EE1 and ISE1 Communications I

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Lecture nine

Lecture Aims

- To examine modulation process
- Baseband and bandpass signals
- Double Sideband Suppressed Carrier (DSB-SC)
  - Modulation
  - Demodulation
- Modulators
  - Nonlinear modulators
  - Switching modulators
  - Diode modulators

Modulation

- Modulation is a process that causes a shift in the range of frequencies in a signal.
- Two types of communication systems
  - Baseband communication: communication that does not use modulation
  - Carrier modulation: communication that uses modulation
- The baseband is used to designate the band of frequencies of the source signal. (e.g., audio signal 4kHz, video 4.3MHz)

Modulation (continued)

In analog modulation the basic parameter such as amplitude, frequency or phase of a sinusoidal carrier is varied in proportion to the baseband signal $m(t)$. This results in amplitude modulation (AM) or frequency modulation (FM) or phase modulation (PM).

The baseband signal $m(t)$ is the modulating signal.

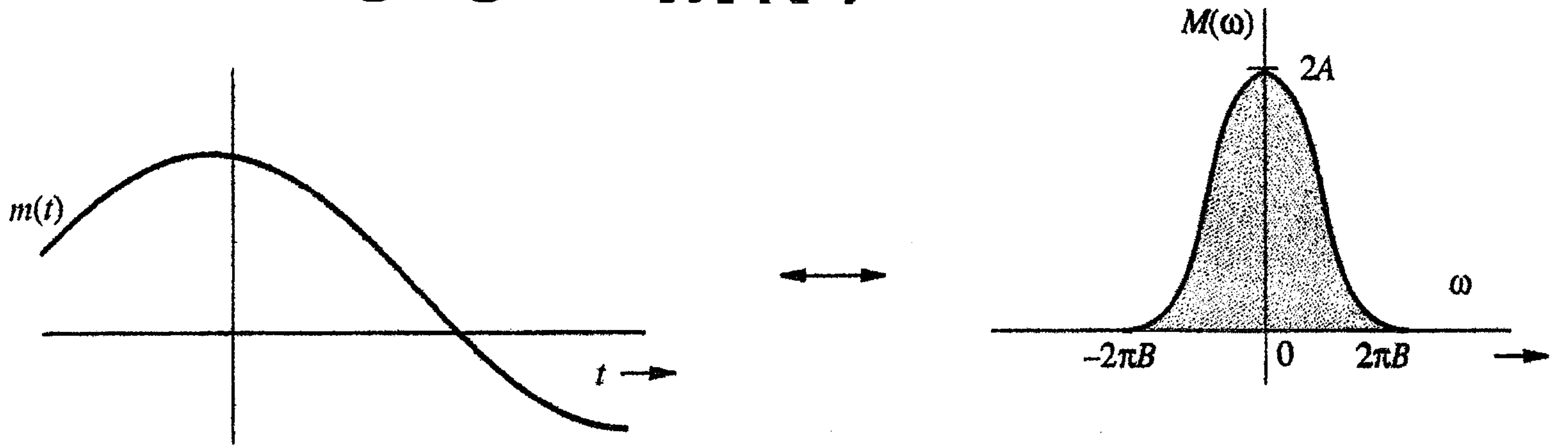
The sinusoid is the carrier or modulator.

Why modulation?

- To use a range of frequencies more suited to the medium
- To allow a number of signals to be transmitted simultaneously (frequency division multiplexing)
- To reduce the size of antennas in wireless links

Amplitude Modulation

- **Carrier** $A \cos(\omega_c t + \theta_c)$
  - **Phase is constant** $\theta_c = 0$
  - **Frequency is constant**
- **Modulating signal** $m(t)$

