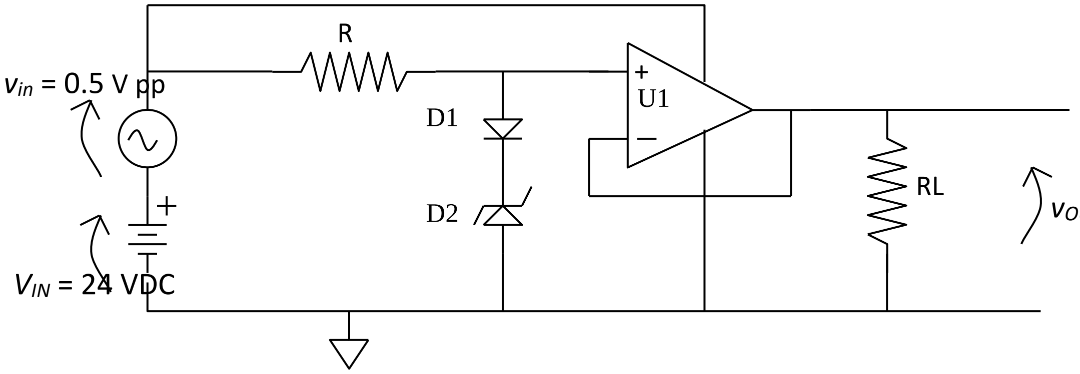
Engineering 1620 -- Spring 2016

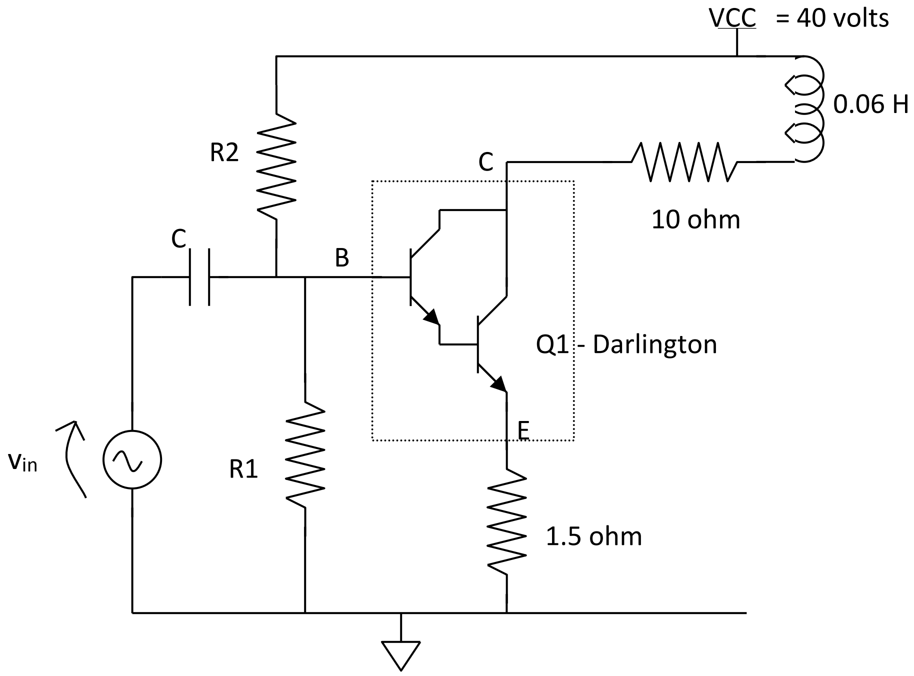
Homework Assignment 3: Diode Applications and Bipolar Transistors

