

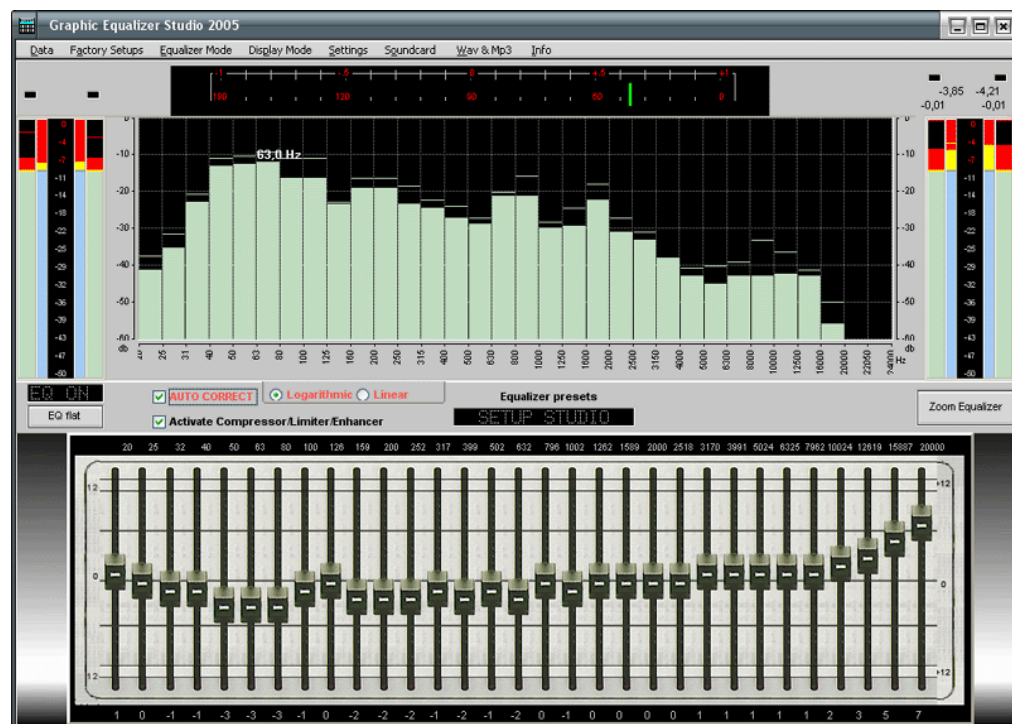
Lab 8

RC Series Circuits – Frequency Filters

What You Need To Know:

Filters ... what are they and why do we need them? A graphic equalizer is a way to control the dynamics of a sound wave. Most sounds aren't just simple tones consisting of a single frequency. Instead, they have many different frequencies playing at the same time. A graphic equalizer allows the listener to selectively adjust certain frequencies without changing the values of others. It can be used to eliminate hiss from a recording, to make a recording sound fuller or warmer, to crank the bass up, and for many other purposes.

Each slider in a graphic equalizer has a filter which only lets certain sounds pass through. The bass and treble sliders only pass frequencies below and above a certain level, respectively. The sliders in the middle all have a range, passing signals through between a certain lower limit and a certain upper one. [Image Reference: <http://www.windows-64.com/Graphic-Equalizer-Studio-393950>, Filters Reference: <http://www.ehow.com>]



Let's recap the last lab, you were using RC series circuits and looking at what happens when you input a square wave signal. The square waveform simulated turning the circuit on and off rapidly. If the frequency was low enough (long period T) then the capacitor could reach full charge and then discharge fully and repeat. Imagine

what would happen if you used too high a frequency. The capacitor would not have time to charge up fully before the discharge cycle begins. The voltage on the capacitor would never reach the maximum signal strength, because of the lack of time to charge up. In fact increasing the frequency at which the voltage source (signal generator) is turned on and off would mean that the capacitor would get progressively less maximum voltage since it has less and less time to acquire charge. How do we use this to make filters?

