Course Code: CSE 3107
Course Title: Communication Engineering

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Lecture # 04-05

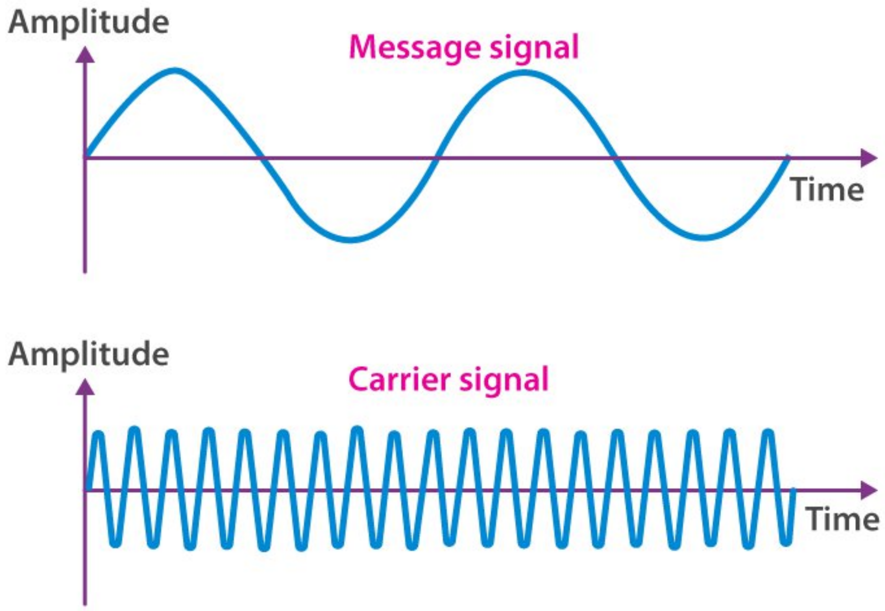
Amplitude Modulation

Outline

- **Amplitude Modulation**
- **Amplitude Modulation Index**
- **Frequency Spectrum for Sinusoidal AM**

Modulation

❑ Modulation and Demodulation?



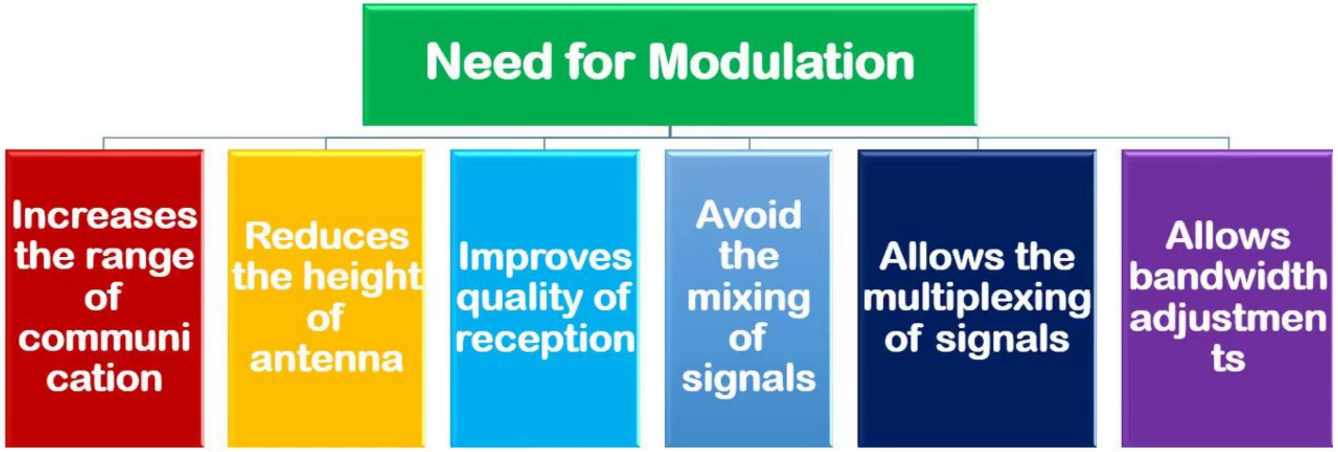
- ✓ **Modulation** is a process of varying the <u>characteristics of a carrier signal</u> (like **amplitude, frequency**, or **phase**) in accordance with a **message signal** (also called modulating signal).
  - *It is the process of encoding information from a message source in a way that is suitable for transmission.*
- ✓ **Demodulation** is the process of extracting the original information-bearing signal or message signal from a modulated carrier wave.
  - *It is the reverse of modulation.*

❑ Why Do We Need Modulation?

We use modulation to-

1. Send data at far distance (by increasing amplitude and frequency).

2. Reduce antenna length $\left(\lambda \propto \frac{1}{f}\right)$.



3. Remove interference, by modulating at different frequencies.

4. Transmit multiple channels of information through a single communication medium

❑ Types of Modulation?

