Overview

The midterm lab report tests your understanding of EECS 16B Labs 1-5, with an emphasis on conceptual and analytical understanding. It also allows you to look at these labs from a bigger picture and reflect on your design process and choices. You may use your homeworks, pre-labs, labs, lab notes, presentation slides, and any other resources we provided throughout the semester to help you. **However, all of your answers and explanations must be in your own words; you are not allowed to directly copy from those resources.**

Requirements

Format

The report is to be done with your lab group using LaTeX or Google Docs/Microsoft Word. **At the top of the report, please include the names and emails of all your group members, as well as the group ID you use for checkoffs.**

Deliverables

For each section 1-5, complete the following:

- First, give a summary in your own words of what you did in that lab. Possible details to include: overview of the lab's objective, new components used, issues you encountered, etc. Details NOT to include: how you left your car at home, fried your BJT, or forgot to enable high-Z mode on your function generator.
- Then, answer all of the questions listed under the section header. Remember to fully and clearly explain your answers, and upload your work if necessary.
- **Debugging Disaster** questions pose possible situations for the circuits built in each lab and ask for possible approaches in identifying the issue. For these problems, all reasonable attempts will be given credit.

Contributions

Under Section 7, please detail each group member's contributions to the lab report. **If we find a highly disproportionate amount of work distribution among the group, we will adjust grades accordingly to penalize non-contributors.** Please cite any sources outside of course materials, if used.

Submission

The midterm lab report is due on Monday, October 10. **Only one group member should submit the lab report to Gradescope and the rest of the group members should be added to the same submission.**

1 Introduction to S1XT33N

Summary

Give a summary in your own words of what you did in this lab.

Questions

1. For the following parts, name one type of lab equipment that would be BEST suited for the situation described.
   a) The output LED of your inverting amplifier from Lab 1 doesn't seem to be turning on. You would like to check the correctness of the LED's voltage.
   b) You just built a brand new low-pass filter and after connecting the output to an oscilloscope, would like to locate the cutoff frequency based on the filter's response to different frequencies.
2. Two peers in your lab section built an ideal op-amp inverting amplifier with a gain of -1, but selected different V_{DD} and V_{SS} values for their op-amp. They ask you which is correct. The input signal to the amplifier is a sine wave with a peak to peak of 3.3V, and centered around 0.
   (1) Student 1: 1.65V and -1.65V
   (2) Student 2: 3.3V and 0V

   Explain which is correct, and justify your answer. (**Hint**: try drawing out the input wave and noting its minimum and maximum voltages.)
3. An inverting amplifier with no reference voltage (non-inverting terminal is connected to GND) is shown in Figure 1. Please upload all of your work for this problem.

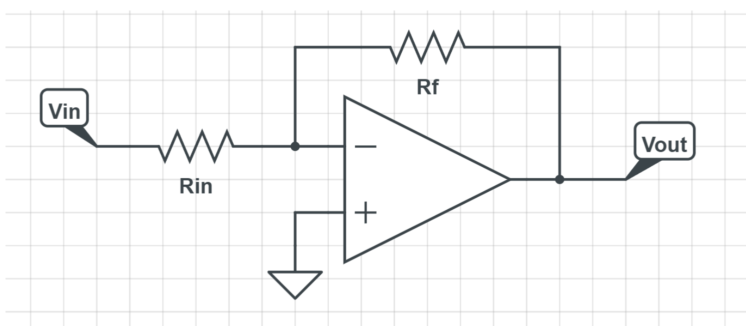

Figure 1: Inverting amplifier

   a) Assume the op-amp has a **finite** gain A. Derive the amplifier gain $\frac{V_{out}}{V_{in}}$ in terms of R_{in}, R_f, and A. (**Hint**: voltage dividers will be useful here.)
   b) Assume the op-amp gain is now **infinite**. Using this information, simplify the expression for the amplifier gain you derived in part (a). Explain why your simplified expression makes sense.
   c) What is the ideal gain of the inverting amplifier you built in Lab 1? What were your values for Rf and Rin? Is this consistent with the expression you derived in part (b)?
4. **Debugging Disaster**: You've just finished your inverting amplifier from Lab 1, but to your disappointment, LED 1 (the input LED) isn't turning on. V_{DD} and V_{SS} both seem to be the right voltages, and the resistor values are all correct. What could be some possible problems that would cause LED 1 to not light up as expected? All reasonable attempts will be given credit.

2 Analog and Digital Interfaces

Summary

Give a summary in your own words of what you did in this lab.

Questions

1. For the following question, answer all parts in terms of V_{ref} (the reference voltage of the ADC). Assume we are using the same resistor values from lab. Please include all of your work.

   a) What is the maximum voltage achievable by an n-bit ADC? Give your answer in terms of n.

   b) What is the smallest step value (resolution) of an n-bit ADC? Give your answer in terms of n.

   c) What is the sum of your answers from a) and b)? How does this relate to V_{ref}? Give an explanation for why this does (or doesn't) make sense.

