1. A transmitter capable of operating at 2.3 Mbps sends a frame consisting of 2200 bytes down a 500-km

$R = 2.3 \times 10^6 \quad L = 8 \times 2200$

$\frac{L}{R} = 7.65 \times 10^{-3}\,s \qquad \frac{d}{c} = t_{delay} = \frac{500 \times 10^3}{2 \times 10^8} = 2.5 \times 10^{-3}\,s$

total delay $= \frac{L}{R} + \frac{d}{c} = 10.15 \times 10^{-3}\,s = 10.15\,ms$

2. A three-color display using 10-bits per color per pixel is to be sent at a frame-rate of 48-FPS (frames

\# of bits in frame $= 1920 \times 1080 \times 3 \times 10 = 62.2 \times 10^6$ bits

\# of bits per sec. $= R = 62.2 \times 10^6 \times 48 = 2.968 \times 10^9$ bps

PCM rate is 64 kbps (8×8000)

$\frac{2.968 \times 10^9}{64 \times 10^3} = 46{,}656$ ← amount by which you would have to compress your signal

3. The signal-to-noise ratio achievable through a channel is 37 dB. What is the minimum channel bandwidth

$SNR = 10^{\frac{SNR\,dB}{10}} = 10^{\frac{37}{10}} = 5011$

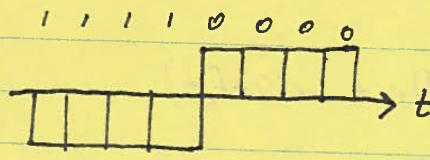
$C = W_c \log_2(1 + SNR)$

$6 \times 10^6 = W_c \log_2(5012) = W_c \cdot 12.3$

$\therefore W_c = 486.5\,kHz = 0.486\,MHz$

4. Problem 3.32

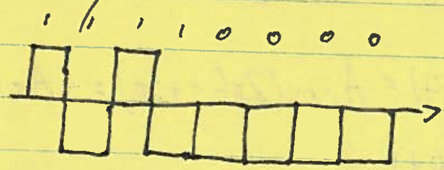
a)



NRZ

• small number of transitions to help synchronizer with recovery

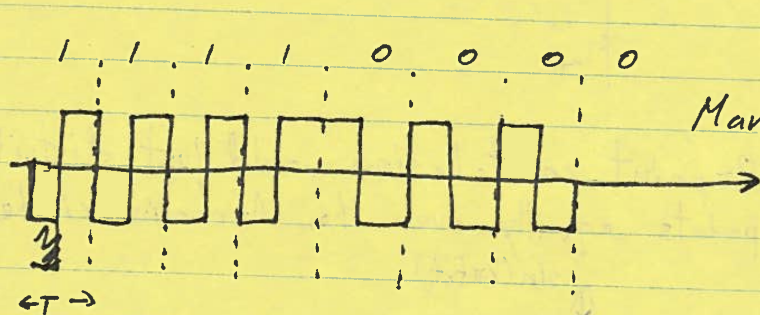
b)



Differential

1 sequence induces transitions, that help with synch, but sequence of 0's still prevents transitions

c)



Manchester

every -T second interval now possesses a transition

but bandwidth of signal is doubles since pulses are now only half as wide, T/2

5. A clever PAM scheme

$\log_2 6 = 2.59$ bits

$2.59 \times 2 \times W_c$

$= 2.59 \times 160 \times 10^6 = 415$ Mbps

6. Constellation size needs

7-MHz can fit 7 Mbps using a simple (1-D) bandpass scheme to get to 30 Mbps need to send at least $\frac{30}{7} = 4.28 \Rightarrow 5$ bits per pulse

$\therefore$ I need a $2^5 =$ 32 point constellation

7. Problem 3.36

(not baseband)

a) 6-MHz **bandpass** normally has

$R = 6 \times 10^6$ bps (not $2 \times 6 \times 10^6$ bps)

