Second Order High Pass Filter

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As per the project specification, a second order high pass filter was constructed with a Sallen-Key topology. The corner frequency for this filter is about 100 Hz.

Design

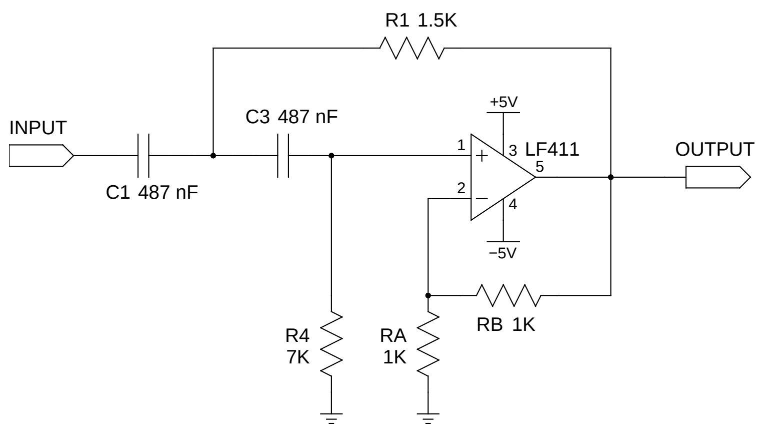

Figure 1: Proposed schematic for the filter.

The first step in the design process was selecting the appropriate components to meet the specification. The specification was a Butterworth filter with a cuttoff frequency of 100 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:

$$\frac{1}{Q} = \sqrt{2} = (1 - K)\sqrt{\frac{R_4}{R_2}} + 2\sqrt{\frac{R_2}{R_4}} \tag{2}$$

Solving this equation, a final constraint becomes evident:

$$R_4 = R_2(3 + \sqrt{5}) \tag{3}$$

The last remaining parameters were C_1 and C_3 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:

$$2\pi f_c = \frac{1}{\sqrt{R_2 R_4 C^2}} \tag{4}$$

This equation can rewrittern to give an expression for C in terms of R_2 R_4. Using the ratio of R_2 and R_4 above, this expression can be simplified to use only R_2. Using this expression, a linear sweep was performed to find a value for R_2 that resulting an a C value that was available in the lab. This theorecal value was 460 nF. Ultimately the capacitors used had a value of 487 nF as measured by a RSR M9803R Multimeter.

Using the measured values for the matched capacitors, new values were calculated for R_2 and R_4. In order to hit the corner frequency correctly while maintaining reasonable resistor values the precise ratio for R_2 and R_4 was broken. The new values for R_2 and R_4 were 1.5 kΩ and 7 kΩ respectively. These values were achieved precisely with parallel/series combinations of 1 k$\Omega \pm 1\%$ resistors. While the Q was off of the correct value for a Butterworth filter, simulation confirmed that the behavior would still agree with a Butterworth response.

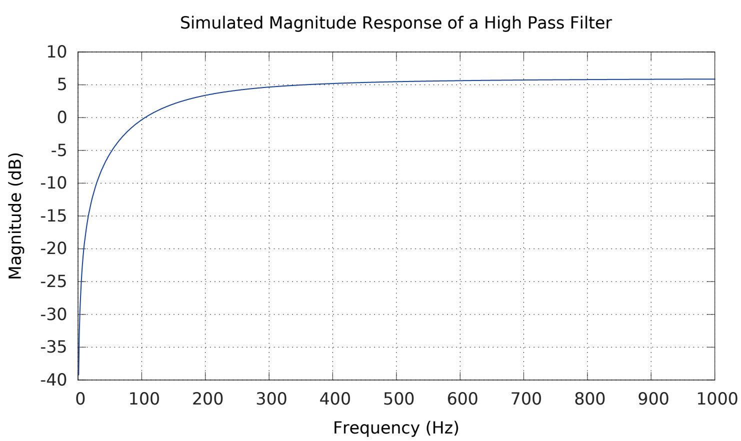

Figure 2: Simulated frequency response of the high pass filter

When constructed, the experimental results did match the simulation. In fact the circuit was unstable, randomly throwing rail voltages at the output. Various attempts at debugging were made, but ultimately the only way the circuit would give a stable response was if the gain of two was forfeited and instead had unity gain. By changing the gain the Q factor was adjusted even further, so the filter did not give the planned Butterworth response, but instead gave a Chebyshev Type 1 response, with a a very weak, long ripple in the passband.

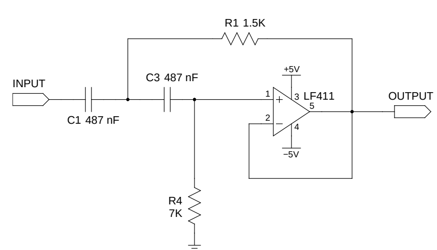

Figure 3: Final schematic for the filter.

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 4. Measurements were made every 5 Hz up to 100 Hz, then every 10 Hz up to 200 Hz, and then every 100 Hz for the remainder of the span. The HP 35660A was responsible for both stimulating the device under test and measuring the response.

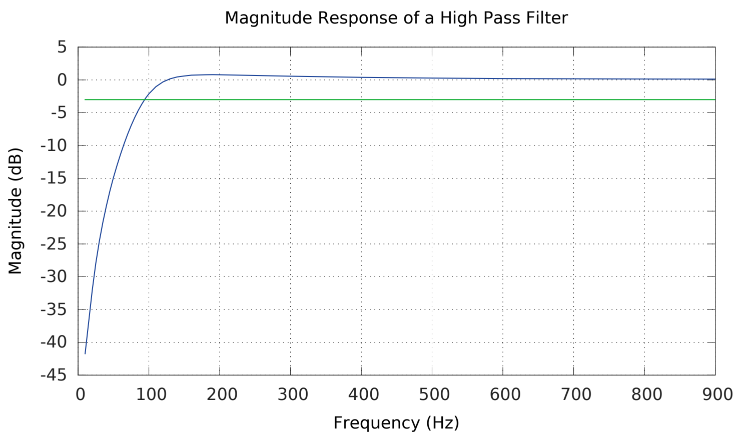

Figure 4: Experimental frequency response of the high pass filter

Power Consumption In order to measure the power consumption for a 100 Hz input signal, the voltage and current readouts on the power supply unit (a Gwinstek GPS-3303) were recorded. From these (probably ridiculously inaccurate) measurements, the power consumption is approximately 200 mW.