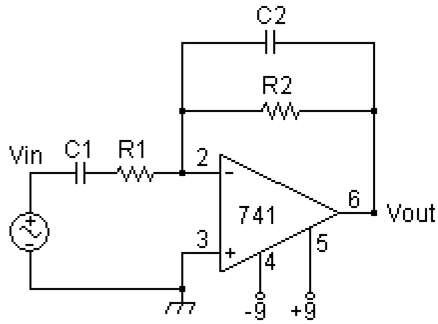
Experiment 42: Active Band-Pass Filter

Introduction

The operational amplifier band-pass filter circuit on the right uses a high-pass and a low-pass filter section to obtain a band-pass response.



The RC network, R2 and C2, in its negative feedback path provides the low-pass portion of the band-pass response.

Series connected C1 and R1 provide the high- pass portion.

This circuit has a typical second order resonant response of the form:

$$H(s)=\frac{K\,s}{s^2+\beta s+\omega_o^2} \qquad \beta = bandwidth \qquad \omega_o = resonant\ frequency$$

Using the node voltage method to solve for the circuit's transfer function:

$$\frac{0-Vin}{R1+\frac{1}{sC1}}+\frac{0-Vout}{R2}+\frac{0-Vout}{\frac{1}{sC2}}=0 \qquad H(s)=\frac{-s\frac{1}{C2R1}}{s^2+s\left(\frac{1}{C1R1}+\frac{1}{C2R2}\right)+\left(\frac{1}{C1R1}\right)\left(\frac{1}{C2R2}\right)}$$

$$H(j\omega)=\frac{-j\omega K\omega_2}{\left(\omega_o^2-\omega^2\right)+j\omega\left(\omega_1+\omega_2\right)} \qquad K=\frac{R2}{R1} \quad \omega_1=\frac{1}{C1R1} \quad \omega_2=\frac{1}{C2R2} \quad \omega_o^2=\omega_1\omega_2$$

Gain when $\omega = \omega_o$: $A_V = \frac{K\omega_2}{(\omega_1+\omega_2)}$

It is important to note that the bandwidth of this filter is the sum of the cutoff frequencies of the individual sections: $\beta=\omega_1+\omega_2$, and not $\omega_2-\omega_1$.

The bandwidth does approach the traditional definition of bandwidth, $\beta=\omega_2-\omega_1$, when the cutoff frequencies are over a decade apart.

The actual cutoff frequencies are the frequencies where the magnitude of the filter's transfer function is equal to -3 dB of its maximum value. The theoretical values of these frequencies are most easily found by simulation. Solutions using Maple are also provided in the analysis section of this experiment.

Objectives

The frequency response of a wide-bandwidth and narrow-bandwidth active band-pass filter will be measured and the results will be compared to theoretical expectations.

Procedure

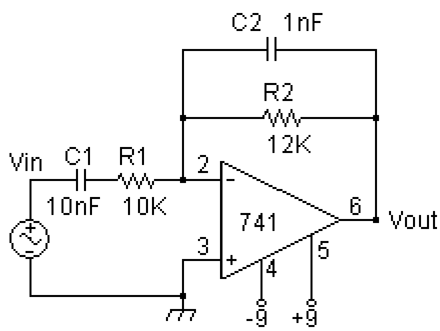
Equipment Required
Function Generator, Oscilloscope, Power Supply, Breadboard. Capacitors: 1 nF, 10 nF, 100 nF, 5%. Op-Amp: LM741, Resistors: 10 KΩ, 12 KΩ, 5%, ¼ watt.

Part 1: Narrow Bandwidth

1. Measure the values of the parts. If possible, measure the values of the capacitors.

   R_{10k} ________ R_{12k} ________ C_{1nF} ________ C_{10nF} ________ C_{100nF} ________

2. Connect the circuit on the right. Connect the function generator to Vin. Connect channel 1 of the oscilloscope to Vin and channel 2 to Vout. Set the trigger to channel 1.



3. Set the function generator to produce a 5 KHz, 1 V peak-to-peak sine wave with no offset.

4. Adjust the function generator frequency to produce the maximum output voltage, Vout, on channel 2.

   Record the value of the voltage, Vout, and the frequency, fo

   Vout ___________volts p-p fo _______________

5. Decrease the function generator frequency to a frequency, f1, below fo where the magnitude of Vout is 0.707 of its maximum value. Record the frequency f1 below.

   Increase the function generator frequency to a frequency, f2, above fo where the magnitude of Vout is 0.707 of its maximum value. Record the frequency f2 below.

   f1 ______________ f2 _______________

Part 2: Wide Bandwidth

1. This procedure is the same as part 1, except change the value of C1 to 100nF.

2. Adjust the function generator frequency to produce the maximum output voltage, Vout, on channel 2. Record the value of the voltage, Vout, and the frequency, fo.

