17.9.18

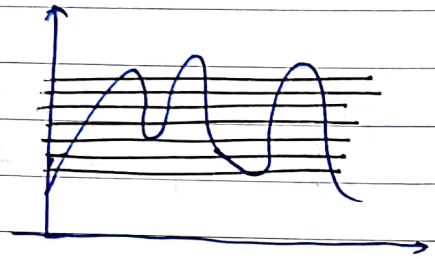
# Digital Communication

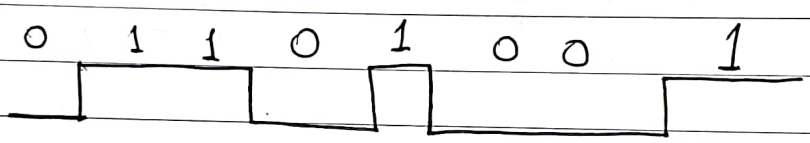
Digitized → discretized in levels
Analog : Information is not digitized
Digital : Information is digitized

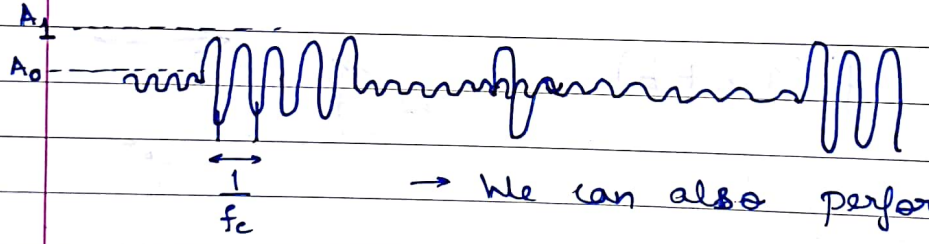
Q→ What is the point of high precision in Analog.

In Digital

AM → ASK (Amp. Shift keying)
FM → FSK (Freq. " ")
PM → PSK (Phase " ")



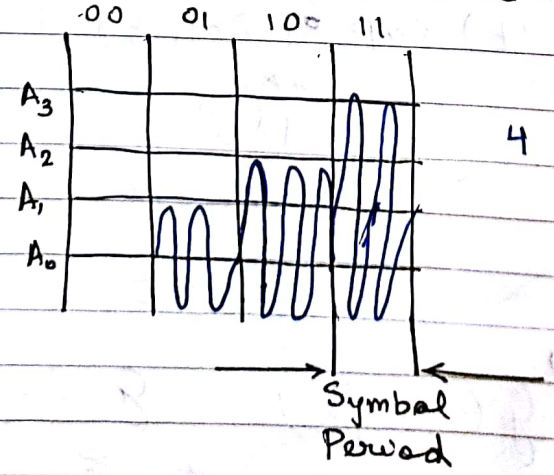



(Ask waveform)

→ We can also perform OOK : On-Off Keying, where Amp. = 0 for Symbol "0"

→ >2 Symbols example (4-ASK) in General M-ASK, M-PSK etc.



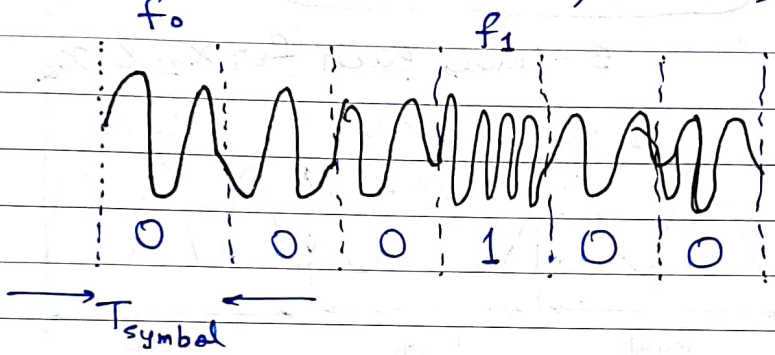

4 levels or 4 possible Symbol values

ex Bit-rate = 1 Mbps

Symbol rate = $\frac{\text{Bit rate}}{\text{Bits/Symbol}}$ = 500 K sym/s for 4-Ask

Sym. rate = $\frac{\text{Bit-rate}}{\lceil \log_2 M \rceil}$ for M-Ask

**FSK** : (2 Symb. FSK, 2-FSK)




**4-FSK**

| | |
|---|---|
| 1 - MHz | $00_2$ |
| 1.1 - MHz | $01_2$ |
| 1.2 - MHz | $10_2$ |
| 1.3 - MHz | $11_2$ |

} trade-off : b/w

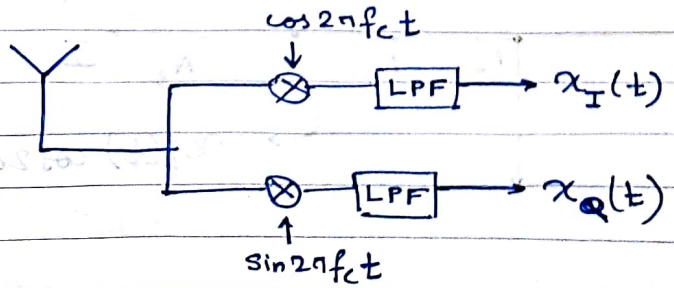
"0"

PM : $\cos(2\pi f_c t + \phi_m(t))$

PSK → $\in \{0, \frac{\pi}{4}, \frac{\pi}{2}, \frac{3\pi}{4}, \pi, \frac{5\pi}{4}, \frac{3\pi}{2}, \frac{7\pi}{4}\}$ ← 8-PSK

