LECTURE #08_ TOPIC 03 (PART-I)

3.2.4 Amplitude Modulation Techniques :—

Amplitude Modulation in short form is also referred as AM. Various AM Schemes are as follows.

3.2.4.1 DSB-AM or DSB-Full Carrier
3.2.4.2 DSB_SC
3.2.4.3 SSB_SC
3.2.4.4 VSB.

Where DSB stands for Double Side Band; SC stands for Suppressed Carrier, SSB stands for Single-Side band and finally VSB stands for Vestigial Side band. These four modulation schemes shall be discussed one by one.

3.2.4.1 DSB_AM (Double side band_ Amplitude Modulation) Scheme or DSB_FC (Double Side band_ Full Carrier) Scheme.

Definition :- Amplitude Modulation is a modulation scheme where the amplitude of a carrier is varied linearly according to the message baseband signal m(t).

We can show this technique by assuming a baseband signal m(t) and a carrier $V_c(t)$. Thus suppose

<u>m(t)</u> is the baseband signal. It is also called the modulating (message) signal. As discussed in earlier lecture #07, m(t) can be single-tone or Multi-tone or more realistically any arbitrary non periodic signal.

$$\boxed{V_c(t) = A_c \cos(2\pi f_c)t} \quad \text{--- (1)}$$

This represents a carrier of amplitude A_c, frequency f_c & phase zero.

$V_c(t)$ is also called the un-modulated carrier. Thus according to the definition the baseband message signal $m(t)$ is used to Amplitude Modulate $V_c(t)$ so that carrier amplitude A_c varies according to message signal $m(t)$ while its carrier frequency f_c is not changed. Similarly we can get frequency Modulation (FM) if A_c is fixed, phase φ is fixed but f_c is varied according to $m(t)$. And if A_c is fixed, f_c is fixed but φ is varied then this is called Phase Modulation.

Thumbs rule 3.4

Let Carrier be $V_c(t) = A_c \cos(2\pi f_c t + \varphi)$

AM → A_c changed by $m(t)$
f_c fixed
φ fixed.

PM – φ changed by $m(t)$;
A_c fixed.
f_c fixed

FM – f_c Changed by $m(t)$
A_c fixed.
φ fixed

Since in all the above Analog Modulation techniques $m(t)$ message signal is used for changing <u>one</u> of the attributes of $V_c(t)$ carrier hence $m(t)$ is called the modulating signal.

Before Modulation $V_c(t)$ is called unmodulated carrier. After Modulation $V_c(t)$ is called to be modulated carrier.

Mathematically an Amplitude Modulated (AM) signal can be represented as:

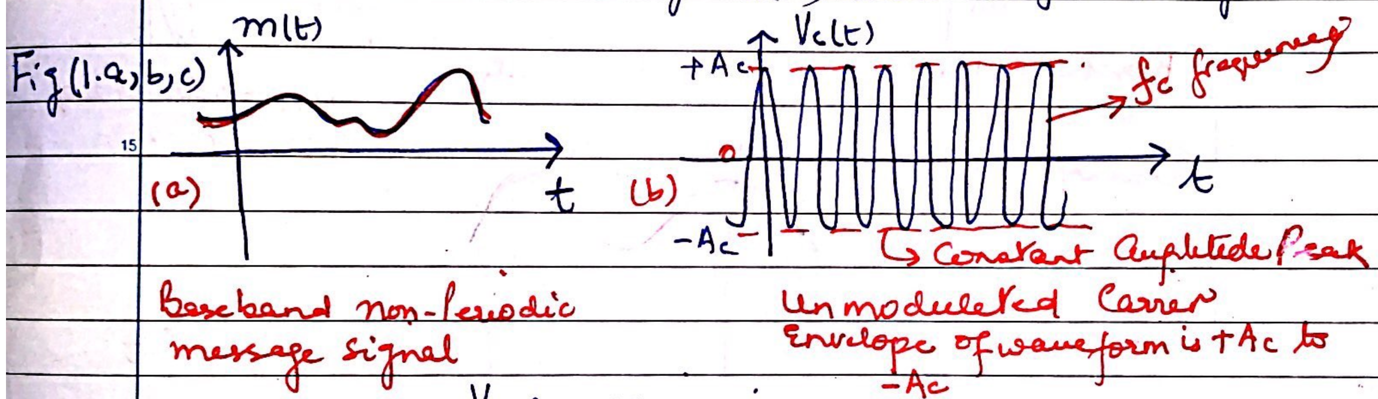
$$V_{AM-Full\ Carrier} = (\text{Baseband Signal})\ \text{Carrier} + \text{Carrier}$$

