Labo 4 active filters

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1. Introduction

Active filters play a crucial role in electronic signal processing, offering precise control over frequency response. Among them, the Sallen-Key filter stands out as a second-order active filter design employing operational amplifiers. Renowned for its simplicity and versatility, the Sallen-Key filter is adept at implementing low-pass, high-pass, and band-pass configurations. With resistors and capacitors strategically arranged, it achieves effective signal filtering in electronic circuits. Engineers often favour the Sallen-Key design for its ease of implementation, making it a cornerstone in applications requiring accurate frequency manipulation and signal conditioning.

2. Design of the band-pass filter

2.1. What quality factor should you use

The application is a band pass filter, an ideal version of this would result in the frequencies outside the band being 0*amplitude and within the band 1*amplitude, this implies there should be no resonance peak/amplification withing the band. The only other requirement is to approach the ideal version as close as possible. A good value of Q in this application is the factor 0.707 as it is the closest value which does not have resonance, with the most ideal curve

2.2. Equations

2.2.1. How did you get them?

The first equation is clearly based on the cutoff frequency for a passive RC filter: $\frac{1}{2\pi RC}$. In the Sallen-key filter there are two of each the C and the R components. These are averaged by multiplication and subsequently taking the root of the result. These values the directly replace the R and C values respectively and you get the final equation: $\frac{1}{2\pi\sqrt{R_1R_2\sqrt{C_1C_2}}}$

In conclusion this is equation is just an expansion of the classic RC filter frequency equation.

There are two Q factor calculations, one for the high-pass and one for the low-pass.

Low pass: $\frac{\sqrt{R_1R_2C_1C_2}}{C_2(R_1+R_2)}$, high pass: $\frac{\sqrt{R_1R_2C_1C_2}}{R_1(C_1+C_2)}$

2.2.2. Why is it enough for a full band-pass filter?

A band pass filter is simply a combination of a high-pass filter and a low-pass filter. Assume the high-pass filter has a cutoff frequency of f_1 and the low-pass a frequency of f_2. This means the filters pass all frequencies between f_1 and f_2 and filter all frequencies outside the range. The above equations are enough because the calculations defining the frequency and Q factor are identical for low- and high-pass filters.

2.3. What values did you choose

The design of the band pass filter can be subdivided in the design of a low-pass and a high-pass filter. Both filters use the same formulas to calculate their cutoff frequencies and Q factors.

The results for the low-pass at 10kHz at Q=0.707 is c1: 2.25nF and c2: 1.13nF, r1: 10k and r2: 10k

The results for the high-pass at 100Hz at Q=0.707 is c1: 10nF and c2: 10nF, r1: 11k, r2: 22.5k