$(000)_2$ $(001)_2$

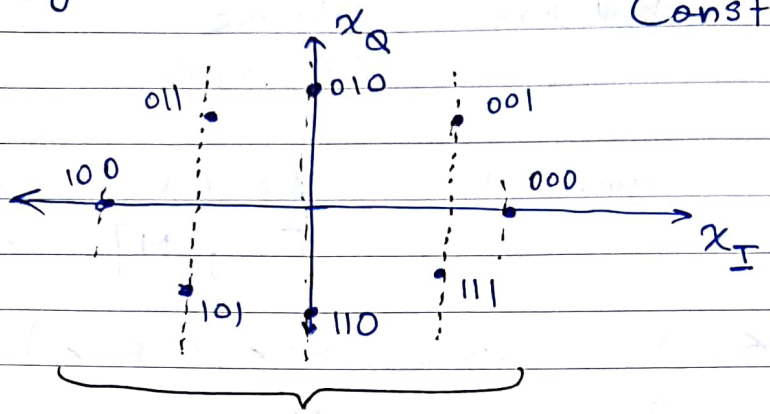
→ How to demodulate this




$\phi_m = \tan^{-1}\left(\frac{x_Q(t)}{x_I(t)}\right)$

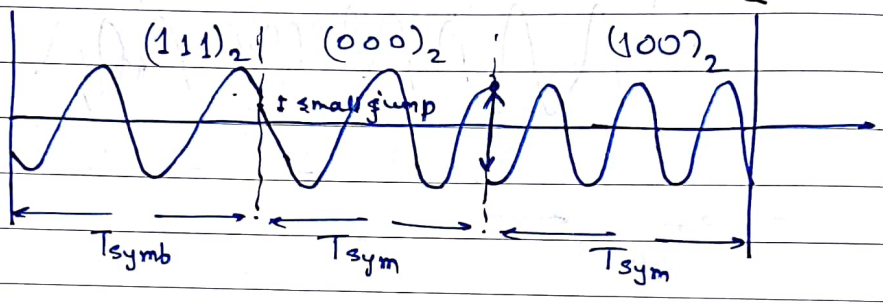
→ Encoding in $x_I$ and $x_Q$

Constellation Diagram

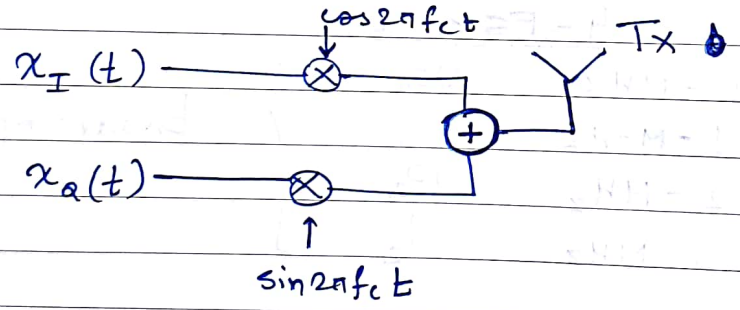



5-Levels each for $x_I$ & $x_Q$

ex

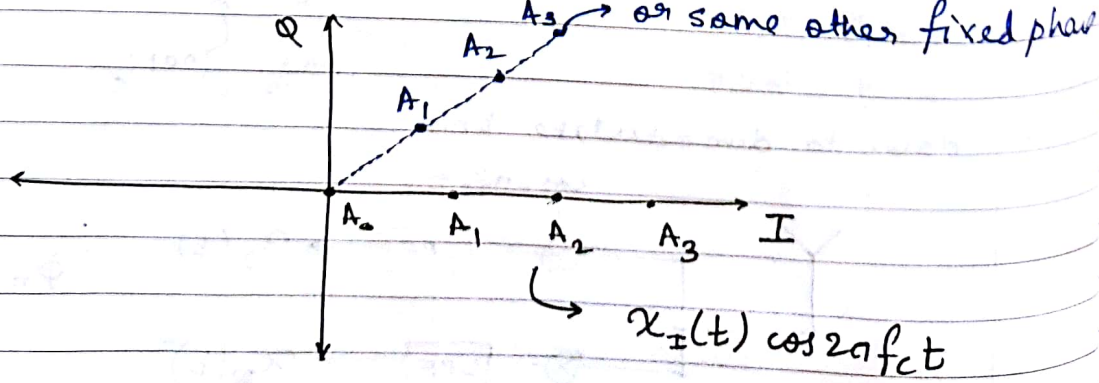


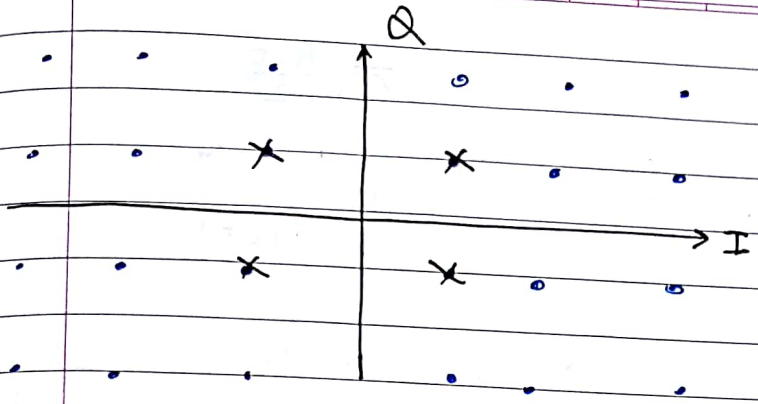

18.9.18




Bandwidth Efficiency = $\frac{(\text{Bits/sec})}{\text{Hz}}$

Constellation Diagram for 4-ASK






× → 4-QPSK

• → 16-QAM

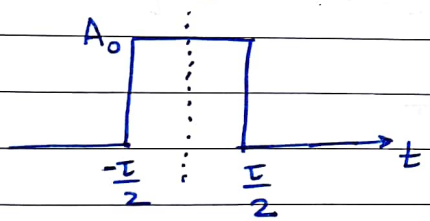
QAM: (General Case): Quadrature Amplitude Modulation
↳ General case

QPSK: Amplitude is constant
↳ modified PSK

18.9.18

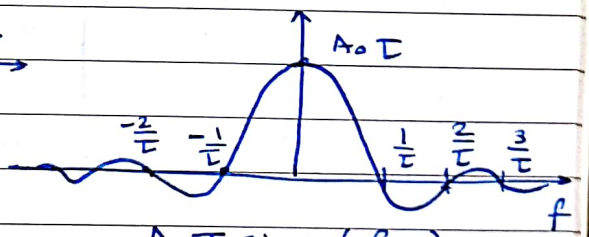
## Lecture

- Recap: Digital modulation Schemes




$A \cdot rect\left(\frac{t}{\tau}\right)$

F.T →



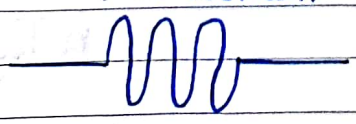

$A_0 \tau \, sinc(f\tau)$

$sinc x$ ~~$\sin x$~~ $\triangleq \frac{\sin x}{x}$ (w/o Normalization)

$\triangleq \frac{\sin(\pi x)}{(\pi x)}$ (Normalized)

→ ASK (Digital AM)

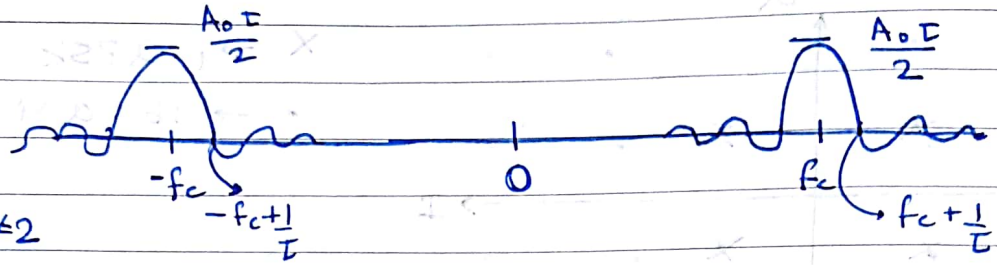
time domain

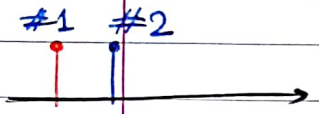


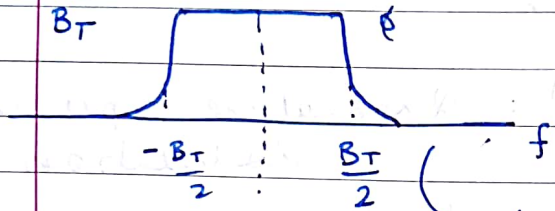
$A_0 \cos 2\pi f_c t \times rect\left(\frac{t}{\tau}\right)$

→ $\frac{A_0 \tau}{2}\left[sinc(f-f_c)\tau + sinc(f+f_c)\tau\right]$

freq. domain

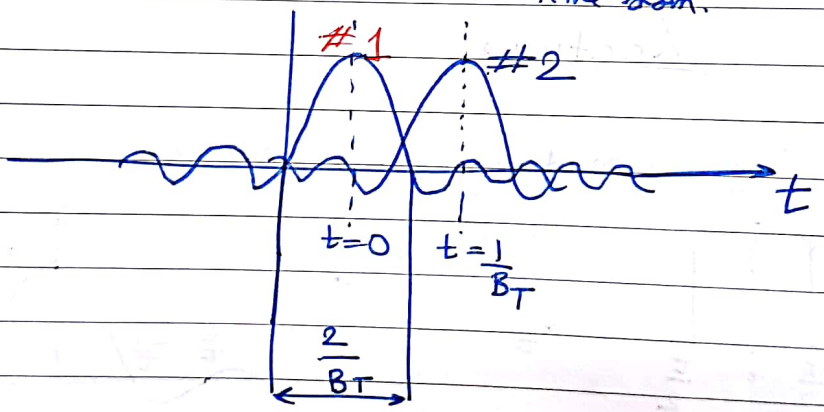


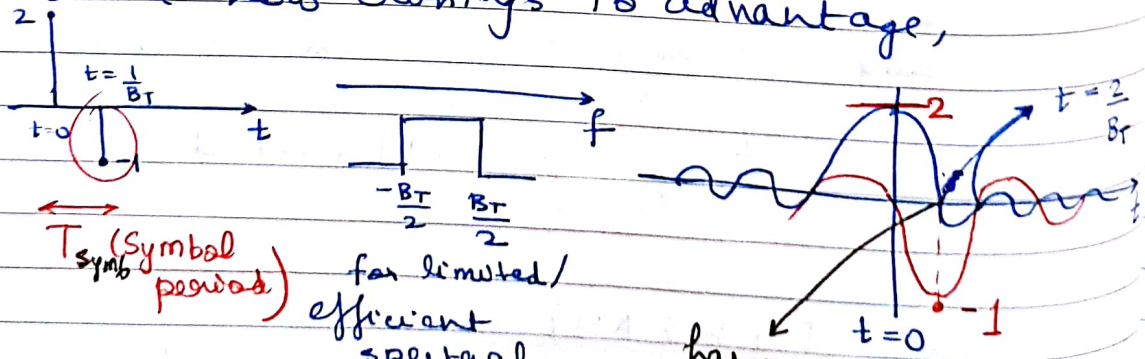




→ To make the signal transfer band limited we use "ideal brickwall filter"

→ taking Convolution with its time domain in time dom.

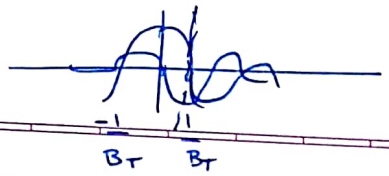



→ So we zero crossings to advantage,

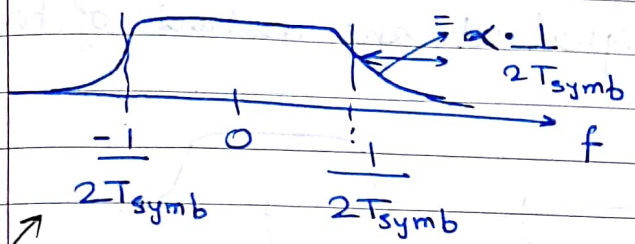



for limited/ efficient spectral usage

has zero crossing at $nT_{symb}$




$B_T = \frac{1}{T_{symb}} (1+\alpha)$

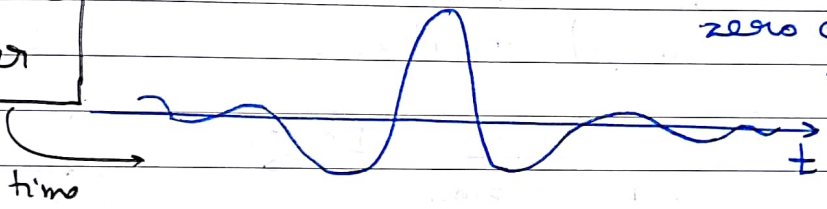



: Pulse shaping filter (PSF)

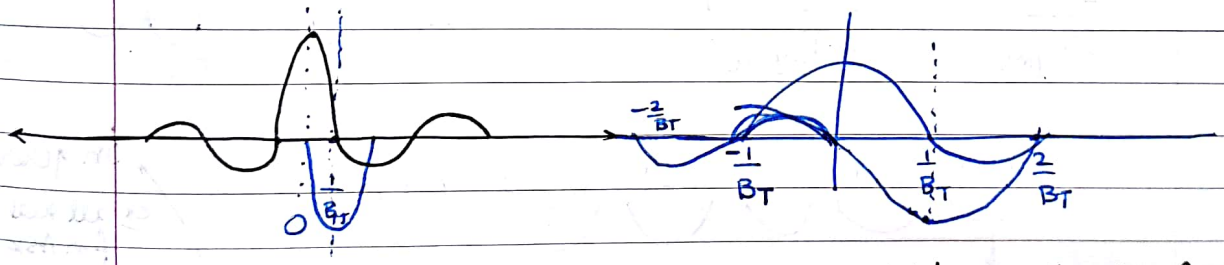
freq $\xrightarrow{ex}$ (Raised cosine filter) $\xrightarrow{\text{Impulse response}}$

Sinc like shape with faster Roll-offs / Decays

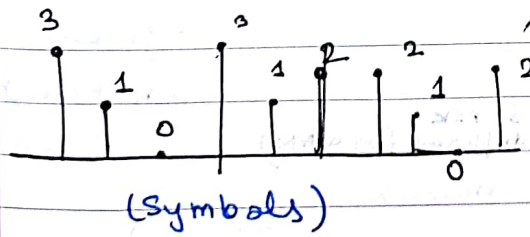
Nyquist filter




zero crossings are still at $n \cdot T_{symb}$ as before



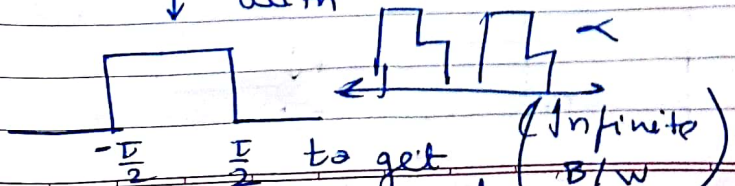

ex




(Discrete samples) → in AM we simply x Impulses with carriers

PSF → $\times \cos(2\pi f_c t)$ → ASK pass band signal

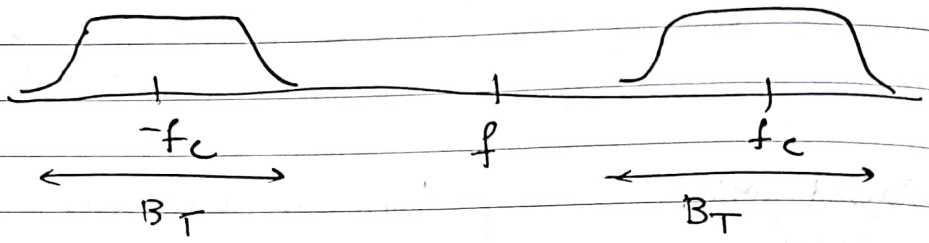
Can't convolve with




to get what we need

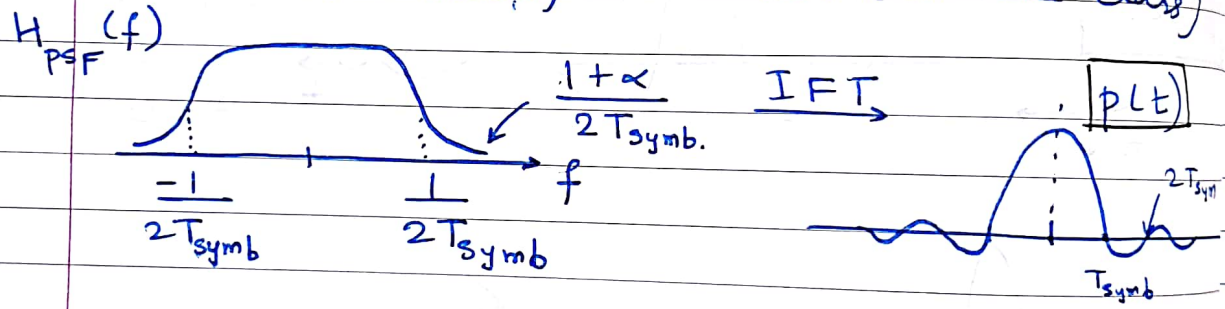
Page No.:
Date:

# Pass-Band Signal at one instant of time



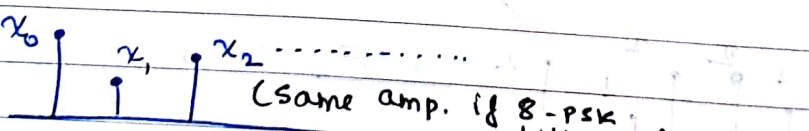

↳ Can be considered at one Instant or an an average

20.9.18 Quib Session: Wed 6-7pm, MS, Q1, Q2
Quiz (10 marks) on Thurs. (in the class)



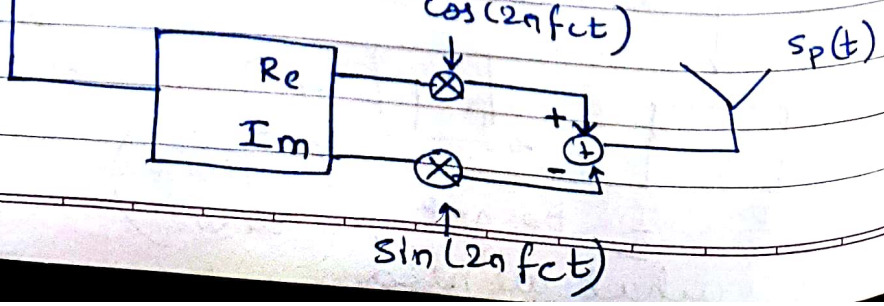

101 001 011 101 000 011

$x_0$ $x_1$ $x_2$ $x_3$ $x_4$ $x_5$ → Complex symbols (Constellation points

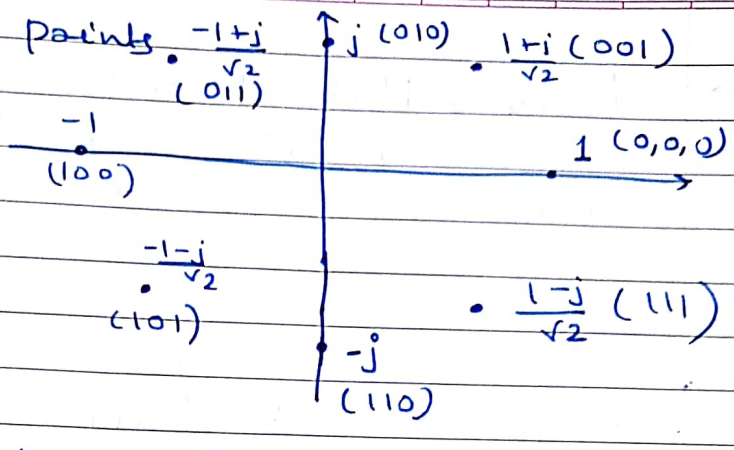



$$x_{BB}(t) = \sum x_k \, p(t - kT_{symb})$$

(complex)



ex of complex points



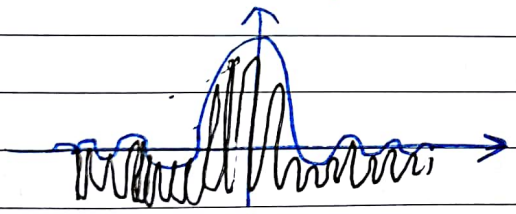

ex Transmit 101 : $\frac{-1-j}{\sqrt{2}}$

$$\text{Re}\left[\left(\frac{-1-j}{\sqrt{2}}\right) \times p(t) \times [\cos 2\pi f_c t + j \sin 2\pi f_c t]\right]$$

→ transmitted signal

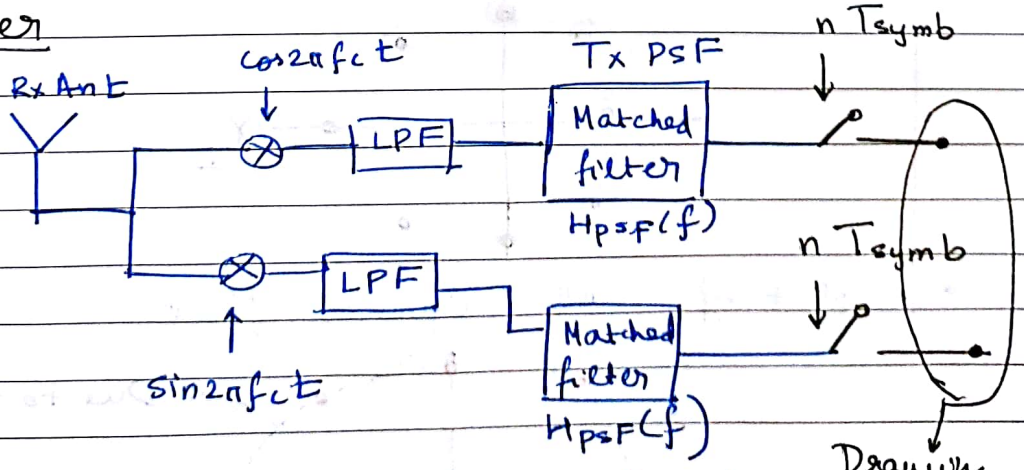
$$= \frac{p(t)}{\sqrt{2}} \left(-\cos 2\pi f_c t + \sin 2\pi f_c t\right)$$

→ envelope → determines phase



(Alignment requires pre-)

Receiver

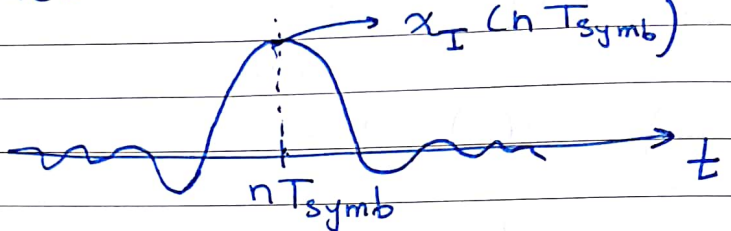


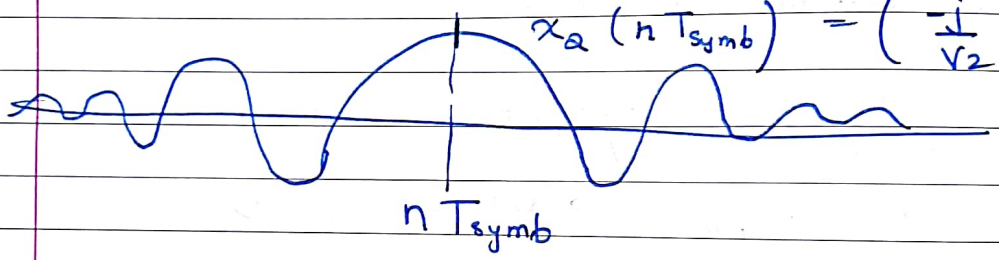

(Matched Filter : Gives best SNR)

→ Applying Matched filter in frequency domain is convolving with same sinc like time domain waveform ($p(t)$) with itself.

O/P

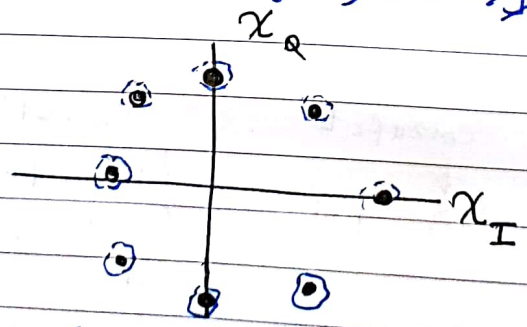
$\cos 2\pi f_c t$ Demod Channel



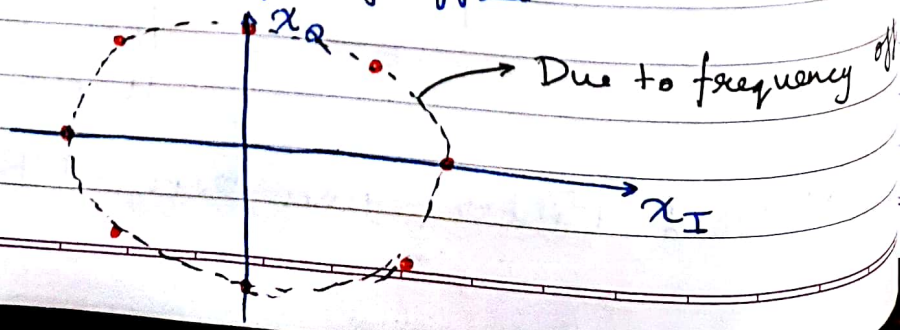




→ Received Complex Symbol

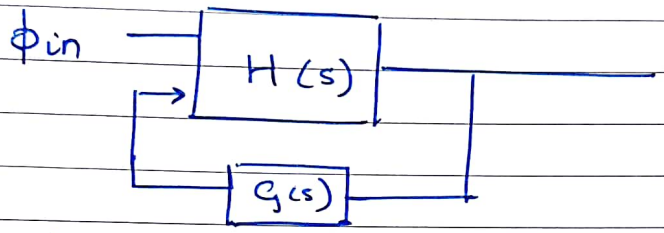
$= x_I(n T_{symb}) + j x_Q(n T_{symb})$




→ Effect of Small frequency offset :



- Solution: Precise Coherent detection,
  Coarse Adjustment: FLL (with Band-edge filters)
  Fine Adjustment: Costas Loop
  → Also does phase in addition to freq.
  → just like -ve feedback in op-amp

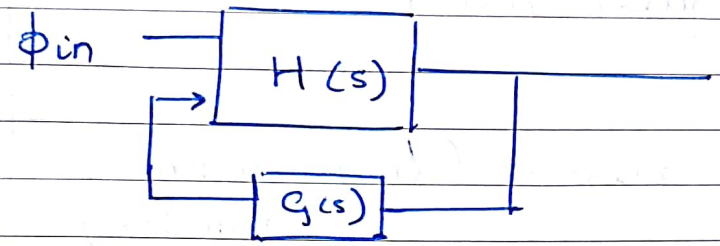



→ Sampling time issues

say $T_{sym} = 1\mu s$ & receiver → has $0.99\mu s$
even then as $n \uparrow$ $nT_{sym}$ will have a large mismatch

→ Precise $T_{symbol}$ matching important

- Solution: Precise Coherent detection,
  Coarse Adjustment: FLL (with Band-edge filters)
  Fine Adjustment: Costas loop
  → Also does phase in addition to freq.
  → just like -ve feedback in op-amp



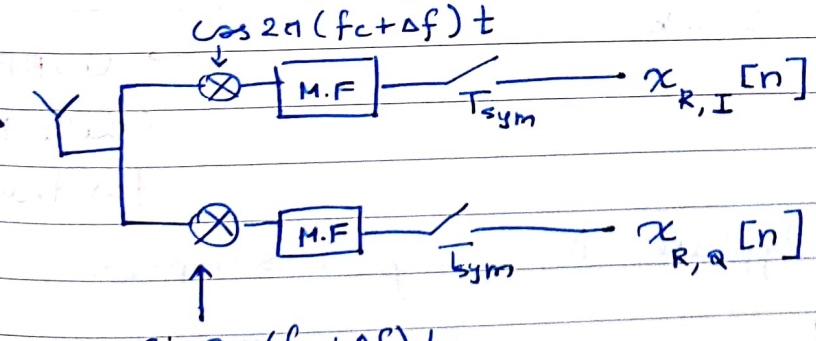

→ Sampling time issues

say $T_{sym} = 1\mu s$ & receiver → has $0.99\mu s$
even then as $n \uparrow$ $nT_{sym}$ will have a large mismatch
→ Precise $T_{symbol}$ matching important

24.9.18

## Carrier Phase / Freq. Offset

$$s_p(t) = Re[x_{BB}(t) \cdot e^{j2\pi f_c t}]$$



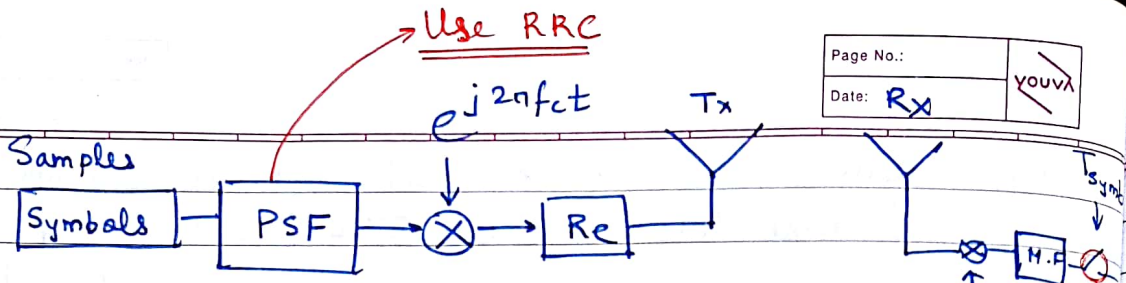

At $t = nT_s$

$x_I \cos(2\pi \Delta f t) + x_Q \sin(2\pi \Delta f t)$

$x_Q \cos(2\pi \Delta f t) - x_I \sin(2\pi \Delta f t)$

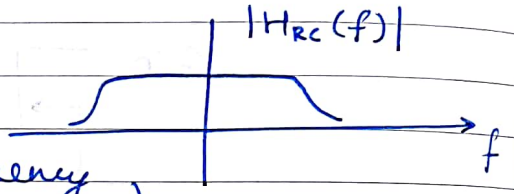
$\begin{bmatrix} x_2 \\ y_2 \end{bmatrix} = \begin{bmatrix} \cos t & \sin t \\ -\sin t & \cos t \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \end{bmatrix}$

· Can see it as Multiplication with Rotation Matrix




→ Issue: if we can't use a RC (raised cosine filter)

→ Recap: RC filter was a Nyquist filter

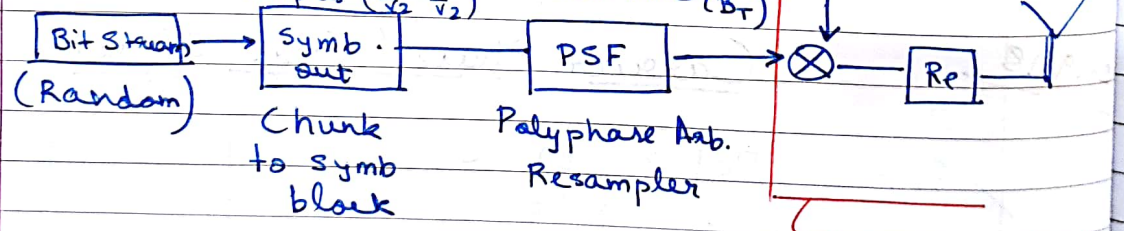



→ If we square it (In frequency domain)

· then we loose the No Interference at sampling point property

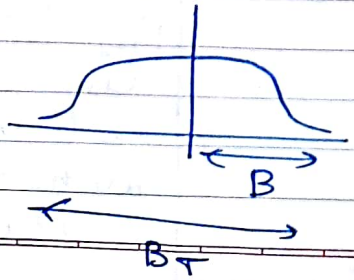
→ Solution: Root Raised Cosine (RRC) = $\sqrt{H_{RC}(f)}$

→ Implementation in GNU Radio



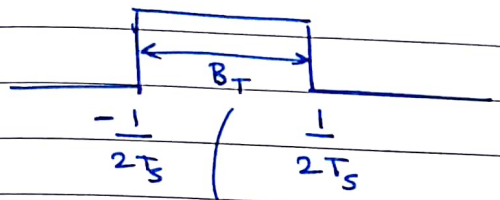

USRP block (like RTL-SDR for transmitter)

