

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
Department of Electrical Engineering and Computer Science

## 6.301 Solid State Circuits

Fall Term 2010  
Lab 1

Issued : Friday, Sept. 17, 2010  
Due : Friday, Oct. 1, 2010

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Work independently. Consultation with the 6.301 staff and other inanimate objects is encouraged. Read this handout and the “Lab Reference” thoroughly. Be sure to read anything written on the blackboard in the lab.

**Prelab** : Read the data sheets included in the “Lab Reference” for the 2N3904 and the 2N3906. These are the devices that we will be using in the lab.

Extract from the data sheets the familiar “hybrid- $\pi$ ” parameters (find  $I_S$ ,  $\beta_0$ ,  $V_A$ ,  $\tau_F$ ,  $c_{je0}$ , and  $c_{\mu 0}$  for both transistors). The data sheets are written in terms of “ $h$ ” parameters (“to obscure the poor quality of the product,” some say), so you may find the following relations helpful:

$$h_{fe} = \beta_0 \quad h_{oe} = \frac{2}{r_o} \quad c_{ob} = c_{\mu} \quad c_{ib} = c_{je} \quad f_T = \frac{g_m}{2\pi(c_{\pi} + c_{\mu})}$$

Note that these “spec sheet” parameters are specified at one particular operating point ( $I_C$ ,  $V_{CE}$ ,  $V_{BE}$ , etc.). In your calculations, you will have to pay close attention to how the transistor is biased for each specification (especially the biasing of the pn-junctions for the input and output capacitances). Assume  $r_b = 200\Omega$  for low currents. For the collector-base junction capacitance use  $\psi_c = 0.6V$  and  $m_c = 0.5$ . Convince yourself that your results are consistent with the “typical” curves shown in the spec sheets. Use only these parameters in your SPICE model and include the results in your lab report.

**Project** : A two-stage common emitter amplifier is a good way to implement a simple high-gain amplifier. Since the specification includes low output resistance, you should include an emitter follower at the output of the two-stage amplifier. For this lab assignment, you are to design, build, and test such an amplifier using NPN transistors that meets the following specifications:

midband gain	> 1000
DC output voltage	$3V \pm 0.5$ (worst case)
AC output swing	> 1 $V_{pp}$
source resistance	1000 $\Omega$
output resistance	< 100 $\Omega$
supply voltage	+5 V only
power dissipation	< 10 mW
devices (3)	2N3904

These are minimal specifications. You should find it easy to design a circuit which exceeds some or all of these performance requirements. Assume that  $\beta_F$  varies between 100 and 400, and that  $V_{BE}$  varies between 0.5V and 0.7V due to manufacturing tolerances and temperature variations. You should NOT design your circuit to work with a particular set of transistors. It should work with any 2N3904 transistor. In your lab write-up, discuss the effects of transistor parameter variations on your operating point.

Work out a preliminary design based upon typical numbers in the device spec sheets. Convince yourself that you understand this topology. Do not attempt to build a circuit until you have finished the design. “ $R_{mysterious}$ ” potentiometers and other parts “to be specified later” reflect VERY poor design practice. It is much easier to debug a circuit if you understand its operation and can predict its performance.

There are many acceptable solutions to this design problem. The goal of this lab is not simply to see if you can get something working which meets the specifications... the goal is to get something working and *understand why it works the way it does*.

**Lab Work** : Construct your design and make all the required measurements : gain, operating point, upper bandwidth, etc. Measure all of your component values.

When building your circuit, try two different layout methods. In the first layout, make the circuit as small as possible, using adjacent rails in your nerdkit for the collector and the base of your transistors. In the second layout, tie every-other rail to ground, and only use the rails in-between the grounded rails. Still attempt a tight layout, but be sure to put a grounded rail between the collector and the base of your transistors. Measure the high frequency 3dB point of each layout. Report and explain your observations in your write-up (hint: the interrail capacitance of the protoboards in your nerdkit is about 2.5pF).

Using the curve tracer, measure the  $\beta_0$  of your transistors around your design operating points. We have a Vector-Impedance meter that can accurately measure  $c_{\mu}$ , with the proper collector-base bias voltage. Measure the devices at several different operating points so that you can check for consistency in the data.

Since we are building a high gain amplifier, you will need a very small input voltage to test your circuit. Since the signal generators in lab cannot effectively produce small signals, you must build a 1000:1 attenuator for your circuit. Also, be sure to properly terminate the output of the signal generator with  $50\Omega$ .

**Write-Up** : Prepare a report describing your design effort. Include a labeled schematic of your design, and a table of specifications comparing calculated, simulated, and measured values. Include an OCT analysis and appropriate SPICE printouts. Be sure to explain any discrepancies between your calculations and observations.

The lab report should explain three basic things: how you arrived at your design (including component values and the constraints involved), how you verified your design in the lab (including what your measurements were, and what they illustrate) and what accounts for the difference between your design calculations and the actual measurements. Calculations supporting your discrepancy analysis should be shown. Refer to the Lab Reference for more detailed guidelines.

While brevity is not graded, a report written in a neat, clear, and concise manner will be most successful. Reports written in cursive with a blunt pencil are expressly discouraged.

**Check Off** : After you have completed all your work — design, debugging and writeup — and have convinced yourself that your results are consistent with the theory, you will be asked to convince a Lab Assistant. Signups for checkoffs will be announced in lecture.

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