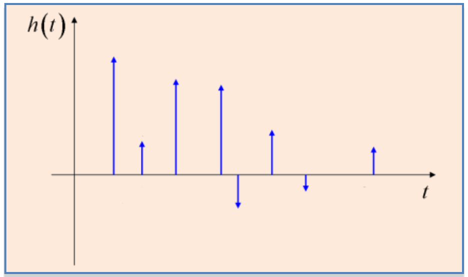
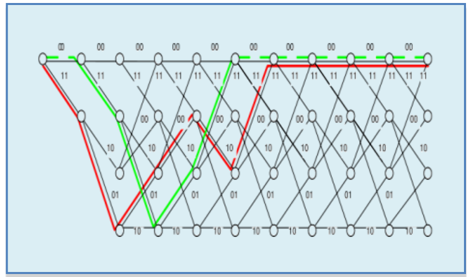
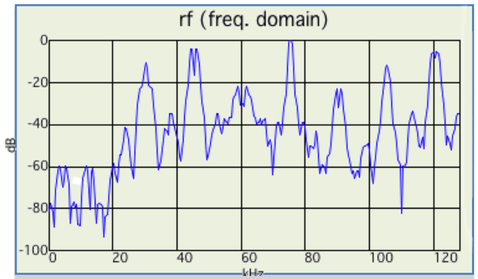
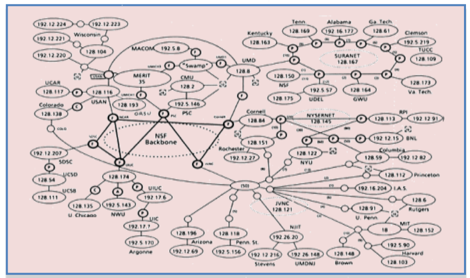








INTRODUCTION TO EECS II

DIGITAL COMMUNICATION SYSTEMS

6.02 Fall 2010
Lecture #2

- Samples and Bits
- Real Wires
- Models
- Linearity and Superposition

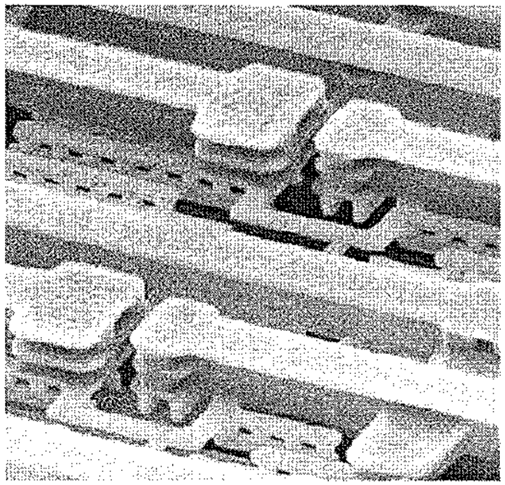
6.02 Lecture 2 - Wires and Models

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

2

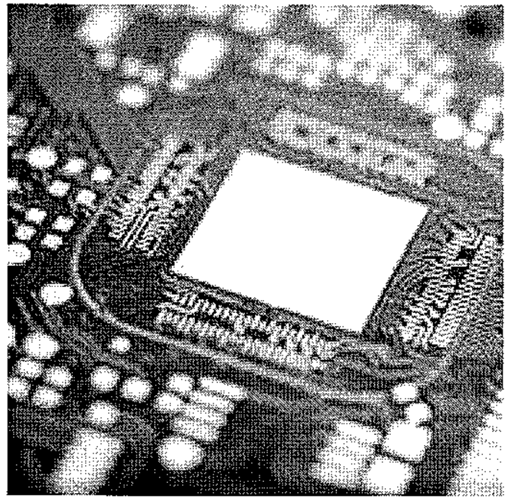
Types of Real "Wires"

IC Interconnect



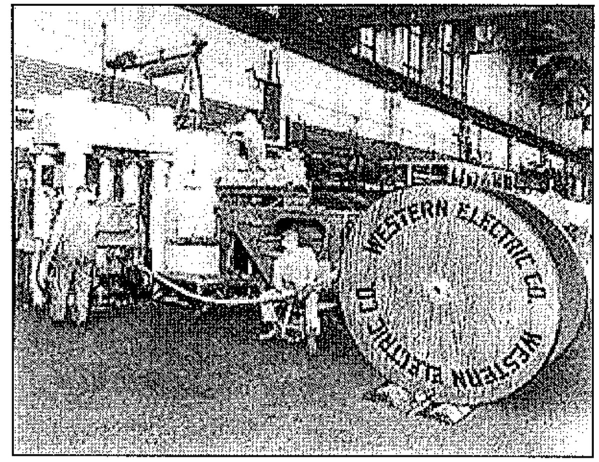
http://materials.usask.ca/images/photos/SEMof3LevelCuInterconP98.GIF

Printed Circuit Board



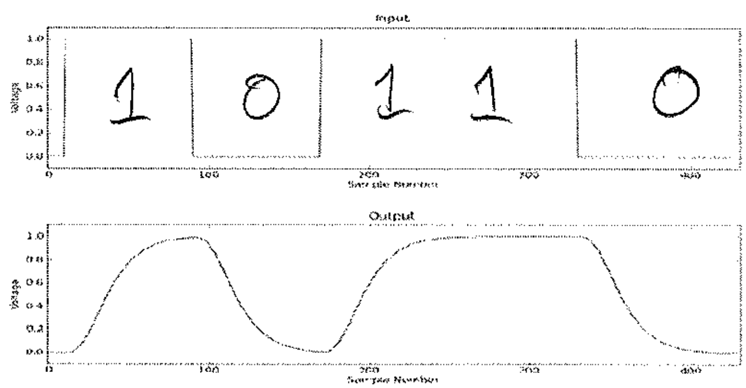
http://www.gpv-pcb.com/Files/Billeder/fabrikker/chemitalic/Chem_pcb_hdi.jpg

Transatlantic Cable

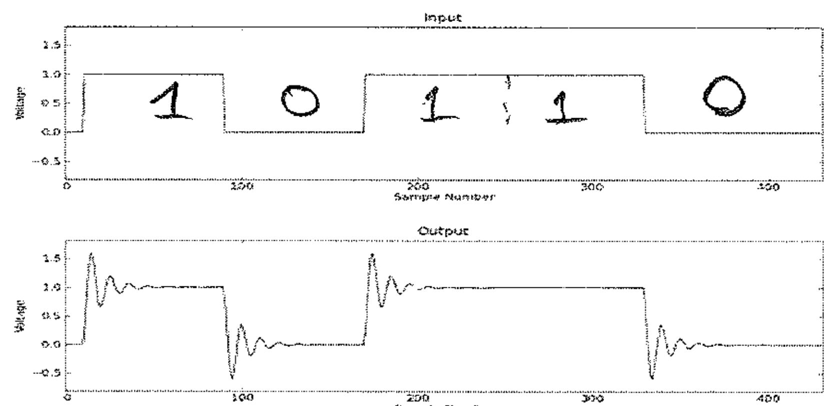


http://www.satamerica.com/imagens/4a27897r1.jpg

Slow Response



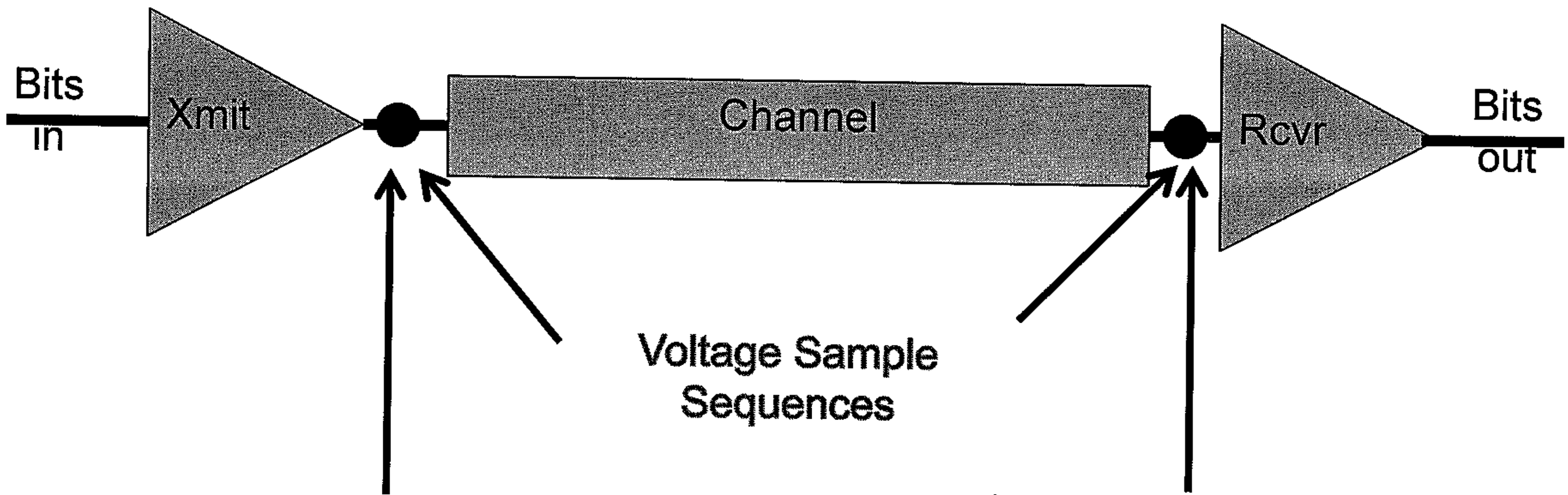
Ringing



May also have long delays (Receiver does NOT know)

3

Transmission Setup and Notation



$X \equiv$ entire sequence

$x[n] \equiv n^{th}$ sample value

$Y \equiv$ entire sequence

$y[n] \equiv n^{th}$ sample value

Sample Rates:

- 4 million Samples/Second (IR Transceiver)
- Up to gigaSamples/Second (Fastest)

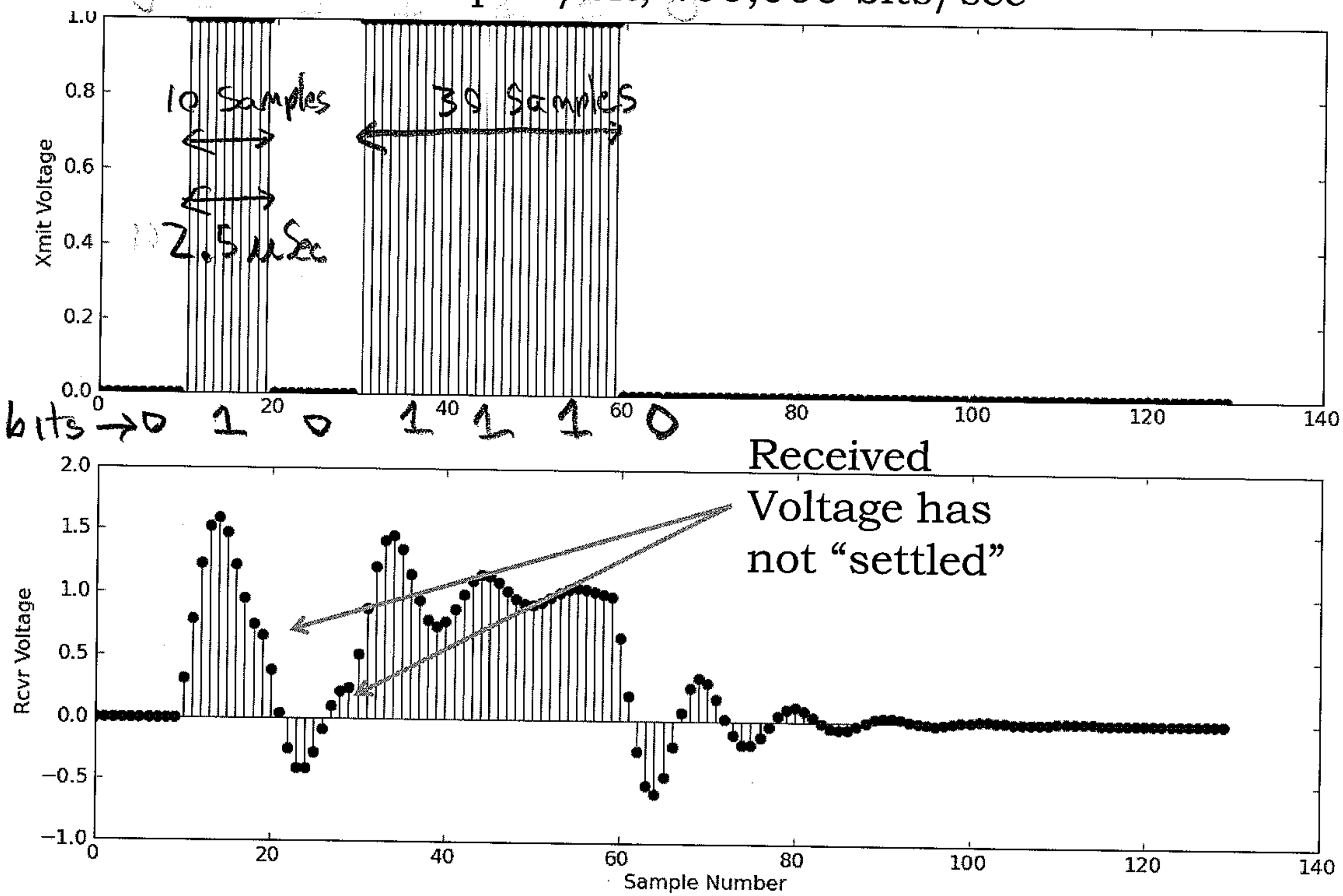
Samples, Bit Period, Bit Rate

4

- Our Hardware
  - Updates transmitter output voltage every ¼ microsecond (4 million times a second).
  - Remeasures receiver voltage every ¼ microsecond (4 million times a second).
- Bit Period and Bit Rate
  - BP = Samples/bit * ¼ microsecond
  - BR = Bits transmitted per second
  - BR = (4 million) / (Samples/bit)
- Slower Bit Rate = Longer Bit Period
  - More time to propagate through channel

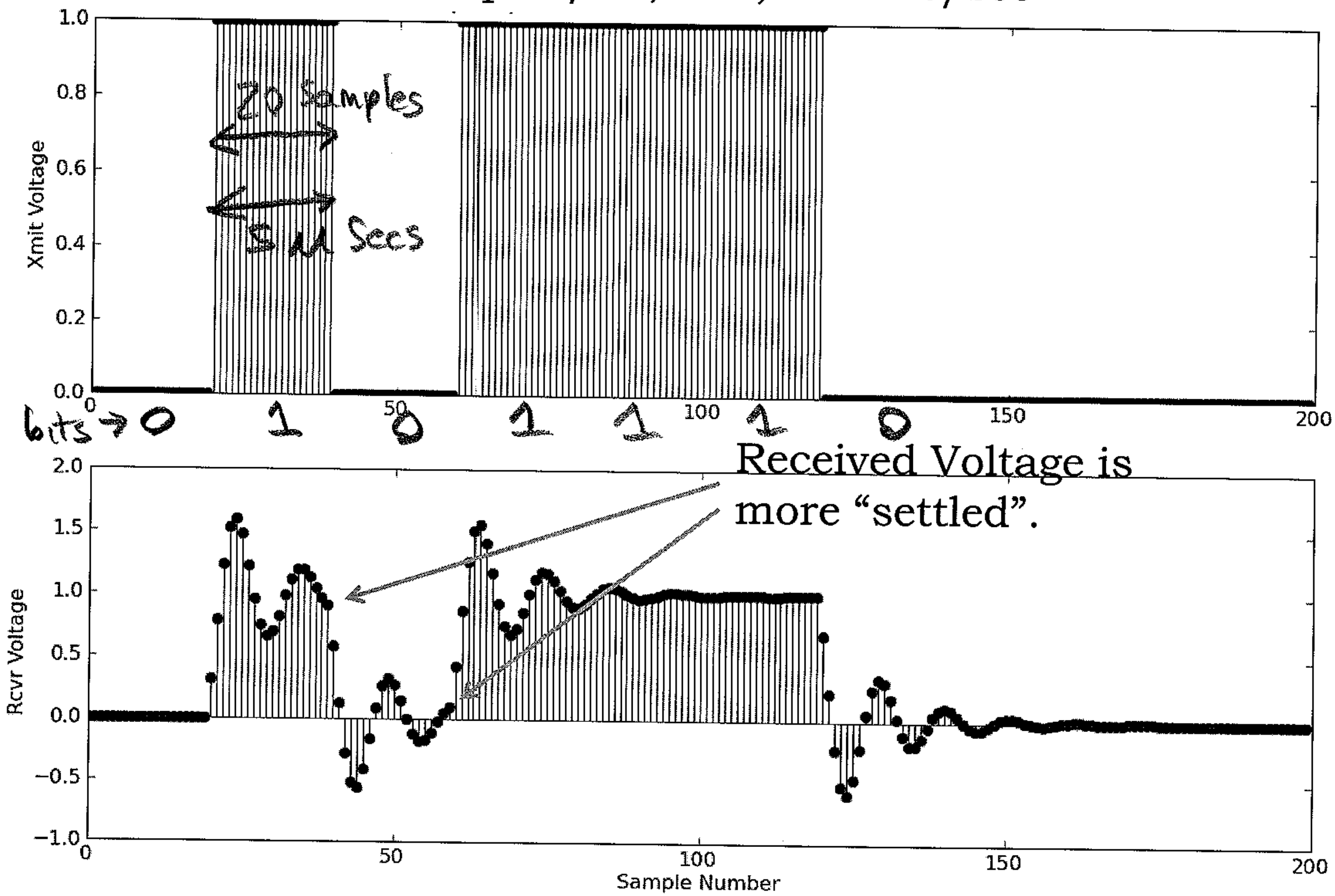
Sending 0101110, 2.5 microseconds/bit

10 samples/bit, 400,000 bits/sec



Sending 0101110, 5 microseconds/bit

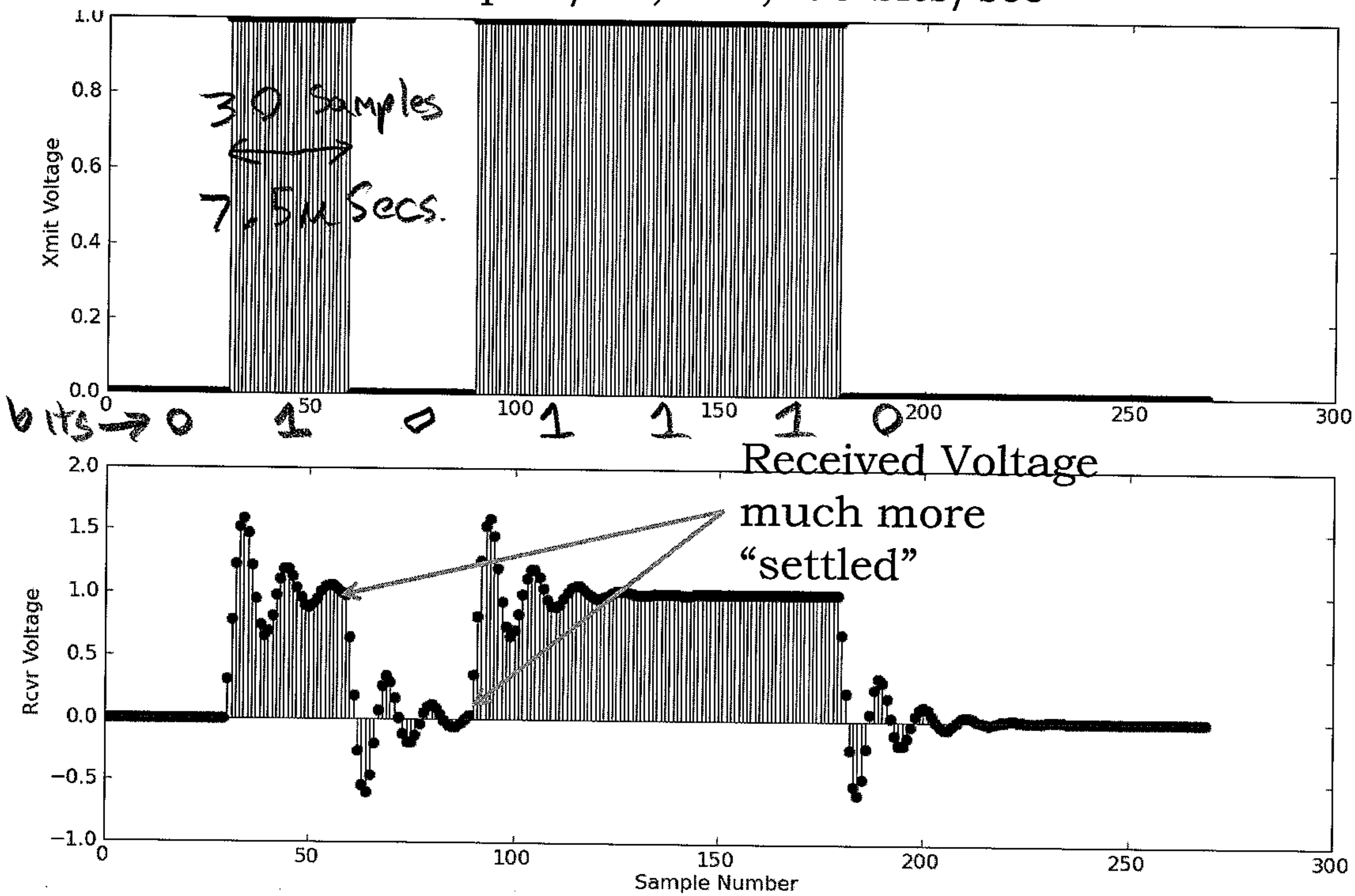
20 samples/bit, 200,000 bits/sec



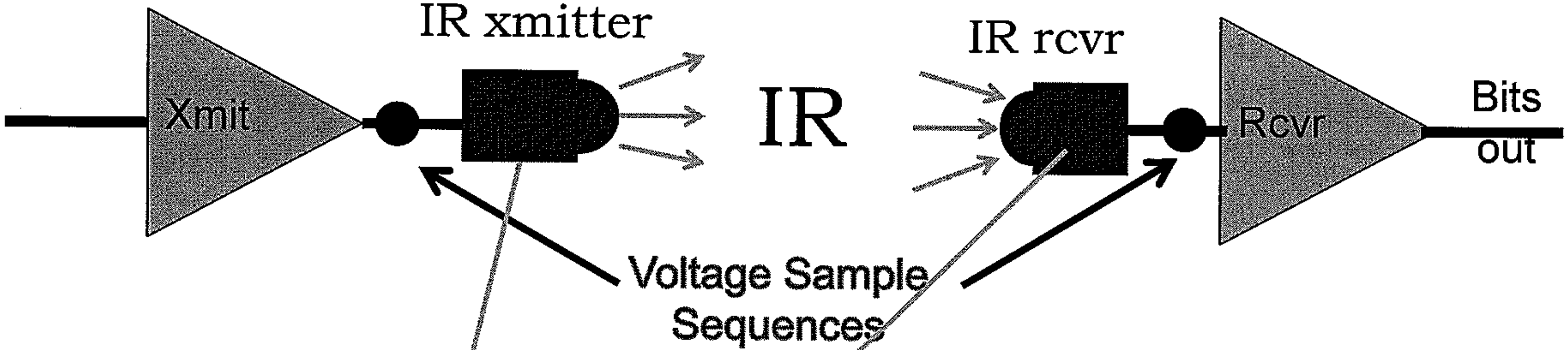
7

Sending 0101110, 7.5 microseconds/bit

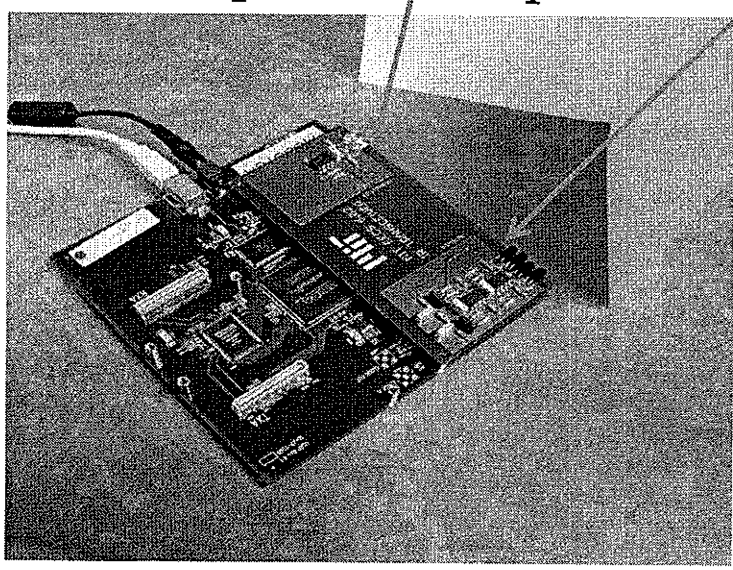
30 samples/bit, 133,333 bits/sec



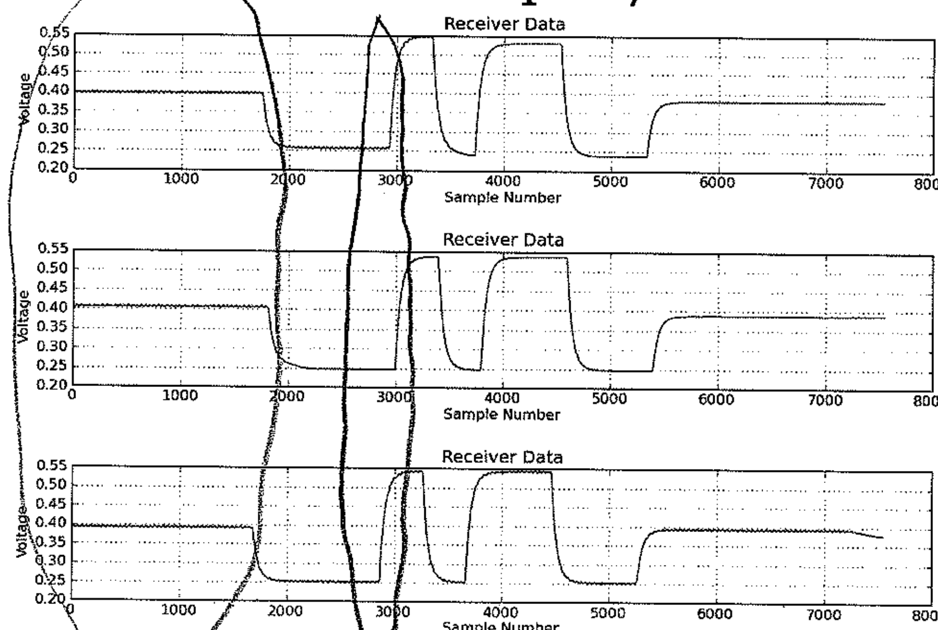
The 6.02 Infrared Transceiver



Loopback Setup



400 Samples/bit



Three Trans Messa...

