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EE 308: Communication Systems
Instructor: Prof. Shalabh Gupta
DAMP info : Follow Book → Simon Haykin
Grading tough, Communication
Surprise Quizzes Systems

16.7.18

Reference

1) Simon Haykin "Communication Systems"
2) Proakin J.G & Salehi M.
"Communication System Engineering"

Grading

Surprise Quizzes (5 or 6) : 30%
M.S : 25%
Final E.S : 45%

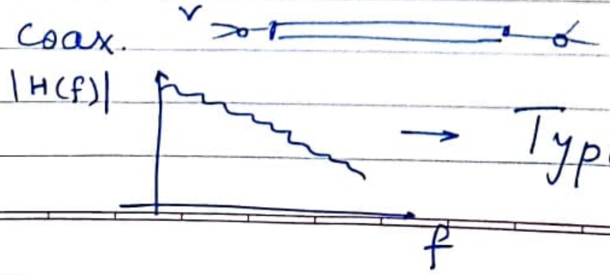
Makeup Classes : Sat : 11-12 July 21, 28
Aug 4

17.7.18 Lecture 2

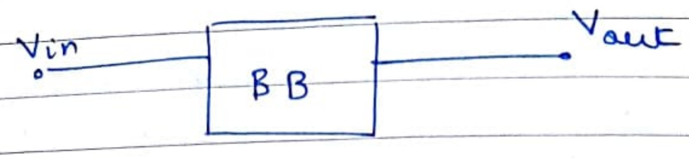
→ Fourier Transforms

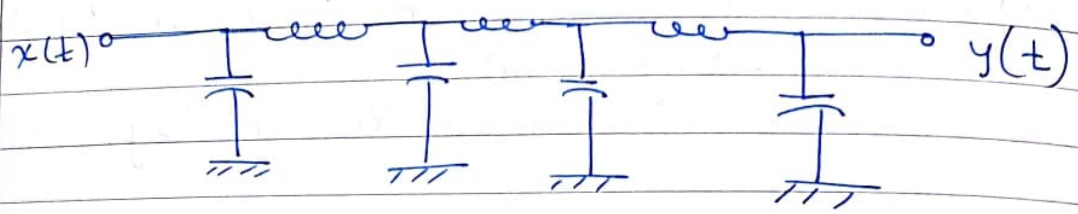
• Why freq. content is imp. : Channles are freq. dep.

ex Coax.



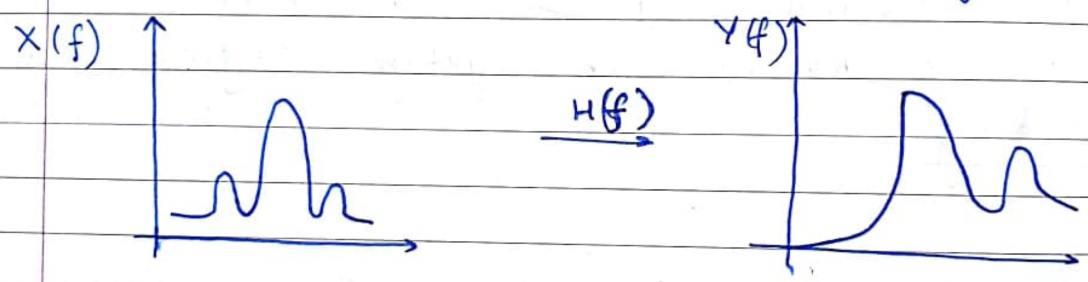
→ Typical





$x(t) \xrightarrow[\text{comp. math}]{\text{convolution}} y(t)$: Inconvenient

$Y(f) = H(f) \cdot X(f)$: Easy



→ Fourier Transforms

$$x(t) \xrightarrow{F.T} X(f)$$

$$X(f) = \int_{-\infty}^{\infty} x(t) \underbrace{e^{-j2\pi f t}}_{\substack{\text{Complex exp.} \\ \text{(sine wave)}}} dt$$

$e^{-j2\pi f t} \rightarrow \cos(2\pi f t) + j\sin(2$

$$x(t) = \int_{-\infty}^{\infty} X(f)\, e^{j2\pi f t}\, df$$

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→ Alternate (EE 210 type) definition

Let, $X_1(\omega) = X\left(\frac{\omega}{2\pi}\right) = \boxed{\int x(t)\, e^{-j\omega t}\, dt}$ (from $X(f)$)

$$x(t) = \int X(f)\, e^{j2\pi f t}\, df$$

$$x(t) = \int X\left(\frac{\omega}{2\pi}\right) e^{j\omega t}\, d\left(\frac{\omega}{2\pi}\right) = \boxed{\frac{1}{2\pi}\int X_1(\omega)\, e^{j\omega t}\, dt}$$

→ Yet Another Symmetric Defn.

$$x(t) \longrightarrow X_2(\omega)$$

$$\boxed{X_2(\omega) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} x(t)\, e^{-j\omega t}\, dt}$$

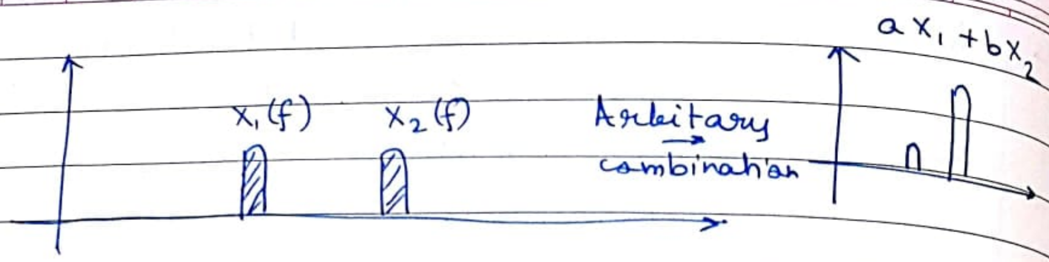
$$\boxed{x(t) = \frac{1}{\sqrt{2\pi}}\int X_2(\omega)\, e^{j\omega t}\, d\omega}$$

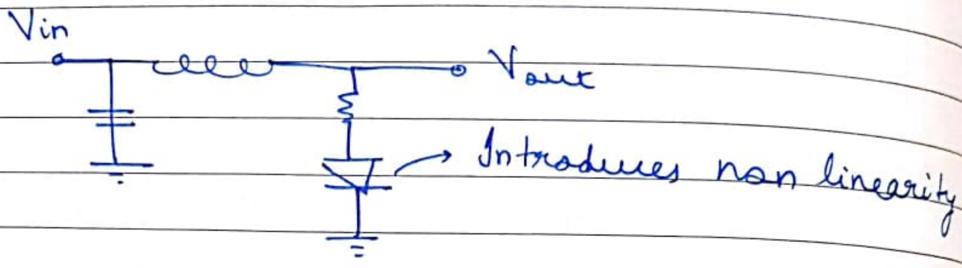
→ Properties of Fourier Transform

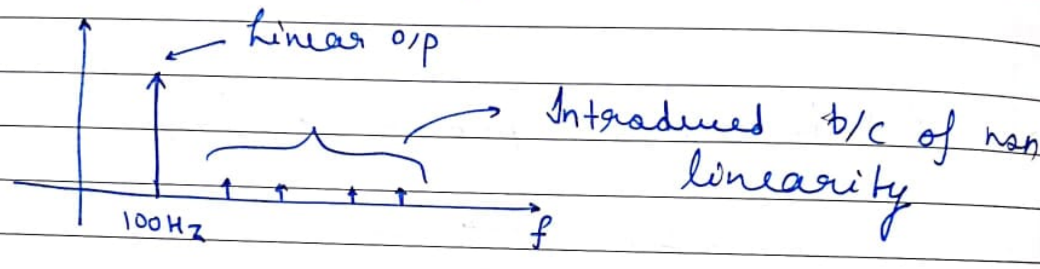
1) Linearity : $x_1(t), x_2(t)$ | a, b
$X_1(f), X_2(f)$

$$a\,x_1(t) + b\,x_2(t) \rightleftharpoons a\,X_1(f) + b\,X_2(f)$$

→ Implication : No new frequencies are created in the system when we superpose 2 waves







2) <u>Time</u> <u>Shift</u> (may come in the form of ϕ delay)

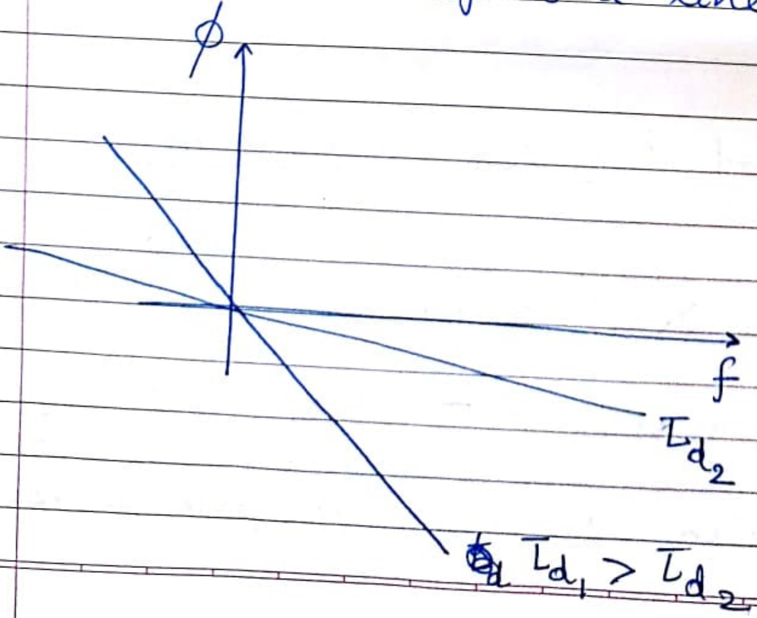
Same, No distortion

$x(t) \longrightarrow X(f)$

$x(t-\tau) \longrightarrow \underbrace{X(f) \cdot e^{-j2\pi f\tau}}$

↳ f-domain is scaled, but o/p signal still the same.

