# Physics 127A Final Exam Information

Spring 2014 Professor Everett Lipman

The final exam will be Tuesday, June 10, from 4:00 to 7:00 P.M. in Phelps 3523 (our usual classroom). You should bring the following items:

- Your student ID or driver's license.
- A pencil.
- An eraser.
- A scientific calculator. Any type of calculator is acceptable. Calculators may **not** be shared. No computers or phones will be allowed. Specifically, you may not have any device capable of other than infrared wireless communication, or any device that can display arbitrary images or documents. Infrared ports on calculators must be turned off or covered. There are no further restrictions regarding what you may or may not do with your calculator.
- Any electronics textbooks of your choosing.

**The test booklet and the items listed above are the only things that will be allowed on your desk.** No paper of any kind other than your exam booklet and textbooks will be permitted. Some constants, conversion factors, and equations will be given on the exam.

Here is a summary of what we covered, and what you can therefore expect to see on the exam.

## 1 Foundations and Passive Components

- You should by now have a solid understanding of charge, voltage, and current at a level somewhat deeper than you did when you finished your introductory physics course.
- Circuits. The behavior of an electronic circuit is described by the voltages at the nodes and the currents flowing between the nodes.
- Resistance. You should understand how Ohm's law relates voltages to currents, and how to use it. You should also understand why it must be the case that power is dissipated in a resistor, and how to calculate that power given any two of the voltage, current, or resistance. The small signal resistance $r = dV/dI$ is for small variations of $V$ and $I$. For a resistor, $r = R$, but for a nonlinear element such as a diode, $r$ will change with $V$.
- Load lines. You should understand how to interpret load lines on a V-I graph.
- Ideal voltage and current sources. An ideal voltage source maintains a fixed voltage between its two terminals, and has zero impedance (because $\Delta V = 0$). An ideal current source produces a fixed current from one of its terminals to the other, and has infinite resistance (because $\Delta I = 0$).

- Kirchhoff's laws for voltage and current. The algebraic sum of the currents into any node must be zero, and the algebraic sum of voltage changes around a loop must also be zero. You should understand why, and know how to apply these laws.

- **Voltage dividers.** This is the single most fundamental circuit we have covered. You should know by heart that for a voltage $V_{\text{in}}$ across a series combination of two resistors $R_1$ and $R_2$, with the side of $R_2$ opposite $R_1$ grounded, the voltage at the node between the two resistors

$$V_{\text{out}} = \frac{R_2}{R_1 + R_2} V_{\text{in}}.$$

- **Input and output impedance.** You should understand the meanings and consequences of the intrinsic resistance of a non-ideal voltage source (its output impedance), and the load resistance across a circuit's input terminals (input impedance). You should be able to calculate these by finding $dV/dI$ at the relevant terminal, or by doing a voltage divider calculation.

- Equivalent circuits. You should know that any two-terminal combination of resistors and independent current and voltage sources can be replaced by a single voltage source in series with a single resistor. You should know how to find the equivalent voltage and resistance from a circuit diagram, and how to measure them.

- Meters and Oscilloscopes. You should understand the functions and input and output impedances of ideal voltmeters, oscilloscopes, and ammeters. You should also know how to model non-ideal versions of these instruments using parallel or series resistances.

- Reactive circuit elements. In your introductory physics course, you learned about capacitors, inductors, and their time-domain behavior. You should now also understand how to use complex representations of current and voltage, along with $Z_C = 1/i\omega C$ and $Z_L = i\omega L$, to analyze linear circuits in the frequency domain. You should know how to calculate voltages in reactive circuits by dividing or multiplying the relevant magnitudes if you aren't interested in phase.

- Filters and frequency response. You should know how passive high- and low-pass filters work (they are generalized voltage dividers), and how to use decibels.

- Diodes. You should understand the functions of basic semiconductor junction diodes and Zener diodes.

## 2 Bipolar Transistors

- Simple transistor model. You should understand the basic bipolar transistor model with fixed $V_{\text{BE}} = 0.6$ V and $\beta \approx 100$. Using this model, you should be able to analyze the behavior of and design bias circuits for saturated transistor switches, emitter followers, transistor current sources, and the common emitter amplifier.

- Gain. You should understand what the small-signal gain of an amplifier is, how to express it in decibels, and how to compute it for transistor amplifiers.

- Input and output impedances of transistor circuits. You should be able to find the input and output impedances of emitter followers, current sources, and common emitter amplifiers.

