EE1L1 IP-1 Project Booming Bass System

Report Power Supply

Subroup B2.2

TU Delft

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by

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Contents

1 Introduction

This group is responsible for making the power supply of the booming bass system. This is an essential part of the booming bass system. This components convert the $17\mathrm{V}$ AC (RMS) from the power socket to the DC voltage that is needed. The requirements for this output voltage are:

- A DC voltage of $\pm 20 - 22\mathrm{V}$ unloaded and a DC voltage of $\pm 17 - 20\mathrm{V}$ at a load current of $1\mathrm{A}$;
- Maximum of 5% ripple;
- Staying within a maximum discharge time of 150 seconds;
- If other considerations are met, efficiency.

With ripple is meant the deviation of the voltage wave compared to the average voltage. The circuit will still store energy in its capacitors when the circuit is turned off, so this power needs to be dissipated to avoid dangerous circumstances. All energy needs to be dissipated in 150 seconds. This discharge time starts when the load is disconnected. So resistors must be added to the circuit to discharge the capacitors.

There are a couple of steps in the design of this circuit. First, the requirements for the power supply need to be identified. Secondly, the values of the components need to be calculated, to ensure that the requirements are met. Than a simulation using computer software needs to be performed to test it digitally. After this simulation and verification that the circuit is correct, the circuit needs to be build using the components that were calculated. When the design is finished, the circuit also needs to be measured to check whether the circuit meets the requirements. If these requirements are not met, the circuit needs to be redesigned. The last step is to document the process. When all groups are finished with their parts, the components can be connected and the complete circuit can be tested.

The schematic of the designed circuit:

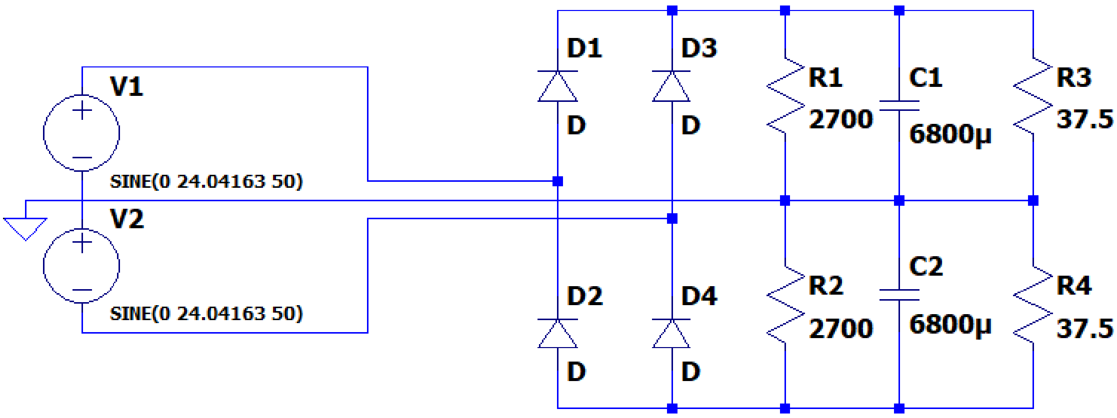

Figure 1.1: Power Supply schematic, all components have SI units

V1 and V2 are AC voltage sources that represent the output of the step-down transformer and the input of the power supply, with $f = 50\text{Hz}$ and $v_{pp} = 24.04163\text{V}$ meaning $v_{RMS} = 17\text{V}$. D1 through D4 are diodes needed for the full-bridge rectifier. These convert the sine wave to an absolute sine wave, so with only positive values. R1 and R2 are 2700Ω discharge resistors, to discharge the capacitors after shutting down. C1 and C2 are $6800\mu\text{F}$ capacitors to smooth the rectified sine wave into DC. R3 and R4 are the 37.5Ω load resistors that each receive 0.5A for a total load of 1A.

The design procedure of this circuit will be explained in this report. The first part explains the complete design process and the problems that were encountered. In the following section all the simulations will be presented and explained. Chapter 4 is about the assembly of the circuit. After the assembly, measurements were done, which will be presented in the following chapter. Finally conclusions and recommendations are given.

