Chapter 3 Amplitude Modulation (II)

Power-Law Modulation (1/3)

- Consider a nonlinear device such as a P-N diode, which has voltage-current characteristic shown in Fig. 3.22
- The power-law AM modulator is shown in Fig. 3.23

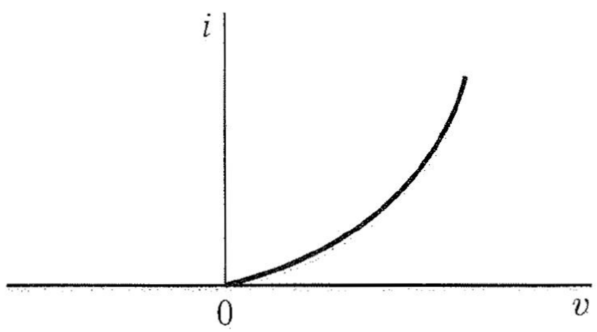

Figure 3.22 Voltage–current characteristic of P–N diode.

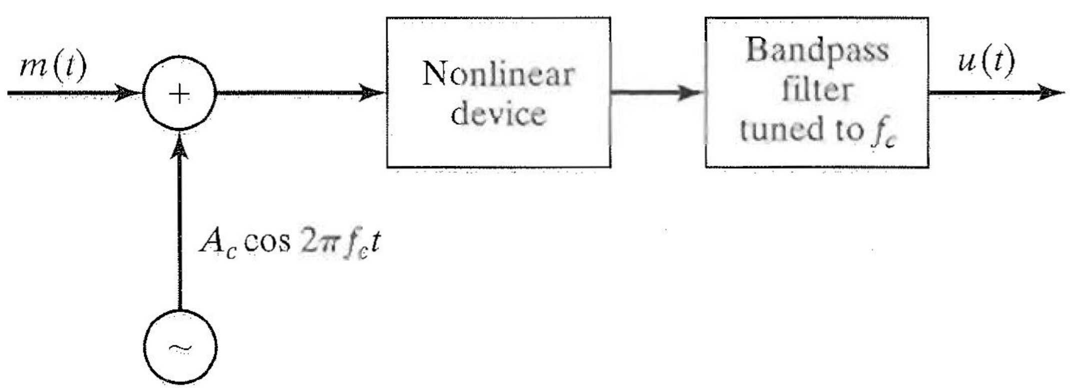

Figure 3.23 Block diagram of power-law AM modulator.

Power-Law Modulation (2/3)

- The nonlinearity will generate a product of the message $m(t)$ with the carrier, plus additional terms
- The desired modulated signal can be filtered out by passing the output of the nonlinear device through a bandpass filter
- Suppose that the nonlinear device has an input-output (square-law) characteristic of the form

$$v_o(t) = a_1 v_i(t) + a_2 v_i^2(t),$$

where $v_i(t)$ is the input signal, $v_o(t)$ is the output signal, and the parameters (a_1, a_2) are constants

- The input to the nonlinear device is

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

Power-Law Modulation (3/3)

- The output is

$$v_o(t) = a_1[m(t) + A_c \cos 2\pi f_c t]$$

$$+ a_2[m(t) + A_c \cos 2\pi f_c t]^2$$

$$= a_1 m(t) + a_2 m^2(t) + a_2 A_c^2 \cos^2 2\pi f_c t$$

$$+ A_c a_1 \left[1 + \frac{2a_2}{a_1} m(t)\right] \cos 2\pi f_c t$$

- The output of the bandpass filter with a bandwidth $2W$ centered at $f=f_c$ yields

$$u(t) = A_c a_1 \left[1 + \frac{2a_2}{a_1} m(t)\right] \cos 2\pi f_c t,$$

where $2a_2 \,|\, m(t) \,|\, / a_1 < 1$ by design

Switching Modulator (1/4)

- Another method for generating an AM-modulated signal is by means of a switching modulator
- The input signal to the switching modulator is

$$v_i(t) = m(t) + c(t)$$
$$= m(t) + A_c \cos(2\pi f_c t),$$

where $A_c >> m(t)$

- The switching modulator is shown in Fig. 3.24(a)
- The input/output relation is shown in Fig. 3.24(b)
  - $v_1(t) = A_c \cos(2\pi f_c t) + m(t)$, $v_2(t) = v_o(t)$
- The switching function $s(t)$ is shown in Fig. 3.24(c)
- The output across the load resistor is

$$v_o(t) = \begin{cases} v_i(t), & c(t) > 0 \\ 0, & c(t) < 0 \end{cases}$$

Switching Modulator (2/4)

