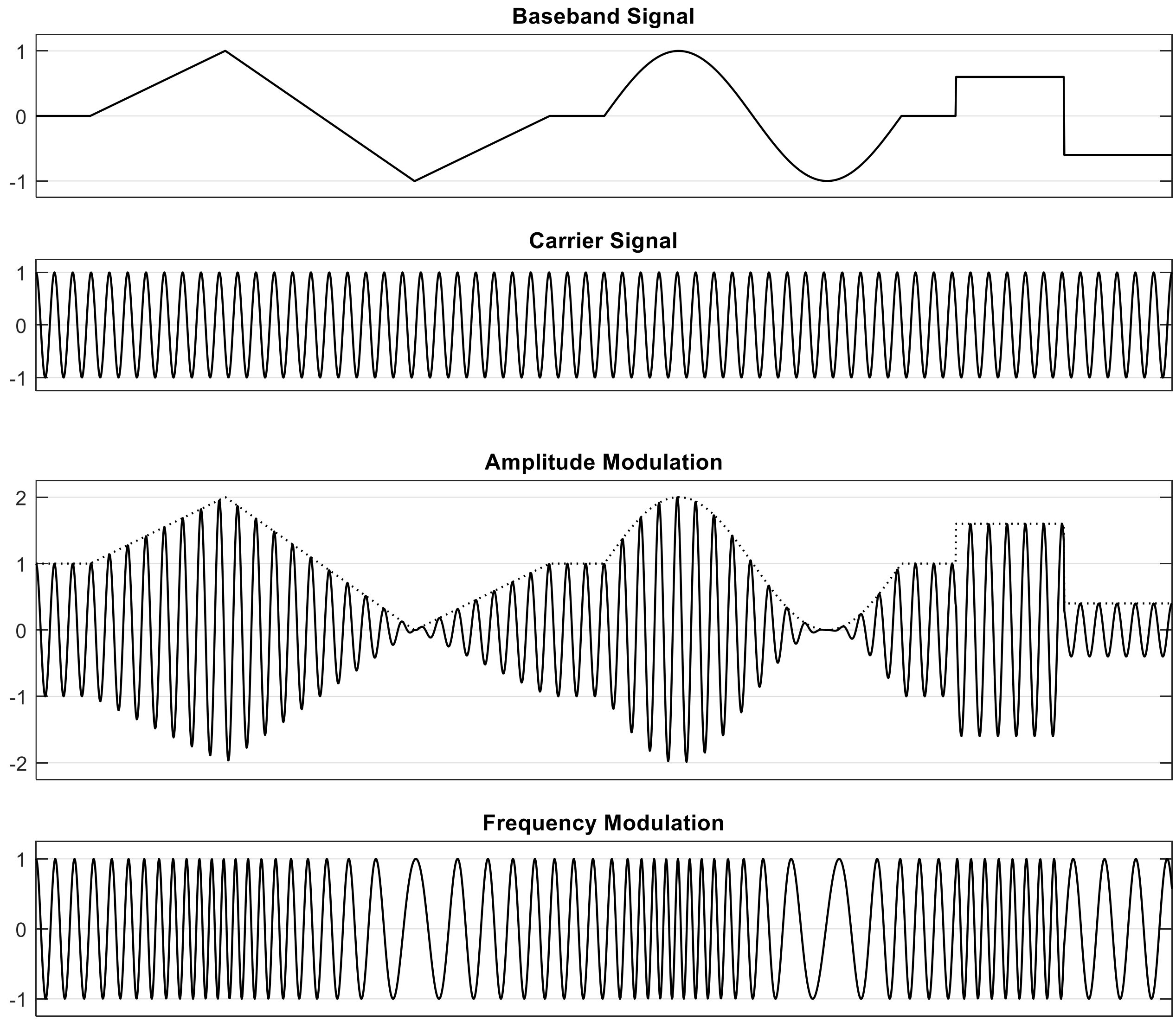
# Part 3 ANALOG MODULATION

## 3.1 INTRODUCTION

Baseband signals produced by various sources are not always suitable for direct transmission over a given channel. These signals are further modified to facilitate transmission using 'modulation', which is simply: is a process that causes a shift in the range of frequencies of a signal.

In this part, we study the principles of continuous-wave (CW) modulation. This analog form of modulation uses a sinusoidal carrier whose amplitude or angle is varied in accordance with a message signal.



