UNIVERSITY OF WEST LONDON

Analogue systems

Assignment

Manuel Alberto Suena Galindez

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Introduction

The task for this assignment was to design a three-channel sound to light unit. A microphone was used to record a sound signal that the circuit then separates into the three channels- bass, mid and high range frequencies. Each channel's output consists of two LEDs representing the low and high sound intensity. The simulations of the circuit and the design of the individual circuits were made using OrCAD. The learning outcomes for this assignment were to design analog circuits using operational amplifiers, to learn to design Sallen-key filters, to use OrCAD for computer simulations of the circuits and to develop practical experimental skills for problem-solving. The structure of this assignment consists of the analysis of each of the individual by showing their calculation explanations and design and then the simulation result. The assignments starts by analyzing the pre-amp used in this circuit, then by analysing the Sallen-key filters followed by the rectifier and the comparator. The assignment concludes by shows the design of the full circuit and the simulations results gathered by all the channels of the circuit.

Pre-amp

For this circuit design, a simple non-inverting amplifier was used by which the gain is calculated in equation 1. Its amplification effect on the input voltage is shown in figure 2. The design of the circuit is found in figure 1.

Calculations

In equation 1 the gain of the pre-amp calculated is 11 so the resister values were set to 10k for R11 and 1k for R12 to achieve this gain.

$$Gain = \frac{1 + R_2}{R_1} = \frac{1 + 10}{1} = 11$$

Equation 1: Gain equation

Circuit diagram

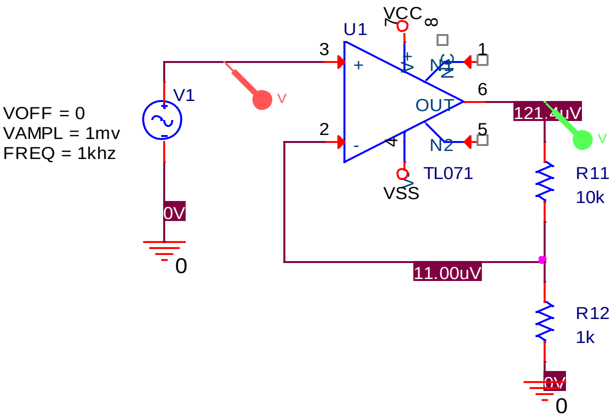

Figure 1: Pre-amplifier diagram

Results

Figure 2 conveys the gain of the pre-amp being tested. The result is as expected from the calculation. The Vin of 1mV is amplified to an 11mV wave at the output.

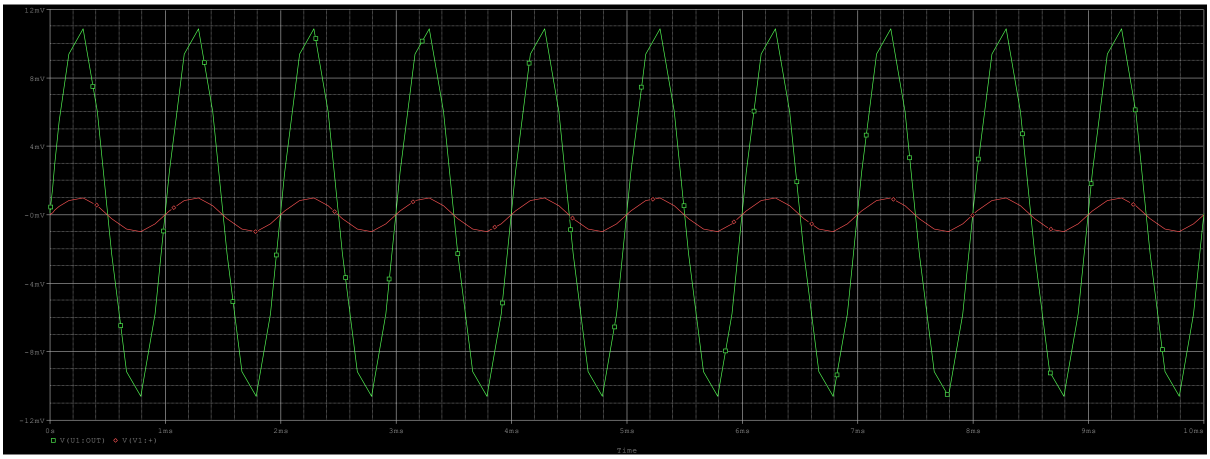

Figure 2: Pre-amp gain response

Lowpass filter

For the design of this filter, a Sallen-key lowpass filter was used. The break frequency was provided and the resistor values needed were calculated using equation 2. The final design of the circuit is shown in figure 3 and its break frequency is found in figure 4.

