CSCD 433
Network Programming
Winter 2017

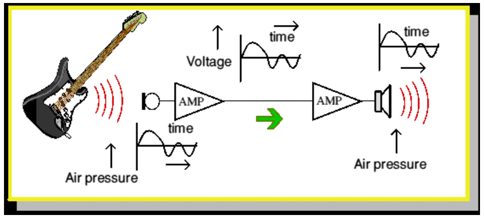
Lecture 4
Digital Line Coding and other ...

Physical Layer Topics

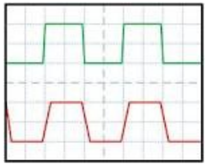
- Digital transmission of digital data
- Physical limits of networks for data
- Encoding digital data onto signals

Summary so Far

- Analog Communication
  - Objective is to transform waveform
  - Varies continuously with time
  - Distortions unavoidable
  - More difficult to reproduce signal at receiver



- Digital Communication
  - Objective is to transmit a symbol
  - Binary is 0 or 1
  - Done by transmitting positive voltage for 1, negative voltage for 0 (other schemes too ….)
  - Receiver interprets symbol
  - Can handle lots of distortion and still discern symbol



Physical Layer

Purpose

Provide services for Data Link Layer

- Converts data to signal
- Controls transmission

Want to know ….

What is relationship between number bits/sec and the required bandwidth to send these bits?

Purpose of Digital Transmission

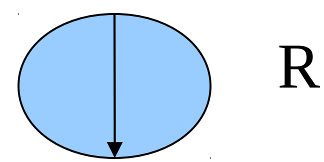
- Transfer sequence of 0's and 1's from transmitter on left to receiver on right

Channel

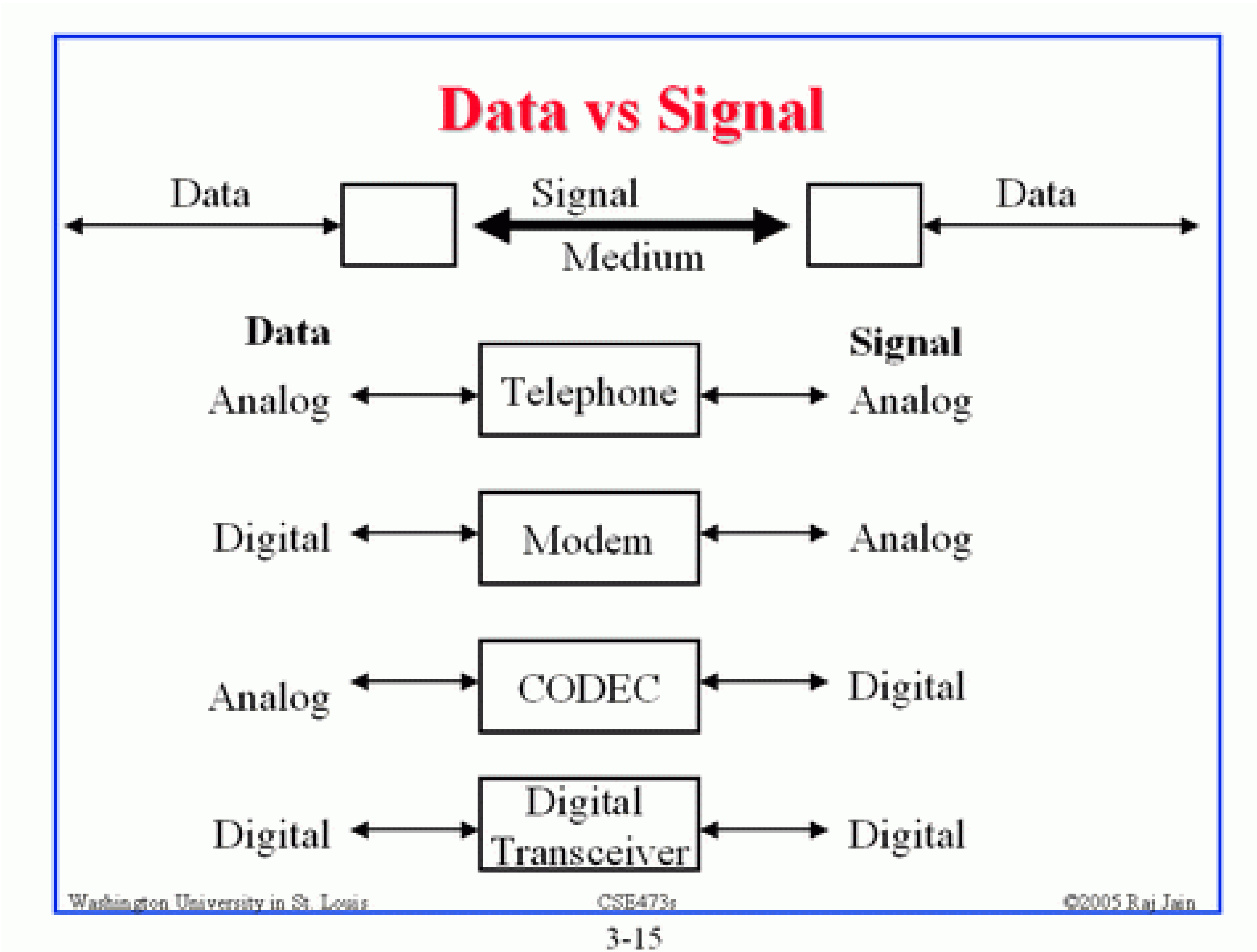
0110101 →  → 0110101

transmit — d meters — receive

- Interested in bit rate in bits/s
- Can look at cross section of pipe, R
- Think of channel as pipe diameter
- As R increases, volume of information flow/s increases



Summary of Analog and Digital Conversions

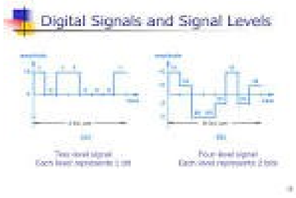


Data Rate Limits

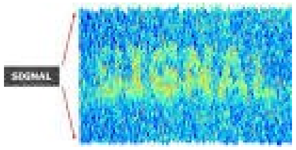
- Important Concern in Data Communications
  - How fast can we send data, in bits per second, over a channel?
  - Plus, what bandwidth is needed to send bits?
  - Also, must consider errors ...

- Data rate depends on three factors:

1. Available bandwidth
2. Number of levels used to represent signals



3. Quality of the channel (level of noise)



Data Rate Limits

- Turns out that there are two formulas establish theoretical limits of data rates

Formula for a noiseless channel – **Nyquist Maximum**

- Uses bandwidth and signal encodings, levels

Formula for a noisy channel – **Shannon Capacity**

- Uses characteristics of channel such as bandwidth but accounts for Signal to Noise ratio (SNR)

Nyquist Maximum

- 1924, Henry Nyquist of AT&T developed an equation for a perfect channel with finite capacity
- His equation expresses
  - Maximum data rate for a finite bandwidth **noiseless** channel
  - Noiseless means no measurement for errors