A carrier is a sinusoid of high frequency and one of its parameters (amplitude, frequency or phase) is varied in proportion to the Baseband signal. Accordingly, we have Amplitude Modulation (AM), Frequency Modulation (FM) And Phase Modulation (PM).

$$y(t) = a(t)\cos\{\theta(t)\cdot t + \varphi(t)\}$$

Changing only [$a(t)$ for AM] or [$\theta(t)$ for FM] or [$\varphi(t)$ for PM].

At the receiver, the modulated signal must pass through the reverse process called Demodulation, to reconstruct the Baseband signal.

FM and PM are very close relatives (in fact you can't have one without the other). Hence, we will consider AM and FM only. Both are used in ordinary radio broadcasts. Commercial radio stations are licensed to use carrier frequencies between about 500kHz to 1600kHz using AM, and frequencies between 88MHz and 108MHz using FM.

Among the most important reasons for using modulation:

- Ease of Radiation: For efficient radiation of electromagnetic energy, the antenna length must be $\geq \lambda/10$. For many baseband signals, the wavelength is too large for reasonable antenna dimension. For example, the frequency band of speech can be extended up to 3kHz or $\lambda = 3000$km i.e. the antenna length ≈ 300km!! ; But if we modulate such audio signal using a 1MHz carrier, the required length for the antenna becomes ≈ 30m which is a reasonable size.
- Simultaneous Transmission of Several Signals: Most Baseband signals occupy the same frequency band, so they cannot be transmitted over the same channel at the same time. So, via modulation, it is possible to send several signals over the same channel at the same time.
- Overcome the Channel Problems.

# 3.2 AMPLITUDE MODULATION

## 3.2.1 DSB-LC (Double Side Band – Large Carrier)

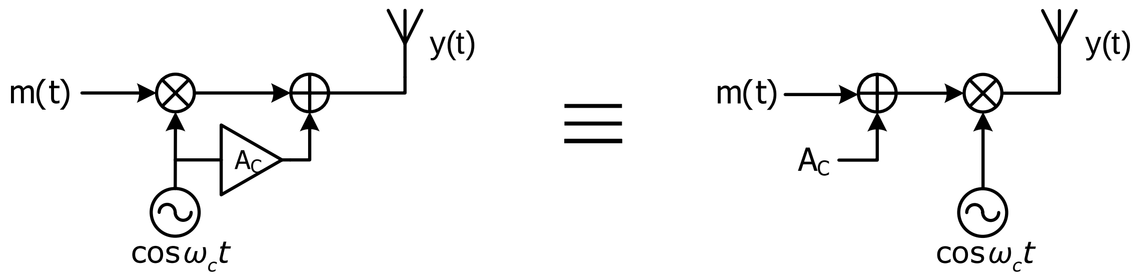
MODULATION

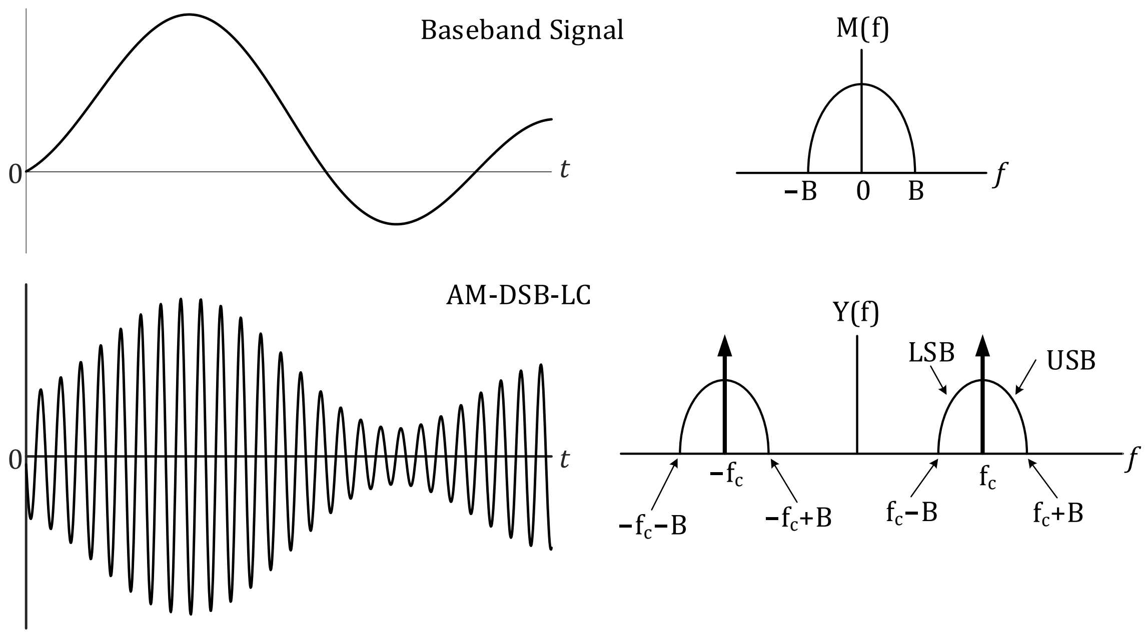
Let $m(t)$ be *the information signal*, *the message signal*, or *the baseband signal*. It is bandlimited to $B$ Hz. This signal can be transmitted through a channel by modulating the carrier signal $c(t) = A_c \cos(\omega_c t)$, where $f_c \gg B$. The amplitude-modulated wave becomes:

$$y(t) = A_c \cos(\omega_c t) + m(t) \cos(\omega_c t)$$

$$= \{A_c + m(t)\} \cos(\omega_c t)$$

Where $A_c$ = the peak value of the unmodulated carrier.




AM shifts the frequency spectrum of a signal from the zero to $\pm f_c$ without changing its shape.

Here, the bandwidth of the AM signal is double of $m(t)$, so it is called DSB:

Positive frequency of $m(t)$ → Upper Side Band (USB)

Negative frequency of $m(t)$ → Lower Side Band (LSB)

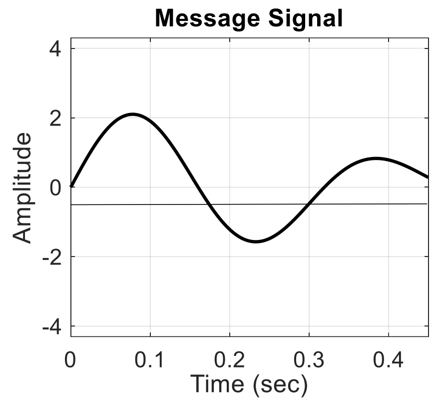
So, the general AM-DSB-LC wave can thus be described as:

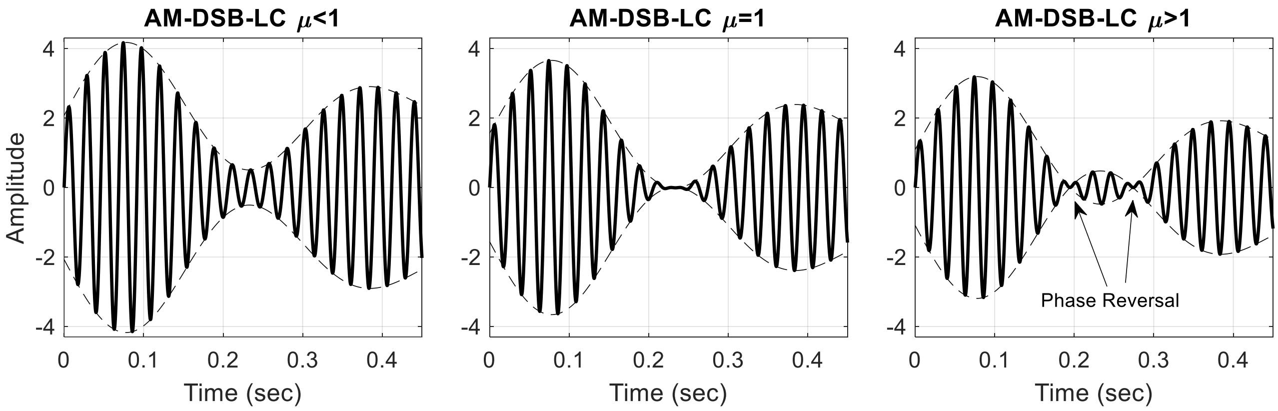
$$y(t) = A_c\{1 + \mu \times m(t)\}\cos(\omega_c t)$$

Where $\mu$ is the modulation index: and $\mu = \frac{|\text{minimum value of the modulating signal}|}{\text{peak value of un-modulated carrier}} = \frac{|A_m|}{A_c}$

Generally, according to the values of $A_c$ and $|A_m|$:

- If $\mu \leq 1$, under-modulation, $y(t)$ trace out $m(t)$, hence correctly demodulation.
- If $\mu > 1$, over-modulation, distortion in demodulation. *Why?*




To ensure proper modulation, we must prevent the phase reversal of the modulated signal. i.e. the term $\{1 + \mu \times m(t)\}$ must be always positive.

