Internal Assessment Test I Solutions – Mar 2018

Sub: Principles of Communication Systems Subject code: 15EC45

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2 a) What is FDM? With a neat block diagram, explain FDM.

Ans: An important signal processing operation in analog communications is *multiplexing*, whereby a number of independent signals can be combined into a composite signal suitable for transmission over a common channel. To transmit a number of these signals over the same channel (e.g. cable), the signals must be kept apart so that they do not interfere with each other, and thus they can be separated at the receiving end. This is accomplished by separating the signals either in frequency or in time. The technique of separating the signals in frequency is referred to as *frequency-division multiplexing* (FDM).

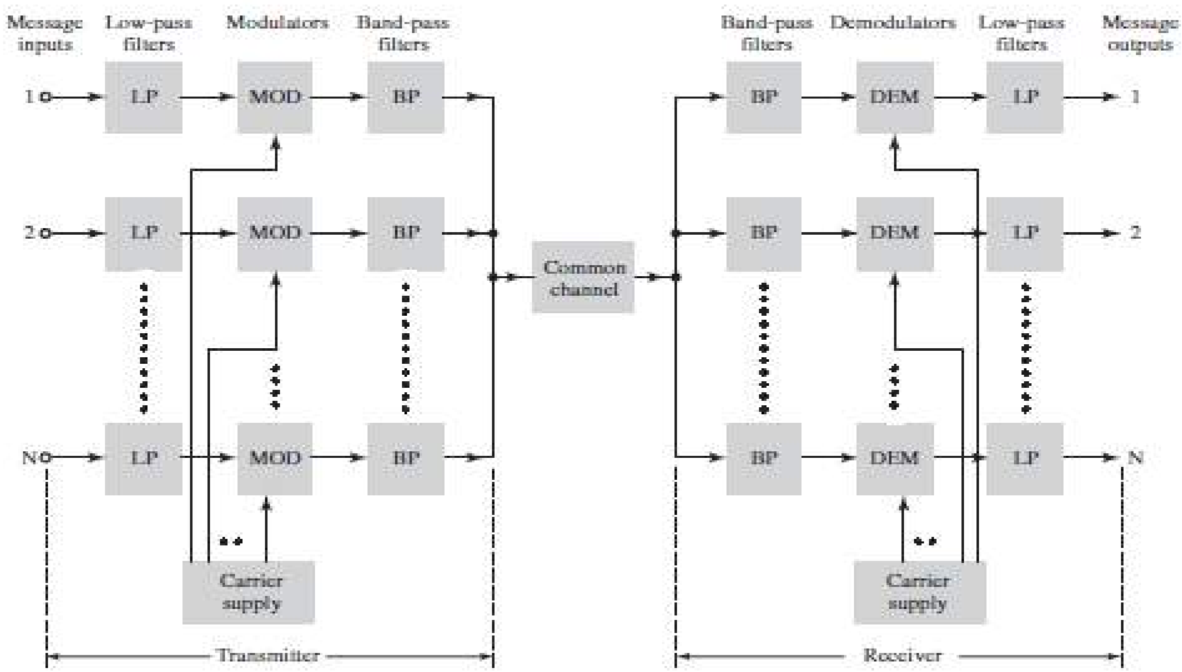


FIGURE 3.29 Block diagram of frequency-division multiplexing (FDM) system.

The block diagram for FDM is shown above.

* The I/p message Signals assumed to be of the low-pass type are passed through the I/p LPF's. This LPF's are designed to remove high-frequency Components that do not Contribute Significantly to Signal representation but are capable of disturbing other message Signals that Share the Common Channel.

* The filtered message Signals are then modulated with the carrier frequencies. The most widely used method of modulation in FDM is Single Sideband modulation, which requires a - bandwidth that is approximately equal to that of original - message Signal.

* The BPF's following the modulators are used to restrict the band of each modulated wave to its prescribed range.

  The resulting BPF o/p's are next Combined in parallel to form the I/p to the Common Channel.

* At the receiving end, BPF's connected to the Common Channel in parallel to Separate the message Signals on the frequency occupancy basis.

* Finally, the original message Signals are recovered by individual demodulators.

2 b) Explain the operation of a mixer with a neat block diagram.

Ans:

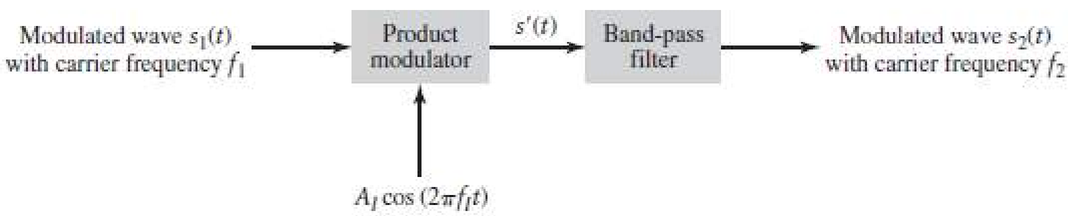


FIGURE 3.21 Block diagram of mixer.

The basic operation performed in single sideband modulation is in fact a form of frequency translation, which is why single sideband modulation is sometimes referred to as frequency changing, mixing, or heterodyning. Suppose that we have a modulated wave whose spectrum is centered on a carrier frequency and the requirement is to translate it upward or downward in frequency, such that the carrier frequency is changed from to a new value This requirement is accomplished by using a *mixer*. As depicted in Fig. 3.21, the mixer is a functional block that consists of a product modulator followed by a band-pass filter.

