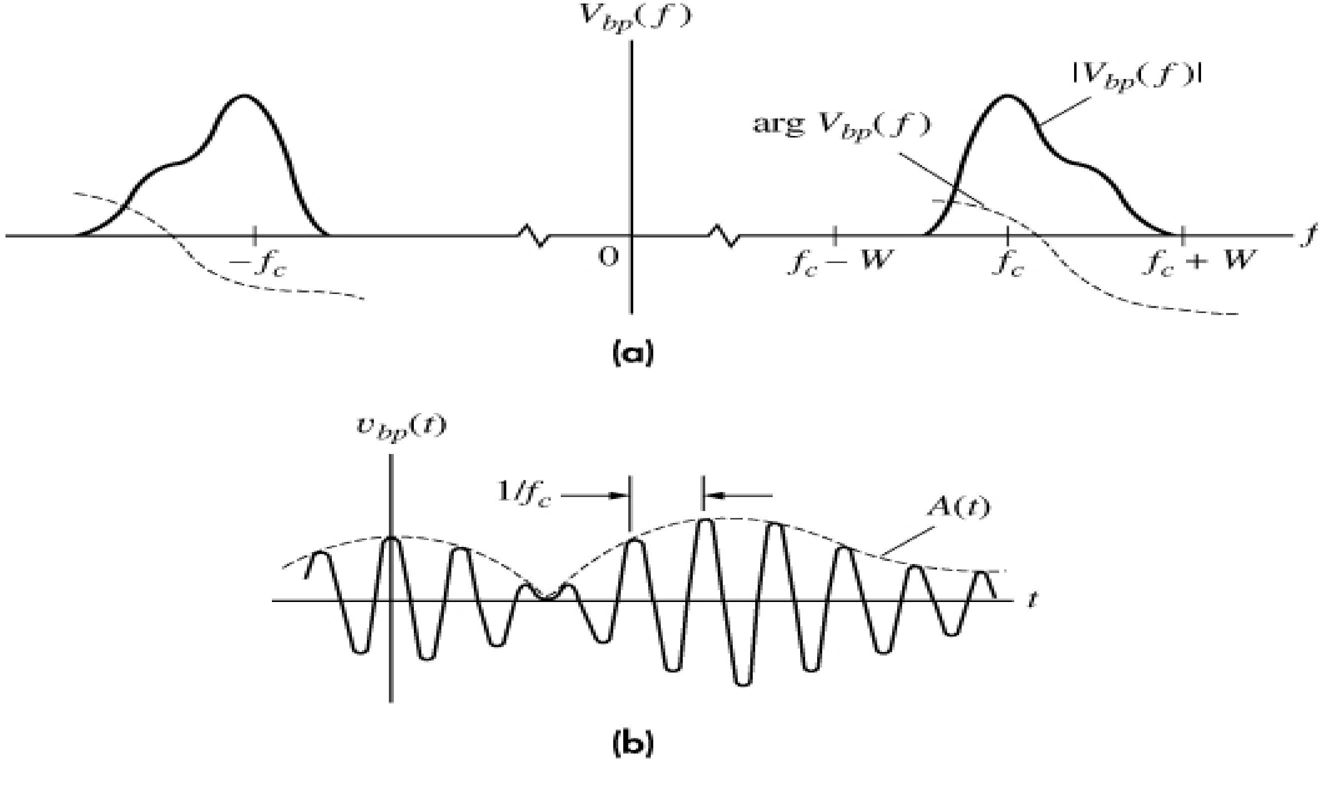
Chapter 4: Linear CW Modulation

- Bandpass signals and systems
- Double-sideband amplitude modulation
- Modulation and transmitters
- Suppressed-sideband amplitude modulation
- Frequency conversion and demodulation

Bandpass signals and systems

Bandpass signal (a) Spectrum; Waveform

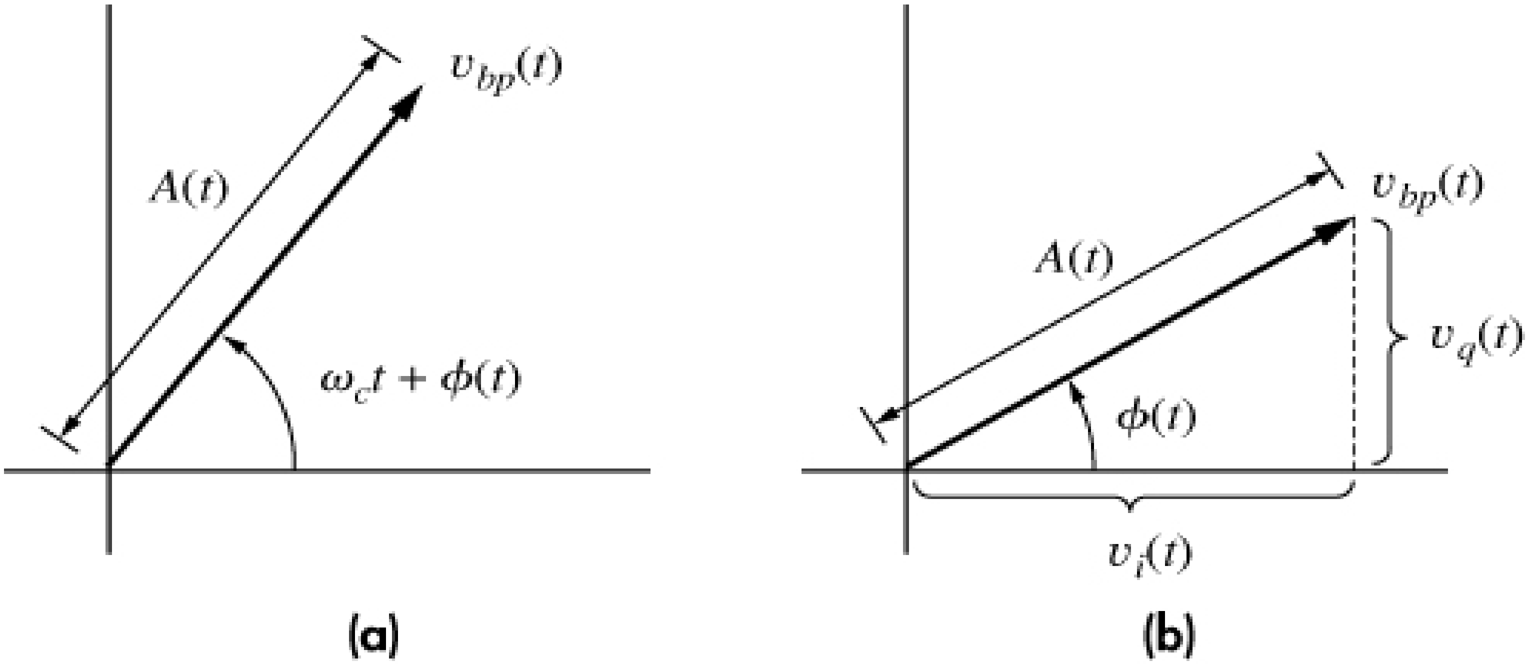


Bandpass signals

Definition: $$V_{bp}(f) = \begin{cases} X(f) & f_c - W < |f| < f_c + W \\ 0 & f_c + W < |f| < f_c - W \end{cases}$$

(a) Rotating phasor; (b) Phasor diagram with rotation suppressed

Figure 4.1-3



Quadrature-carrier representation:

$$v_{bp}(t) = v_i(t)\cos 2\pi f_c t - v_q(t)\sin 2\pi f_c t$$

where:

$v_i(t) = A(t)\cos\phi(t) \quad \Rightarrow$ in-phase component

$v_q(t) = A(t)\sin\phi(t) \quad \Rightarrow$ quadrature component

Envelope-phase representation

$$v_{bp}(t) = A(t)\cos\left[2\pi f_c t + \phi(t)\right]$$

where

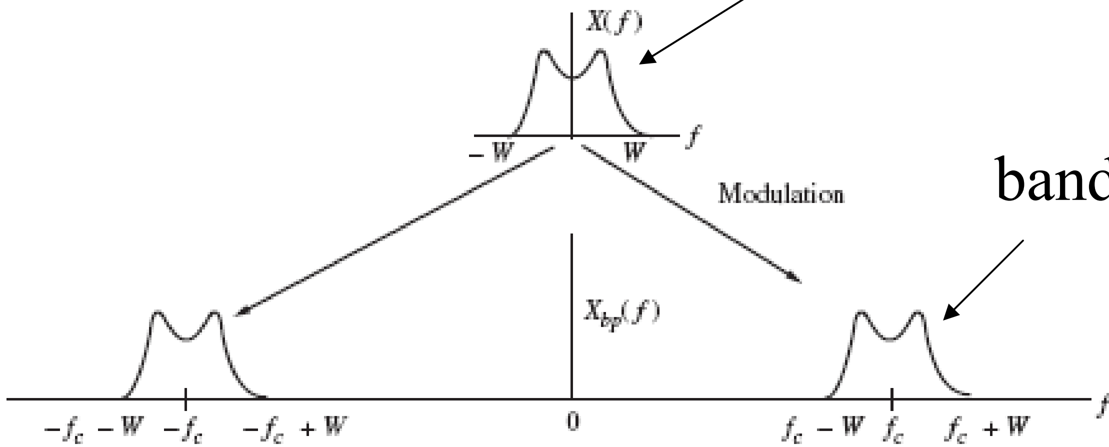
$$A(t) = \sqrt{v_i^2(t) + v_q^2(t)} \quad \text{and } \phi(t) = \tan^{-1}\left[\frac{v_q(t)}{v_i(t)}\right]$$

Modulation to create a BP signal

Modulation is the translation of a band limited LP signal to a band pass signal with some center frequency f_c

message spectrum

bandpass spectrum



Analog message conventions

Message signal: $x(t)$

Amplitude: $\left|x(t)\right| \leq 1$

Power: $S_x = \left\langle x^2(t) \right\rangle = \frac{1}{T_0}\int_{T_0} x^2(t)dt \leq 1$

Thus with a single tone message $x(t) = A_m \cos 2\pi f_m t$

$\Rightarrow A_m \leq 1 \Rightarrow S_x = \frac{A_m^2}{2} \leq \frac{1}{2}$

Message bandwidth = $W \Rightarrow f_m \leq W$

Bandwidth

- Message bandwidth: W
- Transmission bandwidth: B_T

Fractional bandwidth

(a) Relevant to band pass signals

(b) fractional bandwidth defined as $\dfrac{B_T}{f_c}$

(c) For practical systems we require $0.01 < \dfrac{B_T}{f_c} < 0.1$

(d) Upper limit $\Rightarrow$ $f_c > 10B_T$ $\Rightarrow$ prevents spillover into negative frequencies

(e) Lower limit $\Rightarrow$ $f_c < 100B_T$ $\Rightarrow$ economics

How is bandwidth defined?

- Absolute bandwidth: 100% of energy is within some frequency range
- 3 dB, or half power bandwidth: frequency range where magnitude reduction is less than -3 dB
- Noise equivalent bandwidth (see chapter 9)
- Occupied bandwidth: FCC definition where frequency range that contains 99% of energy
- Relative power bandwidth: frequency range where magnitude rolloff is less than a given level of dB (e.g. -40 dB)

Types of linear CW modulation

- Conventional Amplitude Modulation (AM)
- Suppressed carrier double sideband (SCDSB, or DSB)
- Single sideband (USSB and LSSB)
- Vesigal sideband (VSB)

AM, DSB, SSB, and VSB are considered AM because the message alters the carrier's amplitude

However, AM $\Rightarrow$ conventional AM

Double-sideband amplitude modulation

- Conventional AM
- Suppressed carrier DSB, (SCDSB) or simply DSB

Conventional AM, or simply AM

$$x_c(t) = A_c[1 + \mu x(t)]\cos 2\pi f_c t$$

where

$A_c =$ carrier amplitude

$x(t) =$ message, and $|x(t)| \leq 1$

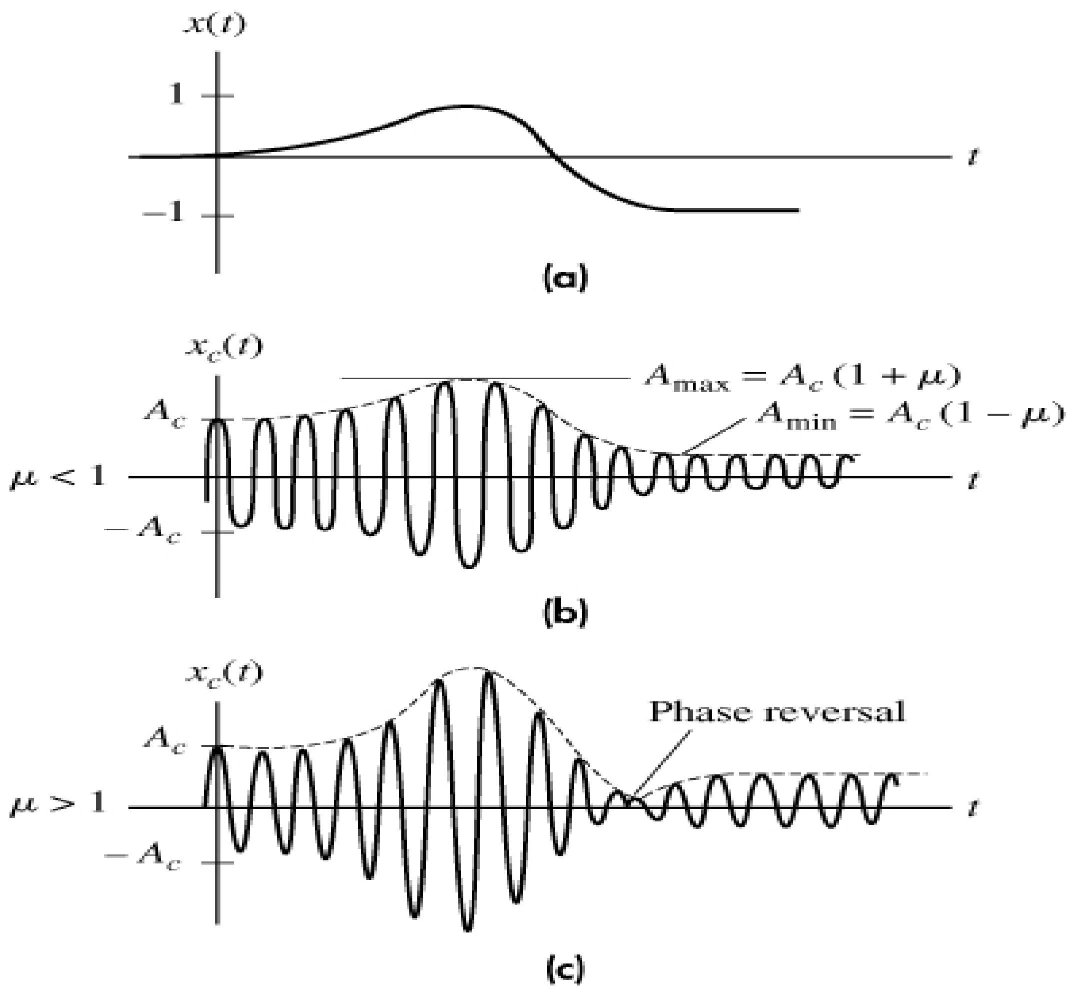
$\mu =$ modulation index, $\mu \leq 1$ and

