Final Exam Information

Rough breakdown of topic coverage:

- 30-50% BJT fundamentals and biasing
- 10-20% MOSFET fundamentals, biasing, and small-signal modeling
- 10-20% Diodes (pn-junction diodes, zener diodes, attenuator circuits)
- 10-20% Basic difference amplifiers, instrumentation amplifiers, and common-mode rejection ratio
- 10-20% Op-amps, especially non-ideal effects

See the “Course Outcomes” section of the Course Description page at the ELEC 350 web site for a more detailed list of specific competencies that are likely to be assessed.

The exam will take place **8:00-11:00 am on Thursday, December 12 in Breakiron 066 (our usual classroom during the semester)**. The exam will be designed to be approximately 1.5 hours in length, but you will have the full three hours to complete it.

You will be allowed to use up to four 8.5 x 11-inch two-sided help sheets. There are no restrictions on the material you may place on the help sheets. Please note that **all help sheets will be collected at the end of the exam** but will be returned to you later if you wish to have them back.

The final exam grade cannot be dropped. Solutions to the final exam will not be posted, but you may review your final exam and discuss it with me after it has been graded.

**Review Topics for Final 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 sheets in addition to those listed below.

Although every effort has been made to ensure that there are no errors in this review sheet, some might nevertheless appear. The textbook is the final authority in all factual matters, unless errors have been specifically identified there either by the authors (in the form of published errata) or by me. You are ultimately responsible for obtaining accurate and authoritative information when preparing for your exam.

Internal structure of bipolar junction transistor (BJT)
- **nnp**: thin p-type base sandwiched between n-type emitter and collector
- **ppn**: opposite of nnp

Qualitative understanding of operation of BJT
- turn-on voltage ($V_F$) of base-emitter junction (approx. 0.7 V for Si)
- effect of changing base current $i_B$
- effect of changing collector-emitter voltage $v_{CE}$
- directions and polarities of important currents and voltages ($i_B, i_C, i_E, v_{BE}, v_{CE}$)
- thin base region required to allow electrons (npn) or holes (pnp) to flow from emitter to collector
- emitter more heavily doped than base – allows base to fill with minority carriers when base current flows
- base-emitter junction is forward biased if $v_{BE}$ is at turn-on voltage ($V_F$)
- i-v characteristic of BE junction is the same as that of a pn-junction diode:
  \[ i_B = ISB e^{v_{BE}/VT} \]
  where $ISB$ = saturation current of BE junction, $n = $ emission coefficient (typically assumed to equal one), and $VT = $ thermal voltage, which is given by
  \[ VT = \frac{T}{11,600} \]
  where $T = $ temperature in kelvins ($V_T = 25 \text{ mV at room temp.}$)
- collector-base junction is usually reverse biased (produces depletion region) or lightly forward biased
- collector current related to base current by $i_C = \beta i_B$ in the active region, where $\beta = $ forward DC current gain (values are typically 20-300, but vary among BJT types, even among individual units of a given type within the same manufacturing batch)

BJT i-v characteristic ($i_C$ vs. $v_{CE}$ for selected values of $i_B$)
- cut-off region ($v_{BE} < V_F$, where $V_F = $ turn-on voltage of BE junction; $i_B = i_C = 0$)
- active (constant-current) region ($v_{BE} = V_F, i_C = \beta i_B, v_{CE} > 0.2-0.3 \text{ V}$)
- saturation region ($v_{BE} = V_F, v_{CE} \approx 0.2-0.3 \text{ V}, \text{ and } i_C < \beta i_B$, but $i_C$ is nonzero)

npn vs. pnp BJTs
- circuit symbols (arrow indicates the emitter terminal and BJT type; arrow of npn is “not pointing in”)
- $v_{BE}$ and $v_{CE}$ of pnp BJTs have negative values in normal operation (use $v_{EB}$ and $v_{EC}$, which are positive, instead)
- $i_B$ and $i_C$ flow into base and collector terminals of pnp BJTs and out of base and collector terminals of pnp BJTs
- i-v characteristics of npn and pnp BJTs have voltages of opposite sign

