EE230 ECG Project

Phase 1 Report

20 April 2025

1 Aim of the Experiment

The aim of this experiment is to design, simulate, and implement an ECG amplifier circuit capable of accurately capturing, amplifying, filtering the weak electrical signals generated by the heart, ensuring proper functionality of the instrumentation amplifier, right leg drive section. The experiment focuses on the development of analog filtering stages—including a 2nd order low-pass filter and a 50 Hz notch filter—to suppress noise and interference, ensuring a clean ECG waveform suitable for medical analysis.

2 Design

2.1 2nd Order Low Pass Filter

The filter was designed to achieve:

- DC Gain of approximately 28 dB (Linear Gain = 25)
- 3-dB Cutoff Frequency of 150 Hz

DC gain needed = 28 dB

$$\Rightarrow 20\log A = 28\,\text{dB} \Rightarrow A = 10^{1.4} \Rightarrow \frac{R_7}{R_6} = 25.12$$

Since $R_6 = 18.8\,\text{k}\Omega$,

$$\boxed{R_7 = 472.32\,\text{k}\Omega}$$

$$\frac{A}{\sqrt{2}} = \left|\frac{A}{(1+s\cdot\tau_1)(1+s\cdot\tau_2)}\right| \Rightarrow \frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1+(\omega)^2(R_8)^2(C_1)^2}} \times \frac{1}{\sqrt{1+(\omega)^2(R_7)^2(C_2)^2}}$$

$$\Rightarrow \boxed{R_8 = 362.123\,\text{k}\Omega}$$

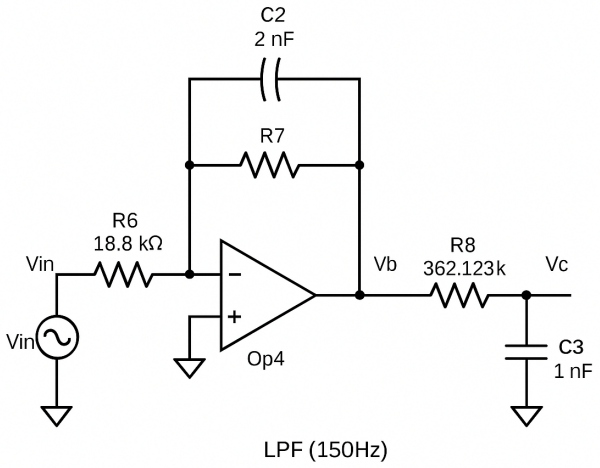

Figure 1: Low Pass Filter

2.2 Notch Filter

- Technique employed: **Twin-T notch filter** (combining the outputs of LPF and HPF to cancel out "50 Hz frequency")
- Cut-off frequency of LPF = 20 to 30 Hz
- Cut-off frequency of HPF = 80 to 90 Hz

To eliminate the 50 Hz power-line noise, we designed a notch filter using a cascaded High-Pass Filter (HPF) and Low-Pass Filter (LPF). The HPF is set to 25 Hz and the LPF to 85 Hz, thus rejecting the 50 Hz band.

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

High Pass Filter (HPF):

$$f_{c1} = 45\,\text{Hz}, \quad C = 100\,\text{nF} \Rightarrow R = \frac{1}{2\pi \cdot 25 \cdot 220 \times 10^{-9}} \approx 28.937\,\text{k}\Omega$$

$$\boxed{R_9 = 28.937\,\text{k}\Omega, \quad C_3 = 220\,\text{nF}}$$

Low Pass Filter (LPF):

$$f_{c2} = 85\,\text{Hz}, \quad C = 100\,\text{nF} \Rightarrow R = \frac{1}{2\pi \cdot 85 \cdot 100 \times 10^{-9}} \approx 18.724\,\text{k}\Omega$$

$$\boxed{R_{10} = 18.724\,\text{k}\Omega, \quad C_4 = 100\,\text{nF}}$$

The combination of these filters creates a notch around 50 Hz, effectively suppressing the power-line interference in the ECG signal.

