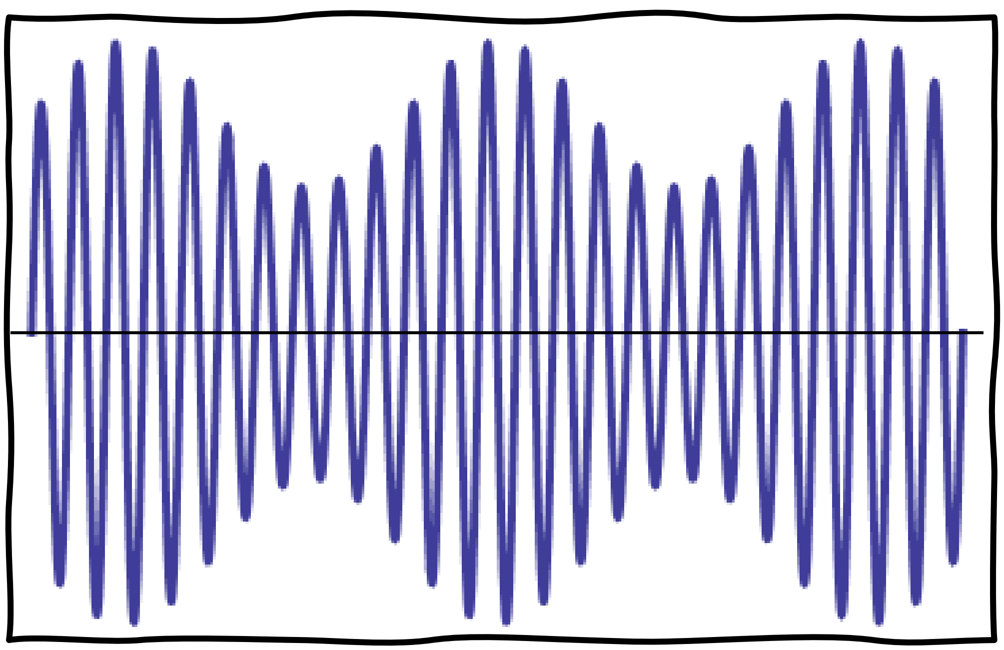
Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & M.Sc. Huda Wasfi Hassoon
Lecture:5

Lecture 5

Part 1

AM Modulation



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Baseband vs. Passband Communication Systems:

Communication systems can be broadly categorized into two types based on the frequency range used for transmitting information: **baseband systems** and **passband systems**. This classification depends on whether the information signal is transmitted directly or after frequency modification.

1. **Baseband Transmission:**
   - In a baseband system, the information signal is sent directly, without any modulation or frequency shifting. This means the signal retains its original frequency range throughout transmission.
   - Baseband signals are typically low-frequency signals, often close to zero. Common examples include:
     - **Human voice** signals, with frequencies ranging between 20 Hz and 5 kHz.
     - **Video signals** from TV cameras, which range from 0 Hz up to about 5.5 MHz.
   - Many systems use baseband transmission when transmitting signals locally, such as in-home or office settings. For instance, in a telephone system, local calls (e.g., calls within a neighborhood) transmit audio in its baseband form without modification.
2. **Passband Transmission:**
   - Passband transmission, on the other hand, involves shifting the original signal to a higher frequency before transmission. This frequency-shifting

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process, known as modulation, is necessary when the signal must travel long distances, especially over wireless mediums.

- In passband systems, the transmitted signal is modulated to fit within a specific frequency band suitable for long-range transmission and is demodulated back to its original form at the receiver.
- A common application of passband transmission is in long-distance telephone calls. When a call is transmitted over microwave or satellite links, the audio signal is modulated to a higher frequency to suit the transmission medium. Similarly, transmitting a video signal from a camera to a television through wires might use baseband transmission, but if sent via satellite, the signal is converted to a passband frequency.

