Communication Systems
EE-351

Lectures 22 to 23

Frequency Demodulation:

- Two devices for frequency demodulation:
  - Frequency discriminator
    - Relies on **slope detection** followed by envelope detection
  - Phase-locked loop
    - Performs frequency demodulation in a somewhat indirect manner

Frequency discriminator:

- It is a demodulator that consists of a differentiator followed by an envelope detector.

Phase-Locked Loop (PLL):

- The *phase-locked loop* is a feedback system whose operation is closely linked to frequency modulation.
- Purpose is to extract message signal.
- Applications: It is commonly used for
  - carrier synchronization, and
  - indirect frequency demodulation

Phase-Locked Loop (PLL):

- Basically, the phase-locked loop consists of three major components:
  - ***Voltage-controlled oscillator*** **(VCO)**, which performs frequency modulation on its own control signal.
  - ***Multiplier***, which multiplies an incoming FM wave by the output of the voltage-controlled oscillator.
  - ***Loop filter*** of a low-pass kind, the function of which is to remove the high-frequency components contained in the multiplier's output signal and thereby shape the overall frequency response of the system.

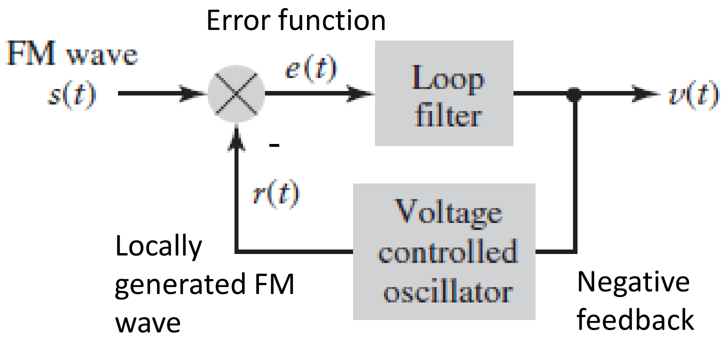


FIGURE 4.14 Block diagram of the phase-locked loop.

Phase-Locked Loop (PLL):

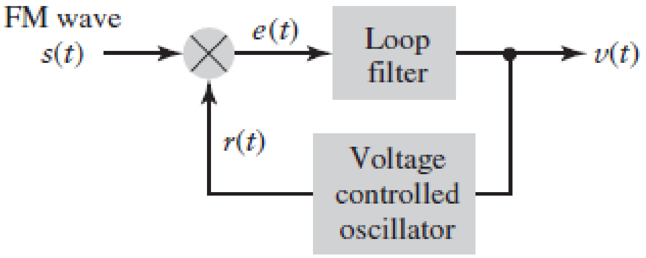


FIGURE 4.14 Block diagram of the phase-locked loop.

These three components are connected together to form a **closed-loop feedback system**.

Purpose is to adjust:

$$\varphi_2(t) = \varphi_1(t)$$

Hence, setting stage for frequency demodulation:

If phase error, $\varphi_e(t) = 0,$

PLL is said to be in phase-lock.

- To demonstrate the operation of the phase-locked loop as a frequency demodulator, we assume that the VCO has been adjusted so that when the control signal (i.e., input) is zero, two conditions are satisfied:

  1. The frequency of the VCO is set precisely at the unmodulated carrier frequency of the incoming FM wave.

  2. The VCO output has a 90-degree phase-shift with respect to the unmodulated carrier wave.

Phase-Locked Loop (PLL):

- Free-running frequency range $\longrightarrow$ (Signal cannot be demodulated)
- Capture range $\longrightarrow$ (Near-phase-lock when phase error $\varphi_e(t)$ is small)
- Lock-in range (ideal case)

Phase-Locked Loop (PLL):

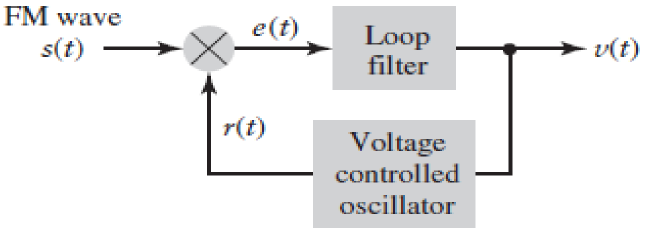


FIGURE 4.14 Block diagram of the phase-locked loop.