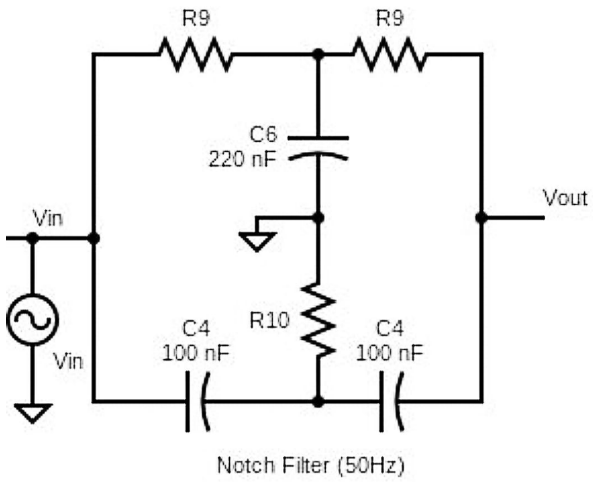

Figure 2: Notch Filter

2.3 Combined 2nd Order Low Pass Filter and Notch Filter Response

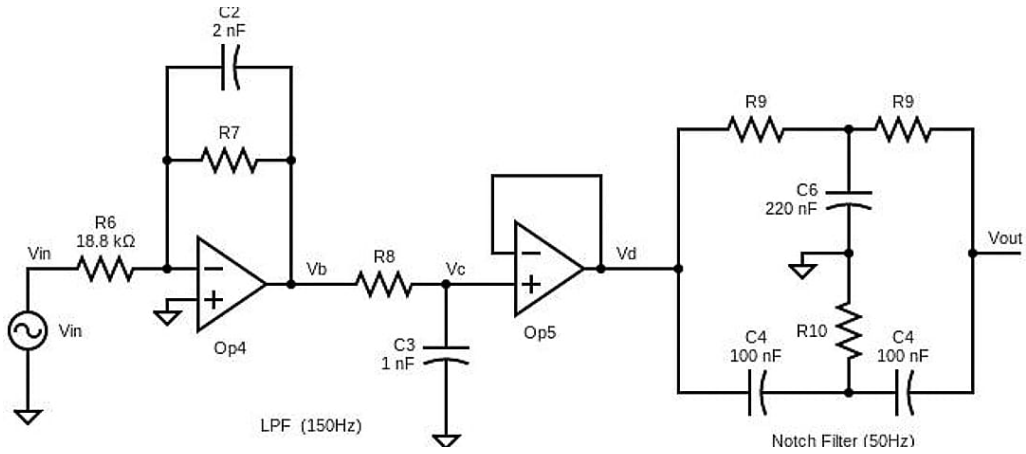

Figure 3: Combined Circuit

3 Simulation Results

3.1 2nd Order Low Pass Filter

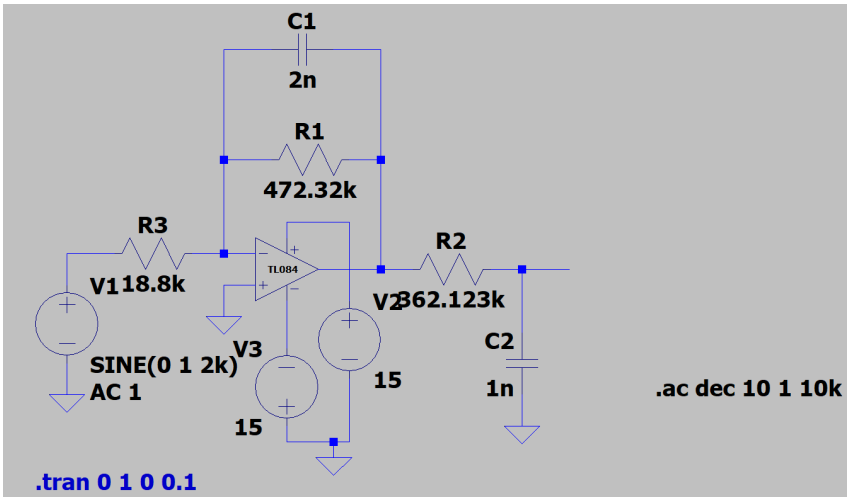

Figure 4: 2nd Order LPF (LTSpice)