For illustration, let $m(t) = A_m\cos(2\pi Bt)$, where in general: $A_m$ can be considered as the *minimum* value of $m(t)$, and $B$ as the maximum frequency component of the baseband signal. This gives:

$$y(t) = A_c\cos(\omega_c t) + A_m\cos(2\pi Bt)\cos(\omega_c t)$$

$$= \{A_c + A_m\cos(2\pi Bt)\}\cos(\omega_c t)$$

$$= A_c\left\{1 + \frac{A_m}{A_c}\cos(2\pi Bt)\right\}\cos(\omega_c t)$$

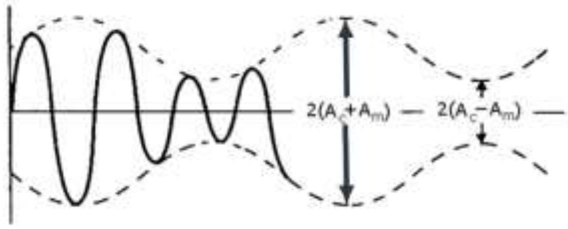
$$= A_c\{1 + \mu\cos(2\pi Bt)\}\cos(\omega_c t)$$

For $m(t) = A_m \cos(2\pi Bt)$, under-modulation can be achieved by considering the following:

$$A_c - |A_m| \geq 0 \;\rightarrow\; A_c \geq |A_m|$$

And $\mu$ can be computed from the time domain signal as:

$$\mu = \frac{\text{max p-p} - \text{min p-p}}{\text{max p-p} + \text{min p-p}} = \frac{2(A_c + A_m) - 2(A_c - A_m)}{2(A_c + A_m) + 2(A_c - A_m)} = \frac{A_m}{A_c}$$

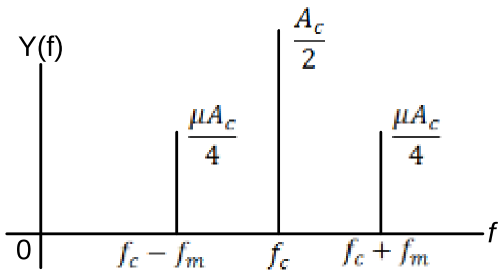


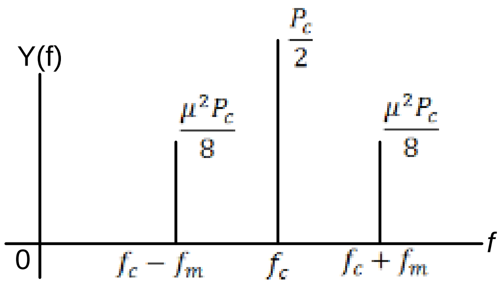

## SPECTRUM OF DSB-LC

For illustration, we reconsider $m(t) = A_m \cos(\omega_m t)$. So, the voltage or current equation is:

$$y(t) = A_c\{1 + \mu \cos(\omega_m t)\} \cos(\omega_c t)$$

$$= A_c \cos(\omega_c t) + \frac{\mu A_c}{2} \cos[2\pi(f_c - f_m)t] + \frac{\mu A_c}{2} \cos[2\pi(f_c + f_m)t]$$




## POWER CALCULATIONS OF DSB-LC

The carrier does not contain any information about $m(t)$, but it is the price to make cheap receivers available.

If $y(t) = A_c \cos(\omega_c t) + A_c \mu \times m(t) \cos(\omega_c t)$, using: $R$=1Ω, $m(t) = \cos(\omega_m t)$, the mean power (mean square value) is:

$$P_{DSBLC} = \overline{y^2(t)} = A_c^2\, \overline{\cos^2(\omega_c t)} + \frac{\mu^2 A_c^2}{4} \overline{\cos^2[2\pi(f_c - f_m)t]} + \frac{\mu^2 A_c^2}{4} \overline{\cos^2[2\pi(f_c + f_m)t]}$$

$$= \frac{A_c^2}{2} + \frac{A_c^2 \mu^2}{8} + \frac{A_c^2 \mu^2}{8} \equiv P_c + P_{USB} + P_{LSB}$$

$$= \frac{A_c^2}{2} + \frac{A_c^2 \mu^2}{4} = P_c + P_{SB} = P_c + \frac{\mu^2}{2} P_c$$

