ENSC327
Communications Systems
4. Double Sideband Modulation

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Outline

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

Required Background

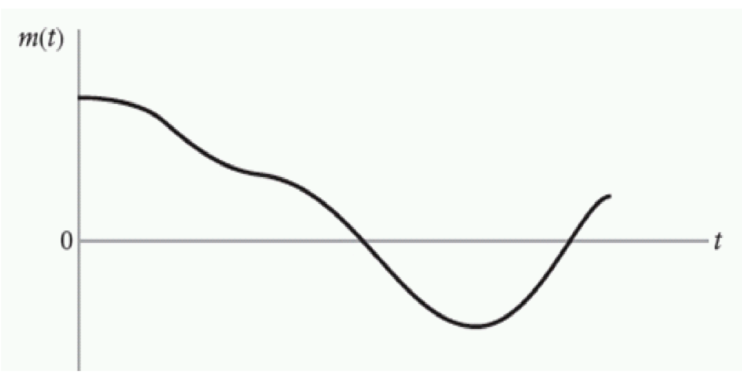
- Multiplication-Convolution property of FT.
- FT of a signal $x(t)$ multiplied by $\cos(2\pi\, f_c t)$
- Trigonometric identities:
  - $\cos^2(\alpha) =$
  - $\sin\alpha\ \cos\beta =$

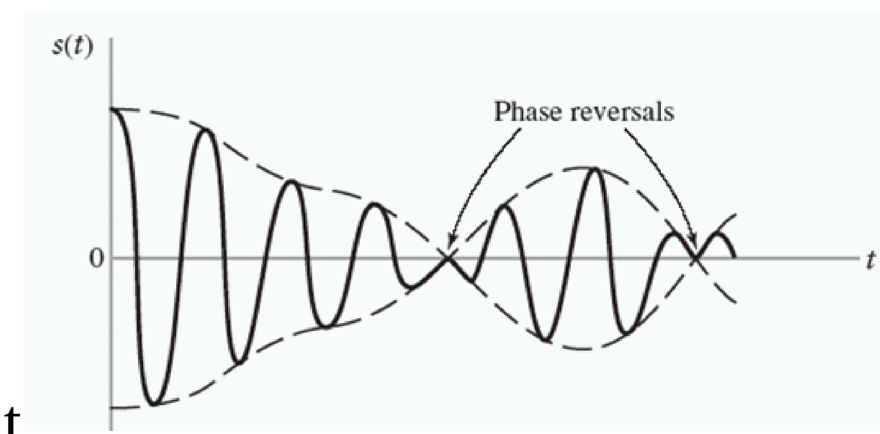
Double Sideband Modulation (DSB)

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

- Input:

DSB Output:

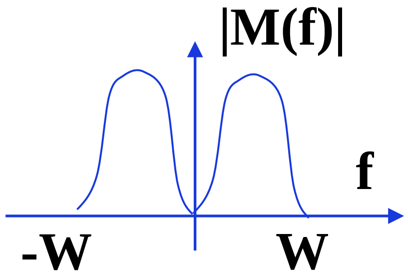




- Envelope is no longer the input,
- Cannot use envelope detector as demodulation.

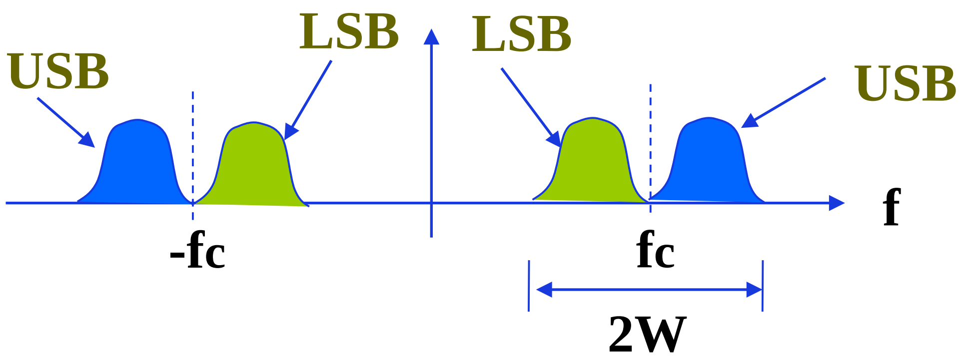
Spectrum of DSB

What is the FT of DSB?