Delay varys randomly

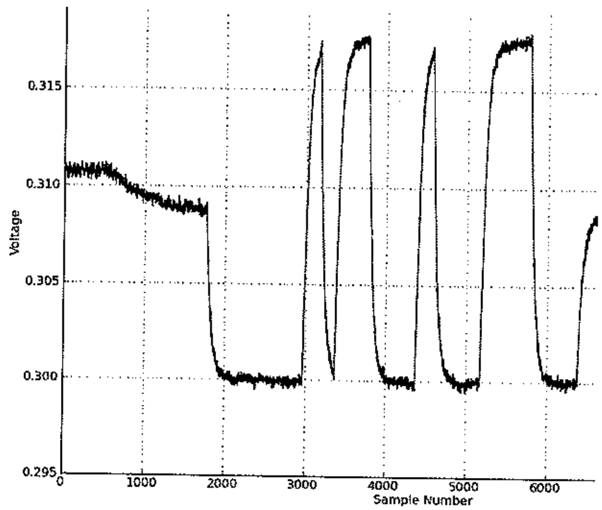
Note bit transition time varies randomly

9

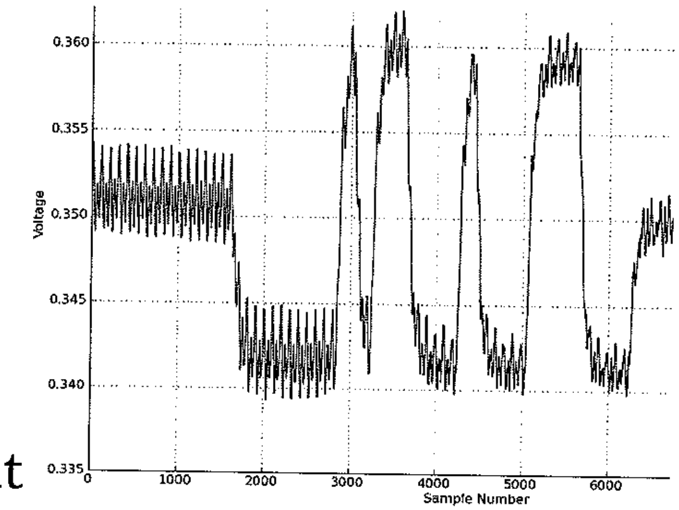
The 6.02 IR Tranceiver - Bounce off ceiling

Dark Room

ΔV 0.017 Volts

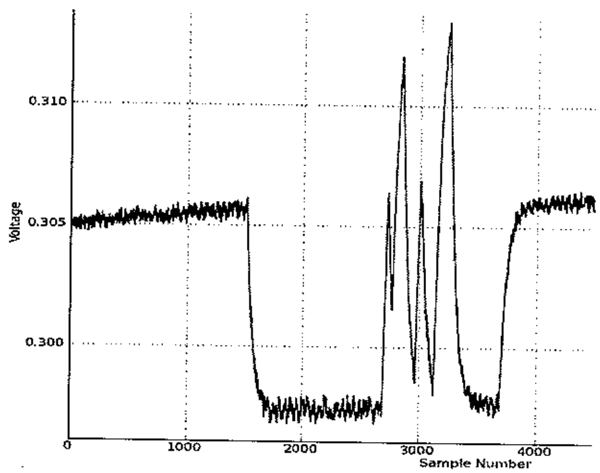


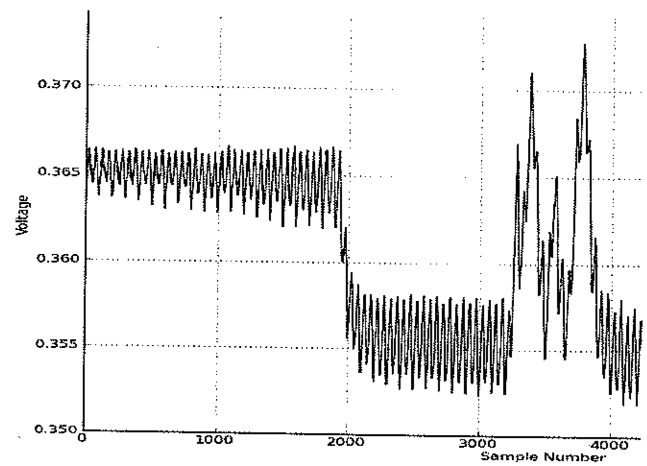
Lights On



200 Samples/bit

Bits sent = [10110001000111]



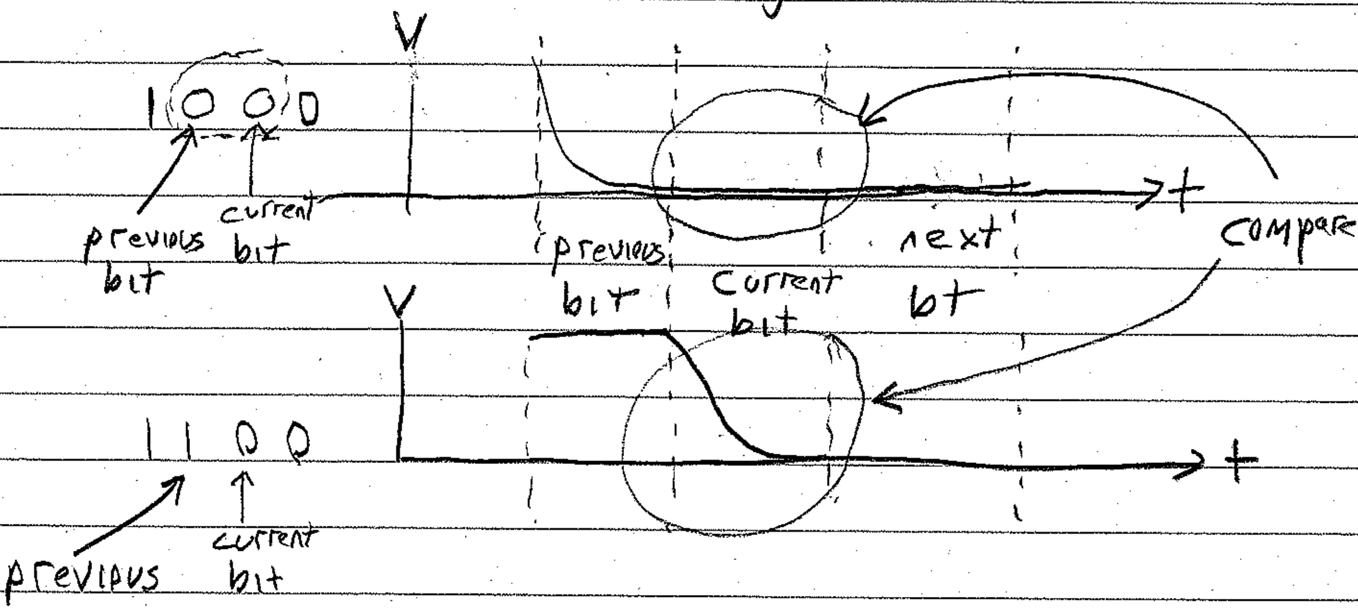


40 Samples/bit

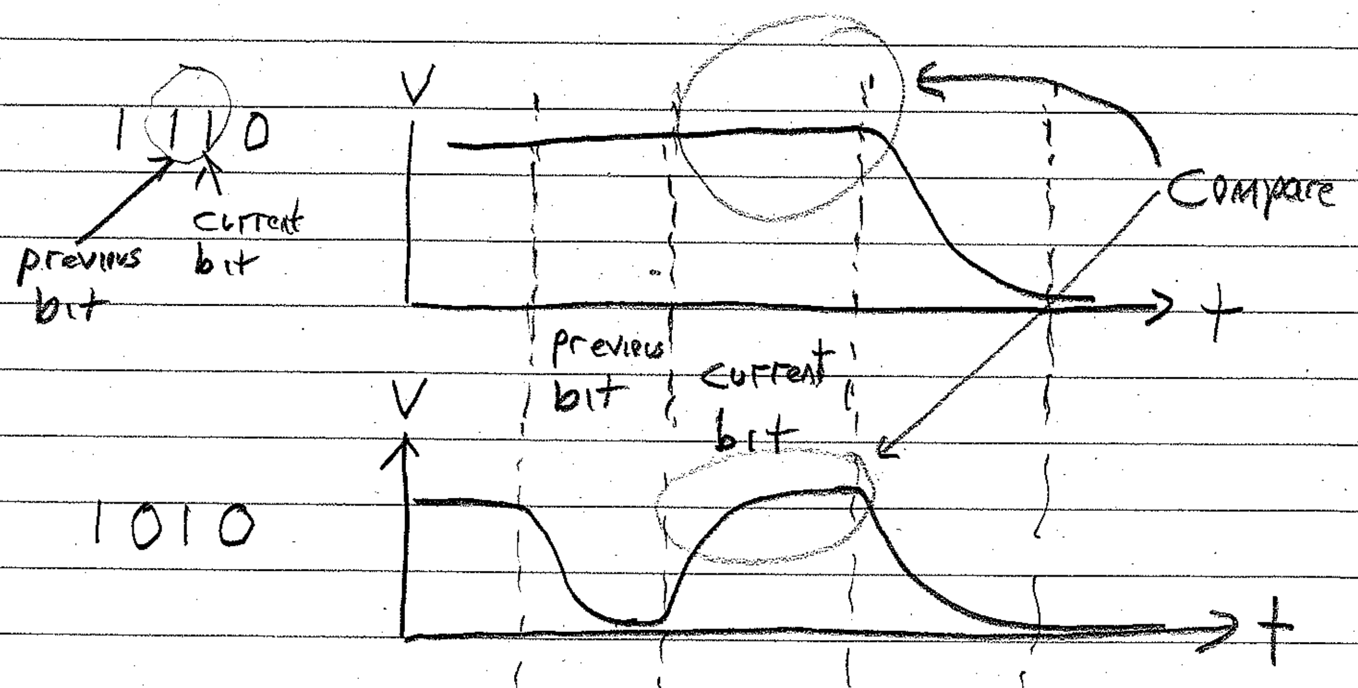
Bits sent = [1011010111]

Intersymbol Interference - Slow Channel

- Consider Transmitting Two bits



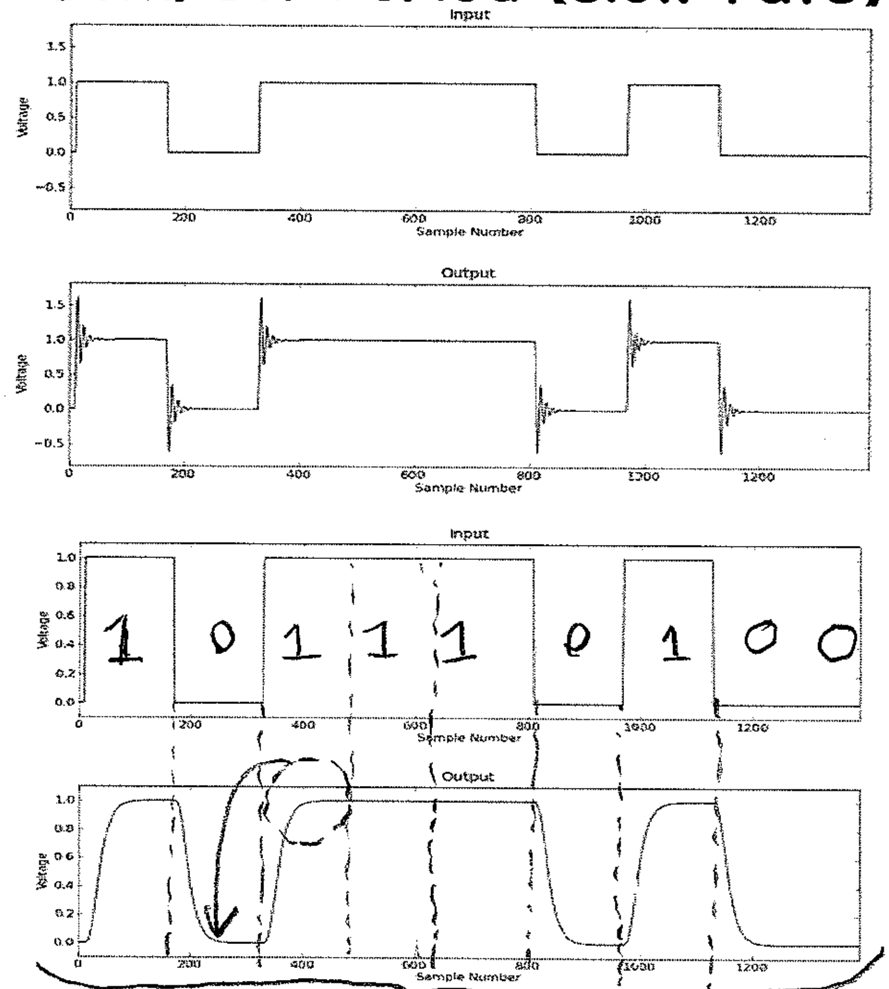
That the previous bit was a <u>one</u> "interferes" with the current bit being a <u>zero</u>



Previous bit = zero interferes with Current bit = 1

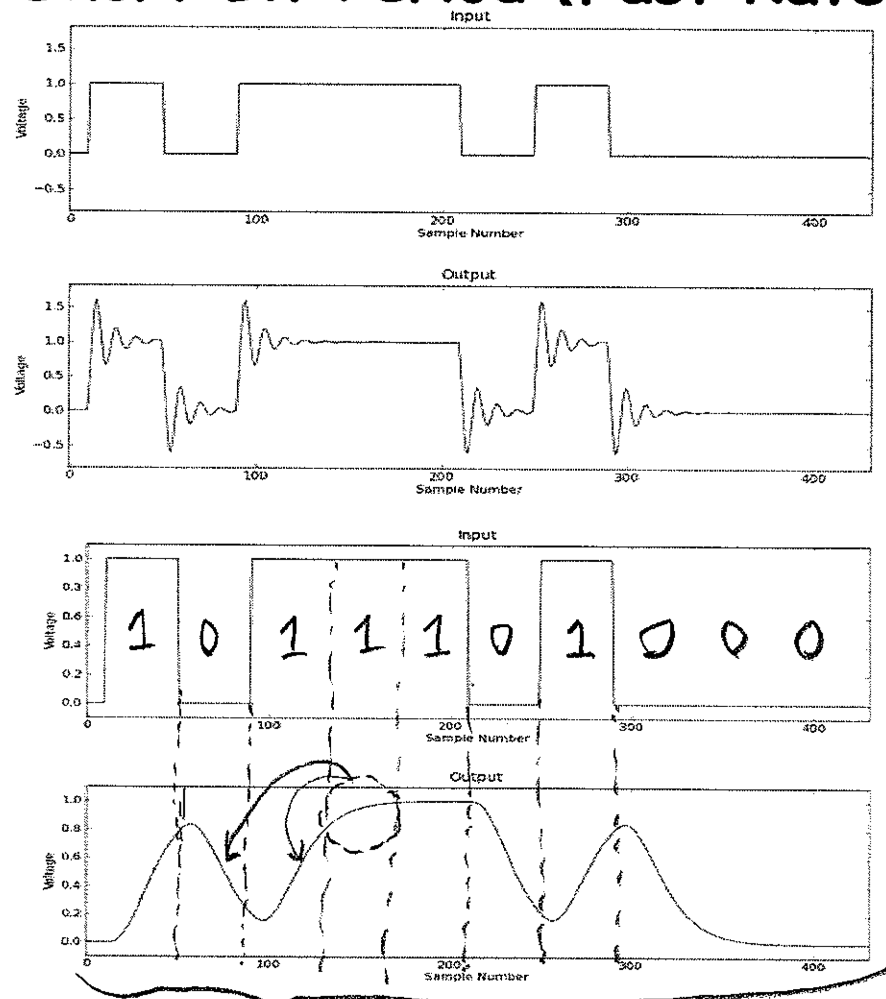
Intersymbol Interference

Long Bit Period (slow rate)



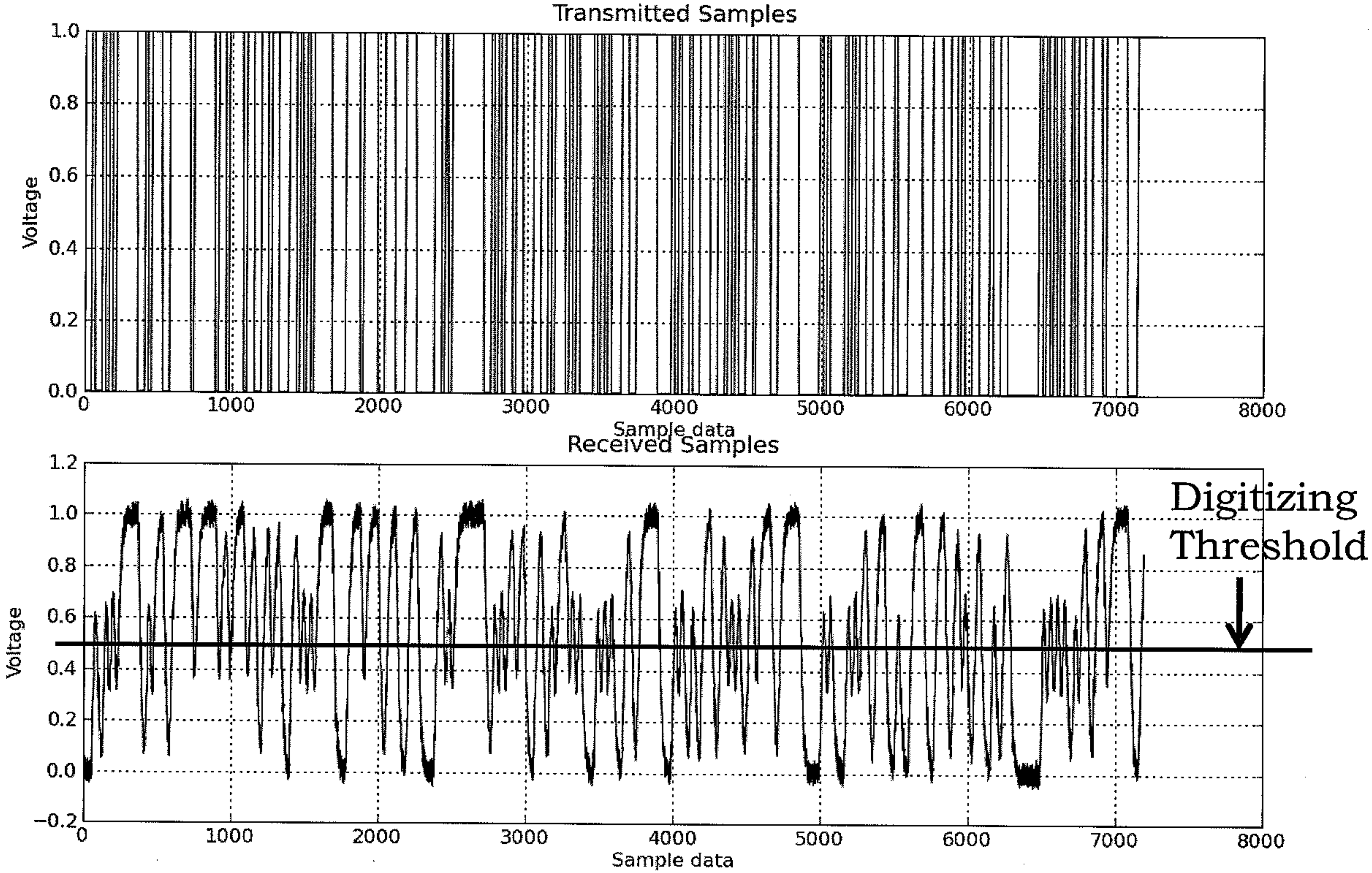
Only previous bit interferes

Short Bit Period (Fast Rate)



Previous two bits interfere.

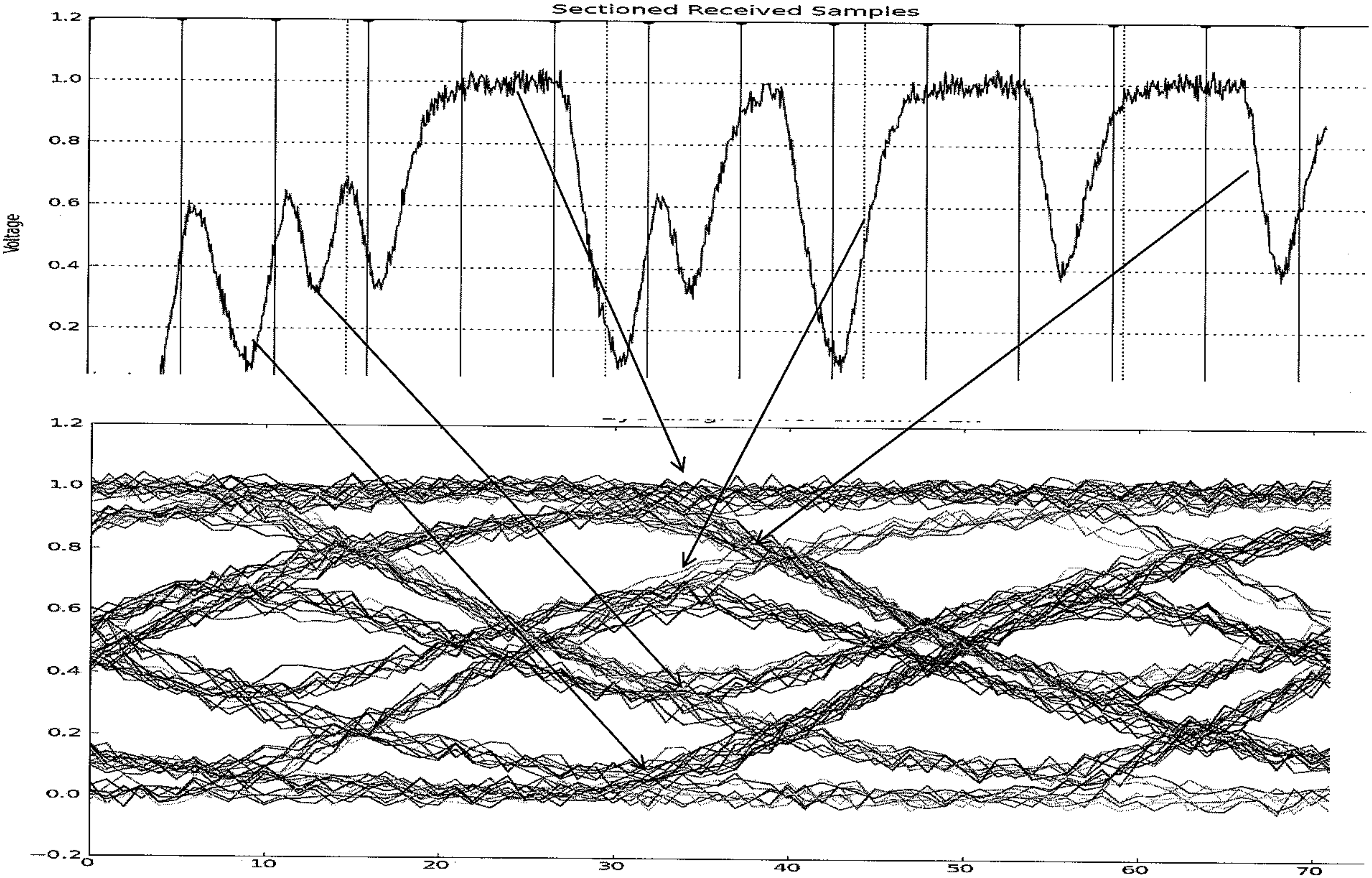
Received Data - Noisy Channel, 24 sample/bit



Any Bit Errors?

(13)

Eye Diagram-Overlay 3 Period Sections



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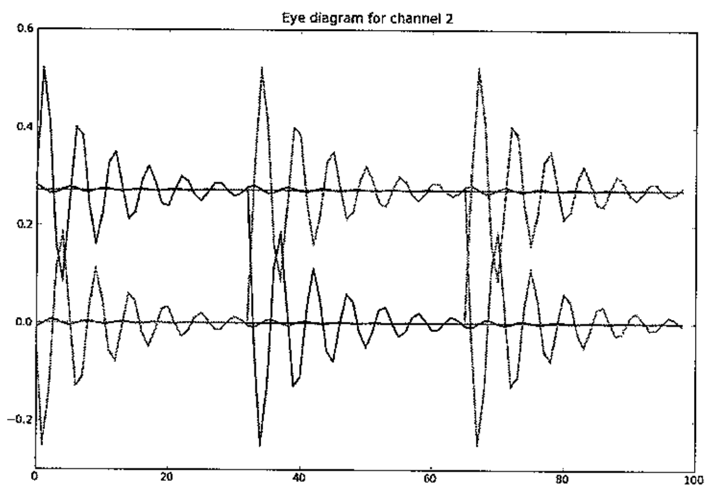
Eyes for Ringing versus Slow System

Medium Bit Period(33 samples)

Short Bit Period(20 samples)



R
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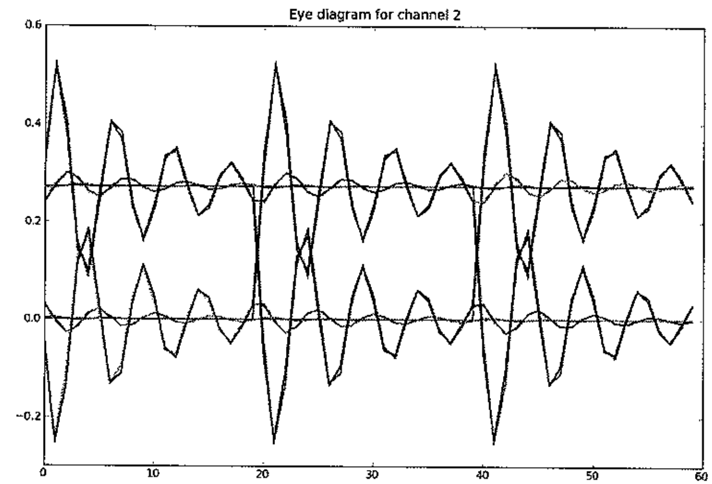
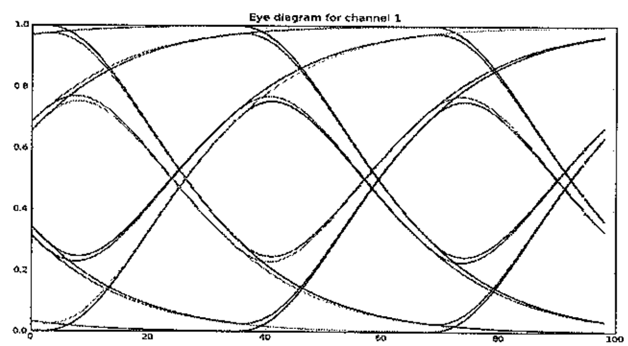
g





S
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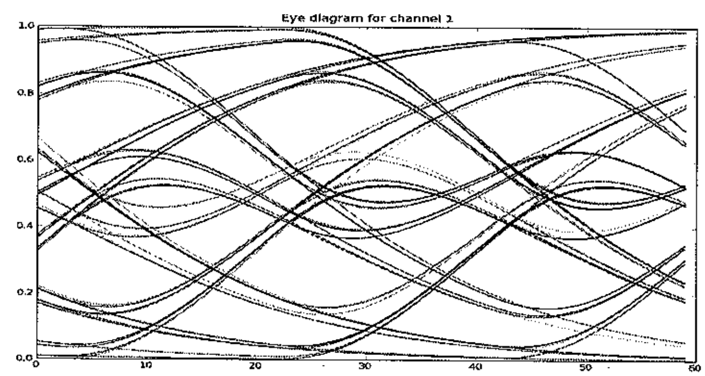
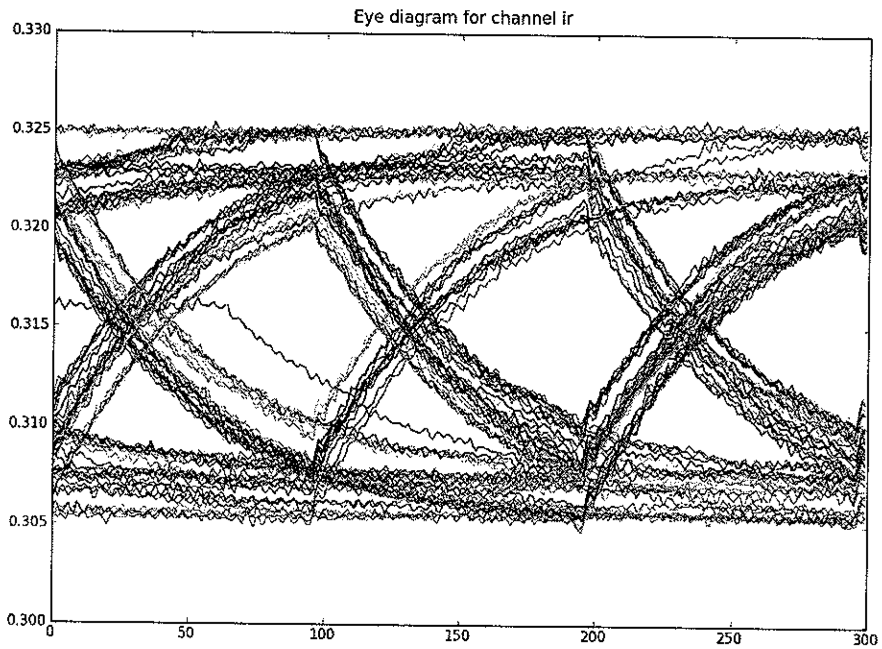
w



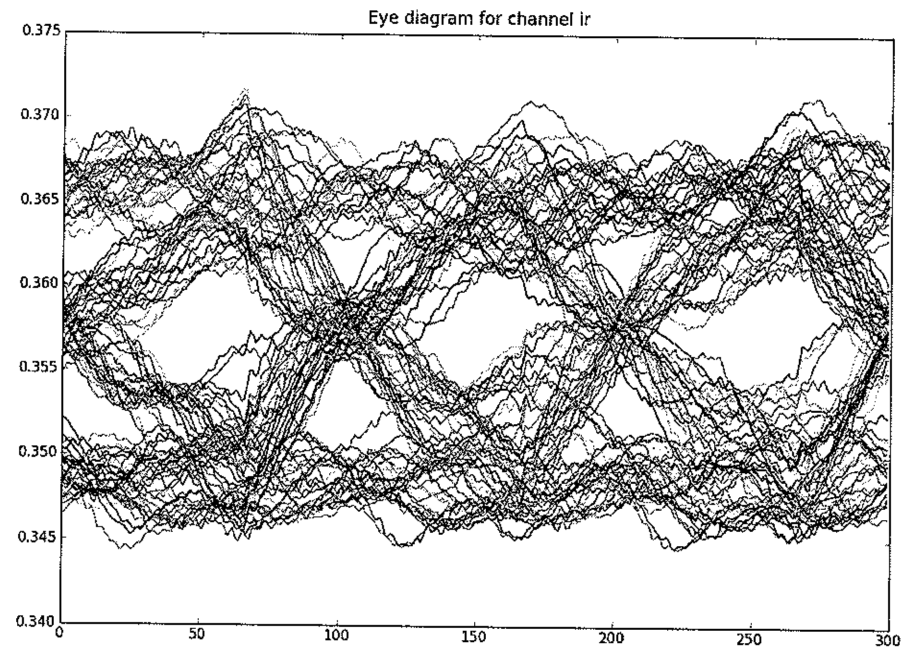
(15)

Eye Diagram for IR Detector

Eye Diagram 40 Samples per bit, dark room



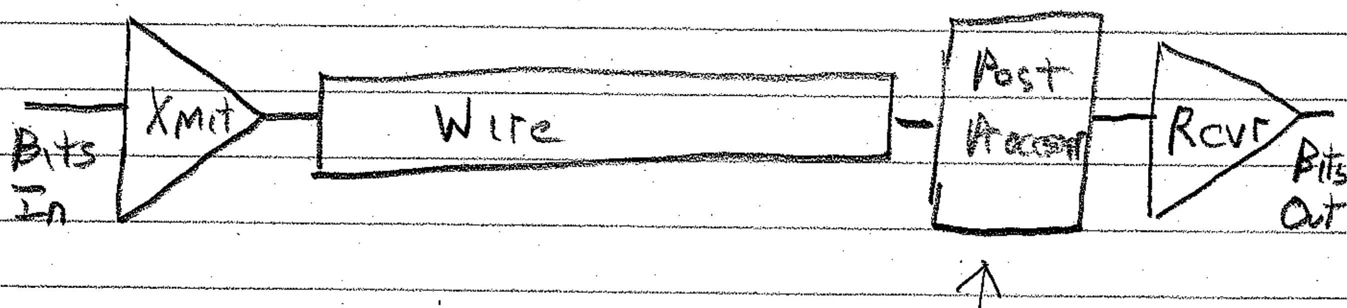
Eye Diagram 40 Samples per bit, lights on!



Non ideal Wires Create Intersymbol Interference

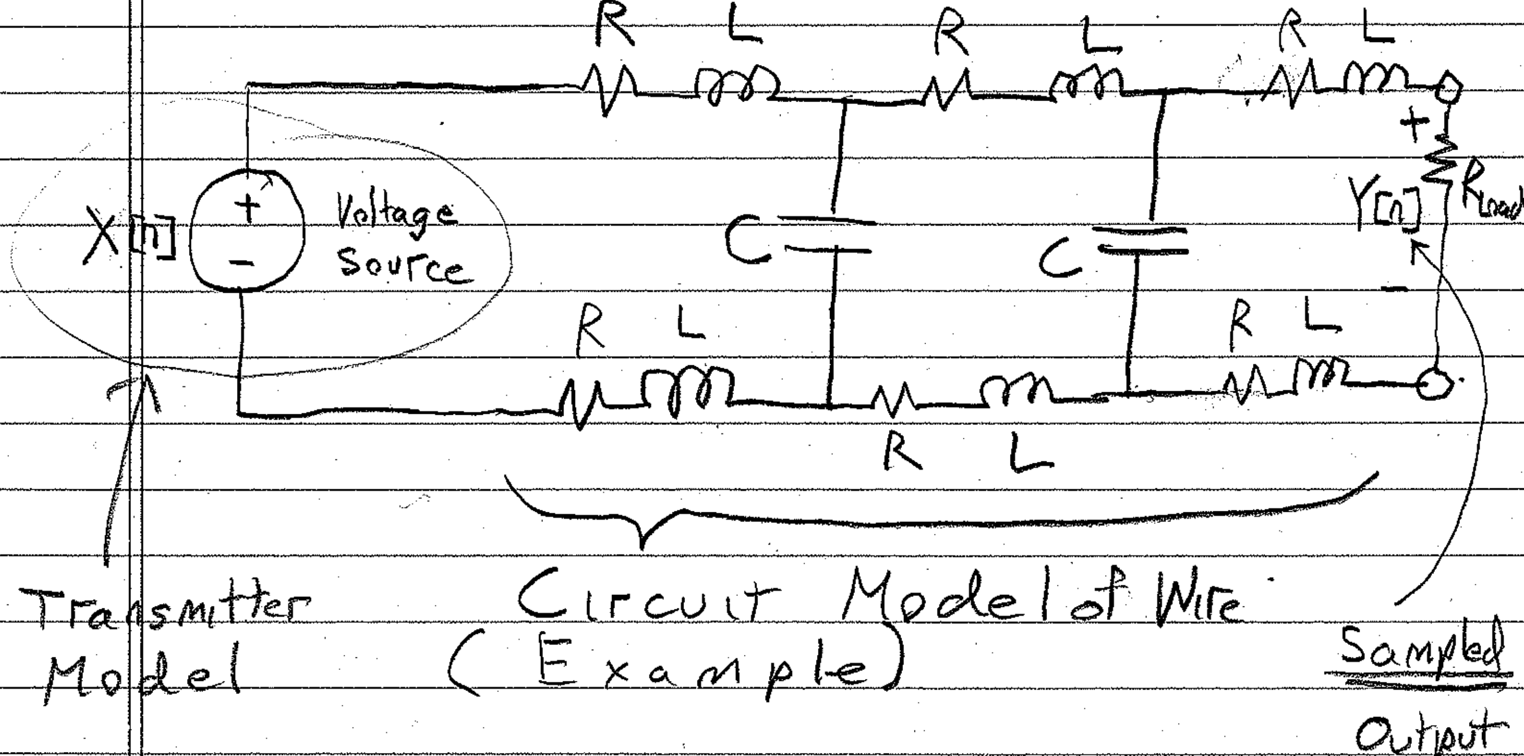
- Makes detecting bits more difficult
- Limits the bits/second that can be transmitted accurately.

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

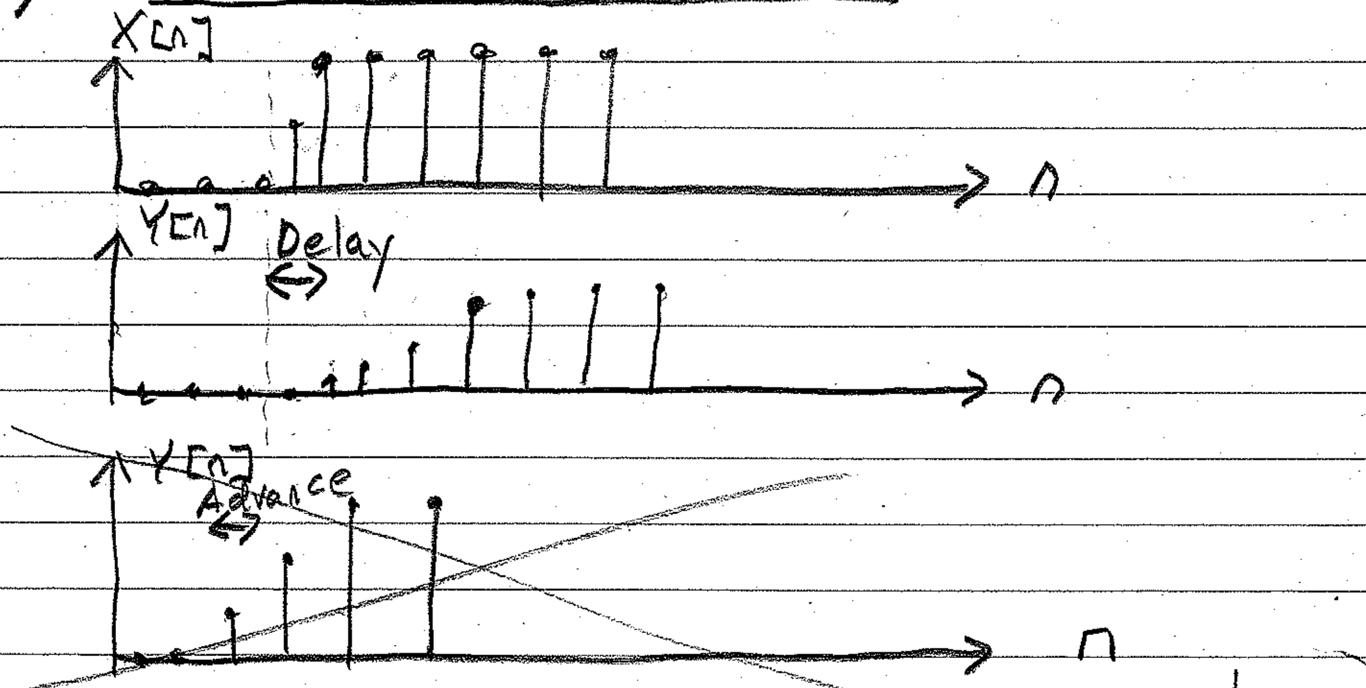


Need a model of the wire to design a post-processor

Example Model of a Physical Wire



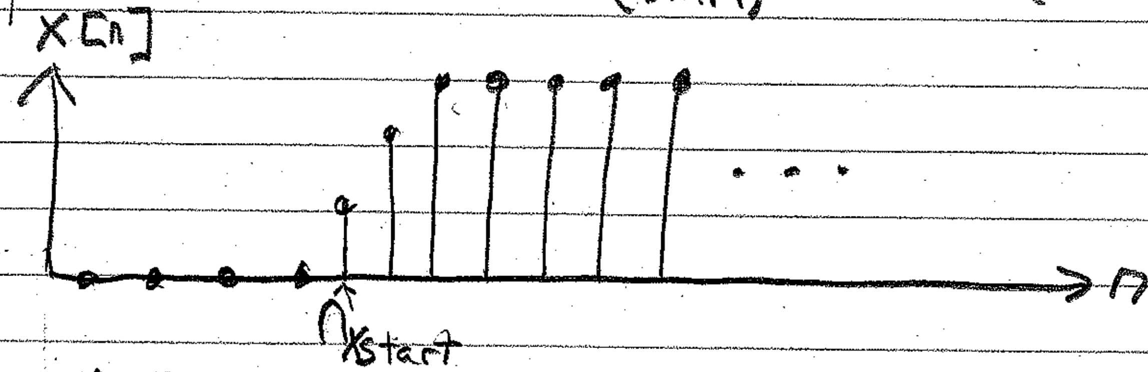
1) Wires are Causal

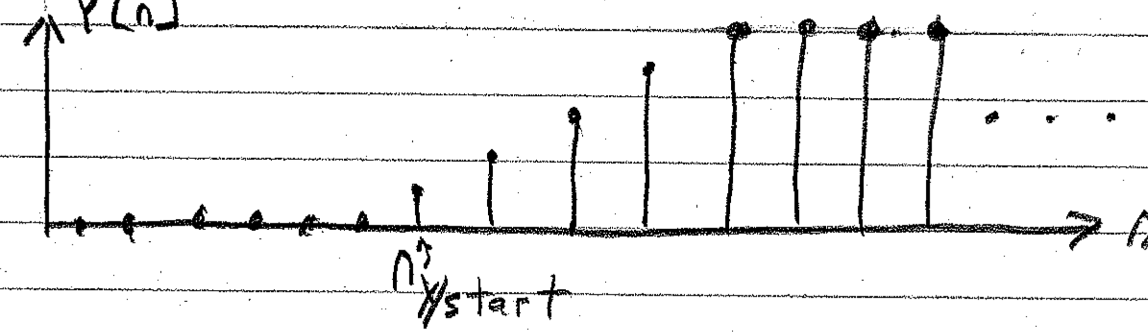


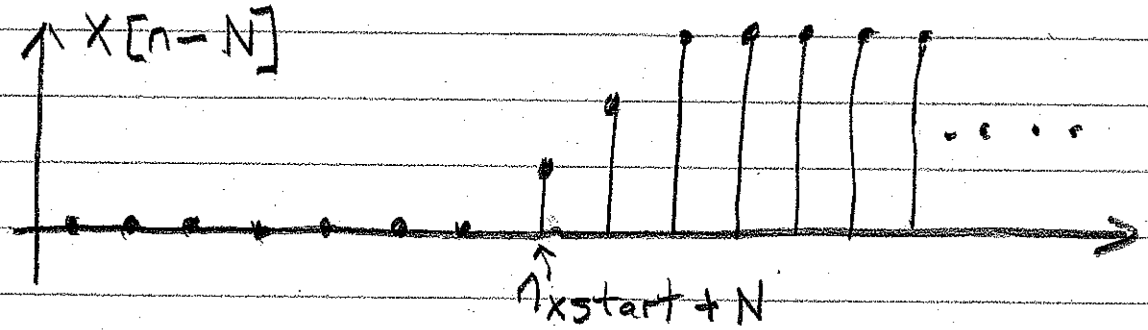
Wires can not predict the future!

A change in X causes a change in Y

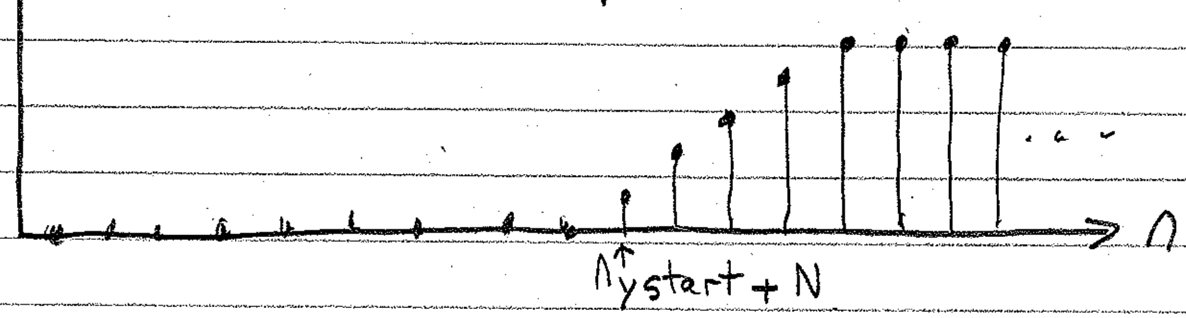
2) Wires are Time-Invariant (Shift)



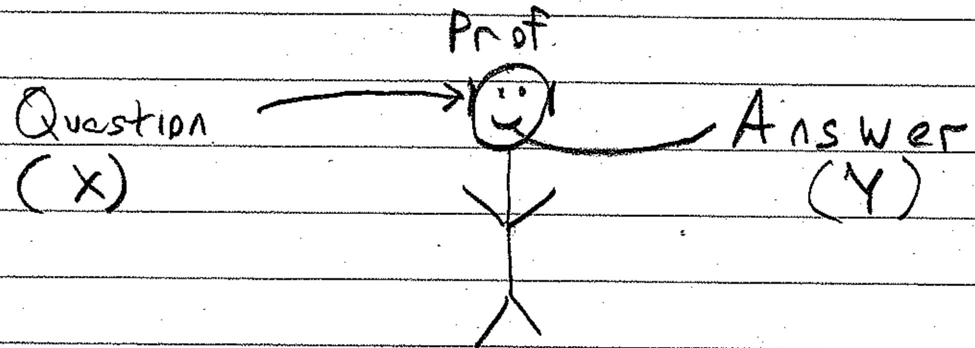




$y[n-N]$ ← A time-shifted input produces a time-shifted output

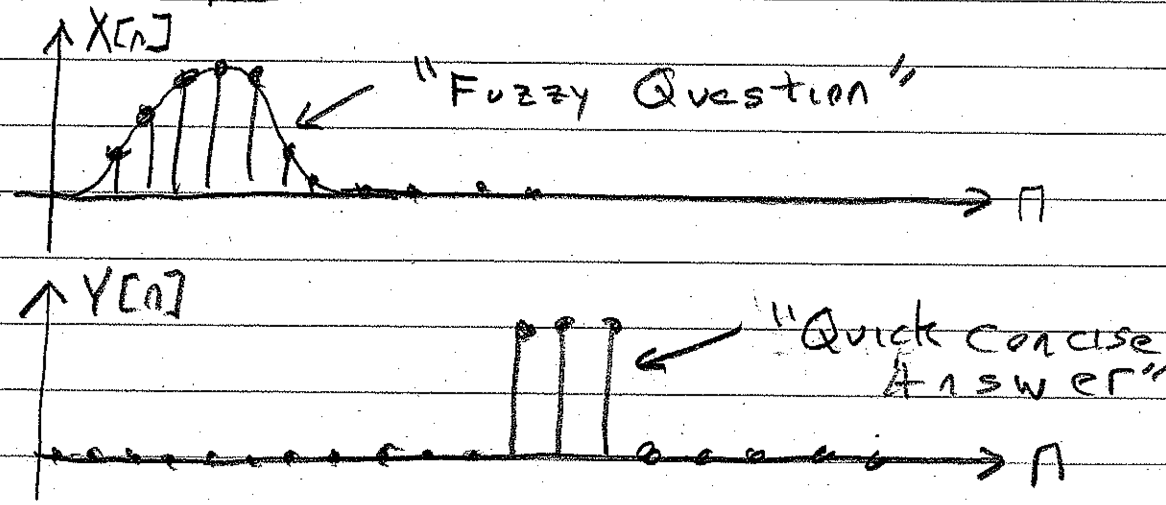


A Non Time Invariant System

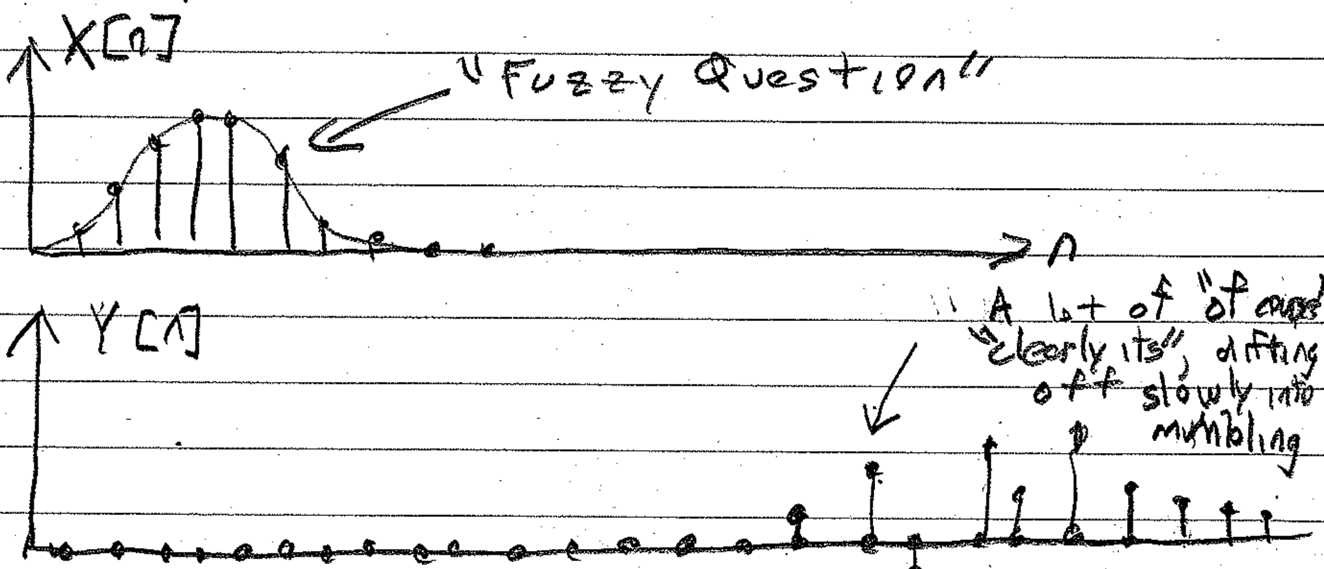


Time Varying System

At 3pm

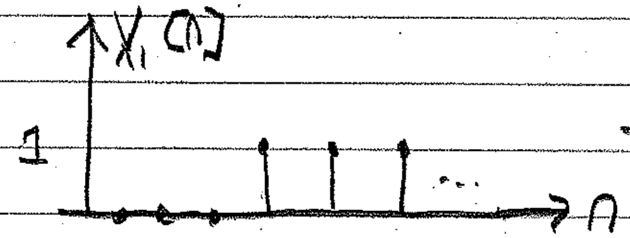


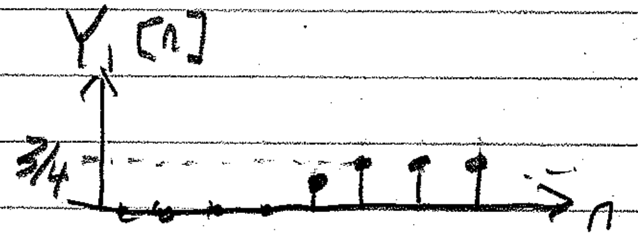
At 9pm

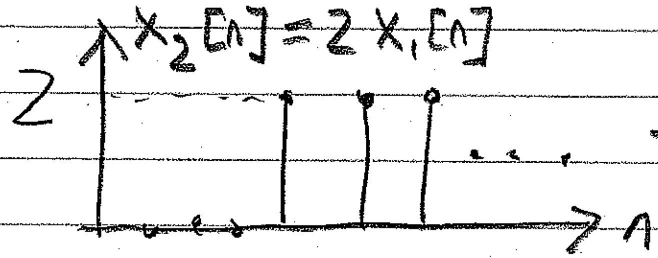


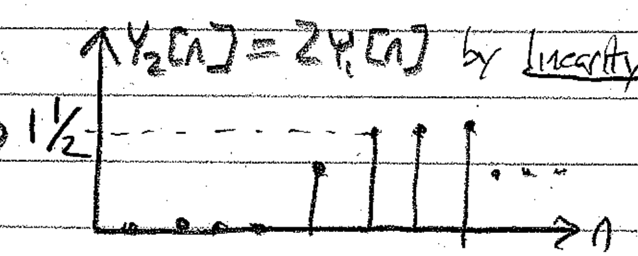
3) Linearity (A Strong Assumption!)

3a) Scaling



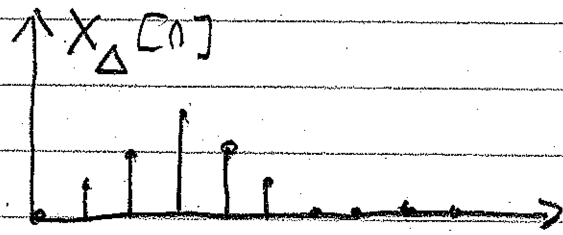


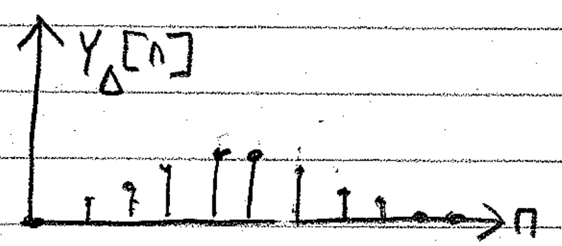


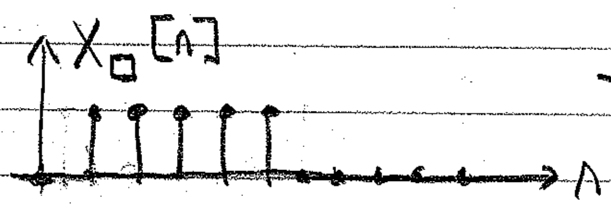


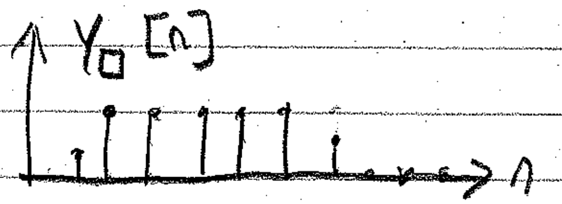
Scale Inputs → Scaled Outputs

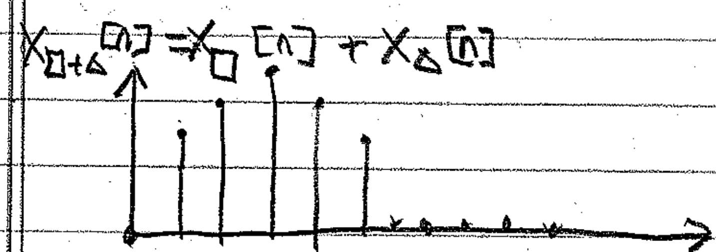
3b) Sum Inputs → Sum Outputs

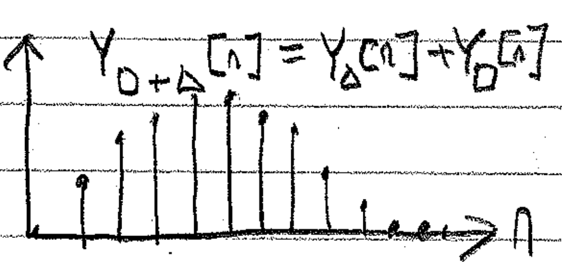






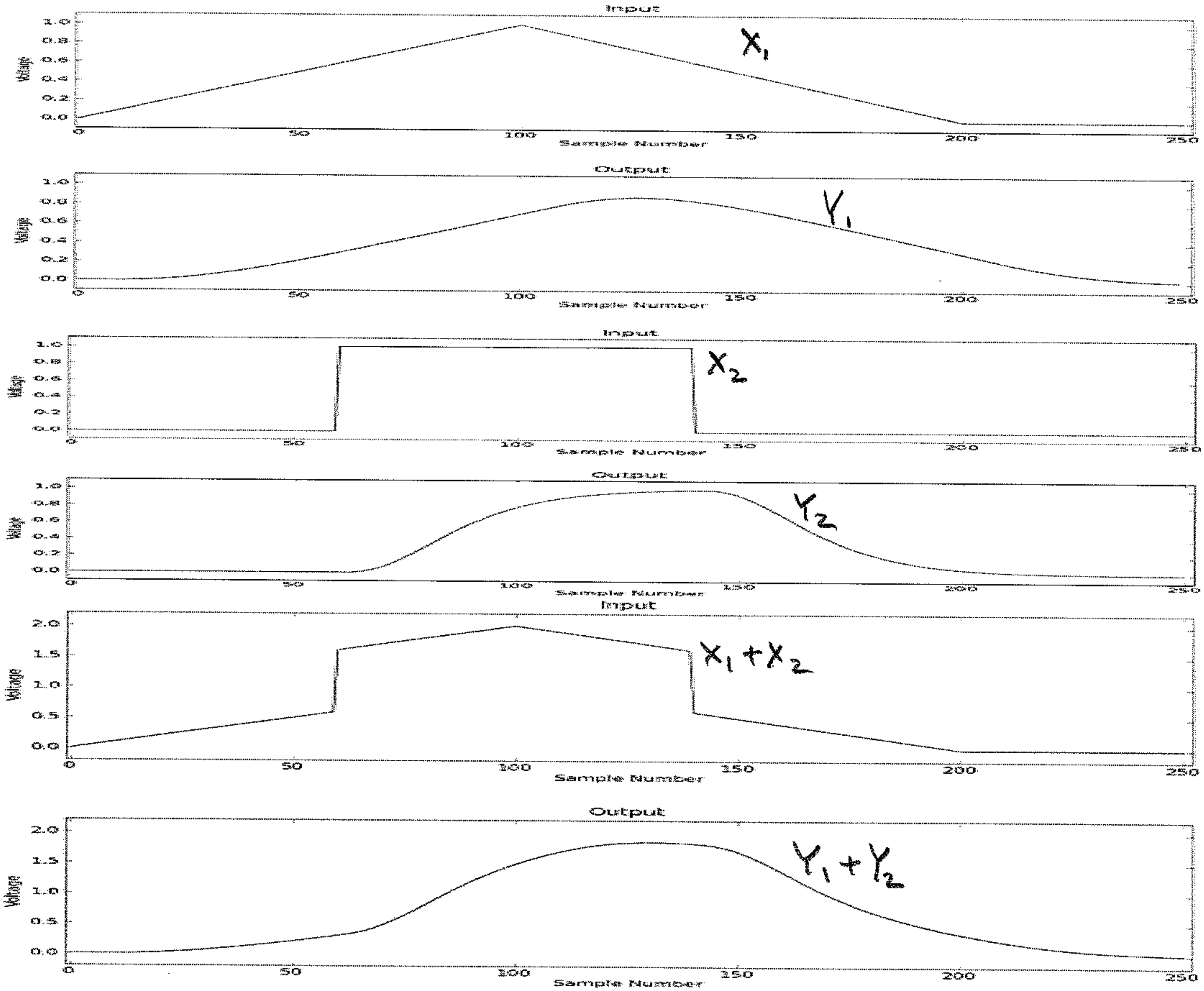






Superposition

SLOW SYSTEM



Linear Time Invariant Systems Examples

LTI

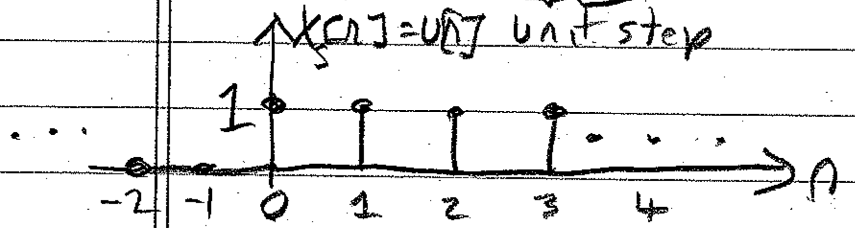
$$x_1[n] \rightarrow \boxed{LTI} \rightarrow y_1[n]$$

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

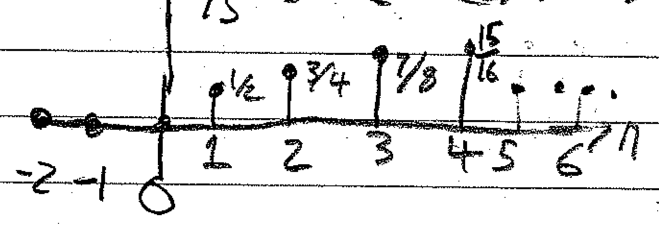
$$\Rightarrow A x_1[n-N_A] + B x_2[n-N_B] \rightarrow \boxed{LTI} \rightarrow A y_1[n-N_A] + B y_2[n-N_B]$$

Example - Unit Step Responses

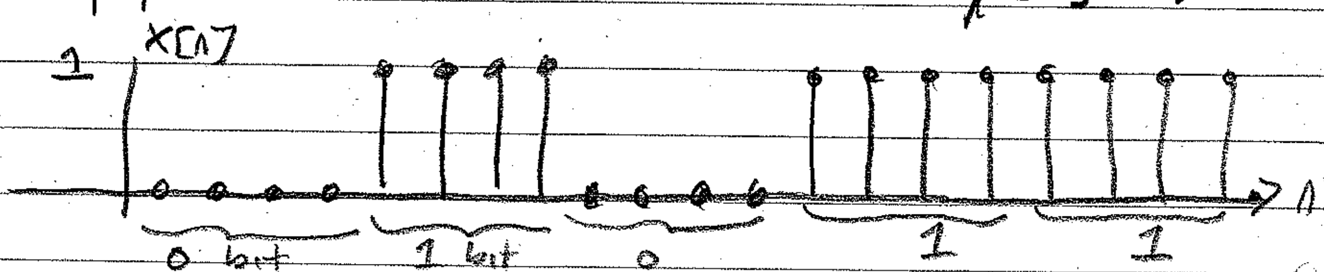
$$x_s[n] = \underbrace{u[n]}_{} \rightarrow \boxed{LTI} \rightarrow y_s[n] = \text{unit step response}$$



$y_s[n] = (1-(1/2)^n)u[n]$



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

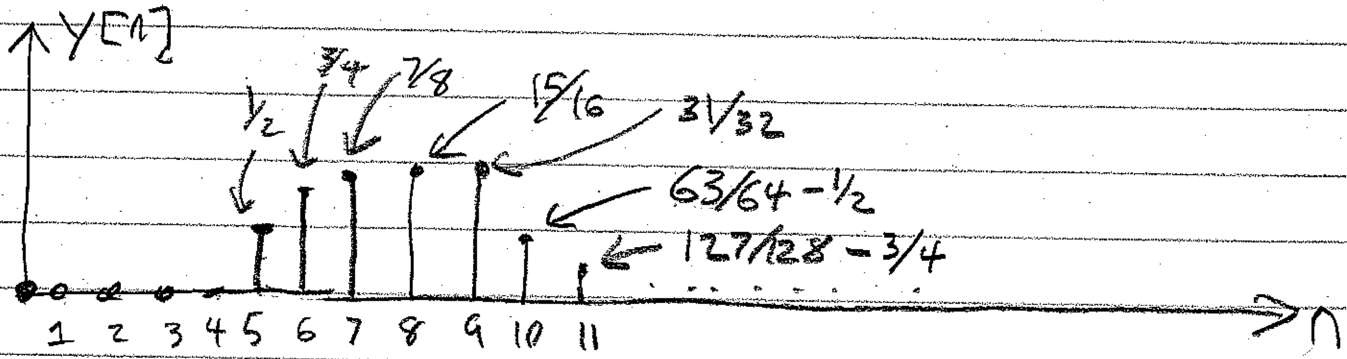


Rewriting $x[n]$

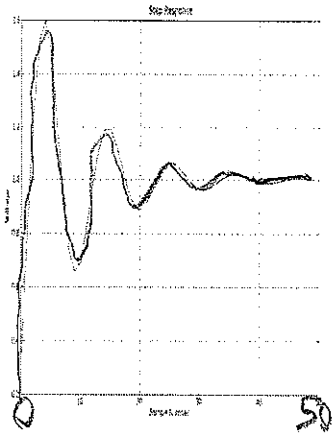
$$x[n] = u[n-4] - u[n-9] + u[n-13] - u[n-21]$$

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

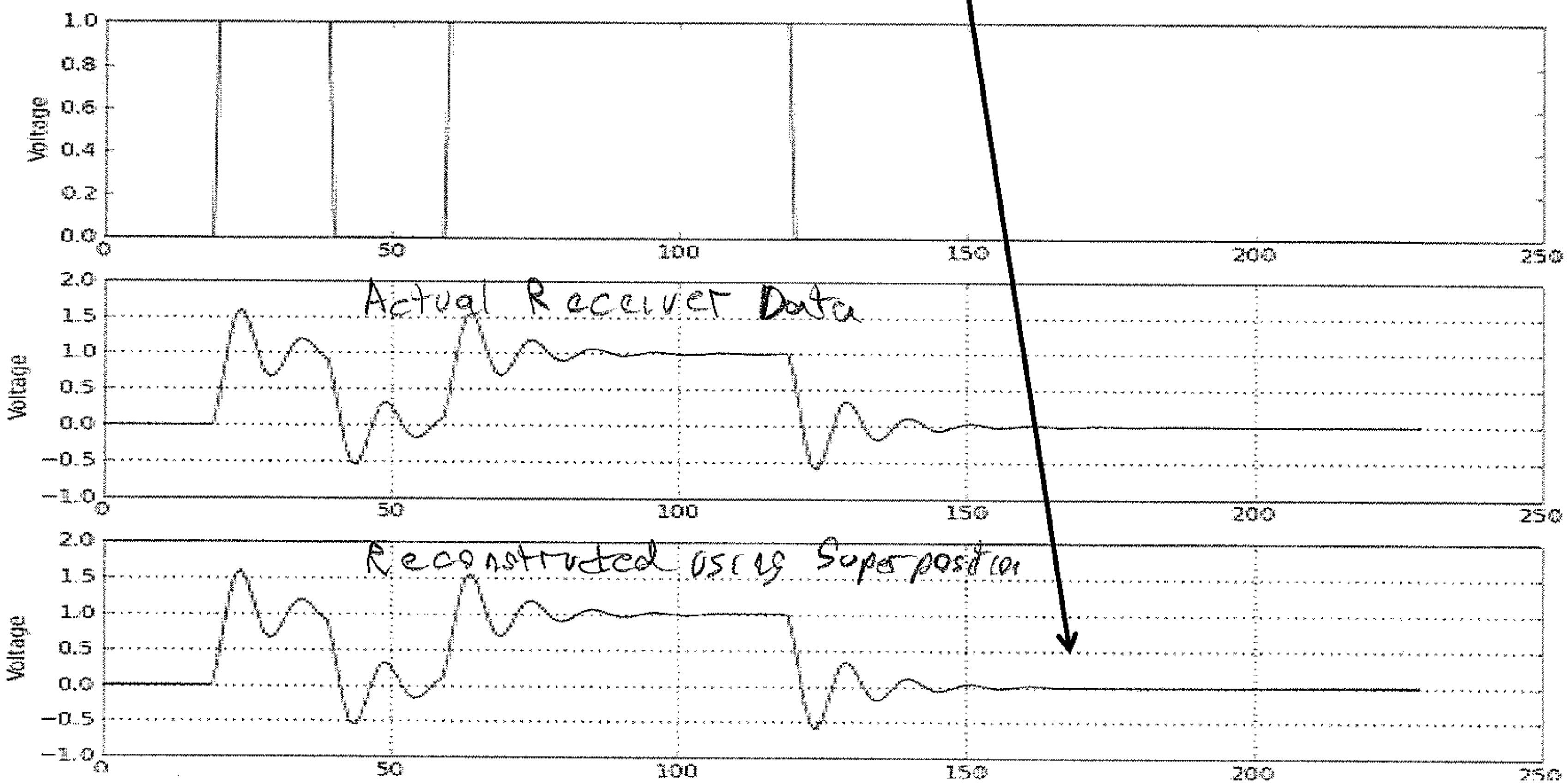
$$= \left(1-\left(\tfrac{1}{2}\right)^{(n-4)}\right)u[n-4] - \left(1-\left(\tfrac{1}{2}\right)^{(n-9)}\right)u[n-9] + \left(1-\left(\tfrac{1}{2}\right)^{(n-13)}\right)u[n-13] - \left(1-\left(\tfrac{1}{2}\right)^{(n-21)}\right)u[n-21]$$



Edge Superposition



Step Response and results from superposition



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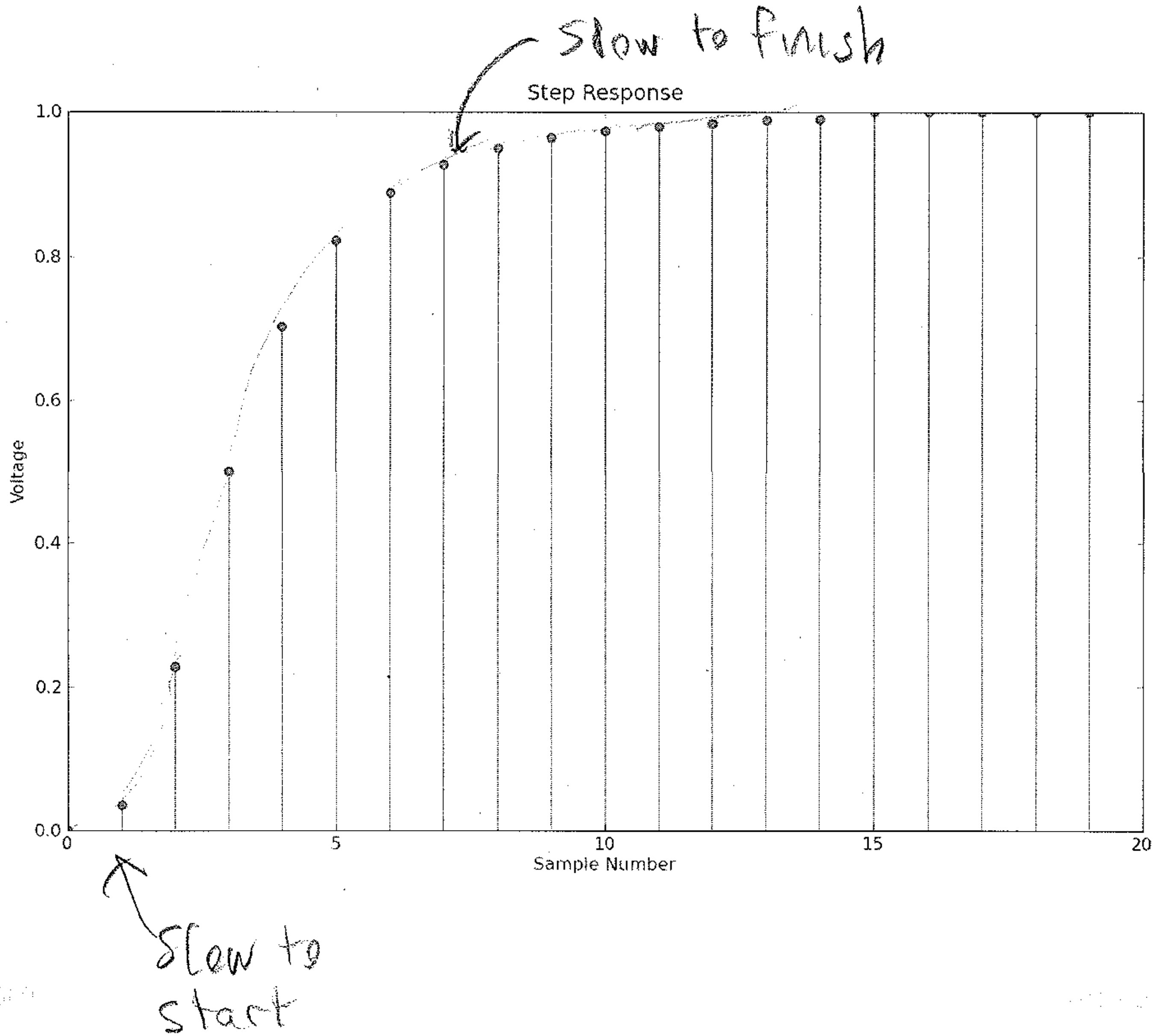
Step Response For Another Example Channel



0 1 0 1 1 0 Transmitted Through Example Channel

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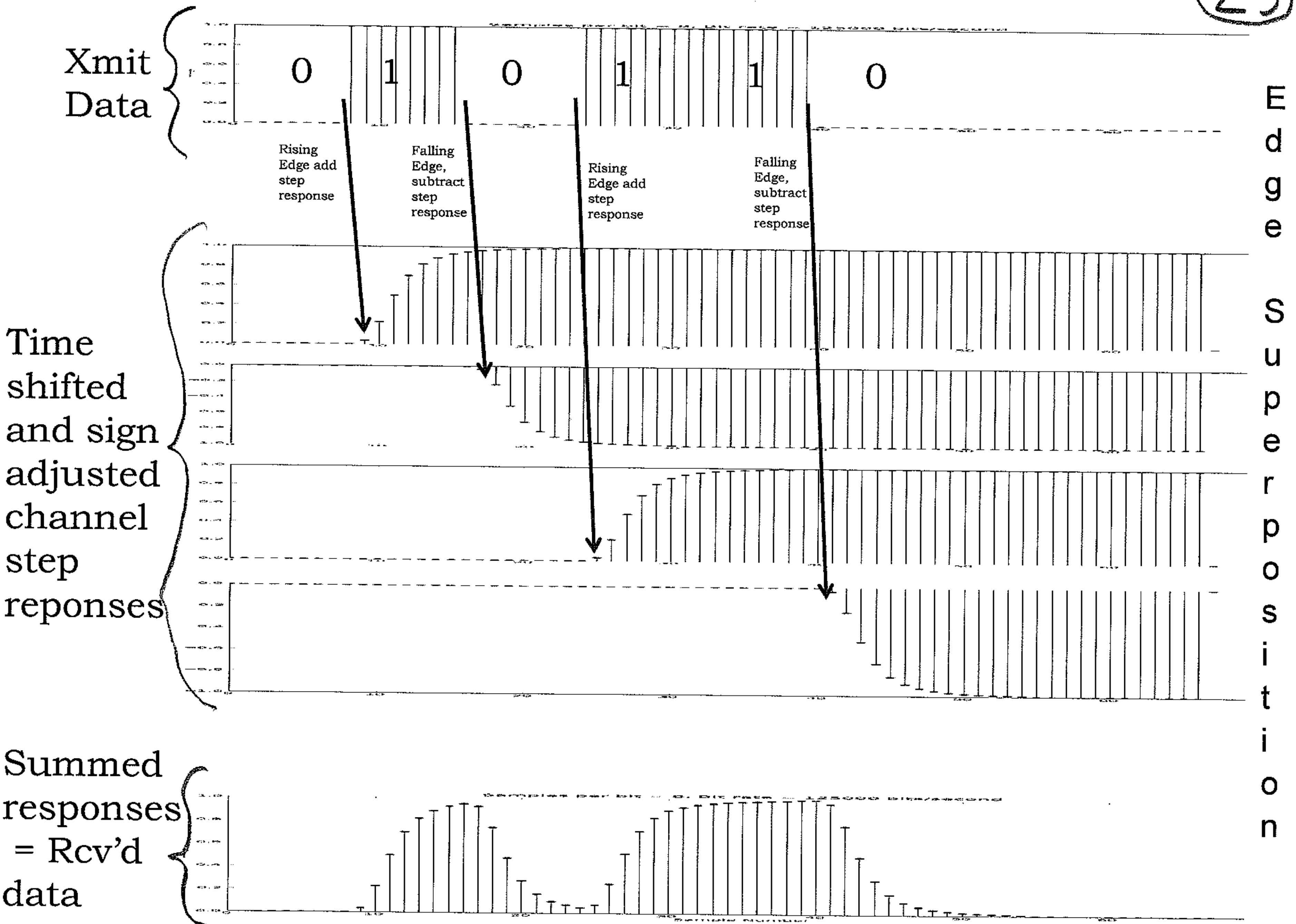

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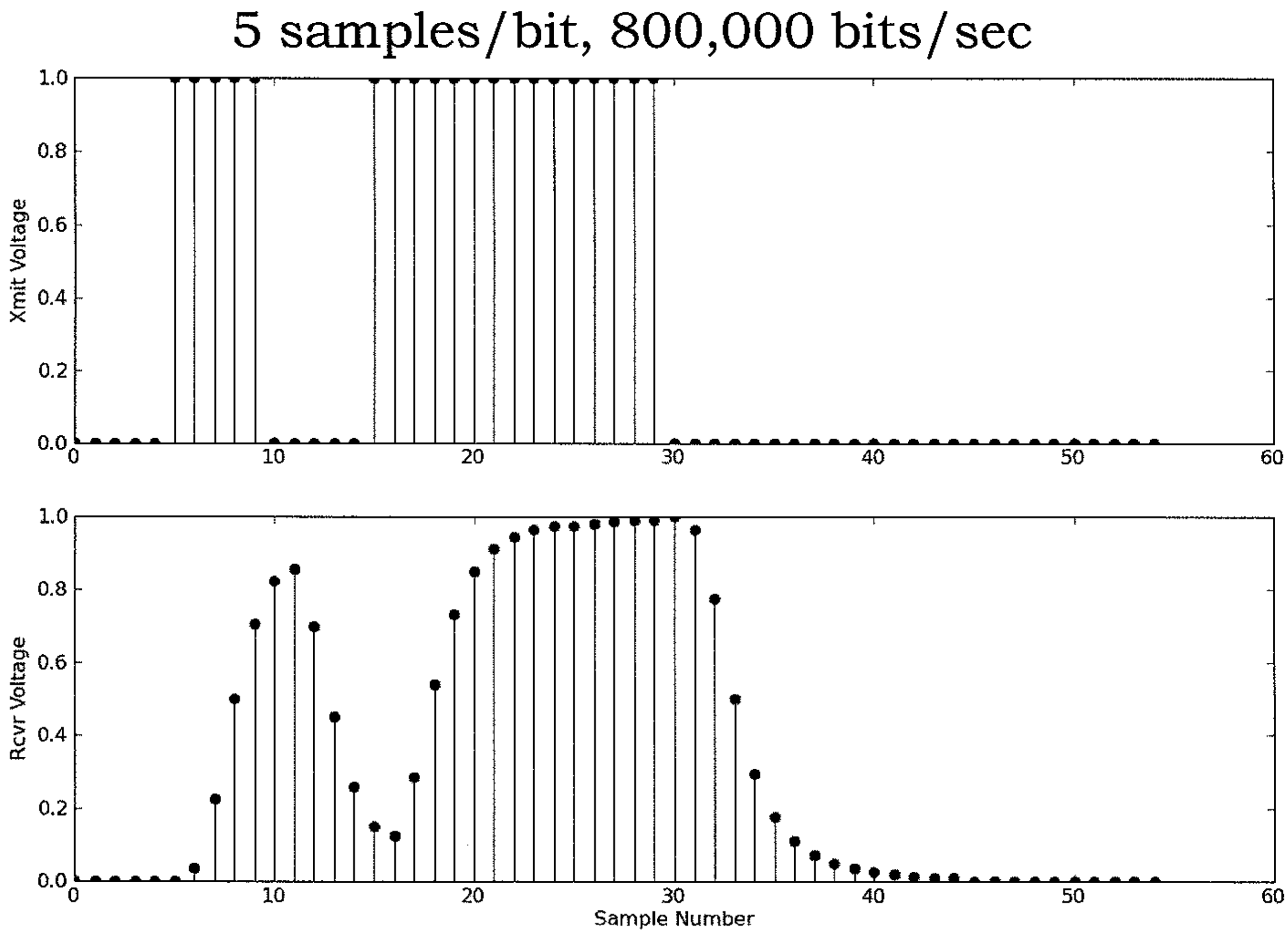
Sending 0101110, 1.25 microseconds/bit



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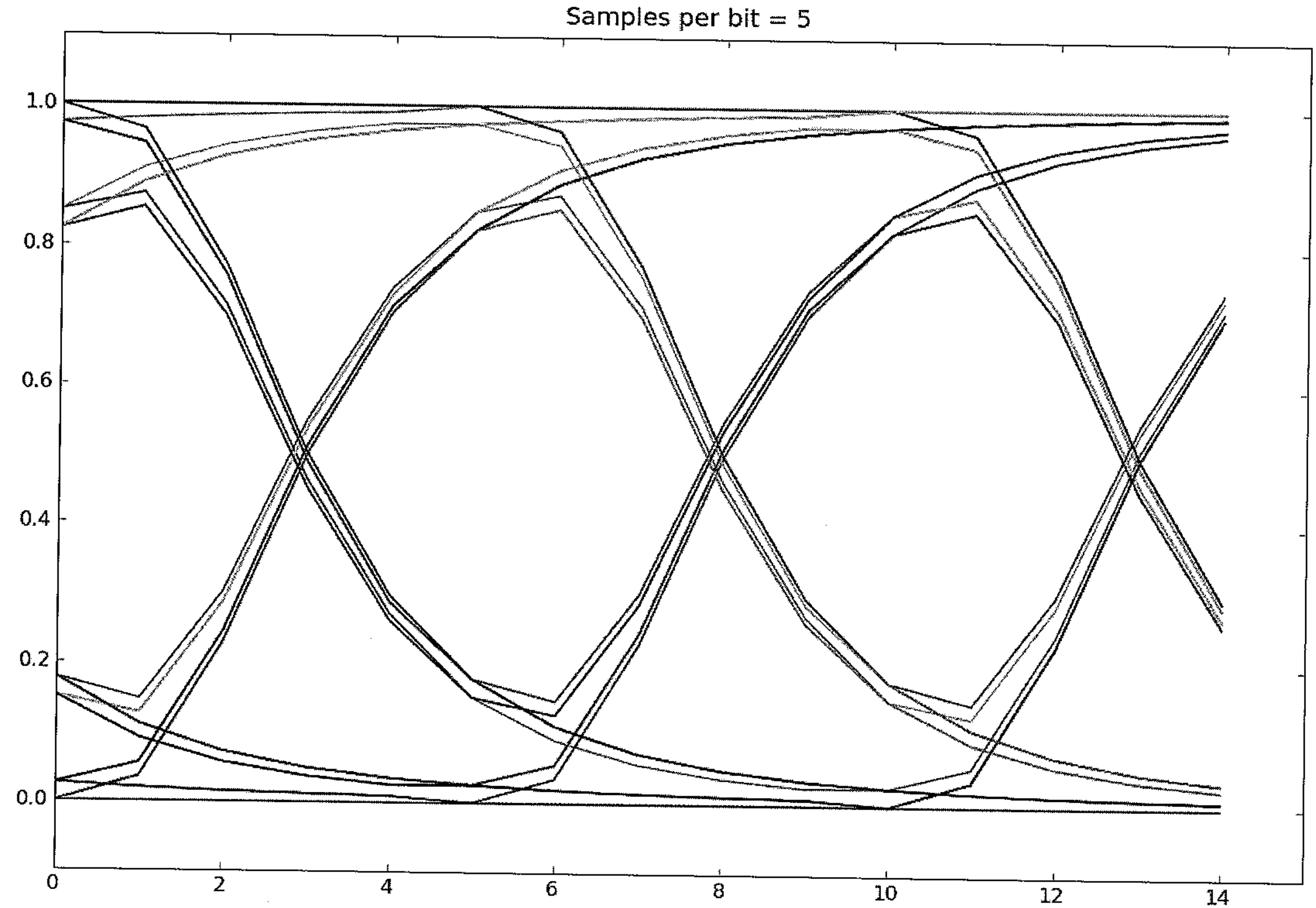
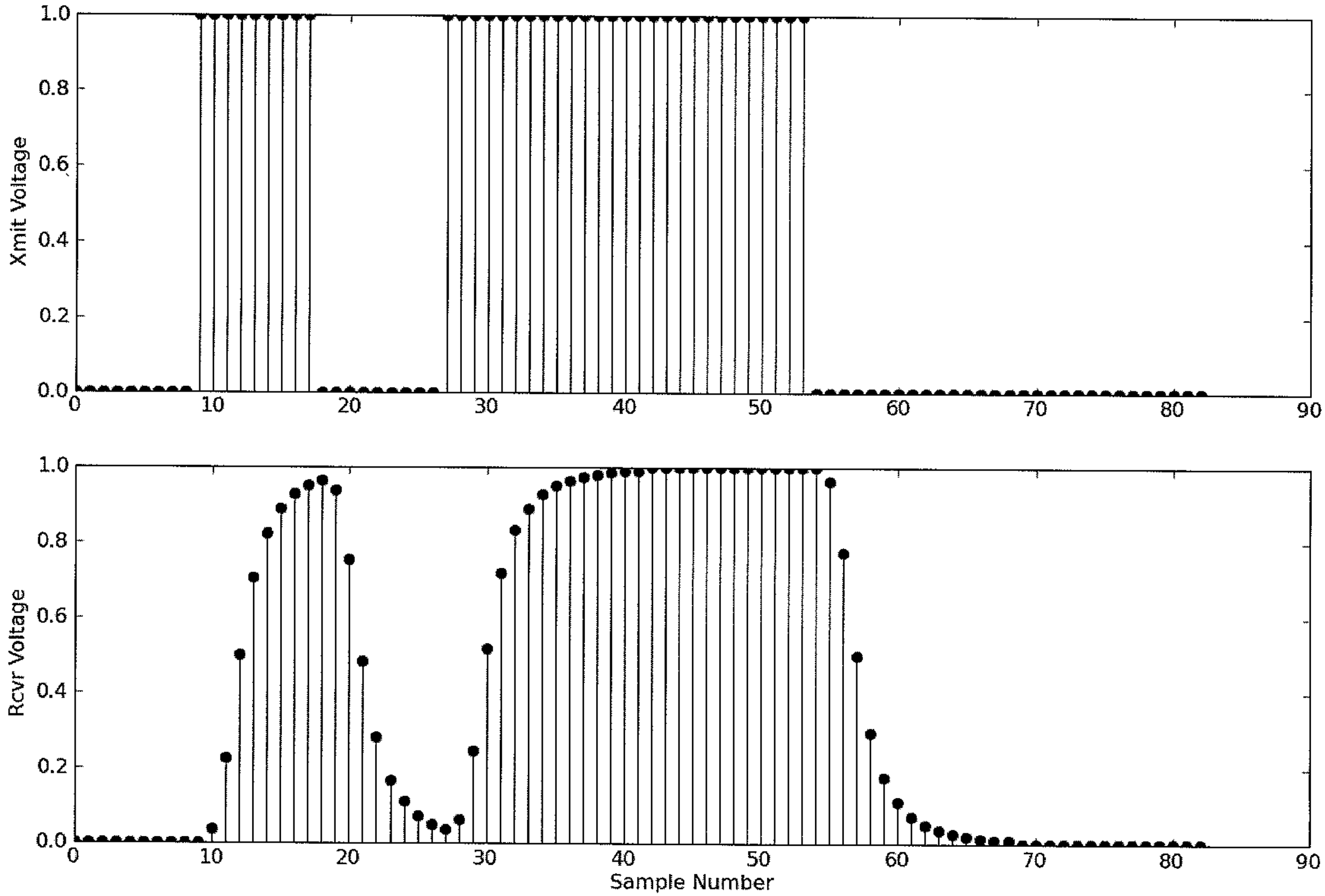
Eye Diagram for 1.25 microsecond bit period

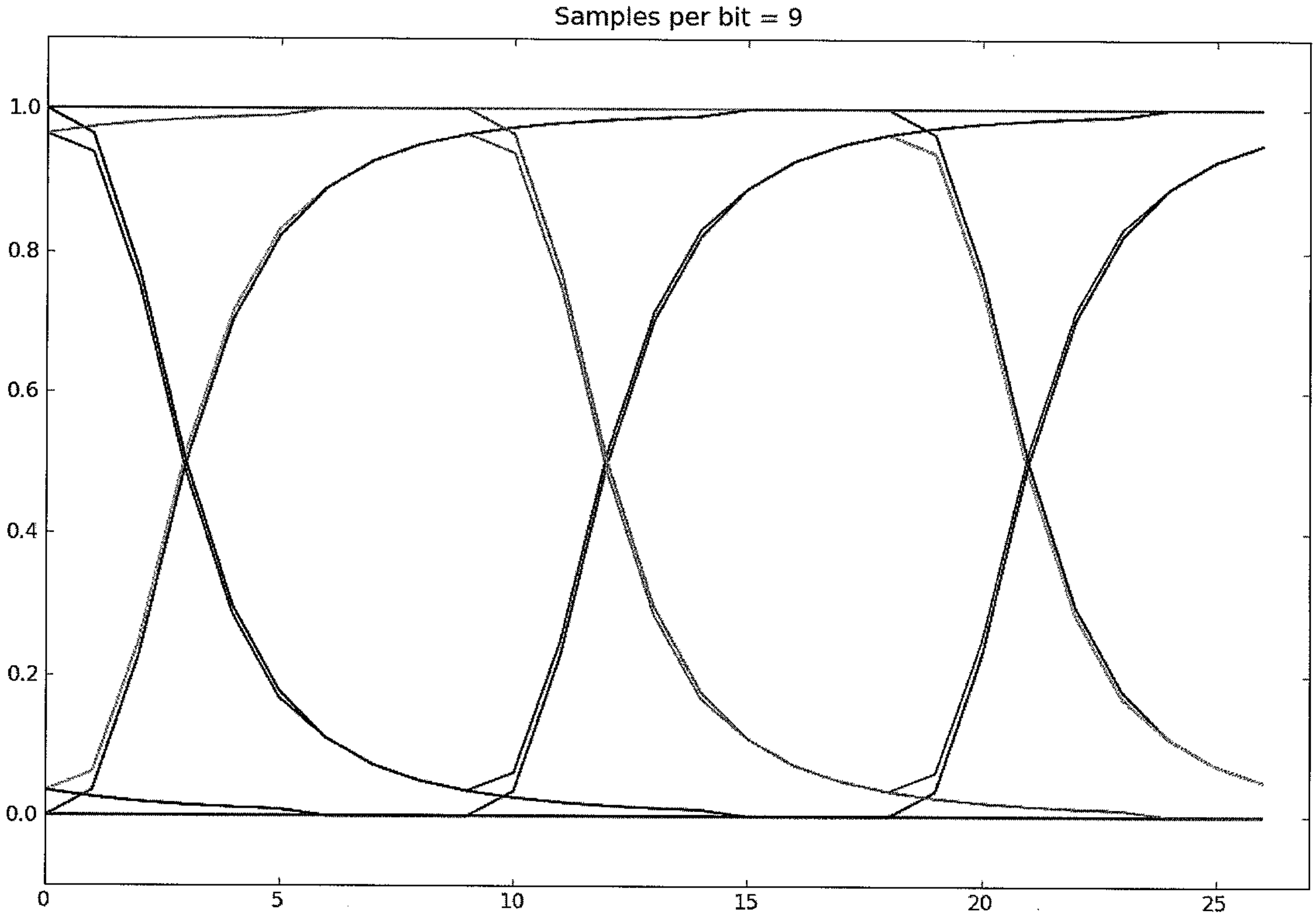


Sending 0101110, 2.25 microseconds/bit



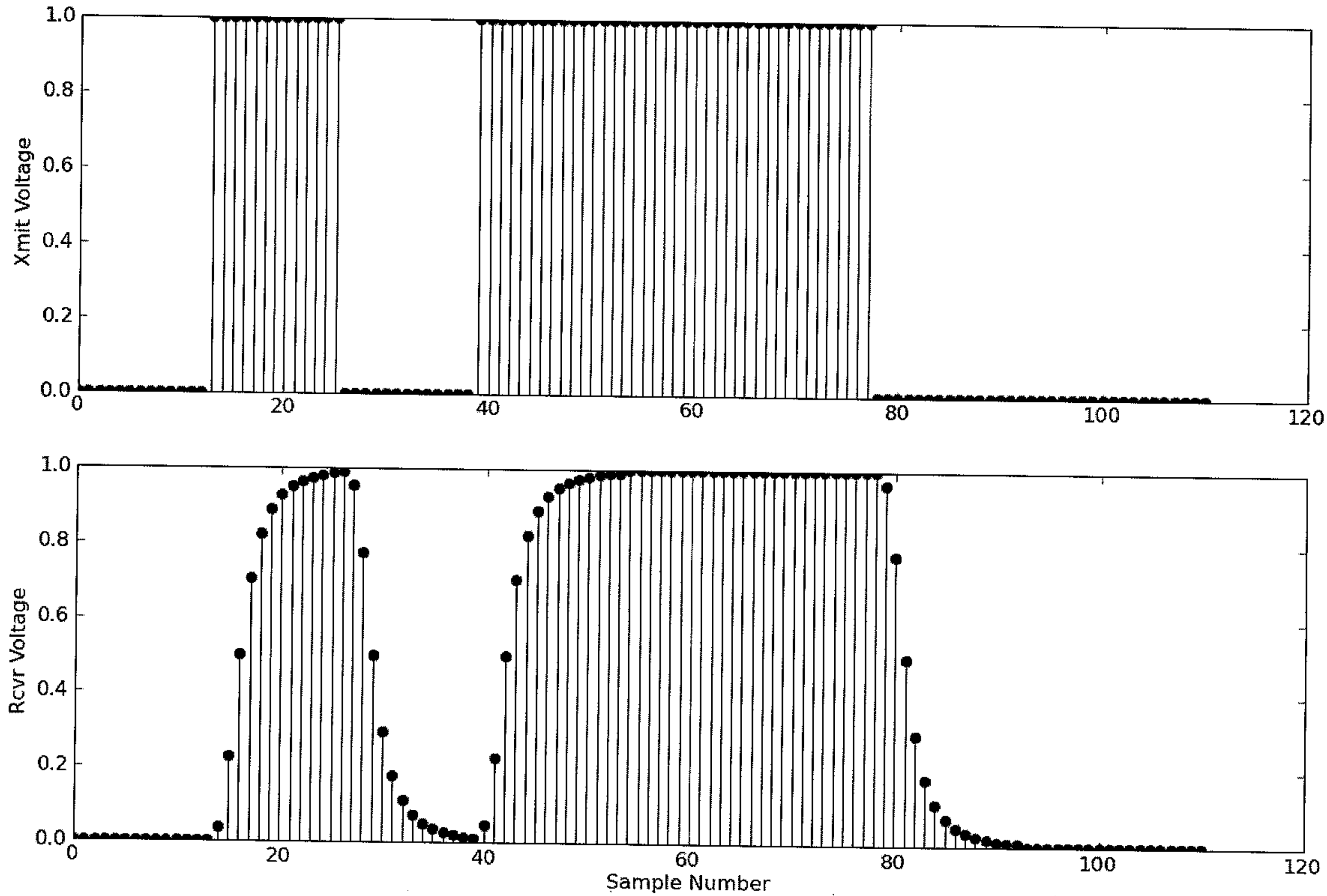
29

Eye Diagram for 2.25 microsecond bit period

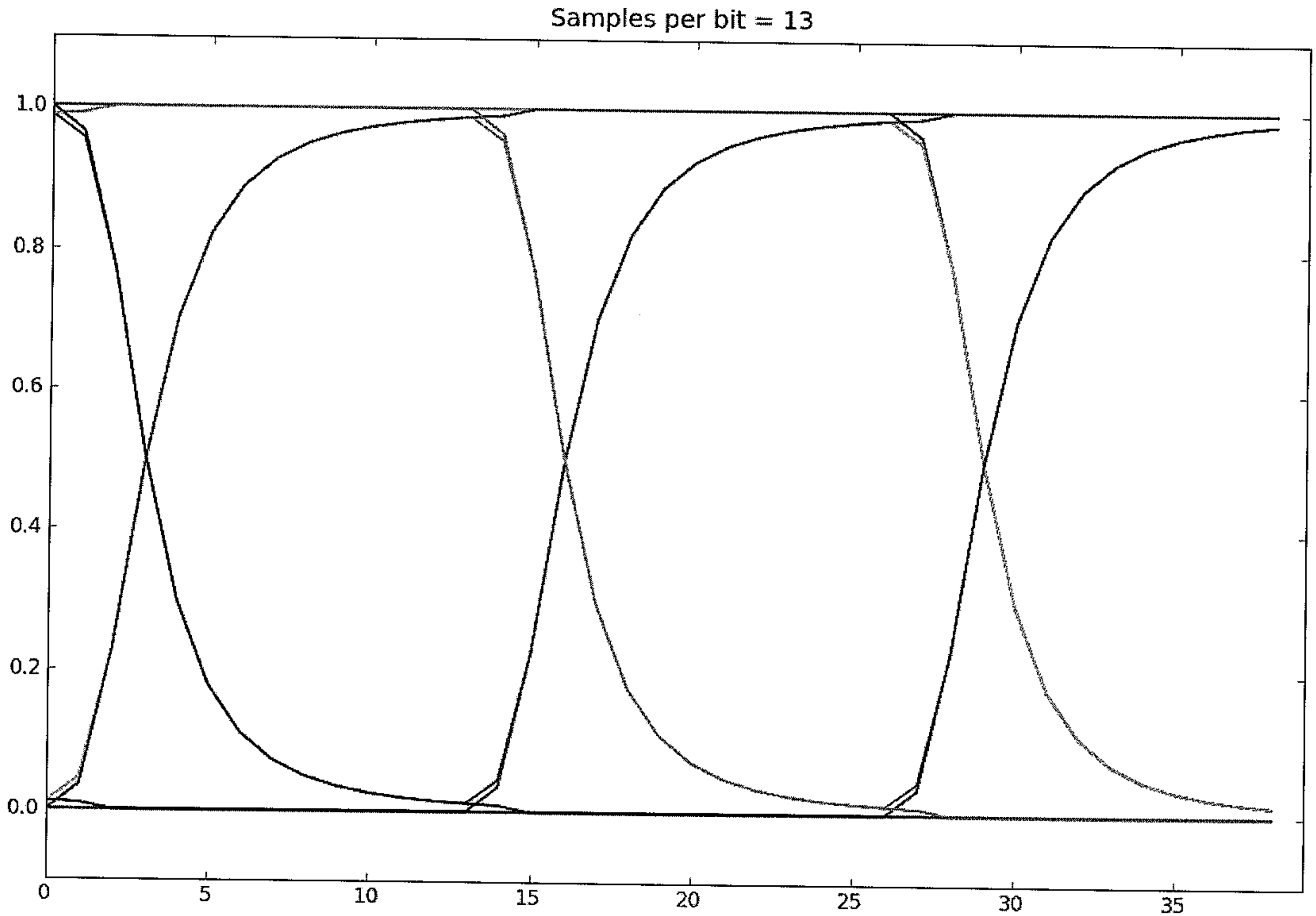


30

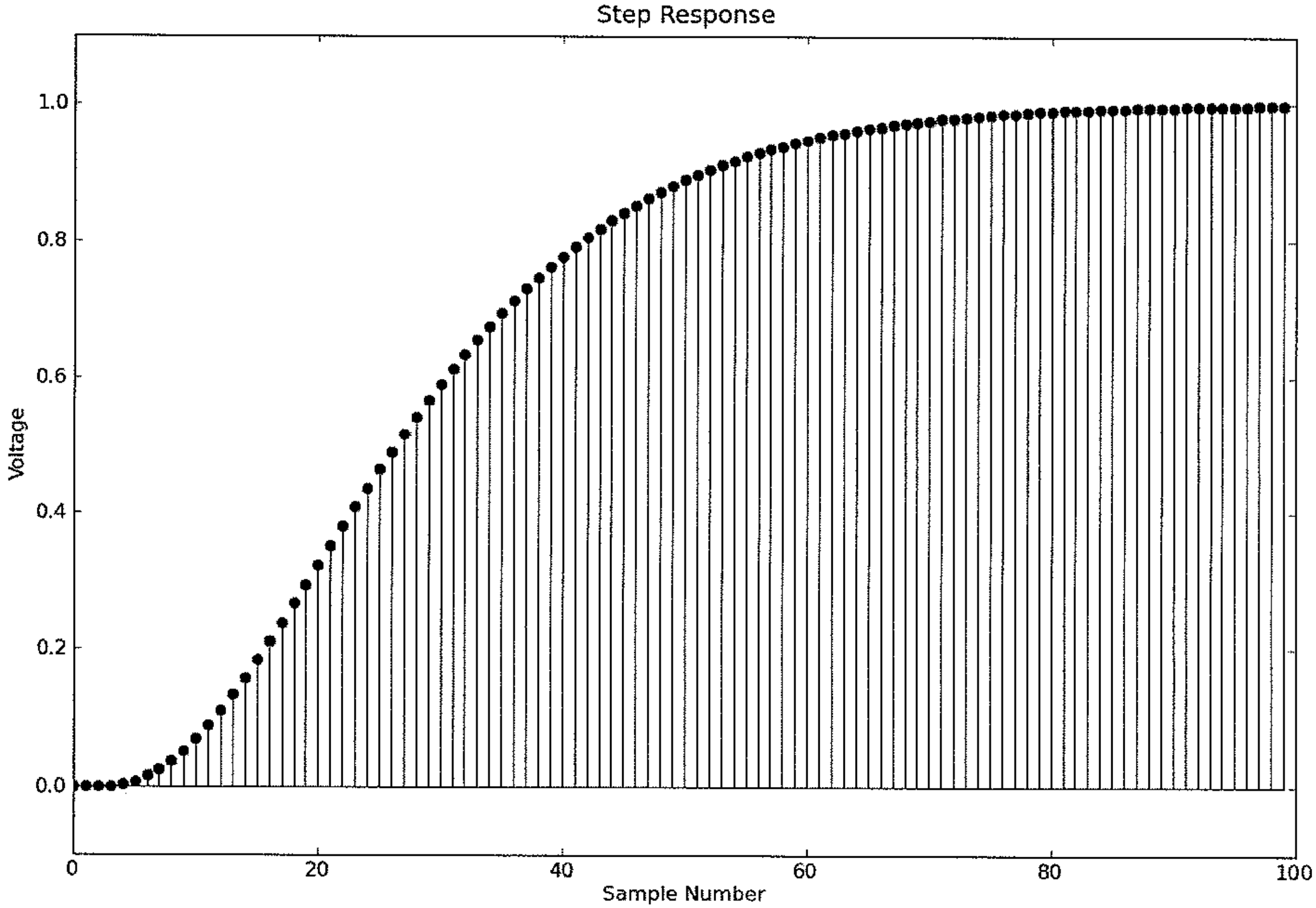
Sending 0101110, 3.25 microseconds/bit



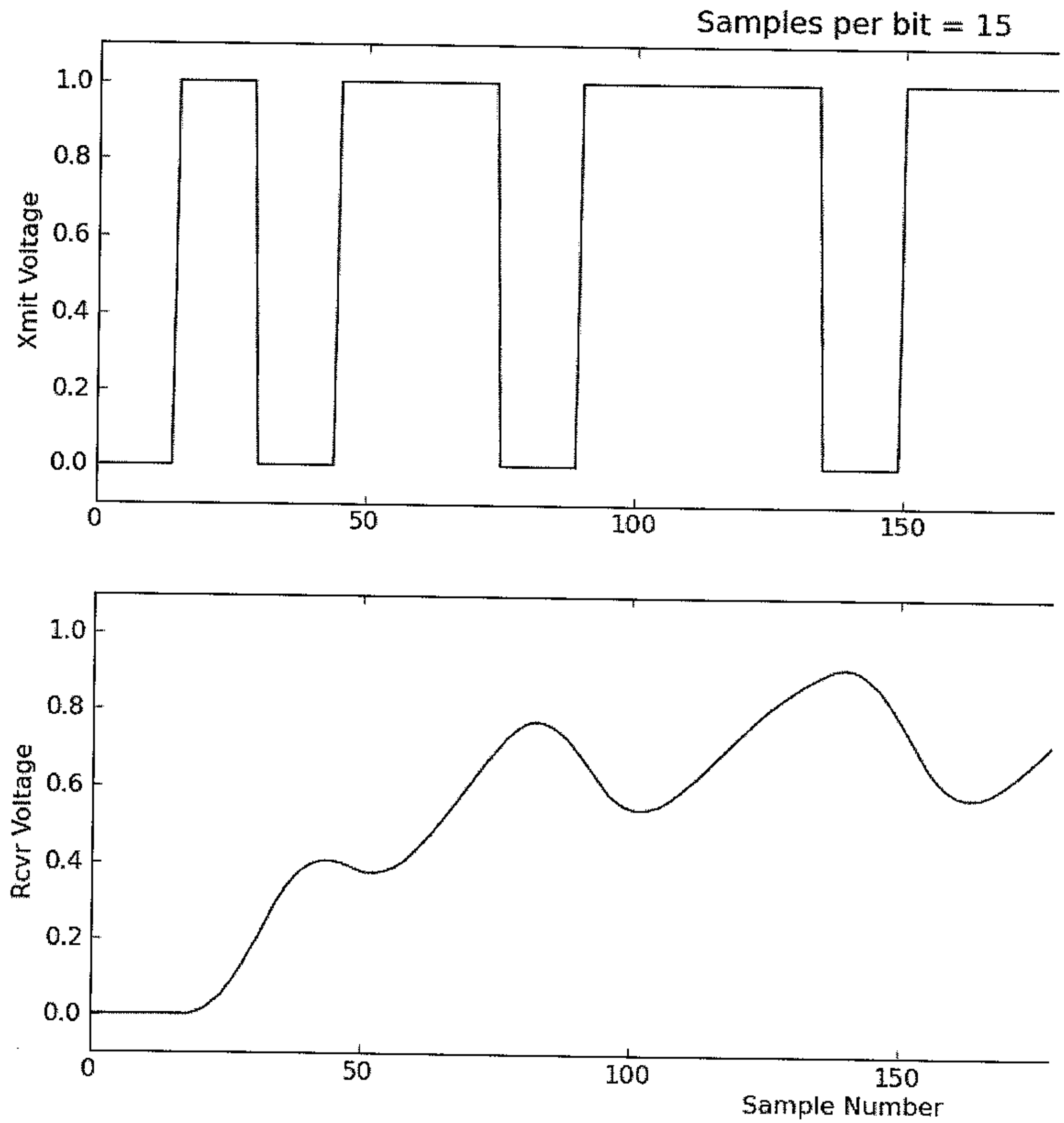
Eye Diagram for 3.25 microsecond bit period



Step Response for Slow Channel



Slow Channel Response



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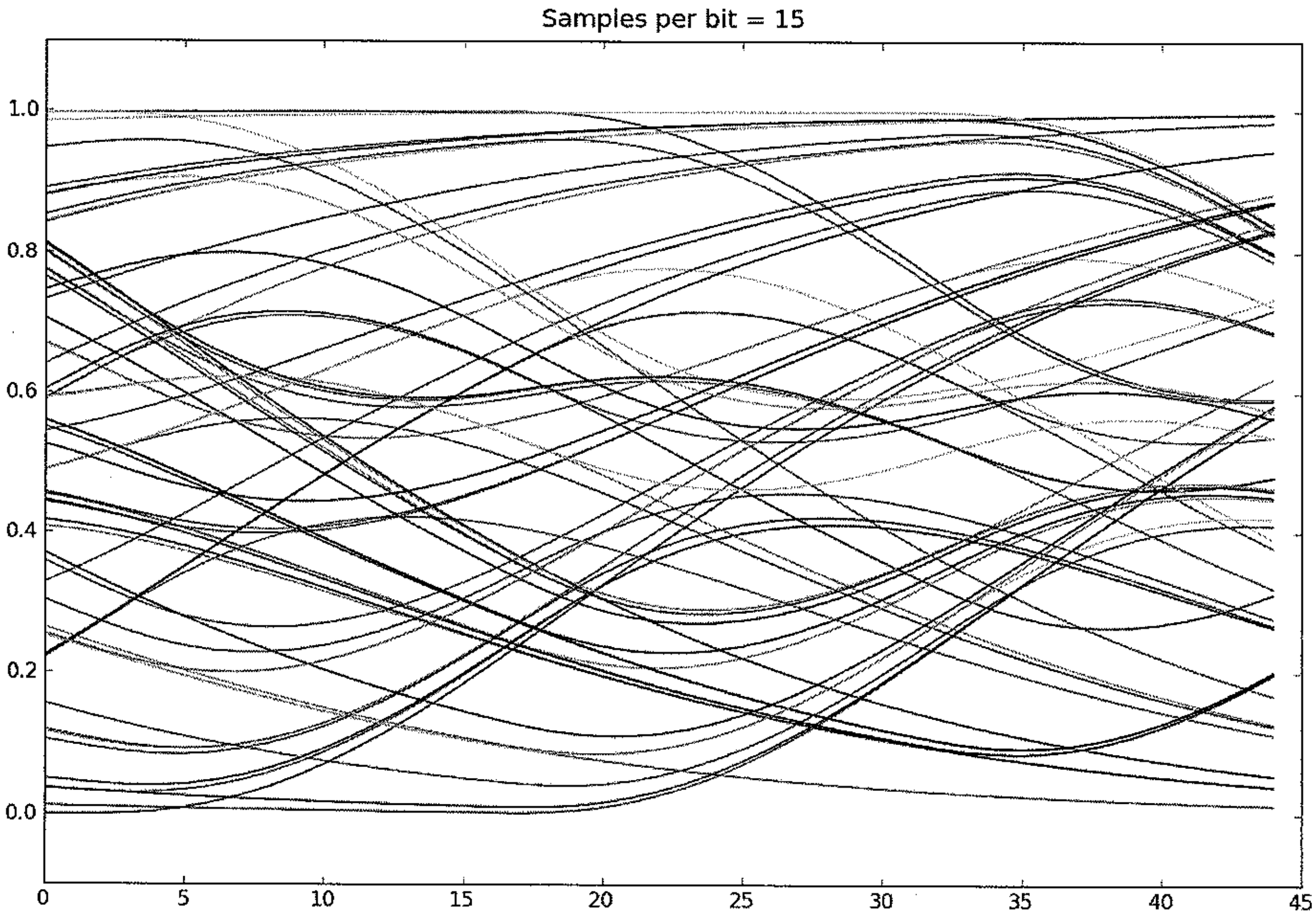
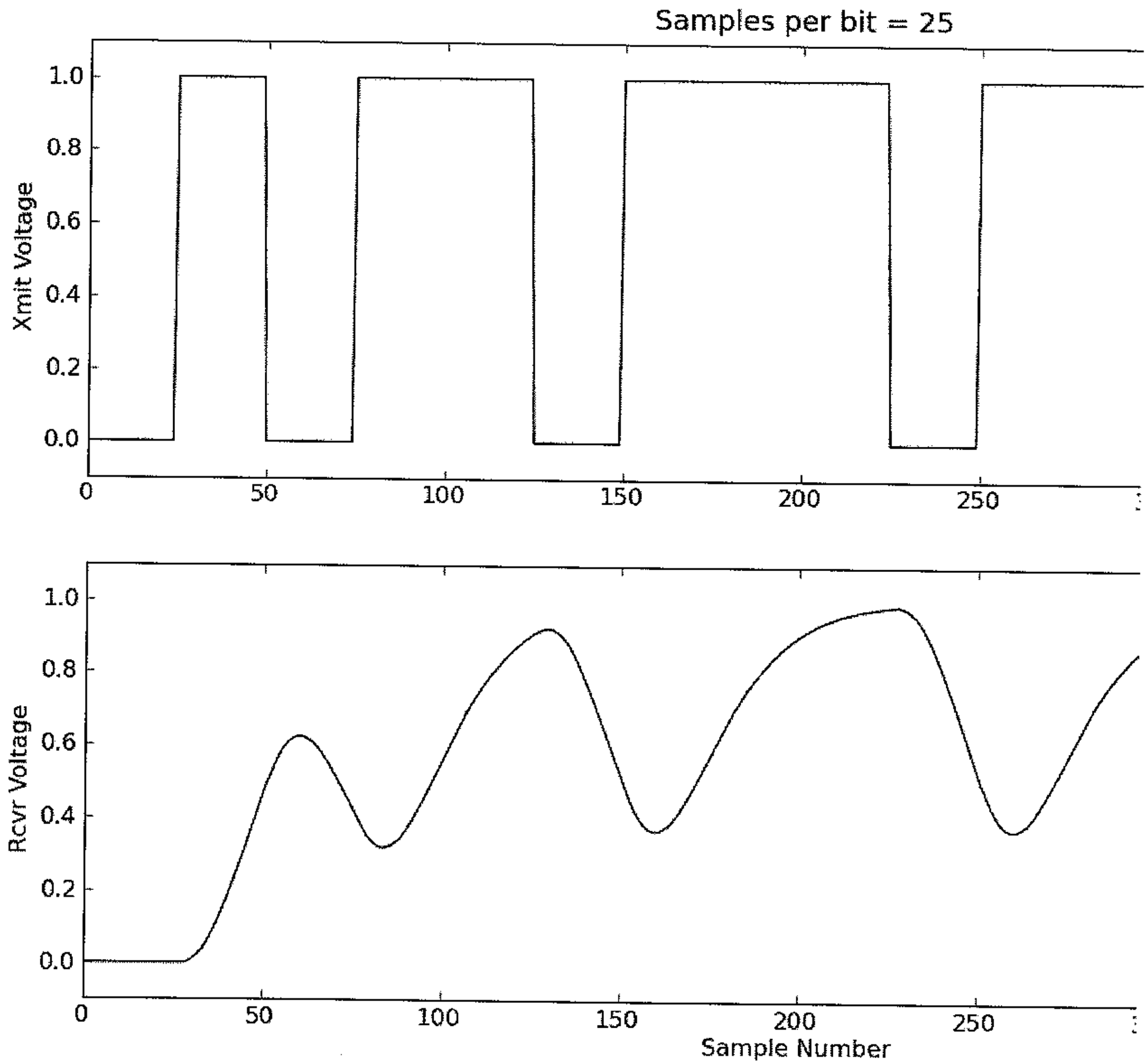
Slow Channel Eye Diagram



Slow Channel Response



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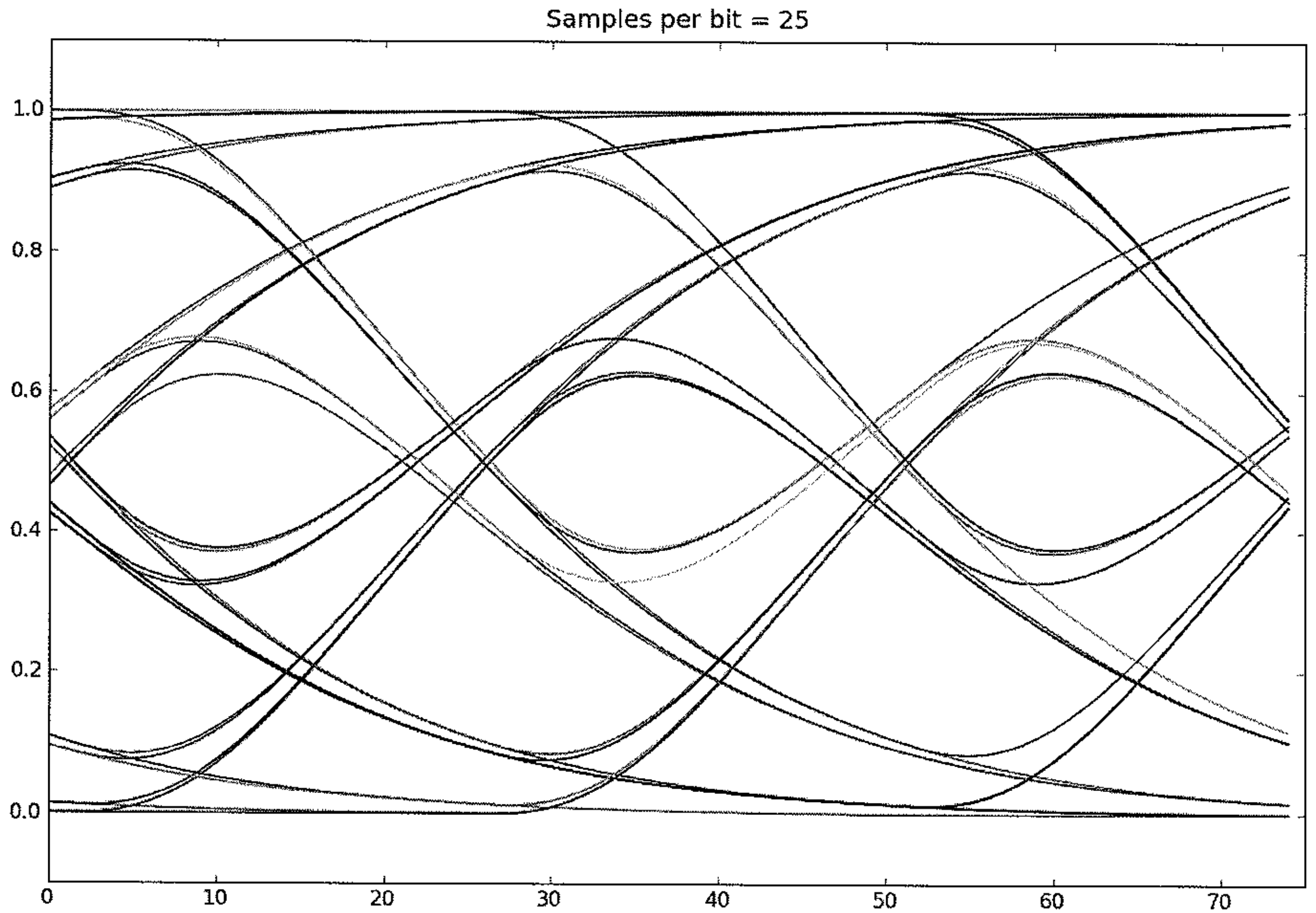
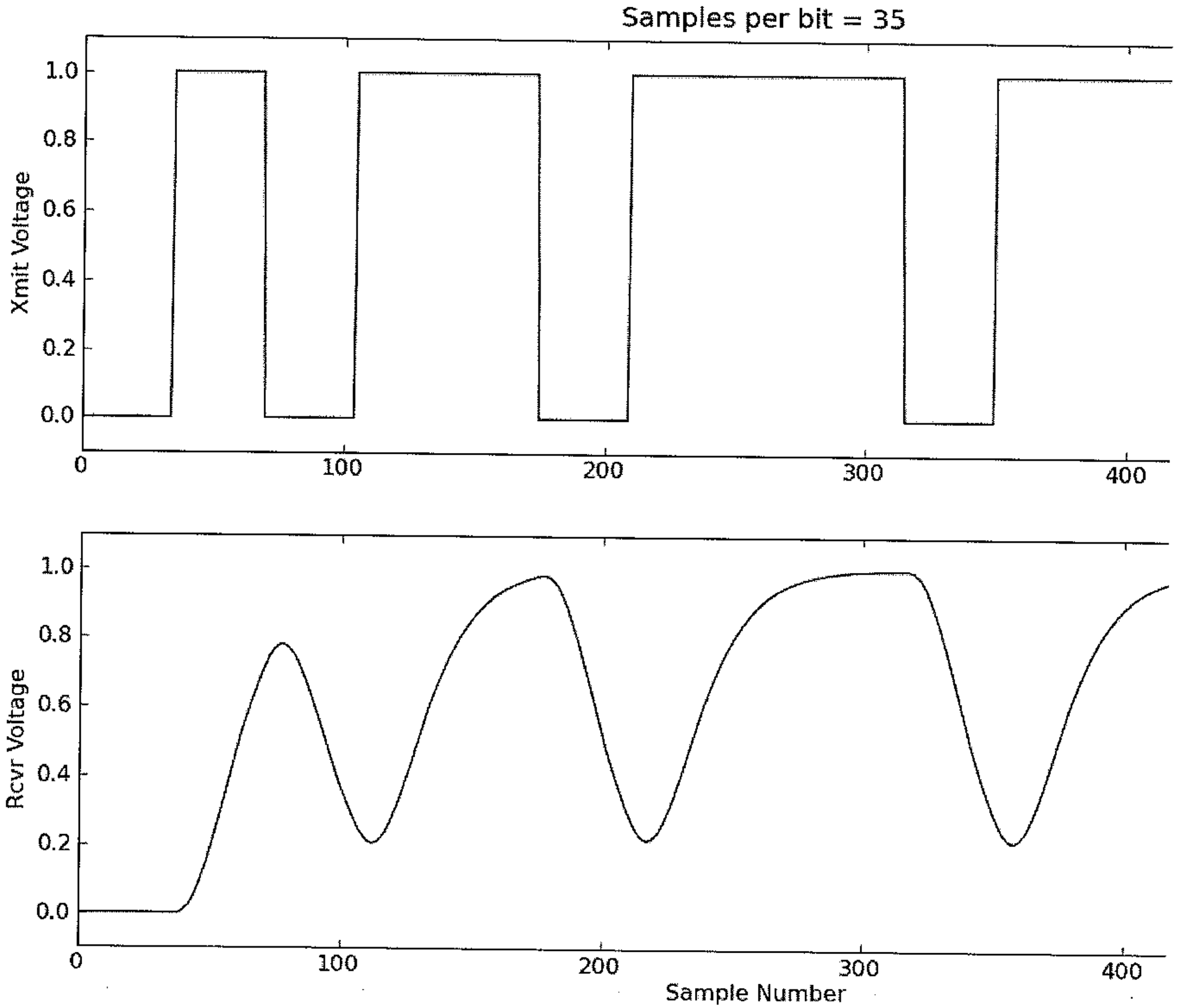
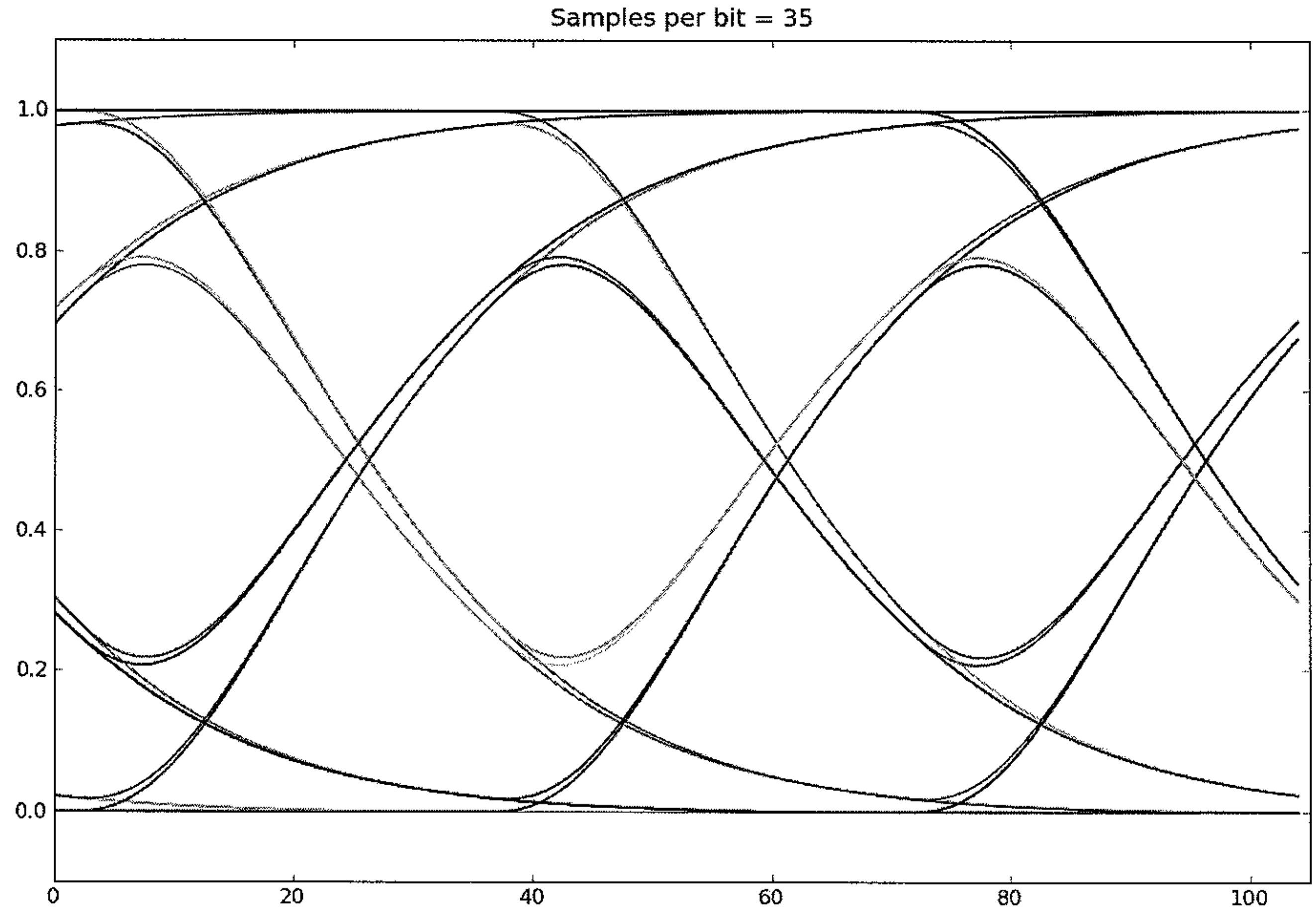
Slow Channel Eye Diagram



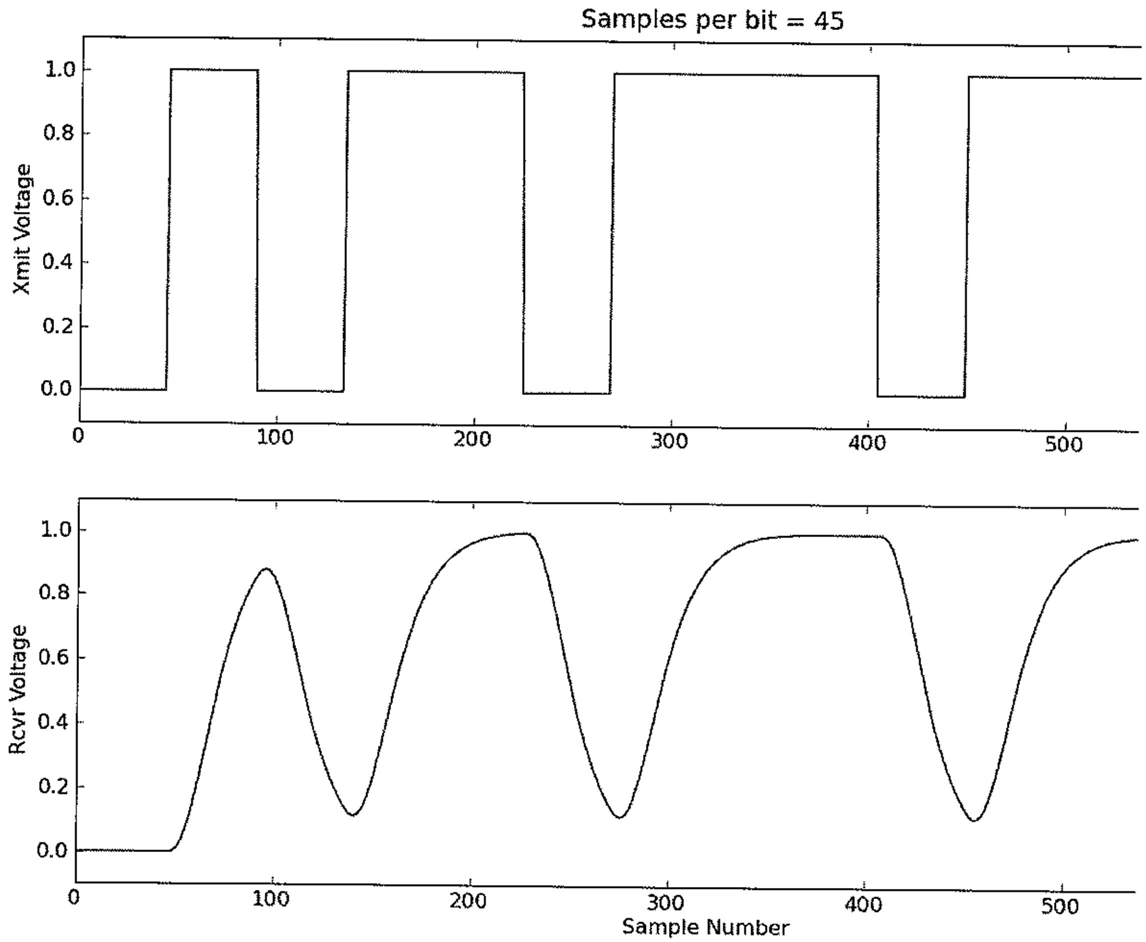
Slow Channel Response



Slow Channel Eye Diagram



Slow Channel Response



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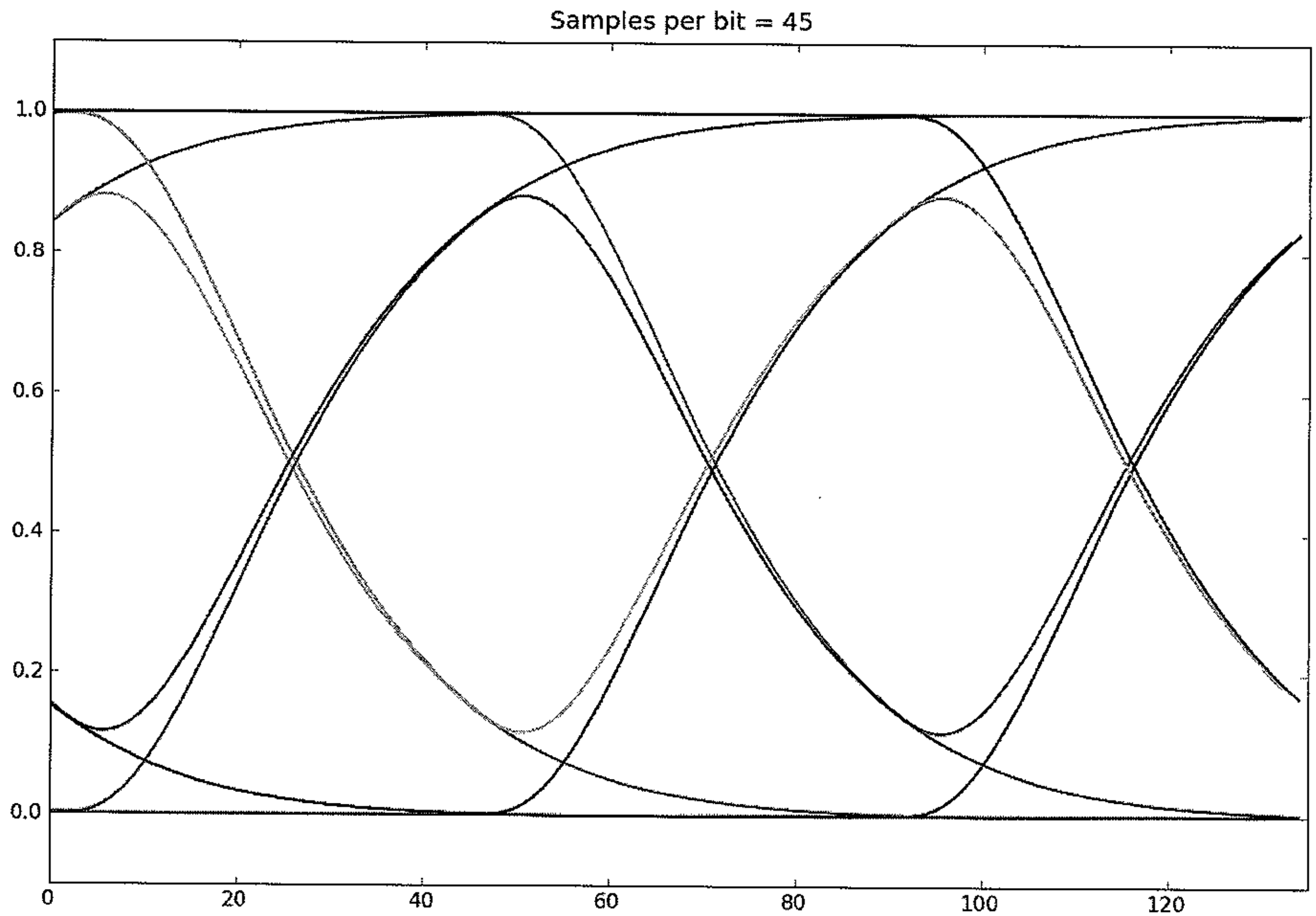
Slow Channel Eye Diagram



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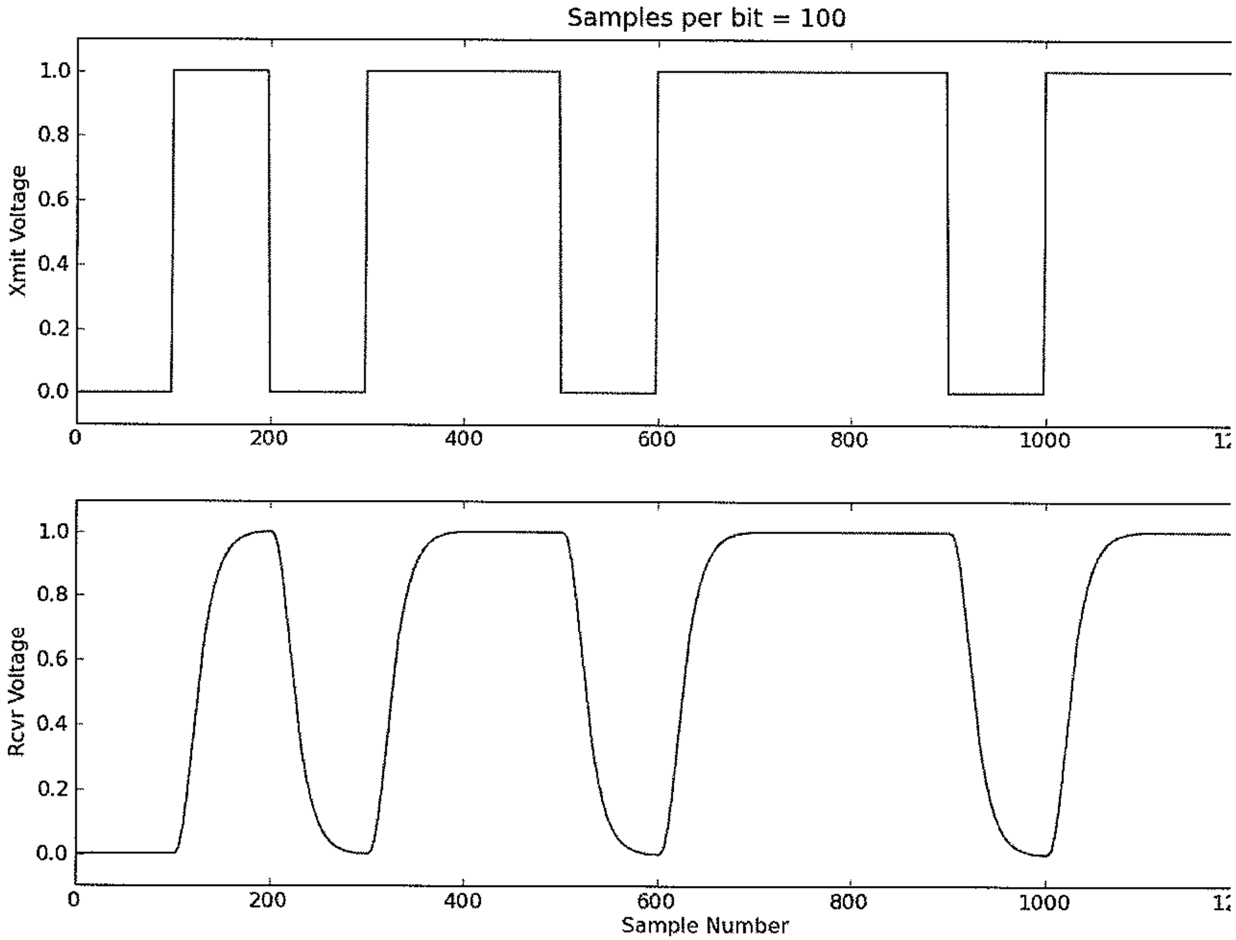
Slow Channel Response



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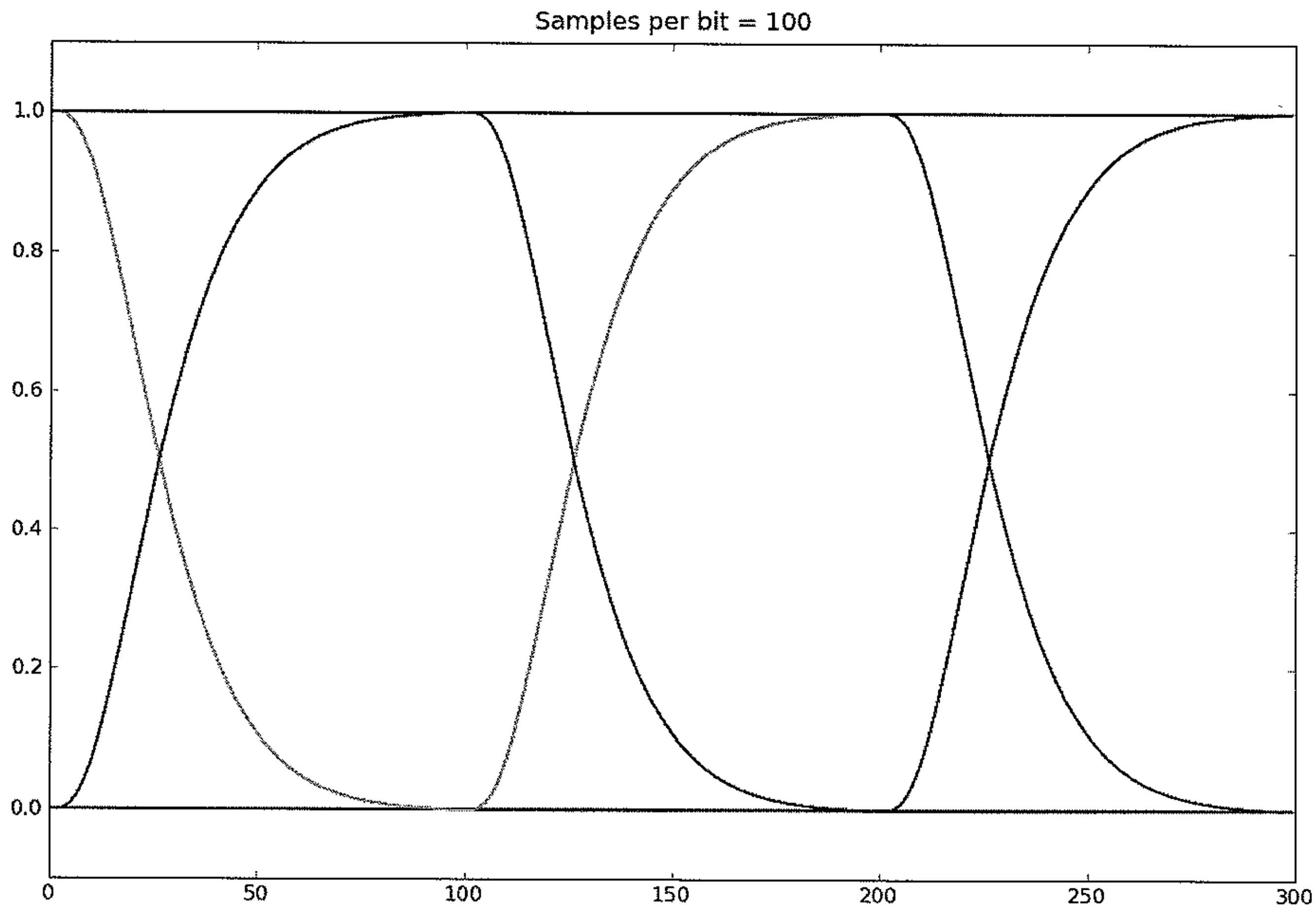
Slow Channel Eye Diagram



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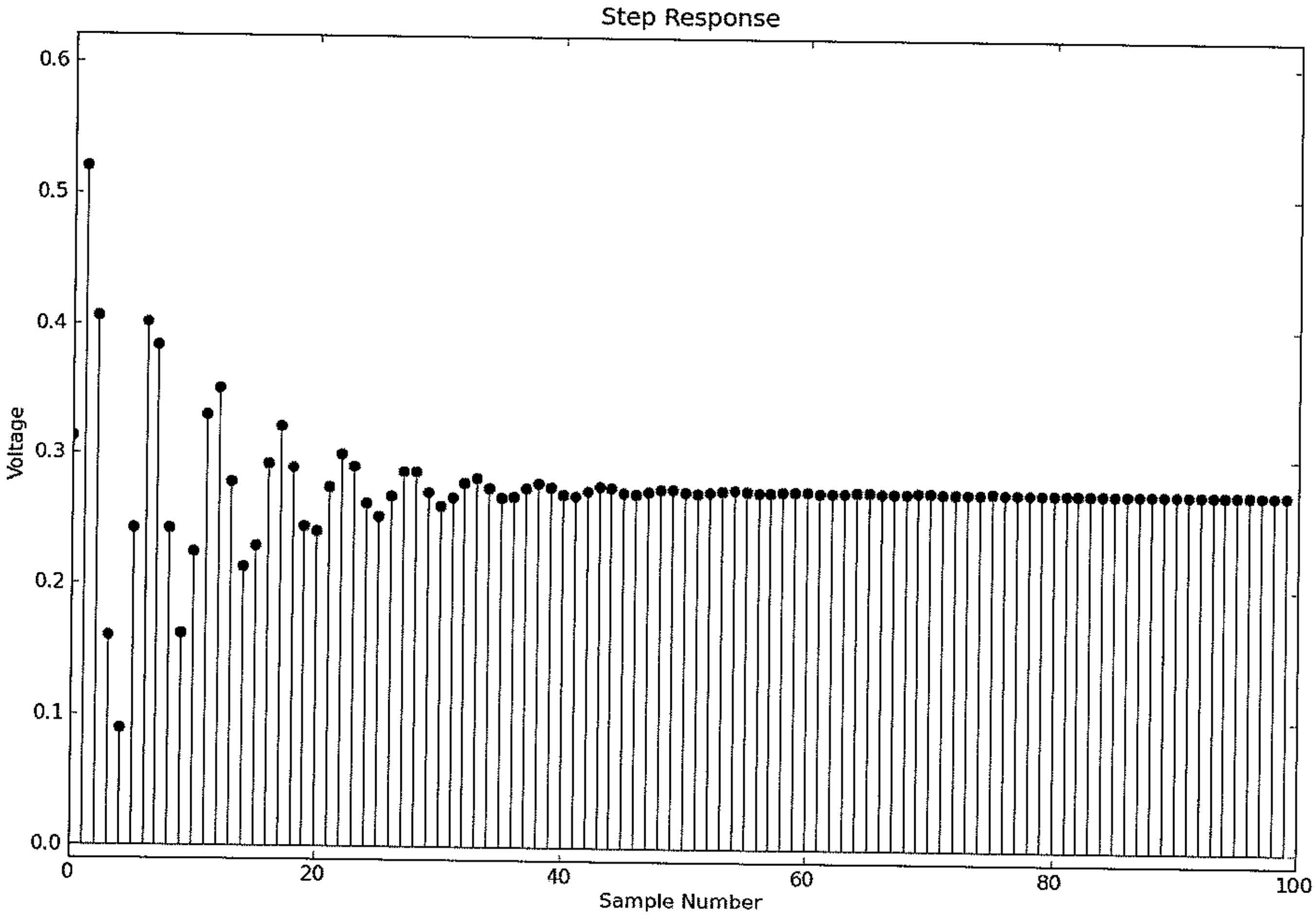
Step Response for Ringing Channel



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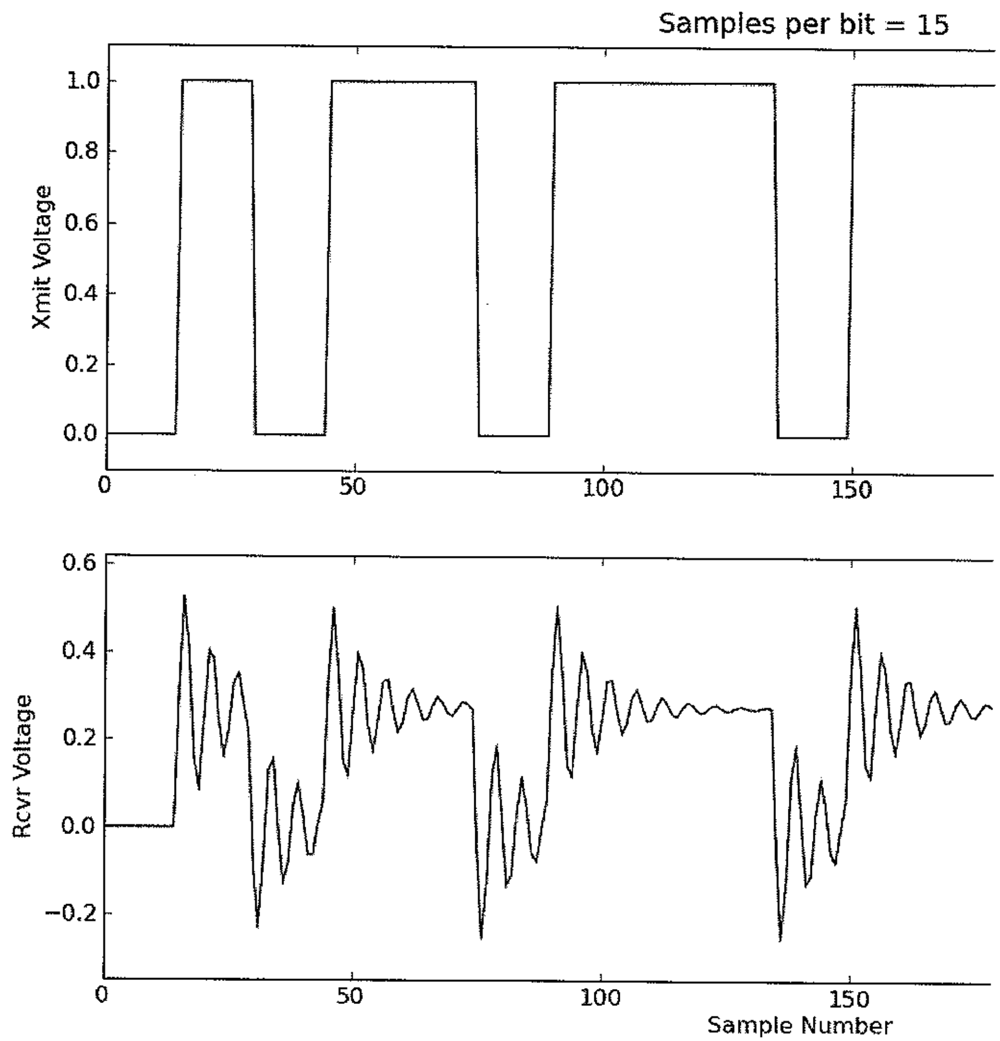
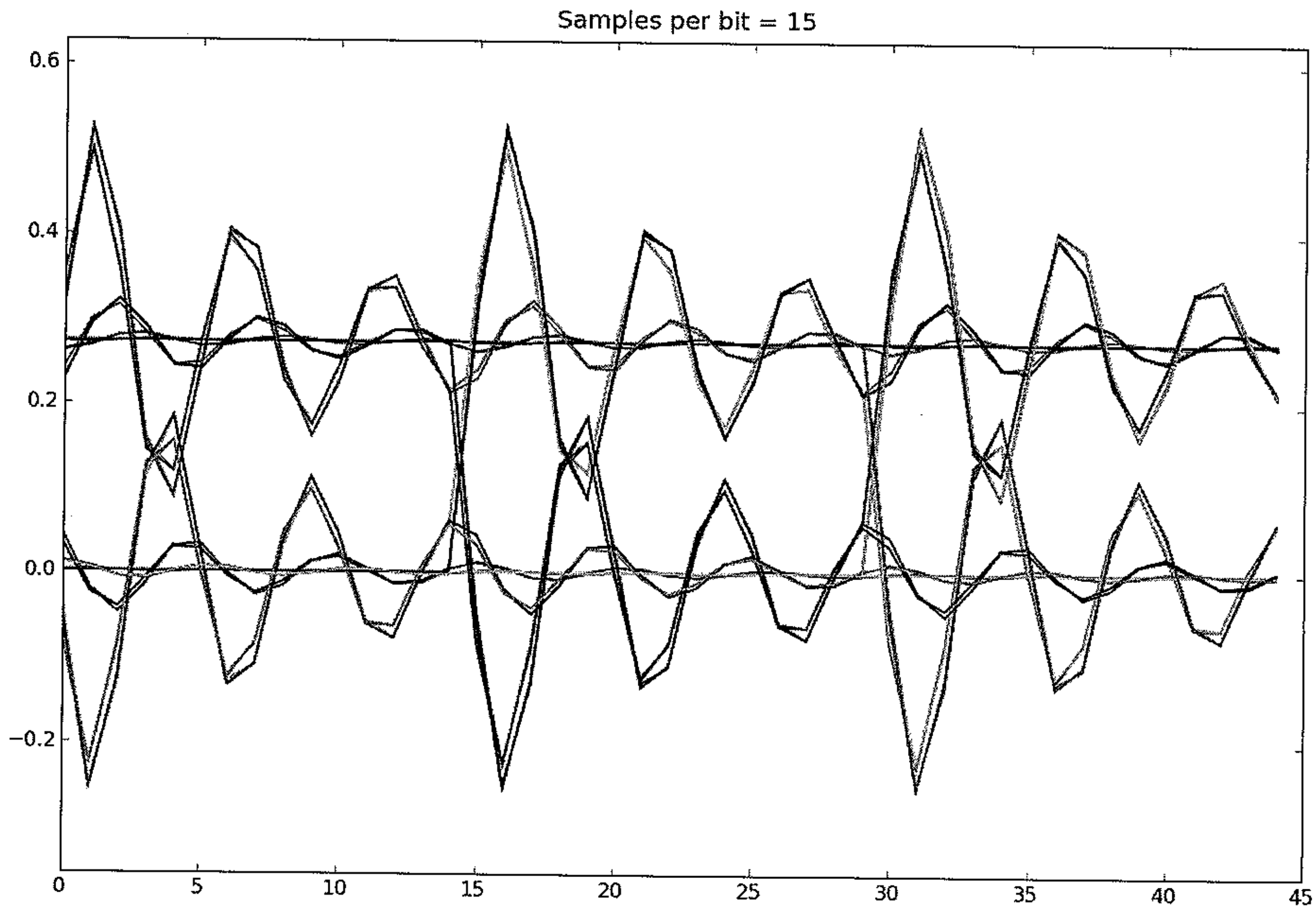
Ringing Channel Response



Ringing Channel Eye Diagram

45



Ringing Channel Response

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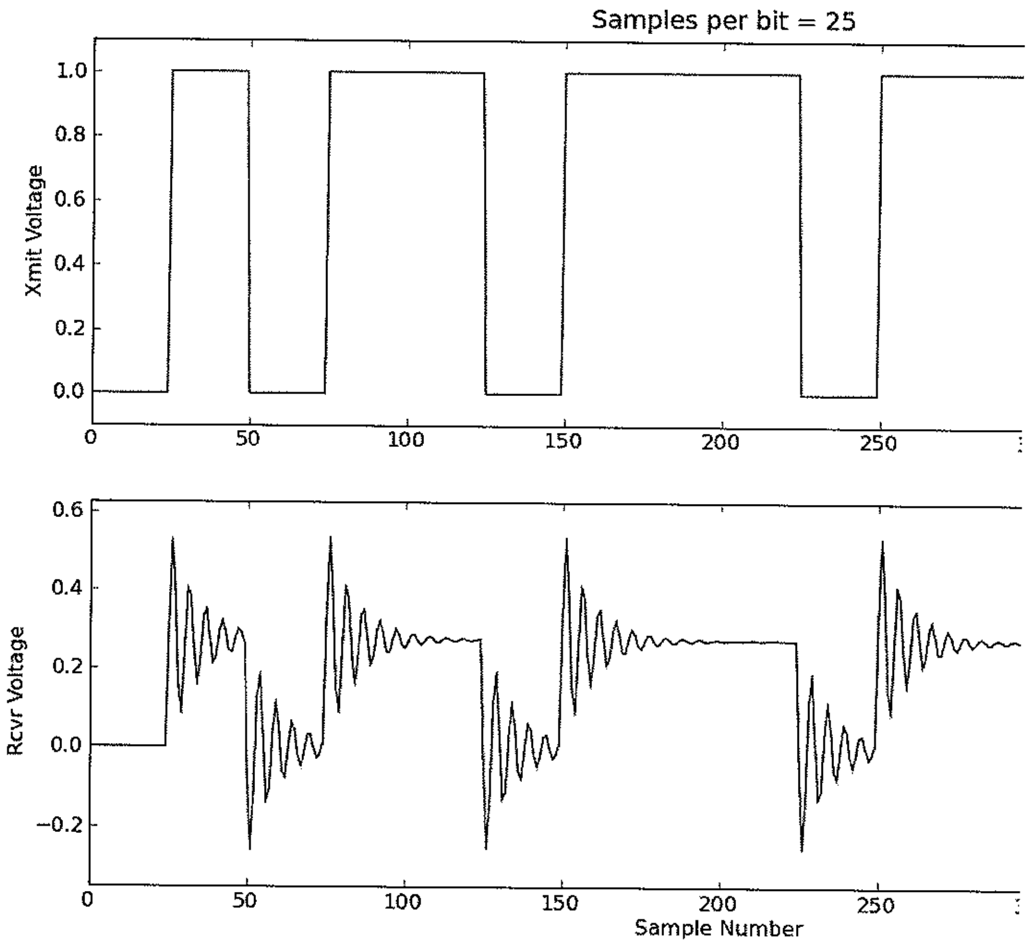

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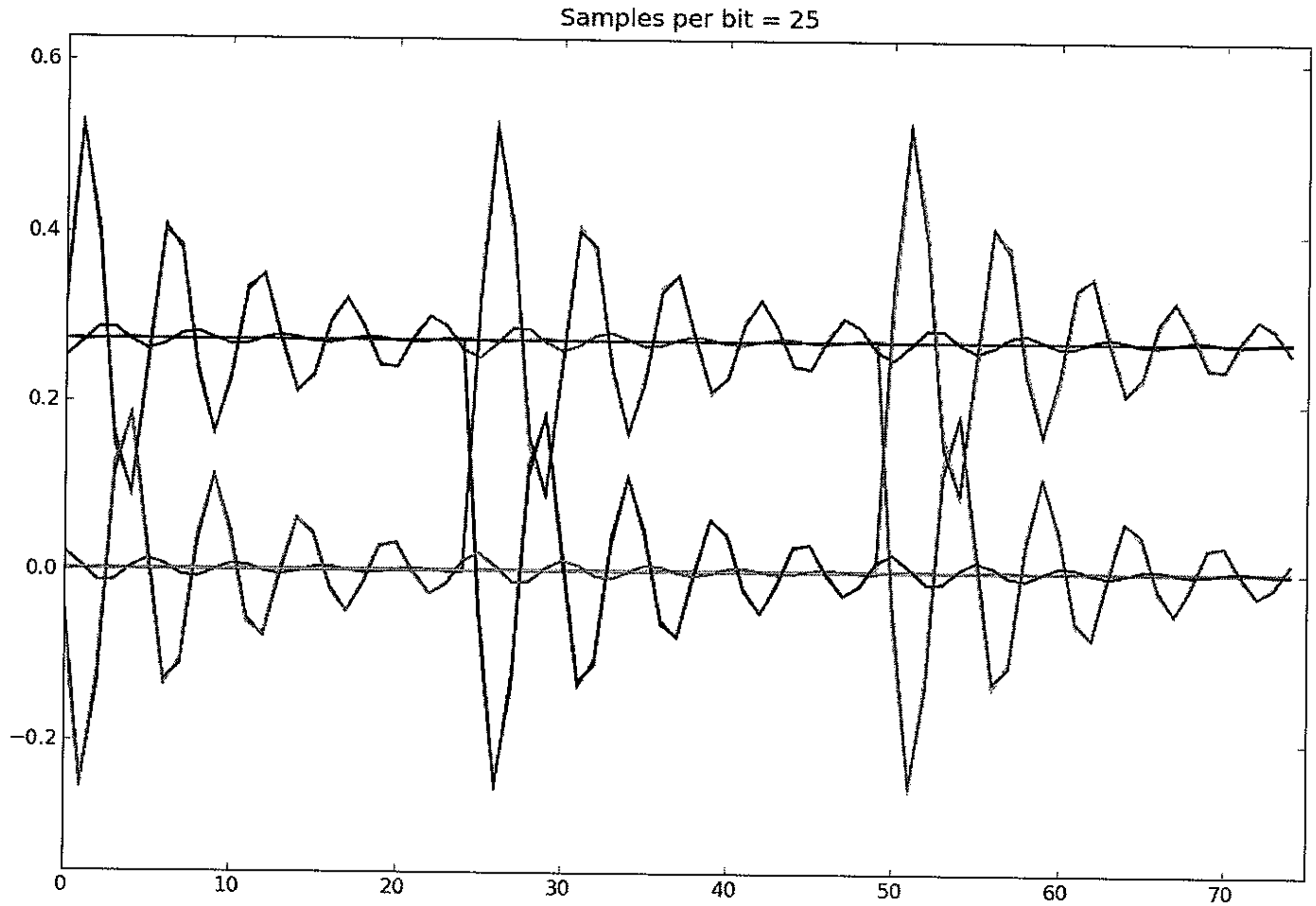
Ringing Channel Eye Diagram



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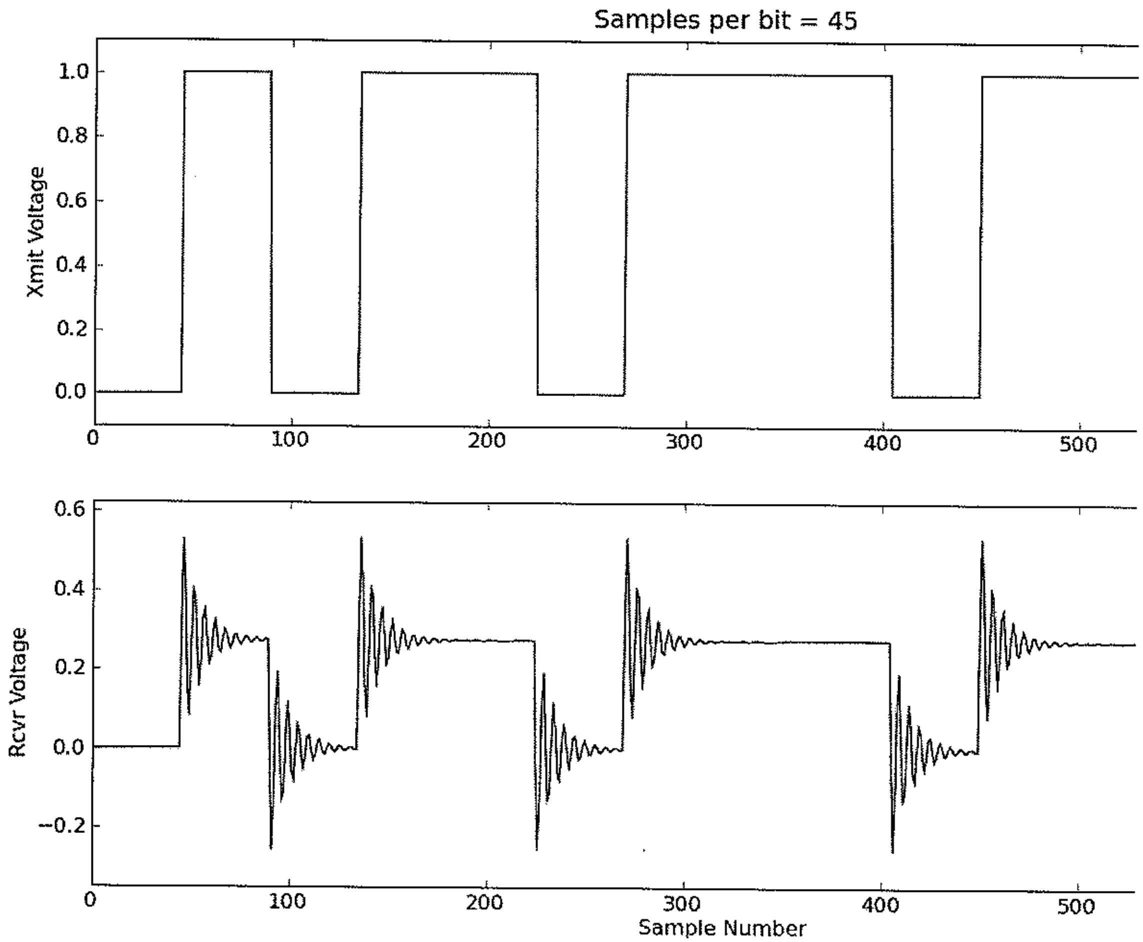
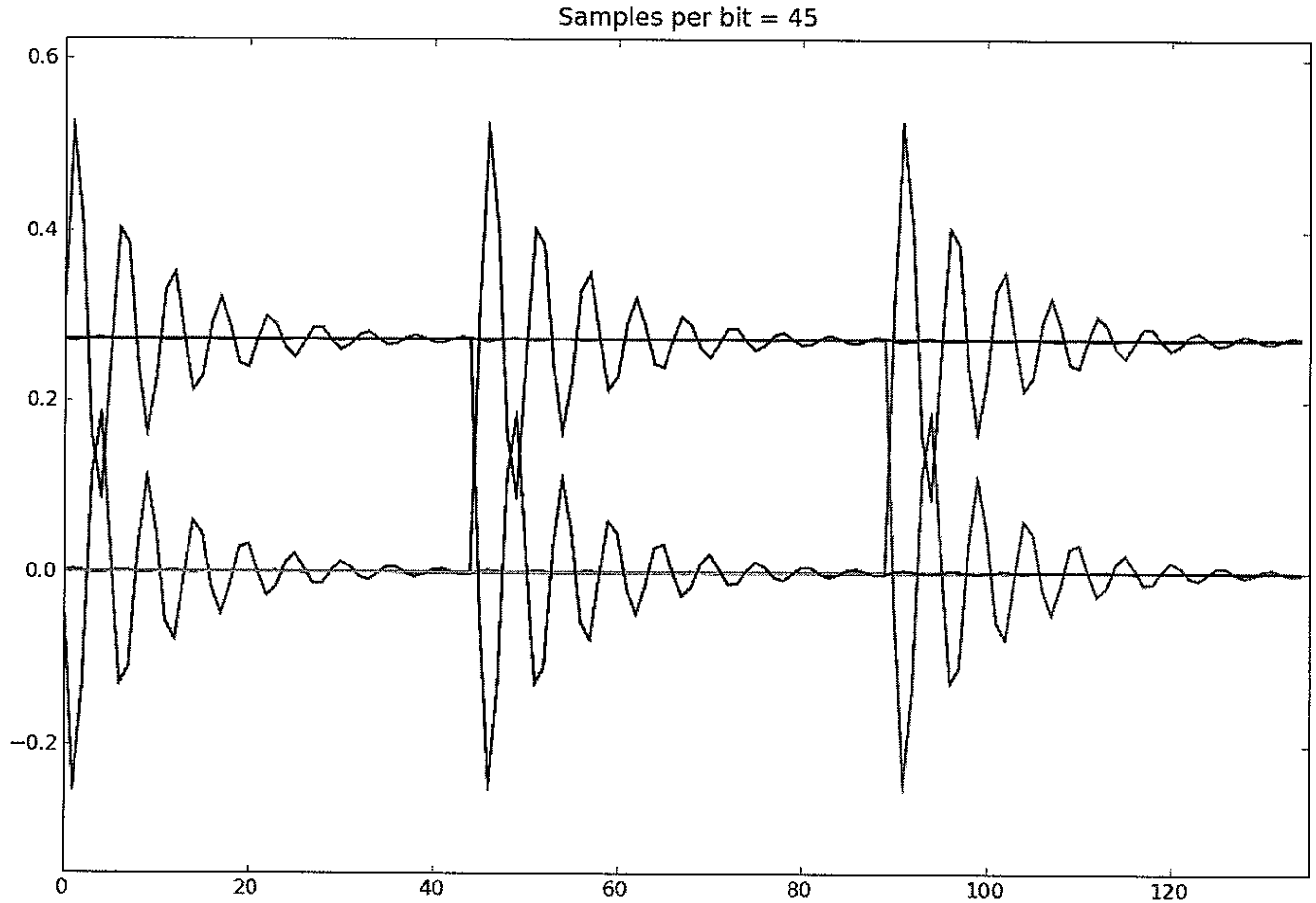
Ringing Channel Response



Ringing Channel Eye Diagram



Ringing Channel Response

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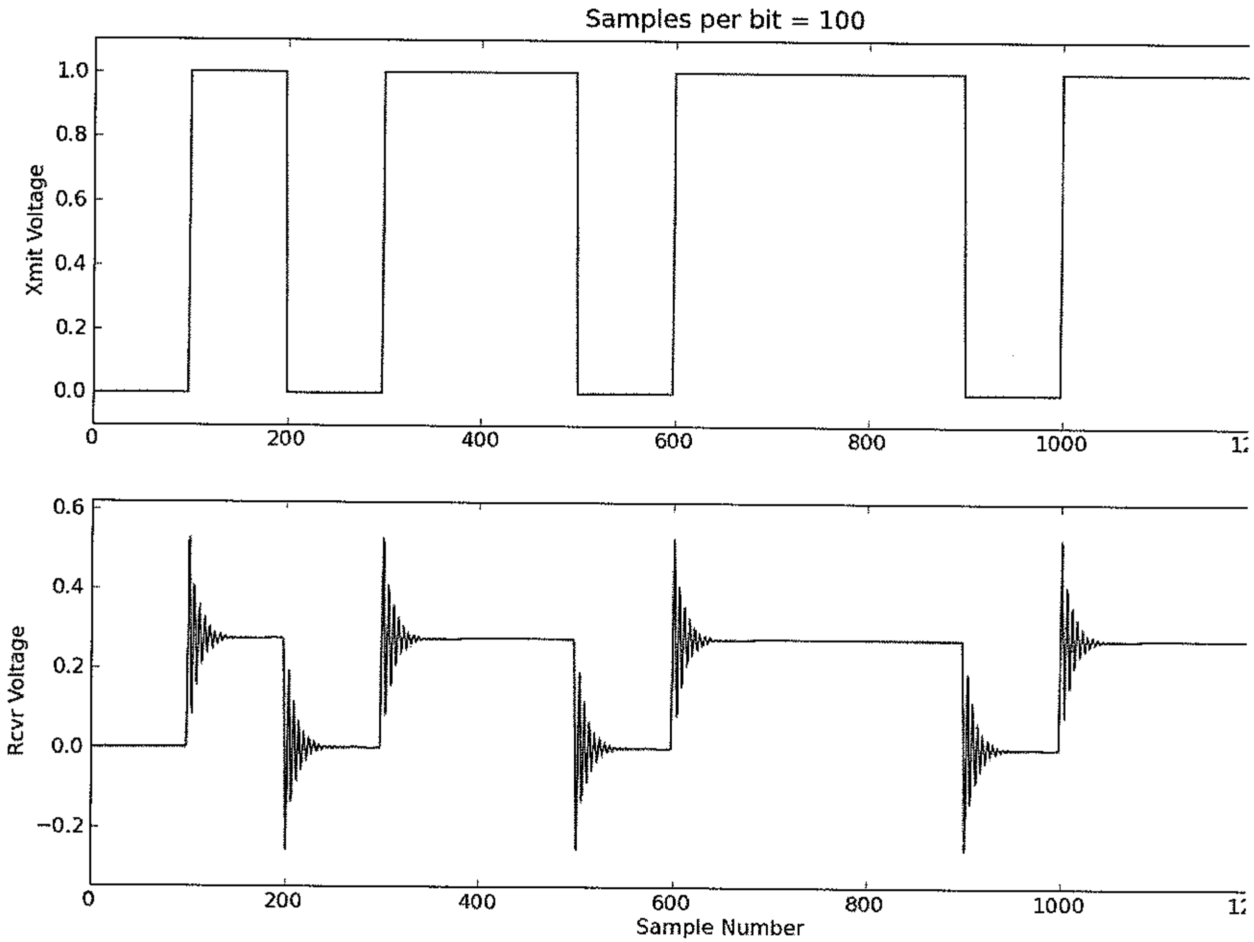
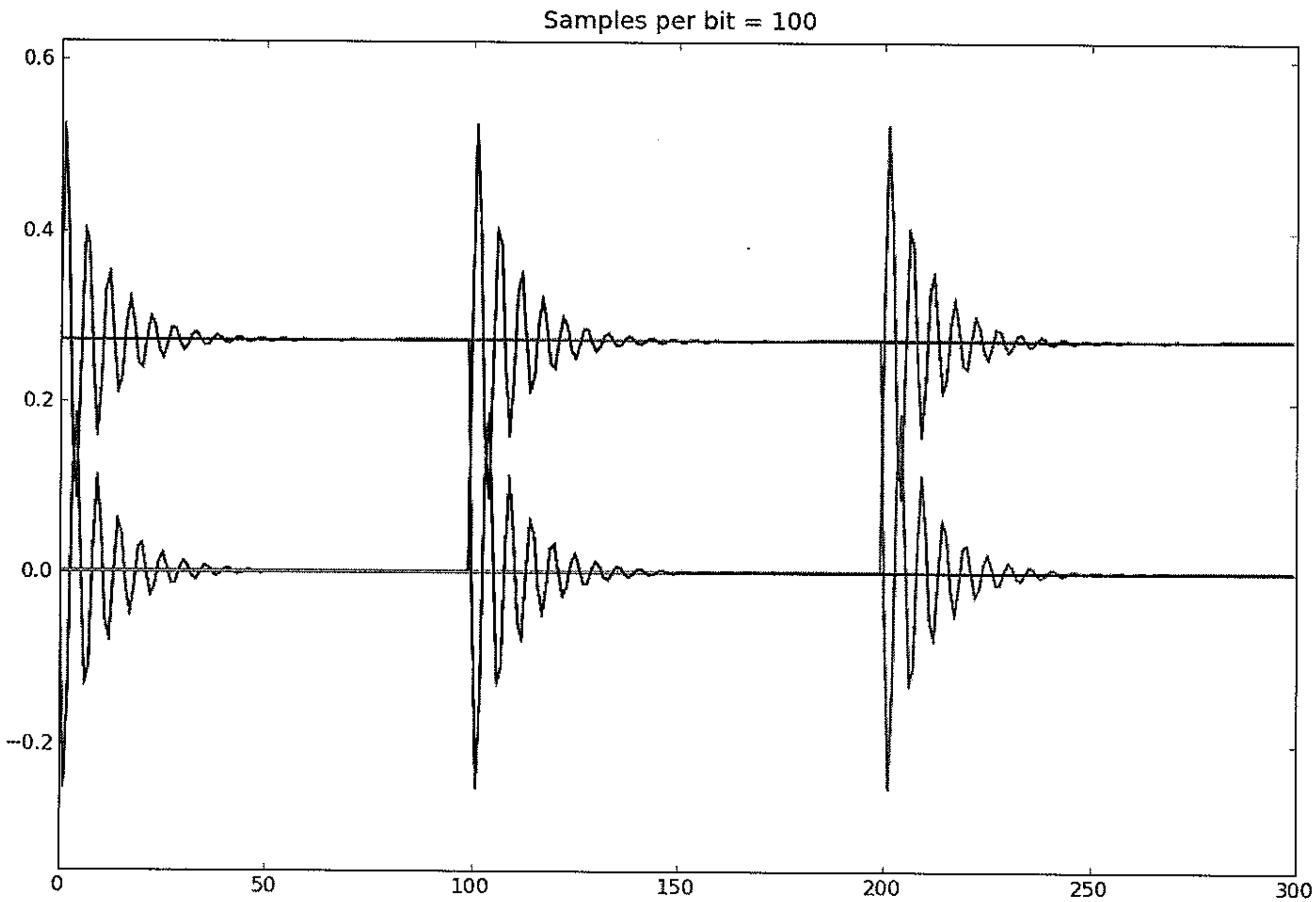