MODULATION TYPES

ANALOG MODULATIONS

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

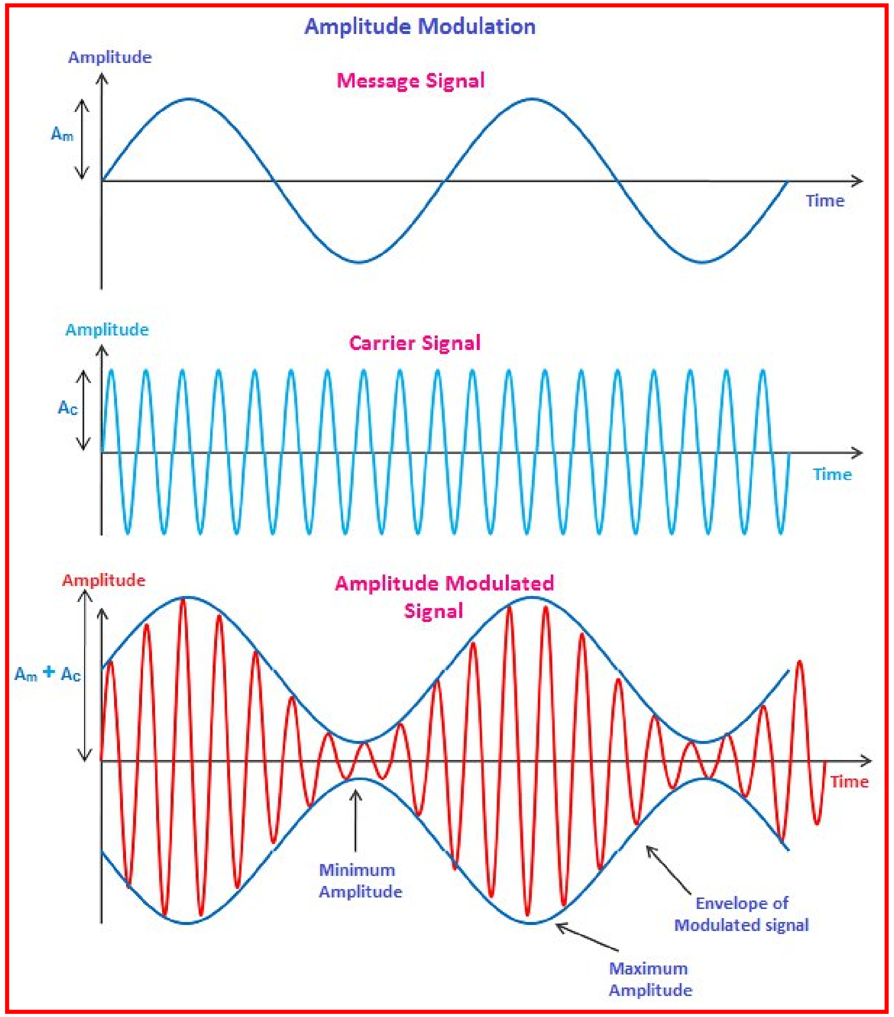
DIGITAL MODULATIONS

- **ASK** (Amplitude Shift Keying)
- **FSK** (Frequency Shift Keying)
- **PSK** (Phase Shift Keying)
- **APSK** (Amplitude-Phase Shift Keying)
- **QAM** (Quadrature-Amplitude Modulation)

❑ Amplitude Modulation?

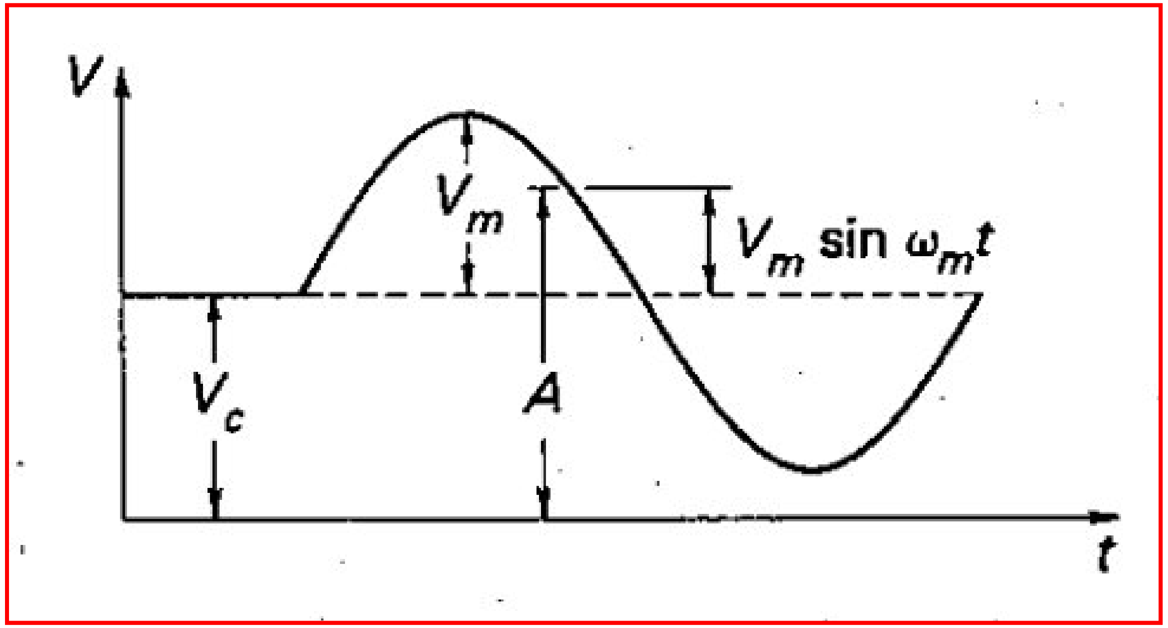
- ✓ Amplitude modulation is the modulation process where the **amplitude of the carrier signal** is varied with respect to the instantaneous amplitude of the message signal (modulating voltage).
- ✓ Example: AM Radio Broadcasting, Analog TV Transmission.

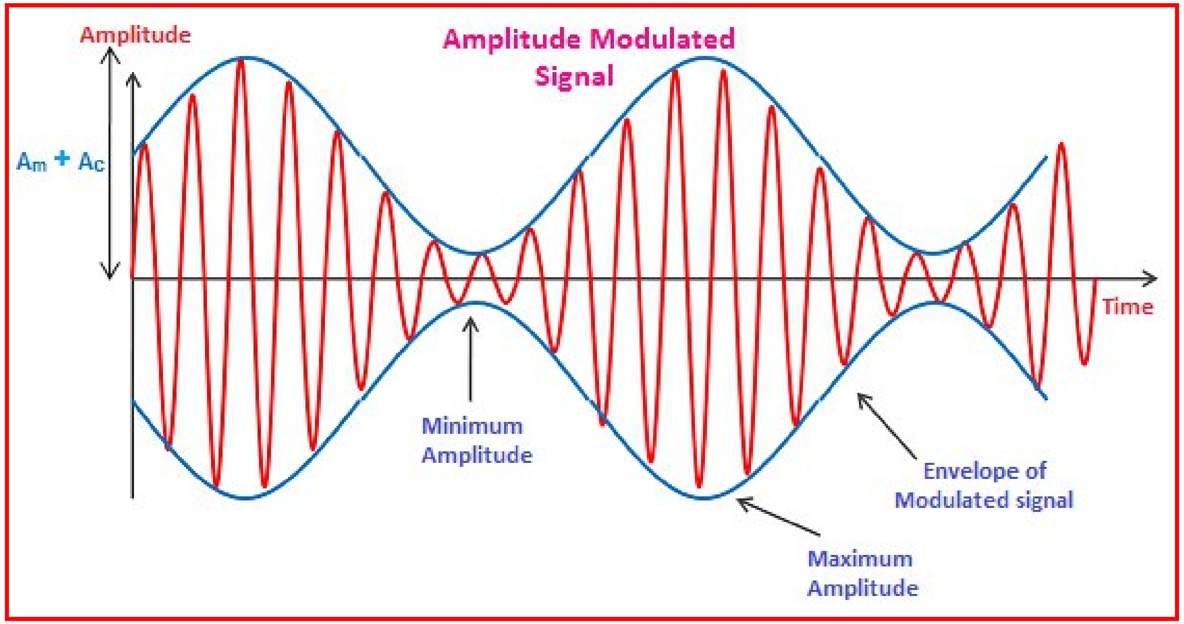
- **Message Signal:** $v_m = V_m Sin\ (\omega_m t)$
- **Carrier Signal:** $v_c = V_c Sin\ (\omega_c t)$
- **Modulated Signal:** $v = (v_m + V_c) Sin\ (\omega_c t)$



❑ Amplitude Modulation?