1.) Many systems require very stable sources of voltage that are independent of the power mains, room temperature, etc. One way to do this is the circuit shown below. The zener diode, D2, has model parameters: I_{ZT} = 10 ma, V_{ZT} = 7.5 volts, and R_{ZT} = 12 ohms. Its temperature coefficient of voltage is +.027 % per degree centigrade. (Its V_{ZT} increases by that percentage for each degree increase of temperature. This number is known to be fairly stable for silicon devices of this breakdown voltage regardless of the details of manufacture.) The regular diode, D1, has a forward drop of .65 volts at 15 ma, an ideality factor of 1.8, and a temperature coefficient of -2.2 mv per deg centigrade. The amplifier, U1, is a power operational amplifier in a circuit that has a voltage gain of +1. What value of R should be used to set the circuit up for operation at 15 ma in D1? Find V_{OUT} and v_{out} in that condition. (Hint: you will need a small signal model for the forward biased diode to get v_{out}.) For a 10 deg increase in temperature, how much will V_{OUT} change? (Express your answer in both volts and percent. Hint: the primary effect of temperature is the change in the model DC sources.) What function does the amplifier serve? (Consider the effect of a load current in RL if the circuit did not have an amplifier and RL were for example 30 ohms.)



2.) The growth, processing, distribution, and preparation of food is the largest single industry in the United States. Personally my favorite products of this industry are baked goods, sugar being my favorite food group. The circuit below is a small piece of a production mixing system for cookie dough. It (in my dreams) is a vibrator that shakes the sugar chute to keep the flow of sugar constant as part of the first continuous casting cookie factory. A flow sensor changes the input signal under closed-loop fuzzy-logic computer control. Your job is to select the biasing resistors R1 and R2 to ensure that the circuit will always be able to shake the chute enough. Determine a set of resistor values and show by direct calculation that the circuit will maintain between 80% and 125% of the optimum I_{CQ} over transistor variations due to manufacture and temperature. (The plant is one of several to be built around the world, and each plant uses several of the shakers. No one wants to tweak each one!) The frequency of the input signal is always 60 Hz. Pick a value of C_{IN} such that the loss in the input coupling circuit is less than 1 DB for nominal $h_{fe} = 4000$.

The two transistors in the dashed box are called a Darlington pair and may be purchased as a single device. They act together like a single transistor with the effective terminals marked C, E, and B. The current gain, h_{FE} is 750 min and 20,000 max. Because there are two base-emitter junctions in series between the base and emitter terminals of the compound device, the effective V_{BEQ} is higher than for a single transistor. You may assume that the measured V_{BEQ} of 1.35 volts at 45 ° C is reliable for all devices. However, remember that each of the internal transistors is temperature sensitive and each of the internal V_{BEQ}'s changes by -2.2 mv per degree C. The circuit must work over a range of temperature from about 10 ° C in winter on startup to 80 ° C in summer operation. Because of the internal compound structure, the saturation voltage of the Darlington pair is high -- about 1.1 volts. Also this circuit is an example of reactive load used over a restricted frequency range and the appropriate formula for the optimum quiescent current in circuits of this type is the same as the one I derived in class for resistive loads even though the load is highly reactive in this case.



3.) Here is a this-and-that problem, the sort of thing one puts together to point out ideas rather than practical applications. You might find it useful to be reminded of a result I cited in class and is in your textbook, namely that the output impedance of a common collector stage is $Z_E \| \left(r_e + Z_S / \left(1 + h_{fe} \right) \right)$ where Z_S was the input signal's source impedance. You may use V_{BE} = 0.7 volts for all transistors.

3.1) What is the stage type for each of Q1 and Q2 (CE, CB, CC)?