B. AC Analysis 2nd Order LPF Circuit

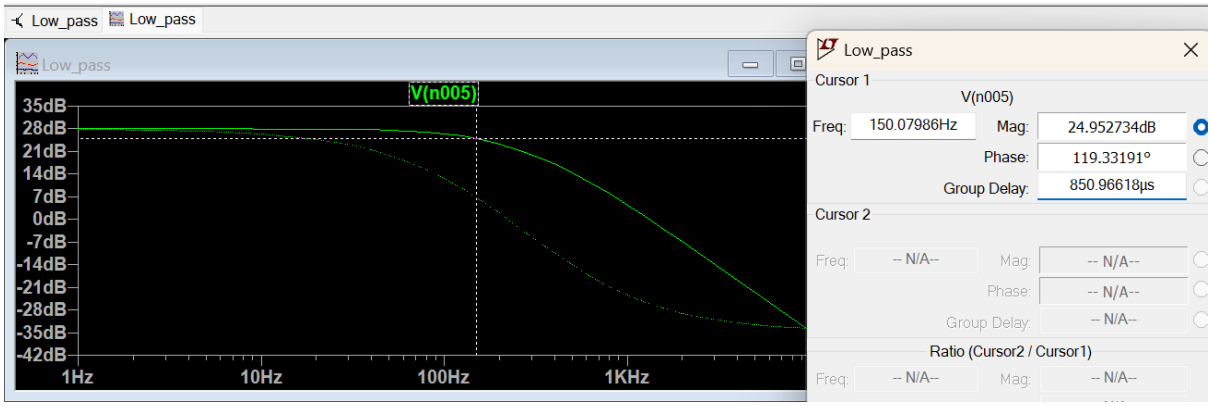

Figure 5: AC Analysis 2nd Order LPF (LTSpice)

Parameter	Value
DC Gain (at low frequencies)	28 dB
3-dB Cutoff Frequency	150 Hz

Table 1: AC Analysis 2nd Order Circuit

C. Sinusoidal signal with 2 KHz frequency and 1 V peak-to-peak

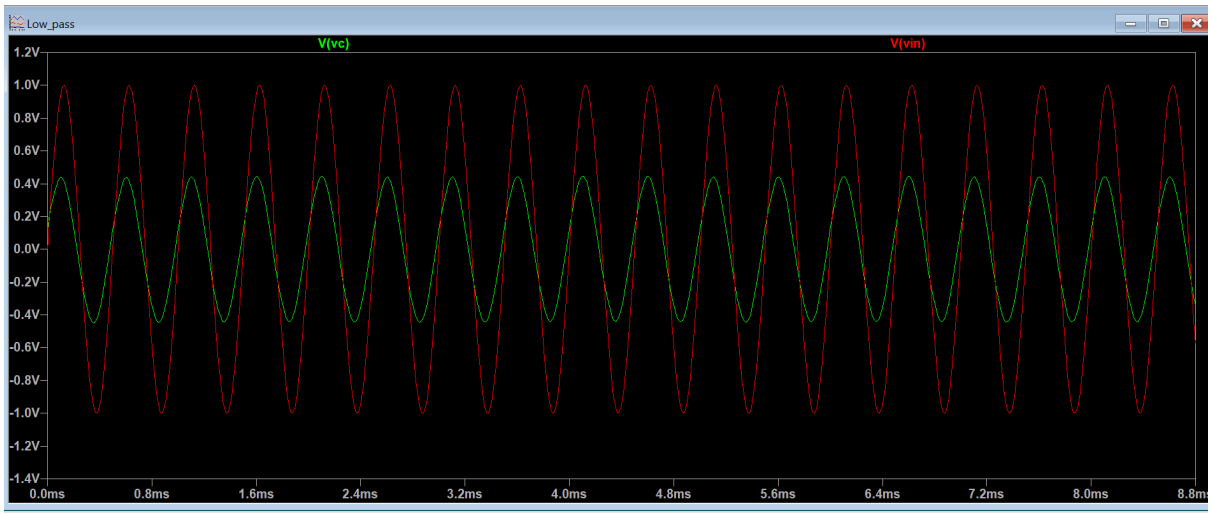

Figure 6: Simulated Output Waveform of 2nd order LPF

3.2 Notch Filter

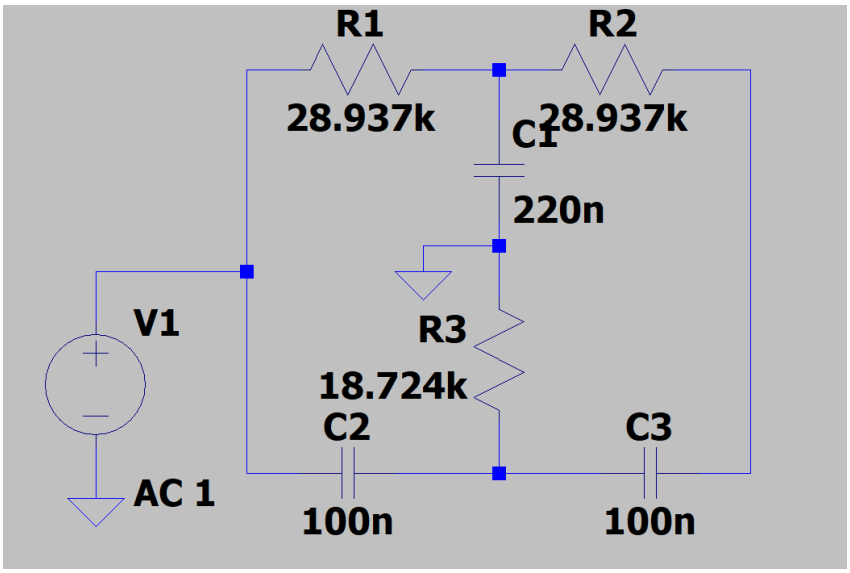

Figure 7: 2nd Order LPF (LTSpice)

