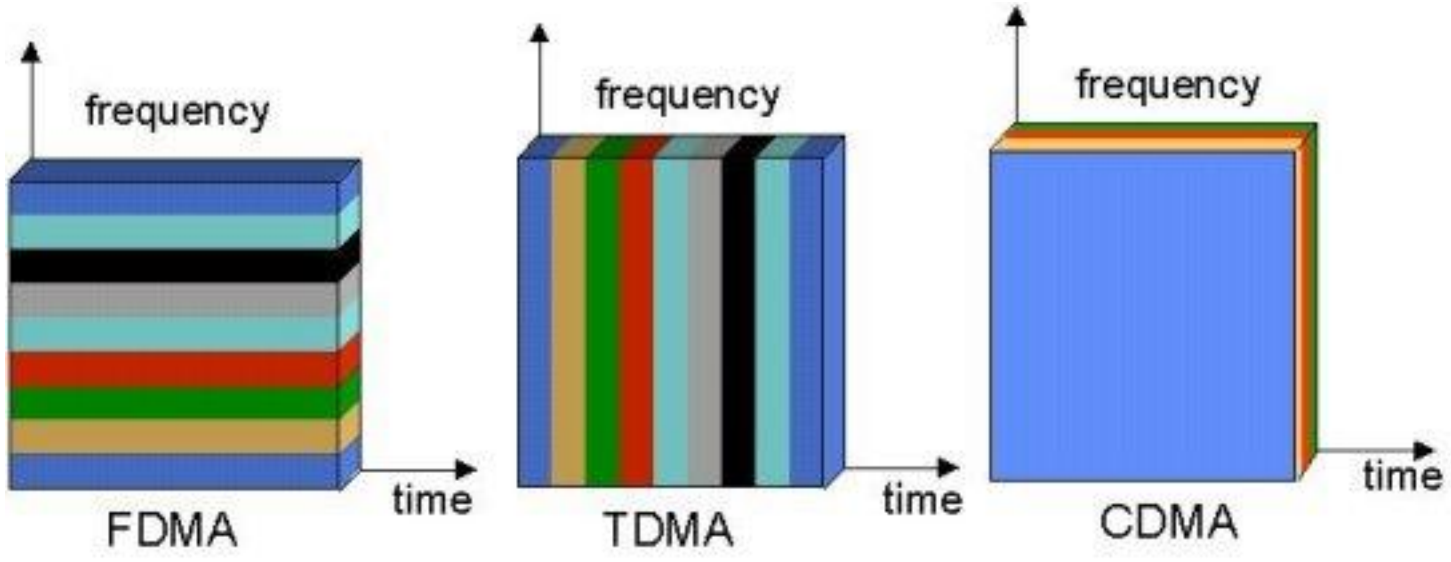
Code Division Multiple Access (CDMA)

- Mobiles receive signals on the same carrier frequency and at the same time, but the signals are labelled by the use of codes, which allow a mobile to separate its own signal from those of the others.





FDMA, TDMA & CDMA



Multiple Access Techniques (continued)

- FDMA was used by the first generation analogue systems.
- GSM uses a mix of FDMA and TDMA, in which every cell has several carrier frequencies that are each shared amongst eight different mobiles.
- LTE uses another mixed technique known as Orthogonal Frequency Division Multiple Access (OFDMA).
- CDMA is used by the third generation communication systems.
- LTE uses a few of the concepts from CDMA for some of its control signals, but does not implement the technique otherwise.

Multiplexing vs. Multiple Access

- Multiple access is actually a generalization of a simpler technique known as *multiplexing*.
- A multiple access system can dynamically change the allocation of resources to different mobiles, whereas in a multiplexing system the resource allocation is fixed.

FDD and TDD Modes

- By using the various multiple access techniques, a base station can distinguish the transmissions to and from the individual mobiles in the cell.
- To distinguish the mobiles' transmissions from those of the base stations, a mobile communication system can operate in different transmission modes:
  - **Frequency Division Duplex (FDD)** – the base station and mobile transmit and receive at the same time, but using different carrier frequencies.
  - **Time Division Duplex (TDD)** – the base station and mobile transmit and receive on the same carrier frequency but at different times.

