ECEN 2420, Electronics for Wireless, Prof. Zoya Popovic

PRACTICE PROBLEMS FOR FINAL EXAM
No calculators, closed everything. You are allowed to bring a formula sheet with 15 equations, and you need to turn in your formula sheet with the exam.

Part I: Questions

Q1. Sketch the block diagram of the radio (1) transmitter and (2) receiver you are building and label all frequencies and power levels.

Q2. What is 2V, 10mW, 1kW, 0.1mV and a gain of 20 in dB? Do this without using a calculator.

Q3. What is -13dBm, 6dBV, -100dBm, 30dBm, 33dBm, 43dBW in volts or watts? No calculator needed.

Q4. Write down expressions for average dissipated power if the following are given:
   (a) Peak (max) voltage and current
   (b) Peak (max) voltage and load
   (c) Peak-to-peak voltage and current
   (d) RMS voltage and load
   (e) RMS current and load

Q5. Name the radio bands and give the frequency range for each.

Q6. What is modulation? Name at least 3 types of modulations and sketch the signal in time domain in each case.

Q7. A mixer has input frequencies of 21MHz and 22MHz. What frequencies exist at the output of the mixer?

Q8. A mixer has input frequencies of 12MHz and 0.003MHz. What frequencies exist at the output of the mixer, and what function do you think this mixer is performing?

Q9. What is the difference between a direct conversion receiver and a superheterodyne receiver? Which type is the radio you are building in the lab?

Q10. What are the Thevenin and Norton equivalent circuits for the circuits below?

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![Circuit Diagrams]
Q11. What is the time constant of a resistor in series with a capacitor? If the input is a voltage $V_0$, sketch the voltage across the capacitor as a function of frequency and find the cutoff frequency.

![Circuit Diagram]

$$\frac{V_0}{+} + V_C - \frac{I}{R}$$

Q12. What is the time constant of a resistor in parallel with an inductor? If the input is a current source $I_0$ turned on at $t=0$ and there is no initial current through the inductors, sketch the currents through the resistor and through the inductor as a function of time. How long will it take for the current through the resistor to drop to half of its initial value?

Q13. For a series R-L circuit fed by a voltage $V=V_{\text{max}} \cos \omega t$, give expressions for (a) the complex power; (b) the reactive power; (c) average power.

Q14. For a parallel R-C circuit fed by a voltage $V=V_{\text{max}} \cos \omega t$, give expressions for (a) the complex power; (b) the reactive power; (c) average power.

Q15. Sketch the IV curve for a diode with a built-in voltage of 0.6V and a reverse breakdown voltage of 30V. Label all relevant regions and write down the equation $I(V)$.

Q16. What are different types of diodes, and what are they used for? Include sketches of relevant circuits and waveforms.

Q17. Find the equivalent Thevenin and Norton circuits of a source (battery) if you measure the open circuit voltage to be 12 V and that for 20mA of current draw the voltage drops to 10V.

Q18. A diode detector circuit is shown below. It is used to detect a 10-MHz carrier modulated with a 1-kHz signal.
- What is the function of the resistor R?
- How are R and C chosen? Give example values that you think would work.

Q19. If the power at some frequency $f$ is 3dB below the maximum power $P_0$ at $f_0$, how is the voltage at $f$ related to the voltage $V_0$ at $f_0$?

Q20. For a T37-2 core with $A_L=4.0\text{nH/turn}^2$, what is the inductance for 30 turns of #28 wire wound around the core?

Q21. Write down the expressions that relate voltage and current for a resistor, capacitor and inductor. What do these expressions become when the voltage and current are time harmonic? From your $V(I)$ and/or $I(V)$ expressions, define the impedance of each component.
Q22. For a series RC circuit connected to a sinusoidal voltage source, derive and sketch the amplitude of the voltage across the (1) resistor and (2) capacitor as a function of frequency. Label the cutoff frequencies.

Q23. Derive and sketch the amplitude of the voltage across the resistor as a function of frequency for a (1) series RLC circuit and (2) parallel RLC circuit. Label all relevant frequencies and amplitudes with their values.

Q24. What is the definition of the quality factor? Write down the expression for the quality factor of a series RLC circuit and a parallel RLC circuit. Explain why the expressions depend on R the way they do.

Q25. Sketch a 5-th order (1) low-pass, (2) high pass and (3) bandpass filter circuit. Sketch a Butterworth and Chebyshev frequency filter characteristics for a 5-th order filter.