2 Design (methodology)

2.1. Role of all elements

The power supply circuit transforms the $17\mathrm{V}$ AC (rms) from the power socket to a lower DC voltage. The requirements for this output voltage are:

1. A DC voltage of +/- 20-22 V unloaded and a DC voltage of +/- 17-20 V at a load current of 1 A;
2. Maximum of 5% ripple;
3. Staying within a maximum discharge time of 150 seconds;
4. If the other requirements are met, efficiency.

The following part will give information how these requirements can be met.

1. For the first requirement, a transformer needs to be used. This transformer is already provided. It converts the 230 V AC (RMS) to 17-19 V AC (RMS). In our circuit a full-bridge rectifier is placed to convert the voltage to an absolute sine wave.
2. To make a smoother voltage, capacitors need to be added. There are two options to choose from: $4700\mu\mathrm{F}$ and $6800\mu\mathrm{F}$. These capacitors charge when the voltage from the transformer is high, and discharge when the voltage from the transformer is low. This way they smooth the voltage, but there is still deviation compared to the average:

$$u_{ripple}\,[\%] = \frac{u_{max} - u_{average}}{u_{average}} \cdot 100\% \tag{2.1}$$

   Where u_{max} is the highest voltage that is measured; $u_{average}$ the mean value of the voltage.[1]

   This percentage must be smaller than 5%. The higher the value of the capacitors, the lower the ripple voltage. That is why $6800\mu\mathrm{F}$ capacitors are chosen.
3. The capacitors need to discharge after switching off, also when the load is disconnected. That is why resistors need to be added. The lower the resistance of these resistors, the quicker the capacitors discharge.
4. The additional resistors also dissipate energy. Preferably, this energy is as low as possible to have a higher efficiency of our circuit. To get this, the resistance must be as high as possible. The resistance of the resistances need to have the lowest energy dissipation but still have a maximum discharge time of 150 seconds.

2.2. Design process

The design had the following steps:

- The project started with reading the IP-1 manual that was provided.[1] This gave the first information about what needs to be designed. The first step was to identify the requirements for the power supply, which are stated in the first part of this chapter. There are also specific components that can be used for the circuit. The transformer that converts 230V to 17V was already available, and there are two types of capacitors ($4700\mu\text{F}$ or $6800\mu\text{F}$) that can be used. There were also a lot of resistors to choose from.
- The next step was to choose between these two capacitors. The higher the capacitance of the capacitor, the smoother the voltage will become. That is the reason why $6800\ \mu\text{F}$ capacitors were chosen.
- The following step was to calculate the optimal value for the internal resistors. The circuit has to discharge within 150 seconds when the load is disconnected. Using a time constant of 30 seconds, there needs to be a resistance of 4400Ω. So discharge resistors of 4400Ω were chosen.
- The design was simulated in LTspice. This gave graphs of the voltage waveforms. It was possible to check whether the ripple voltage matched with the calculations. The calculated ripple voltage was 1.66%. This was well below 5%. This meant the building part could start.
- The components that were chosen were soldered onto the provided circuit board.
- The following step was to measure whether the requirements are met. This can be done using an oscilloscope to measure the voltage waveform. This data could be exported to an USB-drive and than analyzed on a computer. All measurements are explained in the corresponding section.
- In these measurements, the discharge time for the capacitors was longer that calculated. It is suspected that some physical circumstances influenced the discharge time. Therefore, other values for the internal resistors had to be chosen to meet this requirement. Resistors of 2700Ω were selected. After these resistors were changed, measurements were taken again, and this time, the discharge time was within 150 seconds. This indicated that all requirements were now met and that the power supply was completed.
- The last step is to report all measurements. This intermediate report is the first report about this part in the project.
- When all groups are ready with their components, all components can be connected and after that it is possible to test the complete circuit. It is possible that more adjustments needs to be made, but it is impossible to anticipate for that right now.

