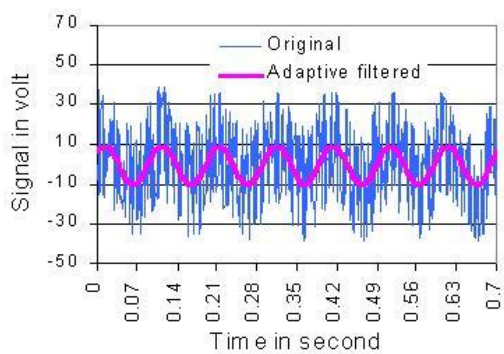
Problem set: RC circuits as signal filters—the Bode plot

Goal: Build and characterize the filtering behavior of two different filter circuits over a range of frequencies.



Source: http://www.chenyang.de/Signalprocessing.htm

Why do we want to filter signals?

Raw signals can contain the information disguised by noise or other unwanted information. *Filters* can help us to get rid of some of the information in the signal that we're not interested in.

A *filter* can be built from different combinations of resistors and capacitors.

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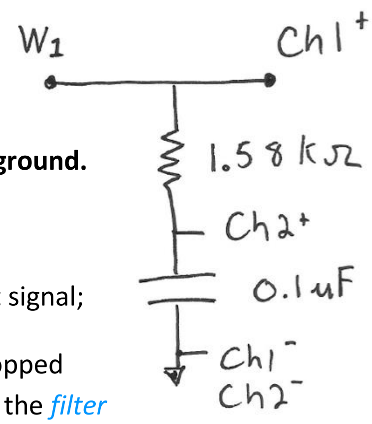
What type of signal was filtered out from the original signal? How do you know?

Testing the RC filter and its behavior

1. Build the RC circuit shown; it will *filter* the input signal.



2. Connect the Discovery to your circuit.

Ensure the Discovery and circuit share a ground.

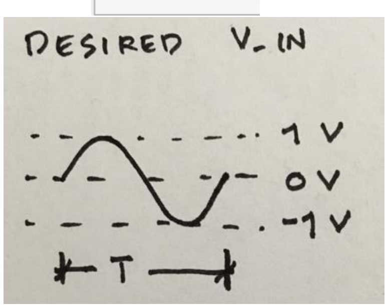
Use Wavegen 1 as the V_input signal.

Use Scope Channel 1 to monitor the input signal;

Use Scope Channel 2 to monitor the V dropped *across* the capacitor; we will consider this the *filter output.*

3. Set 

, then ▶Run



Choose a signal input frequency that will give you a sine wave period, T≅ RC circuit time constant, τ ("tau").

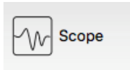
The **sine** function takes an argument in units of *radians**.

*How do you convert cycles/second (Hz) to radians/second (ω) for the **sin** function?*

