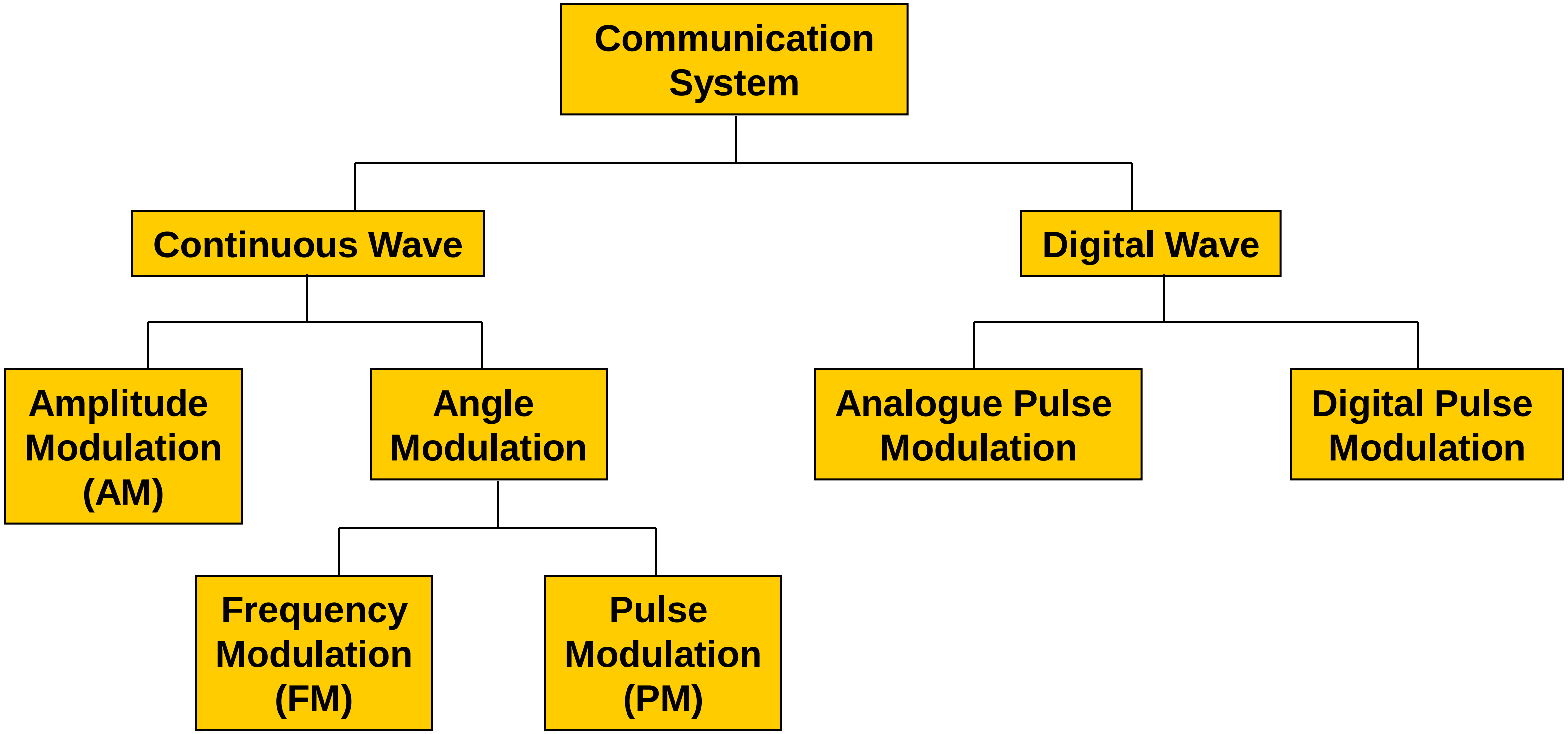
Chapter 2: Modulation

Communication System Chart



Introduction

What is modulation?

"Modulation is defined as the process of **modifying a carrier wave** (radio wave) systematically by the modulating signal (audio)"

This process makes the signal suitable for the transmission and compatible with the channel. The resultant signal is called the modulated signal

In the other words, it is the process of changing/varying one of the parameters of the carrier wave by the modulating signal

Introduction

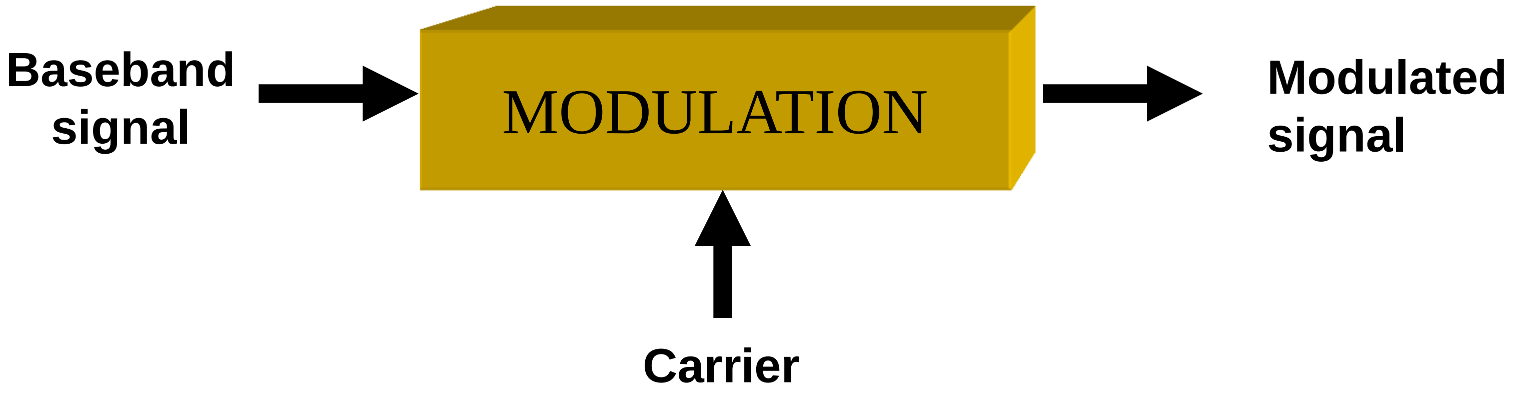
- Modulation is operation performed at the transmitter to **achieve efficient and reliable information transmission**

- For analogue modulation, it is frequency translation method caused by changing the appropriate quantity in a carrier signal

- It involves two waveforms:
  - A modulating signal/baseband signal – represents the message
  - A carrier signal – depends on type of modulation

Introduction

- **Analogue modulations** - frequency translation methods caused by changing the appropriate quantity in a carrier signal.



Introduction

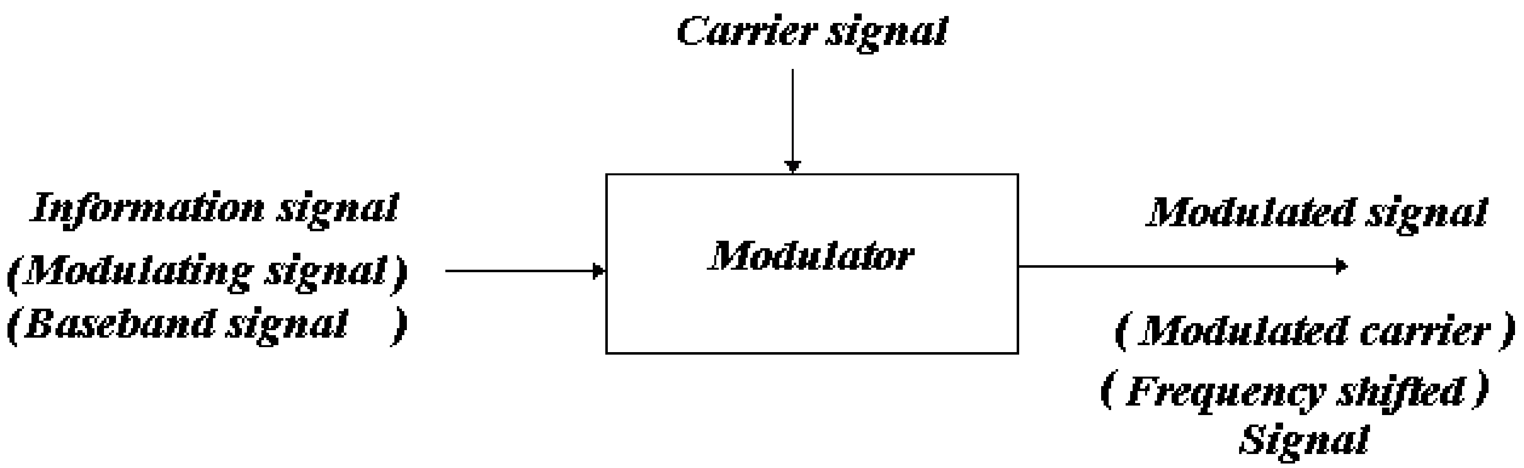


Fig. Process of Modulation

Introduction

•Once this information is received, the low frequency information must be removed from the high frequency carrier.

•This process is known as ***" Demodulation".***

Types of Modulation

Three main type of modulations:

- **Analog Modulation**
  - Amplitude modulation
    - Example: Double sideband with carrier (DSB-WC), Double sideband suppressed carrier (DSB-SC), Single sideband suppressed carrier (SSB-SC), Vestigial sideband (VSB)
  - Angle modulation (frequency modulation & phase modulation)
    - Example: Narrow band frequency modulation (NBFM), Wideband frequency modulation (WBFM), Narrowband phase modulation (NBPM), Wideband phase modulation (NBPM)

Types of Modulation

- **Pulse Modulation**
  - Carrier is a train of pulses
  - Example: Pulse Amplitude Modulation (PAM), Pulse width modulation (PWM) , Pulse Position Modulation (PPM)
- **Digital Modulation**
  - Modulating signal is analog
    - Example: Pulse Code Modulation (PCM), Delta Modulation (DM), Adaptive Delta Modulation (ADM), Differential Pulse Code Modulation (DPCM), Adaptive Differential Pulse Code Modulation (ADPCM) etc.
  - Modulating signal is digital (binary modulation)
    - Example: Amplitude shift keying (ASK), frequency Shift Keying (FSK), Phase Shift Keying (PSK) etc.

Summary of Modulation Techniques

	Volt	***Hertz***	***Radians***
Analogue Modulation	AM	FM	PM
Digital Modulation	ASK	FSK	PSK

$$v(t) = V \sin(2\pi f t + \theta)$$

Types of Modulation

- Changing of the **amplitude** produces

  Amplitude Modulation signal

- Changing of the **frequency** produces

  Frequency Modulation signal

- Changing of the **phase** produces

  Phase Modulation signal

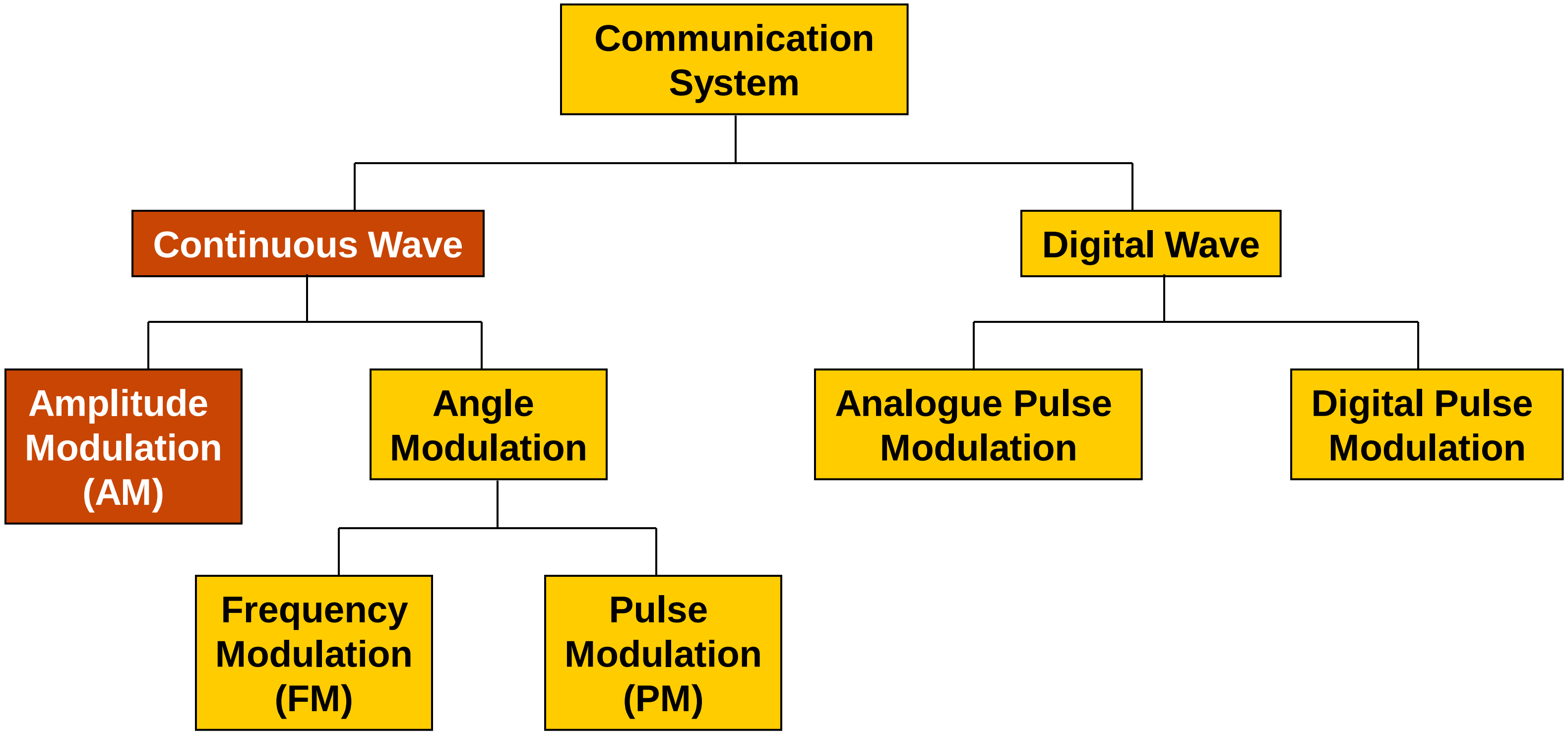
Modulation 1

Analogue Modulation

Amplitude Modulation

(13-60)

Communication System Chart



Amplitude Modulation

Various forms of Amplitude Modulation

- Conventional Amplitude Modulation (Alternatively known as **Full AM** or Double Sideband Large carrier modulation (DSBLC) /Double Sideband Full Carrier (DSBFC)
- **Double Sideband Suppressed** carrier (DSBSC) modulation
- **Single Sideband** (SSB) modulation
- **Vestigial Sideband** (VSB) modulation

Amplitude Modulation ~ DSBFC (Full AM)

"Amplitude Modulation is the process of changing the amplitude of the radio frequency (RF) carrier wave by the amplitude variations of modulating signal"

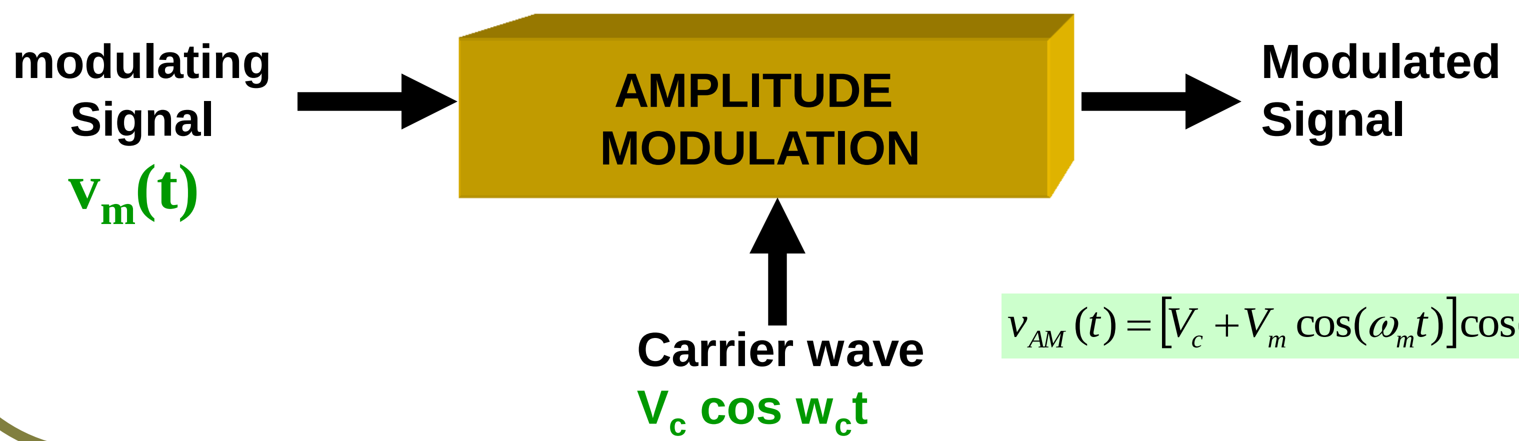
- The **carrier amplitude varied linearly** by the modulating signal which usually consist of a range of a audio frequencies. The frequency of the carrier is not affected

Application of AM	-	Radio broadcasting, TV pictures (video), facsimile transmission
Frequency range for AM	-	535 kHz – 1600 kHz
Bandwidth	-	10 kHz

Amplitude Modulation ~ DSBFC (Full AM)

- In amplitude modulation, the amplitude of the carrier **varies proportional to the instantaneous magnitude** of modulating signal

- Assuming
  - Modulating signal : $v_m(t) = V_m \cos w_m t$
  - carrier signal : $v_c(t) = V_c \cos w_c t$



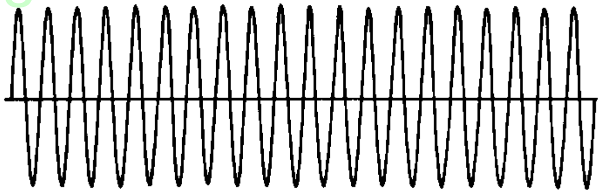
$$v_{AM}(t) = [V_c + V_m \cos(\omega_m t)]\cos(\omega_c t)$$

Amplitude Modulation ~ DSBFC (Full AM)

$$v_c(t) = V_c \cos(\omega_c t)$$

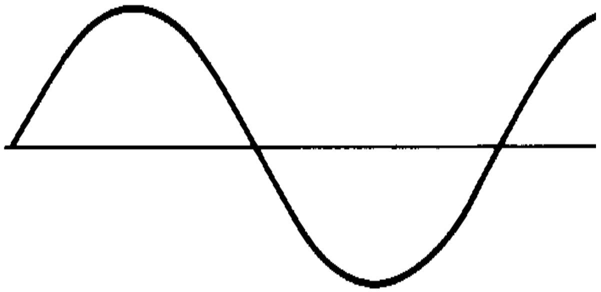
$$\omega_c = 2\pi f_c$$

Carrier signal

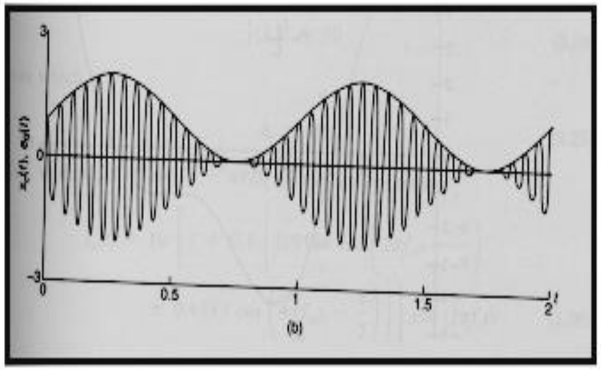


$$v_m(t) = V_m \cos \omega_m t$$

Modulating signal



V_{am}

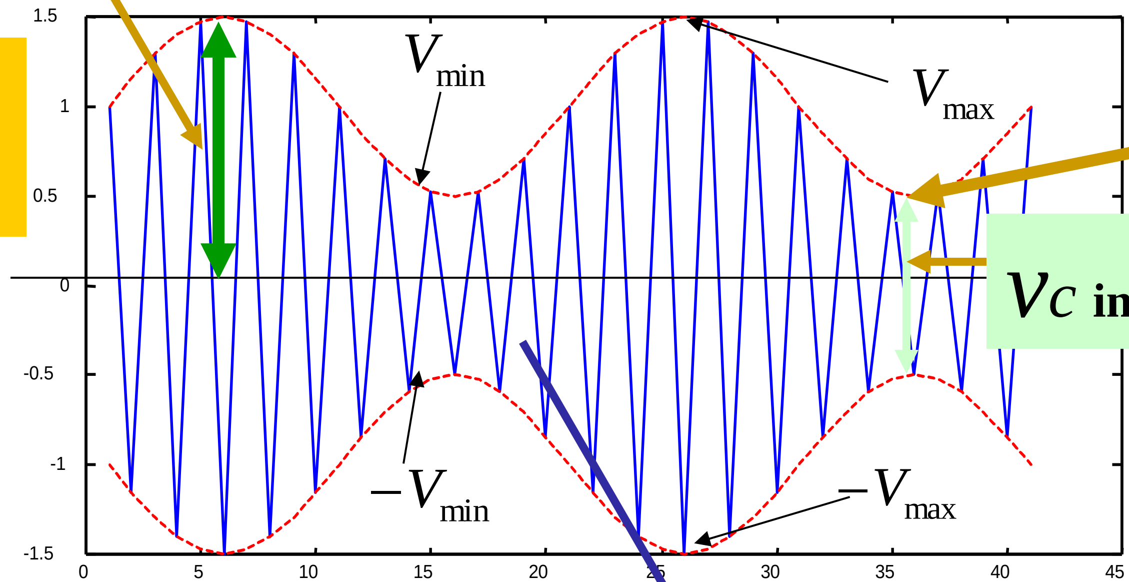


Amplitude Modulation ~ DSBFC (Full AM)

V envelope Vm

V envelope =

Vc + Vm



VC max

VC instantaneous

Vam = amplitude - V envelope frequency - carrier

V modulated signal Vam

Amplitude Modulation ~ DSBFC (Full AM)

Carrier signal

$$v_c(t) = V_c \cos(\omega_c t) \quad \text{where} \;\; \omega_c = 2\pi f_c$$

Modulating signal

$$v_m(t) = V_m \cos \omega_m t$$

Amplitude Modulation ~ DSBFC (Full AM)

The amplitude-modulated wave can then be expressed as

$$v_{AM}(t) = \left[V_c \cos(\omega_c t) + v_m(t)\cos(\omega_c t)\right]$$

$$v_{AM}(t) = \left[V_c + v_m(t)\right]\cos(\omega_c t)$$

$$v_{AM}(t) = \left[V_c + V_m \cos(\omega_m t)\right]\cos(\omega_c t)$$

$$v_{AM}(t) = V_c \cos(\omega_c t)\left[1 + \frac{V_m}{V_c}\cos \omega_m t\right]$$

$$v_{AM}(t) = V_c \cos(\omega_c t)\left[1 + m_a \cos \omega_m t\right]$$

Amplitude Modulation ~ DSBFC (Full AM)

where notation m is termed the modulation index. It is simply a measurement for the degree of modulation and bears the relationship of V_m to V_c

$$m_a = \frac{V_m}{V_c}$$

Therefore the full AM signal may be written as

$$v_{AM}(t) = V_c \cos(\omega_c t)\left[1 + m_a \cos(\omega_m t\right]$$

Amplitude Modulation ~ DSBFC (Full AM)

Using

$$\cos A \cos B = 1/2[\cos(A+B) + \cos(A-B)]$$

$$v_{Am}(t) = \underbrace{V_c(\cos\omega_c t)}_{\text{Carrier component}} + \underbrace{\frac{m_a V_c}{2}\cos(\omega_c + \omega_m)t}_{\text{Upper sideband component}} + \underbrace{\frac{m_a V_c}{2}\cos(\omega_c - \omega_m)t}_{\text{Lower sideband component}}$$

Carrier component

Upper sideband component

Lower sideband component

So, with the modulating process, the original modulating signal is transferred to a different frequency spectrum with a higher value frequency

Amplitude Modulation ~ DSBFC (Full AM)

The frequency spectrum of AM waveform contains ***3 parts**:*

- A component at the carrier frequency f_c
- An upper sideband (USB), whose highest frequency component is at f_c+f_m
- A lower sideband (LSB), whose highest frequency component is at f_c-f_m
- The bandwidth of the modulated waveform is **twice** the information signal bandwidth.