→ Using Polyphase Arbitrary Resampler

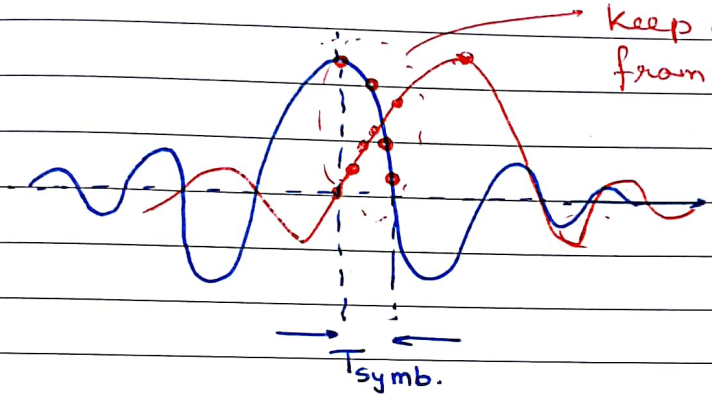



$f_s \geq 2B$

$f_s \geq B_T$




→ Best Case / Ideal




Keep on Adding samples from Shifting since waveforms

→ parameter: samples/symbol (sps)
= 4 here

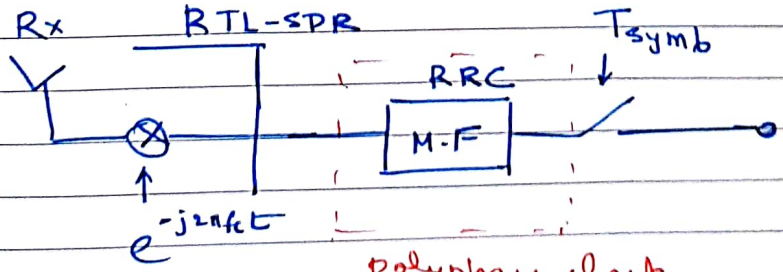
How to Choose sps = $f_s$

Nyquist Criterion : $f_s \geq B_T$

$$f_s \geq \frac{(1+\alpha)}{T_{symb}}$$

$\alpha$ : Excess Bandwidth factor

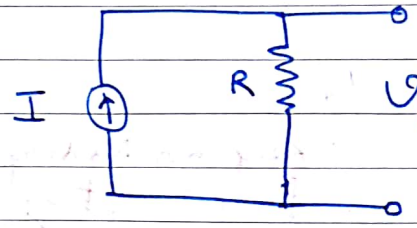
$\alpha \in (0.1, 0.4)$

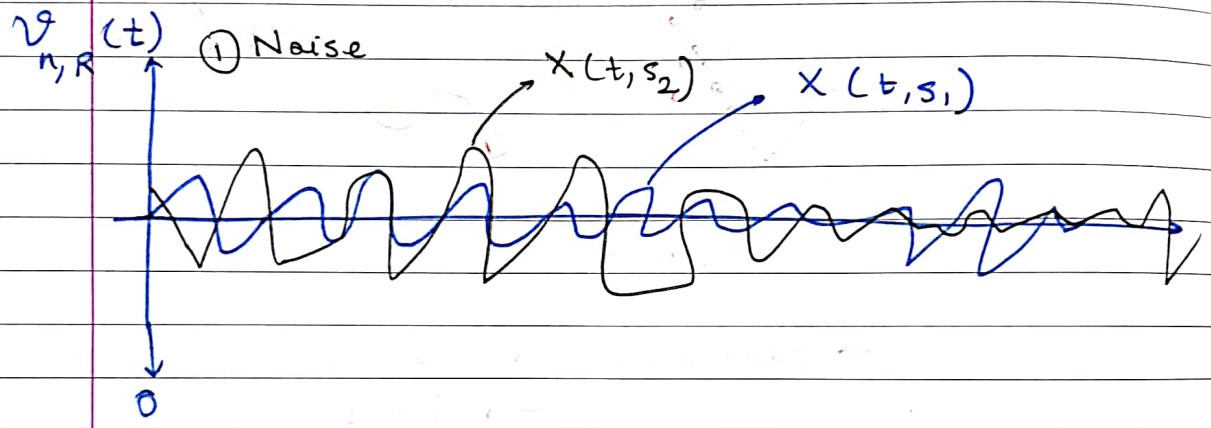



polyphase clock synchronizer

25.9.18

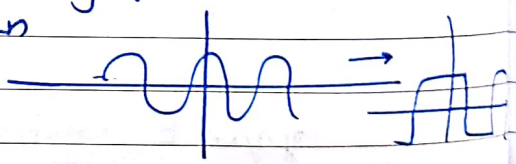
→ In Digital comm. FSK & PSK are interchangeable
(Derivative is Difference reasoning)




→ Other Distorting / Degrading processes

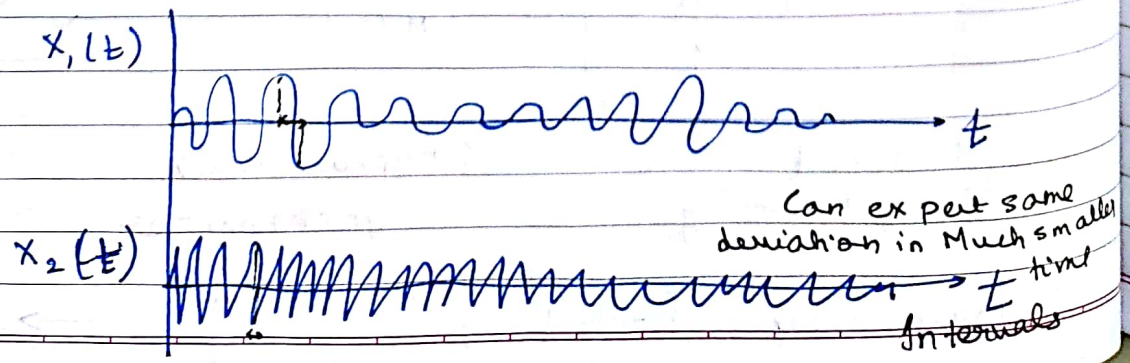
② Non-Linear Amplification



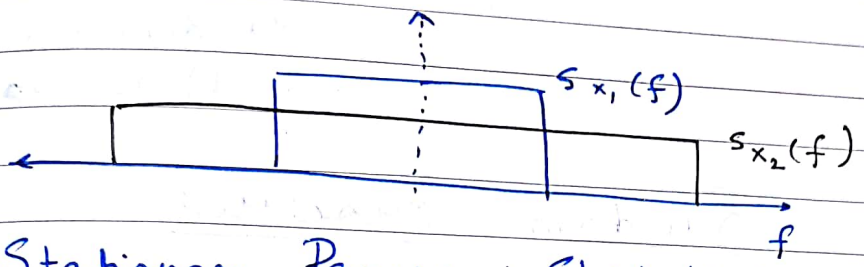
③ Interference

• Random Variables : $X_1(t_1), X(t_2), X(t_3)$ — Random var. (A unique RV for every time instant)