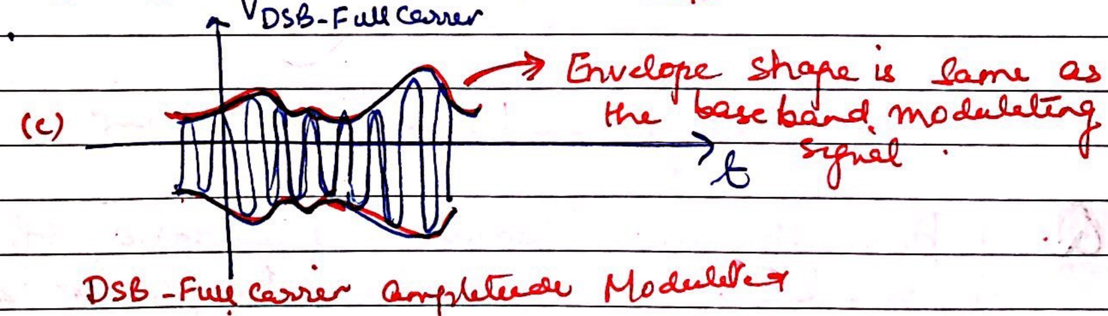
or $$V_{DSB-Full\ carrier} = (m(t)\, A_c \cos\omega_c t) + A_c \cos\omega_c t$$

$$\boxed{V_{DSB-Full\ Carrier} = A_c\,(m(t)+1)\cos(2\pi f_c)t} \quad \text{—— (2)}$$

Following illustration shows DSB-full carrier signal in time domain. See Figures (1.a) below & Fig (1.b) & Fig (1.c)

Fig (1.a, b, c)





DSB-Full carrier Amplitude Modulated Carrier.

The above figure (1.a, b, c) shows illustration of DSB-Full carrier Amplitude modulated signal in time domain where m(t) is an arbitrary signal & is non-periodic.

Another example can be used to explain this DSB-Full carrier modulation scheme where we assume that m(t) is a single-tone message signal

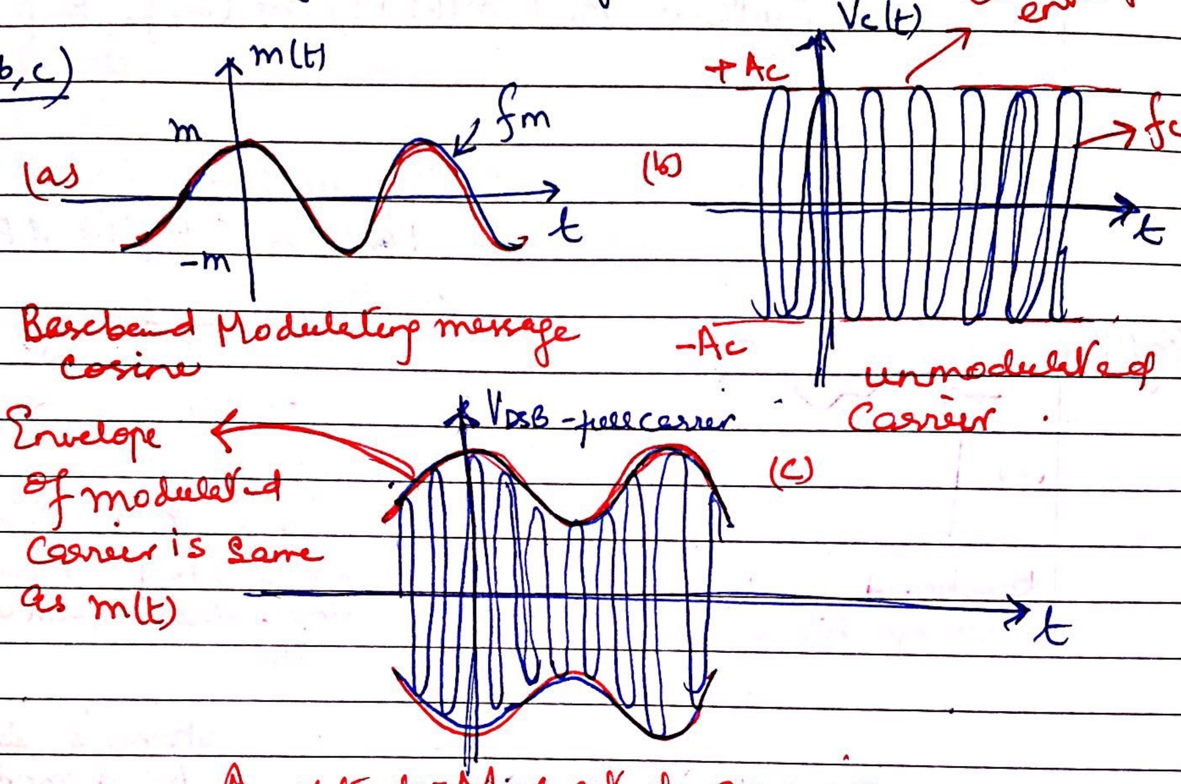
Let $m(t) = m\cos(2\pi f_m)t$ — ③

where $\boxed{m = A_m/A_c}$ — ④

and $f_m \gg f_c$.

