ज्ञानेन प्रकाशते जगत्
INDUS UNIVERSITY

ELECTRONICS & COMMUNICATION ENGINEERING
IITE Ahmedabad

Modern Communication Trends (EC0422)
Unit-1
Principles of Modern Communication System

B.Tech (Electronics and Communication)
Semester-IV

Hardik Prajapati

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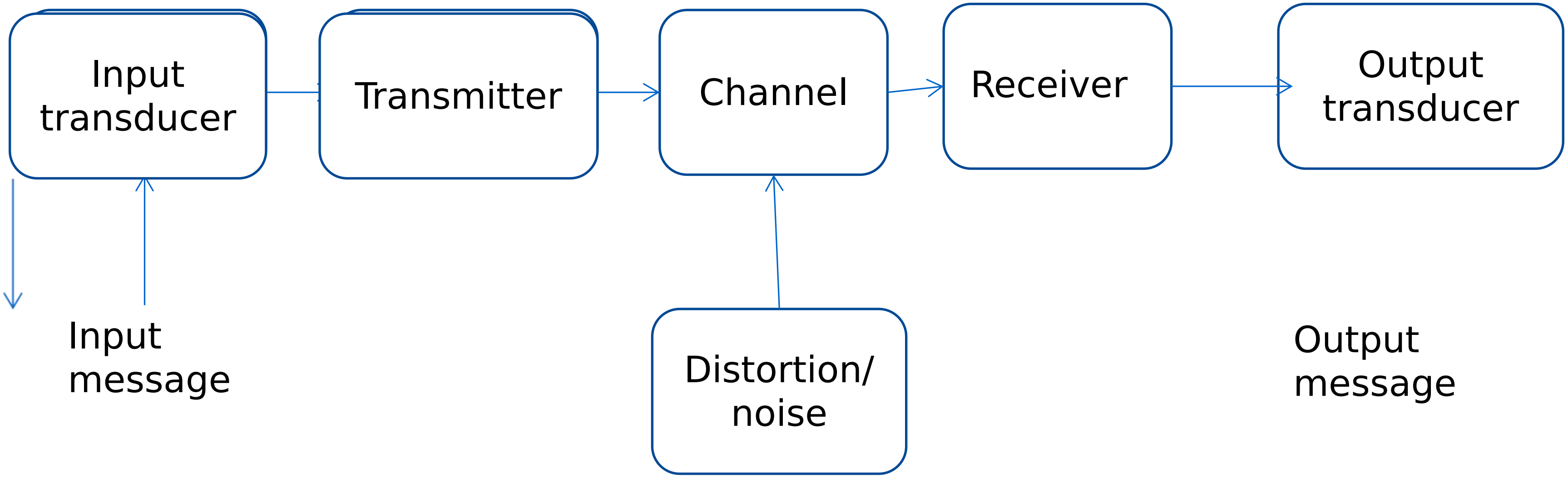
Communication System

- The study of communication system is divided into two types:

- How communication system works?
- How they perform in the presence of noise.?



Input transducer

Transmitter

Channel

Receiver

Output transducer

Input message

Distortion/ noise

Output message

Some basic and important parameters

- Source(i/p message)
- Input Transducer
- Transmitter
- Channel
- Receiver
- Output transducer
- Distortion: linear & nonlinear distortion
- Noise
- Attenuation
- SNR: signal power/noise power

- Bandwidth is defined as the portion of electromagnetic spectrum occupied by a signal
- It may also define as the frequency range over which an information signal is transmitted.
- Bandwidth is the difference between upper & lower frequency limits of the signal.

- Data Rate: The data rate/ Bit rate is a term to denote the transmission speed, or the number of bits per second transferred.
- In telecommunications, it is common use to express the data rate in bits per seconds (bit/s),
- In data communication, the data rate is often expressed in bytes per second (B/s).
- The term bit rate is a synonym for data transfer rate(or simply data rate)

Signal to Noise ratio(SNR)

Signal to Noise ratio(SNR) is defined as the ratio of signal power to the noise power corrupting the signal.

SNR = average signal power/average noise power

Because many signals have a very wide dynamic range, SNRs are often expressed using the logarithmic decibel scale

$$\mathrm{SNR}_{\mathrm{dB}} = 10 \log_{10}\left(\frac{P_{\mathrm{signal}}}{P_{\mathrm{noise}}}\right)$$

High SNR means the signal is less corrupted by noise

Channel Bandwidth

- **Channel Bandwidth** – the range of signal bandwidths allowed by a communication channel without significant loss of energy (attenuation).
- **Channel Capacity** or **Maximum Data rate** – the maximum rate (in bps) at which data can be transmitted over a given communication link, or channel or Channel capacity is the maximum no. of binary symbols that can be transmitted per second with a probability of error arbitrarily zero

Channel Bandwidth

- Nyquist's formulae for multi-level signaling for a noiseless channel is

C = 2 * B * log M,

- where C is the channel capacity in bits per second, B is the maximum bandwidth allowed by the channel, M is the number of different signaling values or symbols and log is to the base 2.
- For example, assume a noiseless 3-kHz channel.
- If binary signals are used, then M= 2 and hence maximum channel capacity or achievable data rate is C = 2 * 3000 * log 2 = 6000 bps.
- Similarly, if QPSK is used instead of binary signaling, then M = 4. In that case, the maximum channel capacity is C = 2 * 3000 * log 4 = 2 * 3000 * 2 = 12000bps.
- For noisy channel ,Shannon capacity

$C = B \log_2 (1+SNR)$ bps

Channel Bandwidth

- For example, for a channel with bandwidth of 3 KHz and with a S/N value of 1000, like that of a typical telephone line, the maximum channel capacity is

$C = 3000 * \log (1 + 1000) = 30000$ bps (approx.)

- Assume that $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. Calculate theoretical channel capacity.

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

The signal-to-noise ratio is often given in decibels. Assume that $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$\mathrm{SNR}_{\mathrm{dB}} = 10 \log_{10} \mathrm{SNR} \rightarrow \mathrm{SNR} = 10^{\mathrm{SNR}_{\mathrm{dB}}/10} \rightarrow \mathrm{SNR} = 10^{3.6} = 3981$$

$$C = B \log_2 (1+ \mathrm{SNR}) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

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

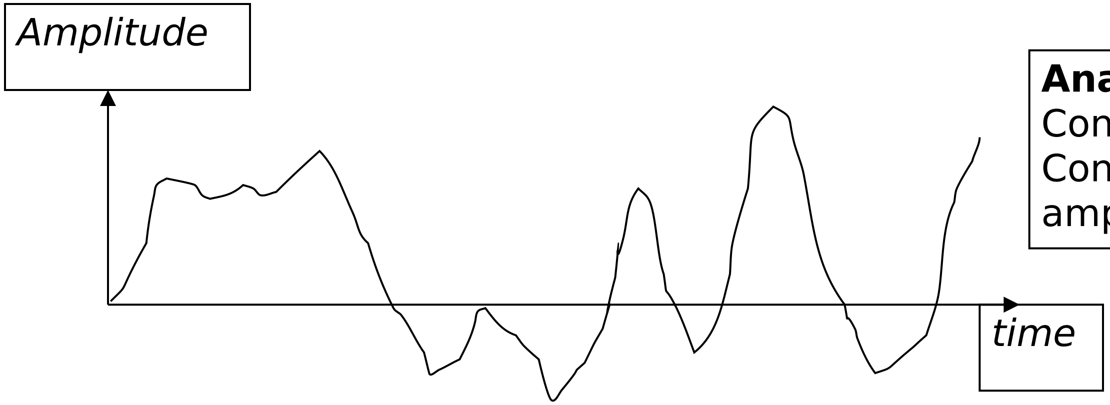
Solution

The values of SNR and SNR_{dB} can be calculated as follows:

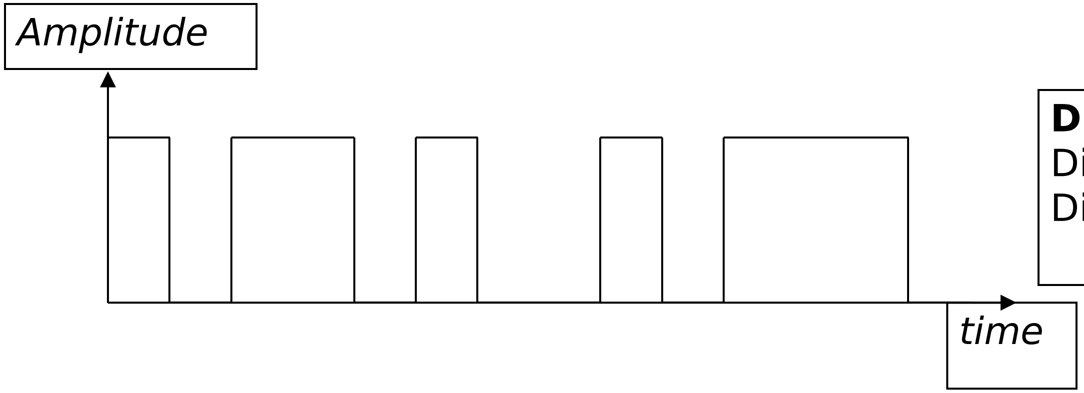
$$\mathrm{SNR} = \frac{10{,}000\ \mu\mathrm{W}}{1\ \mathrm{mW}} = 10{,}000$$

$$\mathrm{SNR}_{\mathrm{dB}} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

Analog and Digital signals



Analog signal
Continuous time
Continuous amplitude



Digital signal
Discrete time,
Discrete amplitude

Advantages of Digital over Analog

- Digital signals can be regenerated
- Digital modulators are more power and bandwidth efficient
- Efficient trade-off between power and bandwidth
- Signal compression
- Error detection and correction
- Common signal format for all types of signals
- Technology offers design flexibility and miniaturization through VLSI, DSP etc.

