# Digital Communications Engineering 1

## (COMM2108)

*Baseband Communication*

*Line Coding*

# *Line Coding*

- In order to be transmitted over a digital communications system, an information signal must first be formatted so that it is represented by digital *symbols* (usually binary digits or *bits*).
- Next, these digital or binary representations must be converted into electrical waveforms that are transmitted over the communications channel.
- In *baseband* digital transmission, the electrical waveforms used are *pulses* and this conversion from digital data to digital waveforms is known as *line coding*.

# *Line Coding*

- A signal whose spectrum extends from dc up to some finite frequency (usually a few MHz) is called a *baseband* signal. Hence line coding is concerned with *baseband digital transmission*.
- In many cases it is not possible to directly transmit electrical pulses over the communications channel (e.g. radio channels).
- In these cases, the digital data must be converted into *bandpass* signals (i.e. modulated onto a sinusoidal carrier wave to make their spectral characteristics more compatible with the communications channel).

# *Line Coding*

- The binary data such as the binary *1's* and *0's* produced by a PCM encoder may be represented in various serial-bit signalling formats known as *line codes*.
- There exists many line codes and each has its own particular advantages and disadvantages depending on the particular application.
- However, there are a number of desirable properties that a line code should exhibit.

# *Line Coding*

- ***Signal Spectrum***: Several aspects of the signal spectrum are important:
  - The spectral occupancy (i.e. the bandwidth) should be as small as possible to ensure good spectral efficiency.
  - There should be no dc component as this permits the use of ac coupling via transformer. This provides for electrical isolation and helps reduce the effects of interference.

# *Line Coding*

- ***Clock Signal*: ** Synchronization between the transmitter and receiver is of critical importance in digital communications systems.
- Ideally, the spectrum of the line code should contain a frequency component at the clock frequency to permit *clock extraction*.
- This avoids having to transmit a separate clock signal between the transmitter and receiver.

# *Line Coding*

- ***Signal Interference and Noise Immunity*:** Ideally, the line code should be rugged in terms of exhibiting an immunity to interference and noise.
- In more technical terms, the line code should have a low probability of error for a given level of transmitted power.
- Certain line codes are more rugged than others, e.g. *polar codes* have a better error performance compared to *unipolar codes*.

# *Line Coding*

- ***Error Detection*: It is useful to have some error detection capability built into the line code to permit transmission errors to be detected more quickly.
- ***Transparency*: The performance of the line code should be independent of the data, i.e. long strings of binary *1's* or *0's* should not affect the performance.
- ***Cost and Complexity*: The line coding scheme should not be excessively complex and/or costly.

# *Line Coding*

- ***Line Coding Formats*:** The various line coding waveforms can be categorized in terms of the following.
  - The duration of the pulses.
  - The way in which voltage levels are assigned to the pulses.

# *Line Coding*

- ***Pulse Duration*: There are two classes used here.**
  - Non return-to-zero (NRZ) where the pulse or symbol duration $T_s$ = the bit period $T_b$.
  - Return-to-zero (RZ) where the pulse or symbol duration $T_s$ < the bit period $T_b$. Usually $T_s = 0.5T_b$.
- The pulse duration will usually have an effect on the synchronization properties of the line code (i.e. it determines the presence or absence of a frequency component at the clock frequency).

# *Line Coding*

- ***Pulse Voltage Levels*: There are many voltage level formats possible:**
  - Unipolar
  - Polar
  - Dipolar
  - Bipolar
  - High Density Bipolar substitution (HDBn)
  - Coded Mark Inversion (CMI)

# *Line Coding*

- ***Unipolar*** signalling is where a binary *1* is represented by a high positive level (+A volts) and a binary *0* is represented by a zero level (0 volts).
- This is sometimes known as on-off keying (OOK).
- There are two variations possible:
  - Unipolar NRZ
  - Unipolar RZ

# *Line Coding*

- ***Unipolar NRZ*** has the following features:
  - Narrow bandwidth
  - Significant dc component
  - No clock component
  - Easy to generate
- ***Unipolar RZ*** has the following features:
  - Large bandwidth
  - Significant dc component
  - Clock component present
  - More difficult to generate
- In both cases, there is no error detection capability and the codes are not transparent.

