Encoding Techniques

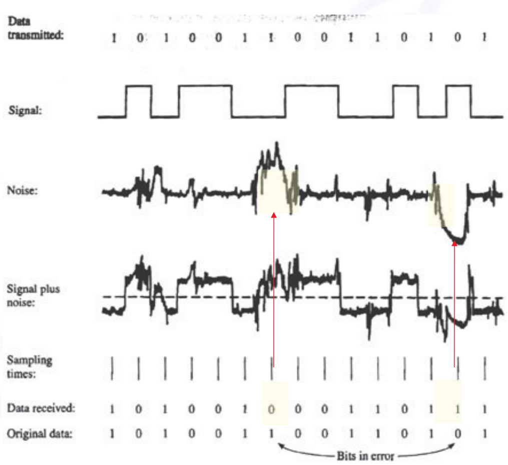
Slide Set 8

Terminology

- **Unipolar Signals**
  - Binary data represented by signals of the *same* polarity, e.g. 0 -> +5 V, 1 -> +10 V ⇒ DC content
- **Bipolar (Polar) Signals**
  - Binary data represented by signals of *opposite* polarity, e.g. 0 -> +5 V, 1 -> -5 V ⇒ ideally Zero DC content
- **Mark and Space**
  - Binary 1 and Binary 0 respectively
- **Duration of a bit (T_b)**
  - Time taken for transmitter to emit a data bit
- **Data rate, R (= $1/T_b$)**
  - Rate of data transmission measured in **bits per second (bps)**
- **Duration of a Signal Element (T_s)**
  - Minimum duration of a signal pulse
- **Modulation (signaling) rate, D ($1/T_s$)**
  - Rate at which the signal level changes with time measured in **bauds = signal elements per second**

> Not always Tb = Ts !!!
> e.g. Multi-symbol transmission
> (M = 4, 8, …): Tb < Ts

Interpretation of the Received Signal



Encoding Schemes

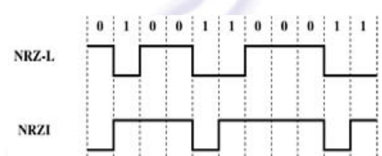
Schemes for encoding digital data as digital signals

- **Non-return to Zero** (NRZ) Group:
  - Non-return to Zero-Level (NRZ-L)
  - Non-return to Zero Inverted (NRZ-I)
- **Multi-level Binary** Group:
  - Bipolar-AMI (Alternate Mark Invert)
  - Pseudoternary
- **Bi-Phase** (RZ) Group:
  - Manchester
  - Differential Manchester
- **Scrambling** Group:
  - B8ZS (Bipolar with 8-Zeros Substitution)
  - HDB3 (High Density Bipolar 3-Zeros)

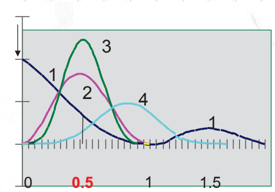
Aspects of comparison between schemes

- **Clocking:** Synchronizing RX to TX can be achieved using:
  - An external clock, or better:
  - A built-in synchronizing mechanism in the **signal** itself! (so, a code with many signal transitions is better)
- **Error detection**
  - Mostly handled by higher layers, e.g. data-link control
  - But error detection capabilities built into the signal encoding scheme would help!
    Advantage: Implemented much faster (in hardware)
- **Performance with interference and noise**
  - Some encoding schemes perform better than others: e.g. with differential encoding: data is encoded as signal transition/no signal transition, and data detection at RX is **less affected by noise.**
- **Cost and complexity**
  - Some codes require signaling at a rate greater than the data rate (e.g. RZ) At higher signaling rates this requires higher bandwidth, faster circuits, etc. (larger costs)

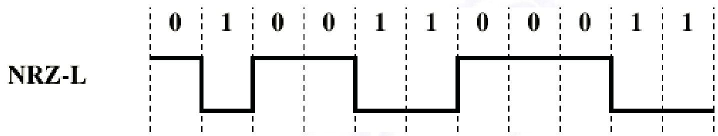
NRZ Group Pros and Cons:



- Pros
  - Easy to implement
  - Modest bandwidth requirements
- Cons
  - Large DC component
  - Poor TX-RX synchronization:
    e.g. **No signal transitions for long strings of 0's or 1's** (so few edges are available for synchronization)
- Used for magnetic recording
- Not used much for signal transmission

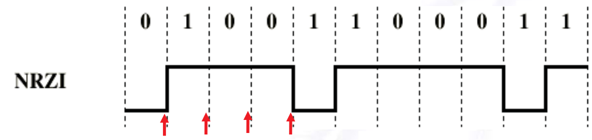


NRZ-L: Non-return to Zero Level



- Two different signal voltages for the 0 and 1 data bits
- Voltage level is constant (no return to zero, so no signal transition) for the full duration of the data bit interval
- e.g. positive voltage for space and 0V for mark
- More often, negative voltage for one data value and positive for the other (bipolar signal) (Why?)
- An example of absolute encoding: Mapping data **directly** to signal **levels**

NRZ-I: Non-return to Zero Invert

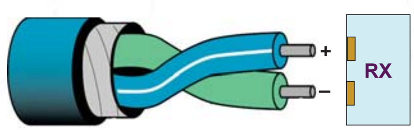


- Still constant voltage level for bit duration of (hence NRZ)
- But data is encoded as presence or absence of signal transition at the beginning of bit time:
  - Transition (low to high or high to low): Denotes binary 1
  - No transition: Denotes binary 0
- This is an example of differential encoding:Encoding data as a change/no change in signal level.