Noiseless Channel: Nyquist Bit Rate

- Defines theoretical maximum bit rate for

Noiseless Channel

$$\text{Bit Rate} = 2 \text{ X Bandwidth X } \log_2 L$$

L = number of signal levels

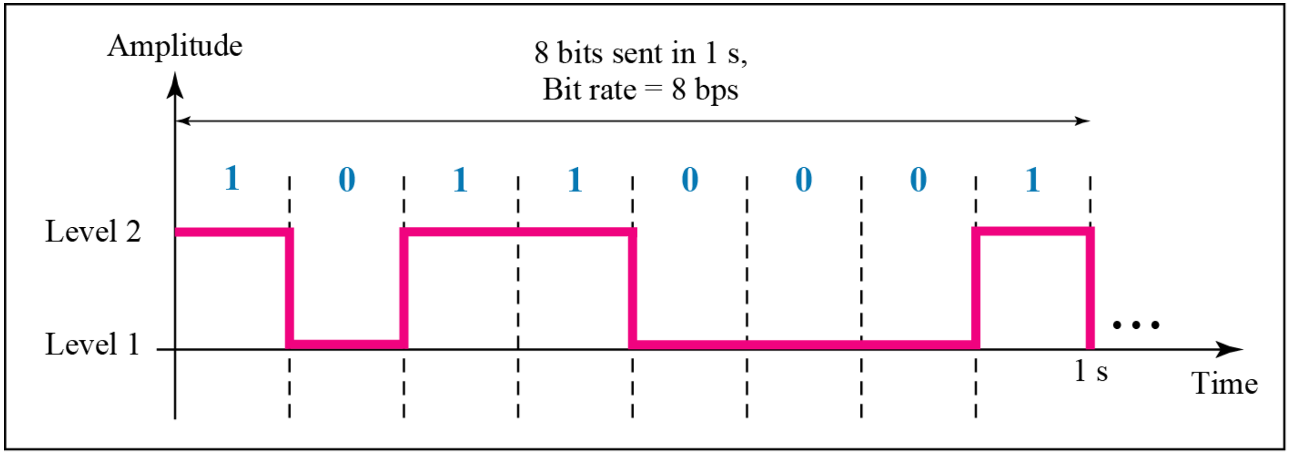
Signal Levels of Digital Signals

- **Digital Signals** can be encoded for optimal transmission
- For example,
  - 1 can be encoded as positive voltage and
  - 0 as zero voltage

- Simplest way to encode a digital signal
  - Limits us to sending 1 bit per level

- But, digital signals can have more than two levels
  - In this case, we can send more than 1 bit for each level

Ex. Two digital signals: Two signal levels and Four signal levels



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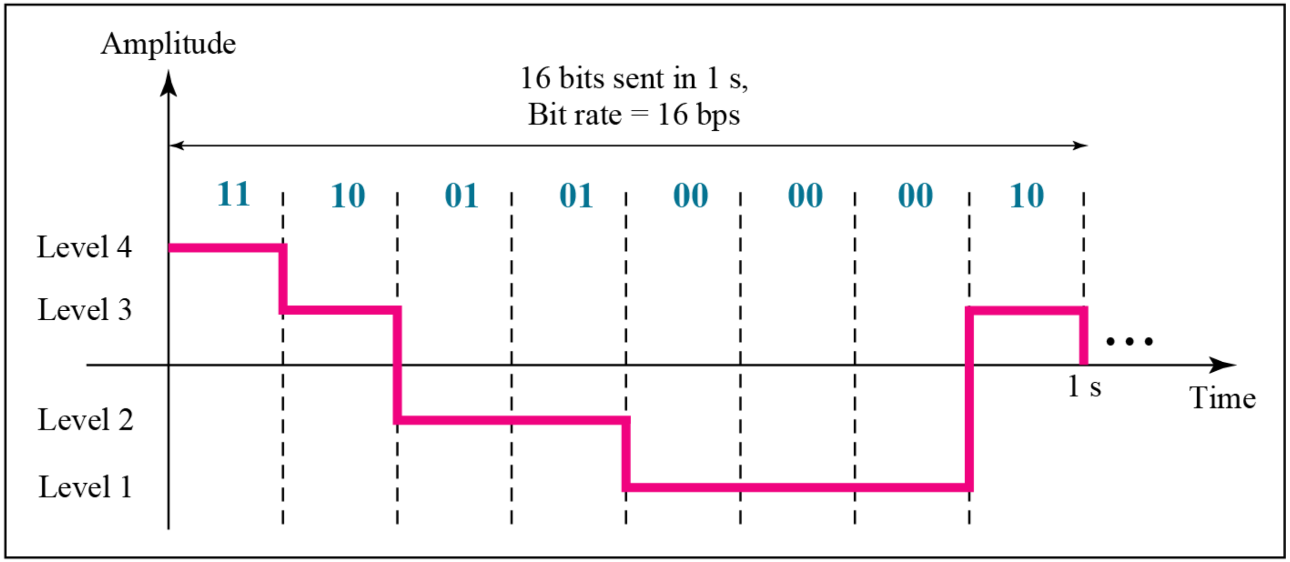


b. A digital signal with four levels

Look at some examples ….

Example 1

Have a noiseless channel

Bandwidth of 3000 Hz transmitting a signal with two signal levels

The maximum bit rate can be calculated as

$$\text{Bit Rate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

$$\log2(2) = 1$$

Example 2

Consider the same noiseless channel

Transmitting a signal with four signal levels

- For each level, we send two bits

The maximum bit rate can be calculated as:

$$\text{Bit Rate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

$$\log2(4) = 2$$

Example 3

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625 \qquad L = 2^{6.625} = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase number of levels or reduce bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

Note

Increasing the levels of a signal may reduce the reliability of the system

Capacity of a System

- Bit rate of a system increases with an increase in number of signal levels we use to denote symbol
- A symbol can consist of a single bit or “n” bits.
- The number of signal levels = 2^n.
- But, as number of levels goes up,
spacing between level decreases ->
Increasing probability of an error occurring presence of transmission noise

Increasing Levels

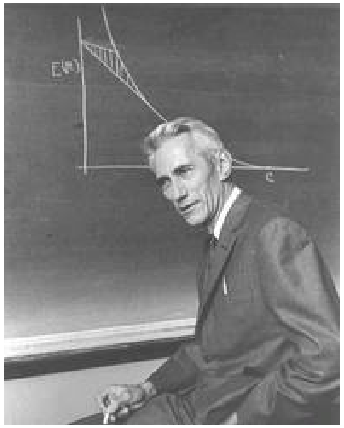
- In theory, can increase the bit rate by increasing the number of levels
- Yet, random noise limits the bit rate in practice
- Noise causes measurement system to make mistakes

Communication Channel Noise

- Noise
  - Interference from sources like radio waves
  - Electrical wires, and
  - Bad connections that alter the data

- Distortion
  - Alteration in signal caused by communication channel itself
  - Noise generated by components is categorized as thermal noise
  - Also known as additive noise.

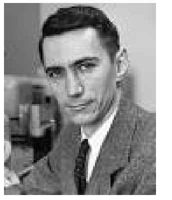
Claude Shannon Noisy Channel



- Claude Shannon, another AT&T scientist
  - Claude Shannon developed mathematical theory in 1940's for noisy channels
  - Then, defined amount of information that a message could carry
  - This allowed networks to plan for capacity of information

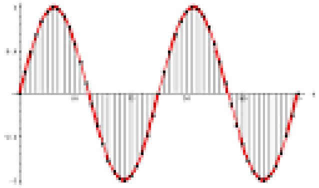
http://www-groups.dcs.st-and.ac.uk/~history/Biographies/Shannon.html

Noisy Channel: Shannon Capacity



- Defines theoretical maximum bit rate for Noisy Channel:

- Capacity = Bandwidth X $\log_2(1+SNR)$



Examples of Nyquist and Shannon Formulas

Example 1

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero

In other words, the noise is so strong that the signal is faint, Eq. Capacity = Bandwidth X $\log_2(1+SNR)$

For this channel capacity is calculated as:

$$C = B \log_2 (1 + SNR) = B \log_2 (1 + 0)$$
$$= B \log_2 (1) = B \times 0 = 0$$

What does this mean for data?

Result of High Noise

$C = B \log_2 (1) = B \times 0 = 0$

This means that the capacity of this channel is zero regardless of the bandwidth

In other words, we cannot receive any data through this channel !!!

Example 2

We can calculate theoretical highest bit rate of a regular telephone line, with noise

A telephone line normally has bandwidth of 3000 bps

The signal-to-noise ratio is usually 3162

For this channel the capacity is calculated as

$$C = B \log_2 (1 + SNR) = 3000 \log_2 (1 + 3162)$$
$$= 3000 \log_2 (3163)$$
$$C = 3000 \times 11.62 = 34{,}860 \text{ bps}$$

Example continued

Result C = 3000 X11.62 = 34,860 bps

This means that highest bit rate for a telephone line is 34.860 kbps

If we want to send data faster than this, we can either increase bandwidth of line or improve signal-to-noise ratio.

Example 3

We have channel with 1 MHz bandwidth

The SNR for this channel is 63,

What is the appropriate bit rate and signal level?

Solution

First, we use Shannon's formula to find our upper limit of channel capacity

$$\mathbf{C = B \log_2 (1 + SNR) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 (64) = 6\ Mbps}$$

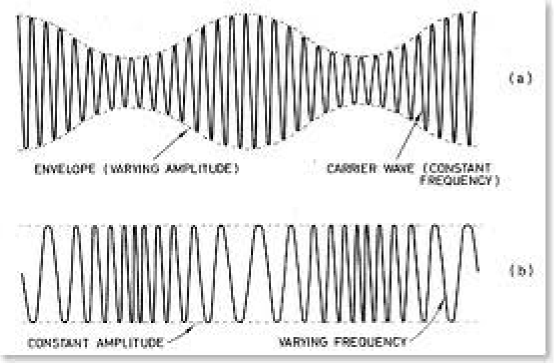
Then we use Nyquist formula to find the number of signal levels.

$$\mathbf{6\ Mbps = 2 \times 1\ MHz \times \log_2 \mathit{L}}$$

$$\frac{6{,}000{,}000}{2{,}000{,}000} = \log_2 L \qquad L = 2^3 \rightarrow L = 8$$

Note

The Shannon capacity gives us the upper limit, assuming noise Nyquist formula tells us how many signal levels we need.



Digital Line Coding

Digital Line Coding

- Method for converting digital binary information into digital signal
- Selecting coding technique involves several considerations
- Previously we said ...
  - Wanted to maximize bit rate over channels with limited bandwidth
- Yet, LAN's have other concerns
  - Ease of timing recovery from signal
    - So, receiving clock can maintain its synchronization with transmitting clock
  - Need to worry about noise and interference

Line Coding

Line Coding Formats:

Line coding methods can be categorized in terms of the following

- The duration of the pulses.
- The way voltage levels are assigned to pulses.

Line Coding

Pulse Duration: There are two classes used

– **Non return-to-zero** (NRZ) where pulse or symbol duration **Ts = the bit period** Tb

– **Return-to-zero** (RZ) where pulse or symbol duration **Ts < the bit period** Tb. Usually **Ts = 0.5Tb**.

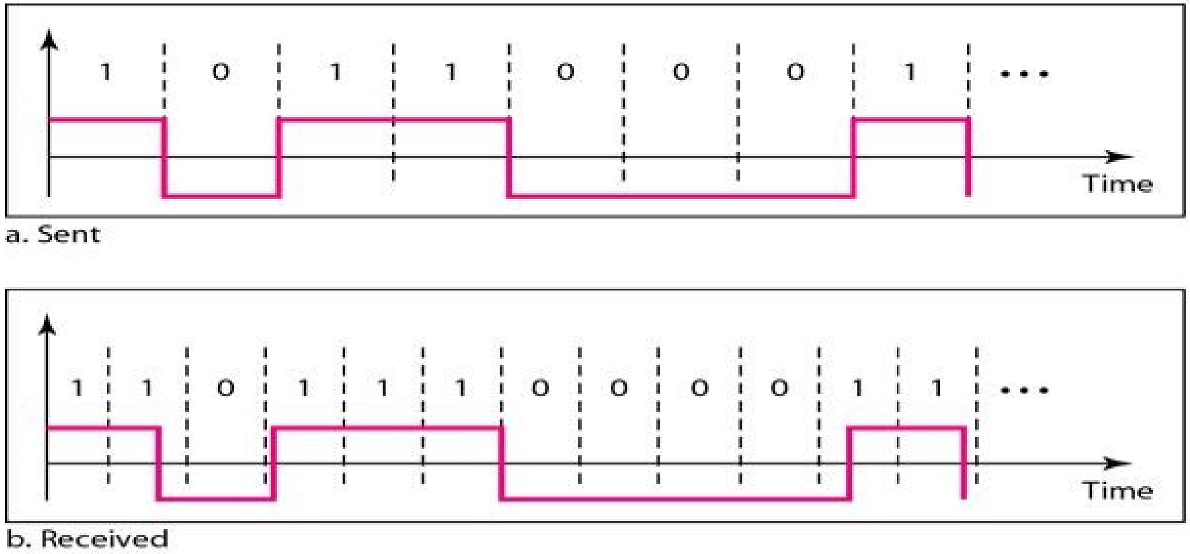
Pulse duration will usually have an effect on synchronization properties of the line code

A clock period is recovered by observing transitions in the received sequence

Called **Self-Synchronization** … network lingo

Self Synchronization Properties

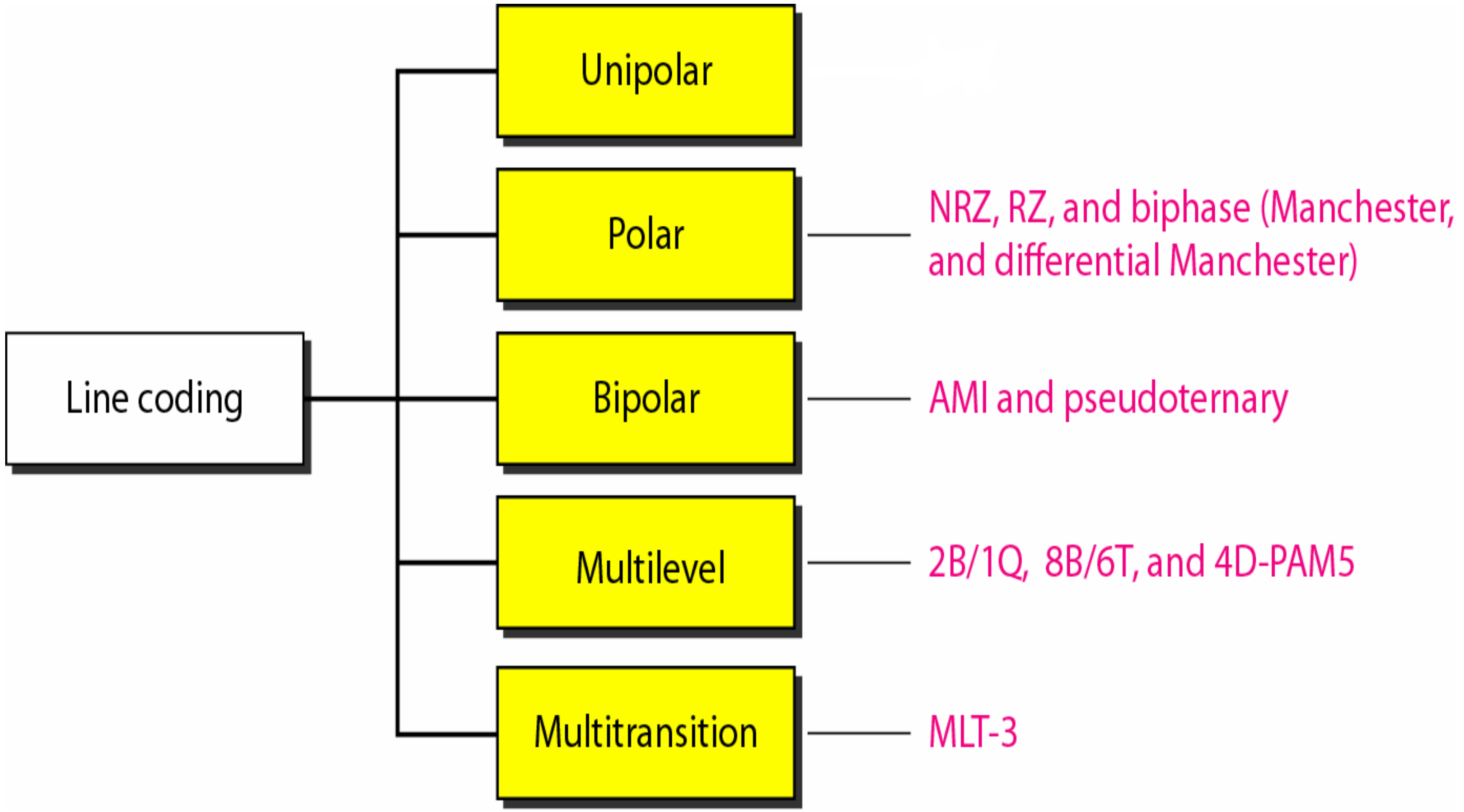
- To correctly interpret signals from sender, receiver's bit intervals must correspond exactly to sender's bit intervals.
    - If receiver clock is faster or slower, bit intervals are not matched and receiver might misinterpret the signals. See below …



Different coding schemes vary in their pulse transitions

Affects clock sync between sender and receiver

Line Coding Schemes

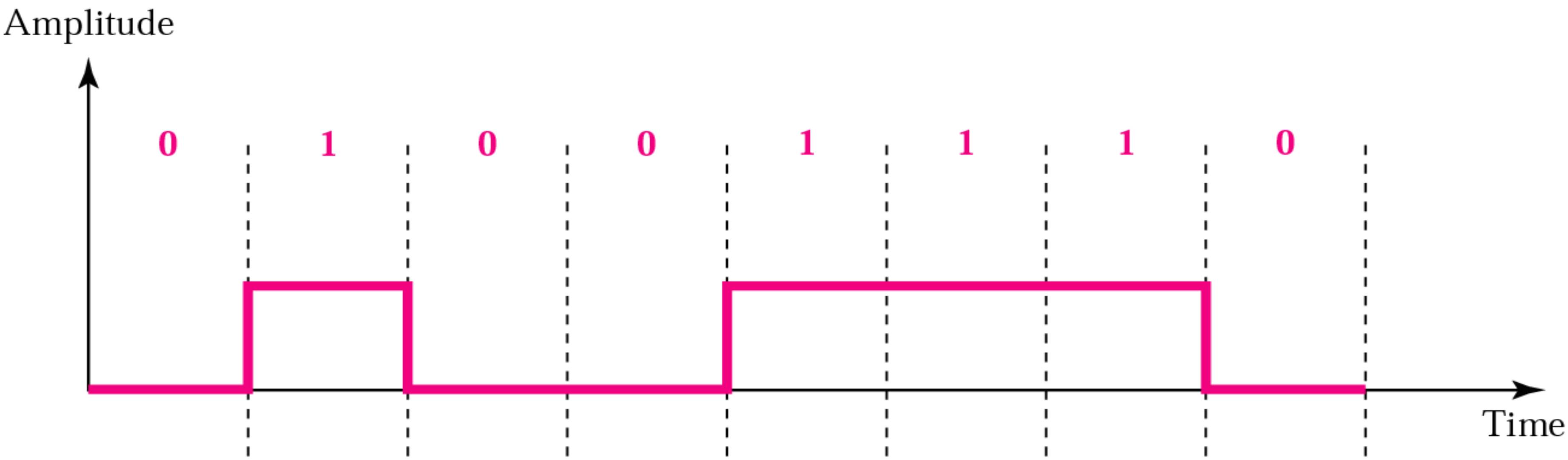


Unipolar: Uses one voltage level
Polar: Uses two voltage levels
Bipolar: Uses three or more voltage levels

Note

In unipolar encoding, we use only one voltage level, positive

Unipolar Encoding



How many bits per clock tick?

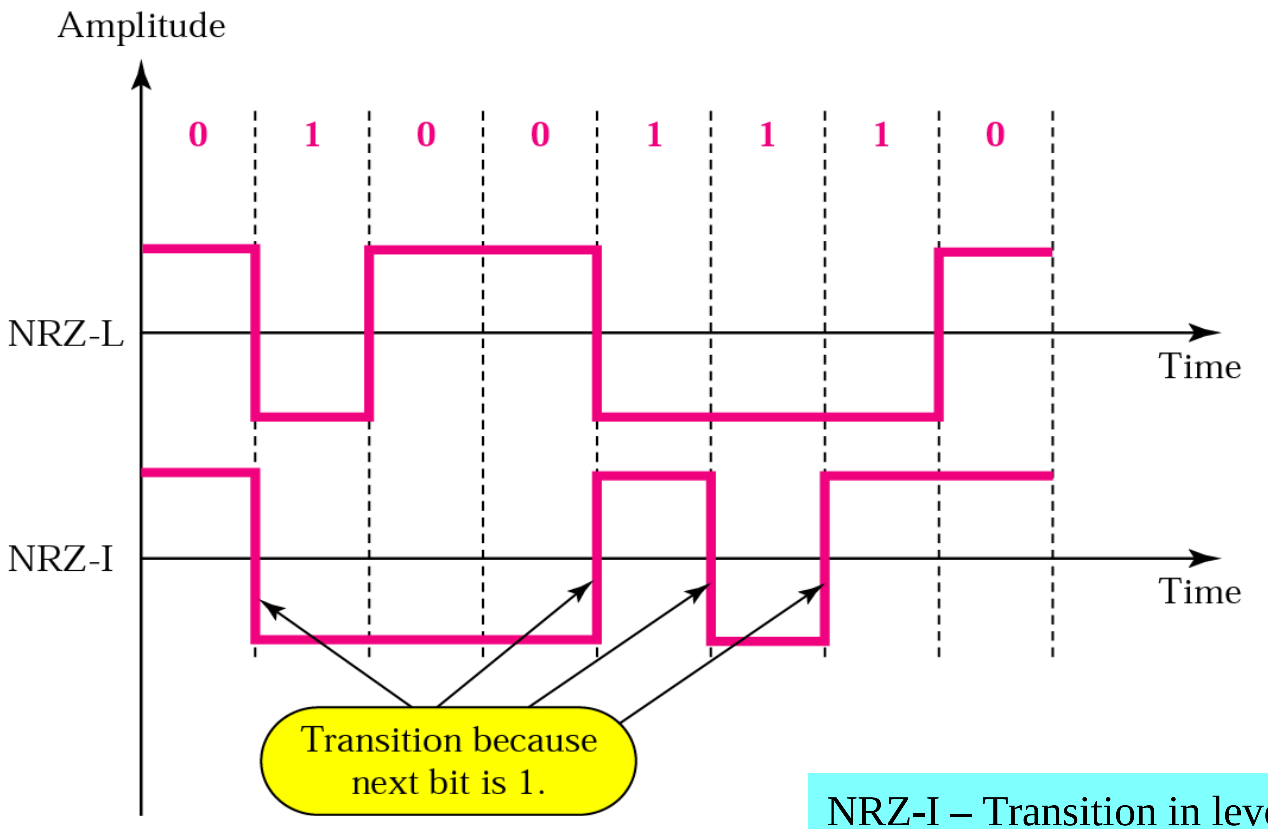
Unipolar Encoding

- Although simple, this method for encoding digital information has some serious drawbacks and is seldom used
    - First, difficult to keep clocks of source and receiver synchronized if there are long sequences of ones or zeros.
        - Receiver uses transitions in level to determine clock cycle boundaries
    - Second, it is impossible to distinguish between a long sequence of zeros and the absence of a signal

Note

In polar encoding, we use two voltage levels: positive & negative

Polar: NRZ-L and NRZ-I Encoding



NRZ-I – Transition in level for every 1 encountered, stays at that level until next 1

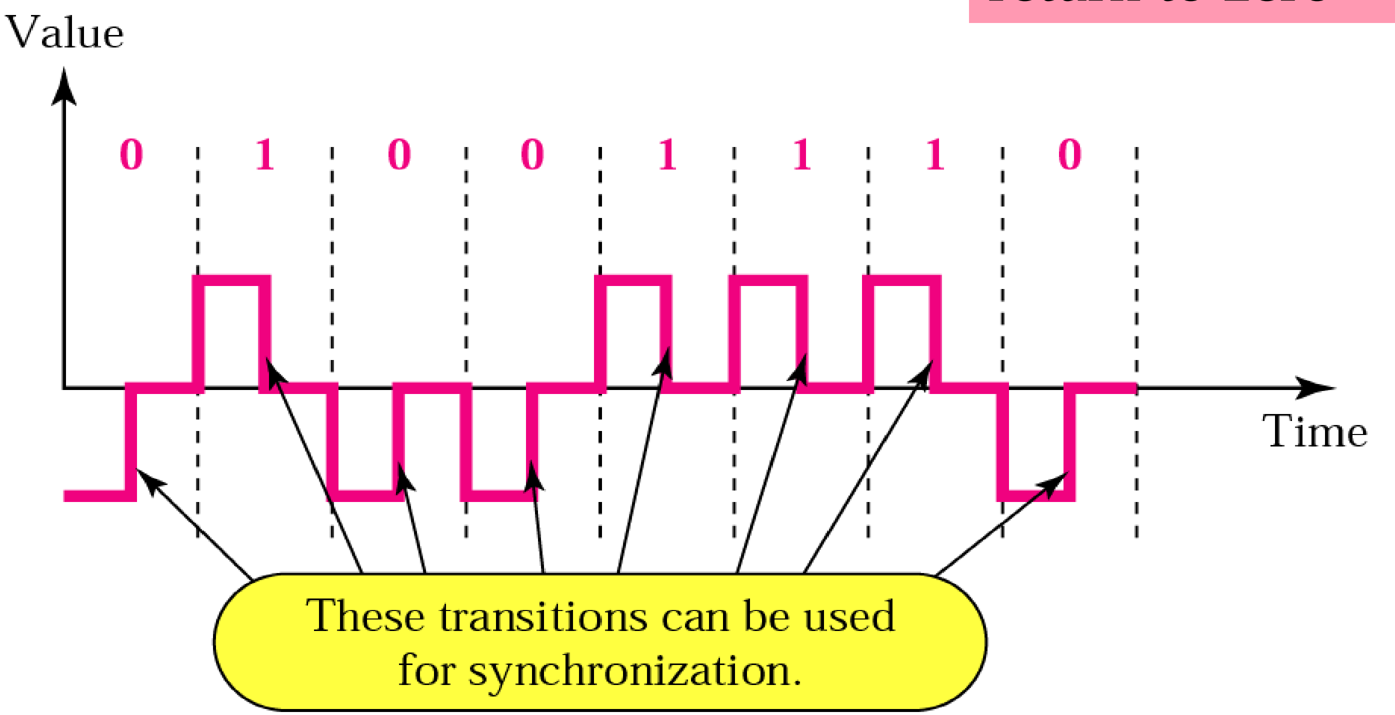
Note

In NRZ-L, level of voltage determines value of the bit

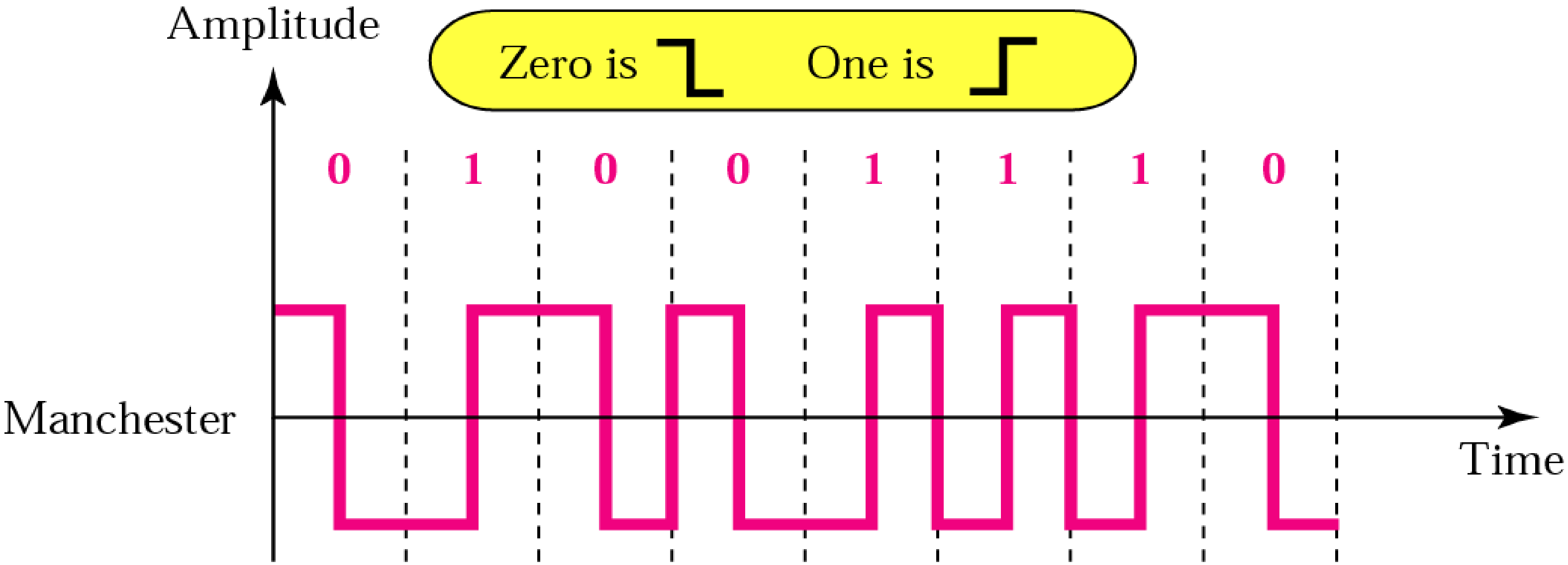
In NRZ-I, inversion or lack of inversion determines value of the bit

Polar: RZ Encoding

Every bit has a return to zero



Polar: Manchester Encoding



Link to Manchester Encoding's Use in Ethernet
http://www.erg.abdn.ac.uk/users/gorry/course/phy-pages/man.html

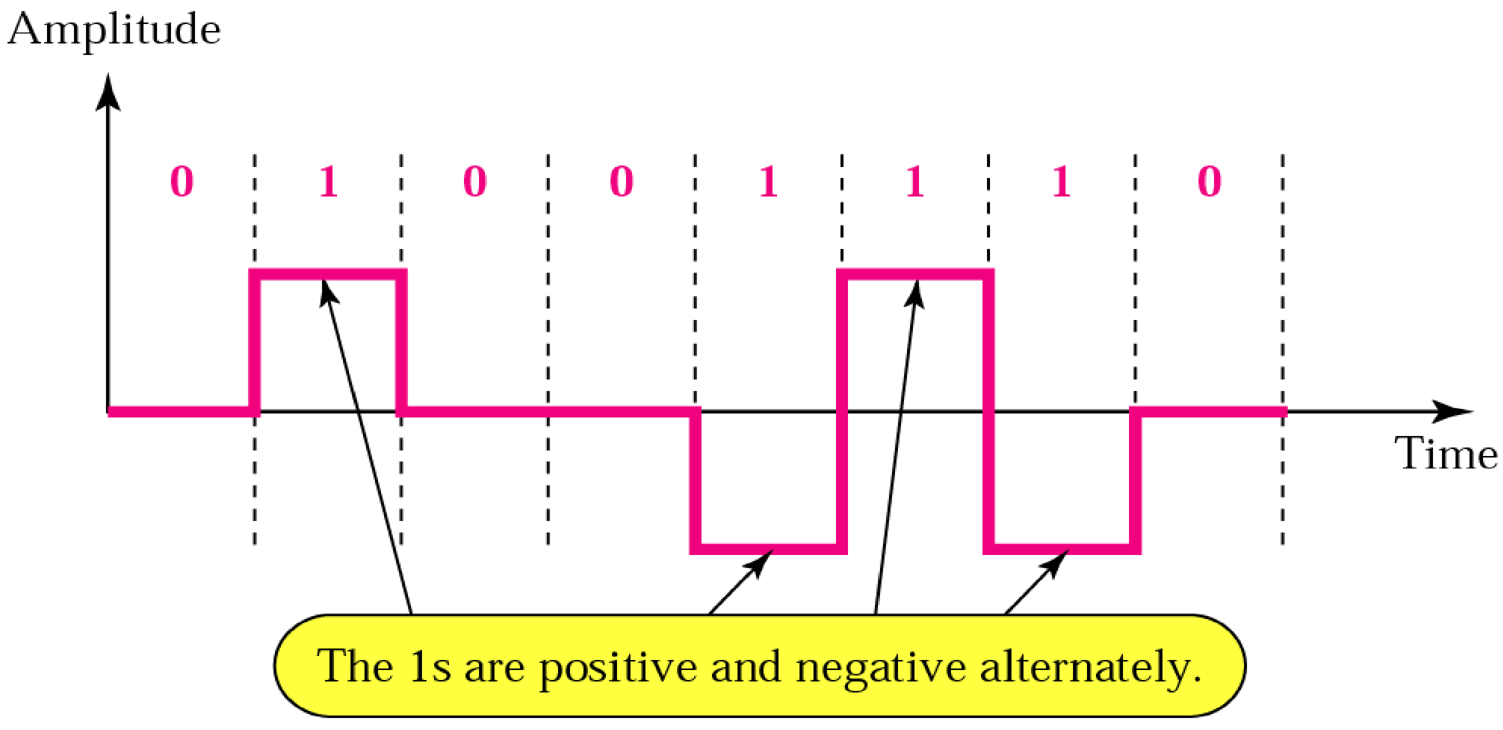
Note

In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for clock synchronization.

Note

In bipolar encoding, we use three levels: positive, zero, and negative.

Bipolar: AMI (Alternative Mark Inversion) Encoding

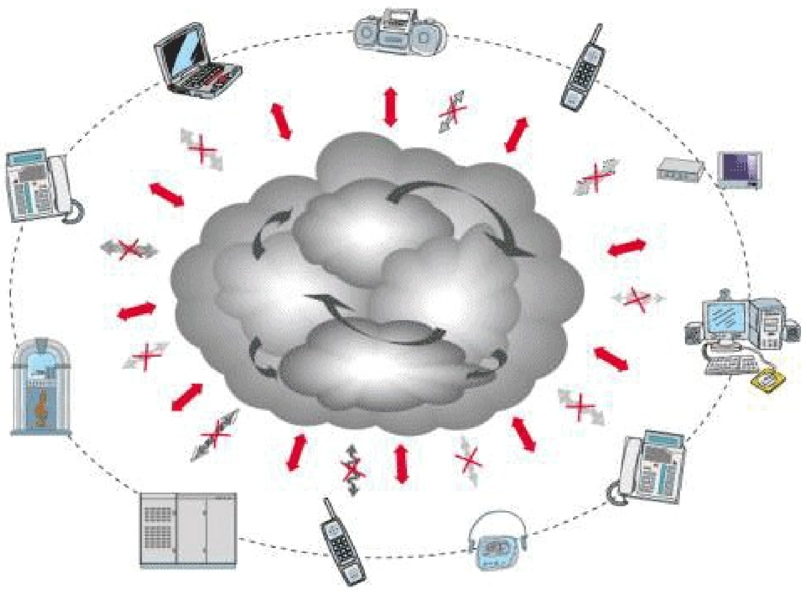


Summary

Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Unipolar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, high bandwidth
Bipolar	AMI	$B = N/2$	No self-synchronization for long 0s, DC
Multilevel	2B1Q	$B = N/4$	No self-synchronization for long same double bits
	8B6T	$B = 3N/4$	Self-synchronization, no DC
	4D-PAM5	$B = N/8$	Self-synchronization, no DC
Multiline	MLT-3	$B = N/3$	No self-synchronization for long 0s

Summary

- Looked at digital data over digital channels
- Theoretical maximum limits of transmitting bits in presence of noise and without
- Line encoding makes it possible to send more data as efficiency of coding increases



Assignment 2 – Is Up

Questions on Lecture Material

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  - Distortions unavoidable
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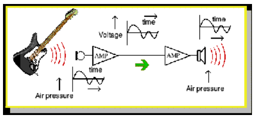

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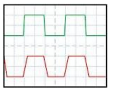

Physical Layer

Purpose

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Want to know ….

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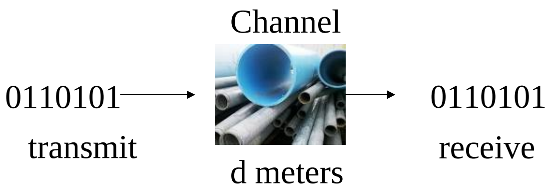
Purpose of Digital Transmission

- Transfer sequence of 0's and 1's from transmitter on left to receiver on right



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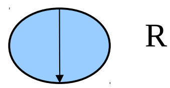
- Can look at cross section of pipe, R
- Think of channel as pipe diameter
- As R increases, volume of information flow/s increases



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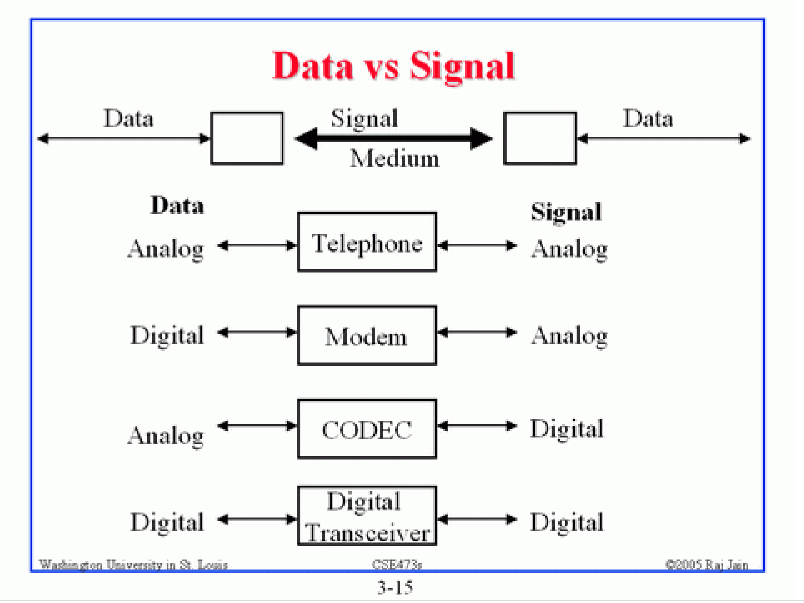

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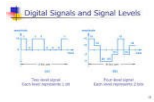

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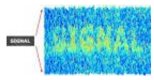

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Data Rate Limits

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- Uses bandwidth and signal encodings, levels

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- Uses characteristics of channel such as bandwidth but accounts for Signal to Noise ratio (SNR)

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Nyquist Maximum

- 1924, Henry Nyquist of AT&T developed an equation for a perfect channel with finite capacity
- His equation expresses
  - Maximum data rate for a finite bandwidth **noiseless** channel
  - Noiseless means no measurement for errors

Noiseless Channel: Nyquist Bit Rate

- Defines theoretical maximum bit rate for

Noiseless Channel

Bit Rate = 2 X Bandwidth X $\log_2 L$

L = number of signal levels

Signal Levels of Digital Signals

- **Digital Signals** can be encoded for optimal transmission
- For example,
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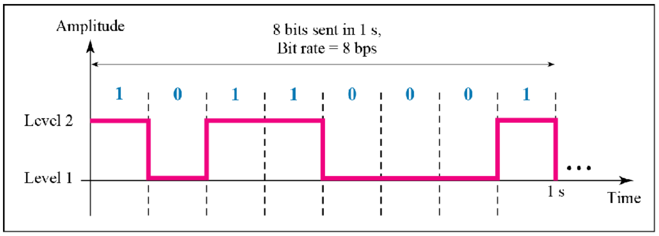
Ex. Two digital signals: Two signal levels and Four signal levels



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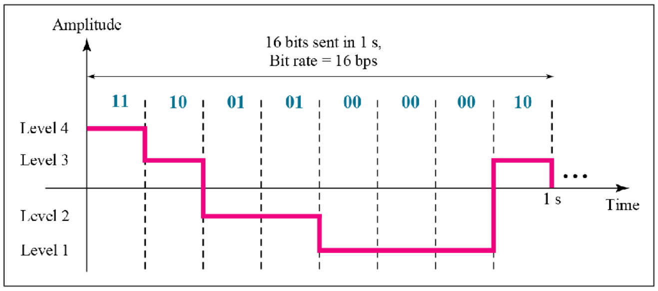

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Look at some examples ….

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Communication Channel Noise

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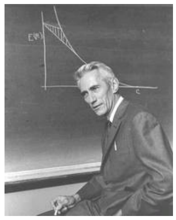
Claude Shannon
Noisy Channel



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  - Then, defined amount of information that a message could carry
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Noisy Channel: Shannon Capacity

- Defines theoretical maximum bit rate for Noisy Channel:
- Capacity = Bandwidth X $\log_2(1+SNR)$

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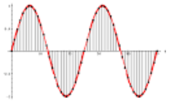

Examples of Nyquist and Shannon Formulas

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Example continued

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We have channel with 1 MHz bandwidth
The SNR for this channel is 63,
What is the appropriate bit rate and signal level?

Solution

First, we use Shannon's formula to find our upper limit of channel capacity

$$C = B \log_2 (1 + SNR) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 (64) = 6 \text{ Mbps}$$

Then we use Nyquist formula to find the number of signal levels.

$$6 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L$$

$$\frac{6{,}000{,}000}{2{,}000{,}000} = \log_2 L \qquad L = 2^3 \Rightarrow L = 8$$

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Note

The Shannon capacity gives us the upper limit, assuming noise
Nyquist formula tells us how many signal levels we need.

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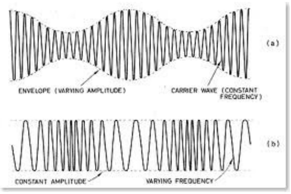

Digital Line Coding

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Digital Line Coding

- Method for converting digital binary information into digital signal
- Selecting coding technique involves several considerations
- Previously we said ...
  - Wanted to maximize bit rate over channels with limited bandwidth
- Yet, LAN's have other concerns
  - Ease of timing recovery from signal
    - So, receiving clock can maintain its synchronization with transmitting clock
  - Need to worry about noise and interference

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Line Coding

Line Coding Formats:

Line coding methods can be categorized in terms of the following

– The duration of the pulses.
– The way voltage levels are assigned to pulses.

Line Coding

Pulse Duration: There are two classes used

– **Non return-to-zero** (NRZ) where pulse or symbol duration **Ts = the bit period** Tb

– **Return-to-zero** (RZ) where pulse or symbol duration **Ts < the bit period** Tb. Usually **Ts = 0.5Tb**.

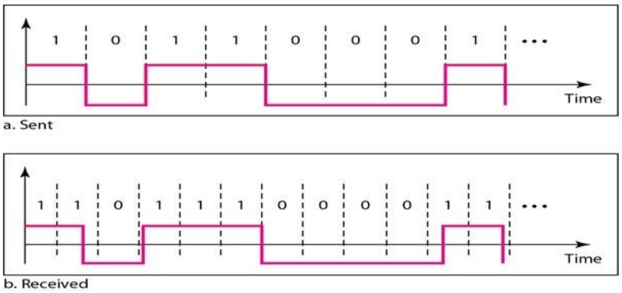
Pulse duration will usually have an effect on synchronization properties of the line code

A clock period is recovered by observing transitions in the received sequence

Called **Self-Synchronization** … network lingo

Self Synchronization Properties

- To correctly interpret signals from sender, receiver's bit intervals must correspond exactly to sender's bit intervals.
  - If receiver clock is faster or slower, bit intervals are not matched and receiver might misinterpret the signals. See below …



Different coding schemes vary in their pulse transitions

Affects clock sync between sender and receiver

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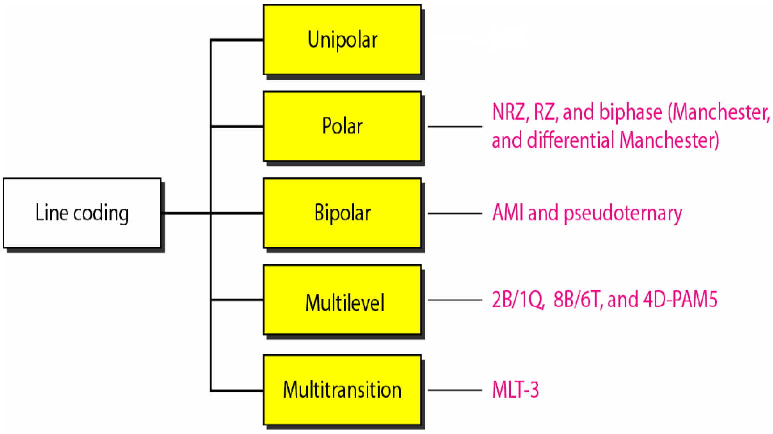
Line Coding Schemes



Unipolar: Uses one voltage level
Polar: Uses two voltage levels
Bipolar: Uses three or more voltage levels

Note

In unipolar encoding, we use only one voltage level, positive

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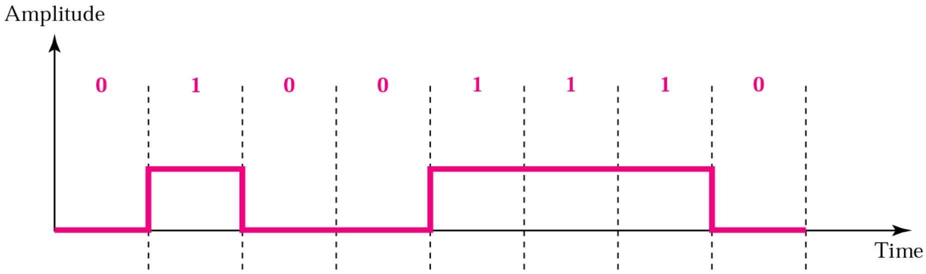
Unipolar Encoding



How many bits per clock tick?

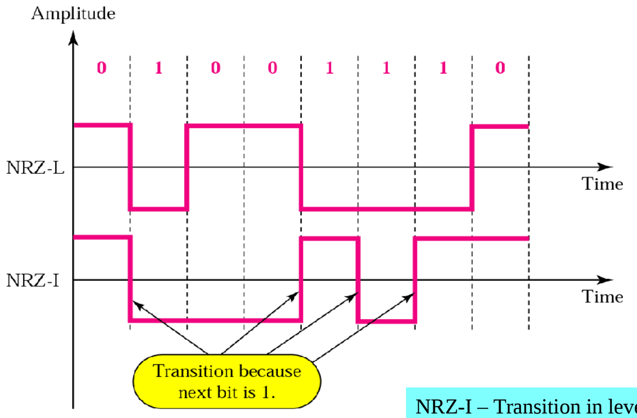
Unipolar Encoding

- Although simple, this method for encoding digital information has some serious drawbacks and is seldom used
  - First, difficult to keep clocks of source and receiver synchronized if there are long sequences of ones or zeros.
    - Receiver uses transitions in level to determine clock cycle boundaries
  - Second, it is impossible to distinguish between a long sequence of zeros and the absence of a signal

Note

In polar encoding, we use two voltage levels: positive & negative

Polar: NRZ-L and NRZ-I Encoding



NRZ-I – Transition in level for every 1 encountered, stays at that level until next 1

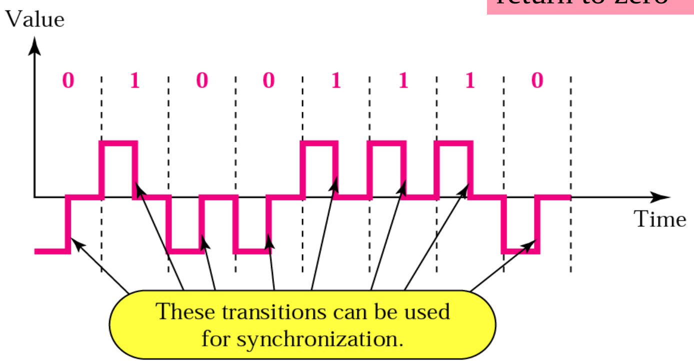
Note

In NRZ-L, level of voltage determines value of the bit

In NRZ-I, inversion or lack of inversion determines value of the bit

Polar: RZ Encoding

Every bit has a return to zero



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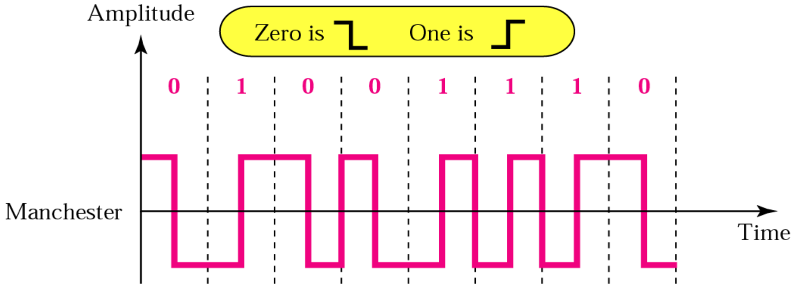
Polar: Manchester Encoding



Link to Manchester Encoding's Use in Ethernet
http://www.erg.abdn.ac.uk/users/gorry/course/phy-pages/man.html

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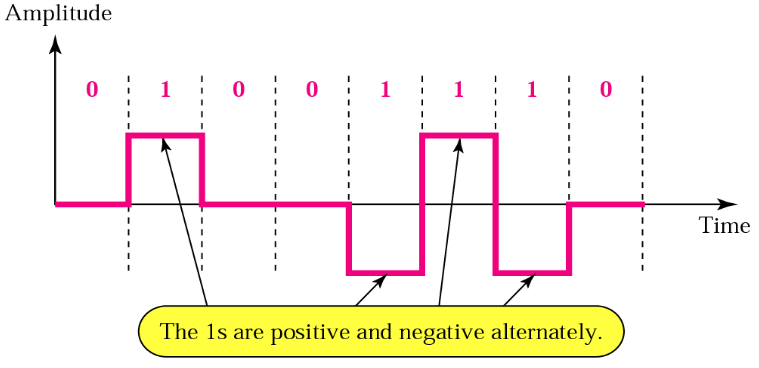
Note

In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for clock synchronization.

Note

In bipolar encoding, we use three levels: positive, zero, and negative.

Bipolar: AMI (Alternative Mark Inversion) Encoding



Summary

Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Unipolar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, high bandwidth
Bipolar	AMI	$B = N/2$	No self-synchronization for long 0s, DC
Multilevel	2B1Q	$B = N/4$	No self-synchronization for long same double bits
	8B6T	$B = 3N/4$	Self-synchronization, no DC
	4D-PAM5	$B = N/8$	Self-synchronization, no DC
Multiline	MLT-3	$B = N/3$	No self-synchronization for long 0s

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