- Principles of Teleommunication
- Module 2_Amplitude Modulation
- Lecture Plan _ Part4

## 1. Generation of AM Waves

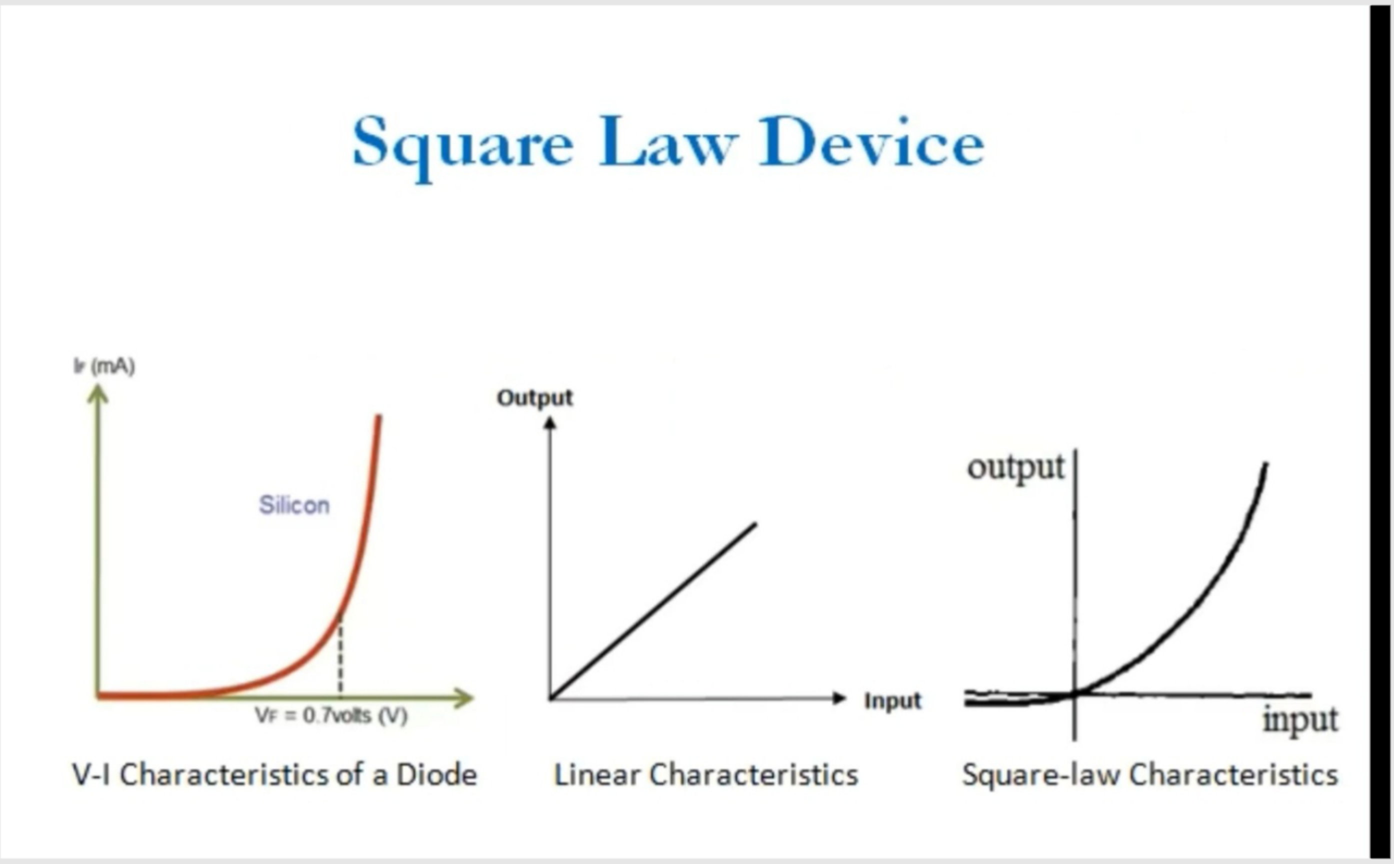
The circuit that generates the AM waves is called as amplitude modulator and in this post we will discuss two such modulator circuits namely :

(a)Square Law Modulator

(b) Switching Modulator

## Square law device

- Both the above circuit use a non linear element such as diode for their implementation.