Q26. The IF filter in the radio receiver is a crystal filter.
   - What type of filter is this?
   - What is the equivalent circuit for a piezoelectric crystal? What are the circuit elements physically?
   - What is the Q factor approximately for each filter element?
   - Could you make this filter with L and C components?

Q27. Sketch the circuit for an ideal transformer, label all currents and voltages. For \( N_p = 5 \) turns on the primary and \( N_s = 15 \) turns on the secondary, find:
   - The secondary current if the input current is 1A;
   - The primary voltage if you measured 12V on the secondary;
   - The impedance seen at the primary for a 300-ohm load connected on the secondary.

Q28. What is the magnetizing current in a transformer? Sketch an equivalent circuit of a transformer which includes the effect of the magnetizing current and explain how you would measure or calculate it.

Q29. Sketch a common emitter amplifier with emitter degeneration, and using a npn bipolar transistor. Label all the elements. Sketch the ac equivalent circuit and explain the important elements.
   - What is the current gain equal to?
   - What is the voltage gain equal to?
   - What happens when the base is not dc biased (Vbb=0) and there is a large sinusoidal voltage applied to the base?
   - Why did we couple the output through a transformer in the driver amp in the Norcal40A?

Q30. Sketch a npn bipolar emitter follower amplifier. Label all the elements. Sketch the ac equivalent circuit and explain the important elements.
   - What is the current gain equal to?
   - What is the voltage gain equal to?
   - How is the output impedance different than in the case of a common-emitter amplifier?
Q31. What is the maximum efficiency of a class-A amplifier? Give the definition of efficiency and show how you got your answer.

Q32. Sketch a differential amplifier and answer the following:
   - What is the differential output voltage if the input differential voltage is \( v_{id} \)?
   - What is the differential output impedance?
   - What is the common-mode voltage gain?

Q33. Sketch the (1) IV curves and (2) ac equivalent circuit for a bipolar and a FET transistor and explain the circuit elements.

Q34. Sketch the circuit of a bipolar transistor common emitter amplifier with the ability to change the gain electrically.

Q35. Derive the wave equation in a lossless transmission line. (See handout Chapter 18 on web page.)

Q36. Calculate the value of capacitance per unit length of a 50-ohm coax if the velocity of propagation in the coax is 2/3 of the speed of light in vacuum.

Q37. Calculate the value of inductance per unit length of a 50-ohm coax if the velocity of propagation in the coax is 2/3 of the speed of light in vacuum.

Q38. What is the reflection coefficient on a transmission line (coax)? Assume that the line has a characteristic impedance \( Z_0 \) (usually 50 ohms) and that it has a load of \( Z_L \) connected at the end.

Q39. What is the characteristic impedance of a coaxial line, and what is the impedance at every point along the coax?

Q40. How does the phase along a line vary for the case of (1) voltage, (2) current and (3) reflection coefficient?

Q41. What is the standing wave ratio (SWR) on a transmission line that is (1) open and (2) shorted at the end?

Q42. How are gain and effective area of an antenna related? Give definitions of gain and effective area.

Q43. Write down the Friis line-of-sight link formula and explain the variables. Repeat for quantities given in dB.
   - Write the Friis formula if only the gains of the antennas are given.
   - Write the Friis formula if only the effective areas of the antennas are given.

Q44. Find the gain of a lossless antenna that has an effective area of \( 12\pi \lambda^2 \), where \( \lambda \) is the operating wavelength in air.
Q45. Ionospheric propagation:
- How high above the surface is the ionosphere? How does it vary in time and why?
- Why is it important for radio communications?
- Under what conditions does the ionosphere allow radio propagation around the earth?

Part II: Problems

P1. When measuring a 9-V battery, the open circuit voltage is found to be 10V. For 200mA of current, the voltage is 8V.
(a) Find the Thevenin equivalent circuit for the battery and sketch the V-I dependence, making sure you label the relevant values and include units.
(b) Assume that the NorCal 40A radio draws 20mA when it is receiving. What voltage would you expect from the battery?
(c) If the battery has an amp-hour rating of 0.04A-hr, how long would you be able to operate the radio in receive mode?

P2. You are given a circuit which is a parallel connection of a 1-kΩ resistor and a 100pF capacitor. Find the elements of an equivalent series circuit at 7MHz. What are the Q-factors of the two circuits ($Q_s$ and $Q_p$) equal to and how are they related?

P3. The transmit filter of your radio is centered at 7MHz and shown in the figure below. Find the expression for the admittance of this filter. For what value of the tunable capacitor $C$ is the resonance at 7MHz? What is the value of $R$ which results in the 3-dB filter bandwidth of 200 kHz?