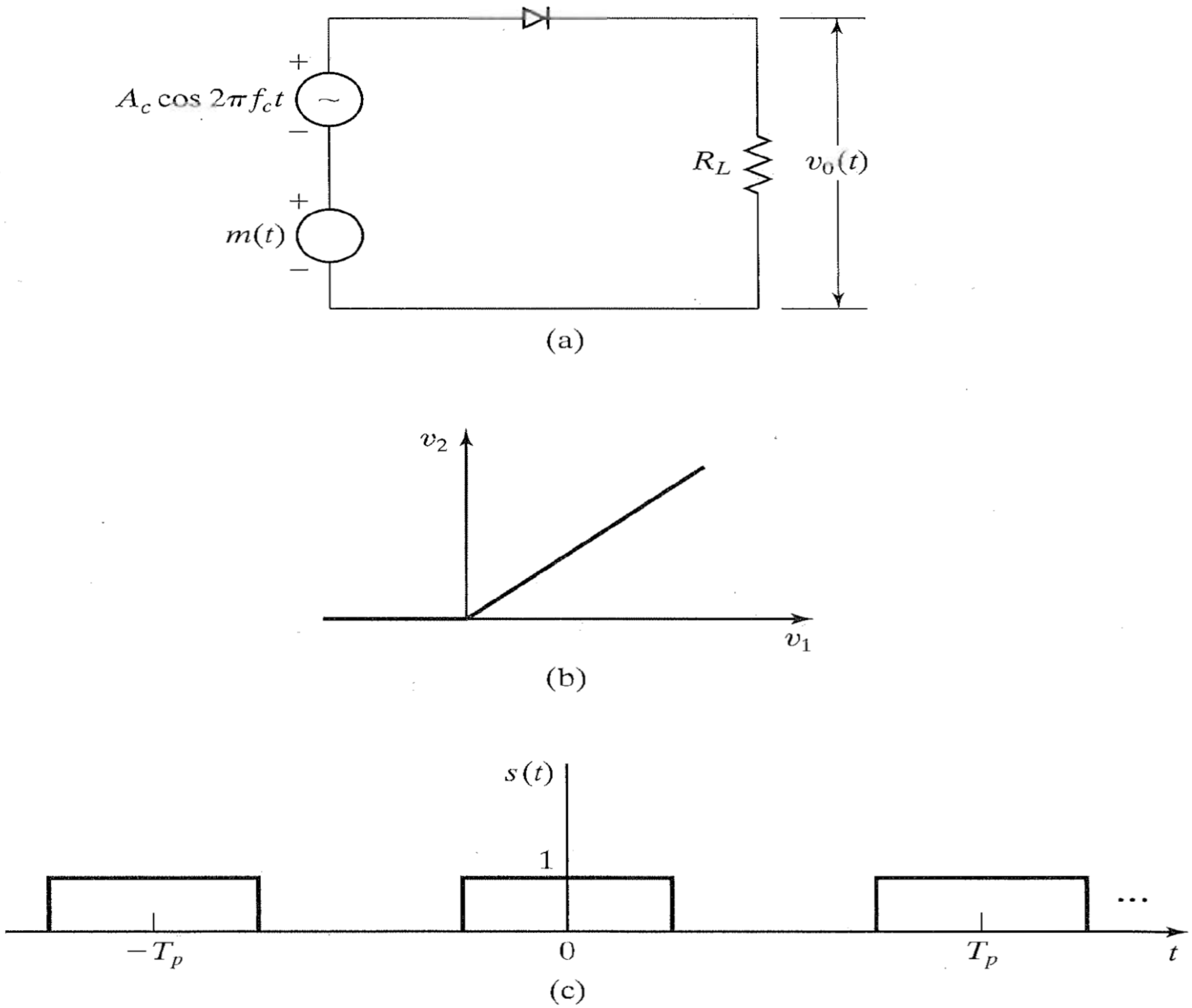

Figure 3.24 Switching modulator and periodic switching signal.

Switching Modulator (3/4)

- The switching operation may be viewed as a multiplication of the input $v_i(t)$ with the switching function $s(t)$, *i.e.*,

$$v_o(t) = [m(t) + A_c \cos(2\pi f_c t)]s(t)$$

  $s(t)$ is a periodic function, it is represented in Fourier series as

$$s(t) = \frac{1}{2} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos[2\pi f_c t(2n-1)]$$

- $v_o(t)$ can be written as

$$v_o(t) = [m(t) + A_c \cos(2\pi f_c t)]s(t)$$

$$= \frac{A_c}{2}\left[1 + \frac{4}{\pi A_c}m(t)\right]\cos(2\pi f_c t) + other\,terms$$

Switching Modulator (4/4)

- $v_o(t)$ is then passed through a BPF with the center frequency $f=f_c$ and the bandwidth $2W$
- The desired AM signal is

$$u(t) = \frac{A_c}{2}\left[1 + \frac{4}{\pi A_c} m(t)\right]\cos(2\pi f_c t)$$

Balanced Modulator (1/1)

- A relatively simple method for generating a DSB-SC AM signal is to use two conventional-AM modulators as shown in Fig. 3.25

