UPPSC-AE 2020

Uttar Pradesh
Public Service Commission

Combined State Engineering Services Examination

Assistant Engineer

Electrical Engineering

Analog Communication and Microwave

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY Publications

Analog Communication and Microwave

Contents

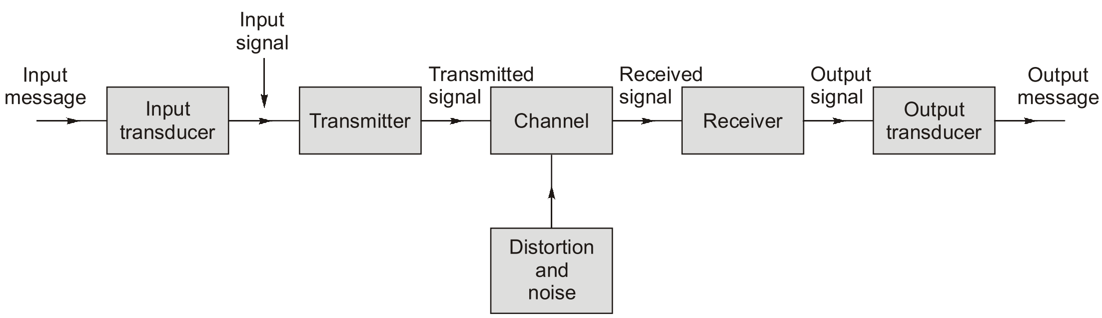
CHAPTER 1

SECTION-A

Introduction to Communication Systems

1.1 Introduction

In a basic sense, communication refers to exchange of information from sender to receiver, through a channel. In a broad sense, the term **communications** refers to the sending, receiving and processing of information by electronic means. The key components of a communication system are as follows:



Model of communication system

1. **Source :**
   - The source originates a message, such as a human voice, a television picture, an e-mail message, or data.
   - If the data is non-electric (e.g., human voice, e-mail text, television video), it must be converted by an **input transducer** into an electric waveform referred to as the **baseband signal** or **message signal** through physical devices such as a microphone, a computer keyboard or a CCD camera.
2. **Transmitter :** The transmitter modifies the baseband signal for efficient transmission. The transmitter may consist of one or more subsystems: an A/D converter, an encoder and a modulator.
3. **Channel :** The channel is a medium of choice that can convey the electric signals at the transmitter output over a distance. A typical channel can be a pair of twisted copper wires (telephone and DSL), coaxial cable (television and internet), an optical fibre or a radio link. Channel may be of two types.

   (i) Physical channel (ii) Wireless cannel
4. **Receiver :** The receiver reprocesses the signal received from the channel by reversing the signal modifications made at the transmitter and removing the distortions made by the channel.
5. **Destination :** The destination is the unit to which the message is communicated.

1.2 Primary Communication Resources

In a communication system, two primary resources are employed:

- **Transmitted power** and **channel bandwidth.**
- The transmitted power is the average power of the transmitted signal. The channel bandwidth is defined as the band of the frequencies allocated for the transmission of the message signal.
- We may therefore classify communication channels as **power limited** or **band limited.** For example, the telephone circuit is a typical band limited channel, where as a space communication link or satellite channel is typically power limited.

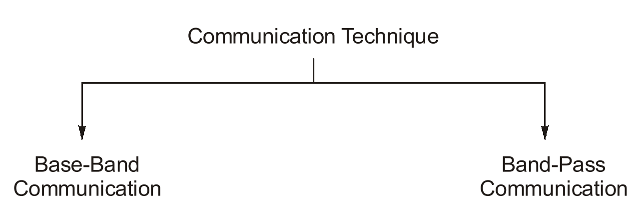
1.3 Modulation

- It is defined as the process by which some characteristics of signal called **"carrier"** is varied in accordance with the instantaneous value of the modulating signal a **modulating signal** or **base-band signal** or **message signal**.
- At the receiving end of the system we reconstruct the original base-band signal and this is accomplished by using a process called **"demodulation"**. **"Demodulation"** is the reverse process of **"modulation"**.

1.4 Different Signals

1. **Base-Band Signal**
   - Message signal, eg. **Voice signal, Video signal**
   - Low frequency range
   - Minimum frequency = 0 Hz
2. **Band-Pass Signal**
   - Frequency other than 0 Hz
   - Minimum frequency ≠ 0 Hz

1.5 Communication Technique



Base-Band Communication
- It doesn't use modulation technique.
- No shift in the range of frequency of the signal.
- Cannot be transmitted over long distance.

Band-Pass Communication
- Using modulation technique.
- Shift the frequency spectrum of base-band signal.
- Long distance transmission is possible.