Calculations

For this circuit design, the break frequency assigned was 300Hz and the capacitor values were set at 1nF, the RC frequency formula in equation 2 was used to obtain the resistor values needed to get a filter with a break frequency of 300Hz, which resulted in a resistor value of 530.5 $k\Omega$.

$$f = 300Hz \qquad C = 1nF$$

$$f = \frac{1}{2\pi CR} \rightarrow R = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 300 \times (1 \times 10^{-9})} = 530.5\ k\Omega$$

Equation 2: RC frequency formula

Circuit diagram

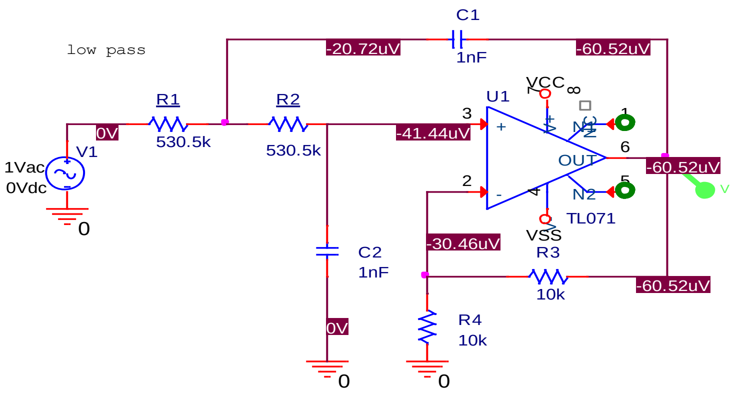

Figure 3: Low-pass Sallen-key filter

Results

Figure 4 shows the break frequency of the low pass Sallen-key filter. As predicted using the calculations, the break frequency is at 300Hz proving that]the filter is working as expected.

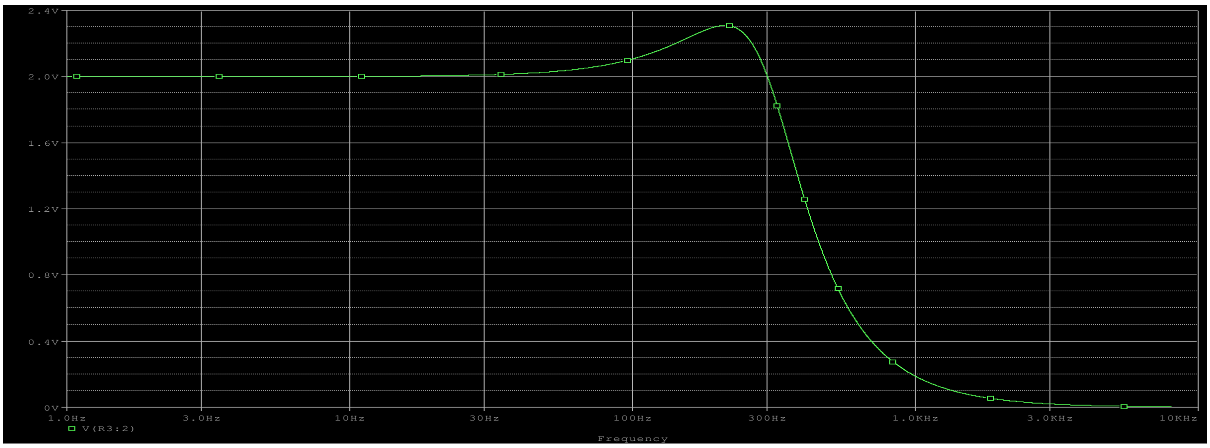

Figure 4: Low-pass filter frequency response

Highpass filter

For the design of this highpass filter, a Sallen-key high pass filter was used. The break frequency was set to 600Hz and the resistor values to 1 $k\Omega$. The capacitor value needed for a break frequency of 600Hz was calculated in equation 3. The design of the circuit is shown in figure 5 and the results of the simulation to test the break frequency of the circuit can be found in figure 6.

Calculations

For the calculations of this circuit, the break frequency was set to 600Hz and the resistor value to 1 $k\Omega$. The capacitor value was then calculated using the RC frequency inverse formula for the capacitor after substituting the values in the formula. The capacitor values for a break frequency of 600Hz was determined to be 265.3nF.

$$f = 600Hz \qquad R = 1k\Omega$$

$$f = \frac{1}{2\pi CR} \rightarrow C = \frac{1}{2\pi fR} = \frac{1}{2\pi \times 600 \times 1000} = 265.3\, nF$$

Equation 3: RC frequency formula

Circuit diagram

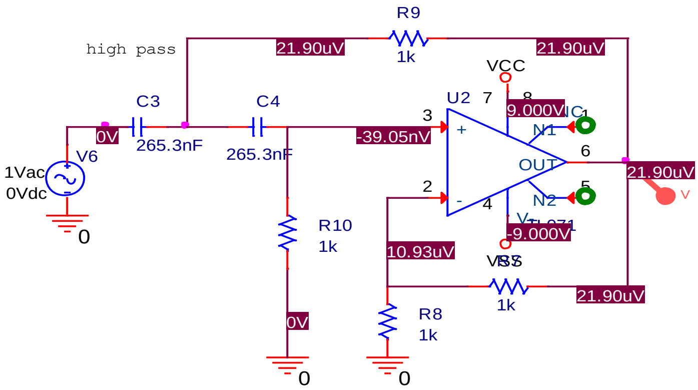

Figure 5: High-pass Sallen-key filter

Results

Figure 6 shows the break frequency of the highpass filter used in this circuit. It can be noted from the simulation result that the break frequency of the filter matches the calculations predictions and the break occurs at 600Hz where the voltage rises.