A. Low pass filter(20-30 Hz)

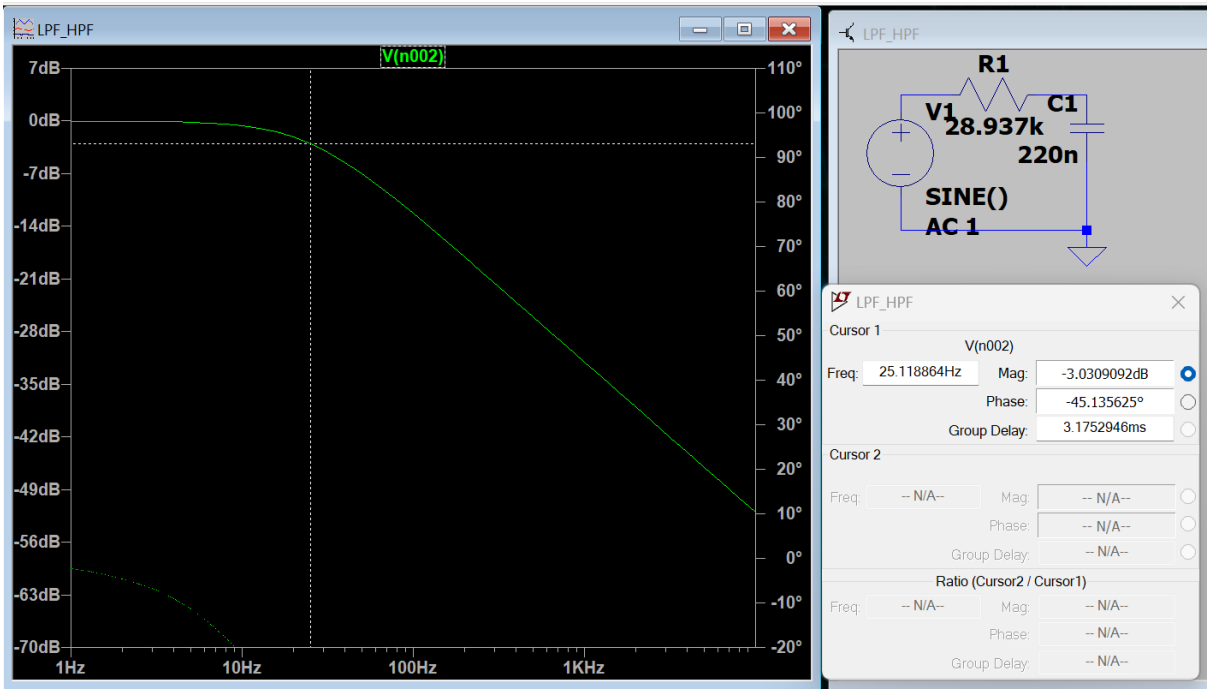

Figure 8: AC Analysis LPF (LTSpice)