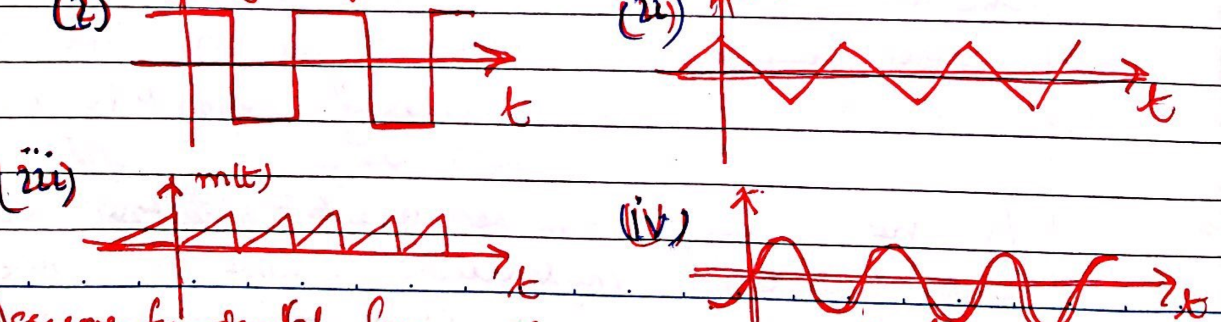
The DSB-Full carrier signals are shown in time domain as follows in Fig(2.a,b,c)

Fig(2.a,b,c)



Amplitude-Modulated carrier

Q. Draw the time domain illustration of Modulating base band signal, Unmodulated Carrier & the resulting modulated (AM) carrier for the following modulating signal waveforms



Assume fundamental frequency of each waveform is $f_m \ll f_c$

Q. Why is a DSB-Full Carrier signal prone to influence of distortion and Noise picked up in the circuitry or the Communication channel?

or

Why does a DSB-Full Carrier signal get easily distorted by such influences?

or

Why is a DSB-Full carrier signal more sensitivity to noise & distortion?

The answer to above question is obtained by observing any example illustrations in time domain of a DSB-full carrier signal.
e.g. From Fig 1 (a,b,c) the message signal as shown in Fig (1.a) is non periodic & has some amplitude variations. If these amplitude variations of Fig (1.a) is also present in envelope of the modulated carrier then this is an example of distortion free & noise free transmission. Similarly for the cosine message signal of Fig (2.a) same cosine amplitude variations are seen in the envelope of the modulated carrier of Fig (2.c) so this is also an example of noise free & distortion free transmission. Such are ideal cases. Normally noise & distortion interfere with transmission and influence the carrier amplitude easily so that a distorted signal get received
eg. See Figure (3.a) & (3.b) showing such influence

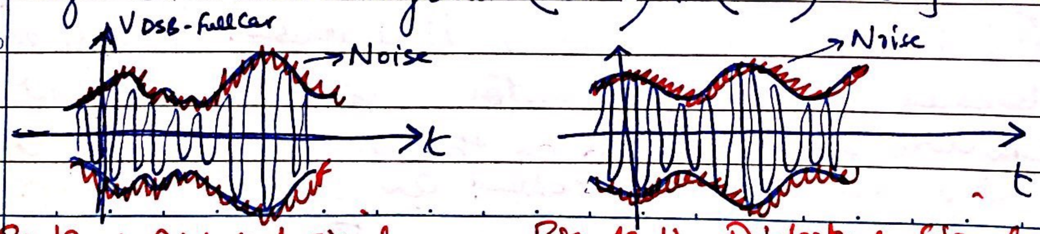


Fig (3.a) Distorted signal of Fig (1.c)

Fig (3.b) Distorted Signal of Fig (2.c)

Modulation Index (m)

The modulation index $\boxed{m = \frac{A_m}{A_c}}$ is the ratio of modulating baseband amplitude to the unmodulated carrier amplitude

For DSB-Full carrier condition to be fulfilled is that

$$\boxed{m \leq 1}$$

or for efficient Amplitude Modulation

$$\boxed{\frac{A_m}{A_c} \leq 1}$$

Otherwise the signal is overmodulated and will result in distorted signal after detection.