Spectrum of DSB

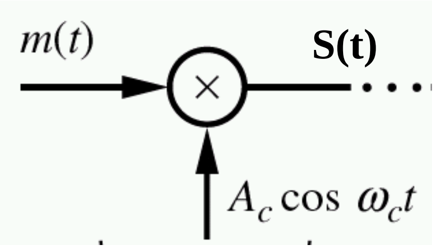
- Upper Sideband and Lower Sideband
  - Upper Sideband (USB): [fc, fc + W], [- fc – W, -fc].
  - Lower Sideband (LSB): [fc - W, fc], [- fc, -fc + W].



- 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



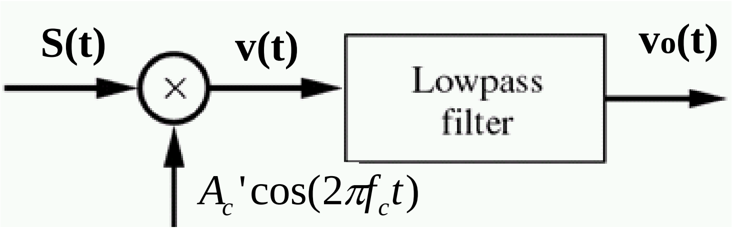
$$s(t) = A_c m(t)\cos(2\pi f_c t)$$

- 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

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

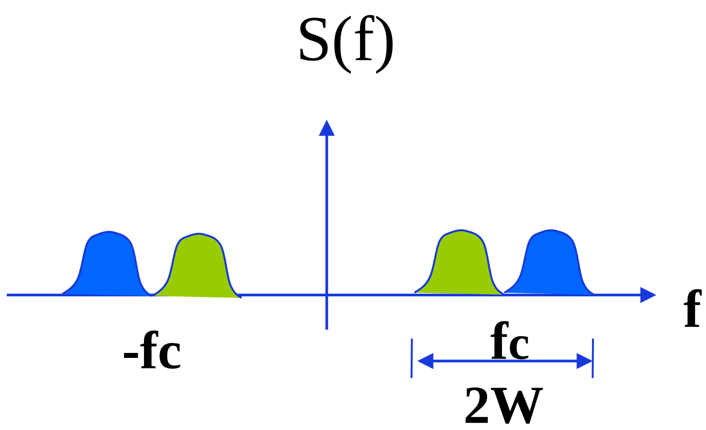
Coherent Detection (Synchronous Demodulation)

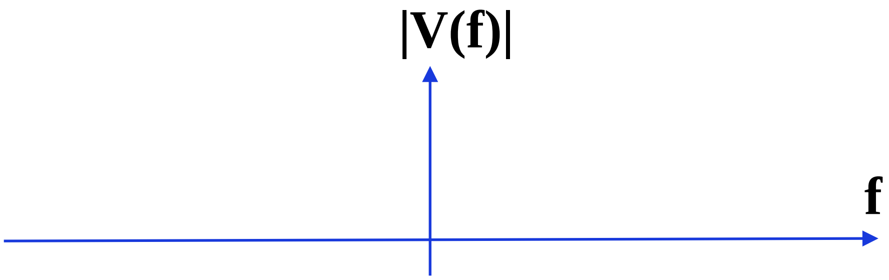
- Assuming a coherent or synchronized carrier signal (in both frequency and phase) is available at the receiver, the message can be recovered by multiplying the received signal with the coherent carrier, followed by a lowpass filter.



