Synchronization

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

- Carrier synchronization
- Symbol/Bit synchronization
- Frame synchronization

Synchronization

- **Carrier synchronization**

  To recover the signal without distortion, receiver needs to 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.

As to digital communication system, symbol/bit synchronization and frame synchronization are also required.

Synchronization

- **Symbol/bit synchronization**

  The output of the receiving filter must be sampled at the symbol rate and at the precise sampling time instants. Hence, we require a clock signal. The process of extracting such a clock signal at the receiver is called symbol/bit synchronization.

- **Frame synchronization**

  Receiver can proceed by every group of symbols instead of every single symbol, such as a frame in TDM system. Similar with symbol/bit synchronization, the process of extracting such a clock signal is called frame synchronization.

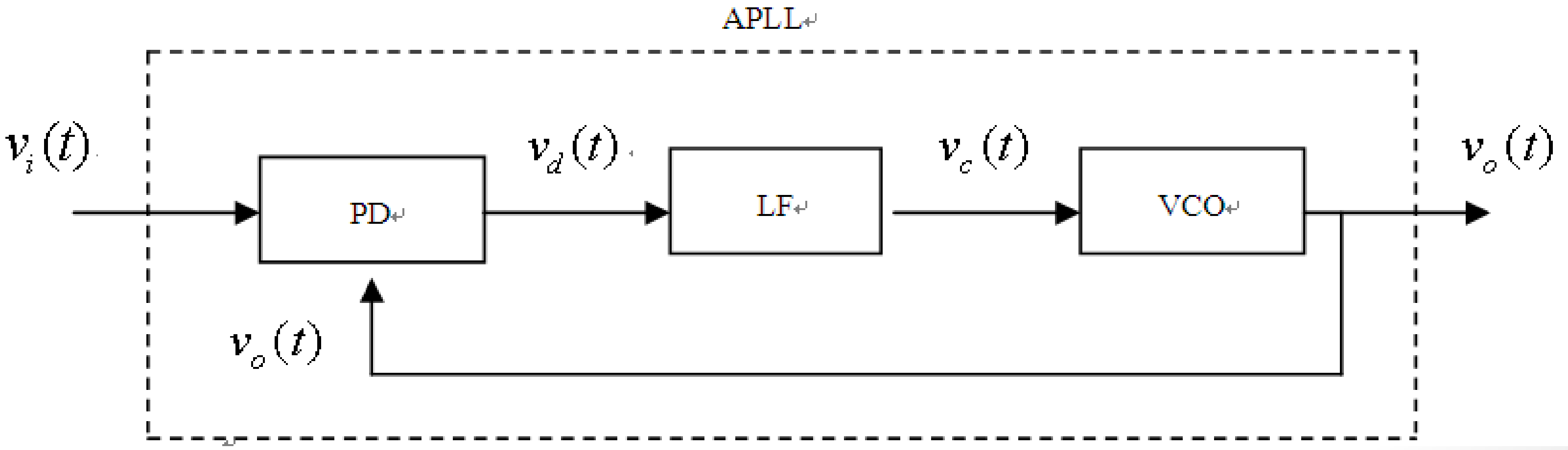
Synchronization

The synchronized system required:

- Synchronous signal must have high noise immunity and be reliable.
- Generating synchronous signal should not consume much extra power and increase implementation complexity.
- Synchronous signal should possess few channel resource.

Phase-locked Loop

PLL is a feedback loop with a voltage-controlled oscillator (VCO), a phase detector (PD)and a loop filter (LF). The PD will generate the phase difference of $v_i(t)$ and $v_o(t)$. The VCO will 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.



Phase-locked Loop

$$v_i(t) = v_i \sin[\omega_0 t + \phi(t)]$$

$$v_o(t) = v_o \cos[\omega_0 t + \hat{\phi}(t)]$$

A PD contains a multiplexer and a lowpass filter. The LPF is for filtering the extra frequency component generated by multiplexing. The output voltage is:

$$v_d(t) = \mathrm{K}_d \sin[\phi(t) - \hat{\phi}(t)] = \mathrm{K}_d \sin \phi_e(t)$$

Loop filter is also a LPF. Active/passive PI filter are most commonly used.