- **Message Signal:** $v_m = V_m Sin\ (\omega_m t)$ **and Carrier Signal:** $v_c = V_c Sin\ (\omega_c t)$
- **Modulated Signal:** $v = (v_m + V_c) Sin\ (\omega_c t)$





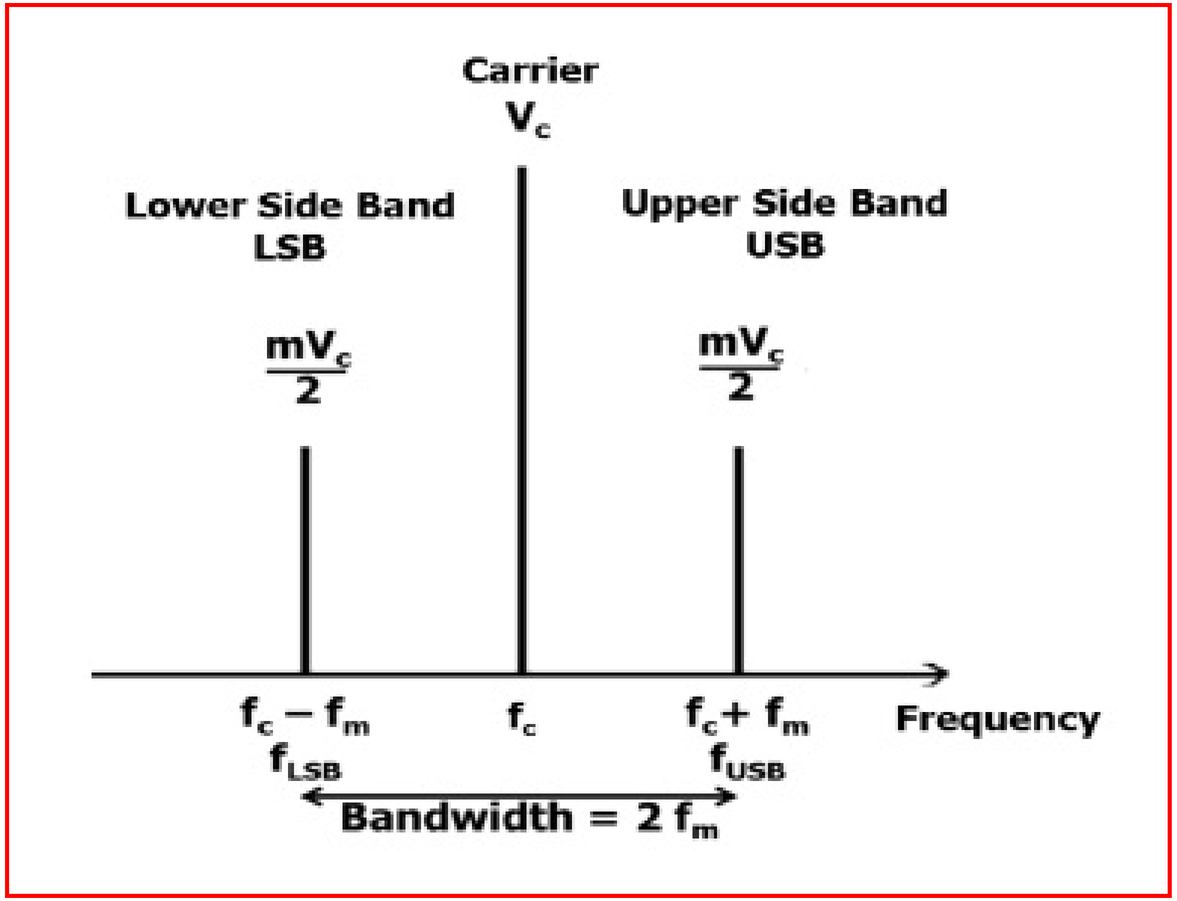
❑ Frequency Spectrum

$$
\begin{aligned}
v &= (v_m + V_c) Sin\ (\omega_c t) \\
&= (V_m Sin\ (\omega_m t) + V_c) Sin\ (\omega_c t) \\
&= V_m Sin\ (\omega_m t) Sin\ (\omega_c t) + V_c Sin\ (\omega_c t) \\
&= V_c \left[Sin\ (\omega_c t) + \frac{V_m}{V_c} Sin\ (\omega_m t) Sin\ (\omega_c t) \right] \\
&= V_c \left[Sin\ (\omega_c t) + \frac{m}{2} \cos(\omega_m - \omega_c) t - \frac{m}{2} \cos\ (\omega_m + \omega_c) t \right] \\
&= \underbrace{V_c Sin\ (\omega_c t)}_{\text{Carrier}} + \underbrace{\frac{mV_c}{2} \cos(\omega_m - \omega_c) t}_{\text{Lower Side Band}} - \underbrace{\frac{mV_c}{2} \cos\ (\omega_m + \omega_c) t}_{\text{Upper Side Band}}
\end{aligned}
$$

Here, m is the modulation index [$m \leq 1$].

Amplitude Modulation

❑ Frequency Spectrum



Modulation index, m= Vm/Vc

The modulation index is a measure of the extent of modulation.

When

- m<1, Under-modulation (low signal strength)
- m=1, Perfect modulation (ideal case)
- m>1, Over-modulation (causes distortion and loss of information)

Amplitude Modulation

❑ Modulation Index:

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Amplitude Modulation

- **Modulation Index:**

$$V_{max} = V_c + V_m$$

And

$$V_{min} = V_c - V_m$$

So,

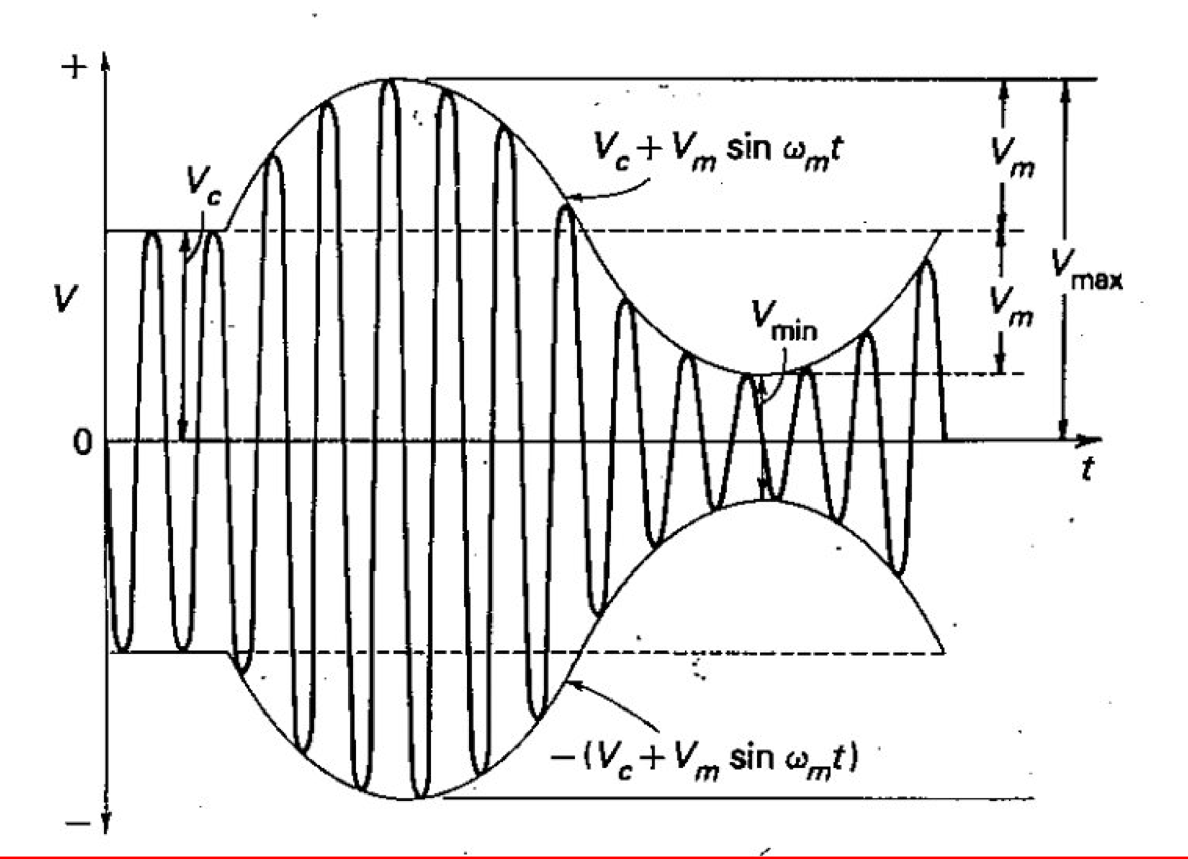
$$V_c = \frac{V_{max} + V_{min}}{2}$$

And

$$V_m = \frac{V_{max} - V_{min}}{2}$$

Modulation Index:

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



❑ Power of AM Signal:

- ✓ In an AM signal, there are three parts. They are, i) Carrier, ii) Upper side band (USB) and iii) Lower side band (LSB) So, total power of an AM signal comes from all three.

$$P_t = \frac{(V_{Carrier})^2}{R} + \frac{(V_{USB})^2}{R} + \frac{(V_{LSB})^2}{R}$$

$$\rightarrow P_t(rms) = \frac{\left(\frac{V_C}{\sqrt{2}}\right)^2}{R} + \frac{\left(\frac{mV_C}{2\sqrt{2}}\right)^2}{R} + \frac{\left(\frac{mV_C}{2\sqrt{2}}\right)^2}{R}$$

$$\rightarrow P_t = \frac{(V_C)^2}{2R}\left[1 + \frac{m^2}{2}\right] = P_c\left[1 + \frac{m^2}{2}\right]$$

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

❑ Power of AM Signal (Problem Solving Examples):

A 400-watt (400-W) carrier is modulated to a depth of 75 percent. Calculate the total power in the modulated wave.

Solution

$$P_{AM} = P_c\left(1+\frac{m^2}{2}\right) = 400\left(1+\frac{0.75^2}{2}\right) = 400 \times 1.281$$
$$= 512.5 \text{ W}$$

A broadcast radio transmitter radiates 10 kilowatts (10 kW) when the modulation percentage is 60. How much of this is carrier power?

Solution

$$P_c = \frac{P_t}{1+m^2/2} = \frac{10}{1+0.6^2/2} = \frac{10}{1.18} = 8.47 \text{ kW}$$

❑ Current of AM Signal:

Let I_c, be the unmodulated current and It, the total, or modulated, current of an AM transmitter, both being rms values. If R is the resistance in which these currents flow, then,

$$\frac{P_t}{P_c} = \frac{{I_t}^2 R}{{I_C}^2 R} = 1 + \frac{m^2}{2}$$

$$\rightarrow \frac{{I_t}^2}{{I_C}^2} = 1 + \frac{m^2}{2}$$

$$\rightarrow \frac{I_t}{I_C} = \sqrt{1 + \frac{m^2}{2}}$$

$$\therefore I_t = I_C \sqrt{1 + \frac{m^2}{2}}$$

❑ Modulation by Several Sine Waves:

Let, there are "n" number of sine waves namely V_1, V_2, …, V_n modulating a single carrier wave. So, we take the rms value of all the modulating signals.

$$V_m = \sqrt{V_1{}^2 + V_2{}^2 + \ldots + V_n{}^2}$$

$$\rightarrow \frac{V_m}{V_c} = \frac{\sqrt{V_1{}^2 + V_2{}^2 + \ldots + V_n{}^2}}{V_c}$$

$$\rightarrow\ m = \sqrt{\frac{V_1{}^2}{V_c{}^2} + \frac{V_2{}^2}{V_c{}^2} + \ldots + \frac{V_n{}^2}{V_c{}^2}}$$

$$\therefore m = \sqrt{m_1{}^2 + m_2{}^2 + \ldots + m_n{}^2}$$

So, **power of the modulated signals**

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

$$= 1 + \frac{m_1{}^2 + m_2{}^2 + \ldots + m_n{}^2}{2}$$

❑ Modulation by Several Sine Waves (Problem Solving Examples):

A certain transmitter radiates 9 kW with the carrier unmodulated, and 10.125 kW when the carrier is sinusoidally modulated. Calculate the modulation index. If another sine wave is simultaneously transmitted with modulation index 0.4, determine the total radiated power.

Solution

$$\frac{m^2}{2} = \frac{P_t}{P_c} - 1 = \frac{10.125}{9} - 1 = 1.125 - 1 = 0.125$$

$$m^2 = 0.125 \times 2 = 0.250$$

$$m = \sqrt{0.25} = 0.50$$

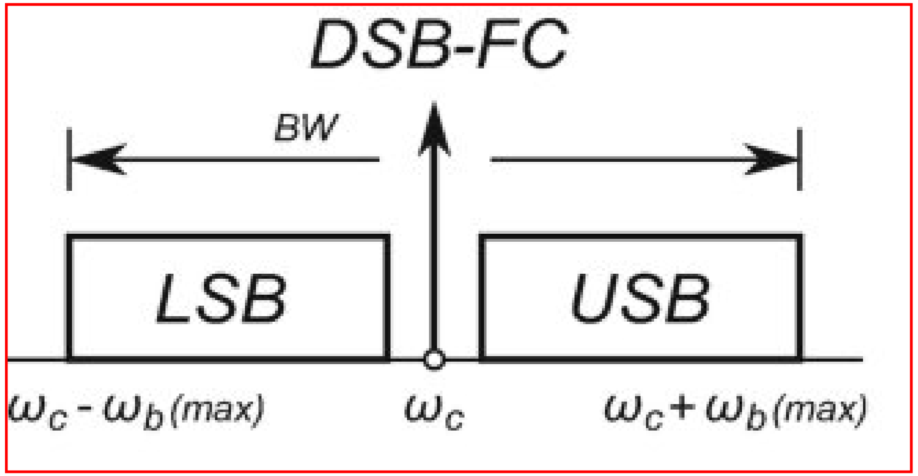
For the second part, the total modulation index will be

$$m_t = \sqrt{m_1^2 + m_2^2} = \sqrt{0.5^2 + 0.4^2} = \sqrt{0.25 + 0.16} = \sqrt{0.41} = 0.64$$

