Angle Modulated Systems

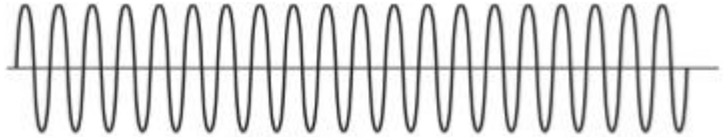
- Angle of carrier signal is changed in accordance with instantaneous amplitude of modulating signal.

- Two types
  - Frequency Modulation (FM)
  - Phase Modulation (PM)

- Use
  - Commercial radio broadcasting
  - Sound transmission in TV.
  - Two way mobile radio
  - Microwave & Satellite Communication Systems

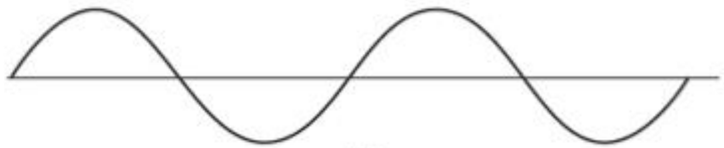
- Advantages over AM
  - Freedom from interference since AM is noisy than FM.
  - Operate in VHF (88MHz – 108MHz)
  - Provide high degree of fidelity

a) Carrier wave



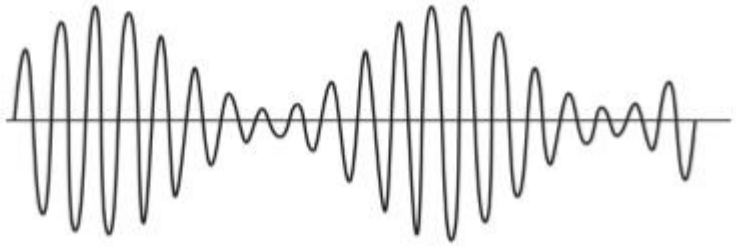
(a)

b) Sinusoidal modulating signal



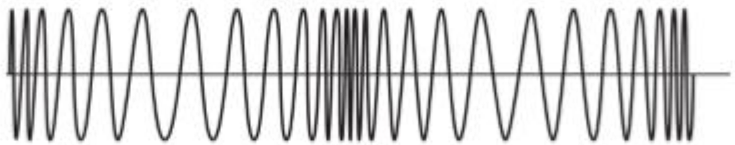
(b)

c) Amplitude-modulated signal



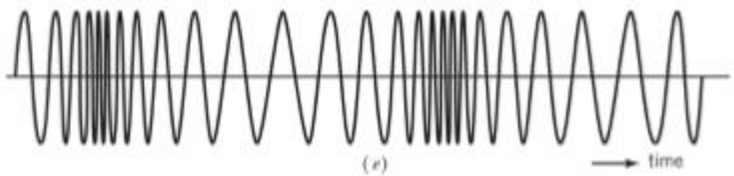
(c)

d) Phase-modulated signal



(d)

e) Frequency-modulated signal



(e)

Angle Modulated Signals

- Amplitude Modulation is linear since all operations performed in AM are linear so superposition applies.
- Angle modulation is a non-linear process.

Angle modulated signal has the general form

$$x_c(t) = A_c \cos[\omega_c t + \emptyset(t)]$$

Also called exponentially modulated signal

$$x_c(t) = A_c \cos[\omega_c t + \emptyset(t)] = R_e[A_c \exp\{j\omega_c t + j\emptyset(t)\}]$$

Instantaneous phase is defined as

$$\theta_i(t) = \omega_c t + \emptyset(t)$$

Instantaneous frequency

$$\omega_i(t) = \frac{d\theta i}{dt} = \omega_c + \frac{d\emptyset}{dt}$$

Function $\emptyset(t)\ and\ \frac{d\emptyset}{dt}$ are referred as instantaneous phase & frequency deviations

For phase modulation: The instantaneous phase deviation of carrier is proportional to message signal i.e.

