Lab 4: Equivalent Circuits and Filters

Prelab

Read sections 2.31 – 2.33 in your textbook. Pay special attention to the four basic categories of filters and to the types of plots used to represent their effects.

Be sure that you or your partner bring the textbook to lab.

Part I: Thevenin's Theorem

- *Calculate the Thevenin voltage and resistance for the circuit in figure 1, between the points A and B.* Follow the guidelines in section 2.19 of your textbook.
- *Construct the circuit and measure the voltage between A and B. Does this agree with your calculated voltage?*
- *Replace the voltage source with a wire and measure the resistance between A and B, does this agree with your calculated resistance?*
- *Connect a 100Ω resistor between points A and B and measure the voltage across it.*
- *Draw the Thevenin equivalent circuit and then construct it on your breadboard.*
- Connect a 100Ω resistor to the output of the Thevenin equivalent circuit. *Do you measure the same voltage across the resistor as you did for the full circuit?*

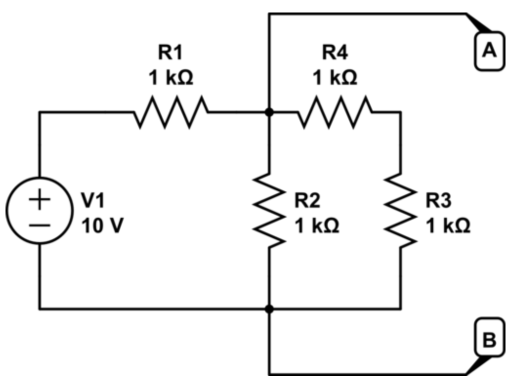

Figure 1: Resistor Network

Part II: Filters

2.1 Background info

Last week you examined the voltage across both the capacitor and the resistor in an RC circuit and found that the output amplitude and the phase angle were frequency dependent. These circuits let through some frequencies preferentially while filtering out others. You also looked at a special frequency at which the phase angle was 45° and the output voltage was $V_{out} = V_{in}/\sqrt{2}$. This frequency is known as the "cutoff frequency" of a filter. Equations (2.1) and (2.2) are the same as the ones you found in lab last week, but they have been recast in terms of the cutoff frequency, as defined in equation (2.3).

$$V_{out} = \left(\frac{Vin}{\sqrt{1+(f/f_c)^2}}\right) \text{at an angle of } \left(\arctan\left(\frac{f_c}{f}\right) - 90°\right) \tag{2.1}$$

$$V_{out} = \left(\frac{Vin}{\sqrt{1+(f/f_c)^{-2}}}\right) \text{at an angle of } \left(\arctan\left(\frac{f_c}{f}\right)\right) \tag{2.2}$$

$$f_c = 1/(2\pi RC) \tag{2.3}$$

While last week you mainly focused on the phase angle, this week you will be focusing on the amplitude. The most common way to represent the effect a filter circuit has on the input amplitude is to calculate the decibels of attenuation over a range of frequencies and then create a plot of decibels on the vertical axis (with a linear scale) and frequency on the horizontal axis (with a log scale). These are known as Bode plots and there are several examples in your book.

Equation (2.4) gives the relationship between the voltage attenuation fraction and the attenuation level in decibels. When at the cutoff frequency the attenuation level is almost exactly -3dB. For this reason, the cutoff frequency is also often referred to as the "$3dB$ point" or f_{3dB}. (Note the lack of negative sign, that is simply convention, which is just the fancy way to say we're all too lazy to keep writing the negative sign.)

Show how the -3dB value is arrived at and what the exact value is.

$$[dB] = (20dB)\log(V_{out}/V_{in}) \tag{2.4}$$

When at a frequency much higher than the cutoff frequency for a low pass filter, the "1" under the square root in equation (2.1) becomes nearly irrelevant. In this range, a doubling of frequency results to a halving of voltage.

Examine the decibel attenuation equation. Every time the voltage decreases by a factor of 2, what is the increase in attenuation in terms of decibels?

2.2 Low Pass Filter

You will be constructing and characterizing the low pass filter circuit in figure 2

1. Measure the components with your multimeter to obtain more accurate values. (Use the "RELΔ" button when measure small capacitors to zero out the capacitance of the probes.)
2. *What do you expect the cutoff frequency to be?*
3. Set the function generator to 50 Hz and overlay channels 1 and 2 on the scope. (As usual, be sure probes and scope are in 10X mode, and set ACQUIRE to average 4 or 16 samples.)
4. The input and output voltages should both be right at 15 volts peak-to-peak. If they are slightly off, adjust the output to be right at 15 volts.
5. *What output voltage do you expect to measure when at the frequency you found in number 2?*
6. Measure the output peak-to-peak voltage starting at 50 Hz and doubling the frequency for each data point until you reach 204.8 kHz. In addition, include a data point at the cutoff frequency you calculated.
7. *How does the V_{pp} you measured at the cutoff frequency compare to the value you calculated?*
8. Using Excel (or similar), calculate the attenuation in decibels for each data point.
9. Make a Bode plot of the results as described earlier in this writeup. Clearly title the plot and label the axes for inclusion in your report.
10. *Far above the cutoff frequency, what do you obtain for the slope of the line? What did you expect the slope to be?*