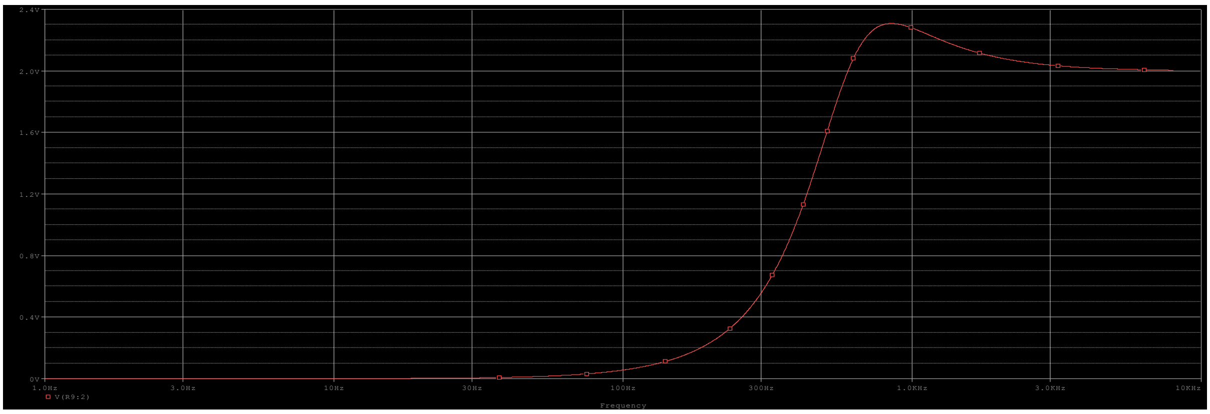

Figure 6: high-pass filter frequency response

Bandpass filter

For the design of this filter, the two previous designs were connected in series so that the output of the lowpass can be supplied to the highpass filter effectively allowing for a bandpass filter of a bandpass break frequency between 300Hz and 600Hz. The same calculations of the previous designs were used in equations 2 and 3 to determine the resistor and capacitor values. Figure 8 shows the bandpass break frequency of the circuit. The completed design is shown in figure 7.

Calculations

Equation 4 shows the formulae used to calculate the bandpass break frequency of the circuit. In these formulae, the resistor and capacitor values are the same as in equations 2 and 3, hence why the resulting resistor and capacitor values are also the same.

$$f = 300Hz \qquad C = 1nF$$

$$f = \frac{1}{2\pi CR} \rightarrow R = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 300 \times (1 \times 10^{-9})} = 530.5\ k\Omega$$

$$f = 600Hz \qquad R = 1k\Omega$$

$$f = \frac{1}{2\pi CR} \rightarrow C = \frac{1}{2\pi fR} = \frac{1}{2\pi \times 600 \times 1000} = 265.3\ nF$$

Equation 4: RC frequency formula

Circuit diagram

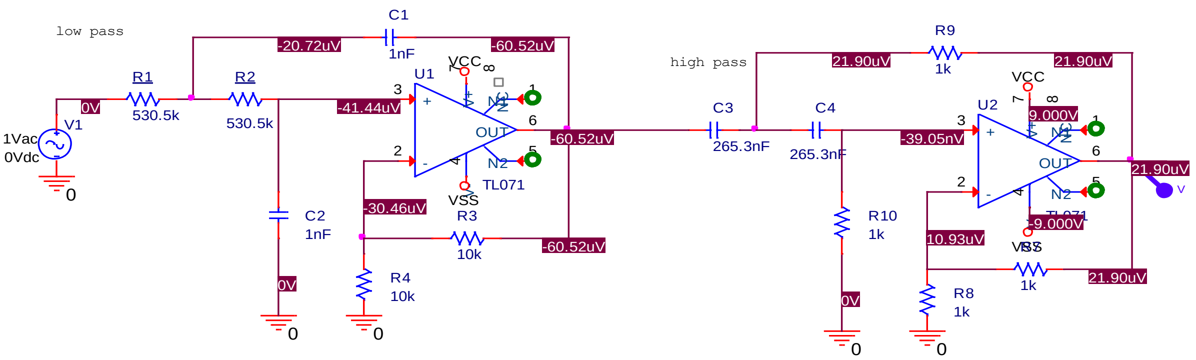

Figure 7: Band-pass Sallen-key filter

Results

Figure 8 shows the simulation of the bandpass filter and the resulting frequency response. The circuit works as expected. That the breaks occur at 300Hz and 600Hz, as predicted in the calculations.

