MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Department of Electrical Engineering and Computer Science

6.301 Solid State Circuits

Final Exam

December 14, 2010

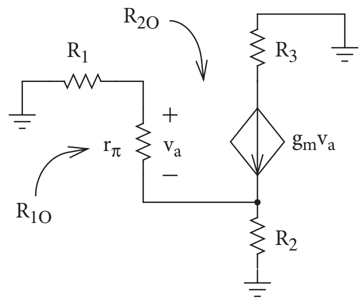
180 minutes

DuPont Gym

1. This examination consists of four problems. Work all problems.
2. This examination is closed book.
3. Please summarize your solutions in the answer sheet provided. Draw all sketches neatly and clearly where requested. Remember to label ALL important features of any sketches.
4. Make sure that your name is on this packet and on each examination booklet.

Good luck.

General equations, worst case OCT:



$$R_{10} = r_\pi \left\| \frac{(R_1 + R_2)}{1 + g_m R_2} \right.$$

$$R_{20} = \underbrace{R_1 \| [r_\pi + (\beta + 1)R_2]}_{R_\|} + R_3 + \frac{g_m r_\pi R_\| R_3}{r_\pi + (\beta+1)R_2}$$

Charge-control Equations (including space charge layers):

$$\begin{aligned} i_C &= \frac{q_F}{\tau_F} - q_R\left(\frac{1}{\tau_R} + \frac{1}{\tau_{BR}}\right) - \frac{dq_R}{dt} - \frac{dq_{VC}}{dt} \\ i_B &= \frac{q_F}{\tau_{BF}} + \frac{dq_F}{dt} + \frac{q_R}{\tau_{BR}} + \frac{dq_R}{dt} + \frac{dq_{VC}}{dt} + \frac{dq_{VE}}{dt} \\ i_E &= -q_F\left(\frac{1}{\tau_F} + \frac{1}{\tau_{BF}}\right) - \frac{dq_F}{dt} + \frac{q_R}{\tau_R} - \frac{dq_{VE}}{dt} \end{aligned}$$

When a transistor is in saturation

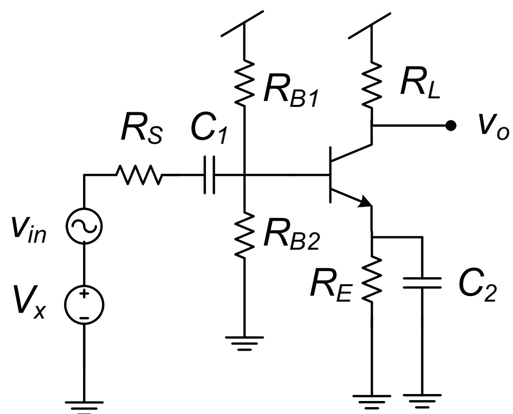
$$i_B - i_{Bo} = \frac{q_S}{\tau_S} + \frac{dq_S}{dt}$$

Problem 1 Multiple Choice with short explanation (30%) For the problems below you should do no or minimal calculation.

Make reasonable approximations. Use $I_C = 0.25$ mA (unless given otherwise), g_m =0.01 $\beta = 100$, $r_b = 0$, $C_\mu = 2$ pF, $C_\pi = 20$ pF, $r_o = \infty$.

Assume C_1 & C_2 are large for mid-band frequencies.

Assume R_{B1} & R_{B2} are large compared to r_π, R_L



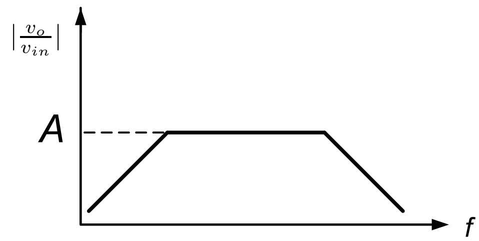
(a) What is the role of C_2?

1. Prevent oscillation / compensation capacitor
2. Reduce c_μ and increase high frequency gain
3. Prevent emitter degeneration
4. Stabilize transistor's bias point

(b) What is the purpose of C_1?

