Lectures 1 & 2

Topics

- Introduction to Modulation
- Amplitude Modulation
- DSB-SC: Modulation & Demodulation
- Nonlinear Modulation

Reference Book

- **Modern Digital and Analog Communication Systems (B. P. Lathi)**

Baseband Communication

Baseband Communication: The term ***baseband*** is used to designate the band of frequencies of the signal delivered by the source. In ***baseband communication***, baseband signals are transferred directly, i.e., without any change in the range of frequencies of the signal.

Modulation/Carrier Communication

Modulation: During modulation, the baseband signal is shifted to a different frequency range using a carrier.

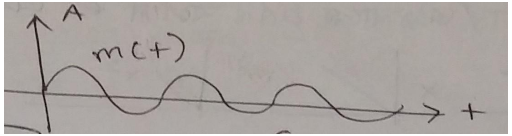
Why do we need modulation?

- To utilize the vast spectrum of frequencies available
- To use all the available bandwidth by modulating several baseband signals and shifting their spectra to non-overlapping bands (using Frequency Division Multiplexing (FDM))
- If the channel is a bandpass filter (cuts off high + low frequencies)
- If the wavelength of the signal to transmit is too large, a larger antenna is needed (length of an efficient antenna= 1/10th of wavelength)

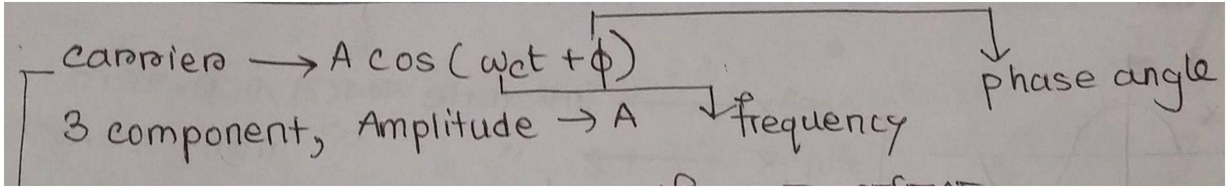
Modulation/Carrier Communication

Carrier Communication: Communication that uses modulation to shift the frequency spectrum of a signal is known as carrier communication

Baseband Signal: m(t)



Carrier:



In baseband communication, m(t) is transmitted directly. In carrier communication, a high frequency carrier will be used. One of the basic parameters of the carrier (amplitude/phase/frequency) will be varied in proportion to the baseband signal m(t).

Types of Modulation

- **Amplitude Modulation**

  The amplitude of the carrier is varied w.r.t m(t)
- **Phase Modulation**

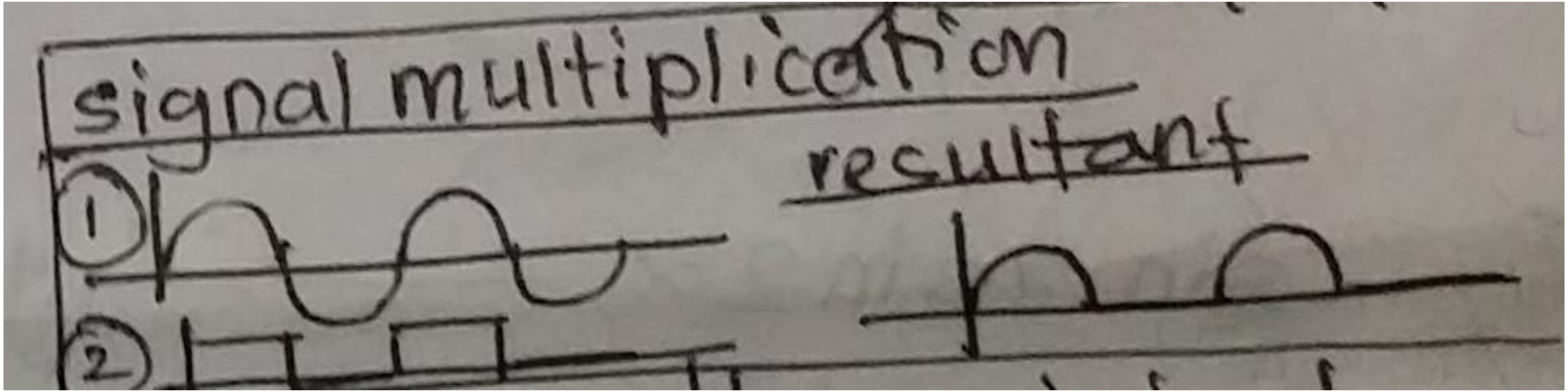
  The phase of the carrier is varied w.r.t m(t)
- **Frequency Modulation**

  The frequency of the carrier is varied w.r.t m(t)

Phase modulation and frequency modulation are similar in nature. Together, they are known as **angle modulation**.

