AQA A-Level Electronics (2430)
ELEC6: Practical System Synthesis
Three band AF spectrum analyser

Milo Noblet
Candidate 0119
Centre 34773
Calday Grange Grammar School
NobletMA@calday.co.uk

29 March 2017

Contents

1 A: Problem Analysis & Solution Design

1.1 Problem

In audio production, the sound technician will often artificially alter the proportion of bass and treble in the mix so as to give the best sound. However, if the technician is located away from the audience the sound heard by the technician may be different to that heard by the audience. It is here where the technician's hearing alone is insufficient, and where a visual guide can be of help.

An AF (audio frequency) visualiser gives one an idea of the 'shape' of sound — the amplitudes of various frequency bands within the mix, and allows the technician to see whether the output is bass- or treble-heavy. Even a simple system indicating the levels of just two frequency bands — low and high — would be helpful.

1.2 Research

To build such a system it is necessary to determine a frequency range for 'bass' and 'treble'.

According to *'Audio Production Worktext: Concepts, Techniques and Equipment'* (D. Reese et al., 6$^{\text{th}}$ edition pub. 2009 by Elsevier, pg.32, ISBN 978-0-240-81098-0), bass frequencies are those between 20 Hz and 250 Hz, and treble frequencies are those from 4.5 kHz to 20 kHz.

teachmeaudio.com (`http://www.teachmeaudio.com/mixing/techniques/audio-spectrum`, 2017-01-08) agrees with these definitions, stating 'sub bass' to be 20 Hz - 60 Hz, and 'bass' as 60 to 250 Hz, while 'presence' spans 4 kHz to 6 kHz and 'brilliance' 6 kHz to 20 kHz.

I looked into various methods of displaying the output of such a system, and discovered that an application-specific integrated circuit for analogue voltage visualisation is the LM3914 from Texas Instruments — the datasheet for this IC is available online from Premier Farnell plc. at `http://www.farnell.com/datasheets/1692734.pdf` (2017-01-09). The LM3914 has an internal voltage reference from 1.2 V to 12 V with an internal 10-step voltage divider. This datasheet also contains information on how the IC should be connected to drive LEDs or other lights in response to an AF input.

1.3 Practical investigations

Voltage output of a mixing desk

It is necessary to have an idea of the amplitudes of the signals that the system shall be handling — hence I carried out an investigation into the voltage output of a professional mixing desk.

A sine wave of ∼10 kHz was fed into the 'line in' input of a Soundcraft mixing desk and the voltage of this signal adjusted until the VU-meter (Volume Unit) attached to the PFL (Pre-Fade Listen) output showed zero. The voltage of the PFL output was then measured using a storage oscilloscope.

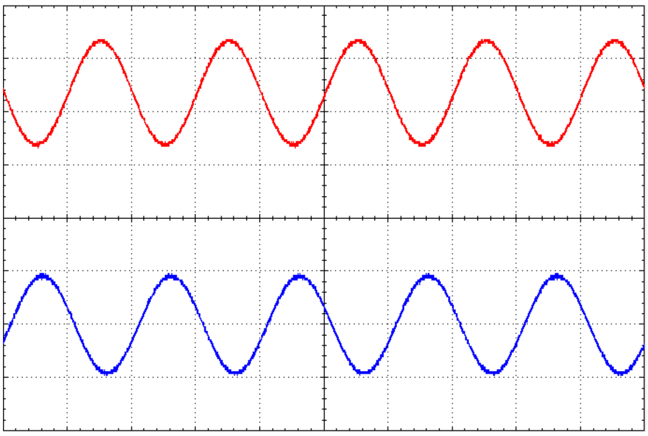


Figure 1: Oscillscope display of input (red, top) and output (blue, bottom) of a mixing desk.
500 mV/div, 50 μs/div

Measurements from the oscilloscope trace:

- Input — Frequency: 9.99 kHz, V_{PK-PK}: 1.18 V
- Output — Frequency: 9.99 kHz, V_{PK-PK}: 960 mV

Current consumption of LM3914 IC

An efficient way of displaying the output of my system is through the use of an LM391x family integrated circuit, which can drive ten LEDs or other indicator lamps in response to a varying voltage input. To check if such an IC would be suitable for my system, I set up an LM3914 driving ten LEDs and recorded the current consumption with no LEDs on, and with all ten LEDs on. As the LM3914, LM3915 and LM3916 all have similar internal circuitry, one can presume that they will have near-identical operating characteristics.

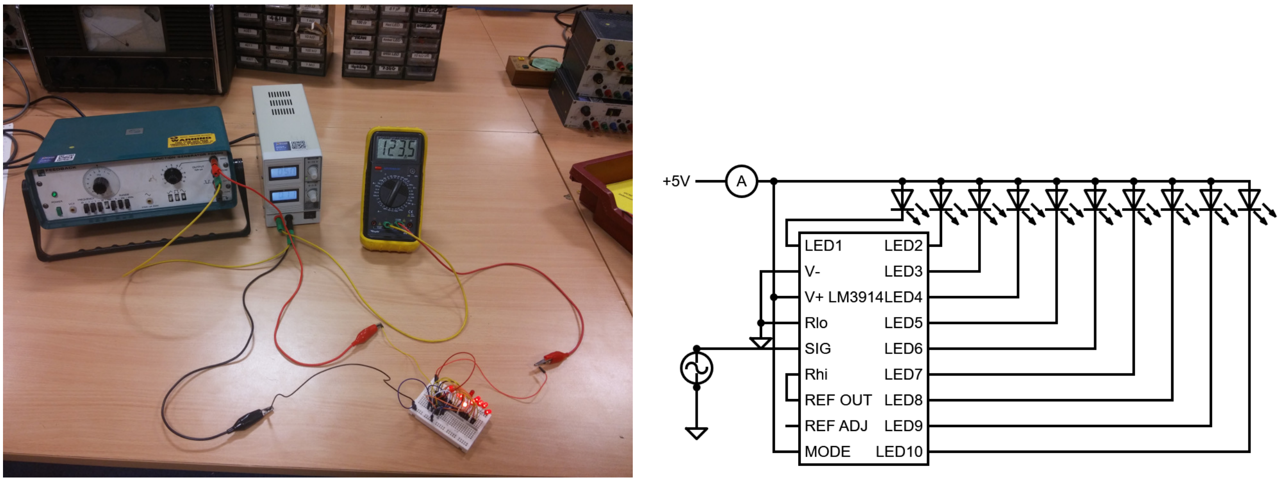


Figure 2: Measuring current draw of an LM3914 driving 10 LEDs

I found the maximum current consumption to be 124 mA with all ten LEDs lit - however, with the circuit still powered but an input signal of 0 V (resulting in no LEDs being lit) the measured current consumption was negligible.