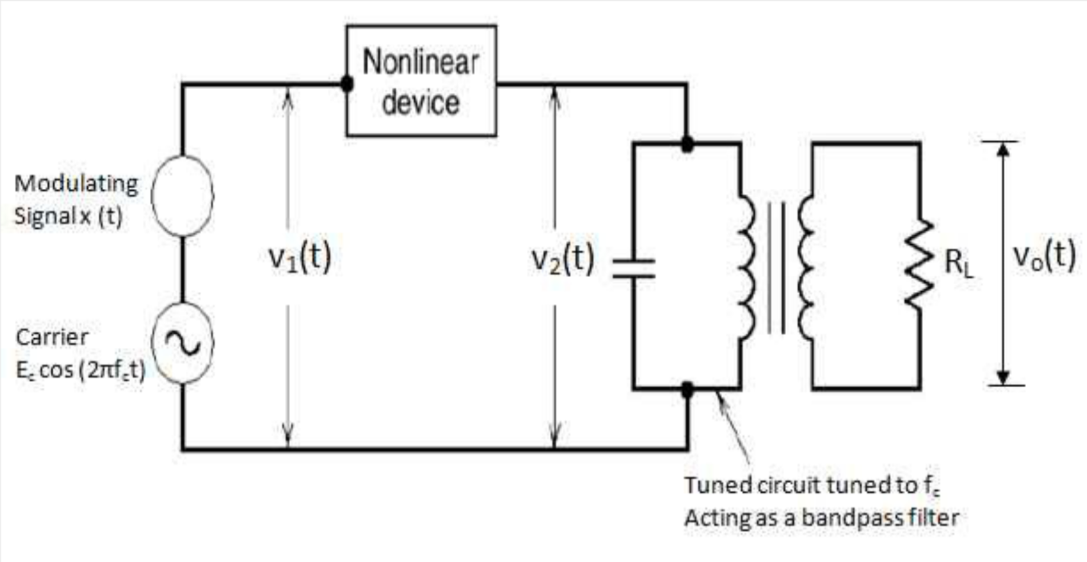



Diode
⇓
Non-linear device
⇓
used in those circuits

Linear

Non-linear relation between its current & voltage (diode)

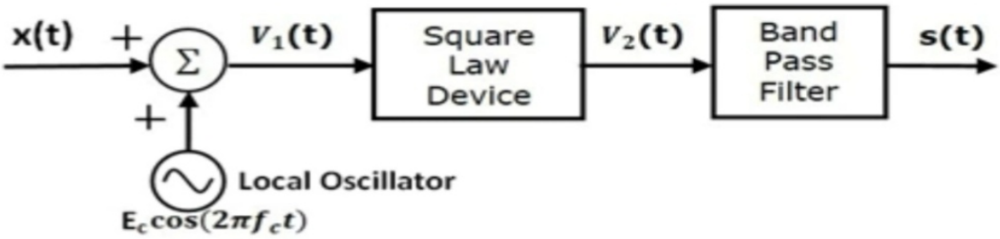
## (a) Square Law Modulator




Square law modulator consist of -

- ▢ A non-linear device
- ▢ A bandpass filter
- ▢ A carrier source and modulating signal

The modulating signal and carrier are connected in series with each other and theirvsum v1(t) is applied at the input of the non-linear device, such as diods and transistor.




$$v_1(t) = x(t) + c(t)$$

$$v_1(t) = x(t) + E_c \cos(2\pi f_c t) \qquad \text{..........................(1)}$$

The input output relation for square law device is given as:

$$v_2(t) = a v_1(t) + b v_1^2(t) \qquad \text{..........................(2)}$$

Where a and b are constants

Now substituting expression (1) in (2), we get

$$v_2(t) = a[x(t) + E_c \cos(2\pi f_c t)] \quad + b[x(t) + E_c \cos(2\pi f_c t)]^2$$

Or ,

$$v_2(t) = ax(t) + aE_c \cos(2\pi f_c t) \quad + b[x^2(t) + 2x(t)\cos(2\pi f_c t) + E_c^2 \cos^2(2\pi f_c t)]$$