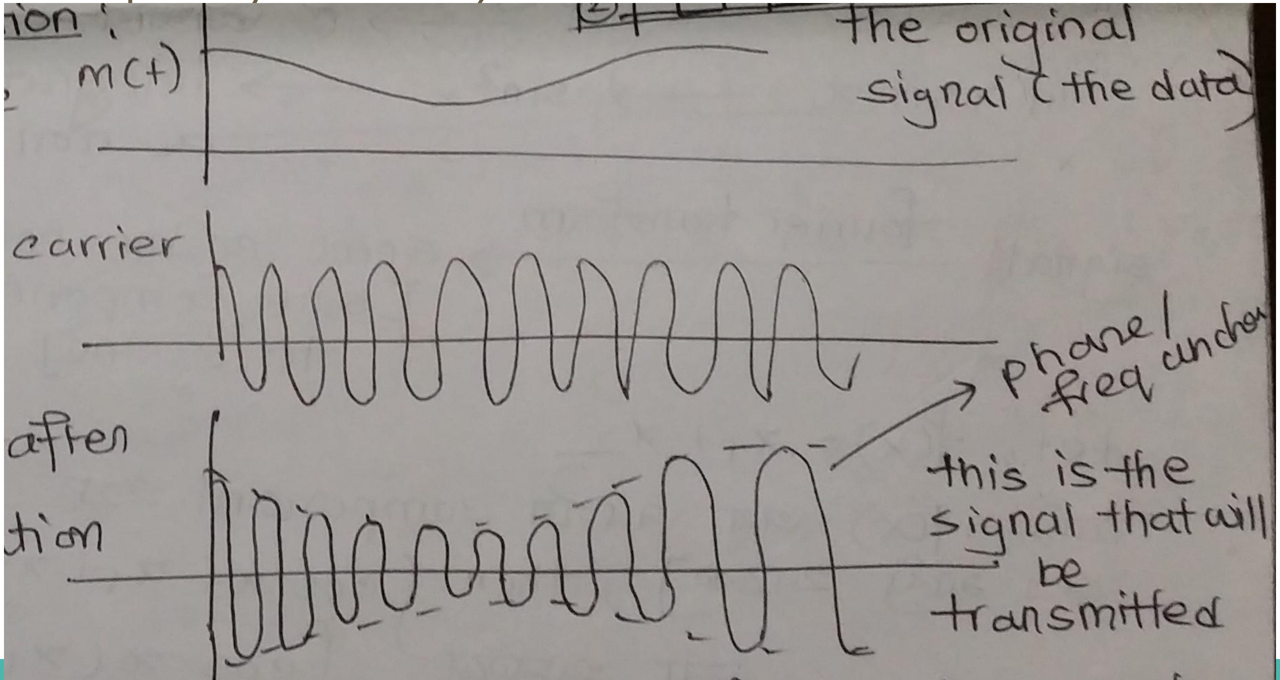
Types of Modulation

- **Signal Multiplication**



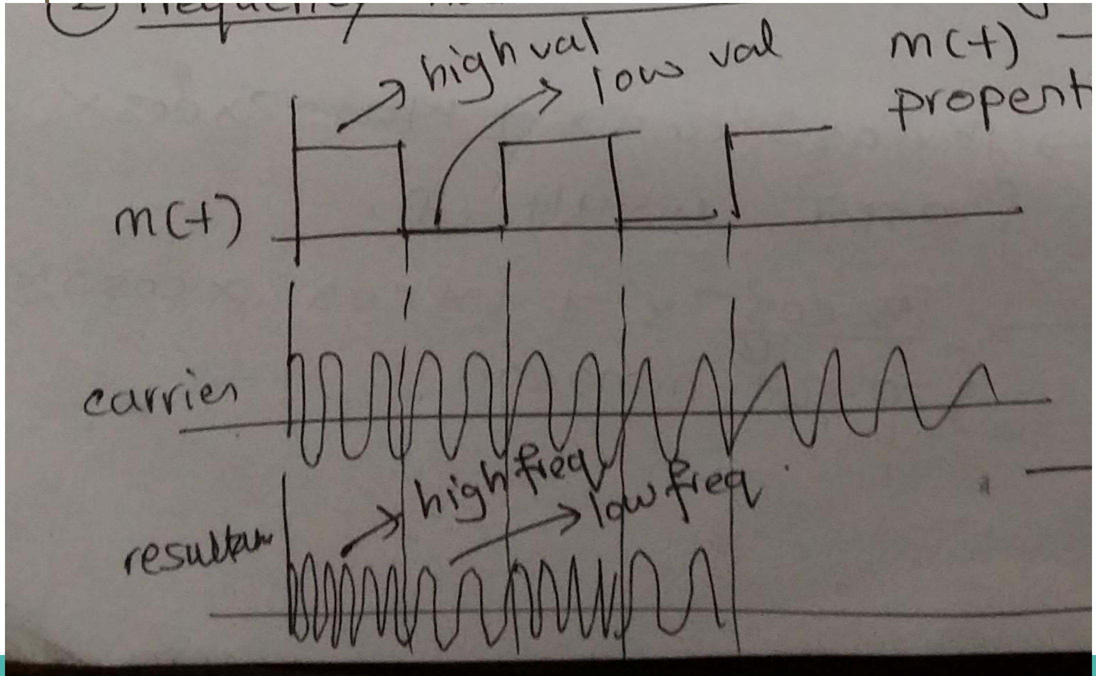
Types of Modulation

- **Amplitude Modulation:** The amplitude of the carrier is varied w.r.t m(t) (phase + frequency constant)



Types of Modulation

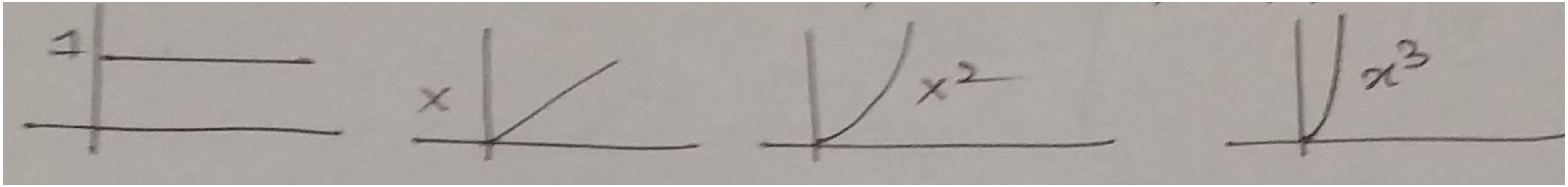
- **Frequency Modulation:** The frequency of the carrier is varied w.r.t m(t) (phase + amplitude constant)



