

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Department of Electrical Engineering and Computer Science

6.301 Solid State Circuits

Midterm Quiz

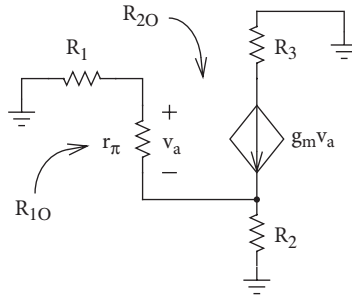
October 16, 2008

120 minutes

1. This examination consists of three 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. All problems have equal weight.
5. Make sure that your name is on this packet and on each examination booklet.

Good luck.

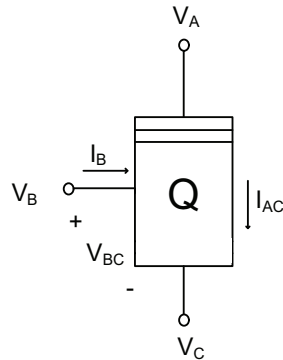
General equations, worst case OCT:



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

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

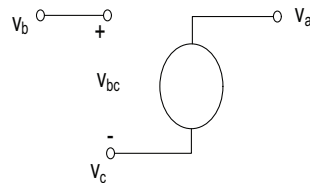
Problem 1 A new 3 terminal device is invented with the following properties:



$$I_{AC} = \kappa(V_{BC}T)^3 \text{ where } T \text{ is the temperature in Kelvin and } \kappa \text{ is a constant}$$

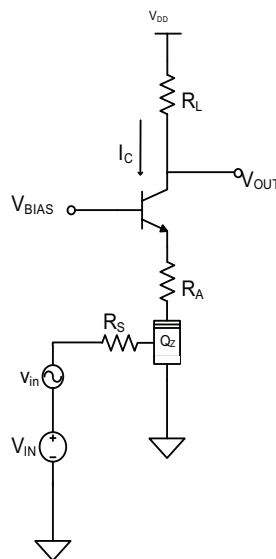
The device has infinite power gain (i.e., $I_B = 0$).

(a) A small-signal model for this device has the form shown below:



On the answer sheet, indicate the type and value of the dependent source in terms of operating point values.

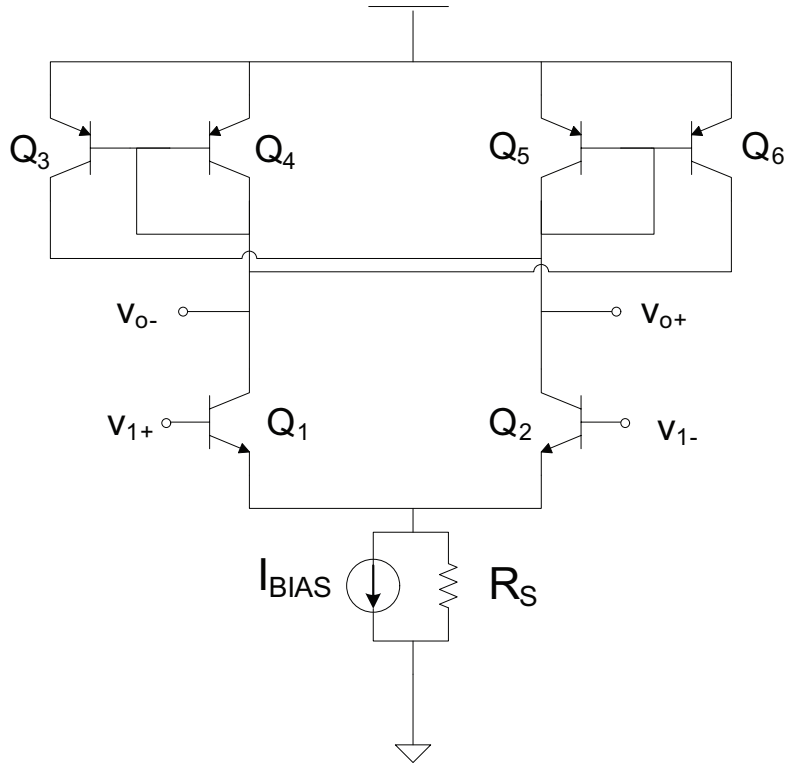
(b) An amplifier is constructed using this device as follows:



Assume the circuit is always biased so that the transistor is in the forward active region. Do not include r_b and r_o in the transistor model. Fill in the grid on the answer sheet. For each row, indicate the effect of the indicated changes on each variable with a "+" if it increases, "-" if it

decreases, and "0" if it does not change. In the grid R_{IN} refers to the input impedance of the amplifier. Points will be deducted for incorrect answers.

