ECEG 470/670 Communication and Information Systems Fall 2025

Policies and Review Topics for Exam #1

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 one 8.5 × 11-inch two-sided handwritten help sheet. 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. 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.
5. **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.

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.

Electromagnetic spectrum (rough idea of frequency ranges and wavelengths)
- MF, HF, VHF, UHF
- AM, FM, and TV/CATV broadcast services
- usefulness of various parts of spectrum for specific services/purposes

Basic wireless system (radio is a kind of frequency division multiplexing)
- baseband signal
- transmitters and receivers (up/down conversion, amplification, and detection)
- transmission lines and antenna(s)

Double sideband, suppressed carrier (DSB-SC, but often called DSB)
- signal representation

  $$\phi_{DSB}(t) = m(t)\cos\omega_c t$$
- pos/neg spectra of $m(t)$ shifted upwards in frequency and centered at f_c (frequency-shifting property of Fourier transform)
- modulation and demodulation methods
- requirement for phase and frequency synchronization between carrier and local oscillator

Frequency mixer

- ideally equivalent to a signal multiplier (i.e., if $x(t)$ and $y(t)$ are inputs, then $x(t)y(t)$ is the output)
- real mixers are equivalent to multiplying the message signal $m(t)$ by a "switching" waveform; most widely used physical circuits:
  - diode ring mixers
  - Gilbert cells
- one type of switching waveform:

  $$w(t) = \begin{cases} 1, & \text{pos. half cycle of driving voltage} \\ 0, & \text{neg. half cycle of driving voltage} \end{cases}$$
- Fourier series of switching waveform consists of harmonics of fundamental frequency with varying weights
- modulation property of Fourier transform (frequency-shifting property)

Conventional AM (formally called DSB-LC)

- strong carrier added to DSB-SC signal
- significant transmitter power is devoted to carrier part of signal
- signal representation

  $$\phi_{AM}(t) = \left[A + m(t)\right]\cos\omega_c t$$

  where $m(t)$ = message signal and A = amplitude of carrier signal
- spectral representation
- modulation index

  $$\mu = \frac{m_p}{A}, \quad \text{where } m_p = \text{peak value of } |m(t)|$$
- overmodulation ($\mu > 1$) leads to distortion of message signal at receiver
- generation methods
  - add carrier to DSB signal via oscillator and summing junction
  - vary power supply current and/or voltage in step with $m(t)$ (old approach)
- demodulation methods
  - synchronous demodulation (requires frequency synchronization between carrier and local oscillator
  - envelope detection
- advantages and disadvantages vs. DSB and/or SSB
  - bandwidth requirements and how they are related to noise
  - ease of demodulation
  - criticalness of receiver tuning
  - power efficiency (power committed to carrier in AM)

Single sideband (SSB, but formally called single sideband, suppressed carrier or SSB-SC)

- USB vs. LSB
- Hilbert transform equivalent to shifting phase of all pos. freq. components of a signal by −90° and all neg. freq. components by +90°
- signal representations

  $$\phi_{USB}(t) = m(t)\cos\omega_c t - m_h(t)\sin\omega_c t$$

  $$\phi_{LSB}(t) = m(t)\cos\omega_c t + m_h(t)\sin\omega_c t$$

  where $m_h(t)$ = time-domain form of Hilbert transform of $m(t)$
- spectral representation

- methods of SSB signal generation (modulation); advantages and disadvantages
  - filter method
  - phasing method
  - Weaver method
- demodulation methods similar to modulation methods
- synchronous demodulation only really necessary for low-redundancy signals like digital data; not really necessary for high-redundancy signals like human voice
- effects of asynchronous demodulation

Fast Fourier transform

- based on continuous-time Fourier transform

  $$X(f) = \int_{-\infty}^{\infty} x(t) e^{j2\pi ft} dt$$

- if $x(t)$ is sampled with N discrete, evenly spaced sample points, then time and frequency are discretized as

  $$t_n = n\Delta t, \quad n = 0, 1, 2, \ldots, N-1 \quad \text{and} \quad f_k = k\Delta f, \quad k = -\frac{N}{2}, \ldots, 0, \ldots, \frac{N}{2},$$

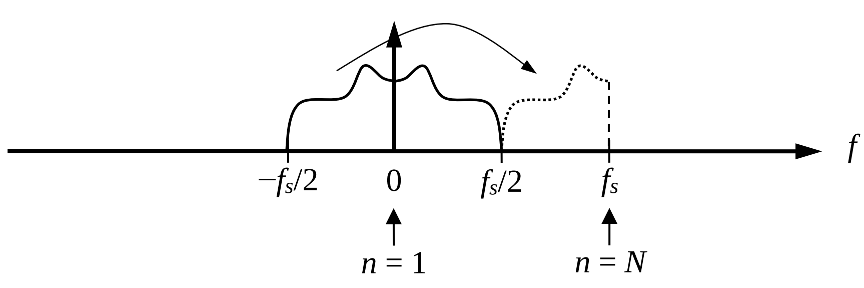
  where $\Delta t = 1/f_s$, and where f_s = sampling frequency
- there are $N + 1$ frequency points but only N elements in the output vector of the FFT; one of the output elements is redundant (i.e., f_k values at $k = -N/2$ and at $k = N/2$ are equal)
- relationships between time/frequency intervals and sampling frequency

  $$f_{\max} = \frac{f_s}{2} = \frac{1}{2\Delta t} \quad \text{and} \quad f_s = N\Delta f \quad \rightarrow \quad \frac{N\Delta f}{2} = \frac{1}{2\Delta t} \quad \rightarrow \quad \Delta f = \frac{1}{N\Delta t} = \frac{f_s}{N}$$

