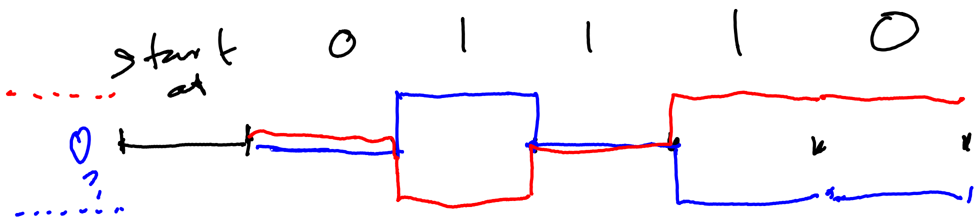
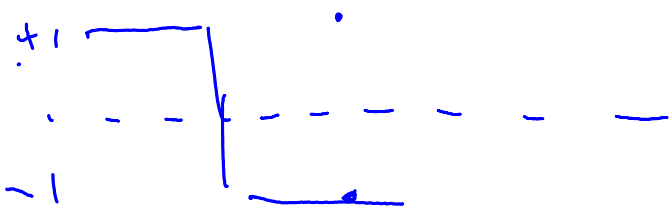
Line Codes

Exercise 1: How would the bit sequence 0110 be encoded using 4B5B followed by MLT3 assuming the starting level is 0V?

0110 → 01110 (4B5B)

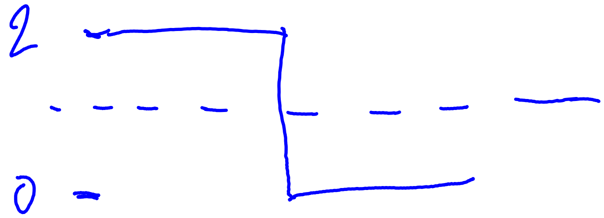


Exercise 2: What noise level is required to cause an error when using a bipolar line code with levels of ±1 V? What are the voltage levels for a unipolar line code with the same noise margin? What are the RMS voltages of these two line codes when transmitting a dotting sequence (alternating 1's and 0's)? Why might you use unipolar line codes anyways?