Again assume that if m(t) amplitude is written relative to carrier amplitude then

$$m(t) = m \cos(2\pi f_m)t$$

$$V_c(t) = A_c \cos(2\pi f_c)t.$$

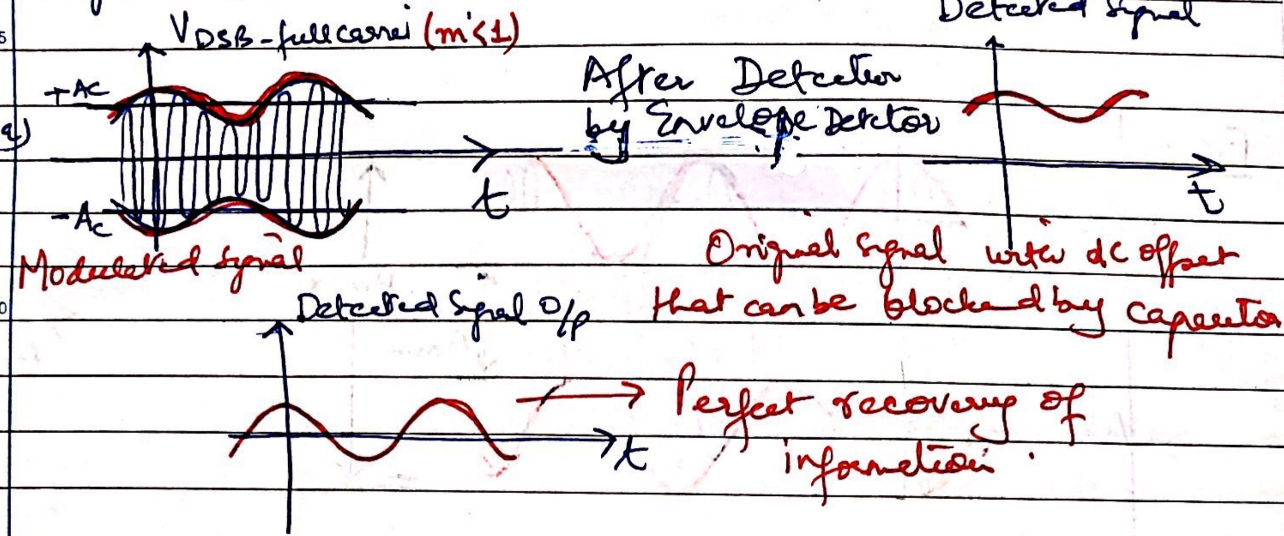
Using Equation (2) on Page 83.

$$\therefore \boxed{V_{DSB\text{-}Full\ Carrier} = A_c\,(1 + m(t)) \cos(2\pi f_c)t} \quad (2)$$

then Figures (4.a) shows modulated carrier when $m < 1$, Fig (4.b) shows modulated carrier when $m = 1$; Fig (4.c) shows overmodulation when $m > 1$, Only permissible condition is $m \leq 1$. This is clear from following illustrations. Problem arises because an envelope detector is used. The output of envelope detector at Rx is the envelope of a modulated signal. That is why it is also called an envelope follower. After removing the dc offset by capacitor $m > 1$ results in totally distorted recovery.

m < 1 : For this condition this means peak amplitude of carrier is greater than peak amplitude of modulating baseband signal. Figure (4.a) show such a case.

Fig (4.a)



m = 1 : For this condition this means that peak carrier amplitude is equal to peak modulating baseband signal amplitude. See Fig (4.b)