3. Simulation of the design

3.1. Show the filter works as intended

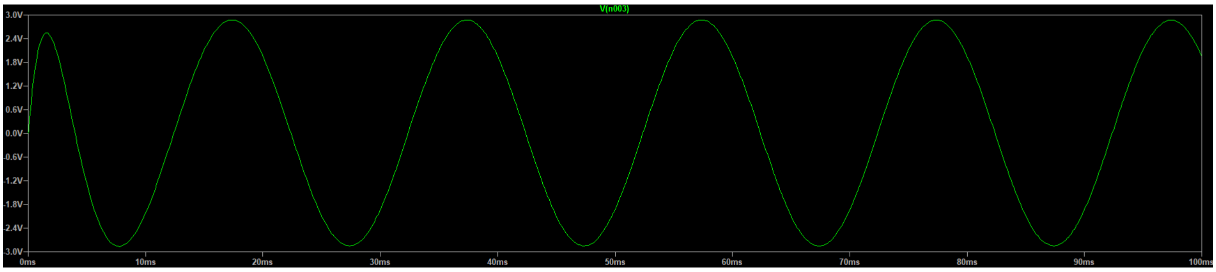

Figure 1: amplitude at 50Hz ~6V p-p

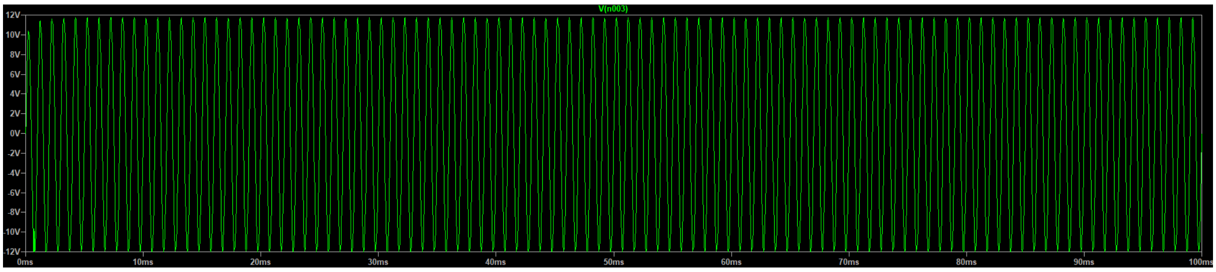

Figure 2: amplitude at 1000Hz ~24V p-p

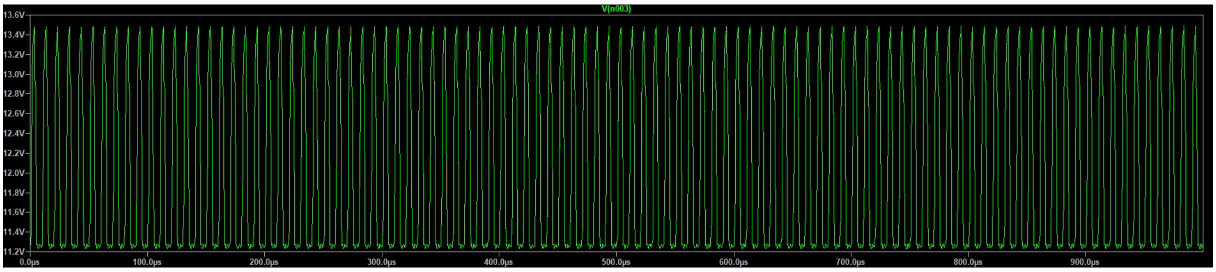

Figure 3: amplitude at 100kHz ~2.3V p-p

As you can see the filter works as intended, as it passes the full signal at 1kHz, within the pass band. Furthermore it attenuates the signals outside the pass band

3.2. Show the specifications are met

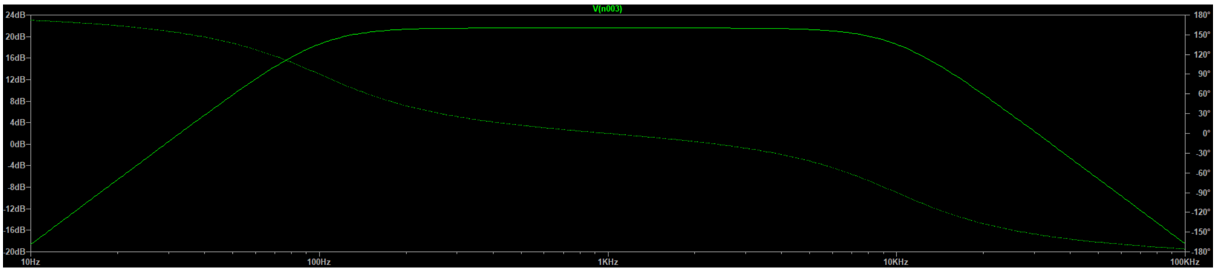

Figure 4: frequency response

As you can see the filter passes the frequencies between 100Hz and 10kHz and attenuates the values outside that range. You can also see the poles at 100Hz and 10kHz by looking at the phase changes.

3.3. Show the advantages and disadvantages of the filter

The advantage of such a filter is that it has a roll-off of 40dB per decade. Furthermore by utilising the OPAMP, the signal does not get attenuated at all within the pass band.
The downside of this approach lies within the OPAMP, the OPAMP does not have ideal behaviour and properties such as bandwidth will affect the actual functioning of the filter. This can be illustrated with the effects visible beyond the 500kHz mark where the amplification stops dropping off.