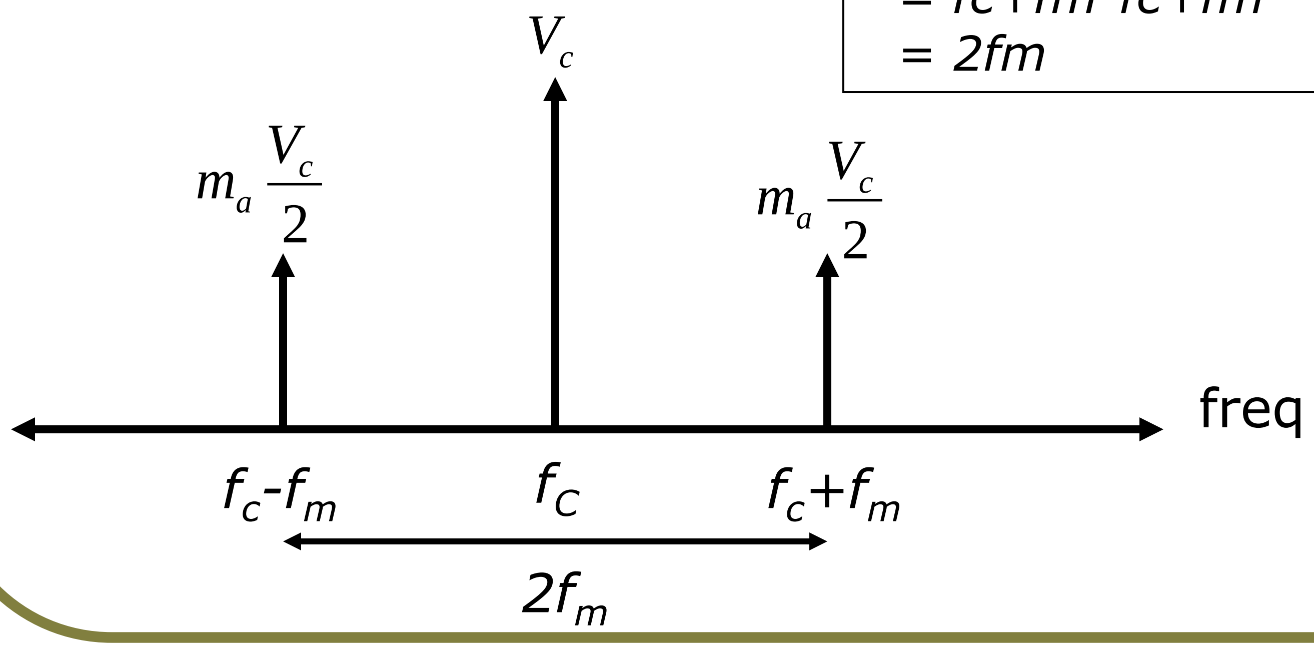
sideband is a component above and below centre frequency
Every sideband contains all the original message, but not the carrier

Amplitude Modulation ~ DSBFC (Full AM)

DSBFC Frequency Spectrum

With single frequency f_m

B = Maximum freq. - minimum freq.
= $(fc+fm)-(fc-fm)$
= $fc+fm-fc+fm$
= $2fm$

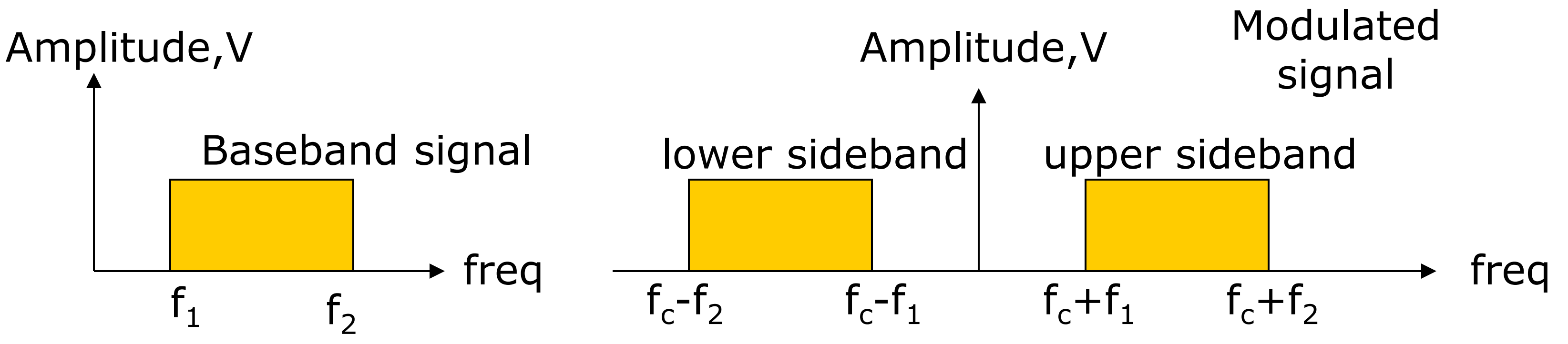


Amplitude Modulation ~ DSBFC (Full AM)

If f_m consists of a range frequencies f_1 to f_2, the component of the sidebands become:

Upper sideband (USB) range is from (f_c+f_1) to (f_c+f_2)

Lower sideband (LSB) range is from (f_c-f_2) to (f_c-f_1)



AM spectrum when the modulating signal is a baseband signal from frequency f_1 to f_2

Bandwidth for this case,

$$B = (f_c+f_2) - (f_c-f_2)$$
$$= 2f_2$$

Amplitude Modulation ~ DSBFC (Full AM)

- For example, if voice signal with the band of frequency of 0 – 4 kHz is transmitted using a carrier of 100 kHz, the modulated signal consists of
  - Carrier signal with frequency of 100 kHz
  - upper side band with frequency of range of 100 – 104 kHz
  - lower side band with frequency of range 96 – 100 kHz

- The bandwidth is 104 – 96 = 8 kHz

Modulation Index *m* (Coefficient of Modulation)

m is merely defined as a parameter, which determines the amount of modulation.

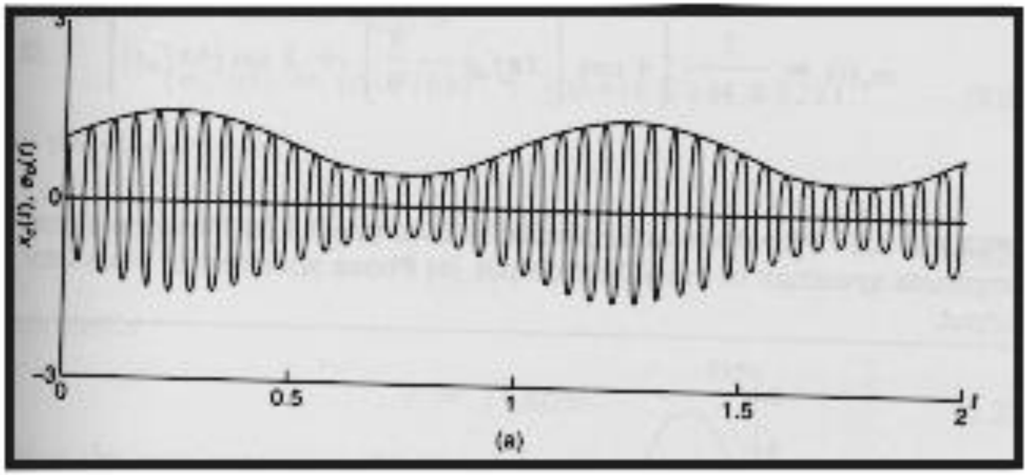
What is the degree of modulation required to establish a desirable AM communication link?

Answer is to maintain m<1.0 (m<100%).

This is important for successful retrieval of the original transmitted information at the receiver end.

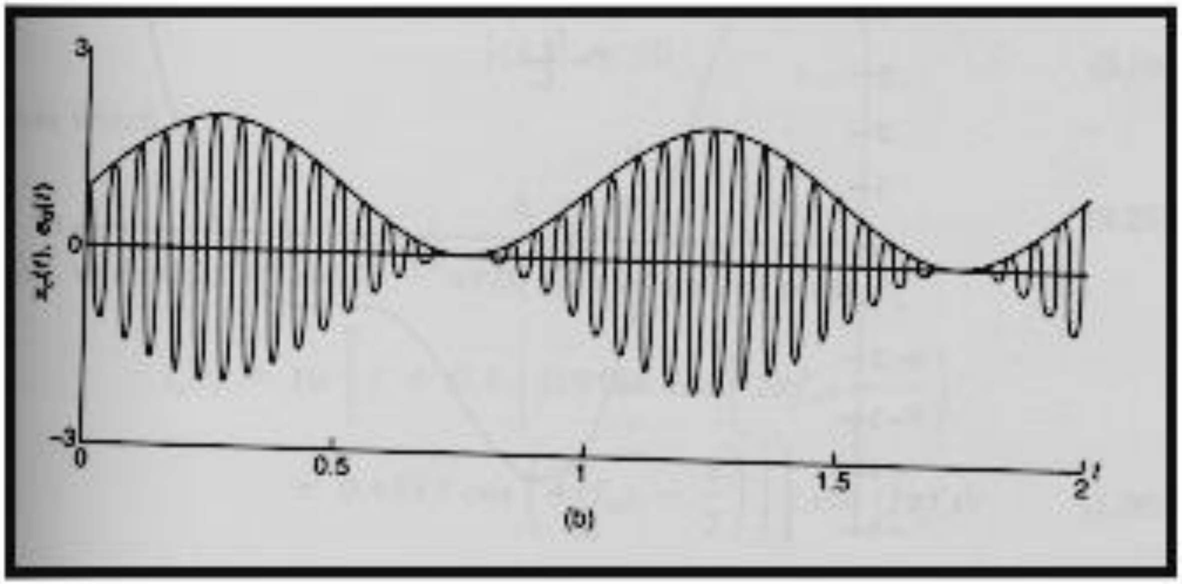
Modulation Index *m*

Modulation carrier and envelope detector outputs for various values of the modulation index



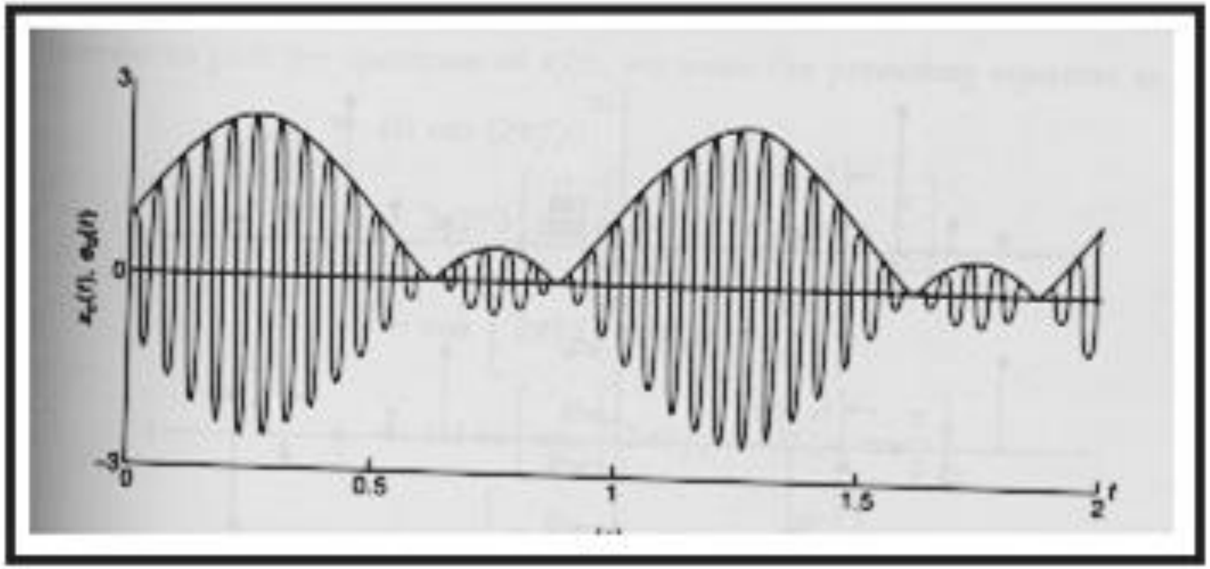
$\mu = 0.5$

Modulation Index *m*



$$\mu = 1.0$$

Modulation Index *m*



$$\mu = 1.5$$

m must have a value between 0 and 1 to avoid over-modulation

This modulation is known as **double sideband with carrier**

Modulation Index *m*

If the amplitude of the modulating signal is higher than the carrier amplitude, which in turn implies the modulation index $m \geq 1.0 (100\%)$. This will cause severe **distortion** to the modulated signal.

Modulation Index *m*

The ideal condition for amplitude modulation (AM) is when ***m=1***, which also means $V_m = V_c$.

This will give rise to the generation of the maximum message signal output at the receiver without distortion.

Modulation Index *m*

If the modulating signal is pure, single-frequency sine wave and the modulation process is symmetrical (i.e., the positive and negative excursion of the envelope's amplitude are equal), then percent modulation as follows:

$V_m = ½ (V_{max} – V_{min})$ and $V_c = ½ (V_{max} + V_{min})$

Therefore, $m = \dfrac{1/2(V\max - V\min)}{1/2(V\max + V\min)} x100 = \dfrac{(V\max - V\min)}{(V\max + V\min)} x100$

$$\frac{1/2(V\max - V\min)}{2} = \frac{1}{4}(V\max - V\min)$$

Modulation Index *m*

The peak change in the amplitude of the output wave (V_m) is the sum of the voltage from the upper and lower side frequencies. Therefore

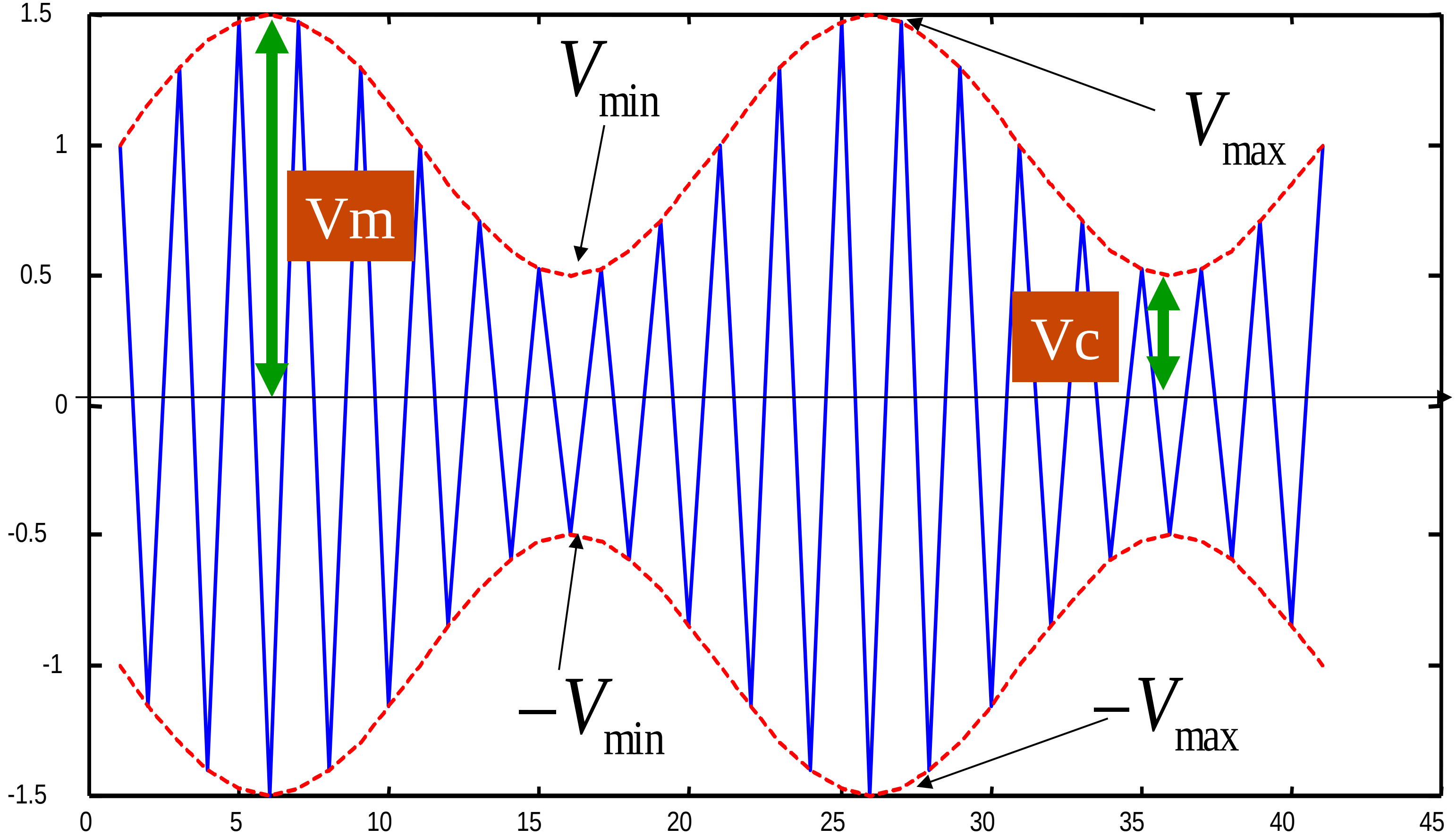
Since $V_m = V_{usf} + V_{lsf}$ and $V_{usf} = V_{lsf}$, then

$$V_{usf} = V_{lsf} = V_m/2 =$$

V_{usf} = peak amplitude of the upper side frequency (volts)

V_{lsf} = peak amplitude of the lower side frequency (volts)

Modulation Index *m*



Modulation Index *m*

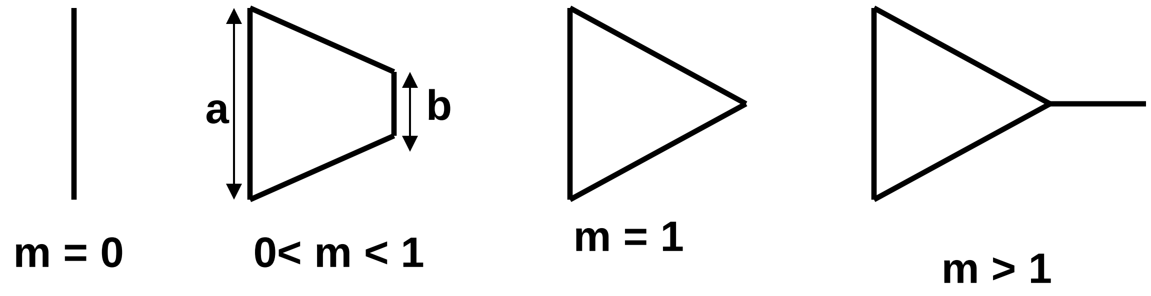
The modulation index can be determined by measuring the actual values of the modulation voltage and the carrier voltage and computing the ratio.

$$m_a = \frac{V_m}{V_c} = \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}}$$

$$V\max = Vc + Vm$$
$$V\min = Vc - Vm$$

Modulation Index *m*

Trapezoid waveform can be obtained from by connecting the modulating signal to x-axis of an oscilloscope and modulated signal to y-axis of the oscilloscope



Thus, m can be calculated as

$$m_a = \frac{a-b}{a+b}$$

AM Power Distribution

$$v_{Am}(t) = V_c(\cos\omega_c t) + \frac{m_a V_c}{2}\cos(\omega_c + \omega_m)t + \frac{m_a V_c}{2}\cos(\omega_c - \omega_m)t$$

- For a single frequency signal, average power for each component is (assume transmission impedance is R):

Next page

AM Power Distribution

Carrier power :

$$P_c = \frac{V_c^2}{2R}$$

Sideband power:

$$P_{USB} = P_{LSB} = \frac{m_a^2 V_c^2}{8R} = \frac{m_a^2 P_c}{4}$$

$$P_{SB} = P_{USB} + P_{LSB} = \frac{m_a^2 P_c}{2}$$

The total transmitted power is the sum of the carrier power and the power in the sidebands.

$$\begin{aligned} P_{total} &= P_c + P_{USB} + p_{LSB} \\ &= P_c + P_{SB} \\ &= P_c\left(1 + \frac{m_a^2}{2}\right) \end{aligned}$$

AM Power Distribution

The efficiency of the AM in term of power consumption is

$$\eta = \frac{P_{SB}}{P_T} = \frac{m_a{}^2}{m_a{}^2 + 2}$$

Thus, at optimum operation (m = 100%), only 33% of power is used to carry information

From previous equation, total current flow in AM is

$$P_{SB} = P_{USB} + P_{LSB} = \frac{m_a{}^2 P_c}{2}$$

Generation and Detection of Full AM

- Both generation and detection require multiplication to be performed.
- The multiplication is achieved by using a network with a nonlinear characteristic.
- Nonlinear networks are not true multipliers because other components are produced and need to be filtered out.

Square-Law Modulator

- Consists of a summer (summing the carrier and modulating signal), nonlinearity (square-law) block and a band pass filter (BPF) of bandwidth (2B) centered at f_c to extract the desired modulation products.

Square-Law Modulator

Square law of nonlinearity:

$$v_2(t) = a_1 v_1(t) + a_2 v_1^2(t)$$

where, a1 and a2 are constants and v1 is the input voltage signal consist of the carrier plus the modulation signal

$v_1(t) = \quad S_c(t) + S_m(t) = V_c \cos(w_c t) + S_m(t)$

$v_2(t) = \quad a_1 V_c(1 + 2a_2/a_1\ S_m(t)) \cos(w_c t) + a_1 S_m(t) + a_2 S_m^2(t) + \ a_2 A_c^2 \cos^2 w_c t$

By letting a1 = 1 , a2 = ½ A_c

$v_o = A_c\ (1 + m\cos(w_m t)) \cos(w_c t)$ ---------Full AM signal

Square-Law Detector

- Although above is described as a modulator, it can also be used as a demodulator provided that the BPF is replaced by a **low pass filter (LPF)** with cutoff frequency at fm (i.e.; bandwidth of B) and a **local carrier signal oscillator**.

Envelope Detector

- However, envelope detector is yet another **full AM detector** commonly employed to replace the square-law detector. Since it is more simple and highly effective device produces a waveform at its output that is proportional to the real envelope of its input;

  i.e. the output of the detector simply follows the envelope of the input signal.

