UESTC4004
Digital Communications

Carrier synchronization

Synchronization

数字通信的2个"(disadvantages)"之一

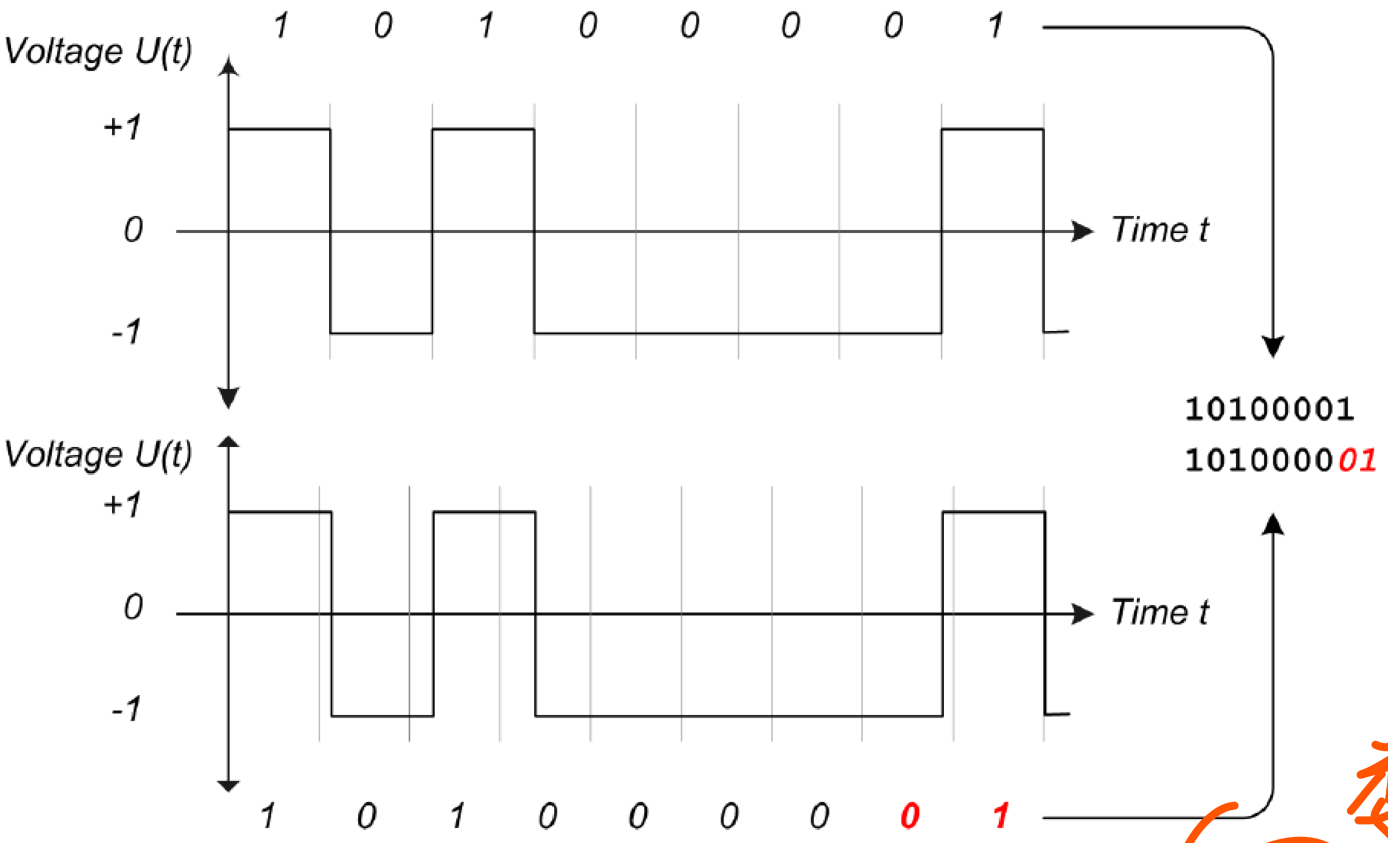
Synchronization is one of the most critical functions of a communication system with coherent receiver. To some extent, it is the basis of a synchronous communication system.

- Carrier synchronization
- Symbol/Bit synchronization
- Frame synchronization

三个同步

Synchronization

Symbol/bit synchronization



Communication system with two Data Terminal Equipment (DTE)

数据终端设备

Synchronization 帧同步

数据帧

Frame synchronization

In frame-based digital systems, receiver also needs to estimate the starting/stopping time of a data frame. The process of extracting such a clock signal is called frame synchronization.

- ✓ Time gap synchronization
- ✓ Start & End Flags

STX	H	e	l	l	o		W	o	r	l	d	ETX

Start and end flags

Synchronization

频率和相位

Carrier synchronization

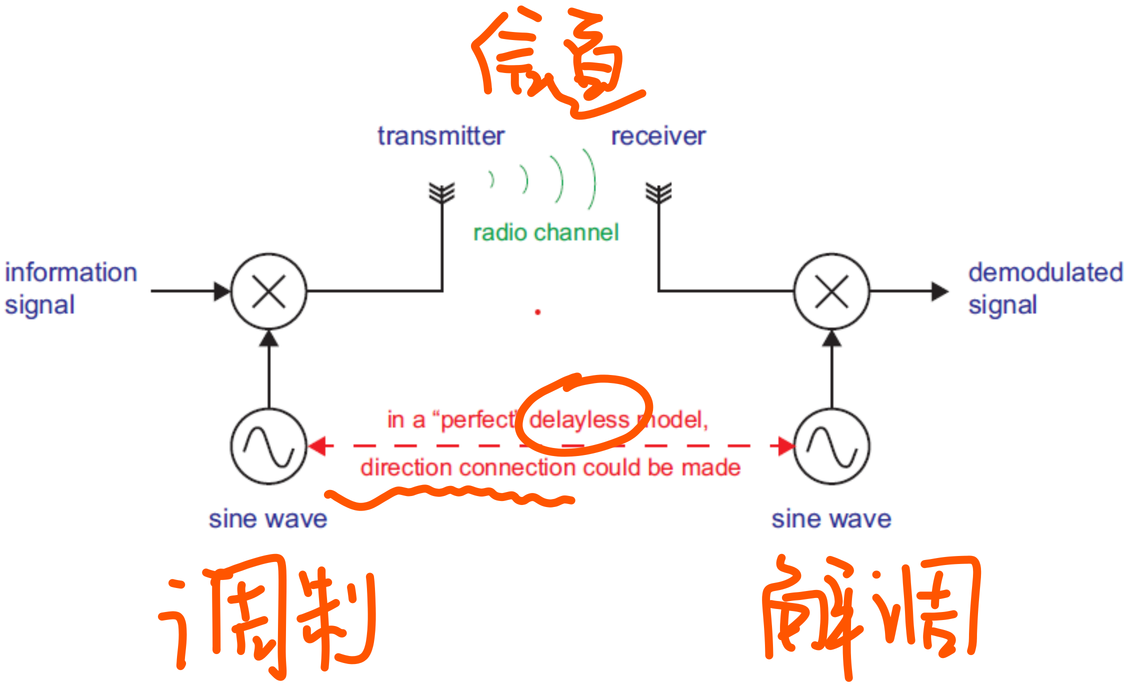
Receiver needs estimate and compensate for frequency and phase differences between a received signal's carrier wave and the receiver's local oscillator for the purpose of coherent demodulation, no matter it is analog or digital communication systems

