ENSC327
Communications Systems
4. Double Sideband Modulation

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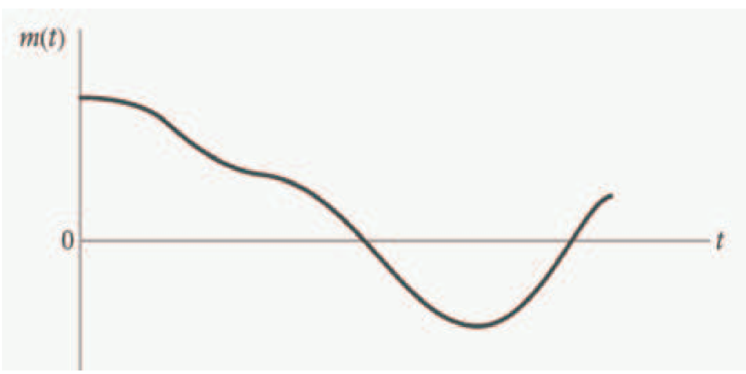
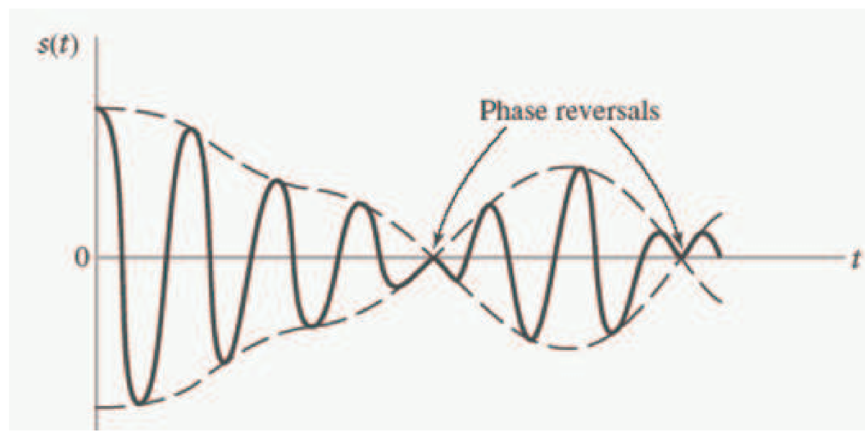
Outline

- DSB:
  - Modulator
  - Spectrum
  - Coherent Demodulator:
    - Three methods
- Quadrature-carrier Multiplexing

Double Sideband Modulation (DSB)

- AM: $$s(t) = A_c\left[1 + k_a m(t)\right]\cos(2\pi f_c t)$$
- DSB: $$s(t) = A_c m(t)\cos(2\pi f_c t)$$
  - No carrier component in the DSB signal.
- Input: DSB Output:





- Envelope is no longer the input,
- Cannot use envelope detector as demodulation.

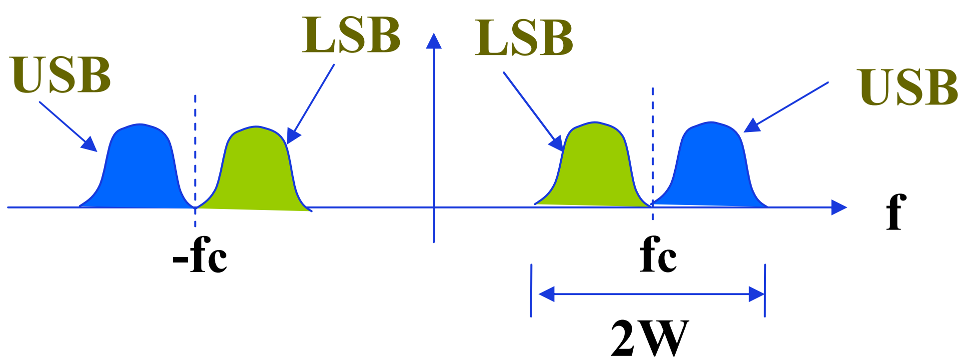
Spectrum of DSB

The FT of DSB signal is $S(f) = \frac{A_c}{2}\left[M(f - f_c) + M(f + f_c)\right]$