Concept of Fourier Transformation

- A signal can be expressed as the summation of some other signals

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$$



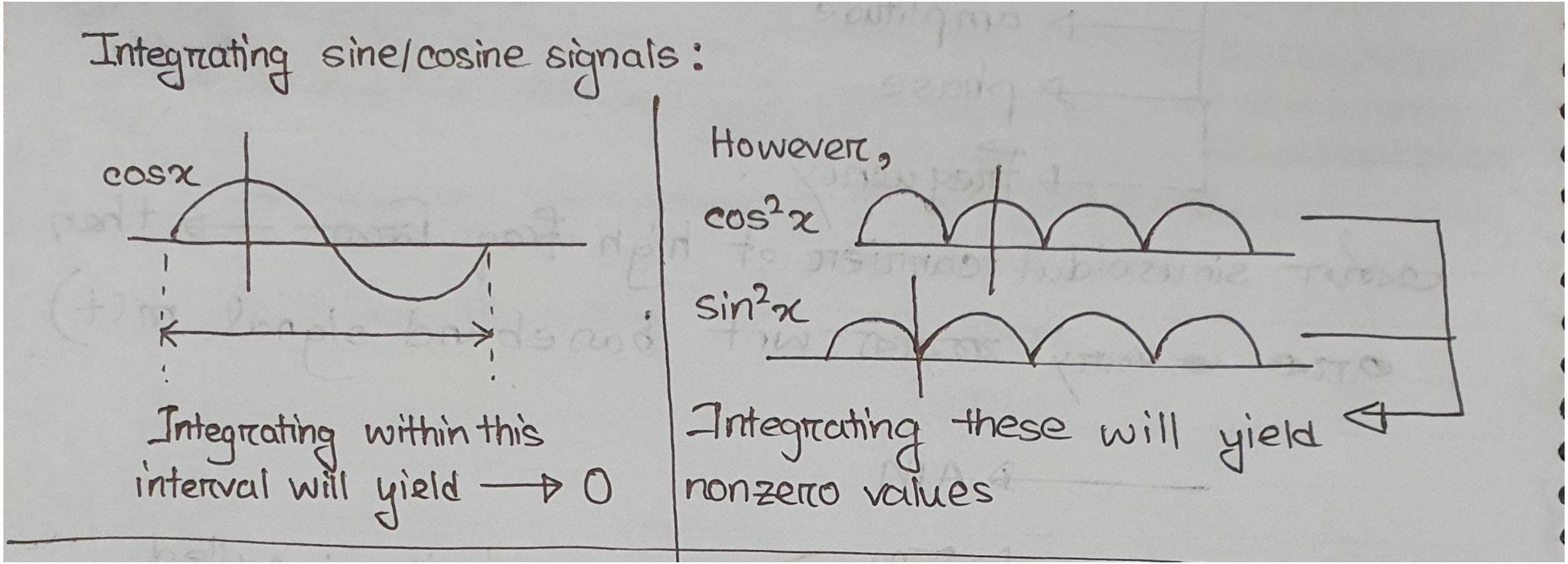
Concept of Fourier Transformation

- Similarly, a signal can be expressed as a summation of sine and cosine components. However, the actual components are unknown.

a non - zero value

signal $\xrightarrow{\text{fourier transform}}$ some cosine components
[sine components can be converted to cosine]

Concept of Fourier Transformation



Concept of Fourier Transformation

$\sin x \sin 2x \longrightarrow$ If integrated within appropriate interval $\longrightarrow 0$

$\sin x \sin x \longrightarrow \sin^2 x \longrightarrow$ Integration will yield a nonzero value

Let,

$$f(x) = x_1 + x_2$$

If $\cos x$ is a component of $f(x)$, then

$$\int \cos x \,(f(x)) \neq 0$$

$$\Rightarrow \int \cos x \,(x_1 + x_2) \neq 0$$

And, if $\cos x$ is not a component of $f(x)$, then

$$\int \cos x \,(x_1 + x_2) = 0$$

Concept of Fourier Transformation

Let, $m(t) = 15\cos 3x + 14\cos 2x$

By applying Brute force :

1. Multiplying with $\cos x$: $15\cos 3x \cos x + 14\cos 2x \cos x$

After integration $\longrightarrow 0$

2. Multiplying with $\cos 3x$: $\underline{15\cos^2 3x} + 14\cos 2x \cos 3x$

This part will yield nonzero result after integration

Now that we already know that $m(t)$ contains $\cos 3x$, we can use this knowledge to find the coefficient of $\cos 3x$.

$$\frac{15\int \cos^2 3x}{\int \cos^2 3x} = 15$$

Amplitude Modulation: DSB-SC

Baseband signal $= m(t)$

$$M(\omega) = \int_{-\infty}^{\infty} m(t)\, e^{-j\omega t}\, dt \quad \& \quad e^{j\theta} = \cos\theta + j\sin\theta$$