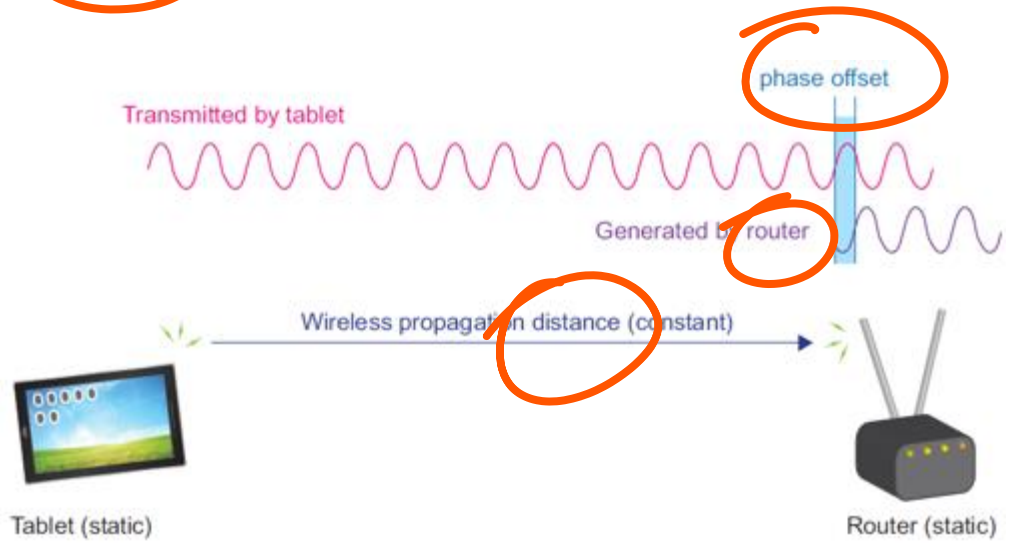
载波

核心：解决f和ph的不同

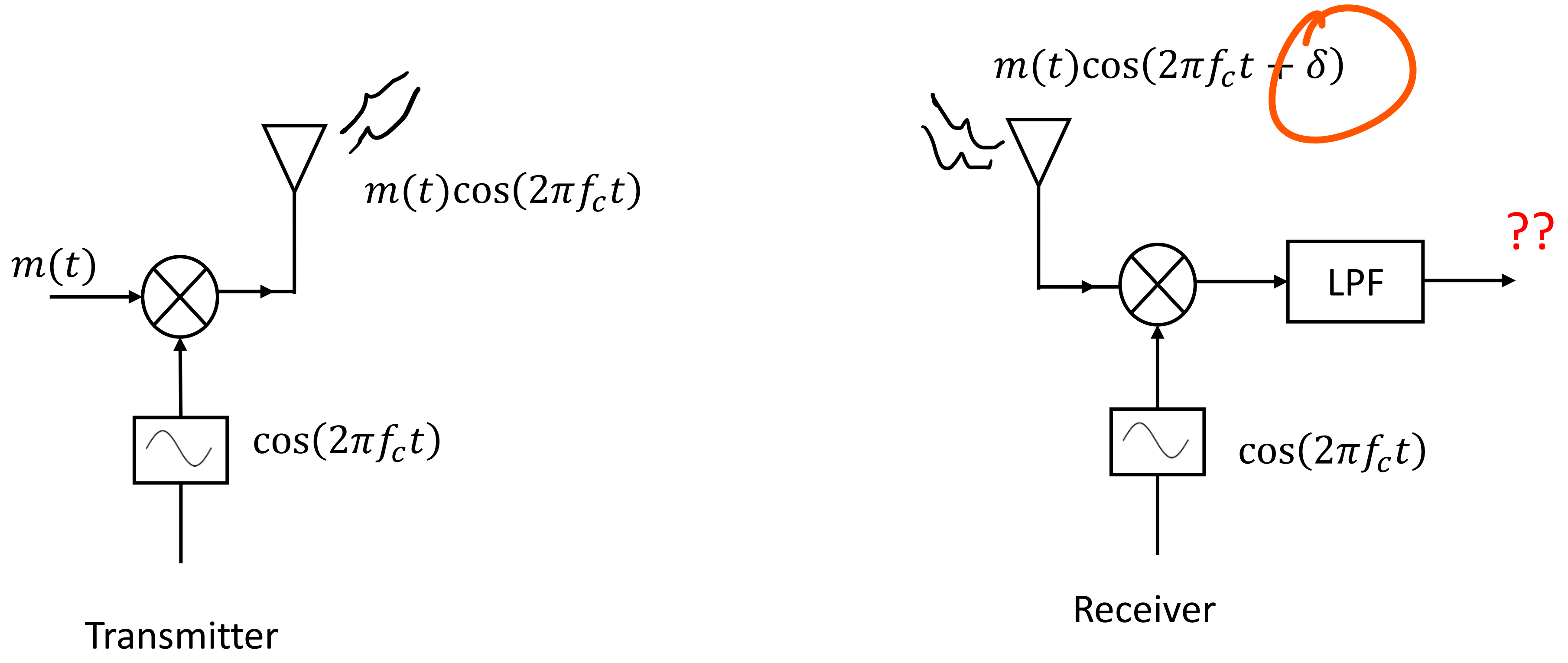
Our focus: Carrier Synchronization

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

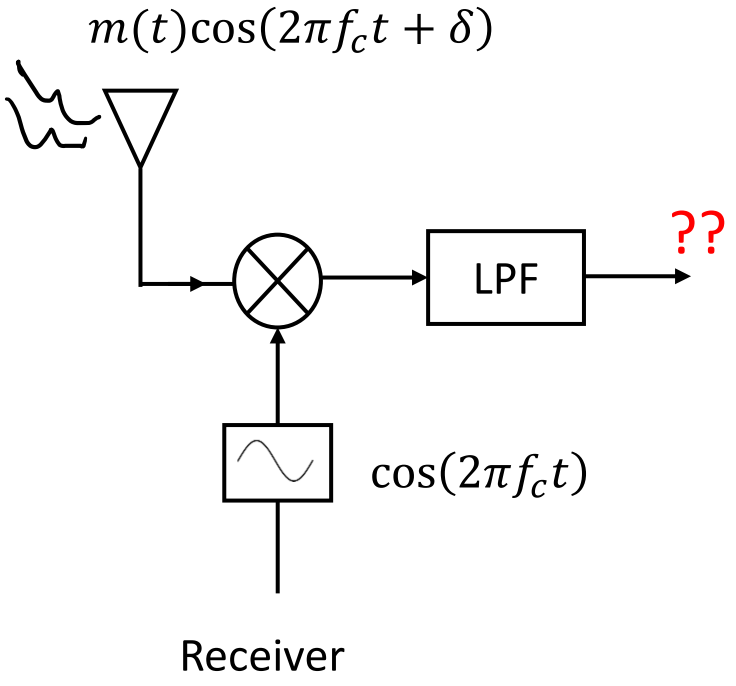




Carrier Demodulation – Phase Offset



Carrier Demodulation – Phase Offset



信息信号

$$= m(t)\cos(2\pi f_c t + \delta) \times \cos(2\pi f_c t)$$ 积化和差

Using trigonometry property

$$\cos(\alpha)\cos(\beta) = \frac{1}{2}(\cos(\alpha+\beta) + \cos(\alpha-\beta))$$