1.4 Specification

The system will be powered from USB ports such as those commonly found on professional mixing desks. As such, the system must comply with the power requirements of the USB 2.0 specification. These state:

- A voltage of $\pm 5.00^{+0.25}_{-0.60}$ V
- A maximum current draw of 500 mA (high power device)

In addition, as my system is to display in discrete form the levels of bass frequencies, mid frequencies and treble frequencies, the filters used must have cutoff frequencies matching those identified in my research:

- Bass filter: cutoff at 250 Hz $\pm$ 25.0 Hz
- Mid filter: lower cutoff at 250 Hz $\pm$ 25.0 Hz, higher cutoff at 4.50 kHz $\pm$ 450 Hz
- Treble filter: cutoff at 4.50 kHz $\pm$ 450 Hz

1.5 Alternative solutions

One option for the system would be the use of a microcontroller such as a PIC or Arduino, combined with an analogue-to-digital converter and driving an LCD display. This would allow for a much greater resolution — a 320×240 display could potentially display 320 different frequency bands — but this would increase current consumption as well as component cost.

Feasibly, the system could output to a 7-segment display, indicating amplitude from 0 to 9 for each channel, or could even use analogue meters. While both of these have their merits in terms of clarity, I determined that a row of LEDs was more intuitive, and much easier to see in a dark environment such as at a concert.

To convert the voltage output into a visual output through the LEDs I could use multiple op-amps in comparator configuration. However, for the resolution I would like (ten steps) this would need ten op-amps per frequency band — thirty in total. The LM3914 integrated circuit available from both National Semiconductor & Texas Instruments operates LEDs or other lamps to indicate the magnitude of an analogue signal — giving a ten-step output, and also takes care of current regulation of the LEDs. Using this IC rather than individual op-amp comparators will massively reduce the complexity, component count, and cost of my final system.

2 B: System Development

2.1 Risk assessment

Risk	Action taken to mitigate
Electric shock	Use only insulated cables and probes. Ensure mains-connected equipment conforms to PAT requirements — perform a visual inspection prior to use, checking for split insulation or fraying.
Injury to the eye	When stripping wire, do so in a downward motion to avoid offcuts flying and causing injury.
Injury from sharp or pointed tools	Exercise caution when using tools.
Release of noxious fumes from components under fault conditions	Ensure components are correctly connected, observing polarity and voltage limitations. Workspace should be sufficiently ventilated to avoid fumes becoming an issue.
Damage to components, power supplies or other test equipment	Ensure components correctly connected. All equipment must be fitted with an appropriate fuse. Power supplies should be switched off whilst adjusting the circuit so that a momentary short will not cause damage. Power supply settings should be checked before connection to the circuit to avoid potential damage from excessive voltage.

Table 1: Assessment of risks

2.2 Stereo to mono conversion

Most music tends to be recorded in stereo — thus it is necessary to combine the left and right channels of the audio source so that no information is missed. I elected to do this using a summing amplifier. By having a voltage gain of $\frac{1}{2}$, the output should be approximately the same voltage as either channel of the stereo input. Using $G_V = -\frac{R_f}{R_{in}}$ I determined that using a feedback resistor of 10 kΩ and input resistors of 20 kΩ for each channel should give the desired effect.
I confirmed this by sending a ∼1 kHz test signal through both one input to the summing amplifier, and also both inputs to the summing amplifier, measuring the input and output voltage using an oscilloscope.

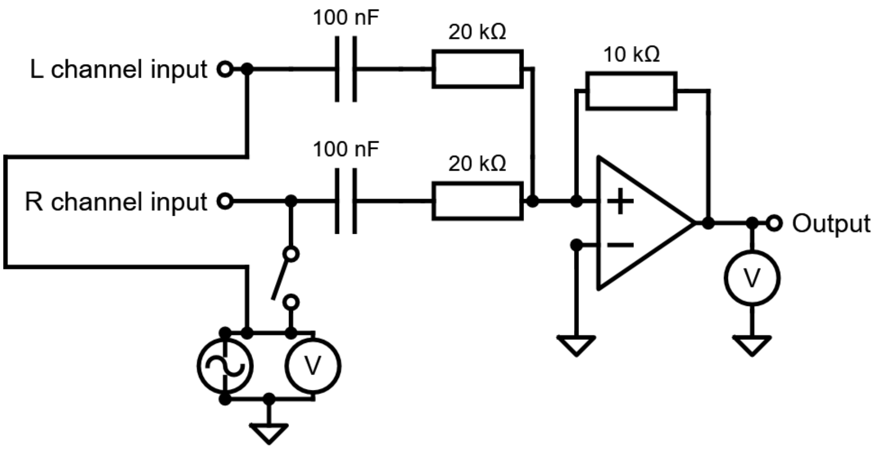


Figure 3: Testing the input summing amplifier
(switch represents connecting one channel vs connecting both)

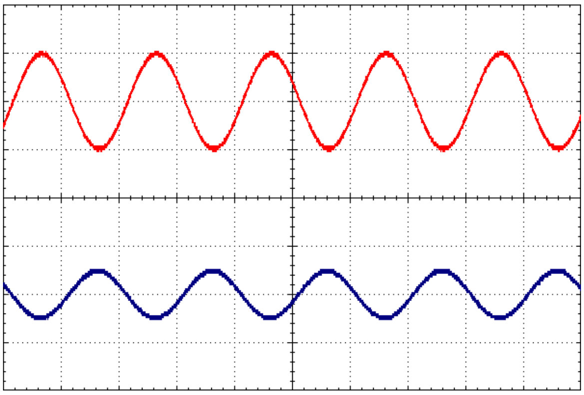


Figure 4: Test signal fed to one input only

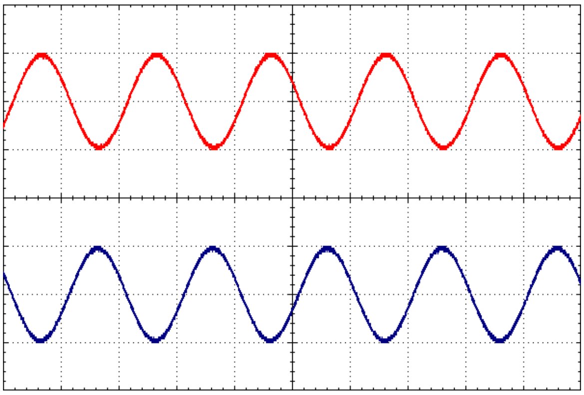


Figure 5: Test signal fed to both inputs

500 μs/div, 500 mV/div
Red (top) input, blue (bottom) output

2.3 Filters

In order for my system to function as desired, I require three filters: a low-pass (treble cut) filter, band-pass filter, and high-pass (bass cut) filter.

