Design of the ISS-Bioreactor

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This is a technical report for ISS-Bioreactor project at Boise State University.

1. INTRODUCTION

2. APPARATUS AND EXPERIMENT

2.1. Basic Lowpass Filter Design

Consider the first-order filter sketched in Figure 1. The current i over the capacitor is $i = C\frac{\mathrm{d}v_c}{\mathrm{d}t}$. Therefore, KVL around the circuit gives

$$RC\frac{\mathrm{d}v_c}{\mathrm{d}t} + v_c = v_{\text{sig}} = A\cos(\omega t) \tag{1}$$

This differential equation has the transfer function

$$G(s) = \frac{1}{RCs + 1}.$$

The steady-state solution of the differential equation (1) is obtained as

$$\begin{aligned} v_c(t) &= A\,|G(j\omega)|\cos(\omega t + \angle G(j\omega)) \\ &= \frac{A}{\sqrt{1+\omega^2R^2C^2}}\cos(\omega t - \arctan(\omega RC)) \end{aligned} \tag{2}$$

Since we do not want our signal to be attenuated by the low-pass filter, we must choose the values of R and C such that $\omega RC \ll 1$ or $RC \ll 1/\omega$. A difference of at least an order of magnitude should do nicely.

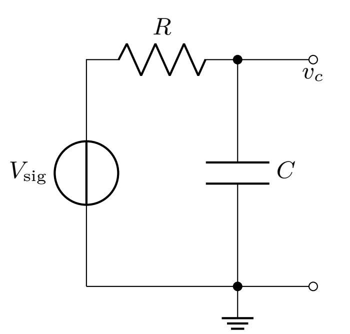

FIG. 1: An R-C low-pass filter circuit.

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2.2. Realistic Simulation

We then perform a more realistic simulation with a second-order low-pass filter with buffer connected to an amplifier op-amp with a gain of 3. One of the important aspects of this design is the selection of the op-amp. In order to keep the common-mode voltage at 0V we choose the op-amps as CMOS type. One such op-amp is the OP292 and this op-amp is used in this more realistic simulation.

The second order filter components are selected such that the resistances and capacitances have the same value, satisfying the equation

$$f_c = \frac{1}{2\pi RC},$$

where f_c is the desired cutoff frequency of the filter, selected to be a decade above the desired bioreactor oscillation at 90Hz. We respect the constraints $R \geq 1\text{k}\Omega$ and $C \geq 220\text{pF}$. The values we used in the simulation were $R = 1\text{k}\Omega$ and $C = 0.1\mu\text{F}$, yielding $f_c = 900\text{Hz}$.

The PWM signal generated by Teensy is simulated exactly with a carrier frequency of 36.6kHz modulating the signal

$$V_{\text{pwm}} = 3.3/2 + 3.3/2\sin(2\pi 90 t).$$

Finally, the impedance of the load (Physik Instrument (PI) controller) is read off from its datasheet and inserted as a 100kΩ resistance. The circuit that is simulated using LTSpice is presented in Figure 2.

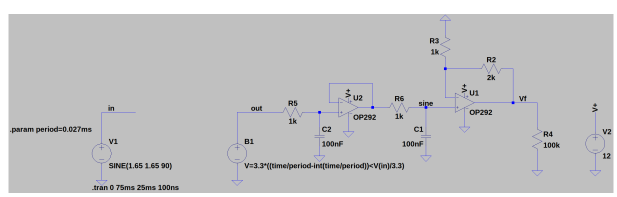

FIG. 2: The realistic signal generator circuit.

The simulation generates the relevant voltage responses, provided in Figure 3. The top plot shows the PWM signal generated by Teensy modulating a sine-wave at 90Hz frequency. The individual plots in the middle show the output of the first (cyan) and the second (green) R-C low-pass filters that extract the modulated signal from its PWM representation. Finally, the last plot shows the amplified signal (gain: 3) through the op-amp OP292. This signal is ready to be sent to the PI controller.

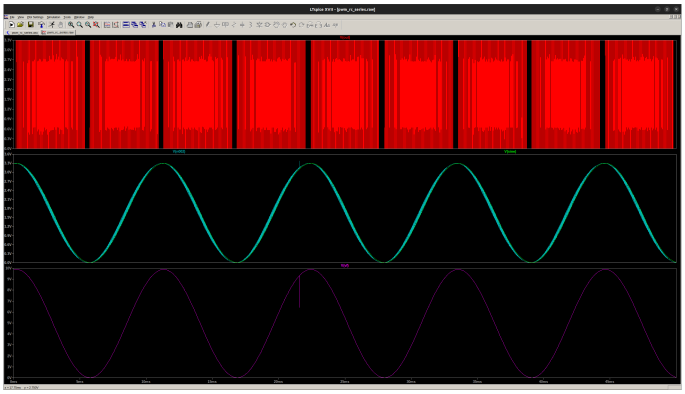

FIG. 3: The response of the realistic simulation.

3. ANALYSIS AND RESULTS

The circuit that LTSpice simulates is redrawn in Figure 4 for analysis.

The $0 - 3.3$V PWM signal is filtered to extract the modulated sine wave with a the first RC combination.

4. DISCUSSION AND CONCLUSIONS

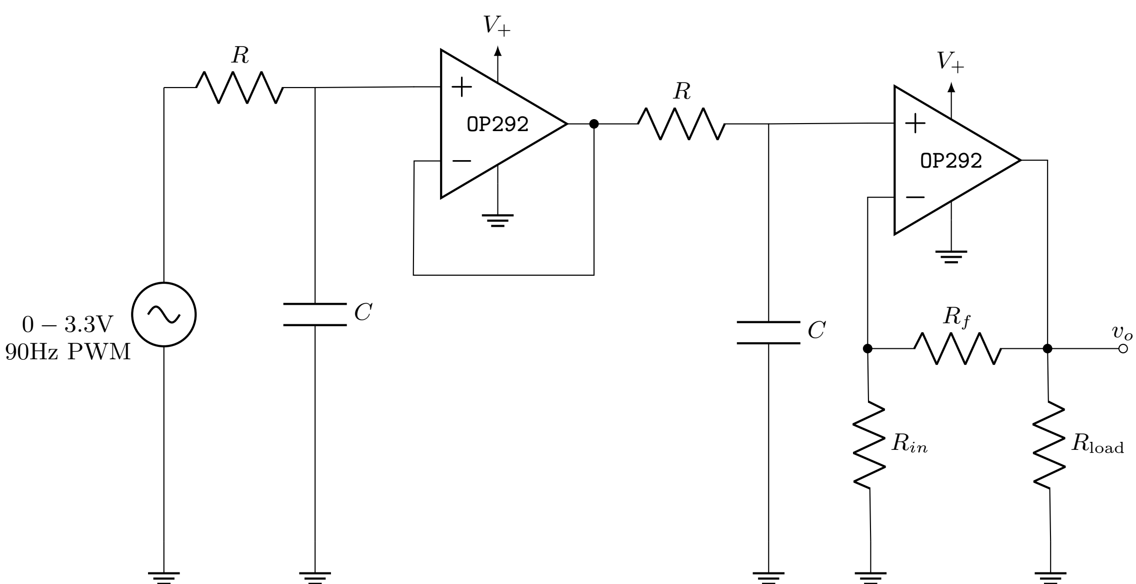

FIG. 4: The signal generator circuit.