Line Codes in Digital Communication (Lab 1)

Shahd Tharwat Elrefai, ID: 8504   Mayar Ashraf ElNaggar, ID: 8404

24 February 2025

1 Introduction

Line codes is the way of representing a digital signal using voltage or current waveform forms. They can be represented using binary signaling or multi-level signaling. Binary bits (0's and 1's) in A/D conversion are represented using several serial-bit signaling schemes.

2 Line Codes Schemes

Almost all schemes are categorized into:

- **Return-to-zero (RZ):** When converting the digital signal to a positive or negative waveform period, the wave stays for a while but not for the whole bit duration because it return to zero.
- **Non-return-to-zero (NRZ):** the bit takes up its whole duration.

3 Power Spectral Density (PSD)

Digital signals they are random data which are non-deterministic, so we can't take its Fourier transform. So in time domain we find its auto correlation function (the correlation of the signal with itself). We then can find the power spectral density (PSD) by taking the correlation function's Fourier transform, which is a frequency domain representation.

4 Metrics of Line Codes

Performance of line codes can be measured using the following metrics:

- **Transmission bandwidth:** Should be as low as possible.
- **Self-synchronization:** rich in transitions for continuous bits which affects clock synchronization.
- **Error detection capability:** Including some correlation in successive bits.
- **Power efficiency:** Total power needed to send data.
- **Transparency:** No reserve sequences for other protocols. Safeguard timing information.

5 Polar

5.1 Polar NRZ

Polar NRZ is a digital line coding scheme used in data communication systems to represent binary data using two distinct voltage levels. It assigns both positive and negative voltages to represent binary digits.

- Positive polarity: represents '1' binary bit
- Negative polarity: represents '0' binary bit

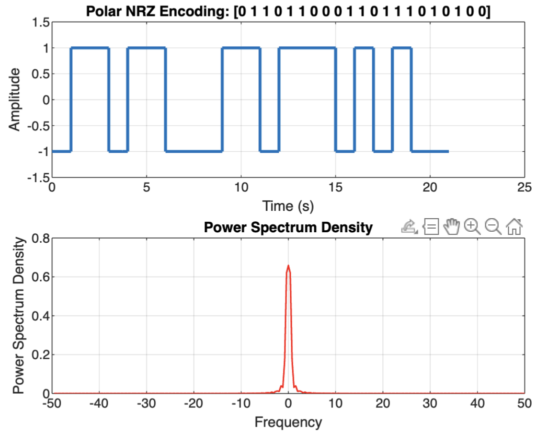

Figure 1: Polar NRZ signal and PSD

5.1.1 Advantages

- Reduced DC Component: Using both positive (+V) and negative (-V) voltage levels, it helps reduce DC offset, unlike unipolar schemes which have a significant DC component.
- Higher Power Efficiency: It doesn't waste energy by keeping one voltage level at 0V during the transmission.
- Efficient Bandwidth Usage: Compared to Manchester encoding, Polar NRZ requires less bandwidth since there are fewer transitions per bit.

5.1.2 Disadvantages

- Synchronization Issues: Long sequences of 1s or 0s cause a constant signal, making synchronization difficult. The receiver lacks transitions to recover the signal.

5.2 Inverted Polar NRZ

Inverted Polar NRZ is a variation of the Polar Non-Return-to-Zero (NRZ) encoding scheme, where the voltage levels assigned to binary bits are reversed compared to standard Polar NRZ.

- Positive polarity: represents '0' binary state
- Negative polarity: represents '1' binary state

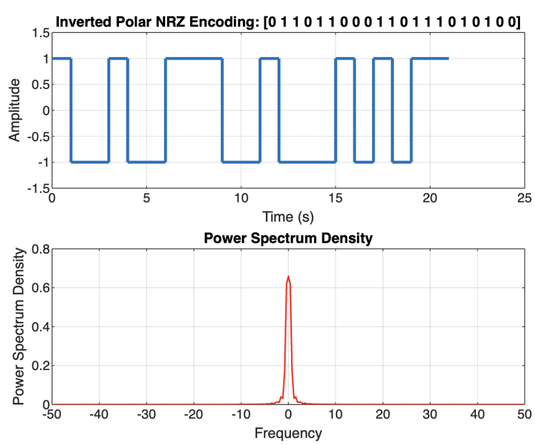

Figure 2: Inverted Polar NRZ signal and PSD

5.2.1 Advantages

- Same Efficiency as Polar NRZ: It maintains simple implementation and bandwidth efficiency of standard Polar NRZ encoding.
- Voltage Reversal for Compatibility: Some systems require negative logic or reversed voltage levels, and Inverted Polar NRZ ensures compatibility without changing the encoding method.
- Easy to Implement: Only requires swapping voltage levels from Polar NRZ.
- Less Power Dissipation: Negative voltages for bit '1' can reduce power use in some circuits.

