

EECE 2150 - Circuits and Signals: Biomedical Applications

Frequency Components, FFT, and Filtering

Introduction

In this lab you will learn how to use Matlab to determine the effect of a filter with a specified transfer function on a periodic input signal (such as a square wave or a ramp wave).

Part I: Understand operation of the FFT-based Matlab filter function.

- 1.1 Run the prototype program given. Describe what is being shown, and make sure each plot is clearly distinguished from other similar plots. The purpose of this exercise is to help you understand the overall operation of the function. **Q1: What is the cutoff frequency of the filter in the function supplied (in Hz, not Rad/s)?**

Part II: Modify the function to filter sine waves of various frequencies.

- 2.1 Now, change the cutoff frequency of the low-pass filter to 10 Hz (f , not ω !), and make the in-band gain of the filter -2 .
- 2.2 Input sine waves with frequencies of 1, 5, 10, 20, and 100 Hz; plot the input and output waveforms on the same graph so that you can see the relative magnitudes and relative phases at the different frequencies. **Q2: Approximately what is the magnitude of $H(\omega)$ from your plots for each frequency (1, 5, 10, 20, and 100)?** **Q3: Approximately what is the phase shift for each frequency, in degrees (for example, 90, 100, 110, ... (Don't need to be precise!)?**
- 2.3 Now compute (with Matlab or a calculator - Matlab is easier!) $H(\omega)$ for $f = 1, 5, 10, 20, \wedge 100$ Hz, in polar form, magnitude, $\angle H(\omega)$ and phase, $\angle H(\omega)$. **Q4: Do these results agree with your answers for 2.2?**

Part III: Filter a 10 Hz square wave.

- 3.1 Next, supply a square wave input at 10 Hz, as in the original function. Note that each frequency in the Fourier transform is multiplied by a different $H(\omega)$, depending on its frequency. **Q5: Carefully compare the magnitudes of the unfiltered and filtered Fourier components at the fundamental frequency, and at 3x, 5x, 7x, and 9x the fundamental frequency. Do the relative magnitudes change?** **Q6: How is the frequency content of the filtered signal different than**

the frequency content of the original signal? Q7: How does the filtered time-domain waveform look? Is this what you expect from the frequency domain information (explain)?

Part IV: Repeat for a high-pass filter.

- 4.1 Now, make the transfer function that of a first-order op-amp high-pass filter with an in-band gain of -2 and a cutoff frequency of 50 Hz . You can assume that R_f is $20 \text{ k}\Omega$.

$$\frac{V_o}{V_i} = H(\omega) = \frac{-Z_f}{Z_i} = \frac{-R_f}{R_s + \frac{1}{j\omega C_s}} \omega_c = \frac{1}{R_s C_s}$$

Part V: Filter a 10 Hz square wave.

- 5.1 Next, supply a square wave input at 10 Hz , as in the original function. Note that each frequency in the Fourier transform is multiplied by a different $H(\omega)$, depending on its frequency. Q11: Carefully compare the magnitudes of the unfiltered and filtered Fourier components at the fundamental frequency, and at $3x$, $5x$, $7x$, and $9x$ the fundamental frequency. Do the relative magnitudes change? Q12: How is the frequency content of the filtered signal different than the frequency content of the original signal? Q13: How does the filtered time-domain waveform look? Is this what you expect from the frequency-domain results (explain)? Q14: Does this result agree with what you saw in the op-amp filter lab?

Part VI: If you have time, filter the square wave with a band-pass filter.

- 6.1 Now, modify the function to have the transfer function of a band-pass filter with a center frequency of 10 Hz , a gain of 2 and a Q of 100 . Remember that $s = j\omega$ for our purposes. A second order bandpass filter is shown in figure 1