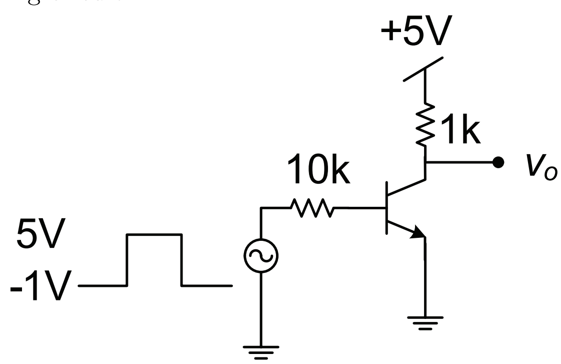
1. Prevents DC input from disrupting the bias point
2. Provides shunting
3. Compensation capacitor
4. Improves DC gain

(c) Another student builds this circuit and measures the frequency response shown below. Your task is to estimate the labeled value, A.

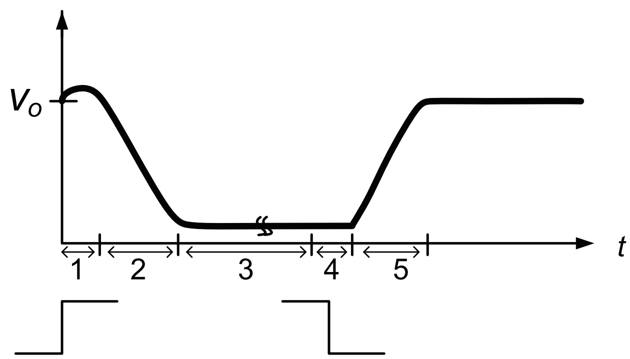


1. $\frac{R_L}{R_E}$
2. $\frac{R_L}{R_E} \cdot \frac{r_\pi||R_{B1}||R_{B2}}{r_\pi||R_{B1}||R_{B2}+R_S}$
3. $g_m R_L$
4. $g_m R_L \cdot \frac{r_\pi||R_{B1}||R_{B2}}{r_\pi||R_{B1}||R_{B2}+R_S}$
5. $g_m \frac{R_L}{R_S+1/j\omega C_2} \cdot \frac{r_\pi||R_{B1}||R_{B2}}{r_\pi||R_{B1}||R_{B2}+R_S+1/j\omega c_\mu}$

(d) Consider the following circuit.



The voltage v_0 is given below



Which of the following processes are happening in each time interval (more than one may apply).

Time Interval #1

1. Charging, discharging SCL
2. Changing saturation charge
3. Changing forward charge
4. Changing reverse charge

Time Interval #2

1. Charging, discharging SCL
2. Changing saturation charge
3. Changing forward charge
4. Changing reverse charge

Time Interval #3

1. Charging, discharging SCL
2. Changing saturation charge
3. Changing forward charge
4. Changing reverse charge

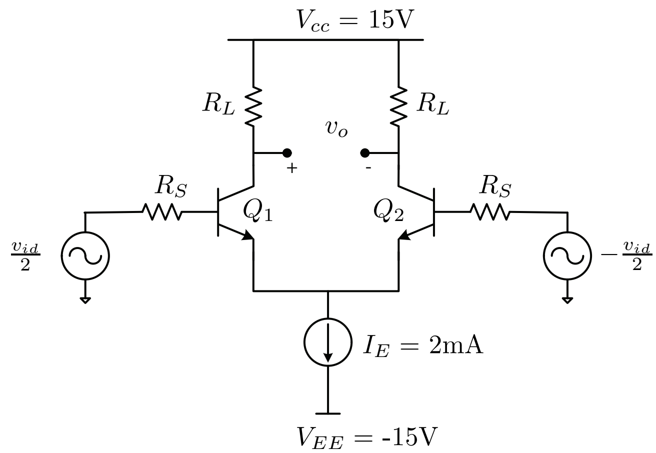
Time Interval #4

1. Charging, discharging SCL
2. Changing saturation charge
3. Changing forward charge
4. Changing reverse charge

Time Interval #5

1. Charging, discharging SCL
2. Changing saturation charge
3. Changing forward charge
4. Changing reverse charge

Problem 2 Differential Amplifiers (30%) Consider the following circuit:



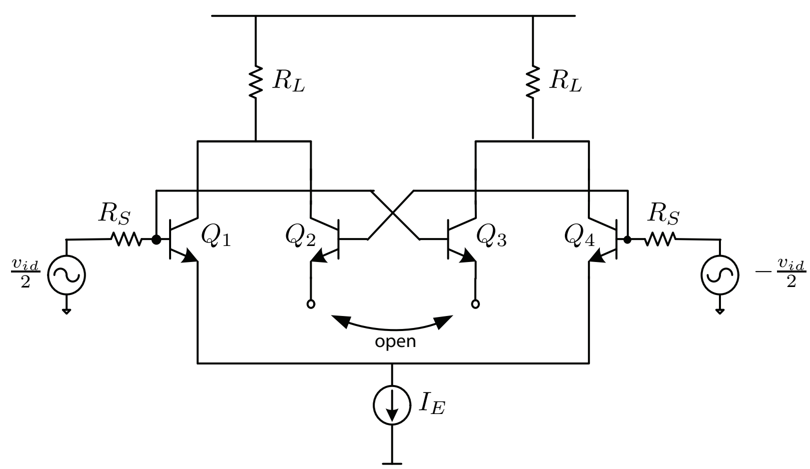
where $R_L = 5k\Omega$, $R_S = 10\Omega$, $\beta = 400$, $c_\pi = 40\text{pF}$, $c_\mu = 4\text{pF}$. Please provide numerical answers to the following parts.

(a) Calculate the midband small-signal gain. You may ignore r_b and r_o.

(b) Calculate the open circuit time constants for this amplifier. You may make reasonable approximations as appropriate.

(c) Estimate the -3dB frequency using the values from (b).

The effect of the base-collector capacitance, c_μ, can be reduced by using the following scheme:



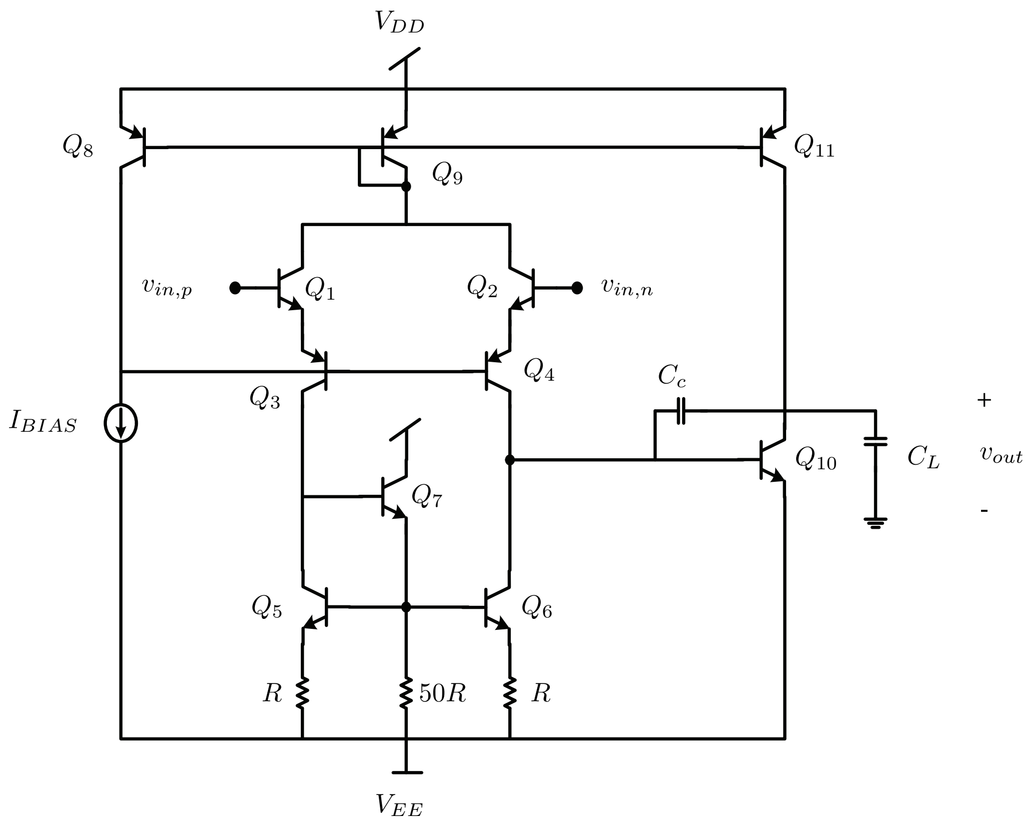
(d) Draw a complete small-signal model of the new amplifier. You may continue to ignore r_b and r_o. Note that you may also omit elements that are open-circuited.

(e) Assume that all four (4) transistors are identical and have the parameters listed at the beginning of this problem. What is the current through c_μ of transistor Q_3 in terms of v_{id} and input frequency

ω? Indicate the direction you are defining as positive current in your answer for part (d). You may make approximations as appropriate.