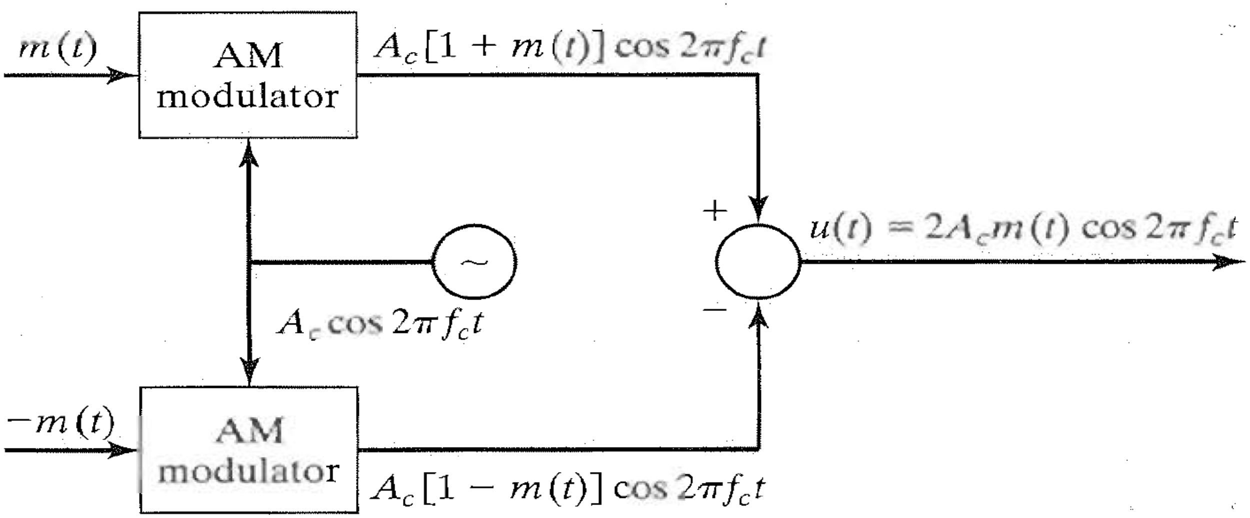

Figure 3.25 Block diagram of a balanced modulator.

Ring Modulator (1/2)

- Another type of modulator for generating a DSB-SC AM signal is called ring modulator
- The switching of diodes is controlled by a square wave $c(t)$ of frequency f_c and values ± 1

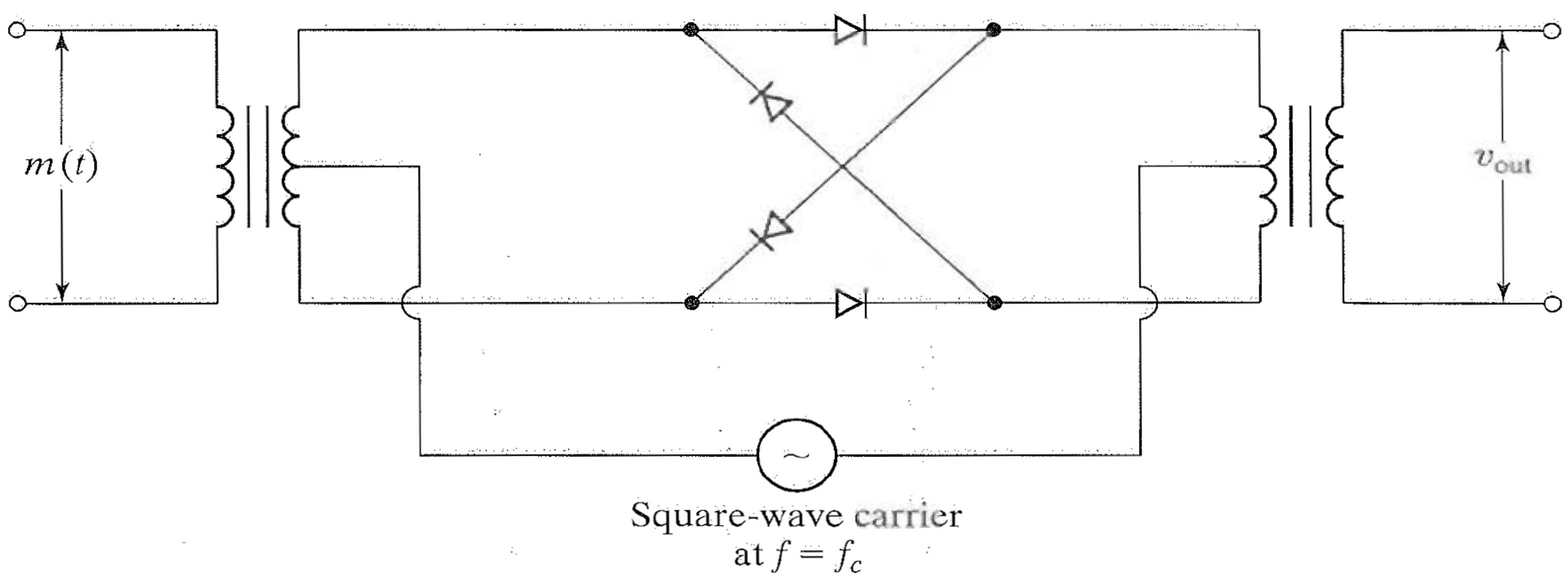

Figure 3.26 Ring modulator for generating a DSB-SC AM signal.

