Lecture 2

Amplitude Modulation

Modulation

- Modulation is a process that shifts the range of frequencies of a signal to higher frequencies.
- Why do we need modulation?

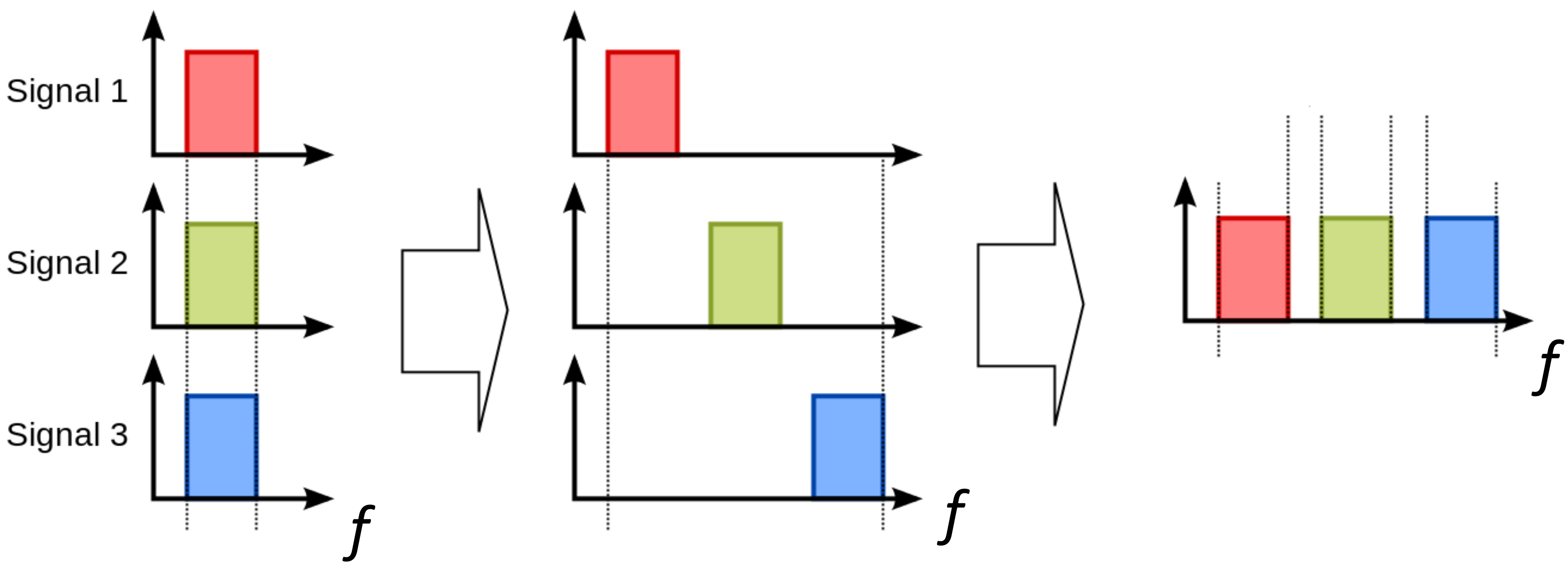
1. Practical antenna dimensions

$$\lambda = \frac{c}{f}$$

   - For efficient radiation of electromagnetic energy, the antenna should be on the order of a fraction or more of the wavelength (e.g. 10%)
   - Speech: 100 Hz to 3 kHz (λ=3000 to 100 km)
   - What about a signal around 100 MHz?

Modulation

2. Simultaneous transmission of multiple signals (frequency division multiplexing)



Baseband vs Bandpass (carrier) communications

Baseband communications:

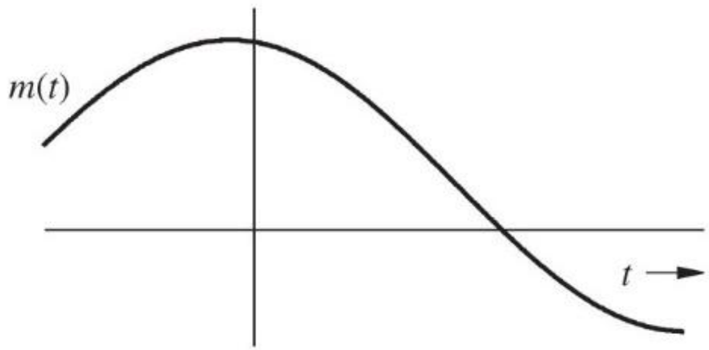
- Baseband (lowpass) message signals are directly transmitted without modification (e.g. telephone)
- Often limited to wired channels, cannot effectively use wireless channels
- Users cannot simultaneously share a common channel