The output of the LF is:

$$v_c(t) = F(p) v_d(t)$$

$$p = \frac{d}{dt}$$

Phase-locked Loop

The output of VCO can be a sinusoid or a periodic impulse train. The differentiation of the output frequency are largely proportional to the input voltage.

$$\frac{d\,\hat{\phi}(t)}{dt} = \mathrm{K}_v v_c(t)$$

If F(p)=1， Then

$$\frac{d\,\hat{\phi}(t)}{dt} = \mathrm{K}\sin\phi_e(t)$$

This kind of loop is called the first-order loop

Phase-locked Loop

In a coherence system, a PLL is used for:

1. PLL can track the input frequency and generate the output signal with small phase difference.
2. PLL has the character of narrowband filtering which can eliminate the noise introduced by modulation and reduce the additive noise.
3. Memory PLL can sustain the coherence state for enough time.

CMOS-based integrated PLL has several advantages such as ease of modification, reliable and low power consumption, therefore are widely used in coherence system.

Carrier Synchronization

To extract the carrier：

1. Pilot-tone insertion method

Sending a carrier component at specific spectral-line along with the signal component. Since the inserted carrier component has high frequency stability, it is called pilot.

2. Direct extraction method

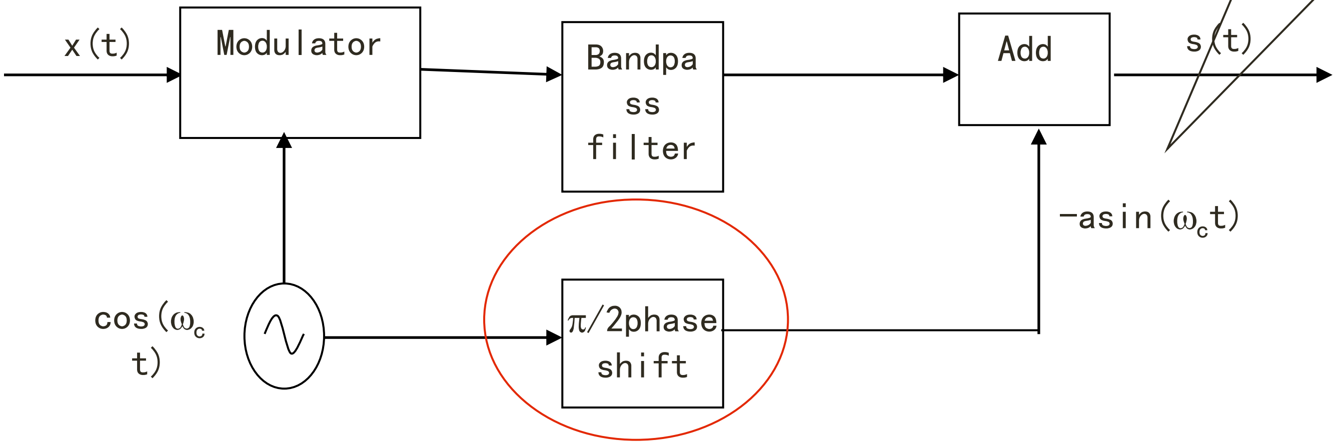
Directly extract the synchronization information from the received signal component.