FDD and TDD Modes (continued)

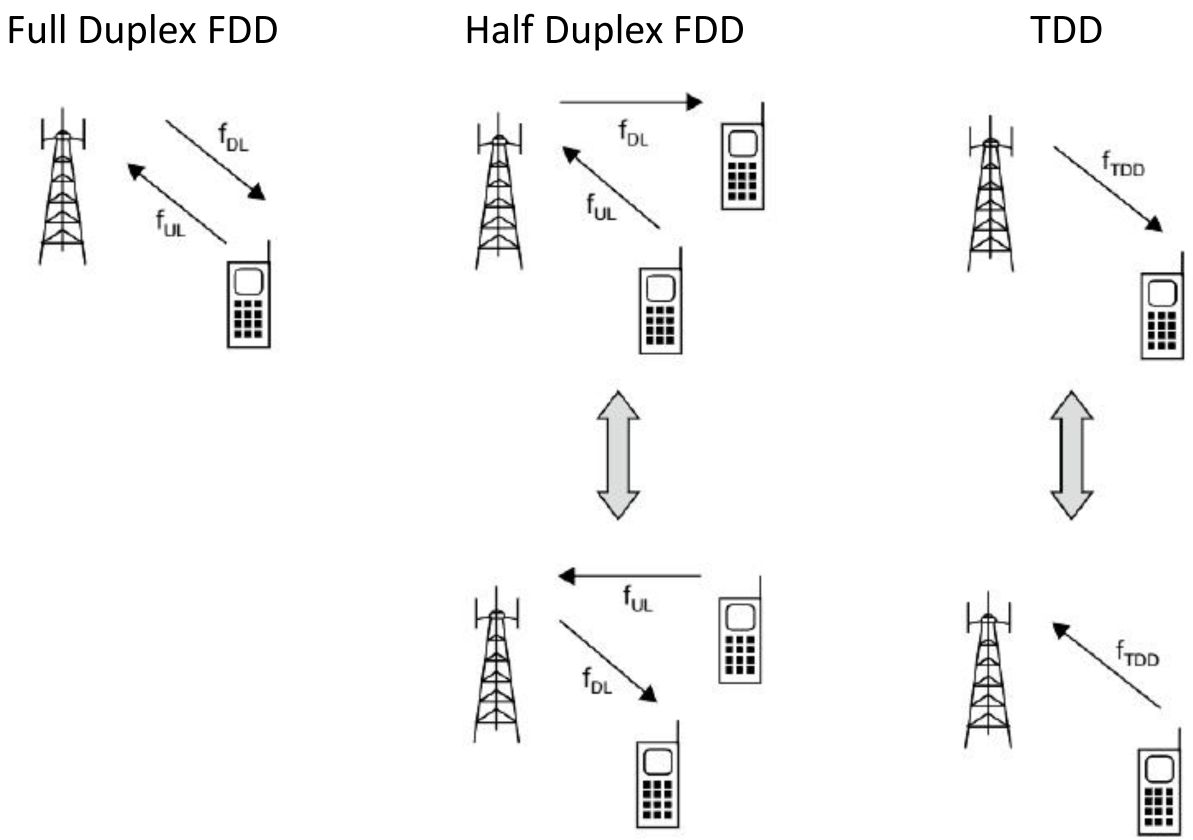


Fig. 6A.7 Operation of FDD and TDD modes

f_{UL} - uplink frequency
f_{DL} - downlink frequency

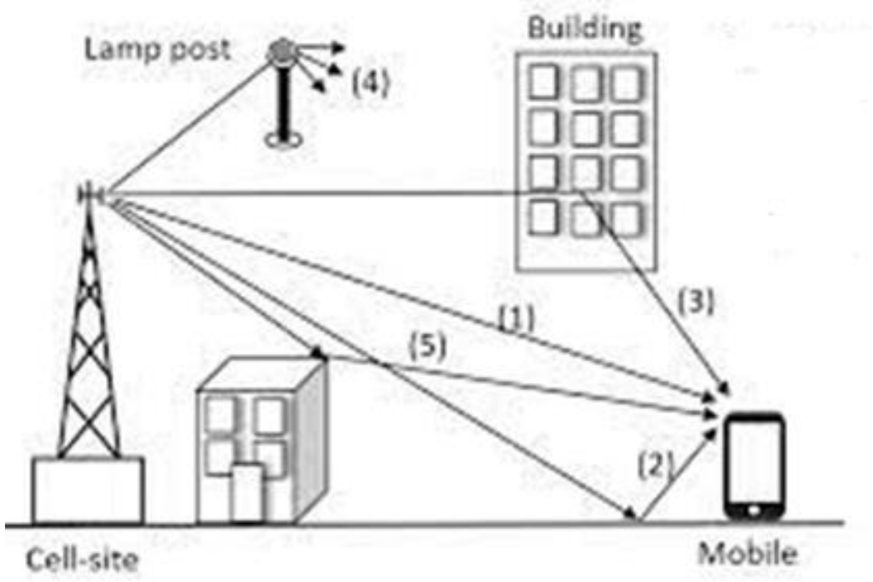
FDD and TDD Modes (continued)