Or ,

$$v_2(t) = \underbrace{ax(t)}_{(1)} + \underbrace{aE_c \cos(2\pi f_c t)}_{(2)} \quad + \underbrace{bx^2(t)}_{(3)} + \underbrace{2bx(t)\cos(2\pi f_c t)}_{(4)} + \underbrace{bE_c^2 \cos^2(2\pi f_c t)}_{(5)}$$

Useful terms (2 & 4)

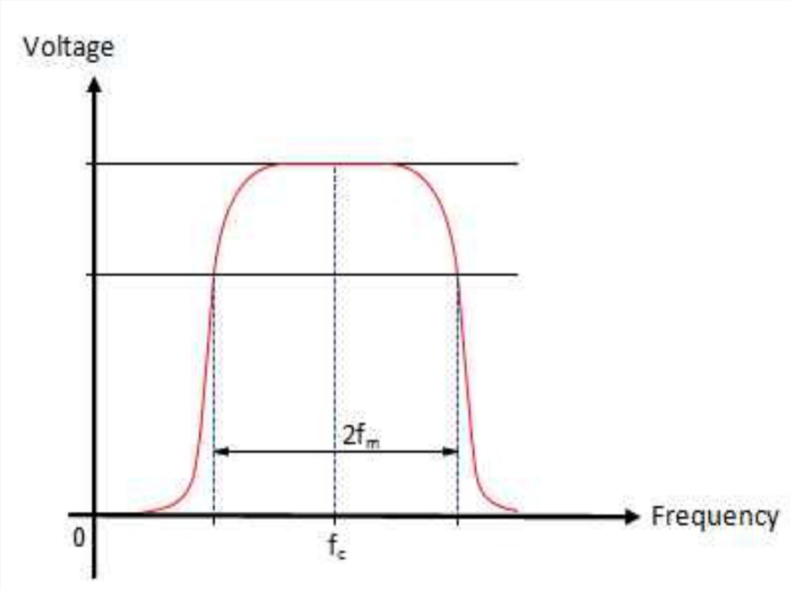
The five terms in the expression for $v_2(t)$ are as under :

- Term 1: $a x(t)$ : Modulating Signal
- Term 2 : $a E_c \cos(2\pi f_c t)$ : Carrier Signal
- Term 3 : $b x^2(t)$ : Squared modulating Signal
- Term 4 : $2 b x(t) \cos(2\pi f_c t)$ : AM wave with only sidebands
- Term 5 : $b E_c^2 \cos^2(2\pi f_c t)$ : Squared Carrier

**Out of these five terms, terms 2 and 4 are useful whereas the remaining terms are not useful.**

Next the LC tuned filter acts as a bandpass filter. It is tuned to frequency $f_c$ and its bandwidth is equal to $2f_m$.
This bandpass filter eliminates the unuseful terms from the equation of $v_2(t)$.

Figure:
Response of Band pass filter –




Output of the BPF can be written as:

$$V_o(t) = aE_c\cos(2\pi f_c t) + 2bx(t)E_c\cos(2\pi f_c t)$$

Or,

$$V_o(t) = [aE_c + 2bx(t)E_c]\cos(2\pi f_c t)$$

Or,

$$V_o(t) = aE_c[1 + \frac{2b}{a}x(t)]\cos(2\pi f_c t) \quad \text{.........................(3)}$$

Comparing this with the expression for standard AM wave. i.e.;

$$s(t) = E_c[1 + mx(t)]\cos(2\pi f_c t)$$

We find that the expression for Vo(t) of equation (3) represents an AM wave with $\boxed{m = (2b/a)}$ .

