UESTC4004
Digital Communications

Instructors: Prof. Muhammad Imran and Sajjad Hussain

This week: Prof. Muhammad Imran muhammad.imran@glasgow.ac.uk

Synchronization

Synchronization is one of the most critical functions of a communication system with coherent receiver. To some extent, it is the basis of a synchronous communication system.

- Carrier synchronization
- Symbol/Bit synchronization
- Frame synchronization

Synchronization

Carrier synchronization

Receiver needs estimate and compensate for frequency and phase differences between a received signal's carrier wave and the receiver's local oscillator for the purpose of coherent demodulation, no matter it is analog or digital communication systems

Our focus: Carrier Synchronization

- Why do we need carrier synchronization?
  - Tx and Rx are not always connected and are apart

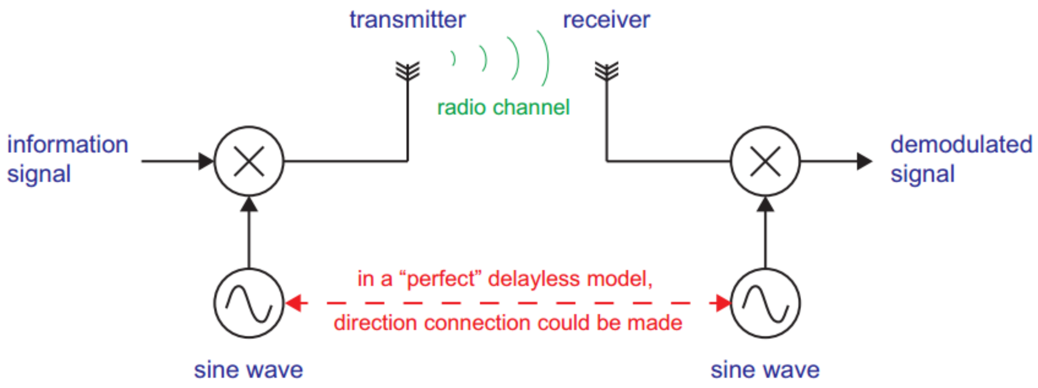


Figure 7.3: Transmitter and receiver with a 'virtual' connection

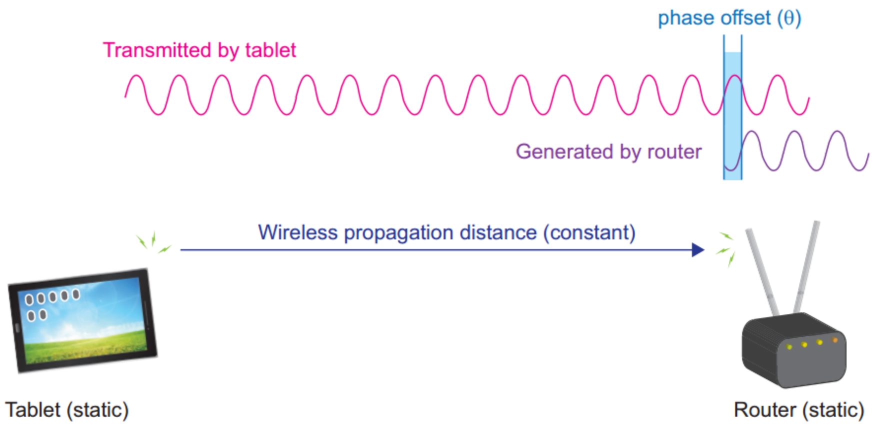


Figure 7.4: Communication between two static terminals, resulting in carrier phase shift