1.6 Need of Modulation

1. **To decrease the length of transmitting and receiving antenna**
   For a message at 10 kHz, the antenna length 'l' for practical purposes is equal to $\lambda/4$ (from antenna theory) i.e.,

$$\lambda = \frac{3\times10^8}{10\times10^3} = 3\times10^4 \text{ m}$$

and

$$l = \frac{\lambda}{4} = \frac{3\times10^4}{4} = 7500 \text{ m}$$

   An antenna of this size is impractical and for a message at 1 MHz

$$\lambda = \frac{3\times10^8}{1\times10^6} = 300 \text{ m}$$

$$l = \frac{\lambda}{4} = 75 \text{ m} \quad \text{(practicable)}$$

2. **To allow the multiplexing of signals**
   By translating the all signals from different sources to different carrier frequency, we can multiplex the signals and able to send the all signals through a single channel.
3. **To remove the interference**
4. **To improve the quality of reception i.e. increasing the value of S/N ratio**
5. **To increase the range of communication**

Example - 1.1 Modulation is Primarily accomplished to:

(a) Produce side band
(b) Mix two-waves of different frequencies
(c) Improve transmission efficiency
(d) Transmit audio-frequency signal over long distance [UPPSC]

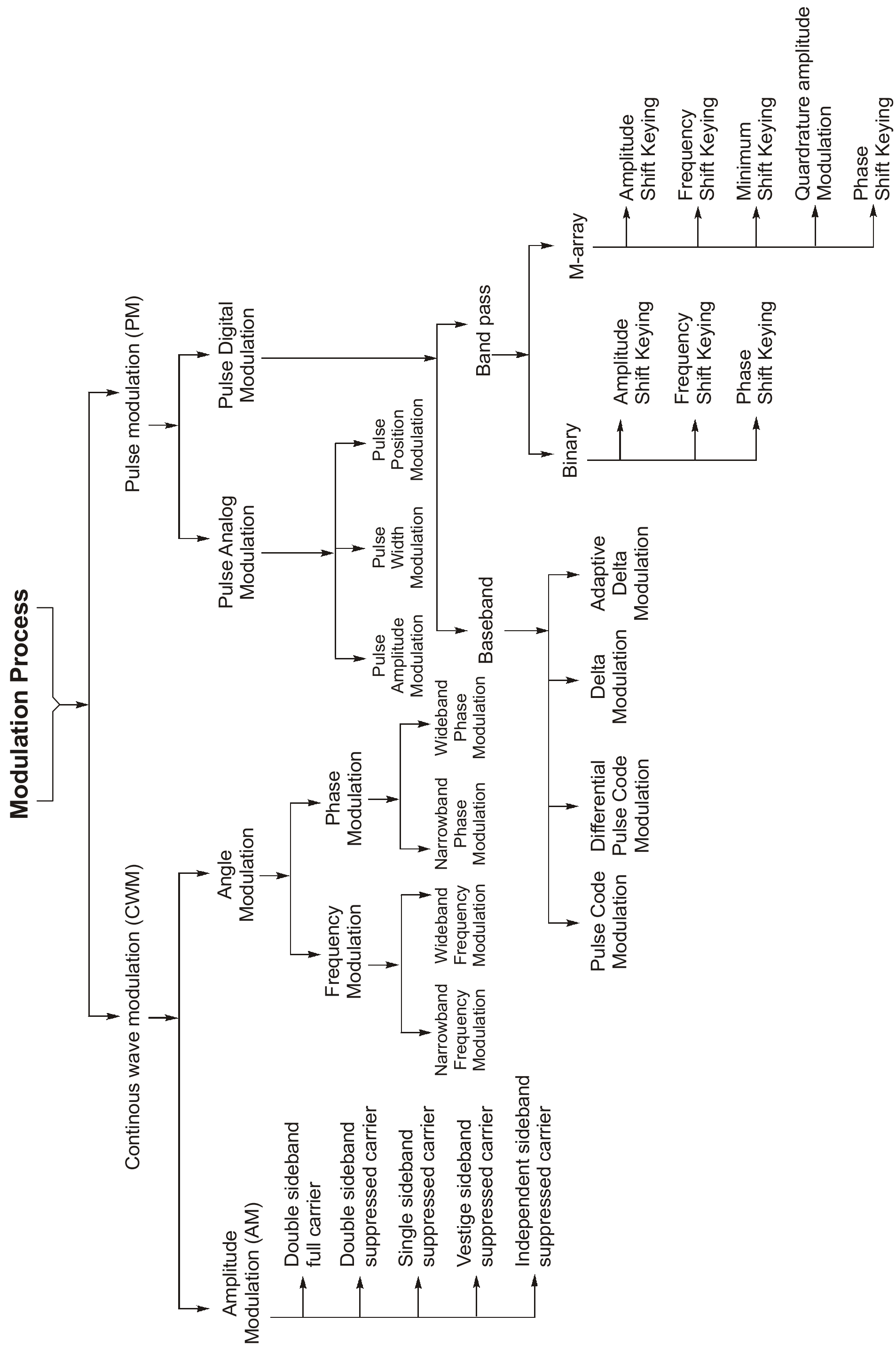
Answer: (d)

NOTE

Important Terms :

- *Baseband signal* is a signal having significant frequency component near to zero or low frequencies.
- *Bandpass signal* is a signal having significant frequency component away from zero frequency or low frequency.
- *Spectrum* means frequency domain representation of a signal.
- *Noise* is mainly added to signal in the channel.
- *Bandwidth* of a signal is defined as band of group of frequencies for which amplitude of signal is not zero.