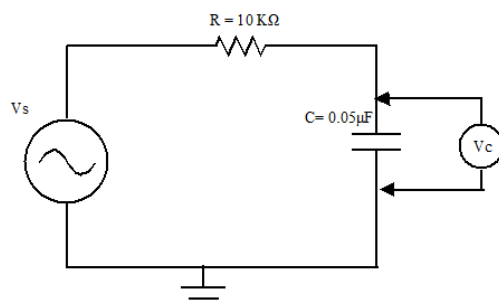
Low Pass Filter

What do you think would happen if you used a sine wave input from the generator instead of a square waveform? It is found that the voltage across both resistor and capacitor are sinusoidal. For periods of the sine wave which are large in comparison to the time constant of the circuit ($\tau = RC$) the amplitude of the voltage across the capacitor will be approximately equal to that of the source. However, as the period of the sine wave becomes small in comparison to the time constant, the max voltage on the capacitor will reduce to a small fraction of the source max voltage.

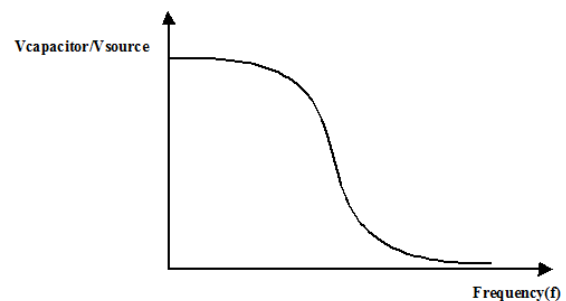
- So for **large period** (low frequency) input signals you get a **large voltage** across the capacitor.
- For **small period** (high frequency) input signals you get a **small voltage** on the capacitor.

The voltage across the capacitor in a series RC circuit constitutes a LOW PASS FILTER. You can put all the voltage you want at high frequency and nothing gets through, voltage only gets through at low frequency. Take the maximum source voltage to be $\varepsilon = V_{source}$ and the voltage across the capacitor to be V_c and the frequency of the signal generator to be f , then ...

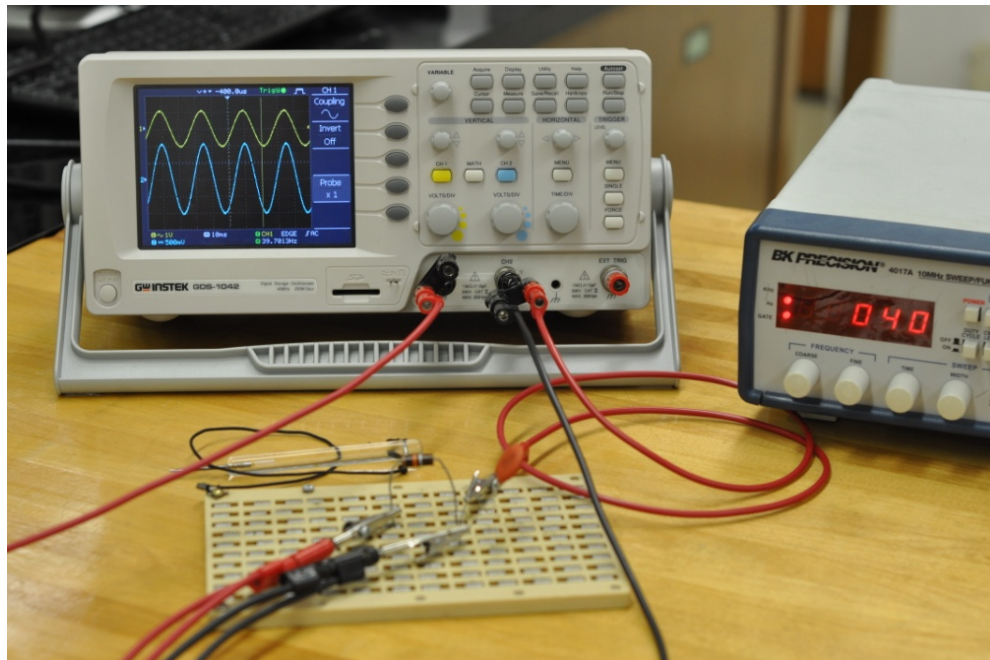
$$V_c = \varepsilon \frac{1}{\left[R^2 + \left(\frac{1}{2\pi fC} \right)^2 \right]^{\frac{1}{2}}}$$



Low Pass Filter Circuit
Note: $V_{capacitor} = V_c$.



