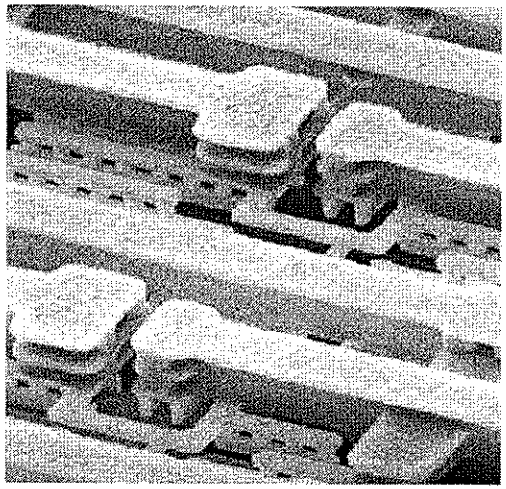
6.02 Lecture 2 - Wires and Models

(Afternotes and Examples)

- Non-Ideal Transmission
  - Example wires and signal impact
  - Intersymbol Interference
  - Eye Diagrams
- Modeling Wires
  - Causality
  - Time-invariance
  - Linearity
- SUPERPOSITION
  - Demonstrating why it is so super

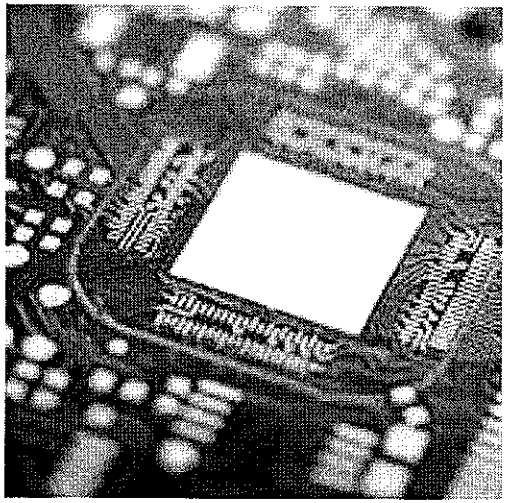
Types of Real "Wires"

IC Interconnect



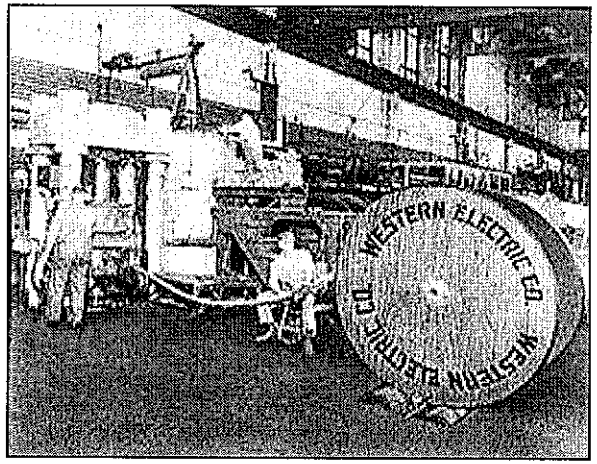
http://materials.usask.ca/images/photos/SEMof3LevelCuInterconP98.GIF

Printed Circuit Board



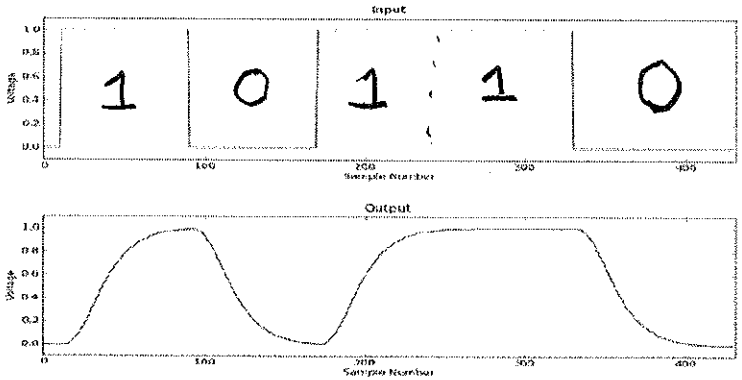
http://www.gpv-pcb.com/Files/Billeder/fabrikker/chemitalic/Chem_pcb_hdi.jpg

Transatlantic Cable

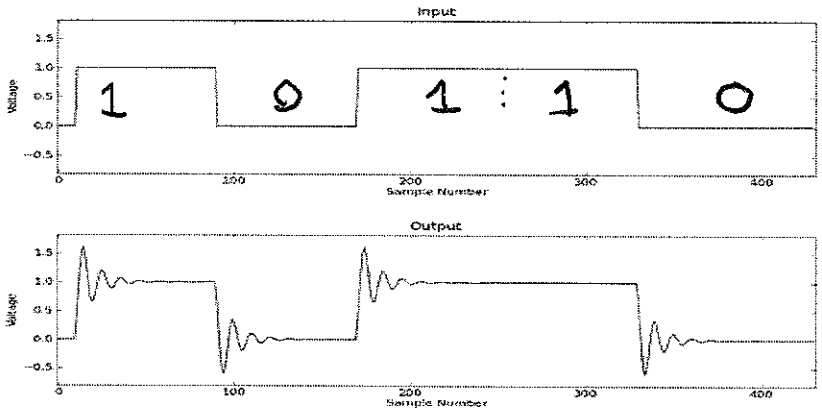


http://www.satamerica.com/imagens/4a27897r1.jpg

Slow Response



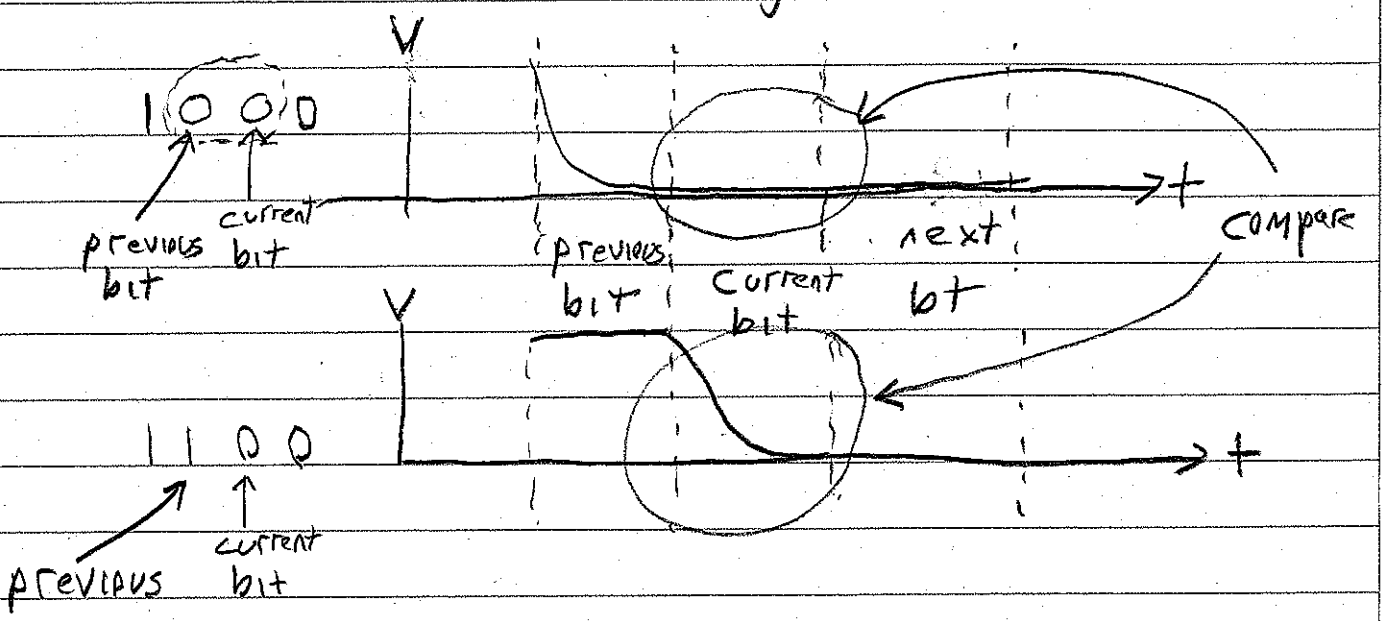
Ringing



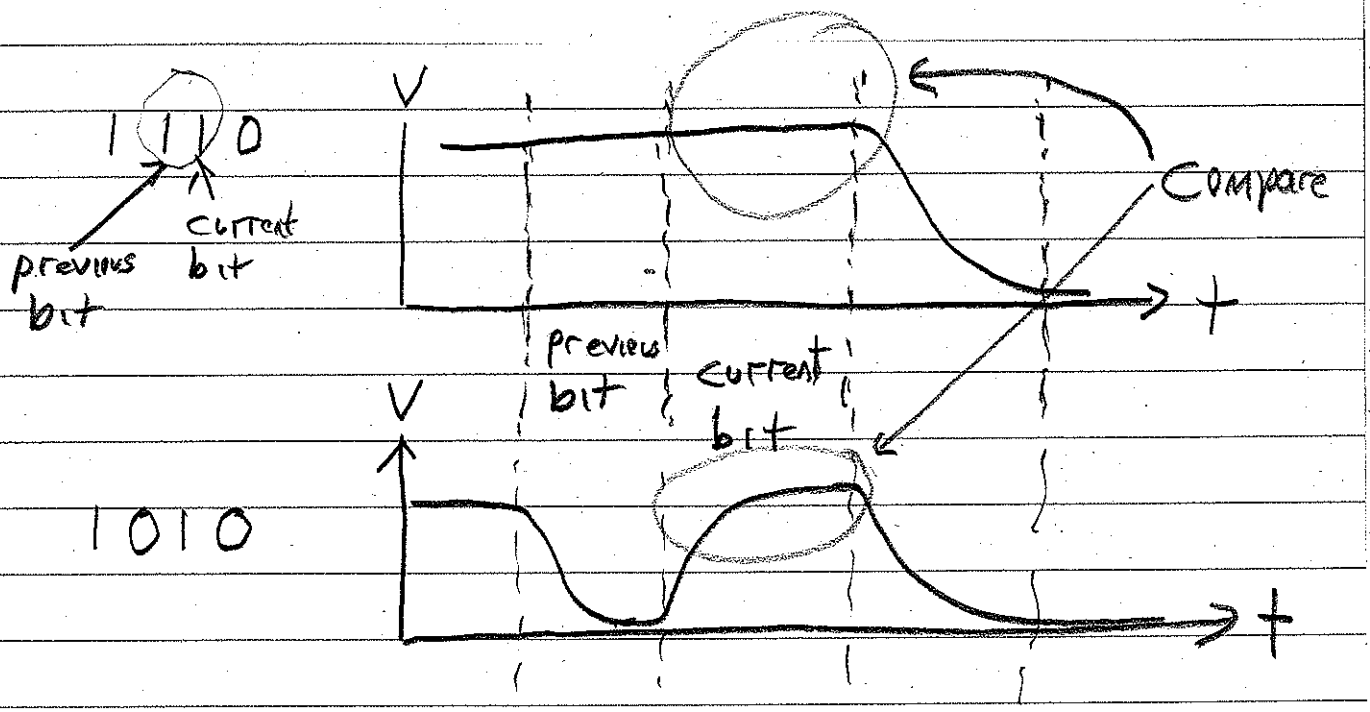
May also have long delays (Receiver does NOT know)

Intersymbol Interference - Slow Channel

- Consider Transmitting Two bits



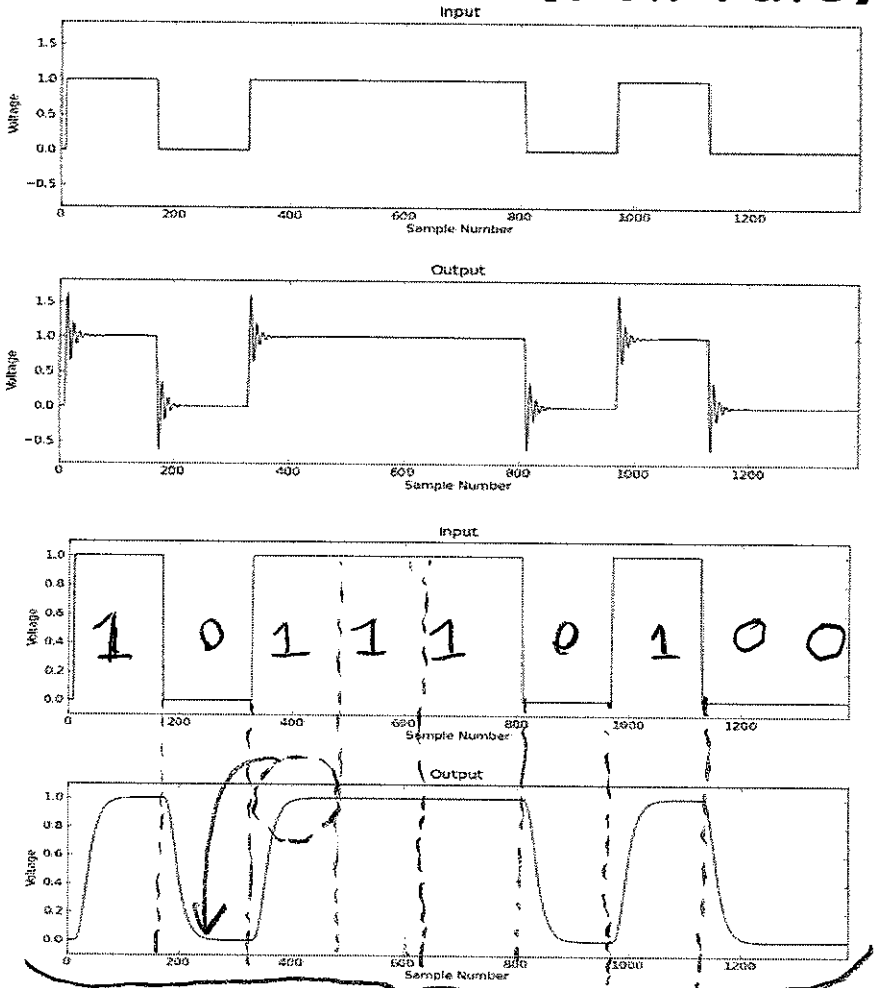
That the previous bit was a one "interferes" with the current bit being a zero



Previous bit = zero interferes with Current bit = 1

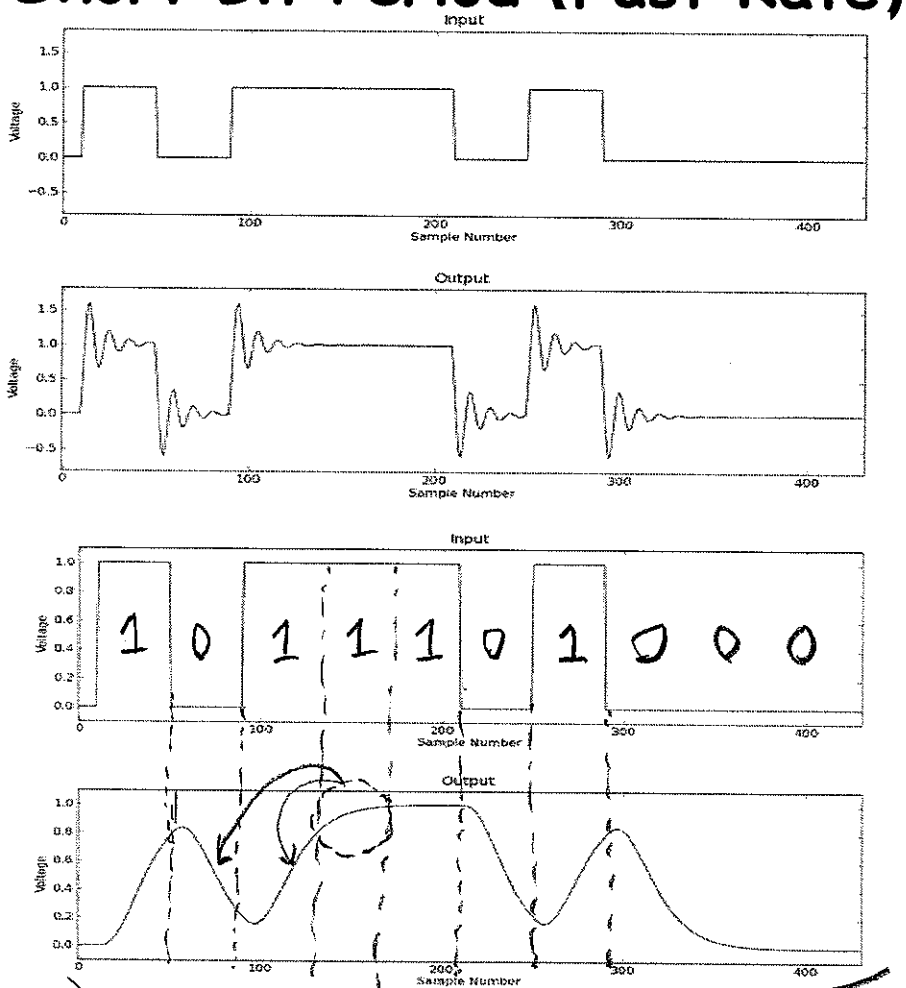
Intersymbol Interference

Long Bit Period (slow rate)



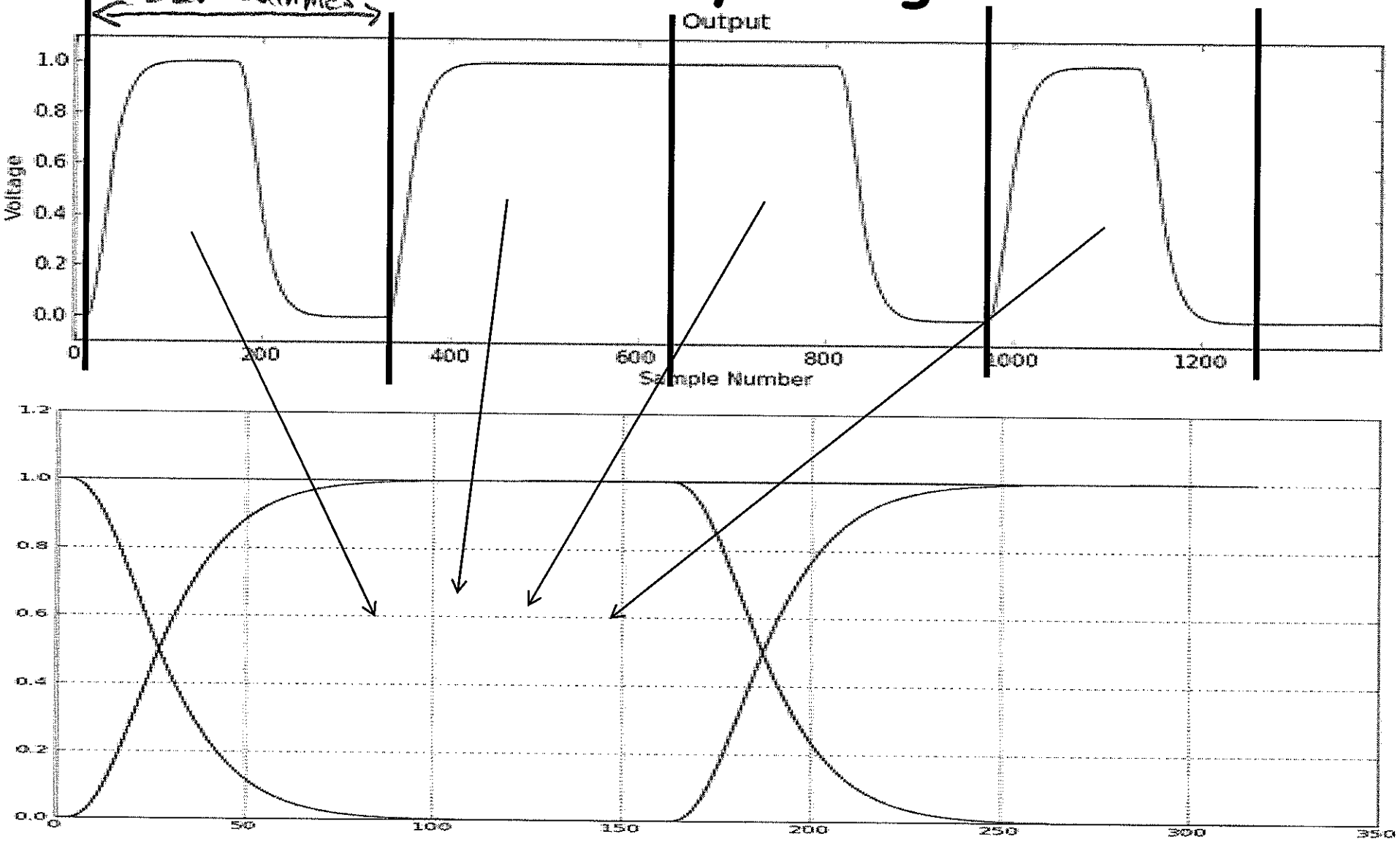
Only previous bit interferes

Short Bit Period (Fast Rate)



Previous two bits interfere.

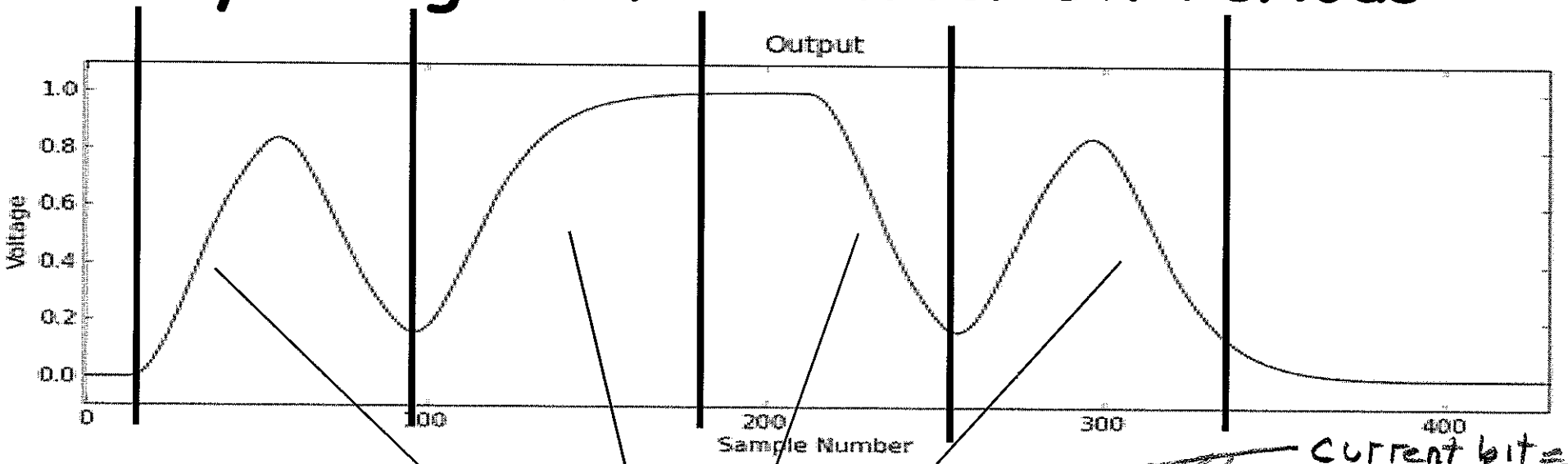
Generate Eye Diagram

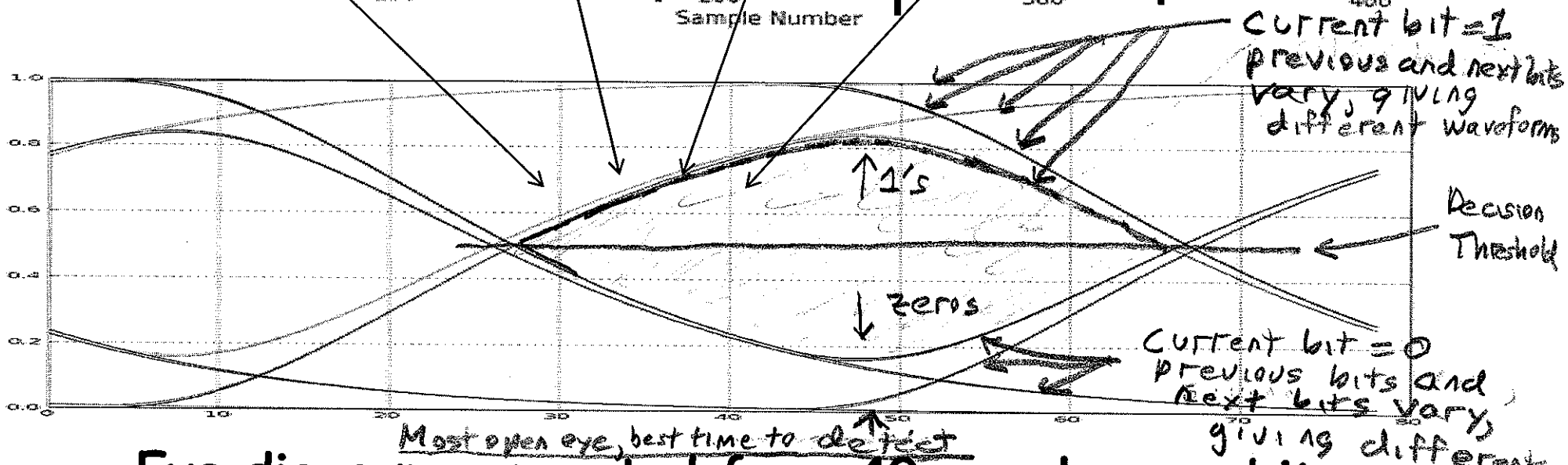


Eye Diagram Generated with 160 samples per bit

Overlap voltage waveforms from every two-bit period section.

Eye Diagram for Shorter Bit Periods

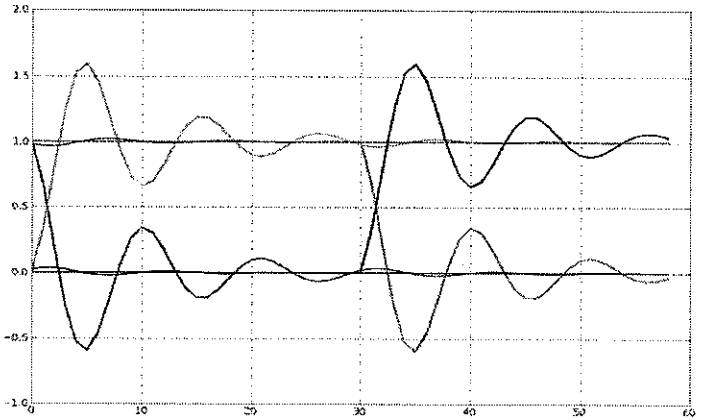




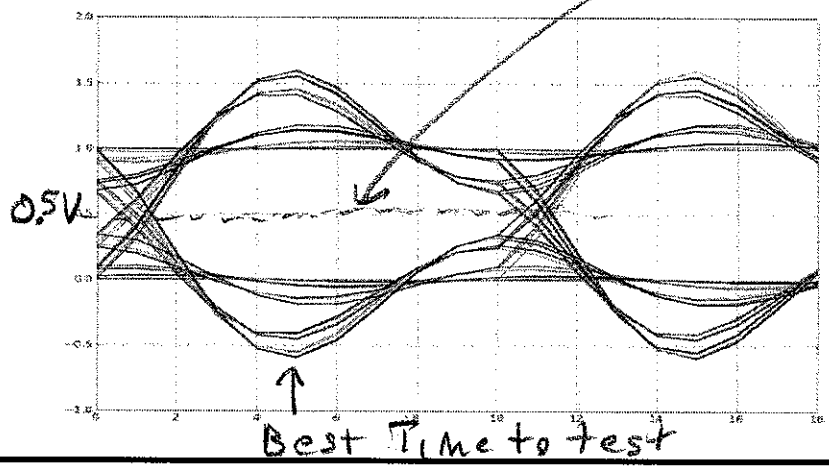
Eye diagram generated from 40 samples per bit and using a 200 bit long random sequence.

Eyes for Ringing versus Slow System

Medium Bit Period



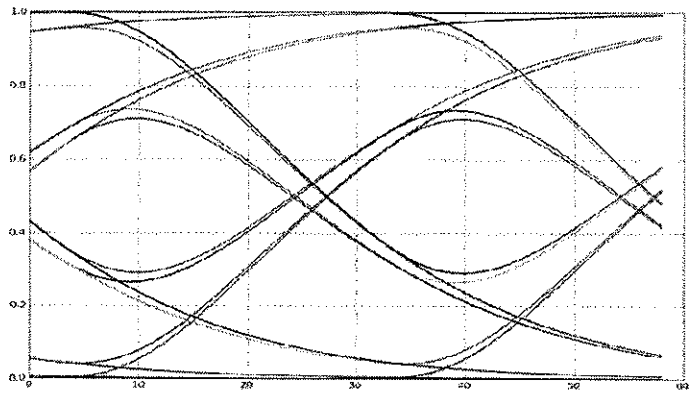
Short Bit Period

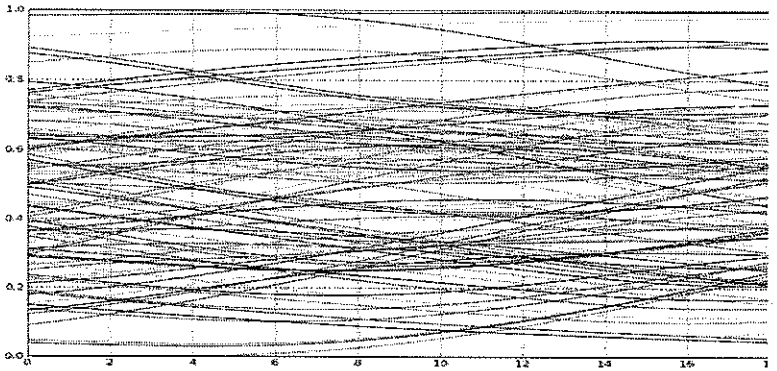


Simple Threshold Detector will determine current bit.

Ringing

Slow

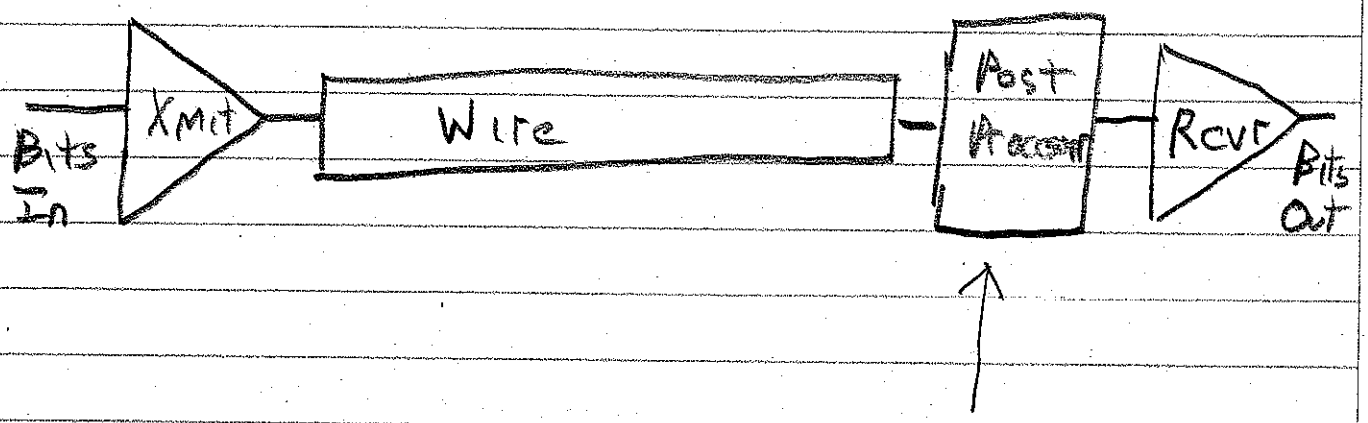




Non ideal Wires Create Intersymbol Interference

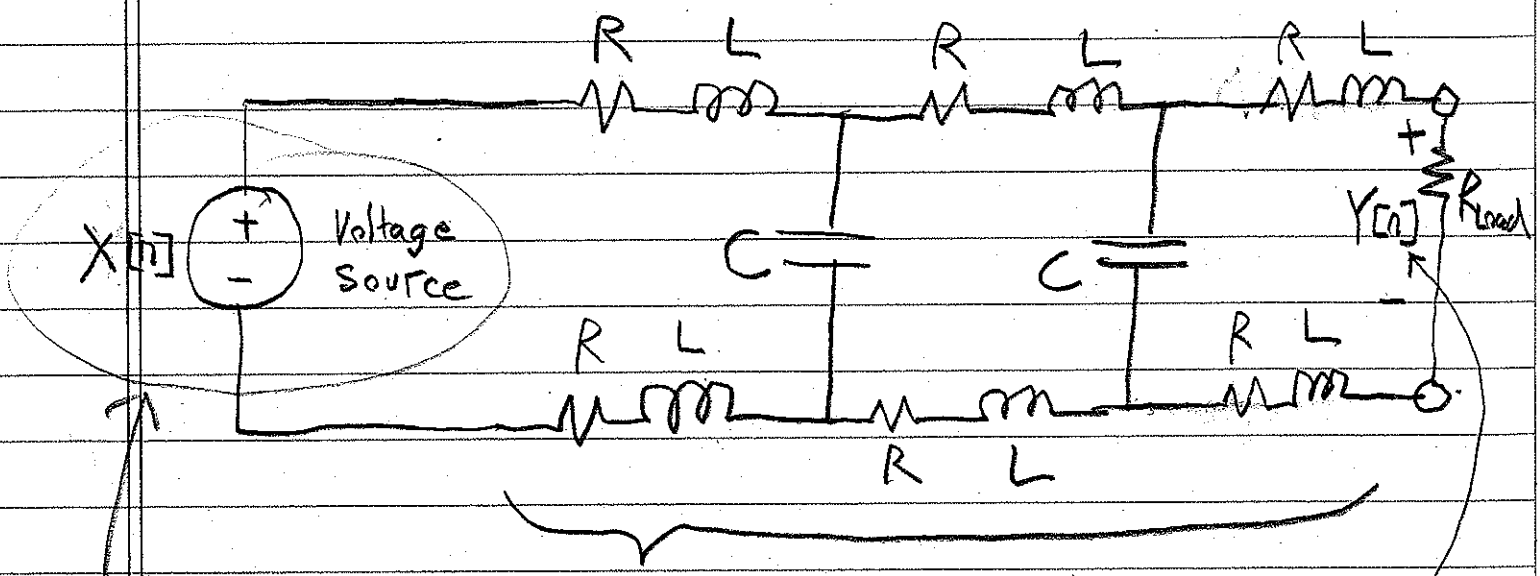
- Makes detecting bits more difficult
- Limits the bits/second that can be transmitted accurately.

Can we post-process the signal from the wire to improve performance?

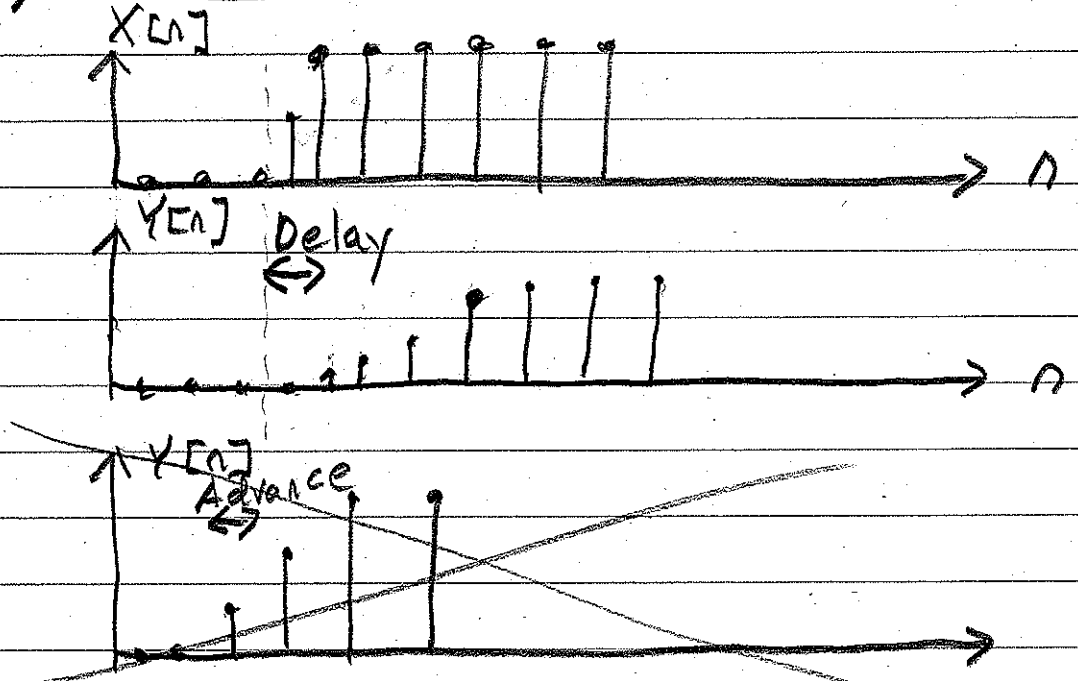


Need a model of the wire to design a post-processor

Example Model of a Physical Wire



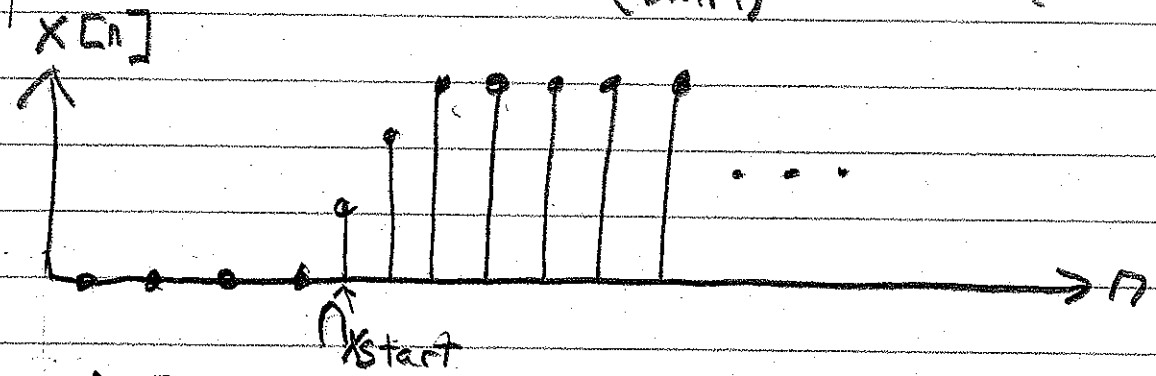
1) Wires are Causal

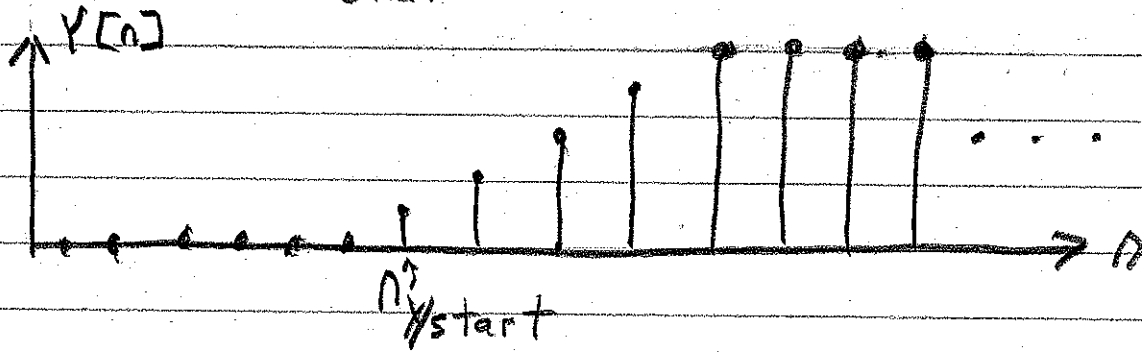


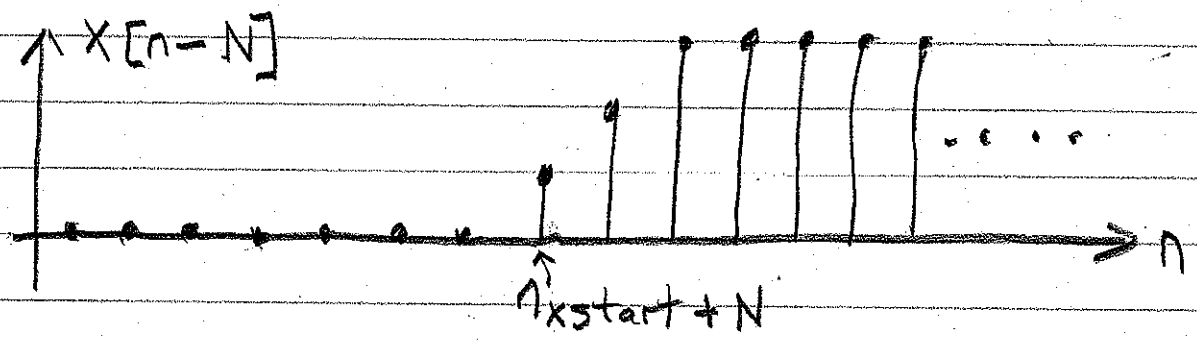
Wires can not predict the future!

A change in X causes a change in Y

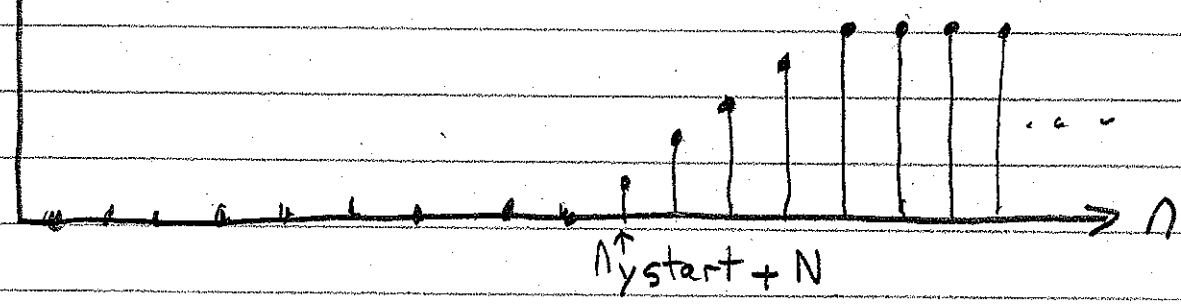
2) Wires are Time-Invariant (Shift)



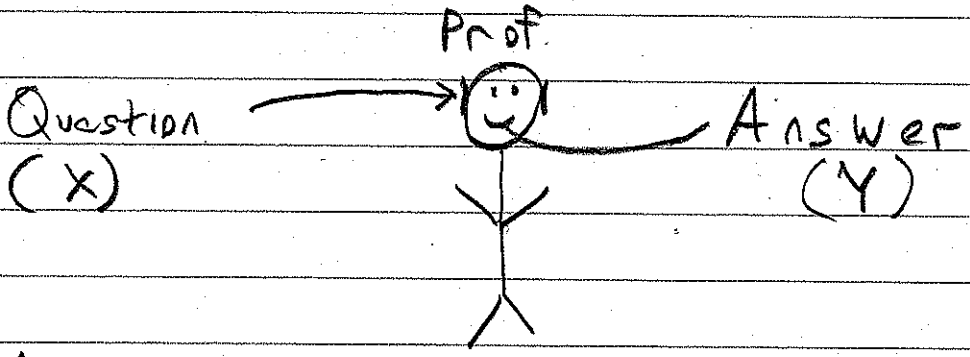




y[n-N] ← A time-shifted input produces a time-shifted output

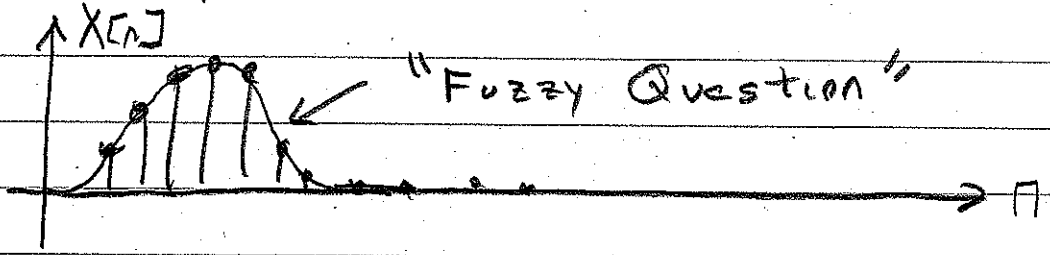


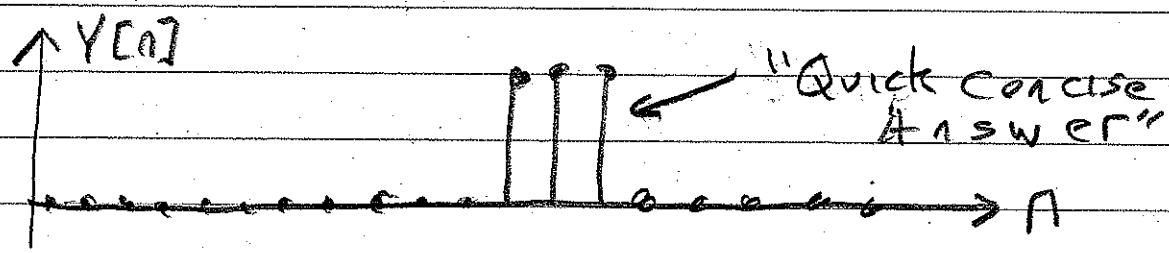
A Non Time Invariant System



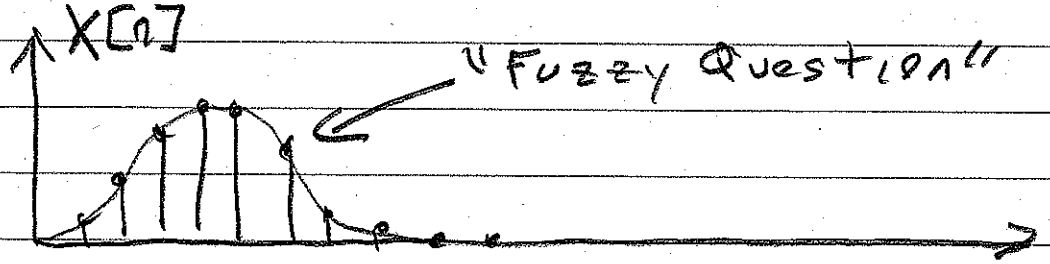
Time Varying System

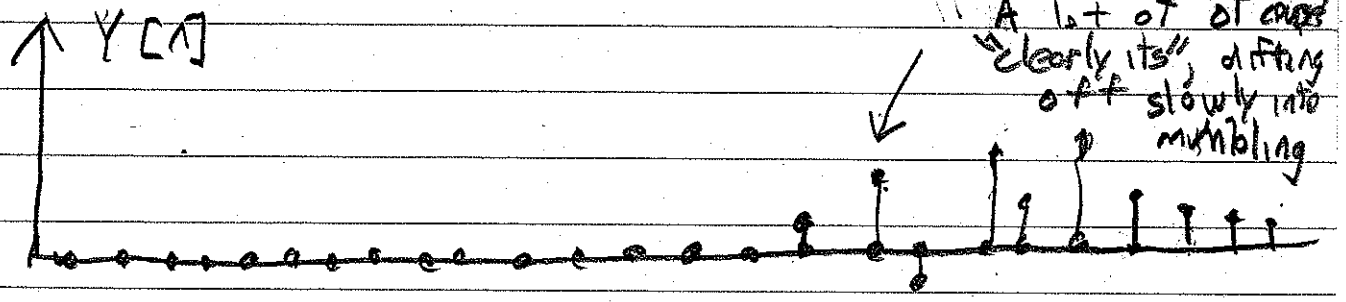
At 3 pm





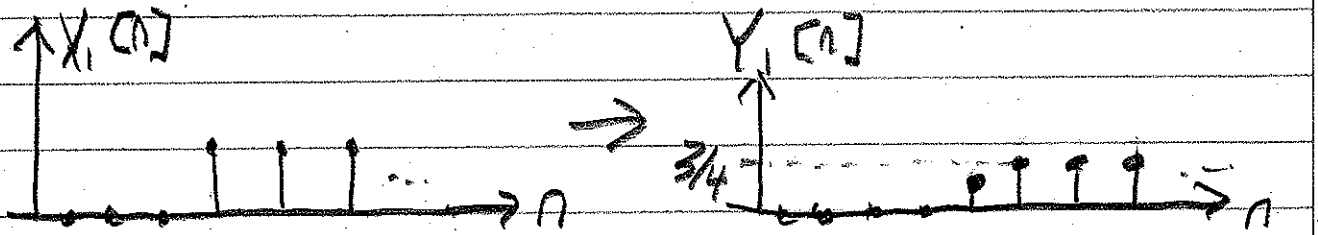
At 9 pm

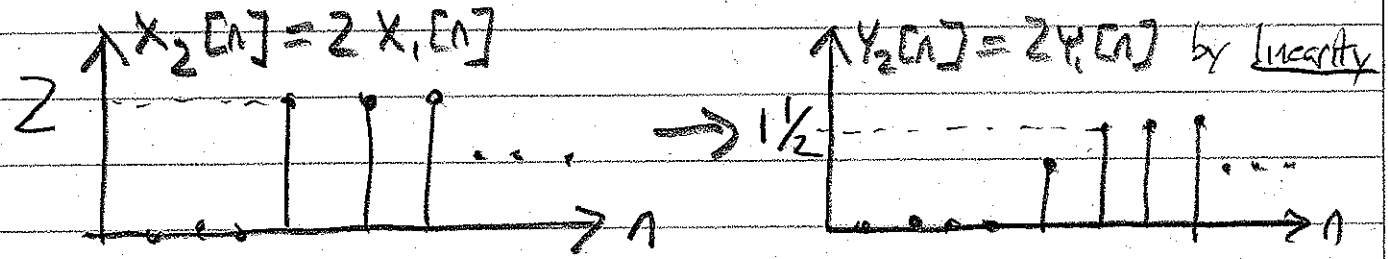




3) Linearity (A Strong Assumption!)

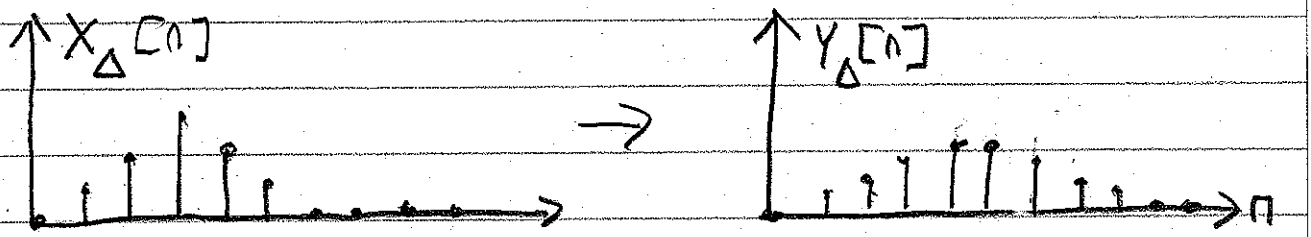
3a) Scaling

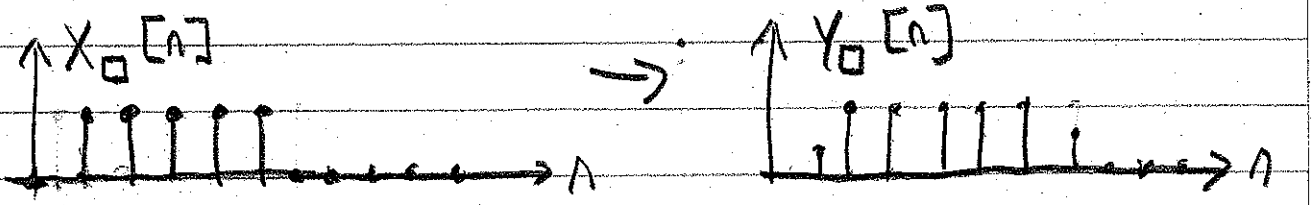


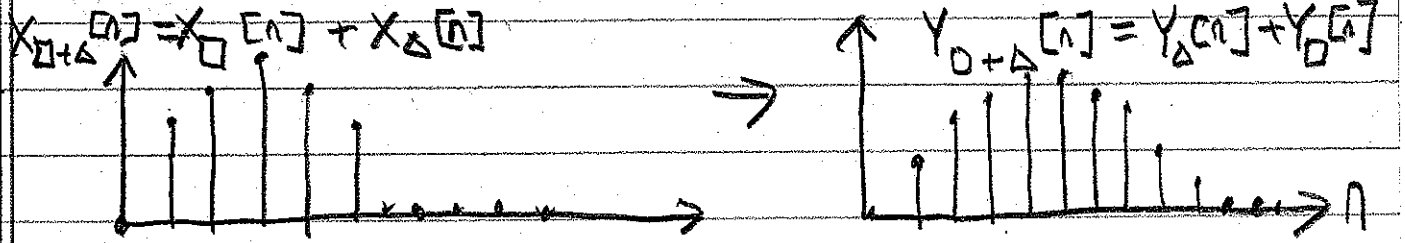


Scale Inputs → Scaled Outputs

3b) Sum Inputs → Sum Outputs

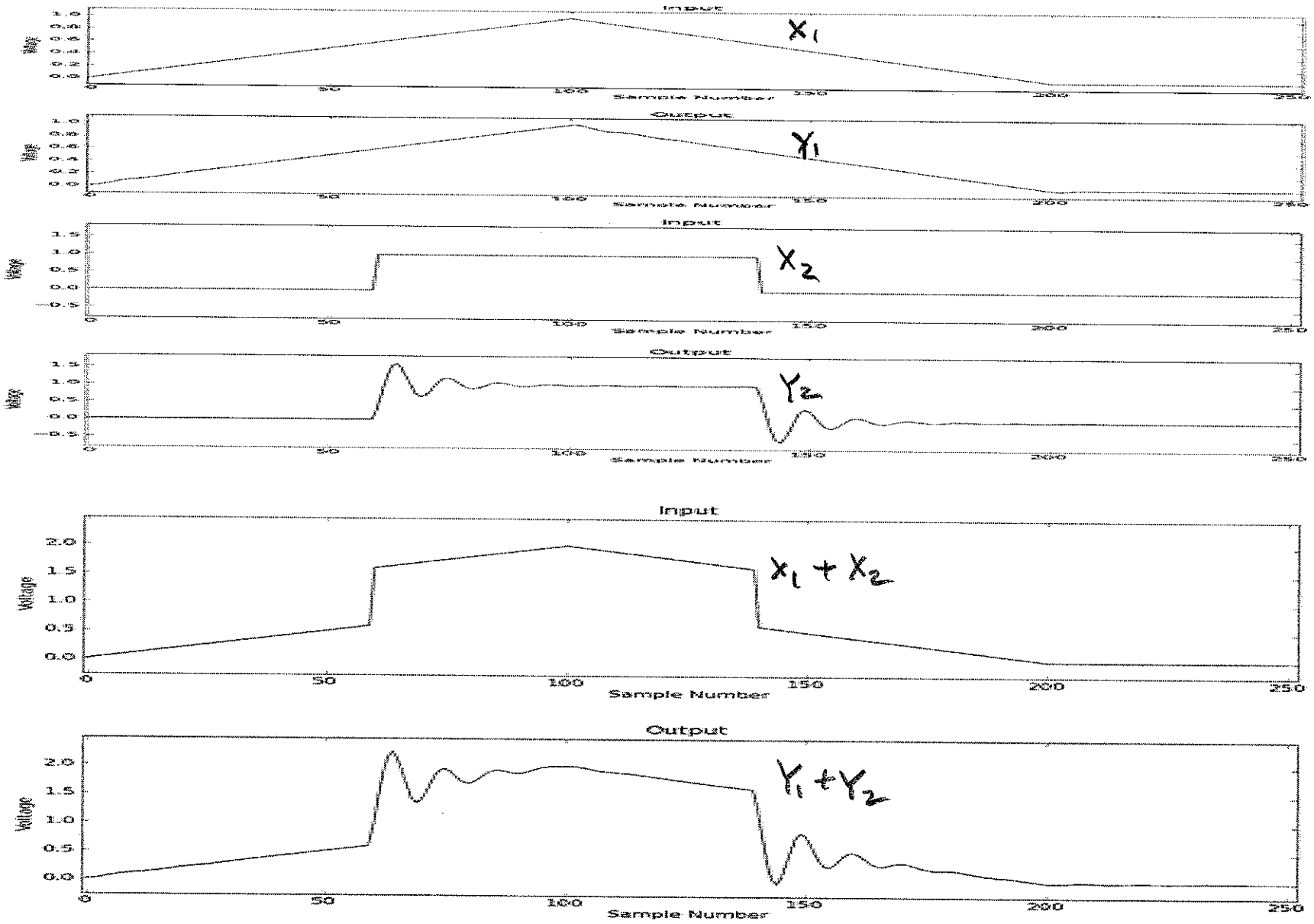






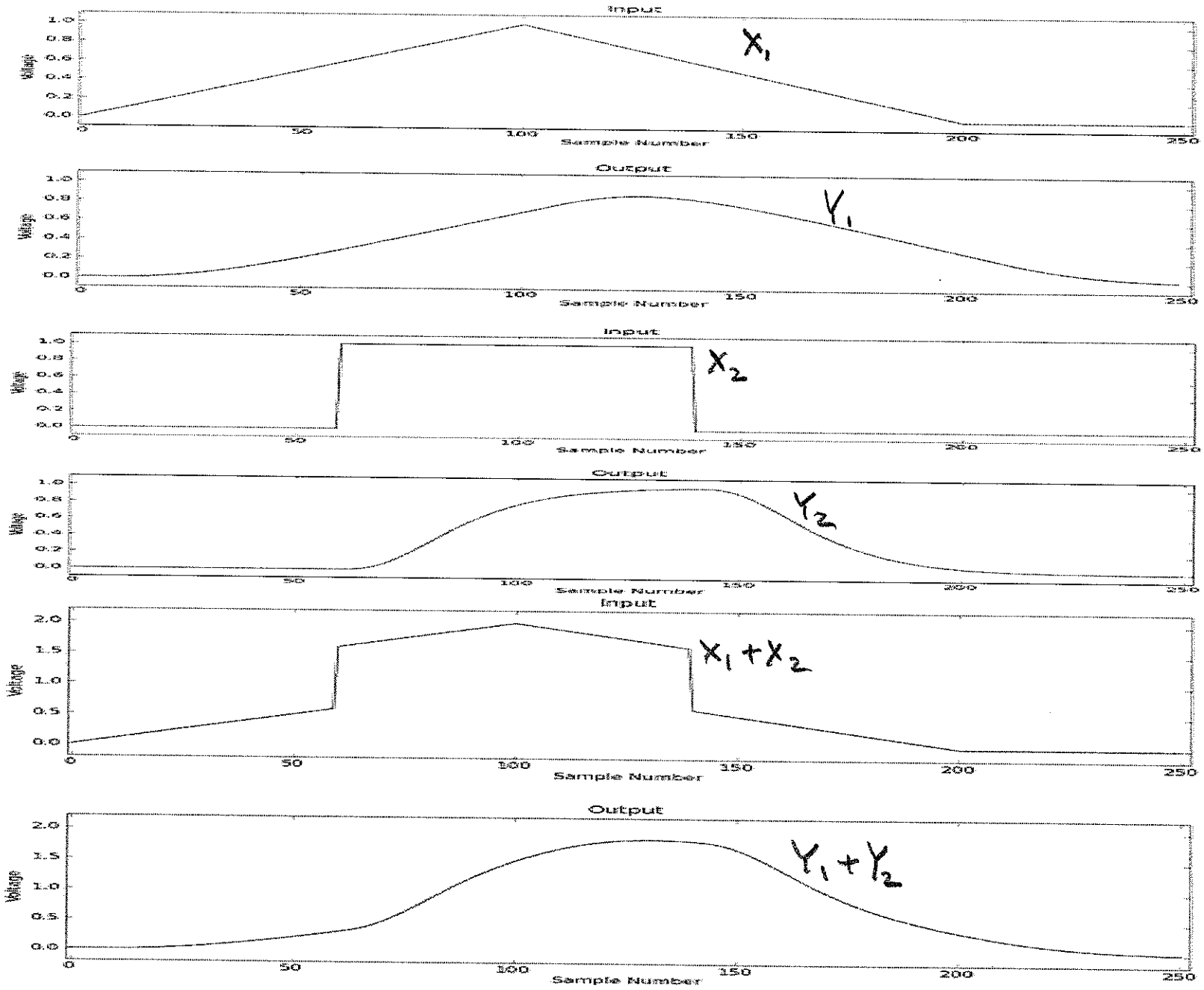
Superposition

RINGING SYSTEM



Superposition

SLOW SYSTEM



Linear Time Invariant Systems

Examples

LTI

$x_1[n] \rightarrow [\text{LTI}] \rightarrow y_1[n]$

$x_2[n] \rightarrow [\text{LTI}] \rightarrow y_2[n]$

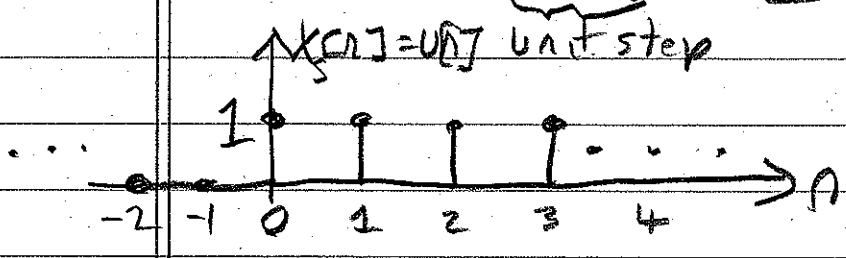
$\Rightarrow A x_1[n-N_A] + B x_2[n-N_B]$

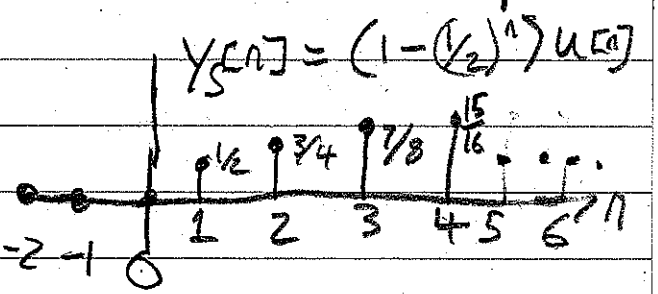
$\rightarrow [\text{LTI}]$

$\rightarrow A y_1[n-N_A] + B y_2[n-N_B]$

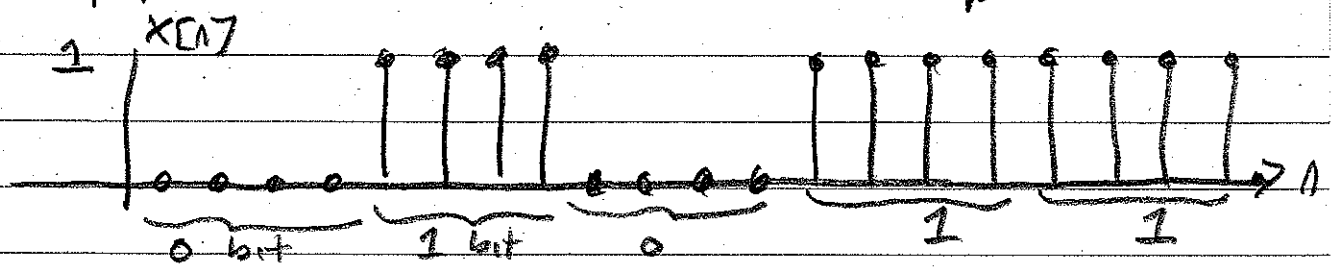
Example - Unit Step Responses

$x_3[n] = u[n] \rightarrow [\text{LTI}] \rightarrow y_3[n] =$ unit step response





Suppose $x[n] =$ $\quad y[n] = ?$



Rewriting $x[n]$

$$x[n] = u[n-4] - u[n-9] + u[n-13] - u[n-21]$$

$$\Rightarrow y[n] = y_s[n-4] - y_s[n-9] + y_s[n-13] - y_s[n-21]$$

$$= \left(1-\left(\tfrac{1}{2}\right)^{(n-4)}\right)u[n-4] - \left(1-\left(\tfrac{1}{2}\right)^{(n-9)}\right)u[n-9] + \left(1-\left(\tfrac{1}{2}\right)^{(n-13)}\right)u[n-13] - \left(1-\left(\tfrac{1}{2}\right)^{(n-21)}\right)u[n-21]$$