$$f_0 = \frac{1}{2\pi RC}$$

$$\text{For } f_0 \text{ of 250 Hz: } R = \frac{1}{2\pi \times 100 \cdot 10^{-9} \times 250} = 6.37 \text{ k}\Omega$$

$$\text{For } f_0 \text{ of 4.50 kHz: } R = \frac{1}{2\pi \times 100 \cdot 10^{-9} \times 4.5 \cdot 10^3} = 354\ \Omega$$

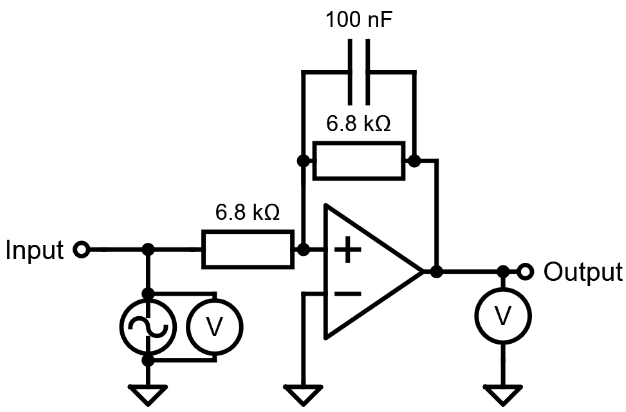


Figure 6: Testing the treble-cut filter

The 'breakpoint' or 'cutoff' frequency of a filter is defined by the frequency at which the power through the system is attenuated by half — or 3 dB. Hence on the graphs of frequency response, there are dotted lines at -3 dB and at the desired cutoff frequency, as well as having marked on the tolerance either side. It can be seen that for all three filters, the line of their frequency response passes through the -3 dB mark within the specified tolerances.

The frequency response graph in Figure 7 was obtained using a digital storage oscilloscope measuring the frequency and voltage of a test signal from a function generator, the frequency of which was varied, and the voltage of the output from the filter subsystem as seen in Figure 6. Knowing V_{in} and V_{out} with the corresponding frequency allows a graph of frequency response to be drawn.

$$\text{Gain in dB} = 20 \log_{10}(\frac{V_{out}}{V_{in}})$$

f (Hz)	Gain (dB)	f (Hz)	Gain (dB)	f (Hz)	Gain (dB)
19.4	-0.247008768	249	-3.14246840	493	-7.269525681
82	-0.560574472	261	-3.368088608	526	-7.635301396
105	-0.812357018	285	-3.717903251	551	-8.017160234
129	-1.248925768	298	-3.959193479	577	-8.416581852
138	-1.248925768	316	-4.334182199	641	-9.052418541
152	-1.164123683	329	-4.462864399	743	-10.45757491
165	-1.708603906	342	-4.726093321	830	-11.24774573
177	-1.996560321	369	-5.136526663	900	-11.81751649
194	-2.193975401	379	-5.421335446	1005	-12.99841214
211	-2.498774732	402	-5.715800582	2319	-19.81319947
225	-2.814660076	435	-6.417284813	5931	-26.02059991
232	-2.814660076	453	-6.664293581	7477	-29.17275698
242	-3.031818628	476	-7.004960367	9950	-31.67153171

