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.** The lab report questions for each lab will be released at the bottom of the corresponding Jupyter notebook. All of the midterm lab report questions will also be compiled together in this document and updated as new questions are released.

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.

Submission

The midterm lab report is due on **Wednesday, March 6. 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. Assume that the following equipment corresponds to what is available in lab.
   a) Describe a situation where you would use a digital multimeter (DMM) instead of an oscilloscope and vice versa.
   b) Describe a situation where you would use a power supply instead of a function generator and vice versa.
2. Given an op-amp amplifier circuit with gain A_v (can be positive or negative) and an input sinusoidal wave with DC offset b and maximum amplitude a, what are the most restrictive values of V_{DD} and V_{SS} for the op-amp such that the output is not distorted? Assume NO virtual ground and provide answers for both $A_v < 0$ and $A_v > 0$.
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.

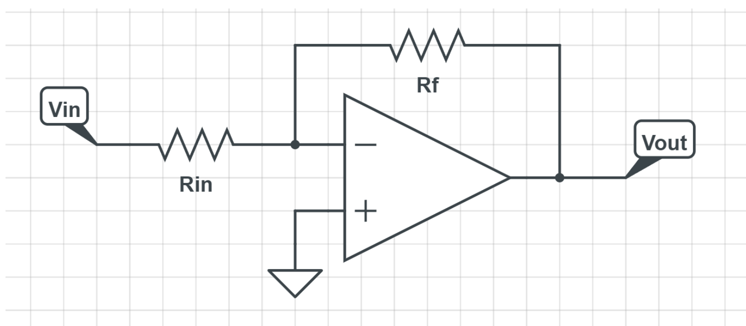


Figure 1: Inverting amplifier

   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.**
4. What are the ideal gain and measured gain of the op-amp circuit in Lab 1? Are there any discrepancies between these two values? Why or why not?

2 Analog & Digital Interfaces

Summary

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

Questions

1. What is the SAR ADC algorithm? What are the steps it goes through in order to find the digital representation of its input analog voltage? Besides quantization error, what is a drawback/limitation of the ADC implementation in Lab 2?

2. For the following question, answer parts a) and b) in terms of V_{ref} (the reference voltage of the ADC) and n (for an n-bit 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?

   b) What is the minimum voltage achievable by an n-bit ADC?

   c) In reality, there are multiple factors, e.g. area, noise, sensitivity of the comparator, that set the limit of the highest resolution (number of bits) we can build. If the smallest Least Significant Bit (LSB, the step size of the DAC voltage in the voltage transfer curve in the lab note) we can have is 2.5 mV, what is the highest resolution (number of bits) we can achieve in the binary SAR ADC with 5V reference voltage? (Note that the step size is constant across codes in the ideal ADC. The answer should be an integer for which the LSB satisfies the constraint.)

3. Refer to the datasheet for the TLC7524 8-bit DAC (also linked in the notebook). Please include all of your work.

   Settling time marks the time that passes between when the input is applied to a component and when the subsequent component output has stabilized (within some error bound). Classes such as CS 61C and EECS 151 will discuss settling time and related concepts in more detail.

   Let's say we want to build a SAR ADC using this resistor-ladder DAC and some microprocessor (i.e. the Arduino). We will assume for this question that there is no delay between the output of one component and the input of the next (e.g. there is no delay between the output of the DAC changing and the inverting input of the comparator changing). We will also assume that the acquisition time for the ADC to read the stable input analog voltage is negligible.

   Assume the settling time of the comparator is 200ns.

   Assume that it takes 100ns for the microprocessor to look at the comparator output and set the bit off or keep it on. Now, the algorithm repeats for the next bit.

   a) What is the worst-case time required to determine the final value of a single bit in the ADC's register? (**Hint**: find the settling time of the DAC.)

   b) How long would it take in the worst case to see the final correct 8-bit ADC output? What is the maximum frequency at which we could sample the output voltage and still be absolutely certain that the value is correct?

   c) At $V_{DD} = 5V$, provide an upper bound for the total energy dissipation (in Joules) of the DAC for the worst-case time to see the final correct 8-bit ADC output. (**Hint**: find the specifications related to power.)

3 Motion

Summary

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

Questions

1. What is a PWM signal? What does duty cycle mean for a PWM signal? If we can control a digital signal between 0V and 5V, what will the average voltage of the PWM signal be if the duty cycle is 75%?
2. The NPN Bipolar Junction Transistor (BJT) serves a very important purpose in our motor controller circuits.
   a) Describe the function of the BJT.
   b) In your own words, explain the model of the NPN BJT in the ON mode from the lab note.
   c) In your own words, explain the model of the NPN BJT in the OFF mode from the lab note.
3. The following sub-problems will check for your understanding of the circuits implemented in this lab.
   a) Describe the function of the resistor in the motor circuit that is connected to the Arduino. What will happen to the rotation speed of the motor when the value of the resistor increases? What will happen if it decreases?
   b) What is the function of the diode? Why do we place it in parallel with the motor?
   c) How are the encoders used to measure velocity? Say we swap your encoder wheels to some with increased cutouts. Would the velocity calculated by the Arduino be faster, slower, or be the same as your actual velocity?