# *Line Coding*

- ***Polar*** signalling is where a binary *1* is represented by a high positive level (+A volts) and a binary *0* is represented by a negative level (-A volts).
- This is an example of *antipodal* signalling.
- There are two variations possible:
  - Polar NRZ
  - Polar RZ

# Line Coding

- ***Polar NRZ*** has the following features:
  - Similar spectrum to unipolar NRZ (narrow bandwidth)
  - Significant dc component
  - No clock component
- ***Polar RZ*** has the following features:
  - Similar spectrum to unipolar RZ (large bandwidth)
  - Significant dc component
  - No clock component present, but clock extraction possible using rectification.
- In both cases, there is no error detection capability and the codes are not transparent.
- However, the polar scheme has a better error performance due to its antipodal format.

# *Line Coding*

- ***Dipolar*** coding is designed to produce a spectral null at 0 Hz, i.e. no dc component.
- The symbol interval $T_s$ is split into half-width pulses.
- An example of dipolar coding is the Manchester code where a binary *1* is represented by a positive half-width pulse followed by a negative half-width pulse. A binary *0* is represented by a negative half-width pulse followed by a positive half-width pulse.
- The Manchester code is transparent.
- Clock extraction is possible at the receiver.
- Large bandwidth relative to NRZ type coding.
- Used on IEEE 802.3 Ethernet LANs.
- Also known as *split-phase* signalling.

# *Line Coding*

- ***Bipolar RZ*** or ***Alternate Mark Inversion (AMI)*** uses three voltage levels to represent the binary *1's* and *0's*.
- A binary *0* is represented by a zero level.
- A binary *1* is represented by alternating positive and negative pulses (i.e. the alternating mark rule).
- This alternating pulse polarity gives bipolar signalling an error detection capability and also produces a spectral null at 0 Hz.
- There is no clock component present but clock extraction is possible through rectification.
- Bipolar signalling is not transparent, but several techniques have been developed to address this deficiency.
- Also known as *pseudoternary* signalling.

# *Line Coding*

- ***High Density Bipolar substitution (HDBn)*** is used to counteract the effects of a long strings of binary *0's* in the AMI line code.
- When the number of continuous binary *0's* exceeds *n* they are replaced by a special code sequence.
- HDB3 is the line code recommended by the ITU-T for PCM systems operating at multiplexed rates of 2, 8, and 34 Mbits/sec. (ITU-T Recommendation G.703). HDB3 is widely used in Europe.
- In HDB3, the fourth zero in a string of zeros is "marked", i.e. forcibly set to *1*, but in a way that violates the alternating mark rule.

# *Line Coding*

- Specifically, string of four binary *0's* is replaced by either *000V* or *100V* where *V* is chosen to violate the alternating mark rule.
- Furthermore, consecutive violation pulses alternate to avoid introducing a dc component.
- The HDB3 spectrum is similar to that of the bipolar RZ spectrum.
- It has a spectral null at 0 Hz and most of the energy is concentrated in a relatively sharp spectral peak around a frequency at half the clock rate.
- HDB3 is well suited to high data rate transmission.

# *Line Coding*

- In North America, a similar line coding scheme known as *Bipolar with 8-Zeros Substitution or B8ZS* is used.
- In B8ZS, an octet of all zeros is replaced with a special code word.
- Under this notation, HDB3 can be considered to be a form of B4ZS.

# *Line Coding*

- ***Coded Mark Inversion (CMI)*** is a variation of the NRZ and RZ codes.
- A binary *0* is represented by a polar NRZ code which uses both amplitude levels (each for half the symbol period).
- A binary *1* is alternately represented by either amplitude level (for a full symbol period).
- CMI is therefore a combination of dipolar signalling for binary *0* and NRZ-AMI for binary *1*.
- CMI has spectral null (i.e. no DC component) and permits clock extraction at the receiver.
- CMI is recommended by the ITU-T for 140 Mbits/sec multiplexed PCM.