5.2.2 Disadvantages

Inverted Polar NRZ has the same disadvantages as Polar NRZ because it is the same encoding method with swapped voltage levels.

- Synchronization Issues: Both suffer from long sequences of 1s or 0s causing no transitions.

5.3 Polar RZ

Similar to Polar NRZ, Polar RZ represents bit '1' with +V and bit '0' with -V. However, unlike NRZ, the signal returns to zero halfway through each bit period instead of maintaining the voltage for the full duration.

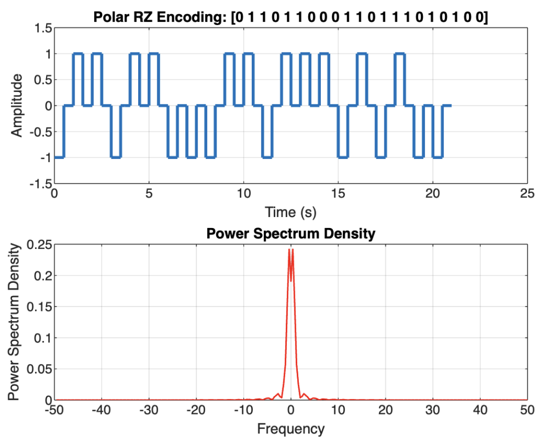

Figure 3: Polar RZ signal and PSD

5.3.1 Advantages

- Better Synchronization: Frequent transitions help maintain synchronization, reducing clock drift issues.
- Reduced DC Component: Since the signal returns to zero, the DC offset is lower than in Polar NRZ, making it more suitable for long-distance transmission.
- Simpler Signal Recovery: The presence of more transitions helps receivers accurately detect bits.

5.3.2 Disadvantages

- Higher Bandwidth Requirement: Since each bit has two voltage changes, it requires more bandwidth than Polar NRZ.
- Lower Power Efficiency: Returning to zero means more power consumption compared to NRZ, where the signal remains constant.

6 Bipolar

6.1 Bipolar NRZ

Bipolar NRZ, also known as Alternate Mark Inversion (AMI), is a type of line code where data is represented by alternating positive and negative voltage levels (polarity), with a neutral or zero voltage level indicating no data.

- Positive polarity: represents one binary state (e.g. '1')
- Negative polarity: represents the same binary state as the positive voltage but alternates with it, so that no two negative voltages follow each other, even with a no data state in between.

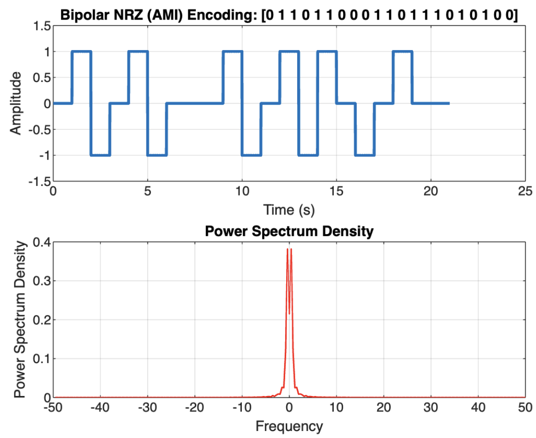

Figure 4: Bipolar NRZ signal and PSD

6.1.1 Advantages

- Good self-synchronization.
- High transparency.
- Error detection: if two consecutive 1's have the same polarity, this indicates an error in transmission.
- Less power consumption: the signal has a balanced distribution of positive and negative voltages, it requires less power to transmit compared to unipolar encoding.

6.1.2 Disadvantages

- Self-synchronization falls off for long sequences of zeros.
- Lower data-rate for the same bandwidth: compared to Manchester encoding, it doesn't have transition for every bit, leading to potential loss of timing information.