Problem 2 Consider the differential amplifier shown below:

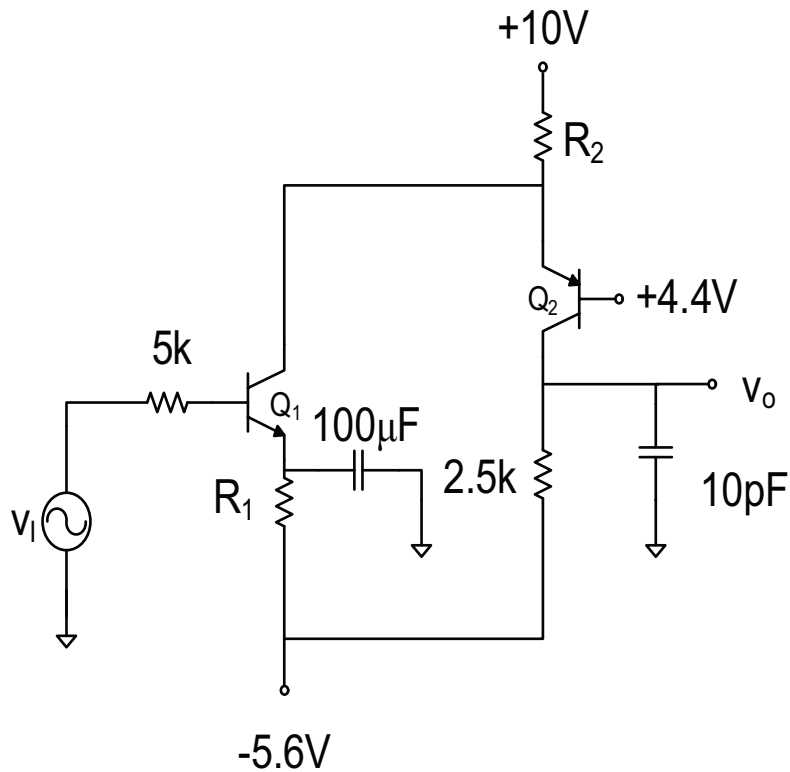


$$\begin{aligned}
 v_{od} &= v_{o+} - v_{o-} \\
 v_{oc} &= \frac{v_{o+} + v_{o-}}{2} \\
 v_{id} &= v_{1+} - v_{1-} \\
 v_{ic} &= \frac{v_{1+} + v_{1-}}{2}
 \end{aligned}$$

Express your answers to the following questions in terms of g_m and r_o , assumed to be the same for all transistors. Assume all transistors have very high β 's and matched I_c vs V_{BE} characteristics.

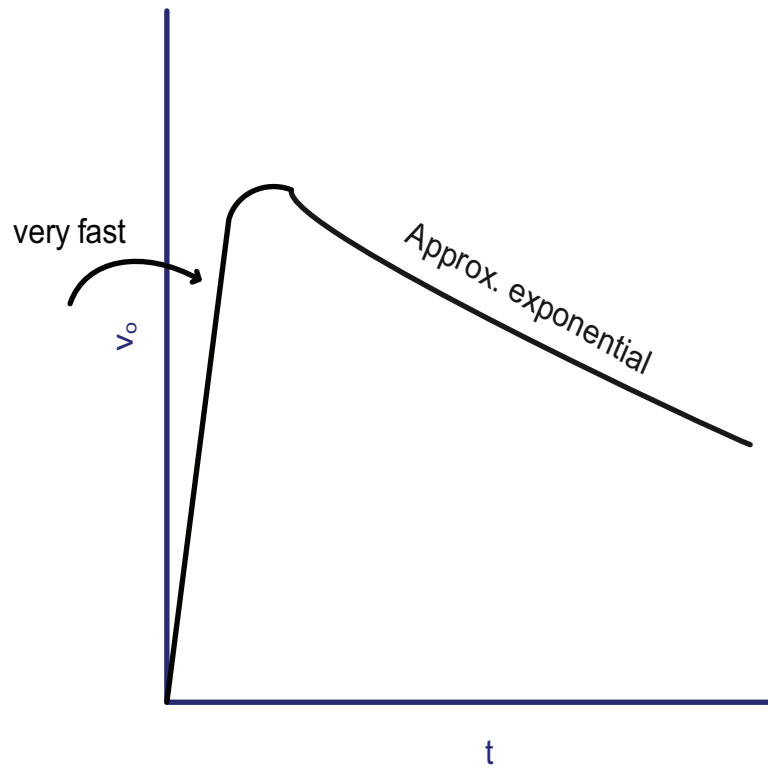
- (a) Draw the differential half-circuit model.
- (b) Derive the small-signal differential-mode gain, $A_{dm} = \frac{v_{od}}{v_{id}}$.
- (c) Draw the common-mode half-circuit model.
- (d) Derive the small-signal common-mode gain, $A_{cm} = \frac{v_{oc}}{v_{ic}}$.

Problem 3 Consider the amplifier shown below:



Both transistors have $r_b = c_\mu = 0$, $r_o = \infty$, $|v_{BE}| = 0.6\text{V}$, $\beta=200$, and $c_\pi=100\text{pF}$ at $I_C=1\text{mA}$. Make reasonable approximations in answering the following questions about this circuit.

- The operating point value of v_I is such that the base of Q_1 is at zero volts. Determine values for R_1 and R_2 that result in $I_C=1\text{mA}$ for both transistors.
- What is the magnitude of the small-signal voltage gain of the amplifier in its mid-band gain frequency range?
- This circuit has three open-circuit time constants. Determine their values.
- The output voltage of the circuit for a small negative value step applied to its input, as observed on an oscilloscope set to a slow sweep speed, is shown below.



What is the time constant of the exponential?

- (e) You may add one transistor and associated components to the circuit. What should be done to provide the largest increase in ω_h ? State the circuit modification with a very brief explanation of why it helps. You do not have to calculate the new open-circuit time constants.

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