$\mu = 1 \Rightarrow 100\%$ modulation

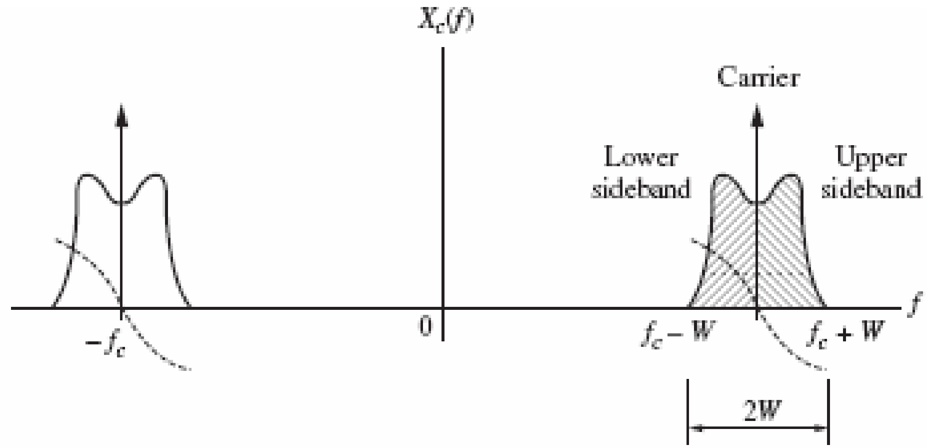
$f_c =$ carrier frequency, Hz

$$x_c(t) \Leftrightarrow X_c(f) = \frac{1}{2} A_c \delta(f \pm f_c) + \frac{1}{2} A_c X(f \pm f_c)$$

AM waveforms (a) Message; (b) AM wave with μ < 1; (c) AM wave with μ > 1 (overmodulation)



AM Spectrum



Note:

(a) carrier impulse at $\pm f_c \Rightarrow$ this impulse carries no information

(b) redundant sidebands: the lower and upper sidebands carry the same information $\Rightarrow$ increased bandwidth

$$\Rightarrow B_T = 2W$$

AM Power

Output power: carrier power + sideband power

$$S_T = P_c + 2P_{sb}$$

where

$$P_c = \frac{1}{2}A_c^2$$

$$P_{sb} = \frac{1}{2}A_c^2\mu^2 S_x$$

Peak envelope power:

$$P_{peak-envelope} = A_{\max}^2 = A_c^2\left[1 + u\left|x(t)\right|_{\max}\right]^2$$

AM Systems

- Relatively simple transmitter and receiver hardware
- The first voice modulation system
- More than half power goes into carrier, but carrier carries no information $\Rightarrow$ inefficient
- Not suited for messages with low frequency content

Suppressed Carrier DSB Signals

$$x_c(t) = A_c x(t)\cos 2\pi f_c t \Leftrightarrow X_c(f) = \frac{1}{2} A_c X\left(f \pm f_c\right)$$

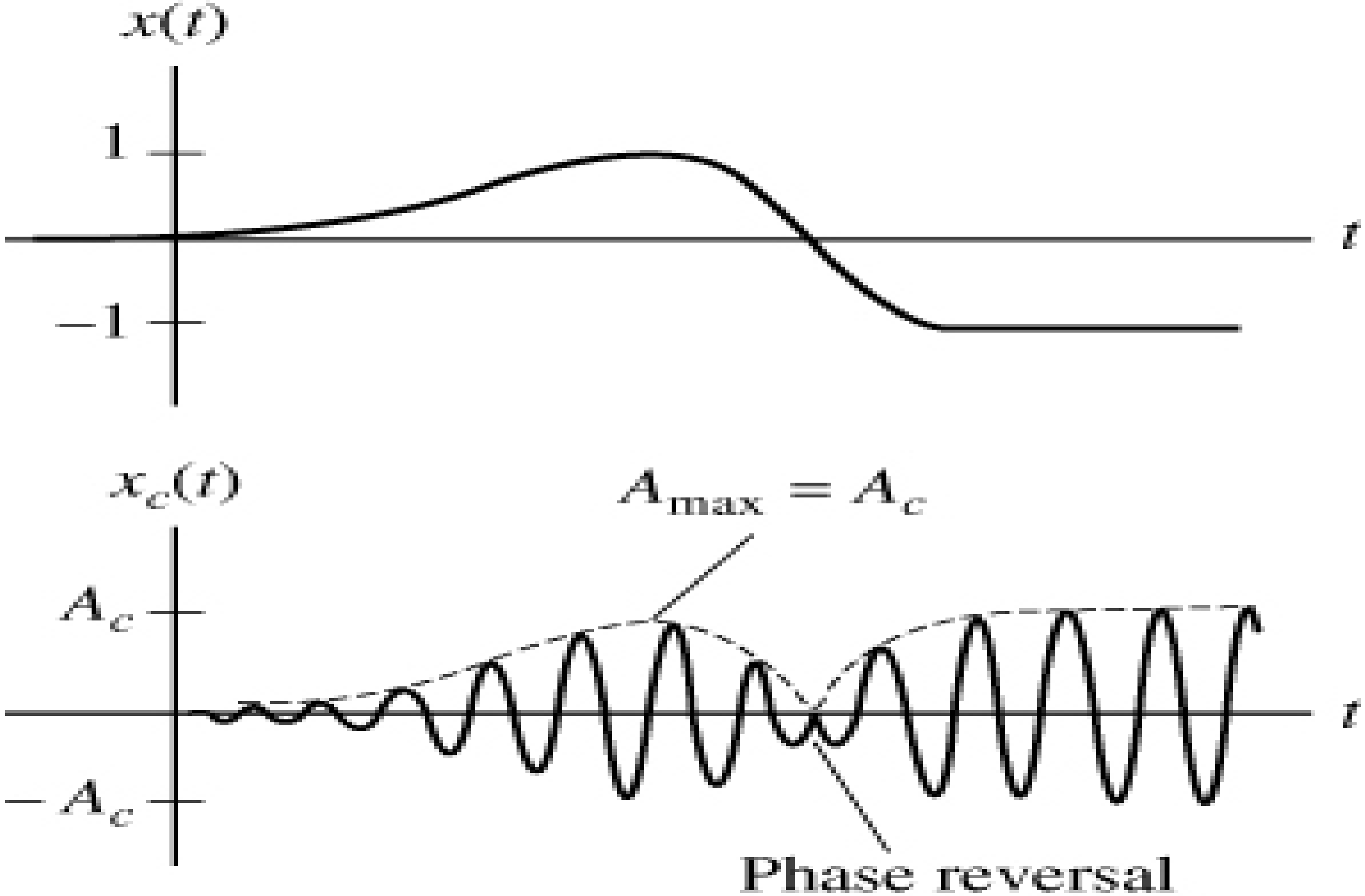
Output power:

$$S_T = 2P_{sb} = \frac{1}{2} A_c^2 S_x$$

Peak envelope power

$$P_{peak-envelope} = A_{\max}^2 = A_c^2 \left|x(t)\right|_{\max}^2$$

DSB waveforms



DSB systems

- Suppressed carrier: typically -40$\rightarrow$ -60 dB
- All power goes into sidebands $\Rightarrow$ more efficient than AM
- Demodulation more complicated than AM; requires synchronization
- Transmitter hardware more complex than AM
- Well suited to transmission of messages with low frequency or DC content