Modulation and Demodulation:

Modulation is the process of shifting a baseband signal to a higher frequency range, known as the passband, to prepare it for transmission. Conversely, demodulation is the process of converting this passband signal back to the baseband frequency range at the receiver end. During modulation, one or more properties of a carrier wave—typically a sinusoidal wave—are altered according to the information signal intended for transmission. The carrier's characteristics that can be modified include amplitude, frequency, or phase, leading to different types of modulation:

- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (PM).

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Amplitude Modulation (AM):

Amplitude Modulation (AM) is a technique in which the amplitude of a high-frequency carrier signal is varied in direct proportion to the instantaneous value of the information signal, while keeping the frequency and phase of the carrier constant. In essence, AM works by changing the carrier wave's amplitude based on the amplitude of the baseband or information signal, $m(t)$ around a constant average value.

The AM process requires two inputs:

1. Carrier Signal: A high-frequency, constant-amplitude signal, usually a sinusoidal wave, which serves as the primary medium for carrying the information.

2. Information Signal: A lower-frequency signal containing the actual information to be transmitted. This could be a simple sinusoidal wave or a complex waveform with multiple frequencies, depending on the nature of the data.

In AM, the carrier's amplitude is adjusted in a linear relationship with the amplitude of the information signal, effectively "embedding" the information within the variations of the carrier's strength. This method makes it possible to transmit the information signal across a communication channel using a high-frequency carrier that can travel greater distances and penetrate obstacles more effectively than low-frequency signals alone.

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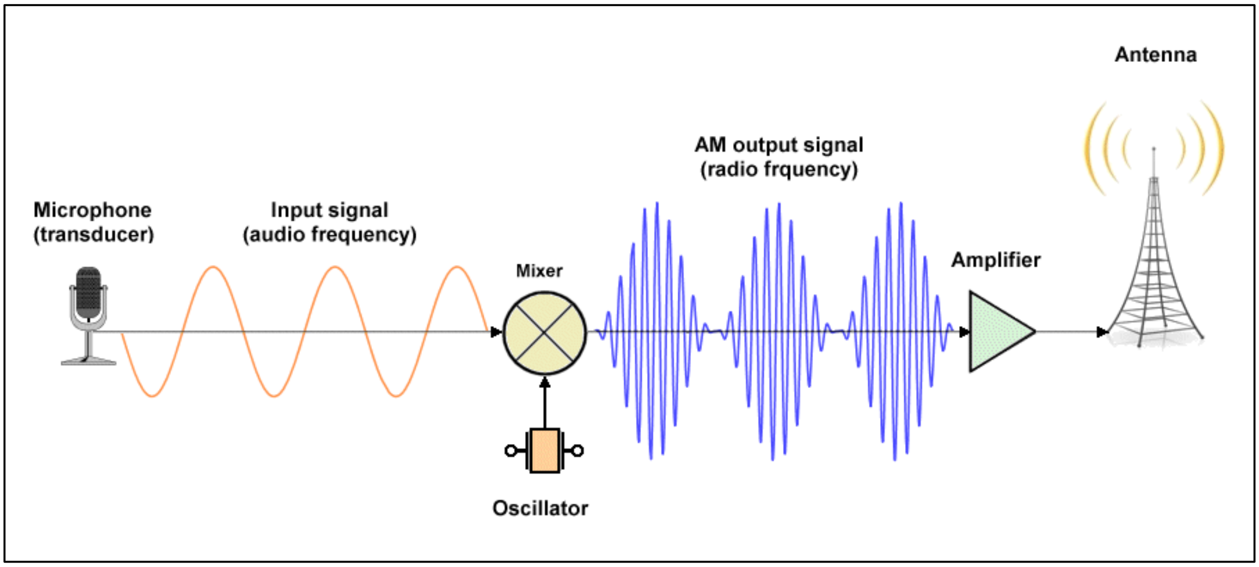

Fig. 1: Block diagram of AM modulation.