LPF

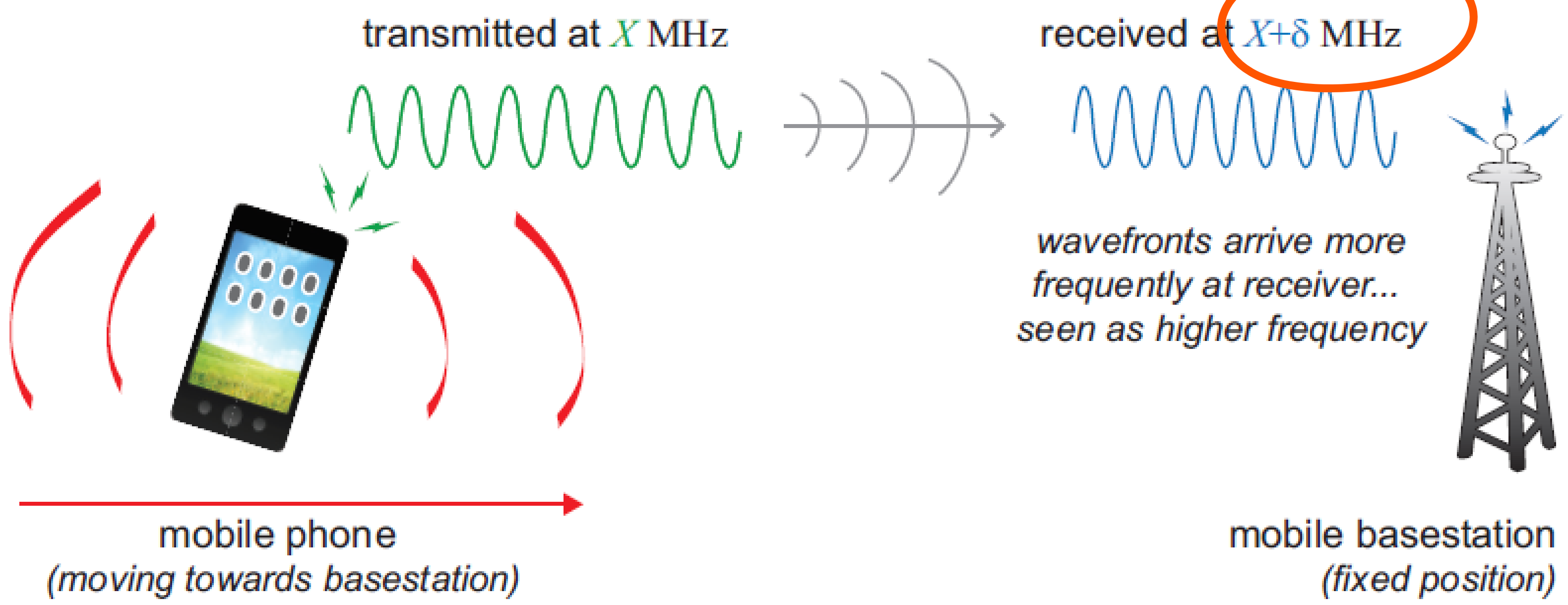
$$= \frac{m(t)}{2}(\cancel{\cos(4\pi f_c t + \delta)} + \cos(\delta))$$

$$= \frac{m(t)}{2}\cos\delta$$

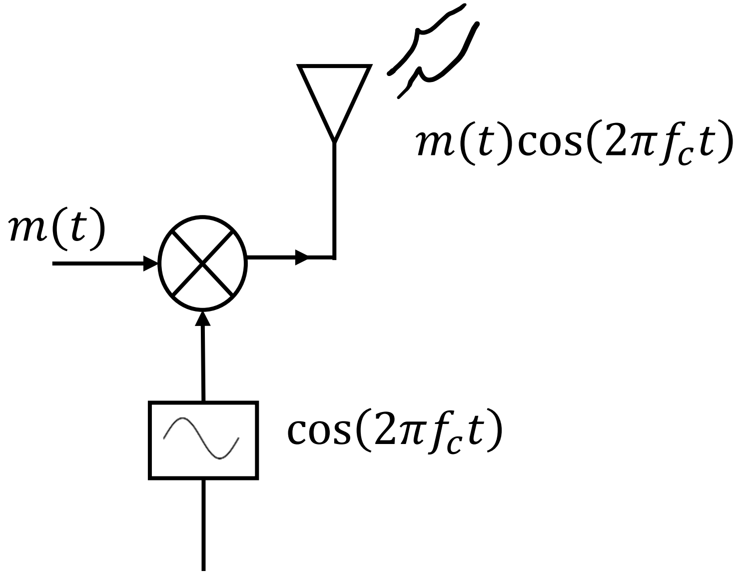
Our focus: Carrier Synchronization

- Why do we need carrier synchronization?
  - Relative motion

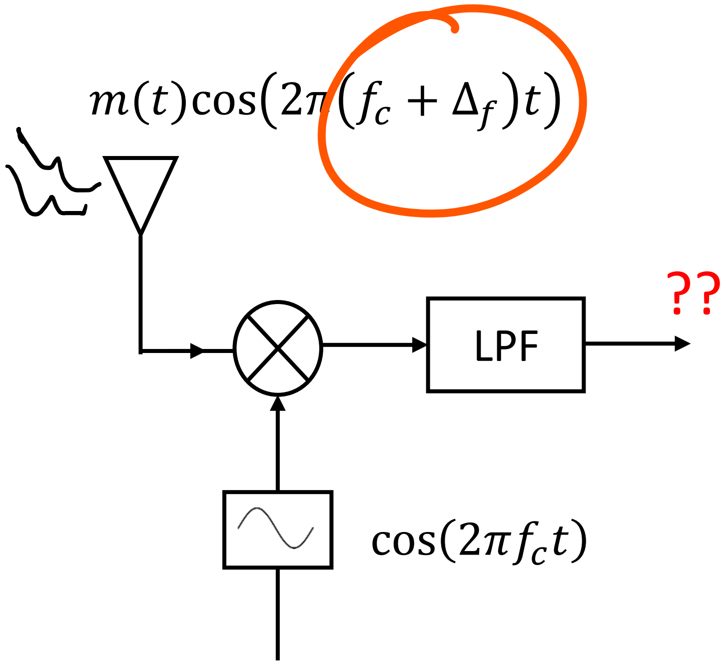
freq 也变



Carrier Demodulation – Frequency offset



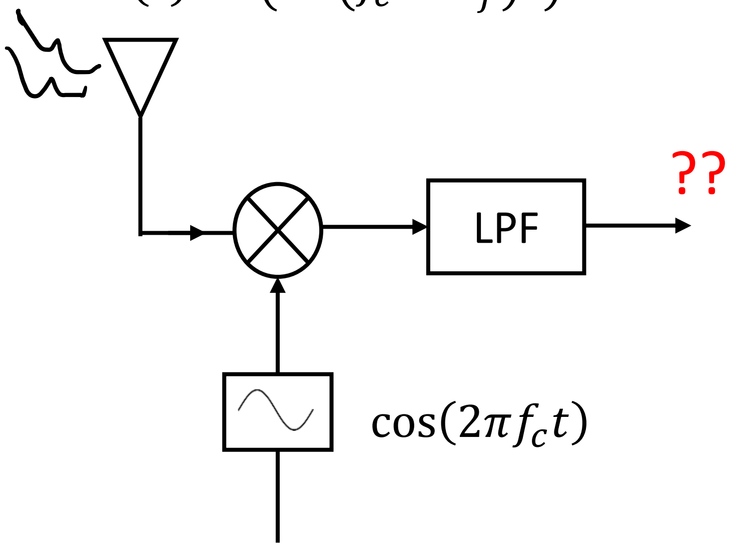
Transmitter



Receiver

Carrier Demodulation – Frequency offset

$$m(t)\cos\big(2\pi(f_c+\Delta_f)t\big)$$



Receiver

$$= m(t)\cos\big(2\pi(f_c+\Delta_f)t\big)\cos(2\pi f_c t)$$

Using trigonometry property

$$\cos(\alpha)\cos(\beta) = \frac{1}{2}\big(\cos(\alpha+\beta)+\cos(\alpha-\beta)\big)$$

