Synchronization

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

Synchronization

Symbol/bit synchronization

In digital systems, the output of the receiving filter (i.e. matched 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

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.

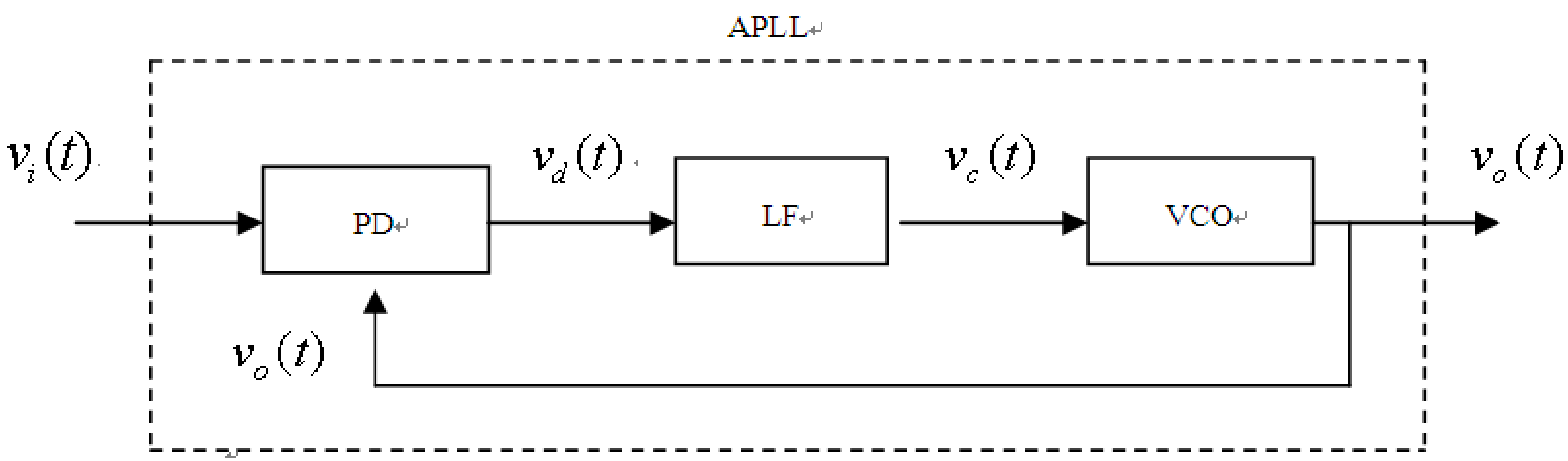
Phase-locked Loop

PLL is often used in carrier syn. and symbol syn. It is a closed-loop control system consisting of

❖Phase detector (PD): generate the phase difference of $v_i(t)$ and $v_o(t)$.

❖Voltage-controlled oscillator (VCO): 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.

❖Loop filter (LF)



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 multiplier and a lowpass filter. The output of PD 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.

The output of the LF is (where F(p) is the transfer function)