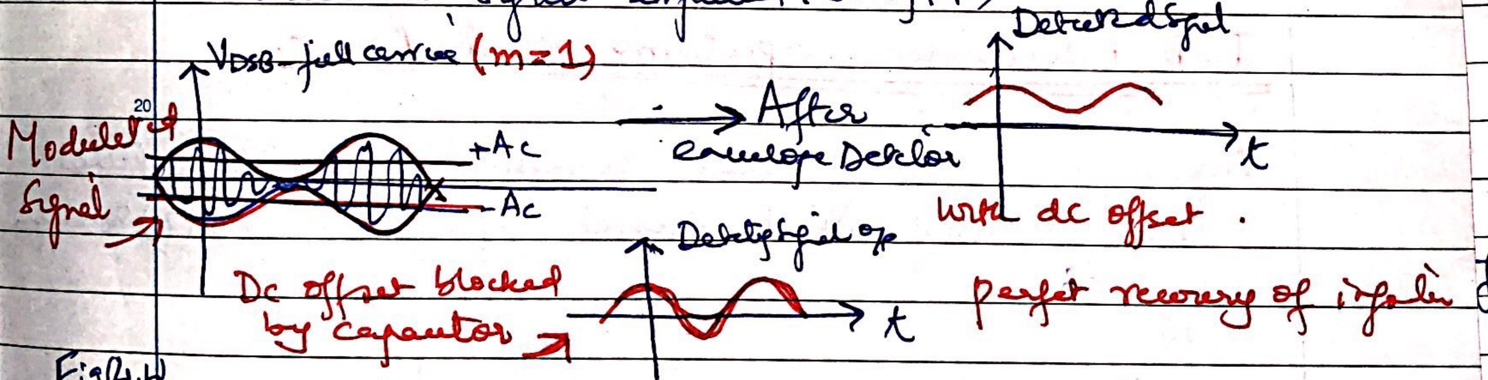
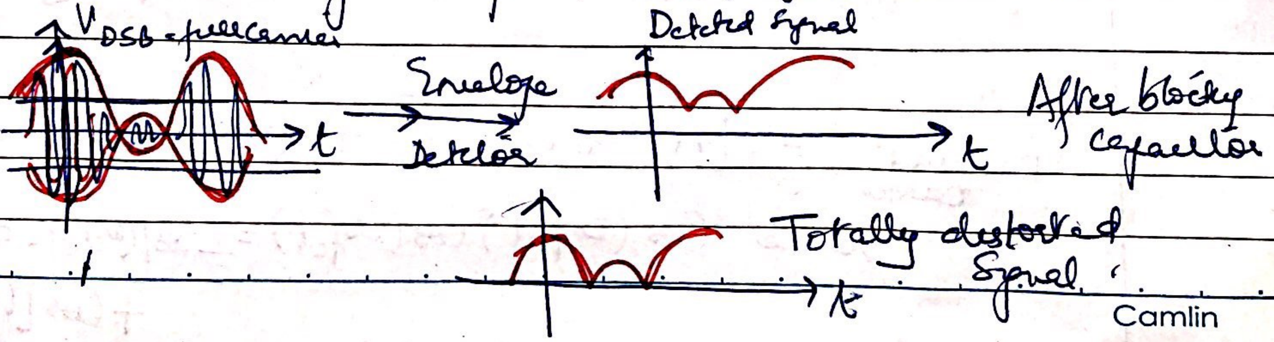


Fig (4.b)

m > 1 : This is called overmodulation where peak carrier amplitude is less than peak baseband signal amplitude. See Fig (4.c)

Fig (4.c)

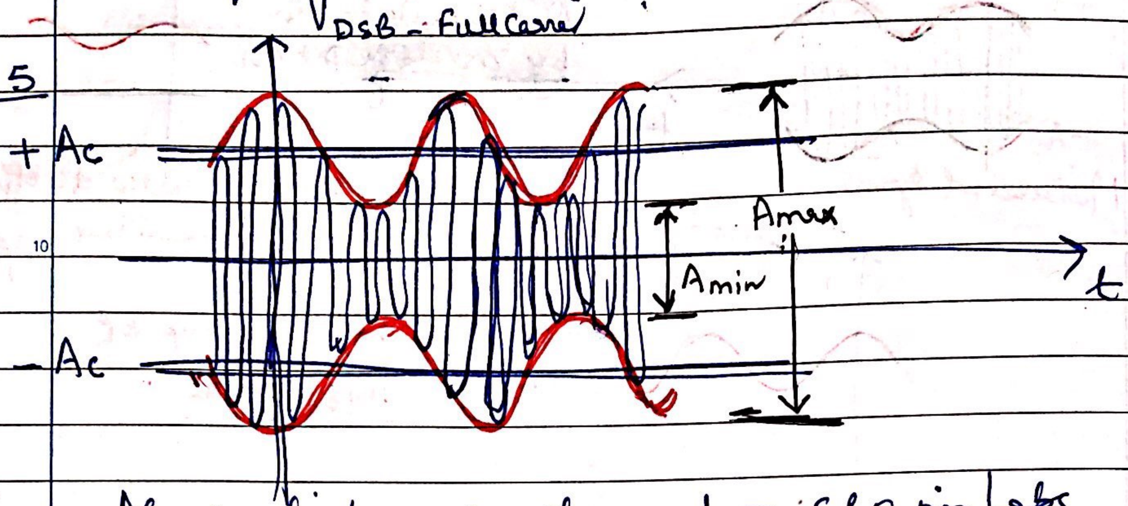


Graphically m is also written as

$$\boxed{m = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}} \quad -④$$

See (figure) 5 below

Fig 5



Above displays are observed on CRO in Labs
This is another way of calculating modulation index by measuring Amax and Amin

DSB - Full Carrier Spectrum and Power.