Modulation and transmitters

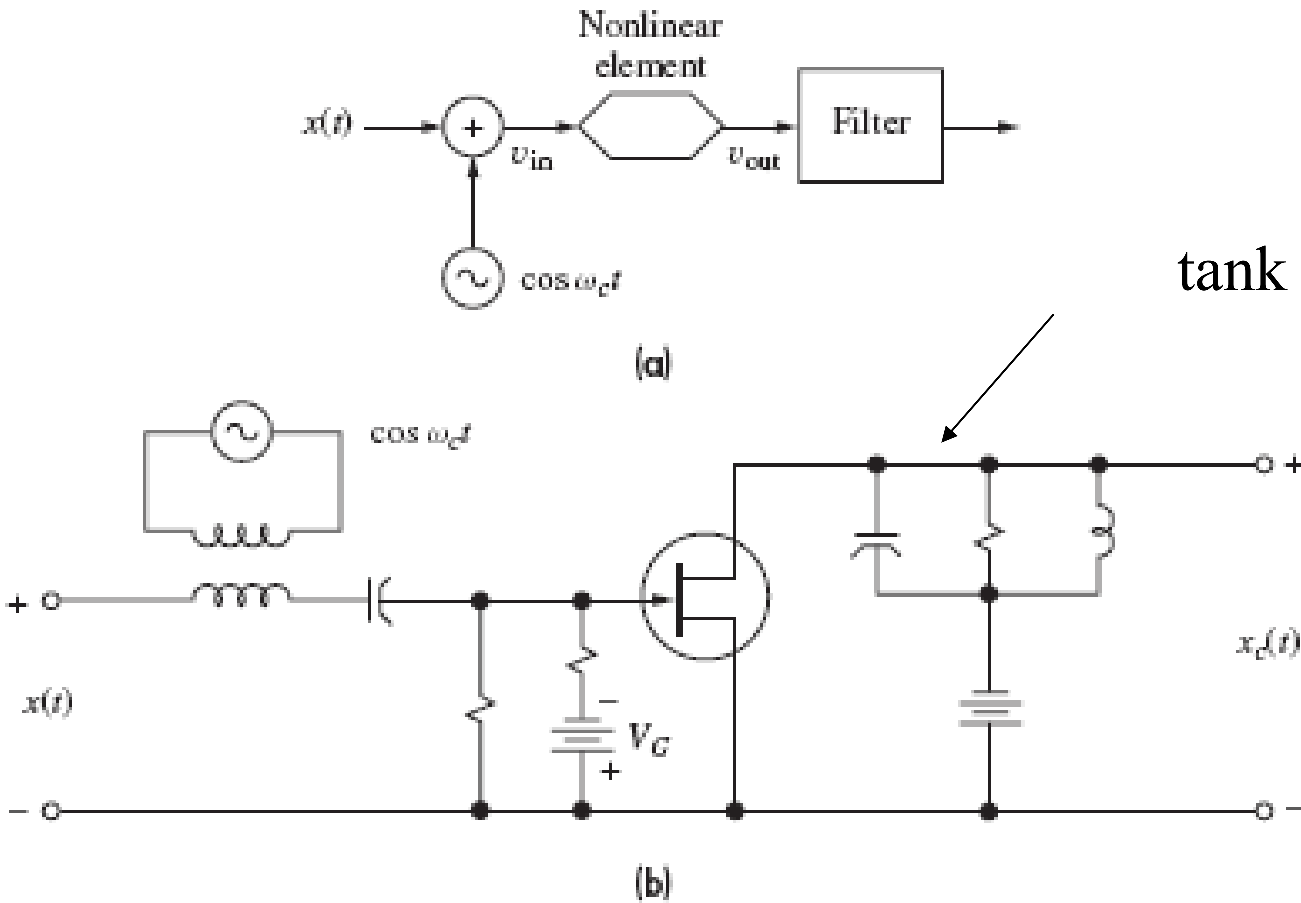
- AM
- DSB

AM transmitters

- Implemented using a nonlinear element or some nonlinear portion of a circuit.
- Often done where the message is superimposed on one of the active device’s terminals (i.e. the base/gate or collector/drain)
- Because of nonlinear elements, may require a tank circuit to remove other of band components

AM modulator example

tank circuit



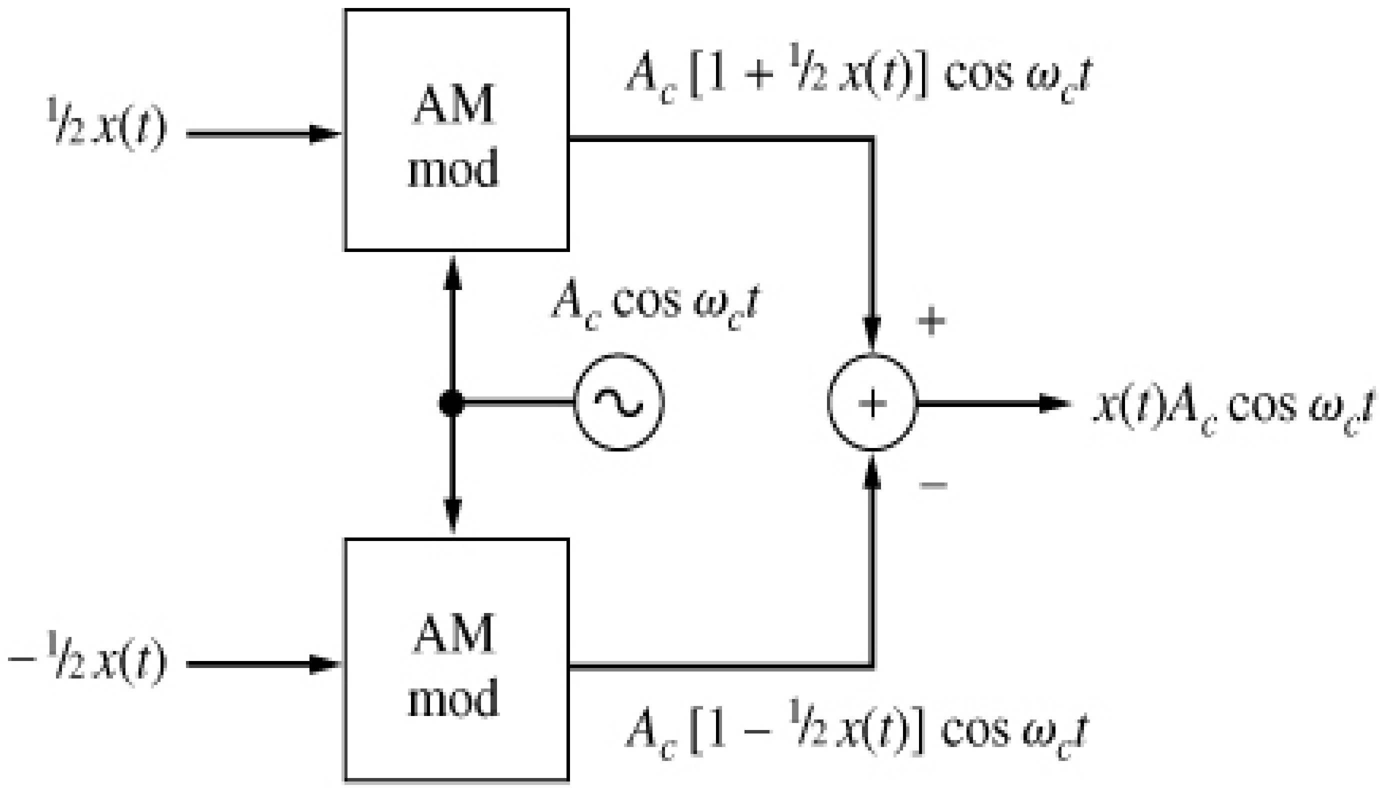
(a) the concept, (b) practical circuit.