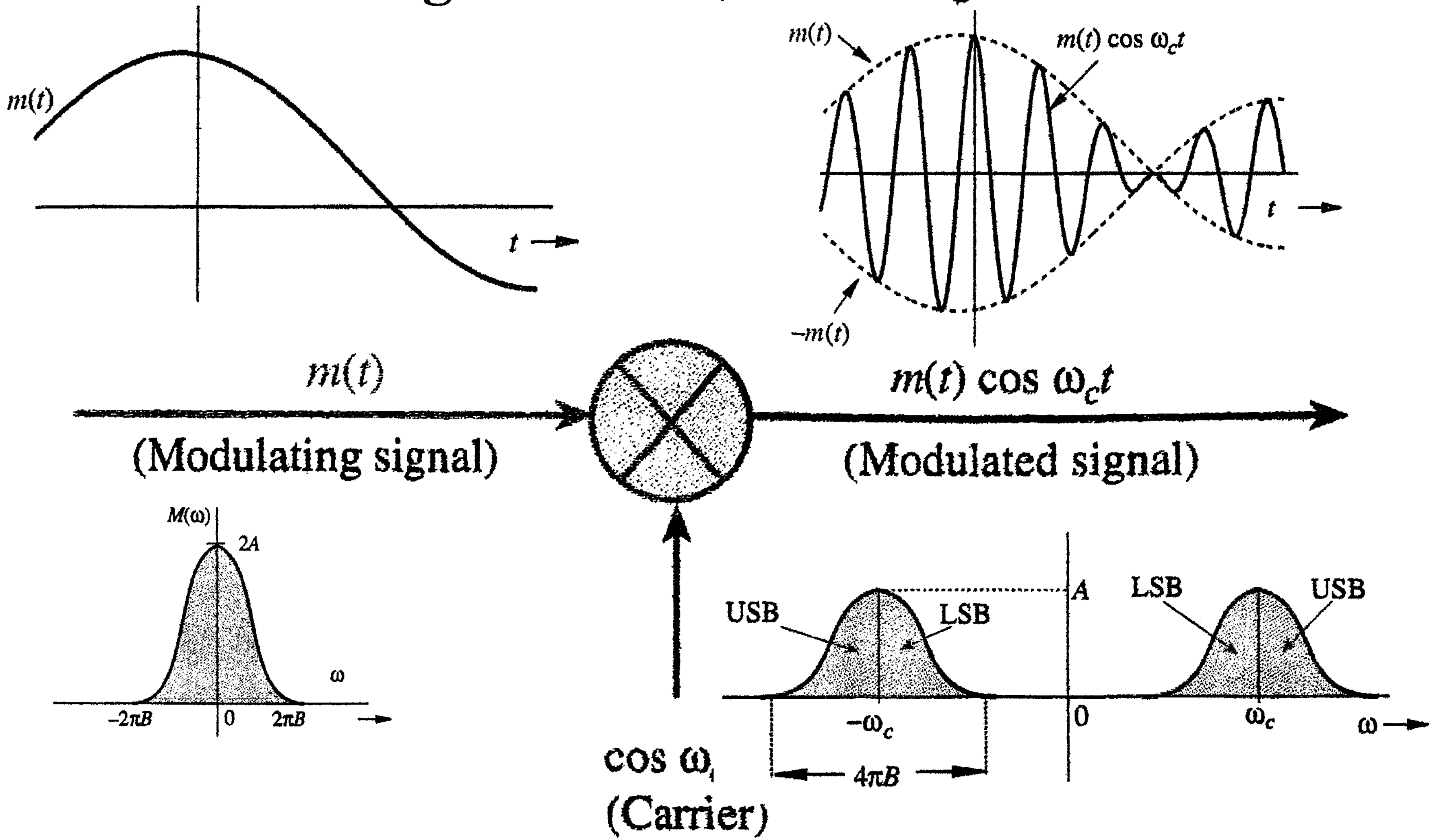


- **With amplitude spectrum**

$$m(t) \Longleftrightarrow M(\omega)$$

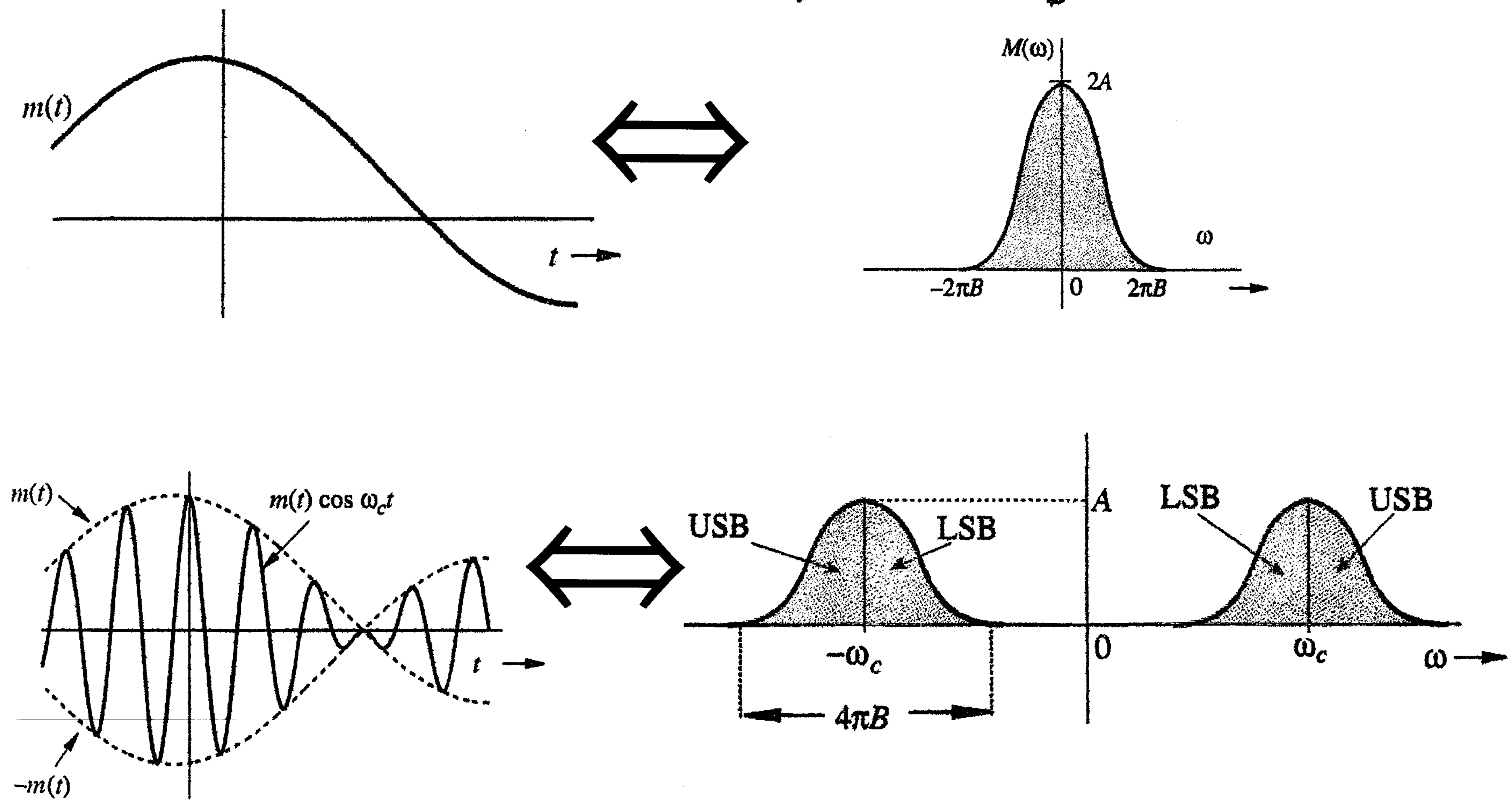
Modulated signal

- **Modulated signal:** $m(t)\cos\omega_c t$



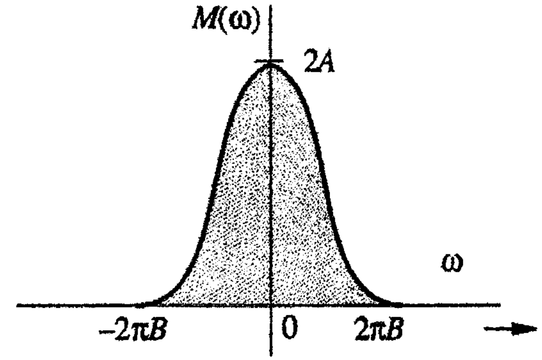
Modulated signal

- **Modulated signal:** $m(t) \cos \omega_c t$