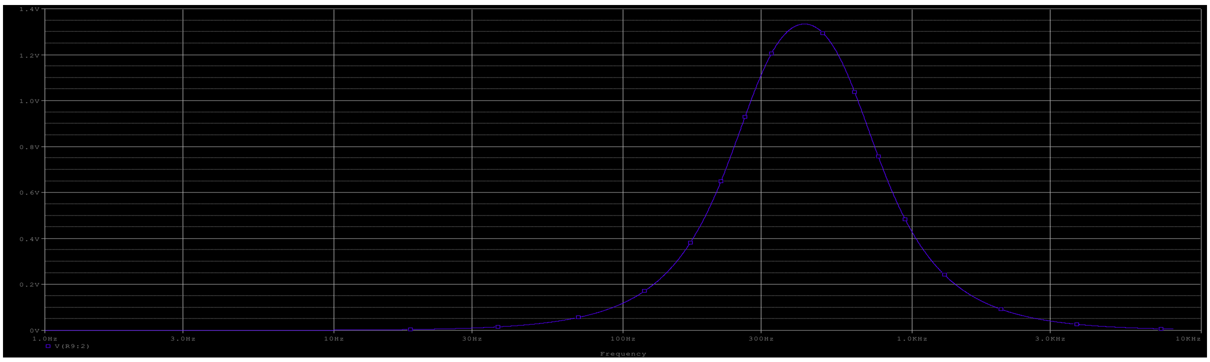

Figure 8: band-pass filter frequency response

Rectifier

To rectify the signal of this circuit, a precision full-wave rectifier was used. This design was taken from [1] which uses two diodes, D2 in forwarding bias and D1 in reverse bias and where the first opamp works as an inverting amplifier and the second as an inverting adder circuit. This design works by inverting the negative half cycle input of the AC wave making both half cycles positive in the same direction and the magnitude. Figure 9 shows the final design of the circuit and figure 10 shows the rectified output signal.

Formula

For equation 5 is taken from [1]. It was determined that the resistor values must be the same except R15 where the value is half that of the other resistors.

$$V_o = -\left[\left(\frac{R}{R}\right) V_{in} + \frac{R}{\left(\frac{R}{2}\right)}\right]$$

Equation 5: Full-wave rectifier circuit formula

Circuit diagram

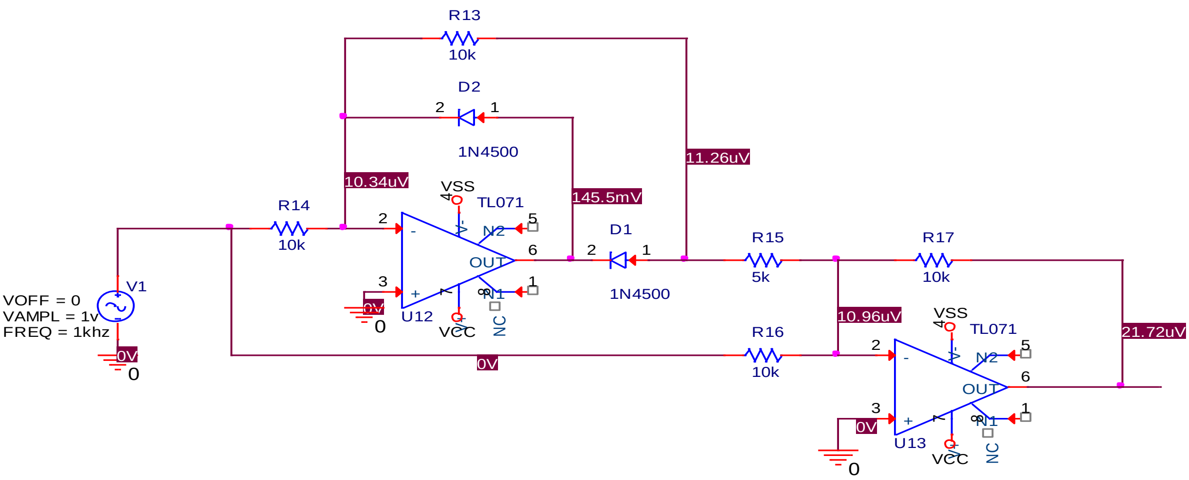

Figure 9: full-wave rectifier diagram

Results

Figure 10 shows the full-wave rectification of the inputted signal. The rectifier circuit works as expected, performing the full rectification of ac signals.

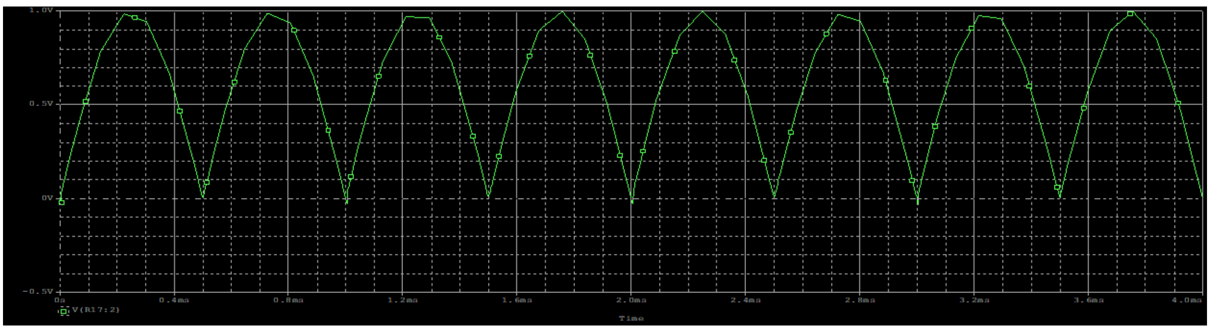

Figure 10: full-wave rectifier frequency response

Comparator

For this circuit, a window comparator design was used to send a signal to LED to show when the signal was high and when it was low. Equation 6 shows the output voltage that is used to compare the input signal. Figure 11 shows the final design and figure 12 shows the simulation results of the comparator.