Depending on whether the carrier frequency is to be translated upward or downward, we may now identify two different situations:

(i) *Up conversion*. In this form of mixing, the translated carrier frequency, denoted by f2, is greater than the incoming carrier frequency f1. The required local oscillator frequency is therefore defined by

Let f_l = local osc. freq.
carrier freq. of modulated s/g i/p is changed by an amount equal to f_l

ie, $f_2 = f_1 + f_l$

$$\boxed{f_l = f_2 - f_1} \Rightarrow \text{Assuming } f_2 > f_1 \text{ (translation is upwards)}$$

(ii) *Down conversion*. In this second form of mixing, the translated carrier frequency f2 is smaller than the incoming carrier frequency f1 as shown by

If $f_2 < f_1 \Rightarrow \boxed{f_l = f_1 - f_2} \Rightarrow$ translation is downward.

$$s'(t) = s_1(t)\, A_l \cos(2\pi f_l t)$$

$$= m(t) \cdot A_c \cos(2\pi f_1 t)\, A_l \cos(2\pi f_l t)$$

$$= \frac{m(t) A_l \cancel{A_c}}{2} \left[\cos 2\pi (f_1 + f_l)t + \cos 2\pi (f_l - f_1)t \right]$$

BPF removes unwanted freq & keeps desired one.

Linear operation.

3) Explain the operation of coherent detection of DSBSC modulating wave along with costas loop circuit.

Ans:

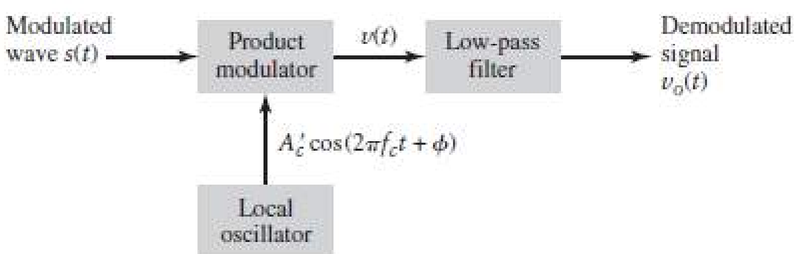


FIGURE 3.12 Block diagram of coherent detector, assuming that the local oscillator is out of phase by ϕ with respect to the sinusoidal carrier oscillator in the transmitter.

→ $m(t)$ can be recovered by multiplying $s(t)$ by locally generated sinusoidal wave & then lowpass filtering the product.

→ Local osc. s/l must be exactly coherent or synchronized both in freq. or phase with ie, coherent detection | synchronous demodulation

$$v(t) = A_c' \cos(2\pi f_c t + \phi)\, s(t)$$

$$= \left[A_c' \cos(2\pi f_c t + \phi)\right]\left[A_c \cos 2\pi f_c t \; m(t)\right]$$

$$= A_c A_c' \cos(2\pi f_c t) \cos(2\pi f_c t + \phi)\, m(t)$$

$$= \frac{1}{2} A_c A_c' \left[\cos(4\pi f_c t + \phi) + \cos\phi\right] m(t)$$

$$= \underbrace{\frac{1}{2} A_c A_c' \cos(4\pi f_c t + \phi)\, m(t)}_{\text{DSB-SC with carrier freq } 2f_c} + \underbrace{\frac{1}{2} A_c A_c' \cos\phi \; m(t)}_{\propto m(t)}$$

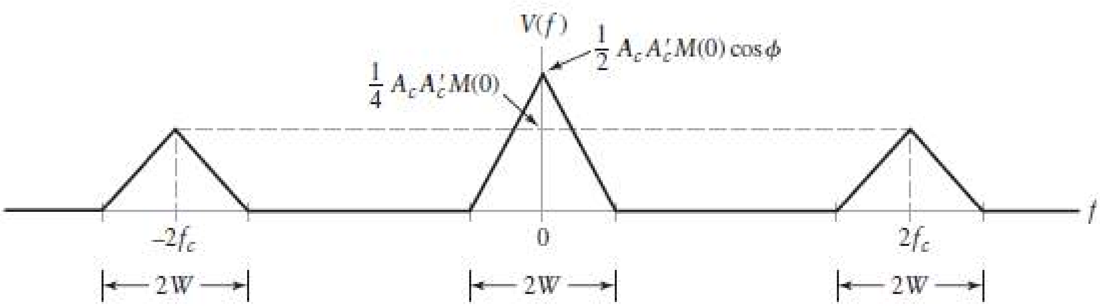


FIGURE 3.13 Illustration of the spectrum of product modulator output $v(t)$ in the coherent detector of Fig. 3.12, which is produced in response to a DSB-SC modulated wave as the detector input.

The first term in the eqn represents a new DSB-SC modulated signal with carrier frequency $2f_c$, whereas the second term is proportional to the message signal m(t).

→ m(t) is band limited to the interval $-W \le f \le W$.

→ First term can be removed by using LPF with cut off freq. $> W$ but less than $2f_c - W$