Note in (b) how the message and carrier source are superimposed onto the gate circuitry.

DSB transmitters

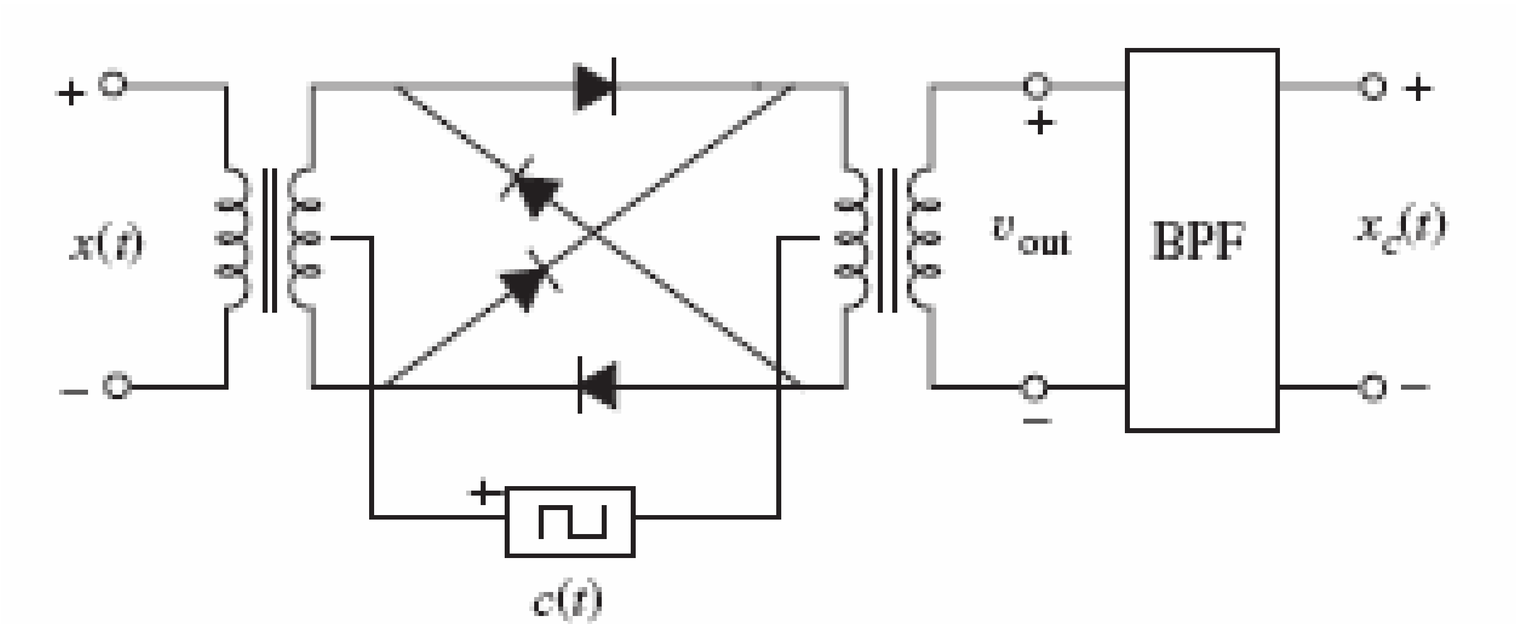
- Due to technological limitations, practical DSB systems are rarely implemented via ordinary multiplers.
- Balanced modulators
- Ring modulators
- Other nonlinear devices

Balanced modulator concept for DSB generation*



*Only for purposes of illustrating the balanced modulator concept. Practical DSB modulators are implemented using nonlinear devices such as diode arrays

Ring modulator for DSB generation



Suppressed-sideband amplitude modulation

- If we have a DSB signal with symmetrical sidebands, we can suppress one of the sidebands without loss of information
- Therefore, we reduce transmission bandwidth from

$$B_{T_{DSB}} = 2W \rightarrow B_{T_{SSB}} = W$$

- Double the number of users on a channel

Types of SSB

- Lower sideband: LSSB or LSB
- Upper sideband: USSB or USB
- The decision to choose one over the other is dictated by:
  - Convention or prior assignment
  - Technological considerations
- Neither USSB or LSSB is inherently better than the other

SSB signals

$$x_c(t) = \frac{1}{2} A_c \left[x(t) \cos \omega_c t \mp \hat{x}(t) \sin \omega_c t \right]$$

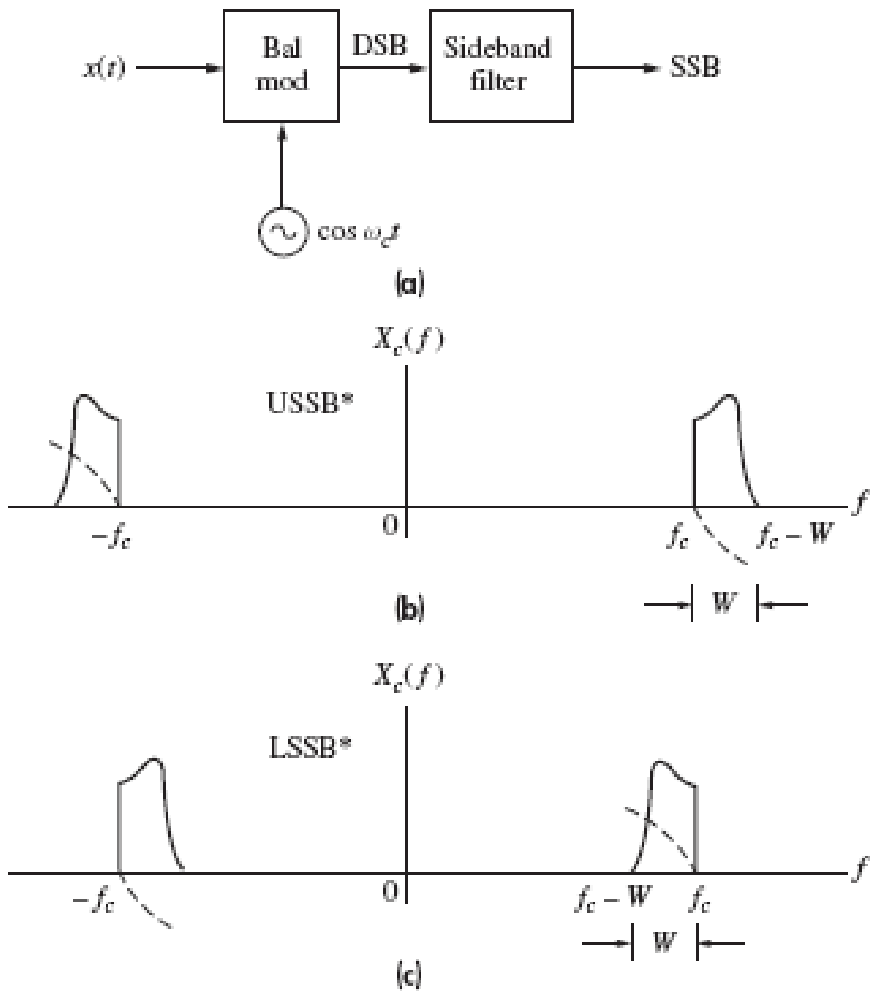
where $\hat{x}(t)$ is the Hilbert transform of the message