Calculation

Equation 6 shows the calculation of the voltage value of the comparator.

$$R = 1k\Omega$$

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2} \rightarrow V_{out\,comparator_1} = \frac{V_{in}}{2} \rightarrow V_{out\,comparator_2} = \frac{V_{in}}{3}$$

Equation 6: Voltage divider formula

Design

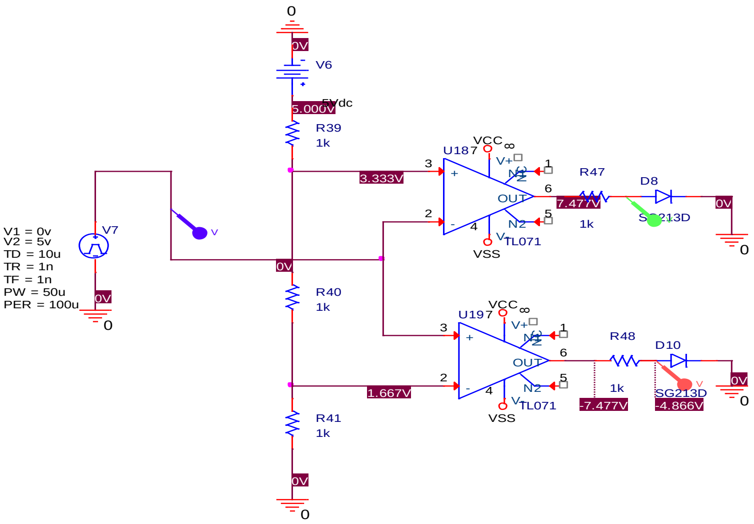

Figure 11: comparator diagram

Results

Figure 11 shows the simulation of the comparator comparing the high and low LED signal with the input signal. The green line represents the low signal and the red- the high. This circuit works as expected.

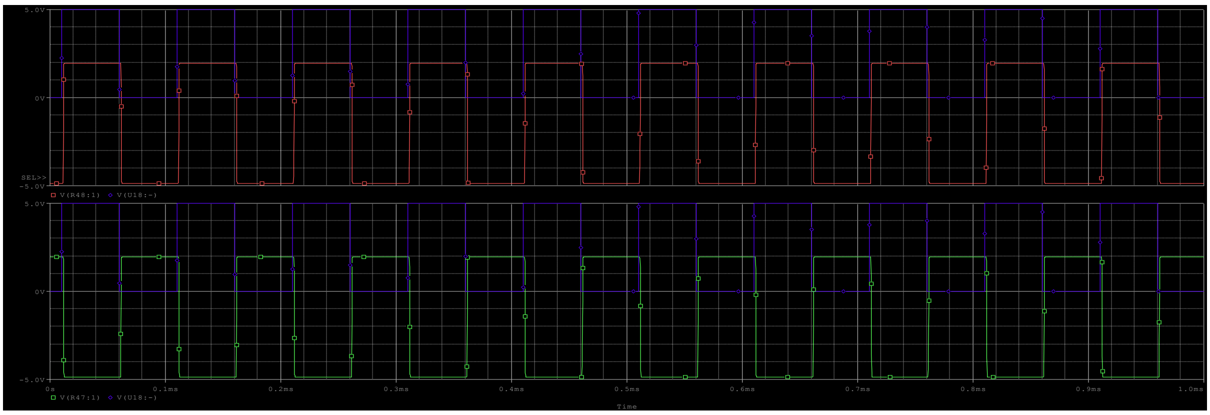

Figure 12: comparator LED test

Full circuit

Figure 13 shows the full circuit design where a pre-amplifier supplies the amplified input signal received from the mic to three channels. The channels used are lowpass, highpass, and bandpass. These channels have full-wave rectification. A comparator then shows through the display of two LEDs the channels working and when their signals are high or low.

