Measurement Report: Tone Control
PRO-Q2

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Group 1

EQ2.a
EQ2.c

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1 The objective of the measurement

The objective of the measurement is to get more insight on how the tone control functions and to determine whether the tone control meets the specifications. The measurement is also a preparation for the assessment of PRO-Q2.

2 Measurement setup

Figure 1 shows the schematic of the tone control.

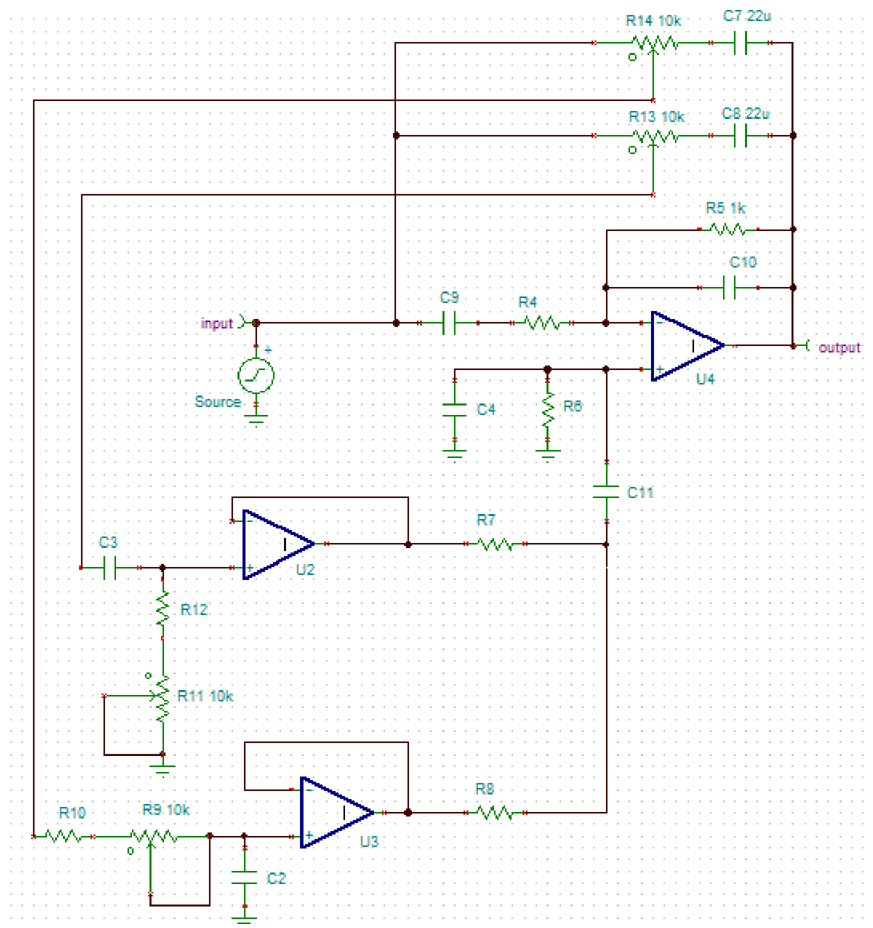

Figure 1: Tone control schematic

The schematic of the tone control in figure 1 has undergone some adjustments. The capacitors C_7 and C_8 are included and these capacitors prevent direct current flowing through the potentiometer and the wiper. Both capacitors have a value of 22uF because these values have almost no effect on the gain of the tone control and these values are available at the lab. Capacitors C_9 and C_{10} are included around opamp U_4. The capacitors C_9 and C_{10} ensure that a band-pass filter (cut-off frequencies of 2Hz and 400kHz) is obtained.

The tone control is soldered on a circuit board as seen in figure 2.

