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EE 202

Final Project Report

Video Link: https://youtu.be/UOmpmq7SaSA

Intro:

The Sallen Key low-pass filter is a versatile circuit design used in audio applications to enhance the sound quality of electric guitars. A Sallen Key low-pass filter is an active filter that reduces high-frequency noises and creates an overall “warmer” sound. By understanding the fundamentals of Sallen Key filters, we can explore its application in adjusting the sound of an electric guitar. In each stage there is an operational amplifier (OpAmp). An OpAmp is an electrical component in linear circuits. It is a voltage amplifier with differential inputs and, in our case, a single-ended output. There is an inverting input (-) and a non-inverting input (+). OpAmps also require a power supply in order to operate. They are denoted as Vdd (or V+) and Vss (or V-).

Body:

In this project, we created a gain-filter circuit for a wooden cigar box electric guitar. The gain-filter circuit was made up of three stages: a gain stage on the left side and then two Sallen Key low-pass filters on the right side. The original circuit was designed to block frequencies above 10kHz and pass frequencies below 10kHz. For our OpAmps, a Vdd of +5V was used and a Vss of -5V was used.

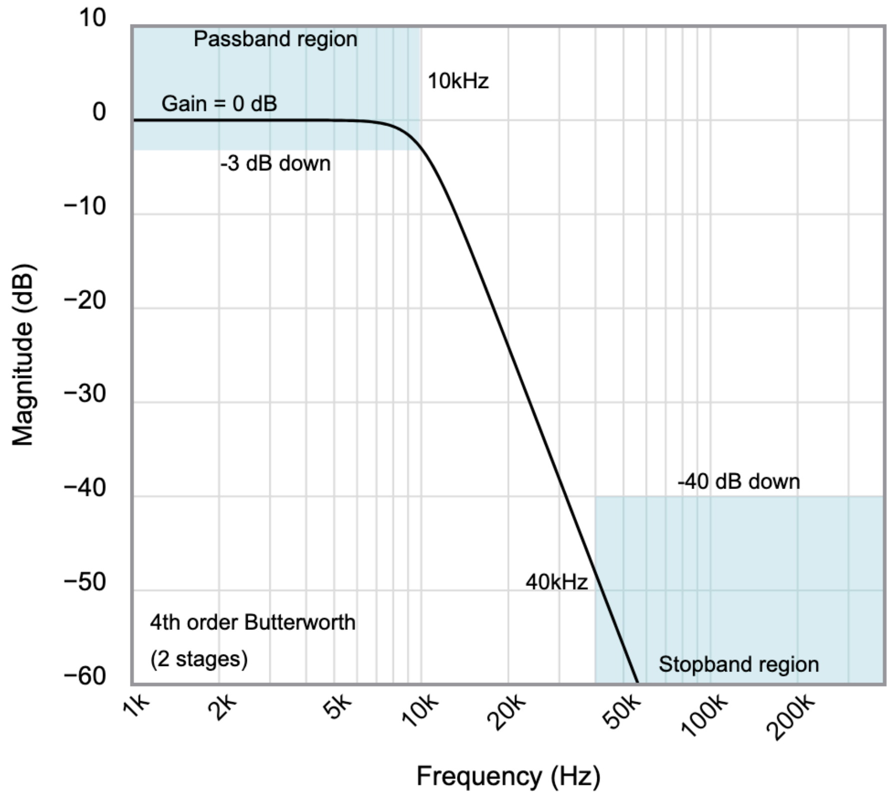

Figure A: Specifications from Analog Filter Wizard

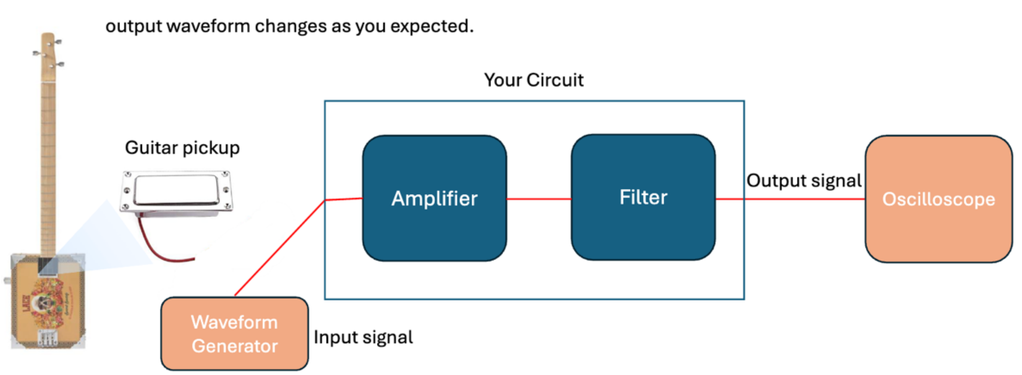

Figure B:

The guitar pickup is the device that produces the input signal that goes into the circuit, starting with the gain stage (amplifier). The gain stage operational amplifier provides amplification which allows the circuit to drive the subsequent stages effectively. In our case, the filter is made up of two low-pass active filters which includes OpAmps as well as passive components. The “filter” passes only certain frequencies by attenuating the amplitude of high-frequency signals. The oscilloscope is how we measure the output input and output signals.

<u>Pictures</u>

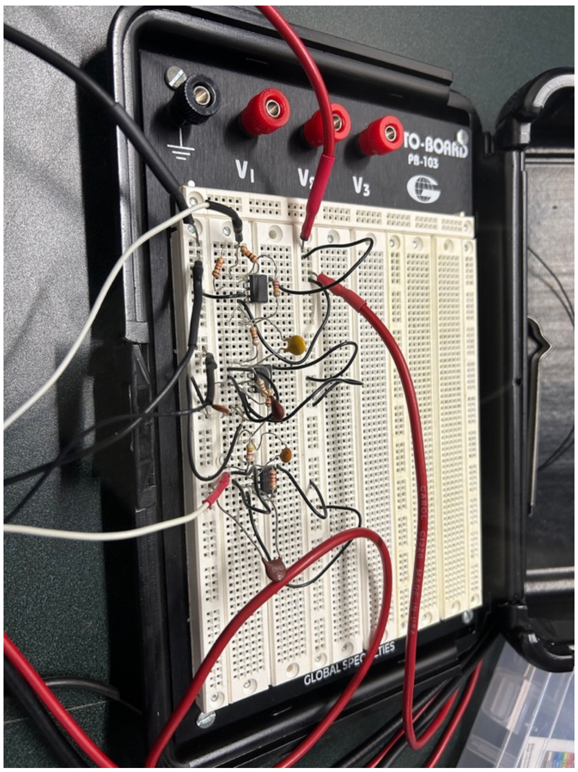

Figure C: Circuit on the breadboard. It has 3 OpAmps for the three different stages. First a gain stage, then two stages of Sallen Key Low-Pass filters.

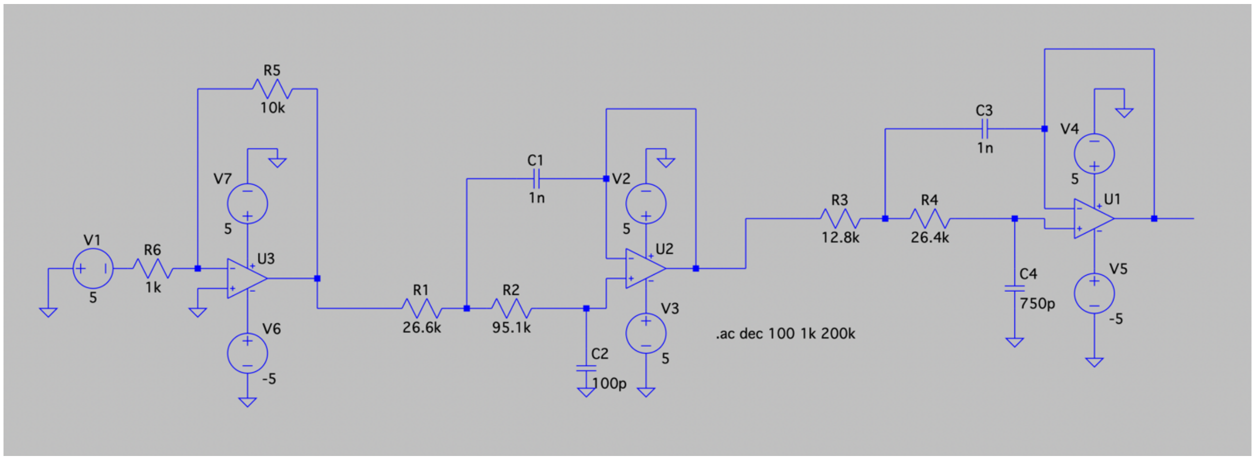

Figure D: Gain stage on the left was designed by us. The two Sallen Key low-pass filter stages in the middle and the right were provided by Analog Filter Wizard. Circuit was built with LTspice. This LTspice file is labeled as LowPassFilterOriginal.asc. This was designed for a gain of 10 dB.

