ECE 440 – Spring 2018
Midterm 2

Instructor: Borja Peleato

Name:..

- Please fill in your name on the dotted line above.
- The exam is closed book and closed notes. You can have a simple scientific calculator without communication capabilities, but you should not need one. You are free to leave your answers in terms of any expression that could be computed with a scientific calculator (e.g., $\sin(\pi/5)$).
- There is a formula sheet at the back of the exam. Feel free to tear it off.
- You should be able to answer all the questions in the space provided, but you can use the blank pages at the back of the exam if you need additional space or scratch paper. However, make sure to include all calculations and explanations with your answer. If you need additional scratch paper, feel free to ask for it.
- You have 50 minutes to complete the exam. That should give you enough time to briefly justify your answers, please do so.

Q1	/20
Q2	/20
Q3	/20
Q4	/20
Q5	/20
Total	/100

Question 1: (20 points) A digital telephone system samples voice signals at 8000 samples per second, and quantizes each of them into seven binary digits.

(a) **(5 points)** How much noise, in terms of a percentage of the peak to peak value, does this quantization yield?

(b) **(5 points)** An additional signaling bit is added to each quantized sample, for synchronization purposes. What is the resulting bit rate for each phone call?

(c) **(5 points)** A T1 carrier consists of 24 calls multiplexed together in time. How much bandwidth do we need to transmit a T1 carrier if we are using a square pulse (BPSK) for each bit? Specify whether you are measuring peak-to-first-null or null-to-null bandwidth.

(c) **(5 points)** How much bandwidth would a T1 carrier require if we used QPSK instead?

Question 2: (20 points) Answer the following questions about inter-symbol-interference (ISI). Make sure to provide a brief justification for your answers. A simple "Yes" or "No" will not receive any partial credit.

(a) **(5 points)** Can ISI happen if we are transmitting a single signal through a cable, without interference from other signals?

(b) **(5 points)** Can ISI be eliminated by increasing the guardbands between signals multiplexed in frequency?

(c) **(5 points)** How does multi-path propagation relate to ISI?

(d) **(5 points)** Can ISI be completely eliminated? How? Propose at least two ways, just the high level idea, no need to provide equations.

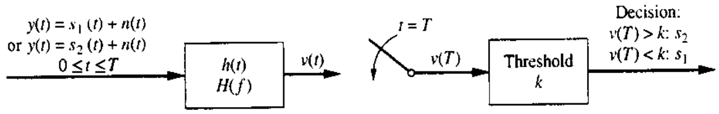
Question 3 (20 points) Under large input SNR conditions, the phase deviation of an angle modulated signal can be approximated as $\psi(t) = \phi(t) + \frac{n_s(t)}{A_c}$, where $\phi(t)$ is the phase deviation due to the signal and $n_s(t)$ is the quadrature noise component. Assume that the modulated signal amplitude is $A_c = 1$ and $n_s(t)$ has power spectral density $N_0 = 10^{-6}$ W/Hz over the whole band. Furthermore, assume that the message $m(t)$ has power 0.5 W and 1 kHz bandwidth (from -500 Hz to 500 Hz).

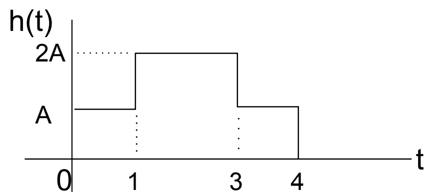
(a) **(5 points)** If we are using PM, with $\phi(t) = m(t)$, and the demodulator outputs $y_D(t) = \psi(t)$, what is the SNR after the post-detection filter?

(b) **(10 points)** If we are using FM, with $\phi(t) = \int m(\alpha)d\alpha$, and the discriminator outputs $y_D(t) = \frac{d}{dt}\psi(t)$, what is the SNR after the post-detection filter? [Hint: treat the discriminator as an LTI filter and look at the Fourier Transform theorems.]