Support video available on Aula

Our focus: Carrier Synchronization

- Why do we need carrier synchronization?
  - Relative motion

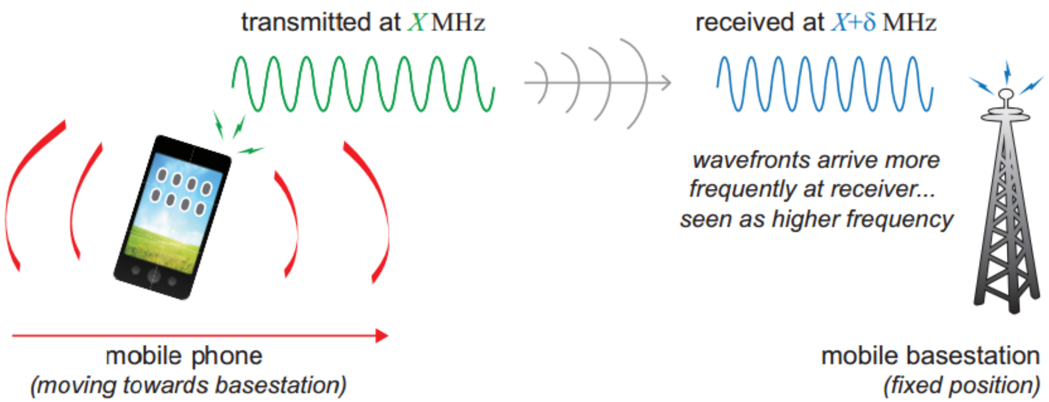


Figure 7.5: Communication between terminals that are moving closer together

Support video available on Aula

Carrier Demodulation

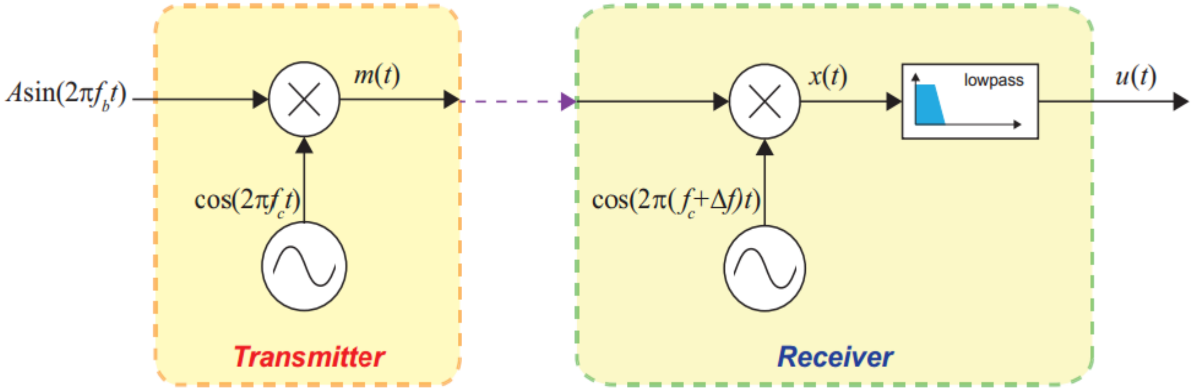


Figure 7.7: Demodulation with a frequency offset

$$m(t) = \frac{A}{2}\left[\sin(2\pi(f_c+f_b)t) - \sin(2\pi(f_c-f_b)t)\right] \tag{7.1}$$

$$x(t) = \cos(2\pi(f_c+f_\Delta)t) \times \frac{A}{2}\left[\sin(2\pi(f_c+f_b)t) - \sin\left(2\pi(f_c-f_b)t\right)\right] \tag{7.2}$$

$$= \frac{A}{2}\left[\cos(2\pi(f_c+f_\Delta)t)\sin\left(2\pi(f_c+f_b)t\right) - \cos\left(2\pi(f_c+f_\Delta)t\right)\sin\left(2\pi(f_c-f_b)t\right)\right]. \tag{7.3}$$

Carrier Demodulation

$$x(t) = \frac{A}{2}\left[\frac{1}{2}\sin\left(2\pi\left((f_c+f_\Delta)+(f_c+f_b)\right)t\right) - \frac{1}{2}\sin\left(2\pi\left((f_c+f_\Delta)-(f_c+f_b)\right)t\right)\right]$$
$$-\frac{A}{2}\left[\frac{1}{2}\sin\left(2\pi\left((f_c+f_\Delta)+(f_c-f_b)\right)t\right) - \frac{1}{2}\sin\left(2\pi\left((f_c+f_\Delta)-(f_c-f_b)\right)t\right)\right] \quad (7.4)$$

and Eq. (7.4) may subsequently be rearranged to give:

$$x(t) = \frac{A}{4}\sin\left(2\pi(2f_c+f_\Delta+f_b)t\right) - \frac{A}{4}\sin\left(2\pi(f_\Delta-f_b)t\right)$$
$$-\frac{A}{4}\sin\left(2\pi(2f_c+f_\Delta-f_b)t\right) + \frac{A}{4}\sin\left(2\pi(f_\Delta+f_b)t\right) \quad (7.5)$$

Although this expression includes two high frequency components, it is not equivalent to the transmitted signal even after lowpass filtering to remove the high frequency components. This is due to the presence of the f_Δ terms.