B. High pass filter(80-90 Hz)

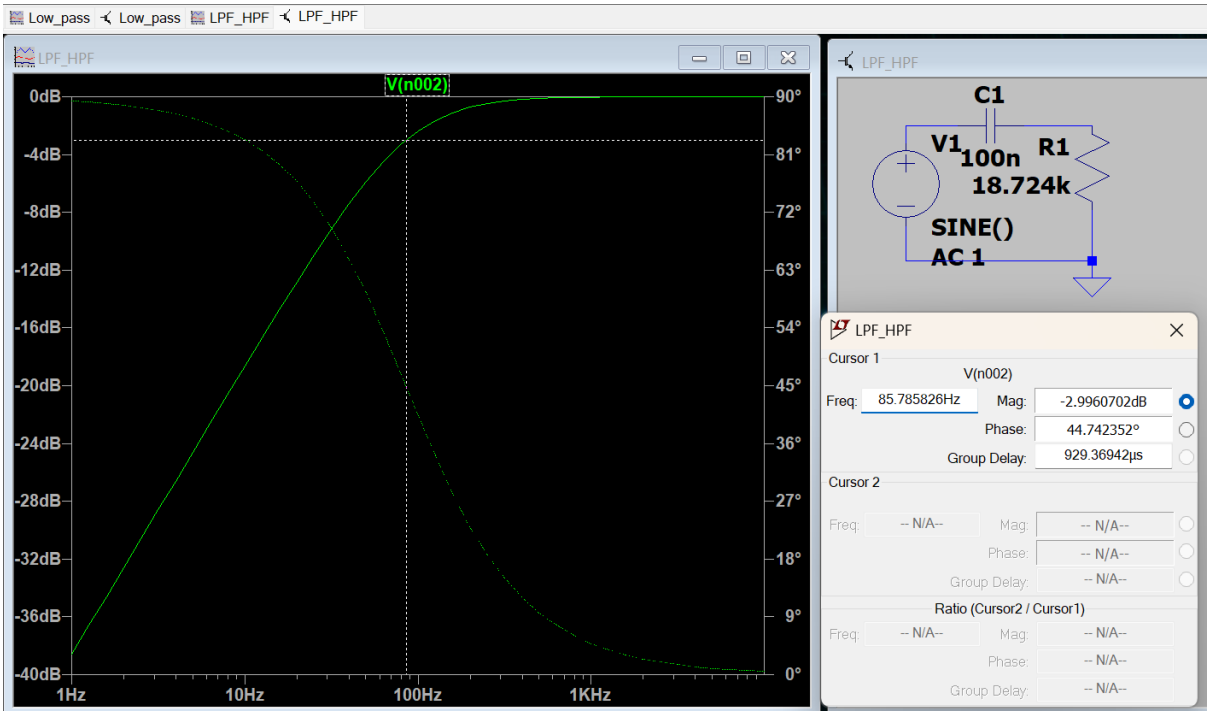

Figure 9: AC Analysis HPF (LTSpice)

C. Notch filter

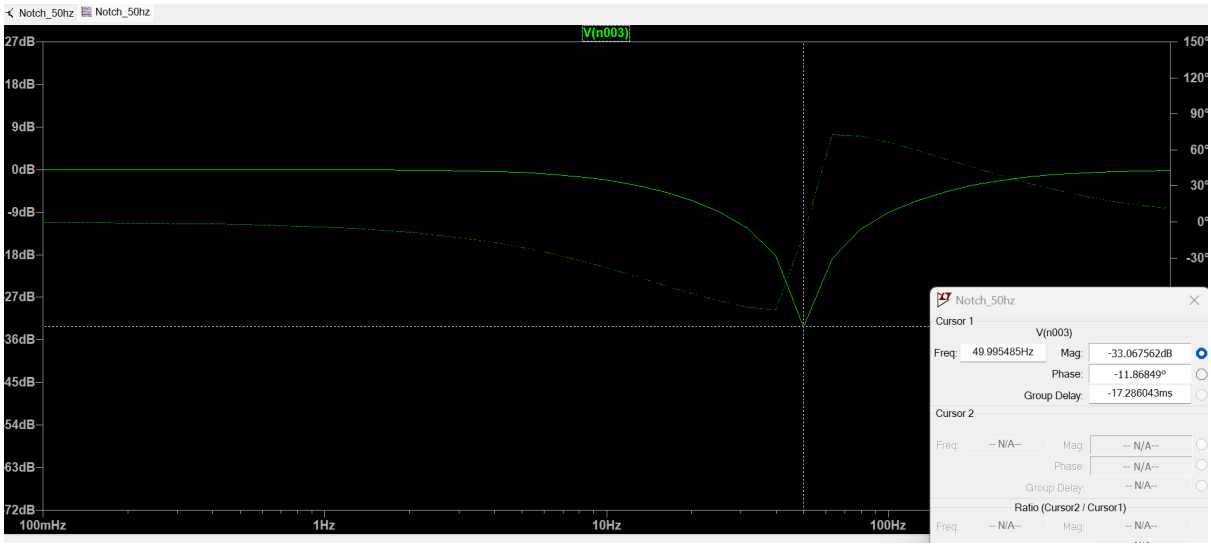

Figure 10: Notch filter Ac analysis

Parameter	Value (Hz)
Lower Cut-off Frequency (f_1)	25Hz
Upper Cut-off Frequency (f_2)	85Hz
Notch Center Frequency (f_0)	50Hz