Again using the general expression for a DSB_ Full Carrier modulated signal of equation no (2) on pg. 83.

$$V_{DSB\text{-}Full\ carrier} = A_c\left[1 + m(t)\right] \cos(2\pi f_c t) \quad -②$$

where $m(t) = m \cos(2\pi f_m)t$.

then

$$V_{DSB\text{-}Full\,Carrier} = A_c\left[1 + m \cos(2\pi f_m)t\right] \cos(2\pi f_c)t \quad -⑤$$

or

$$V_{DSB\text{-}Full\text{-}Carrier} = \left[A_c \cos(2\pi f_c)t\right] + (mA_c)\left[\cos(2\pi f_m t)\cos(2\pi f_c)t\right]$$

Since $\cos(2\pi f_m t)\cos(2\pi f_c t) = \frac{1}{2}\cos\left[(2\pi)(f_c + f_m)t\right] + \cos\left[(2\pi)(f_c - f_m)t\right]$

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On expansion we get

$$\therefore V_{DSB\text{-}Full\,carrier} = \underbrace{A_c \cos(2\pi f_c t)}_{\text{(Carrier)}} + \underbrace{\frac{mA_c}{2}\cos[2\pi(f_c+f_m)t]}_{\text{USB-Compnt}} + \underbrace{\frac{mA_c}{2}\cos[2\pi(f_c-f_m)t]}_{\text{LSB-Compnt}} \quad (6)$$

The frequency Position of each components along with their respective Amplitude gives the Spectrum of the $V_{DSB\text{-}Full\ Carrier}$ Signal.

From Above Equation (6) hence we get the spectrum as follows [See Fig 6].

Fig shows Single sided spectrum

BW = $2f_m$

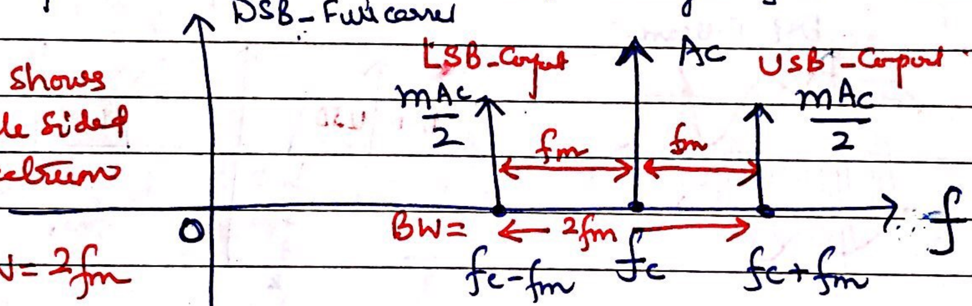


Fig (6) Above shows that the Frequency spectrum of the amplitude Modulated Carrier has three components :- (i) Carrier Component with Amplitude A_c ; (ii) LSB-Component at $f_c - f_m$ (iii) USB-Compnt at $f_c + f_m$.

Carrier Compnt :- Amplitude A_c, Spectral Position f_c

LSB Compnt :- Lower Side band component Amplitude $\frac{mA_c}{2}$ at $f_c - f_m$

USB Compnt :- Upper Side band Compnt Amplitude $\frac{mA_c}{2}$ at $f_c + f_m$

$\therefore$ Amplitude of USB (Upper Sideband) Component = Amplitude of LSB (Lower Sideband) Compnt $= \frac{mA_c}{2}$

Both are Frequency Translated around f_c by $+f_m$ & $-f_m$.

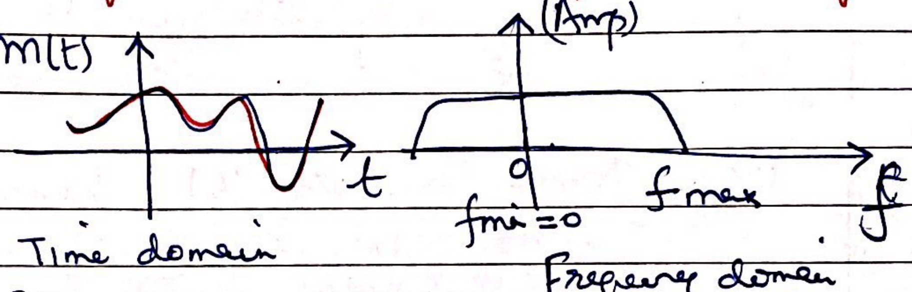
Since BW = Max frequency Component position − Min frequency Compont position

