University of Michigan
EECS 311: Electronic Circuits
Fall 2008

LAB 5 – THREE-STAGE AMPLIFIER

Issued 11/10/2008
Design and Measurement Complete 11/24/2008
Report Due 12/1/2008

Introduction

The goal of this lab is to design and build a three-stage amplifier with the specifications shown in Table 1. Only one design and one report are required per group. It is expected you will work together with your partner to characterize three 2N3904 NPN transistors, design the amplifier through hand-calculations and Cadence simulation, build the circuit and measure the performance, and write the report.

Specification	Value
Mid-band Voltage Gain (with R_L)	$\lvert v_o/v_s \rvert \geq 1000$
Lower 3dB Cutoff Frequency	$f_L \leq 100\ Hz$
Upper 3dB Cutoff Frequency	$f_H = 22\ kHz \pm 2\ kHz$
Input Impedance	$R_{in} \geq 100\ k\Omega$
Output Impedance	$R_{out} \leq 100\ \Omega$
Maximum Output Voltage Swing (at 10 kHz)	$v_{o(max)} \geq 1\ V_{ppk}$
Source Resistance	$R_S = 50\ \Omega$
Load Resistance	$R_L = 1\ k\Omega$
Bypass Capacitors (C_{BIG})	$\leq 47\ \mu F$
Power Supply	$12\ V$
Power Consumption	$\leq 50\ mW$
Optional: Power Consumption	$\leq 12\ mW$

Table 1. Three-stage amplifier specifications.

There is no prelab report due for this lab; however, this is a time consuming lab that requires in-lab measurements be made during both weeks. Your goal should be to have the characterization of the 2N3904s, and all design and Cadence simulation completed by the beginning of Week 2 of this lab.

Amplifier Design

L5.1 Characterize three 2N3904 NPN transistors the same way you did for Lab 4. Measure I_C over a range of I_B and V_{CE} values using the HP4155. Measure C_μ over a range of V_{CB} values. This part should be completed during the first week of lab. Use the colored Liquid Paper to mark the devices to distinguish between them.

http://www.eecs.umich.edu/courses/eecs311/f08/tutorials/hp4155.html

L5.2 Circuit Topology: You are free to use any circuit topology of three stages or less that meets the specifications. The input and source resistance must be AC coupled to your amplifier through a bypass capacitor. The load resistance must also be AC coupled to your amplifier through a bypass capacitor. The suggested topology is stage 1) common-emitter with degeneration, stage 2) common-emitter, and stage 3) common-collector. In order to accurately set the upper cutoff frequency, add a high frequency capacitor somewhere in your amplifier to dominate the OCTC expression for ω_H. Make sure the OCTC resistance for this capacitor is a well-defined value (e.g. r_π is not well-defined; however, resistors you add such as R_C are).

L5.3 Hand Design: Design each stage of the amplifier independently; however, for each stage you may need to consider the loading of the following stage. Model each stage as having an R_{in}, G_m, and R_{out} component. Then cascade the three stages to get the overall performance. Ignore values whenever possible to simplify your expressions and get them in a form that is useful for design. During this part of the design, it is better (and faster) to *over*-simplify your expressions and then go back later to revisit your assumptions if required.

L5.4 Simulation: Put your amplifier in Cadence and simulate the DC, AC, and transient response to verify all specifications are met. Download the *lab5.mod* model file and save it to your Cadence working directory (~/eecs311_f08). This model file will serve as a template.

http://www.eecs.umich.edu/courses/eecs311/f08/labs/lab5.mod

Edit the values of *Bf*, *Vaf*, and *Cjc* in the *lab5.mod* file for each device to match the values measured in lab. Use the base-to-collector junction capacitance model to approximate a value for *Cjc* using $Vjc = 0.75$ and $Mjc = 0.3085$.

$$C_\mu = \frac{\mathrm{Cjc}}{\left(1 + \frac{V_{CB}}{\mathrm{Vjc}}\right)^{Mjc}}$$

For the three *npn's* in your schematic, give each one a different model name, which are found in the *lab5.mod* file: *lab5_npn1*, *lab5_npn2*, *lab5_npn3*. Before running a simulation, within Analog Environment add the *lab5.mod* file under *Setup > Model Libraries …*, click *Browse*… and find your *lab5.mod* file. Click *OK*, *Add*, and *OK*.

Refer to the online Cadence tutorial for additional help using Cadence.

http://www.eecs.umich.edu/courses/eecs311/f08/tutorials/cadence.html

L5.5 Lab Exercises: Build your amplifier in the lab. Measure the values of each resistor used in your circuit. It will help to build and measure each stage separately and confirm the response matches predictions as you go along.

Measure the DC voltages on every node when no input signal is applied and record them for your report.

Build a 100:1 attenuator with a source resistance of 50 Ω and AC couple it to the input of your amplifier. Measure the attenuation factor of the circuit.

Measure the gain over a range of frequencies, specifically capturing the gain around the cutoff frequencies. Measure input and output voltage amplitudes simultaneously when recording the gain.

Record the output signal when the output amplitude is at the specified output peak-peak value, and the frequency is $1\ kHz$. Use Scope Connect to record the waveform and include it in your report.

http://www.eecs.umich.edu/courses/eecs311/f08/tutorials/dso3000.html

When your circuit meets all specifications, have the GSI check you off and sign your results summary sheet.

L5.6 Post-Lab Analysis: Return to Cadence after completing the measurement portion of the lab. Using measured resistor values, and measured bias currents (obtained from measuring DC node voltages), determine the sources of any discrepancies between measured results and simulations. Include this analysis in your lab report.

Report

Guidelines for the report are available in the Lab 5 Report Template. You will be graded based on neatness and the quality of your report. Print Cadence schematics to an EPS or redraw them in your report (no screen captures). Print Cadence simulations to an EPS or replot in Matlab (no screen captures). Plot measured data in Excel or Matlab. Type equations. Be thorough in your analysis and discussion of your amplifier, and explain any discrepancies between measured and predicted values.

http://www.eecs.umich.edu/courses/eecs311/f08/labs/lab5reporttemplate.doc

Grading

Category	Percent
Design Strategy	10%
Hand Analysis and Design	20%
Cadence Simulations	20%
Measured Circuit	10%
Specifications Met	15%
Report	25%
Total	100%

Table 2. Grade weighting.

University of Michigan
EECS 311: Electronic Circuits
Fall 2008

LAB 5 – RESULTS SUMMARY

NAMES: _______________________________ _________________________________

Use the following lab report template to record your measurements. Use the space provided to answer questions.

Results Summary

Parameter	**Spec**	**Measured**	**Units**
$\lvert v_o/v_s \rvert$	≥ 1000		V/V
f_L	$\leq 100\ Hz$		Hz
f_H	$22\ kHz$		kHz
P_{diss}	$\leq 100\ mW$		mW
I_{C1}	n/a		mA
I_{C2}	n/a		mA
I_{C3}	n/a		mA

Table 3. Results summary table.

Have the GSI check you off once your circuit meets all specifications. Be prepared to answer questions about your circuit or the results.

Exercise .... Date Completed

Demonstrated working amplifier..________________