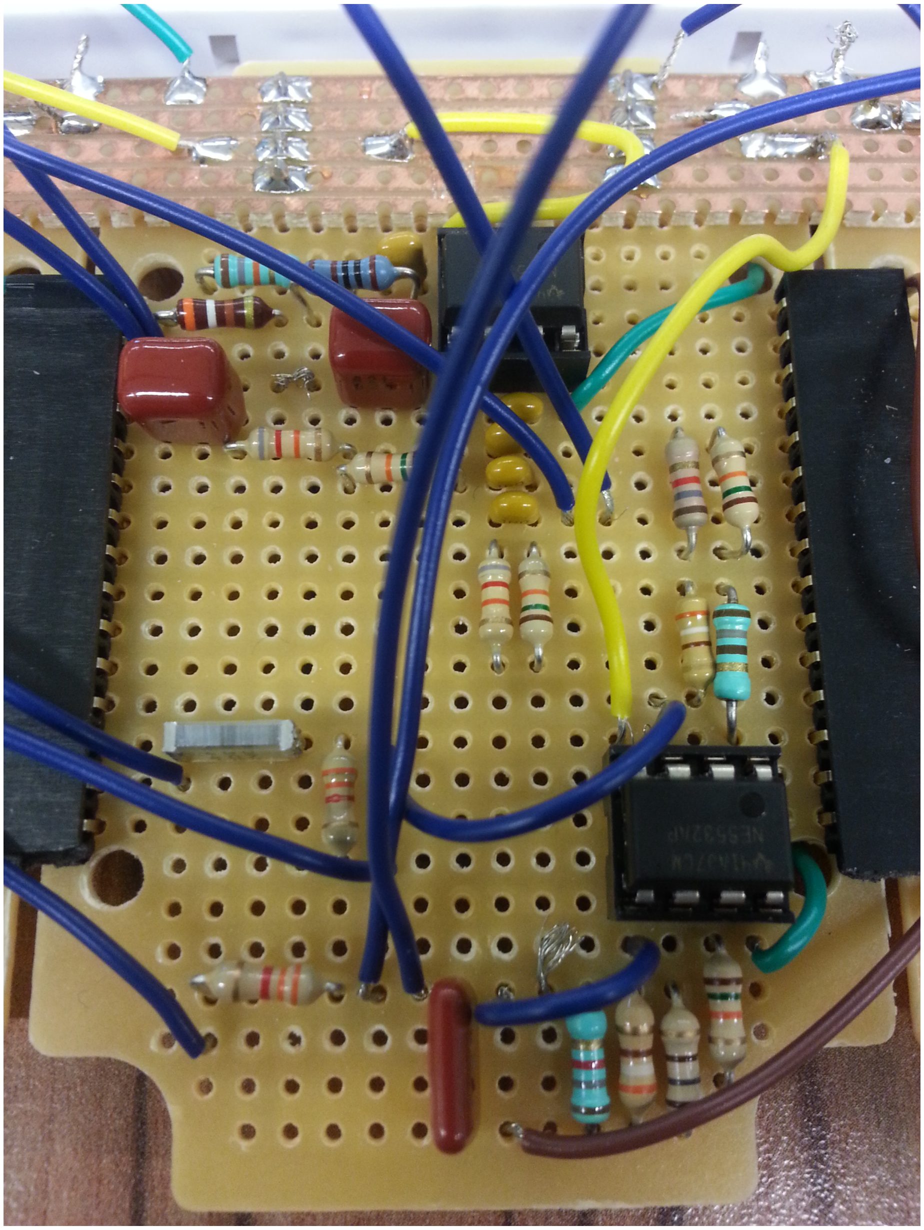

Figure 2: Tone control on a circuit board

Not all components are seen in the tone control circuit in figure 2. The potentiometers and capacitors are attached on a breadboard. With cables, the components on the breadboard are connected with the tone control on the circuit board.

The tone control is connected to the following equipment:

- The input of the tone control is connected to a function generator, 'BK PRECISION 4052'. The input signal is a sinus with an amplitude of $252mV_{\text{pk-pk}}$
- A power supply is connected to the positive (+15V) and negative (-15V) terminals of the amplifier.
- The signals 'output' and 'input' are measured by using the oscilloscope, 'TEKTRONIX DPO2004B'.