   Vout ___________volts p-p fo _______________

3. Decrease the function generator frequency to a frequency, f1, below fo where the magnitude of Vout is 0.707 of its maximum value in step 2 above. Record the frequency f1 below.

   Increase the function generator frequency to a frequency, f2, above fo where the magnitude of Vout is 0.707 of its maximum value in step 2 above. Record the frequency f2 below.

   f1 ______________ f2 _______________

Analysis, Part 1

1. Calculate the maximum output voltage and theoretical cutoff frequencies of the filter. Calculate the percent difference between the calculated and measured results.

2. Simulate the circuit and compare your calculated results to the simulated results.

Analysis, Part 2

1. Calculate the maximum output voltage and theoretical cutoff frequencies of the filter. Calculate the percent difference between the calculated and measured results.

2. Simulate the circuit and compare your calculated results to the simulated results.

3. Compare the filter's bandwidth using BW = f_2 - f_1 and BW = f_1 + f_2, using the theoretical cutoff frequencies for each filter section.

4. Simulate the circuit and compare your calculated results to the simulated results

Maple Example: Frequency and Bandwidth Calculations

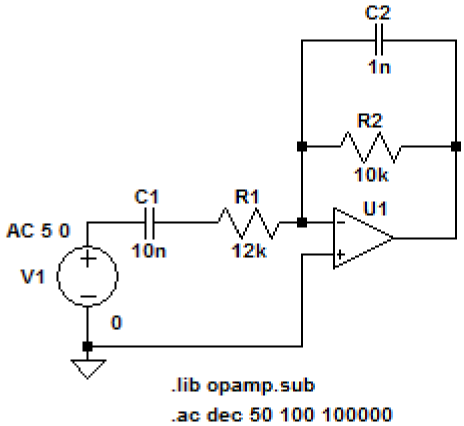
Given: w1 = 1/R1C1 and w2 = 1/R2C2. K = R2/R1. Calculations below are for w1 = 10 and w2 = 100. Input w1 and w2 for your filter. Maple will calculate the filter's cutoff frequencies.

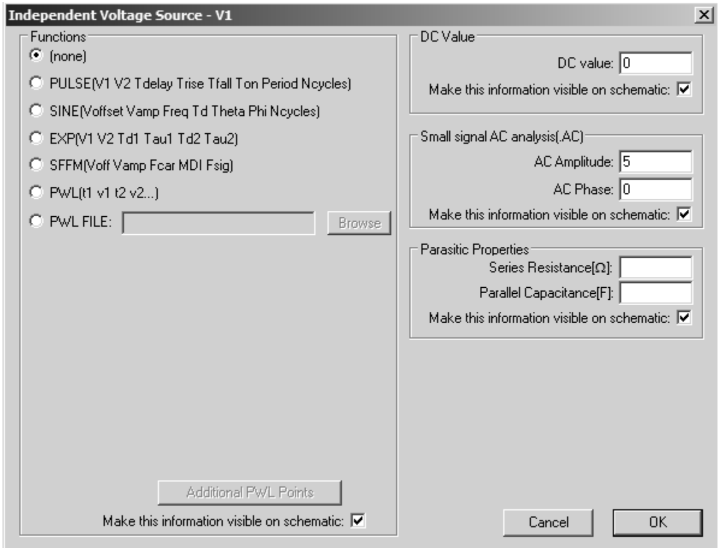
```
> restart;
> w1:=10.0;w2:=100.0;
w1 := 10.0
w2 := 100.0
> fc1:=abs(.5*(-w1-w2+(w1^2+w2^2+6*w1*w2)^.5))/6.283;
fc1 := 1.343766942
> fc2:=abs(.5*(-w1-w2-(w1^2+w2^2+6*w1*w2)^.5))/6.283;
fc2 := 18.85132702
> Amax := w2/(w1+w2);
Amax := .9090909091
> BW:=fc2-fc1;
BW := 17.50756008
> BW2:=(w1+w2)/6.283;
BW2 := 17.50756008
```

LTspice Example: Simulation of Active Band-Pass Filter

This simulation uses the generic "opamp" in the opamp library. It is easy to use and requires no power supply connections. The directive, ".lib opamp.sub" must be added. Click on "op" on the right side of the main menu bar and type in the directive. It will be displayed on the schematic as shown below.

This simulation analysis was set to "AC Analysis", decade sweep, 50 points per decade, start frequency = 100, and stop frequency = 100,000.





Right click on the voltage source to open the above dialog box. AC amplitude is set to 5, DC value is set to 0, and AC phase is set to 0. Move the mouse over the plot to read the x-y coordinates of the cursor at the bottom of the screen.