- however 4 point QAM effectively sends 2-bits per pulse

$\therefore R|_{4\text{-QAM}} = 12$ Mbps

- an 8-point constellation effectively sends $\log_2 8 = 3$ bits per pulse so

$R|_{8\text{-QAM}} = 18$ Mbps

b) for a 4 Mbps signal

$\frac{12}{4} = 3$ channels can be accommodated with 4-QAM

$\lfloor \frac{18}{4} \rfloor = 4$ channel can be accommodated with 8-QAM

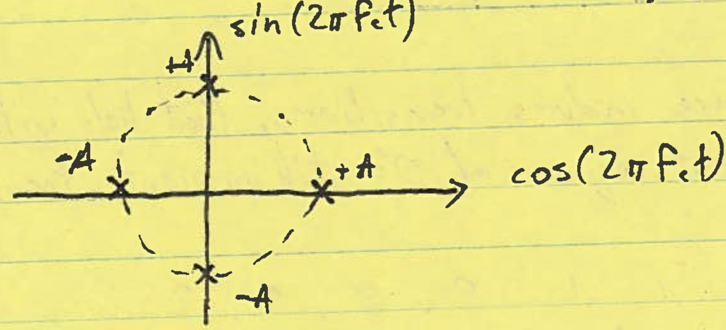
8. Problem 3.39

a) for 00 $\phi = 0 \Rightarrow x(t) = A\cos(2\pi f_c t)$

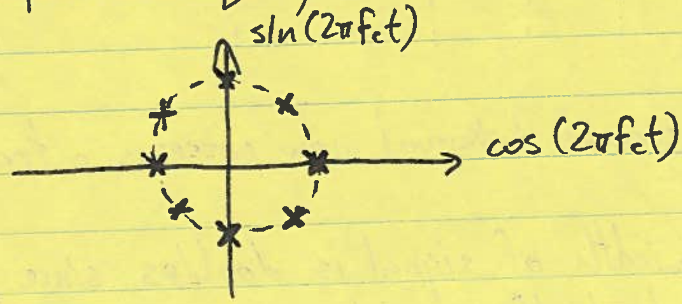
01 $\phi = \pi/2 \Rightarrow x(t) = A\cos(2\pi f_c t + \frac{\pi}{2}) = +A\sin(2\pi f_c t)$

10 $\phi = \pi \Rightarrow x(t) = A\cos(2\pi f_c t + \pi) = -A\cos(2\pi f_c t$

11 $\phi = \frac{3\pi}{2} \Rightarrow x(t) = A\cos(2\pi f_c t + \frac{3\pi}{2}) = -A\sin(2\pi f_c t)$



b) an 8-point constellation would just distribute the points equally over the A-radius circle



9. Problem 3.40

transmitted QAM is

$$y(t) = A_k \cos(2\pi f_c t) + B_k \sin(2\pi f_c t)$$

$$\hookrightarrow \otimes \longrightarrow = A_k\{\cos(\phi) + \cos(4\pi f_c t + \phi)\} + B_k\{-\sin\phi + \sin(4\pi f_c t + \phi$$

$\uparrow$ $2\cos(2\pi f_c t + \phi)$

removed by ensuing LPF leaving...

$$\ldots A_k \cos(\phi) + B_k \cdot (-\sin\phi)$$

if ϕ "small" $\cos\phi \approx 1$, $\sin\phi \approx 0$ & everything is ok

- but as ϕ increases A_k becomes corrupted by B_k.
- same idea for $-\otimes-$ with $2\sin(2\pi f_c t + \phi)$
- the unit that takes care of such a problem is called the phase synchronizer

10. Problem 3.43

$$\frac{20\text{ dB}}{0.7\text{km/dB}} = 28\text{ km}$$

11. Problem 3.55

- signal gets attenuated by a factor of d^2
- referenced relative to the loss experienced over a meter the loss in dB is

$$10 \times \log_{10}\left(\frac{36\times10^7\text{m}}{1\text{m}}\right)^2 = 20\log_{10}(36\times10^7) = 151\text{dB}$$