1.7 Types of Modulation



1.8 An Exam Oriented Approach

Communication is a modern technology is undergoing many changes. The main focus of a student should be to single out on optimum path in which he develops a theoretically strong background of the subject while keeping in mind that he should be able to solve questions asked in various exams using the theory they have studied. Focusing on one aspect leads to failure in written exam or in the interview. Thus this book and communication both have the same approach and that is "optimization" and being a communication engineer one should have this approach too.

EM Spectrum

Frequency (f) range	Wavelength (λ) range	EM Spectrum Nomenclature	Typical Application
30 – 300 Hz	$10^7 - 10^6$ m	Extremely low frequency (ELF)	Power line communication
0.3 – 3 kHz	$10^6 - 10^5$ m	Voice frequency (VF)	Face to face speech, communication intercom
3 – 30 kHz	$10^5 - 10^4$ m	Very low frequency (VLF)	Submarine communication
30 – 300 kHz	$10^4 - 10^3$ m	Low frequency (LF)	Marine communication
0.3 – 3 MHz	$10^3 - 10^2$ m	Medium frequency (MF)	AM broadcasting
3 – 30 MHz	$10^2 - 10^1$ m	High frequency (HF)	Landline telephony
30 – 300 MHz	$10^1 - 10^0$ m	Very high frequency (VHF)	FM broadcasting, TV
0.3 – 3 GHz	$10^0 - 10^{-1}$ m	Ultra high frequency (UHF)	TV, Cellular telephony
3 – 30 GHz	$10^{-1} - 10^{-2}$ m	Super high frequency (SHF)	Microwave oven, radar
30 – 300 GHz	$10^{-2} - 10^{-3}$ m	Extremely high frequency (EHF)	Satellite communication, radar
0.3 – 3 THz	0.1 – 1 mm	Experimental	For all new explorations
3 – 430 THz	100 – 0.7 µm	Infrared	LED, Laser, TV remote
430 – 750 THz	0.7 – 0.4 µm	Visible light	Optical communication
750 – 3000 THz	0.4 – 0.1 µm	Ultraviolet	Medical application
> 3000 THz	< 0.1 µm	X-rays, gamma rays, cosmic rays	Medical application

■■■■

CHAPTER 2

Amplitude Modulation

2.1 Introduction

In amplitude modulation, the amplitude of a **carrier** signal is varied in accordance with the instantaneous value of **modulating voltage,** whose frequency is invariably lower than that of the carrier. In practice, the carrier may be high-frequency (HF) while the modulating signal is audio.

After studying the theory of amplitude modulation techniques, one will be able to know that an AM wave is made of a number of frequency components having a specific relation to one another. Based on this observation, AM can be further classified as double sideband full carrier (DSBFC), double sideband suppressed carrier (DSBSC), single sideband (SSB) and vestigial sideband (VSB) modulation techniques. This is based on how many components of the basic amplitude modulated signal are chosen for transmission. This is followed by a description of different methods for the generation of AM, DSBSC, SSB and VSB signals.

2.2 Amplitude Modulation (AM)

Amplitude modulation is defined as a process in which the amplitude of the carrier wave $c(t)$ is varied linearly with the message signal $m(t)$ keeping other parameters constant.

2.2.1 Equation for AM

Let, $c(t) = A_C \cos \omega_c t$ .... is a carrier wave having; A_C = carrier amplitude; w_c = carrier frequency and $m(t)$ = Base-band modulating signal band limited to maximum frequency "f_m"

Here, $\omega_c = 2\pi f_c$; $f_e >> f_m$

Now, according to amplitude modulation the maximum amplitude 'A' of the carrier will have to be made proportional to the instantaneous amplitude of modulating signal m(t).

The standard equation for AM wave is described as

$$X_{AM}(t) = m(t) \cos\omega_C t + A_c \cos\omega_C t$$

$$\Rightarrow \qquad \boxed{X_{AM}(t) = [A_C + m(t)]\cos\omega_c t}$$

$$= A_C [1 + K_a\, m(t)] \cos 2\pi f_c t$$

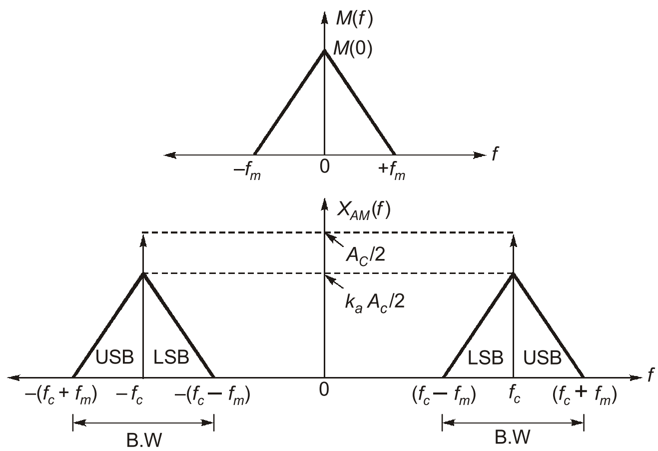
where, K_a = constant called amplitude sensitivity of modulator