→ A fixed time shift is a linear freq. dep. ϕ shift



→ If phase shift is not linear with frequency (Due to ↓ quality filter or Channel char.) then there will be distortion.

$$X(f) \xrightarrow{\ \tau_d\ } X(f)\, e^{-j 2\pi f (\tau_d \,\vdots\, i)}$$

distortion different for different freq.

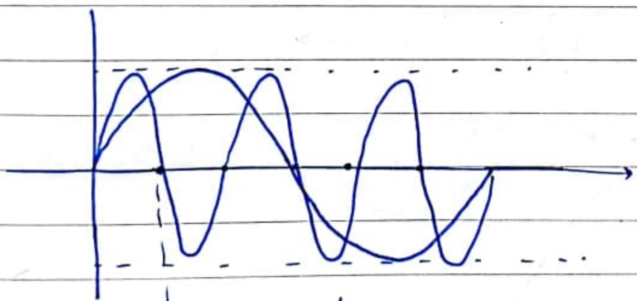
ex

$$x(t) = \cos(2\pi f_0 t) + \cos(2\pi 3 f_0 t)$$

↓ Channel

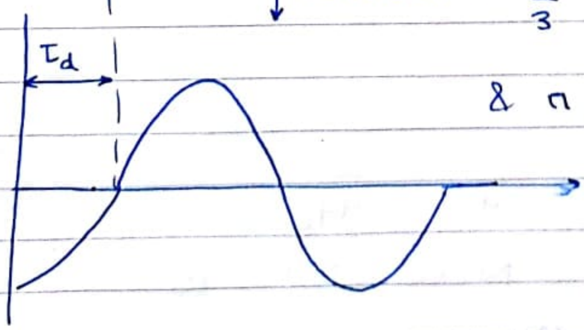
Linear Phase Channel : $\cos\left(2\pi f_0 t + \frac{\pi}{3}\right) + \cos\left(2\pi 3 f_0 t + \pi\right)$

ex



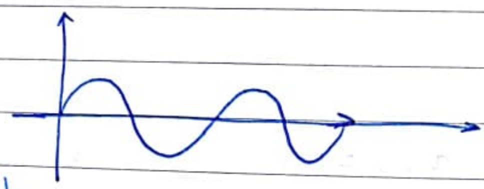
↓ Channel : $\frac{\pi}{3}$ rad phase shift for f_0

& π rad phase shift for $3f_0$



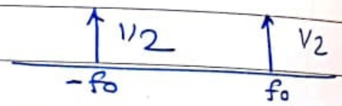
3) <u>Scaling</u>:

$$x(at) \xrightarrow{F} \frac{X\left(\frac{f}{a}\right)}{|a|}$$



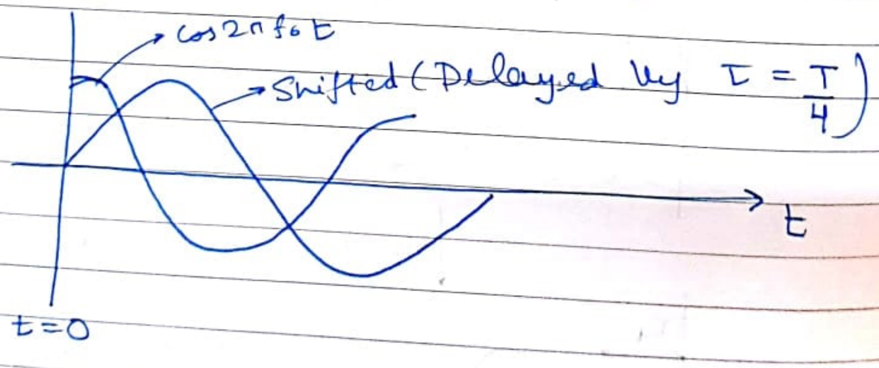
Recap: Time Shift

→ $x(t) = \cos(2\pi f_0 t)$ →



What does a time delay look like in Fourier Domain?

$$x(t-\tau) \longrightarrow X(f)e^{-j2\pi f\tau}$$



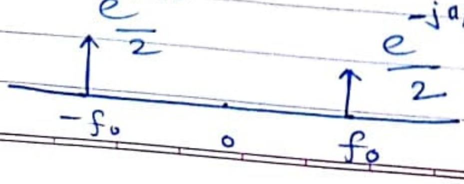
$$\tau = \frac{T}{4} = \frac{1}{4f_0}$$

$$-j \times 2\pi f_0 \times \frac{1}{4f_0}$$

→ Now the New FT is

if $f = f_0$: $e^{-j\pi/2}$

if $f = -f_0$ $e^{j\pi/2}$



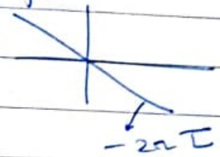
$$\phi(f) = -\cancel{2\pi} f T \; \frac{\phi}{\cancel{2\pi}} \times T$$

$$\cancel{\phi(f) = -Tf\phi}$$

$$\phi = \frac{\phi}{f} = -j\,[2\pi T]$$

Some fixed time shift

slope



→ How does Scaling Change f-domain

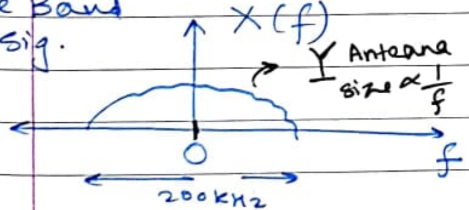
$$x(at) \xrightarrow{\mathcal{F}} \frac{1}{|a|} X\left(\frac{f}{a}\right)$$

$$\cos(2\pi f_0 (at)) \rightarrow \frac{1}{|a|}\left[\delta\left(\frac{f}{a}+f_0\right) + \delta\left(\frac{f}{a}-f_0\right)\right]$$

4) Frequency Shifting / Modulation / Freq. Translation / upconversion

$$x(t) \cdot e^{j2\pi f_0 t} \xrightarrow{F.T} X(f-f_0)$$

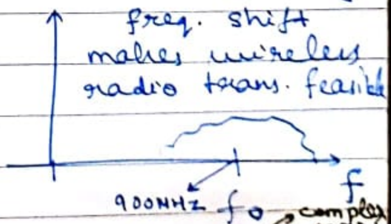
Base Band Sig.



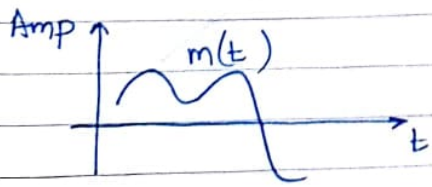
times $e^{j2\pi f t}$ (time domain mult)

Pass Band sig.

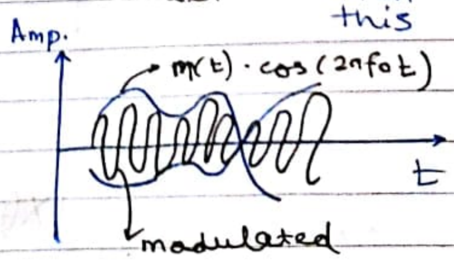
freq. shift makes wireless radio trans. feasible



→ What does \times $e^{j2\pi f_0 t}$ = $\underbrace{\cos 2\pi f_0 t}_{\text{carrier}} + \underbrace{j\sin 2\pi f_0 t}_{\text{Ditch this}}$



\times $\cos 2\pi f_0 t$



Some hints on complex carriers

$$s_p(t) = \left[m_1(t) \times \cos 2\pi f_0 t \mp m_2(t) \sin 2\pi f_0 t \right.$$