3 Results

3.1 Bass and treble control specifications

- Treble: Cut-off frequency adjustable between 2.5 and 10kHz. Maximum boost or attenuation 10dB ($\pm$1dB) at 2.5kHz. From 100kHz and up the transfer function must approach 0dB.
- Bass: Cut-off frequency adjustable between 100Hz and 400Hz. Maximum boost or attenuation 10dB ($\pm$1dB) at 400Hz. From 10Hz and below the transfer function must approach 0 dB.
- Approximate logarithmic control functions for cut-off frequencies and boost / attenuation adjustments.
- No DC currents through potentiometers nor wipers.

3.2 Calculations

The tone control contains two low-pass filters, two high-pass filters and a band-pass filters as seen in figure 3.

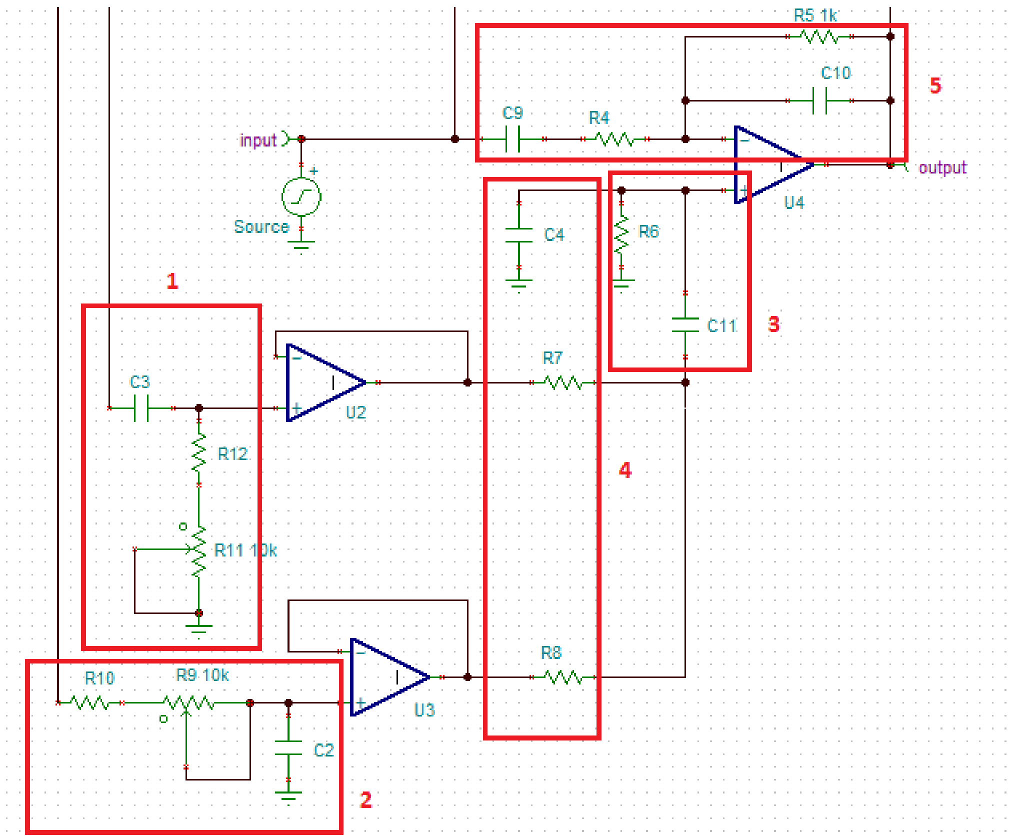

Figure 3: Tone control details

Section 1: A high-pass filter with a cut-off frequency adjustable between 2,5kHz and 10kHz

Section 2: A low-pass filter with a cut-off frequency adjustable between 100Hz and 400Hz

