UNIVERSITY OF CALIFORNIA, BERKELEY

EE100 Summer 2008 Lab 6

RC Filters Guide

Description and Background

In this lab you will determine the input-output characteristics of an RC filter

A. RC Filter Characteristics

Figure 1 below shows an RC filter connected to a sinusoidal voltage source. This circuit is termed a two-port circuit (see Fig. 2) where the voltage source produces the input voltage V_{in} and the output voltage V_{out} appears across resistor R.



Figure 1. RC filter with series capacitor and output resistor R (HPF).



Figure 2. Two-port circuit.

Recall that we customarily represent an AC voltage as a periodic function of time such as $V(t) = V_0 \cos(\omega t)$ where V_0 is the amplitude of the voltage, *t* is time, and ω is the so-called angular frequency, whose units are radians per second. The angular frequency is related to the "ordinary" frequency, *f*, measured in Hertz, by $\omega = 2\pi f$. For example, if the frequency, *f*, of the ordinary power line voltage in the U. S. is 60 Hz, then the associated angular frequency, ω , is 377 radians/s ($2\pi \times 60$).

Transfer Function

A two-port circuit is characterized by its so-called transfer function, whose magnitude is defined as $|V_{out}/V_{in}|$, where V_{out} and V_{in} are phasor (has both amplitude and phase)

voltages (as indicated by the boldface type). The variation of the transfer function with frequency characterizes the frequency response of the circuit (a high-pass filter, low-pass filter or band-pass filter).

If you analyze the RC circuit of Fig. 1 using Kirchhoff's voltage law, the phasor voltages V_{out} and V_{in} , the resistance R and the impedance of the capacitor $Z_C = 1/j\omega C$, you can show that the magnitude of the transfer function is

$$\left|\frac{\boldsymbol{V}_{out}}{\boldsymbol{V}_{in}}\right| = \frac{\omega RC}{\sqrt{1 + (\omega RC)^2}}$$
(1)

An approximate log-log plot of transfer function magnitude vs. angular frequency is shown in Figure 3:



Fig. 3. Log-log plot of transfer function magnitude vs. angular frequency for the HPF.

The filter characteristic is shown in Figure 3 as a high-pass filter which passes frequencies higher than $\omega_B = 1/RC = 1/\tau$, which is the critical frequency used to indicate the pass band. For this high-pass filter (HPF) the pass band is $\omega > \omega_B$. The critical frequency is defined as the frequency at which the output voltage amplitude drops to $1/\sqrt{2}$ of the input voltage amplitude (also called 3 dB point in decibel scales. Please refer to Chapter 6 for more information on Decibels and Bode plots). In order to plot the whole frequency response, one has to plot over a frequency range that covers ω_B (e.g. $0.1\omega_B < \omega < 10\omega_B$).

If we reverse the positions of R and C in the filter circuit (Figure 4), we obtain the transfer function and filter characteristic shown below:



Fig. 4. Circuit with a series resistor R and the capacitor C as the output element (LPF).



Fig. 5. Log-log plot of transfer function magnitude vs. angular frequency for the LPF.

The filter characteristic is shown in Figure 5 as a low pass filter which passes frequencies lower than $\omega_B = 1/RC = 1/\tau$. For this low-pass filter (LPF) the pass band is $0 < \omega < \omega_B$.

Procedures

P1. Connect a $1k\Omega$ resistor and a (non-polarized) 1 nF capacitor in series with a signal generator as shown in Fig 1, making sure that your oscilloscope ground and the signal generator ground are connected together. Set the signal generator to output a 0.5V-Vpp sine wave. Measure and plot the amplitude of the voltage across the resistor versus frequency on log-log graph paper. You can download log-log graph paper from the EE100 web site. First figure out the frequency range and the step of the sample points you are going to use. Should you make the step constant over the range? (hint: take more points when the curve turns, take less points when it is constant.)

P2. Reverse the order of the two components as shown in Fig 4 and repeat. Plot the amplitude vs. frequency in a log-log scale.

P3. Observe the effects of filtering on square and triangular waves. Change the frequency of the signal and observe the shape change of the signal, then explain the change.