![Filter Diagram]

P4. For a T37-2 core with $A_L=4.0\text{nH/turn}^2$, what is the inductance of 8 turns wound around the core? Wind transformer, find magnetizing inductance, find $C$ to resonate at frequency $f=7\text{MHz}$.

P5. The receive filter of your radio is centered at 7MHz and shown in the figure below, where $R$ is the parasitic resistance of the 10-$\mu\text{H}$ inductor coil. Find the expression for the impedance of this filter. For what value of the tunable capacitor $C$ is the resonance at 7MHz? What is the value of $R$ which results in the 3-dB filter bandwidth of 350 kHz?

![Filter Diagram]
P6. Design a circuit with low loss that makes a 80-Ω antenna on one end look like a 500-Ω impedance at the other end.

P7. An impedance inverter is used to transform 200Ω on one side to a 50Ω coaxial cable on the other. Find the elements of the transformer at 7MHz.

P8. A transformer is wound on a FT37-61 core with $A_L = 50$ nH/turn$^2$. The impedance is transformed from 20 Ω on the primary to 2000 Ω on the secondary which has 50 windings. Find the magnetization inductance of the primary. What is the value of the capacitance that resonates this transformer at 10MHz?

P9. In this problem you will convert a parallel (shunt) circuit to an equivalent series circuit.
- Write down the expressions for the impedances of both circuits ($Z_s$ and $Z_p$);
- Write down the expressions for the Q-factors of both circuits;
- Show that if the two circuits have the same impedance, their Q factors $Q_s$ and $Q_p$ are the same;
- Start from the circuit elements given in the parallel circuit, $R_p$ and $X_p$ and derive expressions for the elements of the equivalent series circuit, $R_s$ and $X_s$;
- Find approximate formulas for $X_s$ when Q is large, and for $R_s$ when Q is small.

P10. Use the results from the previous problem to match an antenna that nominally has a 50Ω impedance to the output of a transmitter that has a 5-Ω impedance. The circuit that can be used for this is shown in Figure P12 below.

![Figure P10](image)

Figure P10. (a) A transmitter connected to an antenna and the equivalent circuit. (b) Converting a 50-Ω antenna impedance to a 5-Ω impedance presented to the transmitter.

Use the conversion formulas you derived above to find $X_C = X_p$ and $X_L$. To do this, first find $X_C$ so that when the capacitor and $R_p = 50$Ω resistor are converted to a series connection, the resistance is equal the desired $R_S = 5$Ω. How do you choose $X_L$? Redraw the final circuit that matches the 5-Ω transmitter output impedance to the 50-Ω antenna impedance. Indicate inductor and capacitor values in nH and nF, respectively, for our transmit frequency at 7MHz.
P11. A npn bipolar transistor with $\beta=100$ is used to make a CE amplifier with emitter degeneration, with the load equal to $R_C= 2k\Omega$ and a resistor emitter of $R_E= 20\Omega$. Calculate the voltage gain and input impedance of the amplifier, neglecting the feedback capacitor.

P12. A common-emitter amplifier circuit is shown in the figure below. Draw the ac equivalent circuit and find the input impedance (a) with and (b) without the Miller capacitance.

P13. A transistor circuit is shown in the figure below. Find the following:
- Voltage gain
- Input impedance
- Output impedance
- Power gain in dB

[This could be a common emitter, a emitter/source follower, or a differential amplifier.]

P14. A 50-ohm coaxial line is terminated in a load and fed with a 1-V RMS signal generator. If the reflection coefficient at the load is $\rho=1/3$, find the value of the load and the voltage across it. Repeat for $\rho= -1/3$, $\rho=1$, $\rho= -1$, and $\rho=0$. Find the SWR values in each case.

P15. A coax with a characteristic impedance of $Z_0$ is connected to a quarter-wave transmission line terminated in an impedance of $5Z_0$. What is the (1) input impedance and (2) reflection coefficient?

P16. A coax with a characteristic impedance of $Z_0$ is terminated in a short (or open) circuit. What is the (1) input impedance and (2) reflection coefficient?

P17. A UHF radio system for communication between airplanes uses quarter-wave monopole antennas that have a gain of 2 and are separated by a distance of $r = 100$ km. If the required received power is $P_r = 1$ pW, what is the minimum transmitted power $P_t$ required for successful transmission at 100 MHz, 300 MHz, and 1 GHz?

P18. A line-of-sight link consists of a transmit antenna on top of a 2000-m high hill and a receive antenna at sea-level. The transmit antenna has a gain of 20dB and the receive antenna has a gain of 23dB. What is the received power at maximum line-of-sight range for 10 W of transmitted power?