Capture range: (a range where difference reduces)

$$f_r < f_c$$

Let,

$$r(t) \longrightarrow f_r$$
$$s(t) \longrightarrow f_c$$

$$f_c - f_r \text{ reduces}$$

$v(t)$ allows VCO to produce that frequency f_r which reduces this difference $(f_c - f_r)$.

After sometime, f_r converts into f_c (feedback system)

$$f_c - f_r = 0$$
$$v(t) = 0$$

Phase-Locked Loop (PLL):

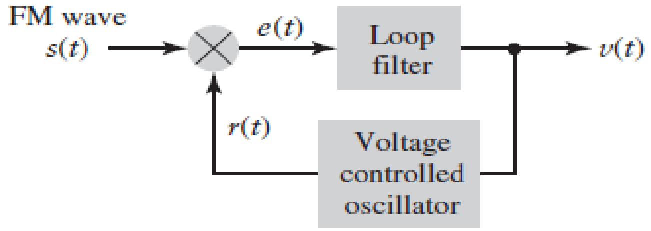


FIGURE 4.14 Block diagram of the phase-locked loop.

$$s_{FM}(t) = A_c cos\left(2\pi f_c t + 2\pi k_f \int_0^t m(t)dt\right)$$

Let,

$$\varphi_1(t) = 2\pi k_f \int_0^t m(t)dt$$
$$s_{FM}(t) = A_c cos\big(2\pi f_c t + \varphi_1(t)\big)$$
$$r(t) = A_v sin(2\pi f_c t)$$

@ Perfect lock-in, $\mathrm{v}(t) = 0$

when $\mathrm{v}(t) \neq 0$, capture range

$$r(t) = A_v sin(2\pi f_c t) + 2\pi k_v \int_0^t v(t)dt$$

Phase-Locked Loop (PLL):

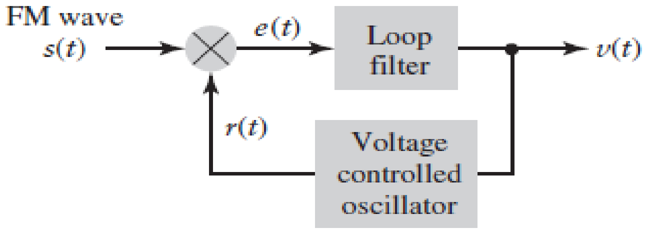


FIGURE 4.14 Block diagram of the phase-locked loop.

$$r(t) = A_v sin(2\pi f_c t) + 2\pi k_v \int_0^t v(t)dt$$

k_v is freq. sensitivity factor of VCO, A_v is the amplitude

$$\varphi_2(t) = 2\pi k_v \int_0^t v(t)dt$$

So,

$$e(t) = s(t) \times [-r(t)]$$

$$= A_c cos\left(2\pi f_c t + \varphi_1(t)\right) \times (-A_v sin(2\pi f_c t) + \varphi_2(t))$$

$$2cosAsinB = \sin(A+B) - \sin(A-B)$$

$$e(t) = \frac{-A_c A_v}{2}[\sin\left(4\pi f_c t + \varphi_1(t) + \varphi_2(t)\right) - \sin(\varphi_1(t) - \varphi_2(t))]$$

Phase-Locked Loop (PLL):