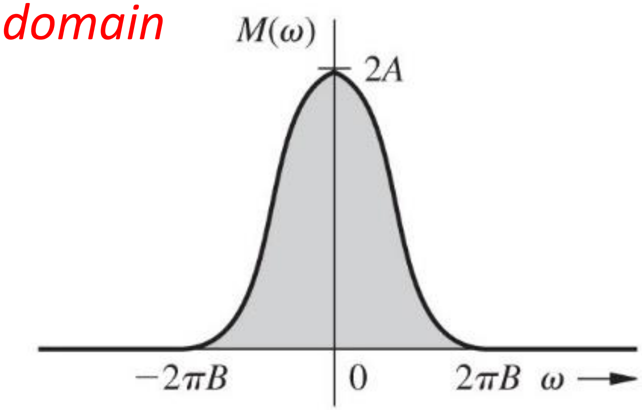
Bandpass (carrier) communications:

- Use Modulation to shift the frequency spectrum of the message signal.

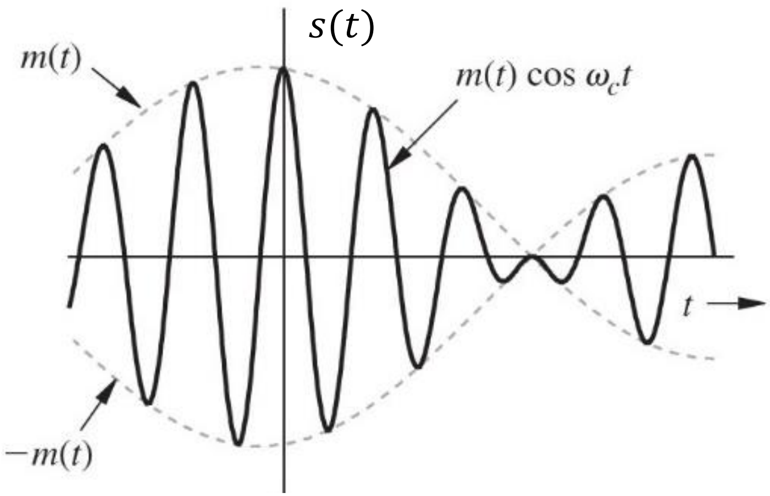
Amplitude Modulation (AM)

