ECEG 497/697 | Wireless System Design | Spring 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 7:00 pm on Thursday, February 20 in Breakiron 264 (our usual classroom). You will have until 9:00 pm 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 authorities in all factual matters, unless errors have been specifically identified there. You are ultimately responsible for obtaining accurate information when preparing for the exam.

Electromagnetic spectrum (rough idea of frequency ranges and wavelengths)
- MF, HF, VHF, UHF
- AM, FM, and TV/CATV broadcast services
- microwave region and band letter designations (L, S, C, X, Ku, K, Ka)
- millimeter wave region and band letter designations (V, W)
- usefulness of various parts of spectrum for specific services/purposes

Impedance matching methods – general types and concepts
- LC (inductor-capacitor) networks
- quarter-wave transmission line sections [not covered in Exam #1]
- transmission line stubs [not covered in Exam #1]
- "good" match criteria often used: $|\Gamma|^2 < 0.1$, VSWR < 2, RL > 10 dB ($|\Gamma| < -10$ dB)
- need for impedance matching
  - maximum power transfer
  - reduce reflections in digital systems to avoid symbol errors
  - avoid dielectric breakdown due to high voltages
  - minimize loss due to multiple trips of signal energy up/down transmission line

- proper impedance terminations for amplifiers, filters, mixers, and other impedance-critical circuits
- many amplifiers will reduce power with a mismatched load

L networks for impedance matching (a type of LC matching network)

- concepts of "source" (or "generator") and "load" impedance
- concept of "lumped element"
- underlying concept: series-to-parallel transformations of resistance and reactance using quality factor Q (the "Q method")
- $R_p = R_s(Q^2+1)$ or $Q = \sqrt{\frac{R_p}{R_s} - 1}$ (p = parallel; s = series)
- for series combinations, $Q = \frac{|X_s|}{R_s}$; for parallel combinations, $Q = \frac{R_p}{|X_p|}$
- individual inductors and capacitors have component Q; Q of inductors is usually much lower than that of capacitors and can be the limiting factor in network Q
- four L network topologies: two for $R_L > R_g$, two for $R_L < R_g$; in each case, can have series-L/shunt-C or series-C/shunt-L (shunt reactance always next to higher resistance)
- If Q is large, $\omega_o^2 \approx \frac{1}{LC}$ and $|X_p| \approx |X_s|$ for all four topologies
- matching bandwidth is inversely proportional to Q
- matching bandwidth can be increased by using multiple L network stages w/low Q
- $r_{\text{stage}} = r_{\text{overall}}^{1/n}$, where n = no. stages, r = impedance transformation ratio
- methods for "absorbing" load reactance into matching network
    - shunt element next to load: $X_p = \frac{X_{load} X_{p,total}}{X_{load} - X_{p,total}}$
    - series element next to load: $X_s = X_{s,total} - X_{load}$

Pi and T networks for impedance matching

- consists of two back-to-back L networks
- concept of "virtual" resistance R_v:
    - $R_v < R_g$ and R_L for pi network
    - $R_v > R_g$ and R_L for T network
    - virtual resistance is not an actual resistor and does not contribute to loss; a resistor is not added to network; it is the equivalent resistance looking into one of the half networks (L networks)
- additional degree of freedom (the third component) allows designer to (choose one):
    - control Q (bandwidth) – one side of network dominates Q
    - avoid unreasonable L and C values
- factors that can affect topology (i.e, whether to use C or L as series or shunt element)
    - avoid or allow DC continuity between stages or to ground
    - avoid problems with stray reactance
    - avoid unreasonable L and C values
    - minimize no. of inductors (can have significant stray resistance, susceptible to mutual inductance, generally heavier and more expensive than capacitors)
    - in general, use T network to match low resistances, pi network to match high resistances

Concept of Γ, VSWR, and return loss as measures of impedance match quality (with or w/o an actual transmission line present):

- $\Gamma_L = \dfrac{Z_L - Z_o}{Z_L + Z_o}$ $\quad$ $\text{VSWR} = \dfrac{1+|\Gamma_L|}{1-|\Gamma_L|}$ $\quad$ $\text{RL} = -20\log|\Gamma_L|$ (pos. quantity)
- An alternative (and widely used) metric is the S-parameter S_{11}. It is equivalent to Γ_L under the right conditions and its magnitude is often expressed in dB; if so, it is equivalent to the negative of return loss.

