

**Summary of Angle (Exponential) Modulation (Ver 2.0)**  
**EE370 : Communication Engineering**  
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- Any sinusoidal (cos) signal can be completely specified by its amplitude and angle

$$x(t) = A(t) \cos(\omega_c t + \varphi(t))$$

- The angle of the cosine  $\theta(t) = \omega_c t + \varphi(t)$
- The **Instantaneous frequency** is given by  $\omega_i(t) = \frac{d\theta(t)}{dt}$ .

- Phase Modulation (PM):** the modulated signal have the form

$$g_{PM}(t) = A \cdot \cos\left[\omega_c t + k_p m(t)\right],$$

The phase and instantaneous frequency of this signal are

$$\theta_{PM}(t) = \omega_c t + k_p m(t),$$

$$\omega_i(t) = \omega_c + k_p \frac{dm(t)}{dt} = \omega_c + k_p \dot{m}(t).$$

- The frequency Modulation (FM):** the modulated signal have the form

$$g_{FM}(t) = A \cdot \cos\left[\omega_c t + k_f \int_{-\infty}^t m(\alpha) d\alpha\right]$$

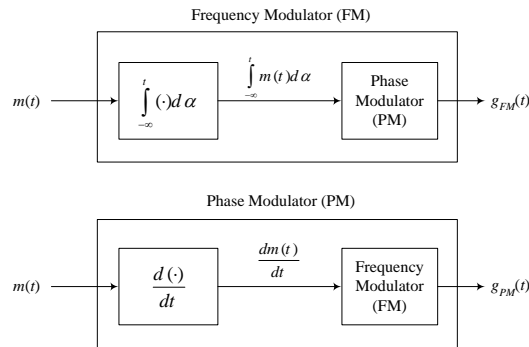
The phase and instantaneous frequency of this signal are

$$\theta_{FM}(t) = \omega_c t + k_f \int_{-\infty}^t m(\alpha) d\alpha,$$

$$\omega_i(t) = \omega_c + k_f \frac{d}{dt} \left[ \int_{-\infty}^t m(\alpha) d\alpha \right] = \omega_c + k_f m(t).$$

- Given a signal  $m(t)$  you should be able to sketch the FM and PM Modulated signals. See Examples 5.1 & 5.2, notice the continuity issue.

- Relation between PM and FM**



- Bandwidth of Angle Modulated signals**

In terms of Bandwidth FM/PM can be classified into Wideband and Narrowband. The condition for Narrowband is  $k_f a(t) \ll 1$  for FM and  $k_p m(t) \ll 1$  for the PM case. Note that

$$a(t) = \int_{-\infty}^t m(\alpha) d\alpha$$

In general FM can also be written as

$$g_{FM}(t) = \text{Re}\{\hat{g}_{FM}(t)\} \\ = A \cdot \left[ \cos(\omega_c t) - k_f a(t) \sin(\omega_c t) - \frac{k_f^2 a^2(t)}{2!} \cos(\omega_c t) + \frac{k_f^3 a^3(t)}{3!} \sin(\omega_c t) + \frac{k_f^4 a^4(t)}{4!} \cos(\omega_c t) + \dots \right]$$

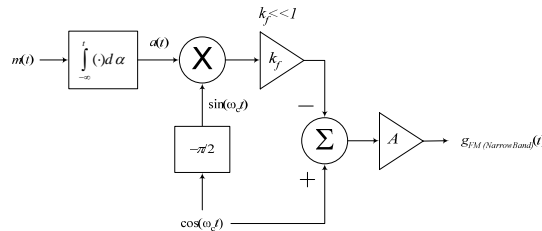
For the case of narrow band

$$g_{FM(Narrowband)}(t) \approx A \cdot [\cos(\omega_c t) - k_f a(t) \sin(\omega_c t)]$$

$$g_{PM(Narrowband)}(t) \approx A \cdot [\cos(\omega_c t) - k_p m(t) \sin(\omega_c t)]$$

Like DSB+C (with some difference). Therefore, the bandwidth of the narrowband FM signal is approximately  $2B$ , where  $B$  is the bandwidth of the message.

### Generation/Construction of Narrowband Frequency and Phase Modulators



Beta is the modulation index (frequency deviation ratio) :  $\beta = \frac{\Delta f}{B}$

$\Delta f_{FM} = \frac{k_f m_p}{2\pi}$ ,  $\Delta f_{PM} = \frac{k_p \dot{m}_p}{2\pi}$ ,  $m_p$  is the maximum negative peak of  $m(t)$ , and  $\dot{m}_p$  is the maximum negative peak of the derivative of  $m(t)$

**Carson's Rule**  $BW = 2(\Delta f + B) = 2B(\beta + 1)$

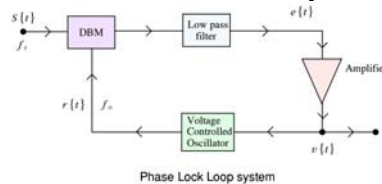
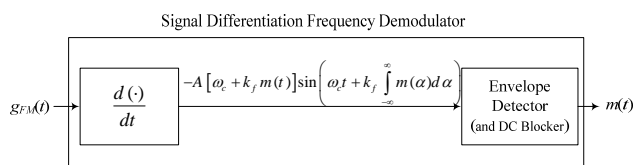
See Examples 5.3, 5.4, 5.5

- If FM is not efficient in terms of BW compared with AM, **Why FM?** (mention three reasons)
- Analysis of performance of FM signals under nonlinearity
- Generation of Wideband FM (WBFM):
  - Direct Method VCO (+,-)
  - Indirect Armstrong Method (See Examples)

### Demodulation of FM/PM signals

- 1) Frequency Discriminator
- 2) Phase Locked Loop (PLL)
- 3) Zero Crossing Detector
- 4) Ratio Detector

- Sketch how their block diagram, how they work, Advantages and disadvantages of each.
- A bandpass limiter which eliminates amplitude variations is a hard limiter followed by a BPF.



DBM: Double balanced modulator (multiplier)

### FM Receiver

88-108 MHz, 200 kHz/ Channel, IF=10.7 MHz

Super-heterodyne concept with envelope detector replaced by PLL or frequency discriminator.

Monophonic & compatibility with stereophonic (1dB). Fully understand Figure 5.19

**Note:**

- Verification of FM Bandwidth Relationship p 220-222 is not required.
- PLL (error analysis is not included p237-241)
- 5.5 is not included (Optional read p243-245 Dolby A,B,C), concept of pre-emphasis & De-emphasis)