ME 473 Instrumentation

Laboratory Experiment #2 v1.1

A low-pass analog filter

In this experiment, a phototransistor is used to measure a changing light intensity. An analog low-pass filter will be used to remove noise from the phototransistor signal.

Objectives

1. Design, construct, debug, and test an analog low-pass filter.
2. Use the filter to separate 120 Hz interference from a low bandwidth signal.
3. Compare the results with frequency analysis.

Introduction

In Fig.1 below an operational amplifier detects the output of a phototransistor. The output voltage v_d is proportional to the intensity of the light incident on the sensitive area of the phototransistor. In our laboratory implementation of this circuit the phototransistor is exposed to the light from the overhead fluorescent lamps. If you partially shade the sensor with your hand, the intensity will change, and the output voltage will vary. We wish to monitor this changing intensity, over a bandwidth of approximately 10 Hz.

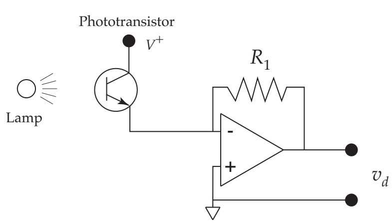

FIG. 1: Existing phototransistor detection circuit.

Due to the operation of the fluorescent lamp, the light intensity consists of a substantial DC component (as expected) and an additional 120 Hz ripple. We will regard this ripple as noise, and design a filter to remove this frequency component, while retaining the relatively low frequency variations produced by waving a hand over the sensor.

To accomplish this signal processing function you will implement a first-order analog low-pass filter as shown in Fig. 2. Notice that this circuit is similar to one that you analyzed in one of your homework problems. Part of your task will be to select the components that meet a specific set of filter requirements.

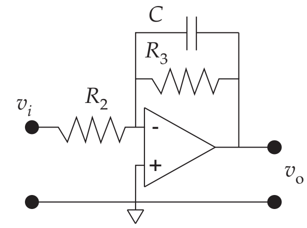

FIG. 2: Low Pass Analog filter.

The design specifications for the filter are:

1. The static gain of the filter v_o/v_d should be unity.
2. The break frequency of the first-order filter should be 10 Hz.

Pre-Laboratory Preparation

Analyze the filter in Fig.2, and derive an expression for transfer function relating the output v_o to the input v_i, in terms of the component values R_2, R_3 and C.

Assuming that $R_2 = 159,000\,\Omega$, what values of R_3 and C should be used to meet the above specifications for the filter? By how many dB will be noise at 120 Hz be attenuated? Check your result by writing a Matlab script that plots the bode diagram for the values you have chosen. If you haven't done this before try the "help" commands for the functions: "tf", and "bode". Use the "tf" command to create a description of the system that "bode" plots. The following script contains some suggestions:

```
tau=1/2/pi/10;
sys=tf([1],[tau 1]);
f=logspace(0,3);
[m,p]=bode(sys,2*pi*f);
m=squeeze(m);
semilogx(f,20*log10(m))
```

Laboratory Procedure

In the lab, a circuit "Proto-Board" will allow you to build your filter easily, and connect it to the output of the existing phototransistor/op-amp circuit. See Fig. 3. The Proto-Board contains two 14-pin LM348 integrated circuits (ICs). A top-view diagram of the LM348 IC is shown in Fig. 4. Each IC contains four op-amps. One of the ICs is dedicated to the phototransistor detector. You will use one of op-amps on the other IC to implement your filter. Please do not alter the phototransistor or its detector amplifier.

The Proto-Board will also provide the +15 V and -15 V voltage sources needed to power the op-amps. Although the op-amp circuits (correctly wired) will require very