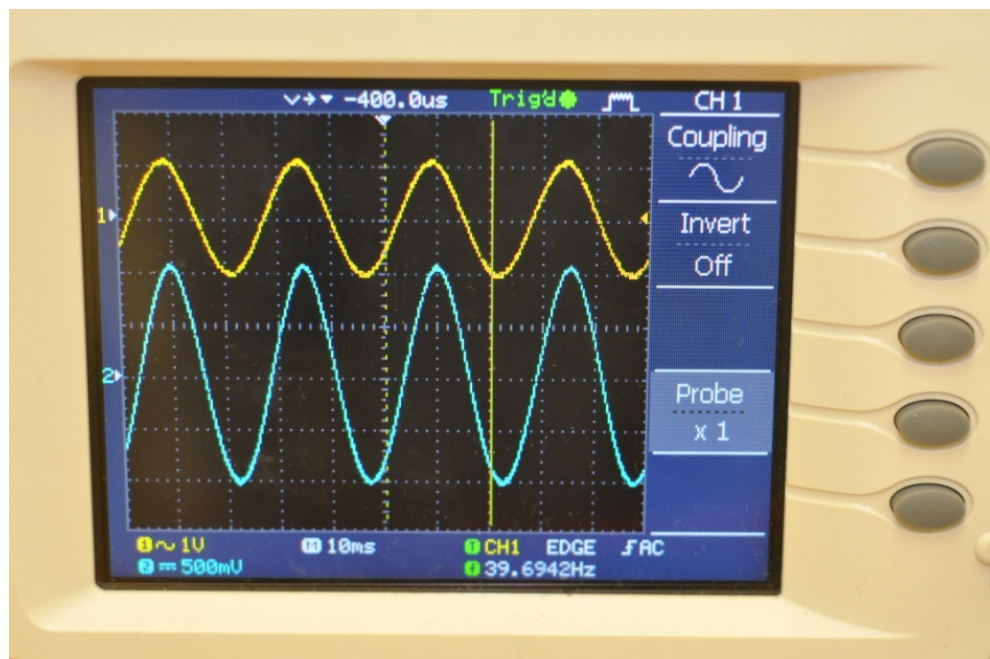
Plot of V_c/V_{source} vs. Frequency
For Low Pass Filter



Low Pass Filter

Shows 40Hz on the signal generator set to sine wave.
AC coupling on scope. (above)

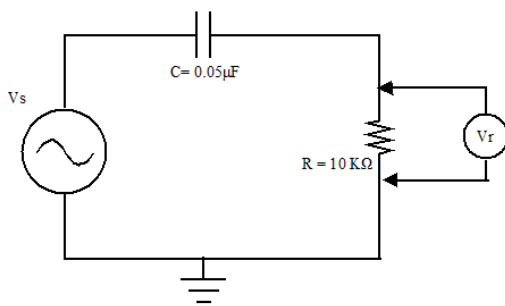
Close up of the scope at 40Hz input signal. (below)
Voltage from signal generator,
 $V_s \sim 1.0$ volt, top, yellow CH 1.
Volts across capacitor, blue CH 2, using 500mV scale
and 10ms time/div.



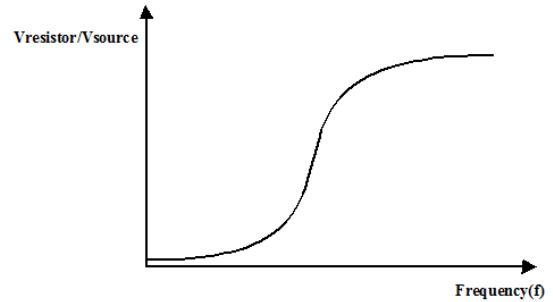
High Pass Filter

You may wonder at this point what is happening to the voltage across the resistor? Recall that the sum of the instantaneous voltages across the resistor and capacitor must equal the voltage of the source. If the voltage at high frequency across the capacitor is very small then it follows that the voltage across the resistor must be high. The opposite is true for low frequencies. Thus the voltage across a resistor is a HIGH PASS FILTER. The resistor will pass high frequencies but not low frequencies. The voltage across the resistor is found to be,

