PS5: Filters in Series

Tuesday, March 23, 2021 4:22 PM

PS5-FiltersI
nSeriesV2

Problem set: Filters in series

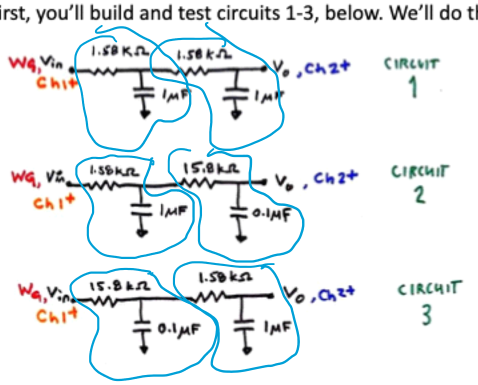
Goal: See how filters work in series and see how they behave at their limits; learn how to design the filters so that they function as if they were independent of one another.

Learning objectives

- Test how RC or CR filters in series behave using a Bode plot;
- Analyze the behavior of filters in series using a model for a single RC or CR filter;
- Compute the expected output from RC and CR filters in series;
- Verify the expected output for RC and CR filters in series;
- Assess the impact of the relative resistance of the RC (or CR filters) that are in series.

In the EKG lab, you used filters in series with one another; the output of one filter was fed to the input of the next. We are now going to assess how these filters alter the input voltage when connected in series.

First, you'll build and test circuits 1-3, below. We'll do this, one at a time, but before you do, let's consider them.



Each circuit has filters that are wired in series. Draw a circle around each of filter. What kind of filter is each?

All: ~100Hz

What is the cutoff frequency, f, in Hz for each filter? ($1 = \omega RC$; $2\pi f = \omega$) $f = \frac{1}{2\pi RC}$

What is the difference between the three circuits? Nothing

$1.58k\Omega \cdot 1MF = 0.0158$

$158k\Omega \cdot 0.1MF = 0.0158$

1. Build Circuit 1. (*This circuit should* ***not*** *be connected to the +5V rail. Also, note that V_o in these circuit diagrams denotes the location of the output voltage rather than a connection to VO.)*

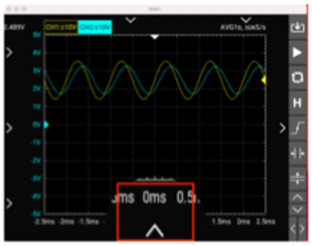
2. Connect the O-Scope to your circuit to generate a Bode Plot. (

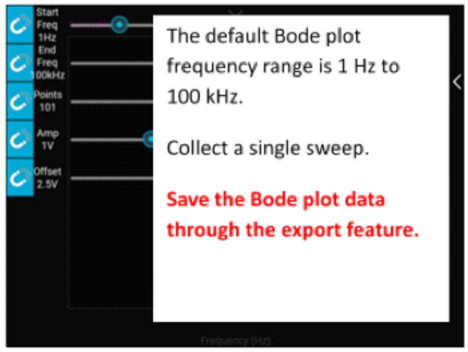
Use Wavegen 1 as the V_input signal.
Use Scope Channel 1 to monitor the input signal;
Use Scope Channel 2 to monitor the V dropped *across* the 2[nd] capacitor; Ch2+ is the *filter output* for the series filter.

Where should you connect Ch1- and Ch2- in your circuit?

3. Collect a Bode plot

The pullout at the bottom of the O-scope screen gives you access to the Bode Plot function.





$A = 10^{dB/20}$

4. Compare the experimental results with the theoretical values

$dB = 20\log_{10}(A)$

Recall that the amplitude of the output sine wave for a single filter of this type is:

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

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

$R = 1580\Omega$

$C = 10^{-6}$

$\omega = 2\pi f$

$$\varphi(radians) = atan(-RC\omega)$$

When we have two of these filters in series with no current flow between them, then the amplitudes multiply and the phases add, namely the ideal response for 2 of these filters in series would be

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

$A = 1/(1+(RC2\pi f)^2)$

Analytical (theoretical) model

$$\varphi = 2atan(-RC\omega)$$

Compare your *experimental* Amplitude Bode plot results to the Amplitude prediction.