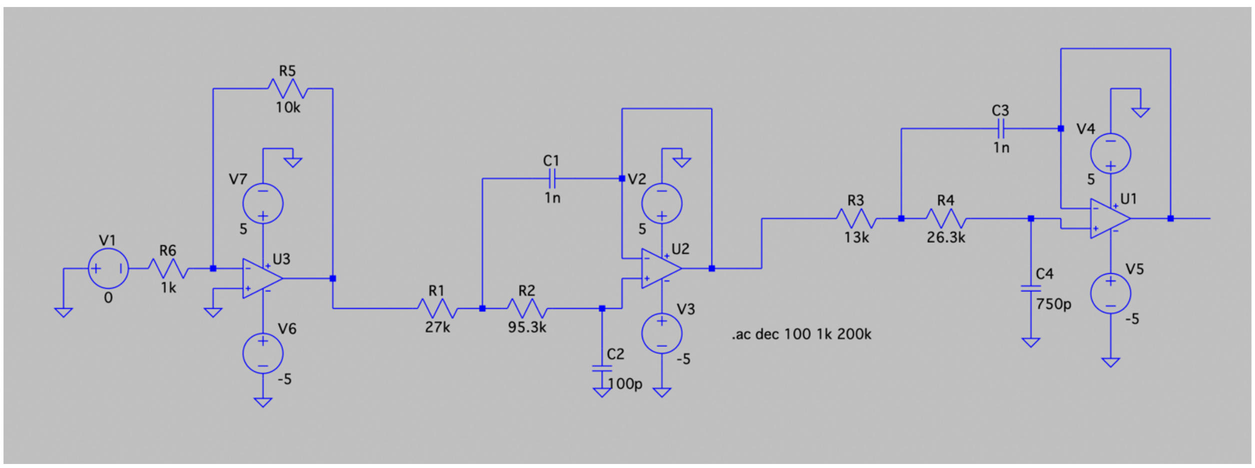

Figure E: These component values have been adjusted based on the available components in class. This LTspice file is labeled as LowPassRealValues.asc.

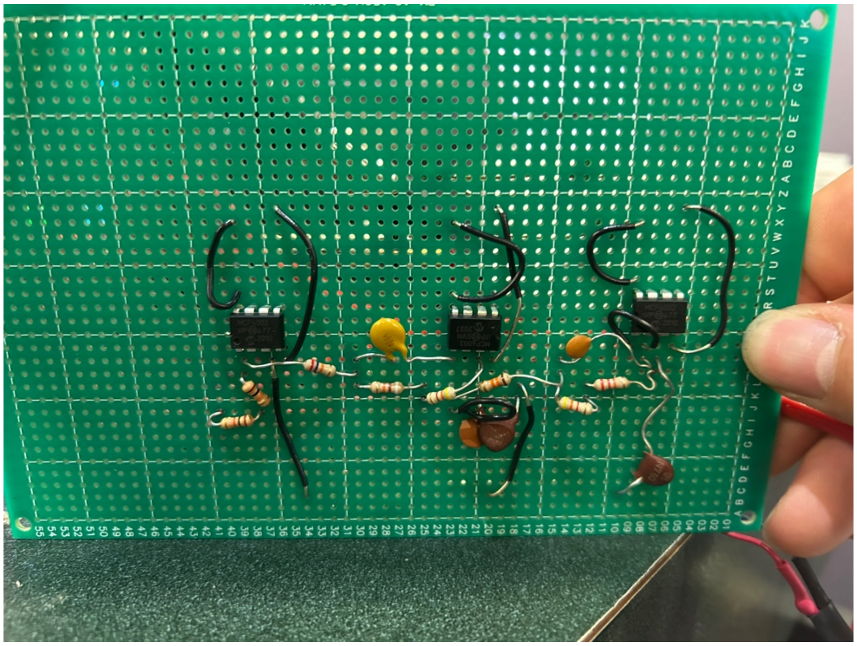

Figure F: Soldered PCB board with gain-filter circuit implementation.