The in-phase and quadrature components are:

$$x_{ci}(t) = \frac{1}{2} A_c x(t) \text{ and } x_{cq}(t) = \pm A_c \hat{x}(t)$$

and the envelope is $A(t) = \frac{1}{2} A_c \sqrt{x^2(t) + \hat{x}^2(t)}$

SSB spectra

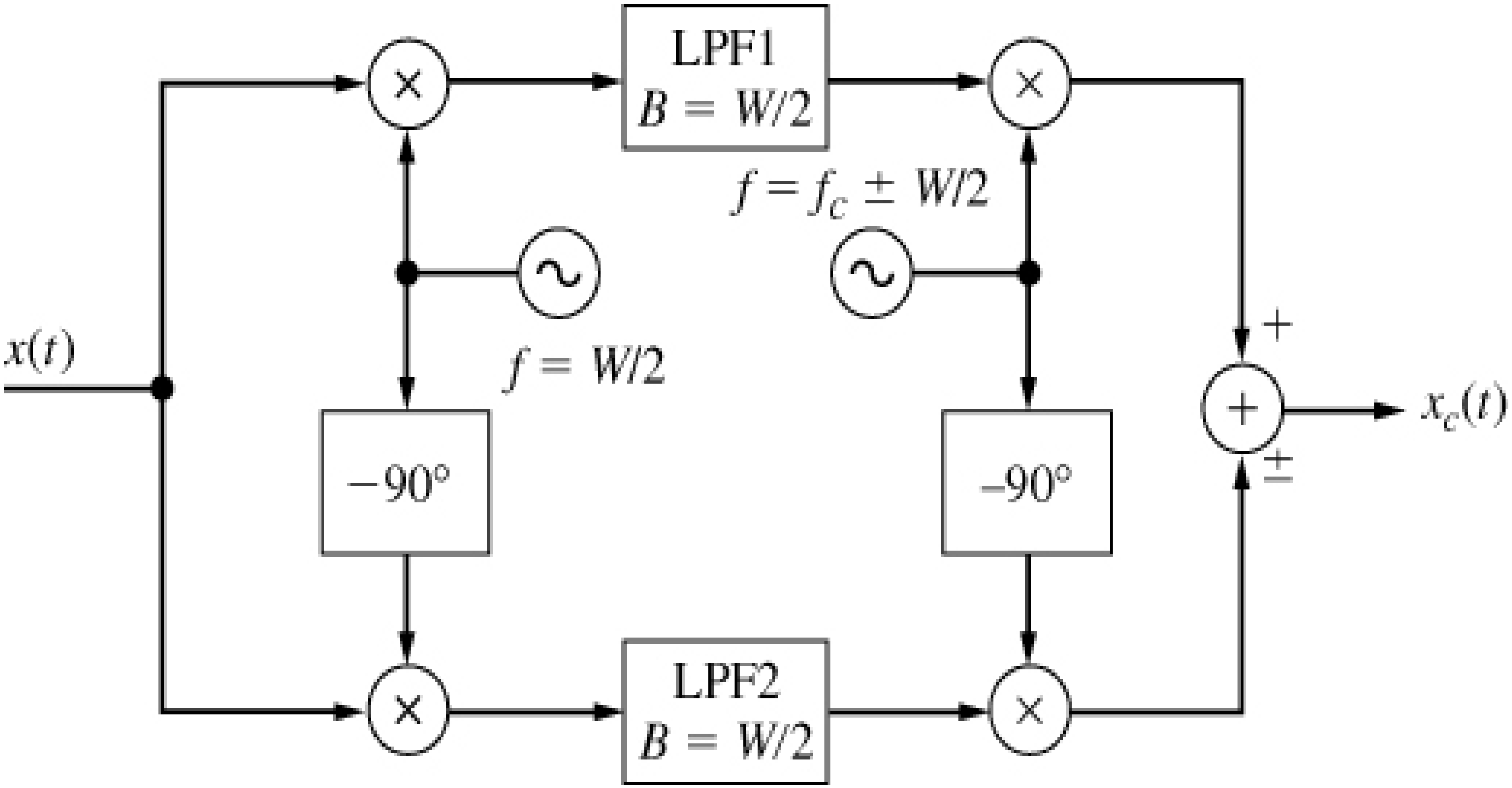


(a) Generation of SSB from DSB using filter method, (b) USSB, (c) LSSB

SSB generation

- Filter method: use a high-Q filter to suppress one of the sidebands.
- Phase methods: shift sidebands using a phase shift method to cancel one of them out
  - Phase shift
  - Weavers

Weaver’s SSB modulator



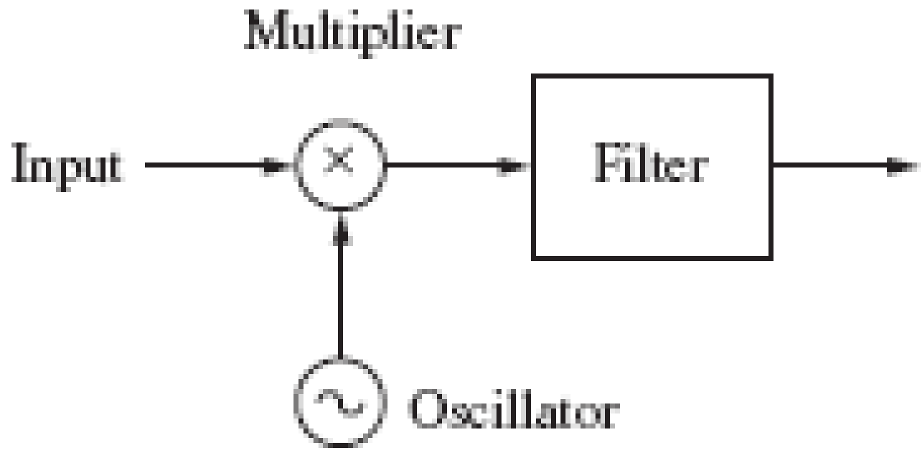
VSB

- SSB method but with a trace of the other sideband left
- Practical SSB systems with imperfect filters are VSB
- VSB allows for messages with low frequency or DC content

Frequency conversion and demodulation

- Modulation: translate message to some carrier frequency
- Frequency translation: move a signal from one carrier frequency to another
- Demodulation: move modulated signal back to baseband
  - Synchronous or product detectors
  - Envelope detectors