LPF

$$= \frac{m(t)}{2}\Big[\cancel{\cos\big(2\pi(f_c+f_c+\Delta_f)t\big)} + \cos(2\pi\Delta_f t)\Big]$$

$$= \frac{m(t)}{2}\cos(2\pi\Delta_f t)$$

Carrier synchronization: Options

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

相位锁循环 / 锁相环

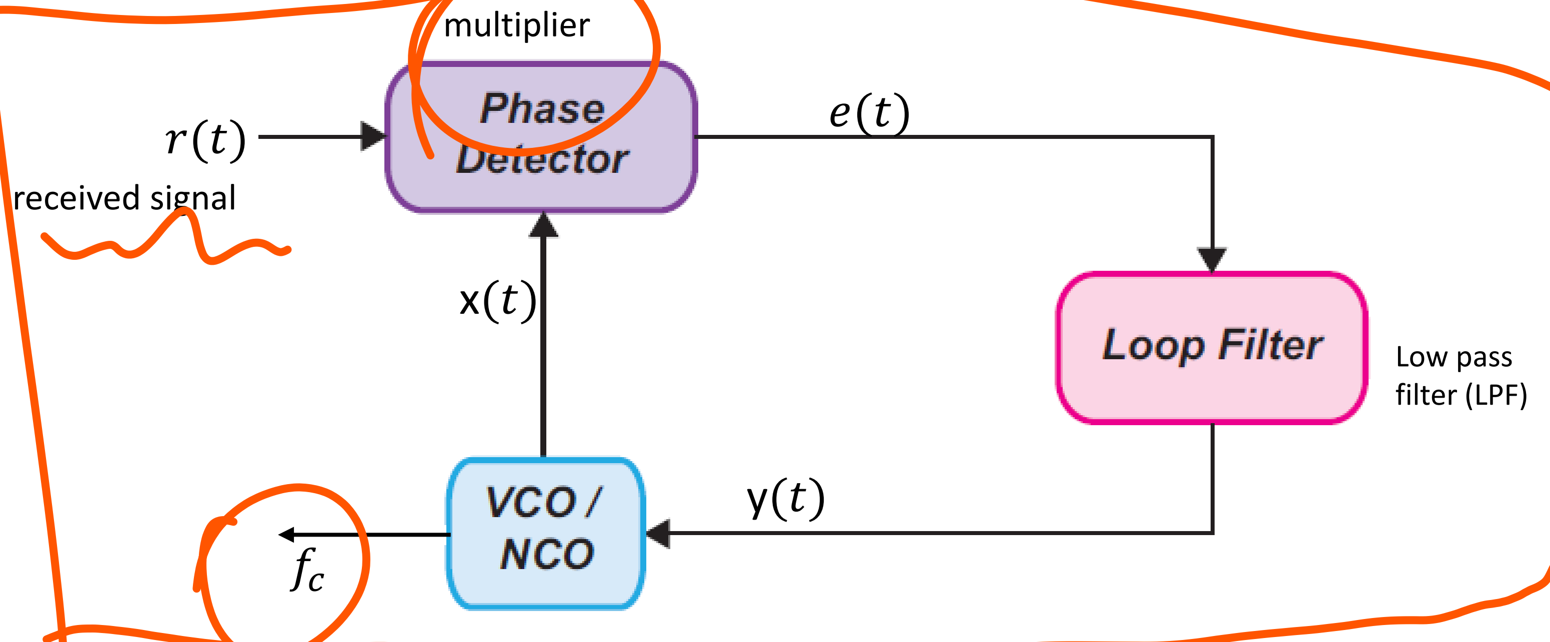
Phase lock loop (PLL)

解调器相位与载波同步

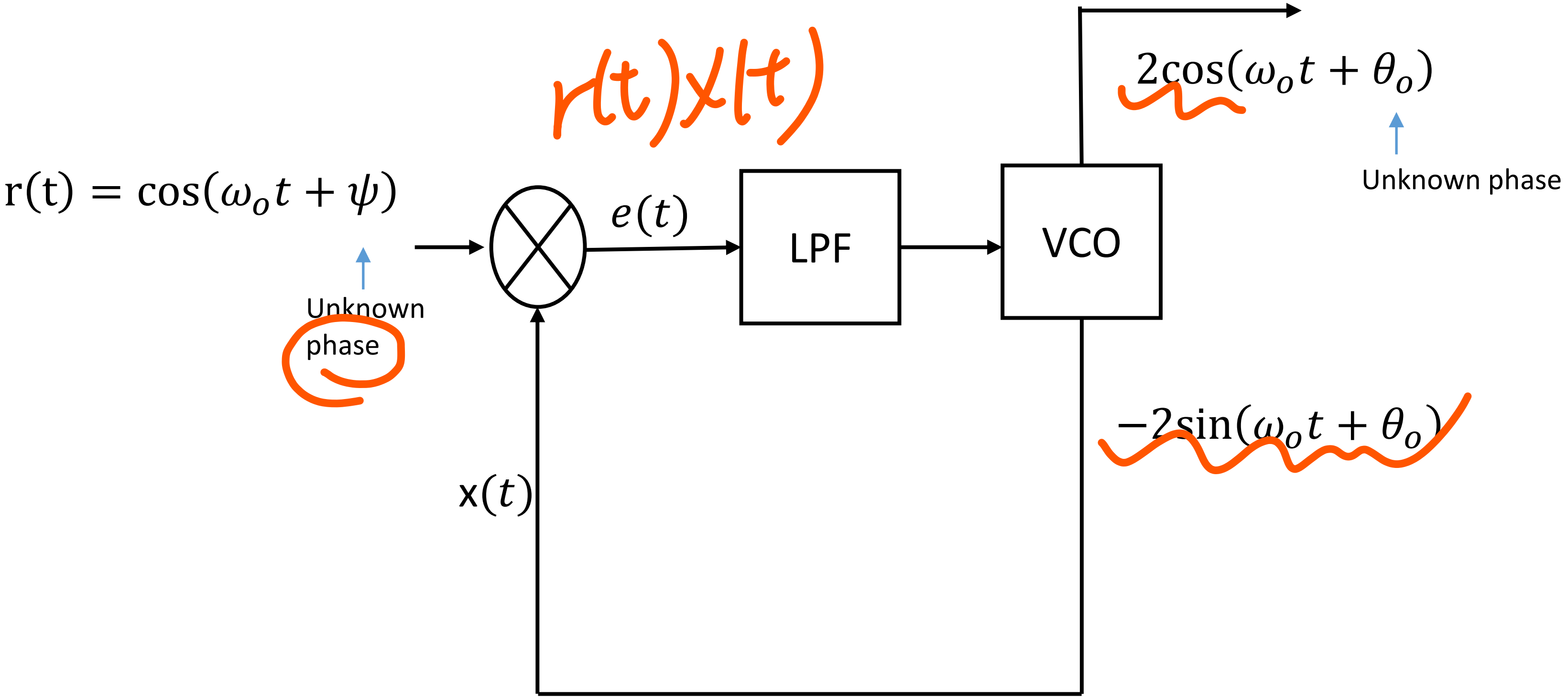
VCO

A PLL is mainly comprised of:

1. Phase Detector: generate the phase difference of $r(t)$ and $x(t)$.
2. Voltage or Numerically Controlled Oscillator: adjust the oscillator frequency based on this phase difference to eliminate the phase difference. At steady state, the output frequency will be exactly the same with the input frequency.
3. Loop Filter: a low pass filter

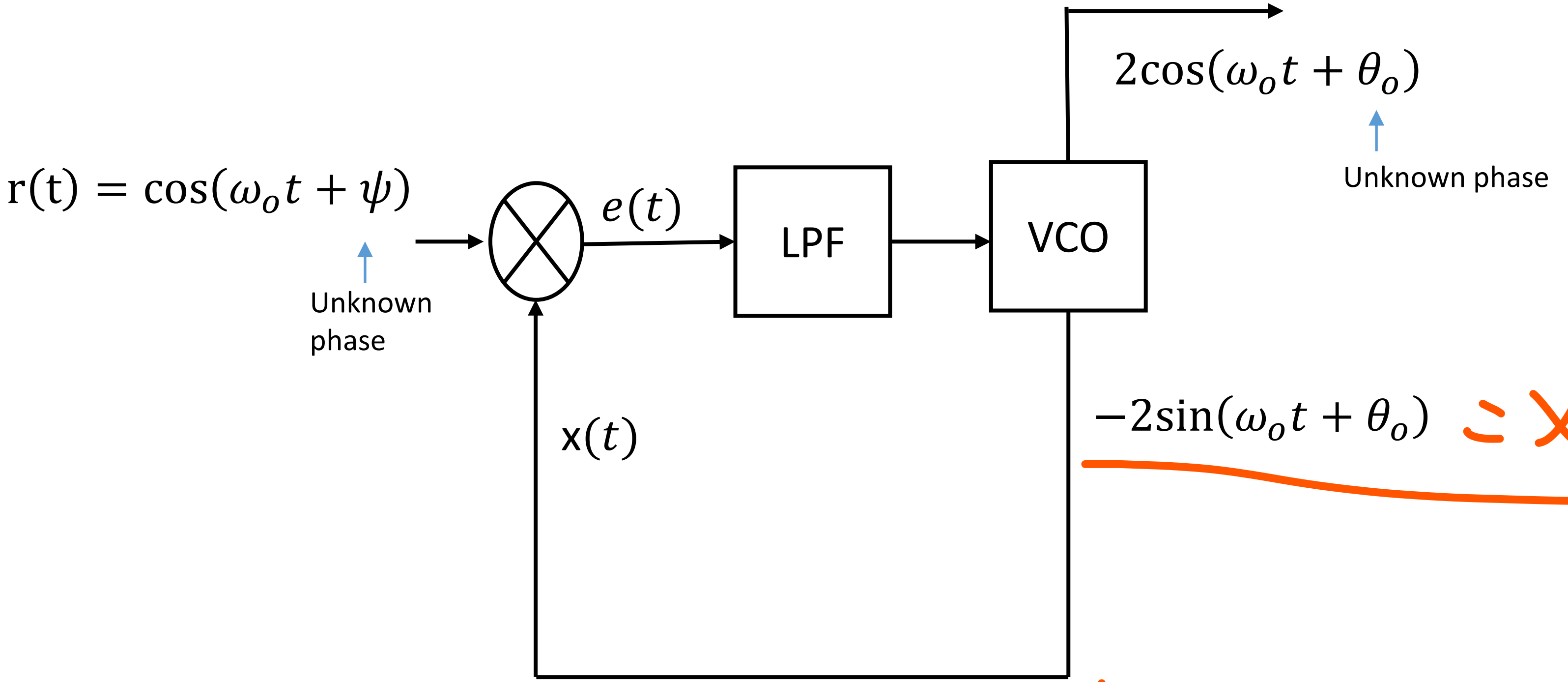


PLL Theory



Why the sine?
Sine and cosine are orthogonal

PLL Theory



$= x(t)$

$$e(t) = -2\cos(\omega_o t + \psi)\sin(\omega_o t + \theta_o)$$ 积化和差

$$e(t) = \sin(2\omega_o t + \theta_o + \psi) + \sin(\psi - \theta_o)$$

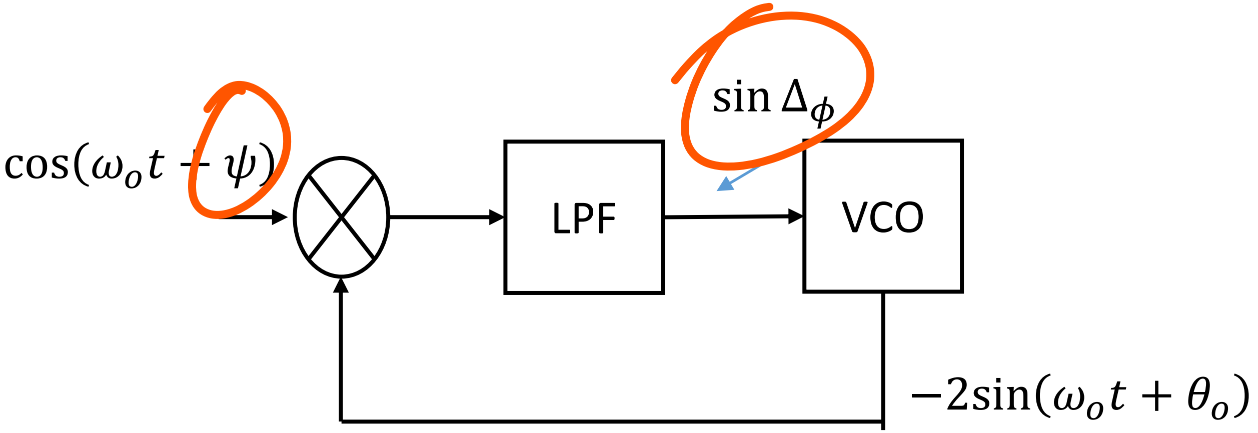
滤波

$$= \sin\Delta_\phi$$

$$\Delta_\phi = \psi - \theta_o$$

Phase difference between the input and the output (VCO frequency)