- In FDD mode,
  - the bandwidths of the uplink and downlink are fixed and are usually the same
  - suitable for voice communications, in which the uplink and downlink data rates are very similar.
- In TDD mode,
  - the system can adjust how much time is allocated to the uplink and downlink
  - suitable for applications such as web browsing, in which the downlink data rate can be much greater than the rate on the uplink.

Multipath and Fading

Multipath and Fading

- As a result of reflections, rays can take several different paths from the transmitter to the receiver.
  - This phenomenon is known as *multipath*.



Multipath and Fading (continued)

- At the receiver, the incoming rays can add together in different ways, which are shown in Fig. 6A.8.

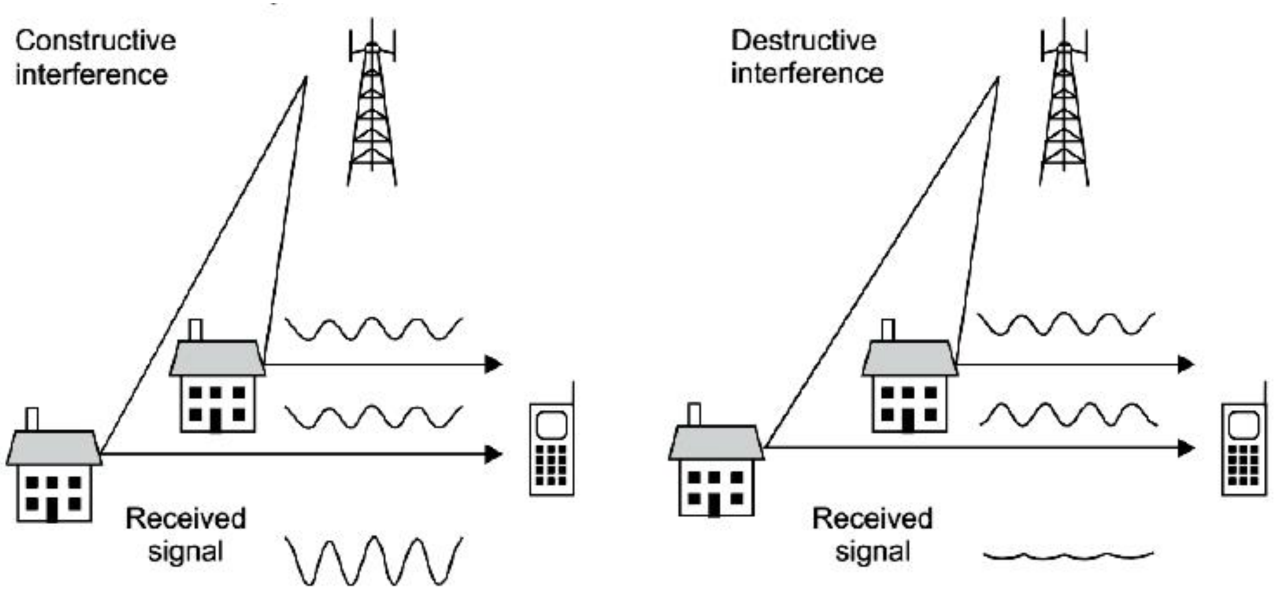


Fig. 6A.8 Generation of constructive interference, destructive interference and fading in a multipath environment

Multipath and Fading (continued)

- Constructive interference – If the peaks of the incoming rays coincide, then they reinforce each other.
- Destructive interference – If the peaks of one ray coincide with the troughs of another, the rays cancel.
- Destructive interference can make the received signal power drop to a very low level.
  - This phenomenon is known as *fading*.

