BIOMEDICAL INSTRUMENTATION LABORATORY
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TAs:
Jason Brooke – mbrooke@bme.jhu.edu
Kartik Murari – kmurari@bme.jhu.edu
Abhishek Rege – arege@bme.jhu.edu

Lab Exercise 1: Introduction to the op-amp: Inverting, Non-Inverting and Differential Amplifiers.

The op-amp or Operational Amplifier is a IC (Integrated Circuit), with some extremely useful features. It forms the basis of a large number of circuits used in the electronics industry. The purpose of the first part of this exercise is to introduce the op-amp and demonstrate some of the circuitry possible.

In order to study electrophysiology, we need to be able to record various biopotentials (i.e. ECG, EM, EOG, EEG, etc.). The basic biopotential amplifier requires an appropriate amplitude amplification range as well as frequency range, and noise reduction. The basic building blocks of biopotential amplifiers are differential and instrumentation amplifiers. In the second part of this lab you will characterize a single op-amp differential amplifier.

LAB EXPERIMENT:

1. An INVERTING AMPLIFIER with a gain of 50 has been constructed for the experiment. To test the circuit, input a sinusoidal wave of frequency 1.0 kHz and amplitude 10mv peak-peak from the signal generator. Look at the output and the input waveforms on the oscilloscope. What do you notice about the peaks and troughs of the input and the output? Record the output waveform amplitude. Increase the amplitude of the input in steps to 500mV. What happens to the shape of the output for higher amplitudes of the input signal? Record the output amplitudes. Plot a graph of the output amplitude vs. the input amplitude.
2. DIFFERENTIAL AMPLIFIER - Common-mode rejection: Apply a sinusoidal signal of frequency 10 Hz and amplitude 1V pk-pk to both the inverting and non-inverting inputs of the amplifier. Record the output voltage amplitude. Tune the potentiometer so that the output signal is minimized. Record the output voltage amplitude. Record the output voltage amplitudes and calculate the common-mode gain.
3. DIFFERENTIAL AMPLIFIER – Differential gain: Apply a sinusoidal signal of frequency 10 Hz and amplitude 25 mV pk-pk BETWEEN the non-inverting and inverting inputs. Record the output voltage amplitude. Repeat the experiment for the same frequencies as in part 1. Calculate the differential gain and plot it against frequency. Now calculate the Common-mode rejection ratio (CMRR).

Lab Exercise 2 : Differentiators , Integrators and Comparators

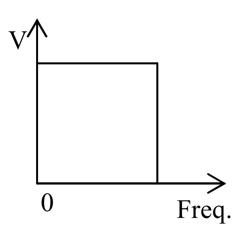
The op-amp is often used in circuits for analog computations (adders, subtractors, multipliers, logarithmic amplifiers , integrators and differentiators among others) . The purpose of this lab is to demonstrate some simple applications of the op-amp in such circuits. Another circuit with immense application is the comparator, a “digital” circuit (with only two values of the output) which compares an input voltage with a reference and outputs a signal based on whether the input is more than or less than the reference.

LAB EXPERIMENT:

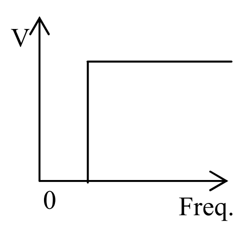
1. Use the INTEGRATOR for this part of the experiment. For the input use a square wave of frequency 1Hz and amplitude of 2V peak-peak, from the signal generator. What is the shape of the output ? Why is it so ? Repeat the experiment for different types of input signals (DC, Sinusoidal, Triangular). Record the output waveforms for the various input signals.
2. Use the COMPARATOR for this part of the experiment. Apply a input sinusoidal signal of frequency 1.0 kHz and a peak-peak amplitude of 2V. What is the shape of the output ? What are the amplitudes of the output voltages? Repeat the experiment with a sinusoidal signal of frequency 100 Hz at the same voltage amplitude and also with a sinusoidal signal of frequency 10 kHz. How does the output change ? Why ?