If we want to ~~transmit~~ transmit $m_1(t)$ & $m_2(t)$ simultaneously

$$m_c(t) = m_1(t) + j\, m_2(t)$$

$$s_p(t) = \mathrm{Re}\left[m_c(t) \cdot e^{j2\pi f_0 t} \right]$$

→ Send this to the Antenna

→ For real $x(t)$, $X(f)$ is necessarily Hermitian

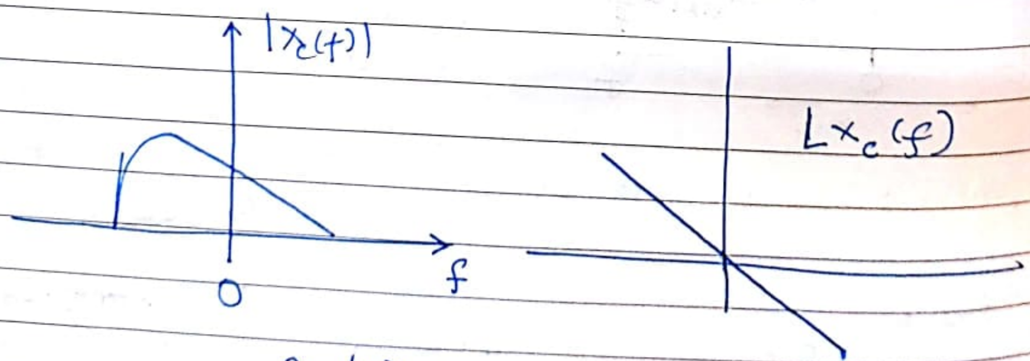
$$\overline{X(f)} = X(-f) \rightarrow |X(f)| = |X(-f)|$$

ex

cos → purely Real
sin → purely im
} Hermitian

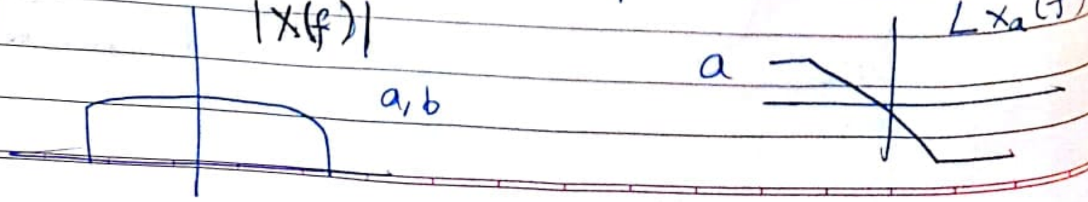
ex 1) $x_c(t)$

1)



$x_c(t)$ is complex

2)



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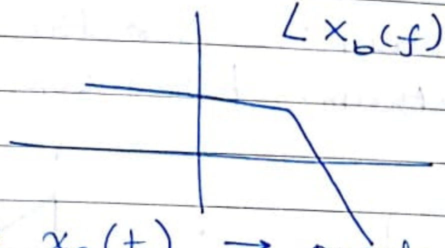
5)

6)

b



$x_a(t) \rightarrow$ purely real

$x_b(t) \rightarrow$ complex.

→ Condition can be called

$|X|$ is even

$\angle X$ is odd

5) Derivative property :

$$\frac{d^n x(t)}{dt^n} \xrightarrow{F.T} (j2\pi f)^n \cdot X(f)$$

$$t^n x(t) \xrightarrow{F.T} \left(\frac{j}{2\pi}\right)^n \frac{d^n X(f)}{df^n}$$

6) Multiplication / Convolution

$$x(t) \times y(t) \xrightarrow{FT} X(f) * Y(f)$$

$$X(f) \cdot Y(f) \xrightarrow{IFT} x(t) * y(t)$$

$$* \Rightarrow \int_{-\infty}^{\infty} x(\tau)\, y(t-\tau)\, d\tau \equiv x * y$$

Lec-4

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Signals : Complex Vs Real

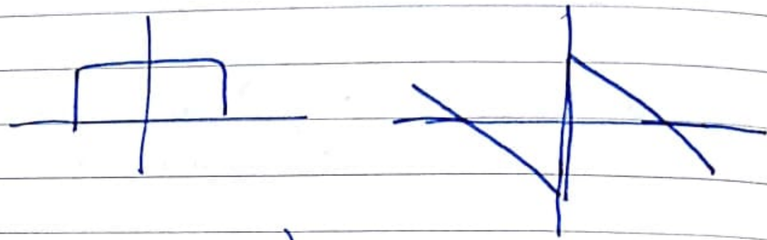
Real Signal : $m(t)$

→ properties of transform

$$M(f) = M^*(-f) = |M(-f)|\, e^{-j\angle M(-f)}$$

for a Real sig. $\begin{cases} \text{Magnitude Spectrum : Symmetric} \\ \text{Phase spectrum : Anti - Symmetric} \end{cases}$

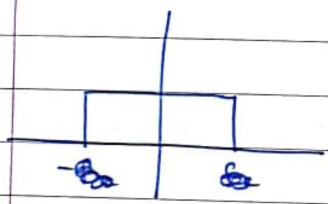
ex



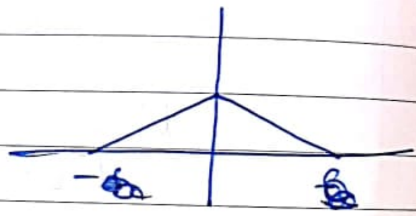
$$s_p(t) = \{ m_1(t) \times \cos(2\pi f_c t) - m_2(t) \sin(2\pi f_c t) \}$$

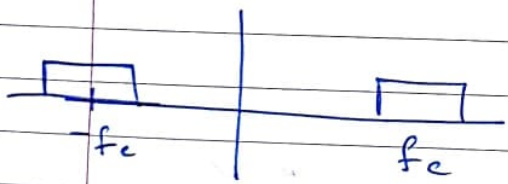
$S_p(f)$ is asym.

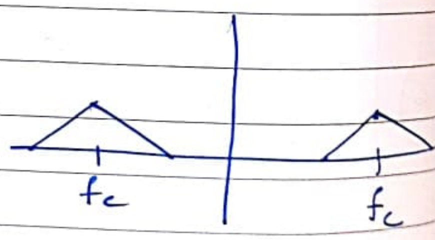
$M_1(f)$ (symm.)



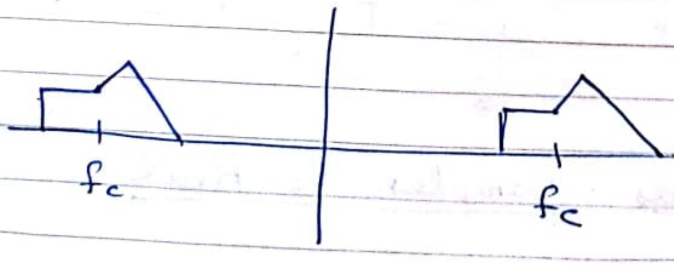
$M_2(f)$ (symm.)







$S_p(f)$



$m_1(t) + j m_2(t) \longrightarrow$

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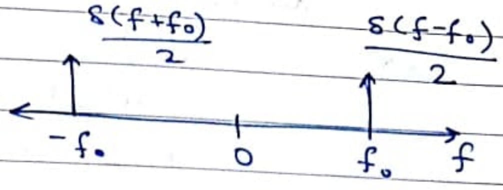
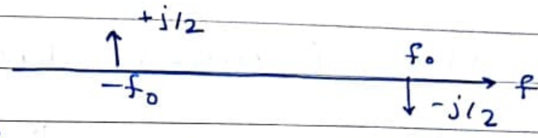
→ **Positive & Negative frequencies**

$\cos(2\pi f_0 t)$

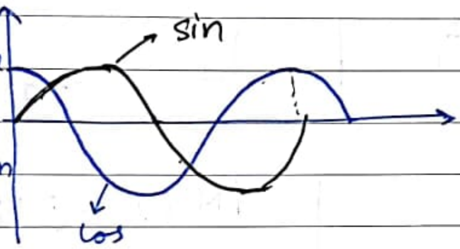


$\sin(2\pi f_0 t)$



→ **To identify +ve/-ve frequencies**

→ We will have to split ~~ø~~ signal into cos/sin comp.

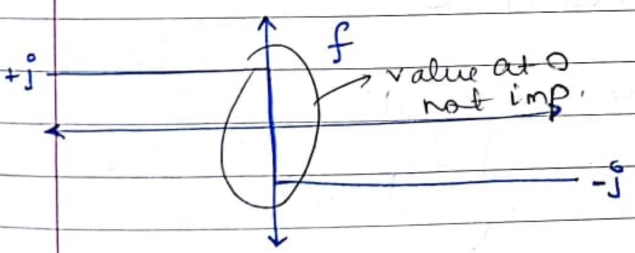


if cos leads sin ⇒ +ve freq.
& if sin leads cos ⇒ -ve freq.

→ **Hilbert transform**

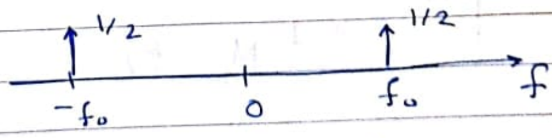
$$H_h(f) = -j\,\mathrm{sign}(f)$$

freq. freq.