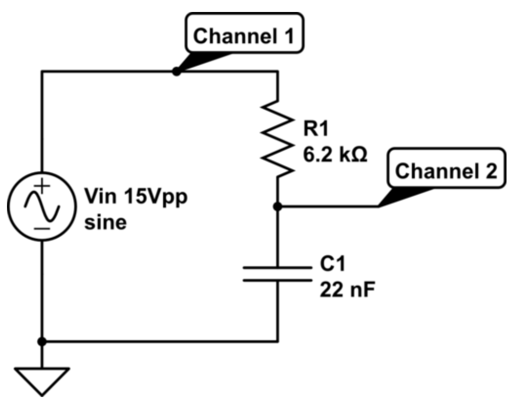

Figure 2: A low pass RC filter

2.3 High Pass Filter

Now you will construct and characterize a high pass filter. Obtain the components in figure 3 and follow the same procedure as for the low pass filter. (Use two 1 nF capacitors in parallel to obtain a value of 2 nF.)

This time, start at 204.8 kHz and work your way down to 50 Hz.

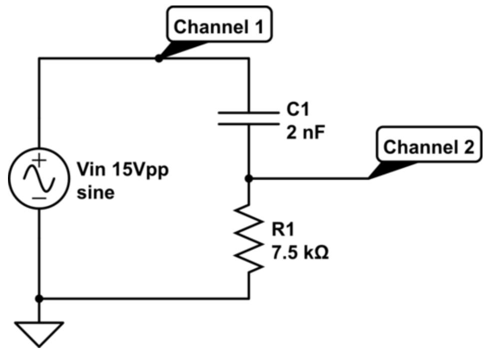

Figure 3: A high pass RC filter

2.4 Notch Filter

Next week we will look more in depth at notch and band pass filters. For now we can quickly get a feel for what they do.

Add a 1000 μH inductor in parallel with the capacitors in the high pass filter circuit. (This configuration is often called a “tank circuit”.)

In lab 1 we mentioned that the VCF input on the function generator is to control the frequency via an external voltage. You are going to use a ramp (triangle wave) signal from one generator to control the voltage of the second generator. We’ll call the generator outputting the ramp signal “gen1” and the generator outputting the sine wave into the filter “gen2.” I suggest using the 5MHz generator as gen1 and the 2MHz as gen2.

You can get a good idea of the central frequency of the the notch filter using the formula $f_0 = 1/(2\pi\sqrt{LC})$. What does this give you?

1. Set gen1 to a triangle wave and the frequency to around 1 Hz. Connect the output to channel 1 on the scope via a coax cable. Be sure channel 1 is in 1X mode and set to DC coupling. Adjust the peak to peak voltage to 10 V and use the DC offset knob to have the signal vary from 0 to 10 V instead of -5 to +5 V.

2. Use a second coax cable and a splitter to send the ramp signal to both channel 1 and the VCF input of gen2.

3. Connect the output of gen2 to the filter and the output of the filter to channel 2 of the scope just as in the previous section. Channel 2 should be still in X10 mode with AC coupling.

4. You should see some fairly crazy signals on the scope. Go to the DISPLAY menu and change the format from YT to XY and increase the persistence to 5 seconds. Also set channel 1 Invert to ‘On’.

5. Set the course frequency knob on gen2 to maximum and select the 100k range. If you see the signal going off one edge of the screen use the zoom and scroll knobs to center it. As the voltage goes from 0 to 10 V, the frequency will go from the F_{max} to approximately $F_{max}/100$, this inverse relationship is why channel 1 needed to be inverted.

In this mode you can’t make any direct measurements using the scope. Instead, remove the splitter from gen1 and connect it to your DC power supply (set to 0 Volts). Now you can slowly vary the frequency of gen2 using the DC supply. *Use this method to approximate the location of the center of the notch. Does this seem reasonable given the calculation from earlier?*

Take a picture of the scope output to include in your report (setting persistence in to infinite might make for a better picture).

2.5 Band Pass Filter

Changing the current setup to a band pass filter is as simple as switching the input and the ground locations so that the scope is measuring the voltage across the resistor instead of the capacitor/inductor combo.

Do this and examine the results on your scope. Where is the center of the peak?

Take a picture to include in your report.