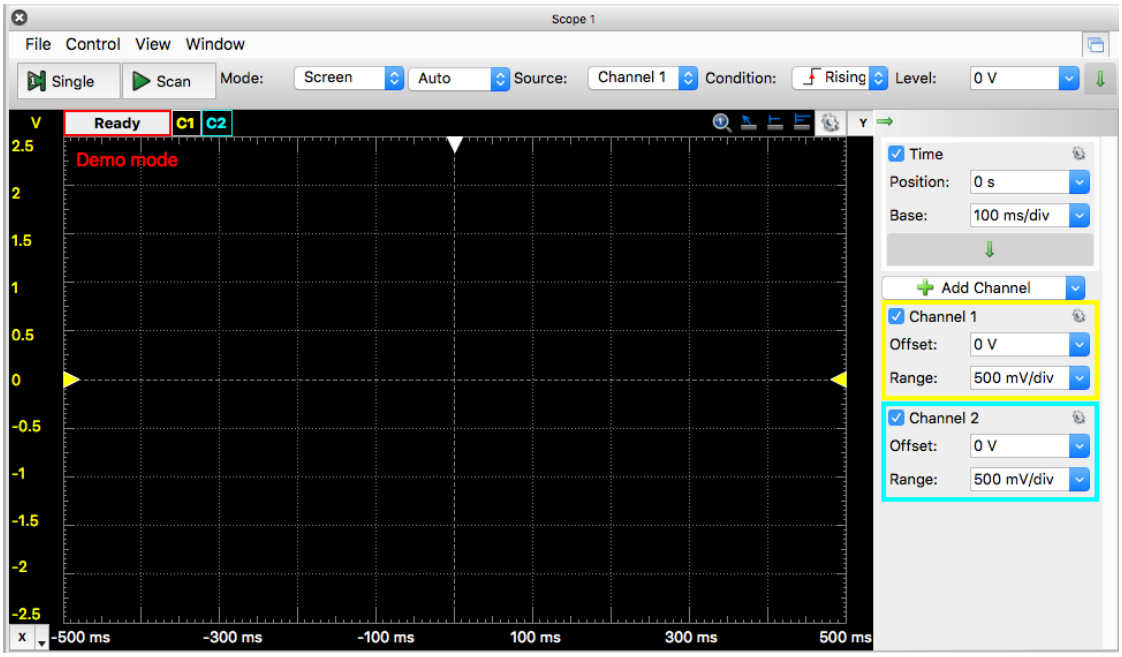
[This animation illustrates Hz ➠ω: How many **π** are in a complete a cycle?]

When you've set up the signal, ▶Run

*But Wavegen displays the **sin** wave in Hz.

4. Add and set up 

, then ▶Scan



How can you adjust the time base to see 3-4 cycles?

What V range will allow you to see your input signal?

5. Test the circuit: Change the input frequency and notice the response

Adjust the frequency of the waveform to be ~10x lower- and ~10x higher- than the characteristic frequency of the filter given by RC.

Observe how the filter behaves qualitatively at both low- and high- frequencies.

Notice the amplitude of the output as well as the shift in time, Δt, between input signal and the output signal.

If your circuit is working as expected, it will allow some frequencies to pass through to V_{out} and it will attenuate other frequencies?

Check with someone else. Are your circuits responding similarly?

6. Measure and quantify how this RC circuit *responds* to different frequency inputs

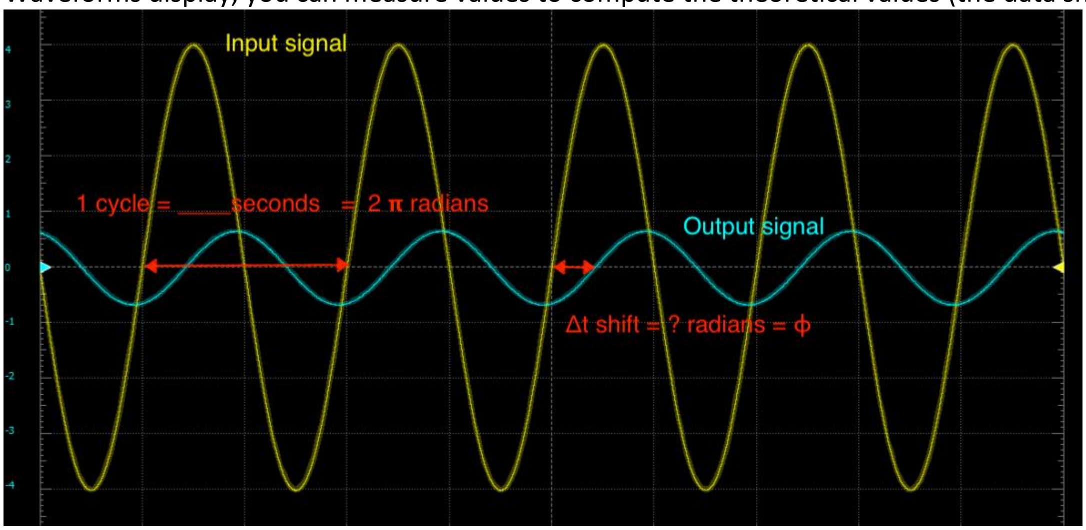
We will model the input to the RC circuit as a sine wave: $V_{in} = \sin(\omega t)$, where ω is the angular frequency in radians/second (also "rads/sec"). The output is expected to be $V_{out} = A \cdot V_{in} \cdot \sin(\omega t + \phi)$. From the book, we know that output amplitude will be:

$$A = \frac{1}{\sqrt{1+(RC\omega)^2}} = \text{voltage gain}^*$$

And the angular shift in phase is:

$$\phi = \operatorname{atan}(-RC\omega)$$

Fill in the table below for the experimental and expected values. If you use the tools in the upper right of the Waveforms display, you can measure values to compute the theoretical values (the data shown are fake).



In Waveforms, the data display in the *time* domain (seconds).

Frequency, Hz (cycles/s)	Angular frequency, ω (rad/s)	RCω (unitless)	A (theoretical)	A (measured)	Φ,theory (degrees)	Δt, shift (seconds)	Φ,measured (degrees)
100							
500							
1,000							
5,000							
10,000							

Looking at the values in the table above, what happens to a 10,000 Hz signal that goes into this circuit?
What about a 100 Hz signal?

Talk to someone in the lab about your results. How does this RC circuit respond to input signals?

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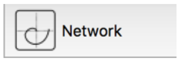
*This might be too much information: A = $\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{1+(RC\omega)^2}}$ = voltage gain. The decibel (dB) was developed as a unit to measure *Power* gain, 1 dB = 10 log (A_{power}). Because $P = IV = V^2/R = I^2R$, $Gain_{Power} = Gain_{Voltage}^2 = Gain_{Current}^2$

7. Analyze the circuit behavior with 

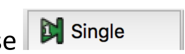
Add a 

component in Wavegen. This component is a Waveform generator and Scope wrapped into one. It is going to do all the work you did by hand in step 6. It displays the frequency response of the circuit in what is called a Bode plot. The Bode plot is the plot of amplitude and phase as a function of frequency.

There is no need to change your circuit or Analog Discovery set up from the last step—it will use the same channels.

Adjust the frequency range, Start: 10 Hz; Stop: 100 kHz.

You may want to adjust this range later.

Use 

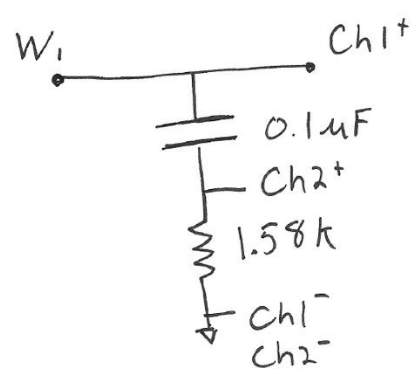
to produce a single sweep.

Save the Bode plot data through the export feature.

Export and plot the amplitude part of your data from the Network Analyzer. Superimpose your data from the table above on the Bode plot as data points.

Remember the experimental output will be in dB while the amplitude, A, is just the ratio of output voltage to input voltage. See the book for converting to (or from) dB.

8. Build and test a CR circuit by hand (step 6.) and with a Network Analyzer (step 7)



In this case the amplitude and phase results change from the previous example. The expected results for amplitude and phase are;

$$A = \frac{RC\omega}{\sqrt{1 + (RC\omega)^2}}$$

$$\phi = \text{atan}\left(\frac{1}{RC\omega}\right)$$

Frequency, Hz (cycles/s)	Angular frequency, ω (rad/s)	RCω (unitless)	A (theoretical)	A (measured)	Φ,theory (degrees)	Δt, shift (seconds)	Φ,measured (degrees)
100							
500							
1,000							
5,000							
10,000							

Recreate the Bode plot using the Network Analyzer as you did with the previous circuit. Create the same plot as you did for the other filter.

Deliverable: You can just turn in two plots from this work. The plots should be well-labeled and clear. This is not a lab and no further explanation is needed.