For our sake of convenience let us take,

$$X_{AM}(t) = A_C \cos 2\pi f_c t + m(t) \cos 2\pi f_c t$$

$$X_{AM}(f) = \frac{A_c}{2}[\delta(f - f_c) + \delta(f + f_c)] + \frac{K_a A_c}{2}[M(f - f_c) + M(f + f_c)]$$

2.2.2 Spectrum of AM Signal



$$B.W = (\omega_c + \omega_m) - (\omega_c - \omega_m)$$

$$\boxed{B.W = 2\omega_m} \text{ rad/sec}$$

$$\boxed{B.W \approx 2f_m} \text{ Hz or kHz}$$

2.2.3 Single Tone Amplitude Modulation (Sinusoidal AM)

$$c(t) = A_C \cos \omega_c t \text{ ....carrier signal}$$

$$m(t) = A_m \cos \omega_m t \text{ .... modulating signal}$$

then after modulation, we get

$$\therefore \qquad \boxed{X_{AM}(t) = [A_C + A_m \cos\omega_m t] \cos\omega_c t}$$

$$X_{AM}(t) = A_C \left[1 + \frac{A_m}{A_c} \cos \omega_m t\right] \cos\omega_c t$$

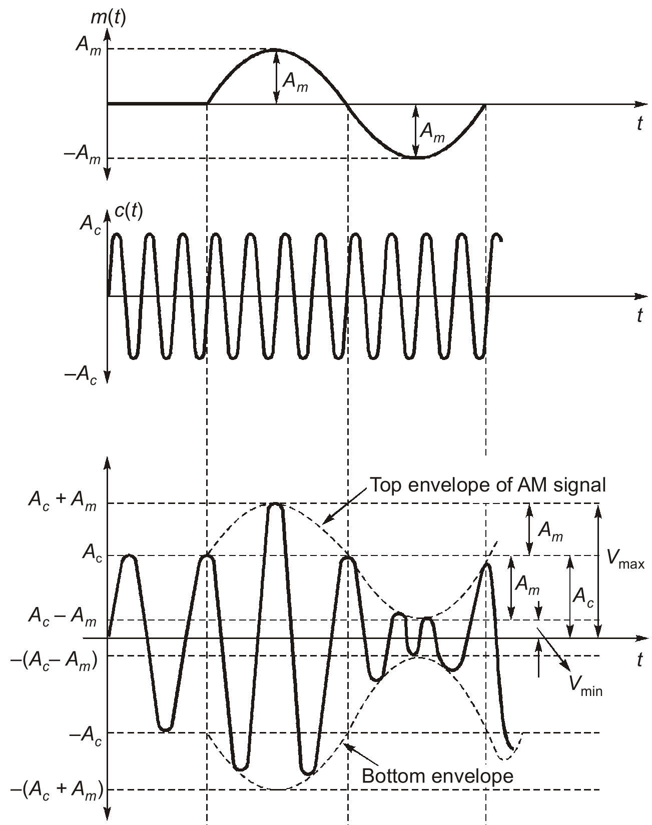
$$\boxed{X_{AM}(t) = A_C[1 + m_a \cos\omega_m t] \cos\omega_c t}$$

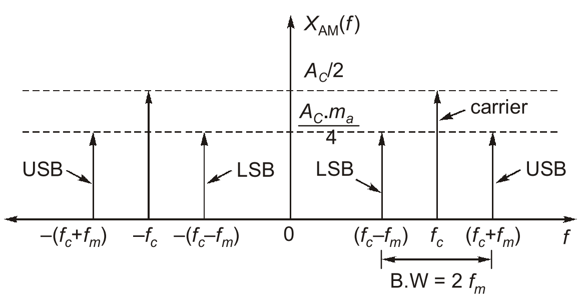
where, $m_a = \dfrac{A_m}{A_C}$ = **Modulation Index or Depth of modulation.**

$X_{AM}(t)$ can also be written as,

$$\boxed{X_{AM}(t) = \underbrace{A_c \cos\omega_c t}_{\text{Full carrier}} + \frac{1}{2} m_a A_c \underbrace{\cos(\omega_c + \omega_m)t}_{\text{USB}} + \frac{1}{2} m_a A_c \underbrace{\cos(\omega_c - \omega_m)t}_{\text{LSB}}}$$

2.2.4 Spectrum of sinusoidal AM signal





$$2A_m = V_{max} - V_{min}$$

$\Rightarrow$
$$\boxed{A_m = \frac{V_{max} - V_{min}}{2}}$$

$$A_c = V_{max} - A_m$$

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

$\Rightarrow$
$$\boxed{A_c = \frac{V_{max} + V_{min}}{2}}$$

Finally we get,

$$\boxed{m_a = \frac{A_m}{A_C} = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}} \rightarrow \text{modulation index}$$

- % modulation = $m_a \times 100$
- Modulation index gives the depth to which the carrier signal is modulated.
- For m(t) to be preserved in the envelope of AM signal, $\boxed{m_a \le 1}$

  i.e. $\boxed{A_m \le A_C}$

  So, range of m_a is, $\boxed{0 \le m_a \le 1}$

Example - 2.1 In an AM wave, V_{max} = 10 V and V_{min} = 5 V. The percentage of modulation is