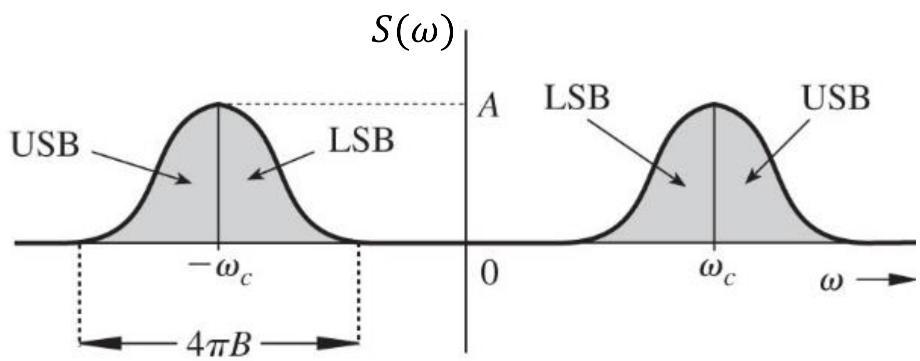
Time domain *Frequency domain*





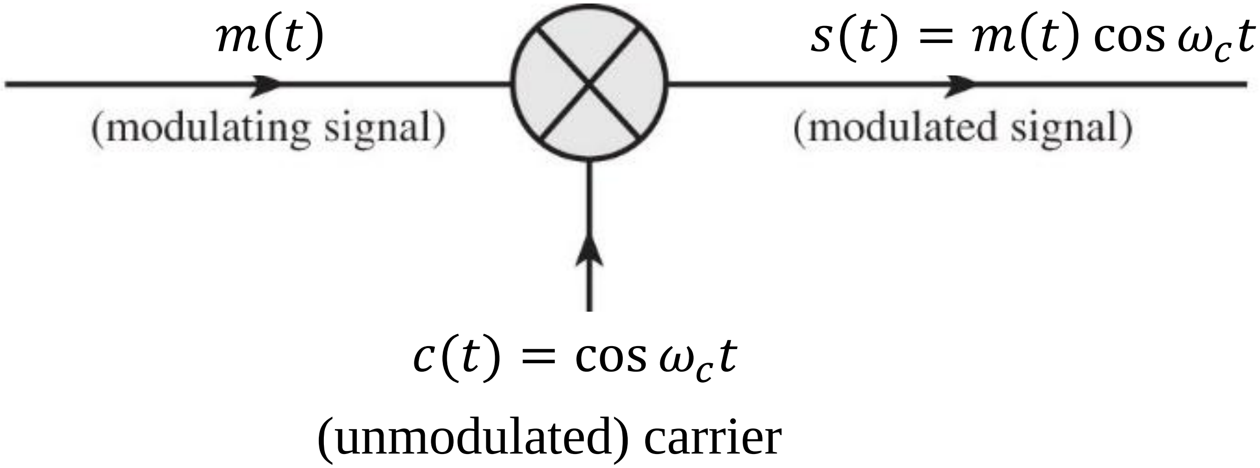
$$m(t)\cos\omega_c t \Leftrightarrow \frac{1}{2}\left[M(\omega+\omega_c)+M(\omega-\omega_c)\right]$$





Amplitude Modulation (AM)

- *Amplitude* of the carrier is modulated (modified) by the message signal $m(t)$



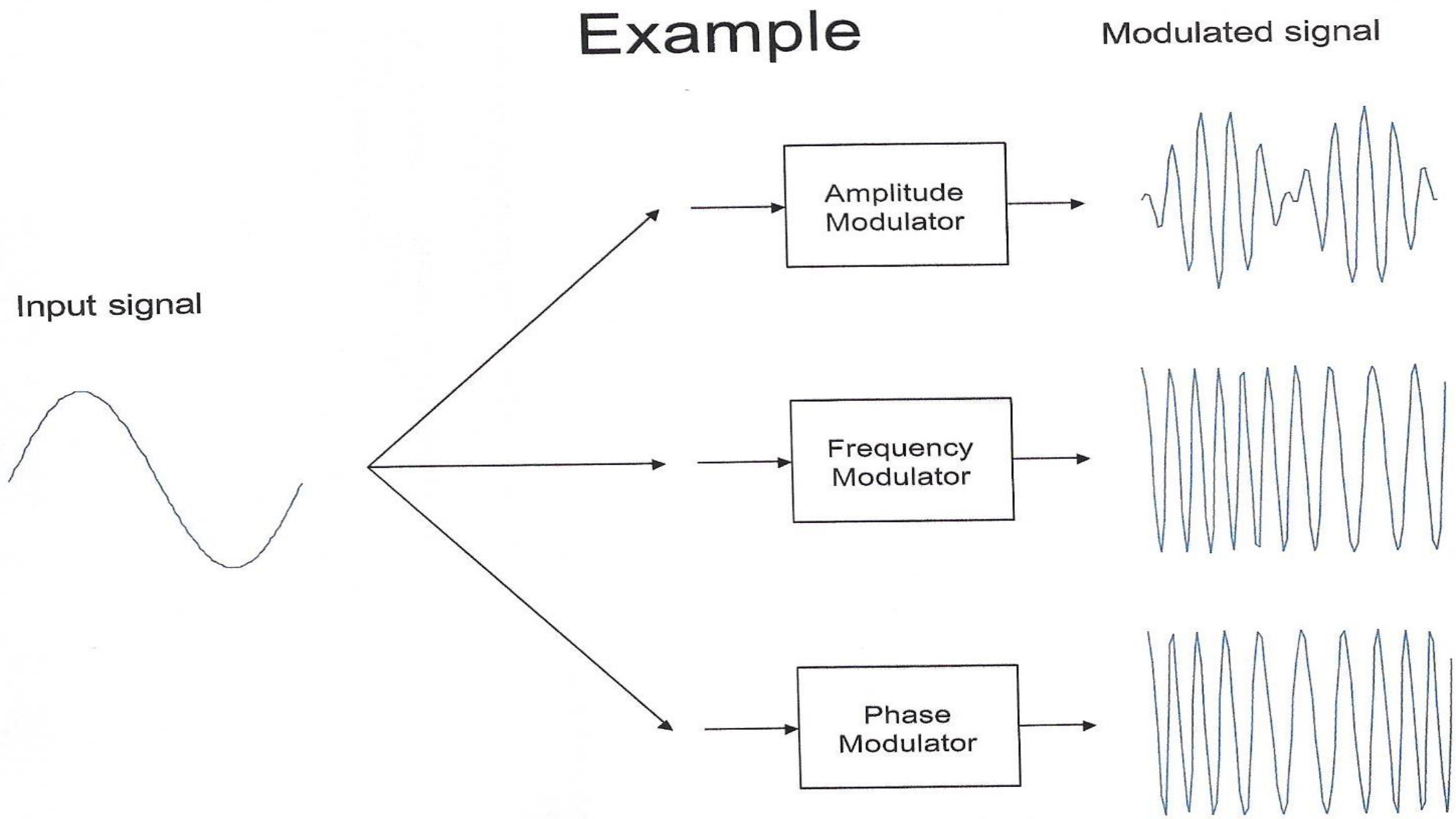
- $\boldsymbol{m(t)}$: **modulating signal** (message signal)
- $\boldsymbol{c(t)} = cos\omega_c t$: unmodulated **carrier** (carries the message)
- $\boldsymbol{s(t)} = m(t)cos\omega_c t$: **modulated signal** (transmitted)