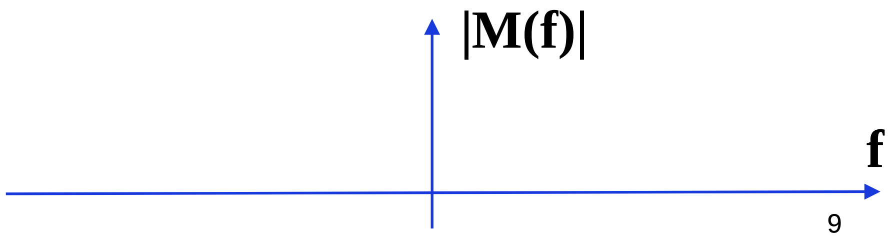
Coherent Detection (Cont.)

- 1- Multiply the received signal with the coherent carrier:





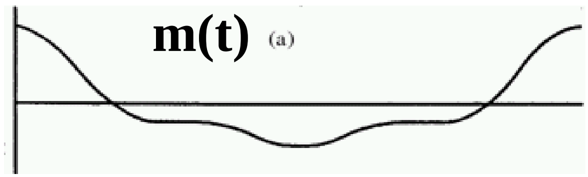
- 2- Pass $v(t)$ through a LPF:

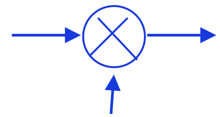


Visual Example

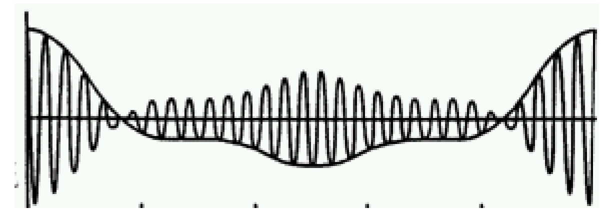
- Modulation:

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

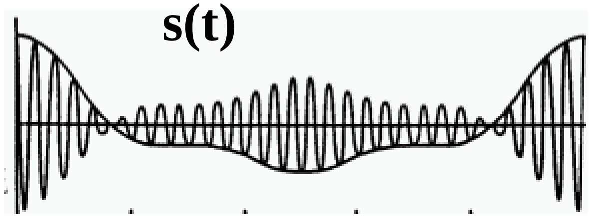


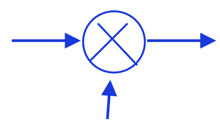


$A_c \cos(2\pi f_c t)$



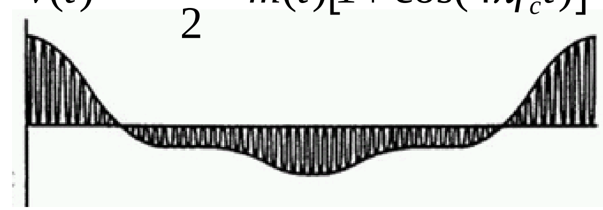
- Demodulation:





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

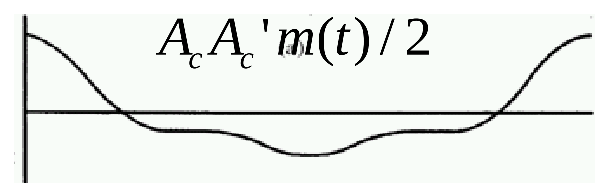
$$v(t) = \frac{A_c A_c'}{2} m(t)\left[1 + \cos(4\pi f_c t)\right]$$



Freq is higher than in s(t).