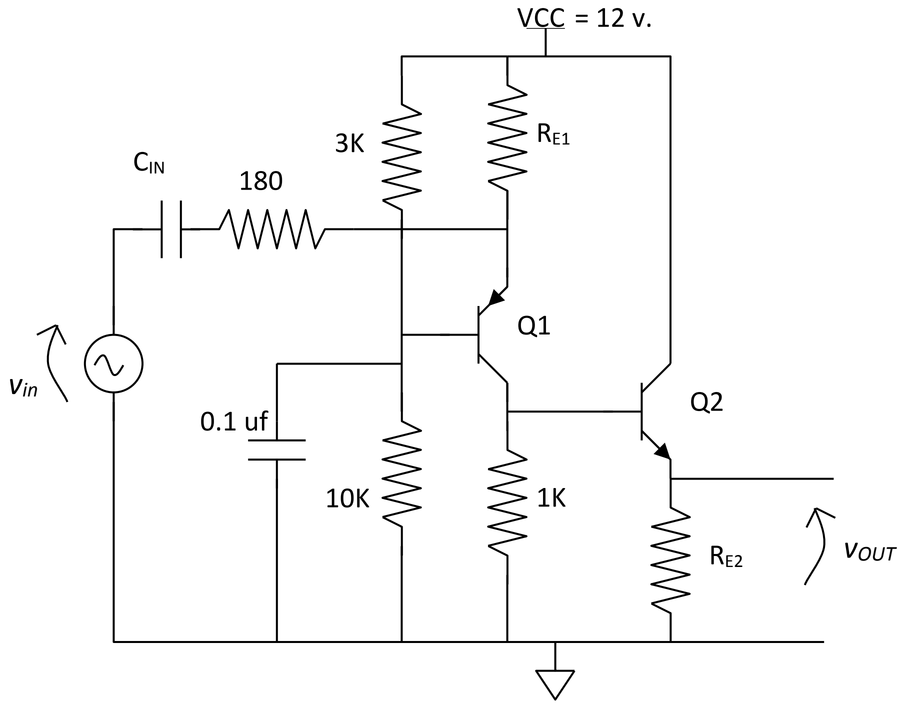
3.2) There are two undetermined resistors in the circuit. Choose one to make I_{C1} = 5 mA.

3.3) Select the other to make the circuit output impedance 18 ohms.

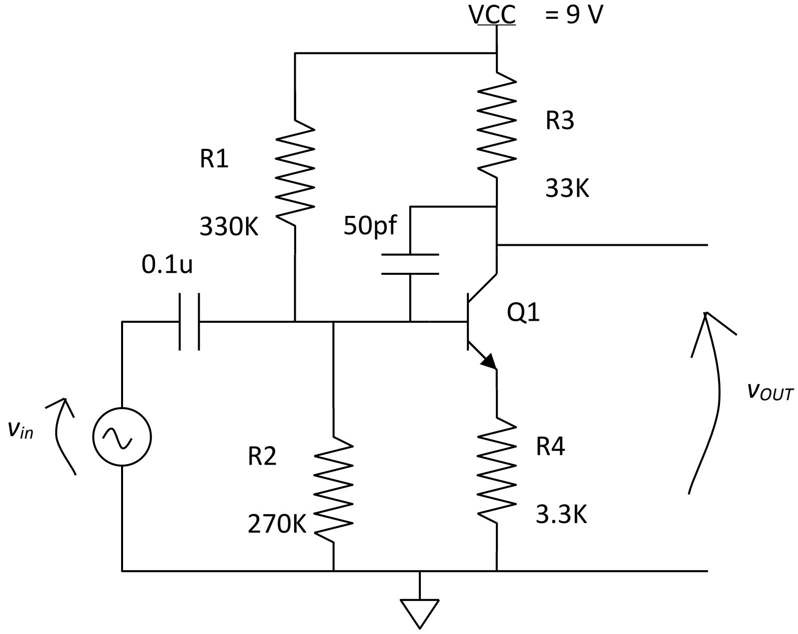
3.4) What is the midband gain of the circuit?

3.5) This circuit probably works best at frequencies around 1 MHz. Select C_{IN} to give it a low frequency cutoff of 10 kHz.

3.6) What is the function or purpose of C_{IN}?



4.) The circuit below is an example of one that might have been used in a long-ago battery-powered consumer product. The transistor, Q1, has a nominal gain of $h_{FE} = 120$, $V_{CESAT} = 0.2$ volts and I_{SE}, the Shockley coefficient for the base-emitter junction, is nominally $1.2 \cdot 10^{-14}$ amps. A reasonable value of V_{OUT} is 5 volts. For the components shown, what are the actual values of I_C and the node voltages of the base and collector terminals? (WARNING: I have deliberately made a mistake in setting up the problem.) Without changing the gain of the circuit or lowering the input impedance, change one component to set the circuit to the 5 volt output quiescent condition. What do you change and what value do you suggest? Finally, for that corrected configuration, what is the range of V_{OUT} for a range of transistor gain from 80 to 160?