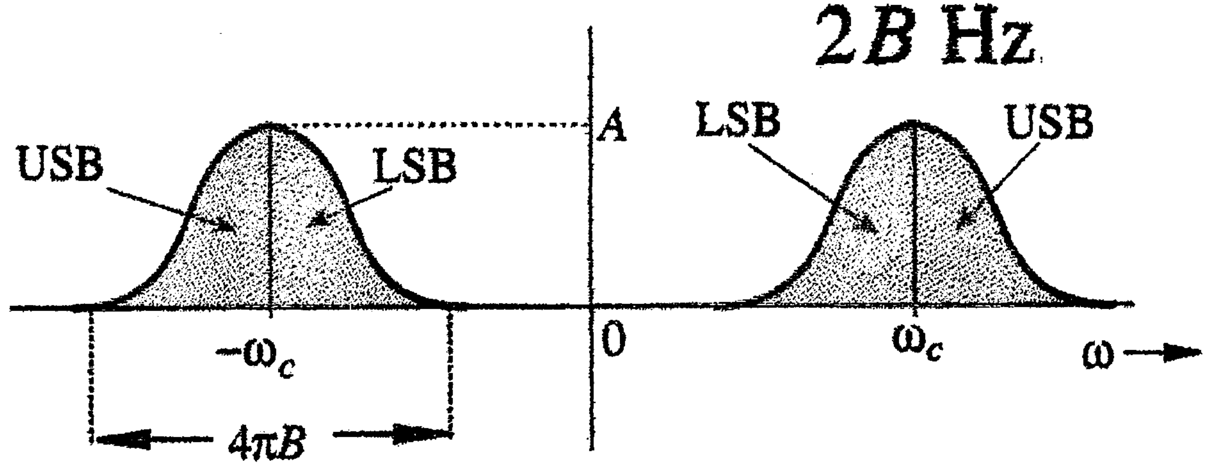
Modulated signal

- **Baseband spectrum:** B Hz



- $M(\omega)$ **is shifted to** $M(\omega + \omega_c)$ **and** $M(\omega - \omega_c)$

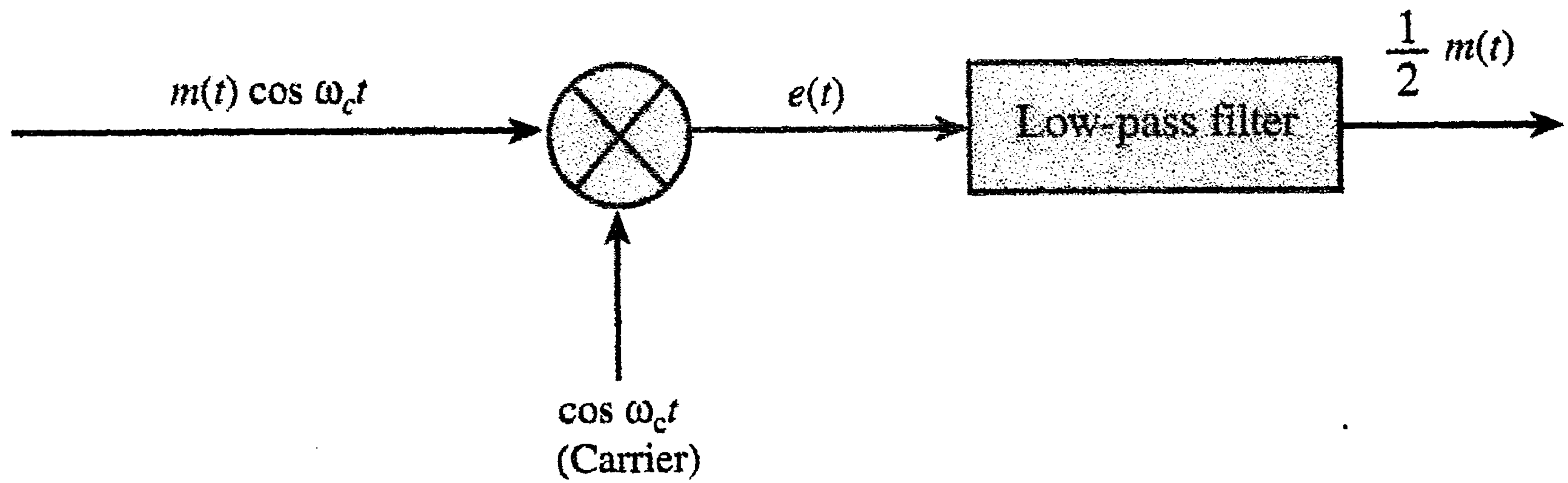
$2B$ Hz



$$m(t)\cos\omega_c t \Longleftrightarrow \frac{1}{2}[M(\omega + \omega_c) + M(\omega - \omega_c)]$$