Table 2: Readings for Figure 7

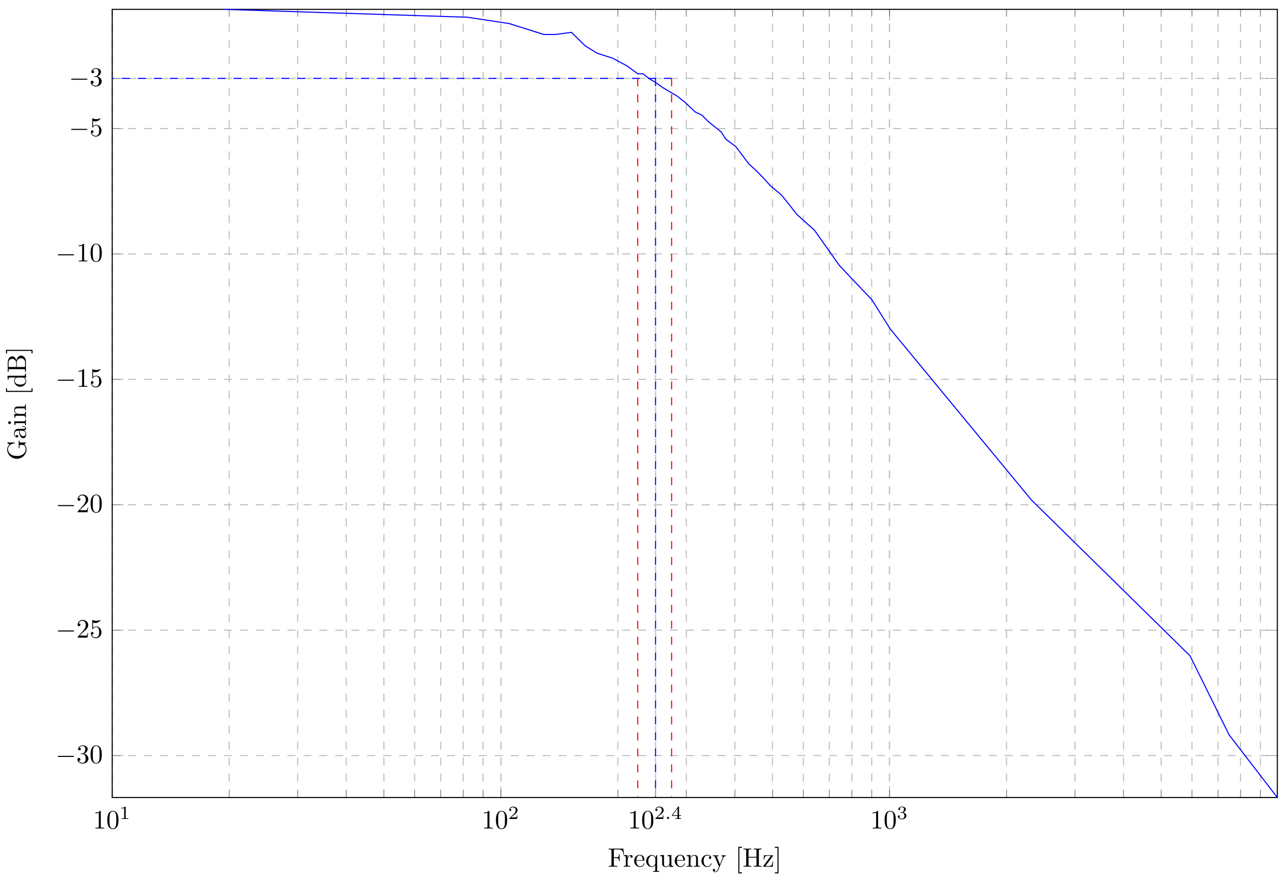


Figure 7: Frequency response of treble-cut filter

2.4 Interfacing issues

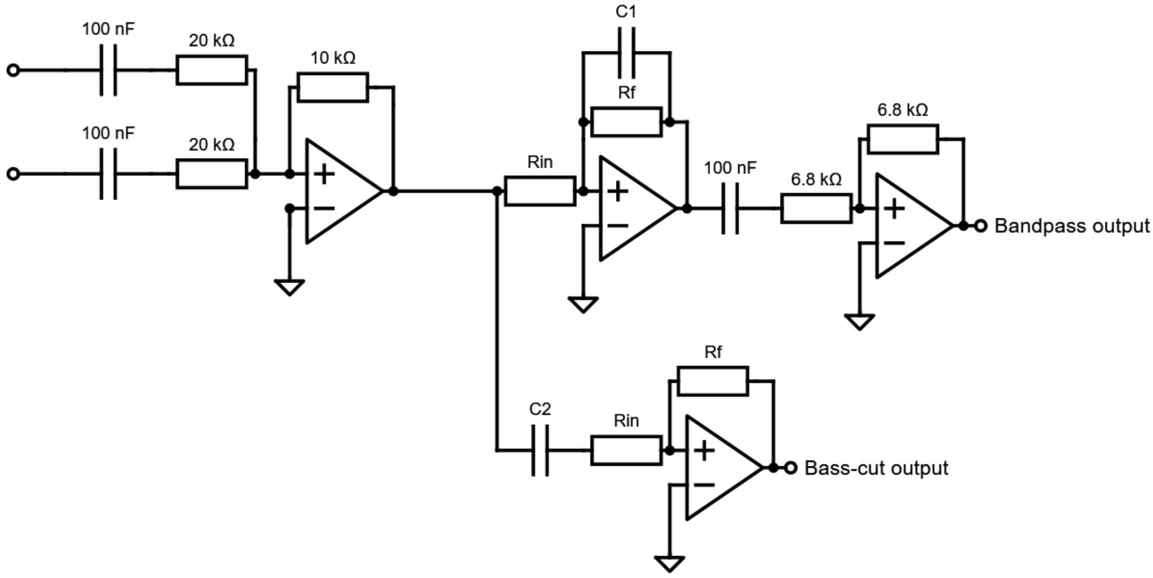


Figure 8: Band-pass and bass-cut filters

I noticed that when interfacing the output of the stereo-to-mono summing amplifier and the bandpass and bass-cut filters (see Figure 8) that there was a 'loading' effect: a large voltage drop compared to the signal source. I realised that this was due to a high current draw from the filters themselves, and had resulted from values for R_{in} and R_f that were too small — 330 Ω. The issue was resolved by using 3.3 kΩ resistors instead and dropping C_1 and C_2 from 0.1 μF to 0.01 μF (so as to maintain the same cutoff frequency).