Table 2: Cut-off and Center Frequencies of the Notch Filter

3.3 Combined 2nd Order Low Pass Filter and Notch Filter Response

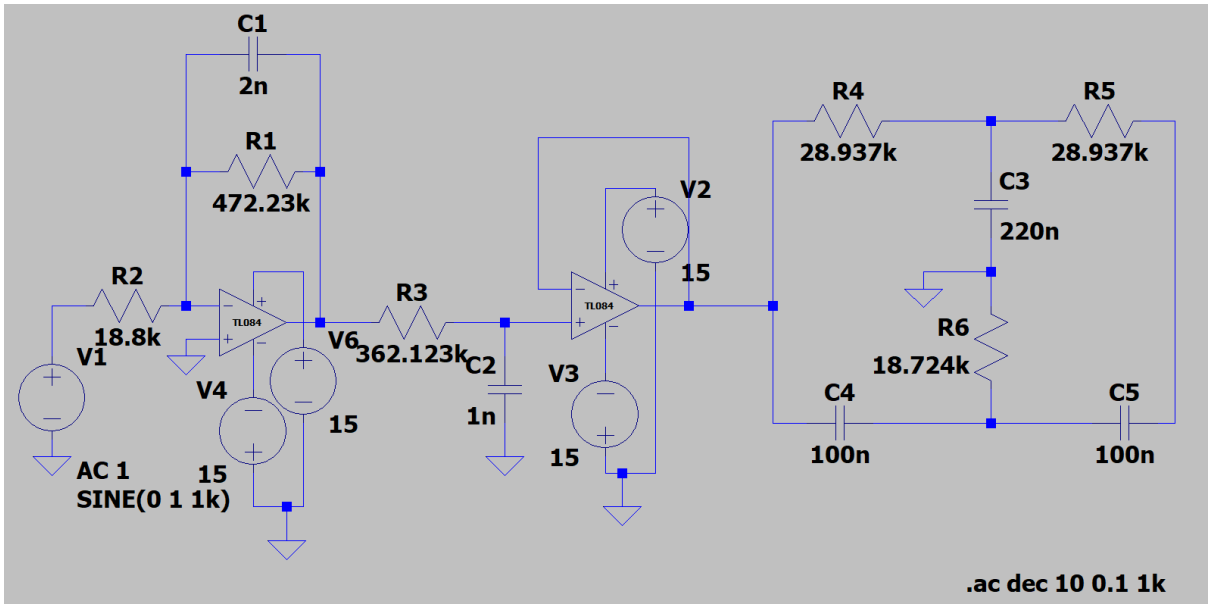

Figure 11: Combined circuit

A. Ac analysis

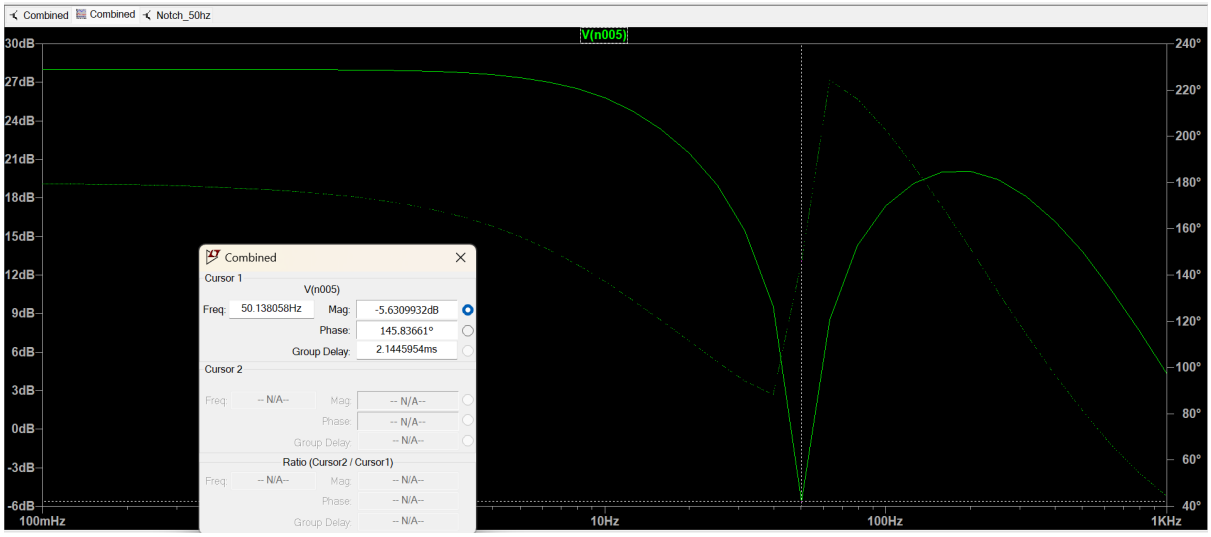