lowpass filtered term

$$u(t) = \cancel{\frac{A}{4}\sin\left(2\pi(2f_c+f_\Delta+f_b)t\right)} - \frac{A}{4}\sin\left(2\pi(f_\Delta-f_b)t\right) \quad (7.6)$$
$$-\cancel{\frac{A}{4}\sin\left(2\pi(2f_c+f_\Delta-f_b)t\right)} + \frac{A}{4}\sin\left(2\pi(f_\Delta+f_b)t\right)$$

lowpass filtered term

Lastly, making use of the general property that $\sin(-x) = -\sin(x)$,we can write

$$u(t) = \frac{A}{4}\left[\sin(2\pi(f_b+f_\Delta)t) + \sin(2\pi(f_b-f_\Delta)t)\right]. \quad (7.7)$$

Carrier synchronization: Options

- Phase lock loop (PLL)
- Costas (classical)

Phase lock loop (PLL)

A PLL is mainly comprised of:

1. Phase Detector
2. Loop Filter
3. Voltage or Numerically Controlled Oscillator

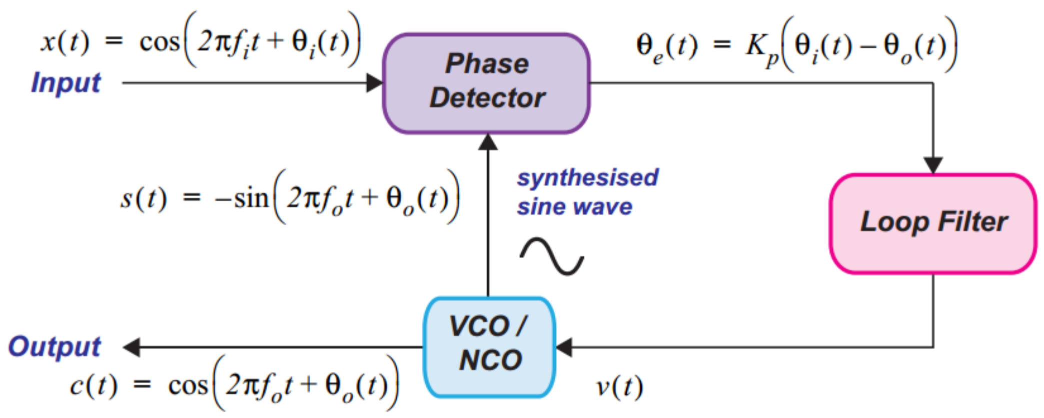
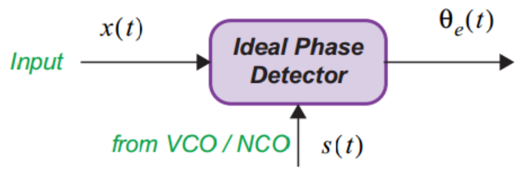


Figure 7.8: Block diagram of a PLL

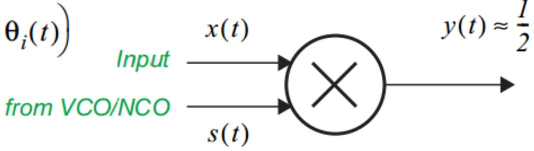
Phase Detector



$$\equiv$$

$$x(t) = \cos\left(2\pi f_i t + \theta_i(t)\right)$$

$$s(t) = -\sin\left(2\pi f_o t + \theta_o(t)\right),$$



$$y(t) \approx \frac{1}{2}\sin\left(\theta_i(t) - \theta_o(t)\right) + \textit{high frequency terms}$$

The output of the multiplier phase detector is:

$$y(t) = x(t) \times s(t) \tag{7.11}$$

$$= \cos\left(2\pi f_i t + \theta_i(t)\right) \times -\sin\left(2\pi f_o t + \theta_o(t)\right)$$

$$= \frac{1}{2}\left[\sin\left((2\pi f_i t + \theta_i(t)) - (2\pi f_o t + \theta_o(t))\right) - \sin\left((2\pi f_i t + \theta_i(t)) + (2\pi f_o t + \theta_o(t))\right)\right]$$

$$= \frac{1}{2}\left[\sin\left(2\pi(f_i - f_o)t + (\theta_i(t) - \theta_o(t))\right) - \sin\left(2\pi(f_i + f_o)t + (\theta_i(t) + \theta_o(t))\right)\right].$$