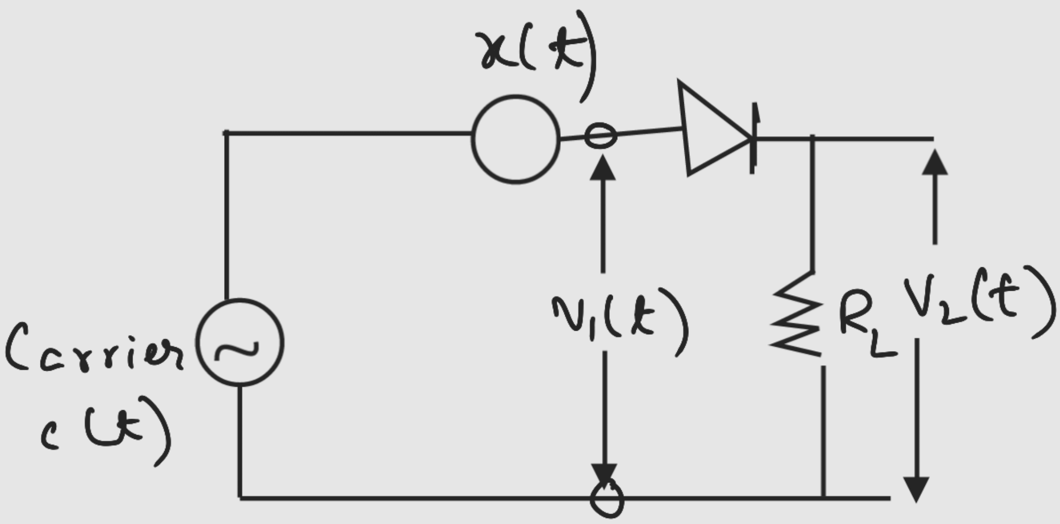
Hence, square law modulator produces an AM wave.

## (b) Switching Modulator

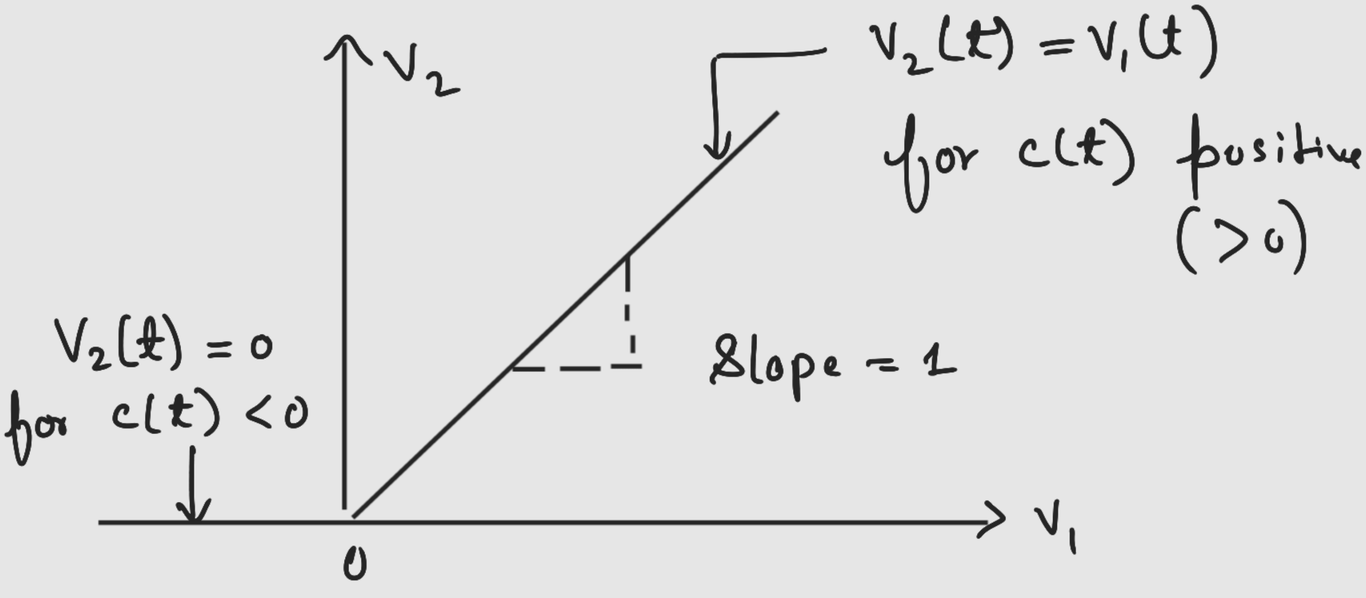
- The switching modulator using a diode has been shown in figure below.
- This diode is assumed to be operating as a switch .
- The modulating signal and carrier signal are connected in series with each other.
- The input voltage to the diode is given by :

$$v_1(t) = c(t) + x(t) = E_c \cos(2\pi f_c t) + x(t)$$

- The amplitude of carrier is much larger than that of x(t) and c(t) decides the status of the diode (ON or OFF ) .




a) Switching modulator




b) Idealized input-output relation

## Working Operation and Analysis

Let us assume that the diode acts as an ideal switch .