(c) **(5 points)** If we narrow the post-detection filter to have a pass-band between -250 and 250 Hz, how would the SNR change in the PM case? How about in the FM case? Assume that the narrower filter is also affecting the signal, discarding half of its power.

Question 4 (20 points)





(a) **(5 points)** Is the filter $h(t)$ causal? How do you know?

(b) **(5 points)** Sketch two possible pulses to represent binary values 0 and 1, for which the above receiver would constitute a matched-filter receiver.

(c) **(5 points)** What would be the optimal decision threshold k_{opt} for the two pulses that you have proposed? Why?

(d) **(5 points)** What would be the optimal sampling time T?

Question 5: (20 points) For each scenario, state which of the suggested modulations you would use and **why it is more suitable than the other two**.

(a) **(5 points)** Fast moving receiver. Doppler effect causes (random) shifts between transmit and receive frequency. Obstacles can also randomly change receive power. Perfect synchronization. Pick between 16-PSK, 16-QAM or 16-FSK.

(b) **(5 points)** Static ad-hoc link. Unknown delays (phase offsets) and signal attenuation. Pick between 16-PSK, 16-QAM or 16-FSK.

(c) **(5 points)** Minimum BER link. We want to minimize the bit error rate under a constraint on the **maximum** transmit power per symbol. Pick between BPSK, QPSK or 4-PAM.

(d) **(5 points)** 16-channel TV Remote. We want to minimize symbol error rate under a constraint on the **average** transmit power. Pick between 16-PSK, 16-QAM, or 16-PAM.

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Formulas and notation:

- Trigonometric:
  - $\sin^2(x) + \cos^2(x) = 1$
  - $\sin(u+v) = \sin u \cos v + \cos u \sin v$
  - $\cos(u+v) = \cos u \cos v - \sin u \sin v$
  - $\sin(\alpha)\sin(\beta) = \frac{\cos(\alpha-\beta)-\cos(\alpha+\beta)}{2}$
  - $\cos(\alpha)\cos(\beta) = \frac{\cos(\alpha-\beta)+\cos(\alpha+\beta)}{2}$
  - $\sin(\alpha)\cos(\beta) = \frac{\sin(\beta+\alpha)-\sin(\beta-\alpha)}{2}$
- Functions:
  - Unit step: $u(t) = 0$ for $t < 0$, $u(t) = 1$ for $t > 0$.
  - Triangle: $\Lambda(t) = 1 - |t|$ for $|t| \leq 1$, $\Lambda(t) = 0$ otherwise
  - Square pulse: $\Pi(t) = 1$ for $|t| \leq 0.5$, $\Pi(t) = 0$ otherwise
  - $sinc(t) = \frac{sin(\pi t)}{\pi t}$
- Fourier transform pairs:
  - $\Pi(t) \leftrightarrow sinc(f)$
  - $\Lambda(t) \leftrightarrow sinc^2(f)$
  - $u(t) \leftrightarrow \frac{1}{j2\pi f} + \frac{\delta(f)}{2}$
  - $\frac{1}{\pi t} \leftrightarrow -jsign(f)$
  - $\sum_{n=-\infty}^{\infty} \delta(t - nT_s) \leftrightarrow f_s \sum_{n=-\infty}^{\infty} \delta(t - nf_s)$ where $f_s = \frac{1}{T_s}$.
- Fourier transform theorems:
  - $ax(t) + by(t) \leftrightarrow aX(f) + bY(f)$
  - $x(t - t_0) \leftrightarrow X(f)e^{-j2\pi f t_0}$
  - $x(-t) \leftrightarrow X(-f) = X * (f)$
  - $\frac{d^n}{dt^n} \leftrightarrow (j2\pi f)^n X(f)$
  - $x(t)\cos(2\pi f_0 t) \leftrightarrow \frac{1}{2}[X(f - f_0) + X(f + f_0)]$
  - $x(t)\sin(2\pi f_0 t) \leftrightarrow \frac{1}{2j}[X(f - f_0) - X(f + f_0)]$