Modulation

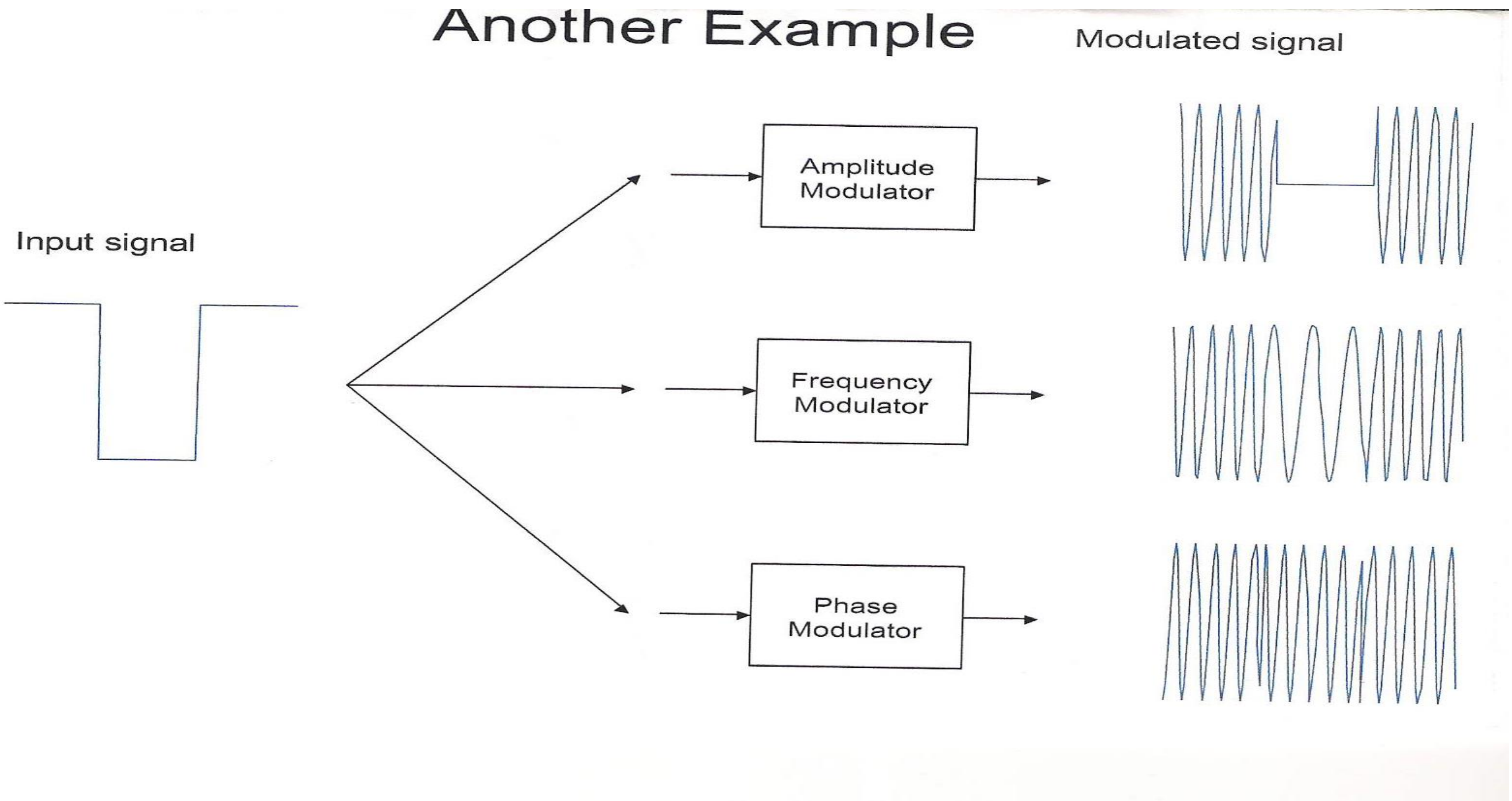
Generally,

- Modulation is the process of **varying** one of the parameters (**amplitude**, **frequency**, or **phase**) of a high frequency sinusoidal carrier with the baseband signal $m(t)$.
- This results in **Amplitude Modulation (AM)**, **Frequency Modulation (FM)** or **Phase Modulation (PM)**, respectively.
- FM and PM are called angle modulation.

Modulation Types (Analog Modulation)



Modulation Types (Digital Modulation)



Analog Modulation

Different analog modulation techniques

For each type:

- Mathematical representation (time and frequency domains)

