UESTC 3018 - Communication Systems and Principles

Lecture 18 — From Bits to Symbols, Baseband to Passband

Dr Hasan Abbas

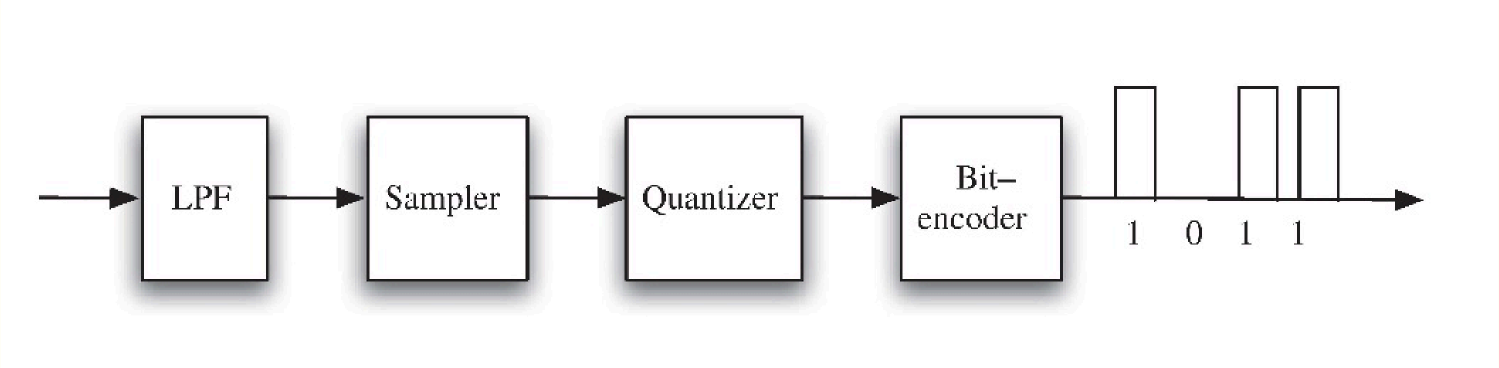
Hasan.abbas@glasgow.ac.uk

From Last Time ⌛

- Quantisation

Today's Lecture 📆

- Line Coding
- Pulse Code Modulation
- Delta Modulation
- Inter-Symbol Interference



Baseband Transmission

Encoding & Line Coding

- We have a logical sequence: `1 0 1 1 0`.
- A wire (medium) doesn't understand (digital) logic; it only understands **voltage**.

Line Coding is the mapping of logical bits to physical waveforms.

Key Design Goals

1. Synchronisation The receiver needs to recover the clock.
2. **Bandwidth Efficiency:** Fit more data in less Hz.
3. **DC Balance:** Ideally zero DC (transformers block DC).

Line Coding Schemes (RZ)

Scheme	Signal Levels	Features
On-Off (RZ)	$V, 0$	High V for half bit, then 0. Simple, clear transitions, requires more bandwidth.
Polar (RZ)	$+V, 0, -V$	$+V$ for half bit (1), $-V$ for half bit (0). Eliminates DC component, good synchronisation.
Bipolar (RZ)	$+V, 0, -V$	Alternates between $+V$ and $-V$ for 1s. No DC component, good error detection.