12. Problem 3.56

'1' = 111

'0' = 000

if 2 or more bits are in error the receiver makes an error

p : probability that a bit is in error

1) Prob that 2 bits out of 3 are flipped

$$P[2] = \underbrace{\binom{3}{2}}_{\text{how many unique choices of 2-bits are there within a 3-bit sequence}} \underbrace{p^2(1-p)^{3-2}}_{\text{for some choice of 2-bits within a 3-bit sequence what's the probability that the 2 bits flipped}}$$

$$= \frac{3!}{2!(3-2)!}\, p^2(1-p) = \frac{6}{2}p^2(1-p) = 3p^2(1-p)$$

2) Prob that 3 bits out of 3 are flipped

$$P[3] = \binom{3}{3}p^3(1-p)^{3-3} = p^3$$

$\therefore$ $P_{error} = 3p^2(1-p) + p^3 \approx 3\times10^{-6}$ for $p = 10^{-3}$

13. Problem 3.57

a) valid codewords

11000	01010
10100	01001
10010	00110
10001	00101
01100	00011

b) 10 possible codewords ∴ 3-bits per codeword can be transmitted if 8 codewords are used

c) each received codeword should have exactly 2 1's & 3 0's to be valid

d) a valid codeword can be changed into another valid codeword by changing a 1 to a 0 AND a 0 to a 1. Thus, two bit errors can cause a detection failure

14. Problem 3.58

b) if one 1 & one 0 of the 10 legal combinations are flipped you'll get an error

↳ there are 6 different ways this can happen

if two 1's & two 0's of the 10 legal combinations are flipped you'll get an error

↳ there are 3 different ways this can happen

$\therefore$

$$P_{error} = 6p^2(1-p)^{5-2} + 3p^4(1-p)^{5-4}$$

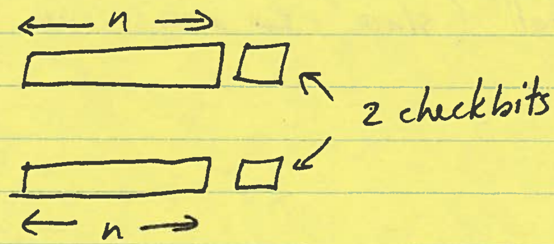
$$= 6p^2(1-p)^3 + 3p^4(1-p)$$

a.) random error vector channel

- for a 5-bit symbol an error vector could generate one of 32 new symbols
- but in our code only 10 legal codewords exist thus no more than 10 of the 32 possible error vectors could lead to detection failure
- ~~since~~ further taking out the all zero's error vector that "converts" the codeword to itself we have a probability of error of $\frac{9}{32}$

15. Problem 3.59

a)



effectively 2 codewords
each codeword is n+1 bits long

- error detectable if each codeword has odd # of errors

b) Can think of the net 2n+2 bit codeword as 2 n+1 bit (sub-codewords)

- let P_d be the probability that ~~either of the~~ a sub-codeword can detect an error

  (this is just the probability that a single parity code word can detect an error)

- then the probability of both sub-codewords failing to detect an error is

  $1 - P_d \cdot P_d$

16. SW ARQ

an out-of-sequence frame at the receiver in SW can only be one with a sequence number of $R_{next}-1$ (R_{next} being the receiver's currently expected frame sequence number)

the arrival of such a frame at ~~Rx~~ the receiver is an obvious indication that the transmitter did not receive an ACK for $R_{next}-1$, $\therefore$ the receiver has to respond with R_{next} implicitly acknowledging the receipt of $R_{next}-1$ and thus prompting the tx to send a frame with sequence R_{next}

17. SW ARQ and errors

a) $1\,MB = 8 \times 2^{20}$ bits must be sent

with bit error rate of $p = 10^{-6}$, probability of not a ~~sig~~ single bit error in the file is

$$(1-p)^n = (1-10^{-6})^{8\times 2^{20}} = 2.27\times 10^{-4}$$

b) $(1-p)^{\frac{8\times 2^{20}}{80}} = 0.9005$ chance of frame being error free

$\therefore$ 10% chance of frame being in error

c) • find the efficiency of this transmission scheme, then use this to calculate the total transmission time