Carrier $= A\cos(\omega_c t + \phi)$

For simplification, we will only consider $\cos(\omega_c t + \phi)$

If phase is constant, then we can only use

$$\boxed{\cos\omega_c t}$$

So, the signal to be transmitted is : $m(t)\cos\omega_c t$

Amplitude Modulation: DSB-SC

Now, $e^{j\theta} = \cos\theta + j\sin\theta$

So, $e^{j\omega_c t} = \cos\omega_c t + j\sin\omega_c t$

(+) $e^{-j\omega_c t} = \cos\omega_c t - j\sin\omega_c t$

$$e^{j\omega_c t} + e^{-j\omega_c t} = 2\cos\omega_c t$$

$$\Longrightarrow \cos\omega_c t = \frac{1}{2}\left(e^{j\omega_c t} + e^{-j\omega_c t}\right)$$

Now, the transmitted signal $\Longrightarrow m(t)\cos\omega_c t$

$$= \frac{1}{2} m(t)\left(e^{j\omega_c t} + e^{-j\omega_c t}\right)$$

$$= \underbrace{\frac{1}{2} m(t) e^{j\omega_c t}}_{\text{1st component}} + \underbrace{\frac{1}{2} m(t) e^{-j\omega_c t}}_{\text{2nd component}}$$

Amplitude Modulation: DSB-SC

For the 1st component, if we take Fourier transform ⇒

$$M_1(\omega) = \int_{-\infty}^{\infty} \frac{1}{2} m(t) e^{j\omega_c t} e^{-j\omega t} dt$$

$$= \frac{1}{2} \int_{-\infty}^{\infty} m(t) e^{-j(\omega - \omega_c)t} dt$$

$$= \frac{1}{2} M(\omega - \omega_c)$$

Amplitude Modulation: DSB-SC

For the second component, after taking Fourier transform

$$M_2(\omega) = \frac{1}{2}\int_{-\infty}^{\infty} m(t)\, e^{-j\omega_c t}\, e^{-j\omega t}\, dt$$

$$= \frac{1}{2}\int_{-\infty}^{\infty} m(t)\, e^{-j(\omega+\omega_c)t}\, dt$$

$$= \frac{1}{2} M(\omega+\omega_c)$$

After modulation, $\frac{1}{2} M(\omega-\omega_c) + \frac{1}{2} M(\omega+\omega_c)$

Amplitude Modulation: DSB-SC

Demodulation:

$$m(t)\cos\omega_c t \times \cos\omega_c t$$

$$= m(t)\cos^2\omega_c t$$

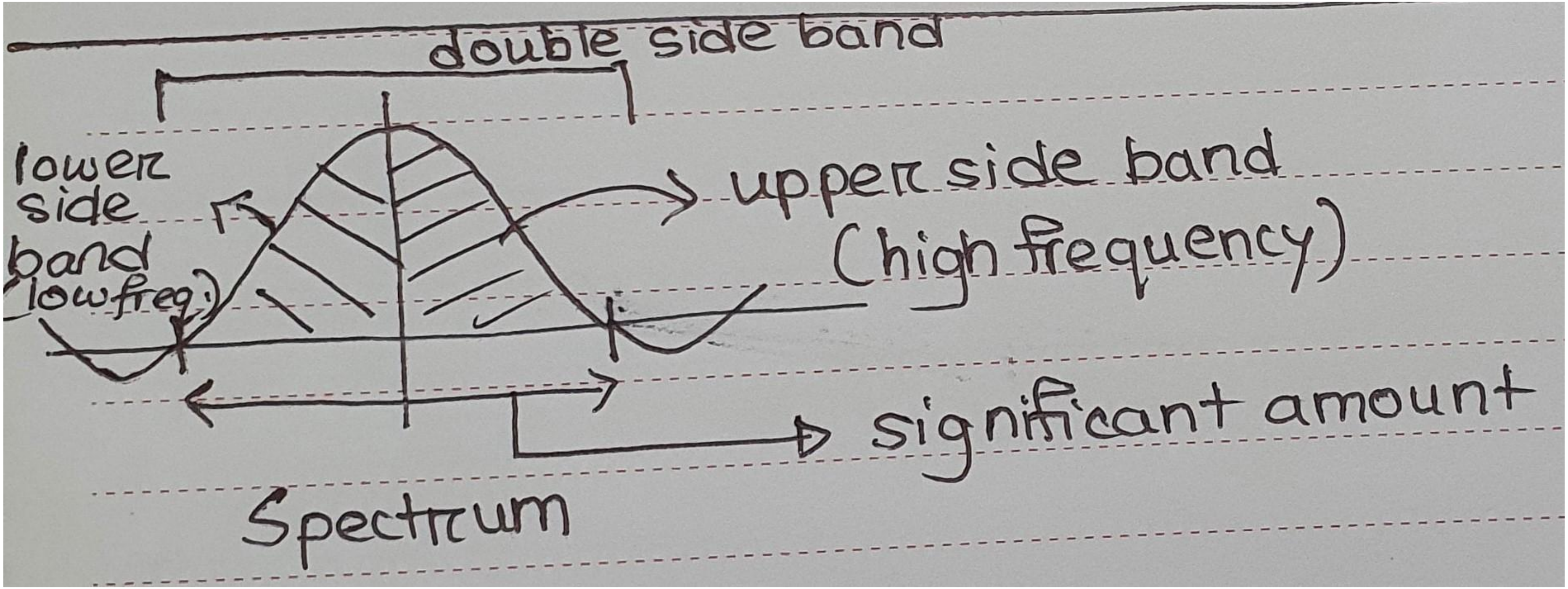
$$= m(t)\left[\frac{1}{2}(1+\cos 2\omega_c t)\right]$$