3

Simulations

3.1. Ripple

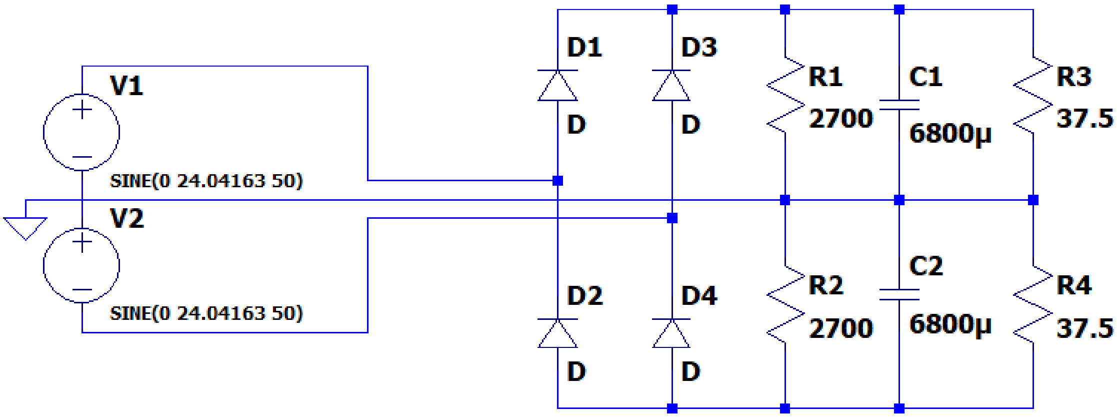

Figure 3.1: Loaded power supply schematic

The schematic shown in Figure 3.1 represents the power supply and test loads. V1 and V2 are AC voltage sources that represent the output of the step-down transformer and the input of the power supply, with $f = 50\text{Hz}$ and $v_{pp} = 24.04163\text{V}$ meaning $v_{RMS} = 17\text{V}$; D1 through D4 are the diodes of the full-bridge rectifier; R1 and R2 are the 2700Ω discharge resistors; C1 and C2 are the $6800\mu\text{F}$ capacitors to smooth the rectified sine wave into DC; R3 and R4 are the 37.5Ω load resistors that each receive 0.5A for a total load of 1A.

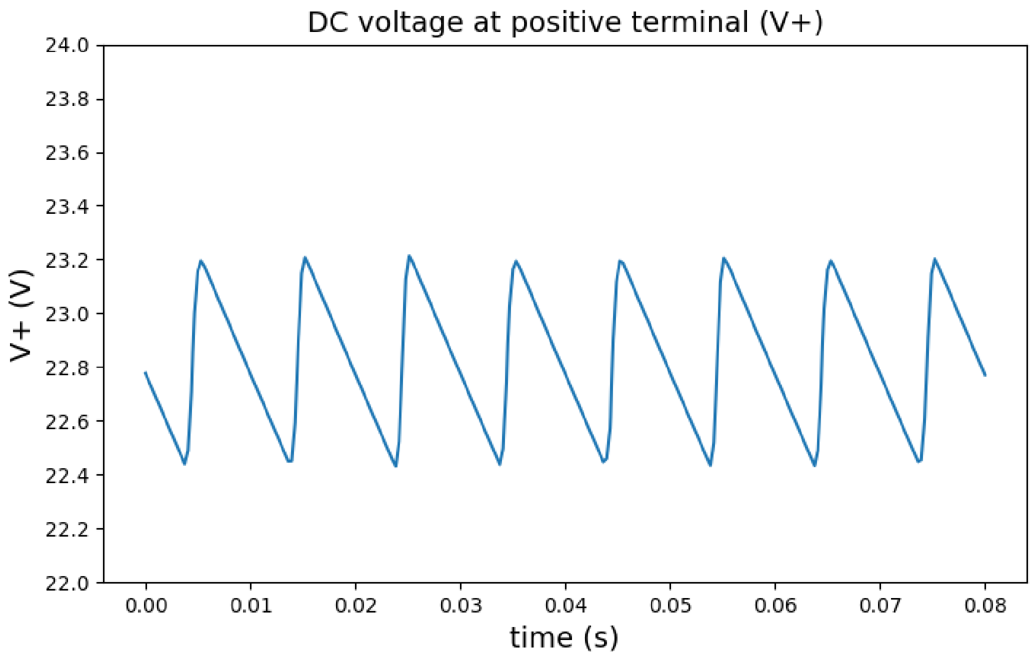

Figure 3.2: Ripple simulation

The graph in Figure 3.2 shows 8 periods of the voltage at the positive terminal of the power supply, while the power supply is loaded as shown in Figure 3.1.

The following values can be obtained:

	Voltage (V)
V_{min}	22.45
V_{max}	23.21

Table 3.1: Simulated ripple voltages

$$V_{average} = \frac{22.45 + 23.21}{2} = 22.83\text{V} \tag{3.1}$$

$$u_{ripple}\,[\%] = \frac{23.21 - 22.83}{22.83} \cdot 100\% = 1.66\% \leq 5\% \tag{3.2}$$

Equation 3.1 and 3.2 show the calculation of the ripple percentage. The simulated value of 1.66% satisfies the condition of being no more than 5%.

