Second Order Butterworth Filter

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As per the project specification, a second order Butterworth filter was constructed with a Sallen-Key topology. The corner frequency for this filter is about 450 Hz meaning it could be used for surface EMG readings.

Design

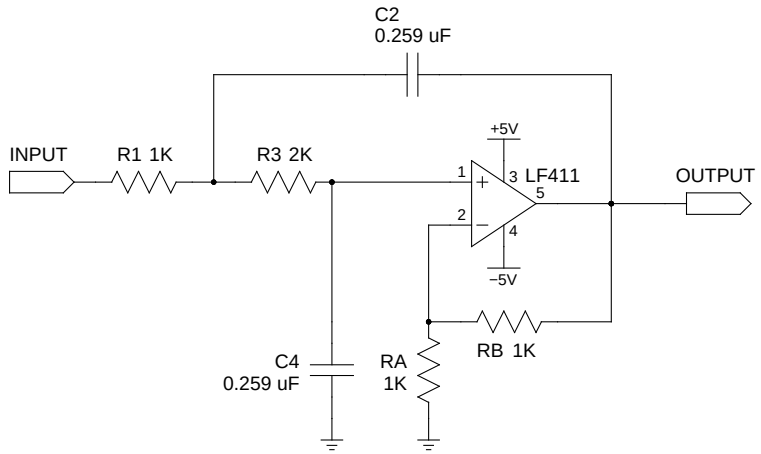

Figure 1: Schematic for the filter.

The first step in the design process was selecting the appropriate components to meet the specification. The specification for a filter useful for surface EMG readings was a cutoff frequency less than 500 Hz. Furthermore two constraints were set which reduced the size of the parameter space; the two capacitors were constrained to be of equal value and the DC voltage gain of the system was set to be 2 (6 dB). The latter constraint imposes the condition that $R_A = R_B$ by the equation:

$$K = 1 + \frac{R_B}{R_A} \tag{1}$$

Combining the constraints and acknowledging the fact that this circuit is Butterworth filter the following equation can be written for the Q-Factor:

$$\frac{1}{Q} = \sqrt{2} = \sqrt{\frac{R_3}{R_1}} \tag{2}$$

Solving for R_3, a final constraint becomes evident:

$$R_3 = 2R_1 \tag{3}$$

Taking this into consideration a value of 1 kΩ was selected for R_1; therefore R_2 is required to be 2 kΩ. These values were selected because 1 k$\Omega \pm 1\%$ resistors were available in the lab, therefore it was easier to meet the correct ratio. Additionally for this R_A and R_B were set to be 1 kΩ as well.

The last remaining parameters were C_2 and C_4 which were already constrained to be equal to each other (denoted as C). Incorporating this constraint and the Sallen-Key topology, the parameter can be solved for with the following equation:

$$2\pi f_c = \frac{1}{\sqrt{R_1 R_2 C^2}} \tag{4}$$

With f_c set by the specification, and R_1 and R_2 set above it was simple to solve for C, which became 0.225 μF. The theoretical value selected for C was 0.22 μF because it was available in the lab. However because the two capacitors present needed to be matched, significant testing was required to discover two matched capacitors. Ultimately the capacitors used had a value of 0.259 μF as measured by a RSR M9803R Multimeter.

Using the actual values of the capacitors and the selected values for R_1 and R_2 the change in the cutoff frequency was calculated to see if it were tolerable for the design specification. The new theoretical cutoff frequency was 434 Hz which is tolerable for surface EMG measurements, per the specification.

Test Procedure and Results

Frequency Response The magnitude frequency response was measured with a Hewlett Packard 35660A Dynamic Signal Analyzer from 10 Hz up to 1000 Hz. These results are summarized in Figure 2. An additional measurement was made at 10 kHz to confirm that the stop band falls off at rate of 40 dB/decade (the measurement showed a falloff of 39 dB in the decade from 1000 Hz). The first measurement was made at 10 Hz, and then at 50 Hz with the following measurements collected up to 1000 Hz at increments of 50 Hz. The HP 35660A was responsible for both stimulating the device under test and measuring the response.

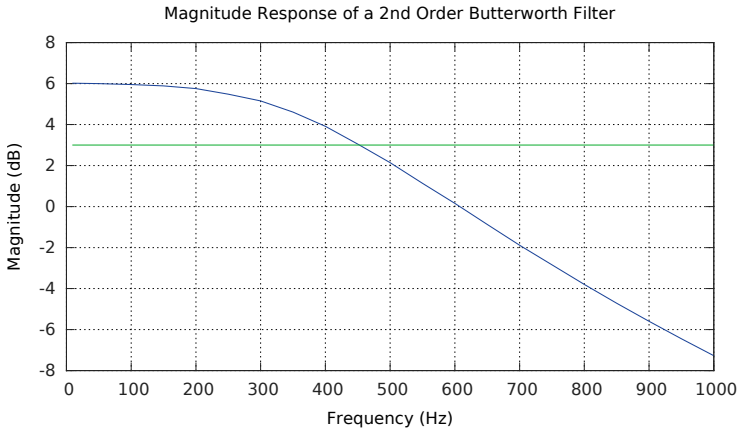

Figure 2: Frequency response of the Butterworth filter