Section 3: A high-pass filter with a cut-off frequency of 10Hz

Section 4: A low-pass filter with a cut-off frequency of 100kHz

Section 5: A band-pass filter with a cut-off frequency of 2Hz and 400kHz

3.2.1 Section 1

At a frequency of 10kHz

$$10000 = \frac{1}{2\pi \cdot R_{12} \cdot C_3}$$

$$C_3 = \frac{1}{2\pi \cdot R_{12} \cdot 10000} \tag{1}$$

At a frequency of 2,5kHz

$$2500 = \frac{1}{2\pi \cdot (R_{12} + 10000) \cdot C_3}$$

$$C_3 = \frac{1}{2\pi \cdot (R_{12} + 10000) \cdot 2500} \tag{2}$$

Substitube (1) in (2) to calculate resistor

$$\frac{1}{2\pi \cdot R_{12} \cdot 10000} = \frac{1}{2\pi \cdot (R_{12} + 10000) \cdot C}$$

$$R_{12} = 3333.33\Omega \tag{3}$$

Substitute (3) in (1) or (2) to calculate the capacitor

$$C_3 = \frac{1}{2\pi \cdot (3333.33 + 10000) \cdot 2500} = 4,8nF \tag{4}$$

3.2.2 Section 2

At a frequency of 400Hz

$$400 = \frac{1}{2\pi \cdot R_{10} \cdot C_2}$$

$$C_2 = \frac{1}{2\pi \cdot R_{10} \cdot 400} \tag{5}$$

At a frequency of 100Hz

$$100 = \frac{1}{2\pi \cdot (R_{10} + 10000) \cdot C_2}$$

$$C_2 = \frac{1}{2\pi \cdot (R_{10} + 10000) \cdot 100} \tag{6}$$

Substitute (5) in (6) to calculate resistor

$$\frac{1}{2\pi \cdot R_{10} \cdot 400} = \frac{1}{2\pi \cdot (R_{10} + 10000) \cdot 100}$$

$$R_{10} = 3333,33\Omega \tag{7}$$

Substitute (7) in (5) or (6) to calculate the capacitor

$$C_2 = \frac{1}{2\pi \cdot (3333,33 + 10000) \cdot 2500} = 119nF \tag{8}$$

3.2.3 Section 3

The maximum value of a ceramic capacitor available in the lab at the Hague University is 820nF.

Capacitor C_{11} is decided and with a cut-off frequency of 10Hz for the HPF, the resistor R_6 can be calculated with the formula:

$$R_6 = \frac{1}{2\pi \cdot C_{11} \cdot 10}$$

$$R_6 = 19,409\Omega \tag{9}$$

3.2.4 Section 4

The maximum boost or attenuation of the bass must be 10dB at 400Hz and the maximum boost or attenuation of the treble must be 10dB at 2.5kHz.

The gain of the boost is equal to:

$$Gain_{Boost} = \frac{R_7//R_8 + R_6}{R_7//R_8}$$

$$20 \cdot log(\frac{R_7|//R + R_6}{R_7|//R}) = 10dB$$

$$\frac{R_7//R_8 + R_6}{R_7//R} = 10^{\frac{1}{2}} \tag{10}$$

The gain of the attenuation is equal to:

$$Gain_{Attenuation} = \frac{R_7//R}{R_7//R_8 + R_6}$$

$$20 \cdot log(\frac{R_7//R_8}{R_7//R_8 + R_6}) = -10dB$$

$$\frac{R_7//R_8}{R_7//R_8 + R_6} = 10^{-\frac{1}{2}} \tag{11}$$

The resistors R_6, R_7 and R_8 can be any values, as long as the values of the resistors meet the requirement for the boost to be 10dB with the potentiometer in maximum position.