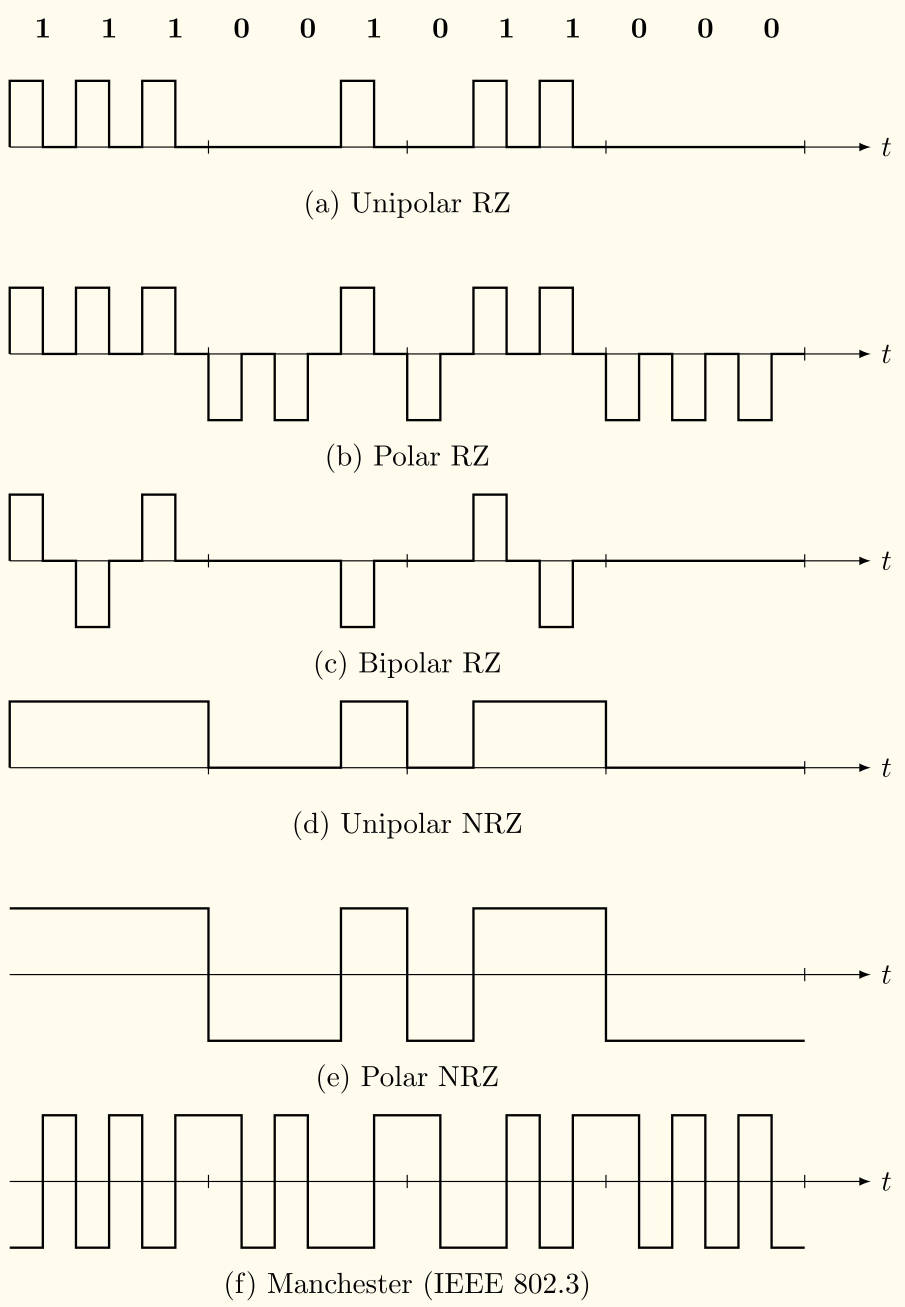
Common Line Codes

1. NRZ (Non-Return to Zero)

- `1` = $+V$, `0` = $-V$.
- 🙂 Simple, low bandwidth.
- 🙁 Long strings of 1s cause loss of sync (DC buildup).

2. Manchester Encoding

- `1` = High $\longrightarrow$ Low; `0` = Low $\longrightarrow$ High.
- 🙂Guaranteed transition every bit (Great Sync).
- 🙁 Uses **2x Bandwidth**.



The Bandwidth of Line Codes

To understand bandwidth, we look at the **Power Spectral Density (PSD)**. This depends on two things:

1. The Shape of the Pulse ($P(f)$):

- A sharp square pulse has a wide frequency spread.

2. The Pattern of the Bits (R_k):

- Do 1s and 0s follow a pattern, or are they random?

$$S(f) = \underbrace{\frac{1}{T_b} |P(f)|^2}_{\text{Shape}} \times \underbrace{\sum R_k e^{-j\cdots}}_{\text{Pattern}}$$

For Random Data ...

In real data (compressed audio/video), bits are random (like coin flips).

1. No Patterns ($R_k = 0$):

- Knowing bit N tells us nothing about bit $N + 1$.
- Because there is no pattern, the complex sum $\sum(\dots)$ vanishes!

1. Average Power ($\sigma^2 \to A^2$):

- For a signal swinging between $+A$ and $-A$, the "Variance" is just the amplitude squared.
- Variance = Power = A^2.