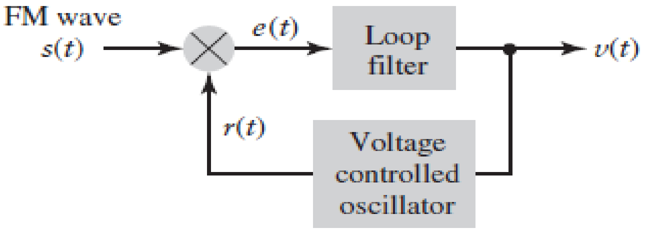


FIGURE 4.14 Block diagram of the phase-locked loop.

$$e(t) = \frac{-A_c A_v}{2}\left[\sin\left(4\pi f_c t + \varphi_1(t) + \varphi_2(t)\right) - \sin(\varphi_1(t) - \varphi_2(t))\right]$$

$$= \frac{A_c A_v}{2}\sin(\varphi_1(t) - \varphi_2(t))$$

$$e(t) = \frac{A_c A_v}{2}\sin\varphi_e(t)$$

where,

$$\varphi_e(t) = \varphi_1(t) - \varphi_2(t)$$

$$\varphi_e(t) \ll 1$$

$$\therefore \sin\varphi_e(t) \approx \varphi_e(t)$$

Phase-Locked Loop (PLL):

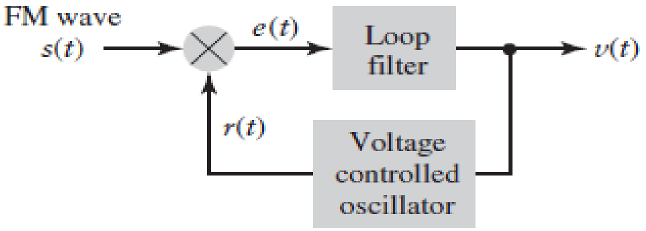


FIGURE 4.14 Block diagram of the phase-locked loop.

$$e(t) = \frac{A_c A_v}{2} \varphi_e(t)$$

Lock-in range > capture range

$$v(t) = e(t) * H(t)$$

$$v(\omega) = e(\omega) \times H(\omega)$$

$$v(t) = \frac{A_c A_v}{2} \varphi_e(t) * H(t)$$

$$v(\omega) = \frac{A_c A_v}{2} \varphi_e(\omega) \times H(\omega)$$

Phase-Locked Loop (PLL):

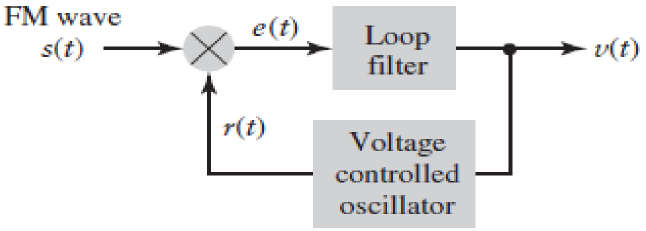


Figure 4.14 Block diagram of the phase-locked loop.

$$\varphi_e(t) = \varphi_1(t) - \varphi_2(t)$$

$$= k_f \int_0^t m(t)dt - k_v \int_0^t v(t)dt$$

$$\varphi_e(t) = \varphi_1(t) - k_v \int_0^t \frac{A_c A_v}{2} \varphi_e(t) * H(t)dt$$

$$\frac{d}{dt}\varphi_e(t) = \frac{d}{dt}\varphi_1(t) - k_v \frac{A_c A_v}{2} \frac{d}{dt}\int_0^t \varphi_e(t) * H(t)dt$$

$$= \frac{d}{dt}\varphi_1(t) - k_v \frac{A_c A_v}{2} \varphi_e(t) * H(t)$$

Phase-Locked Loop (PLL):

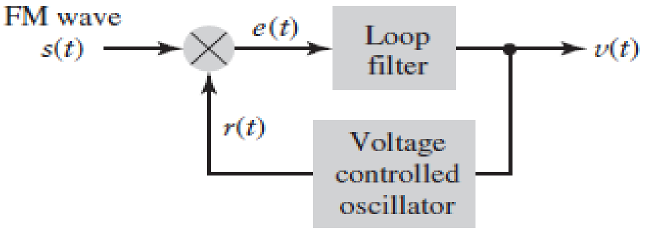


FIGURE 4.14 Block diagram of the phase-locked loop.