Lab Exercise 3: Active Filters.

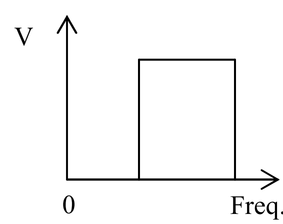
Often, real world signals of interest are mixed with undesirable noise signals (power line interference in ECG signals etc.). Circuits such as filters are used to attenuate the amplitudes of the signals which are not desirable. Depending on the frequencies which are desirable, filters can be low-pass, high-pass or band-pass. The principle of action of ideal filters are shown below:



Low-Pass



High-Pass



Band-Pass

Circuits made with real-world components cannot achieve the sharp cut-off characteristics of the ideal filters shown above, but with some degree of approximation we can get fairly close. Filters are essential in circuits such as ECG monitors where a considerable degree of interference is picked up because of the surrounding electrical equipment as well as the movements of the patient. Another area in which filters could be used is in hearing aids.

LAB EXPERIMENTS:

1. Use the LOW-PASS Filter for this part of the experiment. Apply a sinusoidal signal of frequency 0.5 Hz and 500mv pk-pk amplitude to the input of the circuit. Record the peak to peak amplitude of the output. Increase , in steps, the frequency of the input signal keeping the voltage constant , to 25 kHz. Record the output amplitudes versus frequency. Calculate the decibel gain (20 $\log_{10}$ [Gain]) and plot it as a function of frequency on a logarithmic scale.
2. Repeat the above experiment with the HIGH-PASS filter. Plot the gain as a function of frequency on a logarithmic scale.

(Note: you don't have to draw every frequency. Just find the flat gain region, then find the cut-off frequency where the gain reduces by a factor of 0.707, and then go beyond that frequency to see reduction in gain. You should get by with measurements done at 5-6 frequencies.

<u>Lab Exercise # 4: Hearing Aid</u>

Speech is the most important form of communication. Some people are unlucky to lose their sense of hearing, which greatly impairs their ability to communicate. There is a lot of research being done to invent devices that improve the quality of life of hearing-impaired patients. One of such devices is a hearing aid that interfaces to the cochlear nerve bypassing dysfunctional or destroyed inner hair cells of the inner ear.

This lab is designed to review basic operational amplifier (op-amp) and filter circuits that can be used to build a simple hearing aid.

<u>Lab Procedure</u>

Our first goal is to build a simple device that will amplify sound to compensate for hearing loss. The next stage is to make the device capable of stimulating the cochlear nerve if the inner hairs cells (they are responsible for conversion of mechanical energy of the sound wave into electrical input to the brain via the cochlear nerve) are destroyed.

Connect a speaker to the output of your signal source (you can either use a function generator or your walkman) and reduce the volume until it is barely audible. This is your input signal. Record the peak-to-peak amplitude of this signal. Note: Speakers tend to draw lots of current, so you may need to use a powered speaker or a high-current amplifier before you can hear an undistorted version of your signal. You can also measure the signals on the oscilloscope using a sine wave as the input.

Construct an amplifier with a gain of 20. You may select an inverting or a non-inverting amplifier in your design. Check if you can hear the signal if you connect a speaker to the output.

Construct an active filter with a passband between 200 Hz and 4 KHz. This can be done by cascading separate lowpass and highpass filters. Use op amps in filter construction.

a. Build the highpass filter first. The cutoff should be 200 Hz, and the passband gain should have a maximum gain of 1. The output from the amplifier will serve as input for this stage. If you check the output, it might not have a big difference from the original if the speaker cannot produce tones below 100 Hz.
b. Build the lowpass filter with the cutoff at 4 KHz and a gain of 1 in the passband. The output from the highpass filter will serve as input for this stage. The output of this stage should now be much different from the original.
c. Draw a Bode plot of your circuit performance. This is done by plotting the ratio of the output voltage and input voltage as a function of frequency. Hint: use a function generator to produce a sine wave of known frequency, then plot your results on a dB vs. $\log_{10}$ (freq).

