Project 1

Due Thursday, April 7, 2016 by 5 p.m.

Purpose

The goals of this project include:

• Gain practical experience employing circuit techniques discussed in class and solidify your understanding of material presented in class.

• Improve your ability to understand and solve real-world problems that occur in the design and test of electronic circuits.

• Improve your understanding of the capability and shortcomings of hand analysis and simulation in circuit design.

Specifications

Working in groups of two, design an amplifier to meet the following specifications:

• Operates from single supply of no more than +10 V, and consumes no more than 500 mW of power. This corresponds to 50 mA at a 10 V supply, though proportionally more current can be used if a lower supply voltage is used.

• \( R_{in} \geq 10 \, k\Omega \) when driving a 1 k\( \Omega \) load.

• \( R_{out} \leq 50\Omega \) when driven by a 50 \( \Omega \) source.

• \( |A_V| = 14 \, \text{dB} \pm 1\, \text{dB} \), when driven by a 50 \( \Omega \) source and driving a 1 k\( \Omega \) load.

• Linear input range of at least 50 mV amplitude while driving a 1 k\( \Omega \) load. The ability of your amplifier to handle an input signal of a given amplitude depends on the both the input range and output range of all stages. This should be demonstrated by a measured Carrier-Spur Ratio (CSR, explained below in item 6 of “Test Procedures”) of at least 26 dB.

• Minimize power consumption. Keep in mind that \( P = I \cdot V \), so you may choose to focus on current, voltage, or both. Part of your grade will be determined by how well you design minimizes power consumption. The specified maximum power is a rather high ceiling, so you should work to bring your power consumption well below this.

• Use at least two stages.

• Built from transistors available in ECE parts store.

• Tested at 1kHz.
Design Process

Begin by choosing a topology based on the considerations discussed in class. This means that you will decide how many stages, which structure (e.g., common-base, common-emitter, etc.) to use for each stage, and what type of device to use in each stage. As you are choosing a topology, use hand calculations to estimate the component values and bias currents needed for each stage. You can supplement hand calculations with performance figures from device data sheets; this will be particularly useful for estimating the $g_m$ from $I_D$ in MOS transistors.

Once you have a topology that looks close, you can use SPICE simulations to check your initial estimates. Choose the transistors from those available in the parts store. SPICE models for some of the transistors are on the class web page; others should be available on the internet. Based on your simulation results, you may decide to change your topology or component values.

Use hand analysis to calculate the small-signal gain, input resistance, and output resistance of your amplifier. This hand analysis will be included in your report.

After you have simulation results that meet the specifications, you can begin to build your circuit. You may use either a solderless breadboard, or “perf-board” and solder the components. It is recommended that you test each stage independently before attempting to test them all together.

Test Procedure

![Diagram](image_url)

**Figure 1:** Test setup for measuring gain

1. With no additional source resistance (i.e. $R_{\text{Test}} = 0\, \Omega$ in Figure) and a 1 kΩ load, measure your amplifier’s gain. Do this by measuring both the input and output voltage using the oscilloscope. You may want to use the amplitude measurement provided by the scope. This measurement should satisfy the gain specification listed above. Your input should be a sine wave at 1000 Hz. Capture a screenshot from the scope showing the input and output. The axes should be scaled such that several cycles are visible on the screen and that both the input and output occupy a few vertical divisions.

2. With the same setup as in step 1, gradually decrease the frequency until the gain has decreased by about $\sqrt{2}$ (-3 dB). Make a note of this frequency, which is the lower cutoff frequency of your amplifier. Capture an oscilloscope screenshot at this frequency for your report.

3. With the same setup as in step 1, gradually increase the frequency until the gain has decreased by about $\sqrt{2}$. Make a note of this frequency, which is the upper cutoff frequency of your amplifier. Capture an oscilloscope screenshot at this frequency for your report.

4. Return the frequency to 1 kHz and insert a resistor in series with the function generator ($R_{\text{Test}}$ in Figure). Choose a standard-valued resistor that is close to the expected input resistance of the amplifier. For example, if simulations indicate that your input resistance should be 45 kΩ, you might choose a 47 kΩ $R_{\text{Test}}$. Measure the voltage amplitude on both sides of the inserted resistor. If $R_{\text{In}} = R_{\text{Test}}$, then the amplitude at the input to your amplifier should be one half that at the output of the function generator. Based on the ratio of amplitudes of the two signals you measure in this step, calculate the input resistance of your amplifier.
5. Change the source resistance back to 1 kΩ and insert a resistor between the output and ground (R_{Load} in Figure) roughly equal to the expected output resistance (choose it as in the last step). Measure the gain again as in step 1. Based on the original gain from step 1 and the gain measured here, calculate the output resistance.