→ Time evolution of Random variables

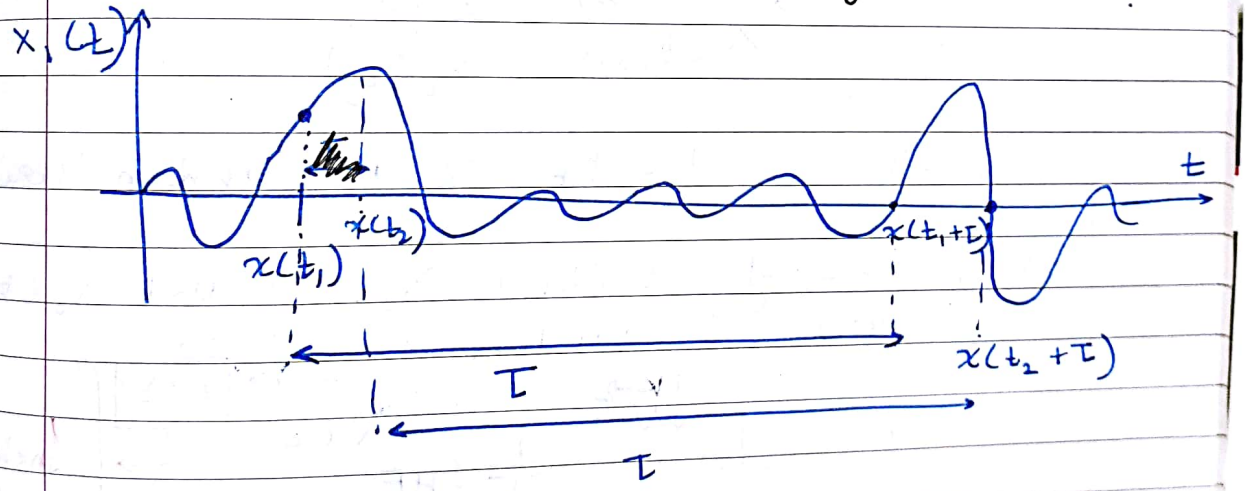


→ $X_1$ and $X_2$ may have same moments, but they are still different due to their frequency content




→ Stationary Process : Statistical properties don't change over time.

## Strict Sense Stationary




$X_2(t)$ : Similar :

→ If the joint distribution of

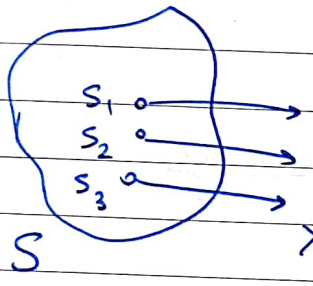
$$X(t) = \sin(2\pi f_0 t + \theta)$$

↳ If $\theta$ is a random number, then $X(t)$ is a R.P

27.9.18

## Random Processes

$X(t,s) = X(t)$ ↳ shorthand for $X(t,s)$



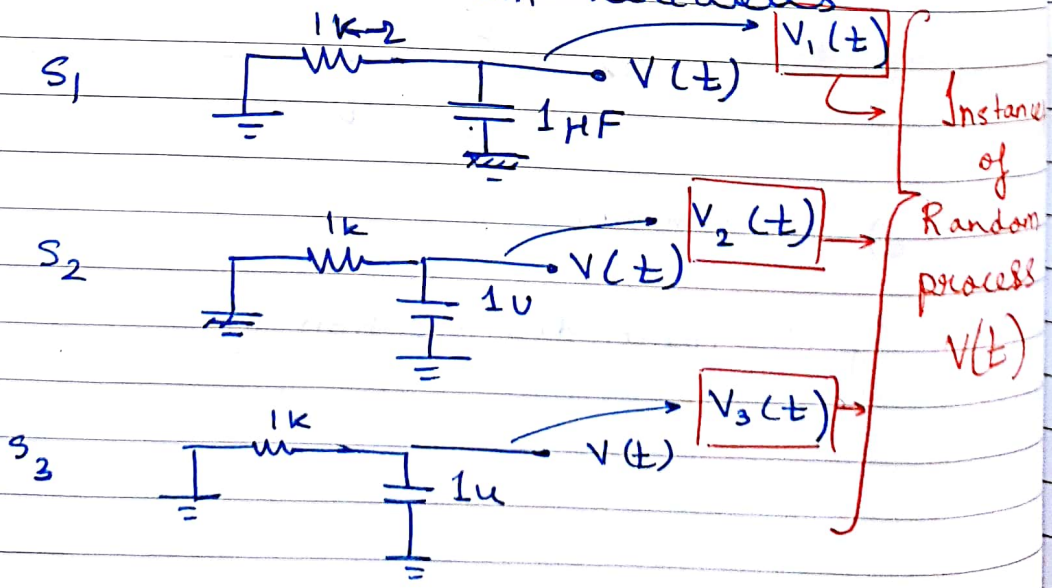

$X(t,s_1) = X_1(t)$

$X(t,s_2) = X_2(t)$

$X(t,s_3) = X_3(t)$

- $X(t)$ at $t = t_k$ is a Random Variable

i.e, all 3 of $X_1(t_k)$, $X_2(t_k)$ and $X_3(t_k)$ are 3 random variables




- $V(t_k)$ : A Random variable with instances $V_i(t_k)$

Each time instant is associated with a Random Variable

→ ~~$V_i(t)$~~ $X_i(t)$ is a waveform, inst. of Rand. Process.

→ Density & Distribution for Random processes

→ R.V : $X(t_k)$ :

$$\mu_x(t_k) = \mathbb{E}[X(t_k)]$$

· Stationary Process $\Rightarrow$ $\mu_x(t_k) = \mu_x \ \forall t_k$

one way implication

· ~~In General~~ : Strict Sense Stationary

$$F_{X(t_1), X(t_2), \ldots, X(t_k)}(x_1, x_2, \ldots, x_k) =$$

$$F_{X(t_1+\tau), X(t_2+\tau), \ldots, X(t_k+\tau)}(x_1, x_2, \ldots, x_k)$$

for every $\tau$

and $\forall k$

→ Why do we need joint Distribution?

→ The Marginal / Individual Distribution is constant at all points, but PSD changed with time