Disadvantages of Digital communication

- Because of analog to digital conversion, the data rate becomes high. Hence more transmission bandwidth is required for Digital communication.
- Digital communication needs synchronization

Regeneration of digital signal

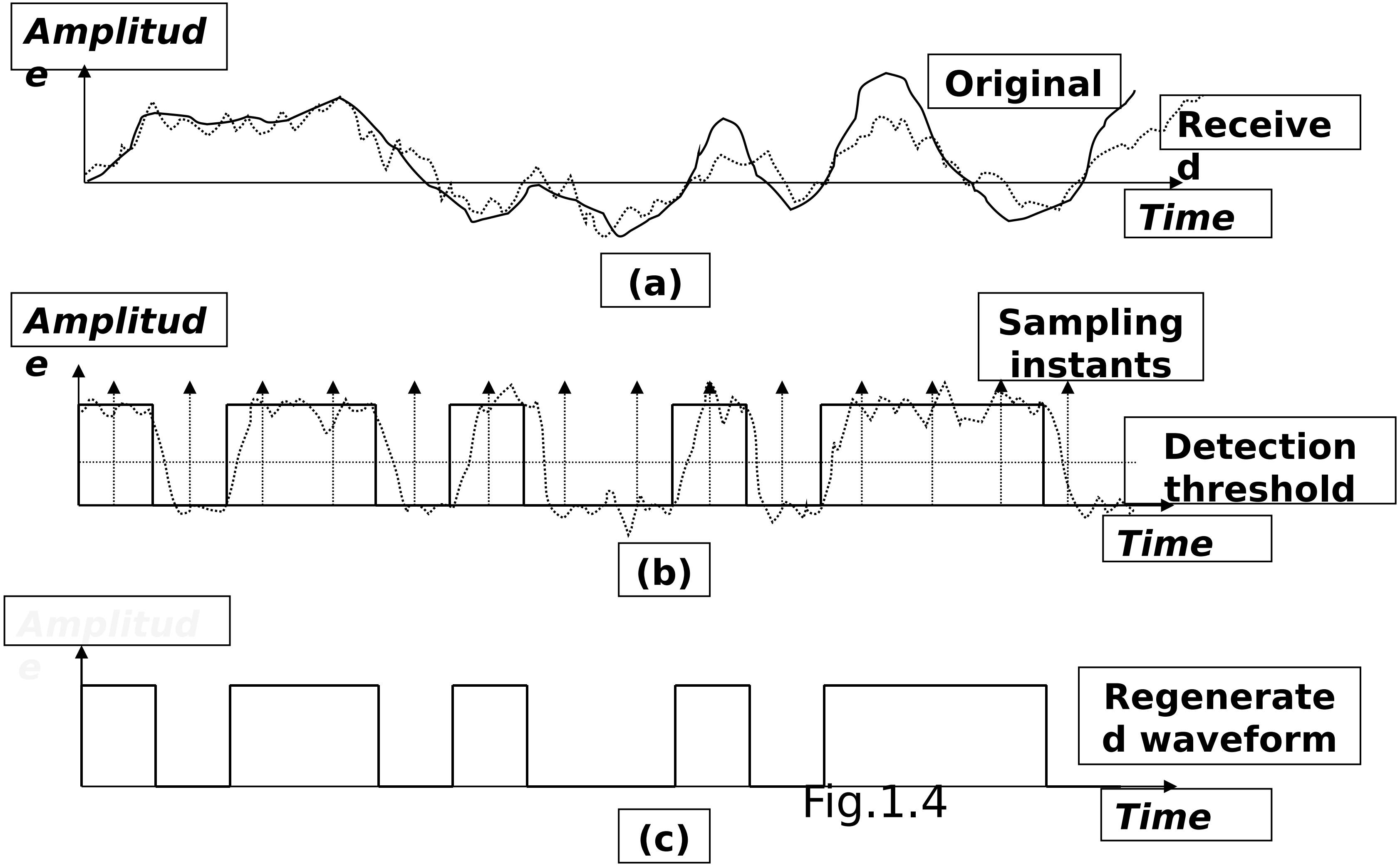


Fig.1.4

Performance of digital systems

Digital circuits, being switching circuits, consume less power

Digital circuit behavior is less susceptible to variations in power supply, temperature, ageing and tolerance in component values

Behavior of digital systems is easily predictable, hence, systems are more reliable

Digital systems are easy to design with many design tools available

Digital circuits are more dense and hence, systems can be compact

Modulation

- Modulation is a way of sending signals of low frequency over long distances without a huge loss of energy by the use of another wave of very high frequency called a carrier wave.

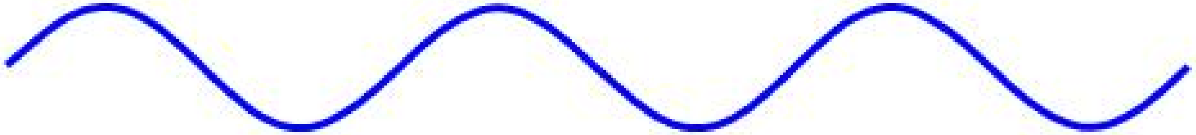


Figure 1

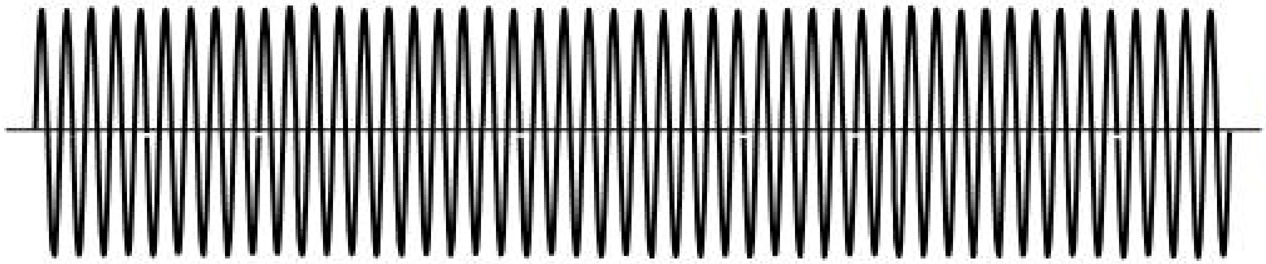


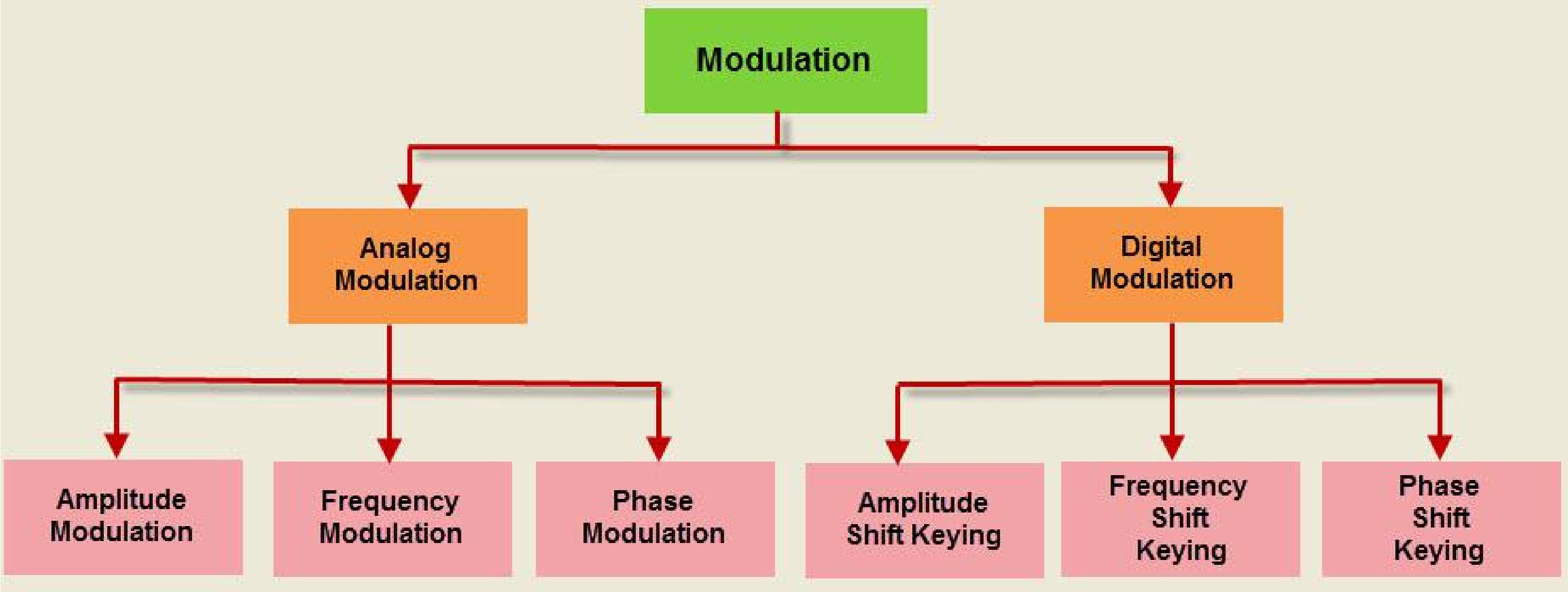
Figure 2

- To remove Interference
- Antenna Size
- Reduction of Noise

Advantages of Modulation

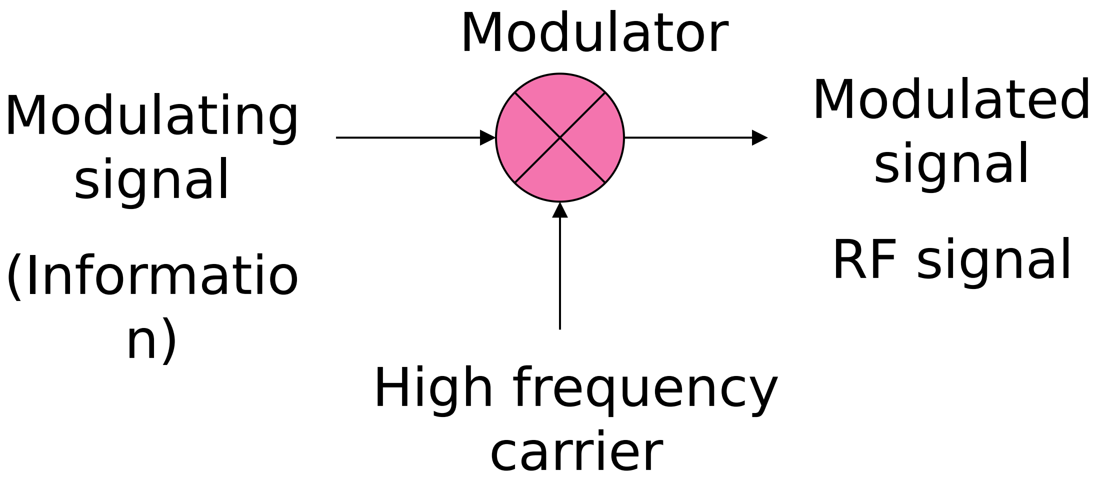
- Reduction in the height of antenna
- Avoids mixing of signals
- Increases the range of communication
- Multiplexing is possible
- Improves quality of reception

Classification of Modulation Methods



Principles of Amplitude Modulation

- A process in which the amplitude of a high frequency carrier signal is varied in proportion to the instantaneous amplitude of the modulating signal
- Obtained by multiplying carrier (high frequency) with the modulating signal (low frequency) using a mixer, multiplier or modulator