→ This can be satisfied by choosing $f_c > W$

At the filter o/P, $\boxed{v_o(t) = \frac{1}{2} A_c A_c' \cos\phi\, m(t)}$

$\propto m(t)$

COSTAS RECEIVER

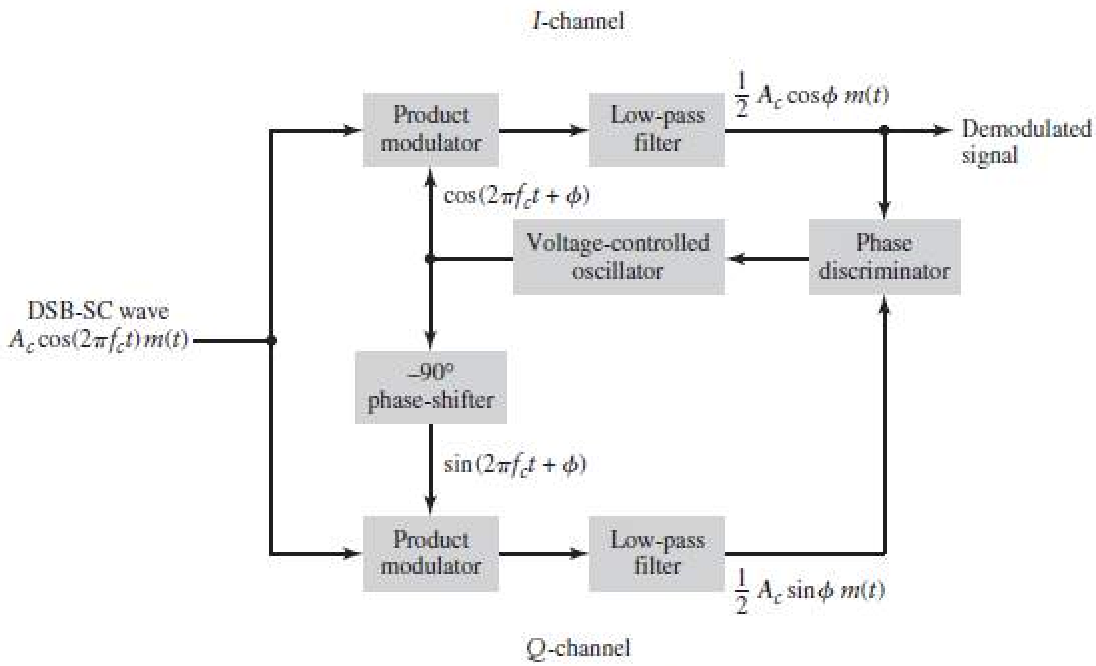


FIGURE 3.16 Costas receiver for the demodulation of a DSB-SC modulated wave.

* The Costas loop is a method of obtaining a practical synchronous receiver system, suitable for demodulating - DSB-SC waves.

* The receiver consists of two coherent detectors supplied with the same I/p signal (DSB-SC wave) $A_c \cos(2\pi f_c t) m(t)$, but with individual local oscillator signals that are in-phase quadrature with respect to each other. (i.e. the local -

oscillator Signal Supplied to the product modulators are 90° out of phase).

* The frequency of the local oscillator is adjusted to be the Same as the carrier frequency 'f_c'.

* The detector in the upper path is referred to as the In-phase Coherent detector or I-Channel and that in the lower path is referred to as the Quadrature-phase Coherent detector or Q-Channel.

* These two detectors are Coupled together to form a Negative Feedback System designed in Such a way as to maintain the local oscillator Synchronous with the Carrier wave.

Operation:-

i) When local oscillator Signal is of the Same phase as the carrier wave $A_c \cos(2\pi f_c t)$ used to generate the incoming DSB-SC wave under these Conditions, the I-Channel o/p contains the desired demodulated Signal $m(t)$, where as Q-Channel o/p is Zero.

$$V_{oI} = \frac{1}{2} A_c m(t) \cos\phi$$

i.e. Whenever the Carrier is Synchronized

$$\phi = 0 \text{ and } \cos\phi = \cos(0) = 1$$

$$\boxed{V_{oI} = \frac{1}{2} A_c m(t)} \quad \text{and}$$

$$\sin\phi = \sin(0) = 0$$

$$\boxed{V_{oQ} = 0}$$

ii) When local oscillator phase changes by a small angle 'ϕ' radians, the I-channel o/p will remain unchanged, but Q-channel produces some o/p which is proportion to $\underline{\sin\phi}$.

The o/p of I and Q-channels are combined in <u>phase-discriminator</u> (which consists of a multiplier followed by a LPF), <u>a dc control</u> signal is obtained that automatically corrects for local phase errors in the voltage controlled-oscillator (VCO).

4) What is VSB modulation? Explain the characteristics of a VSB filter.

Ans:

→ Practical application of SSB to sIls that do not have ely gap at origin leads to <u>VSB</u>

→ One complete side band & a small portion (vestige) of other side band is transmitted.

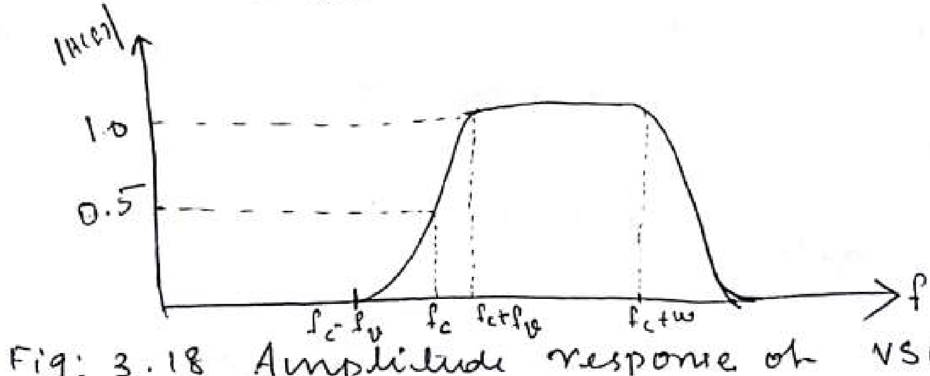


Fig: 3.18 Amplitude response of VSB filter

$$S(f) = U(f)\, H(f)$$
$$= \frac{A_c}{2}\left[M(f-f_c) + M(f+f_c)\right] H(f) \quad \text{---}(1)$$

$v(t) = A_c' \cos(2\pi f_c t)\, s(t)$
($A_c' \cos 2\pi f_c t$ is in sync. with $A_c \cos 2\pi f_c t$)
In freq. domain,
$$V(f) = \frac{A_c'}{2}\left[S(f-f_c) + S(f+f_c)\right] \quad \text{---}(2)$$