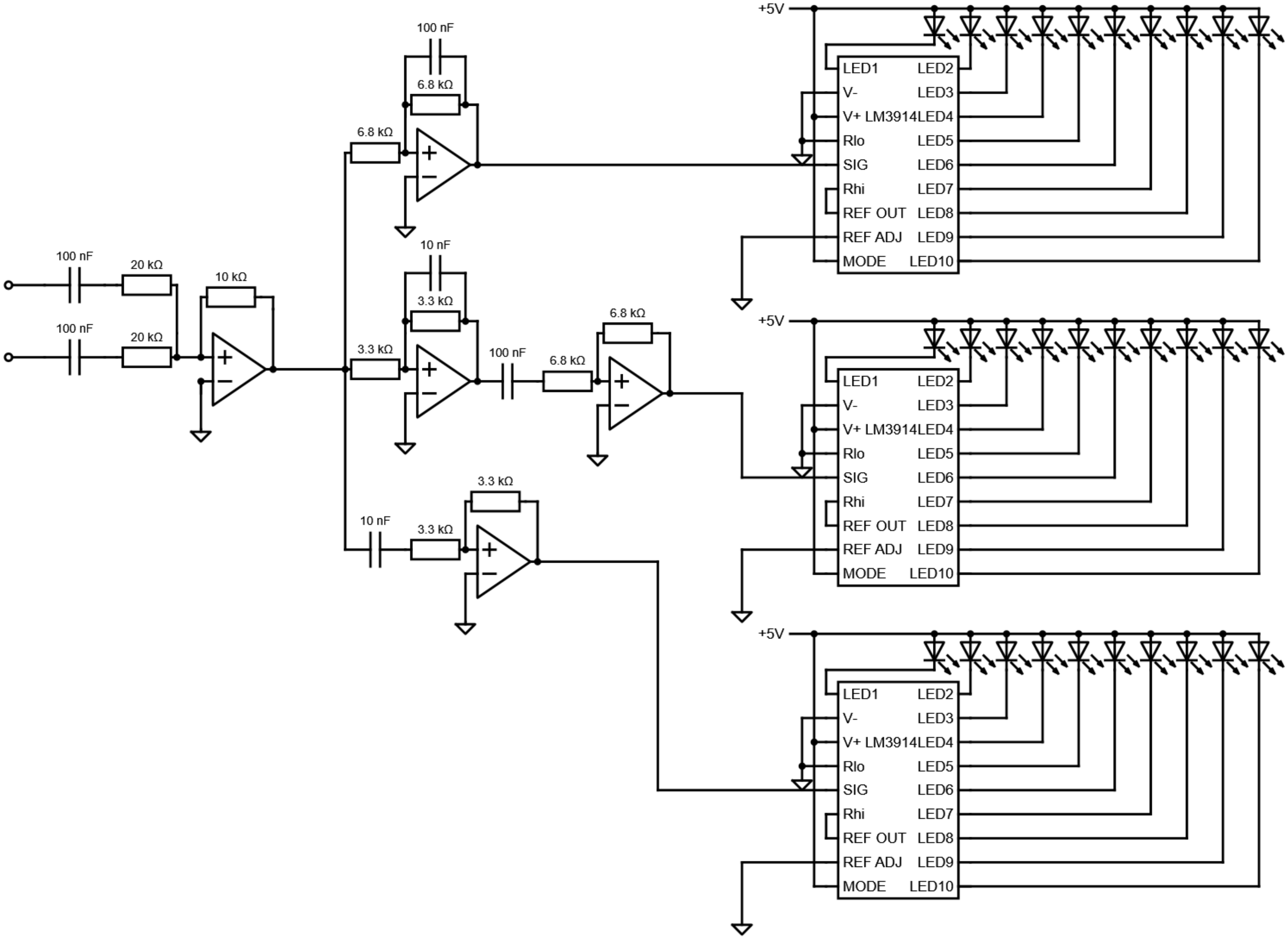


Figure 9: Circuit diagram

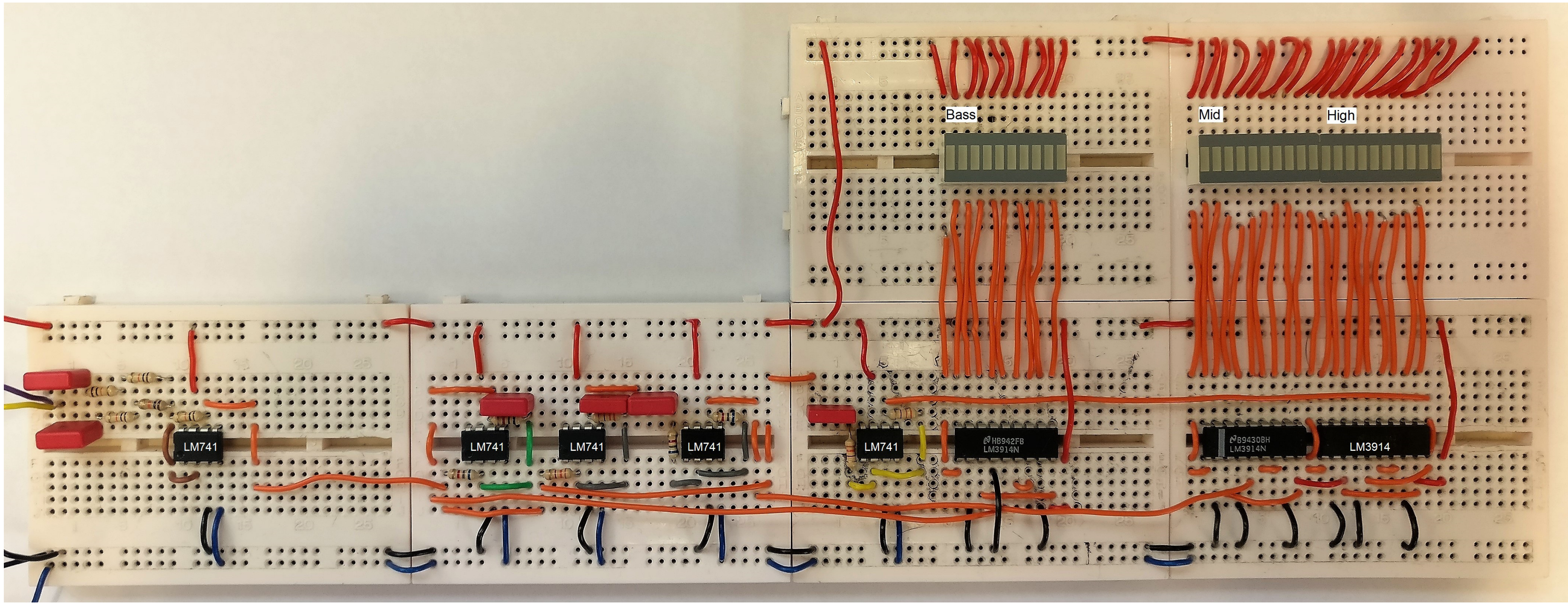


Figure 10: Photograph of built system

2.5 Description of system function

A summing amplifier is used to convert a stereo input from a mixing desk to mono. The output of this summing amplifier then splits and is fed to three filter subsystems. These are active filters with unity gain, giving the advantage of the low-impedance output of op-amps. These three filter subsystems consist of a low-pass filter (treble cut), a bandpass filter (made from a cascaded low-pass and high-pass filter to obtain a unity gain), and a high-pass filter (bass cut).

Each filter subsystem then feeds an LM3914 IC, which drives a ten LED array so as to represent the amplitude of each frequency band visually. For example, the low-pass filter attenuates frequencies above 250 Hz, giving an effectively bass-only output which feeds the SIG input of an LM3914 IC set to the minimum reference voltage of 1.2 V. This is done by taking REF ADJ along with RLO, the lower end of the resistor network, to 0 V, and RHI to REF OUT. The MODE pin is set high so that the 3914 gives a bar-graph style output rather than a dot output as this was easier to see in practice. This is repeated for the mid frequency and high-frequency outputs.

3 C: Testing

A testing phase is necessary to ensure that the specification in subsection 1.4 has been met.

3.1 Plan of testing

Power requirements

- Functionality throughout the specified voltage range ($\pm 5.00^{+0.25}_{-0.60}$ V) will be checked by setting the power supply to the necessary voltage and confirming this with a digital multimeter. The increased in voltage is just 0.25 V, which is within the tolerance of all components used — hence there is little risk of damage occurring during this test. The digital multimeter that I intend to use is accurate to three significant figures for this voltage range.
- Current consumption can be measured by inserting a suitably rated ammeter in series in the positive power connection. Current should first be measured using the 10 A range, ensuring it is safe to move to a lower range. The meter I intend to use here gives up to four significant figures of accuracy.

Frequency range requirements

- Compliance with the cutoff frequency requirements for the filter subsystems can be verified by passing a test signal from a function generator through each subsystem, using a digital storage oscilloscope to measure V_{in} and V_{out} with the corresponding frequency. A graph of frequency response can then be drawn for each filter, on which the cutoff frequency can be verified. The digital storage oscilloscope used, an Owon PDS5022S, gave values for frequency and voltage to four significant figures — a reasonable degree of accuracy.

3.2 Results of testing

Filters

Having already found the frequency response of just the treble-cut filter in my system as part of subsection 2.3, I went on to do the same for my bandpass and bass-cut filters. These graphs are drawn by plotting gain in dB, given by $20\log_{10}(\frac{V_{out}}{V_{in}})$, against f for a range of frequencies. As can be seen in Figures 7, 12 and 11 the cutoff frequencies for each filter subsystem are within the specified tolerance.

f (Hz)	Gain (dB)	f (Hz)	Gain (dB)	f (Hz)	Gain (dB)
19.4	-0.247008768	249	-3.14246840	493	-7.269525681
82	-0.560574472	261	-3.368088608	526	-7.635301396
105	-0.812357018	285	-3.717903251	551	-8.017160234
129	-1.248925768	298	-3.959193479	577	-8.416581852
138	-1.248925768	316	-4.334182199	641	-9.052418541
152	-1.164123683	329	-4.462864399	743	-10.45757491
165	-1.708603906	342	-4.726093321	830	-11.24774573
177	-1.996560321	369	-5.136526663	900	-11.81751649
194	-2.193975401	379	-5.421335446	1005	-12.99841214
211	-2.498774732	402	-5.715800582	2319	-19.81319947
225	-2.814660076	435	-6.417284813	5931	-26.02059991
232	-2.814660076	453	-6.664293581	7477	-29.17275698
242	-3.031818628	476	-7.004960367	9950	-31.67153171