Proof:

Spectrum of DSB

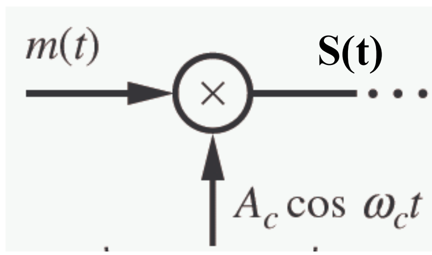
- Upper Sideband and Lower Sideband
  - Upper Sideband (USB): [fc, fc + W], [- fc – W, -fc].
  - Lower Sideband (LSB): [fc - W, fc], [- fc, -fc + W].



- Bandwidth: 2W (same as AM)
- No component at carrier frequency, unless m(t) has a DC:
  - ➔ DSB is also called suppressed carrier DSB (DSB-SC)
  - Better power efficiency
  - The price paid is more complicated demodulation.

Modulator & Demodulator of DSB

- Modulator: The generation of DSB signal is straightforward, Just multiply the message with the carrier.
- This is also called Product Modulator



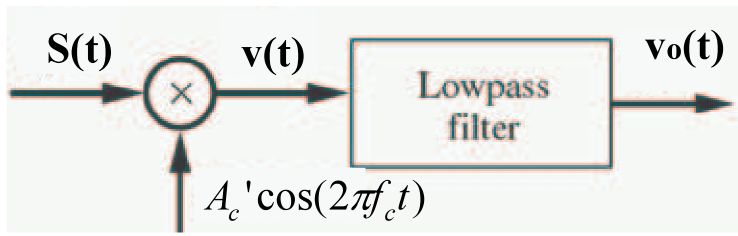
$$s(t) = A_c m(t)\cos(2\pi f_c t)$$

- Demodulator: The demodulation is more complicated than the AM, because the envelop detector cannot be used in DSB.
- The key idea of DSB demodulation: the trigonometric identity

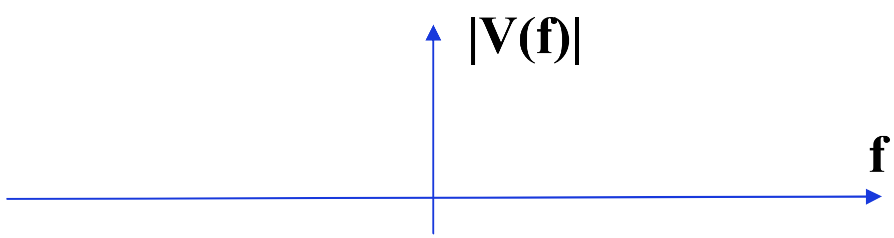
$$\cos^2(2\pi f_c t) =$$

Coherent Detection (Synchronous Demodulation)

- Assuming a coherent or synchronized carrier signal is available at the receiver, the message can be recovered by multiplying the received signal with the coherent carrier, followed by a lowpass filter.



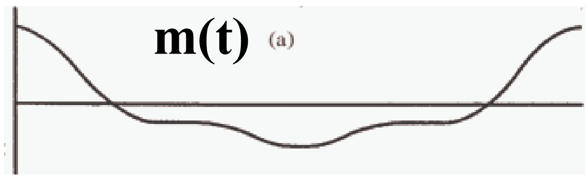
- After multiplying with coherent carrier:

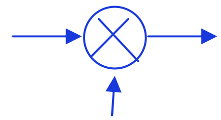


- After lowpass filter:

Example

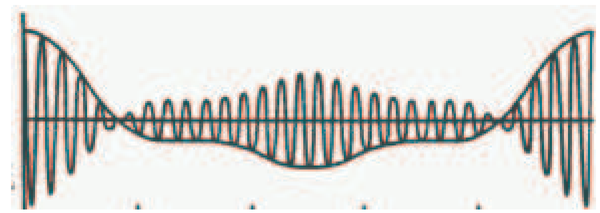
- Modulation:



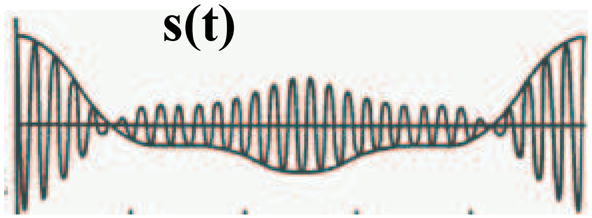


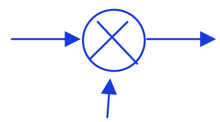
$A_c \cos(2\pi f_c t)$

$s(t) = A_c m(t) \cos(2\pi f_c t)$



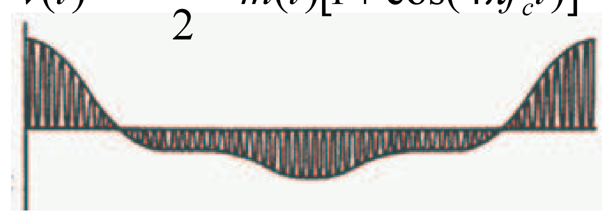
- Demodulation:





$A_c' \cos(2\pi f_c t)$

$v(t) = \frac{A_c A_c'}{2} m(t)[1 + \cos(4\pi f_c t)]$

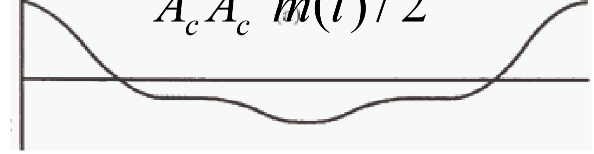


Freq is higher than in s(t).

Sign of v(t) is same as m(t).