    * Bandwidth   * transmitted power

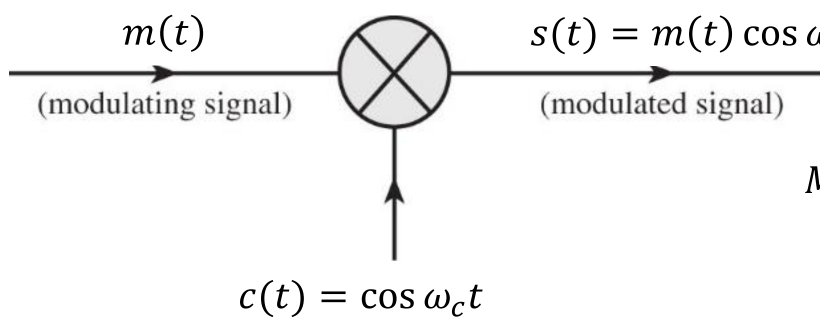
- Modulators

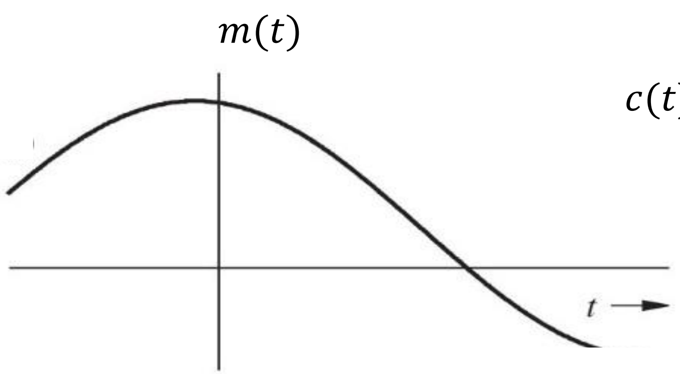
- Demodulators

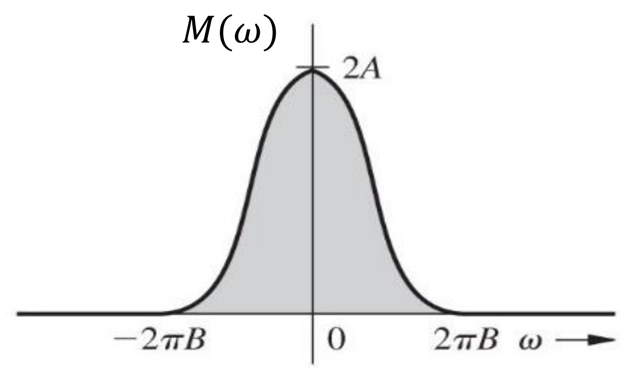
- Applications

1. Double sideband suppressed carrier (DSB-SC)

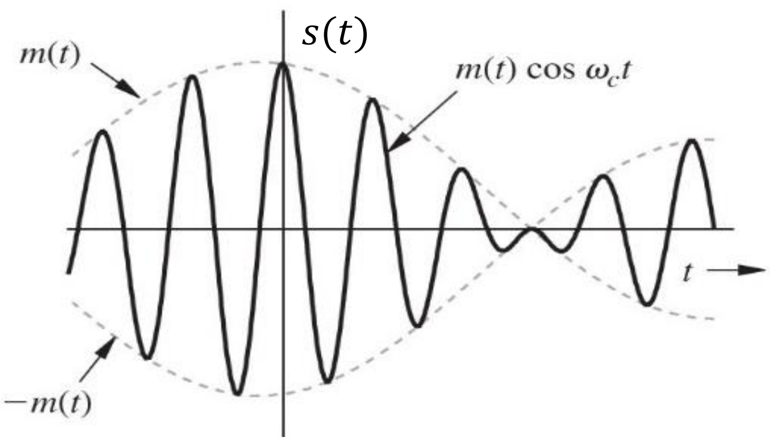
Modulator

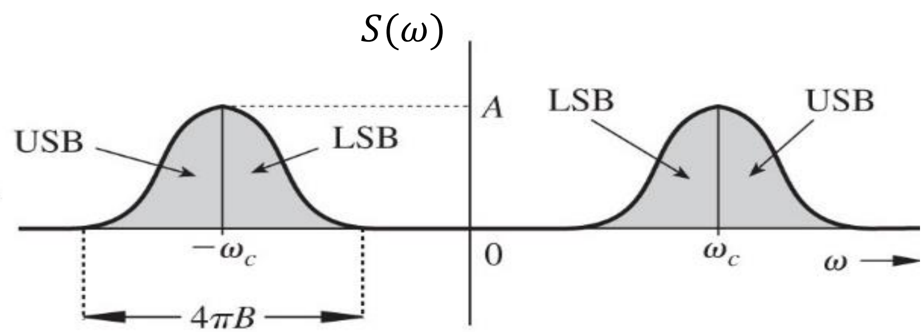






$$m(t)\cos\omega_c t \Leftrightarrow \frac{1}{2}[M(\omega+\omega_c) + M(\omega-\omega_c)]$$