Modulator

Modulating signal

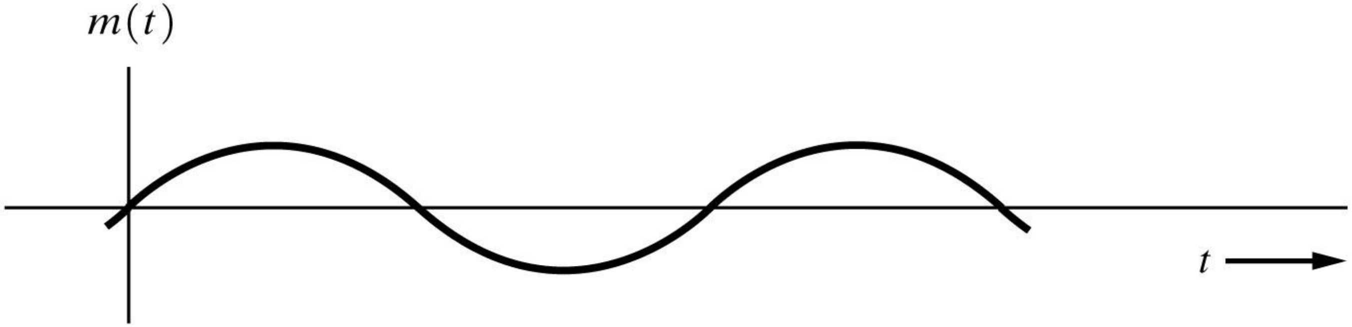
(Information)

Modulated signal

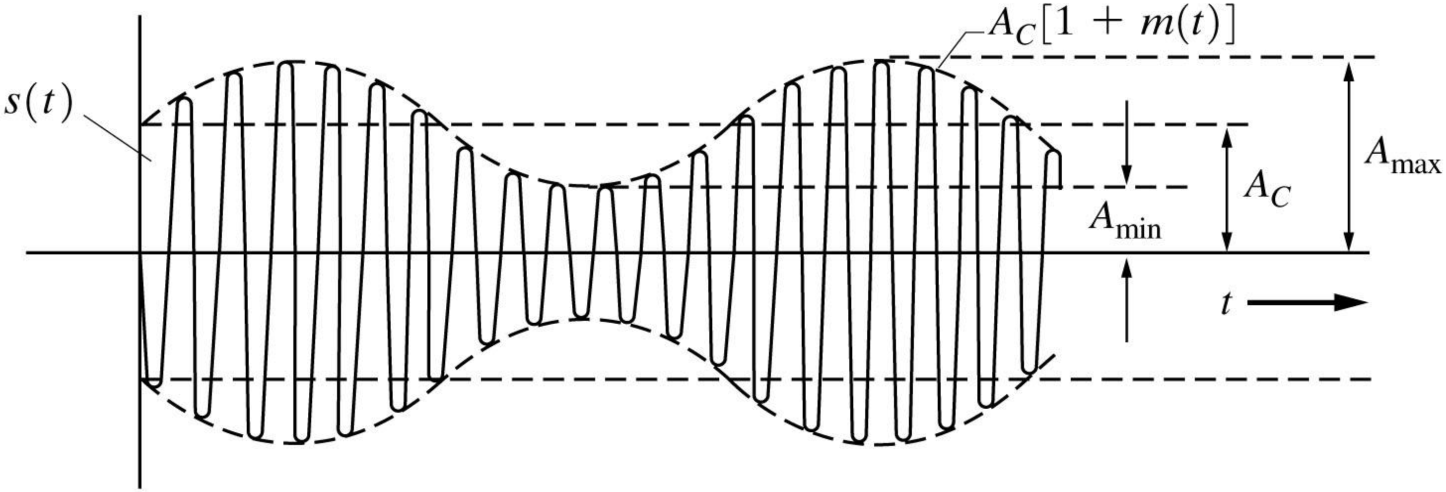
RF signal

High frequency carrier

AM Signal Waveform



(a) Sinusoidal Modulating Wave



(b) Resulting AM Signal

Amplitude Modulation Theory

- Assume a sinusoidal modulating signal

$$\text{Modulating signal} \quad v_m(t) = V_m \cos(2\pi f_m t)$$

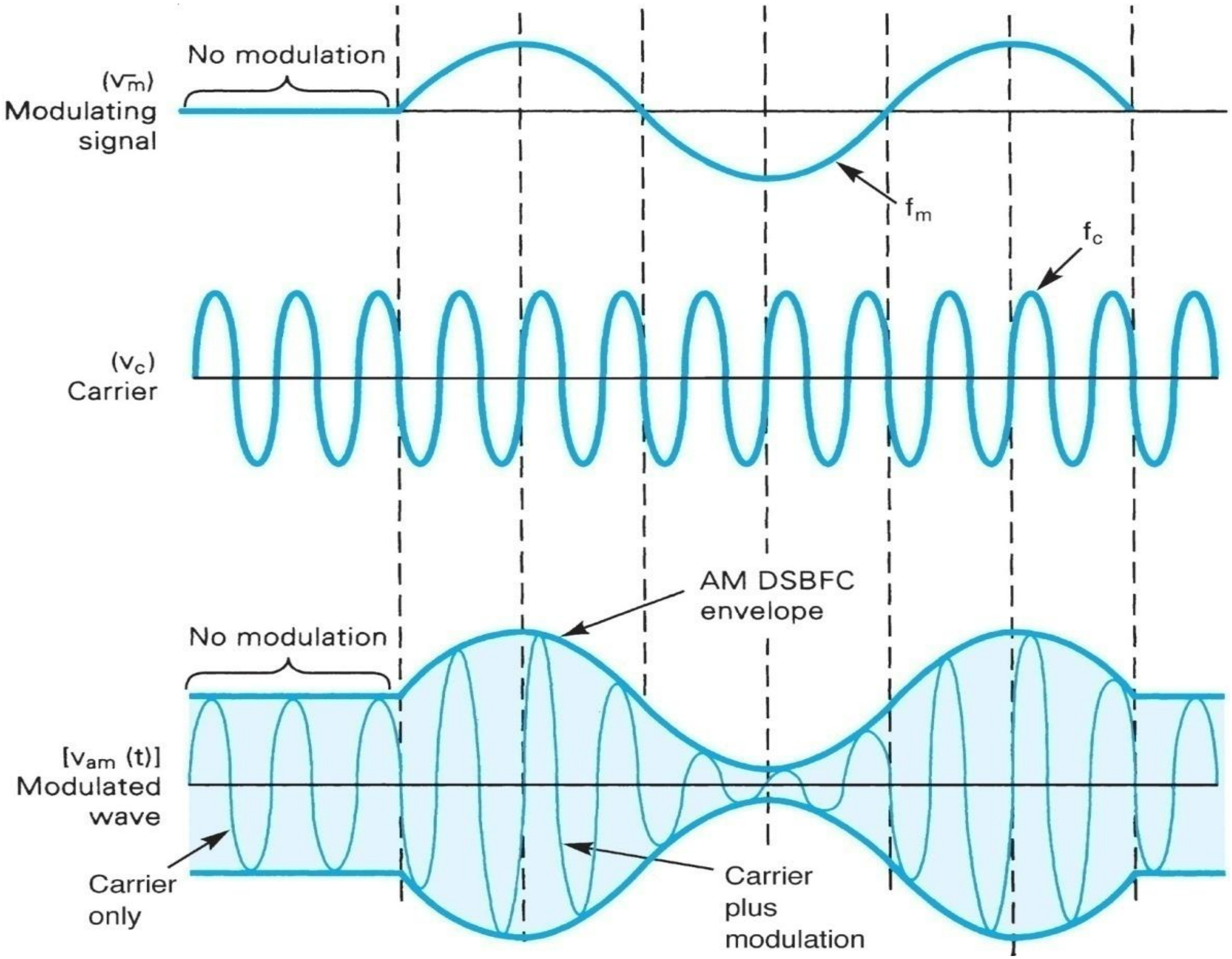
$$\text{Carrier signal} \quad v_c(t) = V_c \sin(2\pi f_c t)$$

$$\begin{aligned}
\text{Modulated signal} \quad v_{am}(t) &= v_m(t) v_c(t) \\
&= V_m \cos(2\pi f_m t) V_c \sin(2\pi f_c t) \\
&= V_m V_c \cos(2\pi f_m t) \sin(2\pi f_c t) \\
&= \frac{V_m V_c}{2} \left[\sin(2\pi(f_c + f_m)t) + \sin(2\pi(f_c - f_m)t) \right]
\end{aligned}$$

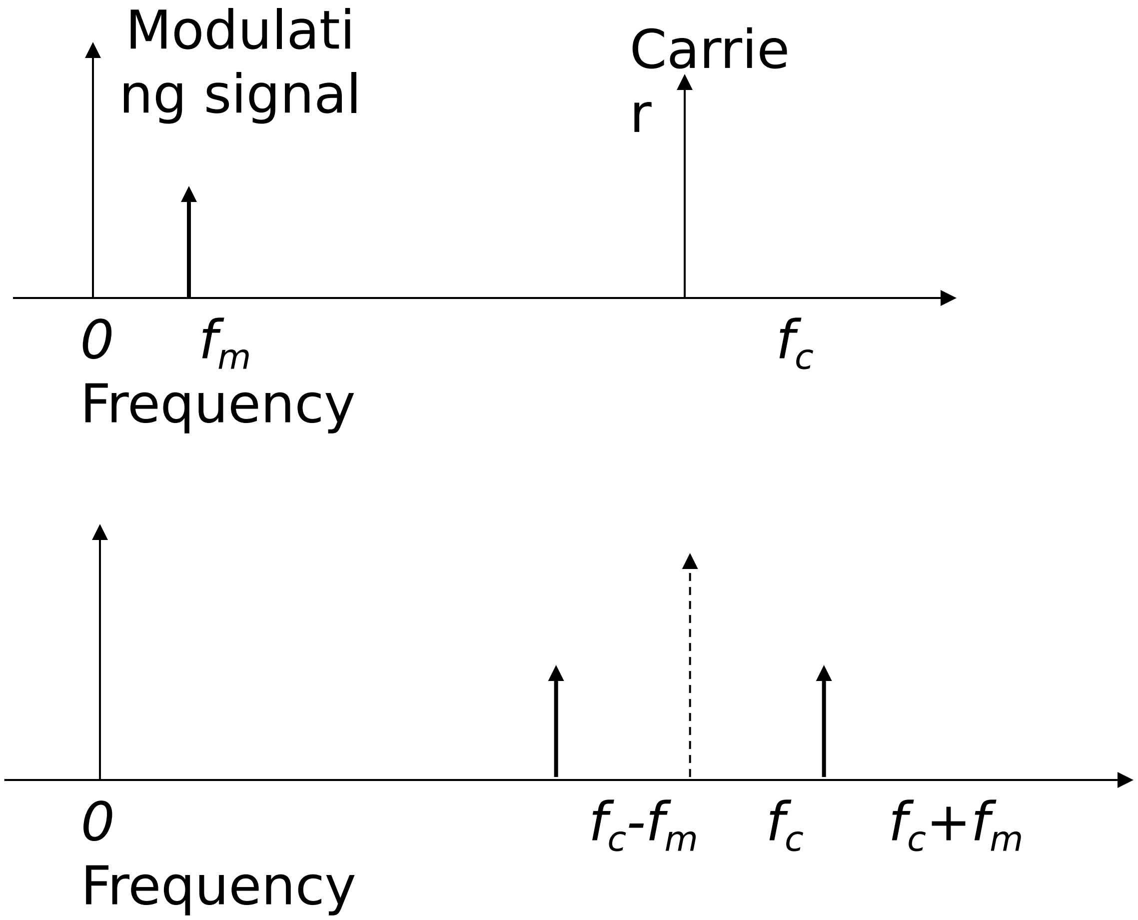
- The modulating signal shows two frequency components around the carrier frequency, separated by the modulating signal frequency