$$\frac{d}{dt}\varphi_e(t) = \frac{d}{dt}\varphi_1(t) - k_v\frac{A_cA_v}{2}\varphi_e(t) * H(t)$$

$$j\omega\varphi_e(\omega) = j\omega\varphi_1(\omega) - k_v\frac{A_cA_v}{2}\varphi_e(\omega) \times H(\omega)$$

$$j\omega\varphi_e(\omega) + k_v\frac{A_cA_v}{2}\varphi_e(\omega) \times H(\omega) = j\omega\varphi_1(\omega)$$

$$\varphi_e(\omega)[j\omega + k_v\frac{A_cA_v}{2}H(\omega)] = j\omega\varphi_1(\omega)$$

$$\varphi_e(\omega) = \frac{j\omega\varphi_1(\omega)}{j\omega[1 + \frac{k_vA_cA_v}{2j\omega}H(\omega)]}$$

Phase-Locked Loop (PLL):

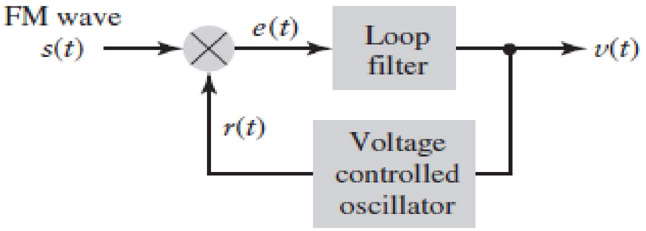


FIGURE 4.14 Block diagram of the phase-locked loop.

$$\varphi_e(\omega) = \frac{\varphi_1(\omega)}{1 + \frac{k_v A_c A_v}{2j\omega} H(\omega)}$$

$$H(\omega) \uparrow \;\Rightarrow\; \varphi_e(\omega) \downarrow$$

$$\Downarrow$$

$$\varphi_1(t) \approx \varphi_2(t)$$

$$H(\omega) = \infty \;\Rightarrow\; \varphi_e(\omega) = 0$$

$$\Downarrow$$

$$\varphi_1(t) = \varphi_2(t)$$

Phase-Locked Loop (PLL):

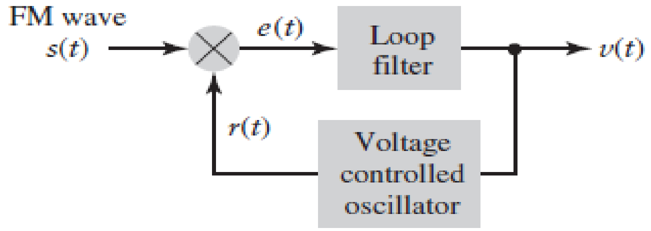


FIGURE 4.14 Block diagram of the phase-locked loop.

$$\varphi_e(\omega) = \frac{\varphi_1(\omega)}{\frac{k_v A_c A_v}{2j\omega} H(\omega)}$$

$$v(\omega) = e(\omega) \times H(\omega)$$

$$= \frac{A_c A_v}{2} \varphi_e(\omega) H(\omega)$$

$$= \frac{A_c A_v}{2} \frac{\varphi_1(\omega)}{\frac{k_v A_c A_v}{2j\omega} H(\omega)} H(\omega)$$

$$v(\omega) = \frac{j\omega \varphi_1(\omega)}{k_v}$$

Phase-Locked Loop (PLL):

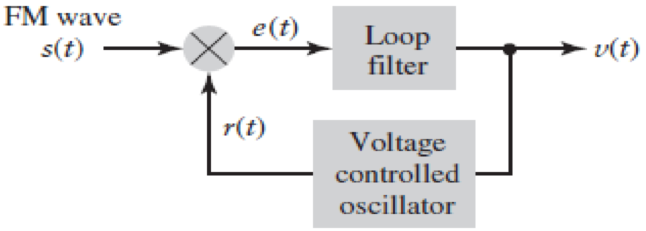


FIGURE 4.14 Block diagram of the phase-locked loop.