It is best if R_7 is equal to R_8 because the boost and attenuation of the bass and treble will differ. R_7 and R_8can be calculated by substituting the value of R_6 in (10) or (11)

$$\frac{R_7//R_8 + 19,409}{R_7//R_8} = 10^{\frac{1}{2}}$$

$$R_7//R_8 + 19409 = 3,16 \cdot R_7//R_8$$

$$R_7//R_8 = 8,900\Omega$$

$$R_7 = R_8 = 17,800\Omega \tag{12}$$

With a cut-off frequency of 100kHz for the LPF, the capacitor C_4 can be calculated with the formula:

$$C_4 = \frac{1}{2\pi \cdot (R_7//R_8) \cdot 100 \cdot 10^3}$$

$$C_4 = 180pF \tag{13}$$

3.2.5 Section 5

The frequency range must be between 2Hz and 400kHz and the gain at these frequencies must be -3dB. Therefore the resistors and capacitors can be calculated for the band-pass filter with the formula:

$$f_{cut-off} = \frac{1}{2\pi \cdot R \cdot C} \tag{14}$$

For the design of the band-pass filter, a value of 820nF is chosen for capacitor C_9. The resistors can now be calculated.

For the HPF part of the band-pass filter is the resistor R_4 equal to:

$$R_4 = \frac{1}{2\pi \cdot 2 \cdot 820 \cdot 10^{-9}} = 97,045\Omega \tag{15}$$

The balance control and the volume control regulate the gain of the preamplifier. Therefore the band-pass filter does not need to amplify the signal. Thus it is neccessary for R_4 to be equal to $R_5$to attain a gain of 1 (0dB).

For the LPF part of the band-pass filter, the capacitor is equal to:

$$C_{10} = \frac{1}{2\pi \cdot 400 \cdot 10^3 \cdot 97,045} = 4.1pF \tag{16}$$

3.3 Simulations

The software 'Tina-TI' is used for the simulation of the tone control.