# *Line Coding*

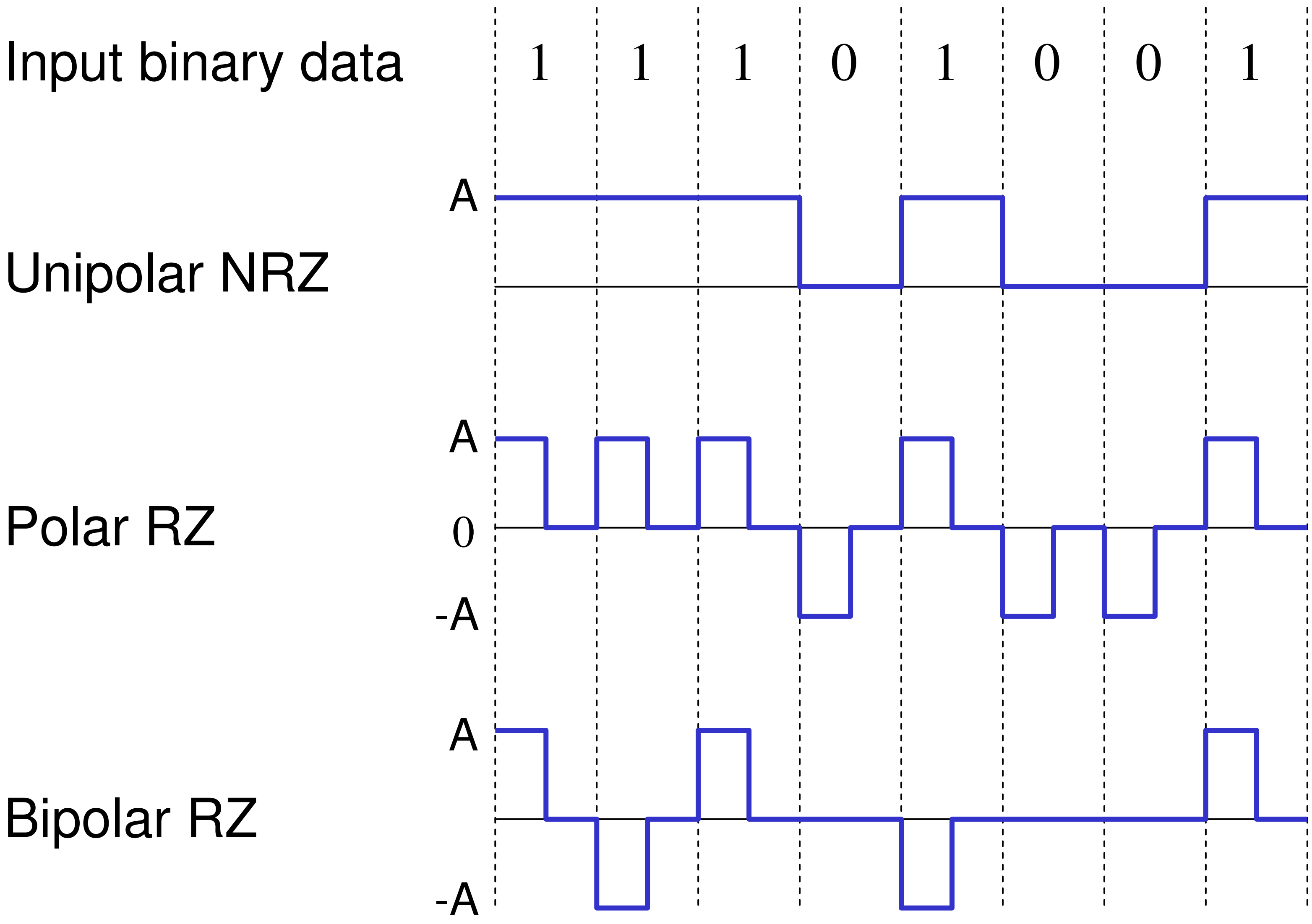
- Accurate timing information is necessary for the synchronisation of the sampling and recovery processes at the transmitter and receiver.
- Certain line codes contain a spectral component at the clock frequency that can be used for clock extraction.
- The clock signal component may be extracted using a resonant LC circuit or a PLL.

# *Line Coding*

- The resonant LC circuit is tuned to the clock frequency.
- The “fly-wheel” effect fills in the gap left by the zero bits.
- The tuned LC circuit has a low Q factor (30-100) which does not give good noise suppression.
- However, its wide bandwidth means that it is relatively intolerant to small changes in the timing of the received signal (known as *jitter*).
- On the other hand, the PLL has a high Q factor (1000-10,000) which offers good noise reduction but is no longer so tolerant to jitter.

# *Line Coding*

- In some systems, timing extraction is achieved by detecting the zero crossing points.
- Here the signal is filtered and then squared using a rectifier.
- For example, the bipolar RZ line code does not contain a spectral component at the clock frequency. However, it may be converted to a unipolar RZ line code by squaring (using a rectifier).
- The unipolar line code contains a spectral component at the clock frequency which may be extracted using a LC circuit or PLL.


Input binary data
1
1
1
0
1
0
0
1
A
Unipolar NRZ
A
Polar RZ
0
-A
A
Bipolar RZ
-A