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

LPF $\longrightarrow$



Phase Error of the Demodulator

- So far we assumed that the demodulator has a carrier that has the same frequency and phase as the transmitter

- If a phase error exists at the receiver:

$$v(t) = A_c \cos(2\pi f_c t) m(t) \times A_c' \cos(2\pi f_c t + \phi(t)) =$$

- After LPF:

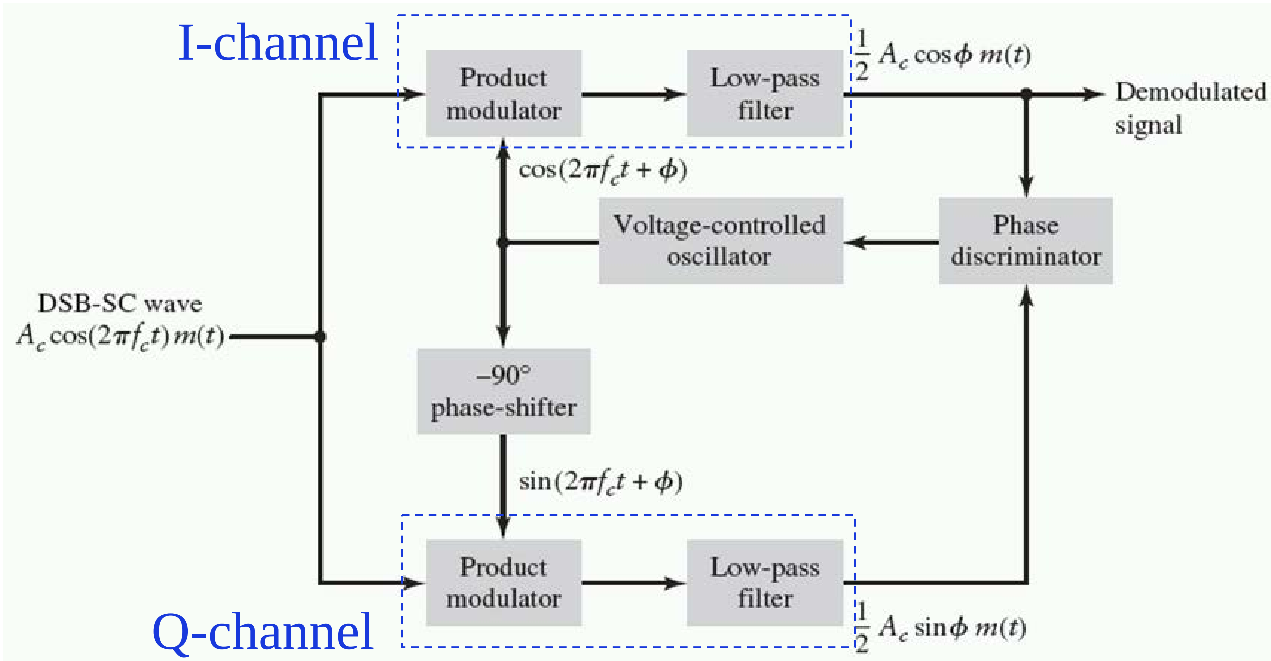
- If the phase error is constant:

- Otherwise:

DSB: Generation of Coherent Carrier

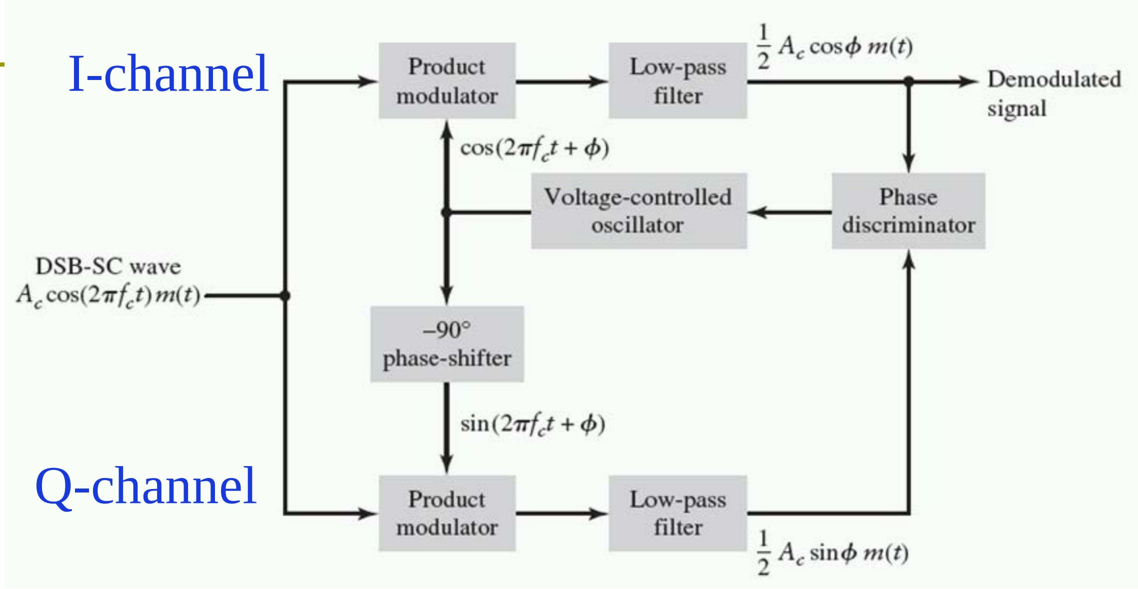
- Methods to generate a phase coherent carrier at the receiver:
- Method 1. Costas receiver
  - Invented by John Costas at General Electric in the 1950s.
  - Also known as Costas Phase Locked Loop (PLL):
  - A negative feedback system that generates a signal, whose phase is locked to the phase of an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

3.4 Costas Receiver



- Two local oscillator signals that are in quadrature:
  - with 90^o phase difference
- 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)

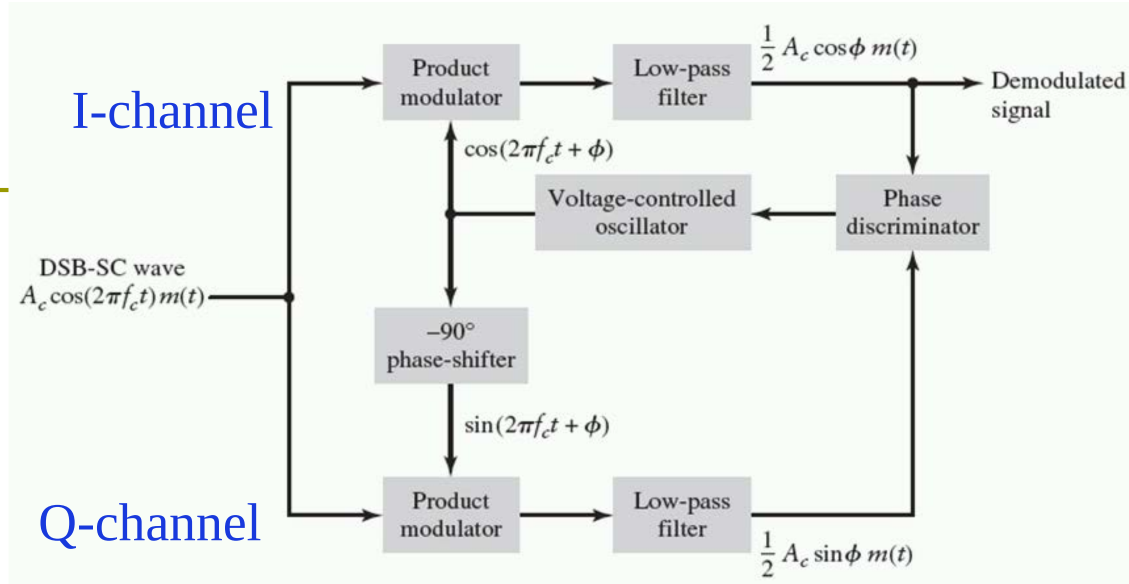
Costas Receiver (Cont.)