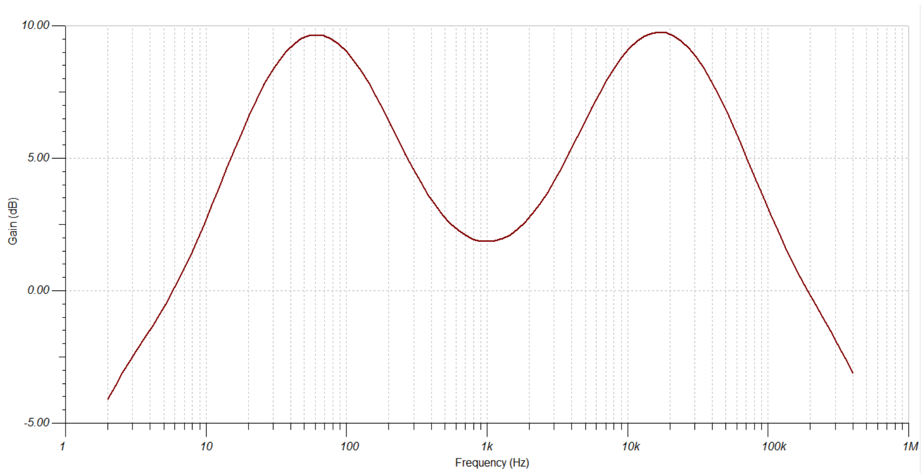

Figure 4: Simulation maximum boost

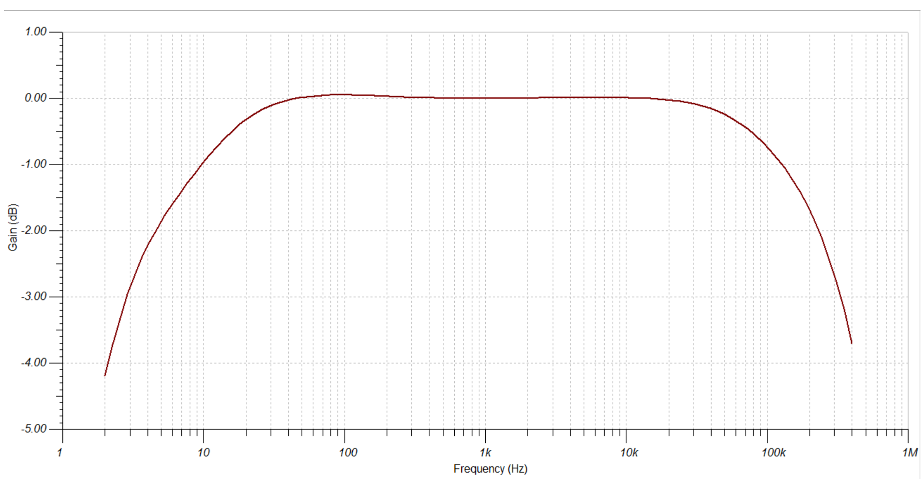

Figure 5: Simulation bass and treble off

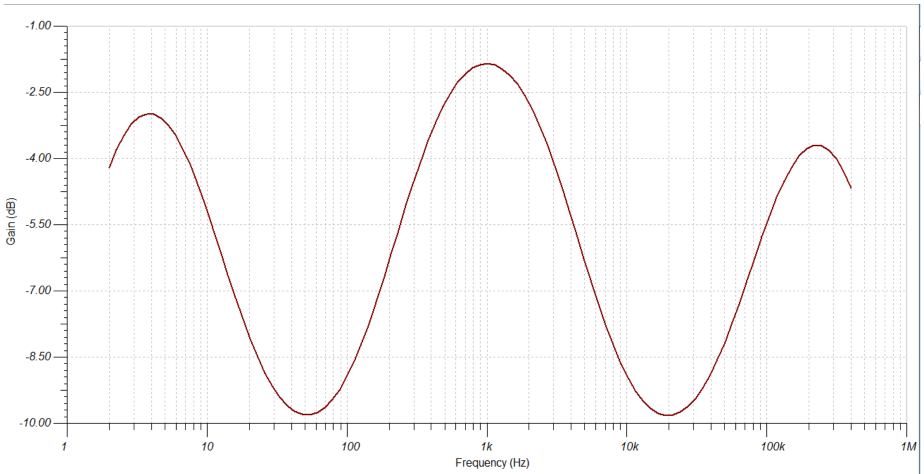

Figure 6: Simulation maximum attenuation

3.4 Measurements

The results of the measurements are in appendix.

