

ECE 214 - Lab #3 — Filter Design

15 February 2021

Introduction

In this lab, you will design, simulate, build, and test a low-pass filter. The block diagram of the filter is shown in **Figure 1**.

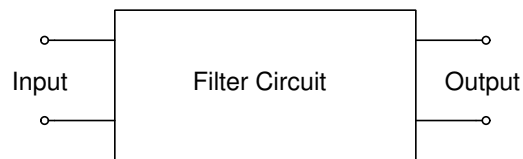


Figure 1: Block diagram of the filter circuit.

The filter circuit should satisfy the following specifications.

1. Input: Square wave with a frequency of 1.25 kHz and a peak-to-peak voltage of 4 V.
2. Magnitude of the input impedance: $|Z_{IN}| \geq 10 \text{ k}\Omega$.
3. Output: Peak-to-peak voltage greater than 2 V and magnitude of the third harmonic at least -20 dB below the fundamental frequency.

These specifications are illustrated by the signals in **Figure 2**.

Parts List

The values and number of resistors and capacitors are dependent on the design.

Pre-Lab

1. Design a low-pass filter that satisfies the above specification.
2. Simulate the filter with a square wave input signal with a frequency of 1.25 kHz and a peak-to-peak voltage of 4 V, and verify that the signal at the output of the filter satisfies the specification. The MATLAB® file ECE214_2021_Lab3.m for NGspice is available at https://ece214.davidkotecki.com/docs/Matlab/ECE214_2021_Lab3.m. The MATLAB® function vt_to_vf, available at https://ece214.davidkotecki.com/docs/Matlab/vt_to_vf.m, is needed to approximate the Fourier series of the time-domain signals, and should be placed in the same directory as the ECE214_2020_Lab3.m file.
3. Plot the voltage at the input of the filter, and the output of the filter, as a function of time.
4. Plot the voltage at the input of the filter, and the output of the filter, as a function of frequency. Show the voltages in dB.