Basic hetrodyne frequency converter



Frequency converson via hetrodyning $\Rightarrow$ takes advantage of the property of the product of 2 cosine functions $\Rightarrow$ sum and difference

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

Frequency conversion via hetrodyning (multiplication)

$$x(t)\cos 2\pi f_1 t \cos 2\pi f_2 t = \frac{1}{2}x(t)\cos 2\pi(f_1 - f_2 t)t + \frac{1}{2}x(t)\cos 2\pi(f_1 + f_2 t)t$$

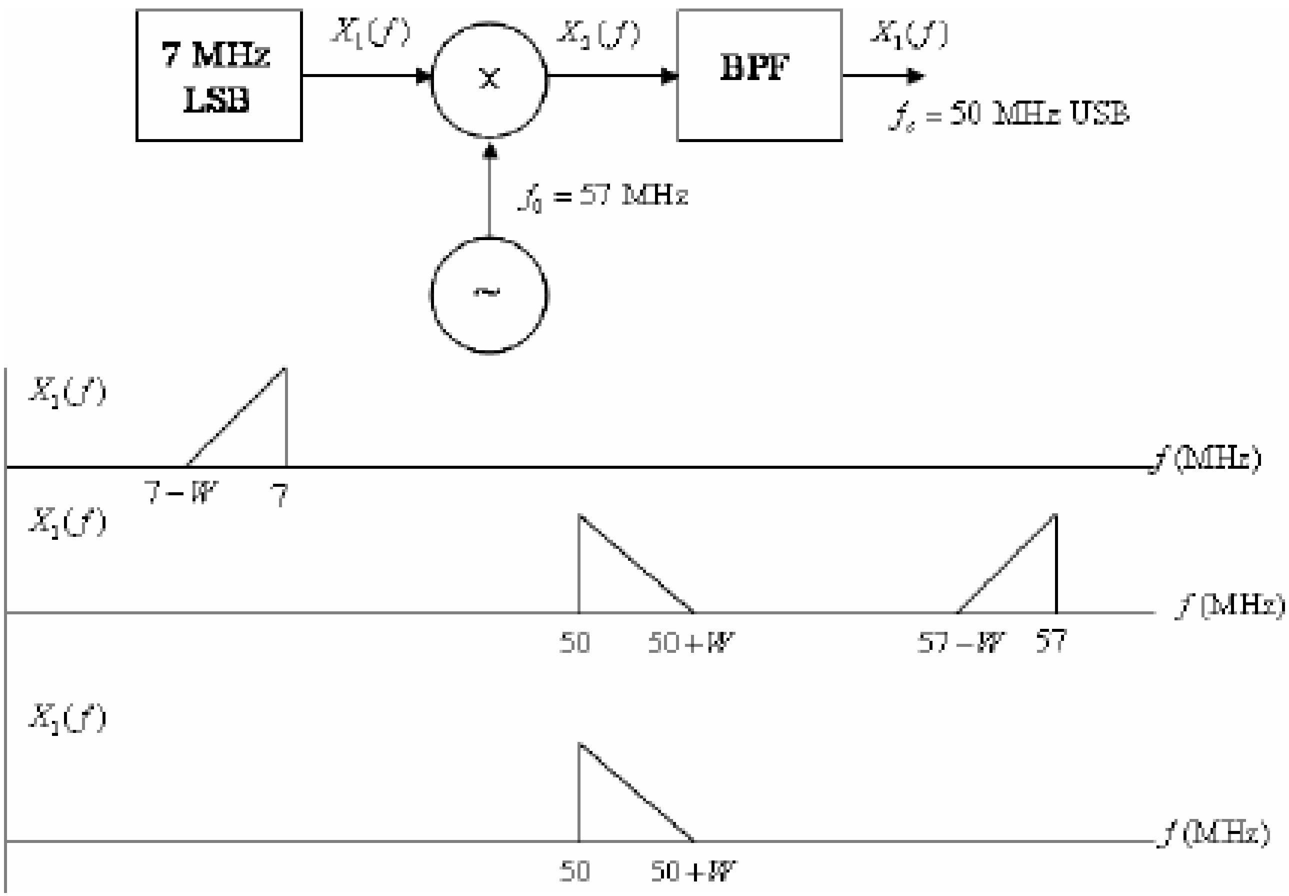
$$\Rightarrow \frac{1}{2}X(f_1 - f_2) + \frac{1}{2}X(f_1 + f_2)$$

$\Rightarrow$ sum and the difference of 2 the frequencies

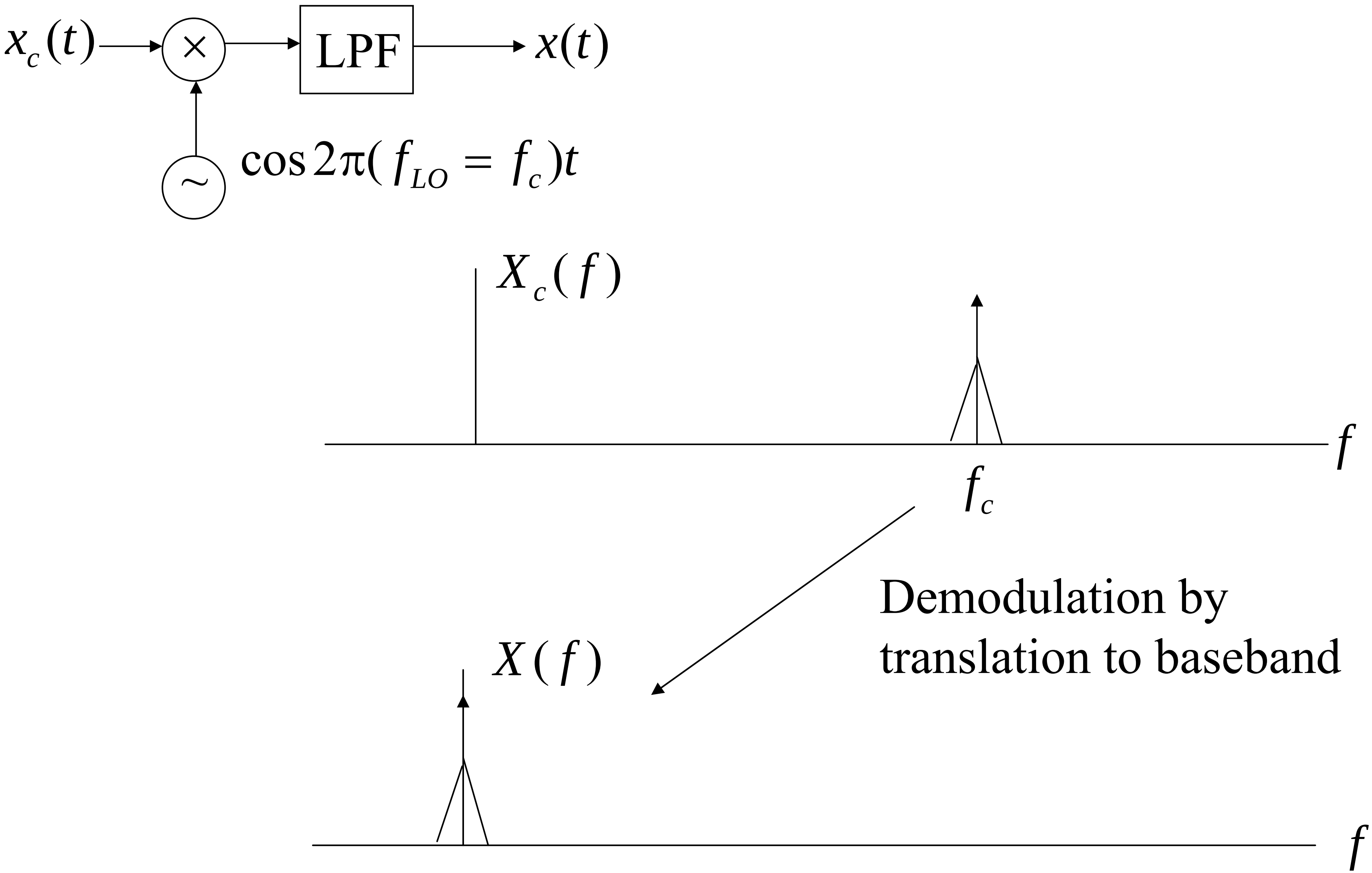
We use a filter to select a particular component