Table 2: Readings for Figure 7 (treble-cut filter)

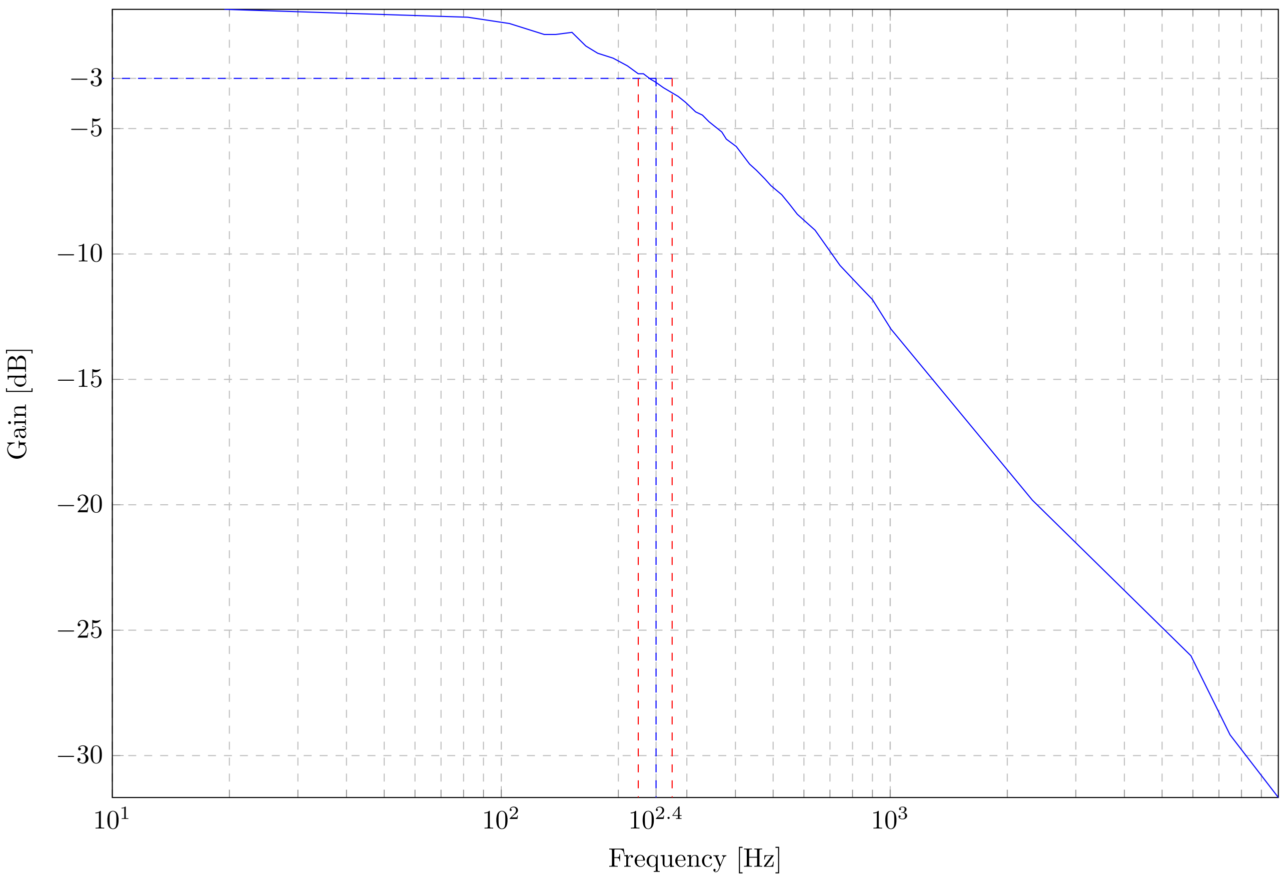


Figure 7: Frequency response of treble-cut filter

f (Hz)	Gain (dB)	f (Hz)	Gain (dB)	f (Hz)	Gain (dB)
65	-33.28415796	4500	-3.342728328	10420	-0.972106669
492	-19.71519122	4552	-3.25454595	13640	-0.74648646
997	-13.76133283	4703	-3.167249842	15940	-0.537442928
1800	-9.161532482	4790	-3.080822366	17500	-0.427261032
3700	-4.436974992	5495	-2.509011492	50220	-0.251782546
4000	-3.857701074	5950	-2.434671935	71620	-0.399004539
4270	-3.431815157	7979	-1.695787607	85040	-0.399004539
4380	-3.431815157	10000	-1.217298176		

Table 3: Readings for Figure 11 (bass-cut filter)