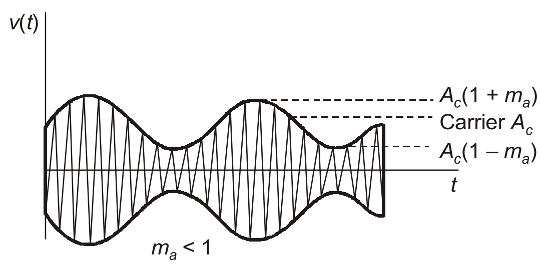
(a) 20.00 (b) 33.33
(c) 50.00 (d) 75.00 [UPPSC]

Answer: (b)

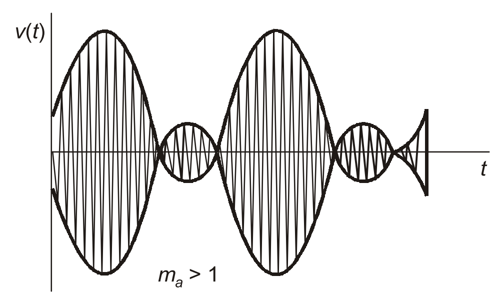
$$\text{Percentage of modulation } (\mu) = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} = \frac{5}{15} = \frac{1}{3} = 33.33\%$$

2.2.5 Overmodulation

When $\boxed{m_a > 1}$ i.e. $\boxed{A_m > A_C}$ Over modulation takes place and the signal gets distorted. Because, the (–ve) part of wave form gets cut from the waveform leaving behind a "square wave type" of signal, which generates infinite number of harmonics. This type of distortion is known as "Non-linear distortion" or "Envelope distortion".



Undermodulated AM wave



Over modulated AM wave

2.2.6 Power (normalized) Relations in AM Wave

$$\boxed{P_{Total} = P_T = P_{carrier} + P_{USB} + P_{LSB}}$$

We know, $$\text{power} = \frac{V_{rms}^2}{R} = \left(\frac{V_m}{\sqrt{2}}\right)^2 \cdot \frac{1}{R} = \frac{V_m^2}{2} \cdot \frac{1}{R}$$

Here, we consider R = 1 for normalized power

∴ $$\text{Power} = \frac{A_C^2}{2} \cdot \frac{1}{R} \approx \frac{A_C^2}{2}$$

Now, we can write,

$$P_T = \frac{A_C^2}{2} + \frac{\left(\frac{m_a A_C}{2}\right)^2}{2} + \frac{\left(\frac{m_a A_C}{2}\right)^2}{2}$$

⇒ $$\boxed{P_T = \frac{A_C^2}{2}\left[1 + \frac{m_a^2}{2}\right] = P_C\left(1 + \frac{m_a^2}{2}\right)}$$

But in general,

$$\boxed{P_T = \frac{A_C^2}{2} \cdot \frac{1}{R}\left(1 + \frac{m_a^2}{2}\right)}$$

$$\Rightarrow \quad \boxed{P_T = P_C + P_{SB} = P_C + \frac{P_C\, m_a^2}{2}}$$

$$P_T = P_C\left[1 + \frac{m_a^2}{2}\right]$$

⇒ Total side band power = Total useful power

i.e. $$\boxed{P_{SB} = \frac{P_C\, m_a^2}{2}}$$

Because, our information content is in the only LSB or USB not in carrier.

2.2.7 Transmission efficiency (η)

$$\eta = \frac{\text{total useful power}}{\text{total transmitted power}} = \frac{P_{SB}}{P_T}$$

$$\therefore \quad \boxed{\eta = \frac{m_a^2}{2 + m_a^2} \times 100\%}$$

Remember

Current Relations in AM Signal:

Let, $P_T = I_T^2 \cdot R$ and $P_C = I_C^2 \cdot R$

$$\therefore \quad \boxed{\frac{I_T}{I_C} = \sqrt{\left(1 + \frac{m_a^2}{2}\right)}}$$

2.2.8 Modulation by Several Sine Waves (Multiple-Tone Modulation)

Let: $c(t) = A_C \cos \omega_c t$; $m_1(t) = A_{m_1} \cos \omega_1 t$; $m_2(t) = A_{m_2} \cos \omega_2 t$

∴ Total modulating signal = $m(t) = m_1(t) + m_2(t)$

So, $$\boxed{X_{AM}(t) = A_C\,[1 + m_1 \cos \omega_1 t + m_2 \cos \omega_2 t] \cos \omega_c t}$$

where, $m_1 = \dfrac{A_{m_1}}{A_C}$ and $m_2 = \dfrac{A_{m_2}}{A_c}$

Power relations:

$$\boxed{P_T = P_C\left[1 + \frac{m_1^2}{2} + \frac{m_2^2}{2} + \ldots\ldots\ldots\ldots\right]} \Rightarrow \boxed{P_T = P_C\left[1 + \frac{m_T^2}{2}\right]}$$

where, $m^2_T = m^2_1 + m^2_2 + m^2_3 + \ldots\ldots$

where, m_T = total or net modulation index

$$\therefore \quad \boxed{m_T = \sqrt{m_1^2 + m_2^2 + \ldots\ldots + m_n^2}}$$

Example - 2.2 A carrier is modulated by two modulating waves *A* and *B* having modulation index of 0.6 and 0.8 respectively. The overall modulation index is