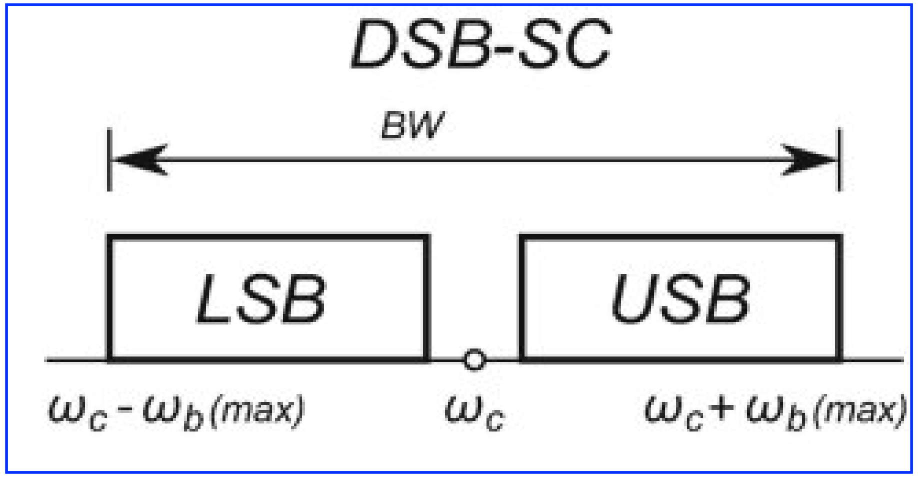
$$P_{AM} = P_c\left(1 + \frac{m_t^2}{2}\right) = 9\left(1 + \frac{0.64^2}{2}\right) = 9(1 + 0.205) = 10.84\ \text{kW}$$

❑ Types of Amplitude Modulation:

- **Double Sideband Full Carrier (DSB-FC):**
  - ✓ Standard AM
  - ✓ Contains carrier + both sidebands



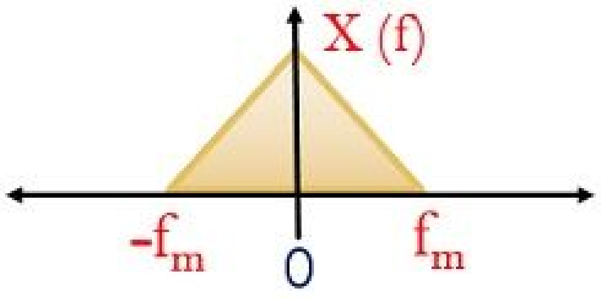
- **Double Sideband Suppressed Carrier (DSB-SC)**
  - ✓ No carrier
  - ✓ Requires coherent detection



❑ Types of Amplitude Modulation:

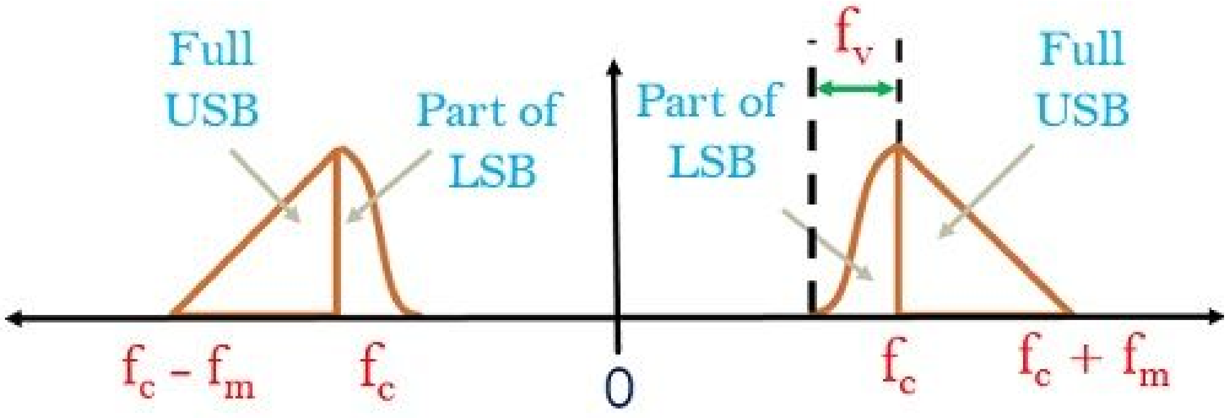
- **SSB (Single Sideband)**
  - ✓ Only one sideband is transmitted (USB or LSB)
  - ✓ More bandwidth and power efficient

❑ Types of Amplitude Modulation:



Spectrum of message signal

- **Vestigial Sideband (VSB)**
  - ✓ One full sideband and part of the other (LSB/USB)
  - ✓ Used in TV broadcasting