Now you should have a functional simple hearing aid that amplifies and filters the signal.

<u>Optional:</u>
Now we will modify the circuit to simulate a single-channel cochlear implant.

d. Half-wave rectify your signal by including a diode at the output.
e. Make a comparator with the reference voltage of 0 V. Check the input and output of the comparator. There should be a variable-width pulse for each half cycle of sound. Bonus: Set the reference voltage so that your circuit does not produce pulses for low-amplitude noise.
f. The comparator will give a +/- 12V output (rail voltage). Make a voltage divider to reduce this to +/- 6V. Then use a voltage follower to buffer the output. Connect the output to the speaker and check if it is intelligible.

References:

Webster, JG. Medical Instrumentation.

Horowitz and Hill. The Art of Eletronics. 1989

Pickles, J.O. An introduction to the physiology of hearing. 1988

HOMEWORK #1:

HOMEWORK #1.1:

1. Why did the output distort for higher values of the input signal? Was there anything special about the value of the output at which the distortion occurred? [Hint: Consider the supply voltages to the op-amp]
2. Design a BUFFER (non-inverting amplifier with a gain of 1). Where could such a circuit be used (suggest an application)?
3. Suggest which frequencies are most important to test for common mode rejection in a biopotential application. I.e. what common-mode interference frequencies are we trying to reject?
4. What are the reasons for using instrumentation amps in bio-potential measurements? I.e. what are the specific benefits of the 3 op-amp configuration in terms of the amplifier performance (e.g. input resistance, etc. etc.).

HOMEWORK #1.2:

1. Design a Differentiator circuit using an op-amp (HINT : The Differentiator is the inverse of an Integrator). What is the time constant of the circuit defined by? Sketch the output you expect for a square wave input (1V pk-pk, 1 Hz). Assume differentiator time-constant of 0.1 s.
2. Give an application where the comparator circuit be used ? How would you design a comparator with hysterisis (hint: see the text-book) ? In what situation would such a circuit be useful ?
3. Draw a circuit that is used to detect light level and turn on a beeper when the light level exceeds a threshold. As an example, we may be interested in detecting when a car crosses a red light. So, we could set up a light beam and when the car crosses the light beam, the amount of light detected is reduced or cut. When that happens, the circuit produces an alarm sound by powering a beeper/buzzer.

HOMEWORK # 1.3 :

1. Design a band-pass filter with frequency cutoffs of 200 Hz and 4 kHz. [Hint : The design of a band pass filter involves both high and low pass filters] . Such a filter could be useful in a hearing aid. Why do you think the particular frequencies were chosen ?
2. What is a Notch filter ? What is one of the prime applications of a notch filter (i.e. what preferred frequency?). Search the book or circuit references and present a circuit reference.

HOMEWORK # 1.4:

1. Telephones use a filter with a passband approximately in the range of 200Hz to 4KHz. Why is this frequency range chosen?
2. Draw the circuits for each stage of the lab. Use the resistor and capacitor values that are available in the lab in planning your circuit. Show your calculation of theoretical gain and cutoff frequencies of the passband.
3. Sketch a theoretical frequency response for your circuit.

Resistors:

Standard resistor values are given below. Just multiply by the appropriate power of ten to get the value you need. For example, you can grab a 2,200Ω (2.2×10^3) resistor right out of the bin. If you wanted a 2,300Ω resistor, you could use a 2,200Ω in series with a 100Ω. We should have resistors from 10 Ω to 8.2 MΩ.

1.0
1.2
1.5
1.8
2.2
2.7
3.3
3.9
4.7
5.6
6.8
8.2

Capacitors:

Capacitor values are a bit less standardized. The values we will probably have on hand are below:

10 pF
22 pF
47 pF
100 pF
470 pF
1000 pF
0.01 μF
0.1 μF
1 μF