Lab 1: Operational Amplifiers and Filters - Simple Hearing Aid

Speech is the most important form of communication. Some people are unlucky to lose their sense of hearing, greatly impairing 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 such device 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.

Lab Procedure

Our first goal is to build a simple device that will amplify sound to compensate for hearing loss, followed by a set of filters that retain the optimal frequency range. The next stage is to make the device capable of stimulating the cochlear nerve if the inner hair cells (they are responsible for conversion of mechanical energy in the sound wave into electrical input to the brain via the cochlear nerve) are destroyed.

1. Instead of an input sound signal, we will use a sine wave as the input. You will vary the input amplitude as well as the frequency to characterize the device that you have constructed.

2. Construct an amplifier with a gain of 20. You may select an inverting or a non-inverting amplifier in your design. Ensure that you are obtaining the desired amplification before moving on to the next step.

3. Construct an active filter with a pass band between 200 Hz and 4 KHz. This can be done by cascading separate low pass and high pass filters. Use op amps in filter construction.
    a. Build the high pass filter first with the cutoff at 200 Hz and a gain of 1 in the pass band. The output from the amplifier will serve as input for this stage.
    b. Build the low pass filter with the cutoff at 4 kHz and a gain of 1 in the pass band. The output from the high pass filter will serve as input for this stage.
    c. Compare the output waveforms at each stage of the circuit (amplifier, high-pass filter and low-pass filter) as you vary the input frequency of the sine wave.
    d. 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. 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. We will modify the circuit to simulate a single-channel cochlear implant.

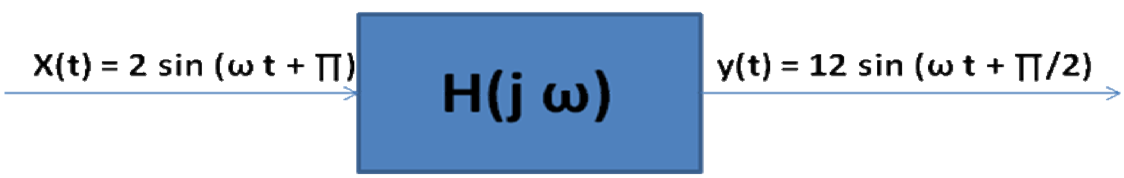
4. Half-wave rectify your signal by including a diode at the output.

5. Make a comparator with a 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.

6. 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.

Pre-lab (due at the beginning of the current lab) [20 points]
The pre-lab is intended to ensure that you understand the theory behind the circuits you will build, and thus maximize the time you have available for lab work. The pre-labs will be collected at the beginning of the lab session. So make sure you keep its copy with yourself, so that you can refer to it during the lab.

1. Telephones use a filter with a pass-band approximately in the range of 200 Hz to 4 kHz. Why is this frequency range chosen? [2]
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 pass-band. [10]
3. Many biomedical and electrical devices are characterized by their **frequency response** which is a measure of the systems response at the output to an input signal of varying frequency but constant amplitude.
   a. A common unit of expressing the magnitude of gain of a device is decibel dB. What is the gain in dB of the following system? [2]



   b. By how much is the signal phase shifted in part (a) [2]
4. Sketch a theoretical frequency response for your circuit. [4]

Lab Write-Up (due at the beginning of the next lab) [40 points]
You must provide clear and concise answers to questions. No credit will be given for elaborate essays that are not on the topic. Show that you know and understand the major concepts taught in class and lab. **While you are allowed to consult with your lab partner, each student must turn in his/her own work and acknowledge any references and collaborators.**

1. Purpose: Briefly explain the purpose of the lab and your circuit. [2]
2. Design:

   a. Briefly explain why you selected certain parameters for your circuit (i.e. physiological/electronic/design reasons). [5]
   b. Show complete circuit schematic with all components properly drawn and labeled. [10]
   c. Show appropriate Bode plot(s). Report your measured and theoretical gains and filter cutoffs and compare them. Compute percentage errors and explain the possible causes of any significant errors. [15]
3. What is meant by cut-off frequency of a circuit? Apart from the cut-off frequency, what additional parameters characterize the filter response? [2+2]
4. What are the advantages of an active filter over a simple RC filter? [2]
5. Why is a logarithmic amplifier better than a linear amplifier for this device? [2]

References

Webster, JG. Medical Instrumentation
Horowitz and Hill. The Art of Eletronics. 1989
Pickles, J.O. An introduction to the physiology of hearing. 1988