1. Double sideband suppressed carrier (DSB-SC)

- Upper sideband (USB) : $|\omega| > \omega_c$ (outside $\pm\omega_c$)

Lower sideband (LSB) :$|\omega| < \omega_c$ (inside $\pm\omega_c$)

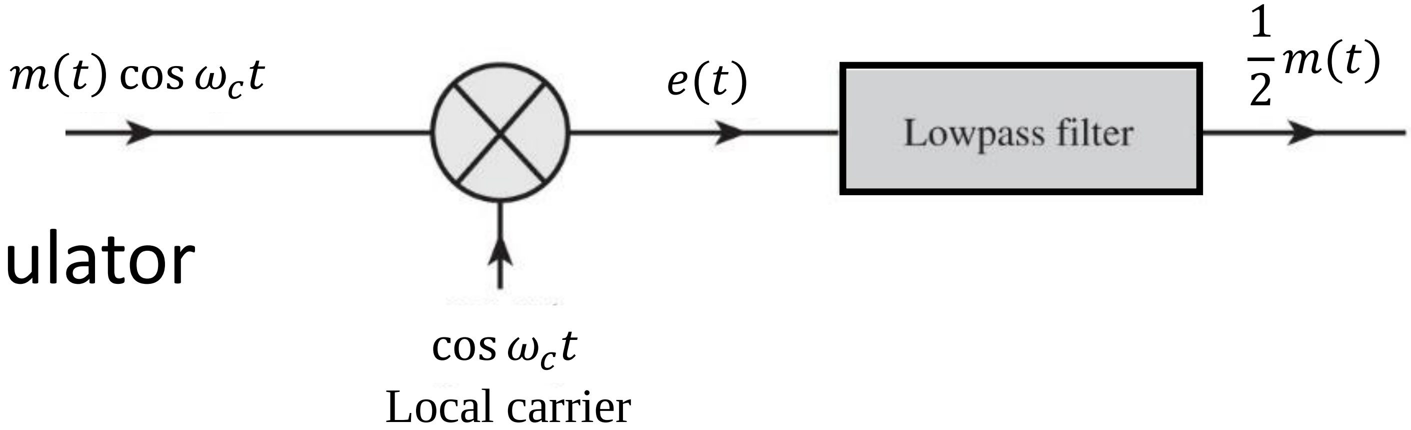
Hence, called Double SideBand (**DSB**)

- No discrete component for the carrier, hence, Suppressed Carrier (**SC**)
- BW of modulating signal $m(t) = B\ Hz$

