B. E. Boser

H5: Bipolar Amplifiers

Due in the "EE 105 box" near 125 Cory Hall by 5pm on Friday 9/28/2012.

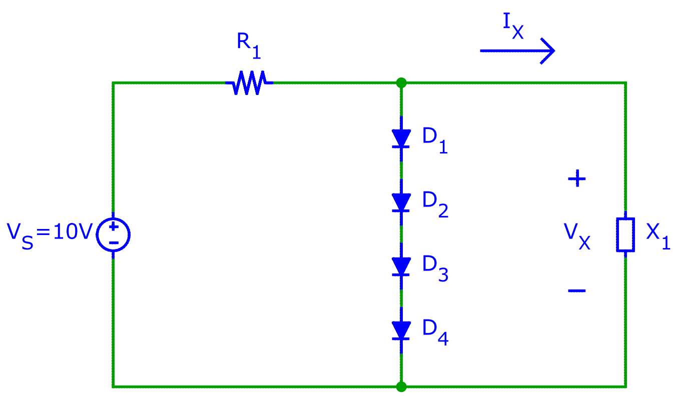
Read Chapter 5 in B. Razavi: Fundamentals of Microelectronics

1. In the circuit below, gizmo X_1 (e.g. a smart phone) draws $I_X = 0 \ldots 50\,\text{mA}$ depending on operating mode. Devices $D_1 \ldots D_4$ are silicon diodes at room temperature.

   a) The current through the diodes is $I_D = 60\,\text{mA}$ for $V_x = 2.7\,\text{V}$. What is the diode current for $V_x = 2.94\,\text{V}$?

   b) The value of R_1 is adjusted such that $I_D = 60\,\text{mA}$ for $V_x = 2.7\,\text{V}$ and $I_x = 0$. Calculate the values of V_x and I_D for $I_x = 50\,\text{mA}$.
   Suggestion: Use the approximation that the current though R_1 does not change. This simplifies the math and introduces only a small error. Why is this a good approximation?

   c) Find the minimum value of R_1 such that V_X remains in the range $2.4 \ldots 2.64\,\text{V}$ for $I_X = 0 \ldots 20\,\text{mA}$.



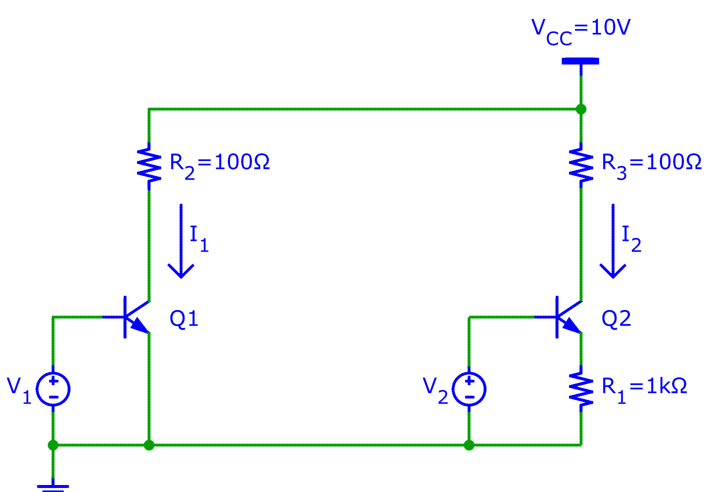
2. In the circuit below V_1 and V_2 are adjusted such that $I_1 = I_2 = I_o = 2\,\text{mA}$. Calculate the fractional change of I_1 and I_2 (i.e. $I_1/I_o - 1$ and $I_2/I_o - 1$) in percent for the following circuit modifications:

   a) The values of V_1 and V_2 are decreased by 30 mV.

   b) The values of V_1 and V_2 are increased by 30 mV.

   Transistor parameters: $I_s = 1\,\text{fA}$, $\beta \to \infty$, $V_A \to \infty$.