6.2 Bipolar RZ

Similar to Bipolar NRZ, represented by alternating polarities for 1's and a zero for 0's. The difference lies in not completing the full bit duration, and returning to the zero instead.

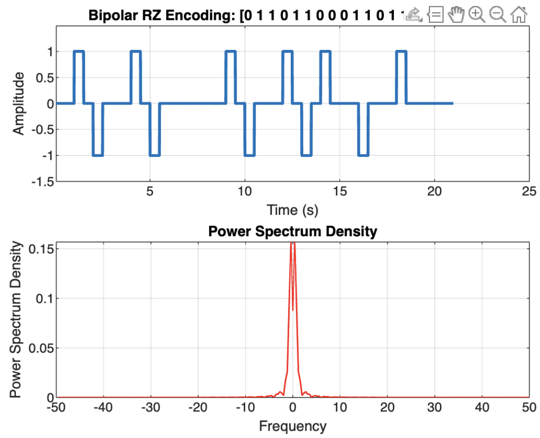

Figure 5: Bipolar RZ signal and PSD

6.2.1 Advantages

- Improves self-synchronization than BNRZ: every bit returns to zero in the second half of the bit period, there are frequent transitions.
- High transparency.
- Error detection like BNRZ.
- Less power consumption than BNRZ: the signal returns to zero in every bit period, it effectively reduces the usable signal time for actual data transmission.

6.2.2 Disadvantages

- Self-synchronization falls off for long sequences of zeros.
- Less efficient bandwidth: each bit returns to zero in the middle of the bit period, twice as many transitions occur compared to Bipolar NRZ, requiring more bandwidth.

6.3 Manchester

Manchester line code relies solely on transitions in the middle of each bit duration, where:

- Signaling a 1: voltage transition from high to low.
- Signaling a 0: voltage transition from low to high.

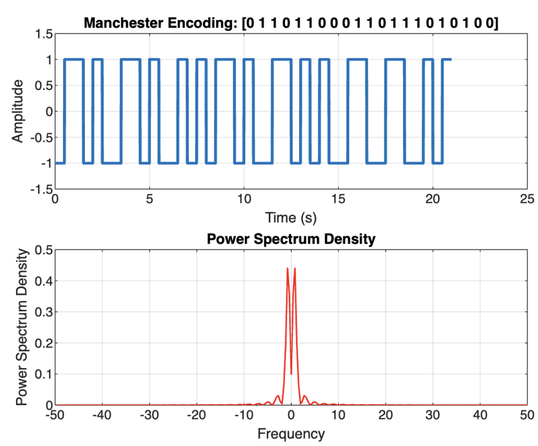

Figure 6: Manchester signal and PSD

6.3.1 Advantages

- High self-synchronization: ensures a transition in every bit period, making it suitable for long-distance communication.
- High transparency.
- High error detection capability: can be more easily detected if transitions are missing or occur incorrectly.
- No DC Component (Low DC Bias): the balanced nature of the encoding eliminates low-frequency components, making it suitable for AC-coupled and wireless transmission.

6.3.2 Disadvantages

- Requires large bandwidth: each bit requires two signal changes (one per half-bit period).
- Higher power consumption
- Complex encoding and decoding: need for accurate phase detection in decoding.

7 Other Line Codes

7.1 Biphase Mark Code (Manchester Encoding Variant)

Biphase Mark Code is a line code that uses transitions in the middle of each bit period to represent data (1s). It's a variant of Manchester Encoding.

- Signaling a 1: a transition in the middle of the bit.
- Signaling a 0: no transition.

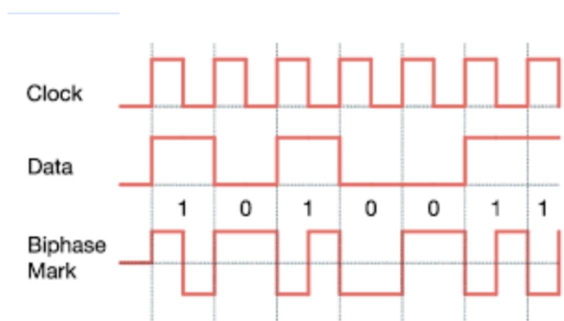

Figure 7: Biphase Mark Demonstration

7.1.1 Advantages

- High self-synchronization like Manchester.
- Good transparency.
- Good error detection capability: due to having transitions in signaling a 1.
- No DC Component (Low DC Bias) like Manchester.