Types of Amplitude Modulation (AM):

AM can be further classified into various types:

1. **Double Sideband with Large Carrier (DSB-LC)**: This is the most commonly used form of AM, especially for AM radio broadcasting, where both sidebands and the full carrier signal are transmitted.
2. **Double Sideband Suppressed Carrier (DSB-SC)**: Similar to DSB-LC, but without transmitting the carrier signal, reducing power requirements.
3. **Single Sideband (SSB)**: In this type, only one of the two sidebands from the DSB-SC signal is transmitted, significantly saving bandwidth and power.
4. **Vestigial Sideband (VSB)**: A modified form of SSB that transmits a portion of the second sideband, simplifying the signal generation and reception process, commonly used in TV broadcasting.

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Double Sideband Large Carrier (DSB-LC)

There are several types of amplitude modulation, with the most widely used being the Double Sideband Large Carrier (DSB-LC) scheme, also known as conventional AM. The figure below demonstrates the relationship between the carrier signal, the modulating signal, and the resulting modulated signal in conventional AM.

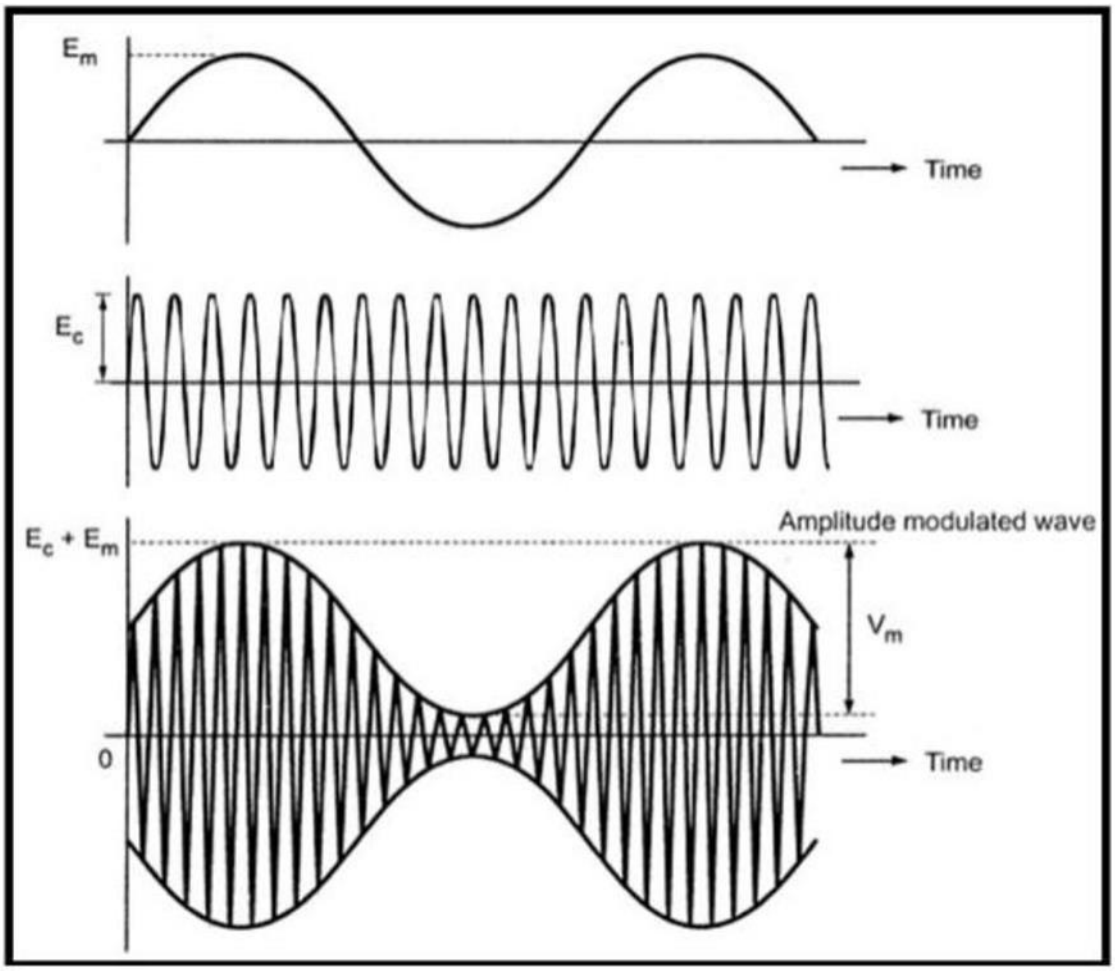

Fig. 2: Waveform of AM modulation.