Pilot-tone insertion method

1. Pilot-tone insertion method

—insert pilot to the modulated signal

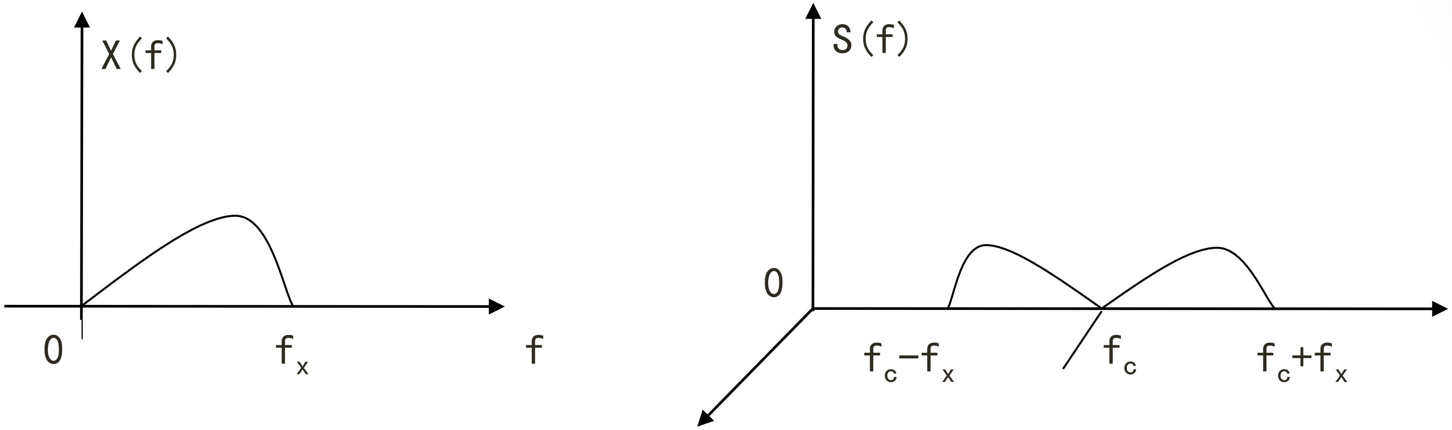
Thinking:
Why 90^0 shift?



The pilot signal is generated by shift the carrier by 90^0 and decrease by several dB, then add to the modulated signal. Assume the modulated signal has 0 DC component, then the pilot is

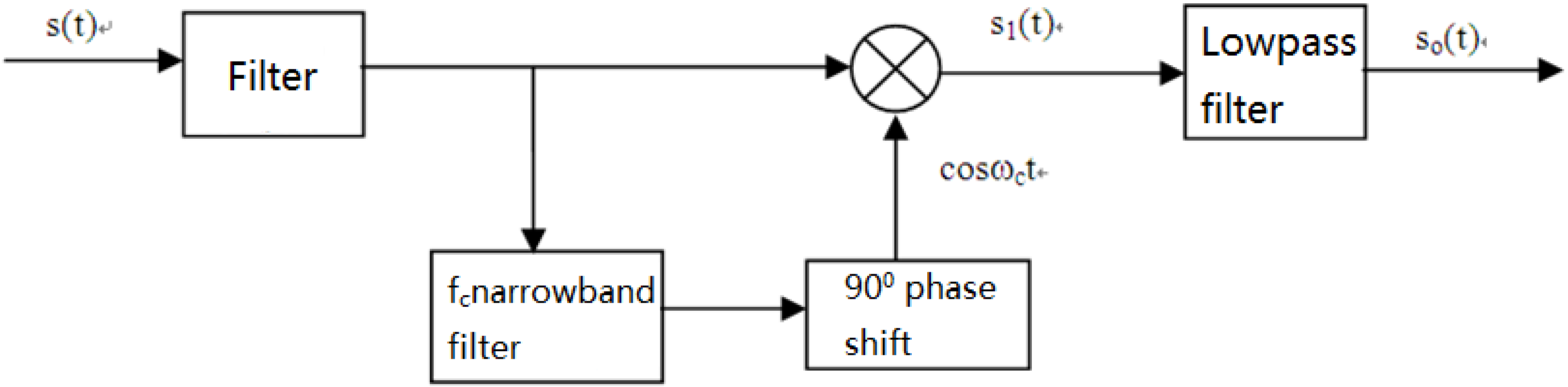
$$s(t) = f(t)\cos\omega_c t - a\sin\omega_c t$$

Pilot-tone insertion method



The receiver uses a narrowband filter with central frequency f_c to extract the pilot $a\sin\omega_c t$ and then the carrier $a\cos\omega_c t$ can be generated by simply shifting 90^0.

Pilot-tone insertion method



$$s_1(t) = s(t)\cdot\cos\omega_c t = f(t)\cos^2\omega_c t - a\sin\omega_c t\cos\omega_c t$$

$$= \frac{1}{2}f(t) + \frac{1}{2}f(t)\cos 2\omega_c t - \frac{1}{2}a\sin 2\omega_c t$$

After the LPF $s_0(t) = \frac{1}{2}f(t)$

DSB, SSB and PSK are all capable of pilot-tone insertion method. VSB can also apply pilot-tone insertion method but it is more complex.