$(f_c + f_m)$ and $(f_c - f_m)$

Amplitude Modulation Waveform



AM Spectrum with single frequency modulation



Modulating signal

Carrier

0 f_m

f_c

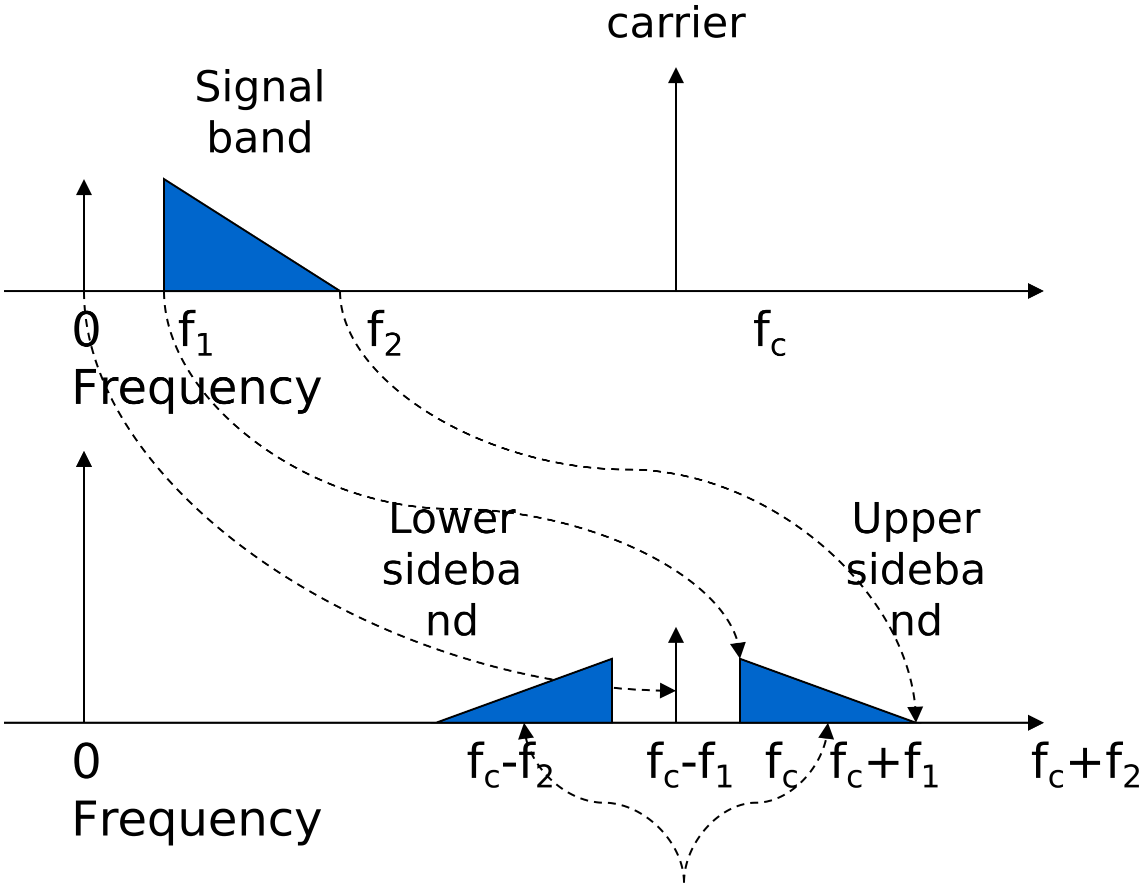
Frequency

0

f_c-f_m f_c f_c+f_m

Frequency

AM Spectrum with a modulation band



carrier

Signal band

0 f_1 f_2 f_c

Frequency

Lower sideband

Upper sideband

0 f_c-f_2 f_c-f_1 f_c f_c+f_1 f_c+f_2

Frequency

Mirror images around carrier

Modulation Index

- Also known as coefficient of modulation, describes the depth of modulation

$$m = E_m / E_c$$

$$\text{where } m = \text{modulation index}$$

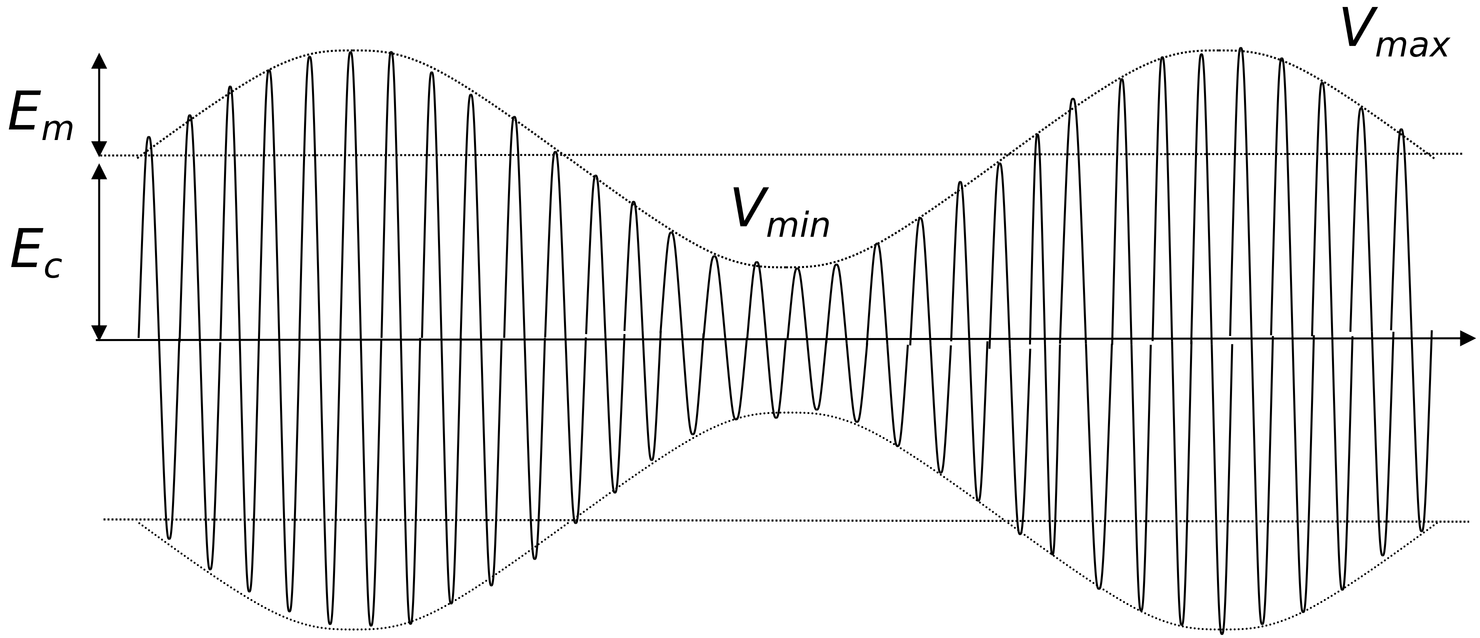
$$E_m = \text{peak amplitude of the modulating signal}$$

$$E_c = \text{peak amplitude of the unmodulated carrier}$$

Percentage modulation

$$\mathrm{M} = \left(E_m / E_c\right) \times 100\% = m \times 100\%$$

Modulation coefficient, E_m, and E_c

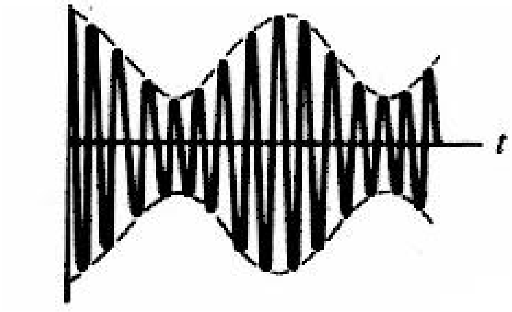


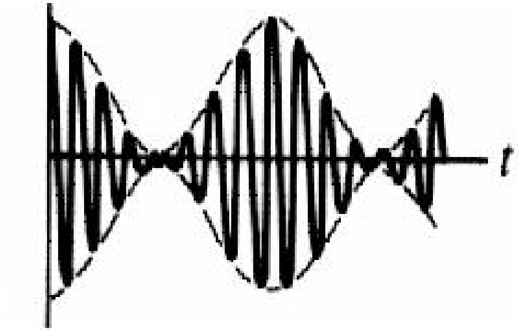
$E_c / E_m = m$,

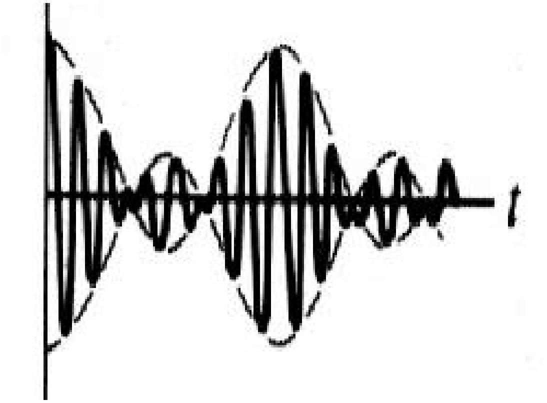
$V_{max} = (E_c + E_m) = E_c (1 + m)$,

$V_{min} = (E_c – E_m) = E_c (1 - m)$

AM – Percentage Modulation







Under modulated (<100%)

100% modulated

Over Modulated (>100%)