- If 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: $1/4\phi\, A_c^2 m^2(t)$
  - Time averaging output (which goes to the input of VCO):

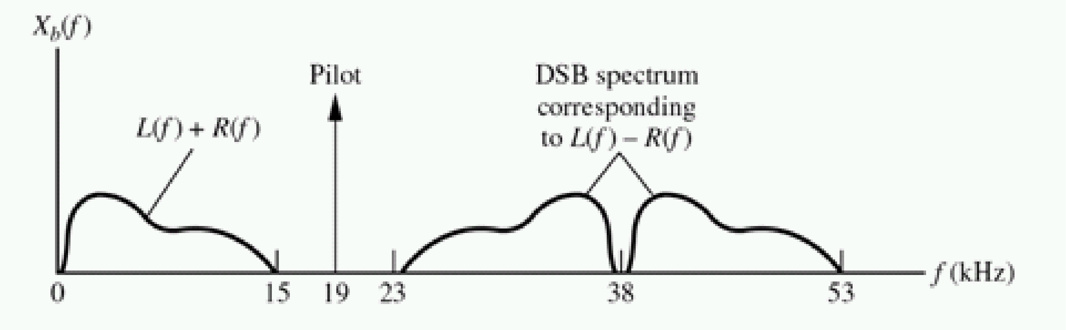
$$\frac{1}{2T}\int_{-T}^{T} 1/4\phi\, A_c^2 m^2(t)dt = 1/4\phi\, A_c^2 D_m, \quad \mathrm{D_m} : \text{DC of } m^2(t)\, in\, [-T,T].$$

➔ The phase discriminator output is proportional to ϕ.

  - 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

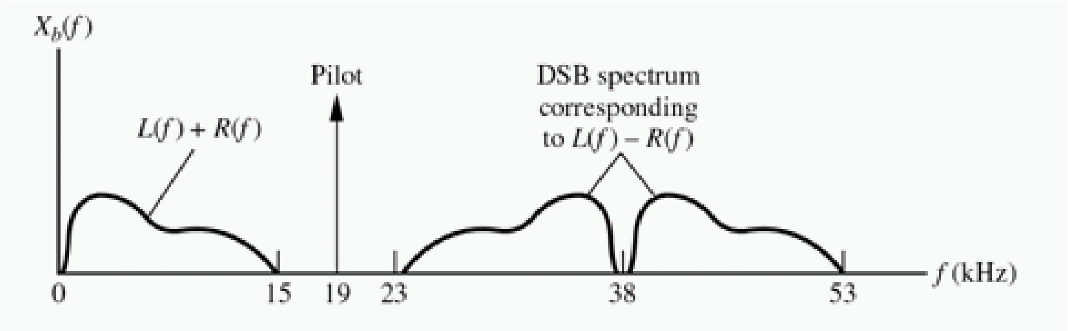
- Method 3. Transmitting a pilot signal outside the passband of the modulated signal:
  - The pilot is a low-power sinusoidal wave whose freq and phase are related to the carrier wave (e.g., divide by 2)
  - Receiver uses a narrowband bandpass filter to extract the pilot signal, and then converts it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



Single-sided spectrum of FM baseband signal.

- Carrier: 38 kHz. Pilot: 19 kHz

Example: Stereo FM



Single-sided spectrum of FM baseband signal.