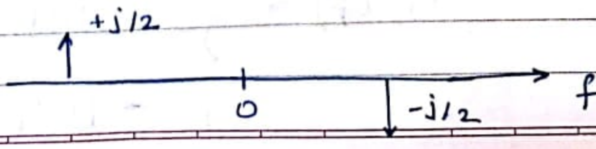
In frequency domain it is simply Multiplication with $H_h(f) : -j\,\mathrm{sign}(f)$

ex $\cos(2\pi f_0 t)$



$\downarrow H_h(f)$

$\sin(2\pi f_0 t)$ ←



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Hilbert Transform

→ $\boxed{H_h(f)}$ introduces a phase delay of 90° in f domain

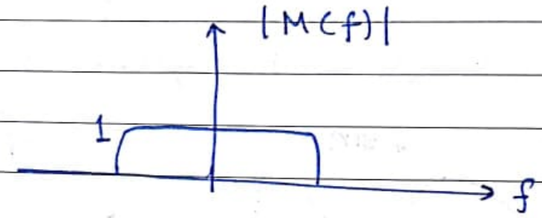
ex $\quad m(t) \xrightarrow{H.T} m_h(t)$

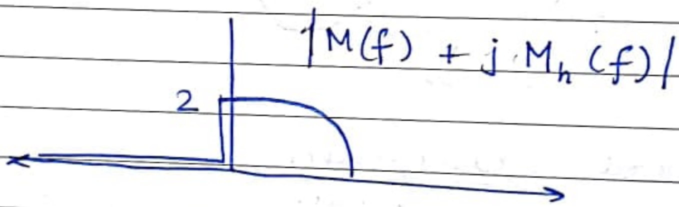
$$m(t) = \cos 2\pi f_0 t$$

$$m(t) + j m_h(t) = e^{+j2\pi f_0 t}$$

ex (General Case) : Real $m(t)$

24.7

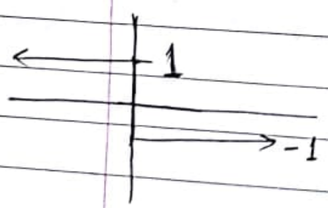




proof

$$M(f) = |M(f)| \cdot e^{j\phi(f)}$$

$$\cancel{M_h(f) \rightarrow M(f) = \begin{cases} |M(-f)| \cdot e^{j\phi(f)} & f<0 \\ |M(f)| \cdot e^{j\phi f} & f>0 \end{cases}}$$



$$M_h(f) = \begin{cases} |M(f)| \cdot \left[e^{j\phi(f) - \frac{j\pi}{2}}\right] & f>0 \\ |M(f)| \cdot \left[e^{j\phi(f) + j\pi/2}\right] & f<0 \end{cases}$$

$$j M_h(f) = \begin{cases} |M(f)| \cdot \left[e^{j\phi(f)}\right] & f>0 \\ -|M(f)| \cdot \left[e^{j\phi(f) \cancel{+ j\pi}}\right] & f<0 \end{cases}$$

Add & get

$$M(f) + j M_h(f) = \begin{cases} 2|M(f)| \cdot e^{j\phi(f)} & f>0 \\ 0 & f<0 \end{cases}$$

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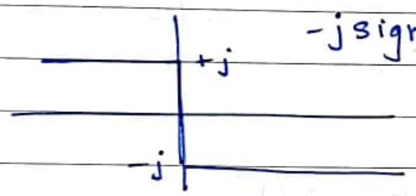
Lecture 5

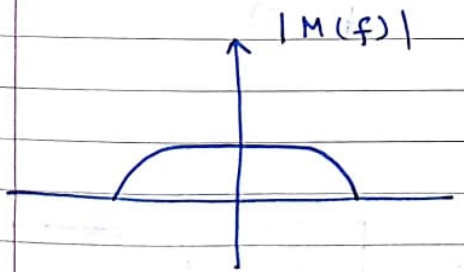
Recap : Hilbert Transform

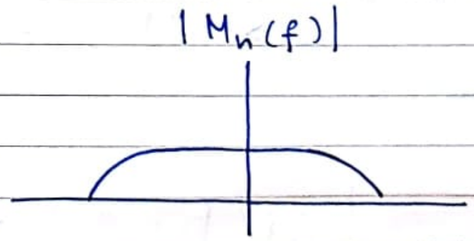


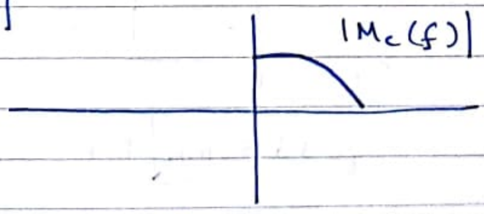
At $f=0$: can take 0, +j or -j doesn't matter

$m(t)$: Real
$m_h(t)$: Real

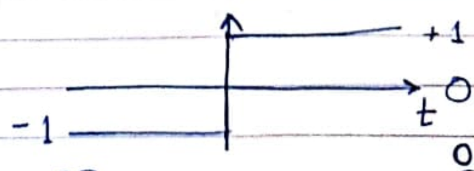
$$\left\{ \begin{aligned} m_c(t) &= m(t) + j m_h(t) \\ M_c(f) &= M(f) + j M_h(f) \end{aligned} \right.$$







→ FT of sgn (t)



$$\mathcal{F}[\operatorname{sgn}(t)] = \lim_{a \to 0^+} \int_0^{\infty} e^{-at} e^{-j2\pi f t}\, dt - \int_{-\infty}^{0} e^{+at} e^{-j2\pi f t}\, dt$$

$$= \lim_{a\to 0^+} \frac{1}{a+j2\pi f} - \frac{1}{a-j2\pi f}$$

$$= \lim_{a\to 0^+} \frac{-j4\pi f}{a^2+(2\pi f)^2} = \boxed{\frac{1}{j\pi f}}$$

Now, $u(t) = \frac{1}{2}\,\mathrm{sgn}(t) + \frac{1}{2}$

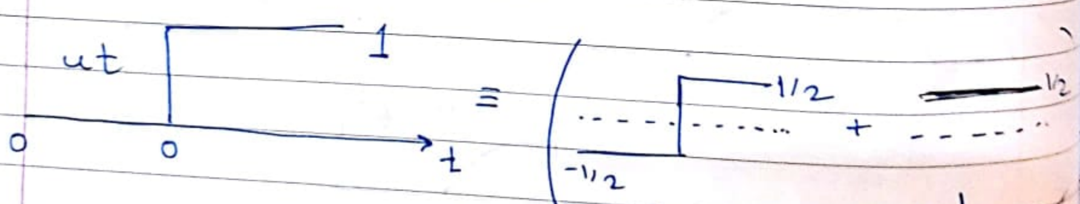
$$\underset{U(f)}{\underset{\parallel}{\mathcal{F}[u(t)]}} = \frac{1}{j2\pi f} + \frac{\delta(f)}{2}$$

same issue refer EE210

$$\frac{d}{dt}[u(t)+c] = \delta(t)$$

$$j2\pi f\,[U(f) + c\cdot\delta(f)] = 1$$

$$\Rightarrow U(f) = \frac{1}{j2\pi f} - c\,\delta(f)$$



(odd symm) ↓ FT

Purely imaginary comp.

↓ FT (even symm)

Purely real

↓

$\frac{\delta(t)}{2}$

$\Rightarrow c = \frac{1}{2}$

$$\mathrm{sgn}(t) \rightarrow \frac{1}{j\pi f}$$

$$h_h(t) : \mathcal{F}^{-1}\left[-j\,\mathrm{sign}(f)\right]$$

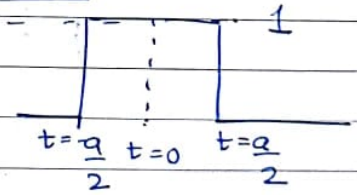
Impulse Response of Hilbert transform

using Duality,

$$\left.\begin{array}{ccc} x(t) & \xrightarrow{F.T} & X(f) \\ X(t) & \xrightarrow{F.T} & x(-f) \end{array}\right] \text{Duality property}$$

$$= -j \cdot \frac{1}{j\pi(-t)} = \boxed{\frac{1}{\pi t}} = h_h(t)$$

→ FT of $\mathrm{rect}\left(\frac{t}{a}\right)$



$$= u\left(t+\frac{a}{2}\right) - u\left(t-\frac{a}{2}\right)$$

$$\downarrow F.T$$

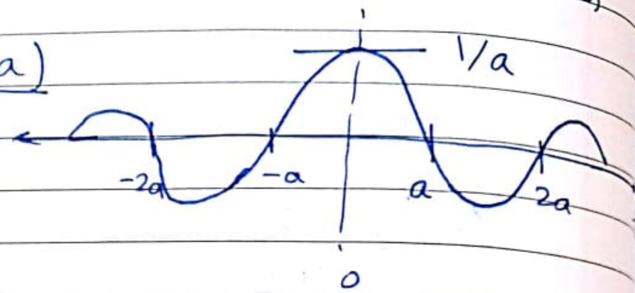
$$\left[\frac{1}{j2\pi f} + \frac{\delta(f)}{2}\right]\left[e^{+j2\pi f\cdot\frac{a}{2}} - e^{-j2\pi f\cdot\frac{a}{2}}\right]$$

$$= \frac{\delta(f)}{2}\cancel{[1-1]}^{0} + \frac{1}{j\pi f}\left[\sin(\pi f a)\right]$$

$$\boxed{= a\,\mathrm{sinc}(af)}$$

or, if we started with rect (at), then

$$\frac{\text{sinc}\,(f/a)}{a}$$

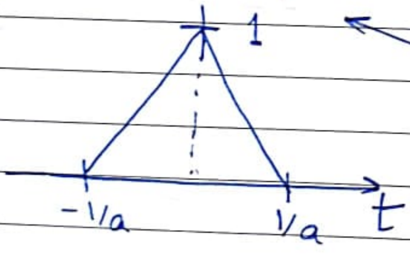


Amplitude / DC component can also be obtained by,

$$X(0) = \int_{-\infty}^{\infty} x(t)\, dt$$

~~Tri~~ $\text{tri}(t/a)$

$$\text{tri}(at) = a\,\text{rect}(at) * \text{rect}(at)$$



$$\updownarrow$$

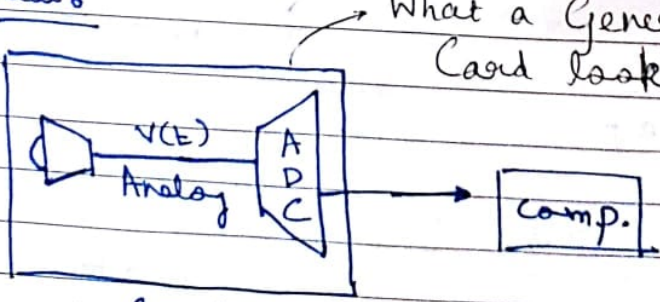
$$\frac{1}{a}\,\text{sinc}^2\left(\frac{f}{a}\right)$$