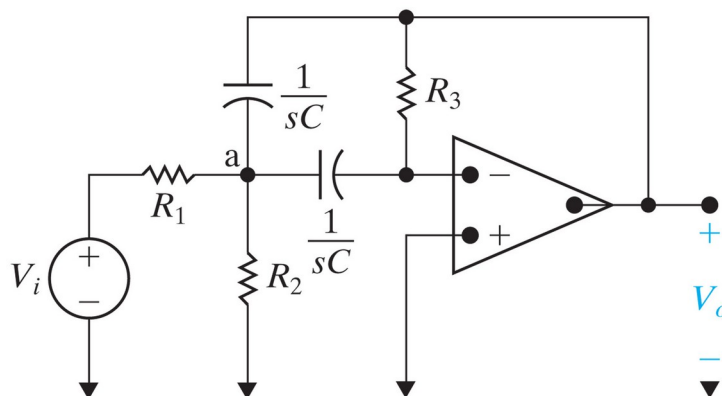


Figure 1: Second order active band pass filter

$$H(s) = \frac{-\frac{s}{R_1 C}}{s^2 + \frac{2}{R_3 C} s + \frac{1}{R_{eq} R_3 C^2}}$$

$$s = j\omega R_{eq} = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

The center frequency of the bandpass filter is $\omega_0 = \frac{1}{C \sqrt{R_{eq} R_3}} \text{ rad/s}$

The passband gain $K = \frac{-R_3}{2R_1} = H(\omega_0)$

The 3dB bandwidth of the filter $\beta = \frac{2}{R_3 C} \frac{\text{rad}}{\text{s}}$

And the quality factor of the bandpass filter is defined as $Q = \frac{\omega_0}{\beta} = \frac{1}{2} \sqrt{\frac{R_3}{R_{eq}}}$

The frequency response of the filter is shown in figure 2, the bandwidth shown is the fractional bandwidth normalized by the center frequency ω_0

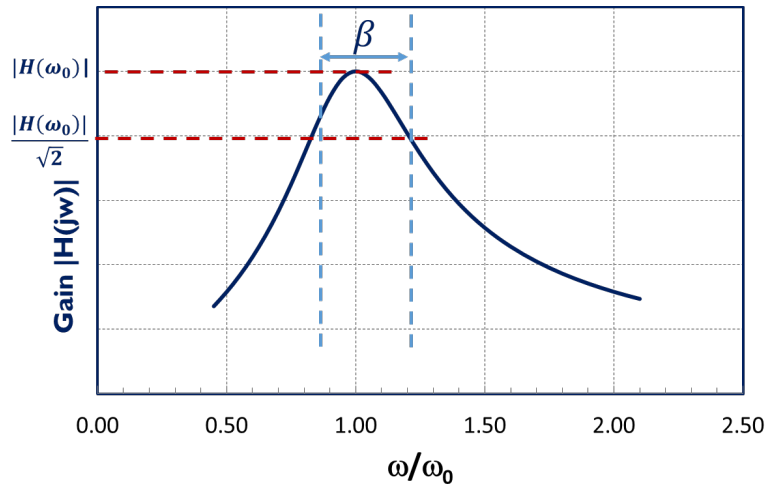


Figure 2: Frequency response of a second order band pass filter

- 6.2 Supply a square wave input at 10 Hz. Note that each frequency in the Fourier transform is multiplied by a different $H(\omega)$, depending on its frequency. **Q5: Carefully compare the magnitudes of the unfiltered and filtered Fourier**

components at the fundamental frequency, and at 3x, 5x, 7x, and 9x the fundamental frequency. Do the relative magnitudes change? Q6: How is the frequency content of the filtered signal different than the frequency content of the original signal? Q7: How does the filtered time-domain waveform look? Is this what you expect (explain)?

IMPORTANT: BEFORE YOU LEAVE THE LAB:

- a. Place all of the components that you removed from the red tool box back in that box and return it to the cabinet that houses them
- b. Collect all used components and wires from your bench and place them in your group's reusable plastic container. If you are not going to use these components or wires again please discard them in the trash bin located in your lab room.
- c. Turn off all of the equipment you have used on your workbench.
- d. Make sure you return your protoboard, the equipment wires and your reusable container to the front window.
- e. Make sure to have your notebook signed by an instructor before you leave the lab.

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Last updated: 11/8/16 by Iman Salama, previously 3/17/2016 by N. McGruer, 10/29/14 by D. Brooks and M. Niedre, 9/10/12 by D. Erdogmus and N. McGruer