



First-Order Filters

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Purpose:

Introduction to first-order filter analysis and design.

Equipment Required:

- 1 - HP 54600B Oscilloscope
- 1 - HP 34401A Digital Multimeter
- 1 - HP 33120A Function Generator
- 1 - HP E3631A Power Supply
- 1 - Protoboard
- 1 - 4.7-k Ω Resistor
- 1 - 1-k Ω Resistor
- 1 - 0.01- μ F Capacitor
- 1 - 741 OP AMP

Prelab:

Review Sects. 12- 1 through 12-3 in the text*.

1. Filter circuit analysis

Write a voltage transfer function $T(s)$ for the circuit of Fig. 1. Use the transfer function for this circuit to construct a plot of the gain versus frequency. Use a CCA program to analyze the frequency response for the circuit of Fig. 1. Plot the gain response and tape the print-out into your lab journal.

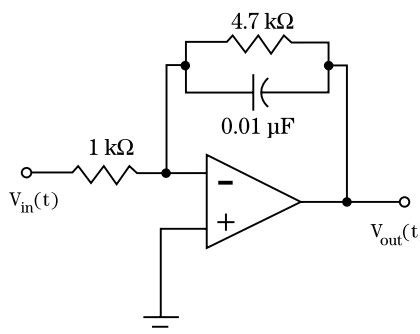


Figure 1

2. Filter design

Select a lab partner and add your student number to your partner's student number. Use the last digit of this sum to look up the cutoff frequency f_c in Table 1. Design a high-pass first-order filter with a passband gain of -1.5 , and a cutoff frequency as specified. Any standard components available in your laboratory may be used in the design. After the design is complete, find the transfer function for the circuit and construct a gain-corner plot. Analyze the frequency response of your design with a CCA program. Plot the gain response results of the CCA and tape the output into your lab journal.



Table 1

Last Digit of Sum	f_c	Last Digit of Sum	f_c
0	1 kHz	5	6 kHz
1	2 kHz	6	7 kHz
2	3 kHz	7	8 kHz
3	4 kHz	8	9 kHz
4	5 kHz	9	10 kHz

Procedure:

On a logarithmic grid, the numbers 1, 2, 5, and 10 (in any decade) are about equal distances from each other. Since gain plots are usually drawn on log-log grids, it is common practice to acquire data in frequency increments of 1, 2, 5, 10. For example, if the desired frequency range starts at 10 Hz, gain information would be acquired at 10 Hz, 20 Hz, 50 Hz, 100 Hz, 200 Hz . . . until the upper end of the desired frequency range is reached. Normally, data is collected over a range of frequencies starting 2 decades below the cutoff frequency, up through a frequency that is 2 decades above f_c . This method should be used for collecting frequency response data in this exercise.

1. Low-pass filter

- Build the circuit of Fig. 1 on a protoboard.
- Create a table in your journal with four columns to record the data. Label the first row with the column titles: Freq., v_{in} , v_{out} , and Gain.
- Set the waveform generator to produce a sine wave with a frequency of approximately 10 Hz, and $2 V_{pp}$. Enter this value in the first column, second row of the data table.
- Verify that v_{in} is still near $2 V_{pp}$. If v_{in} is off by more than $\pm 10\%$, adjust the waveform generator to bring the v_{in} closer to $2 V_{pp}$. Measure the actual v_{in} , and record this value in the second column. Measure and record the peak-to-peak voltage of v_{out} .
- Increase the frequency of the signal produced by the waveform generator to the next increment. Repeat the procedures outlined in step d above. Repeat procedures d and e until you have collected data up to an input frequency of 1 MHz.
- Collect one more data point at the cutoff frequency (-3 dB point) of this filter. To find the "3 dB down" point, compute the gain in the pass band from the data contained in your data table. Multiply this gain by 0.707 (3 dB down). While observing both v_{in} and v_{out} , adjust the frequency until the gain is equal to the 3 dB down gain. Record the signal frequency f , v_{in} , and v_{out} at this cutoff frequency.

2. High-pass filter design

- Build your high-pass filter design.
- Prepare a data table in your journal similar to the one used in part 1, above.



- c. Start collecting frequency, v_{in} , and v_{out} data at a frequency of 10 Hz, using the method described at the beginning of the Procedure section. Continue collecting and recording data up to and including 1 MHz.
- d. Collect one more data point at the cutoff frequency of the high-pass filter, as described in part 1f.

Conclusion

The gain calculations and the plots requested (below) are performed most easily in a spreadsheet program. However, if you prefer, these calculations and plots may be done by hand. If you do the calculations by hand, enter the calculated gain into the data tables in parts 1 and 2 in the Procedure section.

Follow these instructions twice, once for the low-pass filter, and once for the high-pass filter design project.

- a. Enter your data into a spreadsheet program, including the data collected at the cutoff frequency. Sort the data by frequency so that the cutoff data appears in the correct location in the spreadsheet.
- b. In the gain column, create an equation to compute the gain (v_{out}/v_{in}).
- c. Using a log-log grid, plot gain on the vertical axis and frequency on the horizontal axis. Print out the spreadsheet and the plot and tape them into your lab journal.
- d. On the plot of the frequency response, label the pass band, the pass band gain, the stop band and the cut-off frequency.

For both the high-pass and the low-pass filters, compute the percent error between the cut-off frequency predicted from the transfer function $T(s)$, and the actual cut-off frequency measured in the lab. Compute the error between the theoretical and empirical pass band gain. What could be the cause of this error?

At high frequencies the gain curve of the high-pass filter data may roll off or even turn back up. This behavior is not predicted by the transfer function for this circuit. Can you explain what might cause this behavior?

Comment on how well the empirical data agree with the response predicted by the CCA runs.

* Roland E. Thomas and Albert J. Rosa, The Analysis and Design of Linear Circuits, Prentice Hall, (New Jersey, 1994)