Fading as a Function of Time and Frequency

- Fading is a function of time.
  - If the mobile moves from one place to another, then the ray geometry changes, so the interference pattern changes between constructive and destructive.
- The amplitude and phase of the received signal vary over a timescale called the *coherence time*, T_c, which can be estimated as:

$$T_c \approx \frac{1}{f_D}$$

- Here f_D is the mobile's Doppler frequency:

$$f_D = \frac{v}{c} f_C$$

- where f_C is the carrier frequency, v is the speed of the mobile and c is the speed of light ($3 \times 10^8 ms^{-1}$).

Fading as a Function of Time and Frequency (continued)

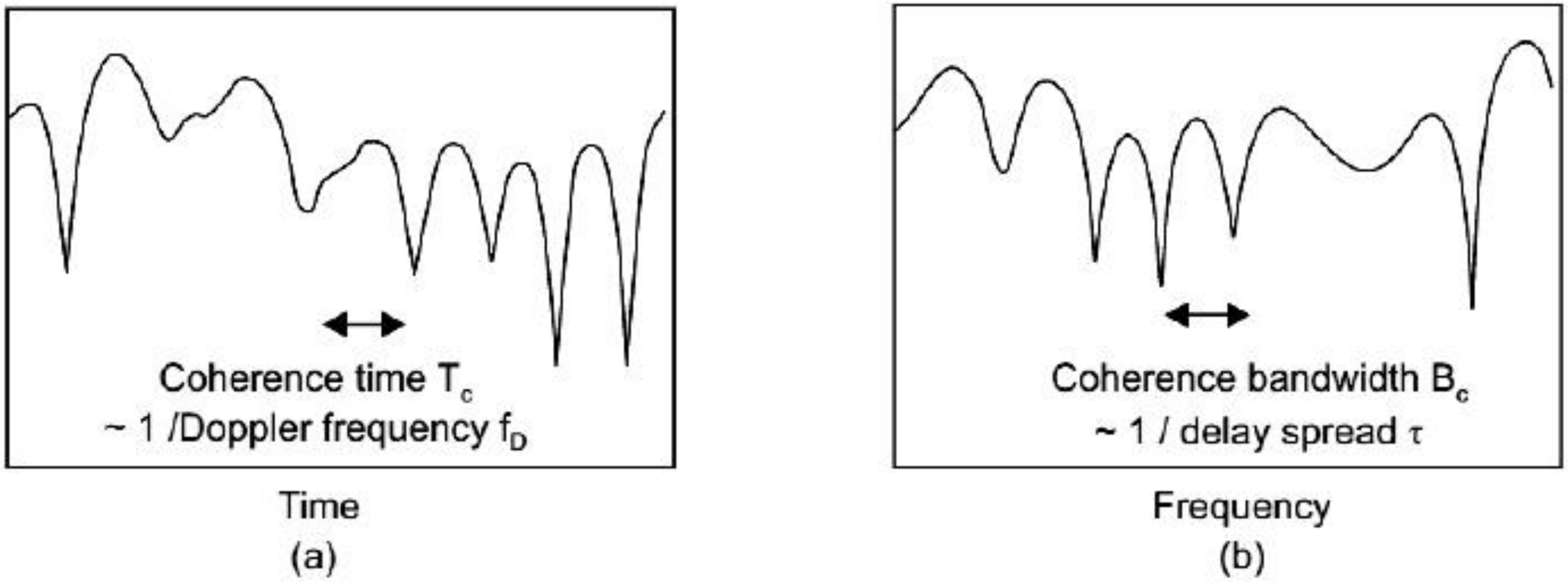


Fig. 6A.9 Fading as a function of (*a*) time and (*b*) frequency

Fading as a Function of Time and Frequency (continued)

- Fading is a function of frequency.
  - If the carrier frequency changes, then the wavelength of the radio signal changes. This makes the interference pattern change between constructive and destructive.
- The amplitude and phase of the received signal vary over a frequency scale called the $coherence\ bandwidth$, B_c, which can be estimated as:

$$B_c \approx \frac{1}{\tau}$$

- Here, τ is the delay spread of the radio channel, which is the difference between the arrival times of the earliest and latest rays. It can be calculated as:

$$\tau = \frac{\Delta L}{c}$$

- where ΔL is the difference between the path lengths of the longest and shortest rays.