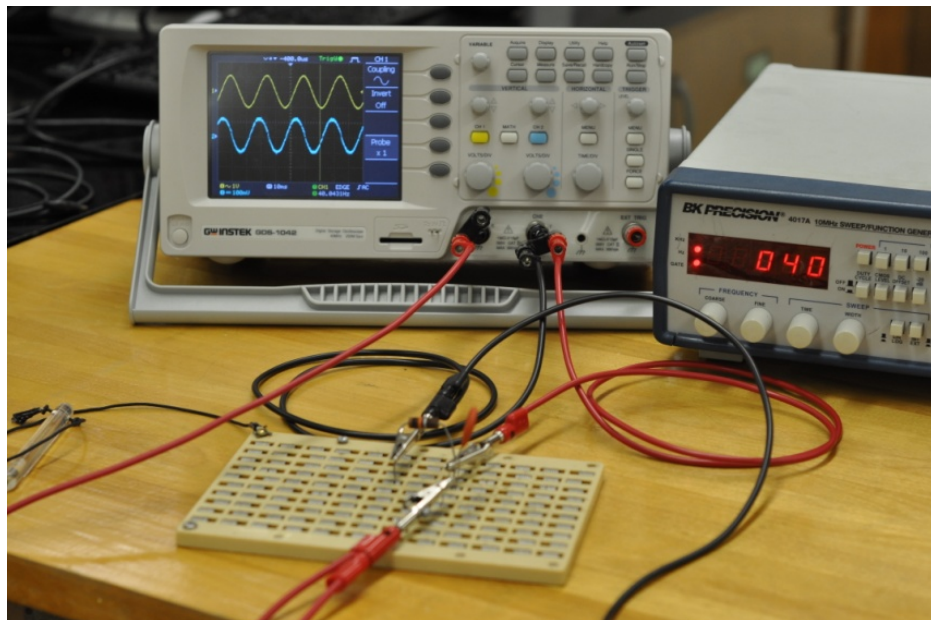
$$V_R = \varepsilon \frac{R}{\left[R^2 + \left(\frac{1}{2\pi fC} \right)^2 \right]^{\frac{1}{2}}}$$



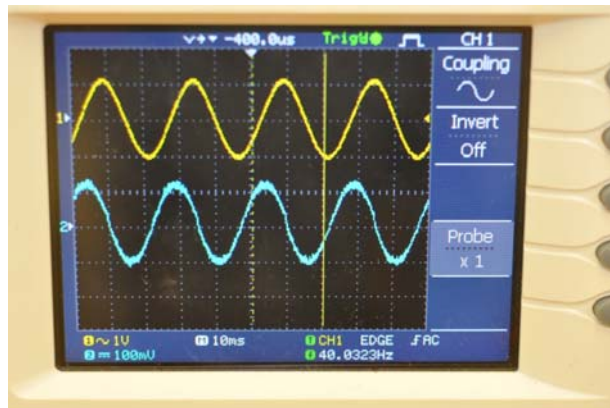
High Pass Filter Circuit
Note: $V_{\text{resistor}} = V_r$.



Plot of $V_{\text{resistor}}/V_{\text{source}}$ vs. Frequency
For High Pass Filter



High Pass Filter
showing 40Hz from signal generator.



Notice CH2 across the resistor is set to 100mV /div and 10 ms time/div.
The blue CH 2 curve appears fuzzy because it's a weak signal we are enlarging to see.

A BAND PASS FILTER is when you use high and low filters back to back so you get a frequency range as an output.

What You Need To Do:

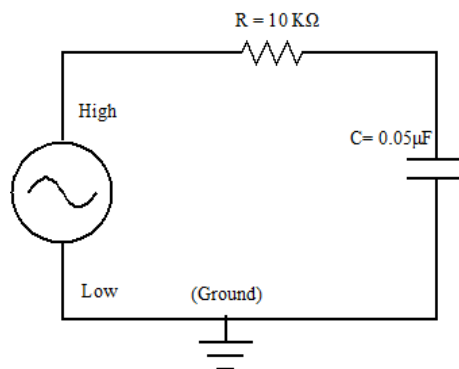
You will be performing 3 experiments.

The equipment is a spring board, resistors, capacitors, signal generator and scope.