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The expression of AM wave is given by:

$$E_{AM}(t) = [E_C + m(t)]\cos(w_c t)$$

$$IF\ m(t) = E_m \cos(w_m t)$$

$$E_{AM}(t) = E_c\, cos(w_c t) + E_m \cos(w_m t)\cos(w_c t)$$

$$E_{AM}(t) = E_c \cos(w_c t) + \frac{E_m}{2}\cos(w_c - w_m)\,t + \frac{E_m}{2}\cos(w_c + w_m)t$$

Where:

E_c : Carrier voltage

E_m: Modulating voltage

$m(t)$: Modulating signal

Generation of Double Sideband Large Carrier (DSB-LC):

The generation of Double Sideband Large Carrier (DSB-LC) signals can be achieved using a variety of techniques. The two main methods are **Nonlinear Modulation** and **Linear Modulation** techniques.

The first type, **Nonlinear Modulation**, is the most commonly used and will be the primary focus of this study. Nonlinear Modulation relies on the properties of nonlinear devices, like diodes or transistors, to produce the modulated signal. It includes methods like the Square-Law Modulator and Switching Modulator. These techniques are valued for their simplicity and cost-effectiveness, especially in low-power applications and basic communication systems.

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A. Square-Law Modulator: is a simple modulator type that relies on the nonlinear properties of components like **diodes**. Both the **carrier signal** and **modulating signal** are applied to the diode, producing an output with sidebands (DSB) and the carrier frequency. A **bandpass filter** is then used to remove unwanted frequencies, leaving only the modulated DSB-LC signal.
B. Switching Modulator: is a type of DSB-LC modulator that uses a switching component, such as a **diode** or **transistor**, to alternately turn the carrier signal on and off according to the modulating signal. This creates a product of the carrier and message signals, generating both the carrier and sidebands.

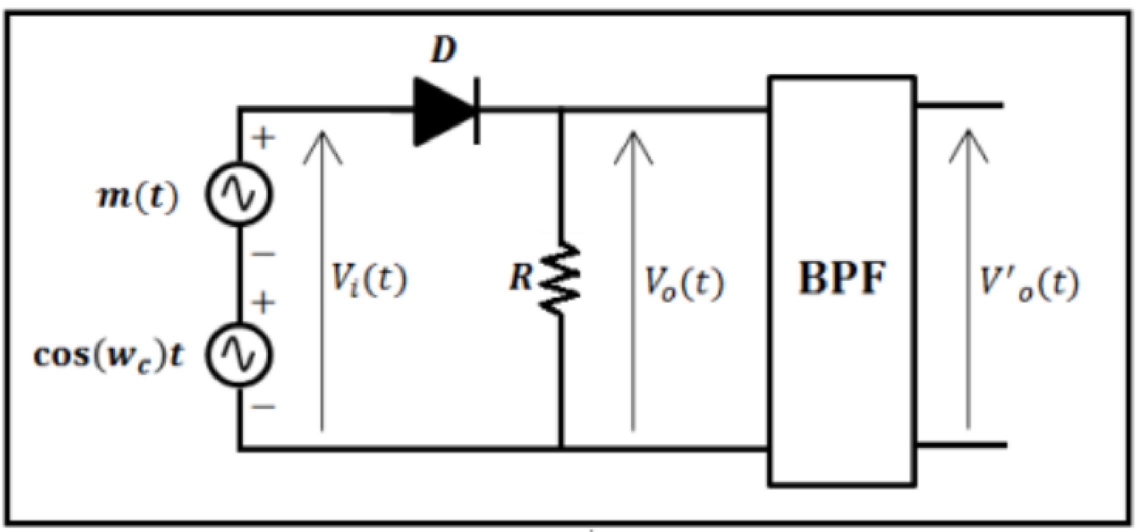

Fig. 3: Generation of AM.