noise margin = 1V

rms voltage $= P(-1)(-1)^2 + P(1)(1)^2 = 0.5 \cdot 1 + 0.5 \cdot 1 = 1 V_{rms}$

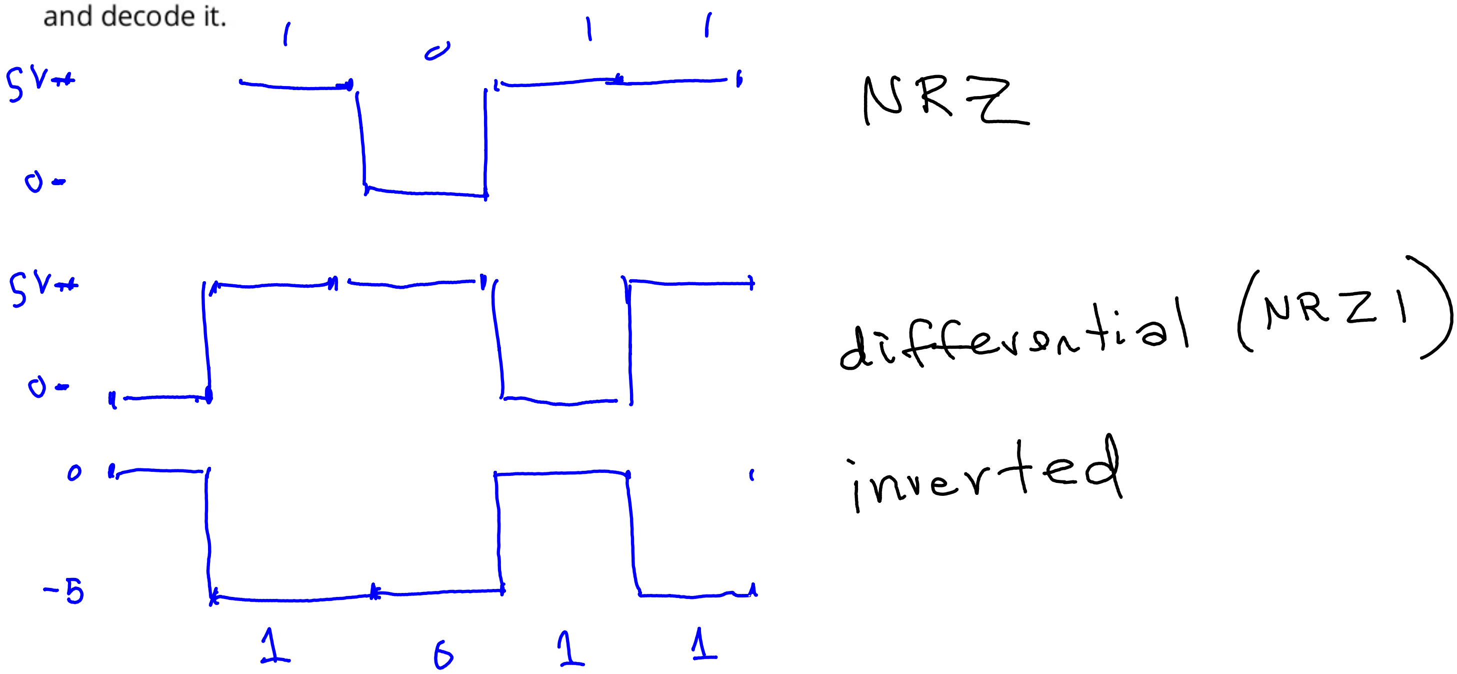


noise margin = 1V

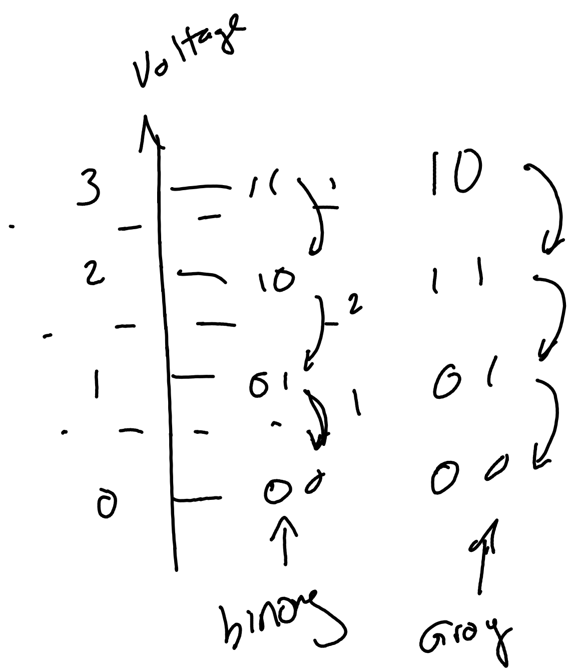
rms voltage $= 0.5(2)^2 + 0.5(0)^2 = 2 + 0 = 2 V_{rms}$

– unipolar codes are simpler to implement even though they are less power-efficient.

Exercise 3: Assume a 1 is transmitted as 5V and 0 as 0V. Draw the waveform for the bit sequence 1011. Draw the waveform if the bits are transmitted differentially with a 1 encoded as a change in level. Assume the initial value of the waveform is 0. Invert the waveform and decode it.



Exercise 4: Show the binary and Gray-coded encodings for PAM4. What is the average number of bits in error if the only errors are between adjacent levels?



average # bits in error =

$$\sum_i P_i X_i$$

assume $P_i = \frac{1}{3}$ (all errors are equally likely).

$$= \frac{1}{3}\cdot 1 + \frac{1}{3}\cdot 1 + \frac{1}{3}\cdot 1 = 1$$

for binary: $\frac{1}{3}\cdot 1 + \frac{1}{3}\cdot 2 + \frac{1}{3}\cdot 1 = \frac{4}{3} = 1.33$

Exercise 5: A link operates at 100 Mb/s. What is the bit period? The transmitter and receiver have independent clocks (oscillators) with accuracies of 100ppm. What is the maximum difference between the two clock periods in ppm? In seconds?

$f = 100 \times 10^6 = 10^8$ Hz $\quad T = 10^{-8}$ s (10ns).

largest difference $= -100 - 100 = 200$ ppm.
$= 200 \times 10^{-6}$

Tx $\qquad$ Rx

$10\text{ns} - 10\text{ns} \cdot 200 \times 10^{-6} \qquad 10 + 10 \cdot 200 \times 10^{-6}$

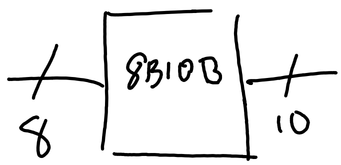
difference $= -20\text{ns} \cdot 200 \cdot 10^{-6}$
$= 20 \times 10^{-9} \cdot 200 \cdot 10^{-6}$
$= 4000 \times 10^{-15}$
$= 4 \times 10^{-12} = 4$ ps / bit.

Exercise 6: How many combinations are there of 3 bits? Of 4 bits? How many bits might be input and output by an 8B10B code? What might a 4B3T code mean?

$2^3 = 8$ combinations of 3 bits

$2^4 = 16$ " 4 bits.

8B10B



0000	LLL ?
0001	LLO
0010	LLH
⋮	⋮
1111	HHH ?

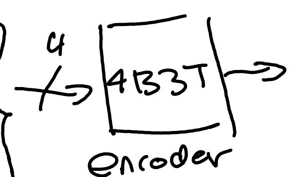
H
O
L

4B3T

4 binary in — 3 ternary out

input

$2^4 = 16$ possible inputs



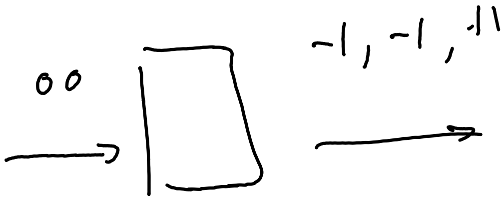
output

$3 \times 3 \times 3 = 3^3 = 27$ possible outputs (but only 16 of these are used).

Exercise 7: Design your own 2B3B line code by choosing the output waveforms that have the lowest average DC value and giving preference to those that start and end at different levels (assume bipolar signalling).

in	out
0 0	− − +
0 1	− + +
1 0	+ − −
1 1	+ + −

	Voltagen	AVG VOLTA	
0 0 0	−1, −1, −1	−3	✓
0 0 1	−1, −1 +, 1	−1	X
0 1 0	− + −	−1	✓
0 1 1	− + +	+1	✓
1 0 0	+ − −	−1	X
1 0 1	+ − +	+1	✓
1 1 0	+ + −	+1	
1 1 1	+ + +	+3	



Exercise 8: What (minimum) delay does a B8ZS encoder add? Receiver? Why is there a zero between successive same-polarity pulses?

(not covered.)