Figure 12: Combined circuit

B. Freq(20 Hz)

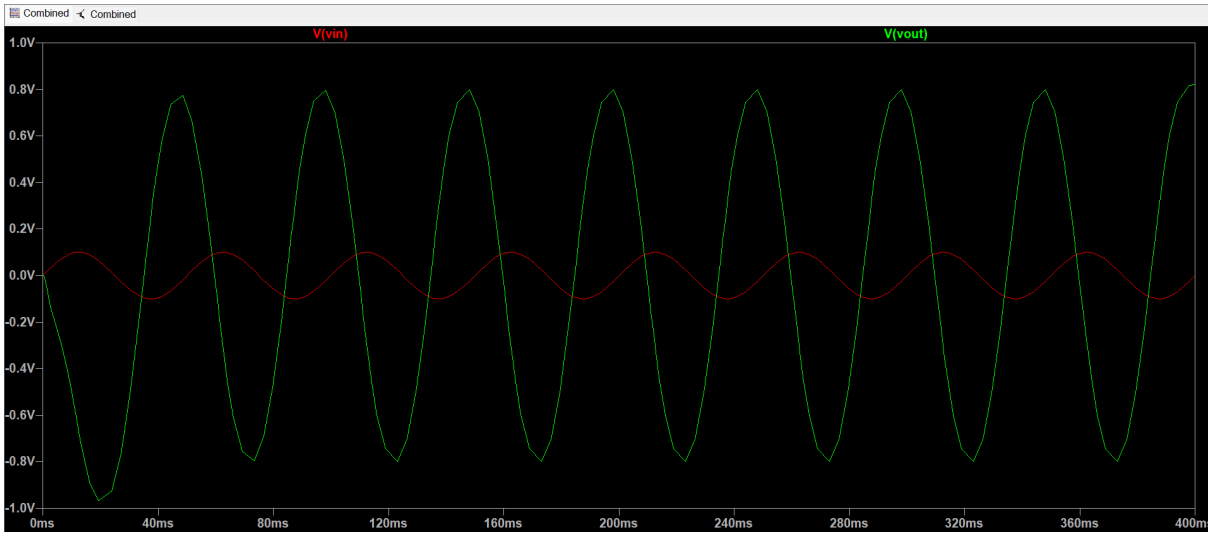

Figure 13: Transient response (20Hz)

C. Freq(50 Hz)

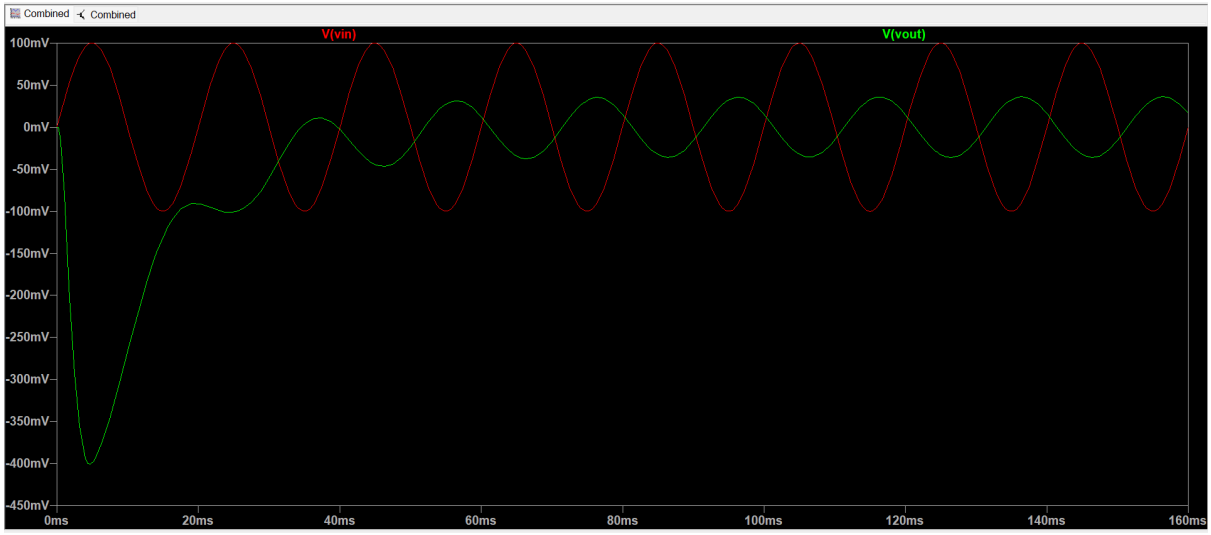

Figure 14: Transient response(50Hz)