Sbtg (1) into (2) $\Rightarrow$
$$V(f) = \frac{A_c' A_c}{2 \times 2}\left\{ (M(f-2f_c) + M(f)) H(f-f_c) + M(f) H(f+f_c) + M(f+2f_c) H(f+f_c) \right\}$$

$\rightarrow$ High freq. components are removed by LPF
$$\therefore V_o(f) = \frac{A_c' A_c}{4}\left\{ M(f) H(f-f_c) + M(f) H(f+f_c) \right\}$$
$$= \frac{A_c' A_c}{4} M(f) \left\{ \underbrace{H(f-f_c) + H(f+f_c)}_{\text{should be } 1} \right\}$$

$-W \leq f \leq W \Rightarrow$
$H(f-f_c) + H(f+f_c) = 2H(f_c)$
$H(f_c) = 1/2 \Rightarrow 2H(f_c) = 1$.
$\therefore H(f-f_c) + H(f+f_c) = 1 \;;\; -W \leq f \leq W$

→ There is a great deal of flexibility in the selection of H(f) to satisfy this condition

$$\therefore \boxed{v_o(t) = \frac{A_c A_c'}{2} m(t)}$$

→ Referring fig. 3.18 ⇒ $|H(f)|_{f=f_c} = 1/2$

→ Cut off portion of freq. response around f_c exhibits odd symmetry.

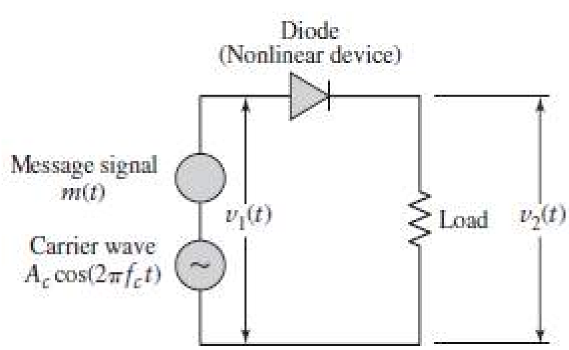
→ Inside the transition interval, $f_c - f_v \le |f| \le f_c + f_v$, the sum of values of $|H(f)|$ at any 2 freq. equally ~~distributed~~ displaced above and below f_c is unity.

→ Width of vestigial sideband = f_v

→ upper cut off portion of H(f) is controlled to exhibit odd symmetry around carrier freq f_c (For VSB s/l containing vestige of upper sideband)

5) Explain the operation of the switching modulator with circuit diagram, and waveform

Ans:



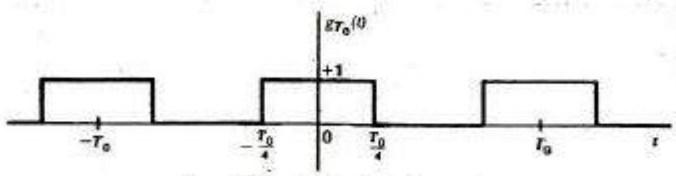


Fig ② Periodic pulse train.

* Consider a Semiconductor diode used as an ideal Switch to which a carrier wave $c(t)$ and an message Signal $m(t)$ are Simultaneously applied as Shown in Fig ①.

* It is assumed that the carrier wave $c(t)$ applied to the diode is large in amplitude.

The total I/p '$V_1(t)$' to the diode is given by

$$V_1(t) = m(t) + c(t)$$

$$\boxed{V_1(t) = m(t) + A_c \cos 2\pi f_c t} \longrightarrow ①$$

Where $|m(t)| \ll A_c$.

* The o/p of the diode is

$$V_2(t) = \begin{cases} V_1(t), & c(t) > 0 \\ 0, & c(t) < 0 \end{cases}$$

i.e. the o/p of the diode varies between 0 & V_1 at a rate equal to carrier frequency $T_0 = \frac{1}{f_c}$.

* The non-linear behavior of the diode can be replaced by assuming the weak modulating Signal compared with the

carrier wave. Thus the o/p of the diode is approximately equivalent to linear - time varying operation.

Mathematically, the o/p of the diode can be written as:

$$V_2(t) = V_1(t).\, g_p(t) \rightarrow (2)$$

$$V_2(t) = \left[m(t) + A_c \cos 2\pi f_c t\right] g_p(t) \rightarrow (3)$$

Where $g_p(t)$ (fig②) is a rectangular pulse train with a period equal to $T_0 = 1/f_c$.

Representing $g_p(t)$ by its Fourier Series, we have

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

$$g_p(t) = \frac{1}{2} + \underbrace{\frac{2}{\pi} \cos 2\pi f_c t}_{n=1} + \text{odd harmonic components} \rightarrow (4)$$

Substituting equation (4) in equation (3)

$$V_2(t) = \left[m(t) + A_c \cos 2\pi f_c t\right]\left[\frac{1}{2} + \frac{2}{\pi} \cos 2\pi f_c t + \cdots\cdots\right]$$

$$V_2(t) = \frac{1}{2} m(t) + \frac{2m(t)}{\pi} \cos 2\pi f_c t + \frac{A_c}{2} \cos 2\pi f_c t + \underline{\frac{2A_c}{\pi} \cos^2 2\pi f_c t} + \cdots\cdots$$