Where the frequencies f_i and f_o are equal, the output reduces to:

$$y(t) = \underbrace{\frac{1}{2}\sin\left(\theta_i(t) - \theta_o(t)\right)}_{\textit{low frequency term}} - \underbrace{\frac{1}{2}\sin\left(4\pi f_i(t) + \theta_i(t) + \theta_o(t)\right)}_{\textit{high frequency term}}. \tag{7.12}$$

$$y(t) \approx \frac{1}{2}\left(\theta_i(t) - \theta_o(t)\right) \approx \theta_e(t) \tag{7.13}$$

Voltage Controlled Oscillator (VCO)

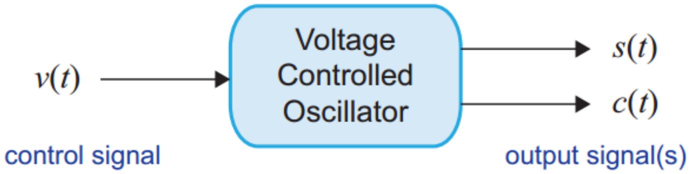


Figure 7.10: Interface of a VCO

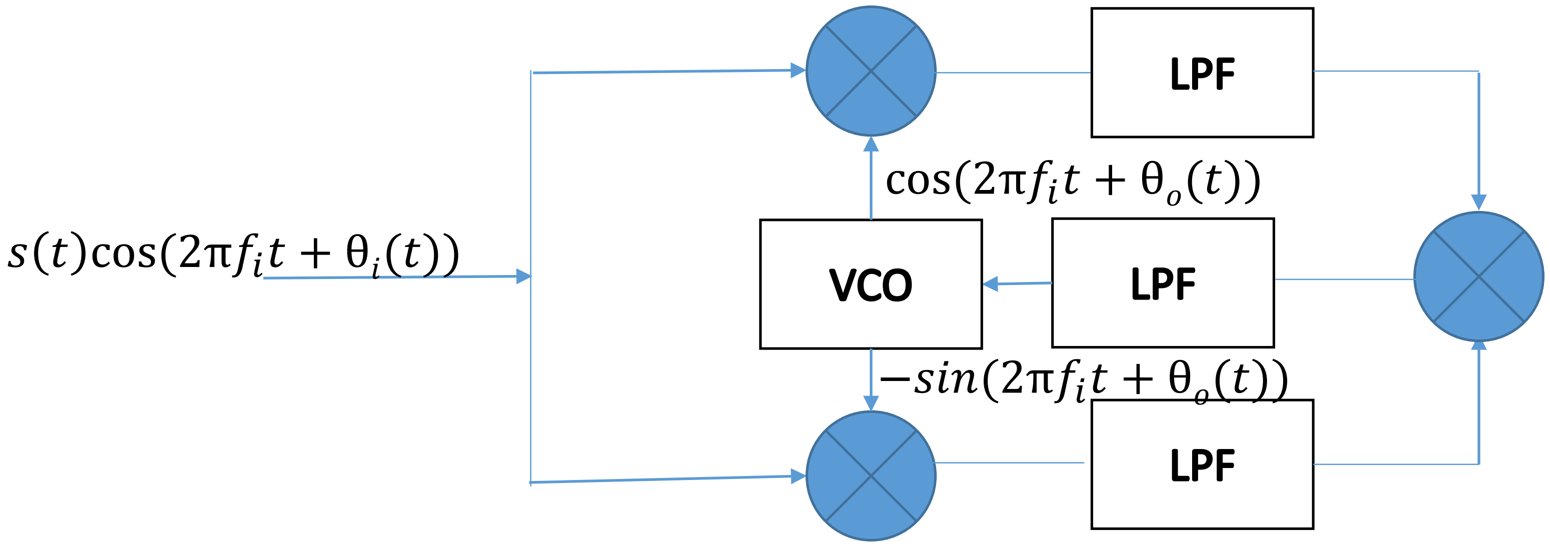
$$c(t) = \cos\left(2\pi f_o t + \hat{\theta}(t)\right) \tag{7.15}$$

$$\hat{\theta}(t) = k_o \int_0^t v(t)\, dt\,, \tag{7.16}$$

PLL problem

- For PSK signals, PLL may never be able to lock to phase as the phase keeps on changing with the information bits or symbols.
- Solution 1: Use a training sequence before actual data transmission to lock to phase.
- Solution 2: Costas loop

Classical Costas Loop



Support video available on Aula