- **Closed switch- forward biased** in the positive half cycle of the carrier and offers zero impedance .
- **Open switch** - **reverse biased** in the negative half cycle of the carrier and offers an infinite impedance .
- Therefore, the output voltage

v2(t) = v1(t) in the positive half cycle of c(t)
v2(t) = 0 in the negative half cycle of c(t) .

We can express v2(t) mathematically as under :

$$v_2(t) = v_1(t)\,.\,g_p(t) = [x(t) + E_c\cos(2\pi f_c t)]\,g_p(t)$$

……………………………(4)

where,  gp(t) is a periodic pulse train of duty cycle equal to one half cycle period i.e. T0 /2 (where T0 = 1/fc) .

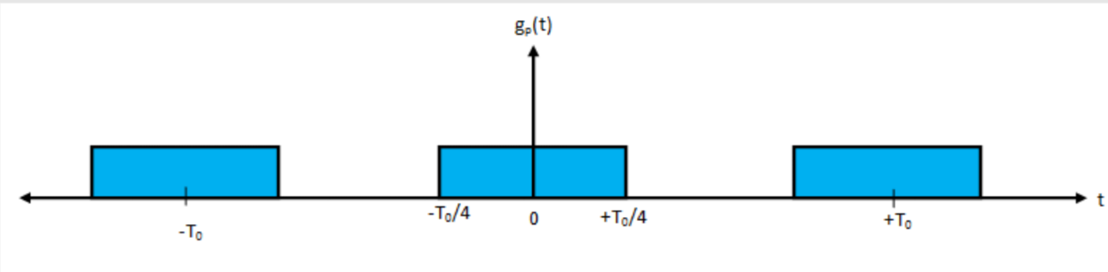



Fig.4

Let us express gp(t) with the help of Fourier series as under :

$$g_p(t) = \frac{1}{2} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos\left[2\pi f_c t(2n-1)\right]$$

………………………………(5)

$$g_p(t) = \frac{1}{2} + \frac{2}{\pi}\cos(2\pi f_c t) + odd\ harmonic\ components$$

……………………………(6)

Substituting gp(t) into equation (4), we get

$$v_2(t) = [x(t) + E_c\cos(\,(2\pi f_c t)]\left\{\frac{1}{2} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos\,[2\pi f_c t(2n-1)]\right\}$$

Therefore,

$$v_2(t) = [x(t) + E_c\cos(\,(2\pi f_c t)]\left\{\frac{1}{2} + \frac{2}{\pi}\cos(2\pi f_c t) + odd\ harmonics\right\}$$

…………………………(7)

The odd harmonics in this expression are unwanted, and therefore, are assumed to be eliminated .

Hence,

$$v_2(t) = \underbrace{\frac{1}{2}x(t)}_{\text{Modulating Signal}} + \underbrace{\frac{1}{2}E_c\cos(2\pi f_c t) + \frac{2}{\pi}x(t)\cos(2\pi f_c t)}_{\text{AM Wave}} + \underbrace{\frac{2E_c}{\pi}cos^2(2\pi f_c t)}_{\text{Second harmonic of carrier}}$$

In this expression, the first and the fourth terms are unwanted terms whereas the second and third terms together represents the AM wave .

Clubing the second and third terms together , we obtain

$$v_2(t) = \frac{E_c}{2}\left[1 + \frac{4}{\pi E_c}x(t)\right]\cos(2\pi f_c t) + unwanted\ terms$$

**<u>This is the required expression for the AM wave with m=[4/πEc]</u>** . The unwanted terms can be eliminated using a band-pass filter (BPF) .