2. You have implemented the SAR ADC algorithm and need to determine which DAC to use in certain situations. Assume you have access to the following:

   (1) A 4 bit DAC

   (2) A 20 bit DAC

   Consider the following scenarios and answer whether (1), (2), or neither would work. For all parts, assume that it takes two clock cycles for each bit (one cycle to set, one cycle to keep/unset).

   (a) You need to approximate a certain voltage within 12 clock cycles. Explain which of the DACs you would use. If neither would work, justify your reasoning.

   (b) Given a V_{in}, you need to approximate a certain voltage to the nearest $\frac{1}{2^{13}}V_{in}$ or smaller. Explain which of the DACs you would use. If neither would work, justify your reasoning.

   (c) Given a V_{in}, you need to approximate a certain voltage to the nearest $\frac{1}{2^{8}}V_{in}$ or smaller and only have 20 clock cycles per approximation. Explain which of the DACs you would use. If neither would work, justify your reasoning.

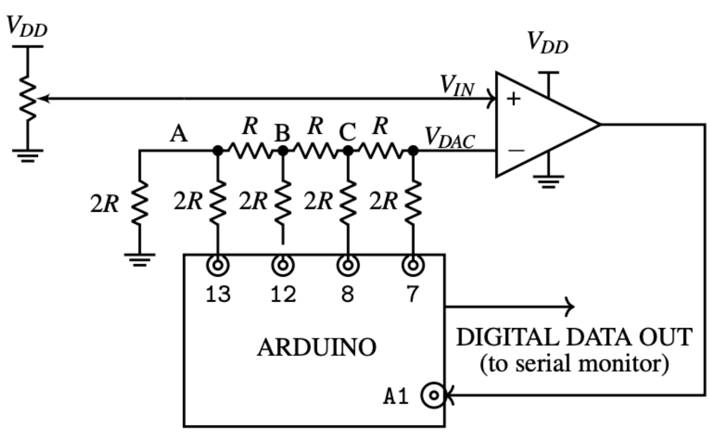

Figure 2: ADC Circuit

3. The SAR ADC circuit implemented in Lab 2 is shown in Figure 2. Consider the following scenarios:

   (a) Oh no! Due to a lack of funding, your lab accidentally gave you a broken op-amp and it looks like your comparator rails to V_{SS}, regardless of input. What would happen to the SAR ADC algorithm? Explain.

   (b) After replacing it, it turns out that the "new" op-amp you got is broken as well. How unfortunate! This time, it seems like the comparator rails to V_{DD}, regardless of input. What would happen to the SAR ADC algorithm? Explain.

4. **Debugging Disaster**: You've just finished building your DAC from Lab 2 and are ready to test. After reviewing the code from lab, you expect your DAC to output evenly stepped voltage, going from 0V to the peak voltage and back in a staircase pattern. However, while your DAC does travel between the correct bottom and top voltages, the output is stepped erratically. On certain steps it even moves in the opposite direction, looking like a rather volatile staircase! What could be the issue? All reasonable attempts will be given credit.

3 Motion and Speed Sensing

Summary

Give a summary in your own words of what you did in this lab.

Questions

1. Due to a staff member interning at Arduino last summer, we now have access to three top-secret Arduino prototypes. For all parts, assume all Arduino pins act identically, and are capable of supplying both analog voltages and PWM signals.

   a) The first Arduino can supply infinite voltage through its pins but very limited current. Do we still need the motor controller circuits? Why or why not?

   b) The second Arduino can supply infinite current but very limited voltage (less than 1V). Now do we need the motor controller circuits? Why or why not?

   c) The third Arduino can supply infinite voltage and infinite current. Do we still need the motor controller circuits? Why or why not?

2. A classmate is convinced that their motors will perform better when given a constant voltage of 6V. They challenge you to a race, oblivious to your stellar understanding of PWM signals. Assume the motor speed is proportional to the duty cycle. (i.e. at 100% duty cycle the motor goes at full speed which is equivalent to being powered by 9V and the motor only stops at 0% duty cycle)

   a) At what duty cycles will your car be slower than theirs? Give the widest range possible.

   b) At what duty cycle will your car go the same speed?

   c) At what duty cycles will your car go faster? Give the widest range possible.

   d) Extra Credit: Unbeknownst to your classmate, you "borrowed" and tested their car before the race and found out that their car finishes within 10 seconds. If they get a two second head start, what is the minimum duty cycle needed to win/tie the race?

3. You are using code from later labs to determine how fast the wheels are moving based on the voltages coming from the encoders. However, you just noticed that your encoder wheels have more cutouts than everybody else's, and realized the speed calculated by your code might be inaccurate. Will the actual speed of your car be slower, faster, or the same as the speed calculated by your code? Explain.