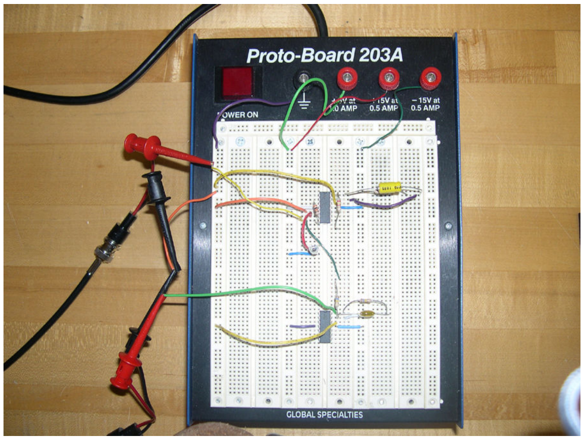

FIG. 3: Proto-Board

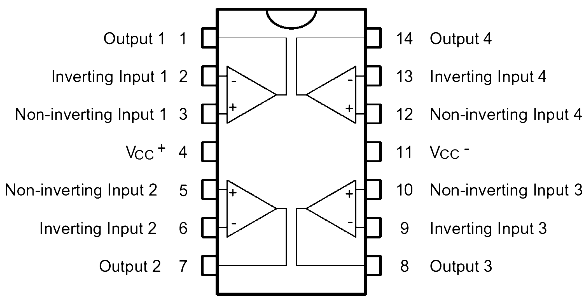

FIG. 4: LM348 Operational Amplifier.

little current, the power supplies capable of providing substantial current through a low impedance load. Be careful not to connect the two supplies directly together, or to ground (common).

The components are connected on the Proto-Board by inserting wires or component leads through holes in the plastic surface. Beneath the surface, conducting clips connect rows of holes. Examine the existing phototransistor/op-amp circuit on the Proto-Board, and be certain that you understand how the connections are made, and how the ICs are powered.

Construct your filter on the Proto-Board, as shown in Fig.2. You may use any of the four op-amps on the LM348. Since resistors and capacitors are supplied in a limited range of values, select the components that most closely match your design values.

Filter Frequency Response

Before you connect your filter to the output of the phototransistor detection circuit, you will measure its frequency response. Do this using a function generator and two channels of an oscilloscope.

1. Set the function generator to produce a 1 v amplitude sine wave, at 1 Hz.
2. Connect the function generator to the input of your filter.
3. Connect one channel of the oscilloscope to measure the input signal to your filter. Adjust the oscilloscope until you can verify the 1 v amplitude and 1 Hz frequency of this signal.
4. Connect the other channel of the oscilloscope to output of your filter. Adjust the oscilloscope so that you can accurately measure the output amplitude.
5. Record the ratio of the output amplitude to the input amplitude. Repeat these measurements for 2, 5, 10, 20, 50, 100, 200, 500, and 1000 Hz. To get accurate readings, you will need to adjust the vertical gain of the oscilloscope when you change frequencies.

Are these results what you expected?

Photosensor Application

Disconnect the function generator and connect the output of the phototransistor/detector circuit to the input of your filter, as shown in Fig.5.

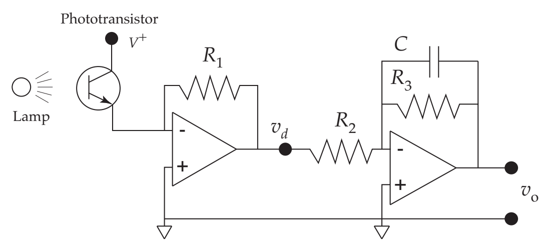

FIG. 5: Phototransistor detector with filter.

Connect one channel of the oscilloscope to the detector output v_d, and the other to the output of your filter v_o. With both channels "DC coupled", you should observe that both voltages rise and fall as you wave you hand over the detector. If the filter has been properly designed and constructed, the signal at the output of the filter v_o should be much less noisy than the detector output v_d. If not, check your circuit.

"AC coupling" of both oscilloscope channels will remove the average values, and allow you to observe the 120 Hz components of both signals.

Analysis

In Matlab, augment your previous script to plot magnitude the your measured frequency response information on the same graph as the theoretical bode diagram (dB v.s. log$f$ Hz). Plot the experimental data with symbols (e.g. "o"), and the theory using a line.

What is the ratio of the photosensor ripple in v_o to that in v_d? Does this agree with the bode plot from your Matlab script?

Report

Be certain to include any figures and data necessary to support your analysis and conclusions, although you may choose to put details in an appendix. This brief report is to be written at a level midway between a homework assignment and a formal report. Handwritten work is acceptable, but must be neat and legible. Binding is not required.

Please include your MATLAB code and the bode plot in your report.