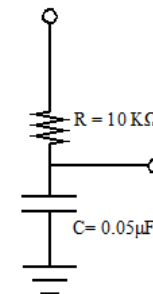
- 1) Set up a low pass filter. Plot curve from data.
- 2) Set up a high pass filter. Plot curve from data.
- 3) Set up a band pass filter using a combination of the two above. Plot curve & listen to output.

It is recommended that you use excel to plot your data, graph paper has been provided for those unable to plot with excel. Remember there are tutorials online! You will eventually be expected to plot data and print it out.

Part 1 – Low Pass Filter Set up the circuit in the diagram below. Both diagrams are of the same circuit, the one on the right is a simplified version.



Basic schematic showing the low side of the function generator connected to the ground.



Simplified schematic where ground connections are inferred.

Use both channels of the scope to see the source voltage and the voltage across the capacitor. Both channel share a common ground so there is no need to hook up both ground cables.

Use the data in the table to plot the ratio V_c / V_s as a function of frequency on the 3-cycle semi-log paper provided at the end of the lab. Be sure to draw a smooth curve through the data points.

As you adjust the frequency you will need to change the time/div setting so smaller values to be able to see the sin wave on the scope.

You might start out with 10 ms/div for 20 Hz and then when you get to 2000 Hz you will be around 250 μ s/div.

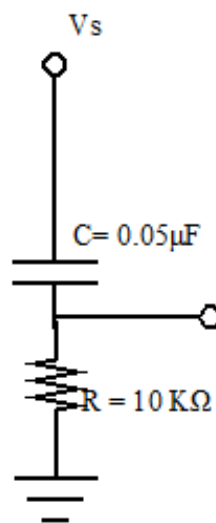
The output voltage for the signal generator is around 1 volt this will remain constant throughout the experiment. Use the vertical adjust buttons to get a good reading for positive voltage.

Low pass filter table:

$$R = 10 \text{ K}\Omega, C = 0.05 \text{ }\mu\text{F} \text{ and } \tau = 5.0 \times 10^{-4} \text{ s.}$$

f (Hz)	V_R (volts)	$V_s = \epsilon$ (volts)	V_R / V_S
20			
40			
60			
80			
100			
200			
400			
600			
800			
1000			
2000			
4000			
6000			
8000			
10000			

Part 2 – High Pass Filter Connect up the circuit like the diagram below, or rearrange the previous one! You will be filling in the same table as before, this time for the high pass filter. You will be plotting the curve again for this data.



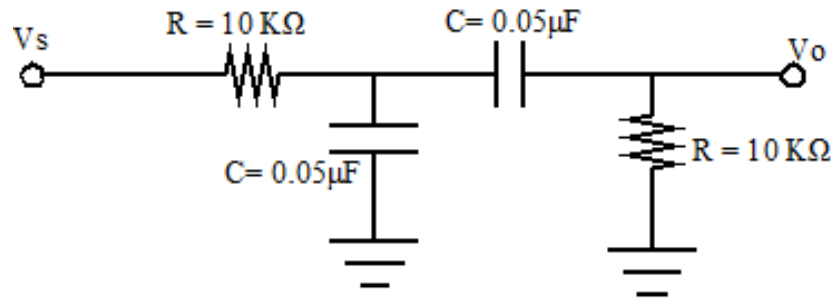
Schematic of High Pass Filter.

High pass filter table:

$R = 10 \text{ k}\Omega$, $C = 0.05 \text{ }\mu\text{F}$ and $\tau = 5.0 \times 10^{-4} \text{ s}$.

f (Hz)	V_R (volts)	$V_s = \epsilon$ (volts)	V_R / V_s
20			
40			
60			
80			
100			
200			
400			
600			
800			
1000			
2000			
4000			
6000			
8000			
10000			

Part 3 – Band Pass Filter Connect up the circuit like the diagram below, fill in the table, and plot the curve.



Schematic of Band Pass Filter.