Envelope Detector - Operation

Make an initial assumption that the input (AM signal) is of fixed amplitude and ignore the present of the resistor *R*. Following this, the capacitor *C* charges to the peak positive voltage of the carrier. It capacitor) then holds this peak voltage, results the diode stop conducting. Suppose now that the input-carrier amplitude is made to increase. Again, the diode resumes conduction, and the capacitor charges to a new higher carrier peak. To ensure that the capacitor voltage v_c to follow the carrier peaks when the carrier amplitude is decreasing, it is required to include the resistor *R*, so the capacitor *C* may discharge. In this case the capacitor voltage v_c has the form shown in (AM waveform); i.e. the positive portion of the modulated signal envelope approximates the modulating information signal. An additional LPF might be needed to effectively smoothen out the saw tooth distortion of the envelope waveform shown in figure (AM waveform) after the envelope detector.

m for Complex Signal

- As most of the signals are complex and can be represented by combination of various sine waves, *m* can be determined by

$$m_a = m_{eff} = \sqrt{m_1^2 + m_2^2 + m_3^2 + \ldots\ldots}$$

- Thus, total power for this complex signal is

$$P_T = P_c[1 + \frac{m_{eff}^2}{2}]$$

Amplitude Modulation ~

Double Sideband Suppress Carrier (DSBSC)

- The previous modulated signal (DSBFC) has two drawbacks; it waste power and bandwidth

- Power sent as the carrier contains no information and each sideband carries the same information independently

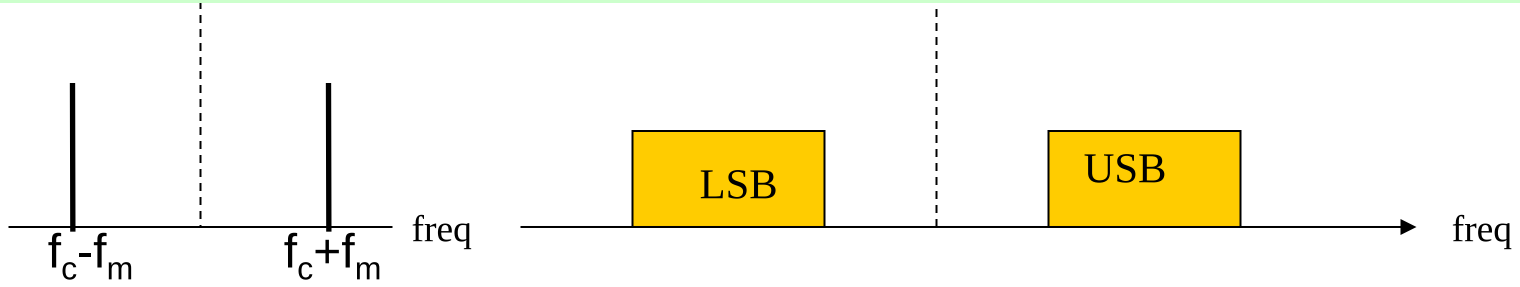
- The double sideband suppressed carrier (DSBSC) is introduced to eliminate carrier hence improve power efficiency

- It is a technique where it is transmitting both the sidebands without the carrier (the carrier is being suppressed)

Amplitude Modulation ~ DSBSC

- The equation, then is simplified to

$$v_{DSBSC}(t) = V_c V_m \cos\omega_c t \cos\omega_m t = \frac{V_c V_m}{2}\left[\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t\right]$$



Frequency spectrum of a DSBSC system

Total power in DSBSC

$$P_{total} = P_{USB} + p_{LSB}$$

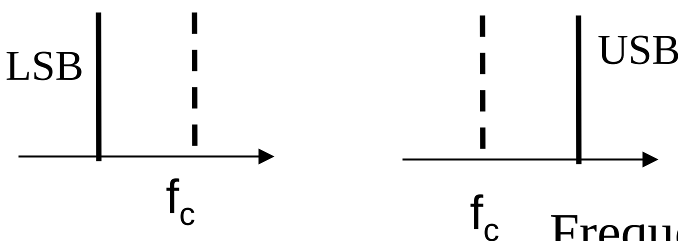
- Although, the power is improved, the bandwidth remain unchanged, that is BW = 2B = 2 fmax

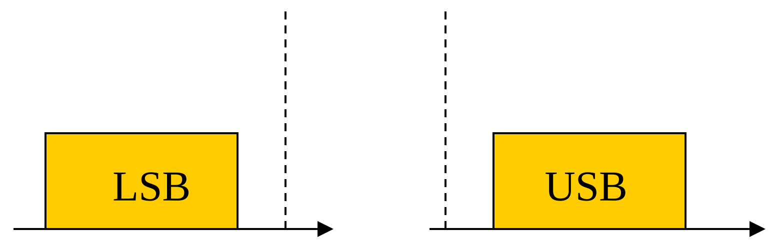
Amplitude Modulation ~ DSBSC

- The suppressed carrier is further improved by sending only one sideband
- This not only uses less power but also only half of the bandwidth and it is called single sideband suppressed carrier (SSBSC)
- There are two possible of SSBSC
  - the lower sideband $V_{LSB} = V_m \cos(w_c - w_m)t$
  - the upper sideband $V_{USB} = V_m \cos(w_c + w_m)t$

Amplitude Modulation ~ Single Sideband (SSB)

- As both DSB and standard AM waste a lot of power and occupy large bandwidth, SSB is adopted
- SSB is a process of transmitting one of the sidebands of the standard AM by suppressing the carrier and one of the sidebands (only transmits upper or lower sideband of AM)
- Reduces bandwidth by factor of 2





Frequency spectrum of a SSB system

Total power in SSB

$$P_{total} = P_{USB} = p_{LSB}$$

Amplitude Modulation ~ Single Sideband (SSB)

SSB Applications:

- SSB is used in the systems which require minimum bandwidth such as telephone multiplex system and it is not used in broadcasting
- Point to point communications at frequency **below 30 MHz** – mobile communications, military, navigation radio etc where power saving is needed

Amplitude Modulation ~ Vestigial Sideband

- VSB is a technique AM transmission where the carrier, one sideband and a part of the other sideband are transmitted

VSB application:

VSB is mainly used in TV broadcasting for their video transmissions. TV signal consists of:

Audio signal – is transmitted by FM
Video signal – is transmitted by VSB

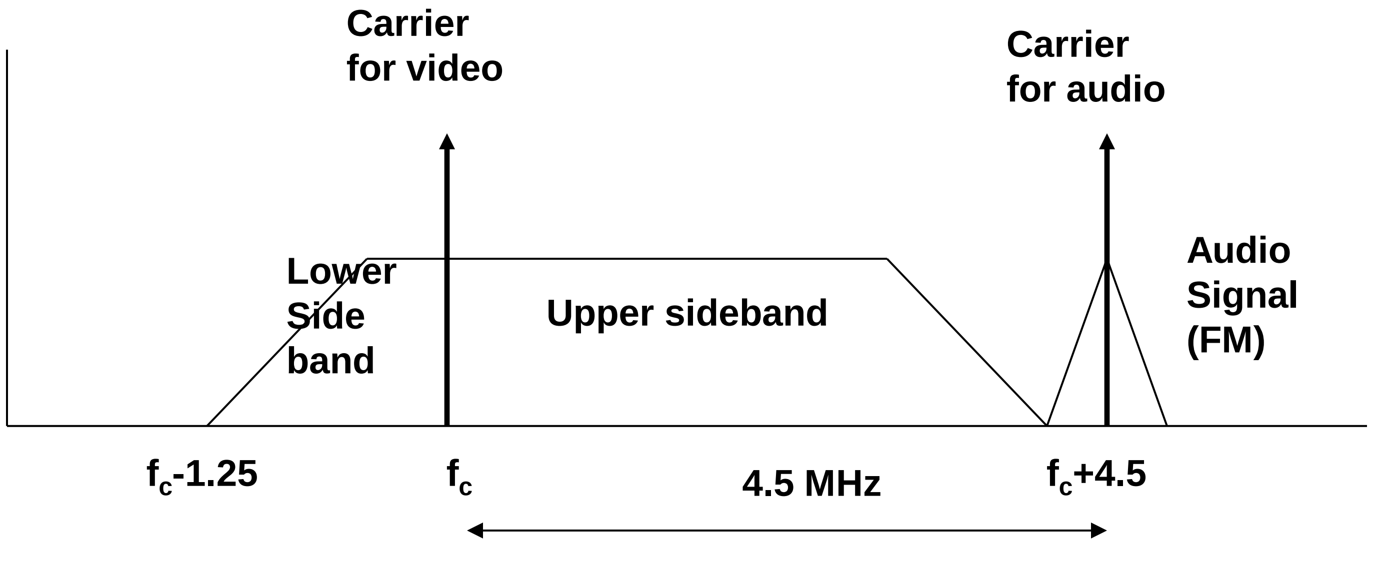
Amplitude Modulation ~ Vestigial Sideband

A video signal consists of range of frequencies and maximum frequency is as high as 4.5Mhz.

If it is transmitted using the conventional AM system, the required bandwidth is 9.0 Mhz (B=2fm). But according to the standardization, TV signal is limited to 6MHz only.

So, to reduce to 6Mhz bandwidth, a part of the LSB is not transmitted. In this case SSB transmission is not applied as it is very difficult to suppress a sideband accurately at high frequency.

Amplitude Modulation ~ Vestigial Sideband



Frequency spectrum of a Vestigial Sideband

Conclusion

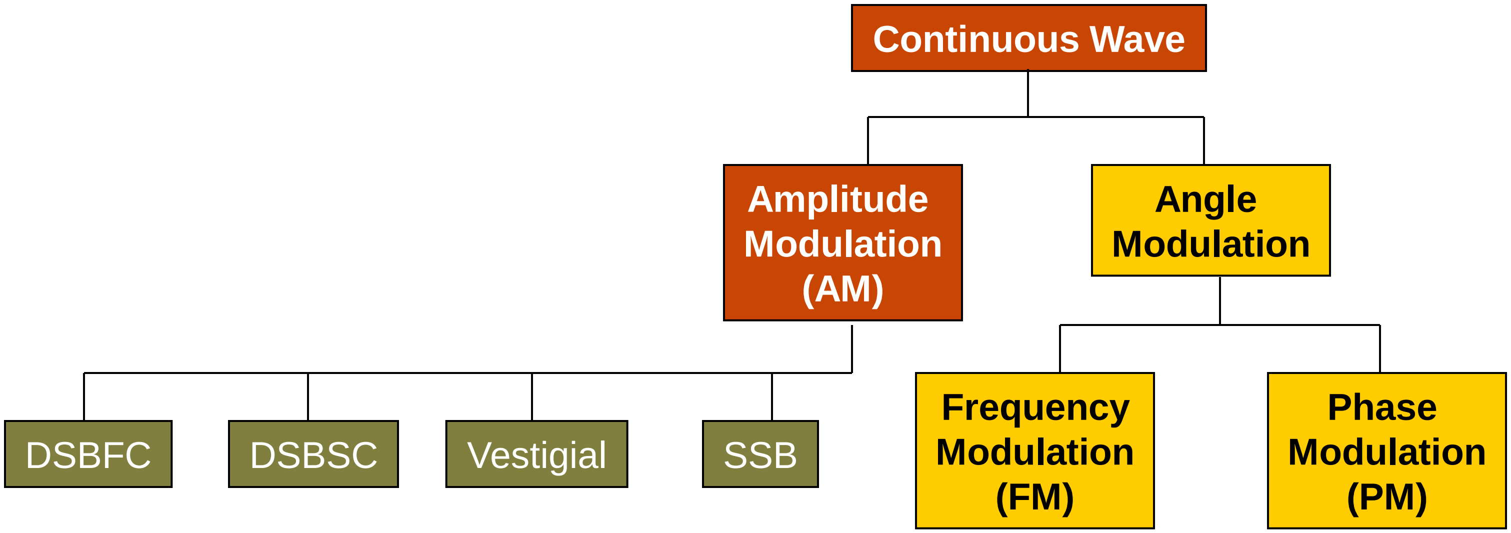
- Only sidebands contain the information
- Lower and upper sideband are identical. Only one sideband is enough to recover the original signal
- Carrier component does not contain any information but constitute 2/3 of the total power, at full modulation (m_a=1)

Advantages and Disadvantages of AM

- Advantages:
  - simple with proven reliability
  - low cost

- Disadvantages:
  - wastage of power as most of the transmitted power are in the carrier component which does not contain information. When m_a=1, 2/3 of the power is wasted
  - AM requires a bandwidth which is double to audio frequency
  - Noisy

AM Communication Chart



Examples

2.1 For an AM modulator with carrier frequency of 150 kHz and a modulating signal frequency of 10 kHz, determine the:

(i) Freq for the upper and lower sideband

(ii) bandwidth

Sketch the output frequency spectrum

Solution:

i) The lower and upper side band frequency

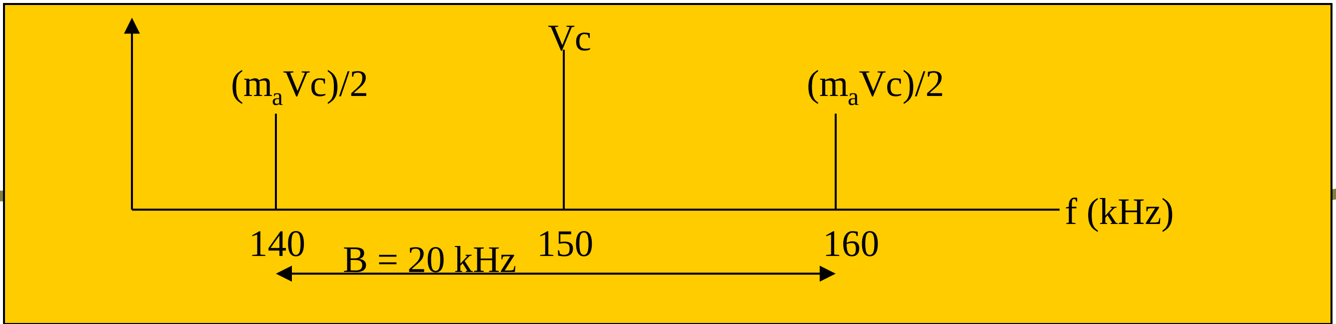
f_{LSB} = fc – fm = 150 kHz – 10 kHz = 140 kHz

f_{USB} = fc + fm = 150 kHz + 10 kHz = 160 kHz

i) Bandwidth

B = 2fm = 2 (10) kHz = 20 kHz

The output frequency spectrum is as shown:



Examples

2.2 For an AM wave with a peak unmodulated carrier voltage Vc = 20 V, a load resistance RL = 20 ohm and a modulation index ma = 0.2, determine :

(i) Power contained in the carrier and the upper and lower sidebands

(ii) Total sideband power

(iii) Total power of the modulated power

Solution:

(i) The carrier power is

$$P_c = \frac{V_c^2}{2R} = \frac{20^2}{2(20)} = 10W \quad P_{LSB} = P_{USB} = \frac{m_a^2 V_c^2}{8R} = \frac{m_a^2 P_c}{4} = \frac{(0.2)^2(10)}{4} = 0.1w$$

(i) The total sideband

$$P_{SB} = \frac{m_a^2 p_c}{2} = \frac{(0.2)^2(10)}{2} = 0.2w \quad \text{OR} \quad P_{SB} = P_{USB} + P_{LSB} = 0.1 + 0.1 = 0.2w$$

(i) The total power in the modulated wave:

$$P_T = P_c[1 + \frac{m_a^2}{2}] = 10[1 + \frac{(0.2)^2}{2}] = 10.2W \quad \text{OR} \quad P_T = P_c + P_{SB} = 10 + 0.2 = 10.2w$$

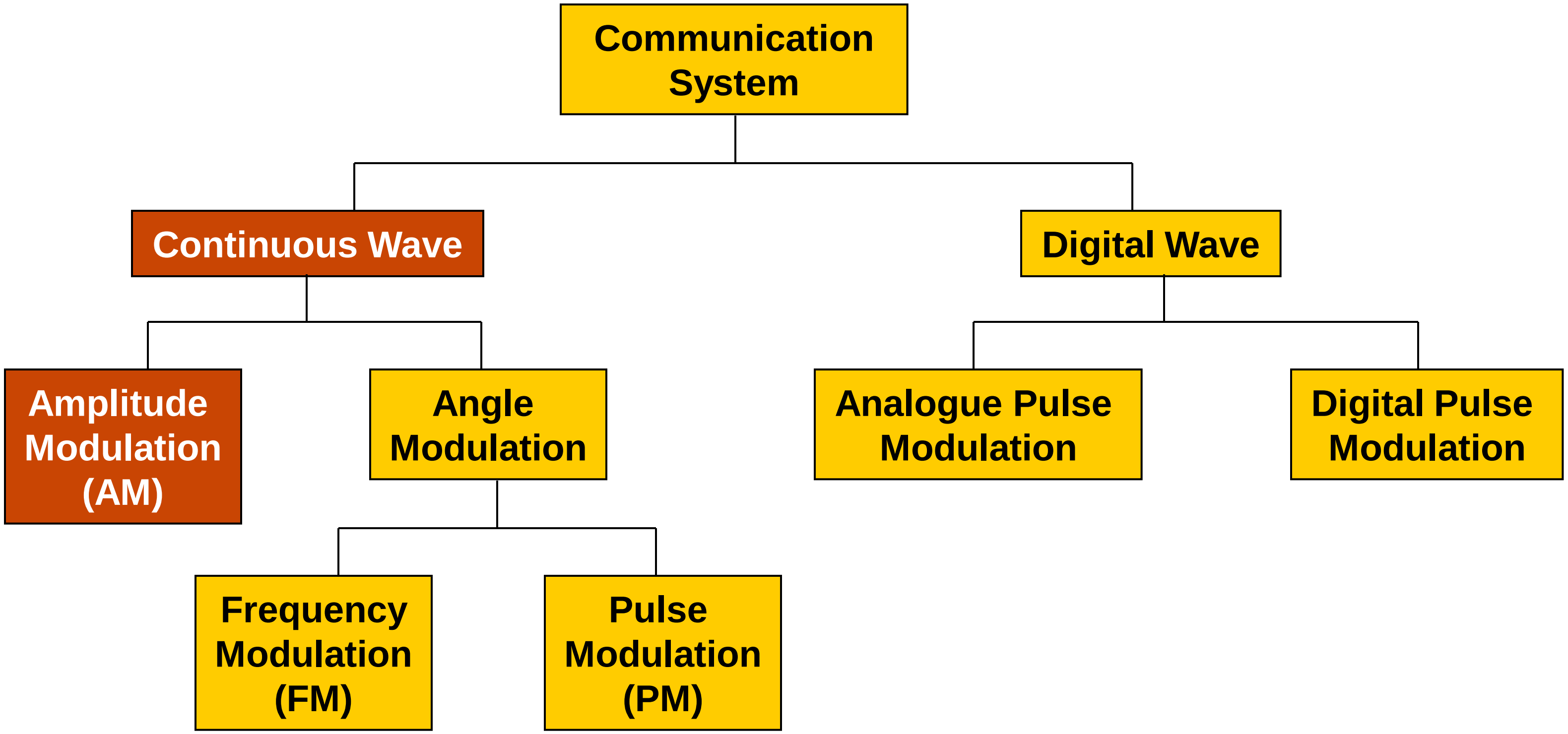
Modulation 2

Analogue Modulation

Angle Modulation

(62-112)

Communication System Chart



Types of Modulation Process

Two Types of Modulation Process:

1. CW (Continuous-Wave) Modulation: a sinusoidal wave is used as the carrier
   - I. AM (Amplitude Modulation)
   - II. Angle Modulation
     - i. FM (Frequency Modulation)
     - ii. PM (Phase Modulation)

Analog Communication

2. Pulse Modulation: the carrier consists of a periodic sequence of rectangular pulses
   - -can itself be of an analog or digital type.

Analog or Digital Communication

Note:

Multiplexing, results from the use of modulation. Multiplexing is the process of combining several message signals for their simultaneous transmission over the same channel.

Three commonly used methods of multiplexing are:

- •Frequency-division multiplexing (FDM), makes use of CW modulation
- •Time-division multiplexing (TDM), makes use of pulse modulation
- •Code-division multiplexing (CDM)

Types of Modulation Process

Pulse Modulation

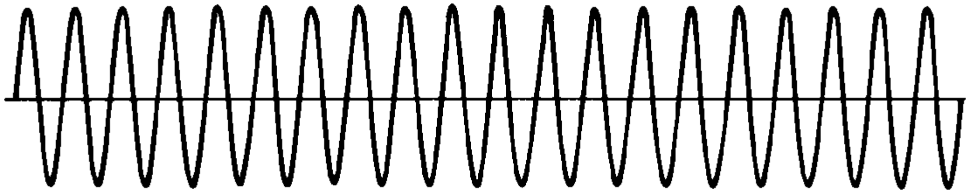
Analog Pulse Modulation

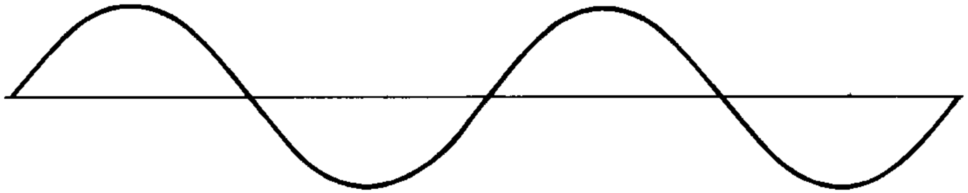
The amplitude, duration, or position of a pulse is varied in accordance with sample values of the message signal:

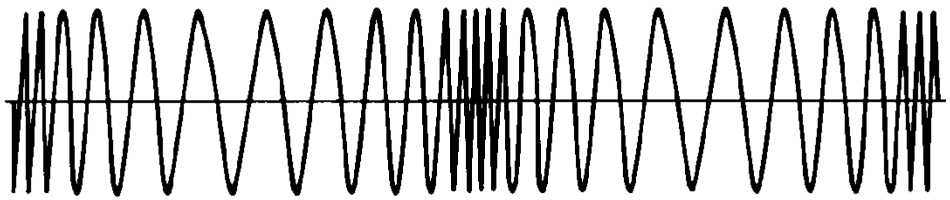
- PAM, Pulse-Amplitude Modulation
- PDM, Pulse-Duration Modulation
- PPM, Pulse-Position Modulation

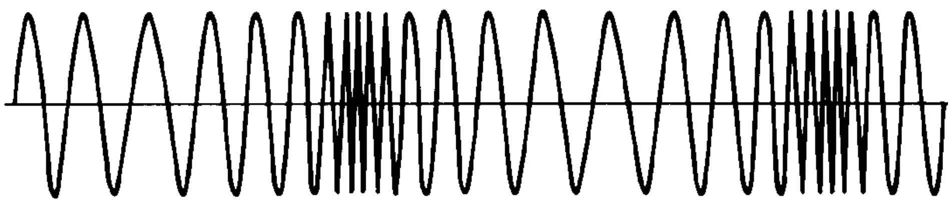
Digital Pulse Modulation

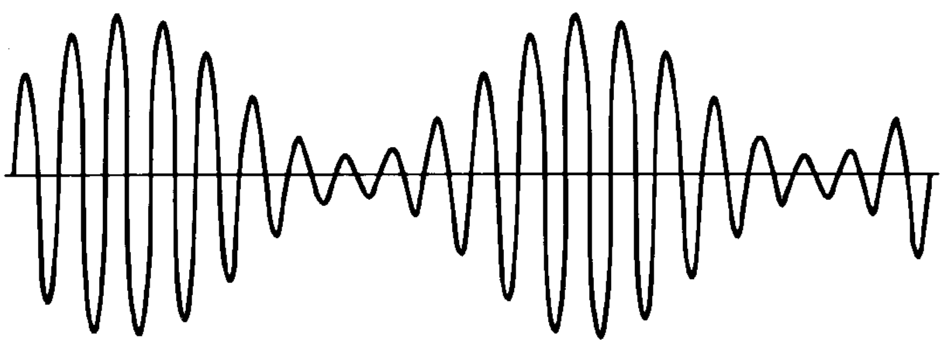
Pulse-Code Modulation, PCM starts out essentially as PAM, but with an important modification: the amplitude of each modulated pulse (i.e., sample of the original message signal) is quantized or rounded off to the nearest value in a prescribed set of discrete amplitude levels and then coded into a corresponding sequence of binary symbols. The binary symbols 0 and 1 are themselves represented by pulse signals that are suitably shaped for transmission over the channel. As a result of the quantization process, some information is always lost and the original message signal cannot therefore be reconstructed exactly.


