ELEC 470 Communication and Information Systems Fall 2014

Final Exam General Information

The final exam will cover primarily the material listed in this review sheet. Please note, however, that this material draws heavily on the material presented earlier in the semester. You should therefore be very familiar with that material even though it will not be tested directly.

The exam format will be divided as follows:

20-30 pts	One take-home problem
70-80 pts	In-class problems with a total length of roughly 1 hour

See the "Course Outcomes" section of the Course Description page at the ELEC 470 web site for a detailed list of specific competencies that are likely to be assessed.

The in-class portion of the final exam will take place **8:00-11:00 am on Wednesday, December 17 in Dana 221** (our usual classroom during the semester). Although this portion will be designed to take approximately one hour to complete, you are expected to arrive at 8:00 am. You will have the full three hours to complete the exam. The take-home portion of the exam will be due in BRKI 368 or via e-mail at **5:00 pm Thursday, December 18**, but you do not have to be on campus when you submit it. Details of the take-home portion of the final exam will be sent to you later.

Please review the "Exam Policies" section of the Exams page at the ELEC 470 web site. You should especially note the following:

1. You will be allowed to use a non-wireless enabled calculator, such as a TI-99.
2. You will be allowed to use three 8.5 × 11-inch two-sided handwritten help sheets. No photocopied material or copied and pasted text or images are allowed. If there is a table or image from the textbook or some other source that you feel would be helpful during the exam, please notify me.
3. All help sheets will be collected at the end of the exam but will be returned to you later if you wish to have them back.

As stated in the "Course Policies and Information" sheet, the lowest score among Exams #1 and #2 and the final exam will be weighted 10%; the two highest scores will be weighted 25% each. Solutions to the final exam will not be posted, but you may review your final exam and discuss it with me at any time after it has been graded.

Review Topics for Final Exam

The following is a list of topics that could appear in one form or another on the exam. Not all of these topics will be covered, and it is possible that an exam problem could cover a detail not specifically listed here. However, this list has been made as comprehensive as possible. You should be familiar with the topics on the previous review sheets in addition to those listed below.

Although every effort has been made to ensure that there are no errors in this review sheet, some might nevertheless appear. The textbook is the final authority in all factual matters, unless errors have been specifically identified there. You are ultimately responsible for obtaining accurate information when preparing for your exam.

Pulse code modulation (PCM)

- sampling and quantization
  - sampling results in a discrete-time (vs. continuous-time) signal
  - quantization results in a finite number of permissible amplitude levels (discrete-amplitude signal)
  - amplitudes of message signal $m(t)$ lie in the range $(-m_p, m_p)$
  - quantization interval size: $\Delta v = \frac{2m_p}{L}$, where L = no. of quant. levels
  - pulse coding allows a quantized signal to be sent as a binary signal (a pulse train of 1s and 0s)
  - $L = 2^n$ (L = no. of quant. levels; n = no. of encoding bits)
  - modern telephone quantization: bandlimited to 3400 Hz; sampling rate = 8 kHz; $L = 256$; $n = 8$
  - compact disc (CD) recording system: bandlimited to 20 kHz; sampling rate = 44.1 kHz; $L = 65{,}536$; $n = 16$
- quantization noise in PCM
  - quantization error lies in interval $(-0.5\Delta v, 0.5\Delta v)$, where $\Delta v = \frac{2m_p}{L}$
  - mean squared quantization error: $\overline{q^2(t)} = \frac{m_p^2}{3L^2}$
  - signal-to-quantization-noise ratio (SQNR): $\text{SQNR} = \frac{S_o}{N_o} = 3L^2 \frac{\overline{m^2(t)}}{m_p^2}$
  - mean square message signal amplitude (related to power level):
    $\overline{m^2(t)} = \lim_{T\to\infty} \frac{1}{T}\int_t^{t+T} m^2(\tau)\,d\tau$
  - for a sinusoid with magnitude m_p, $\overline{m^2(t)} = \frac{m_p^2}{2}$.