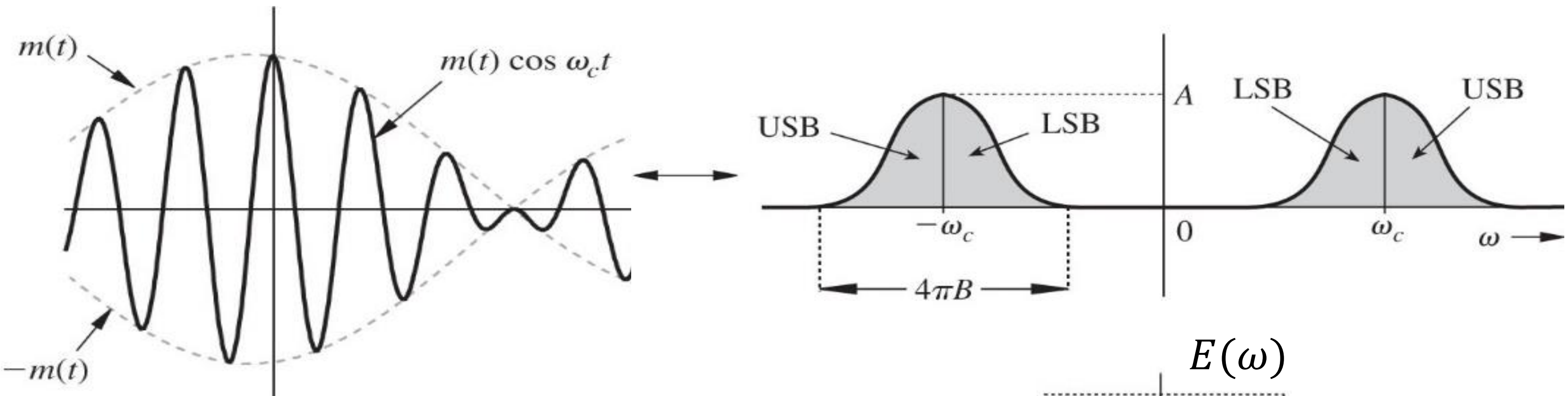
  BW of modulated signal $s(t) = 2B\ Hz$
- If the power in the message signal is P_m, the transmitted power $P_s = \frac{1}{2}P_m$

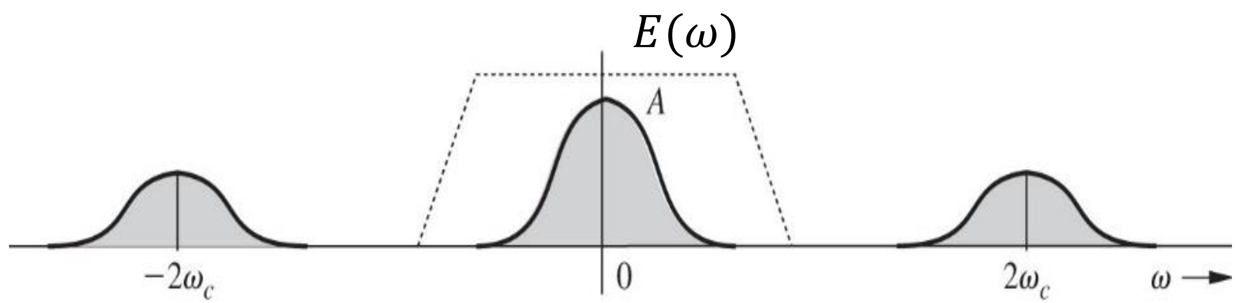
DSB-SC Demodulation

- How to recover the baseband signal $m(t)$ from the modulated signal?