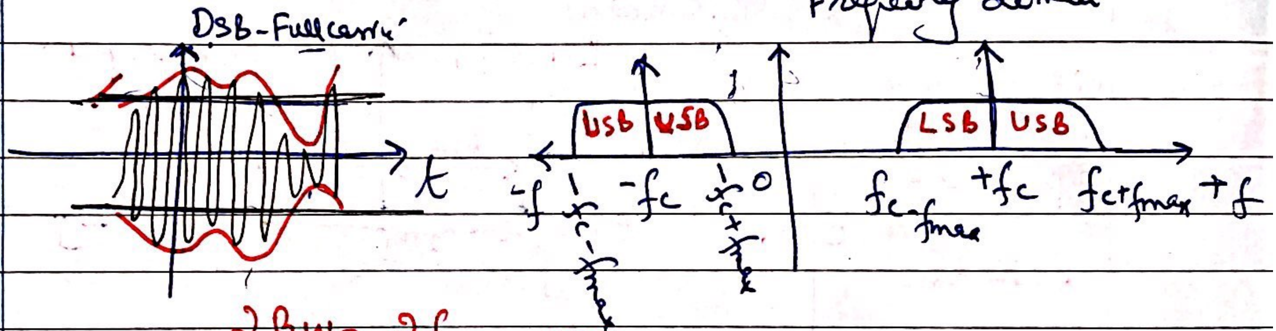
$$\therefore B.W = (f_c + f_m) - (f_c - f_m)$$

$$\therefore \boxed{B.W = 2f_m}$$

Q: Draw the Double sided Spectrum of a DSB-Full carrier modulated signal in case of a non periodic signal

Ans. Assume m(t)





$$2BW = 2f_{max} + 2f_{max}$$

or $\boxed{BW = 2f_{max}}$

Looking closely at the frequency translation around f_c. We can observe that for m(t) where $f_{min} = 0$ & f_{max} = max frequency component then after frequency translation the frequency extension is

$$USB = (f_c + f_{min}) \text{ to } (f_c + f_{max})$$

$$\boxed{USB = f_c + 0 \text{ to } f_c + f_{max}}$$

or $\boxed{USB = f_c \text{ to } f_c + f_{max}}$ on +f side

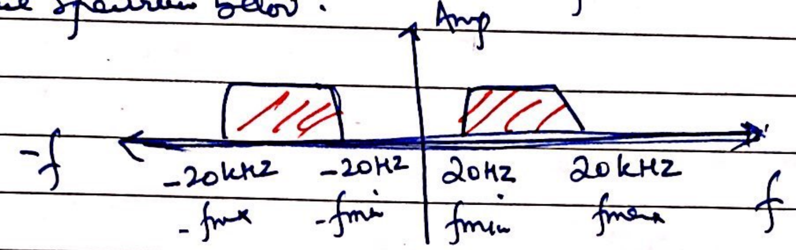
Similarly $LSB = f_c - f_{min}$ to $f_c - f_{max}$

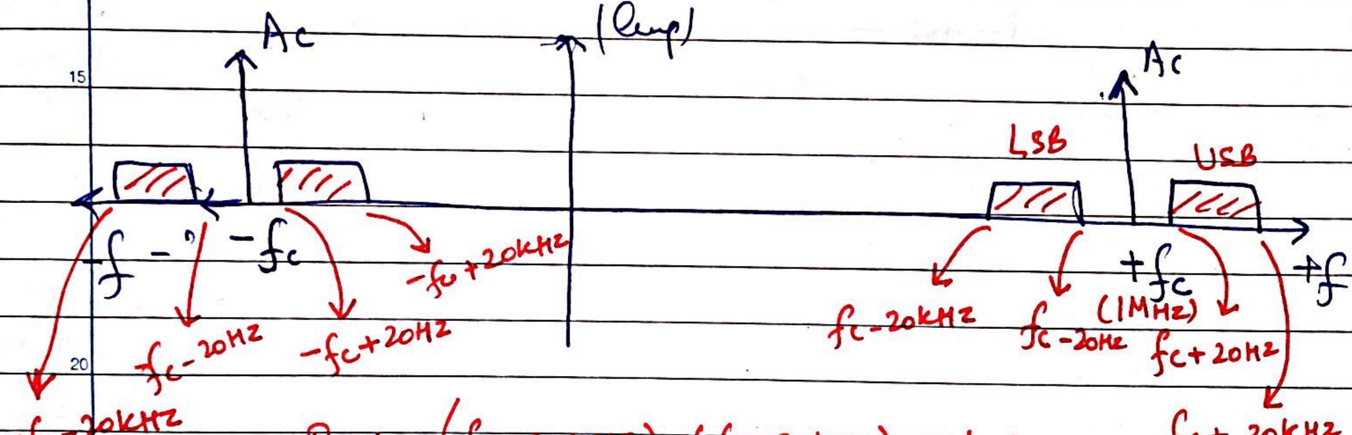
$\therefore LSB = f_c - 0$ to $f_c - f_{max}$ or $\boxed{LSB = f_c \text{ to } f_c - f_{max}}$ on +f side