Why does the PLL Lock on ψ



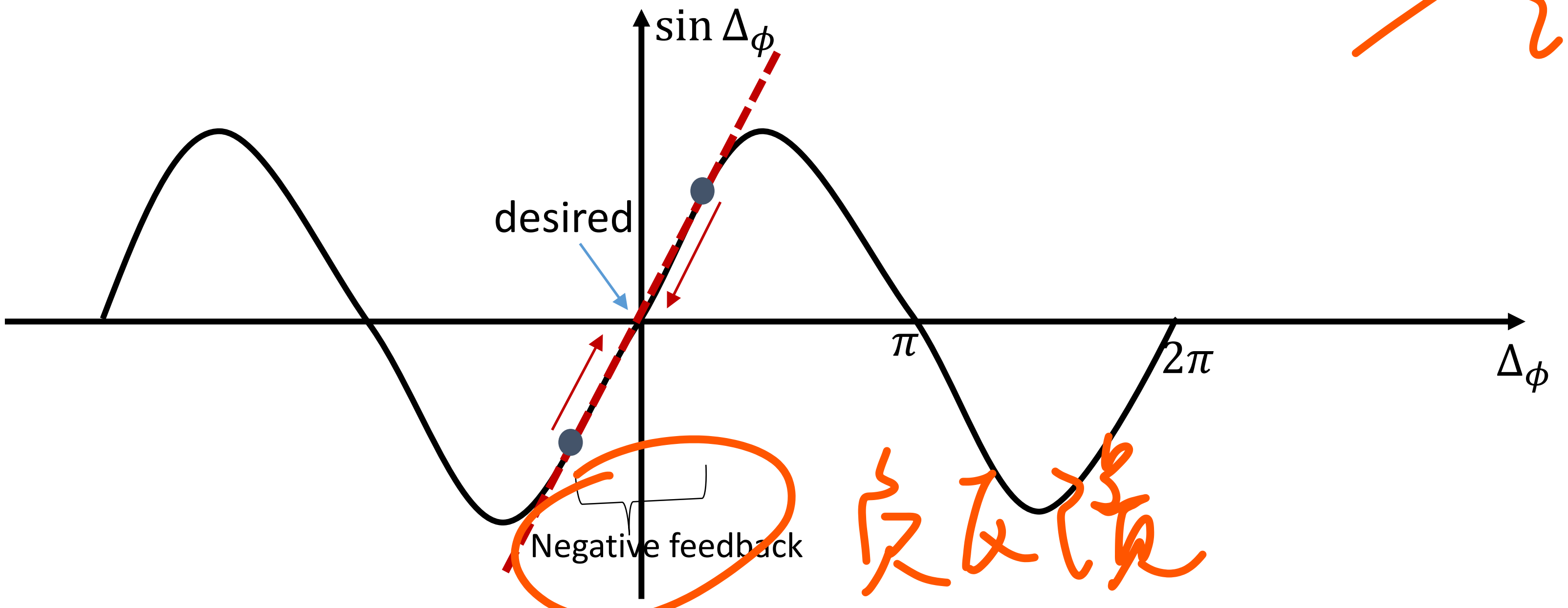
$\Delta_\phi = \psi - \theta_o$

最终目的：知道ψ是多少

$\Rightarrow$ 让$\Delta\varphi = 0$

$\Rightarrow$ 让$\psi = \theta_o$

锁相

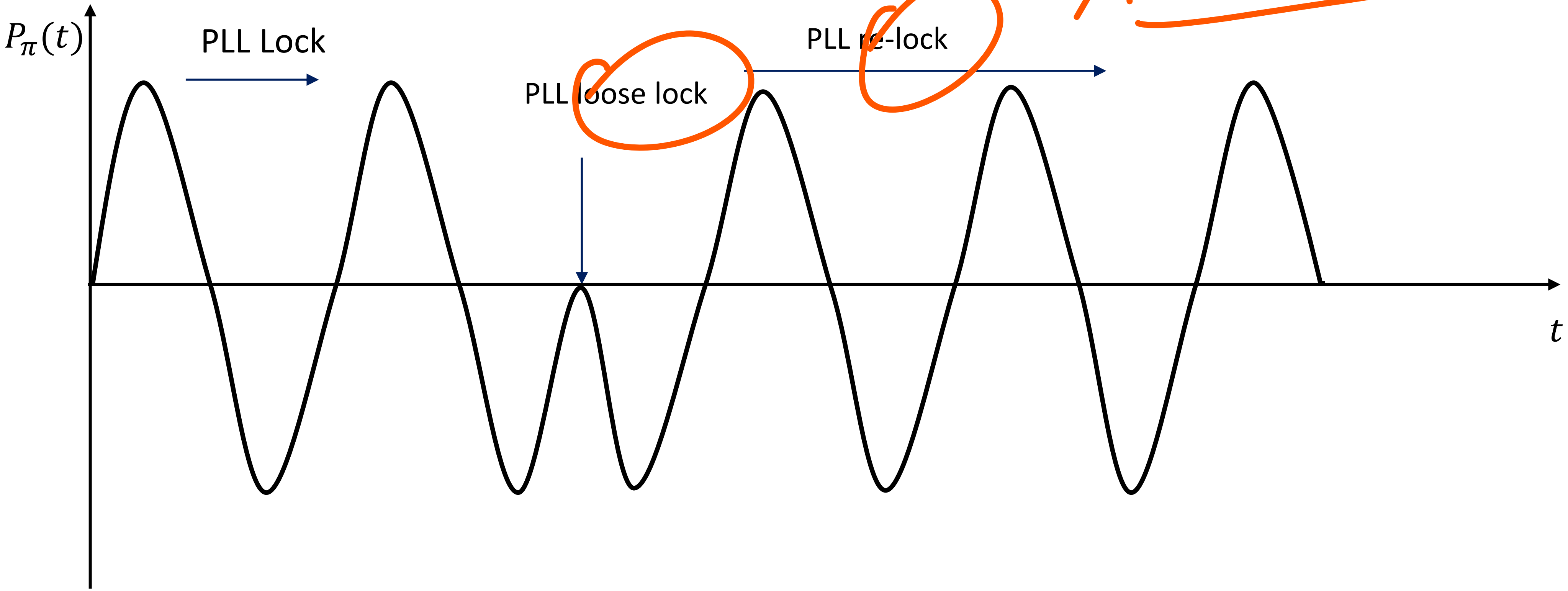


负反馈

PLL Phase modulation Problem

第二轮

- The phase of the received signal is constantly changing



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

只对BPSK有效

QPSK不能

知识创

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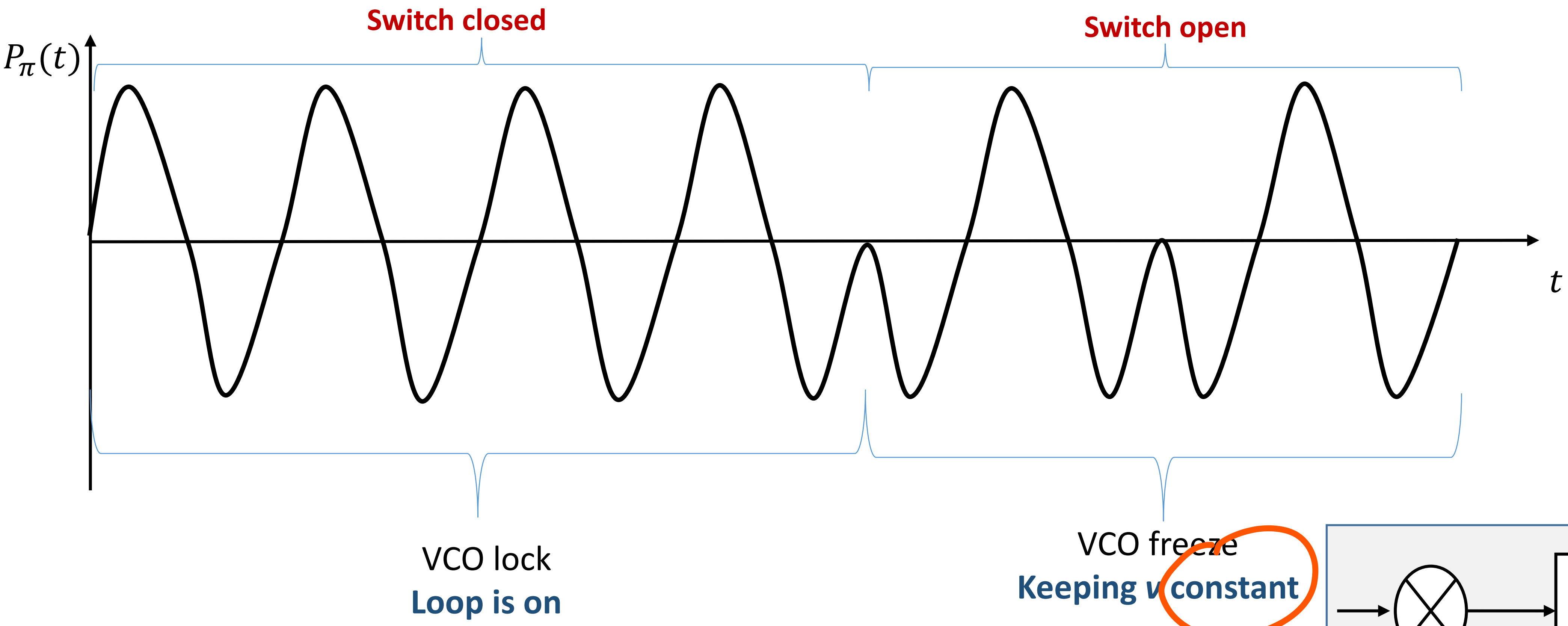