3.2. Discharge

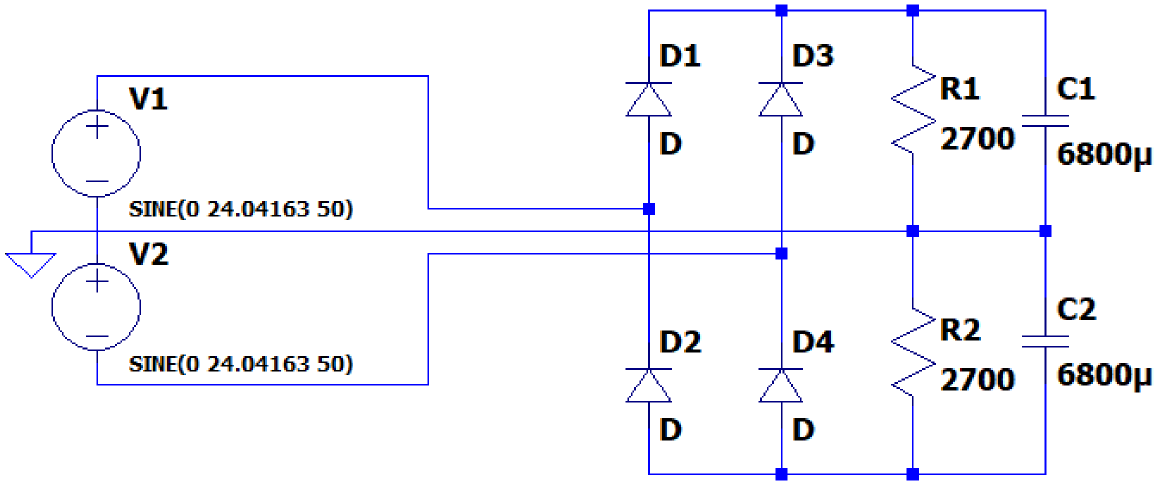

Figure 3.3: Unloaded power supply schematic

The schematic shown in Figure 3.3 shows the powers supply without load in order to simulate the discharge time with the highest possible starting voltage. If the circuit was loaded before discharging, the voltage - and therefore energy stored in the capacitors - would be lower because the voltage drops under load. The simulation was run for 100 seconds or 5000 periods (which is way more than enough) before being disconnected. The last 10 seconds of this are shown in the graph.