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Spectrum of DSB-LC:

Amplitude modulation (AM), specifically Double Sideband Large Carrier (DSB-LC), effectively shifts the spectrum of the modulating signal $\boldsymbol{m(t)}$ to align with the carrier frequency $\boldsymbol{fc}$. This process results in a modulated signal that contains three distinct frequency components:

i. **Carrier Frequency $\boldsymbol{f_c}$**: This is the central frequency of the transmitted signal, which remains unchanged during modulation.

ii. **Upper Sideband Frequency $\boldsymbol{f_c + f_m}$**: This component represents the carrier frequency increased by the frequency of the modulating signal $\boldsymbol{f_m}$. It carries the higher frequency information from the modulating signal.

iii. **Lower Sideband Frequency $\boldsymbol{f_c - f_m}$:** : This component represents the carrier frequency decreased by the frequency of the modulating signal $\boldsymbol{f_m}$. It carries the lower frequency information from the modulating signal.

these three frequency components create the spectrum of the AM modulated wave when the modulating signal consists of a single frequency. The presence of both upper and lower sidebands ensures that the information contained in the modulating signal is fully transmitted.

The bandwidth of the modulated signal is significant in determining how the signal can be transmitted and received effectively. The bandwidth of the DSB-LC signal is calculated as **twice** the frequency of the modulating signal:

$$BW = Maximum\ Freq. - Minimum\ Freq.$$

$$BW = (f_c + f_m) - (f_c - f_m)$$

$$BW = 2f_m$$

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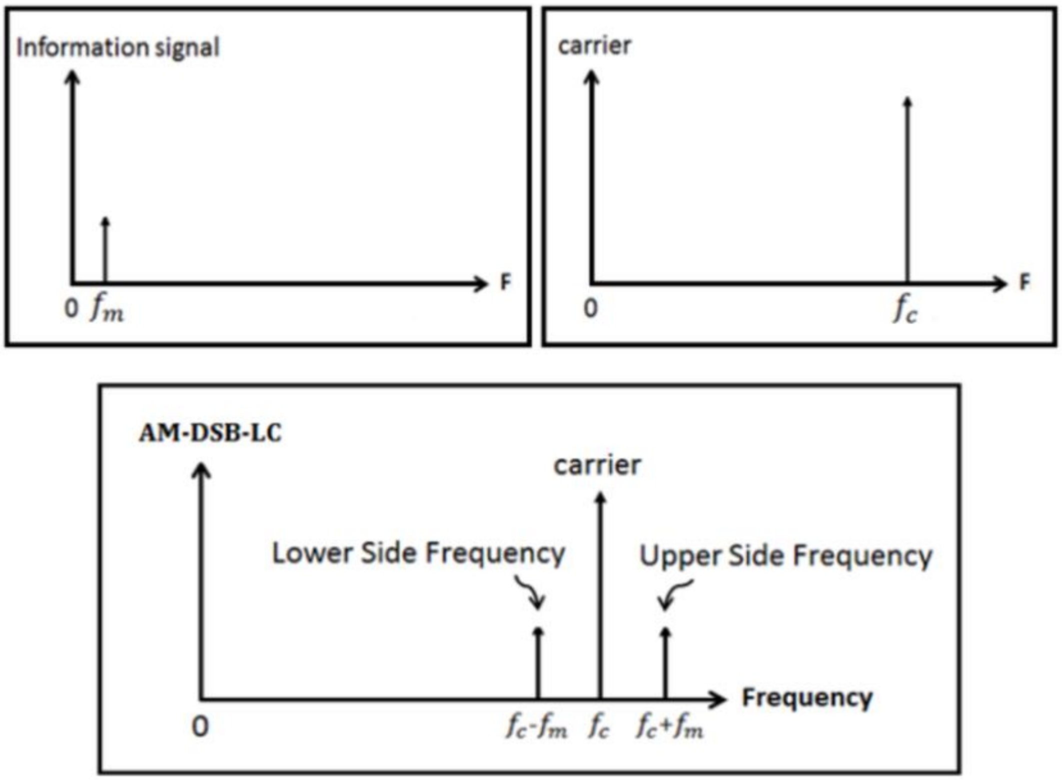

Fig. 4: Frequency Spectrum of AM.