(a) 1.0 (b) 0.7

(c) 0.2 (d) 1.4 [UPPSC]

Solution: (a)

Given: $\mu_1 = 0.6$ and $\mu_2 = 0.8$

$$\text{Overall modulation index} = \sqrt{\mu_1^2 + \mu_2^2} = \sqrt{0.36 + 0.64} = 1$$

Example - 2.3 A 10 kW carrier is sinusoidally modulated by two carriers corresponding to a modulation index of 30% and 40% respectively. The total radiated power is

(a) 11.25 kW (b) 12.5 kW
(c) 15 kW (d) 17 kW

Solution: (a)

Given that: $P_c = 10$ kW ; $m_1 = 30\% = 0.3$; $m_2 = 40\% = 0.4$

$$\therefore \quad \text{Total modulation index} = m_T = \sqrt{m_1^2 + m_2^2} = 0.5$$

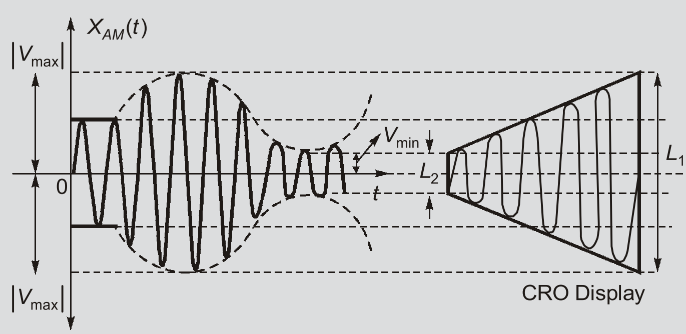
Now,

$$P_T = \text{total radiated power} = P_c\left(1 + \frac{m_T^2}{2}\right) = 11.25 \text{ kW}$$

NOTE

Trapezoidal display of AM Signal:

- modulated wave $\xrightarrow{\text{applied}}$ vertical deflection circuit of CRO.
- modulating wave $\xrightarrow{\text{applied}}$ horizontal deflection circuit of CRO.



Here, $L_1 = 2V_{max}$ and $L_2 = 2V_{min}$

So,

$$m_a = \text{modulation index} = \frac{L_1 - L_2}{L_1 + L_2}$$

Example - 2.4 An AM voltage signal s(t), with a carrier frequency of 1.15 GHz has a complex envelope $g(t) = A_C[1 + m(t)]$, $A_C = 500$ V, and the modulation is a 1 kHz sinusoidal test tone described by $m(t) = 0.8 \sin(2\pi \times 10^3 t)$, appears across a 50 Ω resistive load. What is the actual power dissipated in the load?

(a) 165 kW (b) 82.5 kW
(c) 3.3 kW (d) 6.6 kW

Solution: (c)

Given that: $A_c = 500$ V ; $f_m = 10^3$ Hz = 1 kHz

Since, $g(t) = A_c[1 + m(t)]$

$g(t) = 500[1 + 0.8\sin(2\pi \times 10^3 t)$

$\therefore$ $m_a = 0.8$

$R_L = 50\ \Omega$

Total actual power dissipated in the load,

$$P_T = \frac{A_c^2}{2}\cdot\left[1+\frac{m_a^2}{2}\right]\cdot\frac{1}{R} = \frac{500^2}{100}\left[1+\frac{0.8^2}{2}\right] = 3300 \text{ watt} = 3.3 \text{ kW}$$

2.3 Generation of AM Waves

- In this section we will discuss the devices and methods used for the generation of standard AM wave based on the nonlinear properties.
- The circuit that generates the AM waves is called as amplitude modulator and we will discuss two modulator circuits namely,

  1. Square law modulator 2. Switching modulator

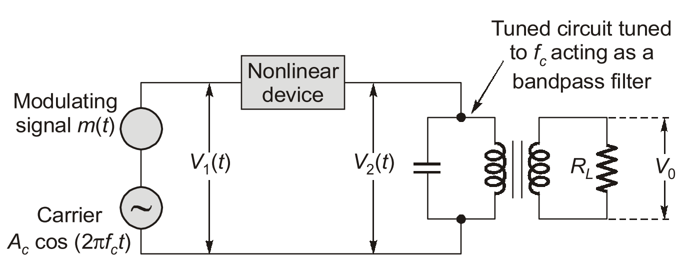
2.3.1 Square-Law Modulator

A square-law modulator requires three features:

- A means of summing the carrier and modulating waves
- A nonlinear element and
- A band-pass filter

For extracting the desired modulation products. Semiconductor diodes and transistors are the most common nonlinear devices used for implementing square-law modulators. The filtering requirement is usually satisfied by using a single or double tuned filter.

- The square law modulator circuit is as shown in figure below. It consists of the following.