Error Management

Error Management

- Noise and interference lead to errors in a wireless communication receiver.
- Errors cause damage to information – voice calls, web pages, emails, etc.
- There are several ways to solve the problem:
  - Forward Error Correction
  - Automatic Repeat Request

Forward Error Correction

- This is a technique used for controlling errors in data transmission over unreliable or noisy communication channels.
- In this technique, the transmitted information is represented using a *codeword* that is typically two or three times as long.
- The extra bits supply additional, redundant data that allow the receiver to recover the original information sequence.

Forward Error Correction (continued)

- For example, a transmitter might represent the information sequence 101 using the codeword 110010111.
- After an error in the second bit, the receiver might recover the codeword 100010111.
- If the coding scheme has been well designed, then the receiver can conclude that this is not a valid codeword, and that the most likely transmitted codeword was 110010111.
- The receiver has therefore corrected the bit error and can recover the original information.

Forward Error Correction (continued)

- **Coding rate** - Number of information bits divided by the number of transmitted bits.
  - Coding rate is 1/3 in the example above.
- Forward error correction algorithms operate with a fixed coding rate.
  - Despite this, a wireless transmitter can still adjust the coding rate using the two- stage process shown in the Fig. 6A.11.

Forward Error Correction (continued)

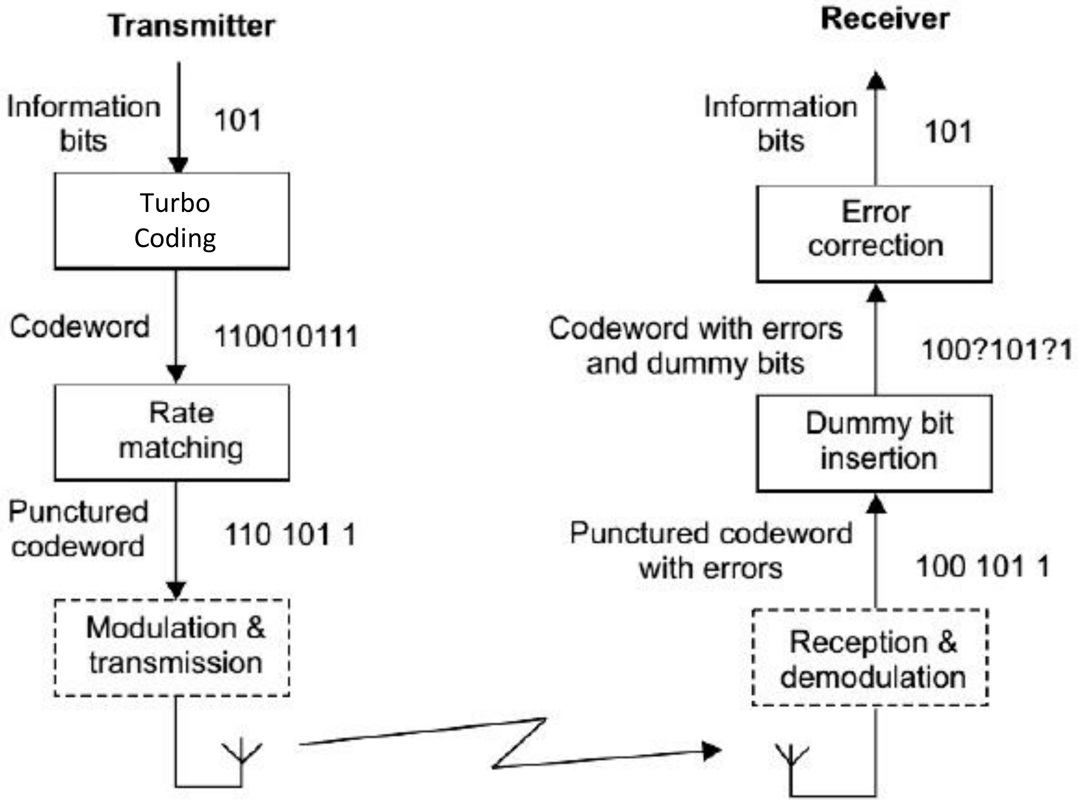


Fig. 6A.11 Block diagram of a transmitter and receiver using forward error correction and rate matching

Forward Error Correction (continued)

- In the first stage, the information bits are passed through a fixed-rate coder.
  - The main algorithm used by LTE is known as Turbo coding and has a fixed coding rate of 1/3.
- In the second stage, called *rate matching*, some of the coded bits are selected for transmission, while the others are discarded in a process known as *puncturing*.
  - The receiver has a copy of the puncturing algorithm, so it can insert dummy bits at the points where information was discarded. It can then pass the result through a turbo decoder for error correction.

