Lab 3: Passive Components
RC Filters

Physics 116A

Modification to writeup Rev. 2
Oct. 11, 2010

Refer to the original writeup for Figure 3

2 RC Filters

2.1 Low Pass Filter Bode Plot

In this section, you will measure the frequency response and phase shift of a low pass filter circuit and characterize its behavior by making a Bode plot of your results. Construct the circuit shown in figure 3 using the function generator as the AC source. Use a 6V peak-to-peak sine wave as the $V_{in}$ source signal. Use both channels of the oscilloscope to monitor $V_{in}$ and $V_{out}$ simultaneously showing their phase relationship as follows. Connect Ch. 1 to $V_{in}$ and Ch. 2 to $V_{out}$. It is best to get in the habit of using the oscilloscope 10X probes for this purpose. Set the oscilloscope to trigger on Ch. 1 only and adjust the trigger level until the trace starts at zero with positive slope. Ch. 1 will now display a sine wave. The phase difference of Ch. 2 will now be evident through the different starting value of its trace and the overall displacement of the Ch. 2 waveform relative to Ch. 1.

The input signal is now

$$V_{in}(t) = V_{in_m} \sin(\omega t)$$

and the output is

$$V_{out}(t) = V_{out_m} \sin(\omega t + \phi)$$

where $V_{in_m}$ and $V_{out_m}$ are the amplitudes of the input and output waveforms, respectively (you have set $V_{in_m} = 3$ V).

Calculate the corner frequency (or break frequency) $f_c = \omega_c / 2\pi$ for this circuit, where $\omega_c = 1/(RC)$. Be sure to use your measured values for $R$ and $C$.

For your measurements, use $f_c$ and 10 other frequencies, 5 above $f_c$ and 5 below $f_c$, spanning a total of at least 3 decades of frequency and preferably more. For each frequency, measure the voltage gain, $A_v \equiv V_{out_m}/V_{in_m}$ and the phase shift, $\phi$ of $V_{out}$ relative to $V_{in}$. The oscilloscope cursors are useful for making these measurements. Note that you can find $\phi$ by dividing the time difference between corresponding points on the input and output waveforms (such as the peak times or the zero crossing times with positive slopes) by the period of the waveform (measured for the input waveform) and multiplying by $360^\circ$. Be sure to take the sign of the phase shift into account. For example, if the output lags behind the input, the phase shift $\phi$ is negative (until you reach $180^\circ$, of course). The goal is to make a Bode plot of the data to
characterize the low pass filter performance. The Bode plot is actually two plots, often done on the same graph, one of voltage gain $A_v$ in dB vs. frequency and the other of output phase shift vs. frequency, plotted on a semilog scale. The voltage gain in dB is defined as

$$A_v(\text{dB}) = 20 \log_{10} \left( \frac{V_{\text{out}}}{V_{\text{in}}} \right)$$

Thus, the Bode plot is actually a log-log plot so power law behavior gives a straight line. Bear in mind that you will want to find the slope of the fall-off of the gain on the Bode plot at high frequencies.

For your lab report, include your $f_c$ calculation, your gain and phase shift data, and a comparison of the data with the theoretical Bode plots for gain and phase angle. You may prefer to use $f/f_c \equiv \omega/\omega_c$ as the abscissa ($x$-axis) of your Bode plots. This gives a “universal” graph since the actual RC value is eliminated.

Answer the following questions.

1. What is the significance of the corner frequency with respect to the asymptotic straight lines for low and high frequency behaviors?

2. What is the measured slope (in dB/decade) of the asymptotic high frequency falloff (i.e., difference of $A_v$ in dB for a factor of 10 change in $f$)?
   
   (a) Is it what you expect from the analysis?

3. Compare measurements and predictions for the following:
   
   (a) $A_v$ at $f = f_c$;
   
   (b) the phase shift at $f = f_c$;
   
   (c) the maximum phase shift as $f \to \infty$.

### 2.2 High Pass Filter Bode Plot

Design an RC high-pass filter with $f_c = 10\text{kHz}$. Build it and take enough data to make Bode plots for gain and phase. For your report, include a description of how you designed the circuit and the two Bode plots (each of which includes data points and a theoretical plot). Make the comparisons suggested in the previous subsection for the low pass filter.