Carrier


Modulating sine–wave signal


Phase–modulated wave

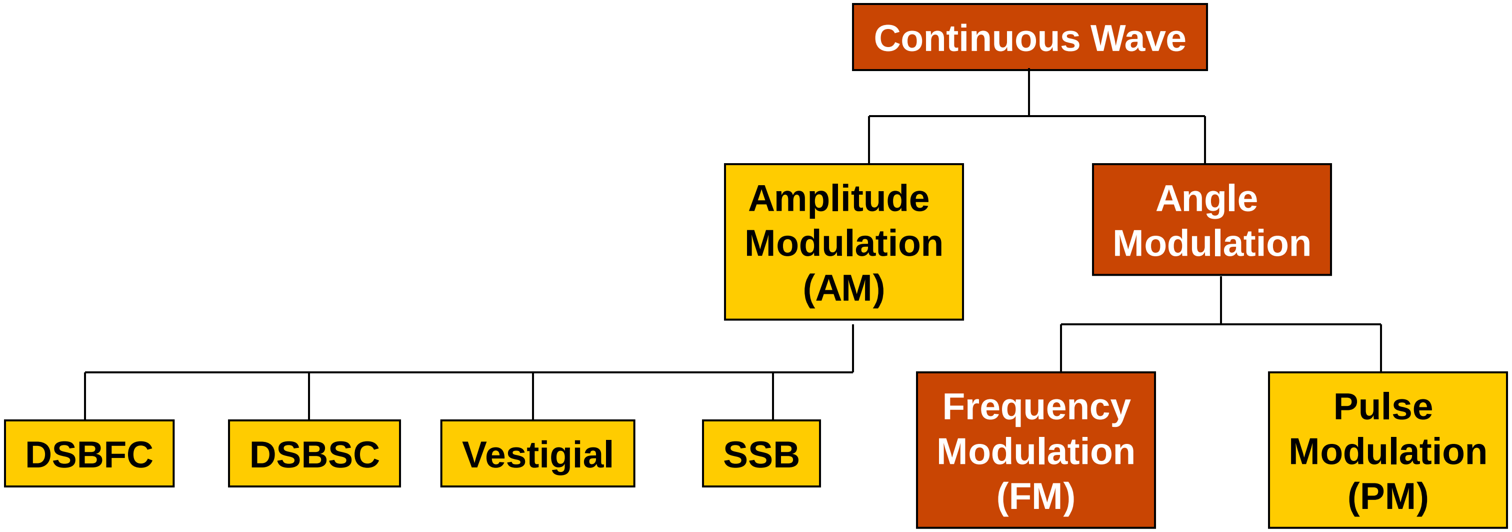

Frequency–modulated wave


Amplitude–modulated (DSBTC) wave

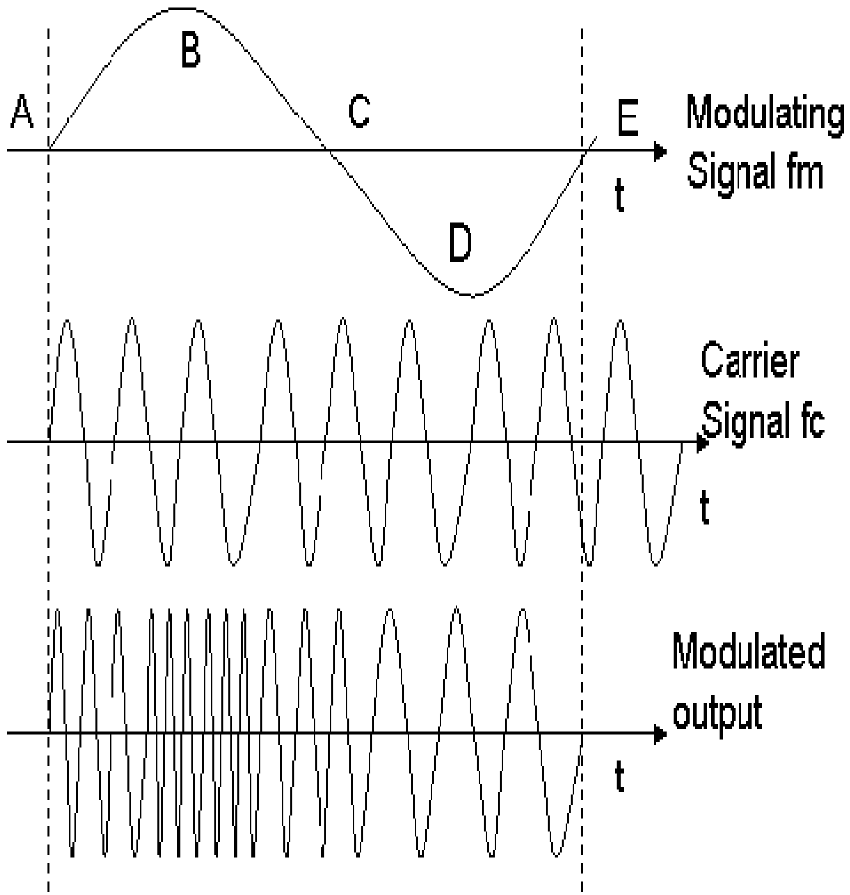
Types of angle modulation

1. FREQUENCY MODULATION (FM)
2. PHASE MODULATION (PM).

FM Communication Chart

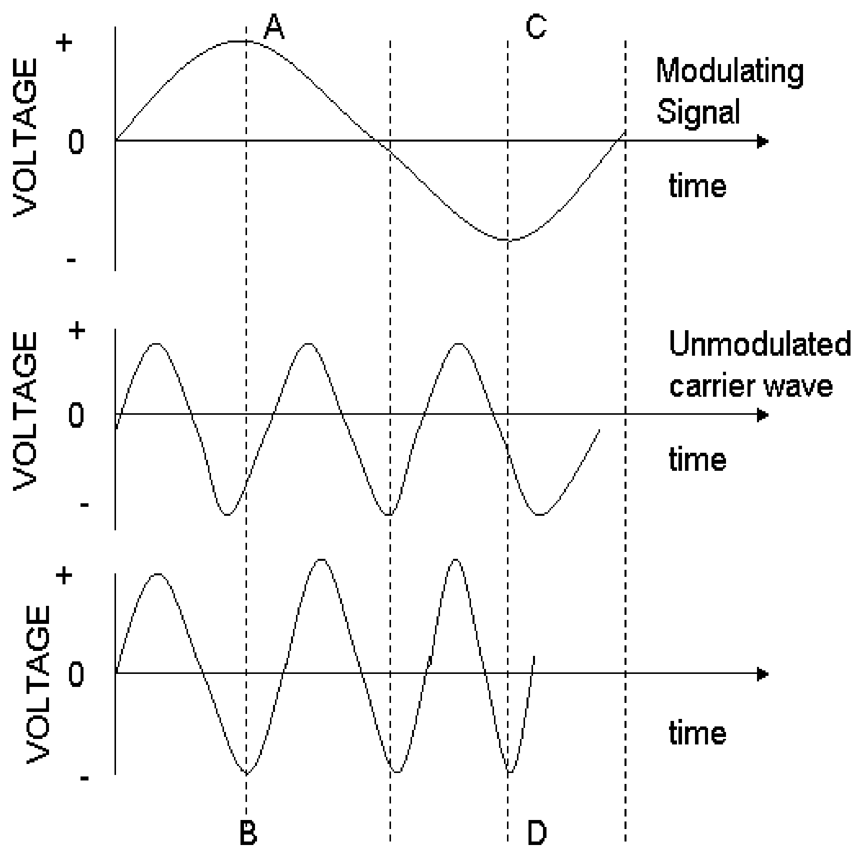


Angle Modulation



Frequency Modulation

FM



Phase Modulated carrier wave

PM

FREQUENCY-MODULATION SYSTEM

Angle Modulation

In angle modulation, the amplitude of the modulated carrier is held constant and either the phase or the time derivative of the phase of the carrier is varied linearly with the message signal $v_m(t)$.

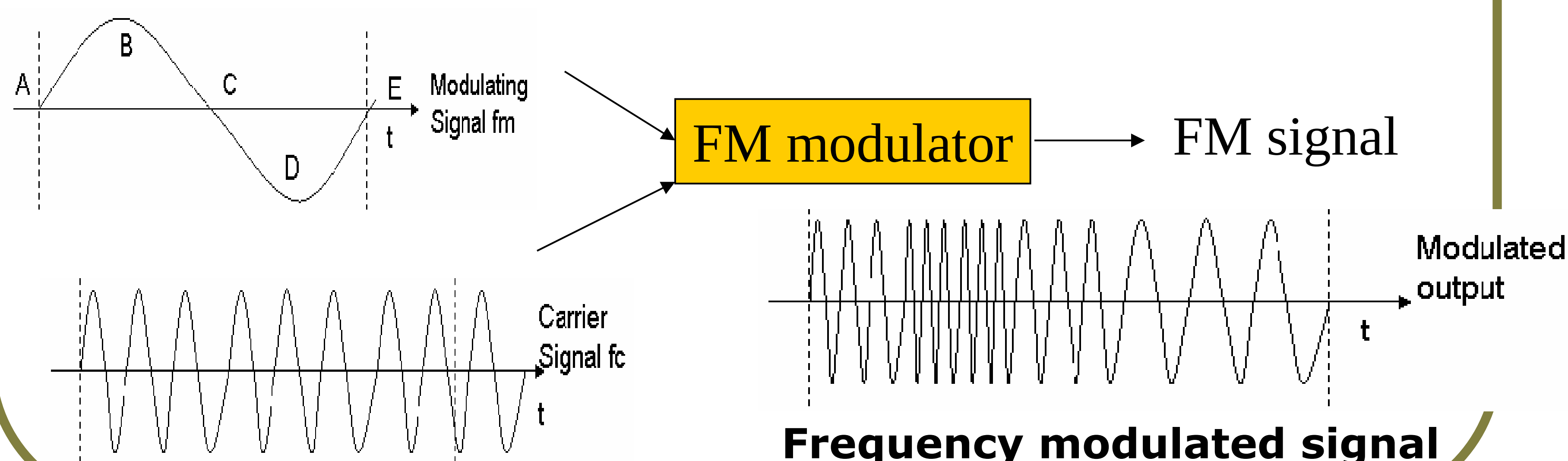
Frequency Modulation Introduction

- As in Chapter 1, the need for modulation arises because the range of frequencies contained in a baseband signal is not, in general, the same as the range of frequencies which can be transmitted by the communications channel.

  - AM – amplitude modulation
    - medium wave (300 kHz to 3 MHz), short wave (3–30 MHz)
  - FM – frequency modulation
    - VHF (30 – 300 MHz)

Frequency Modulation (FM) Introduction

- FM is the process of varying the frequency of a carrier wave in proportion to a modulating signal.
- The amplitude of the carrier is constant while its frequency and rate of changes varied by the modulating signal



Frequency modulated signal

Frequency Modulation (FM) Introduction

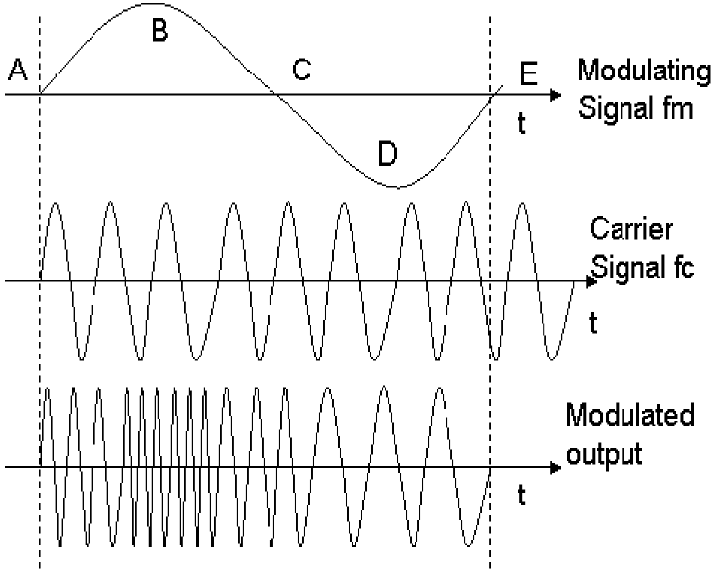
- The FM modulator receives two signals, the information signal from an external source and the carrier signal from a built in oscillator.
- The modulator circuit combines the two signals producing a FM signal which is passed on to the transmission medium.

Frequency Modulation Waveform

- Point A, C and E are where the information signal is at 0V.
- Point B is where the information signal is at the max. positive amplitude, point D is where the information signal is at the max. negative amplitude.
- During the time from point A to B, the FM signal increases in freq.

  to its max. value at point B.
- From point B to C, the FM signal freq. decrease until reaching the freq. of the carrier signal which called

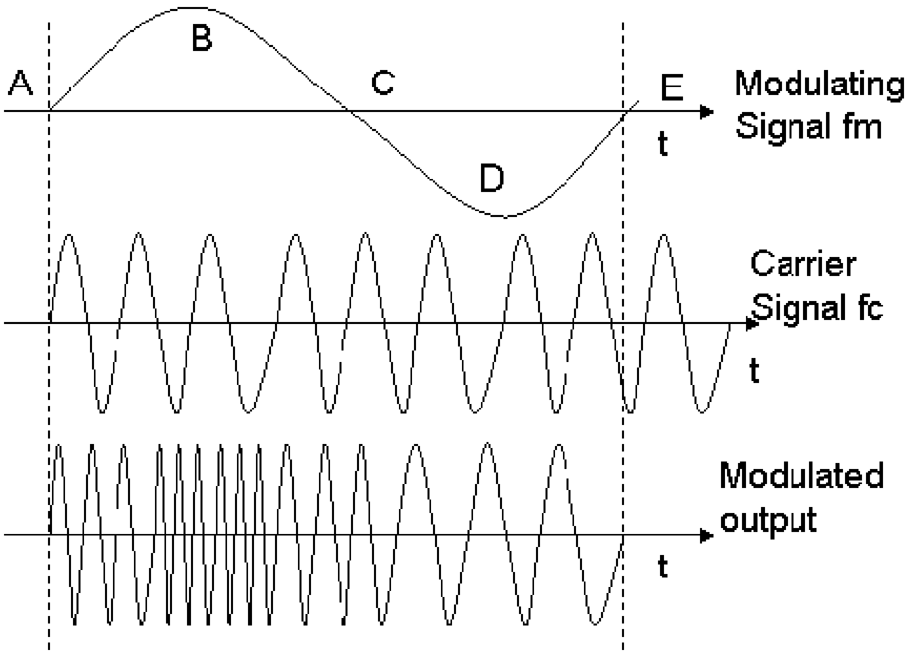
  the center frequency.



Frequency Modulation

Frequency Modulation Waveform

- At point D is where the info signal has the max. negative amplitude.
- From point D to E, the FM signal increases until reaching the centre frequency.



Frequency Modulation

Frequency Modulation (FM)

The important features about FM waveforms are:

i. The frequency varies

ii. The rate of change of carrier frequency changes is the same as the frequency of the information signal

iii. The amount of carrier frequency changes is proportional to the amplitude of the information signal

iv. The amplitude is constant

FM Analysis

Assume : Carrier signal: $v_c(t) = V_c \cos(\omega_c t)$

Information signal: $v_m(t) = V_m \cos \omega_m t$

In FM, frequency changes with the change of the amplitude of the information signal

FM Analysis

- Thus, the instantaneous modulated frequency,

$$\omega = \omega_c + k v_m(t)$$
$$\omega = \omega_c + k V_m \cos \omega_m t$$

or

$$f = f_c + k \frac{V_m}{2\pi} \cos \omega_m t$$
$$f = f_c + \Delta f \cos \omega_m t$$

k is constant proportionality

$$\Delta f = \frac{k V_m}{2\pi}$$
$$\Delta f = k_f V_m$$

Δf = frequency deviation

k_f = frequency deviation constant (deviation sensitivity, Hz/V)

Analysis of FM

The wave equation of the frequency modulation is:

$$v_{FM}(t) = V_c \cos\theta$$

The angle θ is obtained as:

$$\theta = \int w\,dt = \int (w_c + kV_m \cos w_m t)\,dt$$

$$= w_c t + \frac{kV_m}{w_m} \sin w_m t + \phi$$

$$\text{Assuming } \phi = 0$$

$$v_{FM}(t) = V_c \cos\left(w_c t + \frac{kV_m}{w_m} \sin w_m t \right)$$

Analysis of FM

$$v_{FM}(t) = V_c \cos(\omega_c t + m_f \sin \omega_m t)$$

where $m_f = \dfrac{kV_m}{\omega_m} = \dfrac{kV_m}{2\pi f_m}$ $\Delta f = \dfrac{kV_m}{2\pi}$

FM modulation index $m_f = \dfrac{\Delta f}{f_m}$

In the FM, the value of modulation index, m_f can be any value from zero to infinity $0 \leq m_f \leq \infty$

Carrier Frequency (f_c)

- As in AM, the carrier frequency in FM system must be higher than the information signal frequency.

FM radio : Uses carrier frequencies
between 88 MHz and 108 MHz.

Television: Frequency range = 54 MHz – 806 MHz
No. of channels = 67 channels
Bandwidth = 6 MHz

VHF: 54 MHz – 216 MHz (channel 2 – channel 13)
UHF: 470 MHz – 806 MHz (channel 14 – channel 69)
608 MHz – 614 MHz (Radio Astronomy)

Frequency Deviation

- Frequency deviation represents the maximum change of the instantaneous frequency of the FM signal from the carrier frequency.

- A fundamental characteristic of an FM signal is that the frequency deviation is proportional to the amplitude of the modulating signal, V_m and independent of the modulating frequency, f_m

$$\Delta f = \frac{kV_m}{2\pi} \quad \text{or} \quad \Delta f \propto V_m$$

Frequency Deviation

The highest frequency for FM wave is

$$f_{\max} = f_c + \Delta f$$

The minimum frequency for FM wave is

$$f_{\min} = f_c - \Delta f$$

The total change of the frequency from minimum frequency to the maximum frequency is called frequency carrier swing, f_{cs}

$$f_{cs} = 2\Delta f$$

FM Frequency Spectrum

As obtained, the FM signal is

$$v_{FM}(t) = V_c \cos(\omega_c t + m_f \sin \omega_m t)$$

$$v_{FM}(t) = V_c(\cos \omega_c t[m_f(\sin \omega_m t)] - \sin \omega_c t[m_f \sin \omega_m t])$$

FM Frequency Spectrum

By using mathematical expressions:

$$v_{FM}(t) = V_c\{\cos\omega_c t[J_0 + J_2 \cos 2\omega_m t + J_4 \cos 4\omega_m t.......]$$
$$- \sin\omega_c t[J_1 \sin\omega_m t + J_3 \sin 3\omega_m t.....]\}$$

$$v_{FM}(t) = V_c\{J_0 \cos\omega_c t + J_1[\cos(\omega_c + \omega_m)t - \cos(\omega_c - \omega_m)t]$$
$$+ J_2[\cos(\omega_c + 2\omega_m)t - \cos(\omega_c - 2\omega_m)t].....+ J_5....\}$$

- Where Jn is a Bessel Function from first type, nth order
- J0 - will give the amplitude of the carrier
- Jn – will give the amplitude of the sidebands, with frequency $(\omega_c + n\omega_m)$

FM frequency spectrum

From above equation, the FM waveform has a component at the carrier frequency and an unlimited series of frequency, above and below the carrier frequency as below figure.

An important characteristic of Bessel function:

$$\sum_{n=-\infty}^{\infty} J_n^2 = 1$$

or

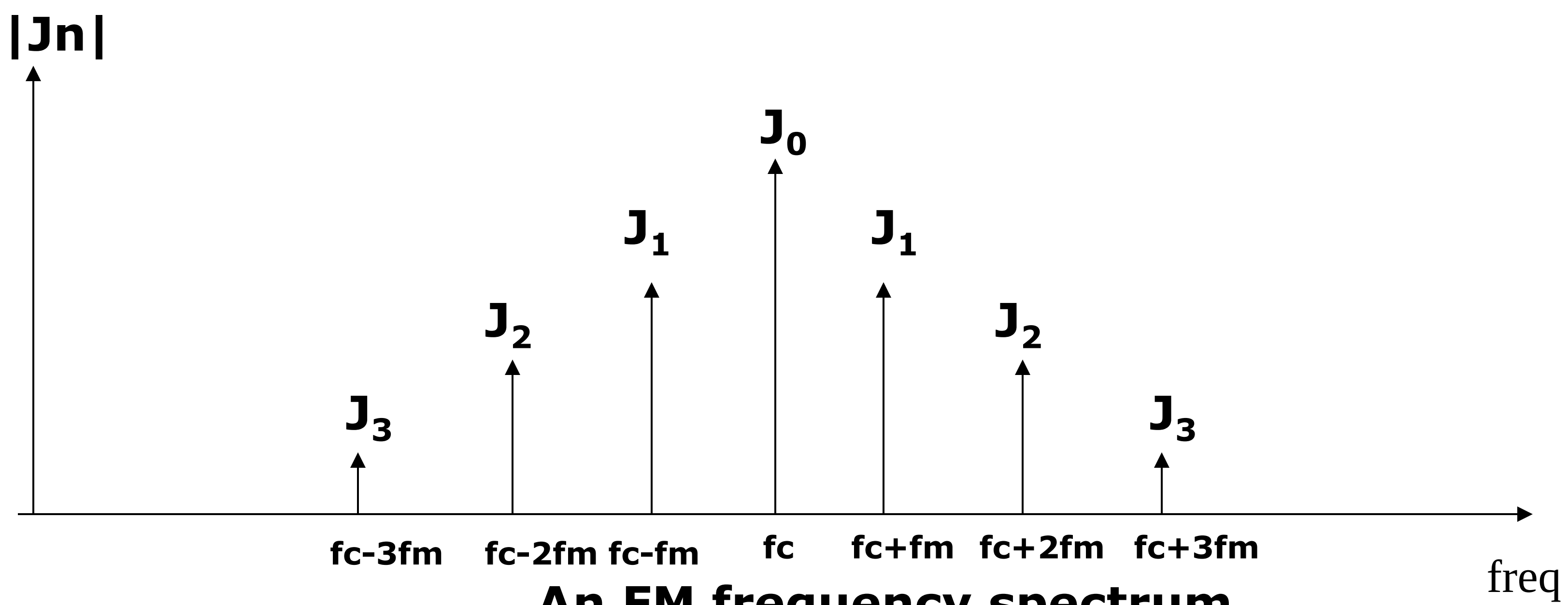
$$\sum_{n=-\infty}^{\infty} V_c^2 J_n^2 = V_c^2 (\propto power)$$

$$J_{(-n)} = (-1)^n J_n$$

Actual amplitude for the sideband = J_n x V_c

Relative amplitude for the sideband = J_n

FM frequency spectrum



An FM frequency spectrum

Bessel Functions

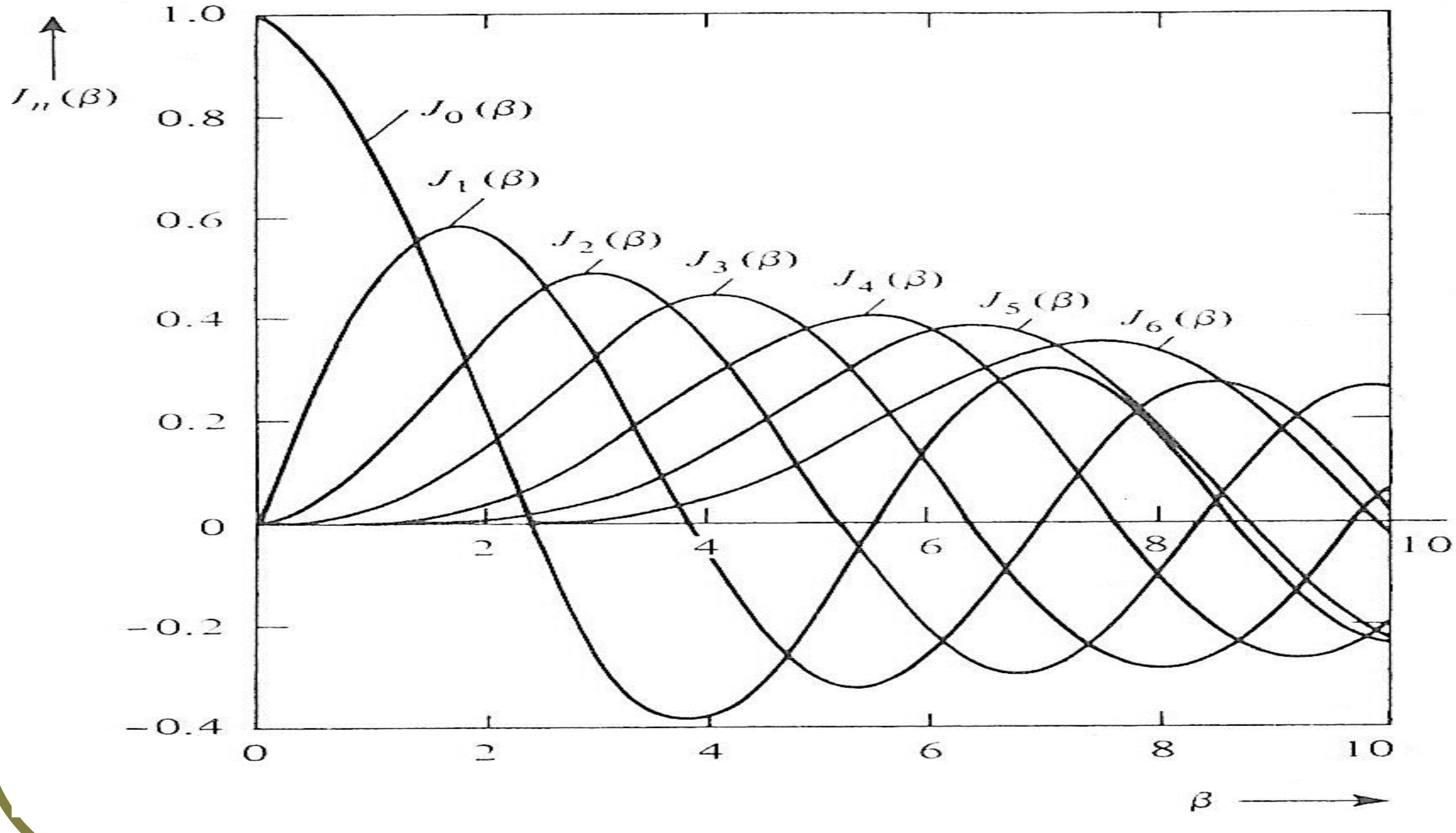


TABLE OF BESSEL FUNCTIONS

n	$\beta = 0.05$	$\beta = 0.1$	$\beta = 0.2$	$\beta = 0.3$	$\beta = 0.5$	$\beta = 0.7$	$\beta = 1.0$	$\beta = 2.0$	$\beta = 3.0$	$\beta = 5.0$	$\beta = 7.0$	$\beta = 8.0$	$\beta = 10.0$
0	0.999	0.998	0.990	0.978	0.938	0.881	0.765	0.224	−0.260	−0.178	0.300	0.172	−0.246
1	0.025	0.050	0.100	0.148	0.242	0.329	0.440	0.577	0.339	−0.328	−0.005	0.235	0.043
2		0.001	0.005	0.011	0.031	0.059	0.115	0.353	0.486	0.047	−0.301	−0.113	0.255
3				0.001	0.003	0.007	0.020	0.129	0.309	0.365	−0.168	−0.291	0.058
4						0.001	0.002	0.034	0.132	0.391	0.158	−0.105	−0.220
5								0.007	0.043	0.261	0.348	0.186	−0.234
6								0.001	0.011	0.131	0.339	0.338	−0.014
7									0.003	0.053	0.234	0.321	0.217
8										0.018	0.128	0.223	0.318
9										0.006	0.059	0.126	0.292
10										0.001	0.024	0.061	0.207
11											0.008	0.026	0.123
12											0.003	0.010	0.063
13											0.001	0.003	0.029
14												0.001	0.012
15													0.005
16													0.002
17													0.001

Bessel Functions

- The first column gives the sideband number, while the first row gives the modulation index.
- The remaining columns indicate the amplitudes of the carrier and the various pairs of sidebands.
- Sidebands with relative magnitude of less than 0.001 have been eliminated.

