MASSACHVSETTS INSTITVTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.002x – Circuits and Electronics
Spring 2004

Problem Set 4

Issued: 23 February 2004

Quiz 1 will be on Friday, March 5 in your recitation section

Reading: Be sure to do the required readings *before class* as indicated.

- Before lecture on February 25, read the "BJTs without tears" handout that was distributed in lecture on February 17.
- If you need further references, read examples 129–134 (pages 513–528) from Agarwal and Lang.

Note: This problem set guides you through the analysis and design of a simple transistor circuit, following the procedure given in the "BJTs Without Tears" handout. You'll find it to be essential preparation for Case 2 tutorials.

The problem set has three parts. Parts 1 and 3 should be written up and handed in at lecture on March 1. Part 2 should be done on line before March 1.

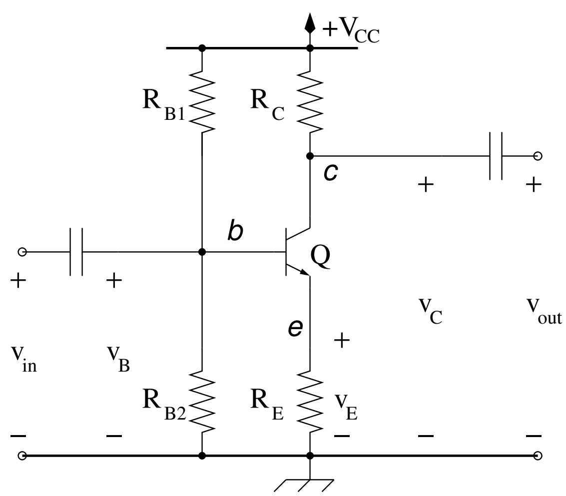

Figure 1: An essential transistor amplifier circuit. $V_{CC} = 15$ Volts

The circuit in figure 1 is an *NPN common emitter amplifier*—one of the most popular configurations of a transistor amplifier stage. We will walk through the analysis of this carefully, because it is one key to understanding how to deal with transistor amplifiers.[1]

[1] The circuit shown includes two capacitors. We have not yet introduced capacitors in 6.002, but we will in a few weeks. For now, just assume that a capacitor is an open circuit for bias voltages and currents and a short circuit for incremental voltages and currents. The purpose of the capacitors in this circuit is to isolate the signal from the bias voltages, so that this amplifier can be connected to any other circuit without the designer of the other circuit having to deal with the biasing of this circuit.

In this problem set we will learn how to design such an amplifier, by appropriately choosing the resistances of the resistors so as to satisfy some specifications. An amplifier designer might specify:

- the *incremental gain*: the ratio of the incremental voltage on the output to the incremental voltage on the input.
- the *output swing*: the largest incremental voltage on the output for which the transistor remains in the amplification region.
- a minimum *input impedance*: The ratio of the incremental voltage on the input to the incremental current into the input. Often one wants a large input impedance to avoid "loading" the signal source, by extracting excessive power from the signal source.
- a maximum *output impedance*: The ratio of the incremental voltage on the output to the incremental current into the output. Often one wants a small output impedance so that the amplifier can drive the load.

We will use the standard notations for bias and signal components of voltages and currents. The convention is to use upper-case letters and subscripts for bias values; lower-case letters and subscripts for incremental values, and lower-case letters with upper-case subscripts for total values.[2] For example, v_{B} is the total voltage on the base of the transistor, relative to the indicated ground. V_{B} is the bias voltage, which is present in the absence of a signal. And v_{b} is the incremental change to the voltage due to the imposition of a signal. So $v_{\mathrm{B}} = V_{\mathrm{B}} + v_{\mathrm{b}}$.

Part 1: To write up and hand in at lecture on Monday, March 1

Assume that $R_{\mathrm{C}} = 5\ \mathrm{k}\Omega$, and $R_{\mathrm{E}} = 1\ \mathrm{k}\Omega$. If the circuit is correctly biased, so that the transistor is operating in the amplification region, then the gain of this amplifier is approximately -5 (an inverting amplifier with a gain of 5). Write a paragraph explaining why this is true. Hint: Consider what happens if there is a small change in the base voltage v_{B} and show how this changes the collector voltage v_{C}.