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

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

Digital PLL

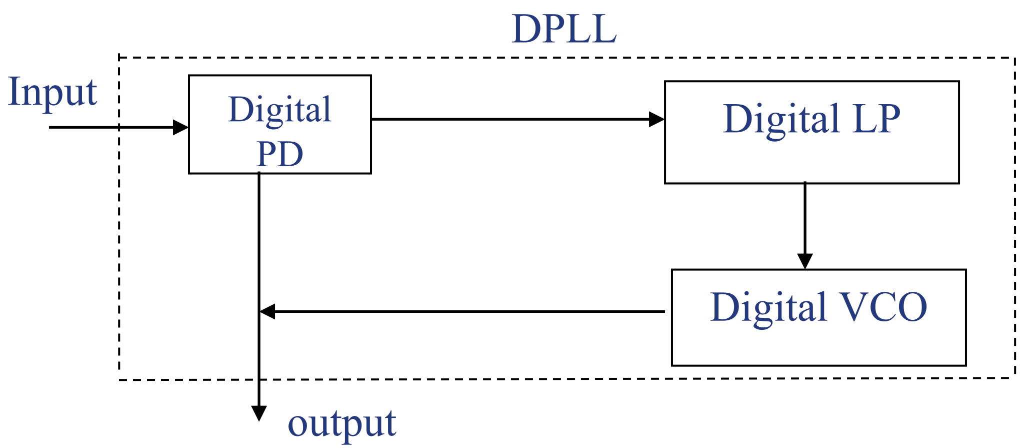


图9-6 DPLL的组成

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

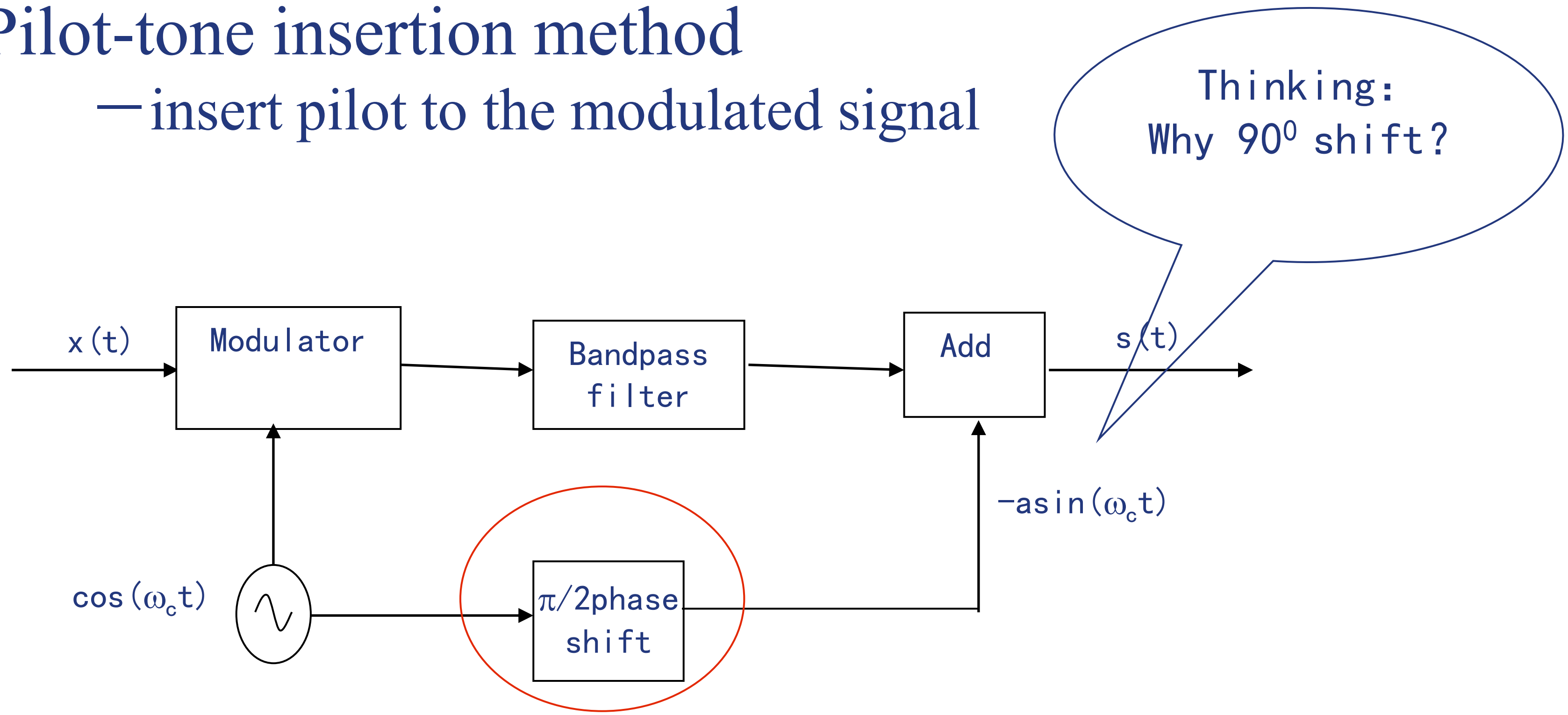
2. Direct extraction method

Directly extract the synchronization information from the received signal component.