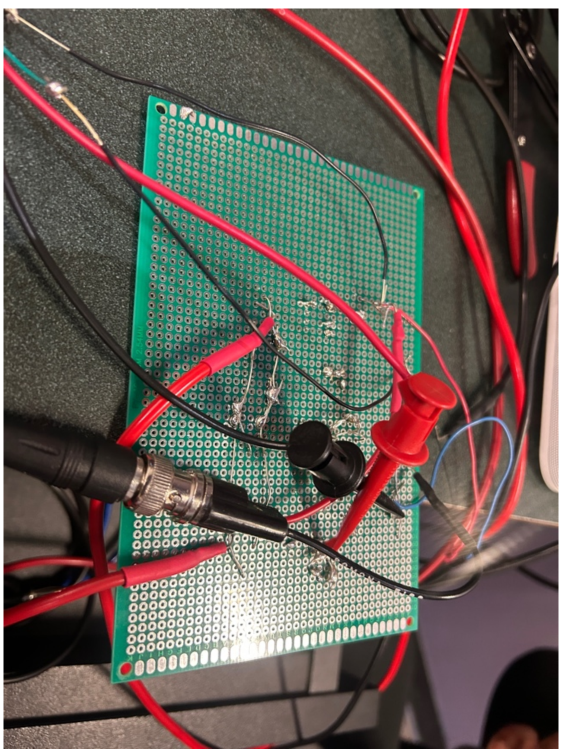

Figure G: Back of the soldered PCB board with voltage sources hooked up (from the electric guitar pickup and for the Vdd and Vss on the OpAmp).

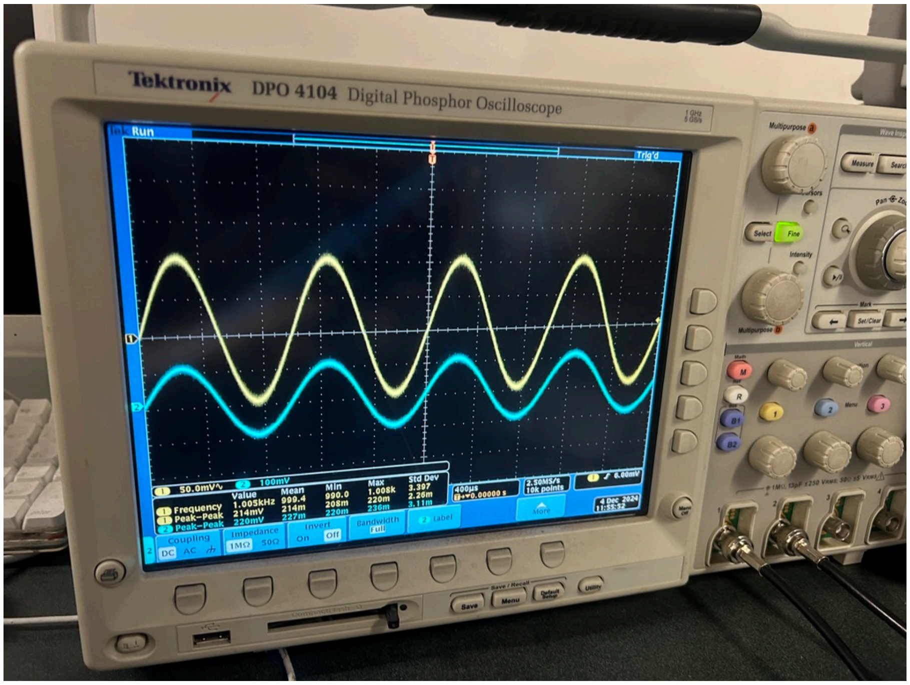

Figure H: A demonstration on the oscilloscope of the gain from the first gain stage.