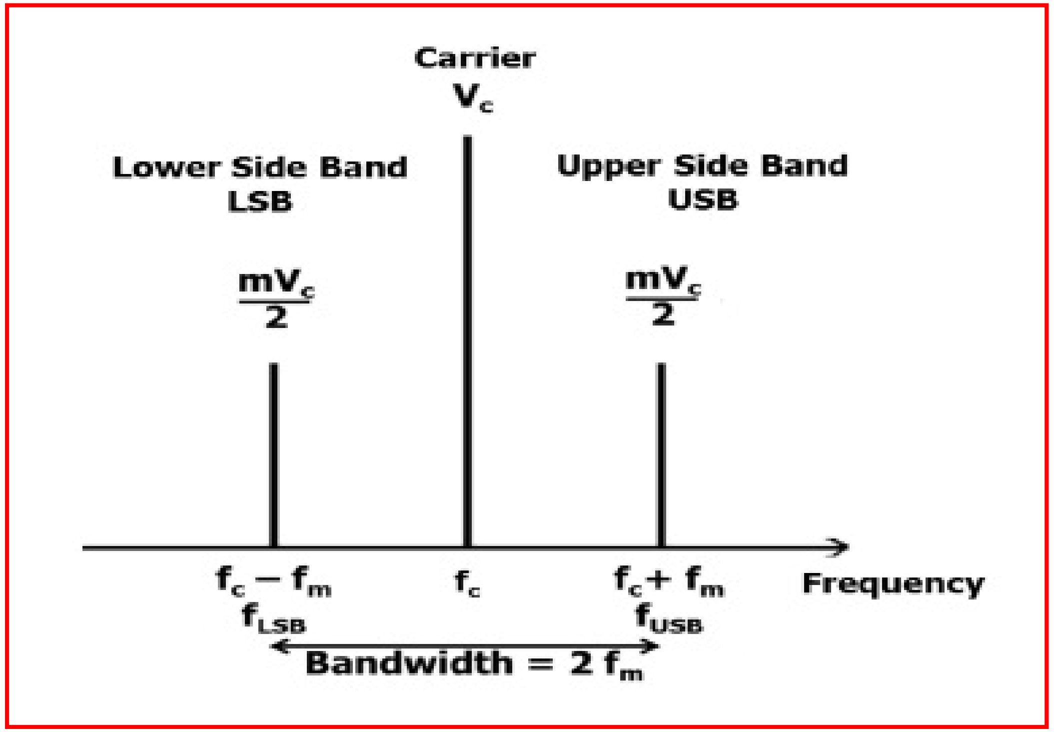


Spectrum of VSB signal

- **SSB-SC:** $$v = V_c Sin\ (\omega_c t) + \frac{mV_c}{2}\cos(\omega_m - \omega_c)t - \frac{mV_c}{2}\cos(\omega_m + \omega_c)t$$

Carrier   Lower Side Band   Upper Side Band

- ✓ The process of suppressing one of the sidebands along with the carrier and transmitting a single sideband is called as Single Sideband Suppressed Carrier system or simply SSB-SC.



❑ Advantages of SSB-SC:

Total power of a Double Sideband Full Carrier (DSBFC) AM signal is

$$P_{t(DSBFC)} = \frac{(V_{Carrier})^2}{R} + \frac{(V_{USB})^2}{R} + \frac{(V_{LSB})^2}{R}$$

$$\therefore P_{t(DSBFC)} = P_c\left[1 + \frac{m^2}{4} + \frac{m^2}{4}\right]$$

So, total power of SSB AM signal is

$$\therefore P_{t(SSB)} = P_c \frac{m^2}{4}$$

- **SSB-SC: Is removing of a band and carrier allowed?**
  - ✓ The carrier is removed because it does not transmit any information.
  - ✓ The remaining sidebands are actually mirror to each other, transmitting the same information.
  - ✓ So, information can be sent using a single side band.

❑ Advantages of SSB-SC:

- ✓ Power is saved.
- ✓ High power signal can be transmitted.
- ✓ Bandwidth or spectrum space occupied is lesser than standard AM and DSB-SC waves.
- ✓ Transmission of a greater number of signals is allowed.
- ✓ Less amount of noise is present.
- ✓ Signal fading is less likely to occur.

❑ Disadvantages of SSB-SC:

- ✓ The discovery & generation process of the single-sideband signal is complex.
- ✓ Higher Cost
- ✓ Signal quality will be affected when the transmitter & receiver of SSB have outstanding frequency strength

❑ Methods of Suppressing Carrier and Unwanted Sideband:

- ✓ Three (3) main systems are employed for the generation of SSB (i.e., for the suppression of carrier and unwanted sideband). They are:

  1. **Filter Method**
  2. **Phase Shift (or Cancellation) Method**
  3. **The third Method**

❑ Effect of Nonlinear Resistance on Added Signal

✓ The relationship between voltage and current in a linear resistance is -

$$\boxed{i = bv}$$

where *b* is some constant of proportionality.

✓ In-a nonlinear resistance (*Using a Nonlinear Resistance Device, e.g.,* ***Diode, Transistor, FET***), the current is still to a certain extent proportional to the applied voltage, but no longer directly as before.

✓ Current now becomes proportional not only to voltage but also to the square, cube and higher powers of voltage.