Envelope Detector

Can be used

Envelope Detector

Gives Distorted signal

Sideband Amplitudes

$$E_m = \frac{1}{2}\left(V_{\max} - V_{\min}\right)$$

$$E_c = \frac{1}{2}\left(V_{\max} + V_{\min}\right)$$

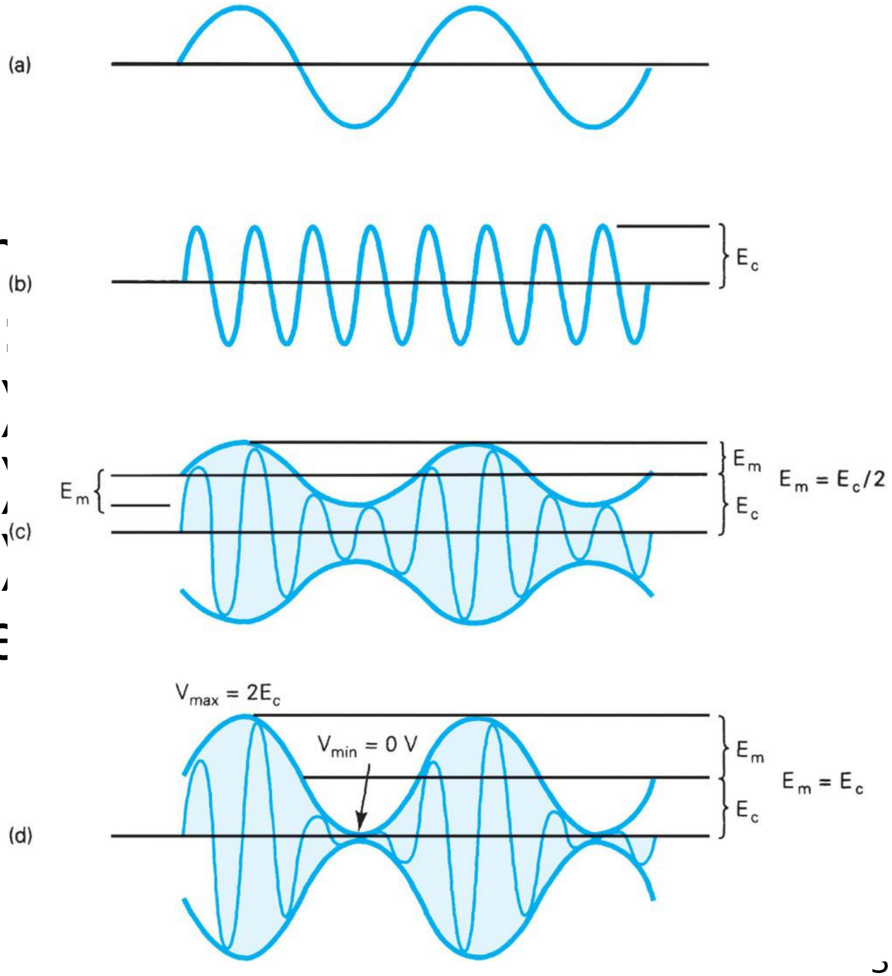
$$m = \frac{\frac{1}{2}\left(V_{\max} - V_{\min}\right)}{\frac{1}{2}\left(V_{\max} + V_{\min}\right)} = \frac{\left(V_{\max} - V_{\min}\right)}{\left(V_{\max} + V_{\min}\right)}$$

$$E_m = E_{usf} + E_{lsf}$$

$$E_{usf} = E_{lsf} = E_m / 2 = \frac{1}{4}\left(V_{\max} - V_{\min}\right)$$

The sidebands have half the modulating signal amplitude

Percent modulation of an AM DSBFC envelope: (a) modulating signal; (b) unmodulated carrier; (c) 50% modulated wave; (d) 100% modulated wave



AM Voltage distribution

When a carrier $v_c(t) = E_c \sin(2\pi f_c t)$ is modulated by $E_m \sin(2\pi f_m t)$

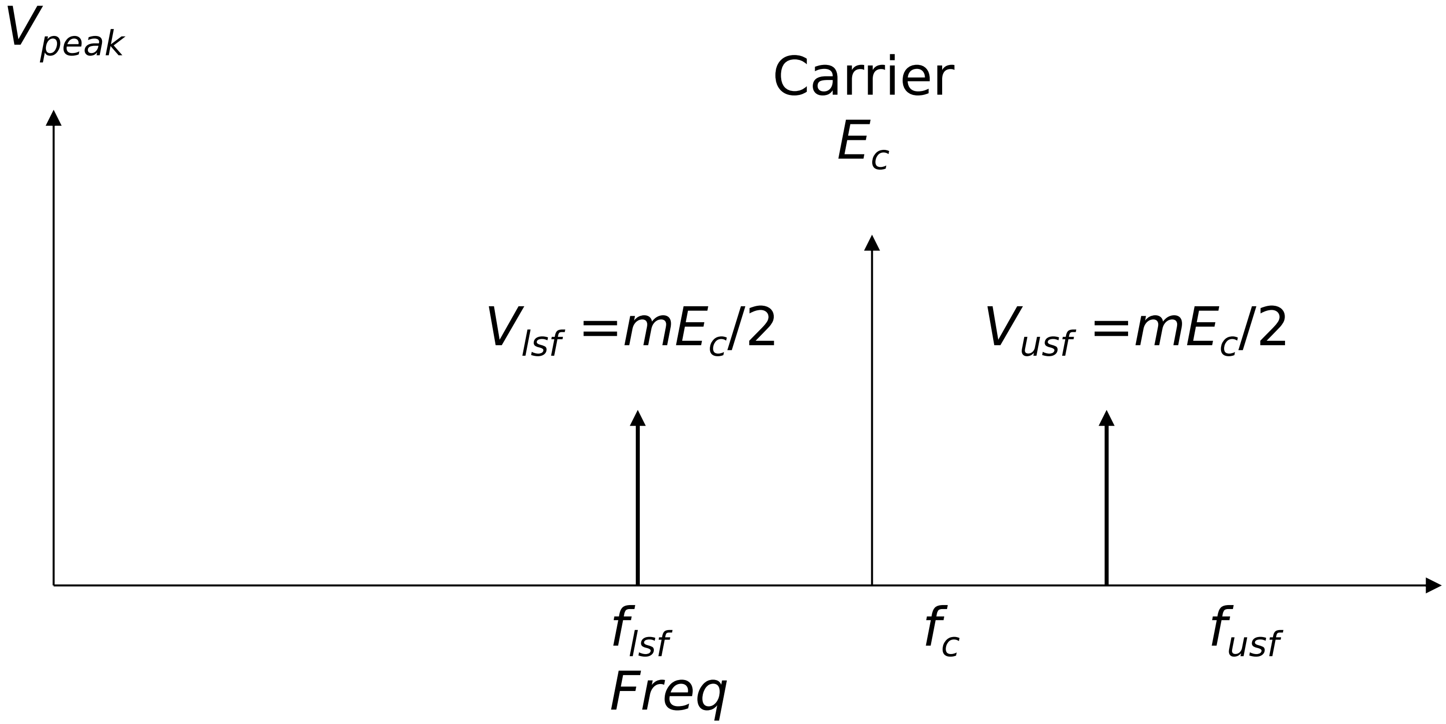
Peak amplitude of modulated carrier is

$$E_{am} = E_c + E_m \sin(2\pi f_m t)$$

$$\begin{aligned} v_{am}(t) &= \left[E_c + E_m \sin(2\pi f_m t)\right]\sin(2\pi f_c t) \\ &= \left[E_c + mE_c \sin(2\pi f_m t)\right]\sin(2\pi f_c t) \\ &= [1 + \underbrace{m\sin(2\pi f_m t)]}_{\text{modulating signal}}\underbrace{E_c \sin(2\pi f_c t)}_{\text{unmodulated carrier}} \\ &= E_c \sin(2\pi f_c t) + m\sin(2\pi f_m t)E_c \sin(2\pi f_c t) \\ &= E_c \sin(2\pi f_c t) + mE_c\left[\sin(2\pi f_c t)\sin(2\pi f_m t)\right] \\ &= E_c \sin(2\pi f_c t) + \frac{mE_c}{2}\cos[2\pi(f_c - f_m)t] - \frac{mE_c}{2}\cos[2\pi(f_c + f_m)t] \end{aligned}$$

Carrier Lower side frequency Upper side frequency

Voltage spectrum for an AM DSBFC wave



V_{peak}

Carrier

E_c

$V_{lsf} = mE_c/2$

$V_{usf} = mE_c/2$

f_{lsf}

f_c

f_{usf}

Freq

Power Spectrum of AM-DSB

Power in the carrier across 1 Ω resistance is $P_c = (E_c/\sqrt{2})^2 = \frac{E_c^2}{2}$

Power in the upper and lower sidebands across 1 Ω resistance is

$$P_{usb} = P_{lsb} = \frac{1}{2}\left(\frac{E_m}{2}\right)^2 = \frac{1}{2}\left(\frac{mE_c}{2}\right)^2 = \frac{m^2E_c^2}{8}$$

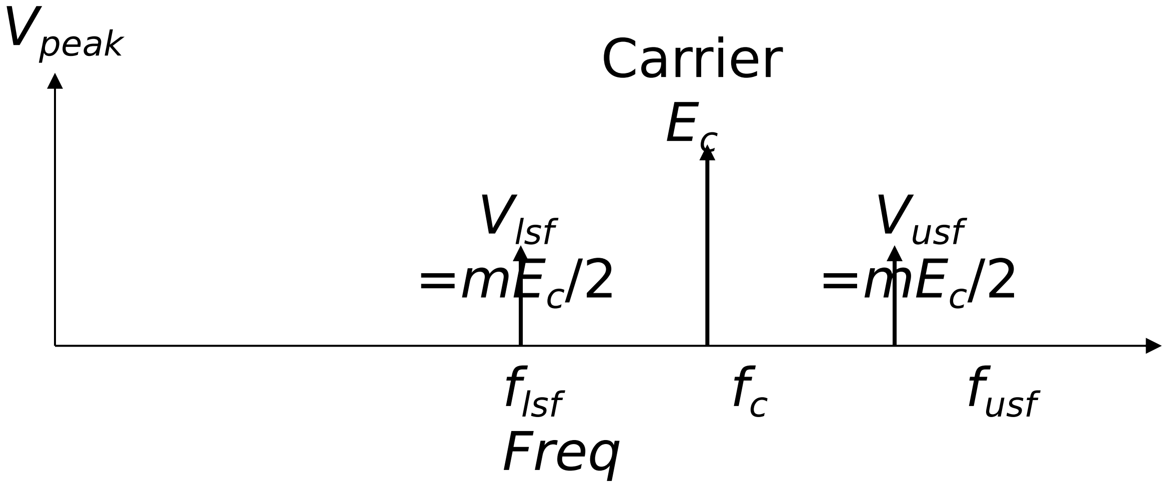
Total power in the modulated signal across 1 Ω resistance is

$$P_t = P_c + P_{usb} + P_{lsb} = \frac{E_c^2}{2} + \frac{m^2E_c^2}{8} + \frac{m^2E_c^2}{8}$$

$$= \frac{E_c^2}{2} + \frac{m^2E_c^2}{4} = \frac{E_c^2}{2}\left(1 + \frac{m^2}{2}\right)$$