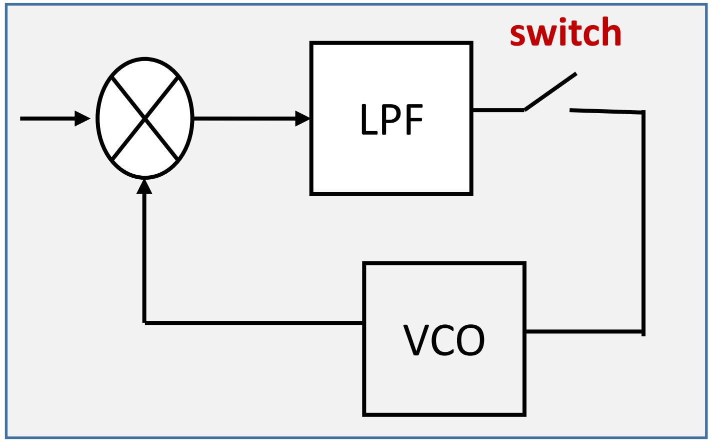
Use a training sequence





Classical Costas Loop

Main Idea: Costas loop eliminate phase information

$$\underbrace{s(t)}_{\text{symbols}}\overbrace{\cos(2\pi f_o t)}^{\text{carrier}}$$

↓

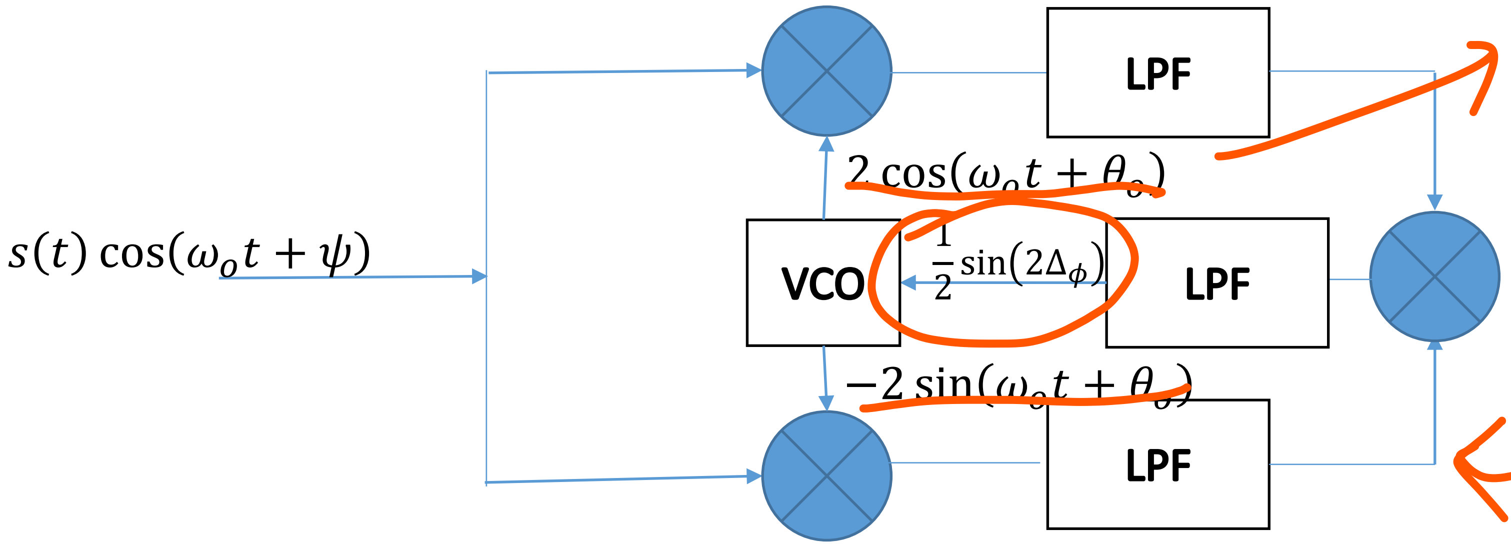
Costas loop ignores or eliminated this term

$$BPSK = A(t)\cos(\omega_0 t)$$

$$A(t) = \begin{cases} 1 \\ -1 \end{cases}$$

Classical Costas Loop

To use both the sine and the cosine from the VCO and create the voltage by combining them