26.7.18

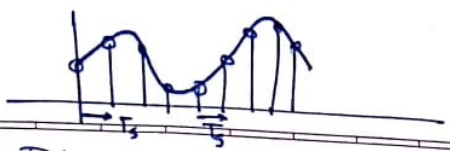
Lecture 6

GNU radio

What a Generic Sound Card looks like



Sound Card



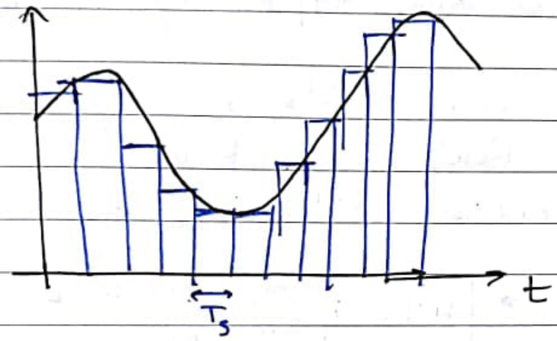
→ Before Digitizing a signal we ~~discretise~~ it.
discretize

$$x[n] = x(nT_s)$$

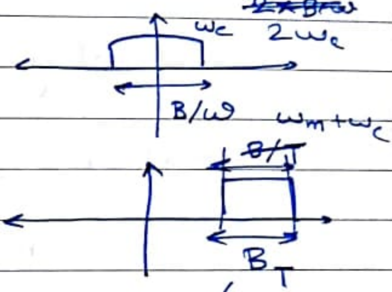
discretisation

Quantize

Whole Number (bits) + { Quantization Noise of ZOH }



Sampling Rates

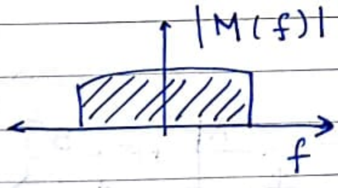


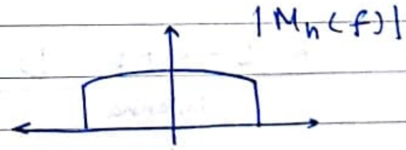
we can do it with $2(\omega_m + \omega_c)$

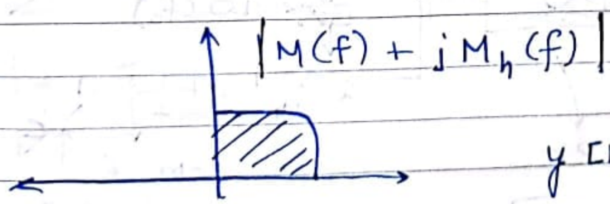
Σ B.W

Recap: Hilbert

(Real) $m(t) \xrightarrow{H.T} m_h(t)$







What does a digital filter look like,

$$y[n] = a_0 x[n] + a_1 x[n-1] + a_2 x[n-2]$$

$$h_h(t) = \frac{1}{\pi t} \rightarrow h_h[n] = \{a_0, \dots, a_n\}$$

$$a_n = nT_s$$

→ Why Noise doesn't peak at 1

→ Power is spread over entire spectrum

→ no peaks as tall as a pure sinusoid in FT

$$\int_{-\infty}^{\infty} |x(t)|^2 dt = \int_{-\infty}^{\infty} |X(f)|^2 df$$

→ In and out ~~to~~ var. types of Hilbert Trans.

Ideally : $m(t) \xrightarrow{HT} m_h(t)$

Real → Real

But in GNU radio Hilbert : Real → Comp.

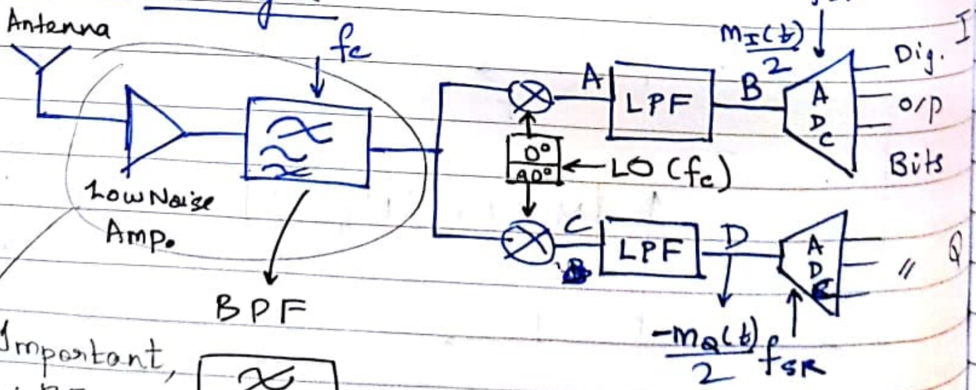
$$m(t) \rightarrow \boxed{\text{Hilbert}} \begin{array}{l} \xrightarrow{Re} m(t-\tau) \\ \xrightarrow{Im} m_h(t-\tau) \end{array}$$

→ o/p is $m(t) + j\,m_h(t)$

28.7.18

Lec. 7

RTL-SDR Dongle



Order Important, Reason: RF Systems course

LO ⇒ Local oscillator

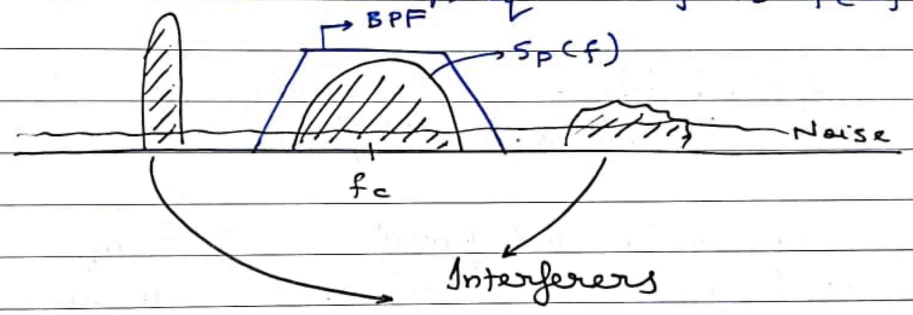
$$\text{Noise} + \text{Inter} + \text{Re}\left[m_c(t)\, e^{j2\pi f_c t}\right] = S_p(t) : \text{Captured by Antenna}$$

$$m_c(t) = \underset{\text{In-phase}}{m_I(t)} + j\, \underset{\text{Quadrature}}{m_Q(t)}$$

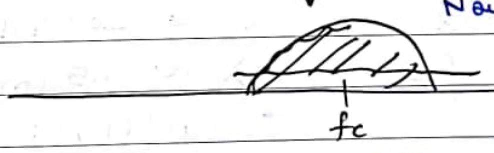
$$S_p(t) = m_I(t)\cos(2\pi f_c t) - m_Q(t)\sin(2\pi f_c t)$$

→ RTL-SDR Block parameters:
Sample Rate : f_{SR}

→ How to select out freq. : Adjust f_c of BPF



↓



$$\text{Now} = m_I(t)\cos(2\pi f_c t) - m_Q(t)\sin(2\pi f_c t)$$

→ Multiplication with LO

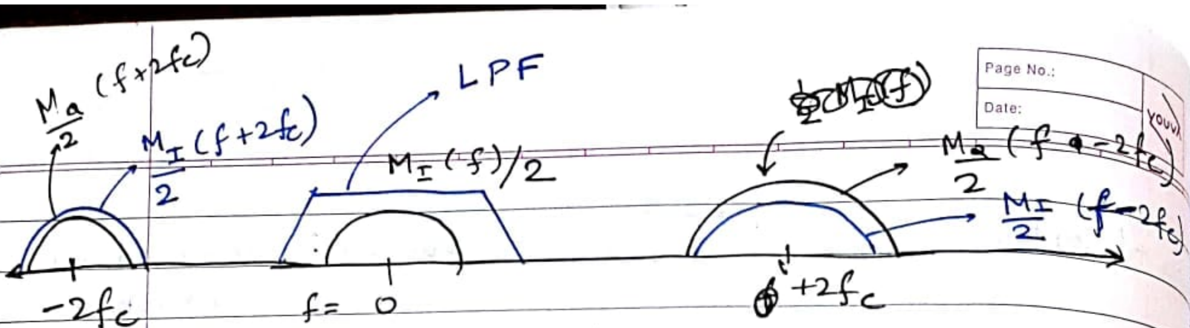
$\times \cos 2\pi f_c t$ ↑ $\boxed{0^\circ / 90^\circ}$ ↓ $\times \sin 2\pi f_c t$

$$A: \; S_p(t) \times \cos(2\pi f_c t) \rightarrow \frac{m_I(t)}{2} + \frac{m_I(t)}{2}\cos(4\pi f_c t) - \frac{m_Q(t)}{2}\sin(4\pi f_c t)$$

↓ LPF

$$= \frac{m_I(t)}{2}$$

$$B: \; S_p(t) \times \sin(2\pi f_c t) \rightarrow \frac{m_I(t)}{2}\sin(4\pi f_c t) - \frac{m_Q(t)}{2}(1 - \cos 4\pi f_c t)$$



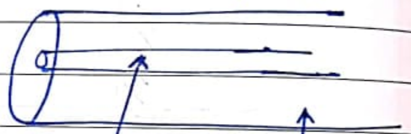
5.