$$= P_c\left(1 + \frac{m^2}{2}\right)$$

AM-DSB: Voltage and Power Spectra



V_{peak}

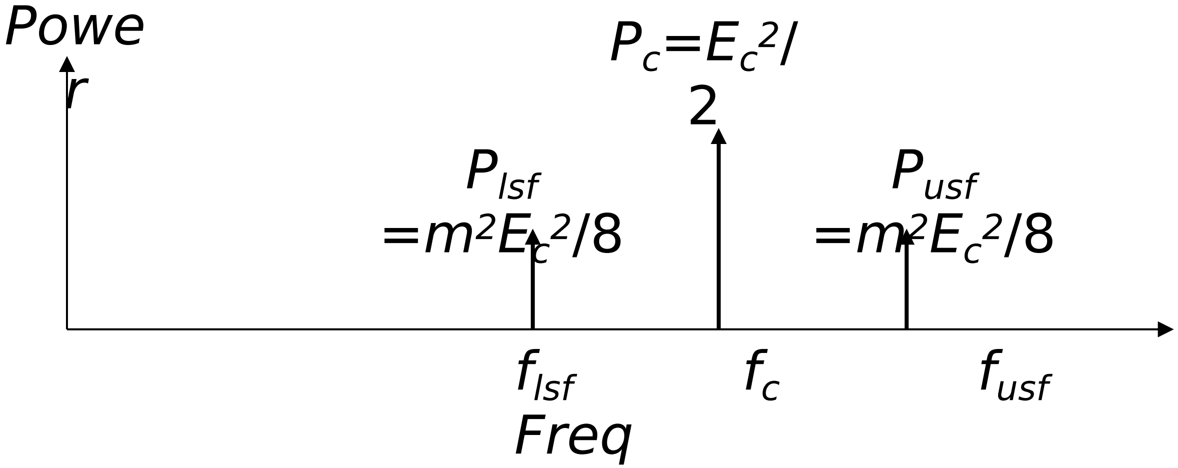
Carrier E_c

$V_{lsf} = mE_c/2$

$V_{usf} = mE_c/2$

f_{lsf} f_c f_{usf}

Freq



Power

$P_c = E_c^2/2$

$P_{lsf} = m^2E_c^2/8$

$P_{usf} = m^2E_c^2/8$

f_{lsf} f_c f_{usf}

Freq

Sideband Amplitudes

$$E_m = \frac{1}{2}\left(V_{\max} - V_{\min}\right)$$

$$E_c = \frac{1}{2}\left(V_{\max} + V_{\min}\right)$$

$$m = \frac{\frac{1}{2}\left(V_{\max} - V_{\min}\right)}{\frac{1}{2}\left(V_{\max} + V_{\min}\right)} = \frac{\left(V_{\max} - V_{\min}\right)}{\left(V_{\max} + V_{\min}\right)}$$

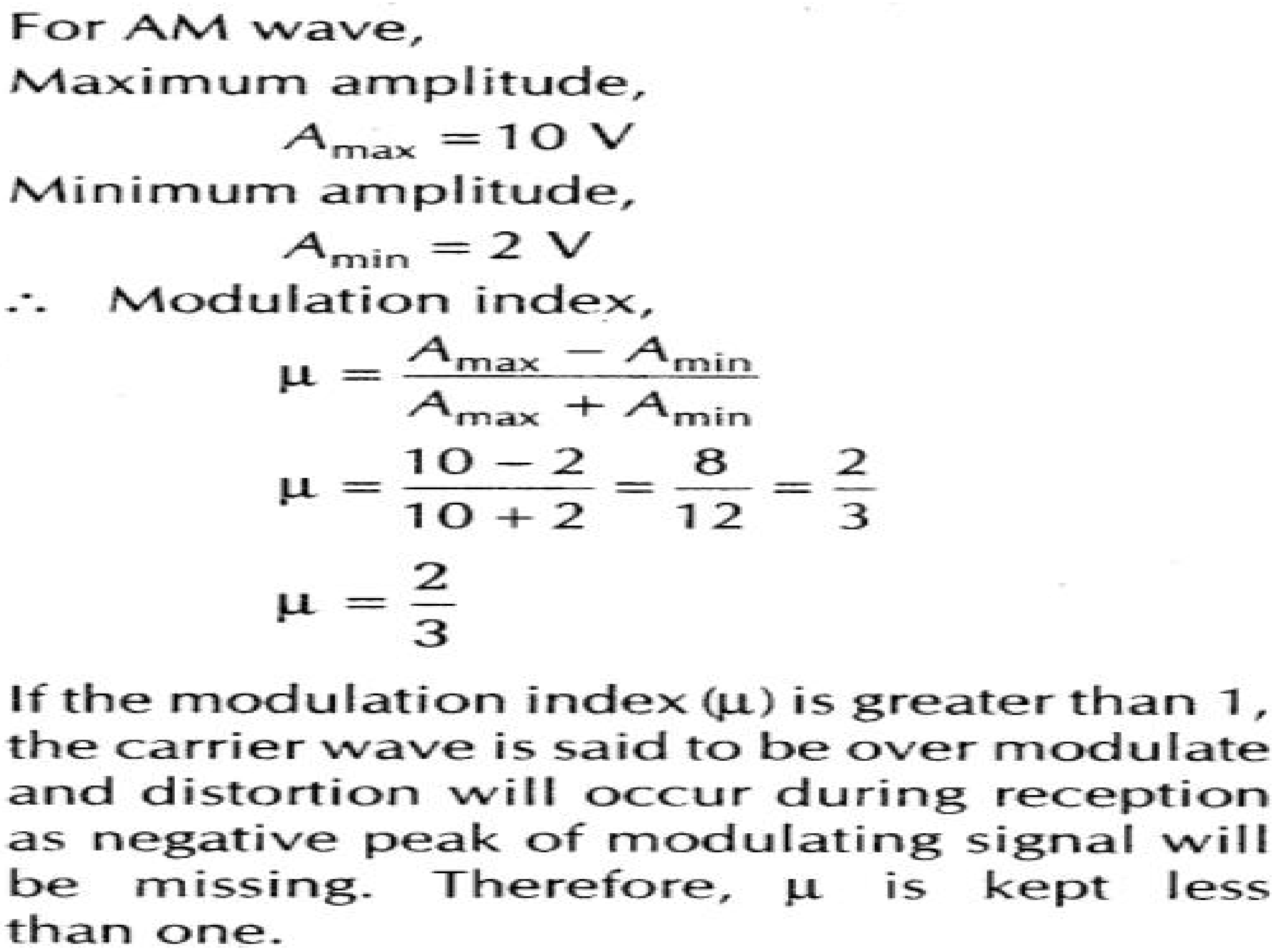
$$E_m = E_{usf} + E_{lsf}$$

$$E_{usf} = E_{lsf} = E_m / 2 = \frac{1}{4}\left(V_{\max} - V_{\min}\right)$$

Amplitude Modulation

- The tuned circuit of the oscillator in a simple AM transmitter employs a 40µH coil & 12nF capacitor. If the oscillator output is modulated by audio frequency of 5KHz, what are the lower and upper sideband frequencies and the bandwidth required to transmit the AM wave? (235K,225K, 10KHz)
- Calculate the modulation index & percentage modulation if instantaneous voltages of modulating signal and carrier are 40 sinw_mt & 50sinw_ct .

  (80%)



For AM wave,

Maximum amplitude,

$$A_{max} = 10 \text{ V}$$

Minimum amplitude,

$$A_{min} = 2 \text{ V}$$

$\therefore$ Modulation index,

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

$$\mu = \frac{10 - 2}{10 + 2} = \frac{8}{12} = \frac{2}{3}$$

$$\mu = \frac{2}{3}$$

If the modulation index (μ) is greater than 1, the carrier wave is said to be over modulate and distortion will occur during reception as negative peak of modulating signal will be missing. Therefore, μ is kept less than one.

- An audio frequency signal 10 sin2π*500t is used to amplitude modulate a carrier of 50 sin2π*10^5t. Calculate

(i) Modulation Index (20%)

(ii) Sideband frequencies (100,99K)

(iii) Amplitude of each sideband frequencies (5V)

(iv) Bandwidth required (1K)

- A broadcast transmitter radiates 20 kw when the modulation percentage is 75. calculate carrier power & carrier current if total power delivered to the load of 600 Ω.
- Calculate total modulation index if the carrier wave is amplitude modulated by three modulating signals with modulation indices 0.6, 0.3 & 0.4 respectively. (0.78)

- The antenna current of an AM transmitter is 8 A if only the carrier is sent, but it increases to 8.93 A, if the carrier is modulated by a single sinusoidal wave. Determine the percentage modulation. Also find the antenna current if the percentage of modulation changes to 0.8 (Ans: m=70%, I=9.19 A)

- A carrier wave is represented by the expression Vc = 10 sin ωt. Draw the waveform of an AM wave for m=0.5

When frequency & phase of the carrier is varied by the modulating signal, then it is called angle modulation.

There are two types of angle modulation
(1) Frequency Modulation (2) Phase modulation

$$
\begin{aligned}
m(t) &= V_c \cos[\omega_c t + \theta(t)] \\
\text{where } \; m(t) &= \text{Angle modulated signal} \\
V_c &= \text{Peak amplitude of carrier (volts)} \\
\omega_{\mathrm{c}} &= \text{Radian frequency of carrier} = 2\pi f_c \\
\theta(t) &= \text{Instantaneous phase deviation}
\end{aligned}
$$

When frequency of the carrier varies as per amplitude variations of modulating signal, then it is called frequency modulation.

When phase of the carrier varies as per amplitude variations of modulating signal, then it is called phase modulation.

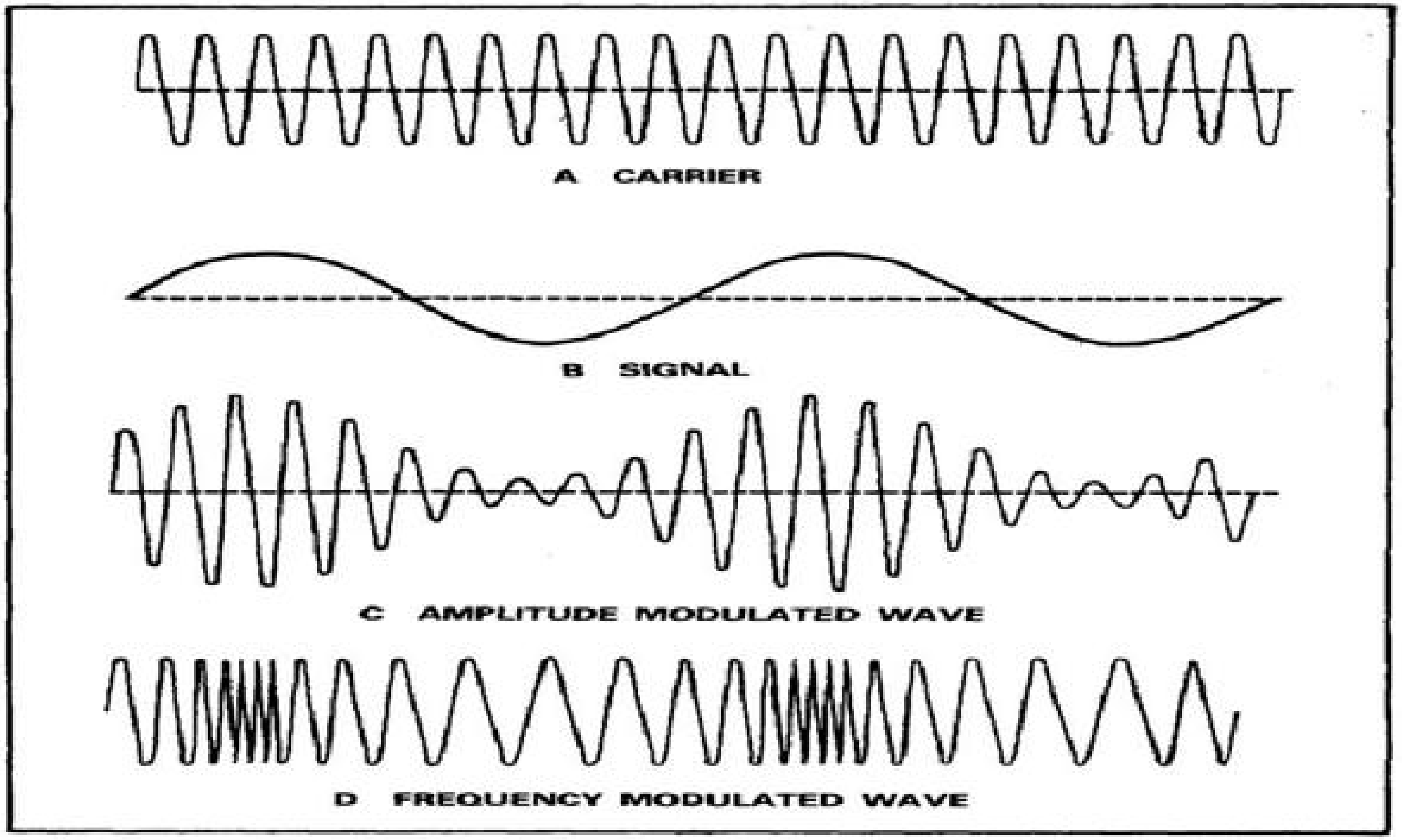
NOTE: in both the cases amplitude of the modulated carrier remains constant