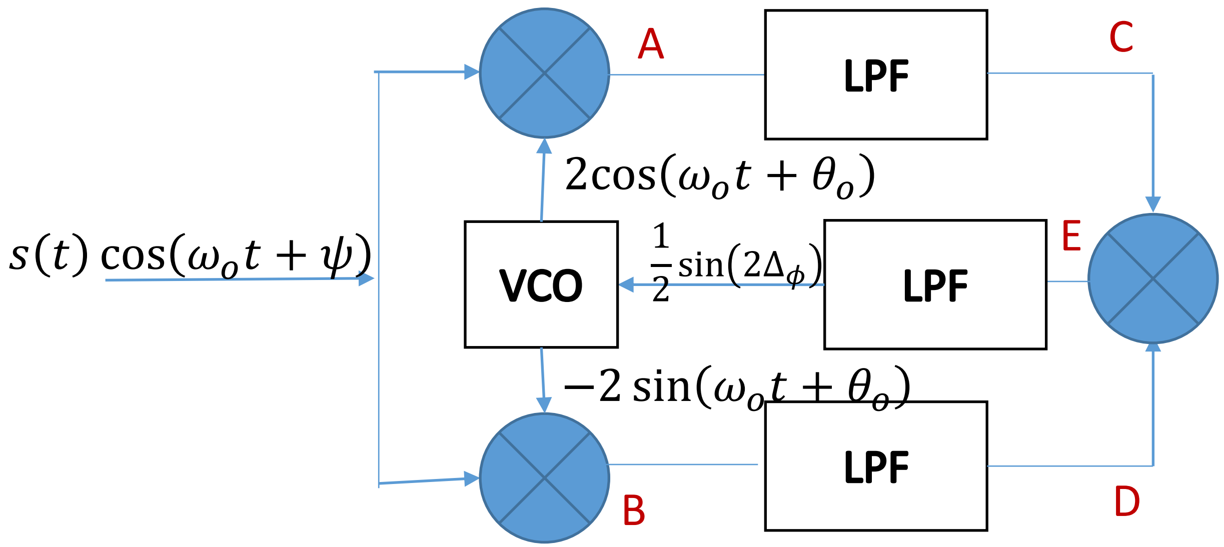


2个都用

(PLL只有一半)

$$\Delta_\phi = \psi - \theta_o$$

Classical Costas Loop



At point **A**: $s(t)\cos(\omega_o t + \psi).2\cos(\omega_o t + \theta_o)$
$=s(t)[\cos(\psi - \theta_o) + \cos(2\omega_o + \psi + \theta_o)]$

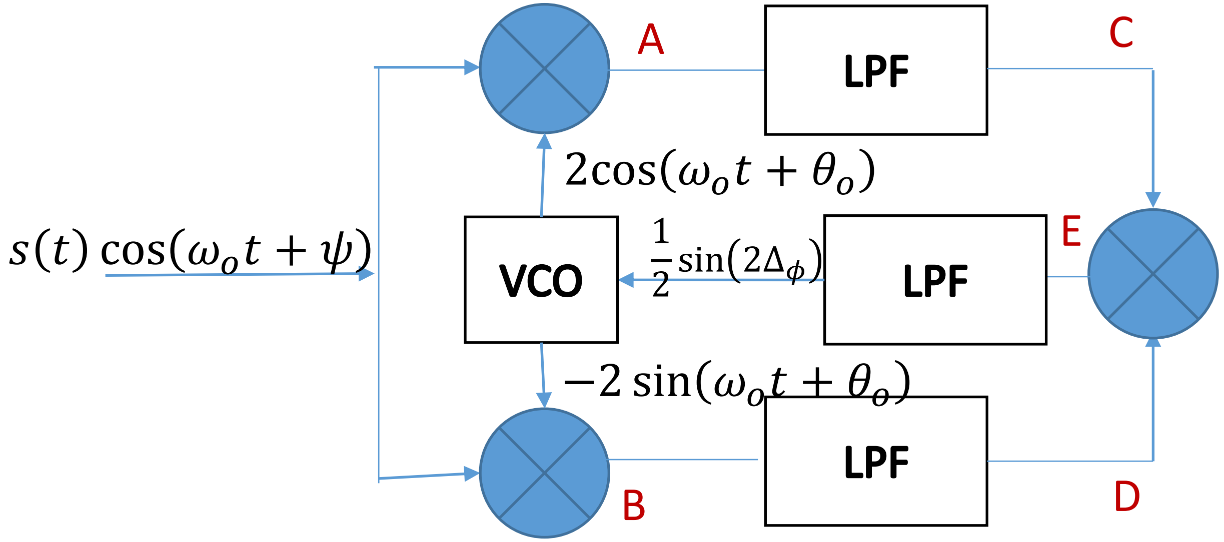
$$\Delta_\phi = \psi - \theta_o$$

At point **C** – after LPF: $s(t)\cos(\Delta_\phi)$

At point **B**: $s(t)\cos(\omega_o t + \psi). -2\sin(\omega_o t + \theta_o)$
$=s(t)[\sin(\psi - \theta_o) + \sin(2\omega_o + \psi + \theta_o)]$

At point **D** – after LPF: $s(t)\sin(\Delta_\phi)$

Classical Costas Loop



$$\Delta_\phi = \psi - \theta_o$$

At point **E**: $s(t)^2 \cos(\Delta_\phi)\sin(\Delta_\phi)$

$$\boxed{= \frac{s(t)^2}{2}\sin(2\Delta_\phi)}$$

$$K\sin(2\Delta_\phi)$$

Note that in $\boxed{\text{BPSK } s(t)^2 = 1}$

$$s(t) = 1 \text{ or } -1$$

忽略相位改变

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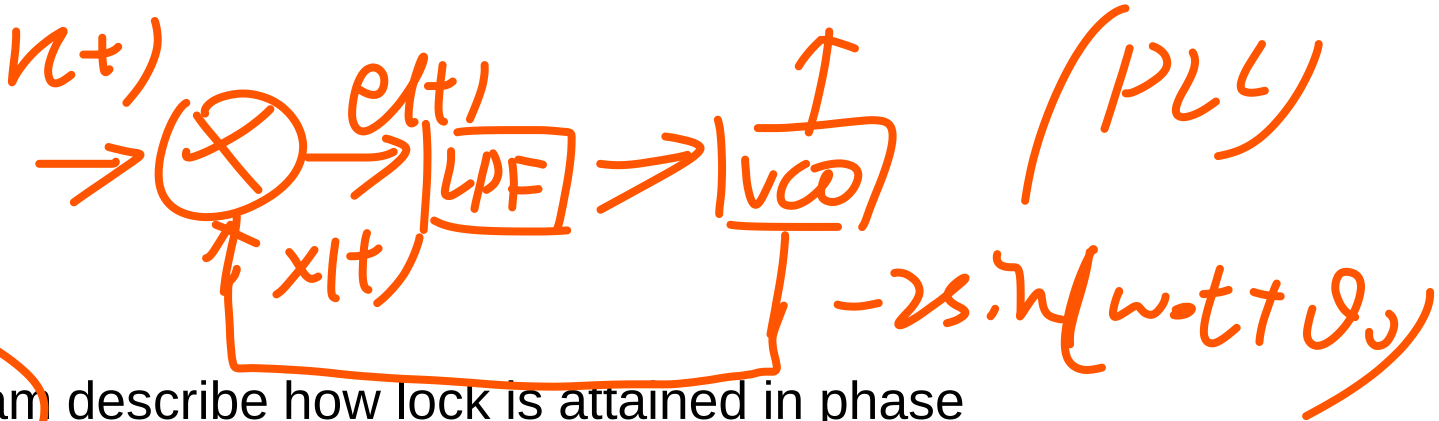
Review Questions



- With the aid of a schematic diagram describe how lock is attained in phase locked loop (PLL) and the Costas loop.
- State the limitation of PLL in PSK and the techniques that can be used to address this problem
- The transmitted BPSK signal experience a doppler shift resulting in a frequency offset Δ_f. Obtain the demodulated signal and comment on the obtained result.
- Explain how Costas-loop can be used to overcome the challenge faced by BPSK in PLL

多普勒频移

$f_0 = \frac{f_s v}{v \pm v_s}$

$\Delta f = f_0 - f_s$

或 $f' = \frac{(v \pm v_0)}{(v \mp v_s)} f$