W.K.T $\boxed{\cos^2\theta = \frac{1}{2} + \frac{\cos 2\theta}{2}}$

$$V_2(t) = \frac{m(t)}{2} + \frac{2m(t)}{\pi} \cos 2\pi f_c t + \frac{A_c}{2} \cos 2\pi f_c t + \frac{2A_c}{\pi}\left[\frac{1}{2} + \frac{\cos 2[2\pi f_c t]}{2}\right]$$

$$V_2(t) = \frac{m(t)}{2} + \frac{2m(t)}{\pi} \cos 2\pi f_c t + \frac{A_c}{2} \cos 2\pi f_c t + \frac{\cancel{2}A_c}{\cancel{2}\pi} + \frac{\cancel{2}A_c \cos 4\pi f_c t}{\cancel{2}}$$

$$V_2(t) = \frac{m(t)}{2} + \frac{2m(t)}{\pi} \cos 2\pi f_c t + \frac{A_c}{2} \cos 2\pi f_c t + \frac{A_c}{\pi} + A_c \cos 4\pi f_c t + \cdots \rightarrow (5)$$

* The required AM wave centred at f_c is obtained by passing '$V_2(t)$' through an ideal 'BPF' having a centre frequency 'f_c' and bandwidth $B_T = 2W$ Hz.

* The o/p of the BPF is

$$V_2'(t) = \frac{2}{\pi} m(t) \cos 2\pi f_c t + \underline{\frac{A_c}{2} \cos 2\pi f_c t}.$$

$$V_2'(t) = \frac{A_c}{2} \cos 2\pi f_c t \left[1 + \frac{2 \cdot 2}{\pi A_c} m(t) \right]$$

$$= \frac{A_c}{2} \cos 2\pi f_c t \left[1 + \frac{4}{\pi A_c} m(t) \right]$$

Where $K_a = \frac{4}{\pi A_c}$ amplitude Sensitivity

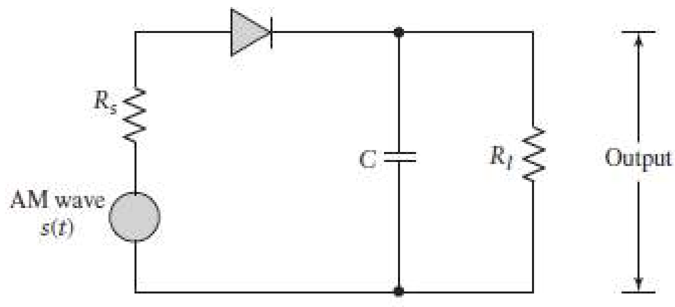
$$\boxed{V_2'(t) = \frac{A_c}{2} \cos 2\pi f_c t \left[1 + K_a m(t) \right]}$$

5 b) Describe the operation of envelope detector with neat diagrams and waveforms. Bring out the significance of RC time constant of the circuit in detection of message signal without distortion

Ans:

* Envelope detector is a simple and highly effective device used to demodulate AM wave. It consists of a <u>diode</u> and a <u>resistor capacitor (RC) filter.</u>

During positive half cycle of the I/p signal, diode is forward-biased and the capacitor 'C' charges upto the peak-value of the I/p signal. When the I/p voltage falls below this value the diode becomes reverse biased and capacitor



(a)

'c' discharges slowly through the load resistor R_L. As a result only positive half cycle of AM wave appears across R_L.

The discharging process continues until the next positive half cycle. When the I/p signal becomes greater than the voltage across the capacitor, the diode conducts again and the process is repeated.

Selection of the RC time constant :-

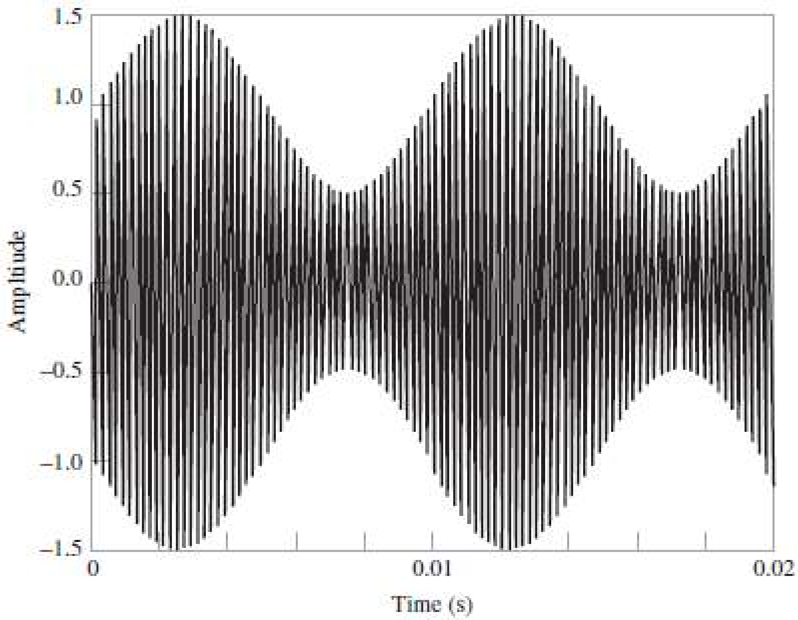
* The capacitor charges through 'D' & R_s when the diode is 'ON' & it discharges through 'R_L' when diode is OFF.