LPF

$A_c A_c' m(t)/2$



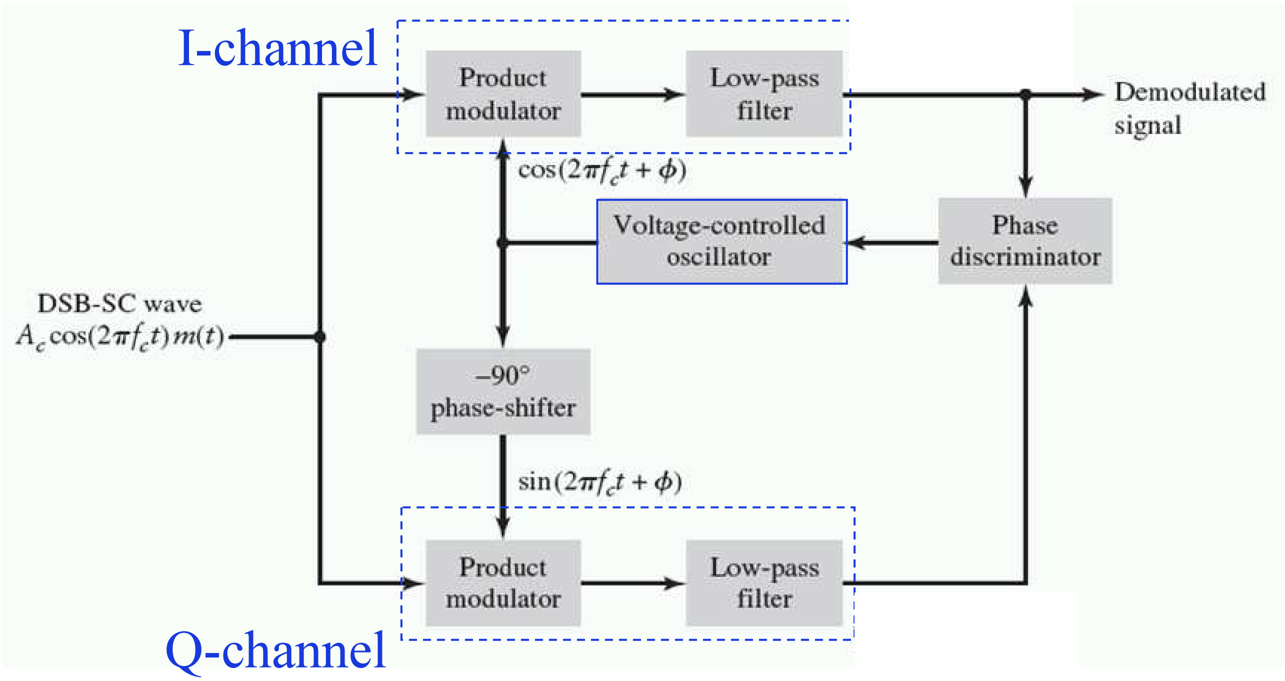
Phase Error of the Demodulator

- So far we assume the demodulator has a carrier that has the same frequency and phase as the transmitter
- If a phase error exists at the receiver:
- After LPF:
- If the phase error is constant:
- Otherwise:

DSB: Generation of Coherent Carrier

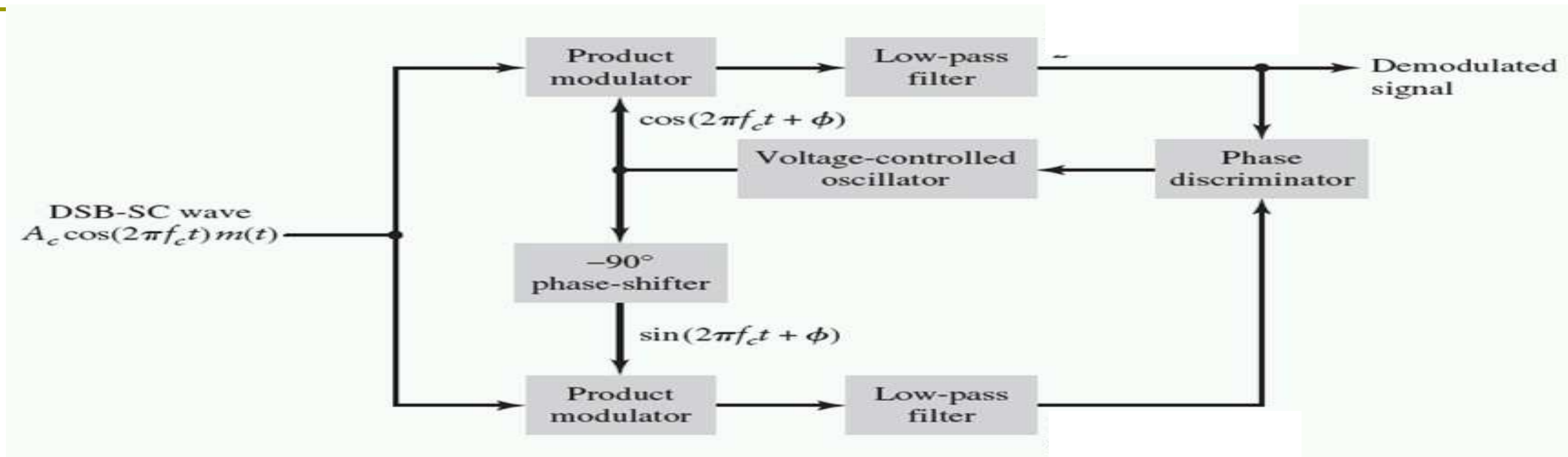
- Methods to generate a phase coherent carrier:
- Method 1. Costas receiver
  - Invented by John Costas at General Electric in the 1950s.
  - Also known as Costas Phase Locked Loop (PLL):
  - A negative feedback system that generates a signal, whose phase is locked to the phase of an input or "reference" signal.
  - Accomplished by a voltage controlled oscillator (VCO)
- Method 2. Squaring the received signal
- Method 3. Transmitting pilot signal
  - Used in stereo FM