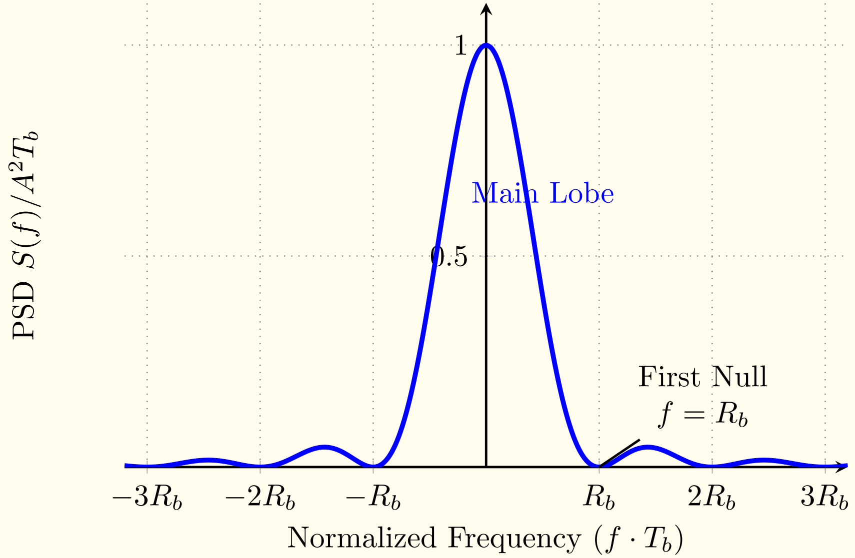
Derivation: NRZ Bandwidth

For NRZ, we use a rectangular pulse.

- Pulse Shape: $P(f) = T_b \text{sinc}(fT_b)$
- Pattern: Random ($R_k = 0$, sum disappears).

The PSD becomes just the Pulse Shape squared $\times$ Power:

$$S_{NRZ}(f) = A^2 T_b \text{sinc}^2(fT_b)$$



Observation

- The first null is at $f = R_b$.
- Most power is packed in the low frequencies

Manchester Bandwidth

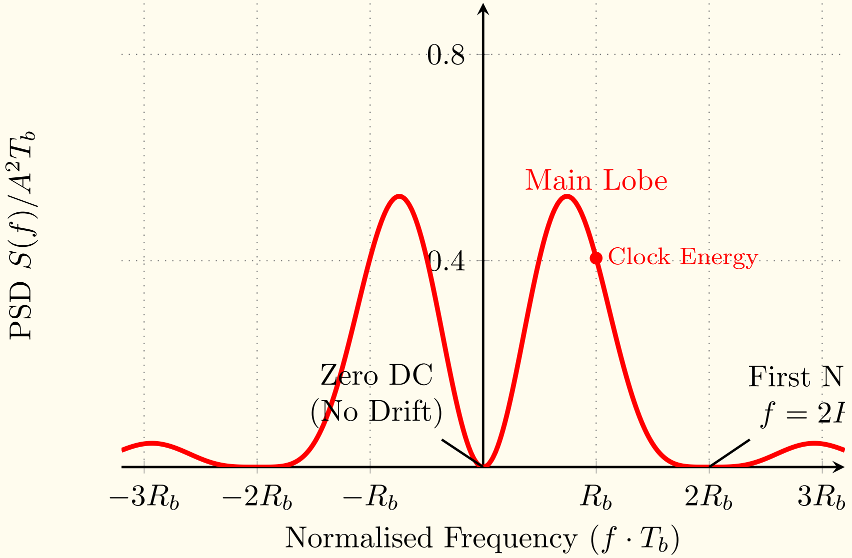
Manchester uses a "split" pulse ($+V$ then $-V$).

$$P(f) = T_b \text{sinc}\left(\frac{fT_b}{2}\right) \sin\left(\frac{\pi f T_b}{2}\right)$$

$$S_{Manc}(f) = A^2 T_b \text{sinc}^2\left(\frac{fT_b}{2}\right) \sin^2\left(\frac{\pi f T_b}{2}\right)$$

Observation

1. $\sin(0) = 0 \rightarrow$ **Zero DC**.
2. The null is pushed to $f = 2/T_b = 2R_b$.
3. Manchester requires **2x Bandwidth**.



Pulse Code Modulation (PCM)

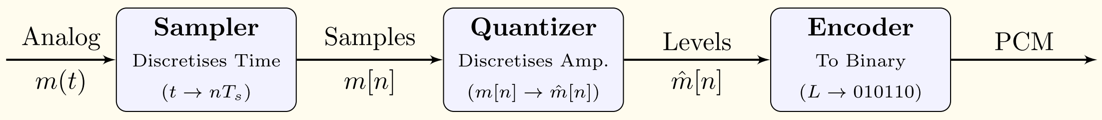
PCM is the standard for uncompressed digital audio (CDs etc).