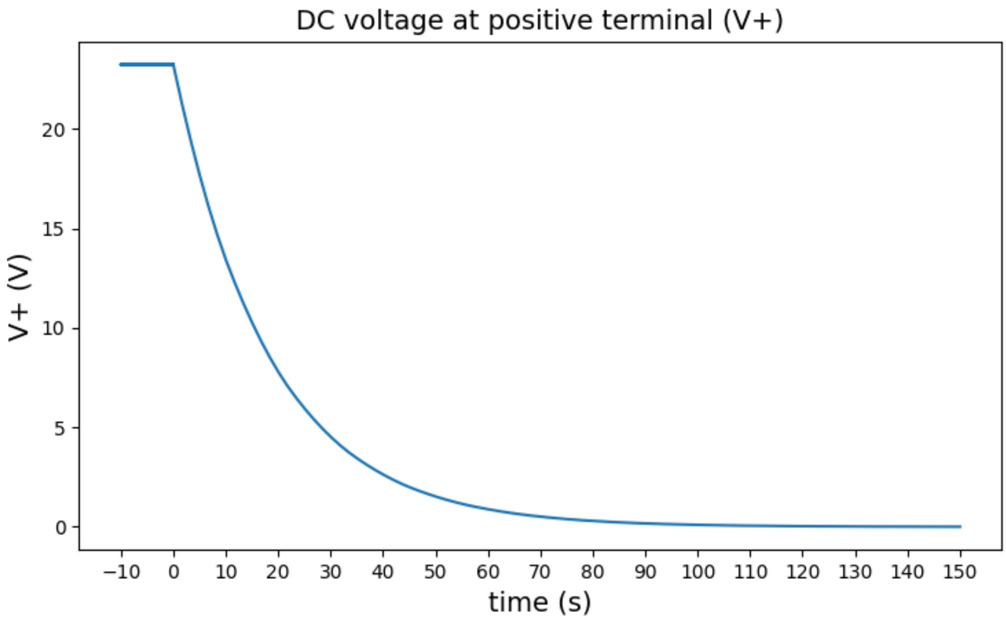

Figure 3.4: Discharge simulation

Figure 3.4 shows the unloaded voltage for 10 seconds prior to disconnecting ($t \leq 0$), and the discharge of the power supply for 150 seconds after being disconnected from the voltage source ($t > 0$). The ripple is hardly visible in the 10 seconds before $t = 0$ because of the scale of the graph and because the ripple is very small while the power supply is unloaded (approximately 0.02%).

$t \leq 0$	23.23V
$t = 150\text{s} = 5\tau$	6.58mV

Table 3.2: Simulated discharge voltages

At $t = 150\text{s} = 5\tau$, the residual voltage is allowed to be no more than e^{-5} times the voltage before disconnecting. With a residual voltage of 6.58mV (see Table 3.2), the power supply is able to discharge well in time:

$$\frac{V_{residual}}{V_{start}} = \frac{6.58\text{mV}}{23.23\text{V}} = 2.83 \cdot 10^{-4} < e^{-5} \tag{3.3}$$

4 Assembly of the power supply

- The transformer from 230 V to 17 V was already available, and there were also two types of capacitors (4700μF or 6800μF) that could be used. There were also a lot of resistors to choose from.
- The next step was to choose between these two capacitors. For this, the following formulas can be used:

$$I = C \cdot \frac{dV}{dt} \tag{4.1}$$

$$\frac{dV}{dt} \approx \frac{\Delta U_{dc}}{\Delta t} \tag{4.2}$$

  where I is the current through the capacitor, C is the capacitance of the capacitor and $\frac{dV}{dt}$ is the derivative of the voltage. The average change in DC voltage $\frac{\Delta U_{dc}}{\Delta t}$ is roughly equal to $\frac{dV}{dt}$ and needs to be minimized to minimize the ripple. In order to minimize this value while delivering the same current I, the capacitance C needs to be as high as possible. The capacitance needs to be large because the derivative of voltage needs to be as small as possible. So the higher the capacitance of the capacitor, the smoother the voltage will become. That is why the $6800\mu\mathrm{F}$ version is chosen.
- The following step was to calculate the optimal value for the internal resistors. The circuit has to discharge within 150 seconds when the load is disconnected. This is considered to be 5τ. This means that the time constant equals $\frac{150}{5} = 30$ seconds. The resistance can be calculated with the following formula:

$$R = \frac{\tau}{C} \tag{4.3}$$

  where τ equal 30 seconds and C equal $6800\mu\mathrm{F}$. Filling in the formula gives a resistance of $4.4\mathrm{k}\Omega$. So discharge resistors of $4.4\mathrm{k}\Omega$ were chosen.
- The components that were chosen were soldered onto the provided circuit board. See figure 4.1 for the printed circuit board that was provided. For C1 and C2 two capacitors of $6800\mu\mathrm{F}$, and for R1 and R2 two resistors of $4.4\mathrm{k}\Omega$ were soldered onto the board.

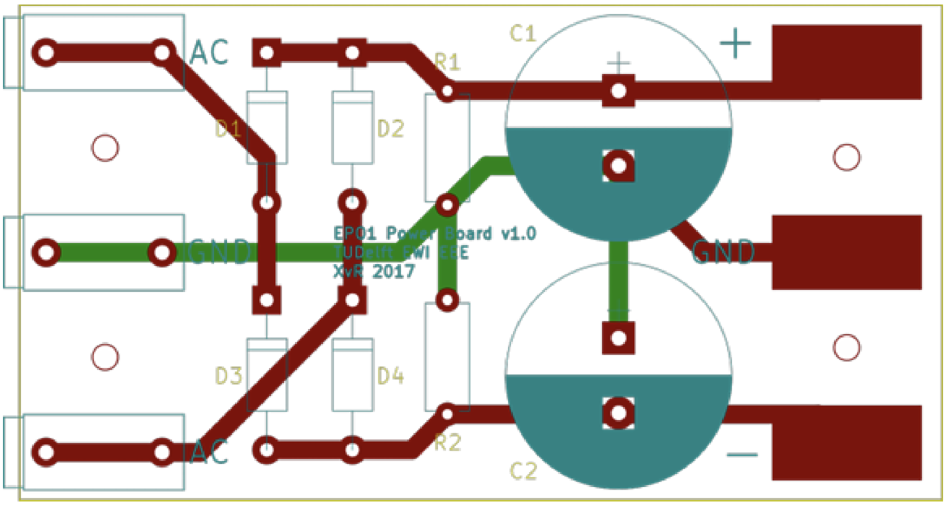

Figure 4.1: Printed circuit board for the power supply. [1]