3.4 Costas Receiver



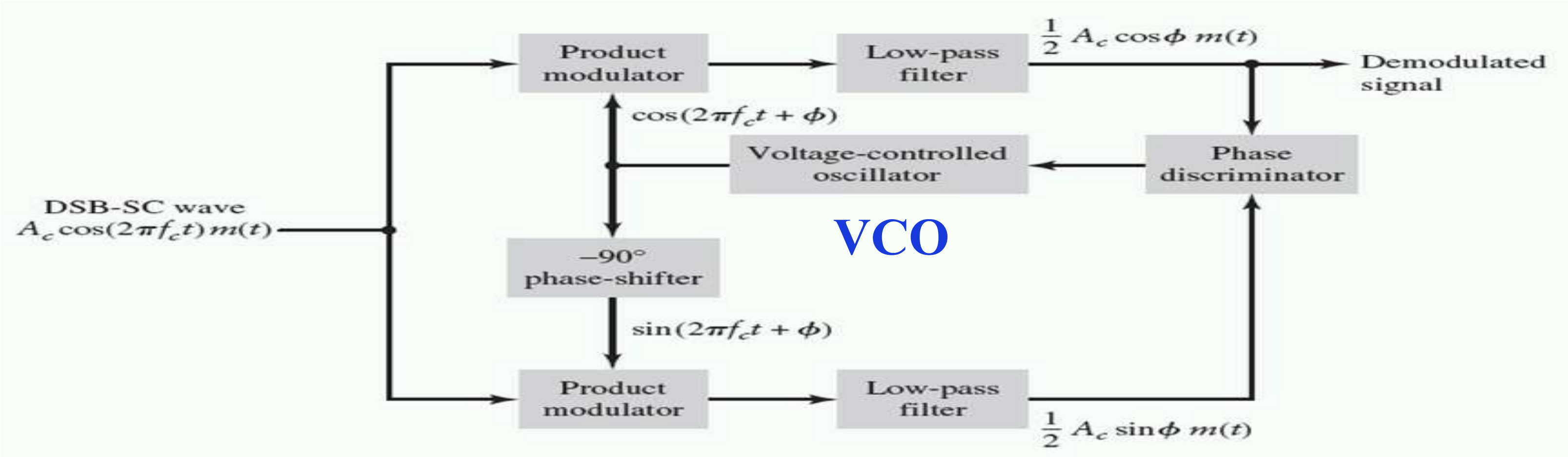
- Two local oscillator signals that are in quadrature: $\cos(2\pi f_c t + \phi)$
  - with 90^o phase difference $\sin(2\pi f_c t + \phi)$
- These local carriers are used by two coherent detectors:
  - In-phase coherent detector (also known as I-channel)
  - Quadrature-phase coherent detector (or Q-channel)