When a non-linear element such as diode is suitably biased and operated in a restricted portion of its characteristic curve, we can represent the output by a square law "In the figure".

$$V_2(t) = a_1 V_1(t) + a_1 V_1^2(t)$$

Where a_1 and a_2 are constants. The input voltage $V_1(t)$ consists of the carrier wave plus the modulating wave, that is,

$$V_1(t) = A_c \cos 2\pi f_c t + m(t)$$

Therefore, $$v_2(t) = av_1(t) + b\, v_1^2(t)$$

$$v_2(t) = a[m(t) + A_c\cos(2\pi f_c t)] + b[m(t) + A_c\cos(2\pi f_c t)]^2$$

$$v_2(t) = am(t) + aA_c\cos(2\pi f_c t) + b[m^2(t) + 2m(t)A_c\cos(2\pi f_c t) + A_c^2\cos^2(2\pi f_c t)]$$

$$= \underset{(1)}{am(t)} + \underset{(2)}{aA_c\cos(2\pi f_c t)} + \underset{(3)}{bm^2(t)} + \underset{(4)}{2bm(t)A_c\cos(2\pi f_c t)} + \underset{(5)}{bA_c^2\cos^2(2\pi f_c t)]}$$

- The five terms in the expression for $v_2(t)$ are as follows:

  Term 1 : $am(t) \rightarrow$ Modulating signal

  Term 2 : $a A_c \cos(2\pi f_c t) \rightarrow$ Carrier signal

  Term 3 : $bm^2(t) \rightarrow$ Squared modulating signal

  Term 4 : $2bm(t) A_c \cos(2\pi f_c t) \rightarrow$ AM wave with only sidebands

  Term 5 : $b A_c^2 \cos^2(2\pi f_c t) \rightarrow$ Squared carrier

- Out of these five terms, terms 2 and 4 are useful whereas the remaining terms are not useful. Let us club terms 2, 4 and 1, 3, 5 as follows to get,

$$v_2(t) = am(t) + bm^2(t) + bA_c^2 \cos^2(2\pi f_c t) + aA_c \cos(2\pi f_c t) + 2bm(t)A_c \cos(2\pi f_c t)$$

- The LC tuned circuit acts as a bandpass filter. The circuit is tuned to frequency f_c and its bandwidth is equal to $2 f_m$.
- Hence the output voltage $V_0(t)$ contains only the useful terms.

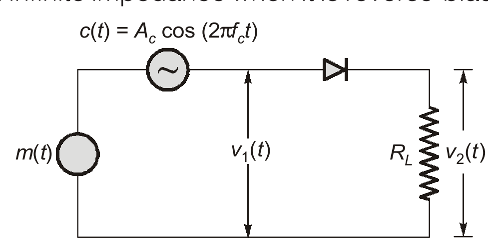
$$V_0(t) = aA_c \cos(2\pi f_c t) + 2\,bm(t)\,A_c \cos(2\pi f_c t)$$

$$= [aA_c + 2\,bm(t)A_c] \cos(2\pi f_c t) = aA_c\left[1+\frac{2b}{a}m(t)\right]\cos(2\pi f_c t)$$

2.3.2 Switching Modulator

A switching modulator is shown in figure below, where it is assumed that the carrier wave $c(t)$ applied to the diode is large in amplitude, so that it swings right across the characteristic curve of the diode.

We assume that the diode acts as an ideal switch; that is, it presents zero impedance when it is forward-biased [corresponding to $c(t) > 0$] and infinite impedance when it is reverse-biased [corresponding to $c(t) < 0$].



We may thus approximate the transfer characteristic of the diode-load resistor combination by a piecewise-linear characteristic, as shown in figure. Accordingly, for an input voltage $v_1(t)$ given by

$$v_1(t) = A_c \cos(2\pi f_c t) + m(t)$$

where $|m(t)| << A$ the resulting load voltage $v_2(t)$ is

$$v_2(t) \approx \begin{cases} v_1(t), & c(t) > 0 \\ 0 & c(t) < 0 \end{cases}$$

The output of this circuit can be analysed as the signal $m(t)$ sampled by the carrier $c(t)$.

We finally get, $$v_2(t) = \frac{A_c}{2}\left[1+\frac{4}{\pi A_c}m(t)\right]\cos(2\pi f_c t) + \text{unwanted terms}$$

This is the required expression for the AM wave with $m = [4/\pi A_c]$. The unwanted terms can be eliminated using a band-pass filter.

2.3.3 Disadvantages of AM

The AM signal is also called as "Double Sideband Full Carrier (DSBFC)" signal. The main disadvantages of this technique are:

1. Power wastage takes place. 2. AM needs larger bandwidth. 3. AM wave gets affected due to noise.

These are explained as follows:

- The carrier signal in the DSBFC system does not convey any information.
- The information is contained in the two sidebands only. Also the sidebands are images of each other and hence both of them contain the same information.
- Thus all the information can be conveyed by only one sideband.

2.4 Detection of AM Waves

The process of detection or demodulation provides a means of recovering the message signal from an incoming modulated wave. In effect, detection is the inverse of modulation. In the sequel, we describe three devices for the detection of AM waves:

(i) The square-law detector (ii) The envelope detector (iii) The synchronous (coherent) detector.