7.1.2 Disadvantages

- Requires relatively large bandwidth but less than Manchester.
- High power consumption.
- Complex encoding and decoding: need for accurate phase detection in decoding.

7.2 Unipolar NRZ

Unipolar Non-Return-to-Zero (NRZ) is a simple line coding scheme where data is represented using only positive voltage levels and zero voltage.. Unlike polar schemes, it does not use both positive and negative voltages.

- '1' bit is encoded as +V
- '0' bit is represented by 0V.

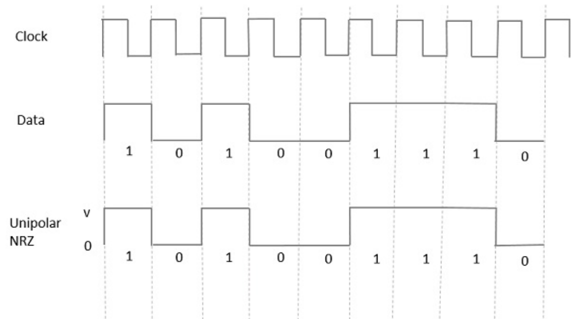

Figure 8: Unipolar NRZ Demonstration

7.2.1 Advantages

- Simple Implementation: Uses only one voltage level (+V and 0V), making it easy to design and implement.
- Low Bandwidth Requirement: Needs less bandwidth than Polar RZ or Manchester encoding.
- Efficient for Short Distances: Works well for short-range communication, such as inside a circuit board or between nearby devices.

7.2.2 Disadvantages

- High DC Offset: The signal always has a positive voltage for '1' and zero for '0', causing a DC buildup. This weakens signal quality over long distances.
- Higher Power Use: Unlike Polar NRZ, it does not use negative voltage, leading to more power consumption.

8 Conclusion

Line codes with more transitions have better synchronization, transparency, error detection, but have a larger bandwidth and consumes more power. Among these, **Manchester encoding has the highest bandwidth** because each bit contains two transitions, effectively doubling the required bandwidth compared to NRZ schemes. Although this improves synchronization, it significantly makes it less efficient for bandwidth-constrained systems.