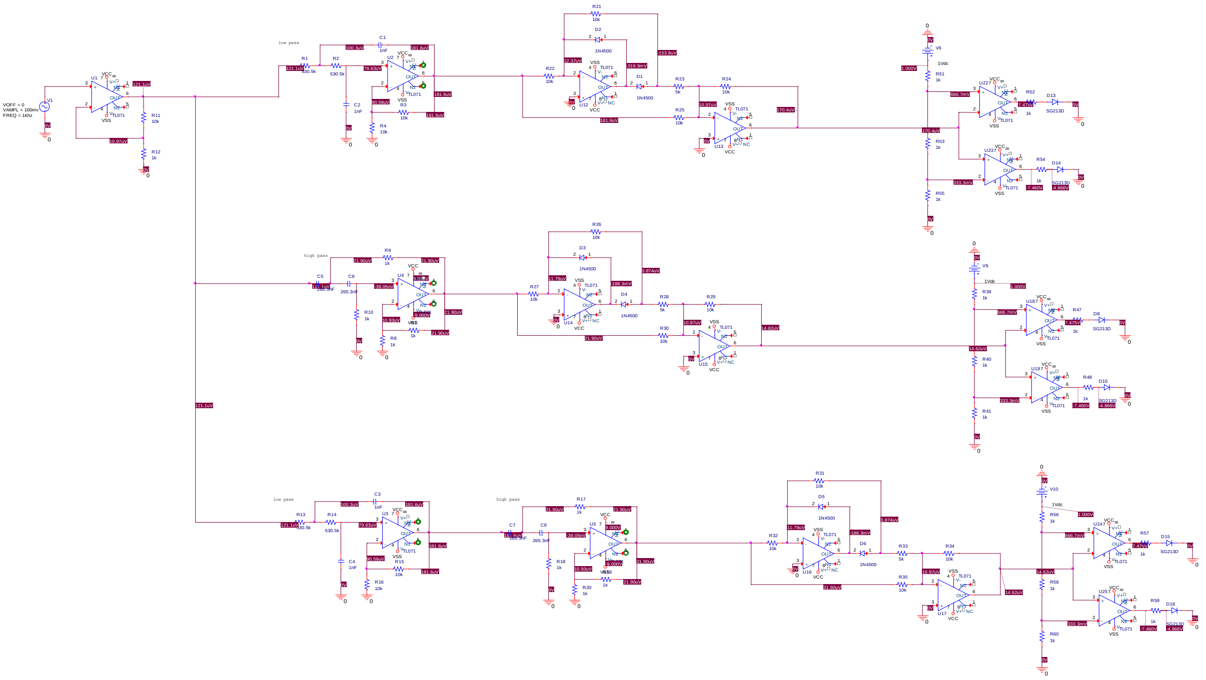

Figure 13: Full circuit diagram

Low pass channel

Figures 14 and 15 show the lowpass channel low and high LED signal working. Both LEDs work as expected, the green represents the low signals and the yellow represents the high signals of the input signal.