Filters – basic concepts

- concept of available power and its calculation via

  $P_A = \dfrac{|V_g|^2}{4R_g}$, where V_g is the source voltage in rms units
- simple one-pole low-pass filters [not covered on Exam #1]:
  - fraction of available power (P_A) delivered to load (P_L), assuming real source and load impedances:

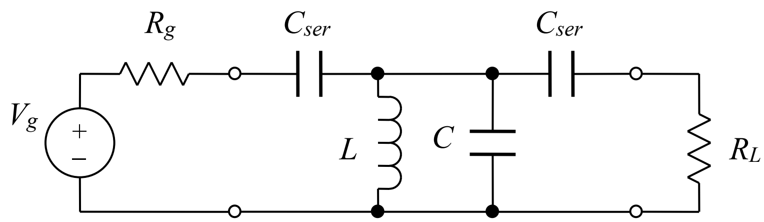
    $$\frac{P_L}{P_A} = \frac{4R_g R_L}{(R_g + R_L)^2}\left[\frac{1}{1+(\omega/\omega_c)^2}\right]$$
  - series inductor: $\omega_c = \dfrac{R_g + R_L}{L}$
  - parallel capacitor: $\omega_c = \dfrac{1}{(R_g \| R_L)C}$
  - stop-band roll-off = –20 dB/decade (–6 dB/octave)
- simple one-pole high-pass filters [not covered on Exam #1]:
  - fraction of available power delivered to load:

    $$\frac{P_L}{P_A} = \frac{4R_g R_L}{(R_g + R_L)^2}\left[\frac{(\omega/\omega_c)^2}{1+(\omega/\omega_c)^2}\right]$$
  - parallel inductor: $\omega_c = \dfrac{R_g \| R_L}{L}$
  - series capacitor: $\omega_c = \dfrac{1}{(R_g + R_L)C}$
  - stop-band roll-off = +20 dB/decade (+6 dB/octave)
- simple series or parallel LC band-pass filters
  - fraction of available power delivered to load ($R_{sys} = R_g = R_L$ if $R_g = R_L$):

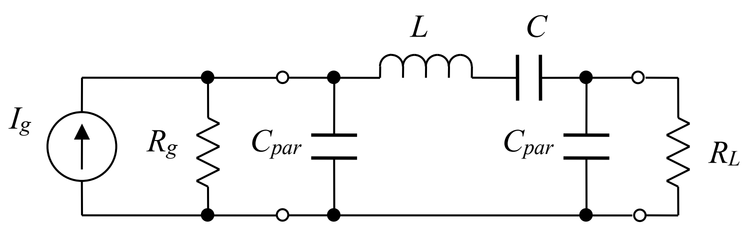
    $$\frac{P_L}{P_A} = \frac{4R_g R_L}{(R_g + R_L)^2}\frac{1}{1+\left(\dfrac{\omega}{\Delta\omega}\right)^2\left(1-\dfrac{\omega_o^2}{\omega^2}\right)^2}$$
  - series LC: $\omega_o = \dfrac{1}{\sqrt{LC}}$, $\Delta\omega = \dfrac{R_g + R_L}{L}$, $Q_{net} = \dfrac{\omega_o}{\Delta\omega} = \dfrac{\omega_o L}{R_g + R_L} = \dfrac{X_L}{2R_{sys}}$
  - parallel LC: $\omega_o = \dfrac{1}{\sqrt{LC}}$, $\Delta\omega = \dfrac{1}{(R_g \| R_L)C}$, $Q_{net} = \dfrac{\omega_o}{\Delta\omega} = (R_g \| R_L)\omega_o C = \dfrac{R_{sys}}{2|X_C|}$
  - stop-band roll-off = ±20 dB/decade (±6 dB/octave)

Coupled-resonator band-pass filters

- goal: maximize stored energy relative to energy dissipated per cycle (i.e., maximize Q) to achieve narrower passband with reasonable component values
- provide larger Q (narrower bandwidth) for given resonator reactances than with simple band-pass filters that do not use coupling components
- parallel LC resonators with series coupling (usually by capacitors); a.k.a. top coupling
    - adding capacitor (or inductor) in series with source/load causes equiv. parallel source/load resistances to be much larger than original values of R_g and R_L
    - $Q_{net} = \dfrac{0.5R_{par}}{X_L}$
    - equiv. parallel reactances of added series elements must be incorporated into the parallel LC resonant circuit



- series LC resonators with shunt coupling (usually by capacitors)
    - adding capacitor (or inductor) in parallel with source/load causes equiv. series source/load resistances to be much smaller than original values of R_g and R_L
    - $Q_{net} = \dfrac{X_L}{2R_{ser}}$
    - equiv. series reactances of added parallel elements must be incorporated into the series LC resonant circuit



- difference between "network" Q (Q_{net}) and "series-parallel transformation" Q (Q_{xfm})
- coupling capacitors usually preferred over coupling inductors; however, a coupling inductor on one side can help ensure good roll-off on both sides of passband
- impedance-matching transformers can be used instead of coupling capacitors (or inductors) to increase/decrease apparent source/load resistances, but they are heavier, bulkier, and lossier than capacitors. Advantage of transformers: broadband impedance transformation

Relevant course material:

Homework: #1 and #2
Mini-Projects: [none]
Reading: Assignments from Jan. 20 through Feb. 14, including the supplemental readings:
"Impedance Matching," from C. Bowick, *RF Circuit Design*, 2nd ed.
"Basic Filters, Part 1: Low-Pass Filters"
"Basic Filters, Part 2: High-Pass Filters"
"Basic Filters, Part 3: Band-Pass Filters"
"Basic Filters, Part 4: Coupled-Resonator Filters"

This exam will focus primarily on the course outcome listed below and related topics:

1. Design lumped-element impedance matching networks using L, T, and pi configurations.

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, such as the design and analysis of simple bandpass filters, could be covered on the exam as well.