Demodulation of DSB signal

- **Process modulated signal** $m(t)\cos\omega_c t$



- **Multiply modulated signal with** $\cos\omega_c t$

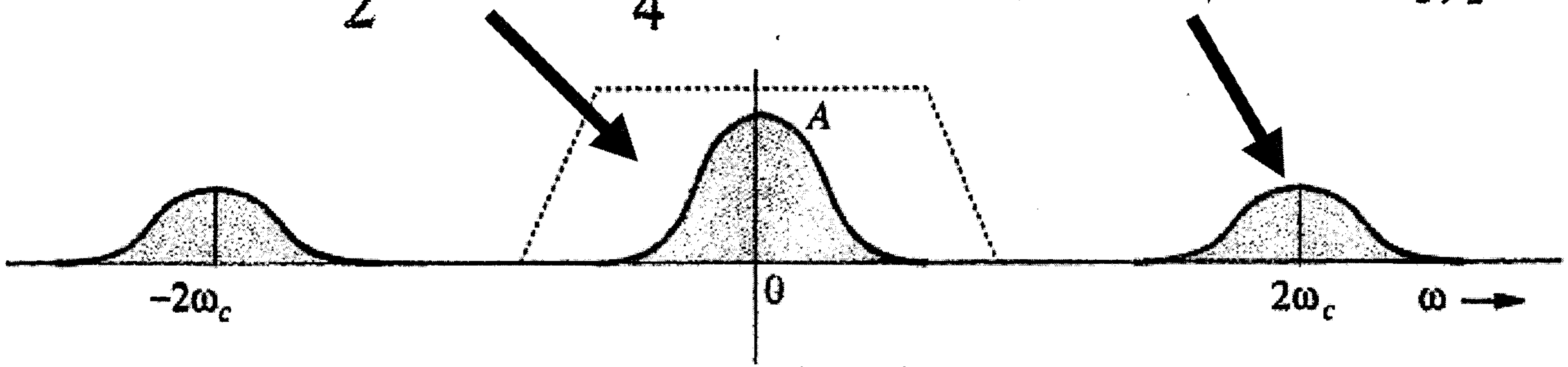
$$e(t) = m(t)\cos^2\omega_c t = \frac{1}{2}[m(t) + m(t)\cos 2\omega_c t]$$

$$E(\omega) = \frac{1}{2}M(\omega) + \frac{1}{4}[M(\omega + 2\omega_c) + M(\omega - 2\omega_c)]$$

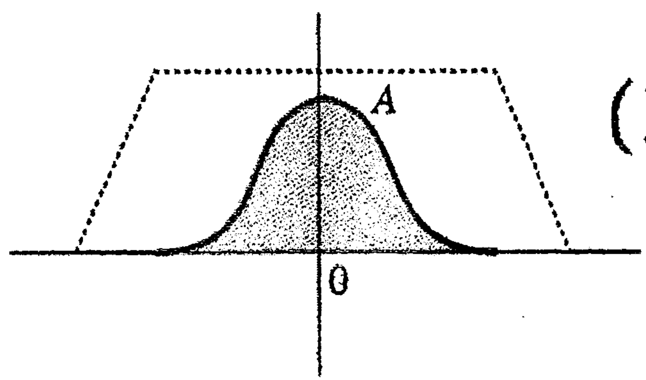
Demodulation of DSB signal

- **Process modulated signal** $m(t)\cos\omega_c t$

$$E(\omega) = \frac{1}{2}M(\omega) + \frac{1}{4}[M(\omega + 2\omega_c) + M(\omega - 2\omega_c)]$$



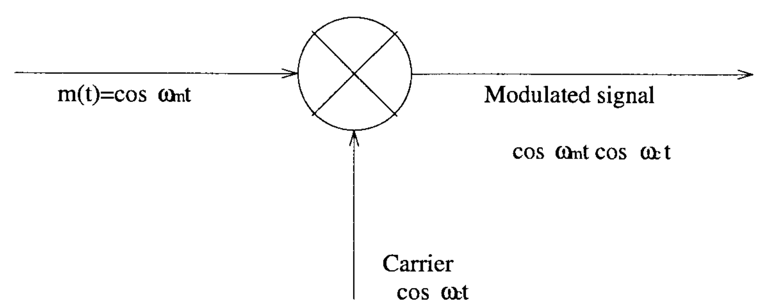
  - **Use a filter to select** $(1/2)m(t)$ remove



$(1/2)m(t)\cos 2\omega_c t$

Example

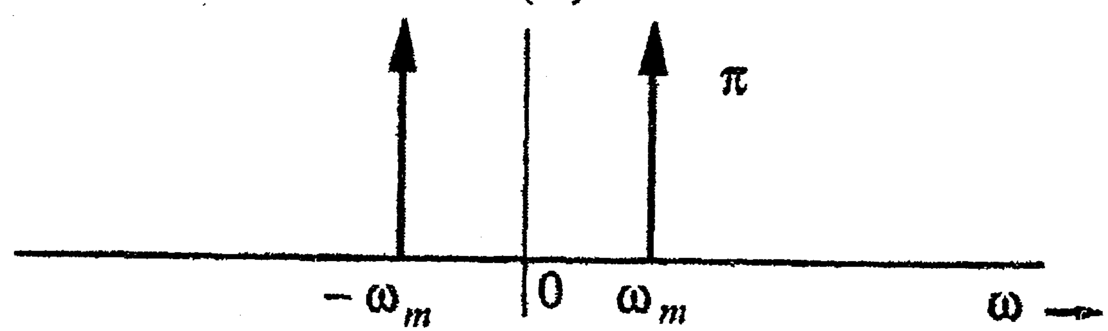
- Modulating signal $m(t) = \cos\omega_m t$.
- Carrier $\cos\omega_c t$.
- Modulated signal $\phi(t) = m(t)\cos\omega_c t = \cos\omega_m t\cos\omega_c t$