- In the measurements, it was found that the discharge time for the capacitors was longer than had been calculated. It is suspected that some physical properties were different than simulated. Therefore, other values for the internal resistors had to be chosen to meet this requirement. Resistors of $2.7\mathrm{k}\Omega$ were selected. After these resistors were changed, measurements were taken again, and this time, the discharge time was within 150 seconds. This indicated that all requirements were now met and that the power supply was completed.
- Thick wires were soldered to the outputs of the PCB to make it easier for the power amplifier to be attached.

The following figure contains the built circuit:

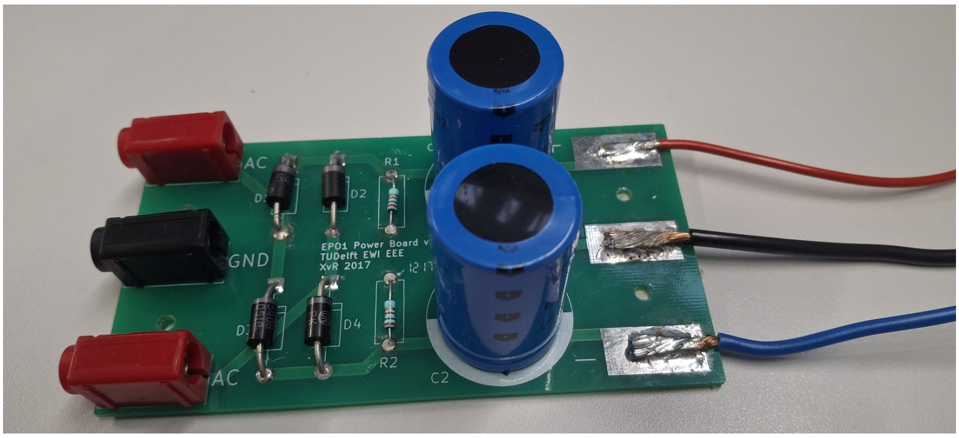

Figure 4.2: The final design of the power supply

The connectors on the left connect to the step-down transformer. The wires on the right connect to the power amplifier, which is the load of the power supply.

5 Measurements

5.1. Ripple

In order to test the ripple percentage, two 37.5Ω load resistors were connected to the power supply: one between the blue $(-)$ and the black lead (ground), and one between the black and the red lead $(+)$. The following voltage was measured between $+$ and ground:

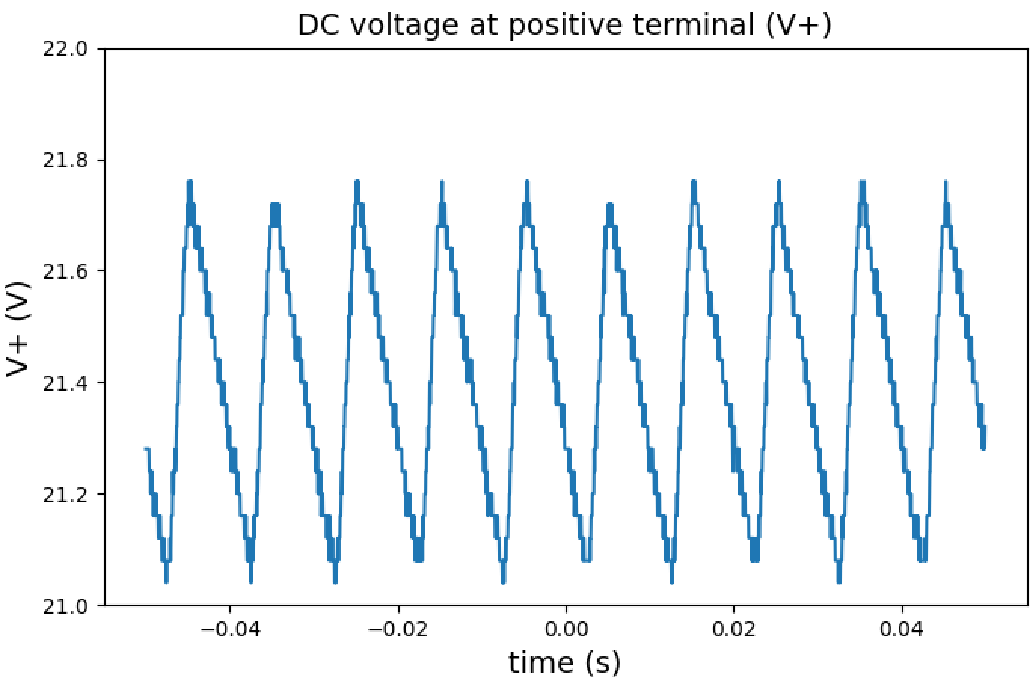

Figure 5.1: Voltage measured at $(+)$

The following values were obtained:

	Voltage (V)
V_{min}	20.76
V_{max}	21.84

Table 5.1: Measured ripple voltages

$$V_{average} = \frac{20.76 + 21.84}{2} = 21.30\text{V} \tag{5.1}$$

$$u_{ripple}\,[\%] = \frac{21.84 - 21.30}{21.30} \cdot 100\% = 2.54\% \leq 5\% \tag{5.2}$$

The measured ripple is, while higher than simulated, within the limit of 5%.

5.2. Discharge

In order to measure whether the power supply had sufficiently discharged within 150 seconds, it was disconnected from the transformer after being left unloaded. 150 seconds later, the remaining voltage was measured with the use of an oscilloscope, to be:

$$\begin{aligned} V_{residual} &= 58\text{mV} \\ V_{start} &= 23.0\text{V} \end{aligned}$$

$$\frac{V_{residual}}{V_{start}} = \frac{58\text{mV}}{23.0\text{V}} = 2.52 \cdot 10^{-3} < e^{-5} \tag{5.3}$$

5.3. Power dissipated by discharge resistors

With an average loaded voltage of 21.30V, the 2700Ω discharge resistors each dissipate the following power:

$$P = \frac{V^2}{R} = \frac{21.30^2}{2700} = 168\text{mW} \tag{5.4}$$

With there being 2 discharge resistors, the total power consumed by the discharge resistors while the power supply is loaded is:

$$2 \cdot 168\text{mW} = 336\text{mW} \tag{5.5}$$

6
Conclusions

The requirements for our power supply are:

1. A DC voltage of +/- 20-22 V unloaded and a DC voltage of +/- 17-20 V at a load current of 1 A;
2. Maximum of 5% ripple;
3. Staying within a maximum discharge time of 150 seconds;
4. If the other requirements are met, efficiency.

The following values determine whether the requirements are met:

1. The power supply gives an unloaded DC voltage of $23.0\mathrm{V}$ and a loaded DC voltage of $21.30\mathrm{V}$. Considering that the transformer delivers anywhere from 17V to 19V, the measured values of the power supply are within specification.
2. When the power supply is loaded, there is a ripple of 2.54%. This is well below 5%.
3. The voltage over the capacitors at 150 seconds is $58\mathrm{mV}$, which is 0.2% of the nominal voltage when it is loaded. A capacitor is considered discharged if it has reached e^{-5}, which is 0.67 %. So this means that the power supply is discharged within 150 seconds.
4. Inasmuch as possible, our circuit is efficient. The discharge resistors combined dissipate $336\mathrm{mW}$, which is low.

7 Recommendations

We have the following recommendations for this project:

- During the analysis of the measurements data, there was a wrong interpretation of the ripple voltage formula. Therefore a ripple was calculated which was twice as big, and therefore getting above 5%. There was already some redesign, which turned out to be useless. It is therefore advised to make sure that all the calculations are done correctly.
- In real-life, our circuit behaved differently than in the simulations as the discharge time we calculated differed from the measurements. This could be because of physical differences between a simulated capacitor and a real-life capacitor. To prevent this, it is advised to implement more realistic capacitors in the simulation.

Bibliography

[1] Dr.ir. G.J.M. Janssen et al. *Booming Bass (Sound) System*. TU Delft, 2024-2025.