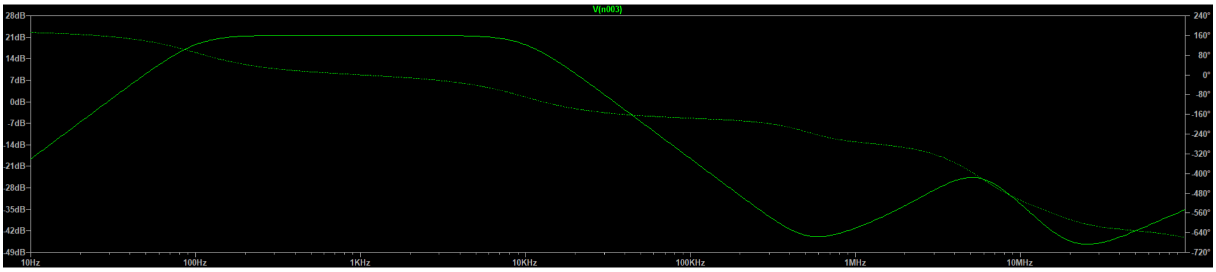

Figure 5: frequency response including the non-ideal behaviour

4. Real-life application

For the real life application, a higher lower corner frequency was chosen of 1kHz instead of 100Hz as the amplifier is unstable at lower frequencies.

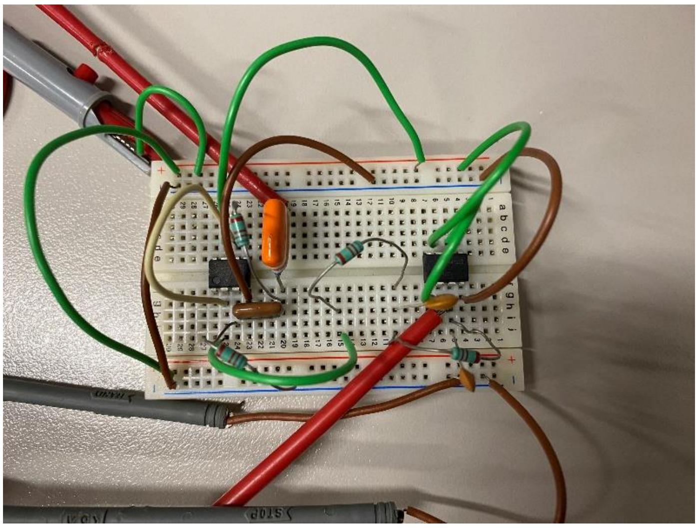

Figure 6: amplifier built on the breadboard

4.1. Show frequencies in your range

Figure 8: Filter response at 2kHz: 9.6V p-p

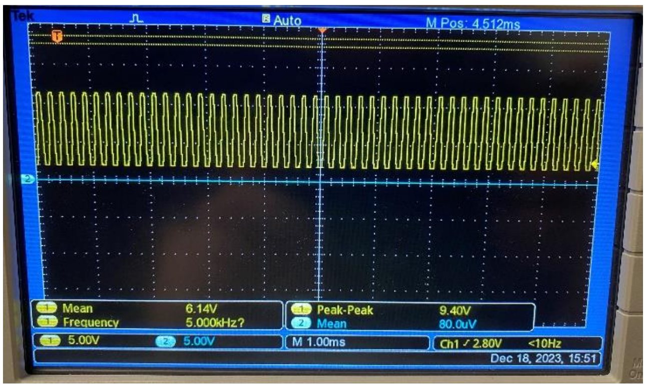

Figure 7: Filter response at 5kHz: 9.4V p-p

The two frequencies within the range show very little deviation (around the precision of the scope readout). Here we can conclude the filter works well.

4.2. Show corner frequencies/other frequencies

I did not measure the corner frequencies but I do have some outside the pass band.