Amplitude spectrum

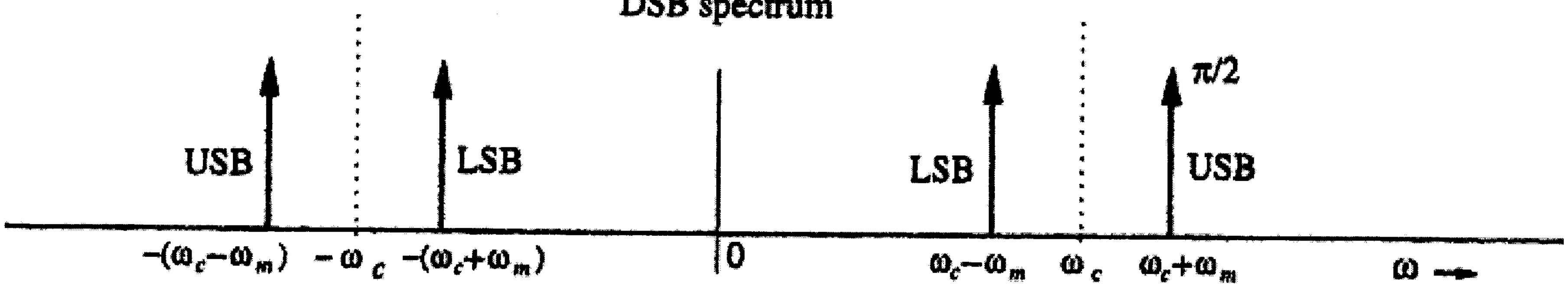
- **Baseband signal**

$$M(\omega) = \pi[\delta(\omega - \omega_m) + \delta(\omega + \omega_m)]$$



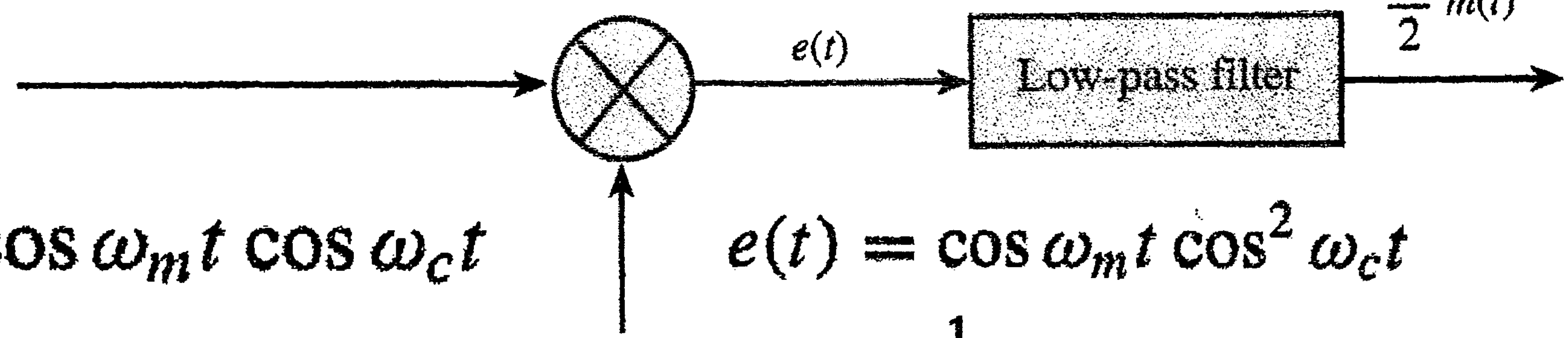
$$\varphi_{\text{DSB-SC}}(t) = \frac{1}{2}[\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t]$$

DSB spectrum



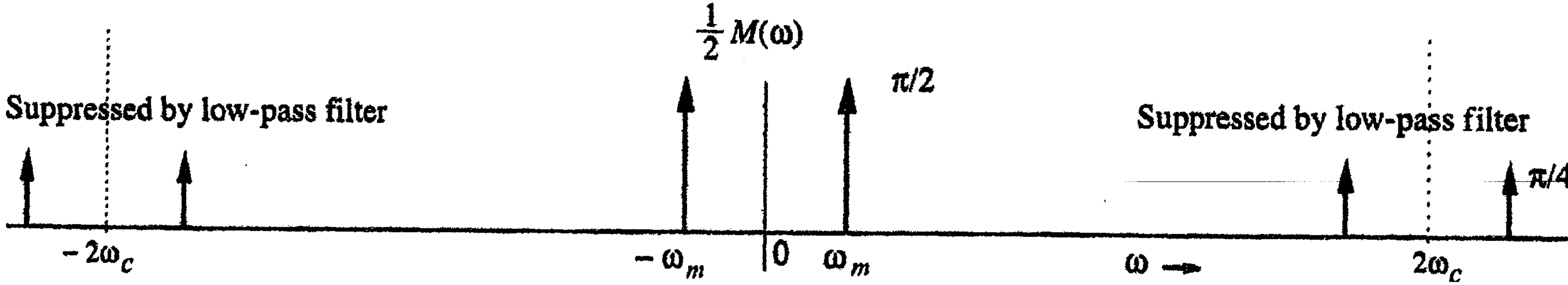
Demodulation of DSB signal

- **Process modulated signal** $m(t)\cos\omega_c t$



$\cos\omega_m t\cos\omega_c t$

$$e(t) = \cos\omega_m t\cos^2\omega_c t$$
$$= \frac{1}{2}\cos\omega_m t\,(1+\cos 2\omega_c t)$$



Modulators

- We need to implement multiplication $m(t)\cos\omega_c t$.
- We can use
  - Nonlinear modulators
  - Switching modulators
- Switching modulators can be implemented using diode ring modulators.

Nonlinear modulator

- Input-output characteristics of a nonlinear element

$$y(t) = ax(t) + bx^2(t)$$

- Where $x(t)$ is the input signal and $y(t)$ is the output signal.