To compare A(theory) to A(measured), what units should you use?
How do you convert from dB to a unitless ratio or vice versa?

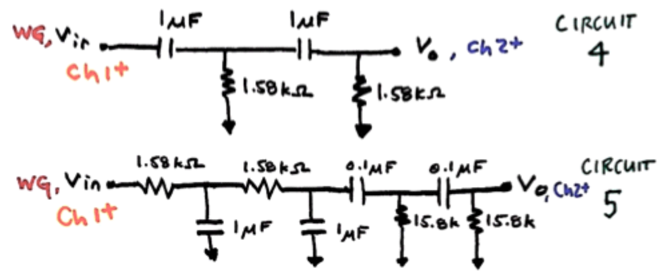
5. Repeat steps 1-4 for Circuit 2.

This strategy will tend to reduce the current flow from one filter to the next. This circuit should be a closer approximation to the ideal behavior where the two filters in series act as though they were each independent.

6. Repeat steps 1-4 for Circuit 3.

For your problem set, compare the Amplitude behavior of these three circuits (1,2,3) to the theoretical model by graphing the amplitudes together.

Now we are going to work with these two circuits (V_o again denotes the location of the output):



Draw a circle around each of filter. What kind of filter is each? What are their cutoff frequencies?

7. Generate and save a Bode plot for Circuit 4.

Generate and save the experimental Bode plot data for the above circuit.

Like the two filters in series above, if these filters were acting independently of one another, we would simply square the equation for the amplitude, A, and sum the phase shifts of each filter.

What are the equations for A and ϕ of the filter shown in the circuit for Step 7?

For your problem set, compare the Amplitude response of this circuit to the theoretical model by graphing them together.

8. Now generate and save a Bode plot for Circuit 5.

Note that if there were no current flow between the filters, the amplitude response would just be the product of the four independent filters.

What do you expect to see for the amplitude response in the Bode plot?

For your problem set, compare the amplitude response of this circuit to the theoretical model by graphing them together.

Compare the experimental amplitude, A, plot to the ideal theory.

(You can ignore the phase relationship.)

Deliverables

For this assignment, turn the Bode plots that compare the Amplitude in the experimental with the theoretical ("analytical") Amplitude. All your plots should be clear, have axis labeled and have a short caption for each one so we know what circuit corresponds to what data and whether the data is a measurement, analytical expression or both.

For each circuit, comment on the change in gain for each factor of 10 above the f_{cutoff} for the low pass filters and below the f_{cutoff} for the high pass filters.

Below is an example of some MatLab script that will produce 2 rows, 1 column of analytical plots. You can download an html version of this script. These plots would be better if they had titles.

```
clear
clf %clears figures

w = logspace(-3,3); % create log-spaced vector for (omega) w from 10^-3 to 10^3

zRC= 1./sqrt(1 + w.^2); % compute the amplitude for an RC filter
zCR = w./sqrt(1 + w.^2); % compute the amplitude for an CR filter


subplot(2,1,1)  %In 2 plots by 1 column, this is plot 1
loglog(w, zRC, "b")
hold on
loglog(w, zCR, "r-")
ylabel("Amplitude(Vout/Vin)")
xlabel("Angular frequency(rad/cycle)")
legend("z_{RC}","z_{CR}")


subplot(2,1,2) %In 2 plots by 1 column, this is plot 2
semilogx(w, atan(w)*57.3, "b")
hold on
semilogx(w, (3.14/2 - atan(w))*57.3, "r-")
ylabel("phase(degrees)")
xlabel("Angular frequency(rad/cycle)")
legend("psi_{RC}","psi_{CR}")
```