Demodulator





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

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

Eliminated by the LPF

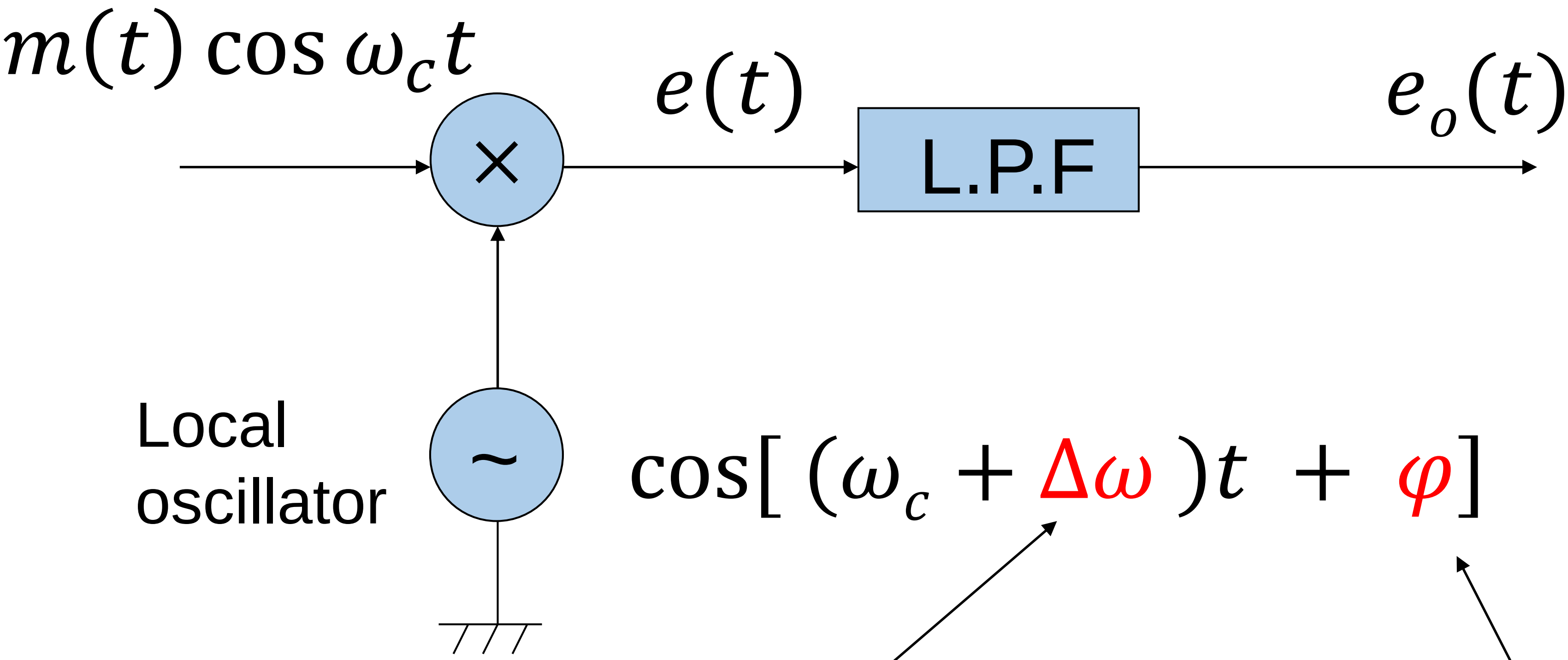
DSB-SC Demodulation

- **Condition:** $f_c \geq B$ prevents overlap between modulated spectra at f_c and $-f_c$.
- Practically, $f_c \gg B$ to avoid distortion by antenna

DSB-SC Demodulation

- Is it that simple?
- Main problem : the **local carrier** at the receiver must be **synchronized** in **frequency** and **phase** with the incoming carrier in the received modulated signal
- Otherwise, we can have serious problems in demodulation as will be seen
- This is called **synchronous** or **coherent detection** (or demodulation).
- It increases the complexity and cost of the demodulator

DSB-SC Demodulation



$$\cos[(\omega_c + \Delta\omega)t + \varphi]$$

Frequency shift

Phase shift

DSB-SC Demodulation

- $e(t) = m(t)\cos(\omega_c t)\cos[(\omega_c + \Delta\omega)t + \varphi]$

$$= \frac{1}{2} m(t)\,\{\cos(\Delta\omega\, t + \varphi) + \cancel{\cos[\,(2\omega_c + \Delta\omega)t + \varphi]}\,\}$$

- Second term will be suppressed by the L.P.F.
- **Case 1:** If $\underline{\Delta\omega = 0 \; and \; \varphi = 0}$

$$e_o(t) = \frac{1}{2} m(t)$$

(no frequency or phase error)

DSB-SC Demodulation

- **Case 2:** If $\underline{\Delta\omega = 0 \text{ and } \varphi \neq 0}$

$$e_o(t) = \frac{1}{2} m(t) \cos \varphi$$

- If $\varphi = $ constant, $e_o(t)$ is proportional to $m(t)$
- Problems for φ either varying with time or equals to $\pm (\pi/2)$
- The phase error may cause attenuation of the output signal without causing distortion as long as it is constant.

DSB-SC Demodulation

- **Case 3:** If $\underline{\Delta\omega \neq 0, \varphi = 0}$

$$e_o(t) = \frac{1}{2}\, m(t) \cos \Delta\omega\, t$$

  - The output is multiplied by a low frequency sinusoid, this causes attenuation and distortion of the output signal.

- In a following lecture, we will study methods to synchronize the local carrier with the incoming carrier in the received signal.