→ Practical Issue: The LO oscillates not exactly at f_c but some $f_c + \Delta f$: Must be solved using signal processing.

Communication Modes

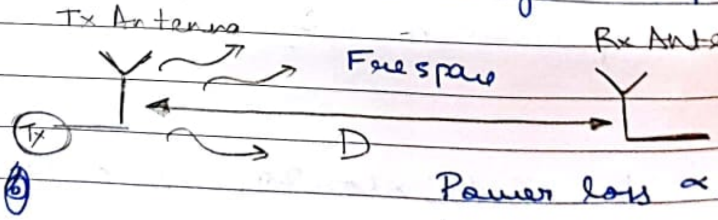
1. Free space
 → Radio Waves (Range of EM waves

2. Optical Fiber
 → ↑ efficient: ~0.18 dB/km



$n_2 > n_1$
→ Uses TIR
$f_c \sim 200$ THz
$\lambda \sim 1.5 \mu m$
→ Challenge: Dispersion

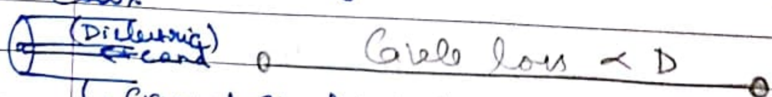
3. Copper (metal wires)
 → Lossy, but loss is less than free space for short dis. & > free space for long distance
 → Reason:



Power loss $\propto D^2$

30.7.18

- Types
 → twisted pair
 → Coax



Cable loss $\propto D$

↳ Ground Shield Mesh

4. Wave Guides: Idea similar to optical fiber

1 GHz – 100 GHz

No glass, lower frequency, (GHz

5. Solids / Liquids : Sound waves & SONAR

Formulas till now

$$\text{rect}\left(\frac{at}{\cancel{a}}\right) \xrightarrow{FT} \frac{\text{Sinc}(f/a)}{a}$$

$$\text{tri}(at) \xrightarrow{FT} \frac{1}{a} \text{sinc}^2\left(\frac{f}{a}\right)$$

$$H_h(f) = -j\, \text{sig}(f)$$
$$h_h(t) = \frac{1}{\pi t}$$

$$M(f) + j M_h(f) = \begin{cases} 2|M(f)|\, e^{j\phi(f)} & f>0 \\ 0 & f<0 \end{cases}$$

Conditions Apply

Hermitian $\Rightarrow$ $\overline{X(f)} = X(-f)$

30.7.18

Lecture 8

- Slides
  1) Effect of Scattering & Absorption on light in Optical fibers
     - Raleigh Scattering
     - OH^- Res. absorption
  2) Atmospheric Opacity
     - Ionosphere reflects EM rad.

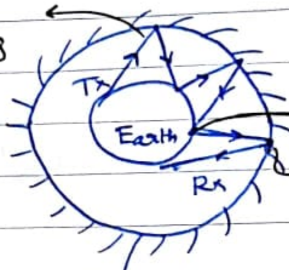
Page No.:
Date:

Tx ———— D ———— Rx

Atten $\propto D^2$

Where?

Called Sky-Waves



Reflection

Reflection

Ionosphere, like a conductor

Can transmit the freq.
Range:
3 MHz – 30 MHz

Bandwidth

$$\text{Capacity} = B \cdot \log_2 (1 + SNR)$$

(bits/s)

$\left(\frac{\text{Signal Power}}{\text{Noise Power}}\right)$

→ <u>Problems with Sky Waves</u>

1) Limited B/W
2) Large Antenna Size

WiFi → 802.11 b/g (2.4 GHz)
WiFi → 802.11 a (5 GHz)

→ Newer comm. technology ⇒ Move to high center frequency for ↑ Bandwidth

5G : ↑ GHz Range

→ Extremely high frequency : (millimetre wa… (MM)

~~$ 30 GHz – 300 GHz

$\lambda =$ 10 mm – 1 mm

Modulation

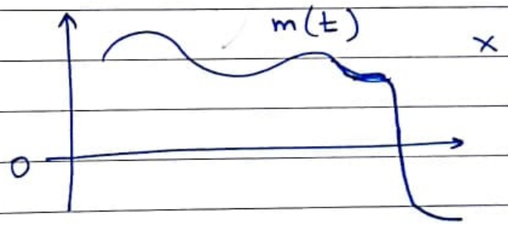
→ If only $f > 0$ spectrum is shown, it means spectrum is Symmetric

→ Message to be trans. by modulation = $m(t)$

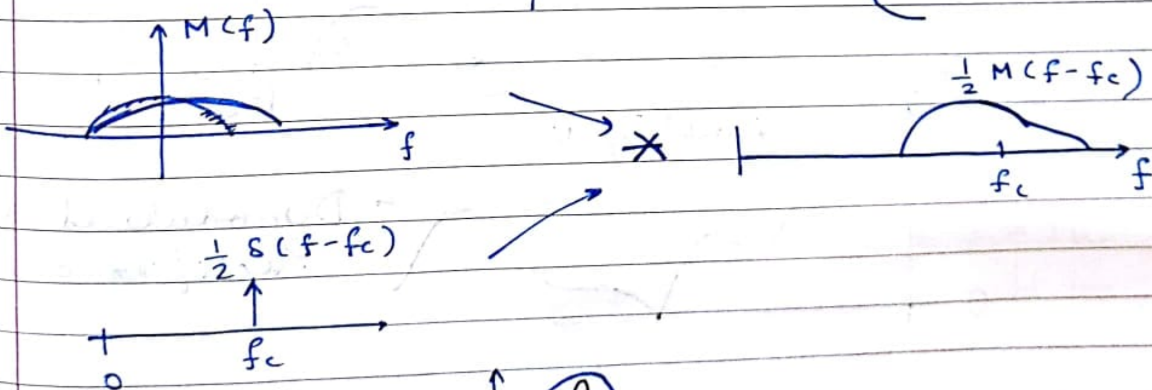
$$\cos 2\pi f_c t \begin{cases} \xrightarrow{AM} A_m \cdot m(t) \cdot \cos(2\pi f_c t) \\ \xrightarrow{PM} A_c \cos(2\pi f_c t + k_\phi m(t)) \\ \longrightarrow A_c \cos(2\pi f_c t + K_f \int^t m(t)\, dt) \end{cases}$$

AM: types

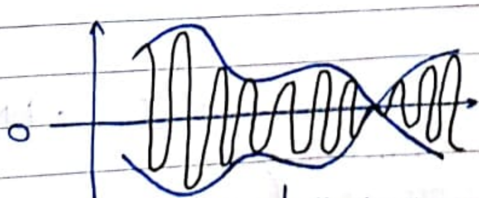
$m(t)$: real



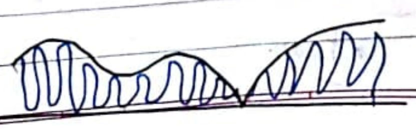
$\times \cos 2\pi f_c t$



Result :

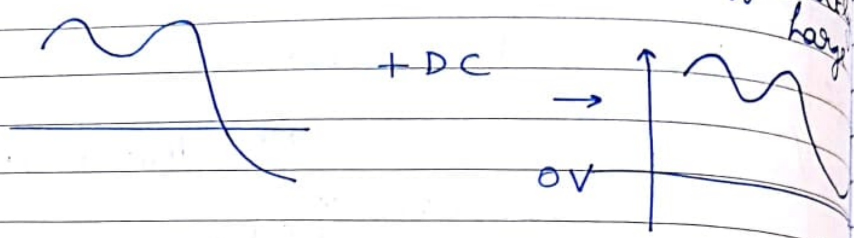


$\downarrow$ $\|\cdot\|$ LPF (Take abs. & then LPF)