Bessel Functions

Some of the carrier and sideband amplitudes have negative signs. This means that the signal represented by that amplitude is simply shifted in phase 180° (phase inversion). As you can see, the spectrum of a FM signal varies considerably in bandwidth depending upon the value of the modulation index. The higher the modulation index, the wider the bandwidth of the FM signal.

Bessel Functions

With the increase in the modulation index, the carrier amplitude decreases while the amplitude of the various sidebands increases. With some values of modulation index, the carrier can disappear completely.

FM Bandwidth

- Theoretically, a FM signal contains an infinite number of side frequencies so that the bandwidth required to transmit such signal is infinite.
- However, since the values of $J_n(\beta)$ become negligible for sufficiently large n, the bandwidth of an angle-modulated signal can be defined by considering only those terms that contain significant power.

FM Bandwidth

From Bessel table: $B.W = 2nf_{m(\max)}$ → actual bandwidth

n = number of significant sideband

Carson's rule is given by the expression

$$BW \cong 2(\Delta f + f_m)$$ → approximate bandwidth

Carson’s rule is an approximation and gives transmission bandwidth that are slightly narrower than the bandwidths determined using the Bessel table.

Examples

Calculate the bandwidth occupied by a FM signal with a modulation index of 2 and a highest modulating frequency of 2.5 kHz.

Solution:

$$B.W = 2nf_{m(\max)}$$

$$B.W. = 2 \times 6 \times 2.5$$
$$= 30kHz$$

Example:

Assuming a maximum frequency deviation of 5 kHz and a maximum modulating frequency of 2.5 kHz, the bandwidth would be

Solution:

$$B.W. = 2(2.5kHz + 5kHz)$$
$$= 2 \times 7.5kHz$$
$$= 15kHz$$

Power in FM

In FM, the amplitude of the modulated signal is the same as the amplitude of the un-modulated carrier signal. Power of FM wave dissipated in a load, R is:

$$P_{FM} = \frac{V_{rms}^2}{R} = \frac{V_c^2}{2R}$$

$$P_{FM} = P_c$$

But the power in the carrier is distributed over the various FM sidebands that results from the modulation. This power is contained at the various frequency Spectrum components, in amounts determined by the m_f and the corresponding Bessel Function

Power in FM

The FM average power is:

$$P_T = P_c [J_0^2 + 2\sum_{n=1}^{n} J_n^2]$$

where
Pc = carrier power
n = number of pairs of significant sidebands

The average power of the modulated carrier (P_T) must be equal to the average power of the un-modulated carrier

Narrow Band FM (NBFM)

1. Modulation index approximates to 1
2. The frequency modulation is between 5 kHz to 10khz
3. Bandwidth : 10 – 30kHz
4. The maximum modulating frequency : 3 kHz
5. NBFM is used for communication, in competition with SSB, having its main applications in various form of mobile communication (eg. Police, ambulances, etc)

Wide Band FM (NBFM)

1. Modulating frequency range from : 30 kHz – 15 kHz
2. The maximum frequency deviation frequency : 75 kHz
3. Modulation index is more than 1 (between 5 to 2500)
4. Bandwidth is approximately 15 times higher than the NBFM system
5. WBFM is used for broadcasting with or without stereo multiplex and for the sound accompanying TV transmission

Advantages of FM compared to AM

1. All the transmitted power in FM is useful, whereas in AM most of it in the transmitted carrier, which contains no useful information

2. FM has the advantages over the AM, of providing greater protection from noise for the lowest modulating frequency

3. In FM, the transmitted amplitude is constant. This characteristic has the advantages of significantly improving immunity to noise and interference

Disadvantages of FM compared to AM

1. Since the reception is limited to line of sight, the area of reception for FM is much smaller than AM

2. Equipments for the transmitter and receiver are more expensive and complex

3. A much wider bandwidth is required by FM, up to 10 times larger than needed by AM. This is the most significant disadvantage of AM

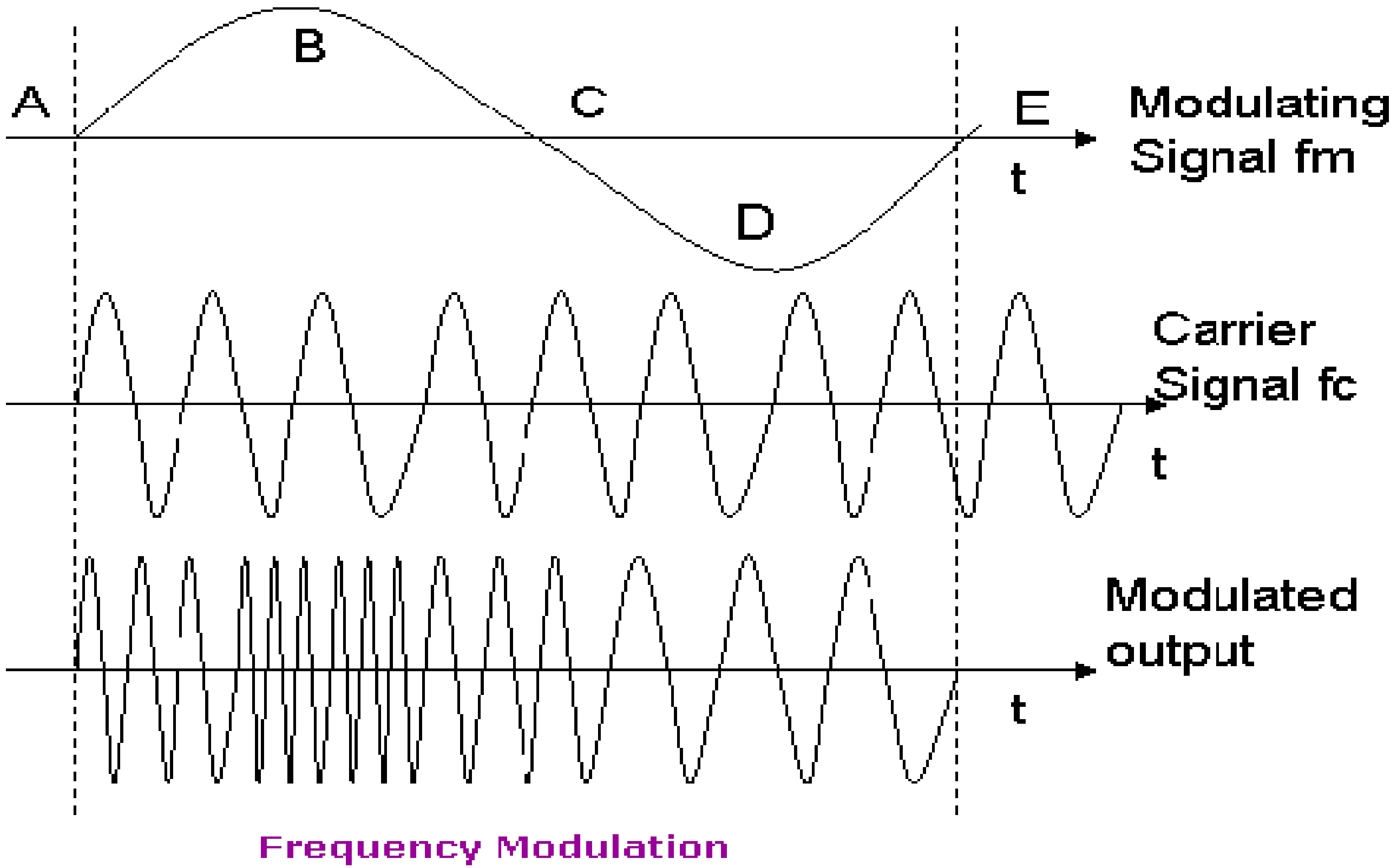
Frequency Modulation

- Amplitude modulation has two drawbacks; that is serious deficiencies in dynamic range and in noise immunity

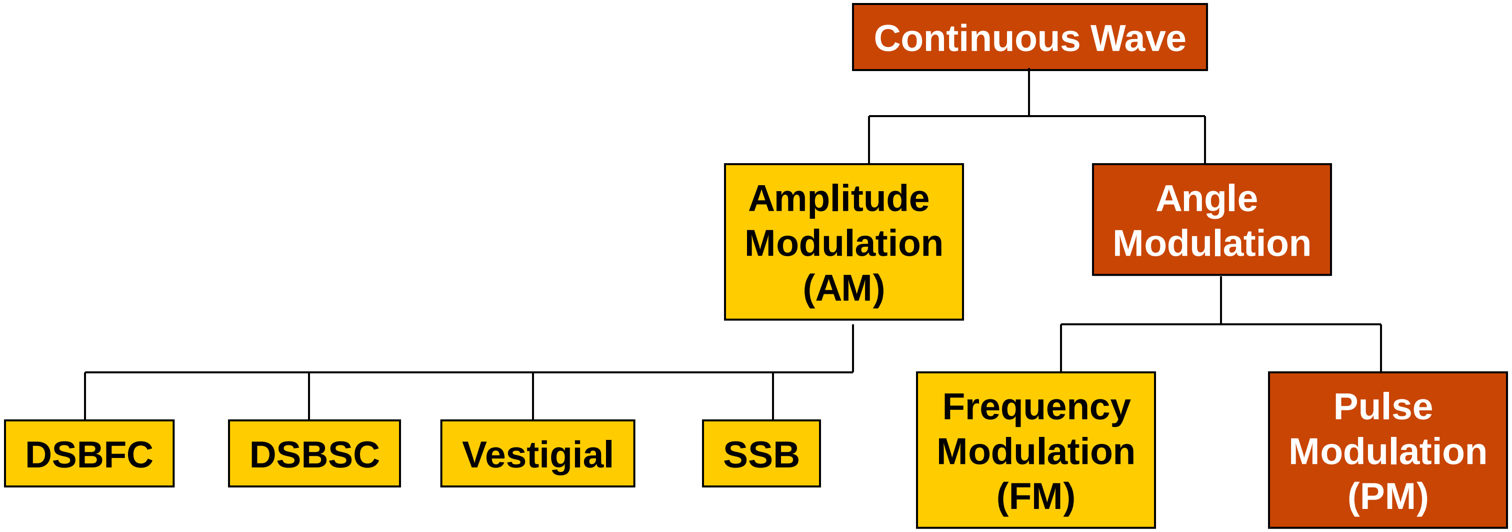
- For these reason, Frequency Modulation (FM) is introduced. This is due FM is offering a wide dynamic range which is suitable for high fidelity system such as in FM stereo and can reduce the effect of noise

- However, it require a wide bandwidth and a complex system transceiver

FM Waveform


A
B
C
D
E
Modulating Signal fm
t
Carrier Signal fc
t
Modulated output
t
Frequency Modulation

PM Communication Chart



Phase Modulation (PM)

Phase modulation is a system in which the phase of the carrier signal is varied by the information signal. The amplitude of the carrier is kept constant.

The phase ϕ in the equation $v = V_c \cos(\omega_c + \phi)$

is varied so that its magnitude is proportional to instantaneous amplitude of the modulating signal.

Phase Modulation (PM)

With PM, the maximum frequency deviation occurs during the zero crossings of the modulating signal. That is, the Δf is proportional to the slope or first derivative of the modulating signal.

Phase Modulation (PM)

PM equation: $v_c(t) = V_c \cos \omega_c(t)$

If Carrier signal $v_m(t) = V_m \cos \omega_m(t)$

Modulating signal

The expression for PM wave is:

$$v_{PM}(t) = V_c \cos(\omega_c + \phi)t$$

where

$$\phi \propto v_m(t) = kV_m \cos \omega_m t$$

Phase Modulation (PM)

Giving $$v_{PM}(t) = V_c \cos(\omega_c t + kV_m \cos \omega_m t)$$

where $$kV_m = \Delta\phi = m_p$$

= is the maximum value of phase change introduced by this particular modulation signal and is proportional to the maximum amplitude of the modulating signal

Phase Modulation (PM)

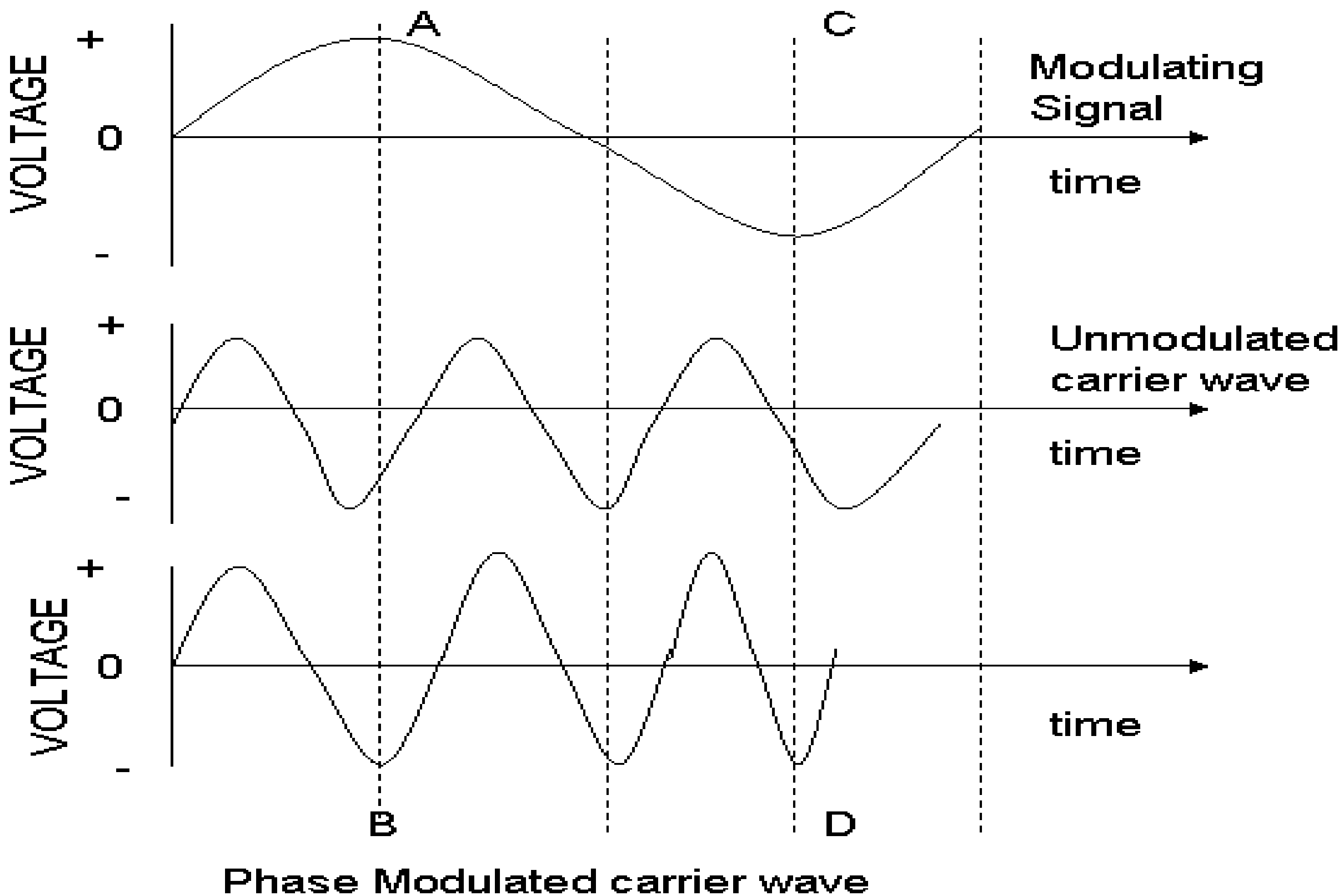
The range for ϕ is $-\pi \langle \Delta\phi \leq \pi$

The value of ϕ is called the modulation index for PM, which is denoted by m_p

So, general equation for PM is

$$v_{PM}(t) = V_c \cos(\omega_c t + m_p \cos \omega_m t)$$

Phase Modulation (PM)



An example of a Phase Modulation Waveform

Comparison between PM & FM

Comparisons between PM and FM

1. The modulation index – is defined differently in each system

In FM its modulation index : $$m_f = \frac{\Delta_f}{f_m}$$

In PM its modulation index : $$m_p = \Delta\phi = KV_m$$

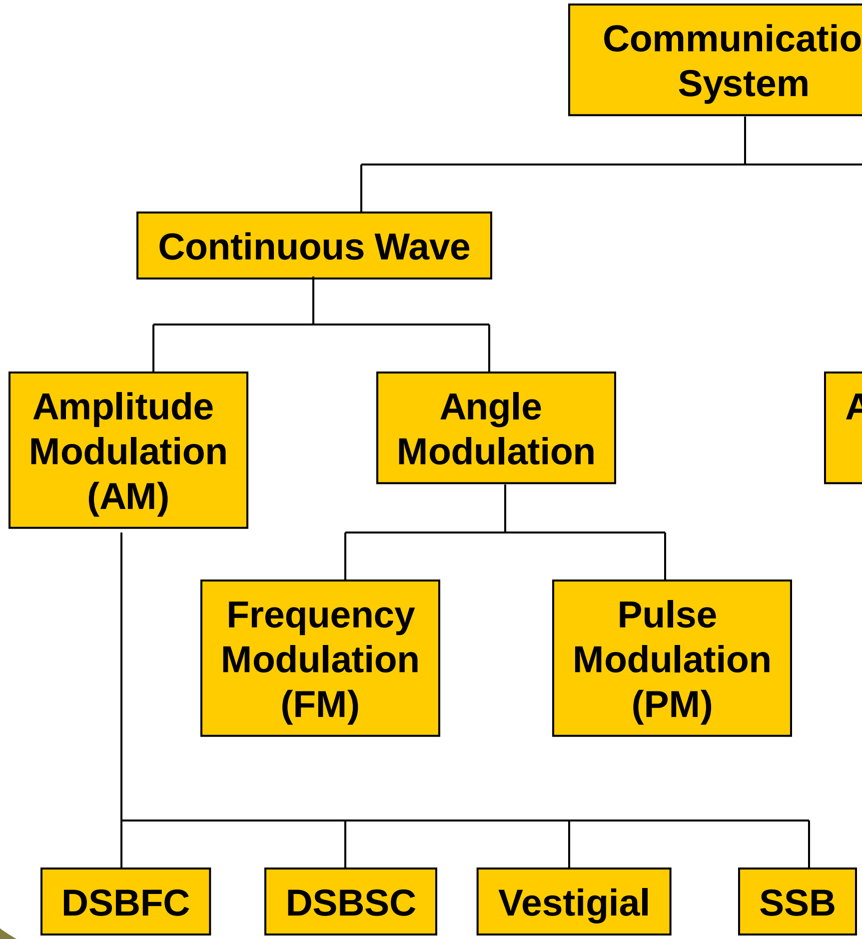
Comparison between PM & FM

2. In PM, the phase deviation is proportionally to the amplitude of the modulating signal and is independent of its frequency

3. In FM, the frequency deviation is proportionally to the amplitude of the modulating signal V_m as well as its frequency, f_m

4. The main difference between PM and FM, is how the information signal will change the carrier signal.

Communication System Chart

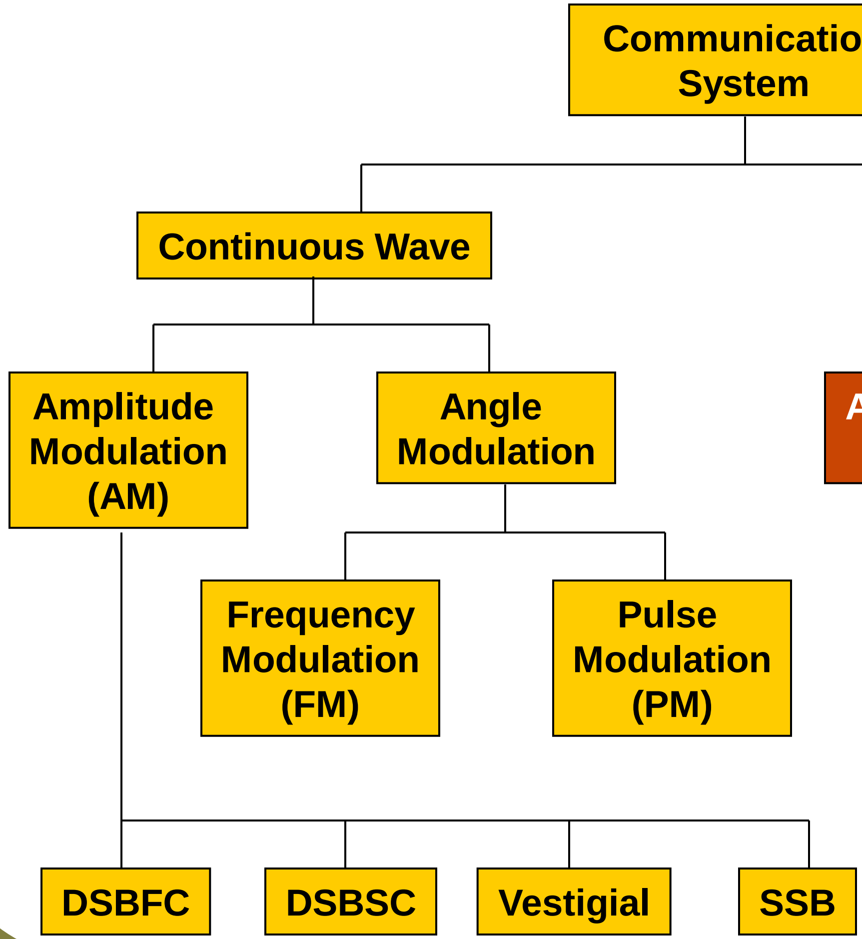


Modulation 3

Digital Modulation

Analogue Pulse Modulation

Digital Modulation Chart



Introduction

- Pulse modulation includes many difference methods of converting information into pulse form for transferring pulses from a source to a destination.

- Pulse modulation
  - Analog Pulse Modulation (APM)
  - Digital Pulse Modulation

- Pulse modulation can be used to transmit analogue information, it is first converted into pulses by the process of sampling.