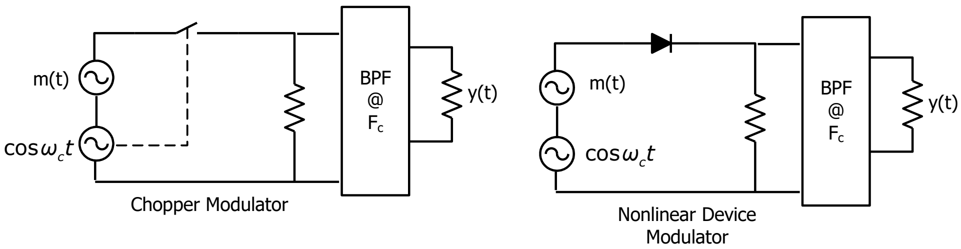
$$\therefore P_T = P_c \left(1 + \frac{\mu^2}{2}\right)$$

Now, let the information power to the total power ratio is Transmission Efficiency:

$$\rho = \frac{P_{SB}}{P_T} = \frac{P_{DSBSC}}{P_{DSBLC}} = \frac{\mu^2}{2+\mu^2}$$

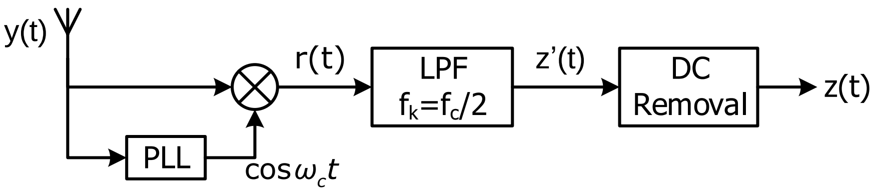
Since the best demodulation occurs at $\mu \le 1$, so best $\rho$ for DSB-LC system is 33%, i.e. 67% of the total power is spent in the carrier and represents a wasted power.

## Generation of DSB-LC



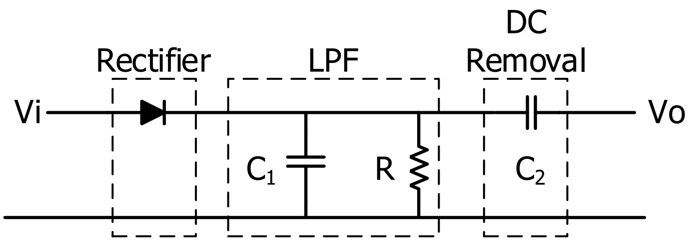

## Demodulation

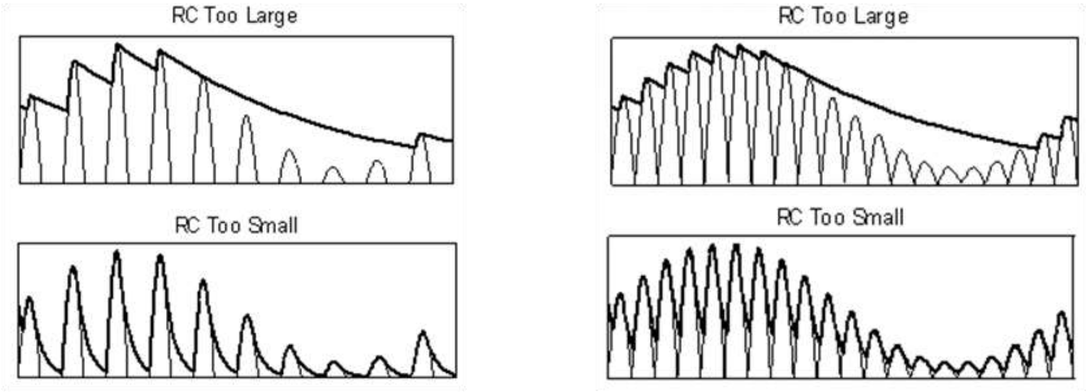
(1) Synchronous (coherent) detector: (via PLL)




*HW:* Given $y(t) = A_c\cos(\omega_c t) + \frac{\mu A_c}{2}\cos(\omega_c t - \omega_m t) + \frac{\mu A_c}{2}\cos(\omega_c t + \omega_m t)$ and $\omega_c \gg \omega_m$ , find $z(t)$.

(2) Asynchronous: (using an envelope detector), as $m(t)$ is available in the envelope of DSB-LC signal, it is possible to use simple envelop detector circuit as a demodulator. Why we use asynchronous detection?






The following is an example that illustrates the asynchronous demodulation of DSB-LC.