Q. Draw the double sided Spectrum of a DSB-full carrier for a non-periodic waveform with min frequency component = 20HZ and max Component of freq is 20KHZ. Let the Carrier used for modulation be 1MHZ. Also calculate BW.

Ans. Here for m(t) = $f_{min} = 20HZ$,
$f_{max} = 20KHZ$

Assume Spectrum below.





B.W = $(f_c + 20KHZ) - (f_c - 20KHZ) = 40KHZ$.

On the +f side of the double sided Spectrum the frequency extension of

$USB = (f_c + f_{min})$ to $(f_c + f_{max})$
$= (1MHZ + 20HZ)$ to $(1MHZ + 20KHZ)$.

$LSB = (f_c - f_{min})$ to $(f_c - f_{max})$
$= (1MHZ - 20HZ)$ to $(1MHZ - 20KHZ)$.

Q. Repeat above question if m(t) $f_{min} = 30HZ$ & $f_{max} = 2KHZ$ and $f_c = 100$ KHZ. Draw the spectrum and give frequency range of USB & LSB & Calculate BW.

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DSB - Spectrum and Power (Contd)

Power Relations. Assume again $V_c(t) = A_c \cos(2\pi f_c)t$
and $m(t) = m\cos(2\pi f_m)t$

Again as per Equation (6)

$$V_{DSB\text{-}full carrier} = A_c \cos(2\pi f_c)t \rightarrow \text{Carrier Compnt}$$
$$+$$
$$\frac{mA_c}{2}(2\pi)(f_c+f_m)t \rightarrow \text{USB Compnt}$$
$$+$$
$$\frac{mA_c}{2}(2\pi)(f_c-f_m)t \rightarrow \text{LSB Component.}$$

$\therefore$ Total Trasmitted power is

$$P_{Total} = P_{carrier} + P_{USB} + P_{LSB}.$$

Let the power be radeated across $R = 1\Omega$ then

$$P = \frac{(V_{peak}/\sqrt{2})^2}{R} = \frac{(V_{RMS})^2}{R} = (V_{RMS})^2$$

$\therefore P_{carrier} = (A_c/\sqrt{2})^2$; $P_{USB} = \left(\frac{mA_c}{2}/\sqrt{2}\right)^2$; $P_{LSB} = \left(\frac{mA_c}{2\sqrt{2}}\right)^2$

$$\therefore \boxed{P_{Total} = \underbrace{\left(\frac{A_c}{\sqrt{2}}\right)^2}_{carrier} + \underbrace{\left(\frac{m}{2}\right)^2\left(\frac{A_c}{\sqrt{2}}\right)^2}_{USB} + \underbrace{\left(\frac{m}{2}\right)^2\left(\frac{A_c}{\sqrt{2}}\right)^2}_{LSB}}$$

or $P_{Total} = \left(\frac{A_c}{\sqrt{2}}\right)^2\left[1 + 2\frac{m^2}{4}\right]$

or $\boxed{P_{Total} = P_{carrier}\left[1 + \frac{m^2}{2}\right]}$, where $\boxed{P_{carrier} = \left(\frac{A_c}{\sqrt{2}}\right)^2}$

and $\boxed{P_{USB} = P_{carrier}\left(\frac{m^2}{4}\right)}$ & $\boxed{P_{LSB} = \left(\frac{m^2}{4}\right)P_{carrier}}$

$\therefore P_{USB} = P_{LSB}$

~~At~~ $m = 1$ ie 100% modulation then $P_{Total} = P_{carrier}(1 + 1/2)$

or $P_{Total} = P_{carrier}(3/2)$. $\therefore \boxed{P_{carrier} = 2/3\, P_{Total}}$

and $\boxed{P_{USB} = 1/6\, P_T.}$ & $\boxed{P_{LSB} = \frac{1}{6}P_T}$

Q: What does this all imply?