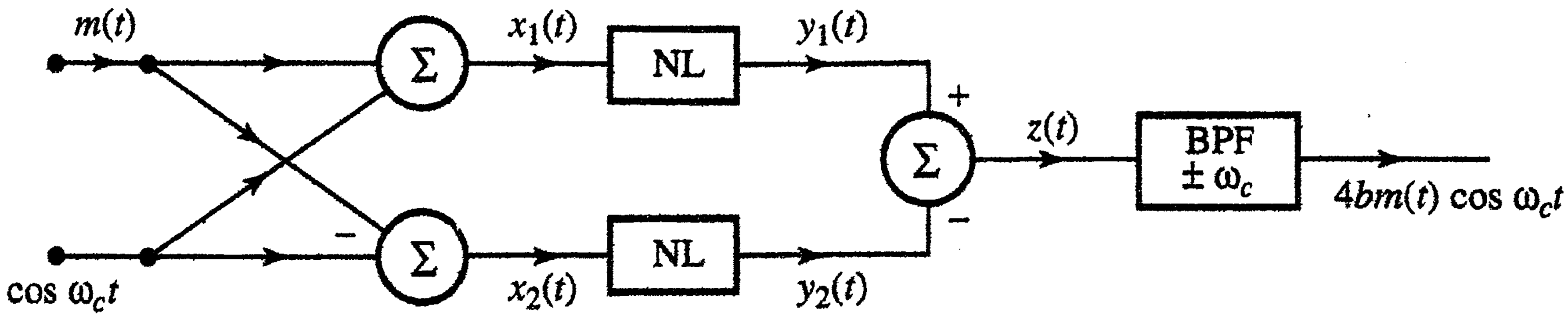
- Consider to input signals
  $x_1(t) = \cos \omega_c t + m(t)$
  $x_2(t) = \cos \omega_c t - m(t)$

Nonlinear modulator

- **Let us implement**

$$z(t) = y_1(t) - y_2(t)$$

$$= [ax_1(t) + bx_1^2(t)] - [ax_2(t) + bx_2^2(t)]$$



$$z(t) = 2am(t) + 4bm(t)\ \cos\ \omega_c t$$

Switching modulators

- **Consider a periodic signal of fundamental frequency** ω_c

$$\phi(t) = \sum_{n=0}^{\infty} C_n \cos(n\omega_c t + \theta_n)$$

- **Multiplication of modulating signal with this periodic signal gives**

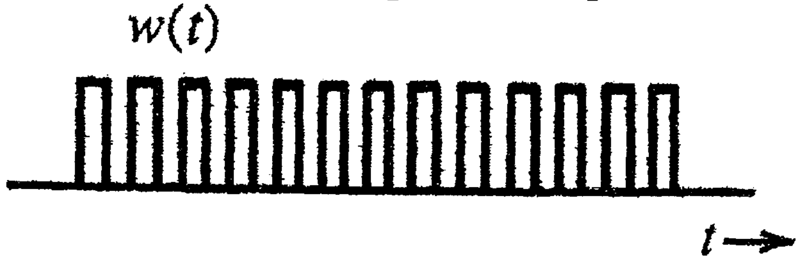
$$m(t)\phi(t) = \sum_{n=0}^{\infty} C_n\, m(t) \cos(n\omega_c t + \theta_n)$$

- **The spectrum of the product** $m(t)\phi(t)$ **is the spectrum** $M(\omega)$ **shifted to**

$$\pm\omega_c,\ \pm 2\omega_c,\ \ldots,\ \pm n\omega_c, \ldots$$

Square Pulse train as a modulator

- **Consider a square pulse train**



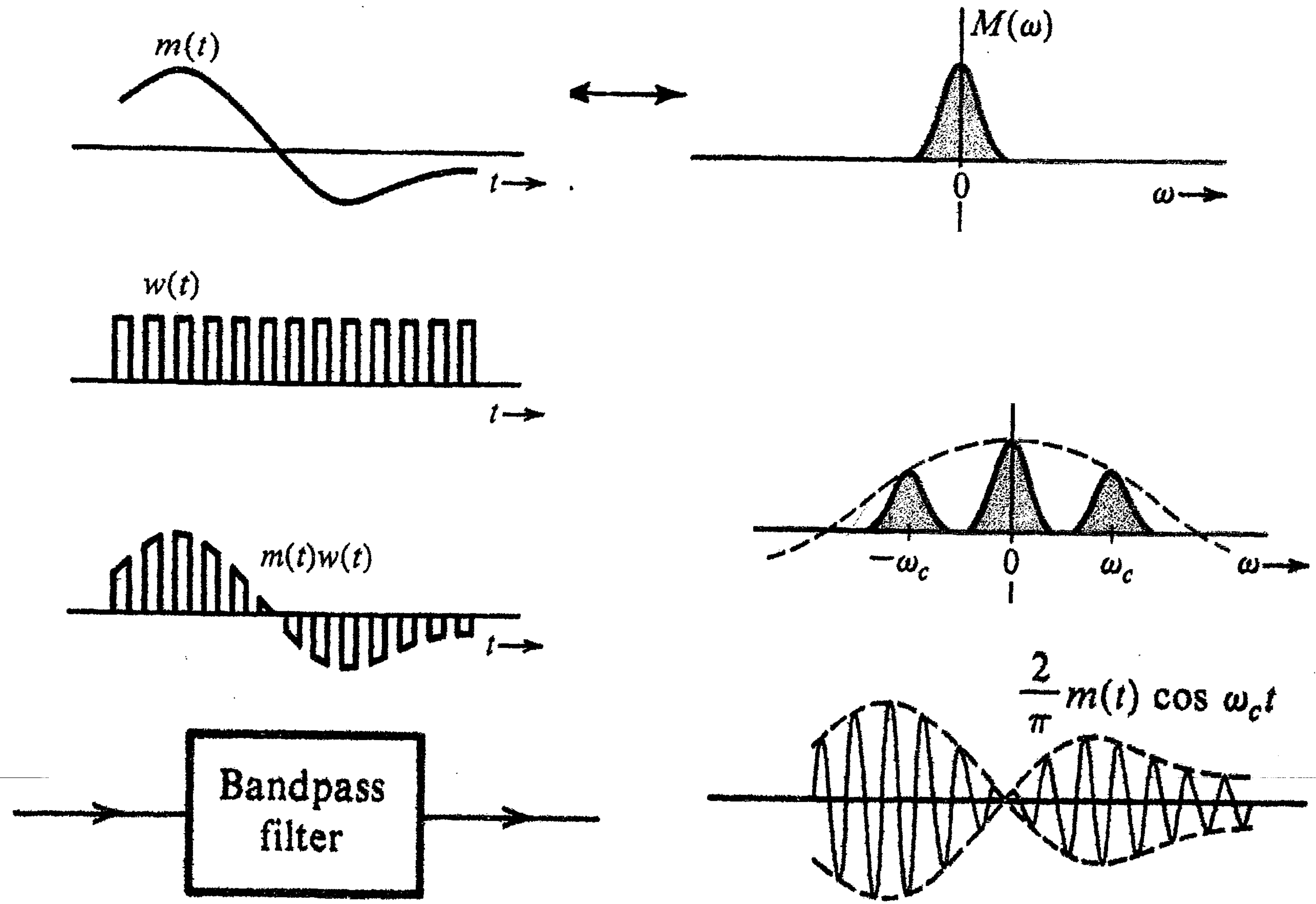
- **The Fourier series for this periodic waveform is**