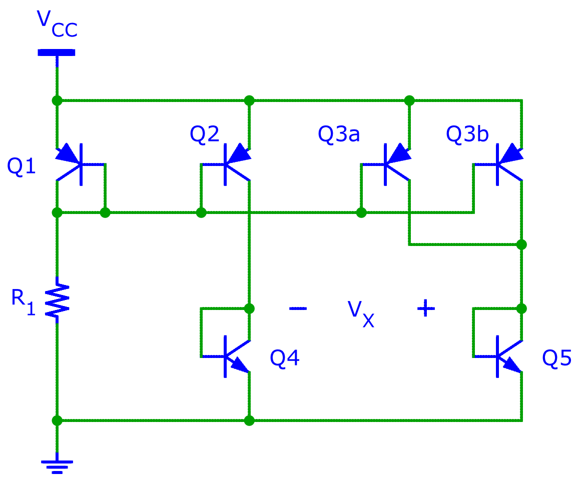
   Keep in mind that the full 30 mV appears across the base-emitter junction of Q_1. For Q_2, however, the change splits between base-emitter junction and R_1. This split is very uneven—most of the change appears about one of the two devices. Which one and why? Why does this realization considerably simplify the problem?



3. The circuit below is called "proportional to absolute temperature" (PTAT) reference.
   a) Derive an analytical expression for the voltage V_X (large signal).
   b) Calculate the value of dV_X/dV_{CC}. Why is this exciting? And why in practice do we not quite get this "ideal" result?
   c) Calculate the value of dV_X/dR_1. Why is this exciting? And why in practice do we not quite get this "ideal" result?
   d) What is the value of dV_X/dT, where T is the absolute temperature?
   e) Suggest possible uses for this circuit. There are quite many!

   Assume that all transistors are in the forward active region, have the same I_s and are at the same temperature. Use $\beta \to \infty$ and $V_A \to \infty$ to keep the equations simple.

   Hint: Determine the ratio of the collector currents in Q4 and Q5 and write equations for their V_{BE}'s.

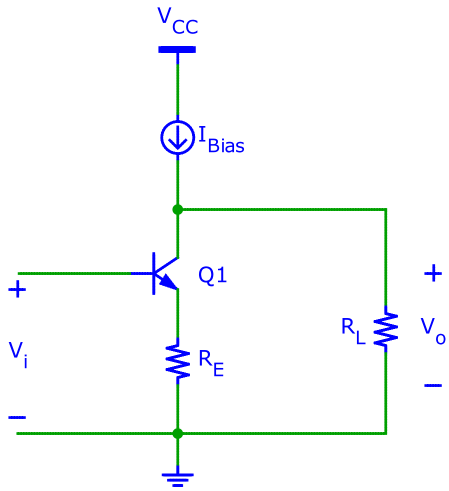


4. Problem 5.18 in B. Razavi: Fundamentals of Microelectronics.

5. Problem 5.42 and 5.43 in B. Razavi: Fundamentals of Microelectronics.

6. Problem 5.55 in B. Razavi: Fundamentals of Microelectronics.

7. The circuit below is called a common-emitter amplifier with emitter degeneration.
   a) Derive analytical expressions for the small-signal input resistance r_i at port V_i and the small signal voltage gain $a_v = v_o/v_i$ as a function of R_E, R_L, g_m, and r_π (assume $r_o \to \infty$).
   b) Determine the g_m required for $a_v = -10$ with $R_E = 1\,\mathrm{k\Omega}$ and $R_L = 10\,\mathrm{k\Omega}$. Use $\beta = 100$.
   c) Determine the large signal parameters, I_C and I_{Bias}. Use $I_s = 1\,\mathrm{fA}$, $\beta = 100$, and $V_A \to \infty$.
   d) What is the value of r_i?
   e) Repeat (b), (c) and (d) for $R_E = 0$. How does r_i change?
   f) Adding a degeneration resistor R_E gives you additional design opportunities. Explain the advantages and disadvantages of increasing R_E and situations where you might use this resistor.



VCC
IBias
Q1
+
Vi
−
RE
RL
+
Vo
−