• the file is broken up into 80 frames

$\therefore$ there are $\frac{2^{20}}{80} = 13{,}107$ bytes per frame

or 1.0486×10^5 bits/frame

• 20 bytes $= 8\times 20 = 160$ bits are overhead ~~AND~~ in the transmitted frame * ACK size

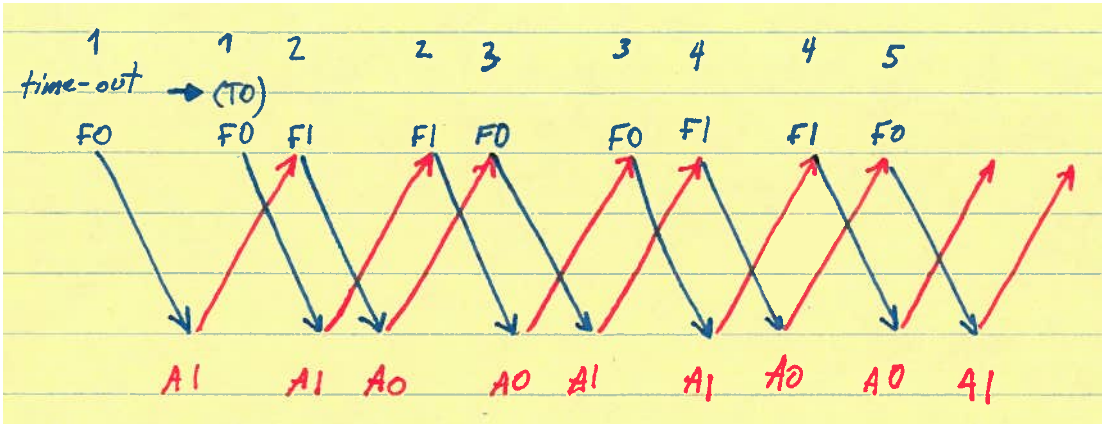
• probability of error-free frame is

$$(1-P_f) = (1-p)^{n_f} = (1-10^{-6})^{(1.0486\times10^5 + 160)} = 0.9003$$

$$\eta = \frac{1-\frac{n_o}{n_f}}{1+\frac{n_a}{n_f}+\frac{2(t_{prop}+t_{proc})R}{n_f}}(1-P_f) \approx (1-P_f) \approx 0.9$$

$\therefore$ total time $= (8\times 2^{20})/10^6 / 0.9 = 9.32$ seconds

18. SW ARQ with fast timeout



note: only one time-out

19. SW and GBN ARQ

b) $$\eta_{GBN} = \frac{1 - n_a/n_f}{1 + (W_s - 1)P_f}(1 - P_f)$$

* a 3-bit sequence implies a max window of $2^3 - 1 = 7$

$$\eta_{GBN} \approx \frac{1}{1 + (7-1)P_f}(1 - P_f) = 0.3859$$

a)
$$\eta = \frac{1 - \frac{n_a}{n_f}}{1 + \frac{n_a}{n_f} + \frac{2(t_{prop} + t_{proc})R}{n_f}}(1 - P_f)$$

$$= \frac{1}{1 + \frac{2(100\times 10^{-3})\cdot 56\times 10^3}{256\times 8}}(1 - 10^{-4})^{8\times 256}$$

$$\eta = 0.126$$

20. SR and GBN ARQ

$$\eta_{GBN} = \frac{1 - \frac{n_o}{n_f}}{1 + (W_s - 1)P_f}(1 - P_f)$$

$$W_s = \left\lfloor 1 + \frac{2t_{delay}R}{n_f} \right\rfloor = \left\lfloor 1 + \frac{2 \times 3 \times 10^6}{500} \right\rfloor = 12001$$

$$= \frac{1 - \frac{76}{500}}{1 + (1200)P_f}(1 - P_f) \qquad P_f = (1-p)^{500} = (1 - 10^{-5})^{500}$$

$$= 0.0139$$

$$\eta_{SR} = \left(1 - \frac{n_o}{n_f}\right)(1 - P_f)$$

$$= \left(1 - \frac{76}{500}\right)(1 - P_f) = 0.8438$$