2.4.1 Square-law detector

A square-law detector is essentially obtained by using a square-law modulator for the purpose of detection. Consider the transfer characteristic equation of a nonlinear device, which is reproduced here for convenience:

$$v_2(t) = a_1 v_1(t) + a_2 v_1^2(t)$$

where $v_1(t)$ and $v_2(t)$ are the input and output voltages, respectively and a_1 and a_2 are constants.

$$v_1(t) = A_c[(1 + k_a m(t))\cos(2\pi f_c t)]$$

$$v_2(t) = a_1 A_c[1 + k_a m(t)]\cos(2\pi f_c t) + \frac{1}{2}a_2 A_c^2[1 + 2k_a m(t) + k_a^2 m^2(t)][1 + \cos(4\pi f_c t)]$$

The desired signal, namely, $a_2 A_c^2 K_a m(t)$, is due to the $a_2 v_1^2(t)$ term-hence, the description "square-law detector." This component can be extracted by means of a low-pass filter.

NOTE

- The output of the low pass filter to the load resistance R_L is as follows,

$$a_2 A_c^2 k_a m(t) + \frac{1}{2} a_2 A_c^2 k_a^2 m^2(t)$$

- The output of the low pass filter to the load resistance R_L is as follows,

$$a_2 A_c^2 k_a m(t) + \frac{1}{2} a_2 A_c^2 k_a^2 m^2(t)$$

- This is an unwanted signal and gives rise to a signal distortion. The ratio of desired signal to the undesired one given by,

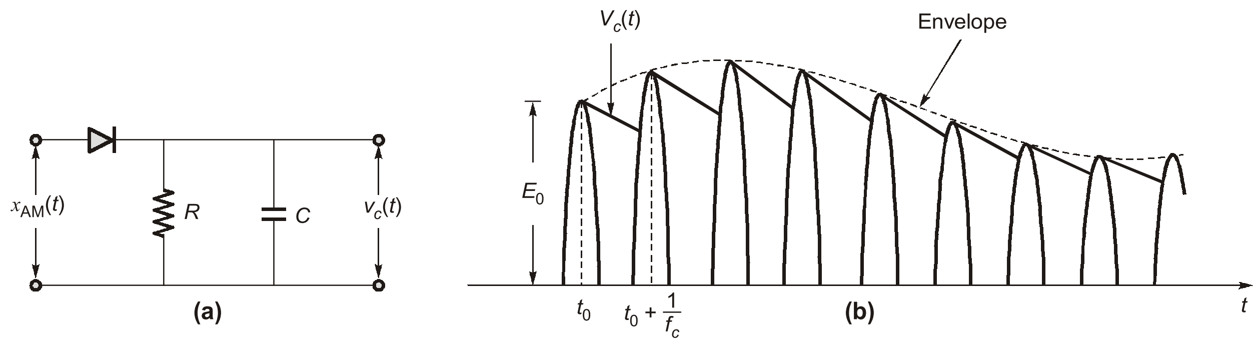
$$\text{Ratio} = \frac{\text{Desired output}}{\text{Undesired output}} = \frac{a_2 A_c{}^2 k_a m(t)}{\frac{1}{2} a_2 A_c{}^2 k_a^2 m^2(t)} = 2 / k_a m(t)$$

- We should maximize this ratio in order to minimize the distortion. To achieve this we should choose $|k_a m(t)|$ small as compared to unity (1) for all values of t. If k_a is small then the AM wave is weak.

2.4.2 Envelope detector

An envelope detector is simple and yet highly effective device that is well-suited for the demodulation of an AM signal for which the percentage modulation is less then 100%. Ideally, an envelope detector produces an output signal that follows the envelope of the input signal waveform exactly.

Figure below shows the circuit diagram of an envelope detector that consists of a diode and a resistor-capacitor filter.



The operation of this envelope detector is as follows:

- On the positive half cycle of the input signal (i.e., modulated signal), the diode is forward biased and the capacitor charges up rapidly to the peak value of the input signal falls below this value, the diode becomes reverse-biased and the capacitor discharges slowly through the resistance *R*. The discharging process continues until the next positive cycle.
- When the input signal becomes greater than the voltage across the capacitor, the diode conducts again and the process is repeated.

NOTE

- The discharging time constant *RC* must be large enough to ensure that the capacitor discharges slowly through the resistor *R* between positive peaks of the carrier wave, but not so long that the capacitor voltage will not discharge at the maximum rate of change of the modulating wave.

  Therefore, $\frac{1}{f_c} << RC << \frac{1}{W}$ where W = message bandwidth.

- Optimum value of *RC* is, $RC \le \frac{1}{W} \frac{\sqrt{1-\mu^2}}{\mu}$

Distortions in the Envelope Detector Output

There are two types of distortions which can occur in the detector output. They are:

1. **Diagonal Clipping:** This type of distortion occurs when the *RC* time constant of the load circuit is too large. Due to this the *RC* circuit cannot follow the fast changes in the modulating envelope.
2. **Negative peak Clipping:**
   - This distortion occurs due to a fact that the modulation index on the output side of the detector is higher than that on its input side.
   - So at higher depths of modulation of the transmitted signal, the over modulation (more than 100% modulation) may take place at the output of the detector.

2.4.3 Synchronous Detector

The synchronous detector consists of a multiplier and a Low Pass Filter (LPF). The multiplier multiplies the AM signal with a locally generated carrier having the same frequency and phase as that of the carrier signal. The output of multiplier is passed through LPF to recover the message signal.