Differential Encoding

- Data is represented by signal transitions rather than signal levels
- Advantages;
  - With noise, signal transitions (or lack of them) are detected more easily than signal levels ⇒ Better noise immunity
  - In complex transmission layouts, it is easy to accidentally lose sense of polarity

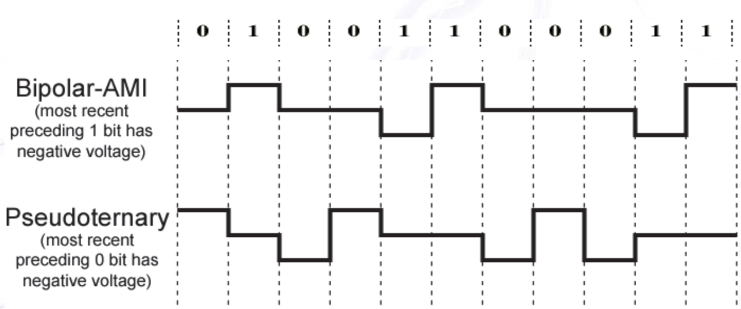
Effect of swapping terminals on:
- **NRZ-L**
- **NRZI**



The Multilevel Binary Group

- Uses more than two signal levels (3 in this case)
- Signal is multi-level but data is still binary!
- Bipolar-AMI (Alternate Mark (1) Inversion)
  - 0 data is represented by no line signal
  - 1 data represented by positive or negative pulse
  - The “1” pulses alternate in polarity (why? 2 reasons!)
  - Advantages:
    - No net DC component (for any data sequence!)
    - Lower bandwidth than NRZ
    - No loss of sync with a long string of 1’z (but zeros still a problem- Will try to solve it later)
    - Alteration of pulse polarity also useful for error detection

Bipolar-AMI and Pseudoternary



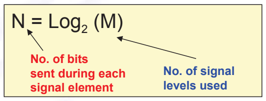
Pseudoternary

- Opposite of Bipolar-AMI:
  - 1 represented by no line signal
  - 0 represented by alternating positive and negative pulses
- Could be called Bipolar-ASI: (Why?)
- No advantage or disadvantage over bipolar-AMI

The Multilevel Binary Group: Advantages

- No net DC component
- Spectrum centered at the middle of the BW
- Lower bandwidth than NRZ
- No loss of sync with a long string of 1'z
  (but zeros still a problem- Will try to solve it later)
- Alteration of pulse polarity also useful for error detection.

Disadvantages of Multilevel Binary



- Coding scheme not as efficient as NRZ:
  - We send only one bit at a time (1 or 0 data)
    ⇒ Only $M = 2^1 = 2$ signal levels should be enough, but we are sending 3 levels > 2 !
  - We use 3 levels ⇒ Enough to represent $\log_2 3 = 1.58$ bits > 1 bit !
- Receiver Design and Noise Performance
  - Now receiver must distinguish between three signal levels (+A, -A, 0) ⇒ Need better receiver design
  - Requires approximately 3dB higher SNR for the same probability of bit error (bit error rate)

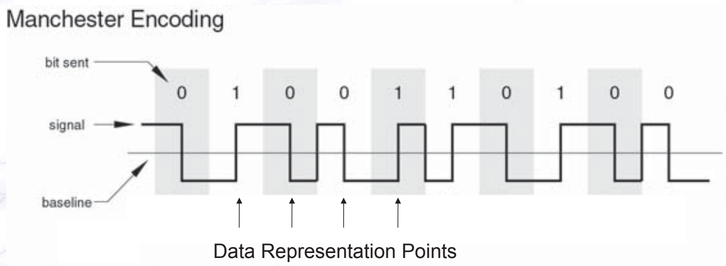
The Biphase Group (2 signal phases per bit)

- Manchester
  - Transition in middle of each bit period
  - Transition serves both as a clock edge and data representation
    - Low to high represents 1
    - High to low represents 0
  - Used by the IEEE 802.3 specification for Ethernet LAN (short distances)
- Differential Manchester
  - Dedicated mid-bit transition used **only** for clocking
  - Data representation is at start of bit:
    - No transition at start of a bit period represents 1
    - Transition at start of a bit period represents 0
      (Inverts on 0's – opposite of NRZ-I)
  - An example of differential encoding
  - Used by IEEE 802.5 specification for Token Ring LAN