Forward Error Correction (continued)

- If the coding rate is low, the transmitted data contain many redundant bits which allows the receiver to correct a large number of errors and to operate successfully at a low SINR (Signal to Interference & Noise ratio), but at the expense of a low information rate.
- If the coding rate is close to 1, then the information rate is higher but the system is more vulnerable to errors.
- A trade-off between information rate and SINR has to be achieved.

Automatic Repeat Request

- *Automatic Repeat Request (ARQ)* is an error management technique, which is illustrated in Fig. 6A.12.

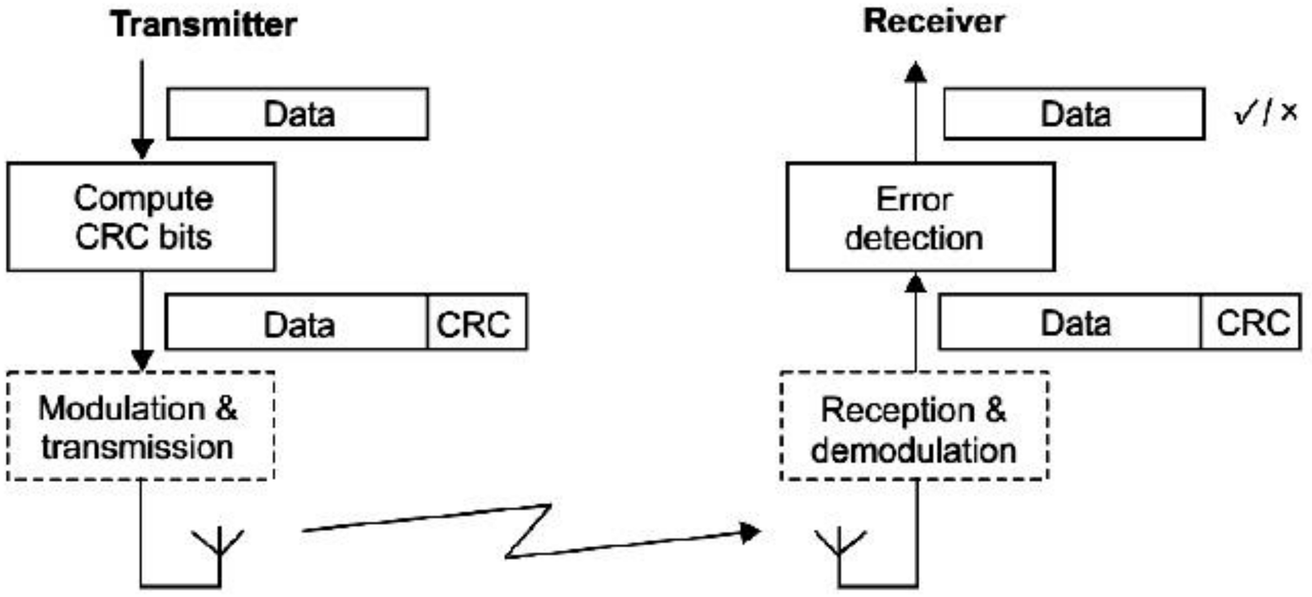


Fig. 6A.12 Block diagram of a transmitter and receiver using automatic repeat request

Automatic Repeat Request (continued)

- The transmitter takes a block of information bits and uses them to compute some extra bits that are known as a *cyclic redundancy check (CRC).*
- It appends these to the information block and then transmits the two sets of data in the usual way.
- The receiver separates the two fields and uses the information bits to compute the expected CRC bits.
- If the observed and the expected CRC bits are the same, then it concludes that the information has been received correctly and sends positive acknowledgement back to the transmitter.

Automatic Repeat Request (continued)

- If the CRC bits are the different, then it concludes that an error has occurred and sends negative acknowledgement to the transmitter to request re-transmission.
- Positive and negative acknowledgements are often abbreviated to ACK and NACK respectively.

Error Management (continued)

- A wireless communication system often combines these two error management techniques.
- Such a system corrects most of the bit errors by the use of forward error correction and then uses automatic repeat requests to handle the remaining errors that leak through.