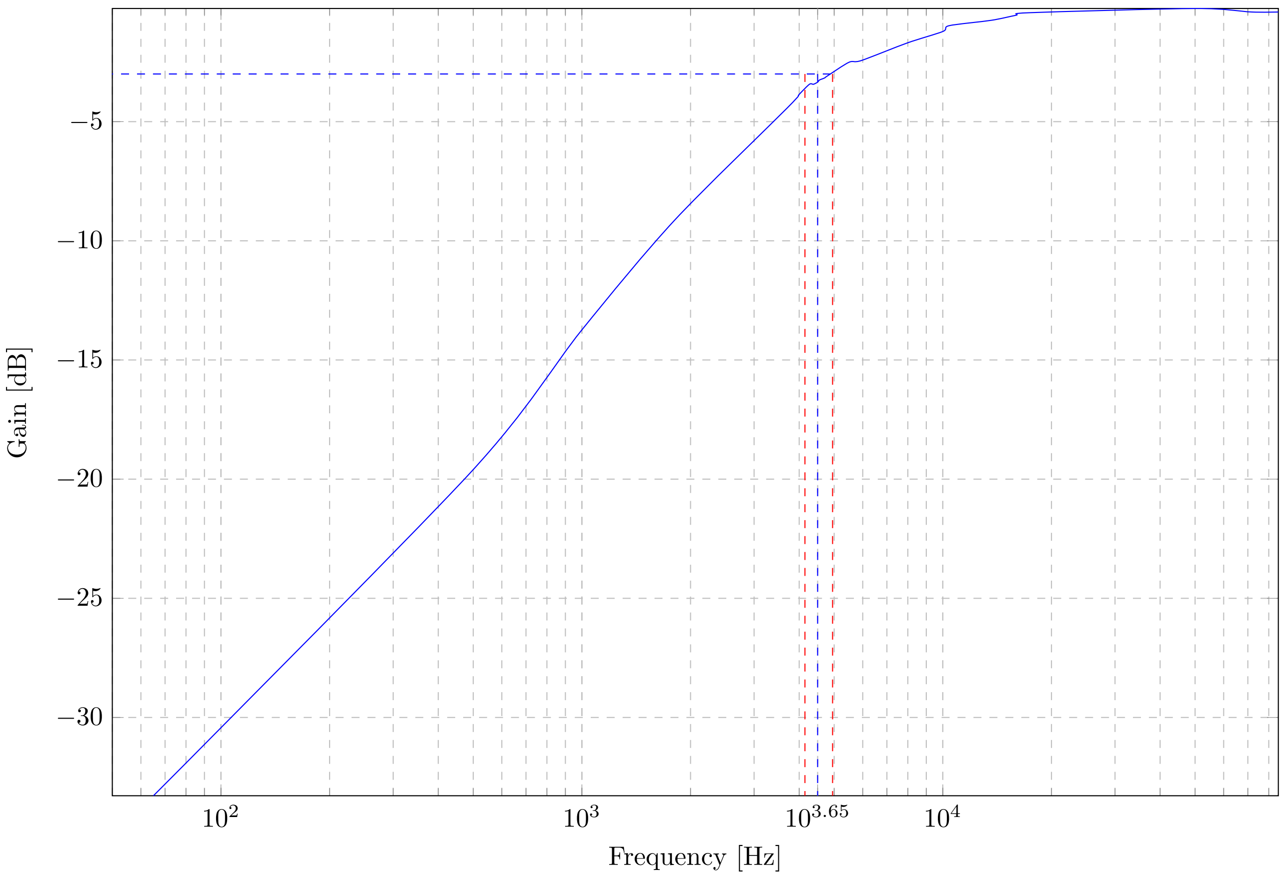


Figure 11: Frequency response of bass-cut filter

f (Hz)	Gain (dB)	f (Hz)	Gain (dB)	f (Hz)	Gain (dB)
19.4	-18.77892069	351	-1.93820026	4314	-2.871240685
59	-11.67670342	594	-0.89762026	4496	-2.961250709
81.5	-9.573501656	1242	-0.462475977	4705	-3.144118298
141	-5.775910785	1597	-0.66847511	4818	-3.330918823
178	-4.540998866	1825	-0.748529959	5011	-3.330918823
197	-3.87640052	2350	-1.182429042	5298	-3.717021927
224	-3.211581858	2620	-1.402336728	5883	-4.146979056
232.5	-3.120629303	2996	-1.622314916	6900	-4.990403524
249.8	-3.009856822	3330	-1.858145411	9930	-7.189635137
266	-2.750557278	3713	-2.266008584	23830	-14.14175789
283	-2.581893928	4052	-2.60667537		
315	-2.017524005	4141	-2.60667537		

Table 4: Readings for Figure 12 (bandpass filter)

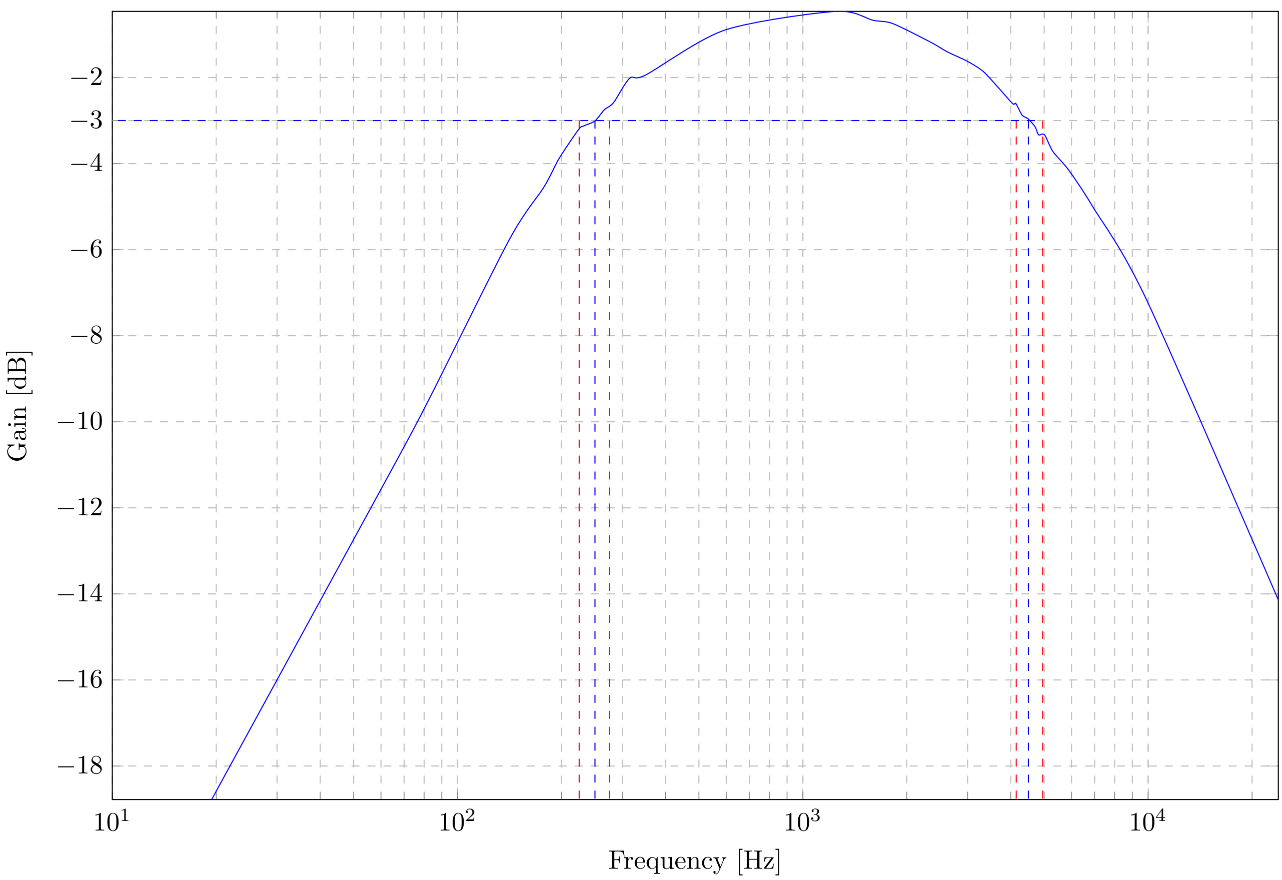
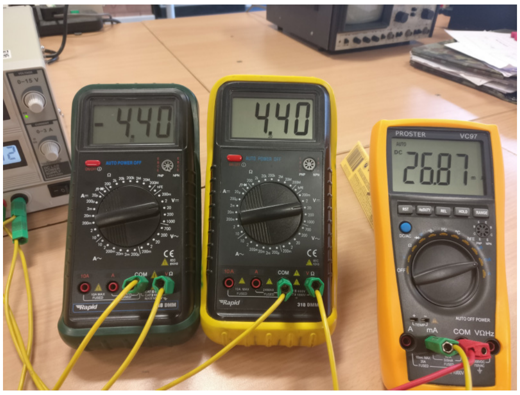