$$w(t) = \frac{1}{2} + \frac{2}{\pi}\left(\cos\omega_c t - \frac{1}{3}\cos 3\omega_c t + \frac{1}{5}\cos 5\omega_c t - \cdots\right)$$

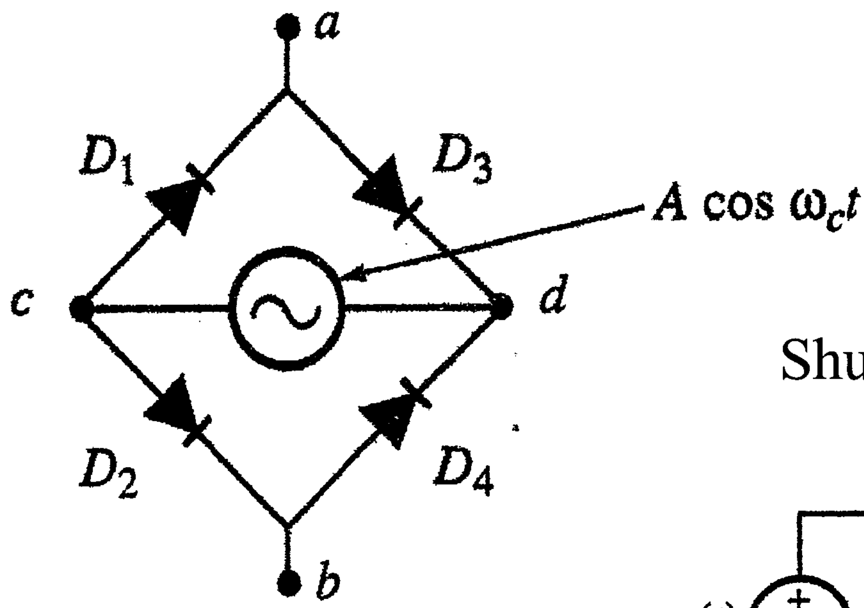
- **The signal $m(t)w(t)$ is**

$$m(t)w(t) = \frac{1}{2}m(t) + \frac{2}{\pi}\left[m(t)\cos\omega_c t - \frac{1}{3}m(t)\cos 3\omega_c t + \cdots\cdots\right.$$