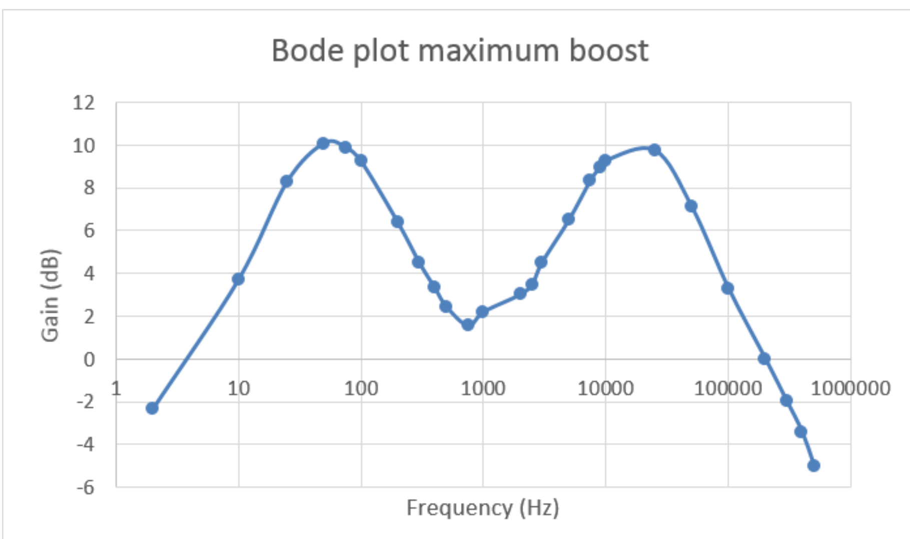

Figure 7: Simulation maximum boost

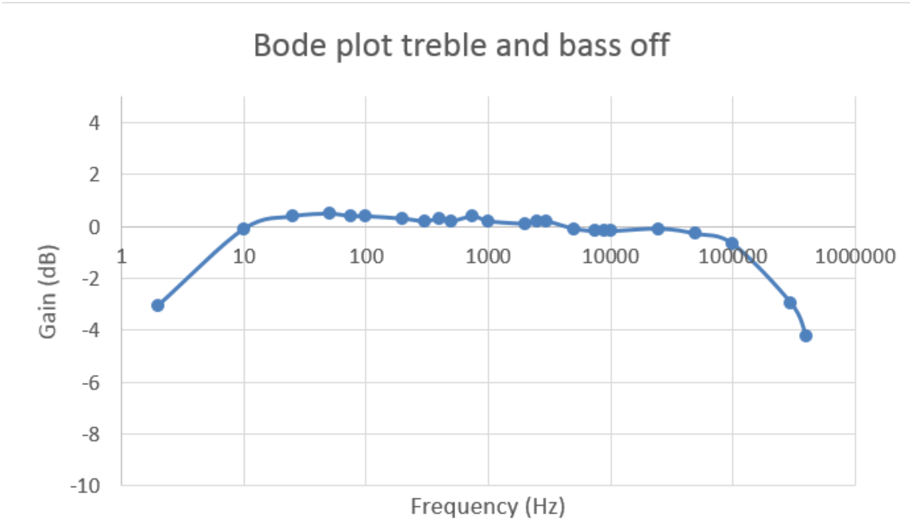

Figure 8: Simulation bass and treble off

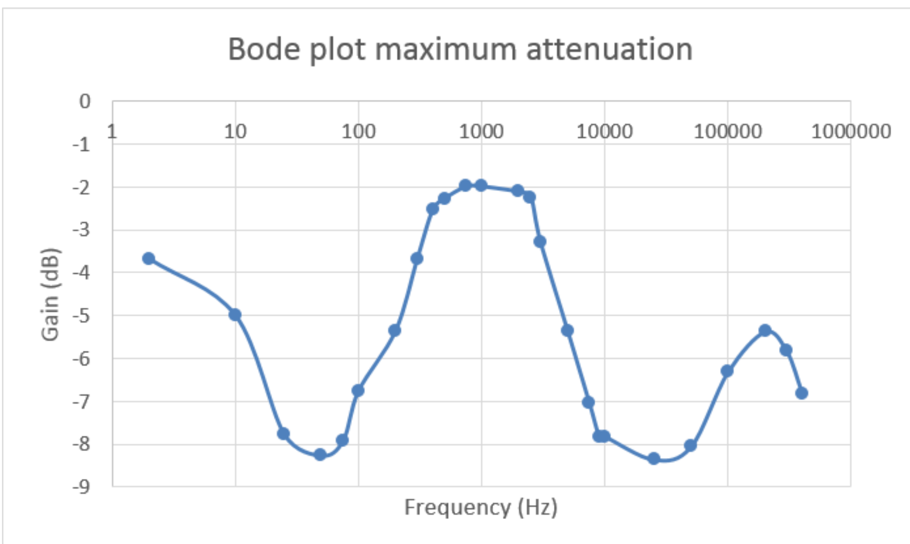

Figure 9: Simulation maximum attenuation

4 Conclusion

The bode plots of the measurement and simulation are a close match. There is however a problem with the bode plot of the measurement in maximum attenuation.

First of all the gain after the treble should rise to 0dB at around 100kHz but instead the gain rises to -6dB and then decreases. A possible reason why this occurs is because the components C_4, R_7 and R_8ensure a cut-off frequency larger than 100kHz. This means that the gain will reach 0dB at a frequency higher than 100kHz after the treble but the band-pass filter takes over at 400kHz to further decrease the gain. The tone control therefore doesn't have time to rise to 0dB before being taken over by the band-pass filter. The value of the components C_4, R_7 and R_8used for building the tone control are not the same as the ones that were calculated because the calculated components are not available in the lab. However the values of C_4, R_7 and $R_8$are chosen as close as possible to the calculated components. .