$$m(t) = V_c \cos[\omega_c t + \theta(t)]$$

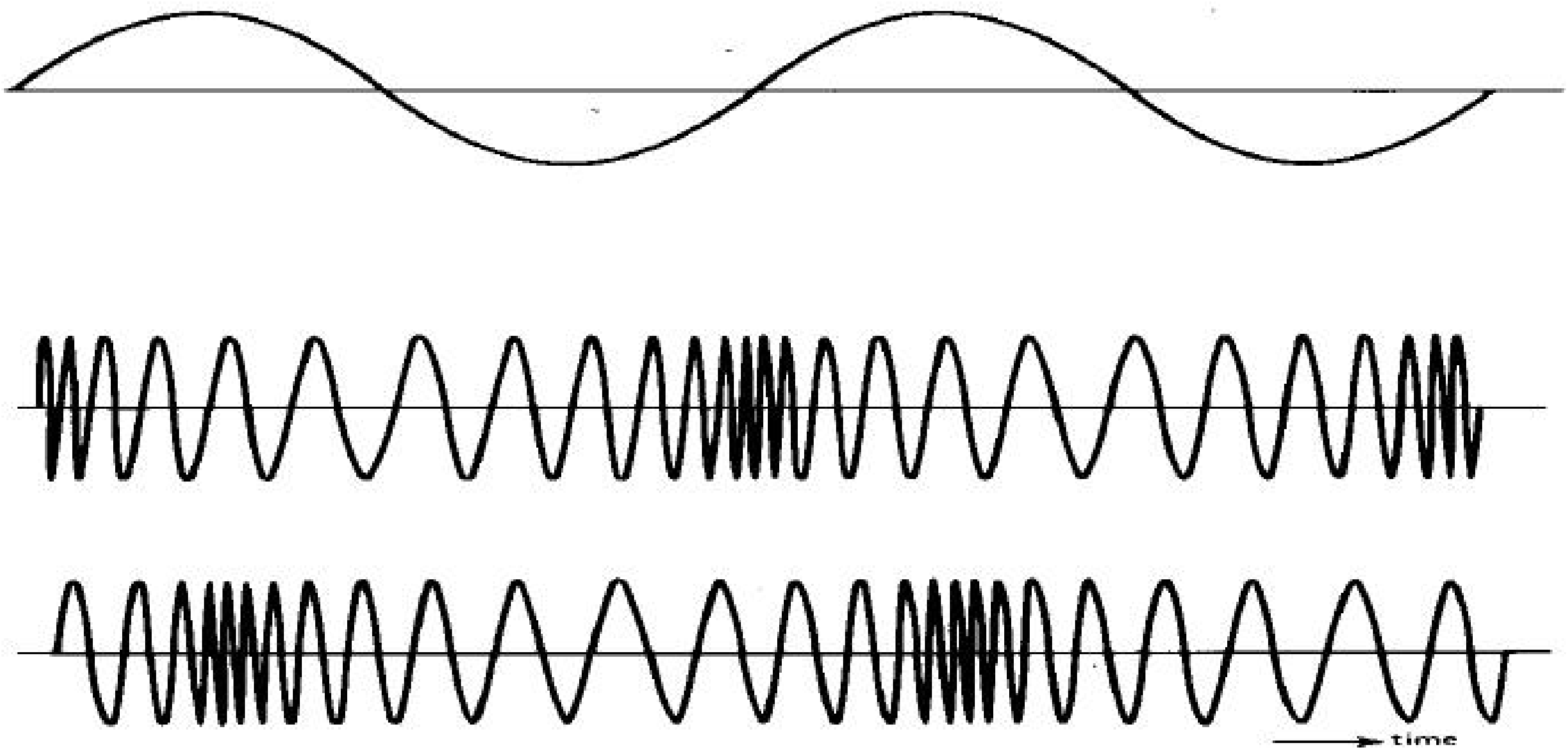
If $v_m(t)$ is the instataneous amplitude of a modulating signal, the angle modulation is expressed as

$\theta(t)$ ⇨ $v_m(t)$

AM and FM


A CARRIER
B SIGNAL
C AMPLITUDE MODULATED WAVE
D FREQUENCY MODULATED WAVE

PM and FM



PM and FM Waveforms with a message signal

FM and PM

For phase modulation $\theta(t) = k_p v_m(t)$

$$m(t)_{pm} = V_c \cos\left[w_c t + q(t)\right]$$

$$= V_c \cos\left[w_c t + k_p v_m(t)\right]$$

$$= V_c \cos\left[w_c t + k_p V_m \cos(w_m t)\right]$$

For frequency modulation $\theta(t) = k_f \odot v_m(t)\,dt$

$$m(t)_{pm} = V_c \cos\left[w_c t + q(t)\right]$$

$$= V_c \cos\left[w_c t + k_f \odot v_m(t)\,dt\right]$$

$$= V_c \cos\left[w_c t + k_f \odot V_m \cos(w_m t)dt\right]$$

$$= V_c \cos \begin{array}{c}\not\supset\\ \subseteq\\ \supseteq\end{array} w_c t + \frac{k_f V_m}{w_m} \sin(w_m t) \begin{array}{c}\vdots\\ \cdots\\ \iddots\end{array}$$

Phase deviation & modulation index (PM)

$$
\begin{aligned}
m(t)_{pm} &= V_c \cos\left[w_c t + k_p V_m \cos(w_m t)\right] \\
&= V_c \cos\left[w_c t + m_p \cos(w_m t)\right]
\end{aligned}
$$

$$
\begin{aligned}
\text{where } m_p &= k_p V_m = \Delta\theta = \text{modulation index} = \text{peak phase deviation (radians)} \\
k_p &= \text{deviation sensitivity (radians per volt)} \\
V_m &= \text{peak amplitude of modulating signal (volts)}
\end{aligned}
$$

The amount by which the carrier frequency is varied from its unmodulated value, called deviation, is made proportional to the instantaneous amplitude of modulating voltage

Modulation index in FM

$$m(t)_{fm} = V_c \cos\left[\omega_c t + \theta(t)\right] = V_c \cos\left[\omega_c t + k_f \int v_m(t)\,dt\right]$$

$$= V_c \cos\left[\omega_c t + k_f \int V_m \cos(\omega_m t)\,dt\right] = V_c \cos\left[\omega_c t + \frac{k_f V_m}{\omega_m} \sin(\omega_m t)\right]$$

$$= V_c \cos\left[\omega_c t + m_f \sin(\omega_m t)\right]$$

$$\text{where} \quad m_f = \frac{k_f V_m}{\omega_m} = \text{modulation index}$$

k_f = deviation sensitivity (Hz/volt)

V_m = peak amplitude of modulating signal (volts)

ω_m = radian frequency (radians/second)

If deviation sensityvity is expressed in Hz/volt

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

Carson's rule for FM Bandwidth

$$B = 2(-f + f_m) = 2f_m(1 + -f/f_m) = 2f_m(1 + m)\ \text{Hz}$$

where

$-f$ = peak frequency deviation (Hz)

f_m = highest modulating signal frequency (Hz)

m = modulation index $= -f / f_m$

Disadvantages of FM compared to AM

- The BW requirement of FM is much larger than AM.
- The FM transmitting and receiving equipments are more complex and costly.
- its area of reception is limited only to LOS, this this is much lower than area covered by AM.

FM & PM

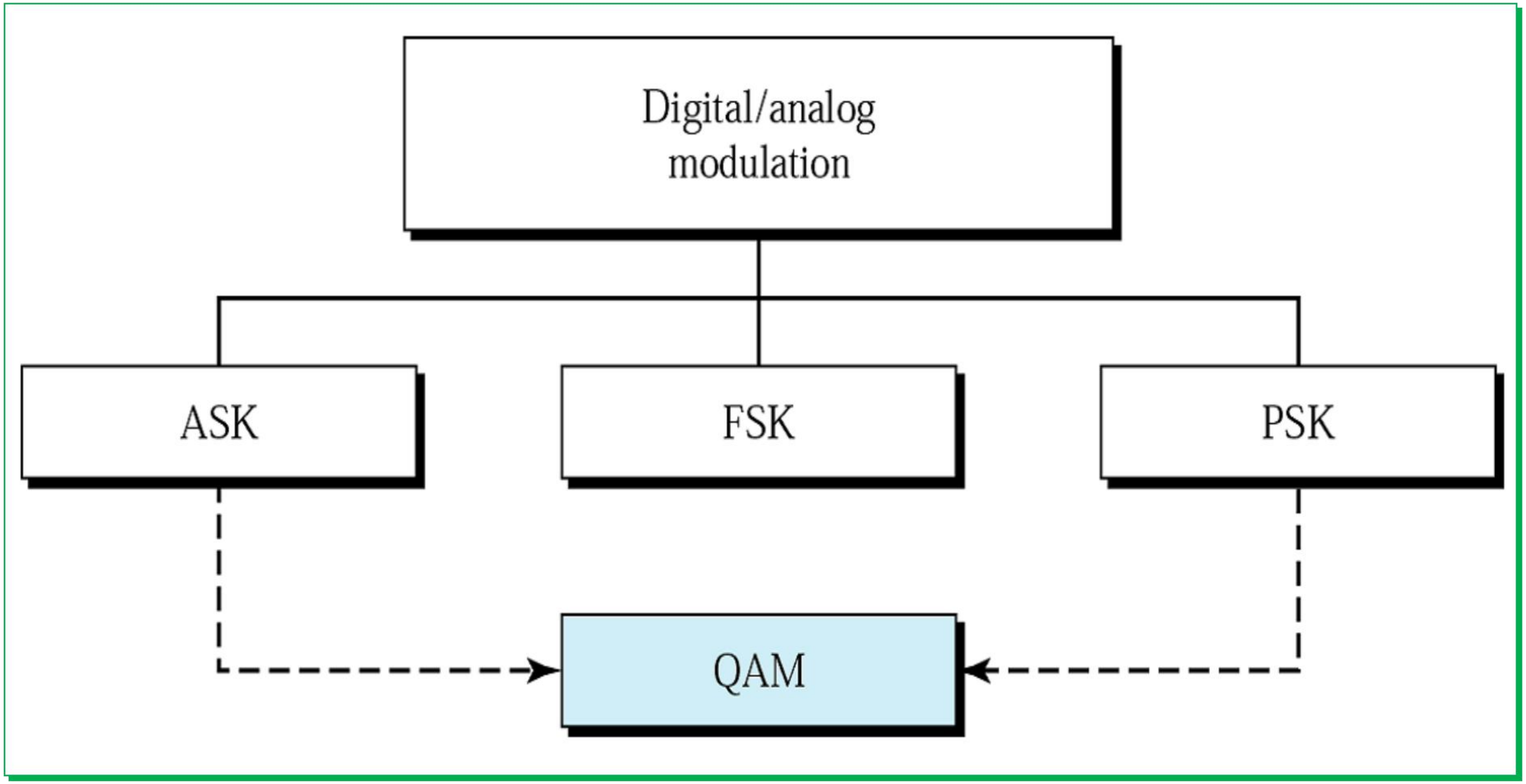
Sr. No.	FM	PM
1	$m(t) = V_c \cos\left[w_c t + m_f \cos(w_m t)\right]$	$m(t) = V_c \cos\left[w_c t + m_p \cos(w_m t)\right]$
2	Frequency deviation is proportional to modulating voltage	Phase deviation is proportional to modulating voltage
3	Associated with the change in carrier frequency, there is some phase change	Associated with the change in phase ,there is some change in carrier frequency
4	Mf is proportional to the modulation voltage as well as the modulating frequency fm	Mf is proportional only to modulating voltage
5	It is possible to receive FM on a PM receiver	It is possible to receive PM on a FM receiver