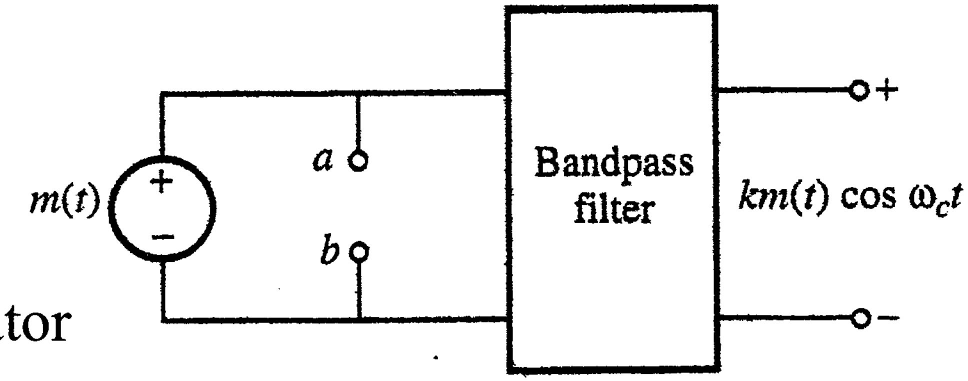
Switching modulator



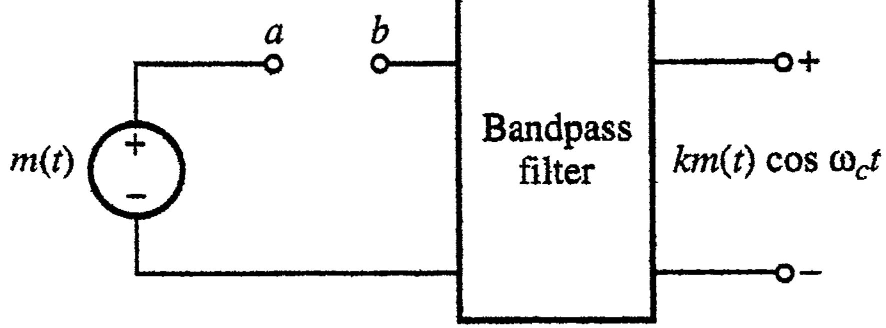
Diode Switches



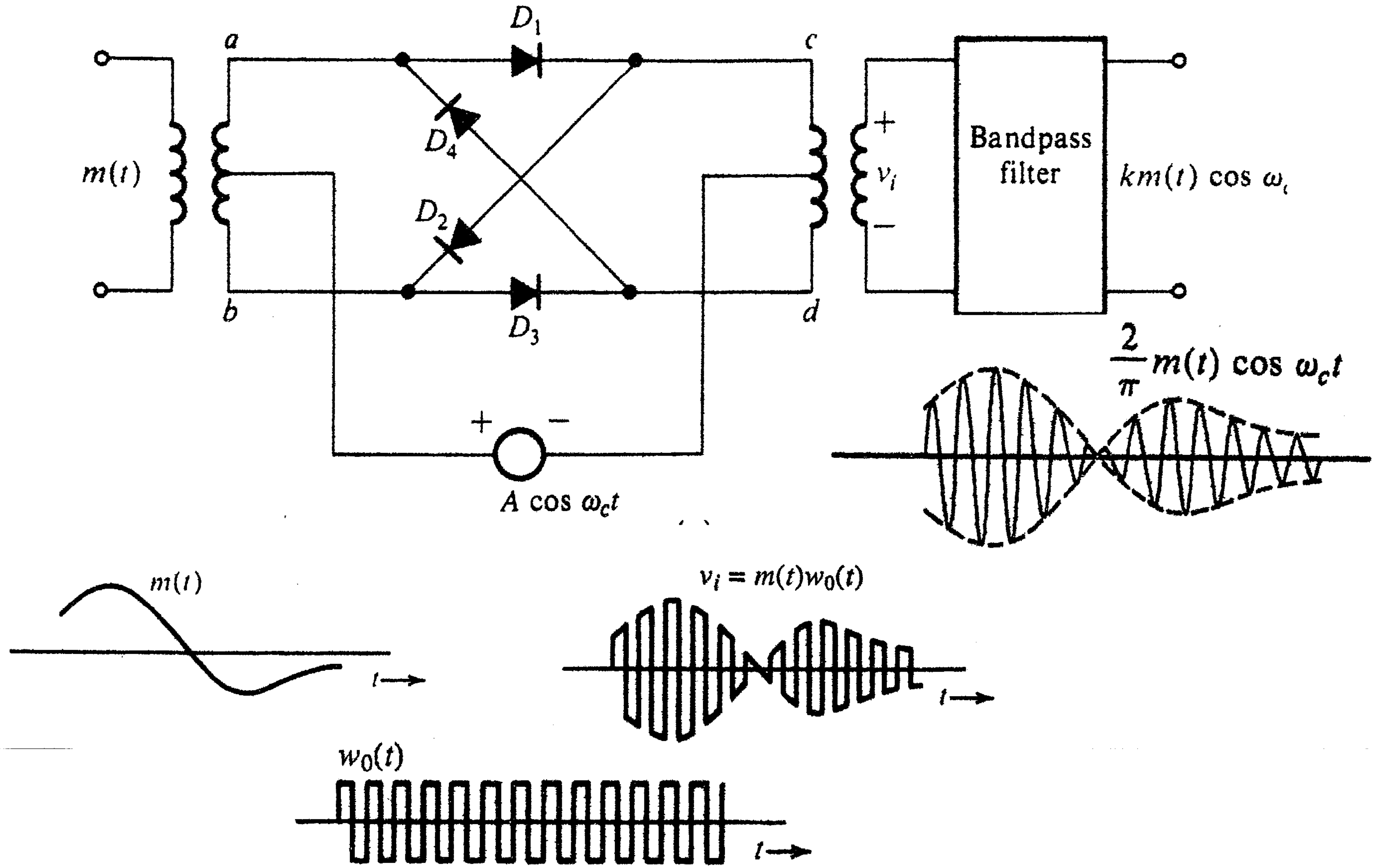
Shunt-bridge diode modulator



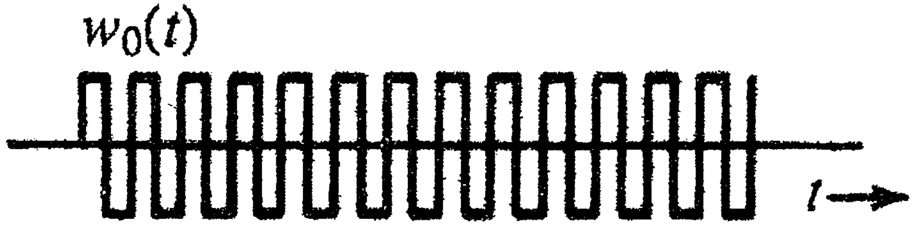
Series-bridge diode modulator



Ring modulator



Ring modulator



$$w_0(t) = \frac{4}{\pi}\left(\cos \omega_c t - \frac{1}{3}\cos 3\omega_c t + \frac{1}{5}\cos 5\omega_c t - \cdots\right)$$

$$v_i(t) = m(t)w_0(t) = \frac{4}{\pi}\left[m(t)\cos \omega_c t - \frac{1}{3}m(t)\cos 3\omega_c t + \frac{1}{5}m(t)\cos 5\omega_c t - \cdots\right]$$

Conclusions

We learned about

- Baseband and Carrier transmission,
- Amplitude modulation (DSB-SC),
- Non-linear modulator,
- Switching modulator,
- Diode switches.