

Experiment 37: Band-Pass Filter Step Response / Convolution Integral

Introduction

A low-pass filter is cascaded with a high-pass filter to create a band-pass filter. An op-amp buffer is used between the low-pass and high-pass filters. This filter is intended to pass the frequencies between the low-pass and high-pass filter's cutoff frequencies. This experiment will measure the time-domain step response of this filter.

It is possible to obtain the time-domain response of this circuit by solving the circuit in the s-domain and converting the result to the time-domain. It is sometimes necessary to solve for the time-domain response in the time-domain using the convolution integral method. This experiment is intended to show an application of the time-domain convolution method.

Objectives

A square wave, V1, will be applied to a two section band-pass filter. The first section is a high-pass filter consisting of C1 and R1. The second section is a low-pass filter consisting of C2 and R2. The time-domain unit step response will be measured for the high-pass filter as V2.

The waveform, V2, is applied to the low-pass filter through an op-amp "buffer". The buffer has a transfer function of "1" (output is exactly equal to the input). The buffer has very high input impedance so that it does not load down the high-pass filter, and very low output impedance so that it acts like an ideal source for the low-pass filter. This makes it possible to calculate the transfer function of each filter independently. The measurement results will be compared to calculations and *OrCAD PSpice* simulation.

Procedure

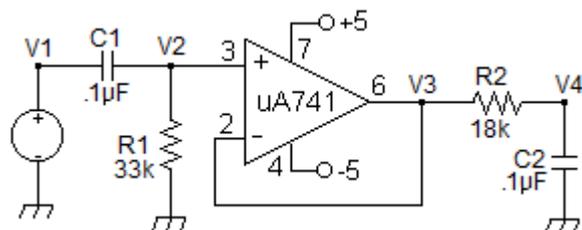
Equipment and Parts

Function Generator, Oscilloscope, DC Power Supply, Breadboard.
18 K Ω and 33 K Ω resistors. μ A741 op-amp.
2 each, 0.1 μ F polyester film capacitors.

1. Measure the values of the parts.

R1 _____ R2 _____ C1 _____ C2 _____

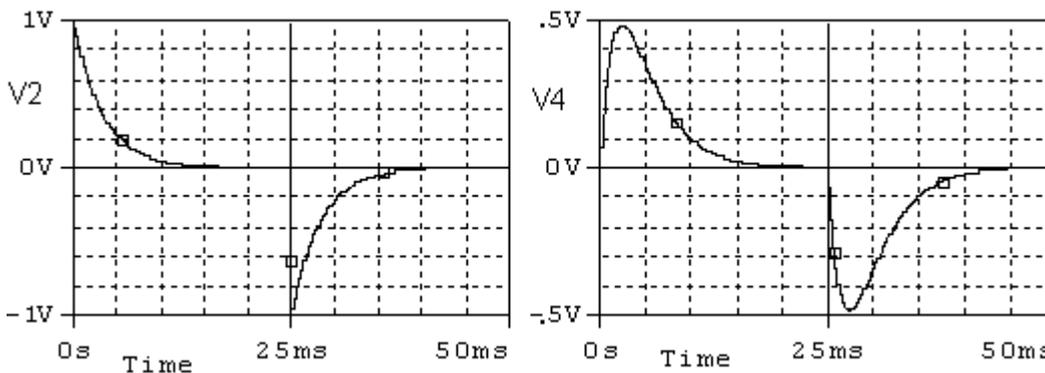
2. Connect the circuit on the right. V1 is the generator set to produce a 20 Hz, 1 V peak-to-peak, square wave, with a plus 0.50 V offset.
3. Connect oscilloscope channel 1 to V1 and channel 2 to V2.



4. Set the oscilloscope's channels 1 and 2 to DC input coupling, and 0.5 V/DIV. Set the zero reference for channel 1 and 2 to the center of the screen.
5. Set the oscilloscope's time base to 5 mS per division, trigger to channel 1, positive slope. Observe channel 1 and carefully adjust the function generator's frequency and amplitude. You should observe exactly one cycle of the function generator waveform.
6. Observe channel 2 only (V2). You should see a waveform similar to the graph below on the left. Measure and record the time constant, τ , of the response by measuring as accurately as possible the time it takes for the waveform's amplitude to decay to exactly 0.368 V.

The reciprocal of the time constant is the decay rate, α , of the exponential response.

τ _____ α _____



7. The signal V3 is the input to the low pass filter. Verify that the signal at the input of the low-pass filter is exactly the same as the signal V2 by moving the channel 2 scope probe to pin 6, V3, of the op-amp. Then move the channel 2 scope probe to display V4. You should observe a waveform similar to the graph above on the right.
8. Set the oscilloscope time base to 2 mS per division (or 2.5) and channel 2 vertical input to measure the signal amplitude as accurately as possible. Measure and record the amplitude, V_P , and the time of occurrence, t_P , of the positive peak.