D. Freq(100 Hz)

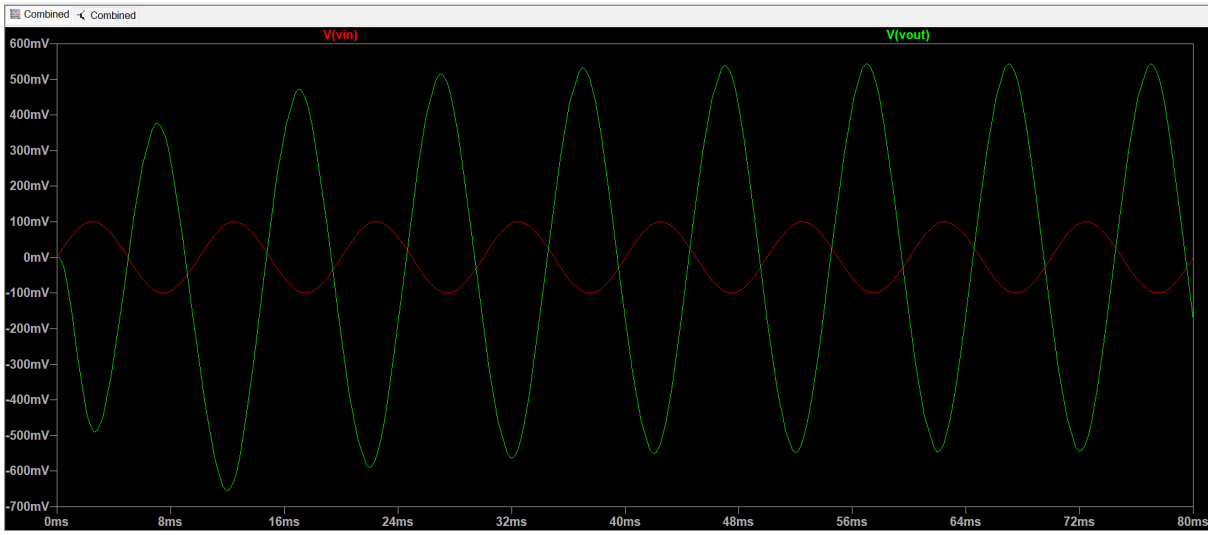

Figure 15: Transient response(100Hz)

E. Freq(2 kHz)

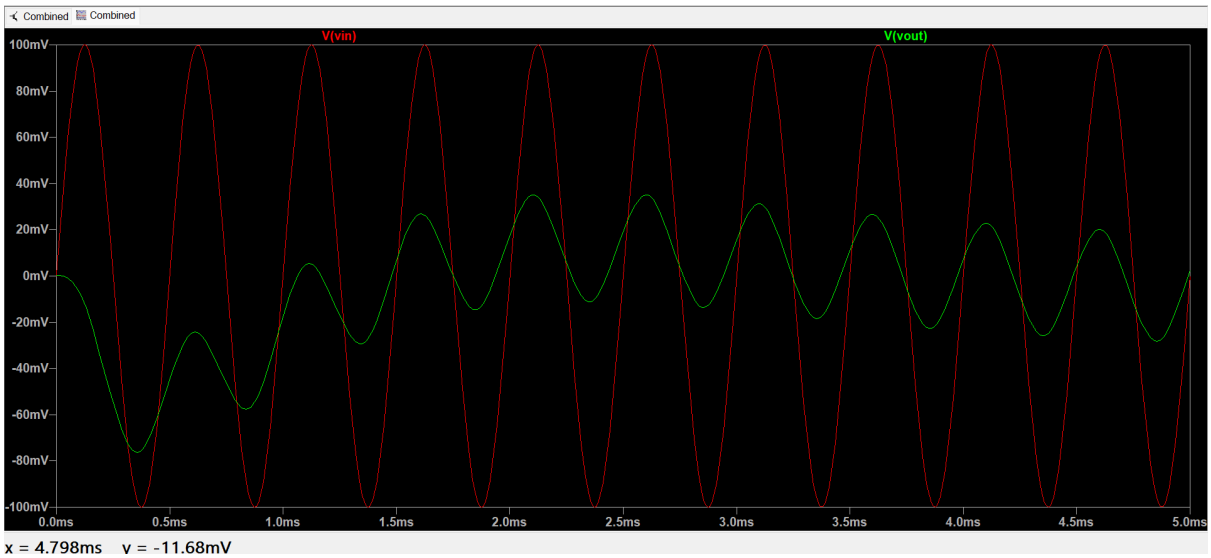

Figure 16: Transient response(2 kHz)

4 Completion Status

100% completion