Sr. No.	FM	PM
6	Noise immunity is better than AM & PM	Noise immunity is better than AM but worst than FM
7	Signal to noise ratio is better than that of PM	Signal to noise ratio is inferior to that in FM
8	FM is widely used	PM is used in some mobile systems
9	Amplitude of FM wave is Constant	Amplitude of the PM wave is Constant
10	The frequency deviation is proportional to the modulating voltage only	The frequency deviation is proportional to both the modulating voltage & Modulating Frequency

AM & FM

Sr. No.	AM	FM
1	Amplitude of carrier is varied according to amplitude of modulating signal	Frequency of the carrier is varied according to amplitude of the modulating signal
2	AM has poor fidelity due to narrow bandwidth	Since the BW is large, fidelity is better
3	Noise interference is more	It is minimum
4	Adjacent interference is present	It is avoided due to wide frequency spectrum
5	Less efficient as most of the power is in carrier.	All the transmitted power is useful

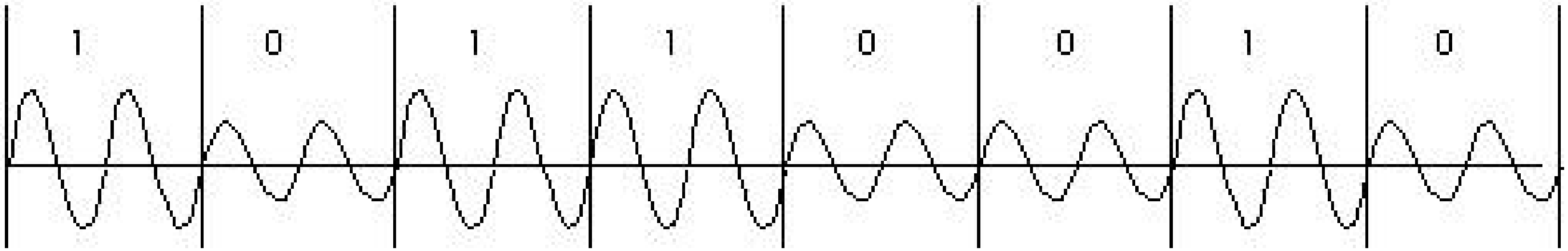
Sr. No.	AM	FM
6	AM broadcast operates in MF & HF range	FM broadcast operates in VHF & UHF
7	In AM only carrier and two sidebands are present	Infinite number of sidebands are present
8	The transmitter equipment is simple	The transmitter equipment is Complex
9	Transmitted power varies according to modulation index	It remains constant irrespective of MI
10	Depth of modulation have limitation, it can not be increased above 1	Depth of modulation have no limitation, it can be increased by increasing frequency deviation.


Digital/analog modulation
ASK
FSK
PSK
QAM

Modulation: Amplitude-Shift Keying (ASK)

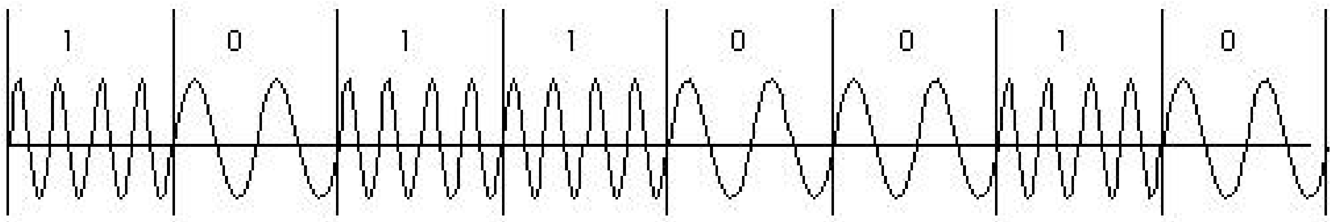
ASK encodes digital data by modulating the carrier's amplitude between two or more levels. Suppose a signal with amplitude 1 represents a binary 0 and a signal with amplitude 2 represents a binary 1. AM is more sensitive to noise than other modulation techniques => AM is not widely used in data transmission

A period is the amount of time before a wave repeats itself.



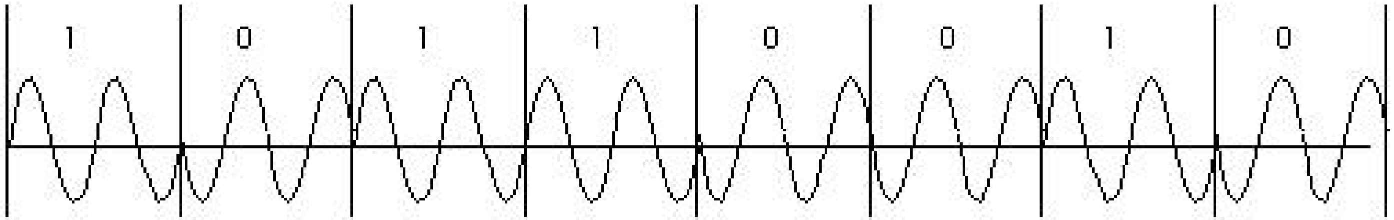
Modulation: Frequency-Shift Keying (FSK)

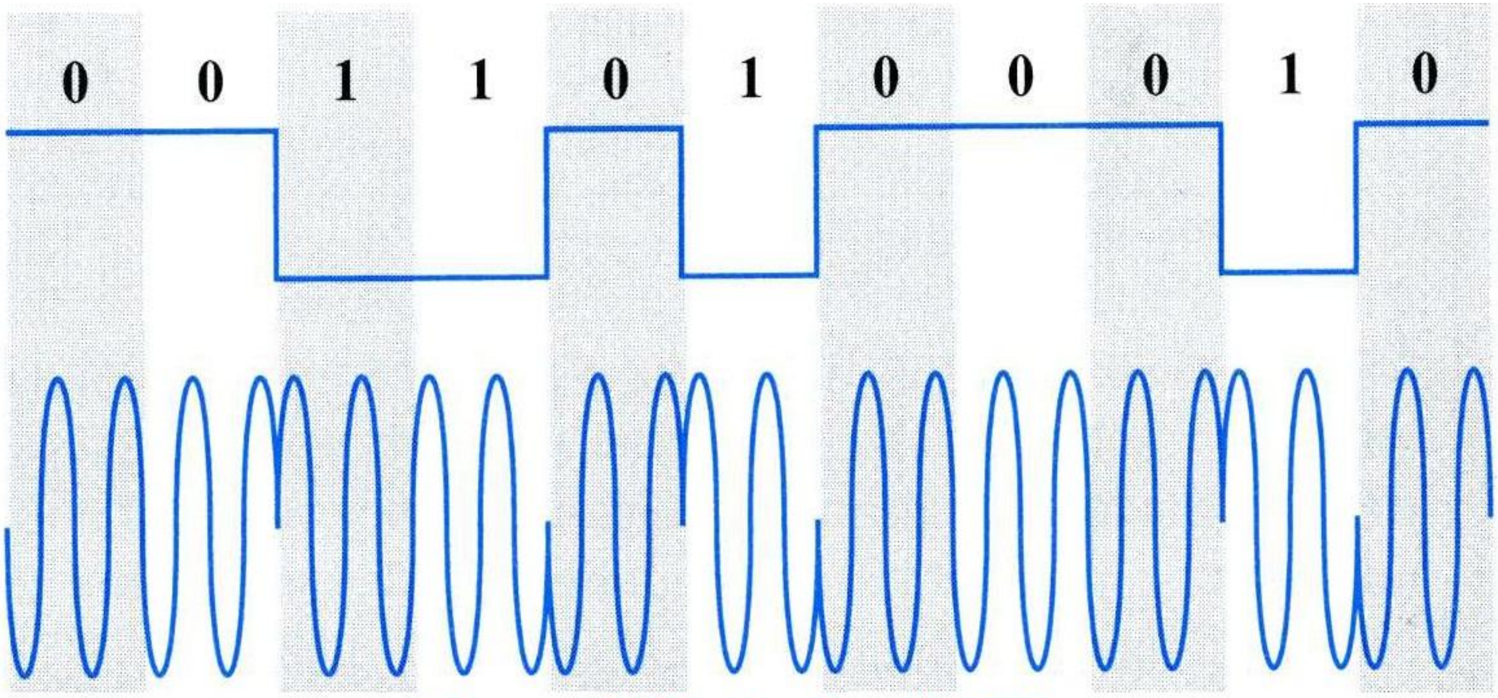
Encodes digital data by modulating the carrier's frequency between two or more values. For example, a binary 0 would be one frequency (or group of frequencies) and a binary 1 would be some other frequency (or group of frequencies). *FSK* is less susceptible to corruption than ASK. Many modems use FSK to convert digital data to analogue signals.



Modulation: Phase-Shift Keying (PSK)

Phase-shift keying encodes digital data by shifting the phase of the carrier. *PSK*-encoded data is highly resistant to corruption.





Phase Shift Keying (PSK)

Or called BPSK, uses two phases to represent 0 & 1