Frequency translation example

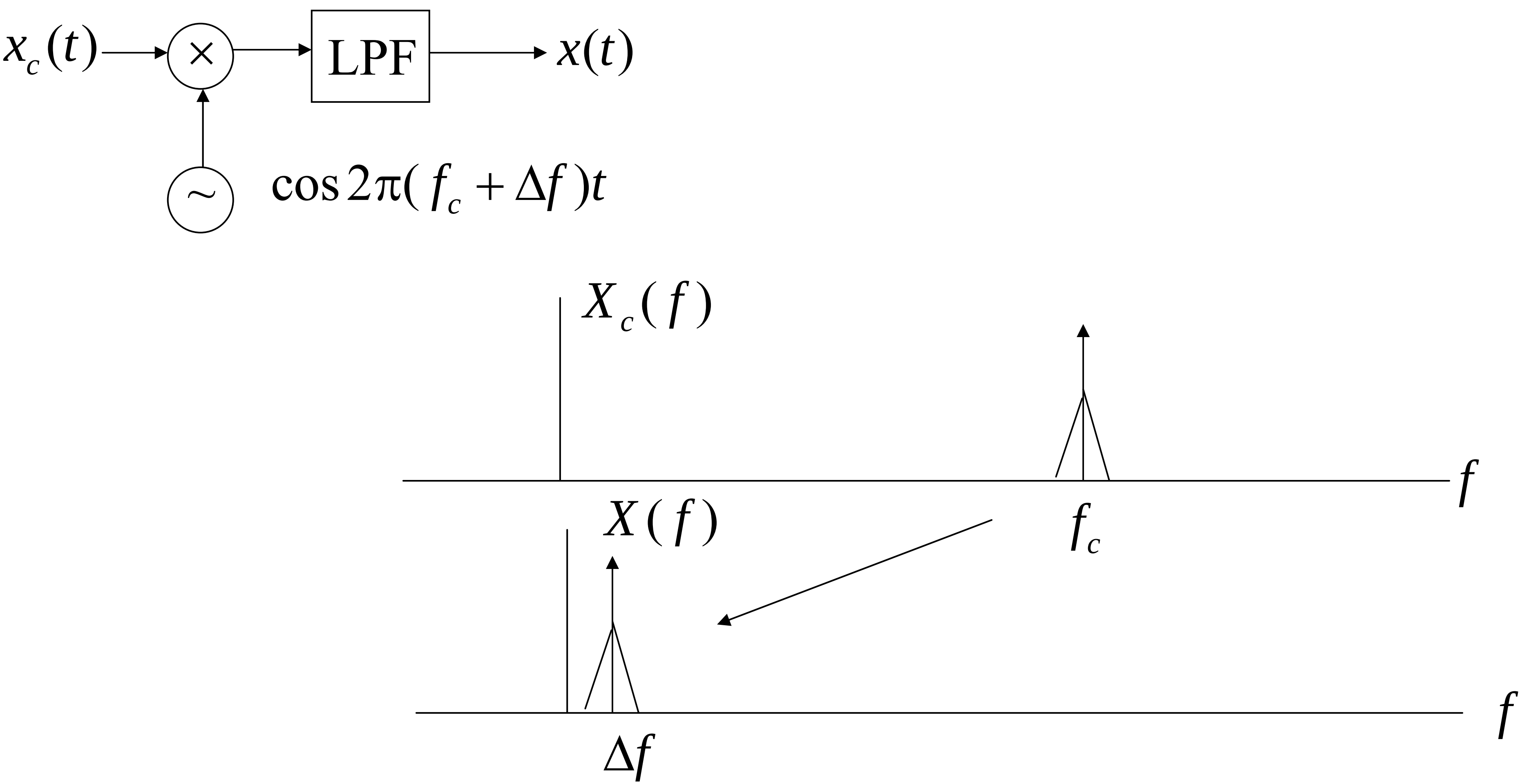
Convert 7 MHz USSB signal into a 50 MHz LSSB signal
via hetrodyning



Synchronous detection example



Synchronous detection when there is an error in the local oscillator



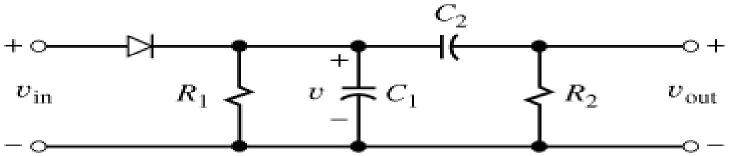
Detector output $\Rightarrow$ single tone at $f = \Delta f$, and message is translated to a center frequency of $\Delta f \Rightarrow$ distorted message and obnoxious background tone

Mandatory that the local oscillator and its phase match the carrier frequency

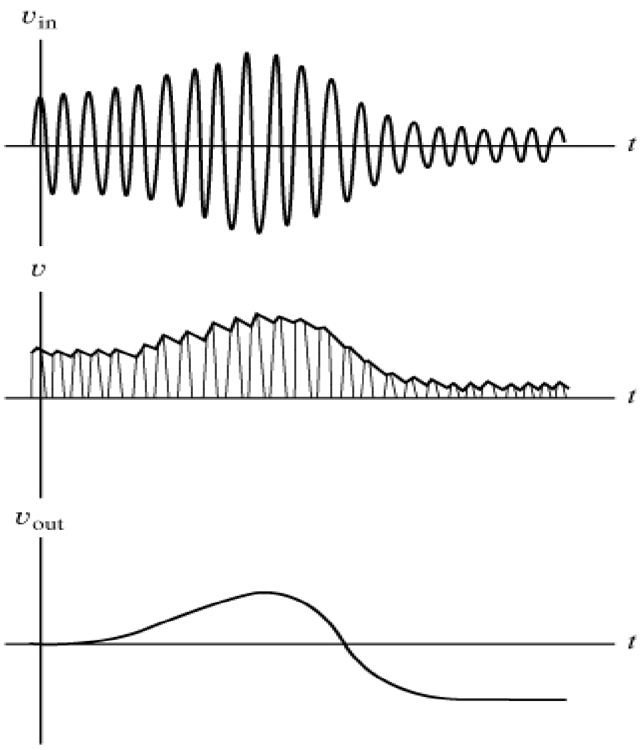
Envelope detection

- Suitable for AM signals or signals with a carrier
- Does not require synchronization
- Simple hardware: diode, resistor, capacitor
- Will work with suppressed carrier modulation systems if the receiver inserts a carrier

Envelope detection (a) Circuit; (b) Waveforms



(a)



(b)