Sampling

- Sampling is the process of taking a periodic sample of the waveform to be transmitted.
- The sampling theorem (Nyquist theorem) is used to determined minimum sampling rate for any signal so that the signal will be correctly restored at the receiver.
- Nyquist's Sampling theorem:

$$f_s \geq 2 f_m$$

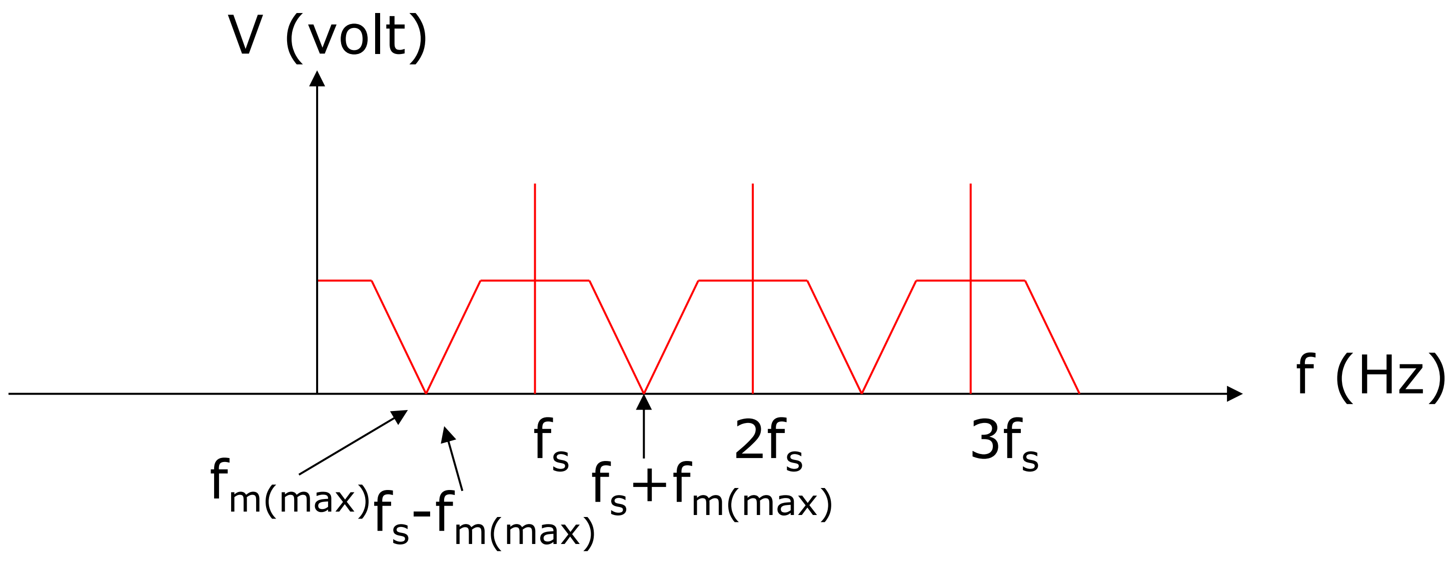
Where f_s = sampling frequency

$f_{m(max)}$ = maximum frequency of the modulating signal

Sampling

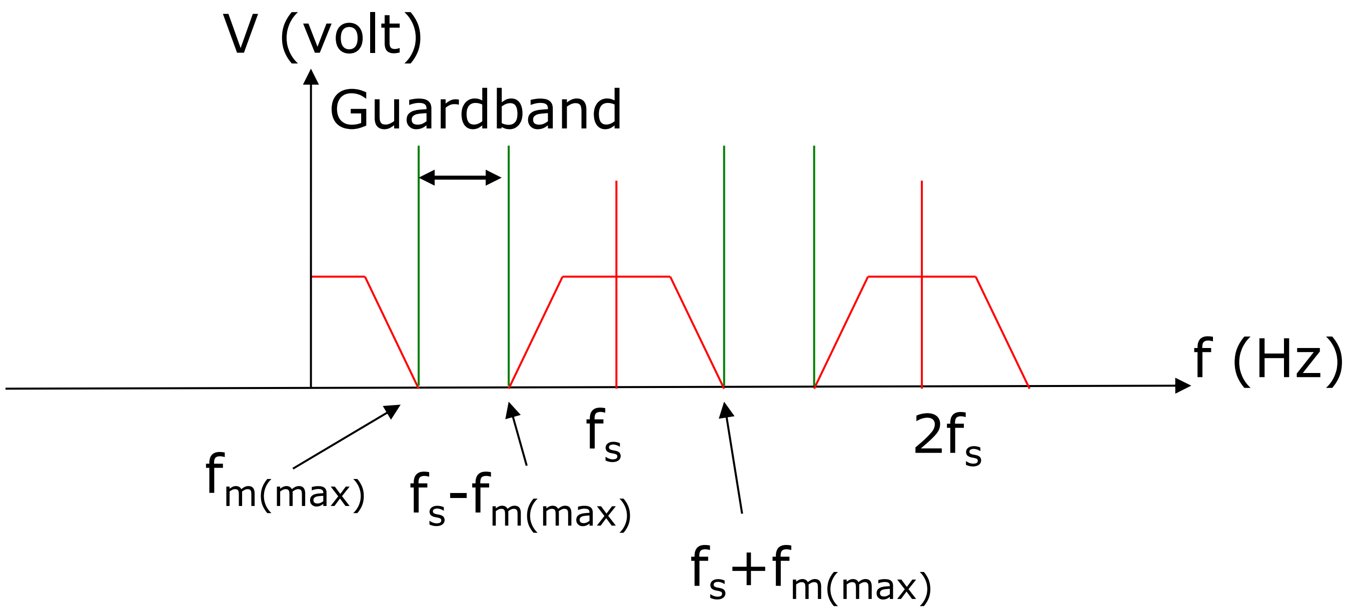
Three basic condition of sampling process:

1. Sampling at $f_s = 2_{fm(max)}$



Sampling

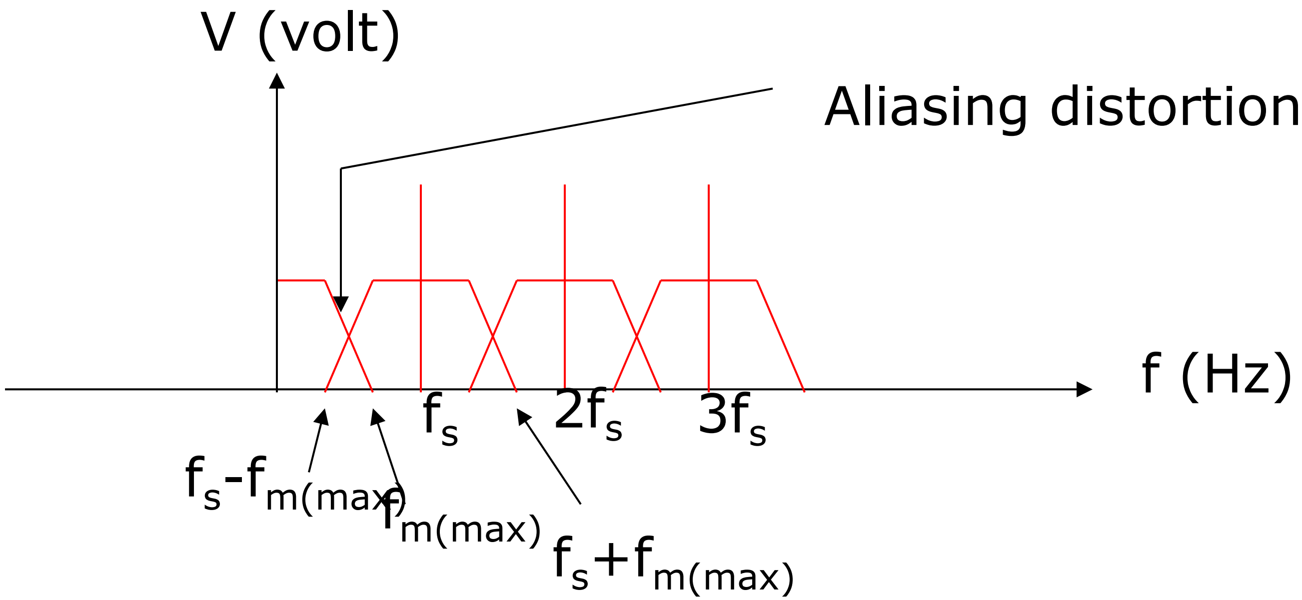
2. Sampling at $f_s > 2f_{m(max)}$



This sampling rate creates a guard band between $f_{m(max)}$ and the lowest frequency component $f_s - f_{m(max)}$ of the sampling harmonics.

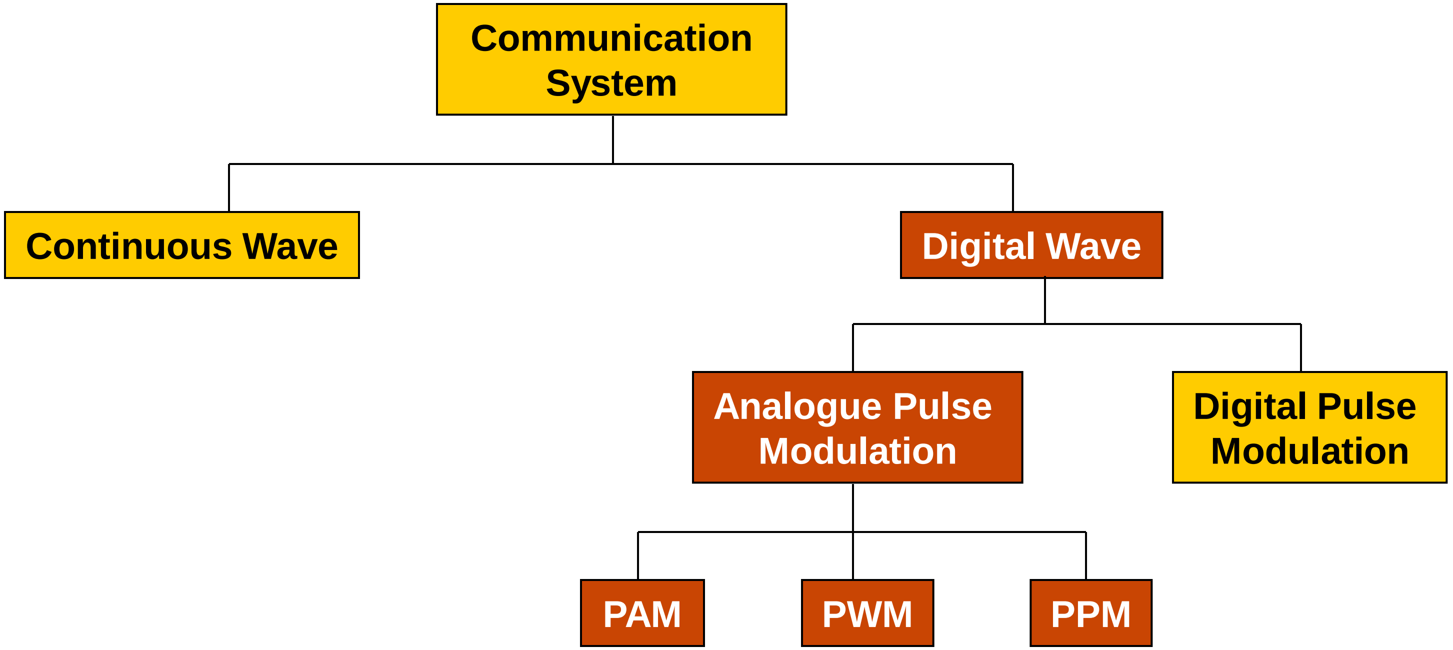
Sampling

3. Sampling at $f_s < 2_{fm(max)}$



- Aliasing: the distortion produced by the overlapping components from adjacent bands
- Aliasing occurs when a signal is sampled below its Nyquist rate

Analogue Pulse Modulation Chart



Analog Pulse Modulation (APM)

- In APM, the carrier signal is in the form of pulse form, and the modulated signal is where one of the characteristics either (**amplitude, width, or position**) is changed according to the modulating/audio signal.

- Three common techniques of APM:
  - Pulse amplitude modulation (PAM)
  - Pulse Width Modulation (PWM)
  - Pulse Position Modulation (PPM)

Waveforms for PAM, PWM and PPM

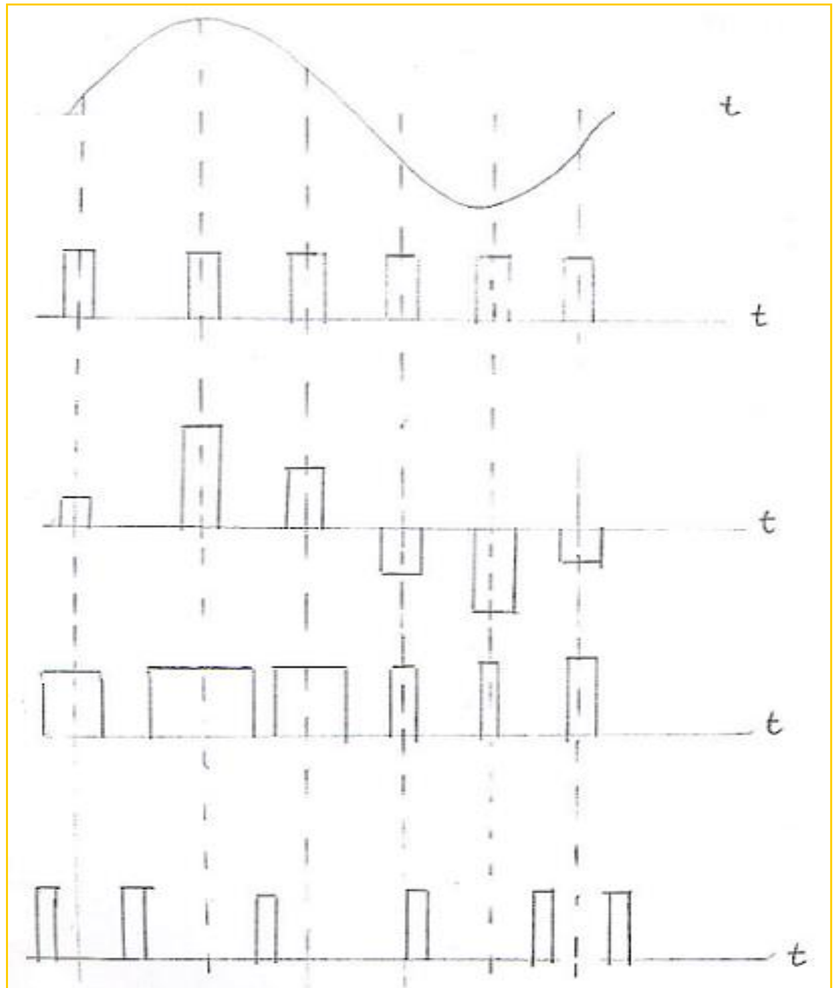
Modulating signal

carrier signal

PAM
(dual polarity)

PWM

PPM



Pulse Amplitude Modulation (PAM)

- It is very similar to AM
- The amplitude of a carrier signal is varied according to the amplitude of the modulating signal.
- Two type PAM
  - Dual- polarity PAM
  - Single -polarity PAM

Pulse Width Modulation (PWM)

- The technique of varying the width of the constant amplitude pulse proportional to the amplitude of the modulating signal.
- PWM gives a better signal to noise performance than PAM

Pulse Position Modulation (PPM)

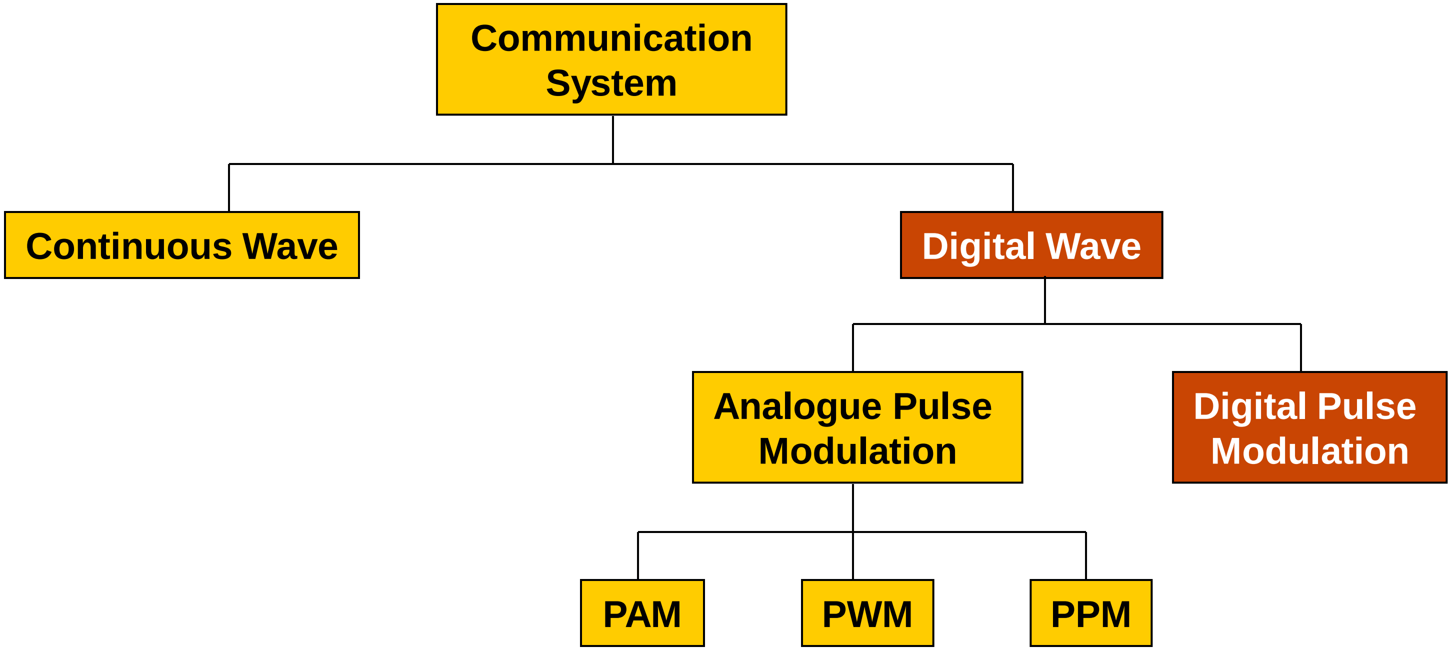
- PPM is when the position of a constant width and constant amplitude pulse within prescribed time slot is varied according to the amplitude of the modulating signal.

Modulation 4

Digital Modulation

Digital Pulse Modulation

Digital Pulse Modulation Chart



Digital Pulse Modulation (DPM)

- Digital modulation is the process by which digital symbols are transformed into waveforms that are compatible with the characteristics of the channel

- In DPM, **a code** is used to represent the amplitude of the samples that has been divided into various levels.

Digital Pulse Modulation (DPM)

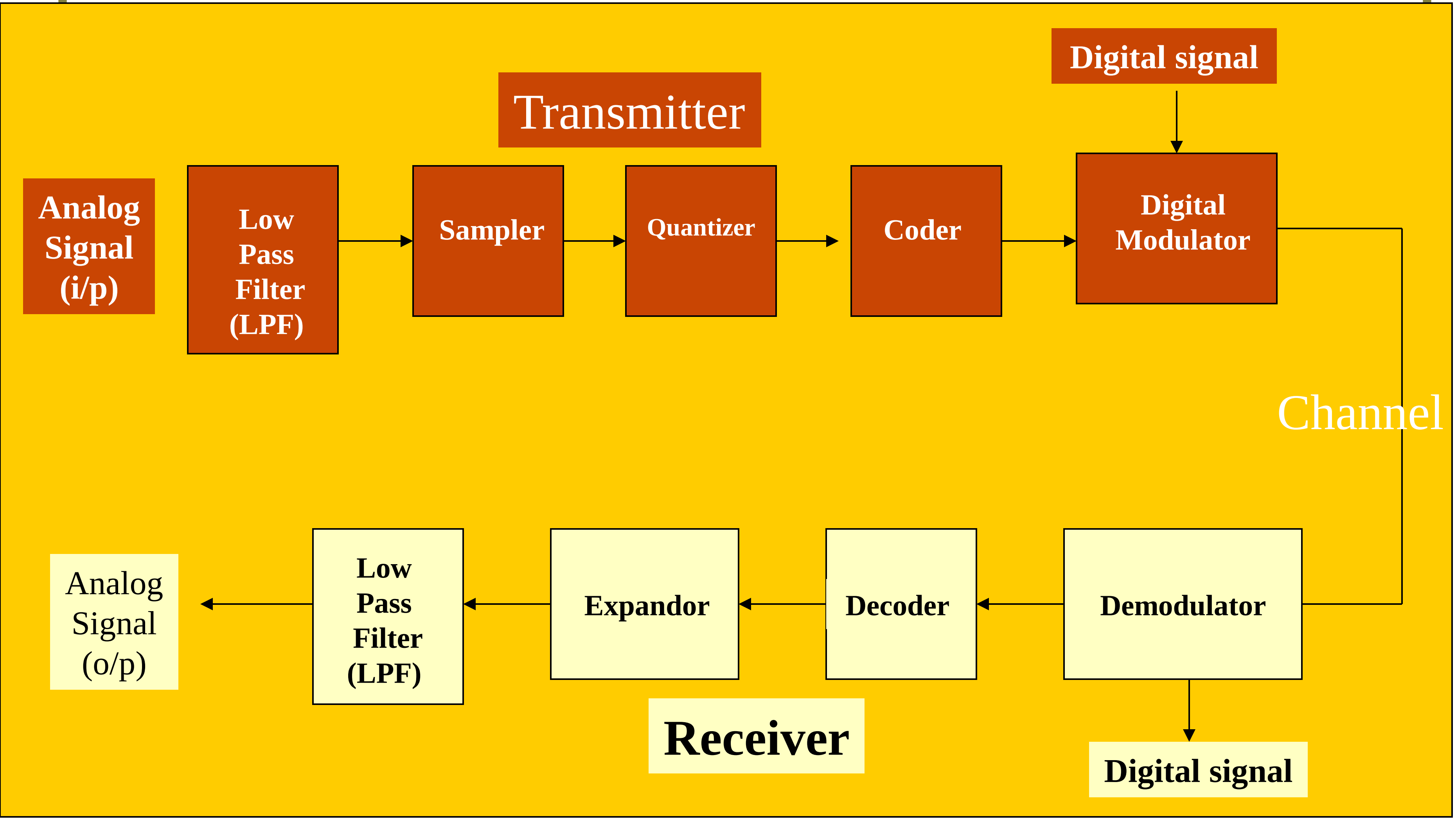
- Digital system offers some advantages compared to analog system. There are:
  - **Immune to channel noise** and interference
  - Signals and messages can be coded for error detection and correction
  - Can carry a combination of traffics
  - It is easier and more efficient to multiplex several digital signal
  - More economical

- Disadvantages:
  - Requires significantly more bandwidth
  - Requires precise time synchronization between the clocks in the transmitter and receivers

Pulse Code Modulation (PCM)

- PCM is a form of digital modulation where groups of coded pulses are used to represent the analog signal.
- The analog signal is sampled and converted to a fixed-length, serial binary number for transmission.