Figure 12: Frequency response of bandpass filter

Power



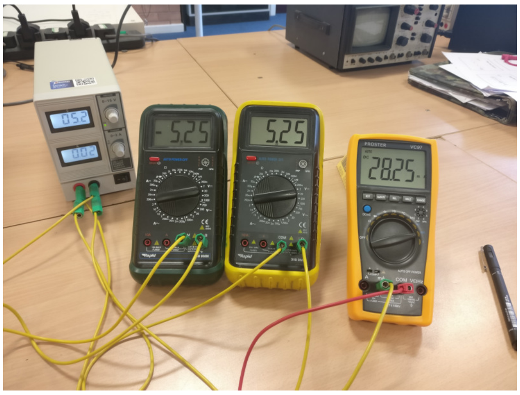
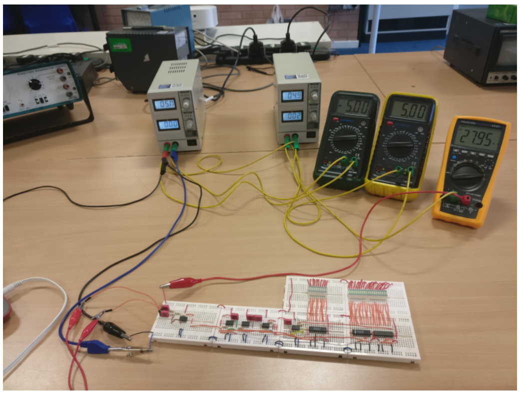


Figure 13: Testing functionality in the specified voltage range
(meters showing voltage, voltage and current from left to right)

The system was confirmed to function satisfactorily at both the upper and lower end of the specified voltage range (Figure 13).



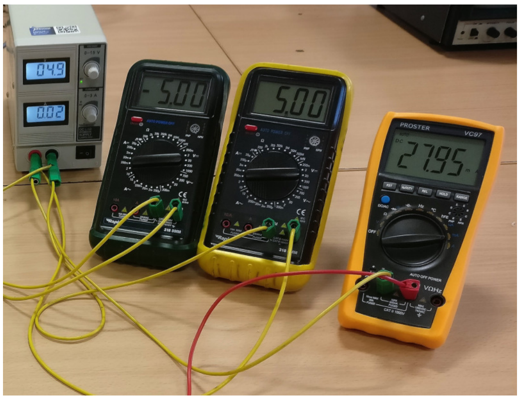


Figure 14: Measuring current draw of the final system alongside supply voltage

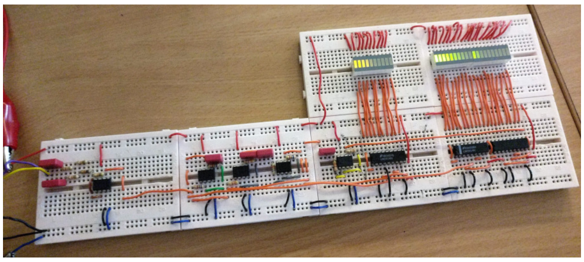
As can be seen in Figure 14 the current draw of the system with all LEDs lit was 28.0 mA. With all LEDs off (ie no input signal), the current consumption was negligible.

Testing conclusion

All measured parameters were within the tolerances and limits set by the specification in subsection 1.4, hence the specification has been met. There are no limitations.

3.3 System functionality

Functionality of the system was confirmed by supervisor C. Mottram on 2 March 2017.



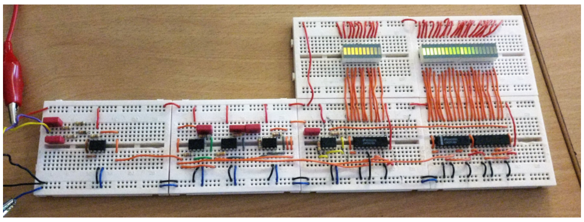


Figure 15: Playing music through the system
The left bar graph shows bass, centre mid frequencies and the right bar graph shows treble frequencies

4 D: Evaluation & Report

4.1 Evaluation against the initial specification

Specification criteria	Meets specification?	Remarks
Supply voltage of $\pm 5.00^{+0.25}_{-0.60}$ V	Yes	The system was tested at the upper and lower end of the range given in section 3.2 and functioned satisfactorily throughout
Maximum current draw of 500 mA	Yes	Current consumption was measured at 28.0 mA (Figure 14), which is below the maximum set.
A cutoff frequency of 250 Hz ± 25.0 Hz for the treble-cut filter	Yes	See Figure 7
A pass-band of 250 Hz ± 25.0 Hz to 4.50 kHz ± 450 Hz for the bandpass filter	Yes	See Figure 12
A cutoff frequency of 4.50 kHz ± 450 Hz for the bass-cut filter	Yes	See Figure 11

Table 5: Comparison with specification

Having tested my system with both music and individual frequencies, it provides clear insight into the magnitude of the various frequency bands within the audio. Thanks to the use of LEDs, it is easy to see in a darkened room (such as a sound pit for a performance), and can inform the decisions of a sound engineer.

The current consumption of the system, at 28.0 mA, is well below the limit set in the specification — this is thanks to the use of low-power LED bar-graph displays, the internal current regulation of the LM3914 integrated circuit, and also that the LEDs themselves are in fact flashing very quickly (but this is not noticeable by the human eye thanks to the persistence of vision effect).

4.2 Bibliography

1. *'Audio Production Worktext: Concepts, Techniques and Equipment'* (D. Reese et al., 6th edition pub. 2009 by Elsevier, pg.32, ISBN 978-0-240-81098-0)
2. teachmeaudio.com (`http://www.teachmeaudio.com/mixing/techniques/audio-spectrum`, 2017-01-08)
3. LM3914 datasheet (`http://www.farnell.com/datasheets/1692734.pdf`, 2017-01-09)
4. 'Special Construction Feature: Using the LM3914-6 L.E.D. Bargraph Drivers', R. Haigh, *Everyday Practical Electronics* magazine, February 2001.

List of Figures

List of Tables