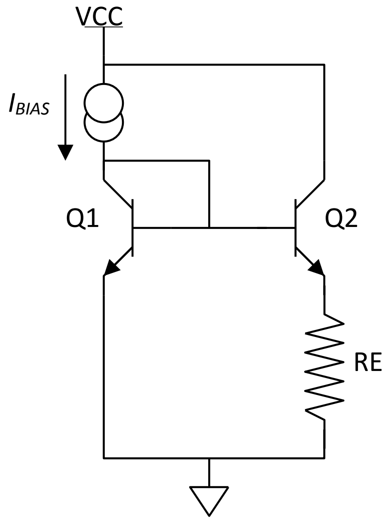


5.) The collector current for a properly biased BJT ought to depend on the base-emitter voltage, v_{BE}, as $i_C = I_{SCE} \exp\left(\frac{qv_{BE}}{nkT}\right)$ where I_{SCE} is a temperature dependent constant of the device and n is the ideality factor, a constant very near unity. I hope that your measurements in lab 2 confirmed this equation, at least for currents that are not too large. (One person in the class gave me lab 2 in pdf and I reduced the data myself, getting n = 1.05.) The circuit below is something we will not get to for another month but its analysis is well within your capability. A constant current source, I_{BIAS}, sets the collector current of Q1 while the base-emitter voltage of Q1 sets the current in Q2. The two transistors are identical so they have the same values of n and I_{SCE}. The current gains of the two transistors are $\beta = 100$. To keep the problem easy, neglect the Early effect in Q2.

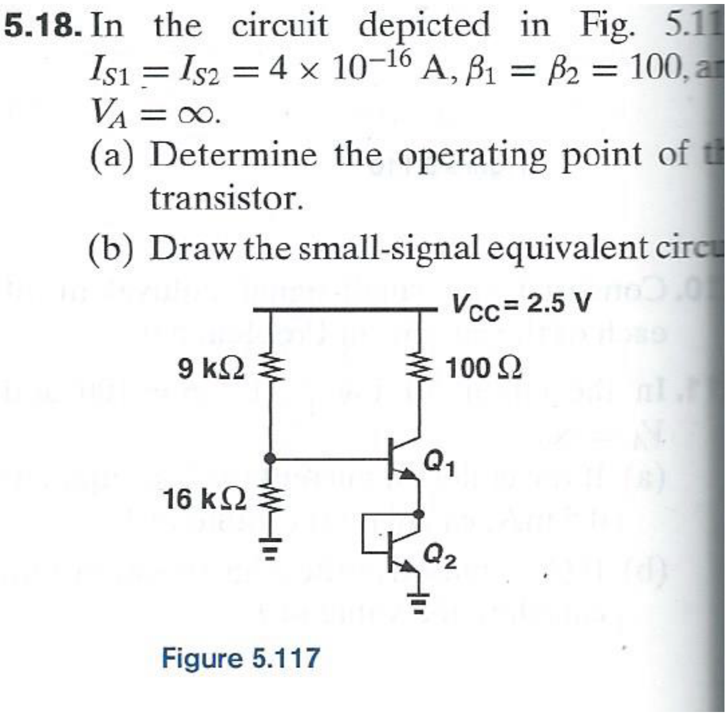
5.1) Find an equation for I_{C1}, the collector current of Q1 by neglecting the base current of Q2 but not of Q1.

5.2) Find a transcendental equation for the collector current of Q2 by using Kirchoff's voltage law. I would like the equation in terms of device parameters and the resistor RE. Again you can neglect the base current of Q2.

5.3) Suppose the current source is 1 mA and you wish the collector current of Q2 to be 50 microamperes. What value of RE should you use?



