

# 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  $i = C \frac{dv_c}{dt}$ . Therefore, KVL around the circuit gives

$$RC \frac{dv_c}{dt} + v_c = v_{\text{sig}} = A \cos(\omega t) \quad (1)$$

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

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

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.

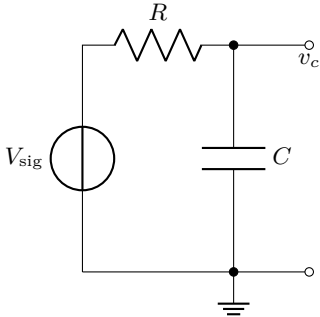


FIG. 1: An R-C low-pass filter circuit.

### 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. cite

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.

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

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

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. cite

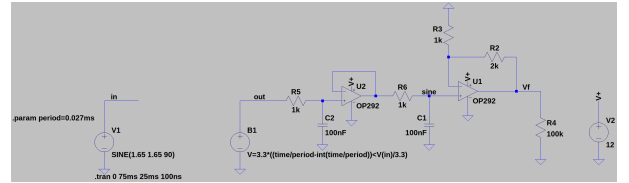


FIG. 2: The realistic signal generator circuit

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.

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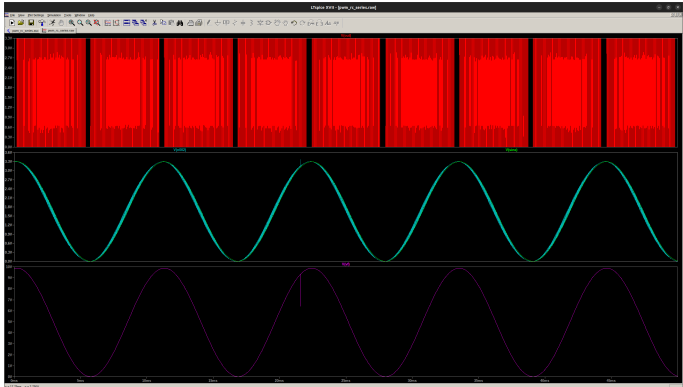


FIG. 3: The response of the realistic simulation

3. ANALYSIS AND RESULTS

4. DISCUSSION AND CONCLUSIONS

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