Ring Modulator (2/2)

- $v_o(t) = m(t)c(t)$
- $c(t)$ is a periodic function and its Fourier series is

$$c(t) = \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos[2\pi f_c(2n-1)t]$$

- The desired DSB-SC AM signal $u(t)$ is obtained by passing $v_o(t)$ through a bandpass filter with the center frequency f_c and the bandwidth $2W$
- The multiplication of $m(t)$ with $A_c\cos(2\pi f_c t)$ is called a mixing operation. Hence, a mixer is basically a balanced modulator

Envelope Detector (1/3)

- An envelope detector is used to demodulate the conventional AM signals
- During the positive half-cycle of the input signal, the diode conducts and the capacitor charges up to the peak value of the input signal. When the input falls below the voltage on the capacitor, the diode becomes reverse-biased and the input disconnects from the output

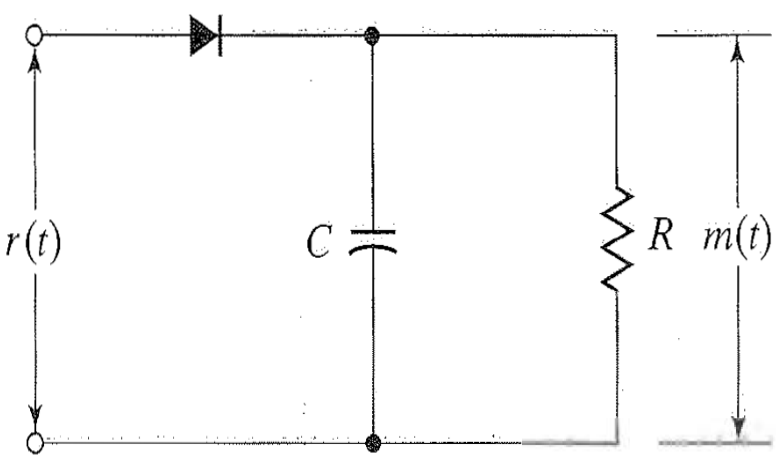

Figure 3.27 An envelope detector.

Envelope Detector (2/3)

