	Bit Rate =	Coding Rate *	Baud Rate
Channel Bandwidth	✓		✓
Pulse Shape	✓	✓	✓
SNR	✓	✓	

↑ transmission power
distance
noise

max Bit rate
(AWGN)
= Shannon capacity

ISI ; distortion
max Baud rate
= Nyquist Rate

Line Coding

① Unipolar NRZ (Non Return to Zero)

2 signal formats : $\begin{cases} +A \\ 0 \end{cases}$

$\begin{cases} \text{"1"} : +A \\ \text{"0"} : 0 \end{cases}$

② Polar NRZ

2 signal formats : $\begin{cases} +\frac{A}{2} \\ -\frac{A}{2} \end{cases}$

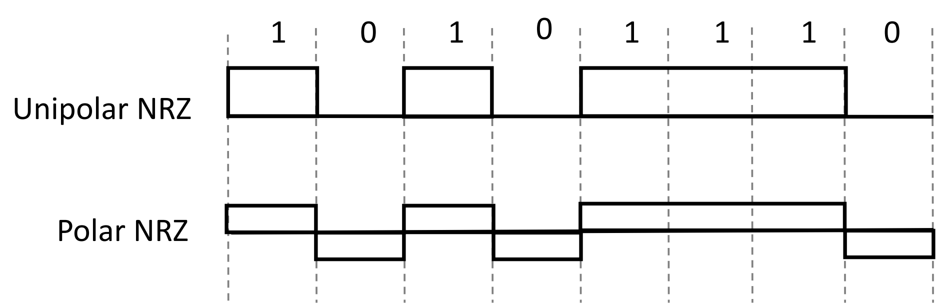
$\begin{cases} \text{"1"} : +\frac{A}{2} \\ \text{"0"} : -\frac{A}{2} \end{cases}$

What is Line Coding?

- One method to convert a binary information sequence into signals that enter the communication channel
  - E.g., “1” maps to +A square pulse; “0” to –A square pulse

- Design considerations:
  - Timing recovery * boundries between signals/bits
  - Low complexity and implementation cost
  - Low power and energy efficient
  - Better immunity to noise and interference
  - Built-in error detecting capability

Unipolar & Polar Non-Return-to-Zero (NRZ) Coding



Unipolar NRZ

- “1” maps to +A pulse
- “0” maps to no pulse
- Average Power: High
  $0.5*A^2 + 0.5*0^2 = A^2/2$
- Long string of “1”s or “0”s
  - Poor timing
- Simple

Polar NRZ

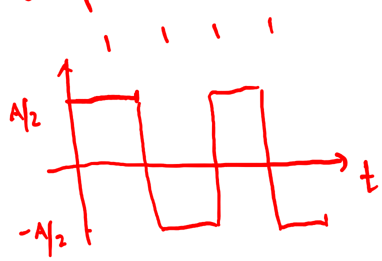
- “1” maps to +A/2 pulse
- “0” maps to –A/2 pulse
- Average Power: Lower
  $0.5*(A/2)^2 + 0.5*(-A/2)^2 = A^2/4$
- Long string of “1”s or “0”s
  - Poor timing
- Simple

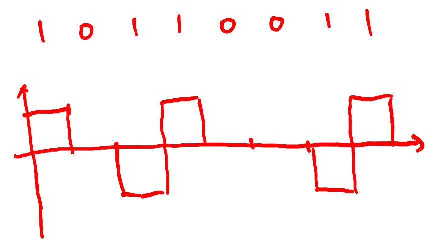
③ Bipolar

- 3 signal formats : $\begin{cases} +A/2 \\ 0 \\ -A/2 \end{cases}$

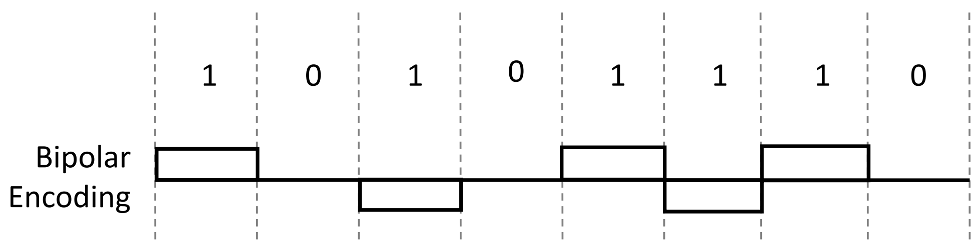
- $\begin{cases} \text{"1"}: \text{ map to } +A/2 \text{ or } -A/2 \text{ in alternation} \\ \text{"0"}: \text{ no pulse} \end{cases}$

Example:



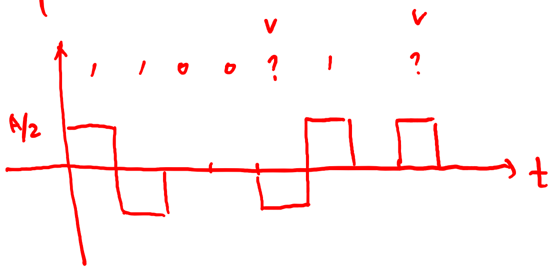


Bipolar Coding



- Three signal formats: {–A/2, 0, +A/2}
- "1" maps to +A/2 or –A/2 in alternation
- "0" maps to no pulse
  - Every + pulse matched by – pulse
- String of "1"s produces a square wave
  - Spectrum centered at 1/(2T)
- Long string of "0"s causes receiver to lose synch
- Zero-substitution codes