Manchester Encoding

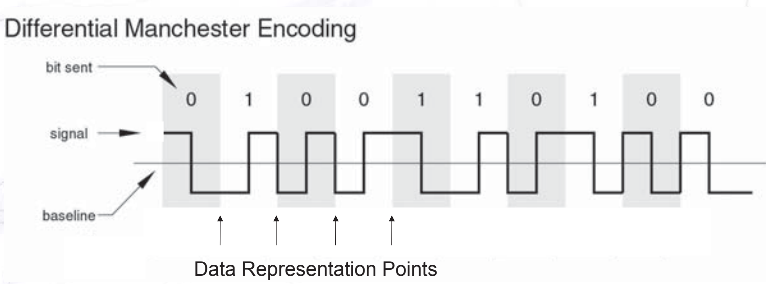
- **Mandatory transition in middle of each bit period**
  → Low to high represents 1
  → High to low represents 0
- **Transitions at start of bit only where required**

Note: This is not differential



Differential Manchester Encoding

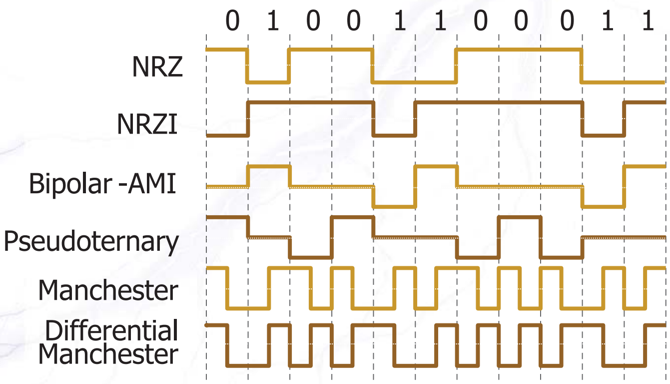
- **Mandatory mid-bit transition for clocking**
- **Data represented by transition or no transition at bit start:**
  → Transition (either direction) represents 0
  (Invert on zeros)
  → No transition represents 1



Biphase Pros and Cons

- Pros
  - Guaranteed mid bit transitions
    - Synchronization facility (self clocking codes)
  - Ideally no dc component (using bipolar signals)
  - Error detection
    - Detecting absence of expected (mandatory) transitions
- Cons
  - At least one transition per bit time and possibly two
    - Modulation (signaling) rate as high as twice that of NRZ
    - So, requires more bandwidth
    - Therefore, used over shorter distances (in LANs)

1. Digital data, Digital signal Encoding



Scrambling Group: B8ZS, HDB3

- Use bit scrambling to replace data bit sequences that would otherwise produce a constant signal voltage, with a more appropriate bit sequence producing signal changes
- Helps overcome constant DC problems with Multilevel Binary codes (poor synchronization)
- So, a "filling" (replacement) bit sequence is inserted where necessary
- Criteria for a "Filling sequence"
  - Should produce enough transitions for synchronization
  - Must be recognized by receiver for replacement with original data
  - Not likely to be generated by noise (difficult for noise/interference to produce it)
  - Should occupy the same bit length as original data (so no extra overhead in the data rate)

Scrambling Group: B8ZS, HDB3

- Advantages:
  - No long sequences of zero level line signal
  - No DC component
  - No reduction in useful data rate (No extra data sent)
  - Built-in error detection capability

B8ZS

- Bipolar With 8 Zeros Substitution
- Improvement on bipolar-AMI
- If an octet of 8 zeros and the last pulse preceding was positive (+):Transmitter encodes the 8 zeros as 000+-0-+

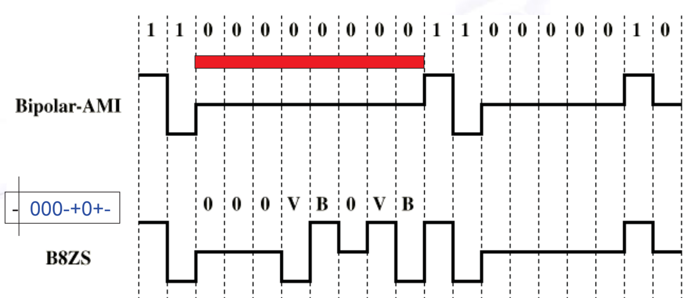
  (how many level changes does this introduce?)
- If an octet of 8 zeros and last voltage pulse preceding was negative (-): Transmitter encodes as 000-+0+-

  (shown in Fig. 5.6)
- Each insertion has *two* intentional violations of the basic AMI code rule: (violations alternate in polarity- no net DC added)

  +000+-0-+

  -000-+0+-
- A strange event ⇒ unlikely to be caused by noise
- Receiver should detect it and interpret as an octet of 8 zeros (original data)
- No additional data sent ⇒ No penalty on genuine data rate

B8ZS



V: Violation

B: Bipolar (Valid)

See how the insertion satisfies the 5 requirements:
- Detectable at RX
- Difficult for noise to generate
- Introduces transitions
- Does not introduce DC (alternate violations)
- Error detection capability