- Ebers-Moll model. A bipolar junction transistor can be thought of as a transconductance device with
$$I_C = I_S \left[ e^{V_{\mathrm{BE}}/V_T} - 1 \right] ,$$
where $I_S \approx 10^{-13}$ A, $V_T \approx 25$ mV at 20 °C, and $V_{\mathrm{BE}}$ is around 0.6 V when the transistor is in its active region.

- Intrinsic emitter resistance. From the Ebers-Moll model you can find that a transistor behaves as though it has a small-signal resistance $r_e \approx 25\ \Omega/I_C$ in series with its emitter, where $I_C$ is expressed in milliamps. You should understand the consequences of $r_e$ for the frequently encountered transistor circuits listed above.

- Current mirrors. You should know how a transistor current mirror works, and how it is explained by the Ebers-Moll model.

- Differential amplifiers. You should know how a bipolar transistor differential amplifier works, and what the common-mode rejection ratio (CMRR) is. You should be able to find the input and output impedances for a transistor differential amplifier.

## 3 Field Effect Transistors

- You should understand the basic operation and limitations of JFETs. Specifically, you should know why $V_{\mathrm{GS}}$ cannot exceed +0.6 V for an N-channel JFET.

- You should understand how the transconductance $g_m$ of a FET relates $I_{\mathrm{DS}}$ to $V_{\mathrm{GS}}$:
$$I_{\mathrm{DS}} = g_m V_{\mathrm{GS}} .$$
You should be able to use this relation to analyze FET versions of basic current source and amplifier circuits.

- You should be able to use JFET and MOSFET characteristic curves to determine how $g_m$ varies with $V_{\mathrm{GS}}$ and $V_{\mathrm{DS}}$ for a particular device.

## 4 Feedback and Operational Amplifiers

- Op amps. An op amp is an integrated circuit differential amplifier with
$$V_{\mathrm{out}} = A\left(V_+ - V_-\right) ,$$
where $V_+$ and $V_-$ are the voltages at the non-inverting and inverting inputs, respectively, and $A$ is the open loop gain.[1] $A$ is very large, typically $10^5$–$10^6$ at DC. To prevent oscillations, $A$ is designed to fall off with frequency for most op amps. A typical gain-bandwidth product is 4 MHz. Op amps are used with negative feedback, which lowers the gain but enables remarkable improvements in output linearity and versatility.

[1] Sometimes a distinction must be drawn between the open loop gains of the op amp itself and the circuit. In that case, we can use $a$ for the gain of the device, and $A$ for the gain of the whole circuit. For followers and non-inverting amplifiers, $A = a$. For inverting amplifiers the situation is more complicated, but this will not be covered on the exam.

- Op amp design approximations. So long as there is negative feedback, the op amp output is not driven to its maximum or minimum values, and the op amp's parameters are not exceeded,
  1. The op amp will attempt to produce at its output whatever voltage is necessary to bring the input voltage difference to zero.
  2. The inputs of the op amp will draw no appreciable current.
- Op amp replacements for transistor circuits. You should know how to use the rules above to analyze op amp current sources and find gains and input impedances for op amp followers, inverting amplifiers, and non-inverting amplifiers.
- Non-ideal op amp behavior. You should understand the limitations of real op amps, and how some of these are corrected. For example, because there is a small nonzero current sourced or sunk at the input terminals, there must always be negative feedback at DC, and a capacitor-coupled input must be accompanied by a resistor to ground. Some limitations you should know about are
  - Offset voltage
  - Nonzero input current
  - Finite slew rate, and therefore bandwidth
  - Finite output current
- The output impedance of an op amp circuit is often very low, but typical op amps cannot source or sink more than a few tens of milliamps.
- Integrators and differentiators. By placing reactive elements in the feedback network, op amps can be used as integrators or differentiators with frequency-dependent gain (active filters). You should know how to analyze these.
- You should understand how an op amp feedback loop can enclose nonlinear elements (like a push-pull transistor pair) and force the output to be linear.
- Comparators and the Schmitt trigger. Comparators measure the voltages at their non-inverting and inverting inputs, and swing the output all the way high or low depending on the sign of difference. Positive feedback can be used to make a "Schmitt trigger" with hysteresis.

Based on my experience, I believe that the only really effective way to study for a physics exam is to work many problems under the conditions of the exam. The homework problems, worked problems in AoESM, and other problems in AoE are a good place to start. The AoE "Bad circuits" problems are particularly useful for testing your understanding.

Good luck!