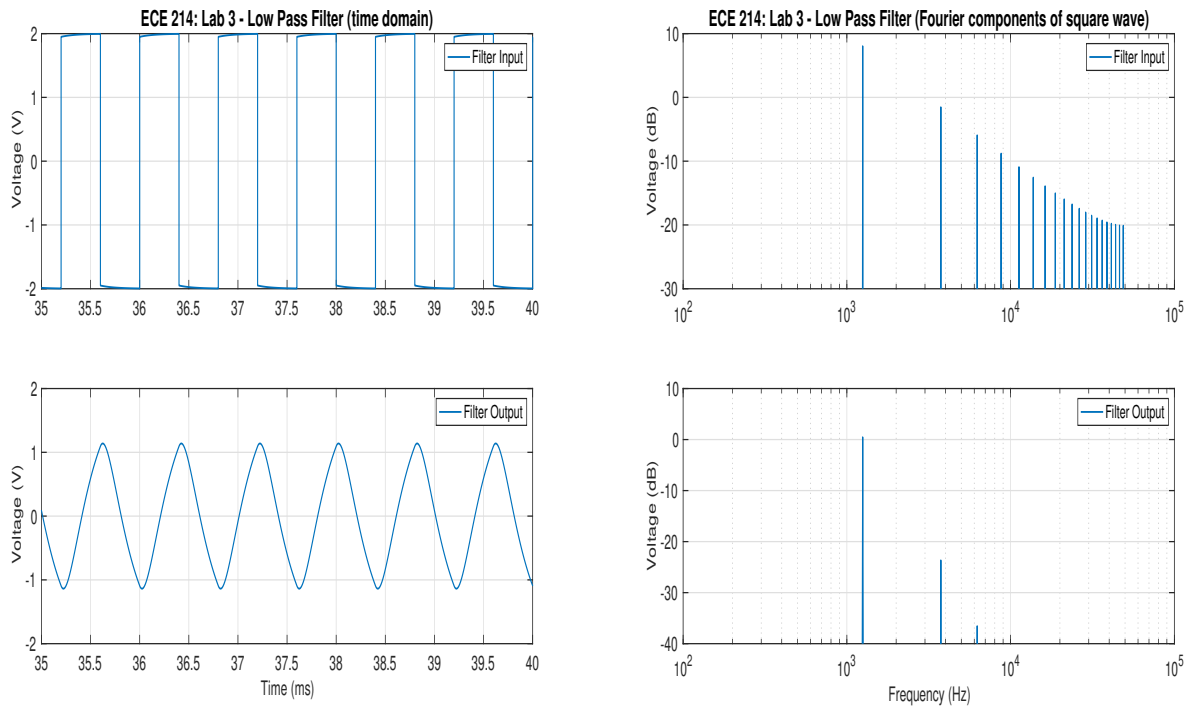


Figure 2: Low pass filter input signal (top) and output signal (bottom) in the time domain (left) and the frequency domain (right).

Lab Procedure

1. Build the filter designed in the Pre-Lab.
2. Connect the WG to the input of the filter. Set the WG to produce a 4 V peak-to-peak square wave signal at a frequency of 1.25 kHz. Measure the input and output signals on the Analog Discovery 2 (AD2) in both the time-domain and the frequency-domain. Record the time- and frequency-domain signals in your notebook.
3. Does the output of the filter meet the specifications?
 - (a) If "Yes" you are done with the Lab Procedure.
 - (b) If "No" repeat this lab starting at step 1 in the Pre-Lab.

Post-Lab

1. Compare the measured results with the simulated results. Make a note of any discrepancies between the measurements and simulations.
2. In addition to the transient simulation, useful information on the response of a filter can be obtained using AC, or small signal, simulations. AC simulations are similar to Phasor

analysis. During AC simulations, the circuit response is simulated as a function of frequency. To learn more about AC and transient simulations, you should read Sections 1.2.2, 15.3.1 and 15.3.9 of the NGspice user manual <http://ngspice.sourceforge.net/docs/ngspice-manual.pdf>.

3. Simulate the frequency response of the circuit using AC simulation. (Uncomment the last sections of the ECE214_2021_Lab3.m MATLAB® file to enable the AC simulation.)
 - (a) Set the AC Voltage of the pulse generator in your schematic to 1 V. The AC Voltage is the magnitude of the voltage used when performing AC simulations.
 - (b) For AC simulations, the frequency variable in the NGspice data file is called FREQUENCY.
 - (c) By adding the .ac dec 201 1e2 1e5 control statement in your .m file, the simulation will perform a frequency sweep containing of 201 frequency values ranging from 100 Hz to 100,000 Hz using a logarithmic scale.
 - (d) Plot the magnitude of the output voltage V_{out} in decibels as a function of frequency. To convert the output voltage to dB, use: $20 \cdot \log_{10}(\text{abs}(V_{out}))$.
 - (e) Plot the phase of the output voltage V_{out} in degrees as a function of frequency. To convert the output voltage to phase, use: $\text{angle}(V_{out}) \cdot 180/\pi$.
4. The AD2 contains a Network Analyzer. The network analyzer drives a circuit with a swept sine wave and measures the circuit response as the input frequency changes. The output magnitude and phase can be displayed in a Bode format. Use the Network Analyzer in the AD2 to measure the frequency response of the filter.
 - (a) Plot the measured magnitude of the output voltage V_{out} in decibels as a function of frequency.
 - (b) Plot the measured phase of the output voltage V_{out} in degrees as a function of frequency.
5. Compare the time domain simulations from Pre-Lab **item 2**, the AC (frequency response) simulations from Post-Lab **item 3**, and the measured frequency response from Post-Lab **item 4**.
 - (a) Explain the relationship between the time domain simulations from Pre-Lab **item 2** and the AC (frequency response) simulations from Post-Lab **item 3**.
 - (b) Do the time domain and frequency domain simulation provide the same information?
 - (c) Are the results from the two simulations consistent?
 - (d) Compare the AC (frequency response) simulations from Post-Lab **item 3** and the measured frequency response from Post-Lab **item 4**.