Modulation index:

The modulation index (or modulation depth) in Amplitude Modulation (AM) quantifies the extent to which the carrier signal varies in response to the modulating (message) signal. It's an essential factor for ensuring signal fidelity and efficient transmission. The modulation index is typically denoted as m and defined as follows:

$$m = \frac{E_m}{E_c}$$

where:

- E_m is the amplitude of the modulating signal (message signal),
- E_c is the amplitude of the carrier signal.

Ranges for the Modulation Index

The modulation index m in amplitude modulation (AM) describes the degree to which the carrier wave is modulated by the message signal, with ideal values typically in the range from (0 to 1):

- $\boldsymbol{m = 0}$: No modulation occurs. The carrier wave maintains a constant amplitude E_c without carrying any information from the message signal.
- $\boldsymbol{0 < m < 1}$: This is the optimal range for modulation, where the carrier is modulated without distortion. As m increases toward 1, the modulation depth increases, enhancing the clarity of the transmitted signal.
- $\boldsymbol{m = 1}$: This represents the maximum modulation without distortion, where the carrier is fully modulated to the maximum amplitude without overlapping sidebands.
- $\boldsymbol{m > 1}$: Known as overmodulation, this range results in distortion due to the excessive amplitude of the message signal, causing overlapping of sidebands and making it difficult to recover the original signal without distortion.

Alternate Expression Using Maximum and Minimum Amplitudes

The modulation index can also be derived using the maximum (V_{max}) and minimum (V_{min}) envelope amplitudes of the modulated signal:

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

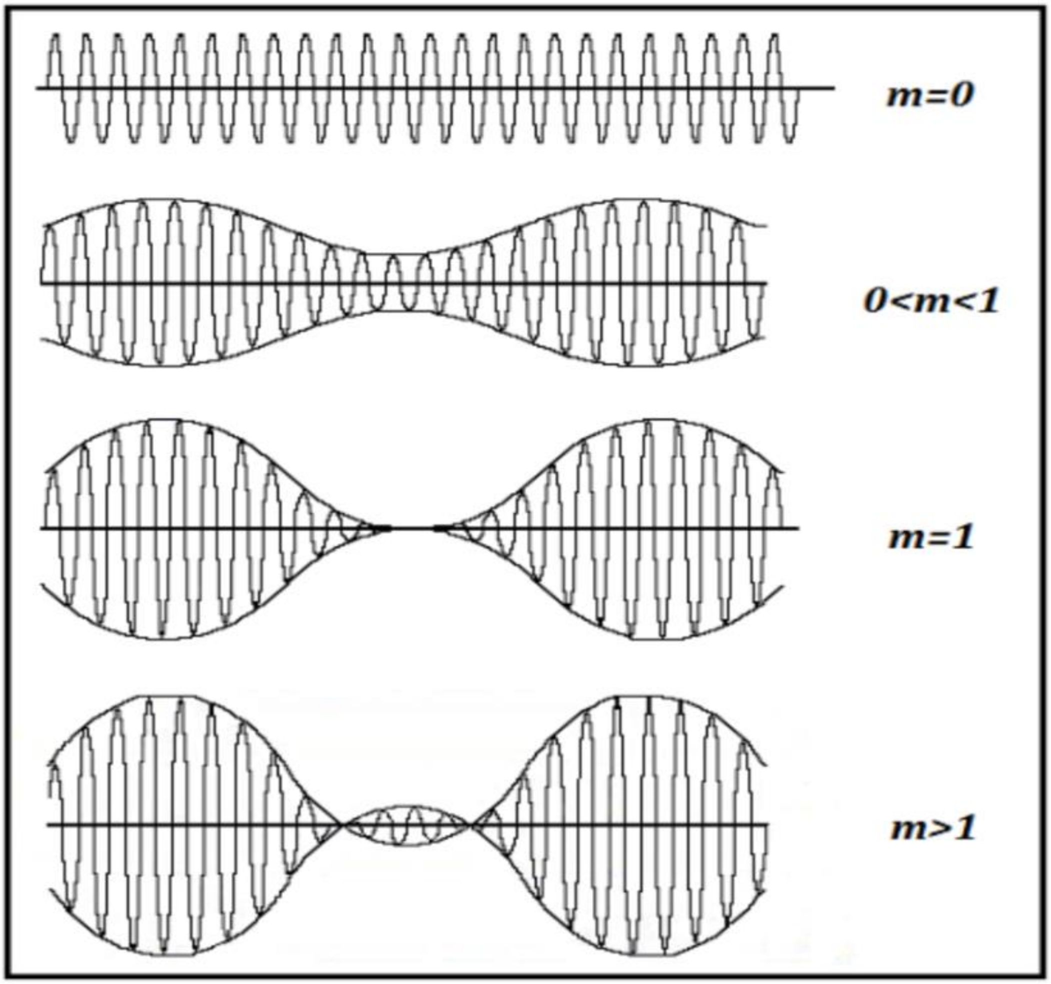

Fig. 5: Modulation index of AM.

Power of DSB-LC

There are three components for any DSB-LC waveform, the upper sideband, the lower sideband, and the carrier frequency. If the powers in the three of these are added up, the total power in the modulated signal will be:

$$P_t = P_c + P_{USB} + P_{LSB}$$

****Carrier Power (P_c):** The carrier power is given by:

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$$P_c = \frac{(E_c)^2}{2R}$$

****Sideband Power**: The power in each sideband is:

$$P_{USB} = \frac{m^2 P_c}{4} \qquad P_{LSB} = \frac{m^2 P_c}{4}$$

the total sideband power is:

$$P_s = \frac{m^2 P_c}{2}$$

****Total transmitted power (P_t):** This total power is expressed as:

$$P_t = P_c + \frac{m^2 P_c}{2}$$

$$P_t = P_c(1 + \frac{m^2}{2})$$

Efficiency of DSB-LC:

The efficiency of Double Sideband-Large Carrier (DSB-LC) modulation refers to the ratio of the power in the sidebands (which carry the information) to the total transmitted power. Efficiency is an important metric because it indicates how much of the transmitted power conveys the message, as opposed to being "wasted" on the carrier.

$$\eta = \frac{P_s}{P_t} \times 100\%$$

Demodulation of DSB-LC:

In Double Sideband-Large Carrier (DSB-LC) signals, the information-carrying waveform is embedded within the envelope of the modulated signal. Although synchronous detection can accurately retrieve this waveform, simpler and more efficient methods are available for demodulating AM signals. The most straightforward and widely used technique is the **envelope detector**, which directly extracts the signal by detecting the envelope of the modulated waveform. This approach is especially popular due to its simplicity and effectiveness in recovering the original signal in DSB-LC systems.

Envelope Detector:

The Envelope Detector is a simple and widely-used circuit for demodulating **Amplitude Modulation (AM)** signals, specifically in **Double Sideband-Large Carrier (DSB-LC)** systems. Its purpose is to retrieve the original message signal from the modulated waveform by capturing the amplitude variations in the carrier wave, which represent the message signal.

- **How the Envelope Detector Works**

An envelope detector typically consists of two main components:

1. **Diode**: The diode allows current to flow only in one direction, effectively rectifying the modulated signal by removing one-half of the waveform.
2. **RC Circuit (Resistor-Capacitor)**: This combination smooths out the rectified waveform, producing a voltage that follows the peaks of the carrier wave, thus forming the envelope of the original signal.