General analysis techniques for BJT circuits
- determination of region of operation (cutoff, active, or saturation)
- $v_{CE}$ (for npn BJTs) is always positive (negative for pnp; i.e., $v_{EC}$ is positive)
- graphical analysis techniques (load lines) can be applied
- $v_{BE} \approx 0.7 \text{ V}$ (for Si npn) in the active and saturation regions
- in cut-off region, $i_B = i_C = 0$ and $v_{BE} < 0.7 \text{ V}$ (for Si npn)
- in active region, $v_{BE} \approx 0.7 \text{ V}, i_C = \beta i_B$ and $v_{CE} > v_{CE|sat} \approx 0.2-0.3 \text{ V}$
- in saturation region, $v_{BE} \approx 0.7 \text{ V}, i_C < \beta i_B$ and $v_{CE} = v_{CE|sat} \approx 0.2-0.3 \text{ V}$
- for more accurate analysis (rarely necessary), use
  \[ i_C = IS e^{v_{BE}/VT} \]
  where $IS$ = saturation current, $n = $ emission coefficient (typically assumed to equal one), and $VT = $ thermal voltage

BJT inverter circuits
- can be used as logical NOT gates
- transfer characteristic ($v_o$ vs. $v_{in}$) has negative slope in active region and nearly zero slope in cut-off and saturation regions
- BJT inverter is also called a common-emitter amplifier
- has an almost linear transfer characteristic in active region
BJT biasing circuits
- design for quiescent output voltage, collector current, and/or voltage drop across emitter resistor (if present)
- usually bias BJT for operation in the active region
- must pay attention to swing range of \( v_C \) (collector node voltage) to avoid cut-off and saturation regions
  o in cut-off region, \( i_C = 0 \); also applies at the boundary between the cut-off and active regions
  o active-saturation boundary defined by (for npn devices):
  \[ V_{CE\text{active-sat.}} \approx 0.2 \text{ to } 0.3 \text{ V} \]
- the parameter \( \beta \) has strong temperature dependence and device variation
- parameter-independent biasing (emitter degeneration) using “4-resistor” bias network
  o makes use of negative feedback via emitter degeneration resistor
  o consists of
    1. collector resistor, usually labeled \( R_C \)
    2. emitter resistor, usually labeled \( R_E \)
    3. base biasing “voltage divider,” often labeled \( R_1 \) and \( R_2 \); quotes because \( I_B \neq 0 \) (i.e., \( R_1 \) and \( R_2 \) do not form a true voltage divider)
  o current through \( R_1 \) and \( R_2 \) is typically designed to be 0.1 to 1 times \( I_E \) (or 10-100 times \( I_B \))
  o trade-off: higher current through \( R_1 \) and \( R_2 \) leads to more stable quiescent point but lower input resistance and higher current demand from power supply
  o key goal: try to keep quiescent voltage \( V_B \) from varying significantly;
    alternatives:
    1. set \( V_B \approx V_{CC}/3 \) and assume \( V_B \approx V_{BB} \) (see definition below)
    2. set current through \( R_2 \) (lower base biasing resistor) to 10-20 times \( I_B \)
  o BJT in active region satisfies \( I_C = \beta I_B \)
  o common design rule of thumb: \( I_C R_C = I_E R_E = \frac{1}{3} V_{CC} \), although the voltage across \( R_E \) is sometimes designed to be less than this (if \( V_B \) set to \( V_{CC}/3 \))
  o for analysis purposes, can represent base biasing network by a Thévenin equivalent circuit consisting of: \( V_{BB} = V_{CC} \frac{R_2}{R_1 + R_2} \) and \( R_{BB} = R_1 || R_2 \)
  o variation for bipolar (pos./neg.) power supplies: use \( R_E \) and \( R_C \) but only a single resistor \( R_B \) from base to ground
- collector-to-base feedback resistor
  o simpler than four-resistor network
  o does not work well for wide variation in \( \beta \)
  o can be acceptable trade-off since there is no emitter resistor to bypass and only two resistors are needed
  o improvement: add third resistor from base to ground; can improve stability of bias point with respect to \( \beta \) variation
- constant current sources can also be used for biasing; common in integrated circuit amplifiers
Relevant course material:

HW:       #8
Labs:     #11 (reinforces concepts covered on Exam #3)
Textbook: Sections 6.1, 6.2.1-6.2.3, 6.3, 6.4.1-6.4.3; 6.7.1-6.7.3
Lecture notes: (none)
Web Links: (none)
Matlab:   (none)