4 Sensing Part 1

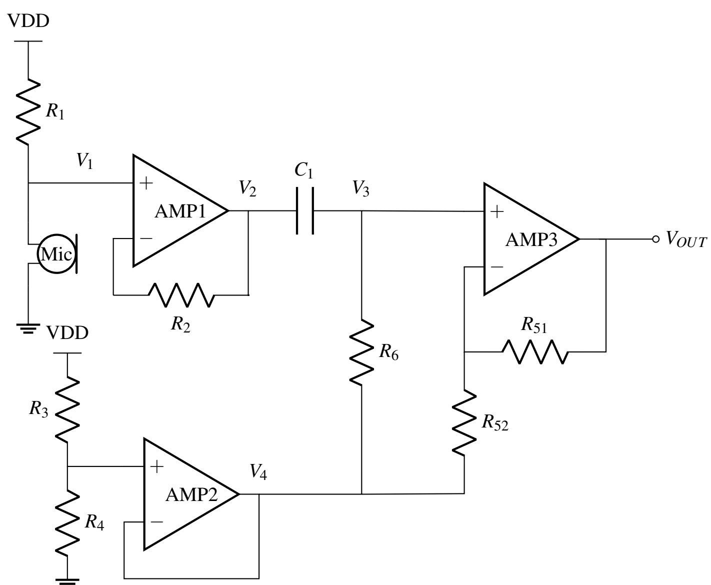
Summary

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

Questions

The following questions will analyze the combined mic board and biasing circuit, which is shown below. The microphone can be modeled as a signal-dependent current source, $I_{MIC} = k\sin(\omega t) + i_{drift}$, where I_{MIC} is the current flowing from VDD to VSS, k is the force[1] to current conversion ratio, ω is the signal's frequency (in rad s^{-1}), and i_{drift} is a constant current offset (in A). Note that R_{51} and R_{52} are resistors of the potentiometer ($R_5 = R_{51} + R_{52}$).

When asked to give an answer in terms of the circuit components, please give your answer only in terms of V_{DD}, R_1, R_3, R_4, R_{51}, R_{52}, k, ω, t, i_{drift}, and/or standard mathematical constants and functions. Throughout this problem, please show all of your work.



1. What is the voltage V_1 in terms of the circuit components?
2. What is the voltage V_2 in terms of V_1? What is the voltage V_2 in terms of the circuit components? Assume that $R_2 = 0$.
3. What is the voltage V_4 in terms of the circuit components?
4. What is the voltage V_3 in terms of V_2 and V_4? What is the voltage V_3 in terms of the circuit components? **Assume that C_1 and R_6 are large enough such that only AC signals pass through C_1.** (Hint: you don't need to derive the transfer function for this question!)
5. What is V_{OUT} in terms of V_3 and V_4? What is V_{OUT} in terms of the circuit components?
6. Did your mic board performance seem to deviate from your model? Why/why not? Please include a graph of your micboard transfer function with your answer.

[1] the force is exerted by the soundwaves on the mic's diaphragm.

5 Sensing Part 2

Summary

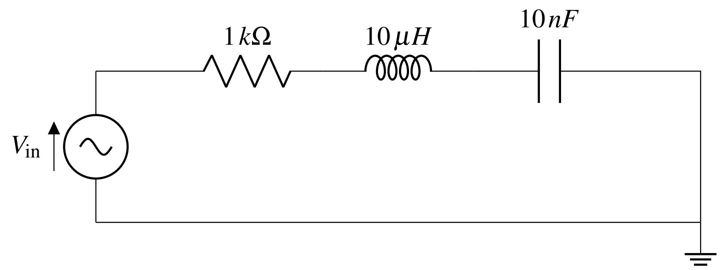
Give a summary in your own words of what you did in this lab.

Questions

1. What is the cutoff frequency for a first order RC filter? What is the resonant frequency for an RLC Notch filter?

2. Why do we place the output of our color organ filters into a non-inverting amplifier and/or buffer?

3. Consider this RLC circuit. We have in series a resistor of 1kOhm, inductor of 10uH, capacitor of 10nF. We connect the components in series respectively and probe V_{out} as the voltage across the inductor and capacitor.



   a) What do you believe the filter's characteristics are? Is it a low-pass, high-pass, band-pass, notch, or neither? Explain your thinking.
   b) Find the transfer function of this system. Leave your answer in terms of R, L, and C, and plot the magnitude response.
   c) What is the actual shape given by the magnitude response of this filter? Was it or was it not what you initially predicted it would be? How does the Q factor of this filter affect the shape of the magnitude response?
   d) When implementing notch filters, do we want a high resistance load or a low resistance load (again, think how R affects the Q factor)? If we have an ideal notch filter, what are its advantages compared to a band-pass filter with cutoff frequencies that are very close to each other?

6 Feedback

1. **Extra Credit:** Please provide feedback about labs. How have labs been going so far? For each lab, put an estimate at about how long it took your group to completed. Talk about pain points as well as things that went well in each lab.

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