Example:



"Bipolar Violation"

- error detection
- "zero substitution"

B8ZS

Bipolar with
8
Zeros
Substitution

0 0 0 0 0 0 0 0

⇓

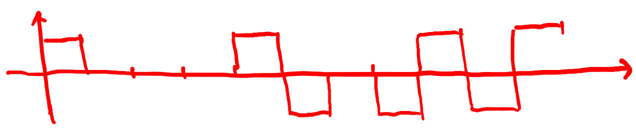
0 0 0 V 1 0 V 1

North American
T1 system
(1.544 Mbps)

Example:

1 (0 0 0 0 0 0 0 0) 1 1

0 0 0 V 1 0 V 1



B6ZS

0 0 0 0 0 0

⇓

0 V 1 0 V 1

B3ZS

0 0 0

⇓

0 0 V or 1 0 V

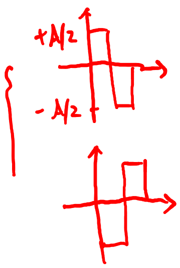
T2 system
6.312 Mbps

T3 system
44.716 Mbps

RZ Coding

④ Manchester Coding

- 2 signal formats :

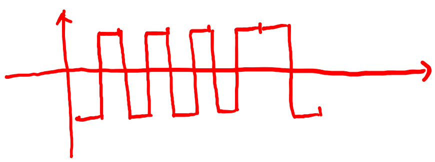


: "1"

: "0"

$$\text{Coding rate} = \frac{1 \text{ bits}}{2 \text{ pulses}}$$

E.g. 0 0 0 0 1



"self-clocking"

bit rate = coding rate * Baud rate

10 Mbps $\qquad \downarrow \frac{1}{2} \qquad$ 20 MHz

$\Rightarrow$ used in bandwidth-rich system such as Ethernet

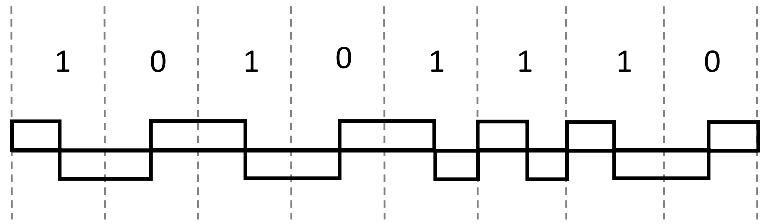
$\underbrace{1B}_{\text{1 Binary Bit}}\ \underbrace{2B}_{\text{2 Binary Pulses}}$ coding = Manchester

$\Rightarrow$ mBnB $\qquad$ Coding Rate $= \frac{m}{n} \le 1$

$2^m \le 2^n \Rightarrow m \le n$

Manchester Coding & *m*B*n*B Coding

Manchester Encoding



Manchester

- "1" maps to A/2 first T/2, -A/2 last T/2
- "0" maps to –A/2 first T/2, A/2 last T/2
- Every interval has transition in middle
  - Easy timing recovery
  - Double the minimum bandwidth
- Simple to implement
- Used in 10 Mbps Ethernet & other LAN systems

*m*B*n*B

- Maps block of *m* information bits into *n* pulses
- Manchester code is *1*B*2*B code
- *4*B*5*B code is used in 100 Mbps Ethernet
- *8*B*10*B code is used in Gigabit Ethernet
- *64*B*66*B code is used in 10 Gbps Ethernet

5

mBnL

$\downarrow$ m Binary Bits

$\downarrow$ n pulses

L: level of pulses
- B: Binary (2)
- T: Ternary (3)
- Q: Quaternary (4)

Coding rate = $\frac{m}{n}$

$2^m \le L^n$

E.g. 2B1Q

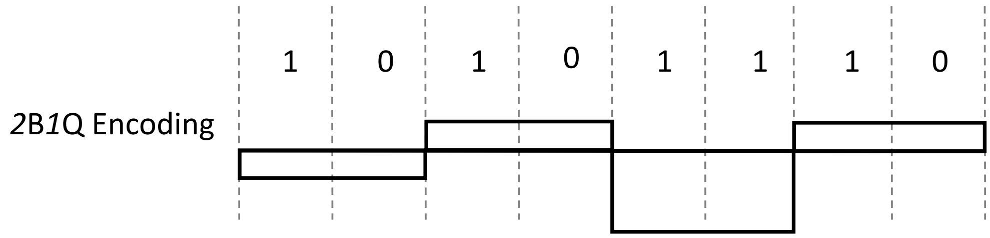
coding rate = 2

used in DSL system

4B3T

$2^4 = 16 < 27 = 3^3$

2B*1*Q Coding* & *m*B*n*L Coding



2B*1*Q

	Previous level: positive	Previous level: negative
Next bits	Next level	Next level
“00”	+A/2	-A/2
“01”	+3A/2	-3A/2
“10”	-A/2	+A/2
“11”	-3A/2	+3A/2

*m*B*n*L

- Maps block of *m* information bits into *n* pulses
- There is a total of L different levels of pulses

** This version of 2B1Q coding is based on “Data Communications and Networking” by Behrouz A. Forouzan.*