Steps in Envelope Detection

1. **Rectification**: The diode rectifies the incoming AM signal, allowing only one polarity to pass through, effectively "clipping" one-half of the signal.
2. **Smoothing**: The RC circuit smooths the rectified waveform by charging and discharging in response to the changes in amplitude. This smoothing action produces an output that closely follows the envelope of the input AM waveform, effectively extracting the modulated message.

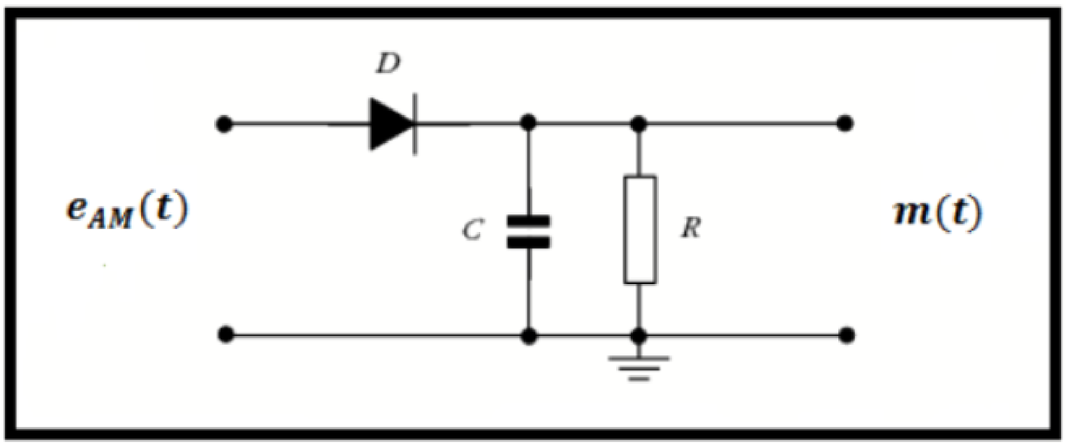

Fig. 6: The Envelope Detector.

Example:

An AM/DSB modulated signal is given by:

$E_{AM}(t) = 3[\,1 + 0.5\,sin(12.566 * 10^3\, t)\,]\, sin(6.28 * 10^6 t)$ Calculate the following

a) Amplitude and frequency of each sideband.

b) Carrier power, sideband power, total power, and efficiency.

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Solution:

$e_{AM}(t) = [\, E_c + m(t)\,] \sin(w_c t)$

$e_{AM}(t) = [\, 3 + 1.5 \sin(12.566 * 10^3\, t)\,] \sin(6.28 * 10^6 t)$

From the equation, we have

$E_c = 3\ V$

$E_m = 1.5\ V$

$$f_m = \frac{12.566 * 10^3}{2\pi} = 2 \text{ KHz}$$

$$f_c = \frac{6.28 * 10^6}{2\pi} = 1000 \text{ KHz}$$

a) The amplitude of each sideband $= \frac{E_m}{2} = \frac{1.5}{2} = 0.75$ V

$F_{LSB} = f_c - f_m = 1000 - 2 = 998$ KHz

$F_{USB} = f_c + f_m = 1000 + 2 = 1002$ KHz

b) $P_c = \frac{(E_c)^2}{2R} = \frac{(3)^2}{2} = 4.5$ W

$$P_{USB} = \frac{(E_m)^2}{8R} = \frac{(1.5)^2}{8} = 0.28125 \text{ W}$$

$$P_{LSB} = \frac{(E_m)^2}{8R} = \frac{(1.5)^2}{8} = 0.28125 \text{ W}$$

$$P_t = 4.5 + 0.28125 + 0.28125 = 5.0625 \text{ W}$$

$$\eta = \frac{P_s}{P_t} \times 100\%$$

$$\eta = \frac{0.5625}{5.0625} \times 100\% = 11.11\%$$

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