Narrowband Filter

The drawback of narrowband filter:

- The pass band is not narrow enough
- f_c is fixed, do not tolerate any frequency drift with respect to the central frequency

- Can be replaced by PLL

Pilot-tone insertion method is suitable for DSB, SSB, VS and 2PSK

Direct extraction method

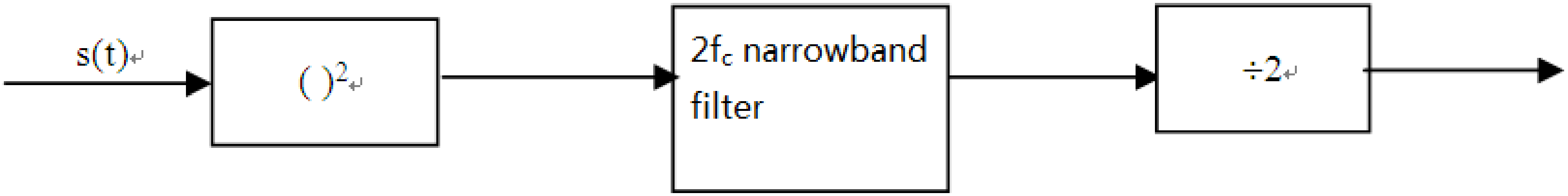
2. Direct extraction method

1）. If the spectrum of the received signal already contains carrier component, then the carrier component can be extracted simply by a narrowband filter or a PLL.

2）. If the modulated signal already eliminates the carrier component, then the carrier component can be extracted by performing nonlinear transformation or using a PLL with specific design.

Nonlinear-transformation-based method

1. Square transformation



$s(t)$

$(\ )^2$

$2f_c$ narrowband filter

÷2

Example: a DSB signal $s(t) = f(t)\cos\omega_c t$

If $f(t)$ has 0 DC component, then $s(t)$ *does not have carrier component*

square transformation: $\mathrm{s}^2(t) = \frac{1}{2}f^2(t) + \frac{1}{2}f^2(t)\cos 2\omega_c t$

now $f^2(t)$ contains DC component, let it be α, so: $f^2(t) = \alpha + f_m(t)$

then $s^2(t) = \frac{1}{2}\alpha + \frac{1}{2}f_m(t) + \frac{1}{2}\alpha\cos 2\omega_c t + \frac{1}{2}f_m(t)\cos 2\omega_c t$

Nonlinear-transformation-based method

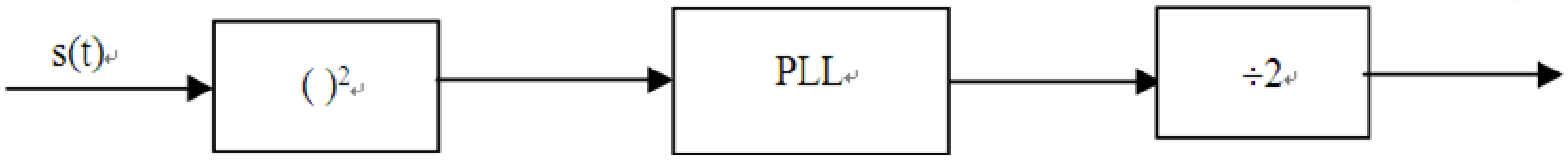
$$s^2(t)=\frac{1}{2}\alpha+\frac{1}{2}f_m(t)+\boxed{\frac{1}{2}\alpha\cos 2\omega_c t}+\frac{1}{2}f_m(t)\cos 2\omega_c t$$

The first term is the DC component. The second term is the low frequency component. The third term is the $2\omega_c$ component. The 4th term is the frequency component symmetrical distributed of $2\omega_c$—modulation noise. After narrowband filtering, only the 3rd term and a small fraction of 4th term left, then the carrier component can be extracted by frequency division.

Since the carrier is extracted by frequency division, its phase may shift by 180^o. Besides, modulation noise may cause random phase jitter.