(f) Estimate the -3dB frequency of this new topology.

Problem 3 Op-Amps (20%) Consider the following op-amp with the input stage of a 741 shown below:



Note: All devices are matched. Please give symbolic answers to the following questions.

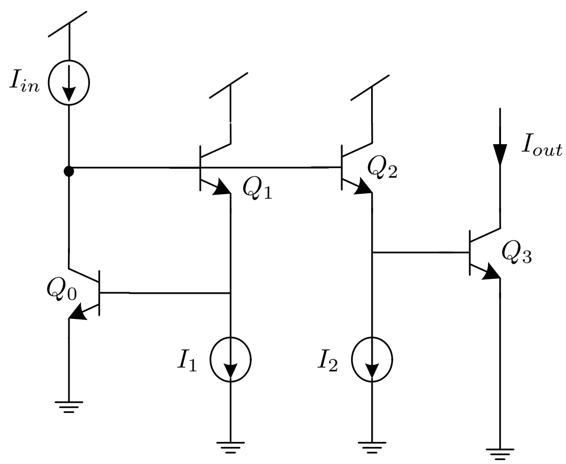
(a) Determine the input resistance, $R_{IN} = \frac{v_{in,p}}{i_{b1}}$, seen at Q_1.

(b) Determine the overall transconductance of the op-amp, $G_M = \frac{i_{sc}}{v_{in,p}}$, where i_{sc} is the short-circuit current at the output of the input stage.

(c) Determine the output resistance of the input stage, R_{out}.

(d) Fill in the table on the answer sheet, indicating whether the circuit parameter increases (↑), decreases (↓), or remains unchanged (×) when the parameters on the left-hand column are <u>increased</u>.

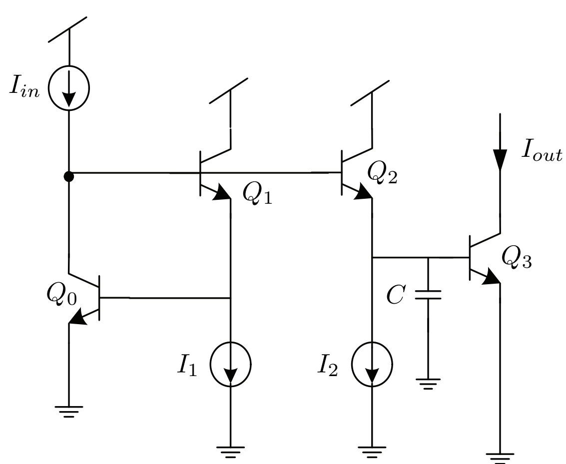
Problem 4 Translinear Circuits (20%) Consider the following circuit:



You may ignore base currents for this problem.

(a) Using the translinear principle, derive a relation between I_{in} and I_{out}. (Assume all parameters are equal.)

Now consider adding a capacitor, C, to the base of Q_3 as shown below.



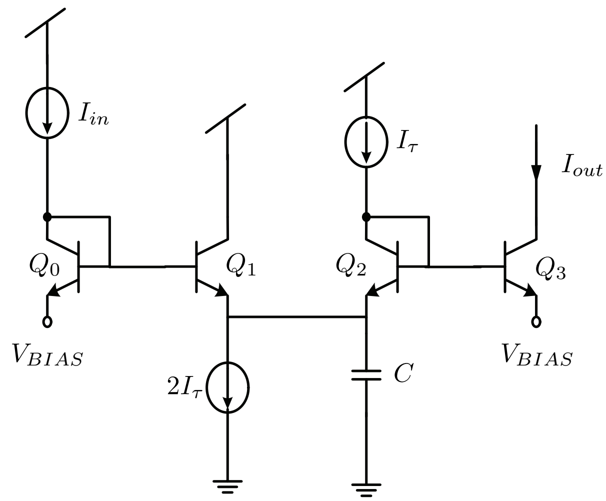
(b) Determine a relationship between the capacitor current, I_{cap}, and I_{out}.

(c) Express the output current, I_{out}, in the following form:

$$\frac{I_{out}}{I_{in}} = \frac{\kappa}{1 + \tau s}$$

Determine κ and τ.

(d) Determine $\frac{I_{out}}{I_{in}}$ for the following circuit.



End of Examination