Antennas

Antennas

- An *antenna* is a device for converting electromagnetic radiation in space into electrical currents in conductors or vice-versa, depending on whether it is being used for receiving or for transmitting, respectively.
- Antennas transform wire propagated waves into space propagated waves
- Antennas receive electromagnetic waves and pass them onto a receiver or they transmit electromagnetic waves which have been produced by a transmitter.

Features of Antennas

- Strictly defined radiation pattern for most accurate network planning
- Growing concern for the level of intermodulation due to the radiation of many HF-carriers via one antenna
- Dual polarization
- Electrical down-tilting of vertical diagram
- Unobtrusive design

Types of Antennas

- Omnidirectional Antennas
  - Dipole Antennas
  - Collinear Omni Antennas
- Directional Antennas
  - Patch Antennas
  - Patch Array Antennas
  - Yagi Antennas

Omnidirectional Antennas

- An *omnidirectional antenna* is an antenna that has a non-directional pattern (circular pattern) in a given plane with a directional pattern in any orthogonal plane.
- It radiates equal power in all directions perpendicular to the axis.
- Examples of omnidirectional antennas are dipoles and collinear antennas.

Dipole Antennas

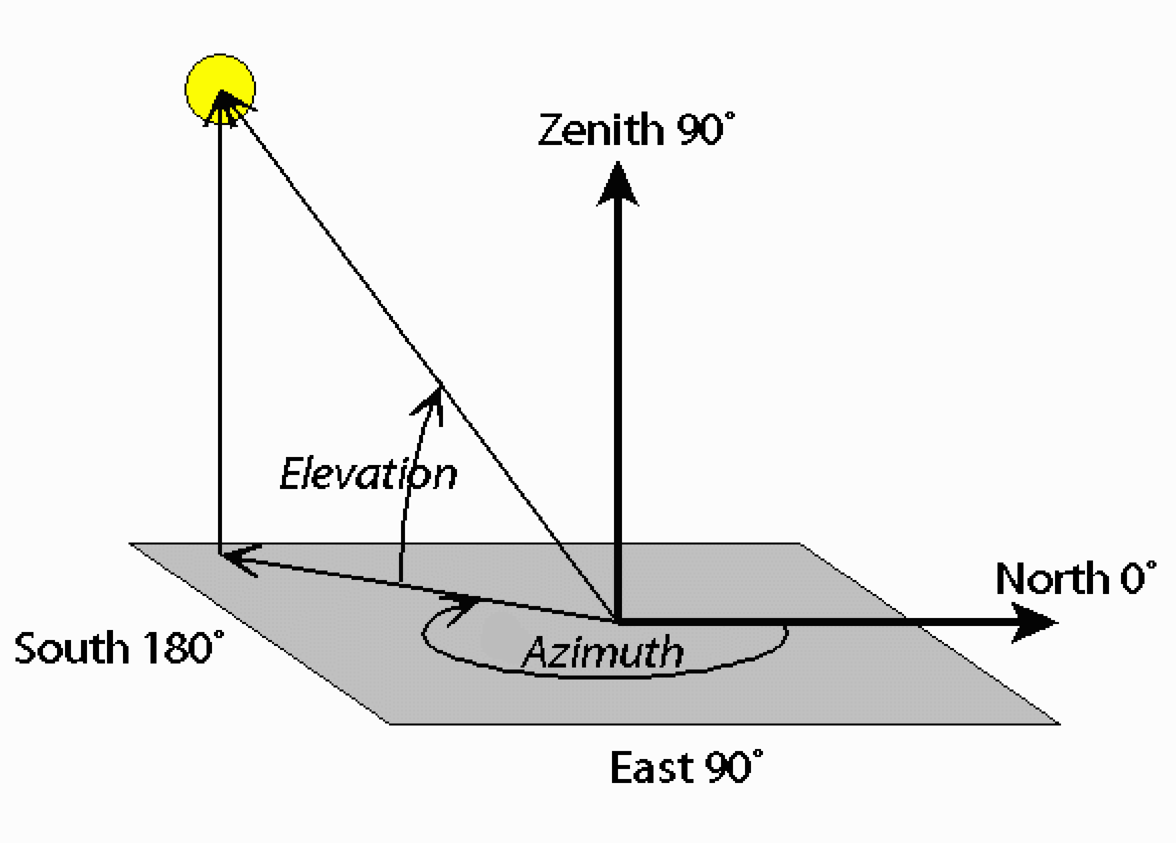
- A dipole antenna most commonly refers to a half-wavelength ($\lambda/2$) dipole.
- The physical antenna is constructed of conductive elements whose combined length is about half of a wavelength at its intended frequency of operation.
- This is a simple antenna that radiates its energy out toward the horizon.