The maximum attenuation of the measurement is not 10dB but approximately 8dB.

The tone control meets the specification in 'maximum boost' and 'bass and treble off' but not in 'maximum attenuation'.

5 Appendix

Table 1: Measurements maximum boost

Frequency (Hz)	V_{in}	V_{out}	Gain (dB)
2	0.087	0.0664	-2.347023465
10	0.087	0.133	3.686647767
25	0.086	0.223	8.276128236
50	0.085	0.271	10.0710073
75	0.085	0.265	9.876538964
100	0.085	0.246	9.230323628
200	0.086	0.179	6.367091595
300	0.086	0.144	4.477280817
400	0.086	0.126	3.317441877
500	0.087	0.115	2.423571755
750	0.087	0.104	1.550281734
1,000	0.087	0.112	2.193975401
2,000	0.087	0.123	3.007717176
2,500	0.087	0.13	3.488481994
3,000	0.081	0.136	4.50107779
5,000	0.087	0.184	6.505971408
7,500	0.086	0.225	8.353681337
9,000	0.089	0.25	8.971000041
10,000	0.086	0.25	9.268831149
25,000	0.086	0.264	9.742109513
50,000	0.087	0.197	7.098939471
100,000	0.087	0.127	3.285689367
200,000	0.088	0.088	0
300,000	0.088	0.07	-1.987692643
400,000	0.089	0.06	-3.424775125
500,000	0.089	0.05	-5.008400046

Table 2: Measurements bass and treble switched off

Frequency (Hz)	V_{in} (mV)	V_{out}(mV)	Gain (dB)
2	0.088	0.062	-3.041819653
10	0.088	0.087	-0.099268391
25	0.089	0.093	0.381858838
50	0.087	0.093	0.480005528
75	0.088	0.092	0.386103104
100	0.088	0.092	0.386103104
200	0.088	0.091	0.291174403
300	0.088	0.09	0.195196746
400	0.088	0.091	0.291174403
500	0.088	0.09	0.195196746
750	0.088	0.092	0.386103104
1,000	0.088	0.09	0.195196746
2,000	0.089	0.09	0.097050056
2,500	0.088	0.09	0.195196746
3,000	0.088	0.09	0.195196746
5,000	0.09	0.089	-0.097050056
7,500	0.09	0.088	-0.195196746
9000	0.091	0.089	-0.193027714
10,000	0.09	0.088	-0.195196746
25,000	0.091	0.09	-0.095977658
50,000	0.091	0.088	-0.291174403
100,000	0.092	0.085	-0.687378033
300,000	0.093	0.066	-2.97878026
400,000	0.093	0.057	-4.252161858

Table 3: Measurements maximum attenuation

Frequency (Hz)	V_{in}(mV)	V_{out} (mV)	Gain (dB)
2	0.087	0.057	-3.672887939
10	0.087	0.049	-4.986463452
25	0.088	0.036	-7.763603428
50	0.088	0.034	-8.260075102
75	0.087	0.035	-7.909024165
100	0.087	0.04	-6.749185226
200	0.087	0.047	-5.348427894
300	0.087	0.057	-3.672887939
400	0.087	0.065	-2.53211792
500	0.087	0.067	-2.268888998
750	0.088	0.07	-1.987692643
1,000	0.088	0.07	-1.987692643
2,000	0.088	0.069	-2.112671628
2,500	0.088	0.068	-2.239475189
3,000	0.089	0.061	-3.281203433
5,000	0.089	0.048	-5.362975385
7,500	0.09	0.04	-7.043650362
9,000	0.091	0.037	-7.816793365
10,000	0.091	0.037	-7.816793365
25,000	0.089	0.034	-8.358221792
50,000	0.091	0.036	-8.054777831
100,000	0.091	0.044	-6.311774317
200,000	0.091	0.049	-5.376906246
300,000	0.092	0.047	-5.833799388
400,000	0.092	0.042	-6.810770739