A Block Diagram of a PCM system (single channel)



PCM

- LPF (Pre alias filter)
  - Is used to attenuate those high frequency components of the signal that lie outside the band of interest
- Sampler
  - The filtered signal is sampled at a rate higher than the Nyquist rate
- Quantizer
  - The conversion of an analog (continuous) sampler of the signal into a digital (discrete) form is called quantizing process. It consists of prescribed numbers of discrete amplitude levels

Principles of PCM

- Three main process in PCM transmission are sampling, quantization and coding.
  - Sampling
  - Quantization
  - Encoding

Principles of PCM

- **Sampling**
  - Process of taking samples of the analog signals at given interval of time. Only samples are being transmitted. If sufficient samples are sent and sampling theorem are met, the original signal can be constructed at the receiver $f_s \geq 2 f_m$
- **Quantization**
  - Quantization is a process of assigning the analog signal samples to a pre-determined discrete levels.
  - The number of quantization levels, L depends on the number of bits per sample, n, used to code the signal where $L = 2^n$

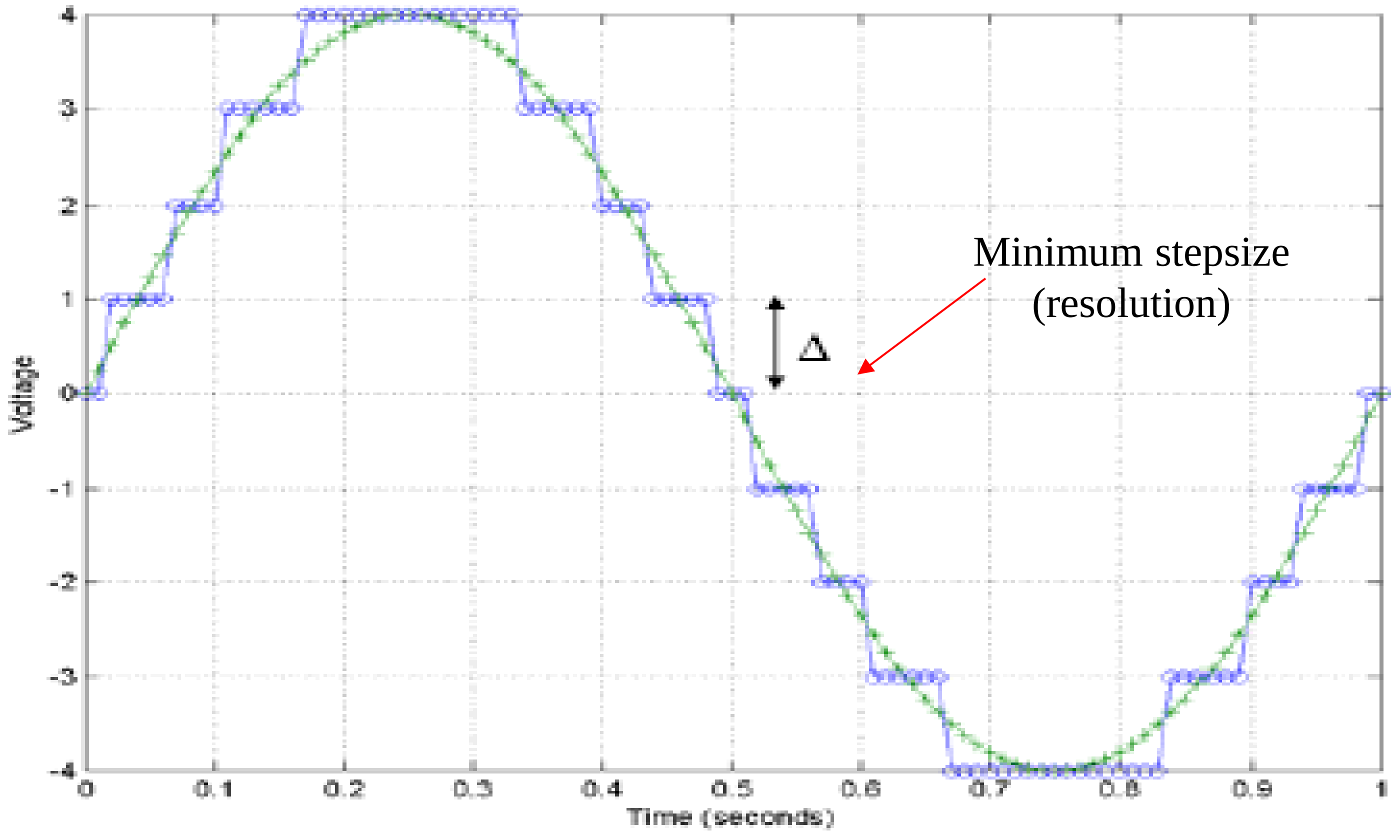
Principles of PCM

- The magnitude of the minimum stepsize of the quantization levels is called resolution, Δv

- The resolution depends on the maximum voltage, V_{max} and the minimum voltage, V_{min} of the information signal, where

$$\Delta v = \frac{V_{max} - V_{min}}{L - 1}$$

Principles of PCM



Principles of PCM

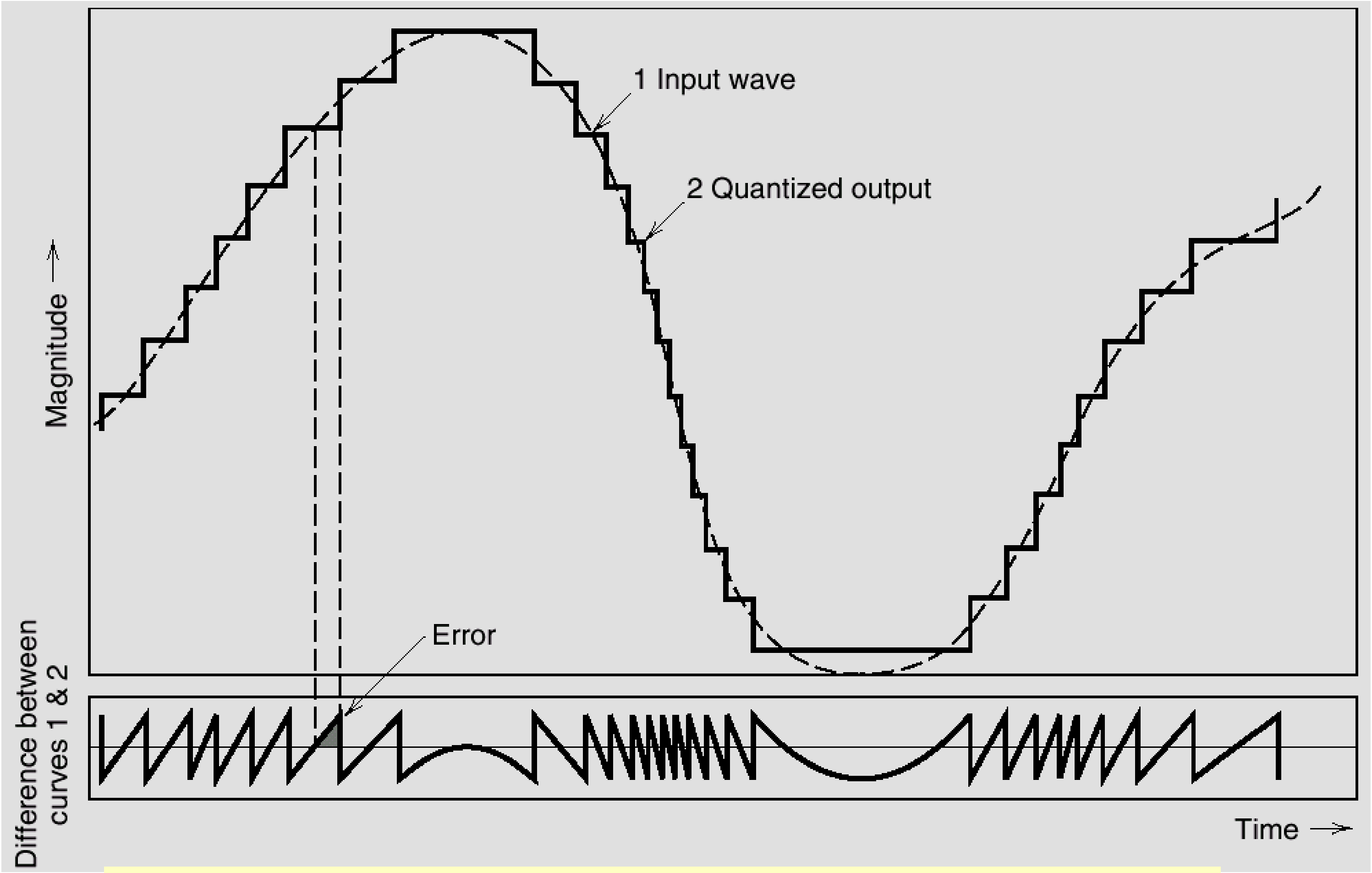


Illustration of the quantization process

Principles of PCM

- Quantization error or quantization noise is the distortion introduced during the quantization process when the modulating signal is not an exact value of the quantization level.
- The maximum quantization error,

$$Q_e = \pm \frac{\Delta v}{2}$$

- Quantization error can be reduced by increasing the number of quantization levels, but this will increase the bandwidth required.

Principles of PCM

- **Encoding**
  - In this process, the samples that has been divided into various levels is coded into respective codes where the samples that are the same number of level are coded into the same code

$$n = \log_2 L$$

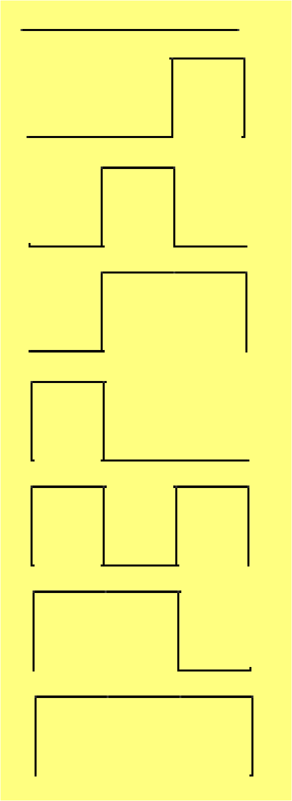
n = no of bit

L = quantization level

Example of binary number and 3-bit pulse code is shown below:

Quantized level	Binary number
1	000
2	001
3	010
4	011
5	100
6	101
7	110
8	111

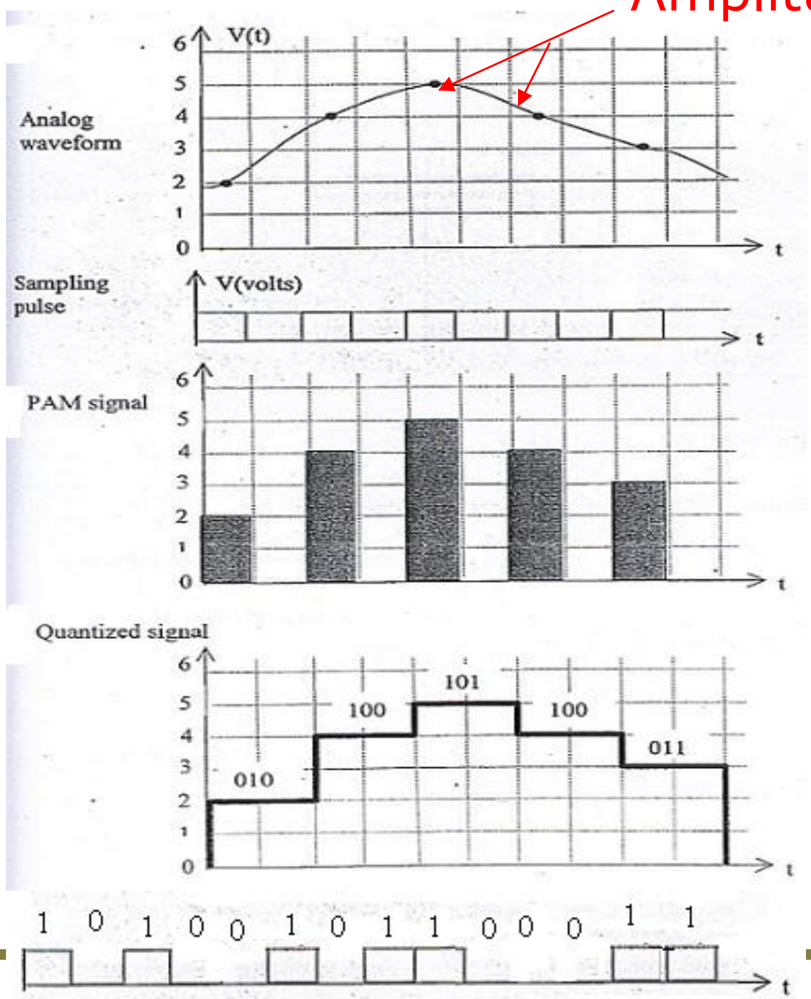
Pulse waveform



3-bit PCM code and waveform

PCM

Amplitude sampling point



Input signal

Sampling pulse

Sampled signal

Quantized signal

PCM code

PCM signal

PCM transmission bit rate and bandwidth

- Transmission bit rate (R) is the rate of information transmission (bits/s).
- It depends on the sampling frequency and the number of bit per sample used to encode the signal.
- Transmission bandwidth is equal to transmission bit rate

$$R = nf_s \quad \text{(bits/sec)}$$

$$Transmission\,bandwidth = nf_s \quad \text{(Hz)}$$

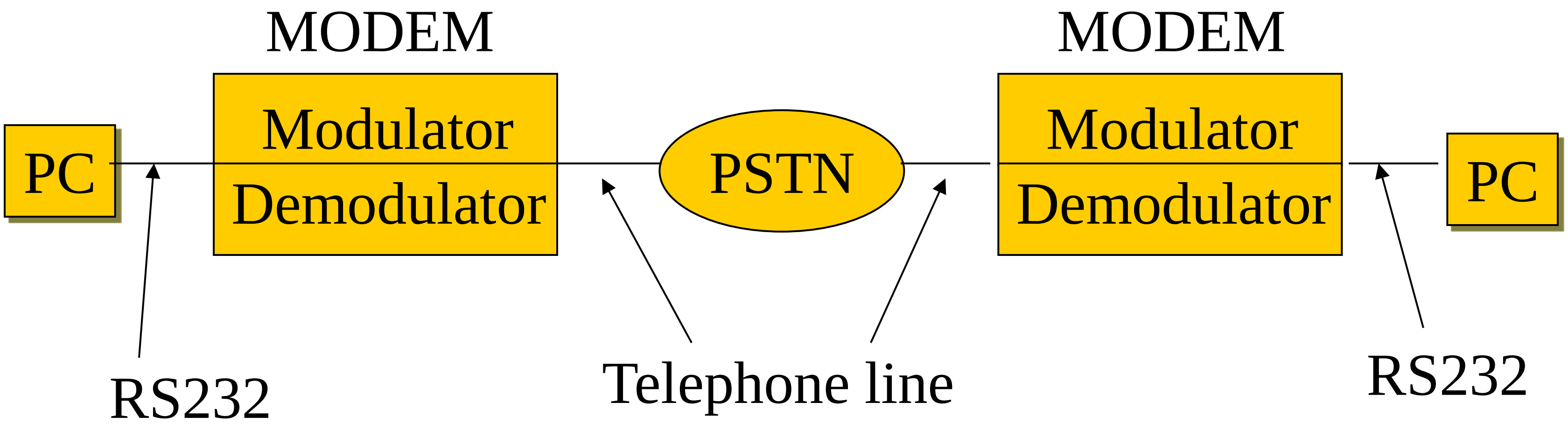
MODEM

- MODEM stands for MODulator and DEModulator.
- Modem is an interface device consists of modulator and demodulator used in point-to-point data communication systems, through the public switching telephone **networks (PSTN).**

MODEM

- Functions of a modem
  - At the transmitter
    - It coverts digital data signal that are compatible to the transmission line characteristics. That is, it converts "1" and "0's" of binary signal into FSK, QPSK or QAM signals. Also it gives voltage and current appropriate for interfacing with the telephone line
  - At the receiver
    - It converts analog signal back to digital data signals. That is, it converts FSK, QPSK or QAM signals into binary signal.

MODEM

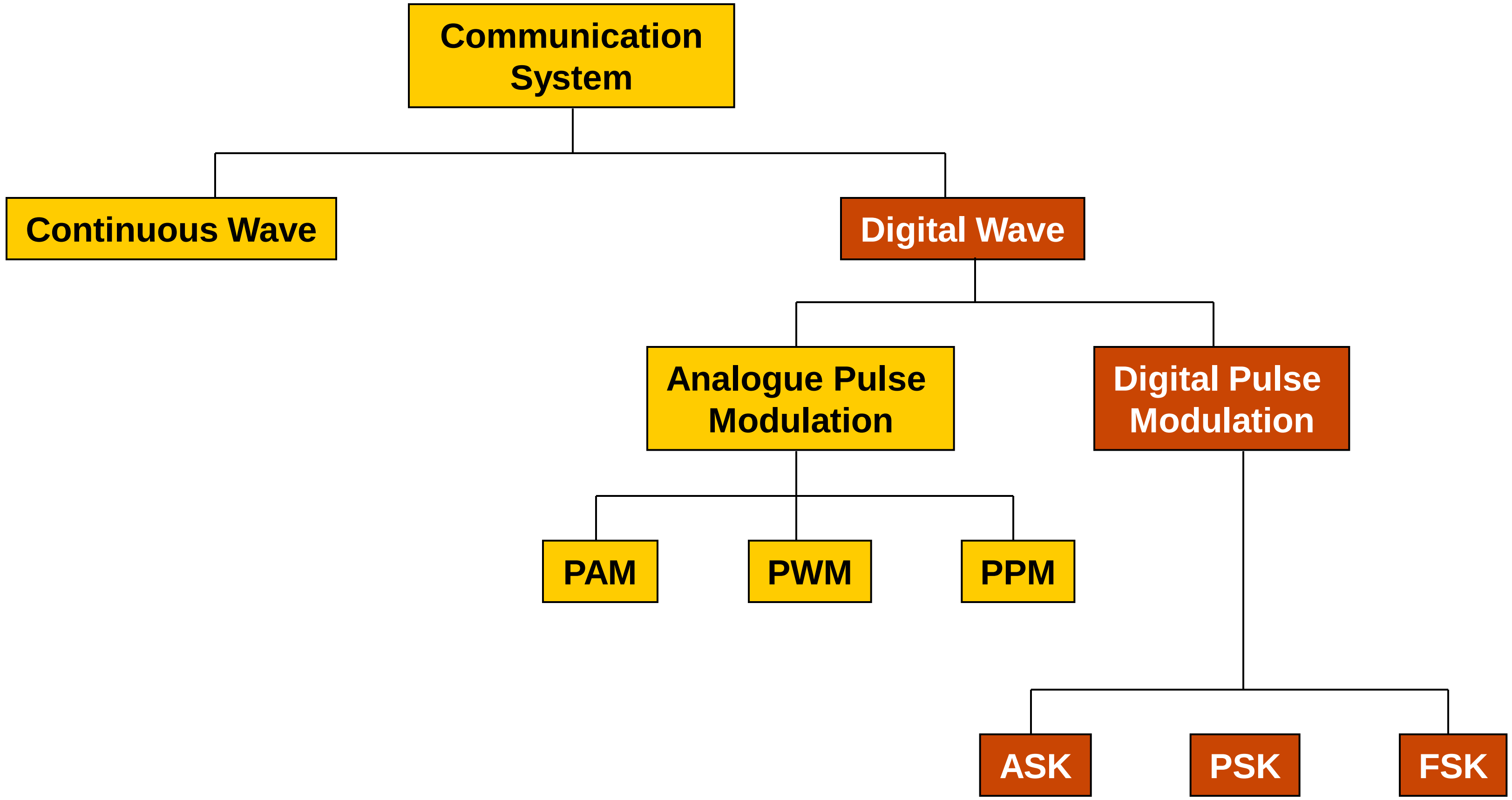


A connection of 2 computer terminals using modems

Digital Modulation Technique

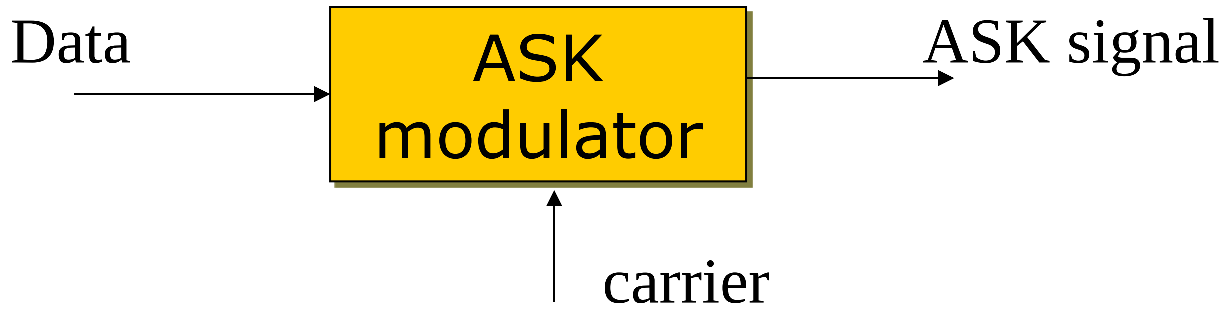
- There are several digital modulation techniques used to modulate digital signal or data, depending on the **application**, **the rate** of transmission required, allocated **bandwidth** and cost.

Digital Pulse Modulation Chart



Amplitude shift keying (ASK)

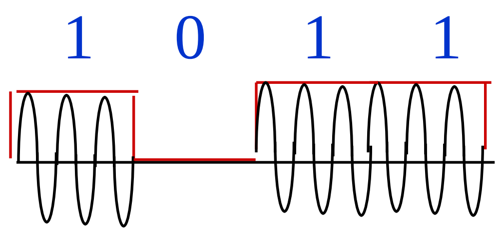
- In ASK, a carrier wave is switched ON and OFF by the input data or binary signals.



ASK generator

Amplitude shift keying (ASK)

- During a "mark" (binary 1), a carrier wave is transmitted and during a "space" (binary 0) the carrier is suppressed. Hence, it is also known as ON-OFF keying (OOK)



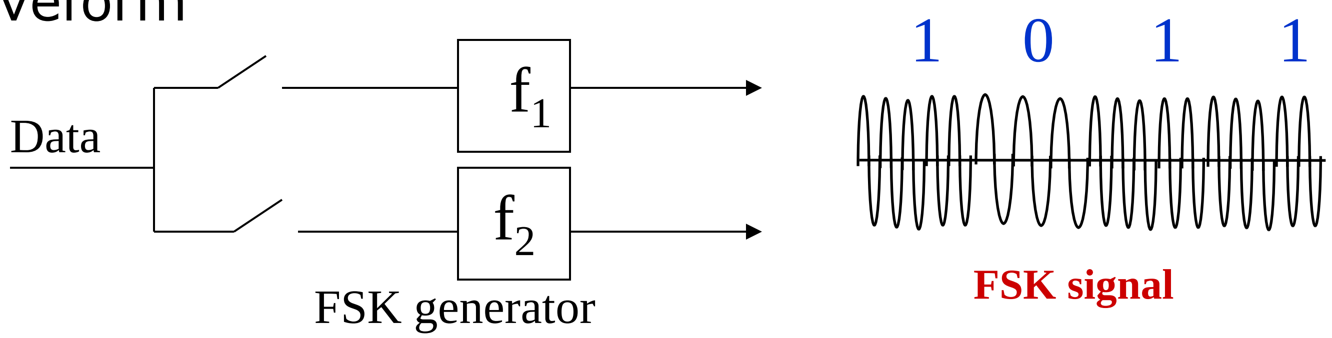
ASK Waveform

Application of ASK

- It is used in multichannel telegraph systems.
- Simple ASK is no longer used in digital communication systems due to noise problems.

Frequency Shift Keying (FSK)

- FSK is a similar to standard FM except the modulating signal is a binary signal that varies between two discrete voltage levels rather than a continuously changing analog waveform



- Two different carrier frequency are used and they are switched ON and OFF by the binary signals

  "1" – ON "0"-OFF

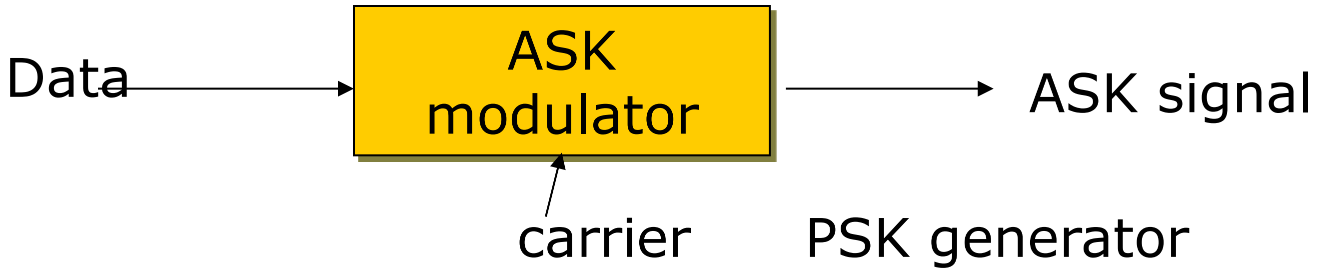
FSK

- Application of FSK
  - FSK signaling schemes are used mainly for low-speed digital data transmissions.

- Advantages of FSK over ASK
  - ASK needs automatic gain control (AGC) to overcome fading effect.
  - Relatively easy for FSK generation
  - The constant amplitude property for the carrier signal does not waste power and does produce some immunity to noise.