$$\emptyset(t) = k_p m(t) \quad -----(i)$$

Where k_p phase deviation constant (radian/volt) and m(t) is message signal

For frequency Modulation:

The instantaneous frequency deviation of carrier is proportional to message signal i.e.

$$\frac{d\emptyset}{dt} = k_f m(t) \text{ ---- ------------ } (i)$$

$$or \;\; \emptyset(t) = k_f \int_{t_0}^{t} m(\lambda)\, d\lambda \; + \emptyset(t_0) \text{ ----- } (ii)$$

Where k_f is frequency deviation constant (radian/sec/volt) and

$\emptyset(t_0)$ initial angle. $[\emptyset(t_0) = 0]$

We get,

$$x_c(t) = \begin{cases} A_c \cos\left[\omega_c t + k_p m(t)\right] & For\ PM \\ A_c \cos\left[\omega_c t + k_f \int_{-\infty}^{t} m(\tau) d\tau\right] & For\ FM \end{cases}$$

Type of Modulation	$\emptyset(\boldsymbol{t})$	$\boldsymbol{f}(\boldsymbol{t})$
Unmodulated	$2\pi f_c t$	f_c
PM Signal	$2\pi f_c t + k_p m(t)$	$f_c + \frac{k_p}{2\pi}\frac{dm(t)}{dt}$
FM Signal	$2\pi f_c t + 2\pi k_f \int_0^t m(\tau)dc$	$f_c + k_f m(t)$

Spectra of Frequency Modulated Signal

- Angle modulation is non-linear process, so exact description of arbitrary message is difficult.
- If m(t) is assumed sinusoidal then spectrum can be obtained.

Tone modulation:

$m(t)$ is sinusoidal (or tone)

$$m(t) = A_m \cos \omega_m t$$

Then instantaneous phase deviation of modulated signal

$$\emptyset(t) = \begin{cases} k_p A_m \cos \omega_m t & For \quad FM \\ \frac{k_f A_m}{\omega_m} \sin \omega_m t & For \quad FM \end{cases}$$

For FM case modulated signal is

$$x(t) = A_c \cos(\omega_c t + \beta \sin \omega_m t)$$

Where β is modulation index

$\beta_f = \frac{k_f A_m}{\omega_m}$ For FM and $\beta_p = k_p A_m$ for PM

To compute spectrum of $x_c(t)$, we can express as

$$x_c(t) = A_c R_e\{\exp(j\omega_c t) exp(j\beta \sin \omega_m t)\}$$

It can be expanded in Fourier series. We get the following expression for FM with tone modulation

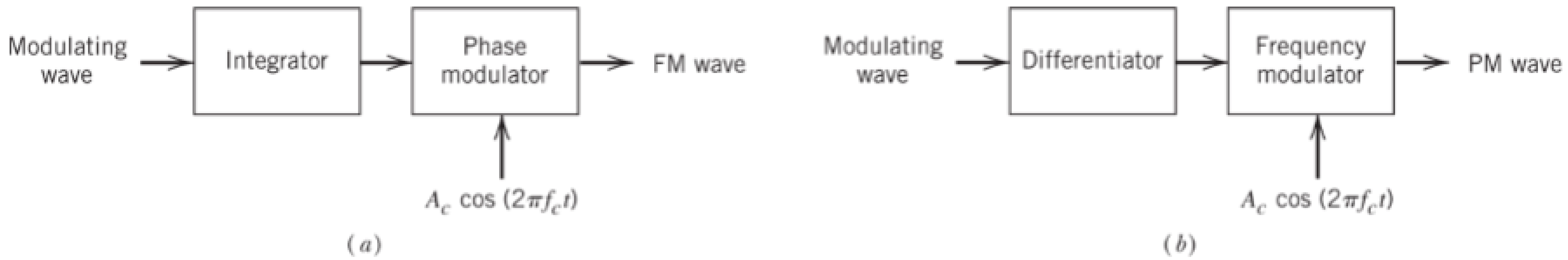
$$x_c(t) = A_c \sum_{n=-\infty}^{\infty} J_n(\beta) \cos[(\omega_c + n\omega_n)t]$$