V_P _____ t_P _____

If you are recording the measurements from the screen, try setting the zero reference to the bottom of the screen and set channel 1 volts per division for the largest display. Measure the amplitude of the positive amplitude response at 2 mS intervals.

If you are capturing data using a digital scope and capture software, set the vertical zero reference to exactly the center of the screen.

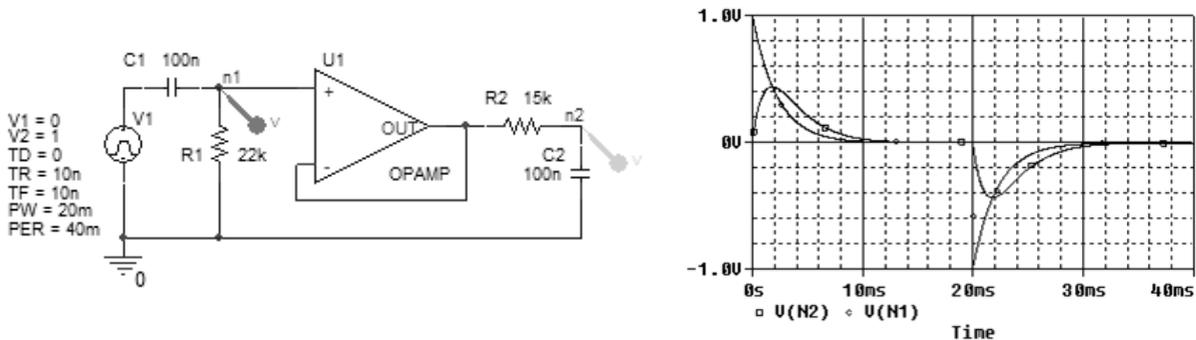
The objective is to record the response at the output of the low-pass filter as accurately as possible for comparison to theoretical expectation. Only the positive response will be analyzed.

Analysis

1. Simulate the band-pass filter circuit using transient analysis. Be sure to use the measured values of your components in the simulation.
2. Compare the following measured results with the simulated results:
 - a) Amplitude and decay rate of the exponential waveform V2.
 - b) Amplitude and time of occurrence of the positive peak of the response at V4.
 - c) Express the percent error of the measurements of (a) and (b) above compared to the simulated results.
3. Use the convolution integral to calculate the response V2 to the input V1. Compare the results of your calculation to your measurements.
4. Use the convolution integral to calculate the response V4 to the input V3. Compare the results of your calculation to your measurements.

PSpice Example: Band-Pass Filter Pulse response

An ideal op amp, "OPAMP" from the analog library, is used in this simulation. It requires no power supply connections. The source "Vpulse" was set to produce a 20 millisecond pulse with a repetition rate of 40 milliseconds.

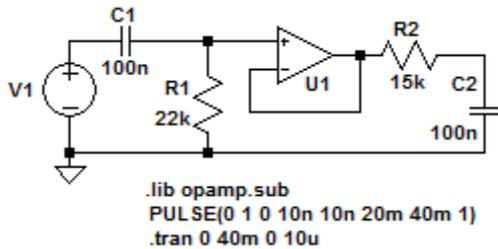


The pulse response of the high-pass filter section is observed at node n1 and the pulse response of the band-pass filter is observed at node n2.

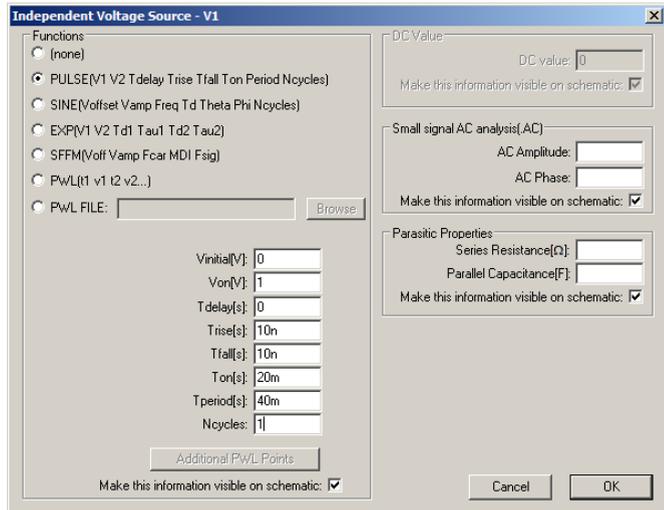
Note that the 20 millisecond pulse width allows the high-pass filter section response and the low-pass filter section response to return to steady state in between each pulse.

LTspice Example: Band-Pass Filter Pulse response

This simulation uses the generic “opamp” in the opamp library. It is easy to use and requires no power supply connections. The directive, “.lib opamp.sub” must be added. Click on “op” on the right side of the main menu bar and type in the directive. It will be displayed on the schematic as shown below.



The source “Vpulse” was set to produce a 20 mS pulse with a repetition rate of 40 mS.



The band-pass filter’s pulse response is plotted below. Note that the 20 millisecond pulse width allows the filter’s response to return to steady state in between each pulse.