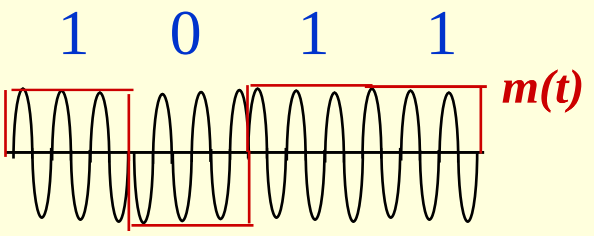
Phase Shift keying (PSK)

- PSK is similar to Phase Modulation except the PSK input is a digital signal and there are limited number of output phase possible
- The binary signal are used to switch the phase of carrier wave between two values which are normally 0º and 180º

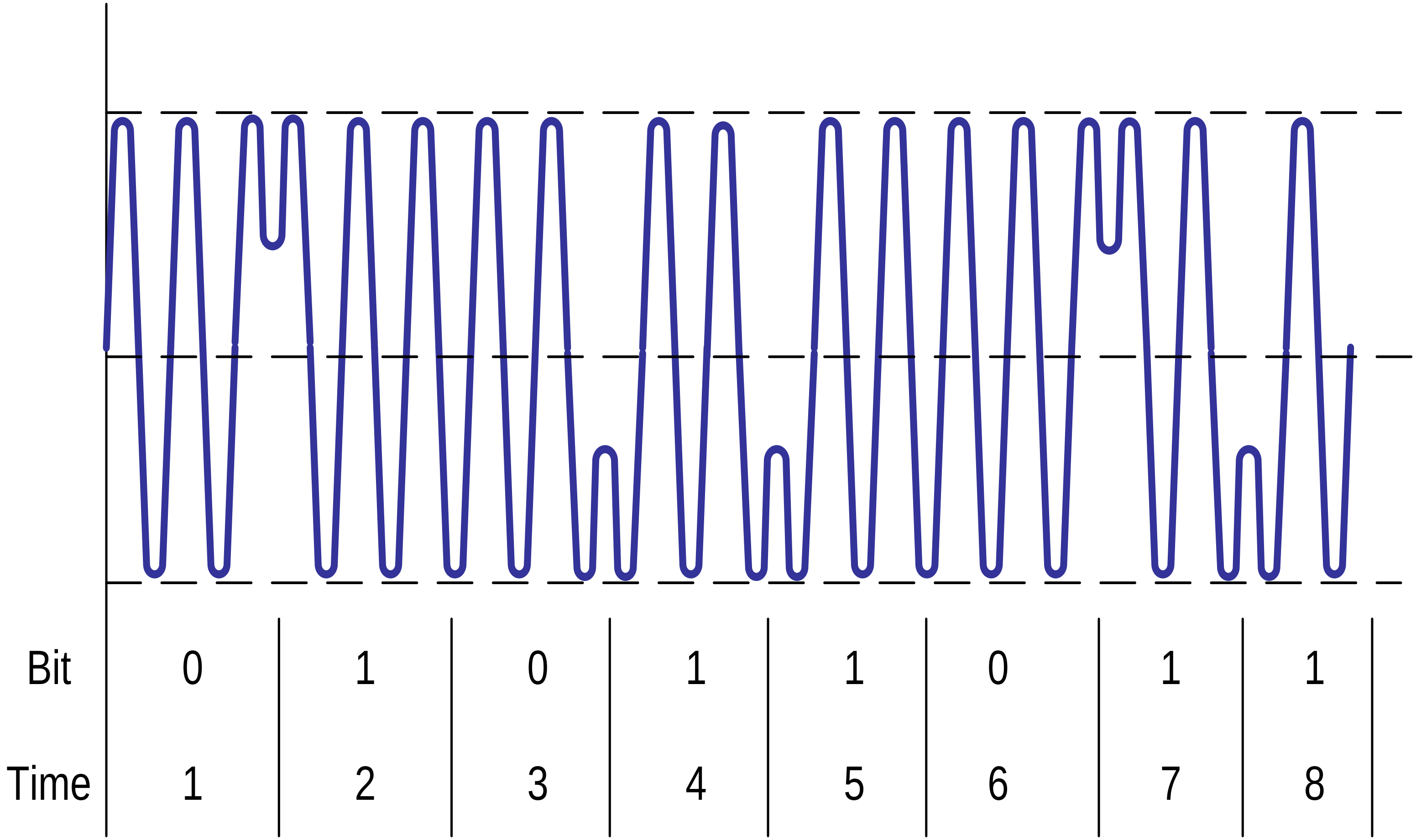


PSK generator

•For binary “1”, the carrier has one phase.
•For binary “0”, the carrier is reversed by 180º



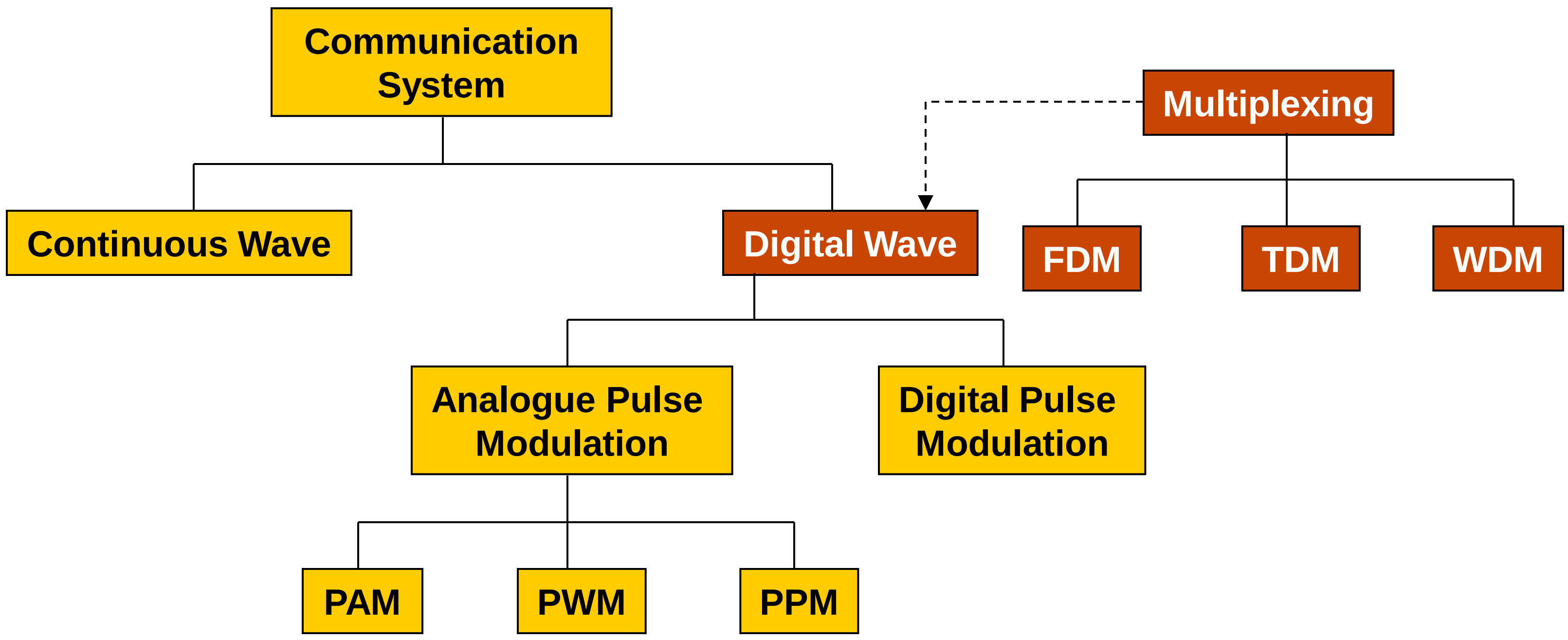
Phase Shift Keying



Modulation 5

Multiplexing

Multiplexing System Chart



Multiplexing

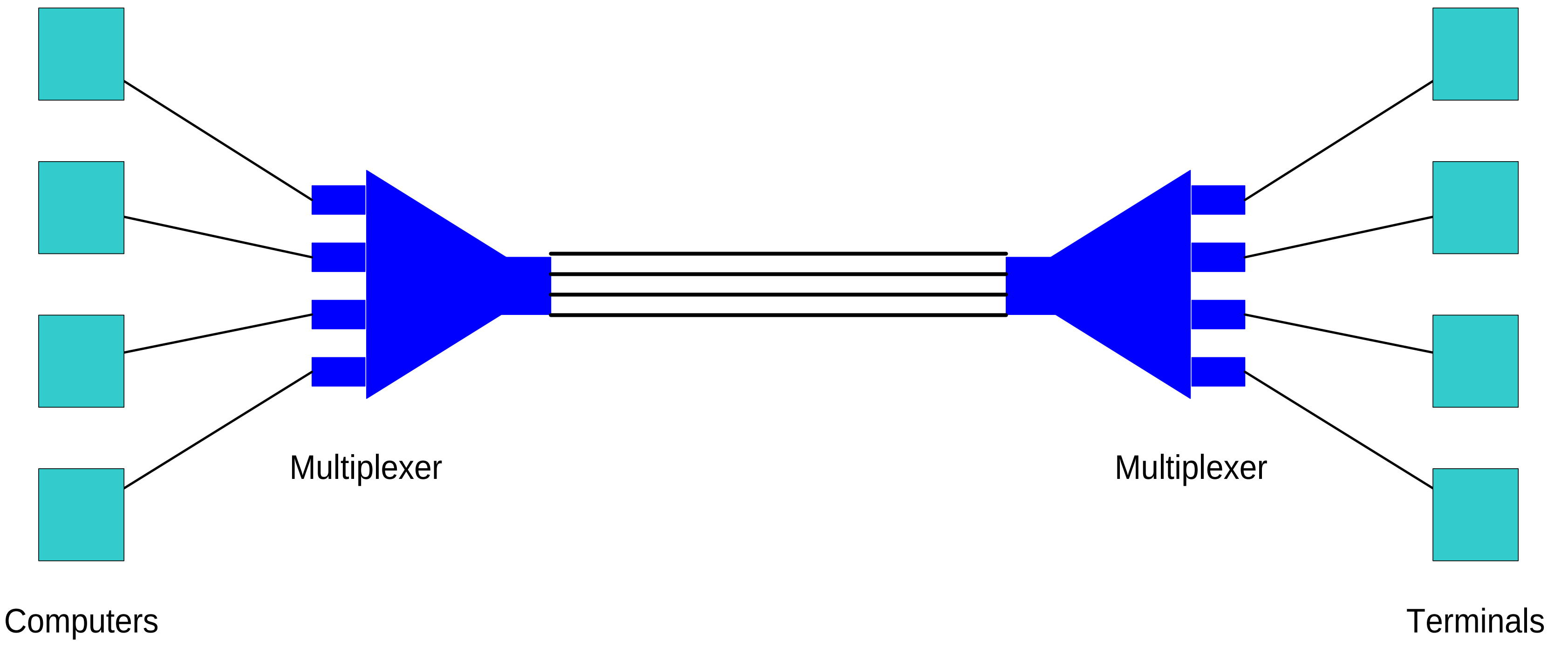
- Multiplex is a technique of transmission of information from more than one source to more than one destination on the same medium or facility.

Advantages:

- Many signals can share an existing channel and make better use of the channel capacity

- allow several different signal to be clustered into a single group, for easy handling and maintenance

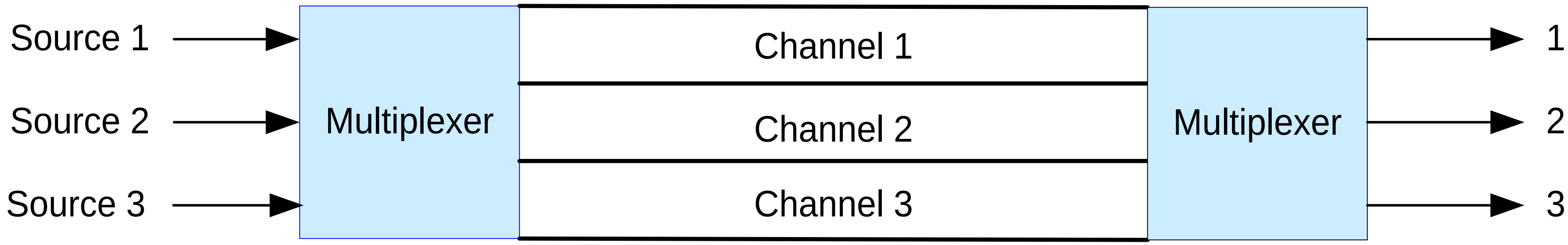
Multiplexing



Multiplexing

- Three common techniques of multiplexing:-
  - Frequency Division Multiplexing (FDM)
  - Time Division Multiplexing (TDM)
  - Wavelength Division Multiplexing (WDM)

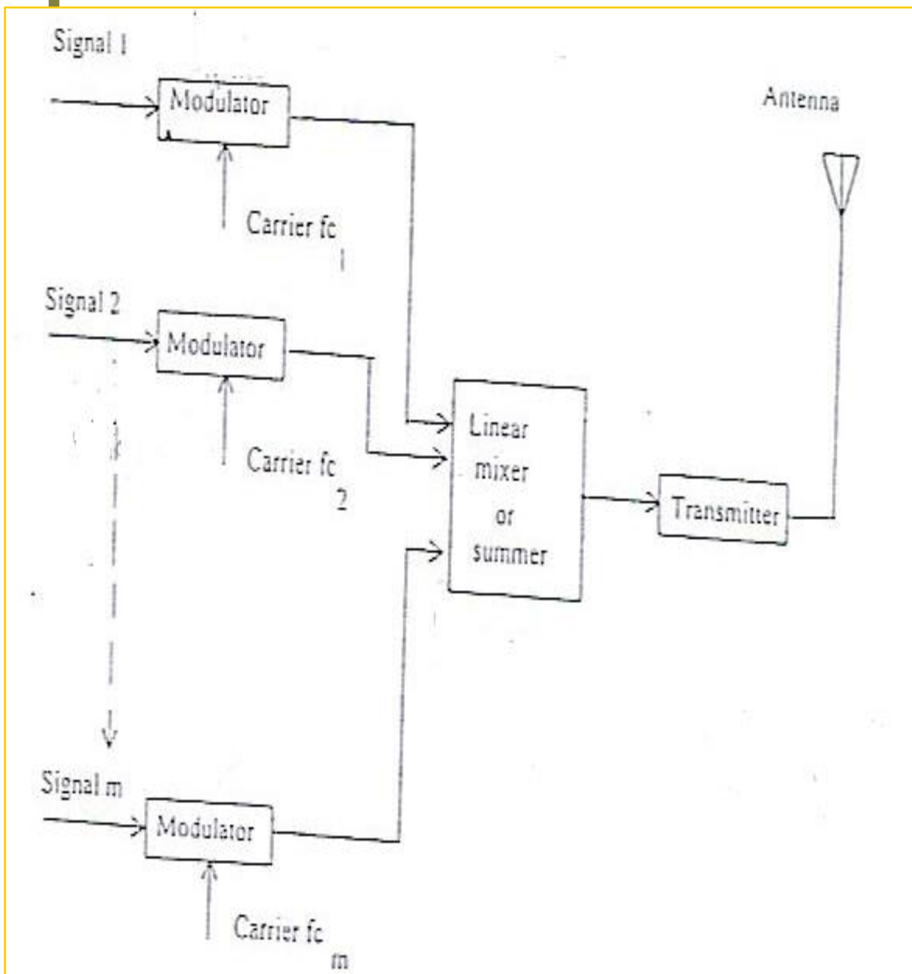
Frequency division multiplexing (FDM)

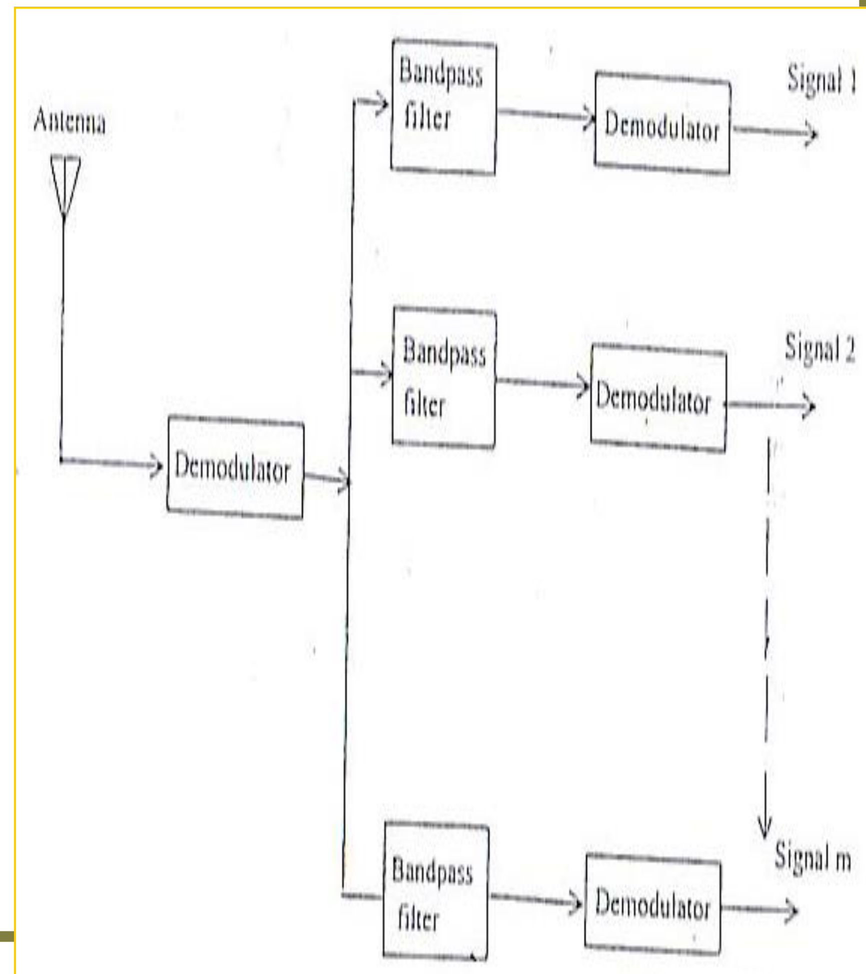


- In FDM, multiple sources that originally occupied the same frequency spectrum are each converted to a different frequency band and transmitted simultaneously over a single wideband transmission system.

- FDM is an analog multiplexing scheme, where the information entering an FDM system is analog and it remains analog throughout transmission

FDM



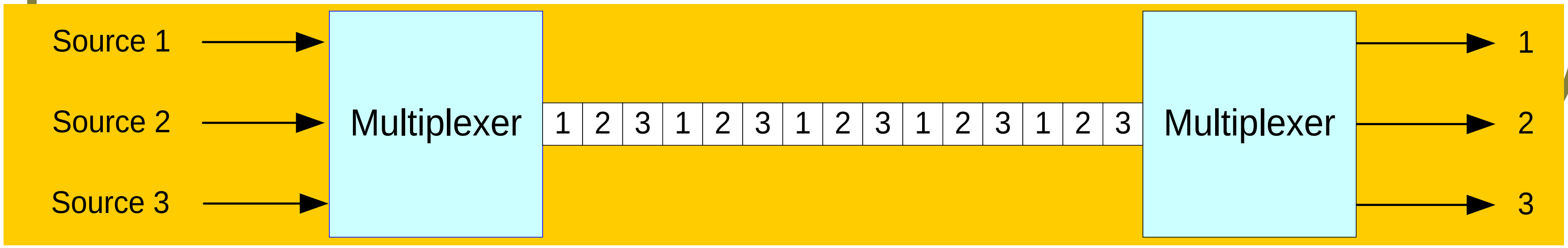


FDM system - transmitter

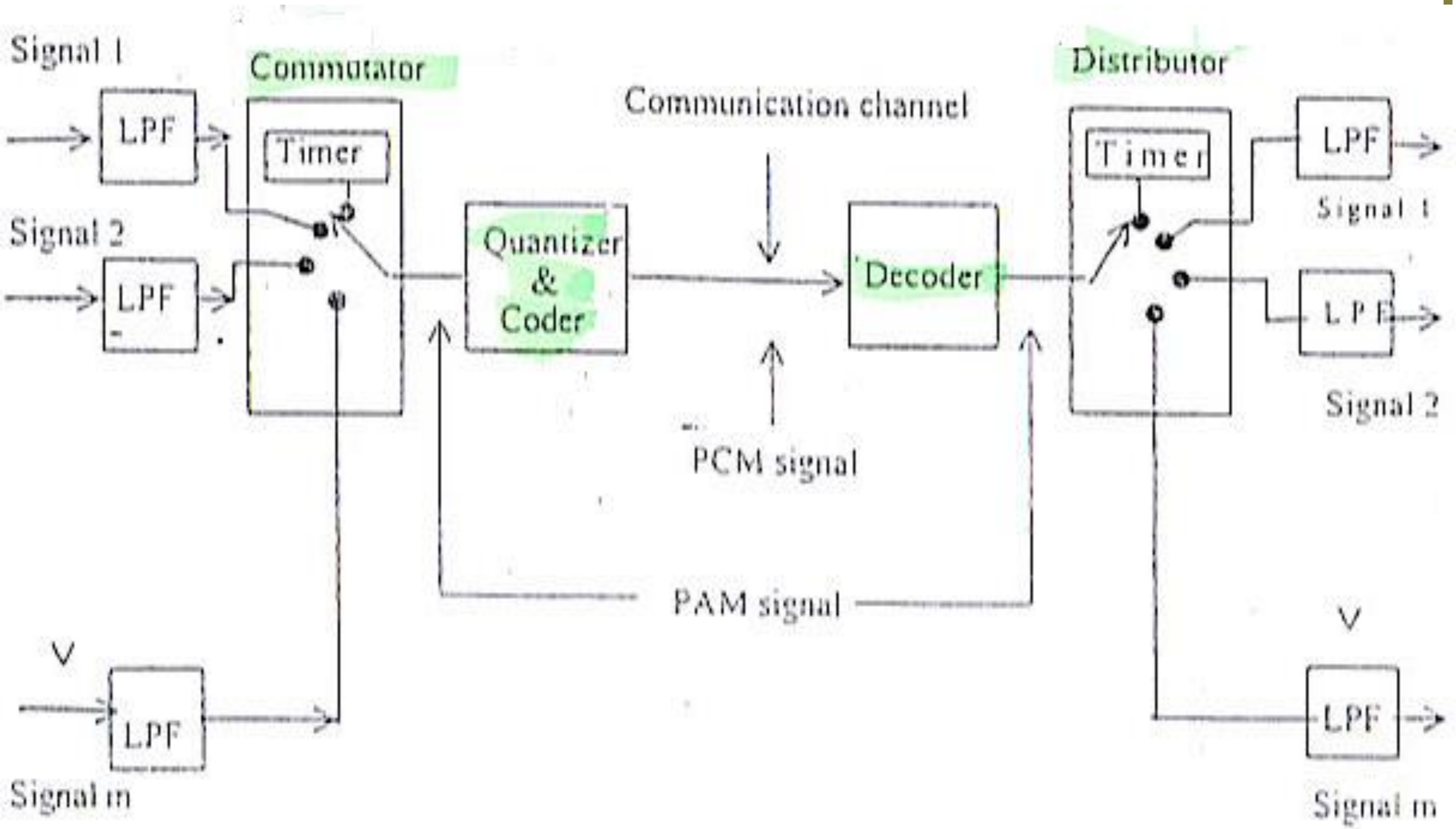
FDM system - receiver

Time division multiplexing

- Time division multiplexing (TDM) shares the circuit's time allocation.
- TDM is compatible with digital signals and makes good use of digital circuitry for these signal
- Simplistically, TDM physically switches from originator to originator to share the time available, and the receiving unit does the same in synchronism.



TDM



TDM system

Comparison between TDM and FDM

- TDM: the individual channels are assigned to different time slots but jumbled together in the frequency domain. FDM : the individual channels are assigned to different frequency slots but jumbled together in the time domain

- TDM offers simpler instrumentation. In FDM, it requires an analog subcarrier modulator, bandpass filter and demodulator for every message signal

Comparison between TDM and FDM

- There is no crosstalk or interference between adjacent channels in TDM as present in FDM. The interference in FDM is normally due to imperfect bandpass filtering and non-linear cross modulation
- In FDM, the bandwidth is used effectively
- The transmission medium of TDM is subjected to fading

Wavelength Division Multiplexing (WDM)

- WDM is a technology that enables many optical signals to be transmitted simultaneously by a single fiber cable
- The basic principle behind WDM involves the transmission of multiples signals using several wavelengths without their interfering with one another.

WDM versus FDM

- WDM is essentially the as FDM, where several signals are transmitted using different carriers, occupying non-overlapping bands of a frequency or wavelength spectrum
- The most obvious difference between WDM and FDM is that optical frequencies (in THz) are much higher than radio frequencies (in MHz and GHz)

WDM versus FDM

- FDM: channels all propagate at the same time and over the same transmission medium and take the same transmission path, but they occupy different bandwidths

- WDM: each channel propagates down the same transmission medium at the same time, but each channel occupies a different bandwidth (wavelength) and each wavelength takes different transmission path.

Communication System Chart