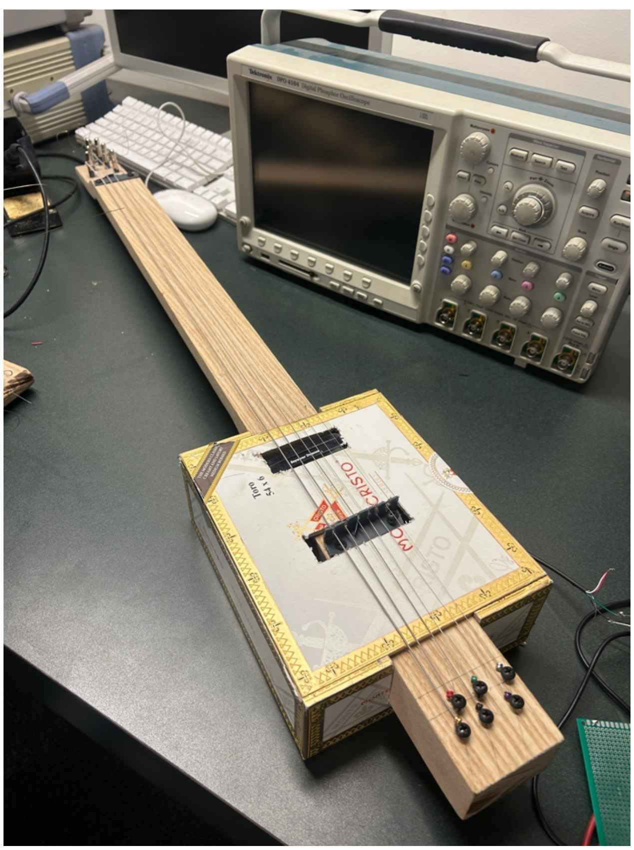

Figure I: Image of the full hand-made guitar. Neck of the guitar was made with a band saw and a block of wood. The body was made with a cigar box.

Hand Calculations

This part was done using the ideal circuit component values instead of the real values used in the actual circuit we built.

Gain stage:

$$V_{out} = K \cdot V_{in} \Big|_{K = -\frac{10k\Omega}{1k\Omega}}$$

$$\boxed{V_{out} = -10 \cdot V_{in}}$$

First Low Pass Filter:

Transfer function:

$$H_1(j\omega) = \frac{1}{1 + j\frac{\omega}{\omega_0}Q + \left(\frac{\omega}{\omega_0}\right)^2}$$

Attenuation:

$$|H_1(j\omega)| = \frac{1}{\sqrt{1 + \left(\frac{\omega}{\omega_0}\right)^2 Q^2 + \left(\frac{\omega}{\omega_0}\right)^4}}$$

Cutoff frequency:

$$f_c \approx \frac{\omega_0}{2\pi}$$

$$\omega_0 = \frac{1}{\sqrt{(R_1+R_2)R_1 C_1 C_2}}$$

$$= \frac{1}{\sqrt{(121.7k\Omega)(26.6k\Omega)(1nF)(100pF)}} \approx 55.58ks^{-1}$$

$$f_{c_1} = \frac{\omega_0}{2\pi} \approx \frac{55.58ks^{-1}}{2\pi}$$

$$\approx \boxed{8.845 Hz}$$

Second low-pass filter:

$$H_2(j\omega) = \frac{1}{1 + j\frac{\omega}{\omega_{02}}Q_2 + \left(\frac{\omega}{\omega_{02}}\right)^2}$$

$$\omega_{02} = \frac{1}{\sqrt{(R_3+R_4)R_3(C_3)(C_4)}}$$

$$= \frac{1}{\sqrt{(39.2\,k\Omega)(12.8\,k\Omega)(1\,nF)(750\,pF)}}$$

$$\approx 51.55\ ks^{-1}$$

$$f_{c2} = \frac{\omega_{02}}{2\pi} = \frac{51.55\ ks^{-1}}{2\pi}$$

$$\approx \boxed{8.2\ kHz}$$

Attenuation

cutoff frequency:

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

$$f = f_c, \quad |H(f)| = \frac{1}{\sqrt{2}} \approx 0.707$$

$$A(f) = -20\log_{10}\left(\frac{|H(f)| \cdot \cancel{V_{in}}}{\cancel{V_{in}}}\right)$$

$$A(f) = -20\log_{10}(0.707) \approx \boxed{-3\ dB}$$

Discussion/Conclusion:

Our circuit passed frequencies below ~60kHz and blocked frequencies above ~60kHz. This was very different from the original circuit built to pass frequencies below 10kHz. This difference could be attributed to the fact that different component values (resistors and capacitor values) were used due to the limited supply of components available to us in class. Additionally, the gain from the first gain amplification stage was calculated to be 10 dB (= 3.16 V/V). Attenuation was calculated to be -3dB.