→ Information lost

→ Hence choose : $m(t) + DC$
↳ sufficiently large

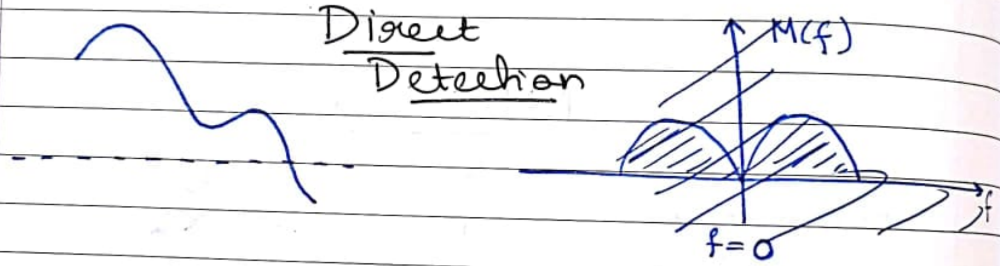


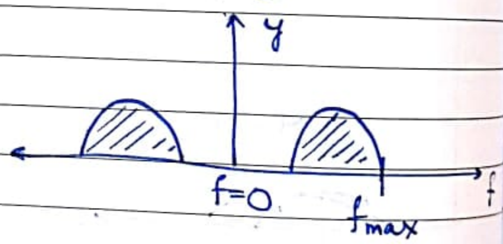
31.7.18

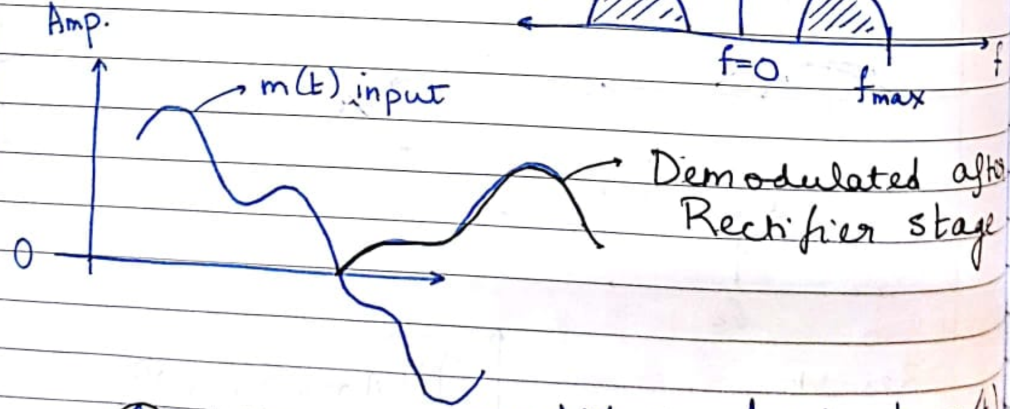
Lec 9

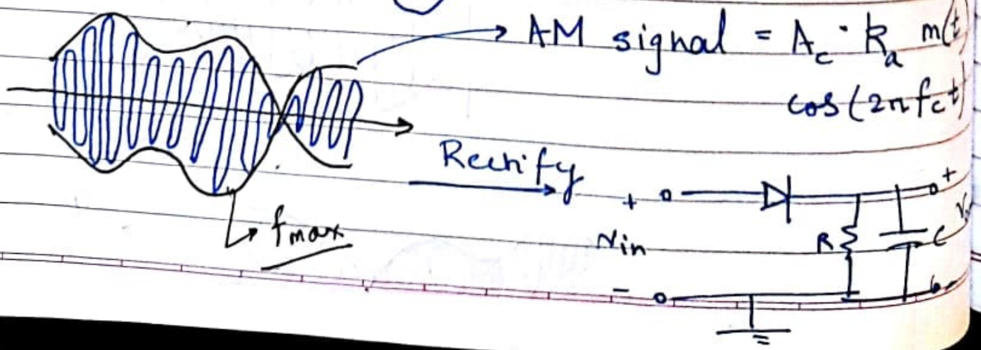
Amplitude Modulation

Direct Detection

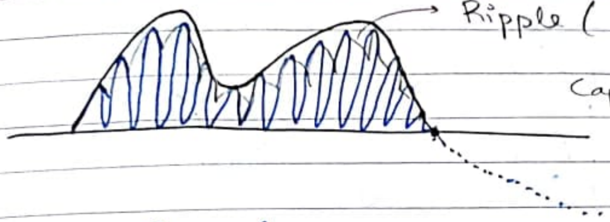








AM signal $= A_c \cdot k_a\, m(t) \cos(2\pi f_c t)$



(i) $f_c >> f_{max}$

(ii) $f_{max} << \frac{1}{2\pi RC} << f_c$

→ Keyword: $\boxed{\text{Envelope Detector}}$: Rectifier based

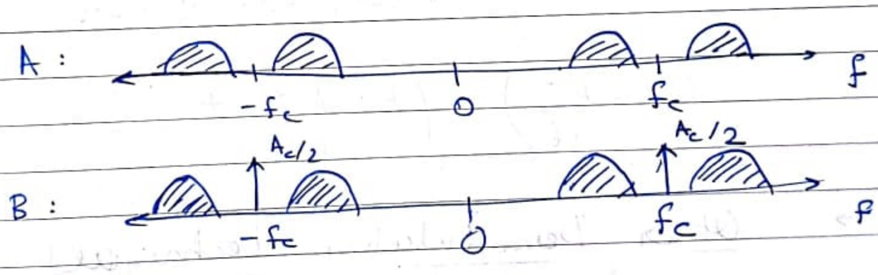
↳ m(t)

AM signal: $= A_c k_a m(t)\cdot\cos(2\pi f_c t)$ — (A)

↳ Double side band with suppressed carrier (DSB-SC)

$A_c(1 + k_a m(t))\cdot\cos(2\pi f_c t)$ — (B)

↳ " " " " Full carrier (DSB-FC)



→ m(t) : Normalized s.t. peak amplitude = 1 unit

→ Hence in B, choice of k_a (M.I) should be

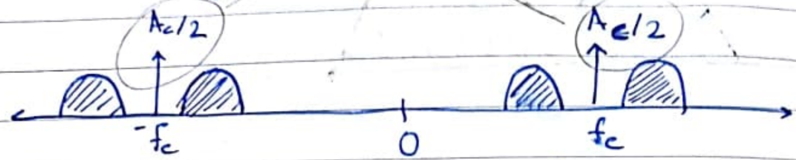
↳(DSB-FC)

~~$k_a > 1$~~ :

$k_a \le 1$: (Envelope m(t) has no zero crossing)

→ ~~We must do this since we have no control over~~

Disadvantage → Transmission requires ↑ Power



Power comparison : $\frac{V_{RMS}^2}{R}$

$\hookrightarrow Z \approx 50\,\Omega$ for Antenna's

ex $k_a = 0.5$

Tx power in A : (RMS Amplitude^2)

$\Rightarrow$ for $m(t)$: $A_c^2 \times (0.5)^2 \times \frac{1}{2} \times \frac{1}{2} = \frac{A_c^2}{16}$

Proof: $\frac{1}{T}\int_0^T \cos^2(2\pi f_1 t)\cdot\cos^2(2\pi f_2 t)\,dt = \frac{1}{4}$

$\left(A : \frac{A_c^2}{16}\right)$ $\left(B : \frac{A_c^2}{16} + \frac{A_c^2}{2}\right)$

→ Other Demodulation techniques

Coherent Detection (Done before, Multiplier based)

Rx: $A_c k_a \cos 2\pi f_c t \cdot m(t) \times \underbrace{\cos(2\pi f_c t)}_{@\ Rx}$