Dipole Antenna Model

Collinear Omni Antennas

- In order to create an omnidirectional antenna with higher gain, multiple omnidirectional structures are arranged in vertical, linear fashion to retain the same omnidirectional pattern in the azimuth plane but a more focused elevation plane beam which leads to higher gain.
- This is frequently referred to as a *collinear array.*
- Higher gain implies same power radiated in a more focused way.

Concept of Azimuth and Elevation Angle



Directional Antennas

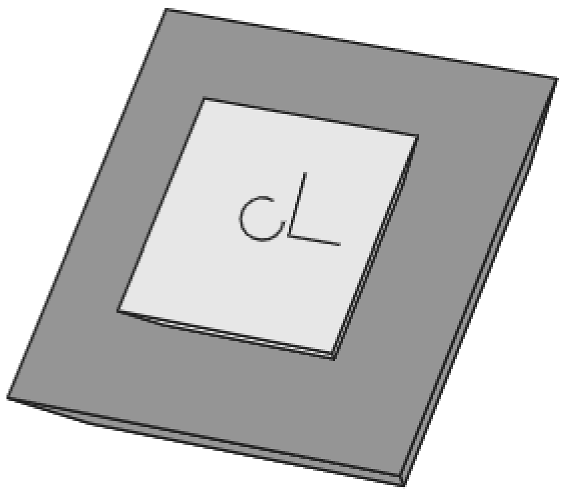
- A *directional antenna* is one that radiates its energy most effectively in one direction than the others.
- They have one main lobe and several minor lobes.
- They are used for coverage as well as point-to-point links.
- Examples of directional antennas are patch, dish and horn antennas.
- They all accomplish the same goal – radiating their energy out in a particular direction.

Dish Antenna

Horn Antenna

Patch Antennas

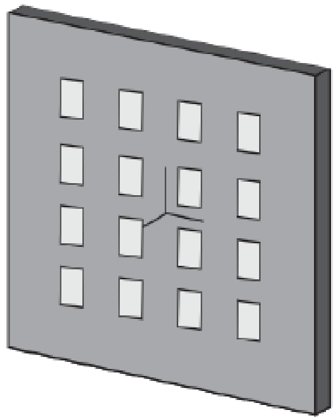
- A *patch antenna*, in its simplest form is a single rectangular(or circular) conductive plate that is spaced above a ground place.
- Patch antennas are attractive due to their ease of fabrication



Patch Antenna Model

Patch Array Antennas

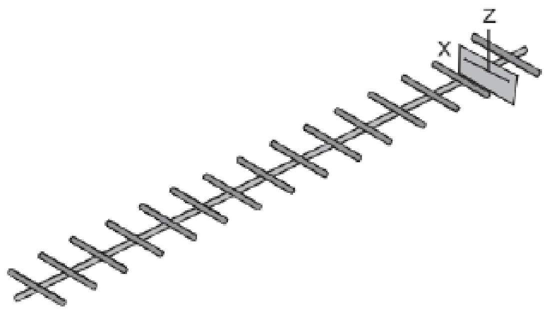
- A *patch array antenna* is an arrangement of multiple patch antennas that are all driven by the same source.
- Frequently, this arrangement consists of patches arranged in orderly rows and columns
- The reason for this arrangement is higher gain.



4x4 Patch Array Antenna

Yagi Antennas

- A Yagi antenna is formed by driving a simple antenna, typically a dipole or dipole-like antenna, and shaping the beam using a well-chosen series of elements whose length and spacing are tightly controlled.
- The Yagi shown in the figure is built with one reflector (the bar behind the driven antenna) and 14 directors (the bars in front of the driven antenna).
- Yagi antenna is a directional antenna that radiates its energy out in one main direction.
- Very often, these antennas are enclosed in a tube, with the result that the user may not see all the antenna elements.



Yagi Antenna Model