4. **Debugging Disaster**: After building your motor controller circuits in Lab 3, your motors are running at full speed instead of responding to the PWM signal's change in duty cycle. What could be the issue? All reasonable attempts will be given credit.

4 Voice Sensing, Part 1

Summary

Give a summary in your own words of what you did in this lab.

Questions

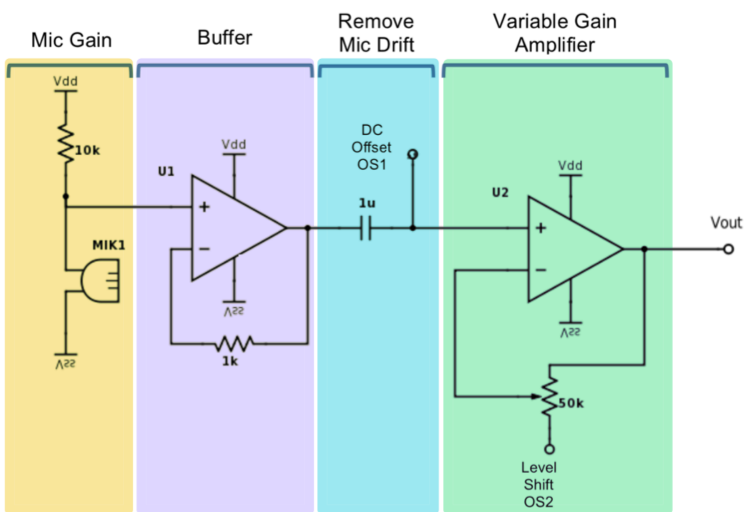

Figure 3: Mic Board Schematic

1. You've been given a box of mic boards varying from the mic board schematic from lab, and asked to determine whether they can be given to other lab groups to use - but when you arrive at Cory 125, every lab station is full! For the following parts, determine whether each mic board can be feasibly used for S1XT33N, and if so, describe the change in output from the normal mic board (see Figure 2). Provide your reasoning.
   a) Mic board #1 omits the 1μ capacitor in the "Remove Mic Drift" section of the mic board schematic.
   b) Mic board #2 uses an 1kΩ resistor instead of the 10kΩ resistor in the "Mic Gain" section of the mic board schematic.
   c) Mic board #3 moves the 1μF capacitor in the "Remove Mic Drift" section of the mic board schematic to be before the buffer.
   d) Mic board #4 doesn't use a level shift in the "Variable Gain Amplifier" section of the mic board schematic (OS2 = GND instead of 1.65V), and uses an inverting variable gain amplifier instead of the non-inverting variable gain amplifier.
2. Why can't we amplify the microphone signal centered at 0V first and then offset it, instead of offsetting first and then amplifying it like we do currently? (**Hint**: Think about the voltage range we have access to.)
3. **Debugging Disaster**: While increasing the output gain of their mic-board in Lab 4, a student notices that the signal output seems to be moving upwards. They discover that the DC component of the output signal is increasing with the gain. What could be the issue? All reasonable attempts will be given credit.

5 Voice Sensing, Part 2

Summary

Give a summary in your own words of what you did in this lab.

Questions

1. A distracted lab assistant accidentally connects their low pass filter to their half rail and grounds their high pass filter during training. How would the behavior of this new circuit compare to the intended behavior of the original filters?

2. We decide to build a second-order low-pass RC filter by chaining two first-order low-pass RC filters together, with a buffer in-between them. Assume that both first-order filters have the same cutoff frequency of f_c, and that the buffer op-amp is ideal.

   a) Calculate the transfer function of the second-order filter. What is the gain of the second-order filter at the original cutoff frequency of its first-order constituents (f_c)?

   b) Calculate the new cutoff frequency of the second-order filter in terms of R and C, the resistor and capacitor values of the first-order filters. Is this the same as the cutoff frequency of the first-order filters? Why or why not?

3. **Debugging Disaster**: A student's band-pass filter from Lab 5 doesn't seem to be outputting anything, but they've confirmed that the input signal looks fine and is being delivered to the filter correctly. They've also validated the buffer between the filters, and all of the wires connecting the components. What could be the issue? All reasonable attempts will be given credit.

6 Feedback

1. **Extra Credit:** The midterm lab report has been reworked quite a bit this semester, and we would love to hear your feedback. To receive extra credit, please provide 1-2 sentences for each of the following parts:
   a) How well do you feel that this assignment evaluated your understanding of labs this semester?
   b) How much time do you think this assignment took you to complete? (Just a number is fine for this part.)
   c) What changes to the midterm lab report would improve your experience?
2. Additionally, please feel free to provide any feedback you have about 16B lab or anything we can do to better support you.

7 Collaborators and Sources

Please detail each group member's contributions to the lab report. Also, cite any sources you used that were not provided with the course materials.

Written by Noah Lee and Dylan Reimer (2022)