- discrete-time and frequency Fourier transform

  $$X_k = \Delta t \sum_{n=0}^{N-1} x_n e^{j2\pi kn\Delta f\Delta t} = \Delta t \sum_{n=0}^{N-1} x_n \left(e^{j2\pi/N}\right)^{kn}$$

- sampling frequency must be at least 2× greater than $f_{\max}$ of sampled signal to avoid aliasing (Nyquist limit)
- no. of sampling points is even and is usually (but does not have to be) a power of 2
- vector output of FFT
  - from $n = 1$ (or $k = 1$) through $n = N/2$ (or $k = N/2$): positive spectrum of sampled signal representing frequencies from $f = 0$ to $f = f_s/2$
  - from $n = N/2 + 1$ through $n = N$: negative spectrum of sampled signal representing frequencies from $f = -f_s/2 + \Delta f$ to $f = 0$
  - visual depiction of spectrum produced by FFT:



Angle modulation

- general signal representation

  $$\phi_{EM}(t) = A\cos\theta(t),$$

  where $\theta(t)$ = time-dependent phase of ϕ_{FM} or ϕ_{PM} signal and where the "EM" subscript means "exponential modulation," a generic term for frequency and phase modulation

- concept of instantaneous frequency
  $\omega_i(t) = \dfrac{d\theta(t)}{dt}$,
- frequency modulation (FM)
  - signal representation
    $\phi_{FM}(t) = A\cos\left[\omega_c t + k_f a(t)\right]$,
    where $a(t) = \int_{-\infty}^{t} m(\tau)d\tau$, $m(t) = \dfrac{da(t)}{dt}$, k_f = freq. modulation constant, and $m(t)$ = message signal
  - Fourier transform of $a(t)$ has the same bandwidth as that of $m(t)$
  - $\theta(t) = \omega_c t + k_f a(t)$ and $\omega_i(t) = \omega_c + k_f m(t)$
  - peak frequency deviation
    $\Delta f_{FM} = \dfrac{k_f m_p}{2\pi}$, where m_p = peak value of $|m(t)|$
- phase modulation (PM)
  - signal representation
    $\phi_{PM}(t) = A\cos\left[\omega_c t + k_p m(t)\right]$,
    where k_p = phase modulation constant and $m(t)$ = message signal
  - $\theta(t) = \omega_c t + k_p m(t)$ and $\omega_i(t) = \omega_c + k_p \dfrac{dm(t)}{dt} = \omega_c + k_p \dot{m}(t)$,
    where dot over m indicates time derivative
  - Fourier transform of $dm(t)/dt$ has the same bandwidth as that of $m(t)$; time differentiation property of Fourier transform:
    $\dfrac{dm(t)}{dt} \Leftrightarrow j\omega M(\omega)$
  - peak frequency deviation
    $\Delta f_{PM} = \dfrac{k_p \dot{m}_p}{2\pi}$, where $\dot{m}_p$ = peak value of $|dm(t)/dt|$
- comparisons of FM vs. PM
- narrowband FM (NBFM) vs. wideband FM (WBFM)
- narrowband PM (NBPM) vs. wideband PM (WBPM)
- comparison of NBFM or NBPM to AM (DSB-LC)
- bandwidth analysis using power series expansion in $k_f\, a(t)$ for FM or $k_p\, m(t)$ for PM
  - $\phi_{FM}(t) = \mathrm{Re}\{\hat{\phi}_{FM}(t)\} = \mathrm{Re}\{Ae^{j\omega t}e^{jk_f a(t)}\}$
  - bandwidth of $a(t)$, $a^2(t)$, $a^3(t)$, etc. [or $m(t)$, $m^2(t)$, $m^3(t)$, etc.]
- deviation ratio
  $\beta = \dfrac{\Delta f}{B}$, where B = bandwidth of message signal $m(t)$ in Hz; in practice, $B = f_{\max}$
- Carson's rule (applicable to FM and PM)
  $B_{FM} = 2(\Delta f_{FM} + B)$ and $B_{PM} = 2(\Delta f_{PM} + B)$,
  where B = bandwidth of message signal (usually assumed to equal $f_{\max}$ of message signal)

Relevant course material:

Homework: #1 and #2
Recitations: "FFT Basics" (identification of mystery signal)
Mini-Projects: [none]
Reading: Assignments from Aug. 25 through Sep. 22

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

1. Evaluate and/or specify the basic performance metrics of an amplitude modulation system (DSB-LC, DSB-SC, and SSB).
2. Evaluate and/or specify the basic performance metrics of an angle modulation system (FM and PM).
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.