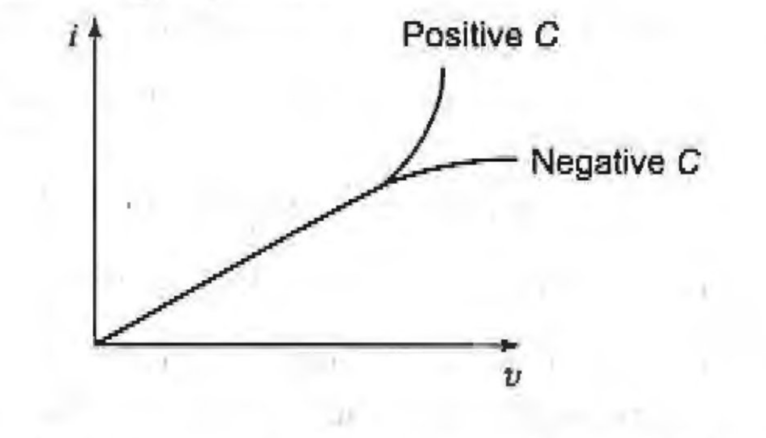


Fig. 3.13 *Nonlinear resistance characteristics.*

✓ This nonlinear relation is most conveniently expressed as

$$i = a + bv + cv^2 + dv^3 + \textbf{higher powers}$$

❑ Methods of Suppressing Carrier: The Balanced Modulator

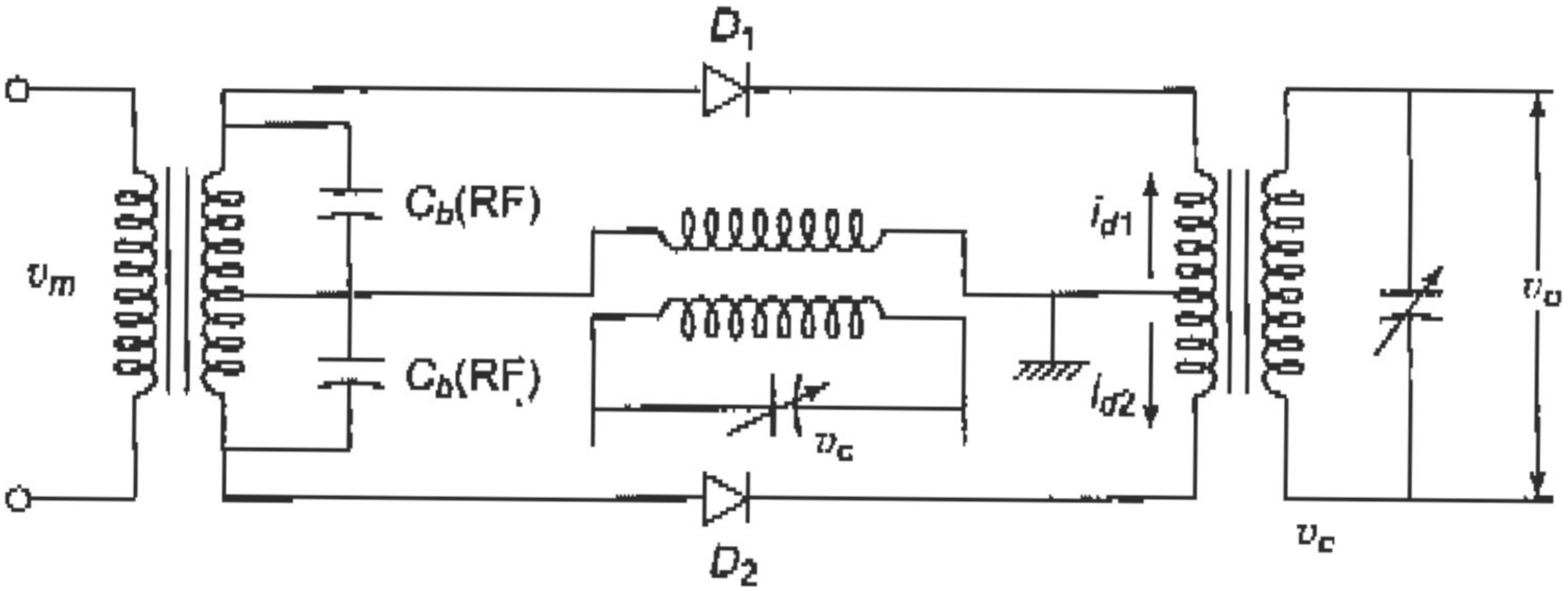


Fig. 3.16 Generation of DSBSC signal using balanced modulator based on nonlinear resistance characteristics of diode

❑ Methods of Suppressing Carrier: The Balanced Modulator

- ✓ As indicated, the input voltage will be (v_m+ v_c) at the input of diode D1 and (v_m - v_c) at the input of diode *D2.*
- ✓ The two diode output currents will be

$$i_{d1} = a + b\,(v_c + v_m) + c(v_C + v_m)^2$$

$$i_{d1} = a + bv_c + bv_m + cv_c^2 + \; cv_m^2 + 2cv_m v_c$$

$$i_{d1} = a + b\,(v_c - v_m) + c(v_C - v_m)^2$$

$$i_{d1} = a + bv_c - bv_m + cv_c^2 + \; cv_m^2 - 2cv_m v_c$$

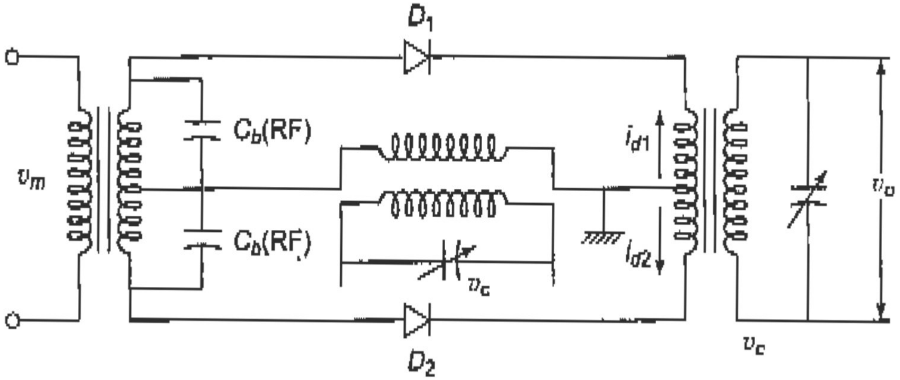


Fig. 3.16 *Generation of DSBSC signal using balanced modulator based on nonlinear resistance characteristics of diode.*

- ✓ Thus, the primary current will be

$$i_1 = i_{d1} - i_{d2} = 2bv_m + 4cv_m v_c$$

❑ Methods of Suppressing Carrier: The Balanced Modulator

Substituting for v_m and v_c and simplifying we get,

$$i_i = 2bV_m sin\omega_m t + 4c\frac{mV_c}{2}\cos(\omega_c - \omega_m)t - 4c\frac{mV_c}{2}\cos(\omega_c + \omega_m)t$$

The output voltage v_0 is proportional to this primary current. Let the constant of proportionality be α then

$$v_0 = \alpha i_1 = 2b\alpha V_m sin\omega_m t + 4\alpha c\frac{mV_c}{2}\cos(\omega_c - \omega_m)t - 4\alpha c\frac{mV_c}{2}\cos(\omega_c + \omega_m)t$$

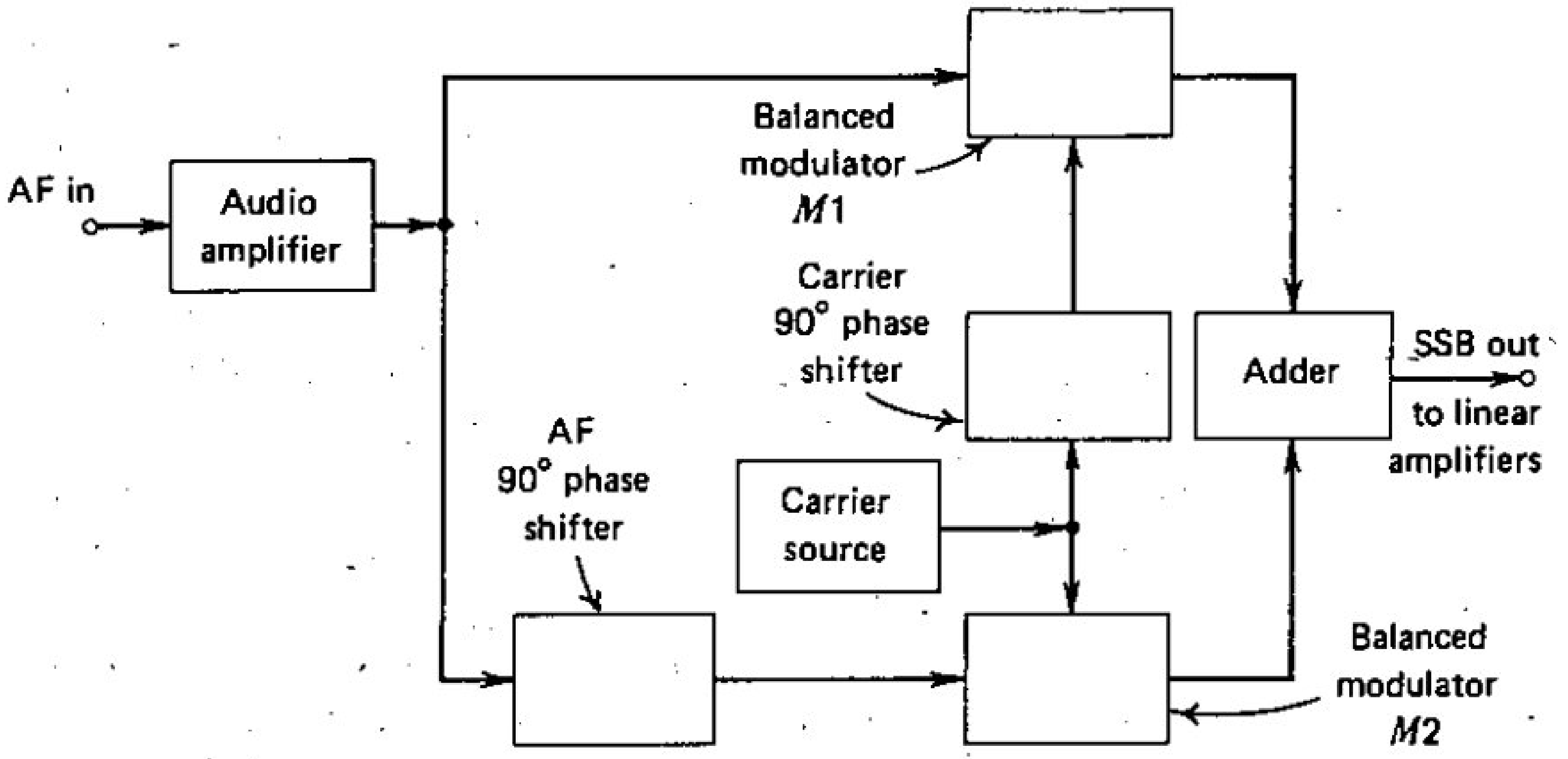
Let $P = 2\alpha bV_m$ and $Q = 2\alpha c\frac{mV_c}{2}$, then