- Bit Rate (R_b):

$$R_b = n \times f_s$$

- Dynamic Range (SQNR):

$$\text{SQNR}_{dB} \approx 4.8 + 6n$$



PCM Bandwidth

Digital signals require significantly more bandwidth than the original analog signal.

- Analog Voice: 4 kHz.
- PCM Voice (8 bits, 8 kHz): 64 kbps.
- Minimum Transmission Bandwidth:

$$BW_{PCM} \geq \frac{1}{2} R_b = \frac{1}{2} n f_s$$

We trade Bandwidth for Noise Immunity and Regenerability.

Delta Modulation (DM)

PCM sends the *absolute* value of every sample.

- 💡 Adjacent samples are usually similar (high correlation). Why send the whole value?
- Only transmit the change (slope) from the last sample.
- 1 bit per sample:
- `1` : Signal went UP ($+\Delta$).
- `0` : Signal went DOWN ($-\Delta$).
- Extremely simple hardware (1-bit ADC).

Inter-Symbol Interference (ISI)

Real channels act like Low Pass Filters. They "smear" pulses.

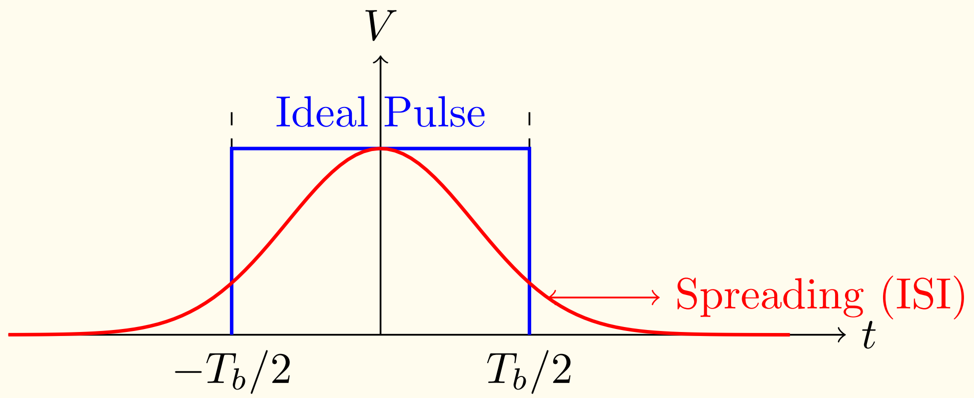
- The "tail" of one pulse spills into the next time slot.
- This is **ISI**. It ruins our ability to distinguish `1` from `0`.

Ideal Pulse:

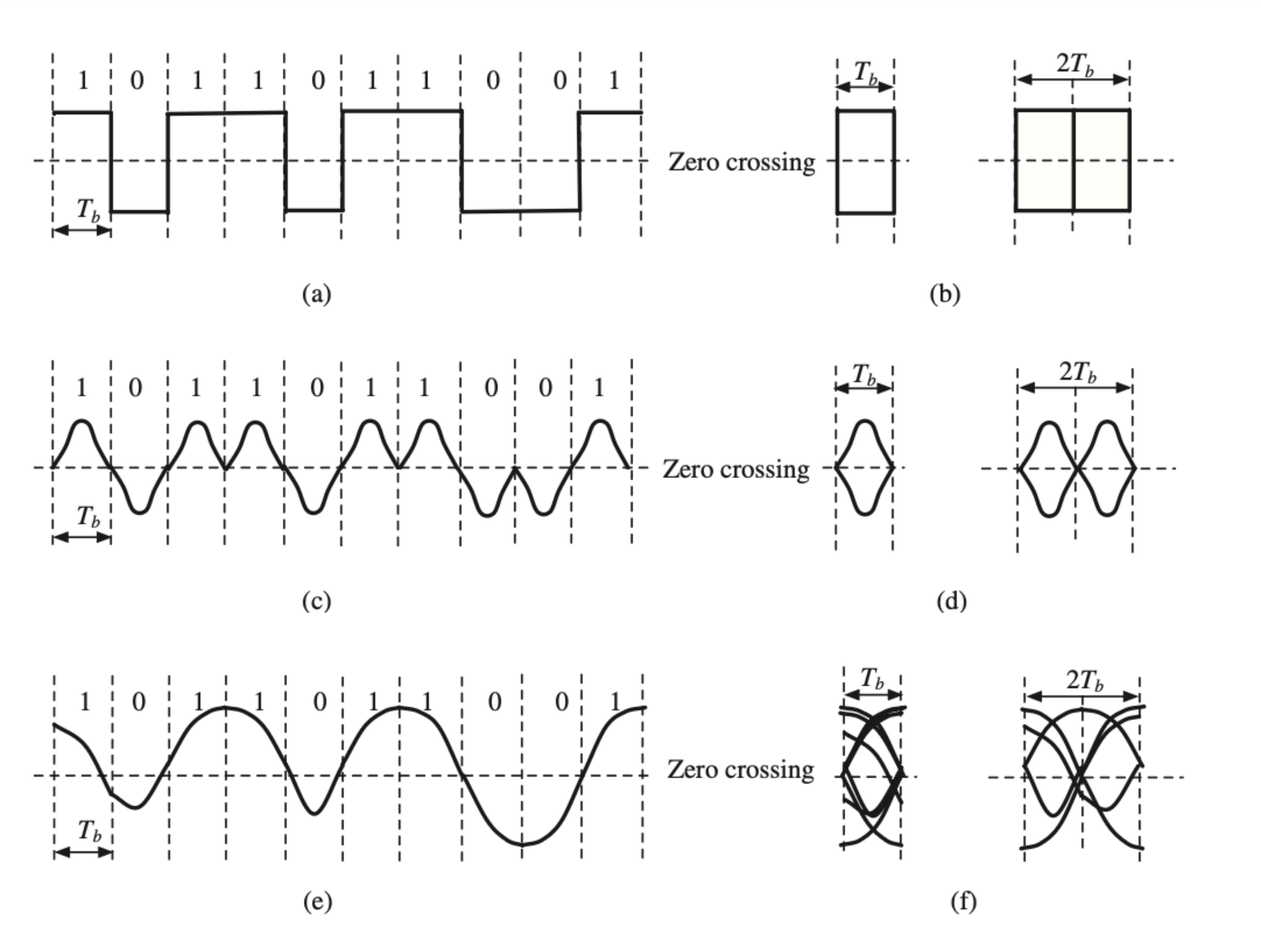
Square (Requires ∞ Bandwidth).

Real Pulse:

Rounded and spread out.



The Eye Diagram



Visualising ISI: The Eye Diagram

If we overlay thousands of received bit periods on an oscilloscope, we get an **Eye Diagram**.

- Vertical Opening (Height): Noise Margin. How much noise can we tolerate?
- Horizontal Opening (Width): Jitter Margin. How sensitive is the timing?
- Closed Eye: The system has failed. ISI is dominant.

The Nyquist Criterion

How do we eliminate ISI without infinite bandwidth?

Nyquist's First Criterion:

Find a pulse $p(t)$ such that $p(nT_b) = 0$ for all $n \neq 0$.

The Sinc Pulse:

$$p(t) = \operatorname{sinc}\left(\frac{t}{T_b}\right)$$

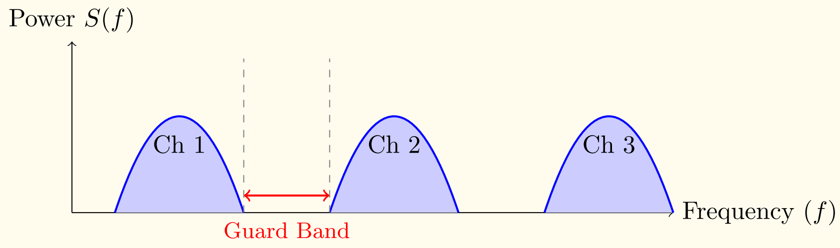
- Bandwidth $= R_b/2$ (Minimum possible).
- Hard to generate, sensitive to timing errors.
- Raised Cosine Filter (Trade a little bandwidth for robustness).

The Guard Band

Nyquist says we *can* transmit at $B = R_b/2$.

- We cannot build perfect "Brick Wall" filters to separate these signals.
- Real filters have a gradual "roll-off" (slope).
- If we pack channels too tightly, their "tails" overlap.
- Adjacent Channel Interference (ACI).

We deliberately leave unused spectrum between channels.



Further Reading

- Sections 6.1 - 6.3, and 6.6
  Modern Digital and Analog Communication Systems, 5^{th} Edition
- B P Lathi and Zhi Ding

Get in touch

Hasan.Abbas@glasgow.ac.uk