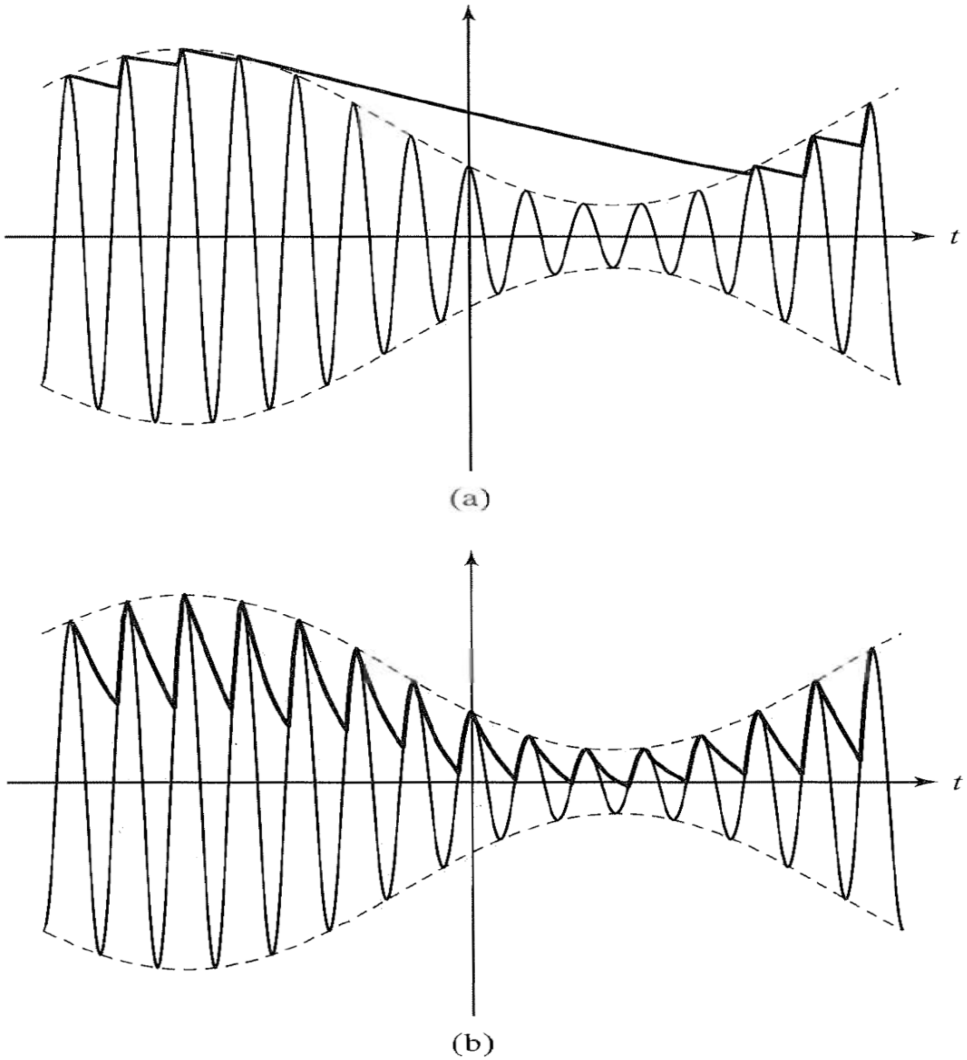

Figure 3.28 Effect of (a) large and (b) small *RC* values on the performance of the envelope detector.

Envelope Detector (3/3)

- For good performance of the envelope detector, the output of the envelope detector should closely follows the message signal. We should have

$$\frac{1}{f_c} << RC << \frac{1}{W}$$

- **Example 3.3.1.** A carrier of frequency 1 MHz is modulated by an audio signal of bandwidth W= 5 kHz. Determine the range of values of RC for successful demodulation of this signal using an envelope detector.
- We must have $\frac{1}{f_c} << RC << \frac{1}{W}$; therefore, $10^{-6} << RC << 2\times10^{-4}$. In this case, $RC=10^{-5}$ is an appropriate choice

Demodulation of DSB-SC AM Signals (1/1)

- The demodulation of a DSB-SC AM signal requires a synchronous demodulator. That is, the demodulator must use a coherent phase reference
- A PLL is used to generate a phase-coherent carrier signal that is mixed with the received signal in a balanced modulator

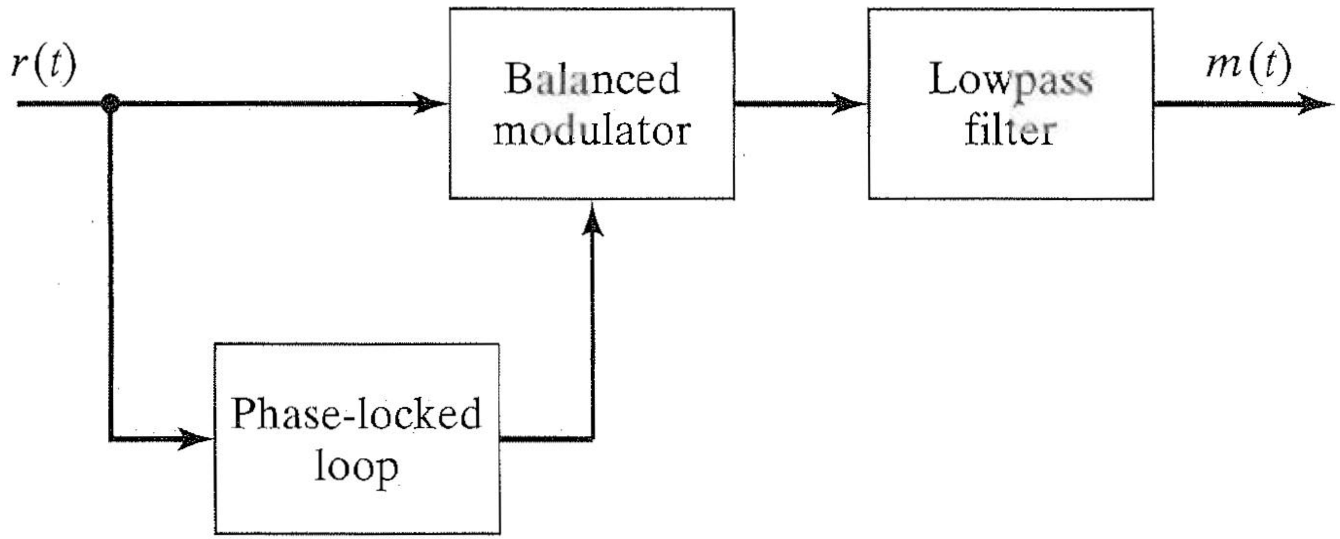

Figure 3.29 Demodulator for a DSB-SC signal.