- Taking IFT of $v(\omega) = \frac{j\omega\varphi_1(\omega)}{k_v}$

$$v(t) = \frac{1}{k_v}\frac{d}{dt}\varphi_1(t)$$

$$\frac{d}{dt}\varphi_1(t) = \frac{d}{dt}k_f\int_0^t m(t)dt = k_f m(t)$$

$$v(t) = \frac{k_f}{k_v}m(t)$$

$$v(t) \propto m(t)$$

Phase-Locked Loop (PLL):

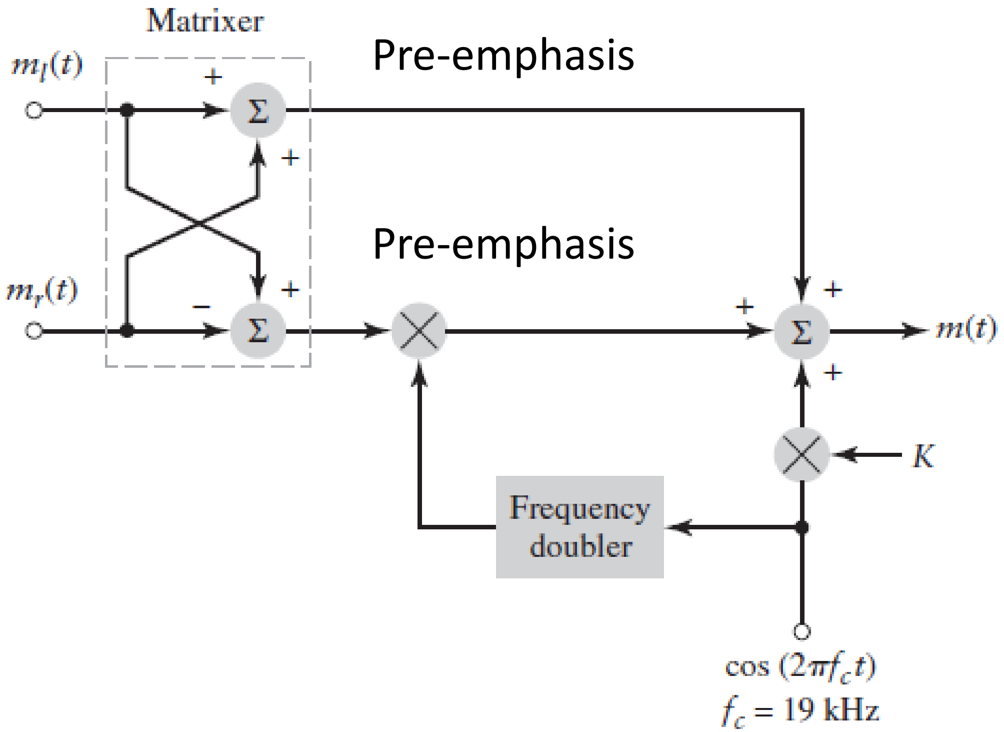
- PLL is advanced in comparison to all receivers.
- Does not depend on change in amplitude
  - Noise does not affect this system
- Highly linear
  - so distortion-less

Stereophonic FM broadcasting:
FM Stereo Multiplexing:

- Spatial and temporal distribution both
  - Left and right ear listening a different sound with the help of stereophonic FM broadcasting

- Range of FM signal: 88 MHz to 108 MHz
- $\Delta f = 75\text{kHz}$ (for 1 signal)
  - For both USB and LSB, 150kHz
- Distance between successive carriers ≈ 200kHz (+ guard band)
- Intermediate freq. 10.7 MHz

FM Stereo Multiplexing:



(a)

FM Stereo Multiplexing: