TCOM 500: Modern Telecommunications

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Outline

- Line codes are used to transmit digital information over guided media.
  - E.g., cables and wires
- Properties of line codes relevant for transmission in practice.
  - Mainly bandwidth and synchronization considerations.
- Some line codes used in practice.

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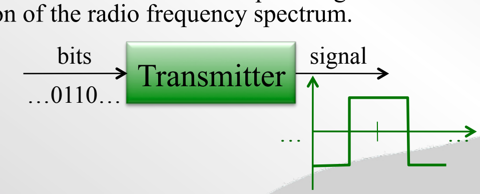
Reminder

- Purpose of a digital communication system:
  - Replicate digital information available at the transmitter's location at the receiver's location.
    - Generally this implies connecting spatially separate locations.
    - Same principle applies for communicating over time – storage of information.
- The communications channel models the link connecting transmitter and receiver.
  - Channel models the degradation that the transmitted signal experiences.

Transmitter

- The transmitter maps a sequence of bits to an analog signal.
  - The transmitted signal must be continuous in time for transmission through a physical link.
- The mapping performed by the transmitter is also called modulation.
- A large number of options exists for this mapping.
  - Choice of mapping depends mainly on the characteristics of the channel.
    - E.g., radio communications requires signals that occupy only a given portion of the radio frequency spectrum.



BASEBAND AND PASSBAND COMMUNICATIONS

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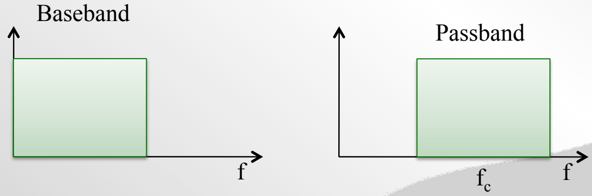
Baseband and Passband

- Transmitted signals occupy a portion of the frequency spectrum.
  - Baseband signals occupy spectrum near zero Hz (DC).
  - Passband signals occupy a portion of the spectrum centered at a carrier frequency f_c.



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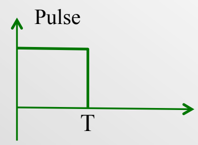
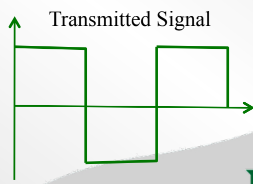
Baseband Signals

- Baseband signals use (baseband) pulses to construct the transmitted waveform.
  - The canonical example of such a pulse is a rectangular pulse.
- We will take a close look at practical choices and trade-offs for constructing baseband signals.
  - This process is often called line-coding.





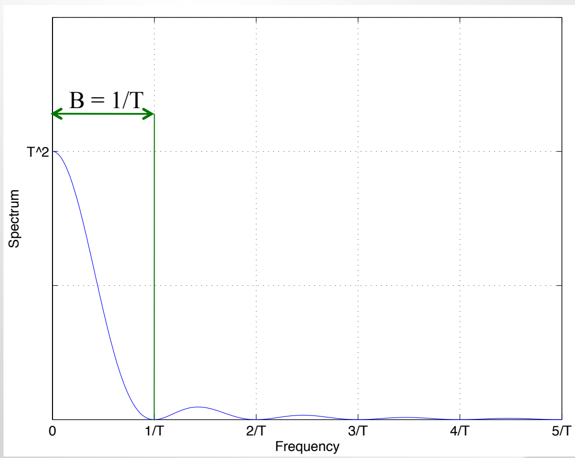
Spectrum of Baseband Signals

- It can be shown that the spectrum of a baseband signal with rectangular pulses of duration T, has the following (power) spectrum:

$$S(f) = T^2 \left(\frac{\sin(\pi f T)}{\pi f T} \right)^2$$

  - For other pulse-shapes, different spectra are obtained.
  - However, the shape of the spectra for different pulses have strong similarities.
    - =>Focus on rectangular pulse.

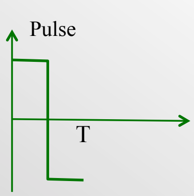
Spectrum of Baseband Signals

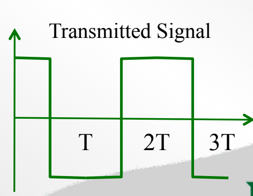


- Bandwidth of the signal is often defined as the location of the first zero.
  - Occurs at 1/T.
- Note that spectrum is not strictly zero outside the bandwidth.

Another Common Baseband Pulse

- A different pulse that we will see in our discussion has a transition in the middle of the symbol period.
  - We will see, that such pulses offer advantages in the ability to synchronize with the received signal.
    - Manchester encoding.





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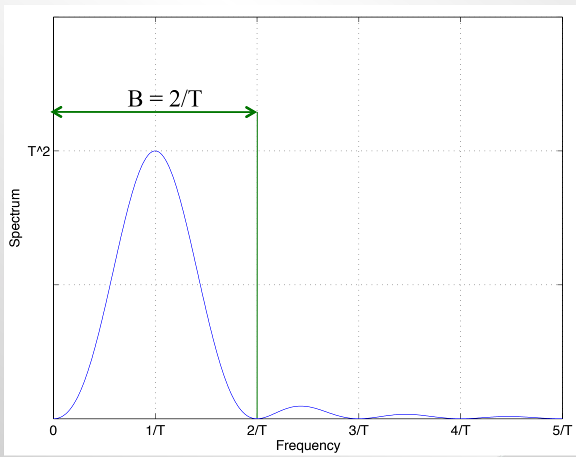
Spectrum of Baseband Signals

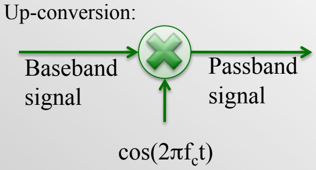


- With this pulse, bandwidth is 2/T.
  - This is related to the fact that signal remains constant for only T/2.
- At frequency zero, spectrum is zero.
  - No DC component.

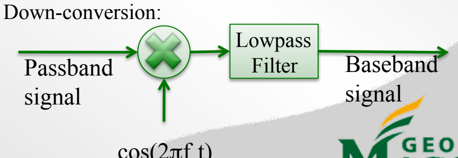
Passband Signals

- Will look more closely at passband signals in a later class.
- Passband signals can be created from baseband signals and vice versa.
  - The respective conversions are called up-conversion and down-conversion.

Up-conversion:



Down-conversion:



PROPERTIES OF LINE CODES

Line codes

- Line codes are used whenever information is transmitted through guided media.
  - Cables or optical fibers.
  - The principles also apply for example with bar codes or IR remote controls.
- We will first state a number of desirable properties of line codes.
- Then, present some specific line codes found in practice.

Comparison of Line Codes

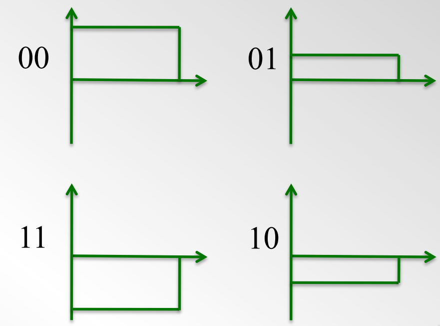
- The following characteristics will be used to compare line codes:
  - Bandwidth – in relation to the data rate.
  - Can code lead to long runs of constant signal?
    - This is undesirable for synchronization or for multi-level codes.
  - Does code have built-in error correction?
    - If not, can always have error coding before line coding.
  - Does code have a DC component?
    - Some channels cannot carry DC, e.g., telephone lines.

Bit Rate and Bandwidth

- Digital communication systems are expected to transport bits at a constant rate.
- To do so, the transmitted signals occupy a portion of the spectrum – bandwidth.
- The relationship hinges on three factors:
  - More than one bit may be transmitted at a time.
    - This leads to the notion of baud rate.
  - The bandwidth of the pulse being used.
    - Specifically, does the pulse have a transition in the middle or not.
    - We saw earlier, that pulses with a transition require twice the bandwidth.
  - With error correction coding, the overhead from coding increases the bandwidth.
    - Proportional to ratio of coded bits and uncoded bits.

Baud Rate

- More than one bit may be transmitted at a time.
  - For example, a line code may use 4 different amplitudes.
  - Then, two bits at a time may be transmitted simultaneously.
- Each multi-bit symbol is called a baud.
- The duration of a baud is denoted T.
- The baud rate R=1/T.
- Bandwidth depends on baud rate, not bit rate.



Baud rate is half of bit rate.

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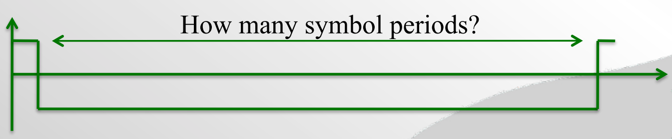
Significance of Long Runs

- It is undesirable for the transmitted signal to remain constant for long periods of time.
  - This may happen with rectangular pulses and a long sequence of zeros or ones.
- The main problem such runs cause is related to synchronization.
  - The receiver, must be able to tell when symbol periods start and end.
  - To do so, it relies on an internal clock which will not be identical to transmitter's clock.
    - Transitions allow the receiver to recalibrate its clock.
    - Without transitions, recalibration is not possible.
  - This can cause either missing or extra bits at the receiver.



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EXAMPLES OF LINE CODES

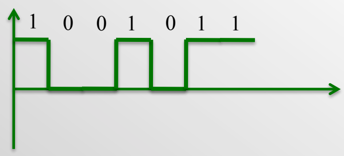
NRZ – Non-Return-to-Zero

- This is the simple scheme using rectangular pulses.
  - A few variations exist:
    - Unipolar vs. bipolar
    - Level vs. inversion
- NRZ line codes are used mainly in standards for connecting computers and peripheral devices:
  - USB
  - RS 232
  - Not common in telecommunications standards.
- Bandwidth: 1/T for all NRZ schemes.
- Potential for long runs exists.

Unipolar and Bipolar NRZ

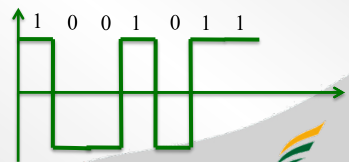
Unipolar NRZ

- 1 -> rectangular pulse
- 0 -> no pulse
- Also called on-off-keying (OOK)



Bipolar NRZ

- 1 -> positive rectangular pulse
- 0 -> negative rectangular pulse
- Also called binary phase-shift keying (BPSK)



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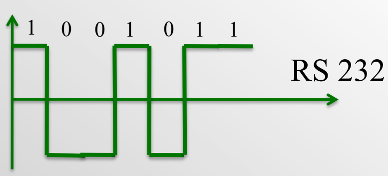
NRZ-L and NRZ-I

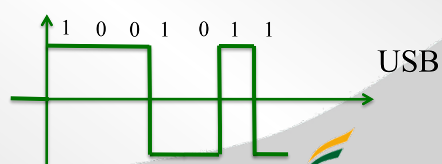
NRZ-L

- Information is encoded in the level of the signal.



NRZ-I

- Information is encode in the difference between consecutive symbols.
  - No change: 0, Change: 1 (or opposite)
  - Also called differential BPSK



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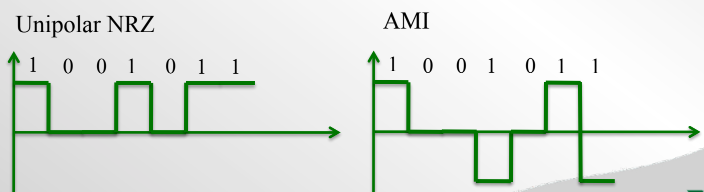
Alternate Mark Inversion

- Alternate Mark Inversion (AMI) partially addresses the problem with long runs.
  - Breaks up long runs of 1's
- AMI is fundamentally, like unipolar NRZ. But, the polarity of pulses (1s) is inverted every time.



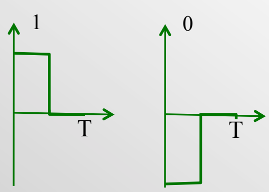
Manchester and RZ Coding

- The main problem with the NRZ coding is the absence of regular signal transitions.
  - This can lead to synchronization problems.
- Both RZ and Manchester coding alleviate this problem by always including a transition in the center of the pulse.
  - Both schemes require twice the bandwidth as NRZ (with the same bit rate)

RZ-coding and Manchester Coding

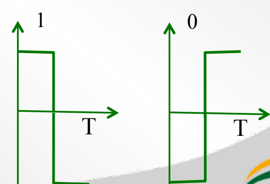
RZ Coding

- RZ coding uses the following pulses to encode bits.
  - Note that the pulses have a non-zero DC component.



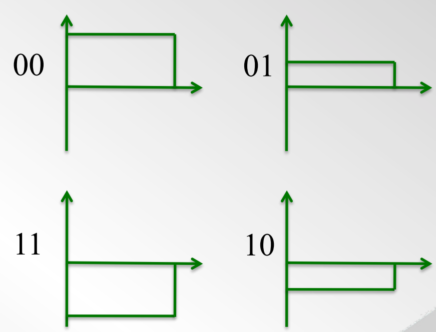
Manchester Coding

- Manchester coding uses the following pulses.
  - DC component is zero.
- Widely used in Ethernet up to 10Base-T.
- A differential version exists.



Multi-Level Coding

- In multi-level schemes, more than two amplitude levels are used.
  - This permits transmission of more than one bit per symbol period.
  - Baud rate is lower than bit rate.
  - Recall that this reduces the required bandwidth.



Example: 2B1Q

Multi-level Schemes: mBnL

- This class of multi-level schemes transmits:
  - m bits , in
  - n baud periods.
  - L – number of signal levels
  - We need $2^m \leq L^n$ to make this possible.
- Example: 2B1Q
  - L=4, m=2, n=1.

Letter	Meaning	L
B	Binary	2
T	Ternary	3
Q	Quartenary	4

Bandwidth is reduced by factor n/m – independent of L.

For reliability, number of levels cannot be incresed arbitrarily.

Scheme: 4B5B

- This scheme actually increases the bandwidth.
  - 4 bits are mapped to a 5 bit pattern.
- Purpose: Eliminate the synchronization problem with NRZI.
  - Achieved by ensuring that each 4 bit pattern is mapped to a 5 bit pattern that contains at least one 1.
  - The resulting sequence is then NRZI encoded.
  - Guarantees regular occurrence of transitions.
    - Recall, each 1 causes a transition in NRZI.
- Used in some of the 100Mb/s Ethernet standards.
- Similar: 8B10B, used in 1Gb/s Ethernet.

Scheme: 8B6T

- Maps blocks of 8 bits to 6 baud periods.
  - Bandwidth reduction by a factor 6/8=3/4.
- Uses three signal levels: +V, 0, -V
  - Called Three-Level Pulse-Amplitude Modulation (PAM 3).
- Redundancy:
  - There are 2^8 = 256 different 8 bit patterns.
  - There are 3^6 = 478 different signal patterns.
  - Therefore, 478-222 signal patterns are redundant.
- Redundant patterns are used to:
  - Ensure regular transitions for error correction.
  - DC balance
  - Error detection.
- Also used in 100Mb/s Ethernet.

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Summary: Line Codes

- Discussed line codes used for transmitting digital information on guided media (wires and cables)
- Addressed:
  - Bandwidth, synchronization, DC balance, and error correction/detection.
- Simple codes:
  - NRZ, RZ, and Manchester coding.
- Recent trends:
  - Multi-level codes for reduced bandwidth, and/or,
  - Good synchronization and DC balance,
  - Error detection or correction.

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