Part 2: To do on line before lecture on Monday, March 1

We start with a simple analysis, assuming that we know all of the resistances. You will be answering questions online, and the system will give you a set of resistances. For this amplifier, typical values might be:

$R_{\mathrm{B1}} = 51\ \mathrm{k}\Omega$, $R_{\mathrm{B2}} = 10\ \mathrm{k}\Omega$, $R_{\mathrm{C}} = 5\ \mathrm{k}\Omega$, and $R_{\mathrm{E}} = 1\ \mathrm{k}\Omega$.

The online system will generate specfic values for you to use in your analysis.

In the questions, you will give numerical values (correct to two decimal places). You will find that it is easy to answer these questions in the order that they are given. For each question you can ask the online system for a hint that says what values can be used to deduce the answer to that question.

[2] Please don't blame us for this convention.

Crude Bias Analysis Consider the bias conditions: there is no signal imposed at the base ($v_{\mathrm{b}} = 0$). We will assume that the transistor is operating in the amplification region. Also assume that $\beta = \infty$ and that the base-emitter voltage is 0.7 volts.

1. What is the bias voltage on the base V_{B}?
2. What is the bias voltage on the emitter V_{E}?
3. What is the bias current leaving the emitter I_{E}?
4. What is the bias current entering the collector I_{C}?
5. What is the bias voltage on the collector V_{C}?
6. What is the collector-emitter voltage $V_{\mathrm{CE}} = V_{\mathrm{C}} - V_{\mathrm{E}}$?

Checking Bias Assumptions

1. Is the transistor operating in the amplification region or is it cutoff or switched on? What bias variables should you examine to determine the operating region of the transistor?
2. Assuming that $\beta = 100$, what is the current entering the base I_{B}?
3. Using this new estimate for the base current, what is the new value of the base bias voltage V_{B}?
4. Which region is the transistor operating in now?

Incremental Analysis Now that we have the bias conditions, and we know that the transistor is neither switched on or cut off, we know that it is amplfying, and we can see how signals are handled. Again, assume that $\beta = \infty$ and that the base-emitter voltage is 0.7 volts. Furthermore, assume that by some magic (not shown here) we are able to impose a signal and vary the voltage on the base by an amount v_{b}.

1. (a) What is the incremental voltage change on the emitter v_{e} caused by the change of base voltage? *We say that "The emitter follows the base."*
   (b) What is the incremental voltage change on the collector v_{c} caused by the change of base voltage?
   (c) What is the ratio $v_{\mathrm{c}}/v_{\mathrm{b}}$? This is the incremental gain of the amplifier.
2. What is the increment of base voltage from the bias point that makes the transistor switch on?
3. What is the increment of base voltage from the bias point that makes the transistor cut off?
4. What is the amplitude of the largest sinusoidal voltage signal that can be generated on the collector without serious distortion? *We call this the "swing."*
5. What is the input impedance of the circuit?

Part 3: To write up and hand in at lecture on Monday, March 1

Increasing the gain

1. Suppose we want 20% more incremental gain, which resistors should we change? How?
2. If we change the gain by changing these resistors how does the change affect the bias point? the swing?

Amplification Assume again that $\beta = \infty$ and that the base-emitter voltage is 0.7 volts, and that the values for the resistors are as in figure 1.

1. Draw the incremental model for the circuit.
2. What is the incremental Thévenin resistance seen, looking into the base of the amplifier (i.e., from the pair of terminals identifed in the diagram by potential difference v_{b}).
3. How much power is absorbed by the amplifier from an incremental voltage source v_{b} driving the base?
4. What is the incremental Thévenin resistance looking into the emitter?
5. What is the incremental Thévenin resistance looking into the collector?