6.02 Fall 2009

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
Types of Real "Wires"

IC Interconnect  | Printed Circuit Board  | Transatlantic Cable

Slow Response  
Input

Ringing
Input

May also have long delays (Receiver does NOT know)

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Lecture 2, Slide #3
Transmission Setup and Notation

\[ X \equiv \text{entire sequence} \]
\[ x[n] \equiv n^{th} \text{ sample value} \]

\[ Y \equiv \text{entire sequence} \]
\[ y[n] \equiv n^{th} \text{ sample value} \]

Sample Rates:
- 1 million Samples/Second (IR Transceiver)
- Up to gigaSamples/Second (Fastest)
Samples, Bit Period, Bit Rate

- **Our Hardware**
  - Updates transmitter output voltage every microsecond (1 million times a second).
  - Remeasures receiver voltage every microsecond (1 million times a second).

- **Bit Period and Bit Rate**
  - $BP = \text{Samples/bit} \times 1 \text{ microsecond}$
  - $BR = \text{Bits transmitted per second}$
  - $BR = \frac{(1 \text{ million})}{(\text{Samples/bit})}$

- **Slower Bit Rate = Longer Bit Period**
  - More time to propagate through channel
Sending 0101110, 20 microseconds/bit

Samples per bit = 20, Bit rate = 50000 bits/second

Received Voltage is more “settled”.
Sending 0101110, 30 microseconds/bit

Samples per bit = 30, Bit rate = 33333.3 bits/second

Received Voltage
much more
"settled"
The 6.02 Infrared Transceiver

100 Samples/bit

Operating System Schedules Transmission
Bounced off paper

Bounced off ceiling

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The 6.02 IR Tranceiver - Faster and Noisier

20 Samples/bit

5 Samples/bit

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Lecture 2, Slide #5
Consider Interference - Slow Channel

1. Previous Symbol
   - Transmitting Two Bits

2. 1000
   - Compare previous bit with current bit

3. 100
   - Compare previous bit with current bit

4. 1100
   - Compare previous bit with current bit

5. 1010
   - Compare previous bit with current bit

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

7. Previous bit = zero interferes with current bit = 1
Intersymbol Interference

Long Bit Period (slow rate) Short Bit Period (Fast Rate)
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.

Best Time to Test

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Eye Diagram for IR Detector

Eye Diagram 20
Samples per bit, dark room

Eye Diagram 20
Samples per bit, lights on!

Small Eye \( (I = \sim 0.07 \text{Vols}) \)

Lecture 2, Slide #10
To design a post-processor, need a model of the wire.

From the wire, to improve performance:
- Can we post-process the signal?
- Can be transmitted accurately?
- Limits the bits/second that can be transmitted.
- Makes detecting bits more difficult.
- Non-ideal wires create interference.
A change in $X$ causes a change in \textit{Wires} can not predict the future.

\textbf{1) Wires are Causa}

\textbf{Model (Example) Circuit Model of Wire}

\textbf{Transmitter}

\textbf{Sampled Output}

\textbf{Example Mode} of a Physical Wire
A + time-shifted input → [Y - N]

Y ← [Y - N]

X ← [Y - N]


(shift)
3) Linearity (A Strong Assumption)

3a) Scaling

\[ y[n] = \frac{1}{4} x[n] \quad \text{by linearity} \]

\[ y_2[n] = 2y_1[n] \quad \text{Scale Inputs} \rightarrow \text{Scaled Outputs} \]

3b) Sum Inputs \rightarrow Sum Outputs

\[ y_\Delta[n] = \sum y[n] \]

\[ y_0[n] = \sum y[n] \]

\[ x_{\Delta+n}[n] = x_\Delta[n] + x_0[n] \]

\[ y_{\Delta+n}[n] = y_\Delta[n] + y_0[n] \]
Suppose \( X_{UV} \) and \( X_{UV} \) be unit step responses.

\[
X_{UV} = (1-\alpha) \quad \text{and} \quad X_{UV} = \mu_{UV}^{\text{unit step}}
\]

Example - Unit Step Responses

\[
A \times [u - N_u] + B \times [v - N_v] \leq \left\lfloor \frac{A}{\sqrt{A + \mu_{UV}} + B} \times [u - N_u] \right\rfloor
\]

Linear Time-Invariant Systems
\[ X \in \mathbb{L} = U \in \mathbb{L}^{-47} - U \in \mathbb{L}^{-22} \]

\[ Y \in \mathbb{L}^{-11} - Y \in \mathbb{L}^{-22} \]

\[ + Y \in \mathbb{L}^{-22} - Y \in \mathbb{L}^{-13} \]

\[ + (1 - \frac{1}{2})(\in_{-3} - \in_{-13}) \]

\[ = (1 - \frac{1}{2})(\in_{-2}) \]

\[ - (1 - \frac{1}{2})(\in_{-22}) \]

\[ + \mathbb{L}^{-13} \]

\[ \mathbb{L}^{-22} \]
Step Response and results from superposition
Step Response For Another Example Channel
Xmit Data

Time shifted and sign adjusted channel step responses

Summed responses = Rcv'd data

010110 Transmitted Through Example Channel
Sending 0101110, 5 microseconds/bit

Samples per bit = 5, Bit rate = 200000 bits/second

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Threshold
Eye Diagram for 5 microsecond bit period

Notice many different cases →

Implies more than single bit ISI

Notice smaller Eye
Sending 0101110, 9 microseconds/bit

Samples per bit = 9, Bit rate = 111111 bits/second

Xmit Voltage

Sample Number

Recieved Data Looks Clear
Eye Diagram for 9 microsecond bit period

Note: Wider Eye (than BP = 5us)
Sending 0101110, 13 microseconds/bit

Samples per bit = 13, Bit rate = 76923.1 bits/second
Eye Diagram for 13 microsecond bit period

Almost perfect eye