(51)

Ringing Channel Eye Diagram



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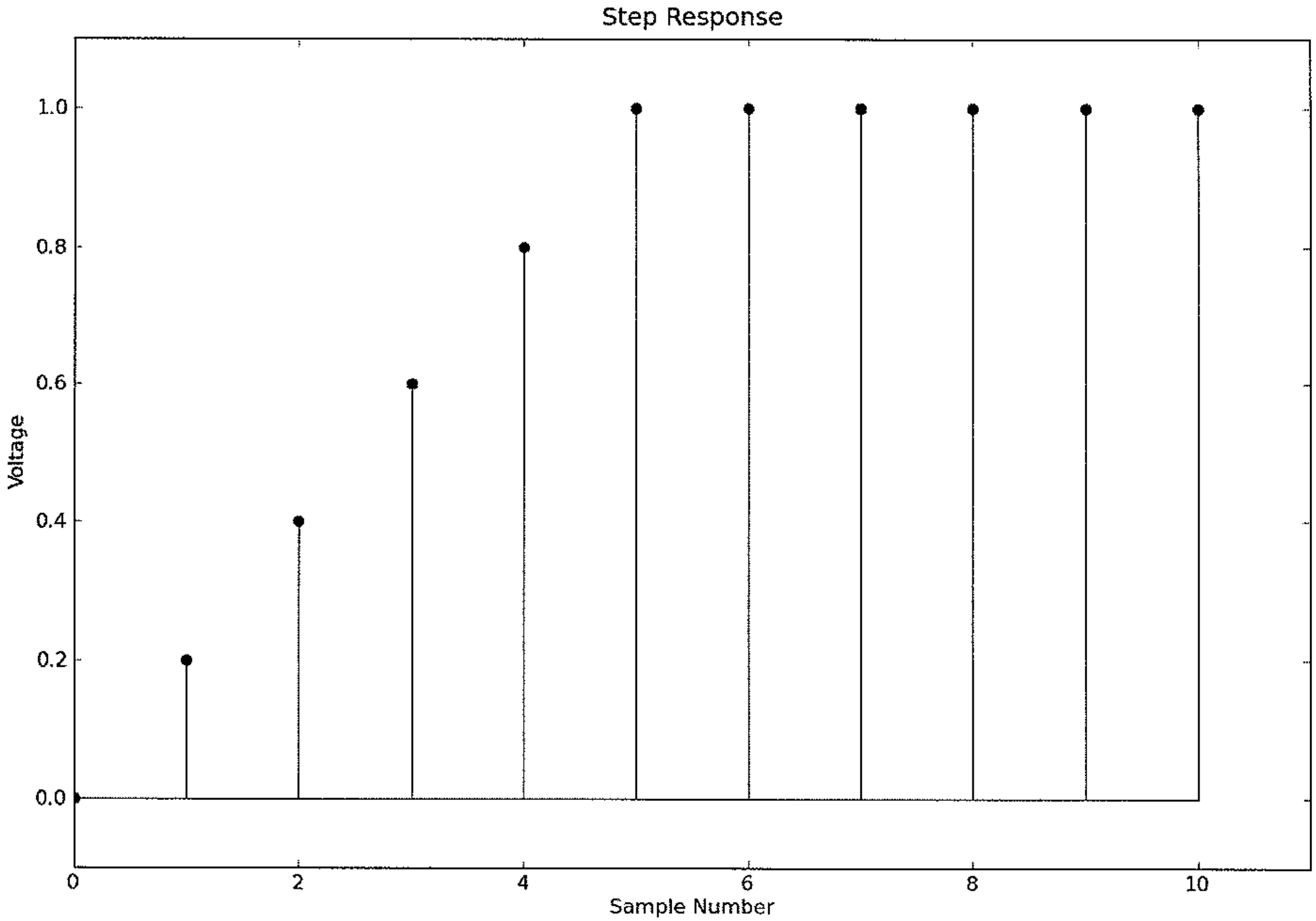
Straight Rise Step Response



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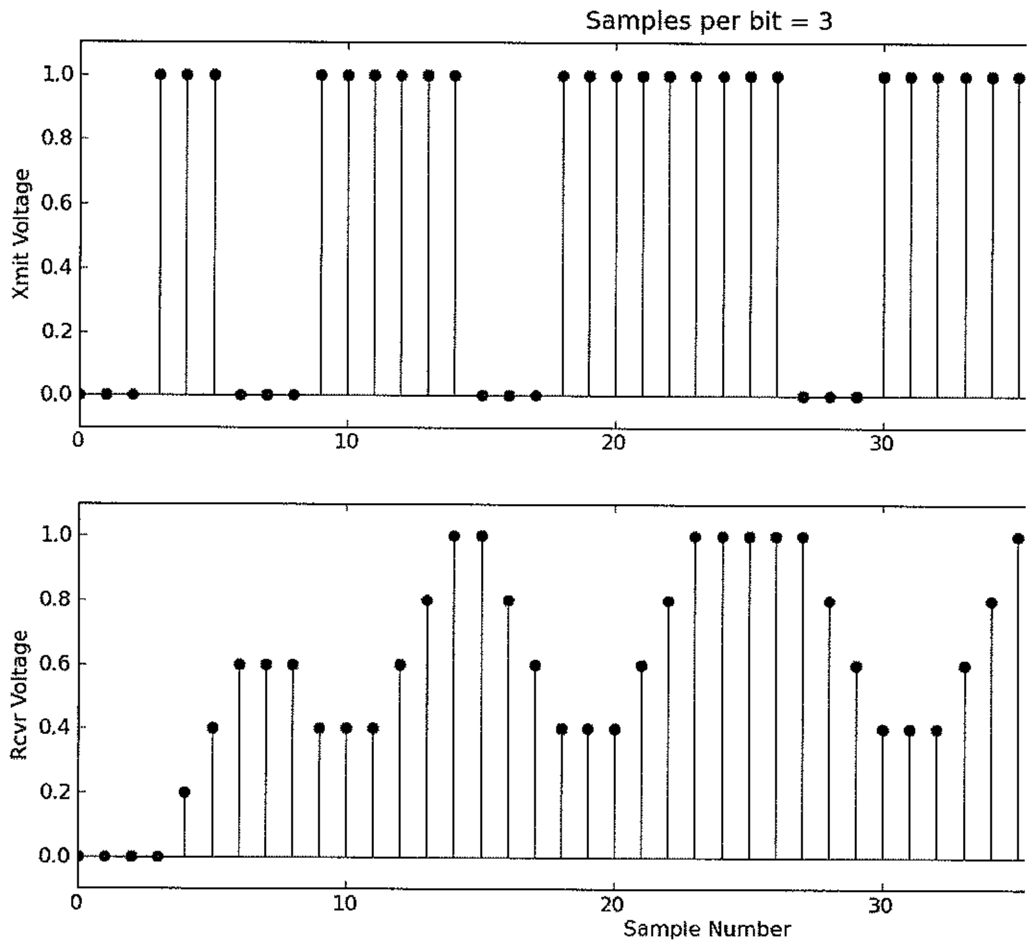
Straight Rise Response



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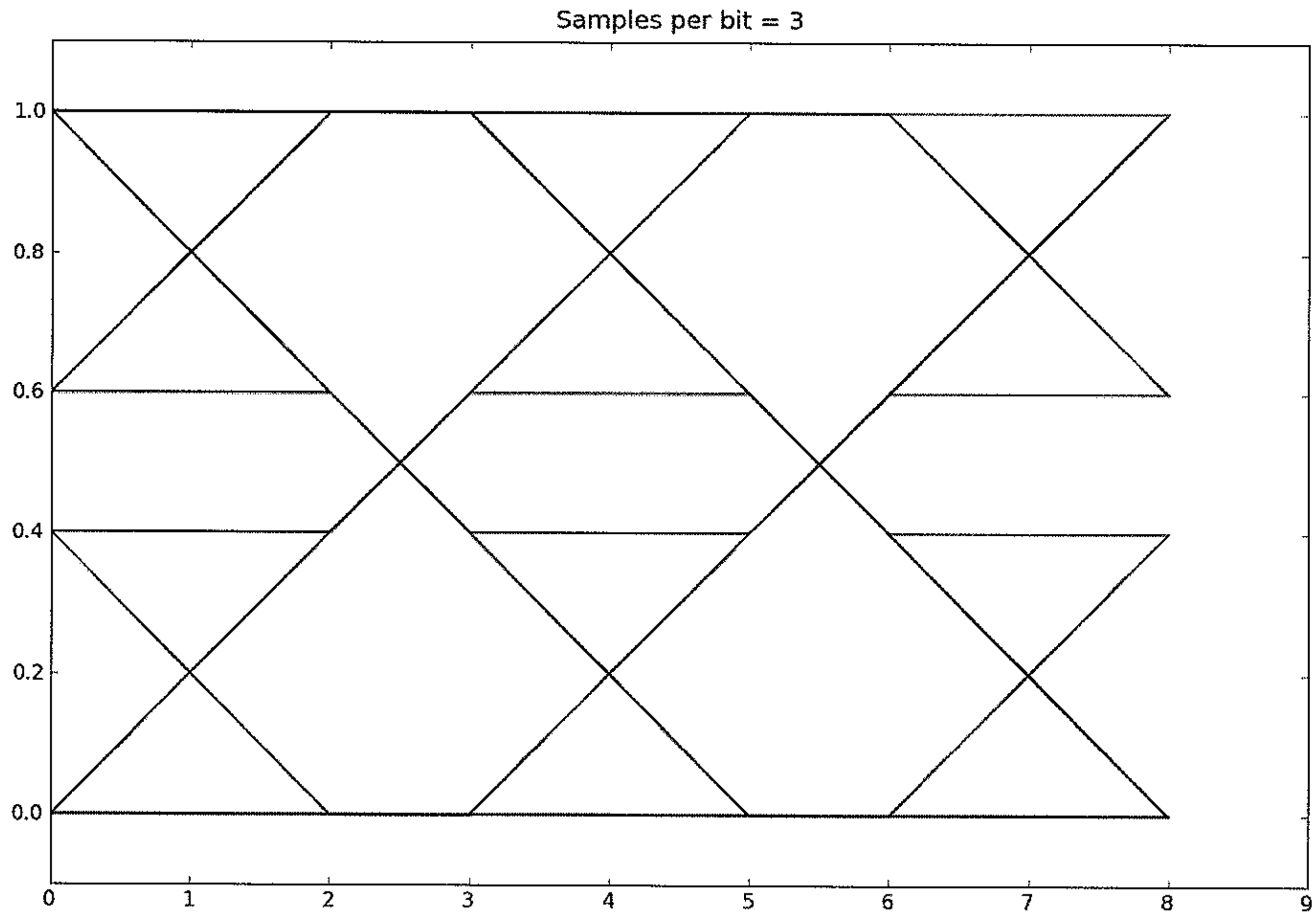
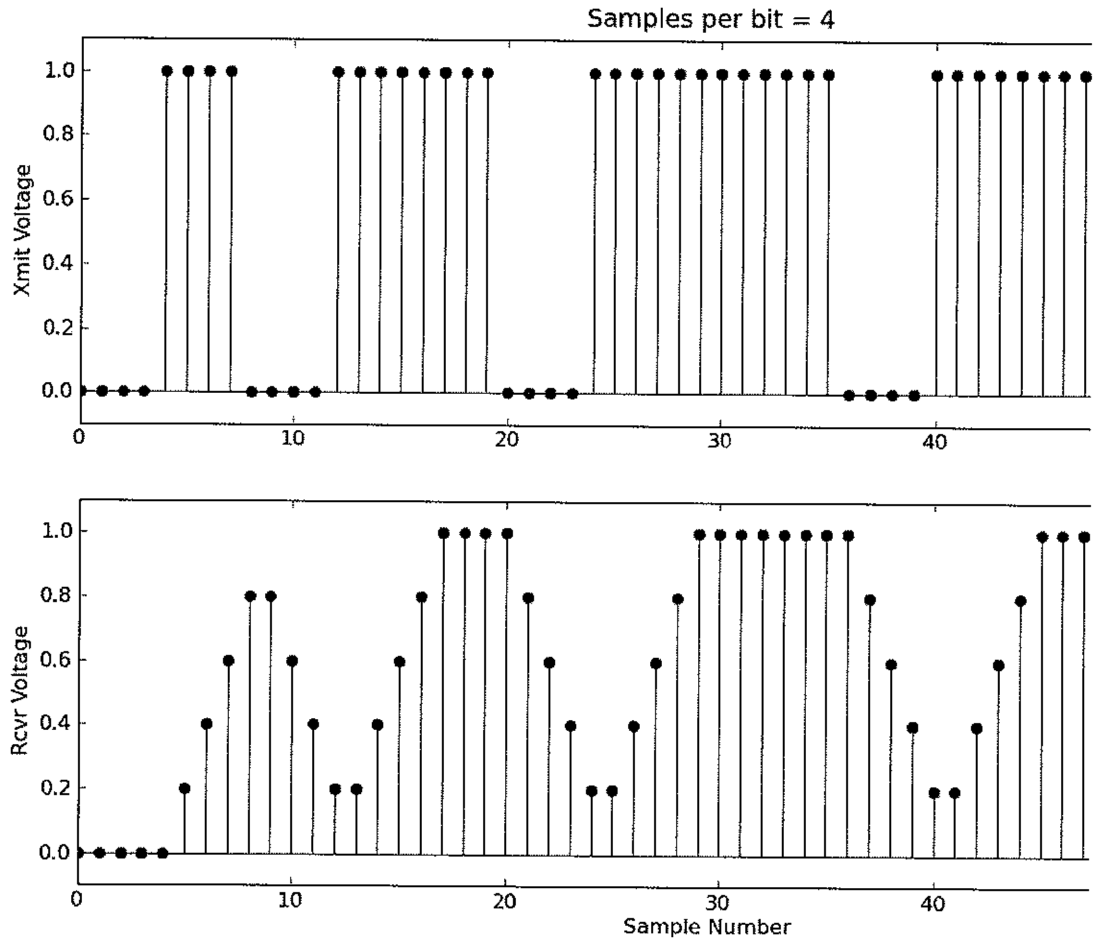
Striaght Rise Eye Diagram



55

Straight Rise Response



Striaght Rise Eye Diagram

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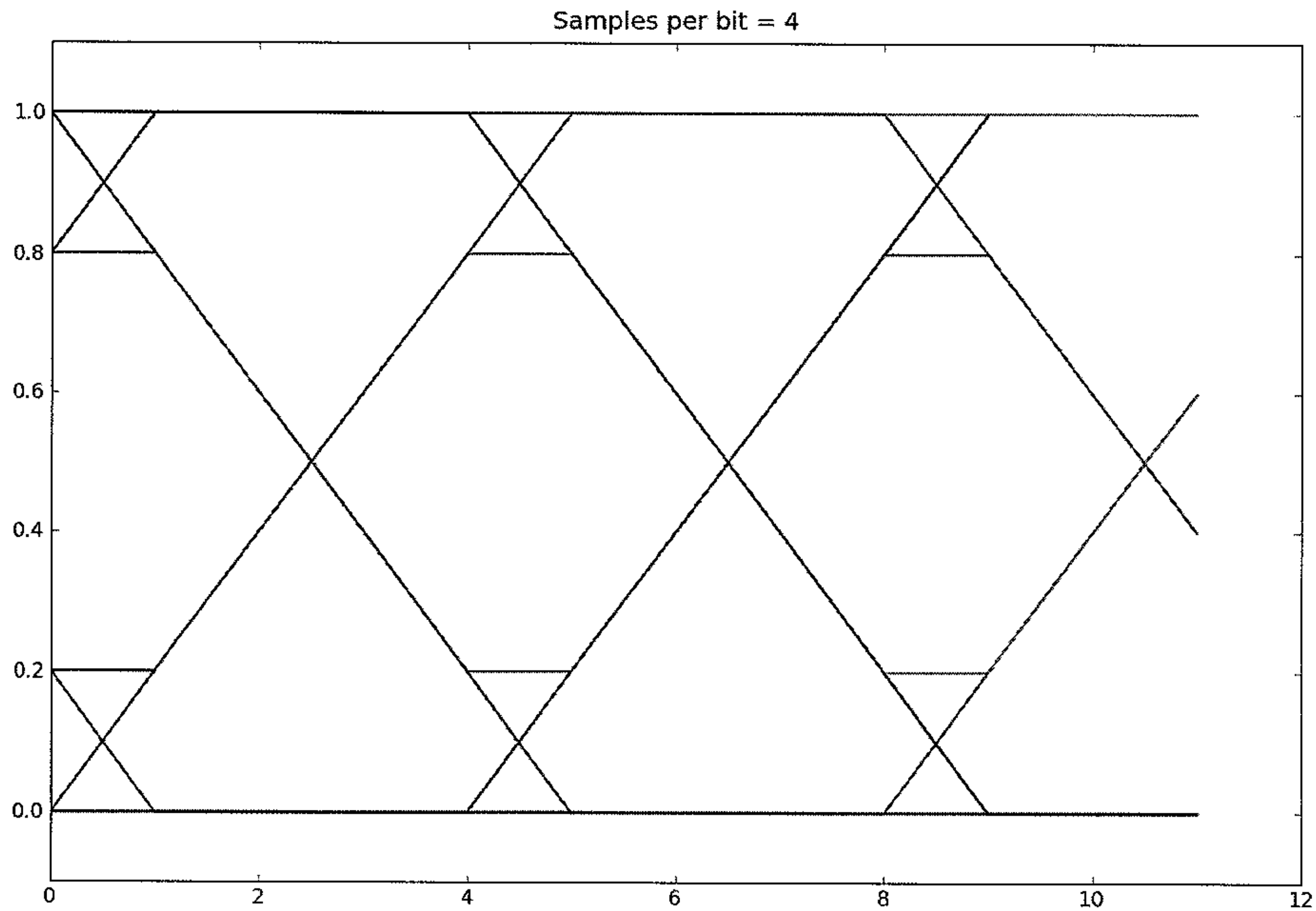

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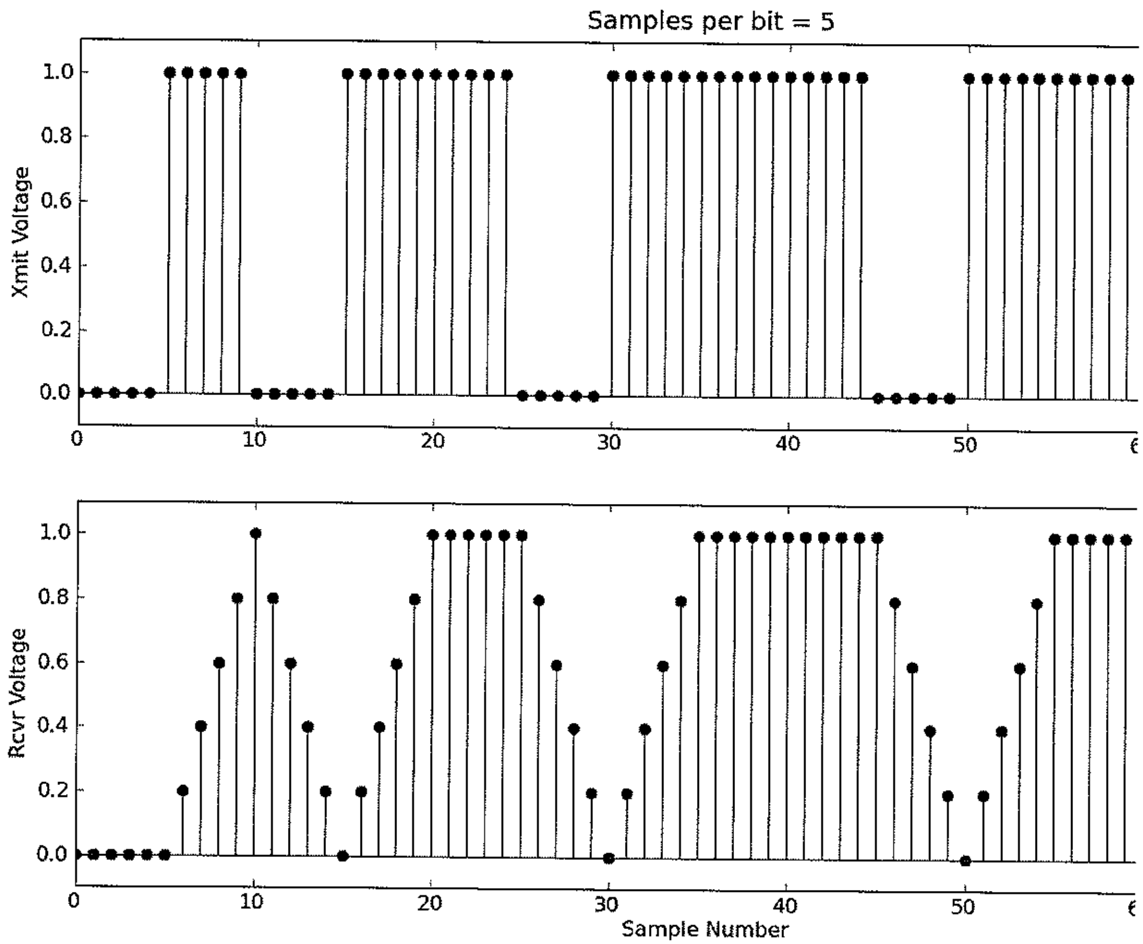
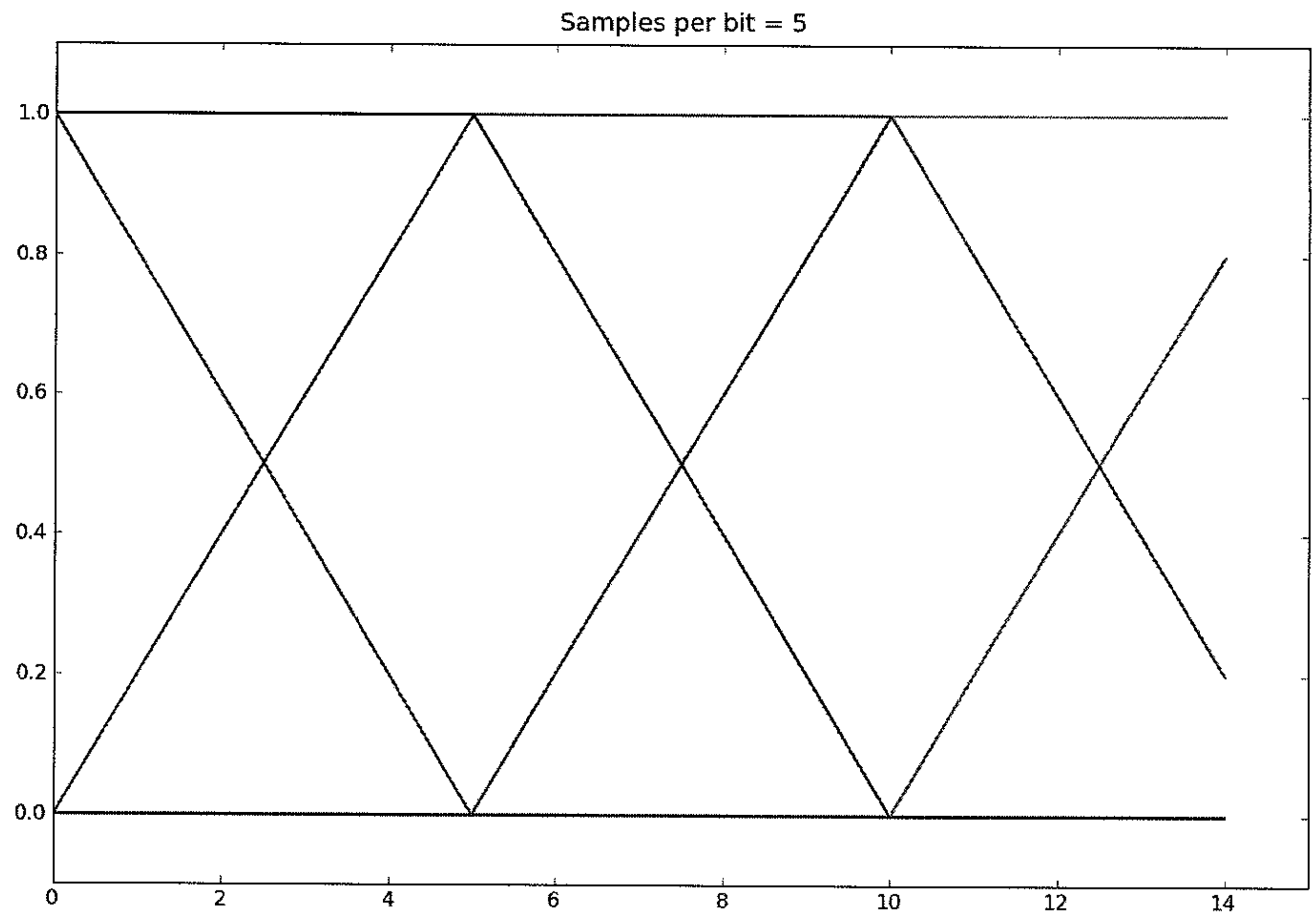
Straight Rise Response

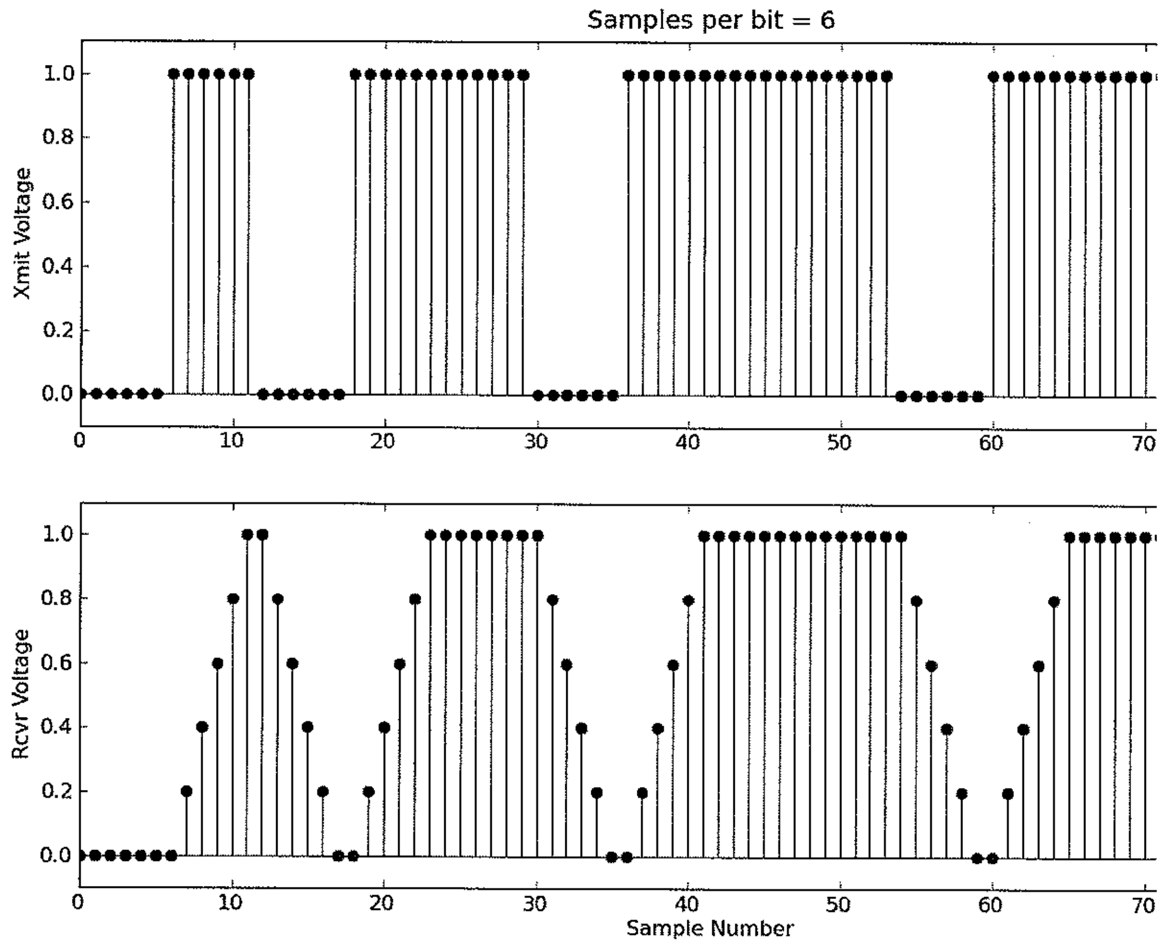


Striaght Rise Eye Diagram



59

Straight Rise Response



Striaght Rise Eye Diagram

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