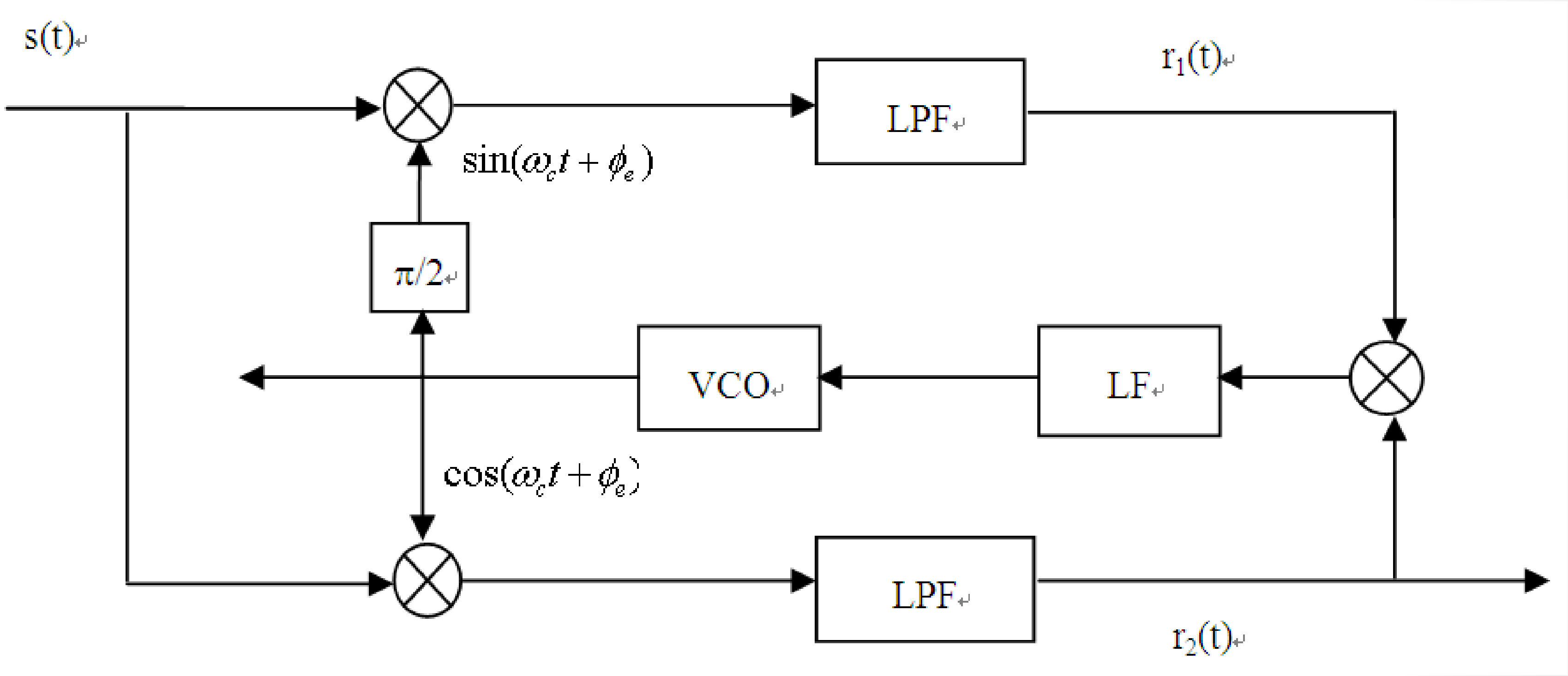
Nonlinear-transformation-based method

- Square PLL



In-phase orthogonal loop—Costas Loop

2. In-phase orthogonal loop —Costas Loop



Contains in-phase branch and orthogonal branch. All parts except LF and VCO are similar with a “phase detector”.

In-phase orthogonal loop—Costas Loop

Let $s(t)=f(t)\cos\omega_c t$

(1) upper branch

$$f(t)\cos\omega_c t\cdot\sin(\omega_c t+\phi_e)=\frac{1}{2}f(t)\sin\phi_e+\frac{1}{2}f(t)\sin(2\omega_c t+\phi_e)$$

ϕ_e is the phase difference between generated carrier and the original carrier

After LPF $r_1(t)=\frac{1}{2}f(t)\sin\phi_e$

When ϕ_e is small， $r_1(t)=\frac{1}{2}f(t)\phi_e$

(2) lower branch

$$r_2(t)=\frac{1}{2}f(t)\cos\phi_e\to\frac{1}{2}f(t)$$

(3)$r_1(t)\cdot r_2(t)\to\frac{1}{4}f^2(t)\phi_e=v_d(t)$