- Spectrum consists of carrier component plus infinite number of sideband components
  i.e. $f_c \pm nf_m \ where \ n = 1,2,3, \dots \dots \dots$

Where $J_n(\beta)$ is n[th] order Bessel function of first kind and argument β

- Relative amplitude of spectral component depends on $J_n(\beta)$. Relative amplitude of carrier depends on $J_0(\beta)$
- Large value of β implies large bandwidth
- When $\beta \ll 1$ *only* $J_0 \& J_1$ are significant (like AM)

Similar analysis can be done for phase modulated signals.



Power and bandwidth of FM:

- It is observed that large portion of total power ($\cong 98\%$) is confined to some finite bandwidth
- For tone modulation bandwidth of FM signal is given by
- $BW = 2(\beta + 1)f_m \text{ where } \beta = \frac{\Delta f}{f_m}$

$$BW = 2(\Delta f + f_m)$$

This expression for BW is referred as **Carson's rule.**

FM bandwidth is twice the sum of maximum frequency deviation and the bandwidth of message signal.

- If $\beta \ll 1$, FM signal is called narrow band FM (NBFM)
  When $\beta \gg 1$, FM signal is wide band FM (WBFM)

Narrowband FM

- Narrow band FM is similar to DSB or AM. Bandwidth of NBFM is 2 f_m (same as AM)
- NBFM no inherent advantage over AM except at UHF frequencies. It is also intermediate step in generation of WBFM
- NBFM is used in mobile communication services such as police wireless, ambulances, taxi cabs etc.

Wideband FM:

- Modulation index $\beta \gg 1$
- Modulating frequency from 30 Hz to 15 KHz
- Maximum frequency deviation ±75 KHz
- Allowable bandwidth per channel 200 KHz
- Need large bandwidth, typically 15 times that of narrow band.
- Used in entertainment broadcasting.

Comparison of FM with PM

S. No.	FM	PM
1	Frequency deviation is proportional to modulating voltage	Phase deviation is proportional to the modulating voltage.
2	Noise immunity is better than AM and PM.	Noise immunity is better than AM but worse than FM
3	SNR is better than PM	SNR is worse than FM
4	Used for radio broadcasting	Used in some mobile systems
5	Possible to receive FM on PM Receiver.	Possible to receive PM on FM receiver

Comparison of and FM and AM

S. No.	FM	AM
1	FM receivers are immune to noise	AM receivers are not immune to noise
2	It is possible to decrease noise by increasing deviation	This feature is absent in AM
3	Bandwidth is higher and depends on modulation index	Bandwidth is lower than FM and independent of modulation index
4	FM transmission and reception equipment’s are more complex	Equipment’s are less complex
5	All transmitted power is useful	Carrier power and one sideband power is useless

Generation of FM

Two methods

(i) **Direct method:** Requires VCO. Provides frequency deviation. Carrier frequency needs to be stabilized
   (a) Reactance modulator
   (b) Varactor diode modulator

(ii) **Indirect method:** Frequency up conversion.
   (a) Heterodyne method
   (b) Multiplication method

   Most popular method is Armstrong modulator.

FM detection

- To get back original modulating signal.
- It is achieved by converting
  (i) Frequency deviation of FM signal to the variation of equivalent voltage. Such circuits called frequency discriminator.
  (ii) Message signal recovered from the AM signal by envelope detector.

Most common demodulator is PLL demodulator. Used for both NBFM and WBFM.

Advantages of FM

1. Amplitude of FM wave remains unaffected.
2. Decrease in noise, hence large S/N.
3. Noise reduces by increasing deviation

Disadvantages of FM

1. FM wave cannot cover large area.
2. Transmitting and receiving equipment's for FM are complex and costly.
3. A much winder channel $\cong 200\ KHz$ is needed for FM.