    Note that this is the mean squared amplitude averaged over a complete cycle of amplitude values. The mean squared *peak* amplitude for such a signal is m_p^2.
- companding in PCM
  - μ-law compression (used mainly in North America and Japan)

    $$y = \frac{1}{\ln(1+\mu)} \ln\left(1 + \mu \frac{m}{m_p}\right), \quad 0 \le \frac{m}{m_p} \le 1$$

    for positive m; multiply by -1 for negative m, where m = message sig. amplitude and y = output amplitude of compressor stage (normalized to 1)

  - *A*-law compression (used mainly in rest of world and on international routes)

    $$y = \begin{cases} \dfrac{A}{1+\ln A}\left(\dfrac{m}{m_p}\right), & 0 \le \dfrac{m}{m_p} \le \dfrac{1}{A} \\ \dfrac{1}{1+\ln A}\left(1+\ln\dfrac{Am}{m_p}\right), & \dfrac{1}{A} \le \dfrac{m}{m_p} \le 1 \end{cases}$$

    for positive *m*; multiply by -1 for negative *m*, where *m* = message sig. amplitude and *y* = output amplitude of compressor stage (normalized to 1)

- min. channel bandwidth of PCM signals:
  - $B_T = nB$, if sampling rate is exactly equal to Nyquist limit
    or $B_T = 0.5nf_s$, where f_s = sampling rate
  - in practice, $f_s > 2B$, so actual bandwidth of PCM signal is greater than B_T

Transmission of PCM signal over RF channels

- amplitude-shift keying (ASK)
  - simplest is on-off keying (OOK)
  - *M*-ary ASK is possible, where *M* = no. of amplitude levels sent and $M = 2^k$, where *k* = no. of bits sent at a time
- frequency-shift keying (FSK)
  - binary 1 represented by one frequency; binary 0 represented by a 2nd frequency
  - *M*-ary FSK is possible, where *M* = no. of frequencies used and $M = 2^k$, where *k* = no. of bits sent at a time
- phase-shift keying (PSK)
  - binary 1 represented by one phase (e.g., 0°); binary 0 represented by a 2nd phase (e.g., 180°)
  - *M*-ary PSK is possible, where *M* = no. of frequencies used and $M = 2^k$, where *k* = no. of bits sent at a time
  - *M* = 2 corresponds to BPSK (binary PSK); allows 1 bit to be sent per pulse
  - *M* = 4 corresponds to QPSK (quadrature PSK) ; allows 2 bits to be sent at a time
- *M*-ary quadrature amplitude modulation (M-ary QAM, or *M*-QAM)
  - can be used to send combinations of *k* bits at a time, where $M = 2^k$
  - note that *k* might or might not equal *n* (no. of bits used to encode PCM samples)
  - 64-QAM and 256-QAM used in IEEE 802.11 "Wi-Fi" wireless networking
  - signal representation:

    $$\phi_{M-QAM}(t) = a_i\, p(t)\cos\omega_c t + b_i\, p(t)\sin\omega_c t, \qquad i = 1, 2, \ldots, M\ ,$$

    where a_i and b_i and quantized amplitudes that together represent *M* different bit combinations, and *p*(*t*) = time-domain baseband pulse (with peak amplitude of 1); simplest choice for *p*(*t*) is a rectangular pulse, but pulse shaping is usually used to minimize bandwidth

    or

    $$\phi_{M-QAM}(t) = r_i\, p(t)\cos(\omega_c t - \theta_i), \qquad i = 1, 2, \ldots, M\ ,$$

    where $r_i = \sqrt{a_i^2 + b_i^2}$ and $\theta_i = \tan^{-1}\left(\dfrac{b_i}{a_i}\right)$
  - ASK and PSK are special cases of *M*-QAM (ASK is amplitude only; PSK is phase only)

- *constellation diagram*: plot of all possible a_i, b_i amplitude combinations on rectangular coordinate system with a_i plotted along horizontal axis and b_i along vertical axis
  - square constellations are widely used; in this case, M is a power of 4, and points are evenly spaced along a square grid
  - circular constellations also widely used (corresponds to M-PSK); in this case, r_i = constant for all i, and points in constellation are evenly spaced around a circle
  - time-average (rms) power of each pulse is given by $r_i^2/2R$, where r_i is the magnitude defined above (assumed to be a *voltage*), and R is the equiv. resistance across which pulse voltage is measured; if r_i is the *current* magnitude, then rms power of each pulse is given by $r_i^2R/2$

<u>Relevant course material:</u>

Homework:	#5
Mini-Projects:	#2
Textbook:	Sections 6.1 (for background), 6.2, 7.8.1, 7.8.3, 7.9
Supplements:	(none)
Web Links:	(none)
Matlab:	(none)