$$= \frac{1}{2}m(t) + \frac{1}{2}m(t)\cos 2\omega_c t$$

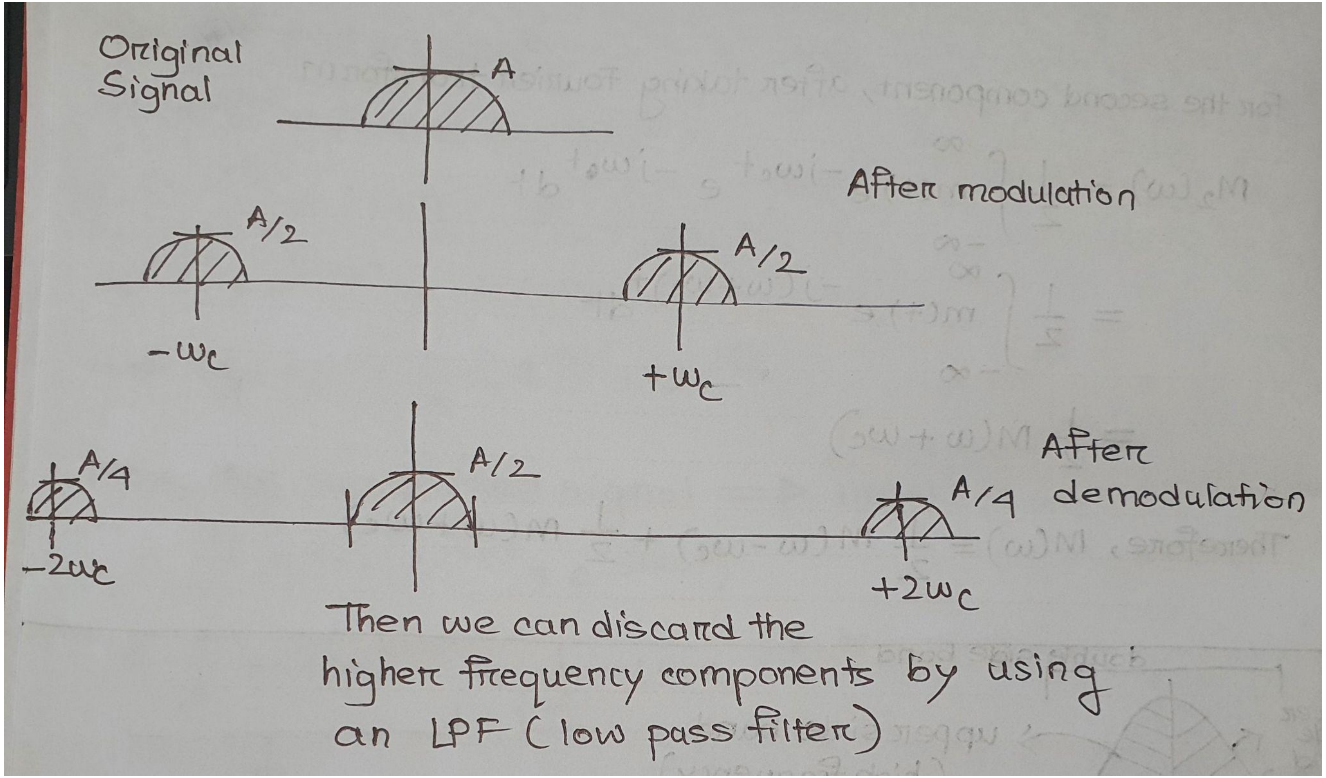
$$\Rightarrow \frac{1}{2}M(\omega) + \frac{1}{4}M(\omega+2\omega_c) + \frac{1}{4}M(\omega-2\omega_c)$$