$$v_0 = Psin\omega_m t + 2Qcos(\omega_c - \omega_m)t - 2Qcos(\omega_c + \omega_m)t$$

This equation shows that the carrier has been cancelled out, leaving only the two sidebands and the modulating frequencies. The tuning of the output transformer will remove the modulating frequencies from the output.

$$v_0 = 2Qcos(\omega_c - \omega_m)t - 2Qcos(\omega_c + \omega_m)t$$

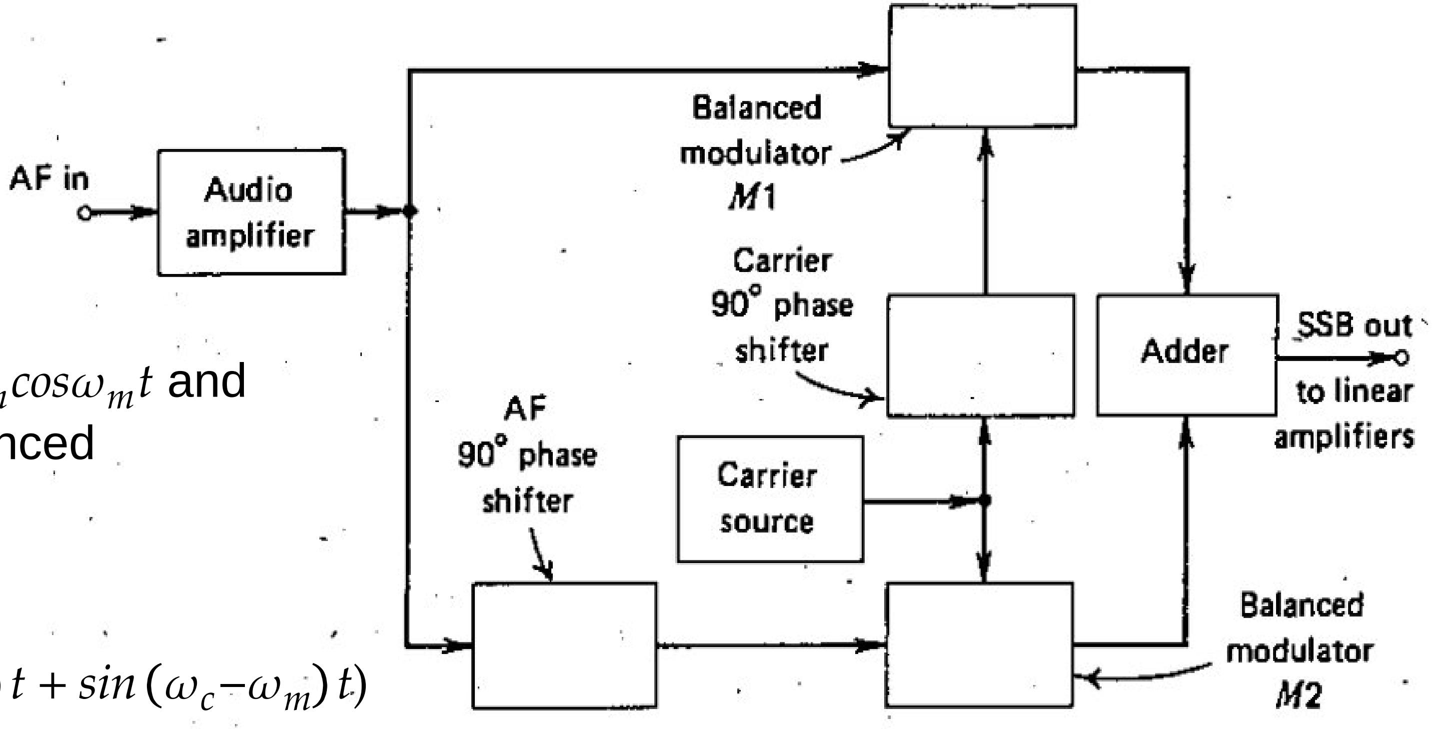
❑ Methods of Suppressing SB: The Phase Shift Method



$V_m sin\ (\omega_m t + 90°)$

❑ Methods of Suppressing SB: The Phase Shift Method

Let $v_m = V_m sin\omega_m t$ be the message and $v_c = V_c sin\omega_c t$ be the carrier. The $90°$ phase shifted version of them are $V_m cos\omega_m t$ and $V_c cos\omega_c t$ respectively. The output of the balanced modulator M_1 is given by,



$$v_1 = V_m V_c sin\omega_m t cos\omega_c t = \frac{V_m V_c}{2}(\sin(\omega_c + \omega_m)t + sin(\omega_c - \omega_m)t)$$

$V_m sin\,(\omega_m t + 90°)$

❑ Methods of Suppressing SB: The Phase Shift Method

The output of the balanced modulator M_2 is given by,

$$v_2 = V_m V_c cos\omega_m t sin\omega_c t = \frac{V_m V_c}{2}(\sin(\omega_c + \omega_m) t - sin(\omega_c - \omega_m) t)$$

The output of the adder is

$$v = v_1 \pm v_2$$

In one case we have

$$v = V_m V_c \sin(\omega_c + \omega_m) t$$

In the other case we have

$$v = V_m V_c \sin(\omega_c - \omega_m) t$$

Thus resulting in the generation of SSB signal

Thank You All