Demodulation of SSB Signals (1/1)

- The demodulation of SSB-AM signals also requires the use of a phase-coherent reference
- Speech has relatively little or no power content at DC, it is simple to generate the SSB signals and insert a small carrier component that is transmitted along with the message

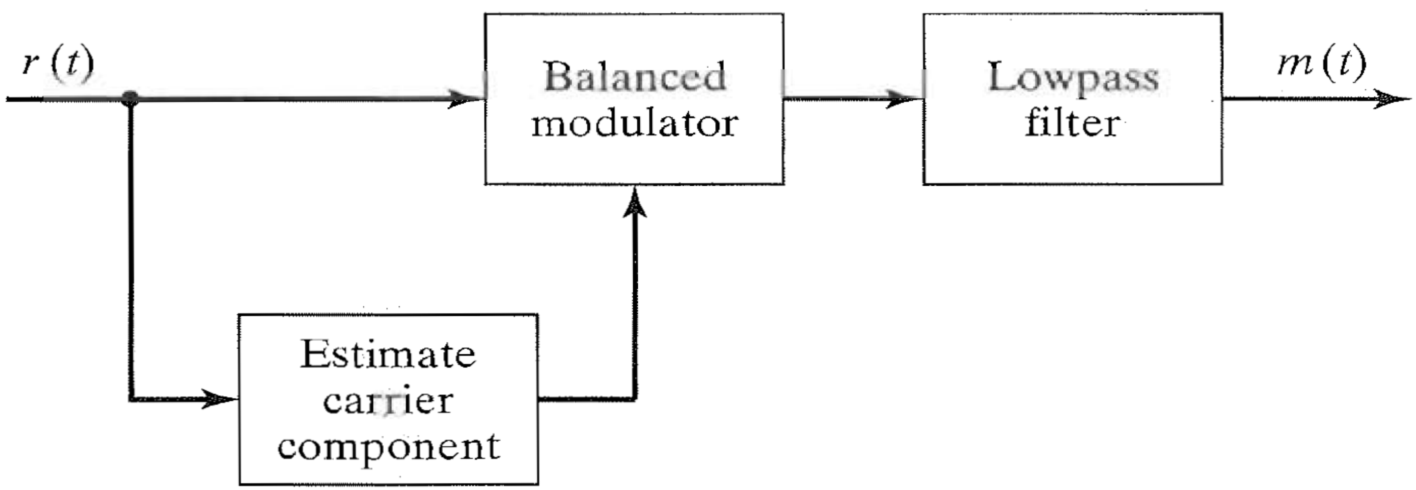

Figure 3.30 Demodulation of SSB-AM signal containing a carrier component.

Demodulation of VSB Signals (1/1)

- In VSB, a carrier component is generally transmitted along with the message sidebands. The existence of the carrier component makes it possible to extract a phase-coherent reference for demodulation

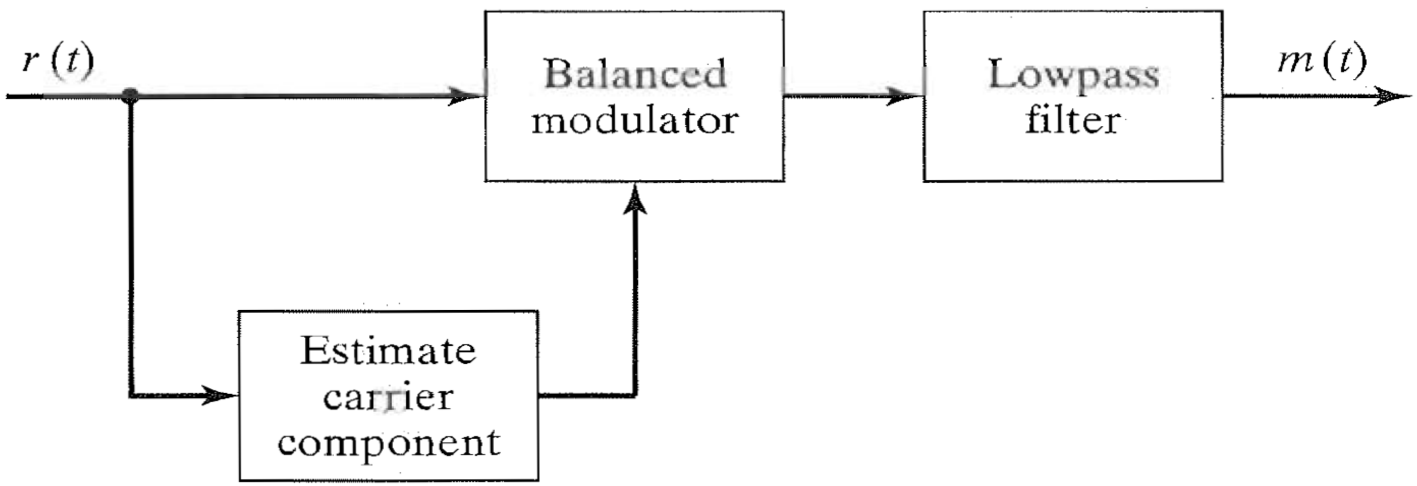

Figure 3.30 Demodulation of SSB-AM signal containing a carrier component.