Pilot-tone insertion method

1. Pilot-tone insertion method

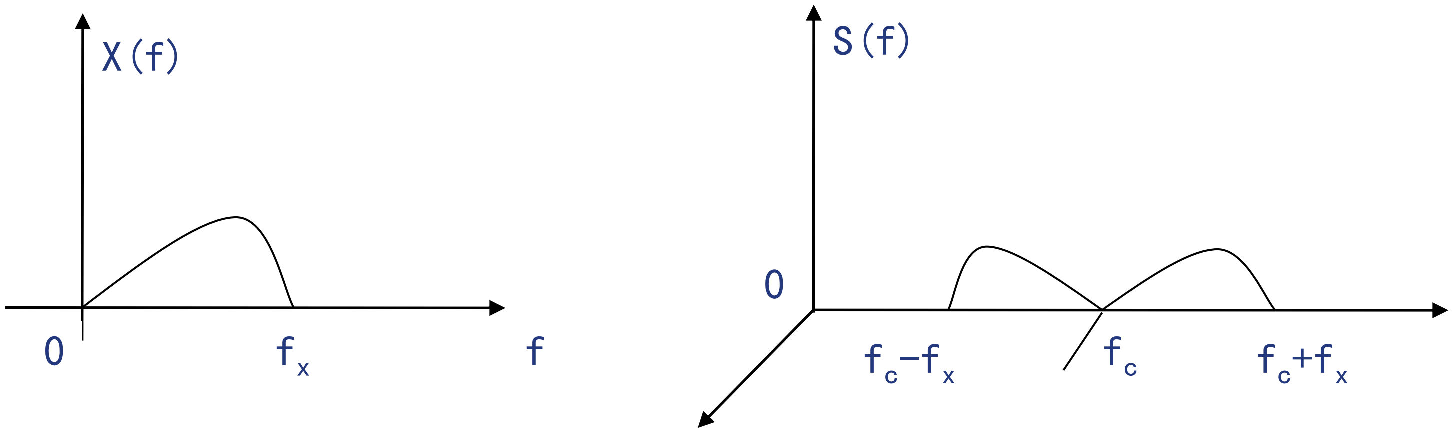
—insert pilot to the modulated signal



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

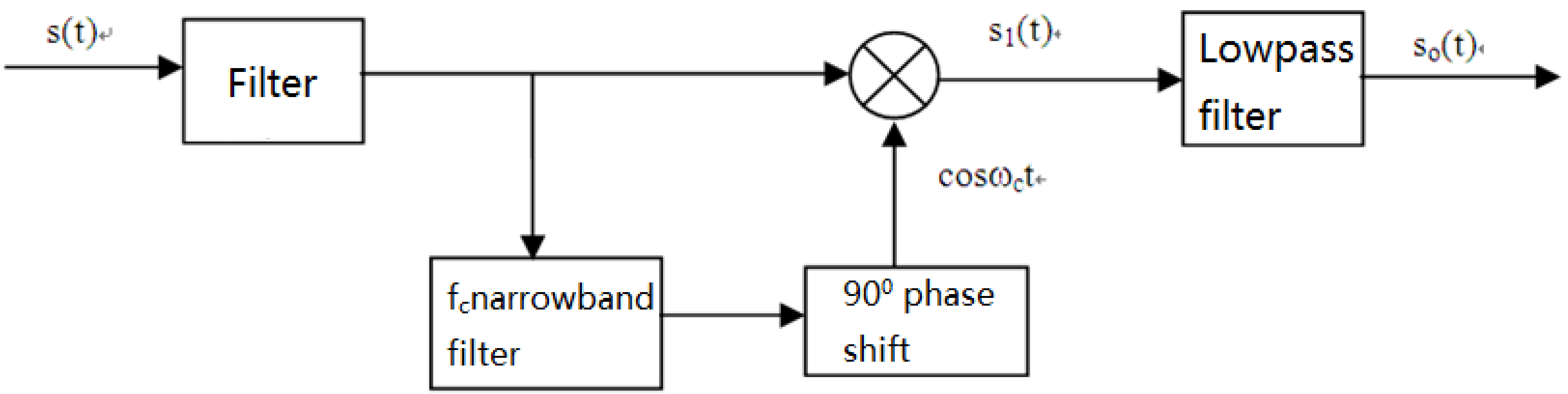
$$s(t) = f(t)\cos\omega_c t - a\sin\omega_c t$$

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 with certain modification.

Narrowband Filter

The drawback of narrowband filter:

- The pass band is not narrow enough
- f_c is fixed, cannot 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

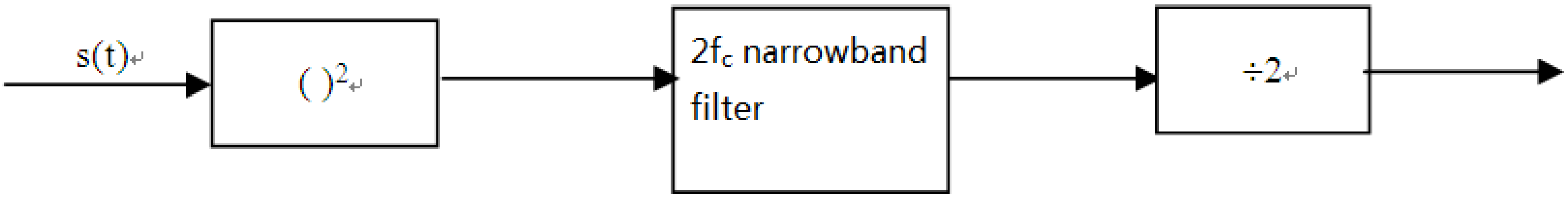
2. Direct extraction method

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 supresses the carrier component, then the carrier component may be extracted by performing nonlinear transformation or using a PLL with specific design.