3.4 Costas Receiver

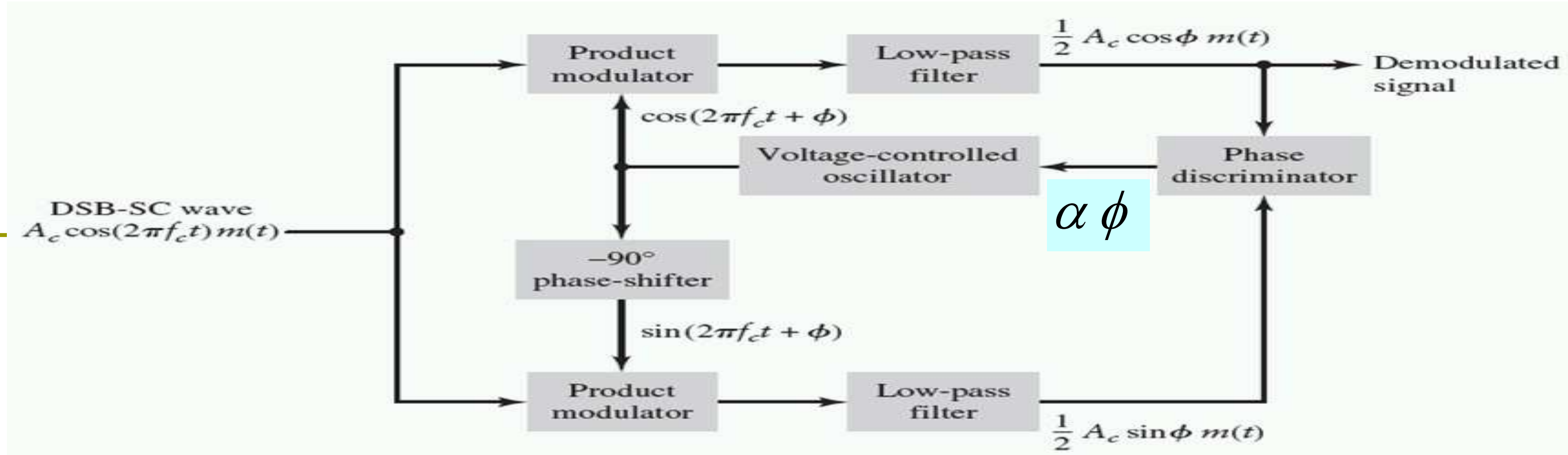


- The I-channel output is
- The Q-channel product modulator output:
- The output after lowpass filter:

3.4 Costas Receiver



- When phase error is 0:
  - I-channel output:
  - Q-channel output:
- If the phase of the local carrier drifts by a small value ϕ :
  - I-channel output:
  - Q-channel output:



- The phase discriminator consists of a multiplier followed by a time-averaging unit:
  - Multiplier output:
  - Time averaging output (which is input of VCO):

→ The phase discriminator output is proportional to

- VCO is a negative feedback system:
- The VCO will drive the local carrier phase to 0.
- Synchronization with the input is thus achieved.

DSB: Generation of Coherent Carrier

- Method 2. Squaring the received signal

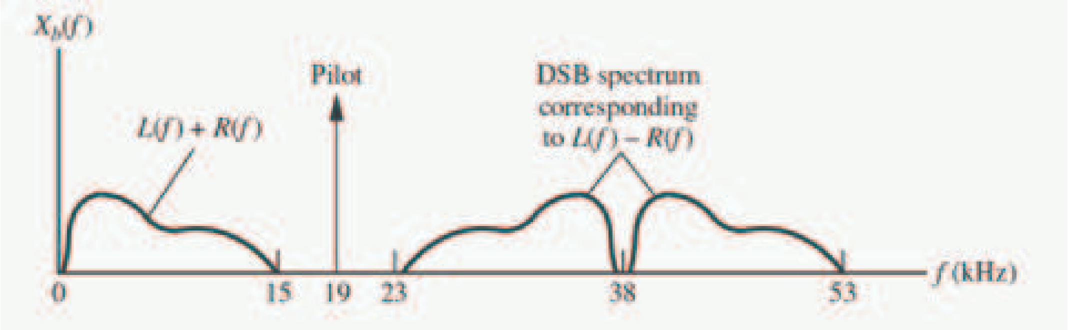
$$s(t) = A_c \cos(2\pi f_c t) m(t)$$

$\Rightarrow$

- A coherent carrier can be obtained by:

DSB: Generation of Coherent Carrier

- Method 3. Transmitting a pilot signal outside the passband of the modulated signal:
  - The pilot is a low-power sinusoidal wave whose freq and phase are related to the carrier wave (e.g., divide by 2)
  - Receiver uses a narrowband bandpass filter to extract the pilot signal, and then converts it to the correct frequency (e.g., double the freq)
- Example: Stereo FM (page 183)



Single-sided spectrum of FM baseband signal.