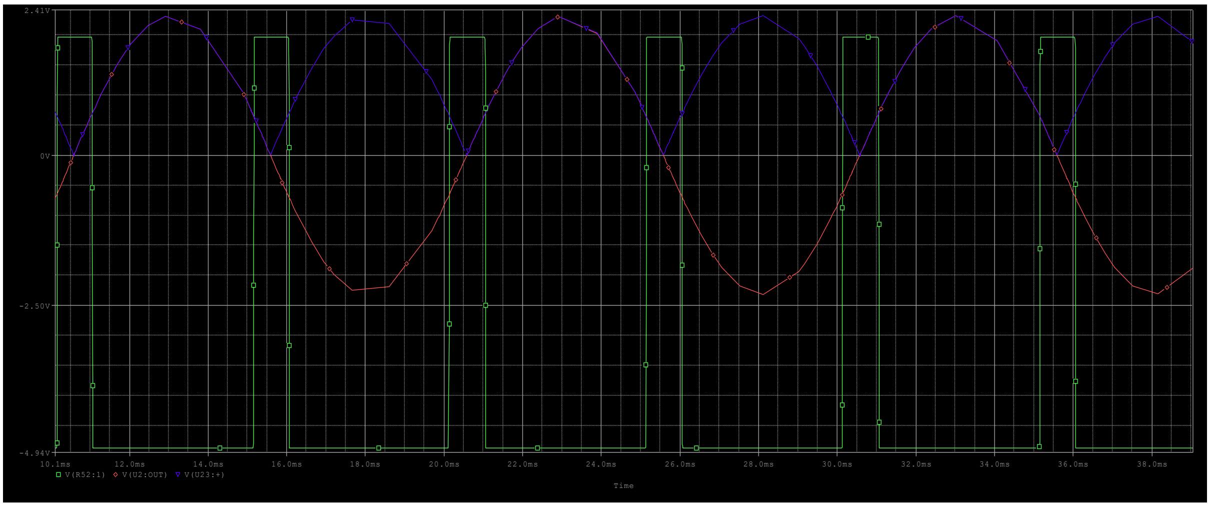

Figure 14: Low channel full circuit low LED test

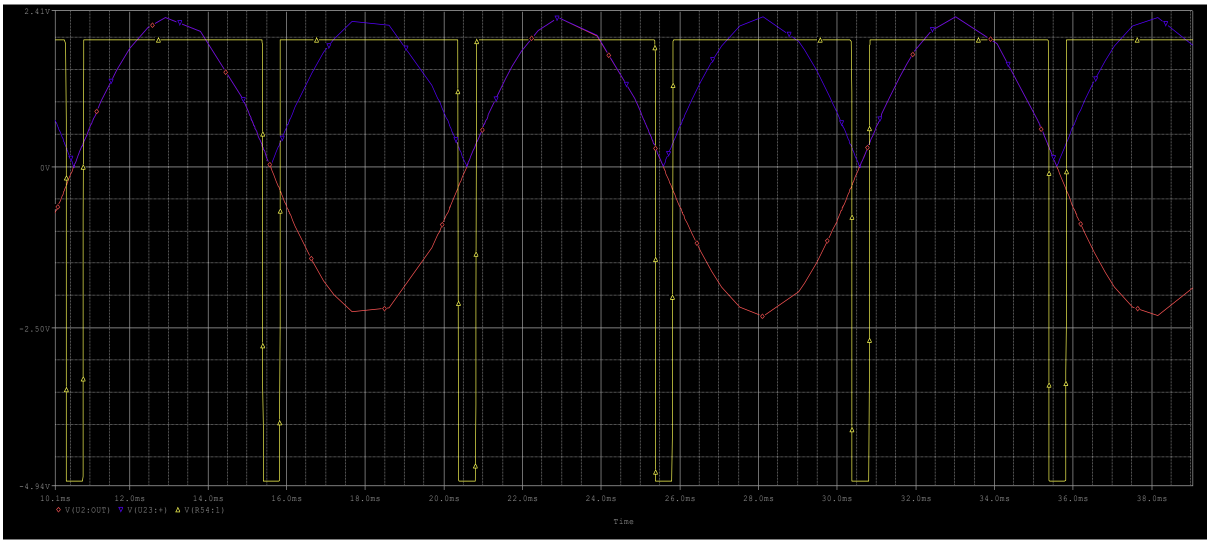

Figure 15: Low channel full circuit high LED test

High pass channel

Figures 16 and 17 show the simulations of the highpass channel signals. The received signals by the LEDs are shown, the green signal shows the signal of low LED signal and the yellow signal shows the high LED signal. Both LEDs work as expected.

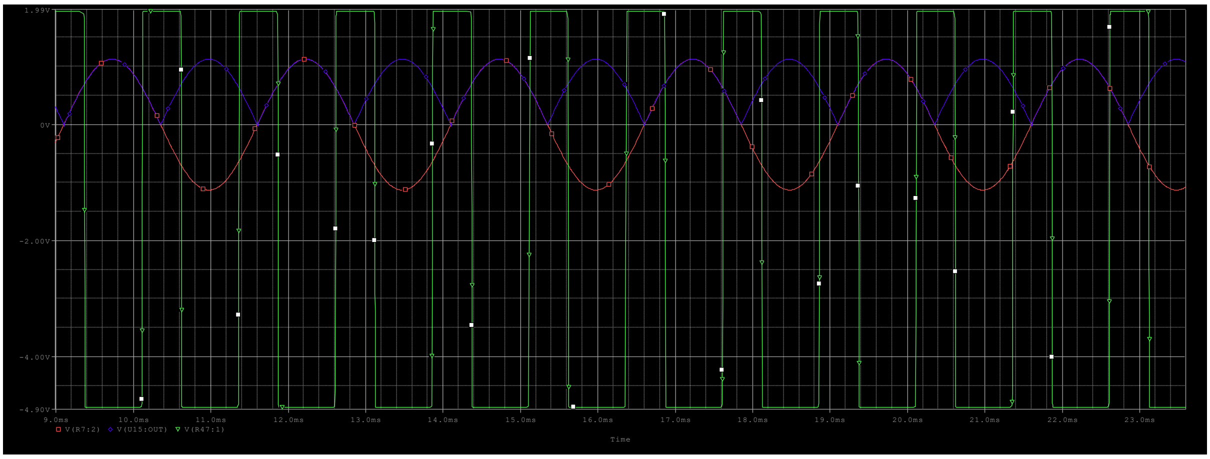

Figure 16: High channel full circuit low LED test

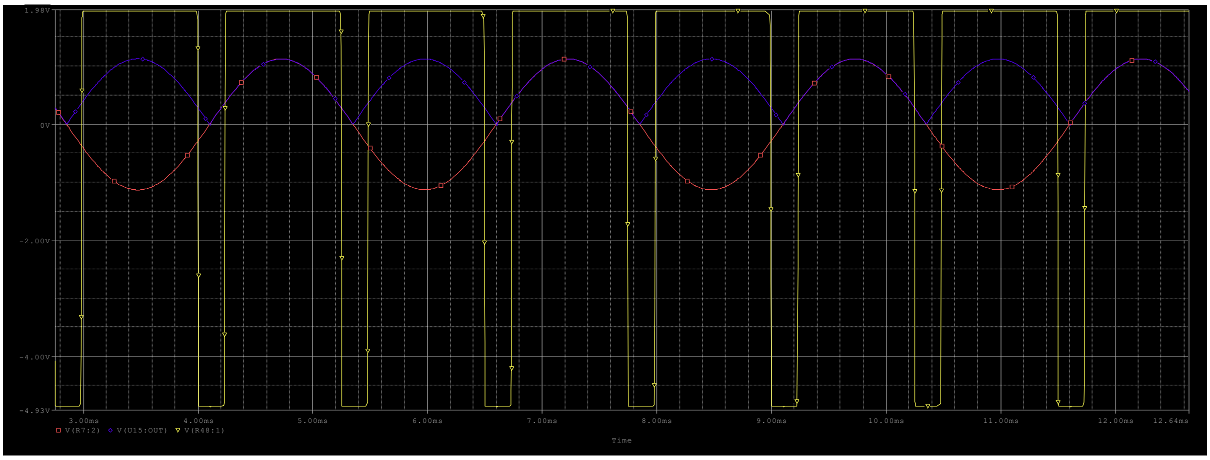

Figure 17: High channel full circuit high LED test

Bandpass channel

Figures 18 and 19 show the bandpass channel simulations of the LEDs. The green signal shows the low LED signal and the yellow signal shows the high LED signals. All channels work as expected.