6. Using the “Math” function of the oscilloscope, display the FFT of the output signal. Set the y (amplitude) axis to “dBVrms.” Adjust the x and y scales so that you can easily see the fundamental (1 kHz) and up through the third harmonic (3 kHz). Reasonable settings here are 10 or 20 dB/div for the y scale and 500 or 1000 Hz per division for the x scale. As you increase the input amplitude, you should see that the harmonics increase faster than the fundamental. The ratio of the fundamental to the largest harmonic is the Carrier-Spur Ratio (CSR). Find the input amplitude where the largest harmonic (probably the second at 2 kHz) is 26 dB below the fundamental. Record this as your linear input signal range and capture an oscilloscope screen shot.

7. Using the precision ammeter, measure and record the current consumption from the positive power supply, both with zero input amplitude and again with the maximum input amplitude you determined in step 6.

Report Contents and Format

Document the design and testing of your amplifier in a report formatted to be easily readable and clear. The IEEE paper format is acceptable, but not required. Templates for the IEEE format in both MS Word and LaTeX are available on the class web page. Figures should be included in the body of the document, not printed separately and stapled to the back. **Note:** Be sure your figures are readable. In particular, they should use a white background and the font size should be large enough to be readable. This can be configured in the LT-Spice options dialog. Your report should include the following sections:

**Introduction** Describe the purpose of the project, what you intended to accomplish, and inform the reader about the upcoming sections. Two to three paragraphs should be sufficient.

**Design Process** Discuss the reasons behind your choice of topology and the process by which you arrived at the component values. If you have typed your hand analysis, include it in this section. If not, include it as an appendix, and reference it from this section. You should at least have calculations that predict your required small-signal parameters (e.g. what g_m is required in each stage?). Your schematic should also be included in this section, drawn using the software tool of your choice (Visio, LTSpice, etc.). Be sure that the images are on a light or white background are are readable in the report; this may require some experimentation in the export process.

**Results** Include the measurements and oscilloscope screen shots that you took during testing as well as the following simulation results:

- Transient simulation analogous to the experiment in step 1 above. Include plot of waveform.
- Magnitude bode plot from an AC simulation, showing the upper and lower cutoff frequencies.
- Simulated values of R_{In} and R_{Out}.
- Find the maximum signal amplitude through simulation, following the same procedure as in step 6 above.
- Find the simulated current consumption as you did in step 7 above.

Also include a table summarizing the following performance measurements: initial gain, gain with R_{Test} = 0Ω and R_{load} = 1000 Ω, upper and lower cutoff frequencies, current consumption, power consumption, and maximum input amplitude.

**Discussion** Compare your measurement results, simulation results, and predictions based on hand analysis for each of the items listed in the testing procedure and in the results section. Were they similar? What might account for the difference? Describe any difficulties you encountered in the design or testing phase.

**Conclusion** Briefly summarize your results. Did you meet the specifications? What did you learn? What might you do differently if you were doing the design again? Were there modifications you might have explored given more time?

Your lab checkoff sheet should be included at the end of your report.
**Electronic Performance Summary**

Additionally, send an email to the instructor with a subject of “Project 1 Results” and a single line summarizing your performance in the following format:

<Gain in dB>; <supply voltage>; <supply current in mA>; <input resistance>; <output resistance>; <maximum input amplitude>; <sequence of stages>

Sequence of stages should be abbreviations for the stages you used from input to output (common-collector=CC, common-source = CS, etc.). For example,

20.3;4.5;0.8;48.8;758;0.142;CBCD

would indicate that $A_V =20.3$ dB, $V_{CC} =4.5$ V, $I_{CC} =0.8$ mA, $R_{In} =48.8\Omega$, $R_{Out} =758\Omega$, the maximum input signal amplitude is 142 mV, and the amplifier was built with a common-base input stage and a common-drain output stage.