6. Razavi textbook problem 5.18 reproduced below.



5.18. In the circuit depicted in Fig. 5.11
$I_{S1} = I_{S2} = 4 \times 10^{-16}$ A, $\beta_1 = \beta_2 = 100$, a
$V_A = \infty$.

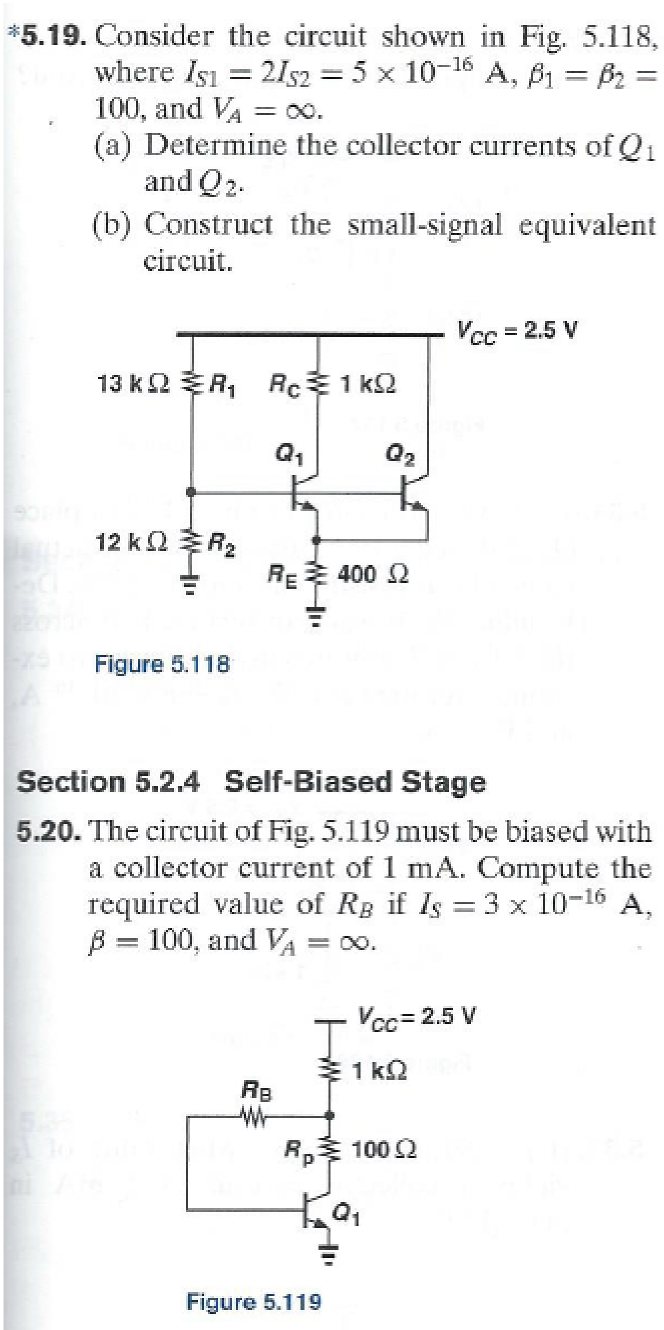
(a) Determine the operating point of t
transistor.

(b) Draw the small-signal equivalent circu

Figure 5.117

7. Razavi textbook problem 5.19 reproduced below.

8. Razavi textbook problem 5.20 reproduced below.



***5.19.** Consider the circuit shown in Fig. 5.118, where $I_{S1} = 2I_{S2} = 5 \times 10^{-16}$ A, $\beta_1 = \beta_2 = 100$, and $V_A = \infty$.

(a) Determine the collector currents of Q_1 and Q_2.

(b) Construct the small-signal equivalent circuit.

Figure 5.118

Section 5.2.4 Self-Biased Stage

5.20. The circuit of Fig. 5.119 must be biased with a collector current of 1 mA. Compute the required value of R_B if $I_S = 3 \times 10^{-16}$ A, $\beta = 100$, and $V_A = \infty$.

Figure 5.119