$\downarrow$

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

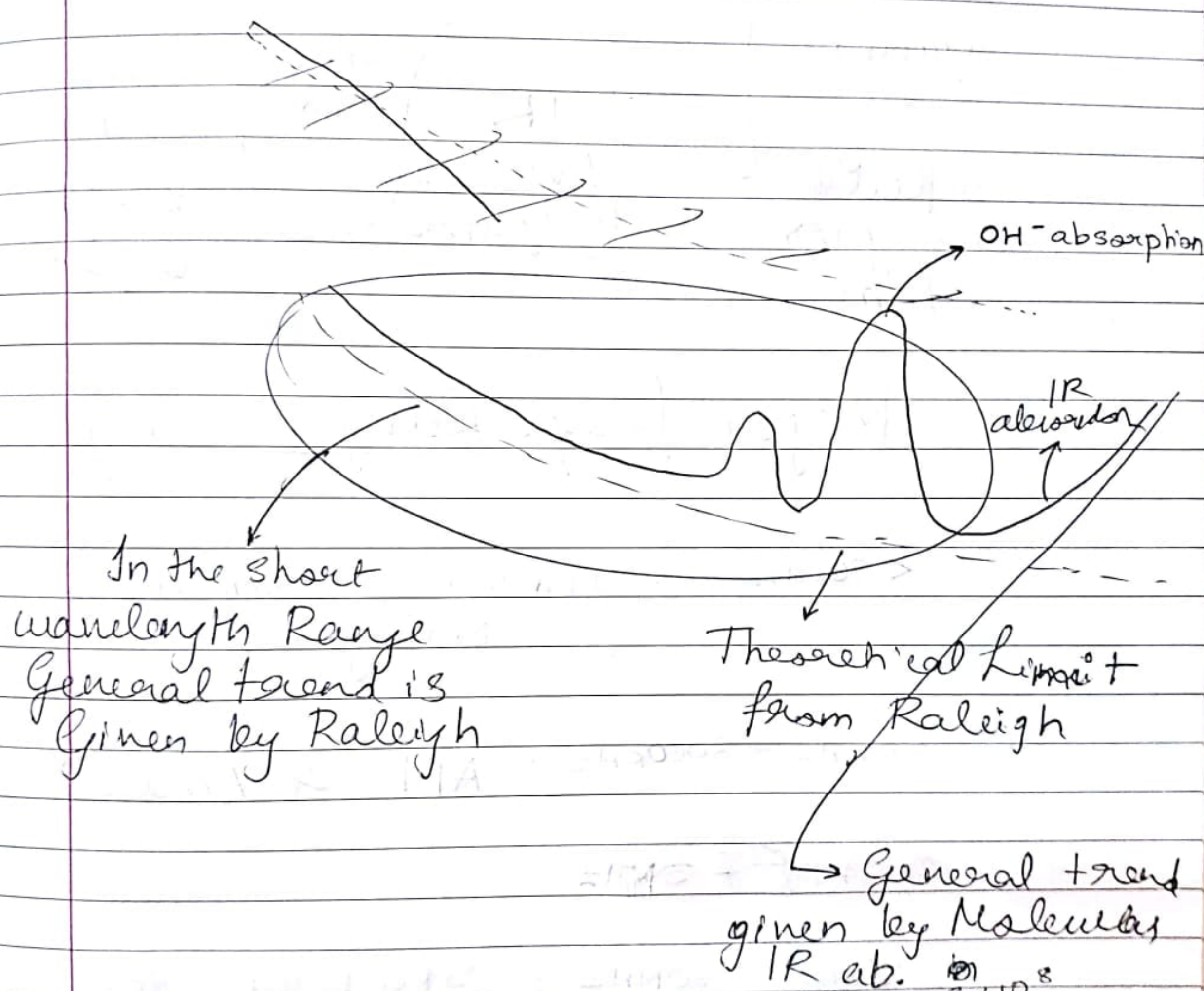
$\downarrow$ LPF

$$\frac{A_c k_a}{2} m(t)$$

$\frac{3\times10^{8}}{10^{-2}}$ 3×10^{10} 30 GHz

Quiz - 1 preparation

- Attenuation in optical fibers

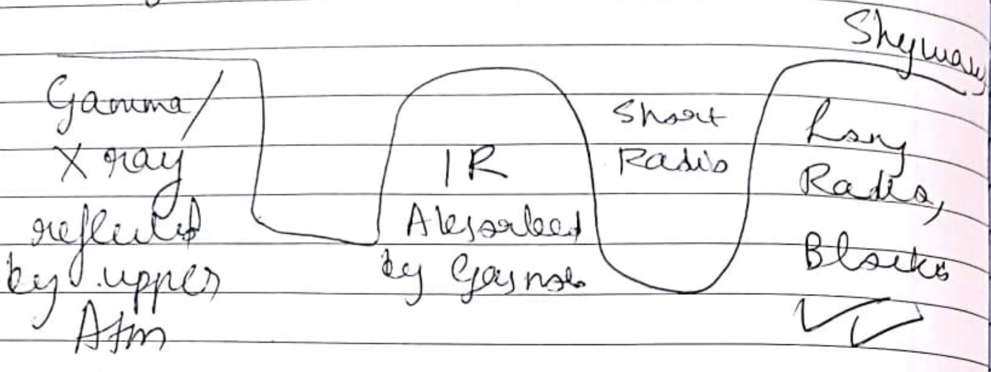


$\frac{3\times10^{8}}{3\times10^{6}}$ 100 m

→ Sky waves

- Propagation of Radio waves Ref/Refracted back to earth.
- From ionosphere
- Used for Short wave high freq. transmission in the range 3 MHz - 30 MHz

Opacity of Atmosphere towards diff. Ranges



Major freq. Ranges (EM)

2.8.18

< 30KHz : Underwater Communication, Navigation

30KHz - 3000KHz : AM & Amateur radio

~~300KHz - 3MHz~~

3MHz - 30MHz : Sky Waves for Aviation, Radio etc.

30 - 300MHz : FM

300MHz - 3GHz : Television, oven, Mobile phones, Wifi, Bluetooth

3 - 30 GHz : More Wifi

30 GHz - 300 GHz : ~~As~~ Radio Astronomy

> 300 GHz : Medical Imaging

Formulas:

$$\text{rect}(at/a) \xrightarrow{FT} \text{sinc}(f/a)$$

$$\text{tri}(at) \xrightarrow{FT} 1/a\ \text{sinc}^2(f/a)$$

$$H_h(f) = -j\,\text{sign}(f)$$

$$h_h(t) = \frac{1}{\pi t}$$

$$M(f) + jM_h(f) = \begin{cases} 2|M(f)|e^{j\phi(f)} & f>0 \\ 0 & f<0 \end{cases}$$

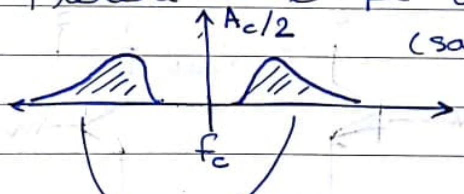
2.8.18

Lec 10

Recap: AM (Amplitude Modulation)

Method 1) Present envelope 0 crossing

DSB - FC (same at $-f_c$)



Double Side Band

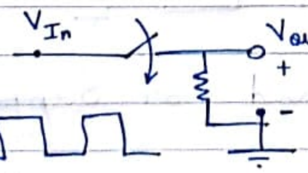
$1 + k_a m(t)$ → ⊗ → AM

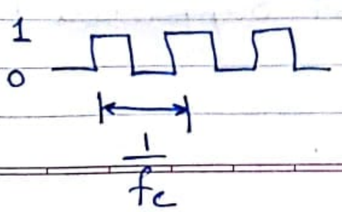
$\cos(2\pi f_c t)$

How can we Multiply?

↓

Explained

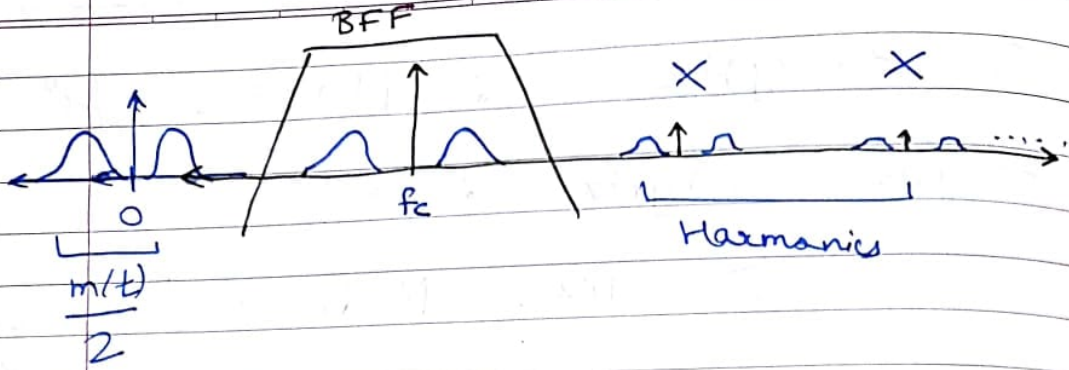




$V_{out} = m(t) \times$ square wave

$$= m(t)\left[\frac{1}{2} + \underbrace{k\cos(2\pi f_c t)}_{\text{Desired carrier}}\right.$$

Undesired Harmonic carriers $\left\{ + \frac{k}{5}\cos(2\pi \cdot 5 f_c t) + \ldots \right.$



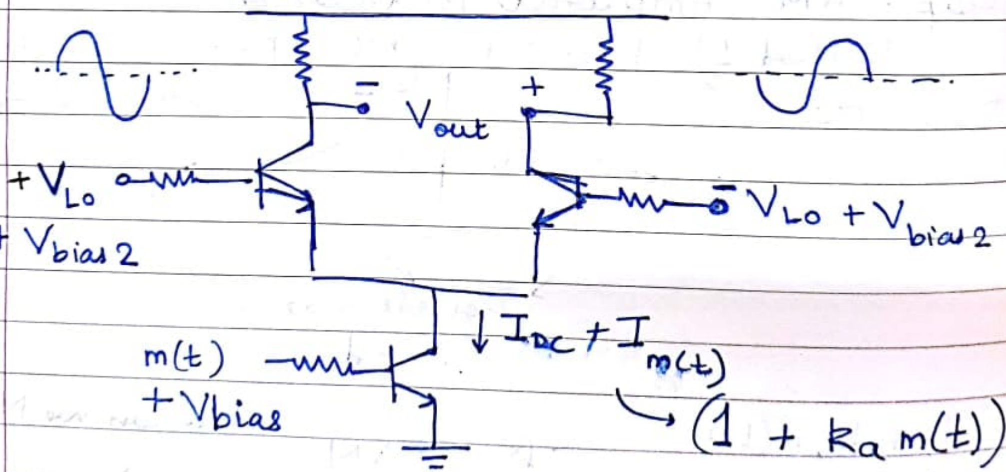
→ Implementation 1

- A simple diode implementation

$m(t) + \cos(2\pi f_c t)$

V_{out} → Has DC offset & other new har[monics]

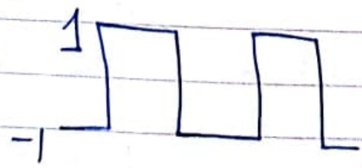
→ 2) ~~Gilbert cell~~ & Diff. Amp Based(2) →



↳ $(1 + k_a m(t))$

⇒ DSB - FC

$m(t) \times \text{Gain} \times$



→ This was the method for ~~Suppressed~~ FC Modulation

→ For SC modulation, we must use Gilbert cell based Multiplication