* The charging time constant R_sC should be short as compared to the carrier period $1/f_c$ $\therefore$ $\boxed{R_sC \ll \frac{1}{f_c}}$ So capacitor 'c' charges rapidly.
* on the other hand the discharging time constant R_LC should be long enough to ensure that the capacitor discharges slowly

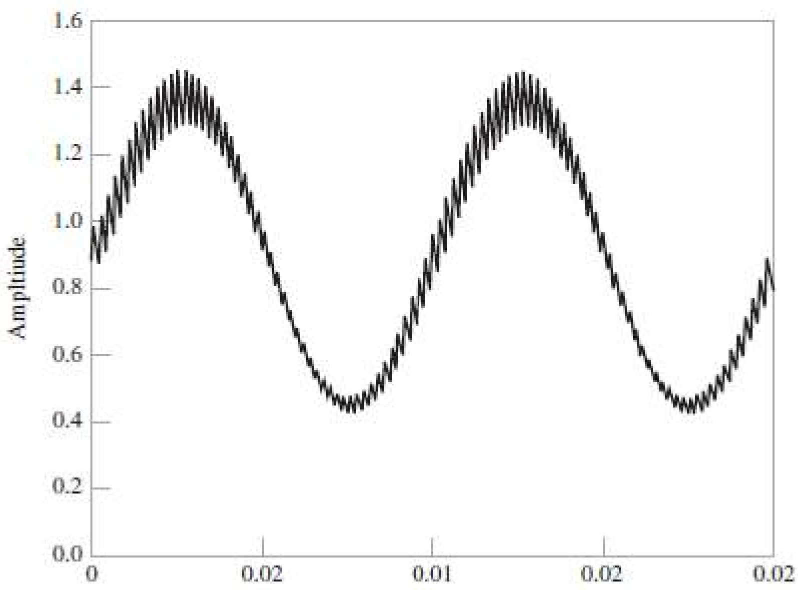
through the load resistance 'R_L' b/w the peak of the carrier wave

i.e. $\boxed{\frac{1}{f_c} \ll R_L C \ll \frac{1}{W}}$, Where W = Maximum modulating frequency.

Result is that the capacitor voltage or detector o/p is very nearly the same as the envelope of AM wave. The detector



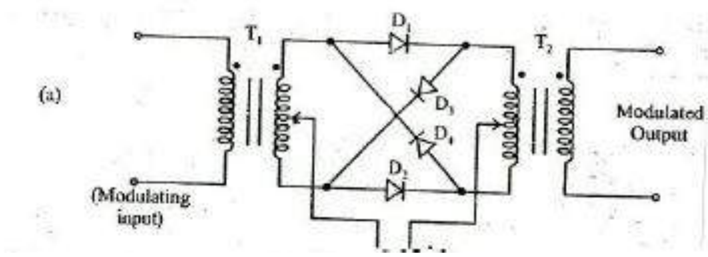
(b)

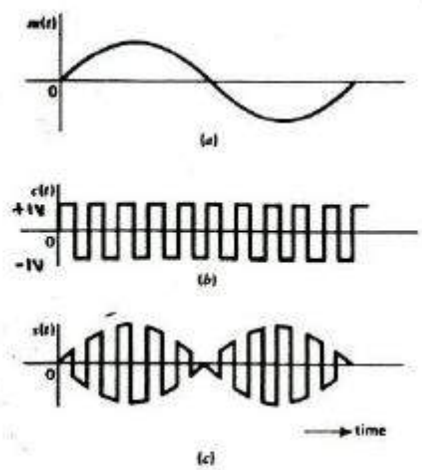


o/p usually has a small ripple at the carrier frequency. This ripple is easily removed by <u>Low pass filter</u>.

6 a) Discuss briefly, the operation of the ring modulator with circuit diagram and relevant waveforms.

Ans:





Ring modulator is a product modulator used for generating DSB-SC modulated wave. The ring modulator consists of :-

1) I/p transformer 'T_1'
2) o/p transformer 'T_2'
3) Four diodes connected in a bridge circuit (Ring)

The carrier amplitude 'A_c' is greater than the modulating

Signal amplitude 'A_m' i.e. $A_c > A_m$ and Carrier frequency 'f_c' is greater than modulating Signal 'f_m' $= W$ i.e. $f_c > W$. These Conditions ensures that the diode operation is controlled by $c(t)$ only.

* The diodes are controlled by a Square Wave carrier $c(t)$ of frequency 'f_c' which is applied by means of two center-tapped transformer.
* The modulating Signal $m(t)$ is applied to the I/p transformer 'T_1'. The o/p appears across the Secondary of the transformer 'T_2'.

operation :-

i) When the Carrier is +ve, the diodes D_1 & D_2 are forward-biased and diodes D_3 & D_4 are reverse biased. Hence the modulator multiplies the message Signal $m(t)$ by $+1$ i.e. $V_0(t) = m(t)$.

ii) When the Carrier is -ve, the diodes D_3 & D_4 are forward biased whereas D_1 & D_2 are reverse biased. Thus the modulator multiplies the message Signal $m(t)$ by -1 i.e. $V_0(t) = -m(t)$.

* The Square wave carrier $c(t)$ can be represented by a Fourier Series as:

$$c(t) = \frac{4}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos\left[2\pi f_c t (2n-1)\right]$$

$$c(t) = \frac{4}{\pi}\Big[\underbrace{\cos 2\pi f_c t}_{n=1} - \underbrace{\frac{1}{3}\cos 6\pi f_c t}_{n=2} + \cdots\cdots\Big] \rightarrow (1)$$

The ring modulator o/p is

$$s(t) = c(t)\cdot m(t) \rightarrow (2)$$

Substituting equation (1) in equation (2), we get

$$s(t) = \Big[\frac{4}{\pi}\cos 2\pi f_c t - \frac{4}{3\pi}\cos 6\pi f_c t + \cdots\Big]\, m(t)$$

$$s(t) = \frac{4}{\pi} m(t) \cos 2\pi f_c t - \frac{4}{3\pi} m(t) \cos 6\pi f_c t + \cdots\cdots\Big] \rightarrow (3)$$

{ Taking Fourier transform on both sides of equation (3), we get

$$S(f) = \frac{\cancel{4}^{\,2}}{\cancel{2}\pi}\Big[M(f-f_c)+M(f+f_c)\Big] - \frac{\cancel{4}^{\,2}}{\cancel{2}\times 3\pi}\Big[M(f-3f_c)+M(f+3f_c)\Big]$$

$$\boxed{S(f) = \frac{2}{\pi}\Big[M(f-f_c)+M(f+f_c)\Big] - \frac{2}{3\pi}\Big[M(f-3f_c)+M(f+3f_c)\Big]}$$