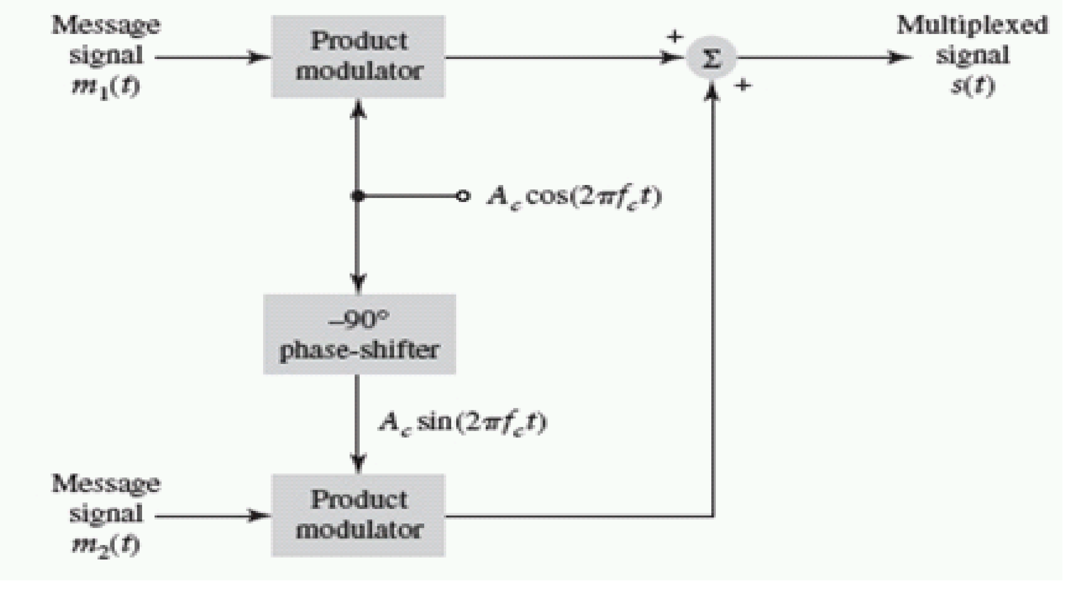
- Carrier: 38 kHz. Pilot: 19 kHz
- DSB Signal:

- At the receiver the 19 kHz signal is separated using a BPF.
- Then it foes through a mixer to double the freq:

3.5 Quadrature-Carrier Multiplexing

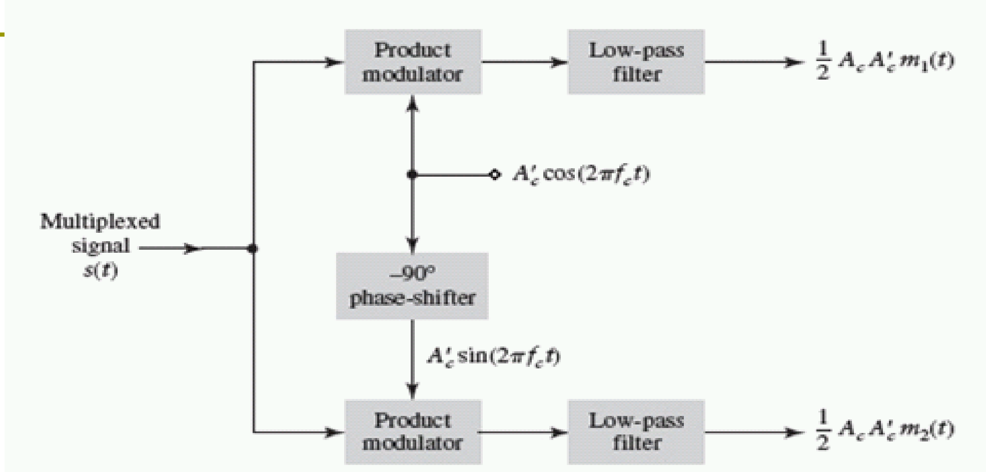
- Also known as Quadrature-Amplitude Modulation (QAM):
  - Transmit two DSB-SC signals in the same spectrum region.
  - Use two modulators with quadrature phases.

Transmitted signal:



$$s(t) = A_c m_1(t)\cos(2\pi f_c t) + A_c m_2(t)\sin(2\pi f_c t)$$

Demodulation of Quadrature-Carrier Multiplexing



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

$$\left[A_c m_1(t)\cos(2\pi f_c t) + A_c m_2(t)\sin(2\pi f_c t)\right]A_c'\cos(2\pi f_c t) =$$

- After LPF:

- Similarly, m2(t) can be recovered by the 2nd detector.

Quadrature-Carrier Multiplexing (Cont.)

- 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.