Nonlinear-transformation-based method

1. Square transformation



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

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

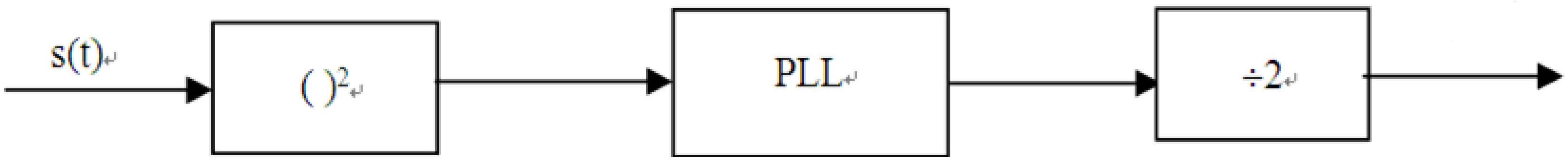
$$s^2(t)=\frac{1}{2}\alpha+\frac{1}{2}f_m(t)+\frac{1}{2}\alpha\cos 2\omega_c t+\frac{1}{2}f_m(t)\cos 2\omega_c t$$

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.

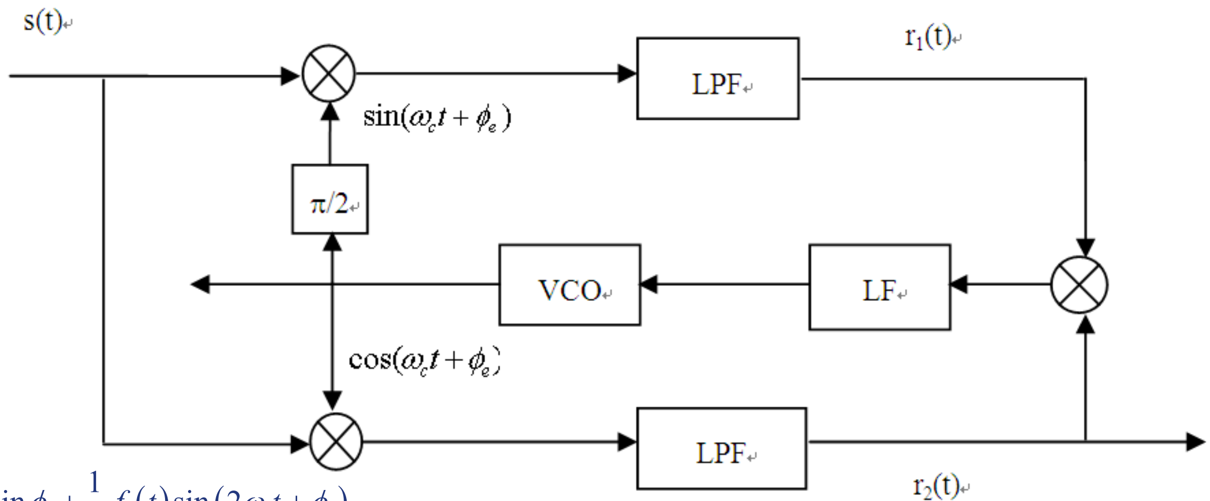
Since the carrier is extracted by frequency division, its phase may shift by 180^o. Besides, modulation noise may cause random phase jitter.

Nonlinear-transformation-based method

- Square PLL



2. 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

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

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

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

Advantages of Costas loop:

1.Costas loop works on f_c instead of $2f_c$, so when f_c is large, Costas loop is easier to realize

2.The output of in-phase loop $r_2(t)$ is the signal $f(t)$

3. Performance of carrier synchronization technique

1) Phase error: steady-state phase error, random phase error
2) Synchronization build time and hold time

Symbol Synchronization

- In a digital communication system, the output of the receiving filter must be sampled periodically at the symbol rate and at the precise sampling time instance.
- To perform this periodic sampling, we need a clock signal at the receiver
- The process of extracting such a clock signal is called symbol synchronization or timing recovery
- One method is for the transmitter to simultaneously transmit the clock frequency along with the information signal. The receive can simply employ a narrowband filter or PLL to extract it. This method requires extra power and bandwidth and hence, but frequently used in telephone transmission systems.
- Another method is to extract the clock signal from the received data signal by using some kind of non-linear transformation.