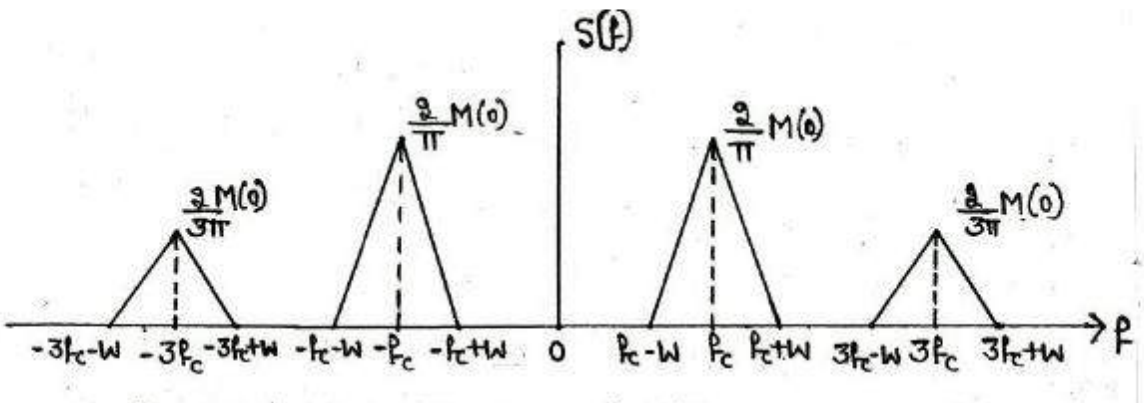


Fig : Amplitude Spectrum of S(f).

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* The DSB-SC wave is extracted from S(t) by passing equation ③ (S(t)) through an Ideal BPF having centre frequency 'f_c' and bandwidth equal to 2W Hz.

The o/p of the BPF is

$$\boxed{S(t) = \frac{4}{\pi} m(t) \cos 2\pi f_c t}$$

6 b) A carrier signal $c(t) = 10\cos(2\pi 10^6\, t)$ is modulated by a message signal $m(t) = 2\cos(8\pi\, 10^3\, t)$ to generate a DSB SC signal. Sketch the spectrum and calculate the bandwidth, power and modulation efficiency.

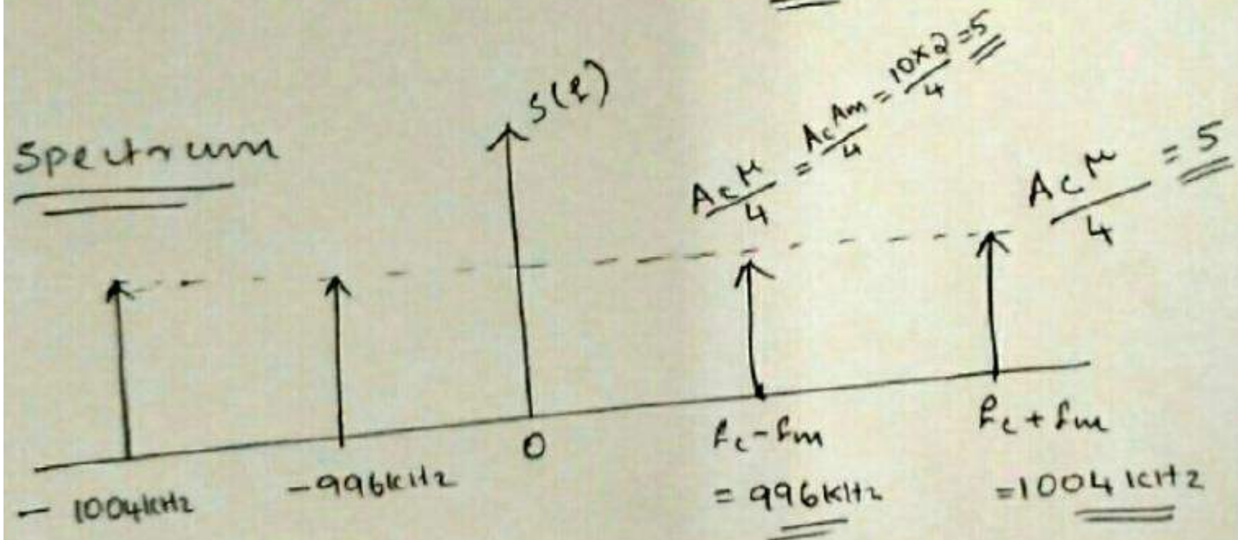
Ans:

Given $c(t) = 10\cos(2\pi 10^6 t)$

$m(t) = 2\cos(8\pi 10^3 t)$

$A_c = 10V$ $\quad A_m = 2V$ $\quad f_c = 10^6 Hz = \underline{1000 kHz}$ $\quad f_m = \underline{4 kHz}$

Spectrum



Band width $= 2 \times$ Max. freq. of msg s/l

$= 2 \times 4 \times 10^3$

$= \underline{8\ \text{kHz}}$

Power $= \dfrac{A_c^2 A_m^2}{4} = \dfrac{10^2 \times 2^2}{4} = \underline{100\text{W}}$ $(\because R = 1\Omega)$

Modulation efficiency, $\eta = \dfrac{P_{SB}}{P_T} = \dfrac{P_{SB}}{P_{SB}} = 1 \Rightarrow \underline{100\%}$

