ECEG 470/670 Communication and Information Systems Fall 2025

Policies and Review Topics for Exam #2

The following policies will be in effect for the exam. They will be included in a list of instructions and policies on the first page of the exam:

1. You will be allowed to use a non-wireless enabled calculator, such as a TI-89.
2. You will be allowed to use two 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 either immediately or soon after the exam.
4. Use of a help sheet that is not completely handwritten will result in an automatic 5-point score reduction.
5. If you begin the exam after the start time, you must complete it in the remaining allotted time. However, you may not take the exam if you arrive after the first student has completed it and left the room. The latter case is equivalent to missing the exam.
6. **You may not leave the exam room without prior permission except in an emergency or for an urgent medical condition. Please use the restroom before the exam.**

The exam will begin at 9:00 am on Monday, September 29 in Dana 307 (our usual MWF classroom). You will have until 9:50 am to complete the 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 sheet in addition to those listed below.

Although significant effort has been made to ensure that there are no errors in this review sheet, some might nevertheless appear. The textbook and the supplemental readings are 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.

Radio/wireless receiver architectures
- tuned radio frequency (TRF)
- homodyne (direct conversion)
    - “homodyne” refers to the local oscillator (LO) being at roughly the same frequency as the RF signal
    - translates RF signal frequency directly to baseband
    - results in double-signal reception unless the baseband image is eliminated via special circuits (like an image rejection mixer)

- superheterodyne
  - "heterodyne" refers to the LO being at a substantially different frequency than the RF signal
  - "super" literally refers to the LO frequency being higher than the incoming desired RF signal frequency (high-side injection). In common usage now, however, a superheterodyne receiver could have an LO either above or below (low-side injection) the RF frequency.
  - desired signal is downconverted (usually, although upconversion is sometimes used) to one or more intermediate frequencies (IFs)
  - highly selective IF filters are practical since they do not have to be tuned
  - amplifier gain in the receiver is distributed among RF, IF, and baseband frequencies, which aids in preserving amplifier stability (excessively high gain not required at a single frequency)
  - image signal frequency is $2f_{\text{IF1}}$ away from desired signal frequency (where f_{IF1} is the first IF frequency), so image rejection is easy to achieve
  - message signal spectrum "flipping" can occur in the frequency translation process
  - IF and LO frequencies are usually selected to avoid heavily occupied sections of the electromagnetic spectrum

Angle modulation and immunity to interference (capture effect)

- if A = FM signal amplitude, $I \cos \omega t$ = interference signal at input of receiver, and $A >> I$, signal strength of interference at output of FM detector is

$$y_d(t) = \frac{I\omega}{A}\cos\omega t$$

- if A = PM signal amplitude and $I \cos \omega t$ = interference signal, signal strength of interference at output of PM detector is

$$y_d(t) = \frac{I}{A}\sin\omega t$$

- signal strength of weak interference is suppressed in an FM/PM detector; thus, the desired signal "captures" the receiver output

Local carrier synchronization methods

- transmit pilot tone
- pass signal through nonlinear device (such as a squaring stage)
- phase-locked loop
- Costas loop

Direct method of generating FM signals using variable capacitance or inductance in frequency-determining part of oscillator circuit

Demodulation of FM signals using differentiator and envelope detector

Direct digital synthesis (DDS)

- major parts of DDS system: tuning word register (holds value of M), phase accumulator, ROM containing sine look-up table (also called phase-to-amplitude converter), clock oscillator, digital-to-analog converter (DAC), low-pass filter
- output frequency f_o is given by

$$f_o = M\,\frac{f_c}{2^n}$$

  where f_c = clock frequency, M = digital tuning word (ROM address increment), and n = no. of bits representing phase quantization level

- in theory, output frequency can be as high as $f_c/2$ (Nyquist limit), but in practice the upper limit is much lower than $f_c/2$ (usually around $f_c/3$) because ideal low-pass filters are not available to apply to output of DAC
- binary sine wave amplitude representation in ROM look-up table is sometimes truncated to N bits, where $N < n$
- a primary disadvantage of DDS is the generation of quantization noise, which is inversely proportional to the number of quantization levels squared L^2 (where $L = 2^N$); however, quantization noise can be made arbitrarily small by making N (and L) large enough.
- hybrid frequency synthesizers can combine DDS and PLL (e.g., DDS can supply a tunable reference frequency signal to PLL)

Phase-locked loop (PLL)

- feedback-based system
- can be used to generate LO signals or synchronize phase with incoming signals
- consists of modulator (multiplier or mixer), loop filter, and voltage-controlled oscillator (VCO), and sometimes a clock circuit (reference oscillator)
- divide-by-N stage can be added to generate a signal at the frequency Nf_c, where f_c is the clock frequency
- multiloop PLLs can be used to provide fine frequency control without compromising phase lock performance
- clock signal and VCO signal are often 90° out of phase (in some circuits, it's 180°) so that the output of the multiplier is proportional to $\sin(\theta_i - \theta_o) \approx \theta_i - \theta_o$, where θ_i is the phase of the incoming signal (or clock) and θ_o is the phase of the VCO

- noise can be treated as a type of interference, so in the case of additive Gaussian white noise at input to receiver (see Fig. 5.14 on p. 286 of supplemental reading "Interference Effect [on FM Signals]"),
  - noise spectral density at the output of an *FM* detector is directly proportional to frequency
  - noise spectral density at the output of a *PM* detector is uniform with frequency
- frequency dependent noise effect in FM can be accounted for using pre-emphasis in the transmitter and de-emphasis in the receiver

Pulse code modulation (PCM)

- sampling and quantization
  - sampling results in a discrete-time (as opposed to continuous-time) signal
  - quantization results in a finite number of permissible amplitude levels (discrete-amplitude signal)
  - amplitudes of quantized message signal 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 3.4 kHz; sampling rate = 8 kHz; $L = 256$; $n = 8$
  - compact disc (CD) recording system: bandlimited to 20 kHz; sampling rate = 44.1 kHz; $L = 65{,}536$; $n = 16$

<u>Relevant course material:</u>

Homework: #3 and #4
Recitations: "Downconversion of FM Broadcast Stations" (demonstration)
Mini-Projects: #2
Reading: Assignments from Sept. 24 through Oct. 24, including the supplemental readings
"Interference Effect [on FM Signals]"
"Direct Generation [of FM Signals]"
"Fundamentals of Direct Digital Synthesis (DDS)"

This exam will focus primarily on the course outcomes listed below and related topics.

2. Evaluate and/or specify the basic performance metrics of an angle modulation system (FM and PM).
3. Perform basic analysis and/or design calculations for phase-locked loops and direct digital synthesizers.
4. Demonstrate how pulse code modulation systems encode analog signals into digital form.
7. Apply the fast Fourier transform (FFT) to basic signal analysis problems.

The course outcomes are listed on the Course Policies and Information sheet, which was distributed at the beginning of the semester and is available on the Syllabus and Policies page at the course web site. The outcomes are also listed on the Course Description page. Note, however, that some topics not directly related to the course outcomes could be covered on the exam as well.