- Carrier: 38 kHz. Pilot: 19 kHz

Outline

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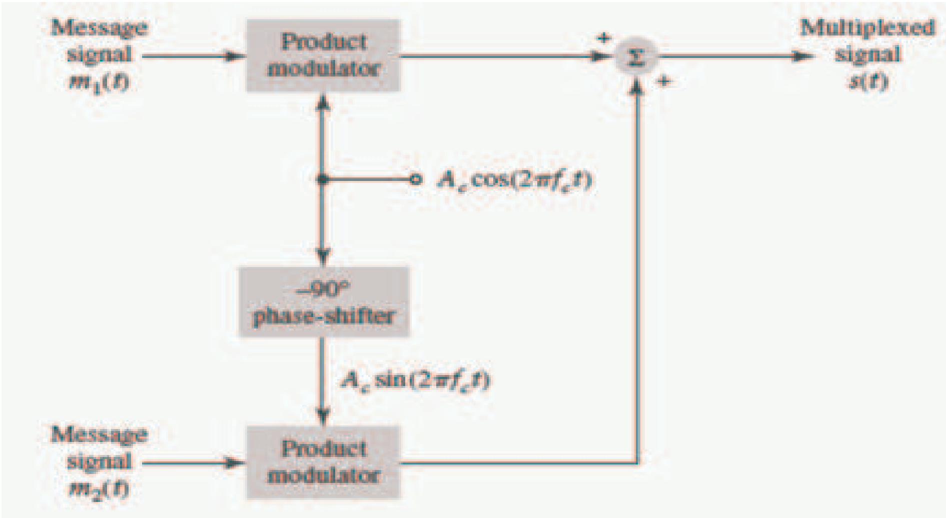
  - Modulator
  - Spectrum
  - Coherent Demodulator:
    - Three methods
- Quadrature-carrier Multiplexing

3.5 Quadrature-Carrier Multiplexing

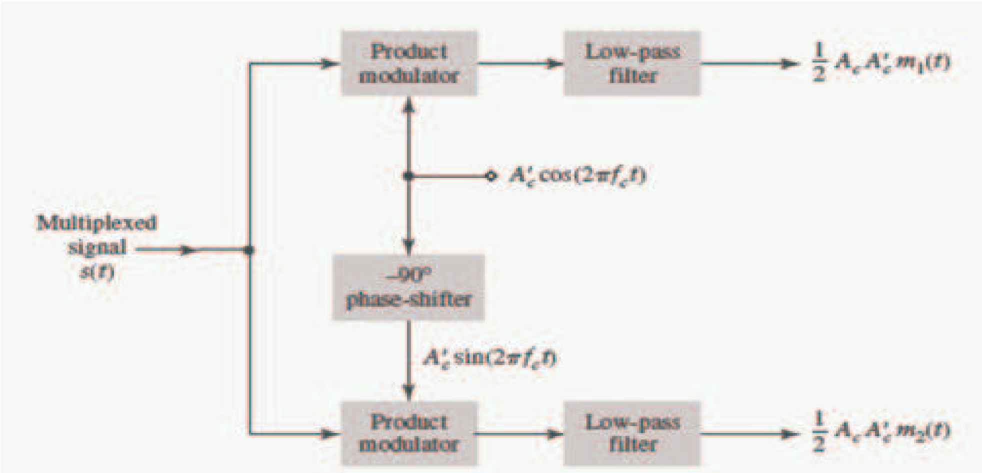
- Also known as Quadrature-amplitude modulation (QAM):
  - Transmit two DSB-SC signals in the same spectrum region.
  - Use two modulators with quadrature phases.



Transmitted signal:

$s(t) =$

3.5 Quadrature-Carrier Multiplexing



- Demodulator: two coherent detectors with 90 degree phase shift
- Output of the top product demodulator:

- After LPF:
- Similarly, $m_2(t)$ can be recovered by the 2nd detector.

3.5 Quadrature-Carrier Multiplexing

- It is important to maintain the synchronization of the oscillators at the transmitter and at the receiver.
- This can be achieved using the Costas Receiver or the pilot signal method.