$\underline{\eta = 100\%}$

1) A modulating signal given by $m(t) = 2\sin(1000\pi\ t)$ amplitude modulates a carrier given by c $(t) = 10\sin(2\pi\ \ 10^6\ t)$ with a modulation index of 0.5. Find:

a) Frequencies present in the modulated signal
b) Amplitude of each side band.
c) Bandwidth required.
d) Total transmitted power before and after modulation
e) Sketch the spectrum

Ans:

Given $m(t) = 2\sin(1000\pi t)$

$c(t) = 10 \sin(2\pi 10^6 t)$ $\mu = 0.5$

$\therefore A_m = 2\text{V}$ $A_c = 10\text{V}$ $2\pi f_m = 1000\pi$ $\therefore f_m = \underline{500\ \text{Hz}}$ $2\pi f_c = 2\pi \times 10^6$ $\therefore f_c = \underline{10^6\ \text{Hz}}$

General equ of AM =>

$s(t) = A_c(1 + k_a m(t)) \cos 2\pi f_c t$. (Here, $\sin 2\pi f_c t$)

But, $m(t) = 2 \sin(1000\pi t)$

$\therefore s(t) = A_c(1 + k_a \times 2 \sin 2\pi(500)t) \sin 2\pi f_c t$

a, Frequencies present in the modulating s/l

$f_c = 10^6 Hz = 1000 kHz$

$f_c + f_m = 1000.5 kHz$

$f_c - f_m = 999.5 kHz$

b, Amplitude of each side band

For single tone AM, side band amp $= \frac{A_c \mu}{2}$

$= \frac{10 \times 0.5}{2}$

$= 2.5 V$

c, $BW = 2 \times$ Max. freq of msg s/l

$= 2 \times 500$

$= 1 kHz$

d, Total transmitted power before mod $= \frac{A_c^2}{2}$

$$= \frac{100}{2} = \underline{\underline{50W}}$$

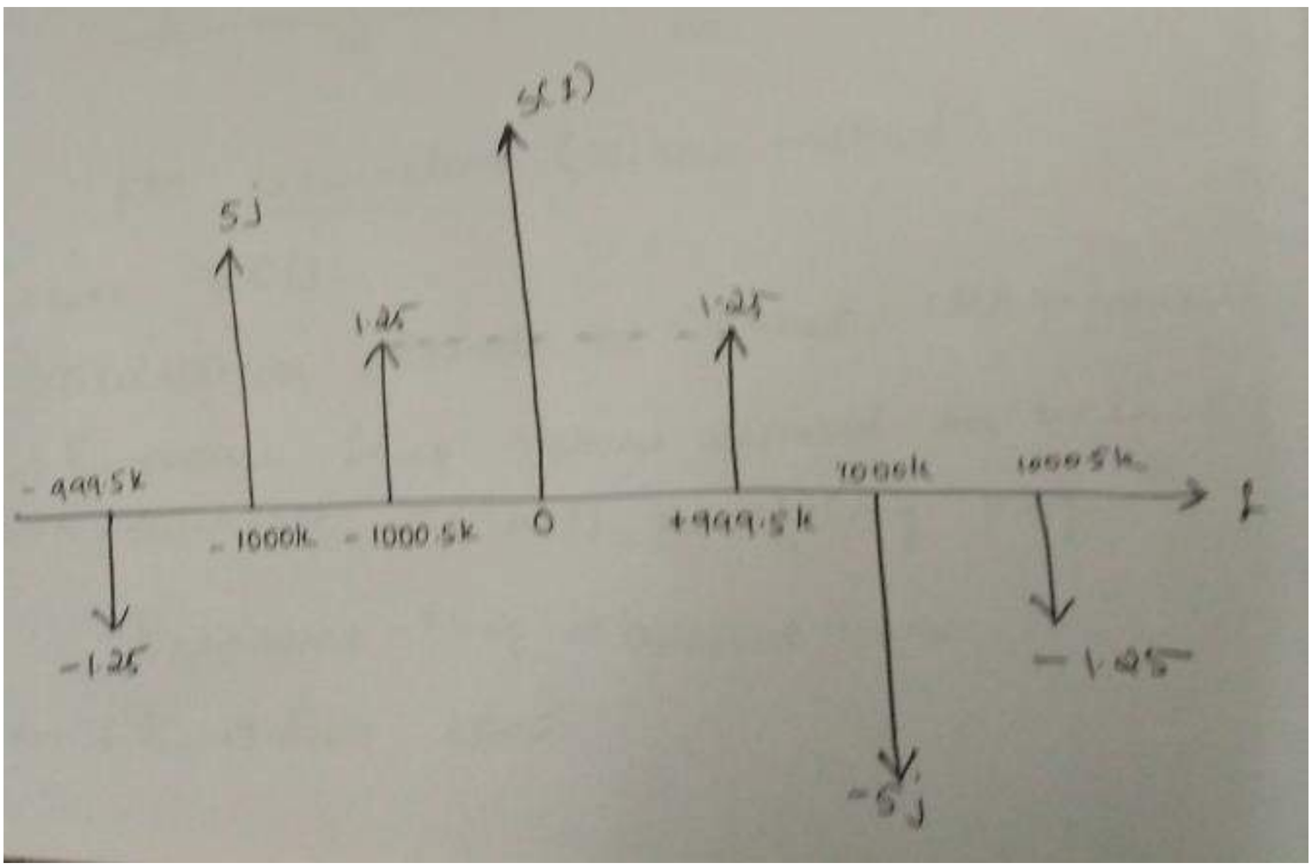
Total transmitted power after mod $= \frac{A_c^2}{2}\left(1 + \frac{\mu^2}{2}\right)$

$$= \frac{10^2}{2}\left(1 + \frac{0.5^2}{2}\right)$$

$$= 50\left(1 + \frac{0.25}{2}\right)$$

$$= \underline{\underline{56.25W}}$$

25V



(spectrum)