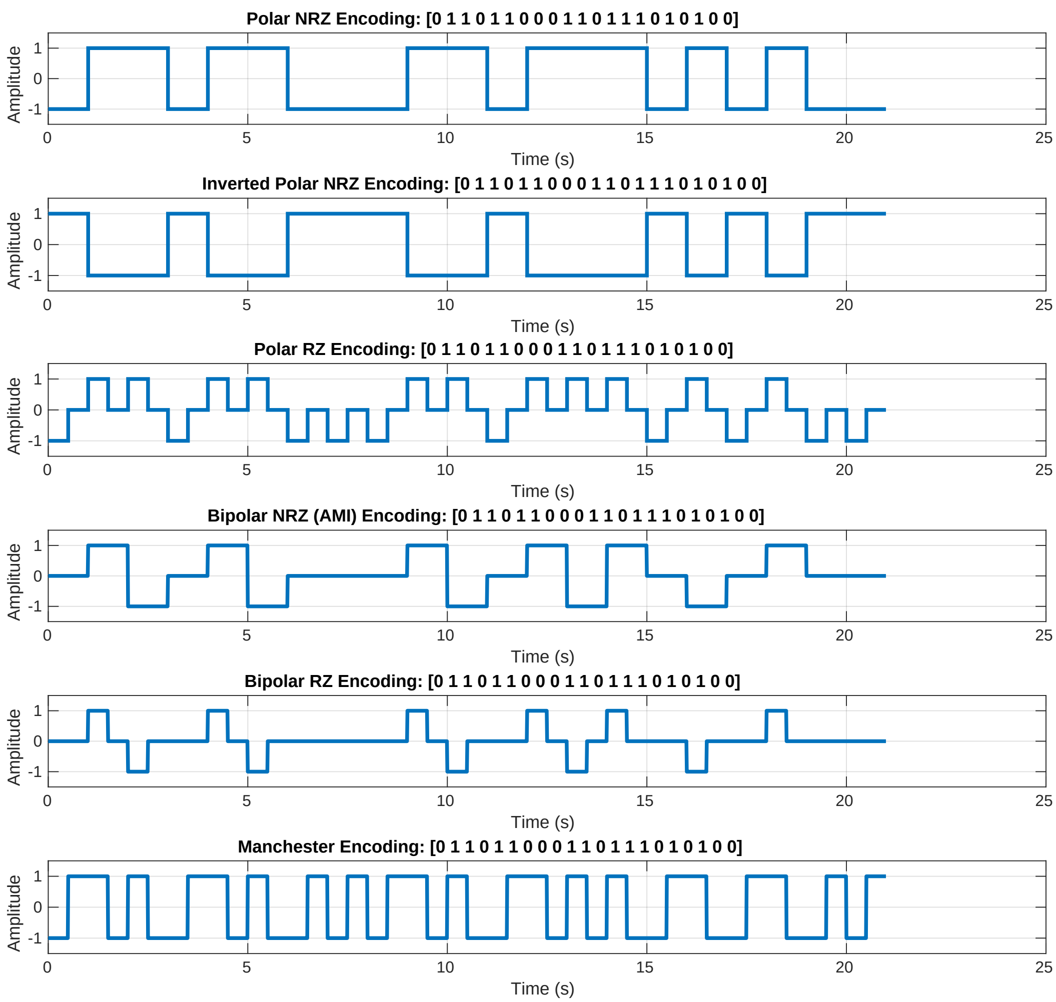

Figure 9: All Line Codes Signals

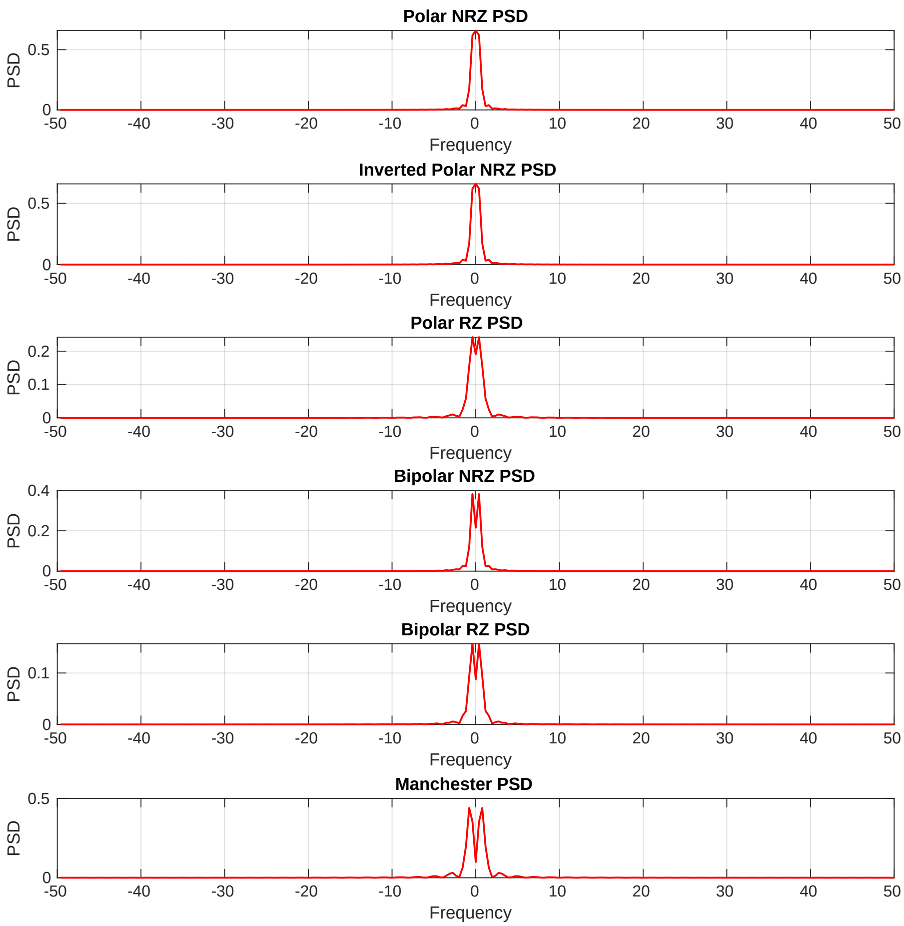

Figure 10: All Line Codes Power Spectral Densities