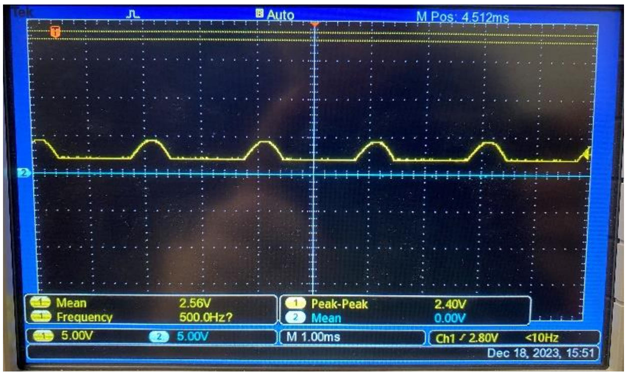

Figure 10 Filter response at 500Hz: 2.4V p-p

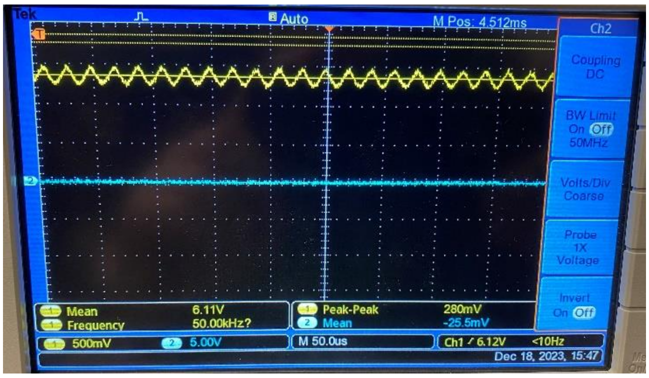

Figure 9: Filter response at 50kHz: 280mV p-p

These values clearly show the signal gets attenuated at frequencies outside the pass band. Furthermore the non-ideal effects of the OPAMP are clearly noticeable at the lower frequencies.

4.3. Bode plot

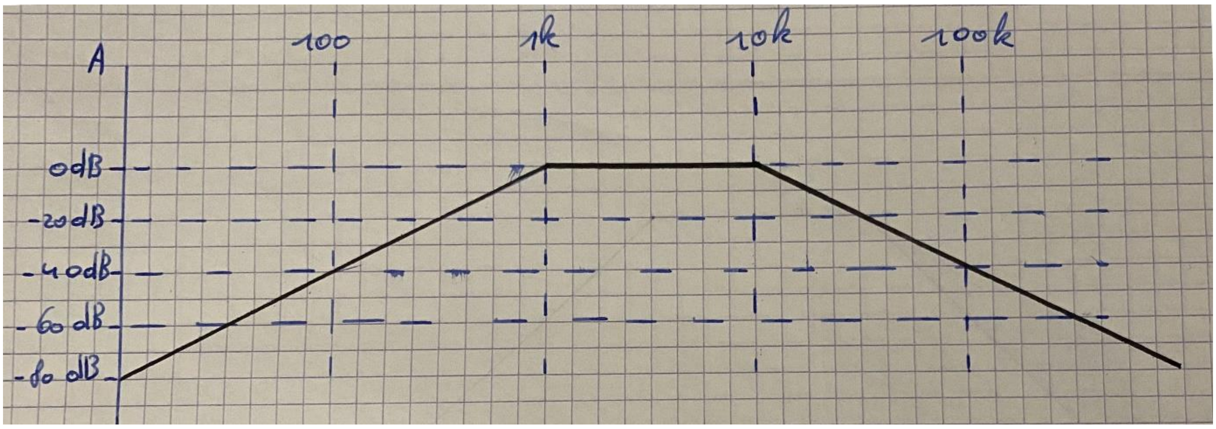

Figure 11: bode plot of the physical filter

5. Conclusion

The active filter is an interesting alternative to the passive filter as it offers more control of the filter such as roll-off and keeping the signal high with the amplifier. Due to not attenuating the voltage outside the filter, multiple filter can be cascaded to achieve an even higher roll-off. The downsides of these filters are their complexity and specifically the OPAMPs. The OPAMPS introduce an additional amount of non-ideal properties to the system resulting in a limited bandwidth and unpredictable behaviour outside these areas, as seen in figure 5. The calculation can be rather complex to do as there are 4 potential variables and choosing the optimal components in these cases can be challenging.

In conclusion the active filter has benefits but it is also limited by its complexity.