Signal Multiplexing (1/1)

- If we have two or more message signals to transmit simultaneously over the communication channel, we can have each message signal modulate a carrier of a different frequency
- The minimum separation between two adjacent carriers is either $2W$ (for DSB AM) or W (for SSB AM), where W is the bandwidth of each of the message signal
- Combining separate message signals into a composite signal for transmission over a common channel is called *multiplexing*
- Time-division multiplex (TDM)
- Frequency-division multiplex (FDM)

Frequency-Division Multiplexing (1/2)

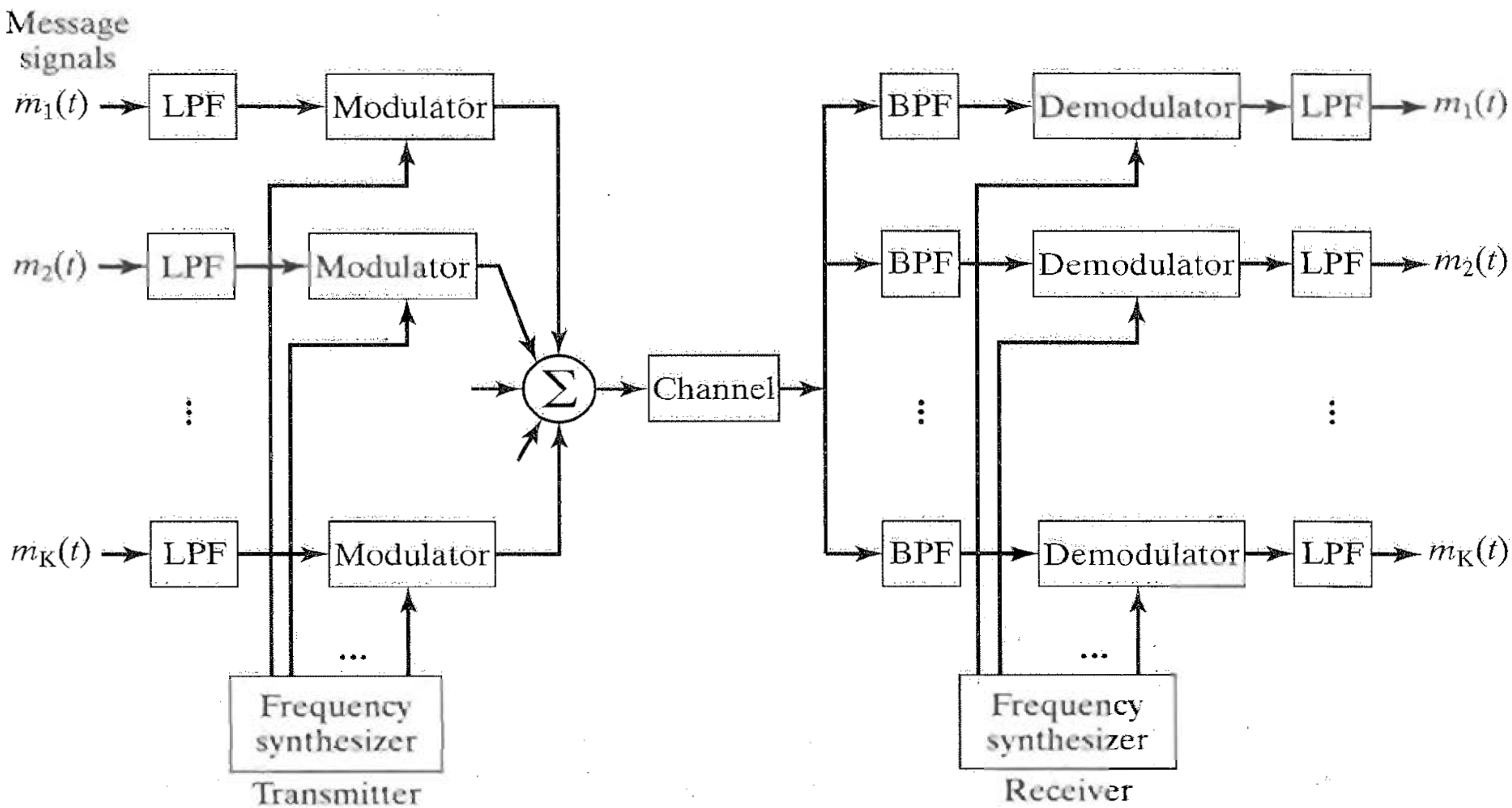

Figure 3.31 Frequency-division multiplexing of multiple signals.

Frequency-Division Multiplexing (2/2)

- An FDM hierarchy is employed in telephone communication systems
- In telephone communications, each voice-message signal occupies a nominal bandwidth of 4 kHz. The message signal is single-sideband modulated for bandwidth-efficient transmission
- In the first level of multiplexing, 12 signals are stacked in frequency, with a frequency separation of 4 kHz between adjacent carriers
- A composite 48 kHz channel is called a group channel
- In the next level of FDM, a number of group channels (typically five or six) are stacked to form a super group channel

Quadrature-Carrier Multiplexing (1/3)

- The message signal $m_1(t)$ amplitude modulates the carrier $A_c\cos(2\pi f_c t)$, and the signal $m_2(t)$ amplitude modulates the quadrature carrier $A_c\sin(2\pi f_c t)$.
- The two signals are added together and transmitted over the channel. The transmitted signal is