In frequency domain

Amplitude Modulation: DSB-SC



Amplitude Modulation: DSB-SC



Amplitude Modulation: DSB-SC

DSB-SC: Double Sideband - Suppressed Carrier

Here, the carrier is not sent separately

Modulation: Multiplying with $\cos\omega_c t$

Demodulation: Multiplying with $\cos\omega_c t$

Here,

- Demodulation needs multiplication (but multiplication is costly!!)
- Multiplier has to be a perfect match
- Also known as synchronized/coherent detection

Amplitude Modulation: DSB-SC

To solve the problems associated with synchronized detection

- **DSB-WC (with carrier):** Demodulation can also be done using envelope detection, which is less costly compared to coherent detection
- **Next Class (Lecture 3)**

Amplitude Modulation: Nonlinear DSB-SC Modulation

If we want to eliminate multiplication from the modulation part, we can use a nonlinear DSB-SC modulator

Nonlinear modulator : multiply without multiplying.

$$y_1(t) = a x_1(t) + b x_1^2(t) \text{ ——— (i)}$$

$$y_2(t) = a x_2(t) + b x_2^2(t) \text{ ——— (ii)}$$

Now, $z(t) = y_1(t) - y_2(t)$

$$= [a x_1(t) + b x_1^2(t)] - [a x_2(t) + b x_2^2(t)]$$

Now, $x_1 = \cos w_c t + m(t)$

$$x_2 = \cos w_c t - m(t)$$

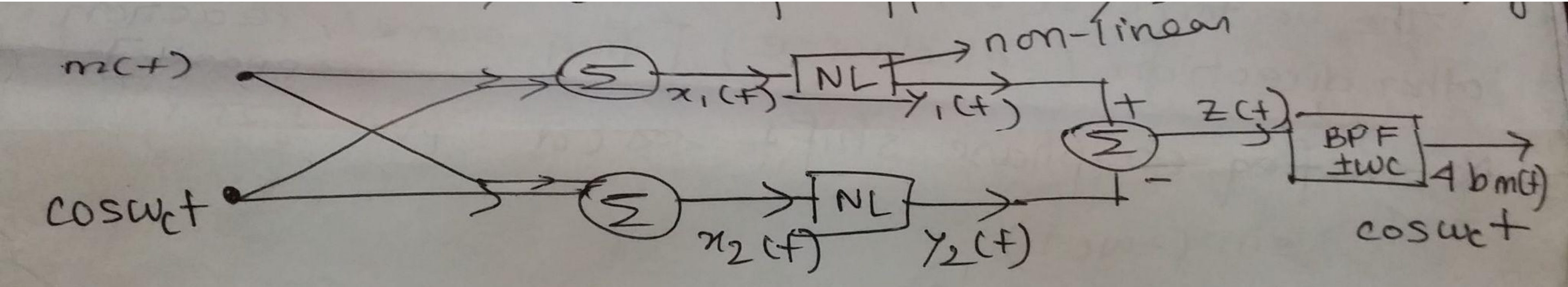
$$z(t) = \cancel{a \cos w_c t} - \cancel{a \cos w_c t} + a m(t) + a m(t) + b(\cos w_c t + m(t))^2 - b(\cos w_c t - m(t))^2$$

$$= 2am(t) + b[(\cos w_c t + m(t))^2 - (\cos w_c t - m(t))^2]$$

$$= 2am(t) + \cancel{4m}\ 4 b\, m(t) \cos w_c t$$

$\longrightarrow$ (effectively, no multiplying

Amplitude Modulation: Nonlinear DSB-SC Modulation



Nonlinear DSB-SC modulator.