Mixed Electronics Lab 2
RC Filters

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1 Introduction

This lab will introduce students to analog filters. They will build and test a low pass RC filter of their own design. This will provide practice for frequency analysis, before the principles are applied to design a high pass and a bandpass filter.

2 RC Filters

Passive circuit elements such as resistors and capacitors can be characterized by their impedance. Impedance is represented in the form of a complex number with real and imaginary components. Analyzing a circuit by utilizing complex impedance makes it possible to assess the predicted voltage across any element using Ohms Law.

When analyzing filters, a key component is the cutoff or corner frequency. This is the point where the output of the filter, or other frequency dependant circuit, has fallen to some given proportion of the input. Commonly, this is an attenuation of 3dB, which corresponds to approximately a 50% power reduction. Recall that attenuation (or amplification) in decibels is given by the function $L_p = 20\log_{10}\left(\frac{output}{input}\right)$, and such, a change of -3dB corresponds to a $\frac{1}{\sqrt{2}}$ change in output with regards to the input. To calculate the frequency at which this occurs, solve the transfer function for the circuit where $|H(j\omega)| = \frac{1}{\sqrt{2}}$

First, the value of each component should be confirmed independently. Students explain the methods they develop to verify the performance of the passive components. Then, the RC circuits will be assembled, and the behavior will be confirmed by a frequency sweep. Students will practice basic troubleshooting independently.

In order to measure voltage across the circuit we will use an oscilloscope and probes. Remember to consider the effect of the internal circuitry of the probe on the measurements. When measuring a circuit it is important that every source shares a common ground, so that relative voltages are related. Consider how to measure different voltages across the circuit, without moving the common ground.

2.1 Low pass Filter

1. Based on the circuit shown in Figure 1, determine the transfer function $H(j\omega) = V_{out}/V_{in}$
2. Use MATLAB to create bode plots of the frequency response from 1 kHz to 1 MHz, given $R_1 = 1\,\text{k}\Omega$, and $C_1 = 1\,\text{nF}$.
3. Show with a bode plot how the results would change if R_1 was replaced with a $100\,\text{k}\Omega$ resistor. Identify the cutoff frequency on your plot.
4. Given an input signal $\sin(2000\pi t)$, what is the amplitude and phase of the output?
5. Build the circuit shown in Figure 1

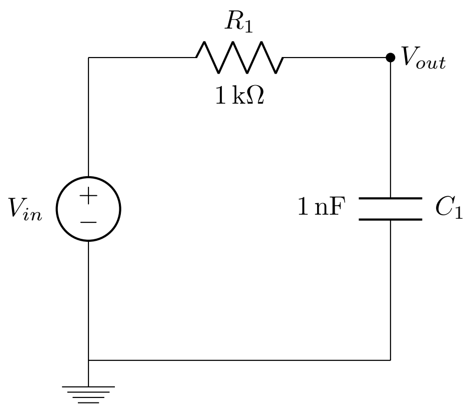

Figure 1: A low-pass RC circuit can be assembled very easily. The characteristics of the filter are determined by the value of the resistor and capacitor

6. Using the cursors on the o-scope, measure the phase and amplitude response of the filter across a range of frequencies
7. Plot the results of your frequency sweep against the results from parts 1–3. What sources of error are there?
8. How does the behavior of the filter change at very high frequencies? Why?

2.2 High Pass Filter

High pass filters are inversions of low pass filters, such that the placement of the resistor and capacitor are switched. The cutoff frequency remains the same, however it is a lower bound rather than an upper bound.

1. How would you redesign the filter from figure 1 to cut off frequencies below 40kHz?
2. Repeat the steps from the previous section for the new filter.

2.3 Bandpass Filter

A second order bandpass filter can be designed using a combination of a low pass and a high pass filter. The low pass filter should cut off at the upper bound of the pass band, and the high pass filter should cut off at the lower bound of the pass band.

1. How would you design a bandpass filter about 40kHz, with a pass band of 10kHz, (35kHz - 45kHz).
2. Consider how to implement a very narrow pass band, and a very wide pass band.
3. Determine the theoretical Q value of each filter, and measure it experimentally.
4. Higher order filters can also be designed to capture a given pass band. Consider some ideas for how these might be implemented. Especially consider how filters can be implemented using op-amps to control the gain on the pass band. Discuss your thoughts on alternative methods of designing band pass filters in your lab book.