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

- Each message signal is transmitted by DSB-SC AM. This type of signal multiplexing is called quadrature-carrier multiplexing

Quadrature-Carrier Multiplexing (2/3)

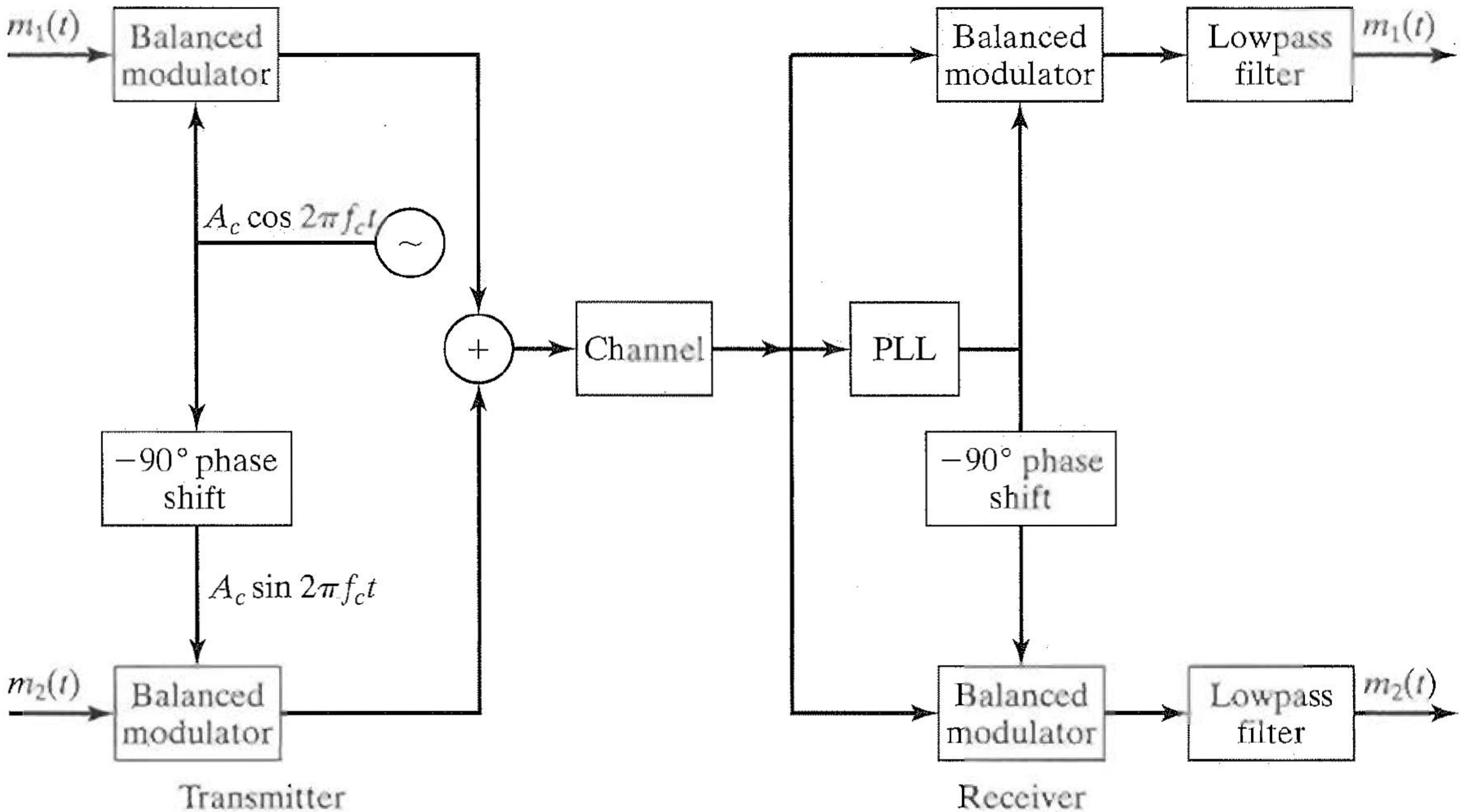

Figure 3.32 Quadrature-carrier multiplexing.

Quadrature-Carrier Multiplexing (3/3)

- Demodulation of $m_1(t)$ is done by multiplying $u(t)$ by $\cos(2\pi f_c t)$ and then passing the result through a lowpass filter. We have

$$
\begin{aligned}
u(t)\cos(2\pi f_c t) &= A_c m_1(t)\cos^2(2\pi f_c t) + A_c m_2(t)\cos(2\pi f_c t)\sin(2\pi f_c t) \\
&= \frac{A_c}{2} m_1(t) + \frac{A_c}{2} m_1(t)\cos(4\pi f_c t) + \frac{A_c}{2} m_2(t)\sin(4\pi f_c t).
\end{aligned}
$$

- The lowpass component $A_c m_1(t)/2$ is then separated using a lowpass filter
- To demodulate $m_2(t)$, we multiply $u(t)$ by $\sin(2\pi f_c t)$ and then pass the product through a lowpass filter