Band pass filter table:

$$R = 10 \text{ K}\Omega, C = 0.05 \text{ }\mu\text{F} \text{ and } \tau = 5.0 \times 10^{-4} \text{ s.}$$

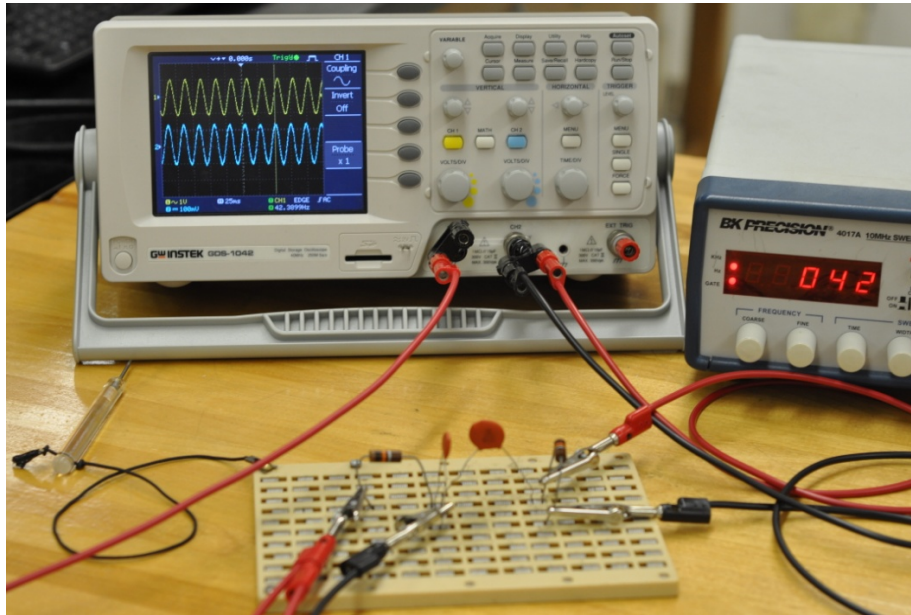
f (Hz)	V_R (volts)	$V_s = \epsilon$ (volts)	V_R / V_s
20			
40			
60			
80			
100			
200			
400			
600			
800			
1000			
2000			
4000			
6000			
8000			
10000			

Using a band pass filter as a one stage of a graphic equalizer.

Let's listen to the output of your band pass filter. Connect the earphone in parallel with the oscilloscope leads which are across the resistor, V_0 . Watch and listen as you run the function generator through the frequency range from 100 Hz to 10,000 Hz. Concentrate on the loudness not the pitch.

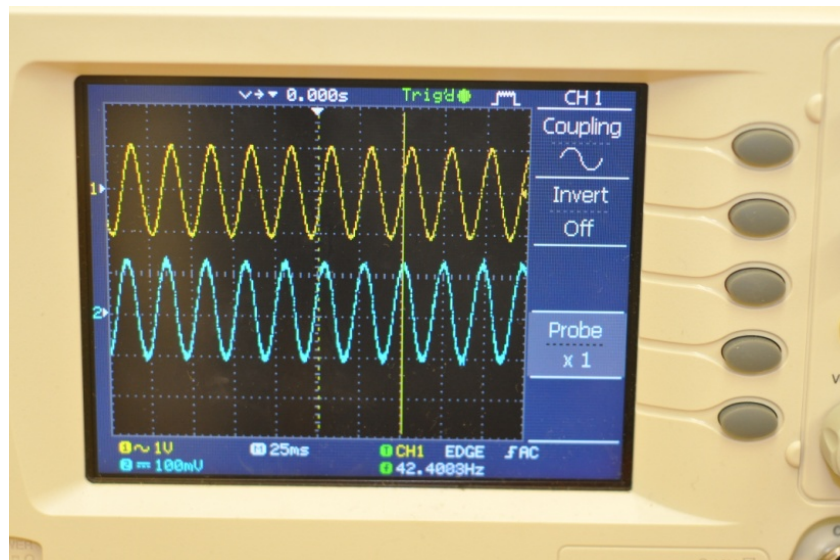
Can you hear the loudness reach a maximum?

Does the maximum loudness correspond to the max voltage of the band pass filter?



To hear the output of the band pass filter hook up the earpiece across the same points as the CH 2 leads.

The tone reaches maximum loudness (and highest voltage V_0) between 200-800 Hz. If you don't hear anything try readjusting the contacts of the earpiece, it is very sensitive.. you may need to hold one contact in place while you adjust the frequency to hear the difference it makes. The curve V_R/V_S vs. freq, should show a maximum, like a bell curve.



Close up of scope for band filter at about 40 Hz.
Note 100mV setting for CH 2 and 25ms/div time setting.