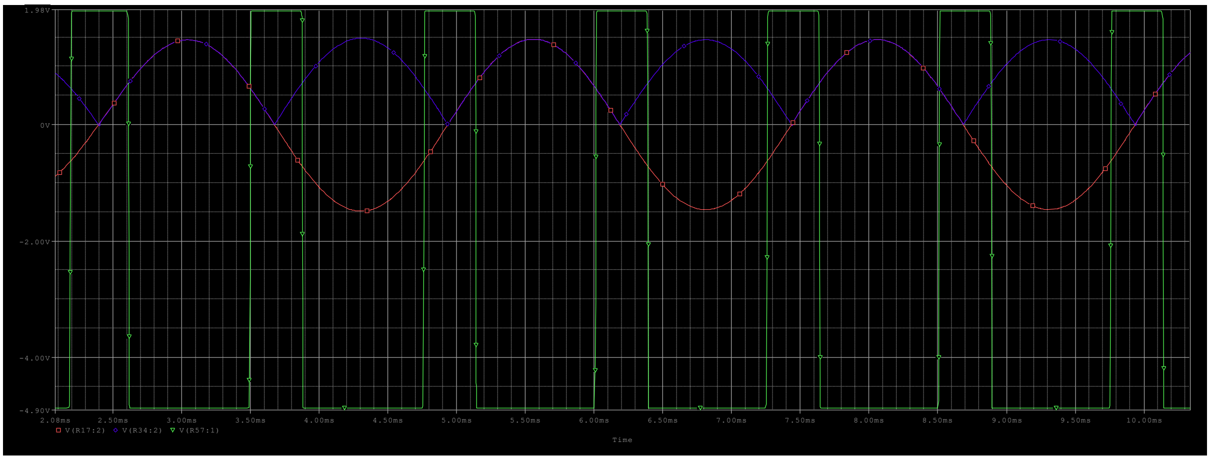

Figure 18: Band channel full circuit low LED test

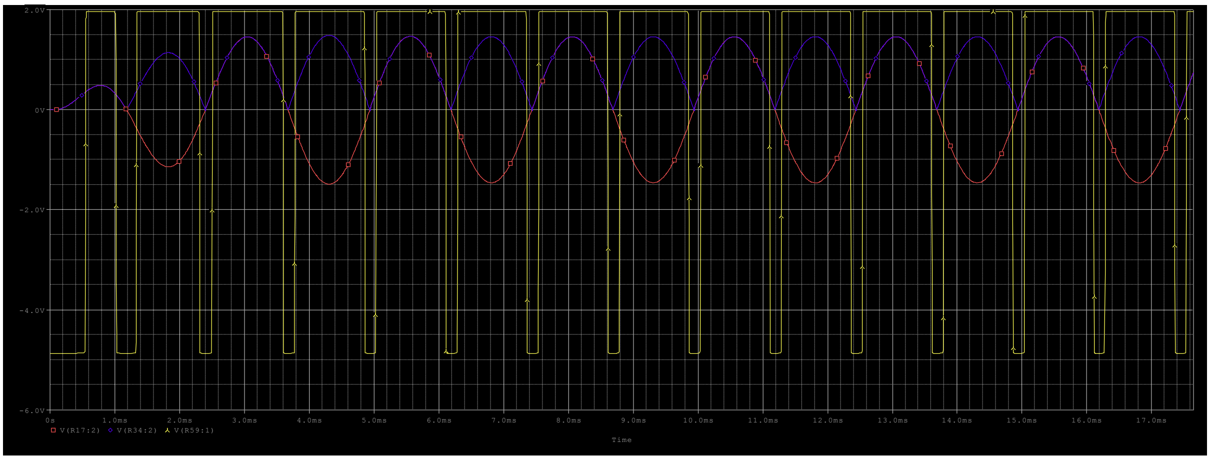

Figure 19: Band channel full circuit high LED test

Conclusion

In conclusion, all the individual circuit designs were analysed and the calculation for their components explained. All circuits were tested using OrCAD simulations and they were shown to work as predicted by the calculations. In addition to this, each individual channel of the full circuit design in figure 13 was tested and both low and high LEDs worked for all three channels as shown in figures 14 to 19.

References

[1] Precision full-wave rectifier:https://www.electronics-tutorial.net/analog-integrated-circuits/precision-rectifier/precision-full-wave-rectifier/