EE1L1 IP-1 Project Report

Power Supply

(Sub)Group A1-1

TUDelft

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Power Supply

by

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1 Introduction

This report presents the design, simulation, and construction of a power supply system for use in a speaker module. The objective is to explain the steps taken during each phase of the process, from design to simulation and assembly, as well as the approach taken to select the ideal components. The report includes the results of tests and simulations conducted with various combinations of components, along with a comparison of these results against theoretical predictions.The goal is to provide information to those involved in the design and development of audio systems and anyone interested in understanding the process of creating an efficient and reliable power supply for speaker modules.

2

Theory and Analysis (design methodology)

2.0.1. Design Requirements

The power supply design needed to meet the following specifications:

- An avarage unloaded output voltage within the range of ± 20-22 V DC.
- Under a load current of 1.0 A, an average output voltage within the range of 17-20 V DC.
- A ripple voltage that does not exceed 5%.
- A discharge time (5τ) of less than 2.5 minutes.

Several pieces of information were already provided in the manual[1], including the power supply circuit diagram (Figure 2.1) and the specifications of the transformer.

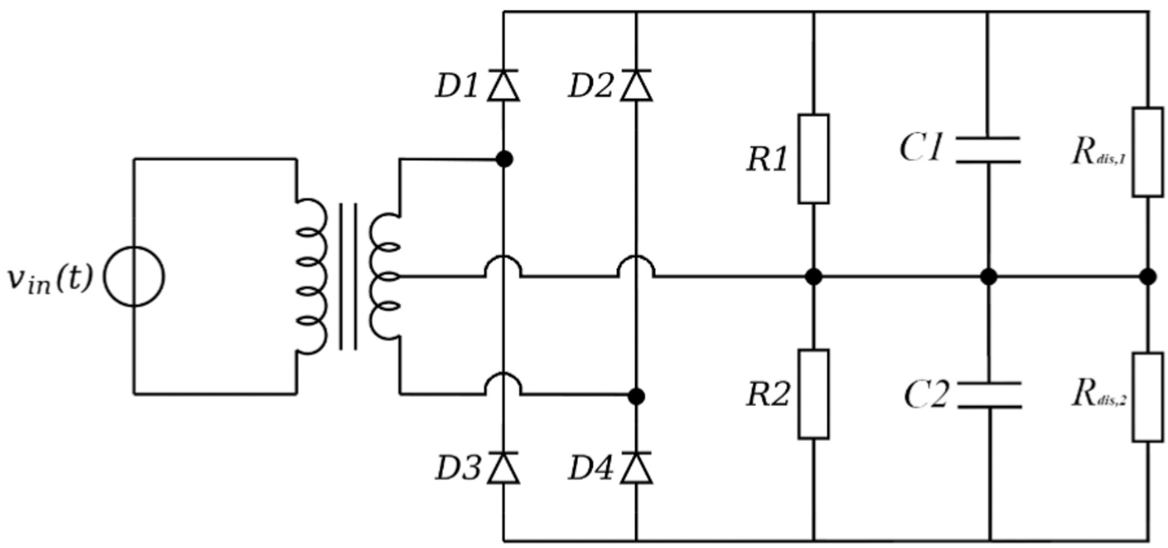

Figure 2.1: Power supply Circuit Provided in the Project Manual

The provided transformer had the following characteristics:

- Primary voltage: 230 V AC.
- Secondary voltage: symmetric 2 x 15-17 V AC (at nominal load), with a center tap.
- Power: 80 VA.

From these specifications, it was possible to infer that the positive and negative output lines would have approximately 21.3-23.3 V DC (the rectified output).

2.0.2. Calculations

To meet the requirement of maintaining a ripple voltage of less than 5%, the selection of the capacitor and resistor became crucial. The capacitance had to be large enough to effectively filter out the ripple.

For the design of this power supply, two types of capacitors (4700μF and 6800μF) have been provided in the lab. To choose the optimal capacitor with the least percentage of ripple, a series of calculations had to be carried out for both capacitors.

The time constant has been derived for the discharge of the capacitor when the circuit is unloaded :

$$5\tau = 150s$$

$$\tau = 30s$$

After deriving the time constant for the unloaded circuit, the resistance needed for each capacitor to discharge in 30 seconds has been calculated using the time constant formula, setting τ=30s(equation 2.1) :

$$\tau = R \, . \, C \tag{2.1}$$

Table 2.1 shows the calculated resistance values for their respective capacitors:

Capacitance(μF)	Resistance(kΩ)
6800	4.4
4700	6.4

Table 2.1

The formula to calculate the ripple percentage has been provided in the manual as:

$$Ripple\% = \frac{V_{max} - V_{average}}{V_{average}} \tag{2.2}$$

Maximum voltage (V_peak) given in the formula 2.2 is the secondary voltage through the transformer. RMS value of the used transformer has been stated as 15-17V.The maximum voltage was calculated (using formula 2.4) as 24V. Subsequently, voltage drop of 0.7V across the diode from the rectifier has been subtracted to derive the initial voltage.

$$V_0 = 24 - 0.7 = 23.3V \tag{2.3}$$

$$V_{RMS} = V_{peak} x \frac{2\sqrt{2}}{\pi} \tag{2.4}$$

To calculate the average voltage (V_average) of the ripple, the minimum voltage of both capacitors have been derived by finding the intersection points of the supply voltage, and the exponential discharge of the capacitors. This has been carried out by plotting individual graphs for each capacitor(figure 2.2).

The minimum voltage can be calculated by using formula 2.5(see appendix A.1) with the corresponding intersection time as ”t”, or by looking at the equivalent voltage at intersection time from the plot. Derived average voltages for 6800µF and 4700µF capacitors can be seen on Table 2.2. (See A.2 for step by step calculation of the avarage voltages.)

Discharge formula of a capacitor:

$$V = V_0 e^{\frac{-t}{\tau}} \tag{2.5}$$

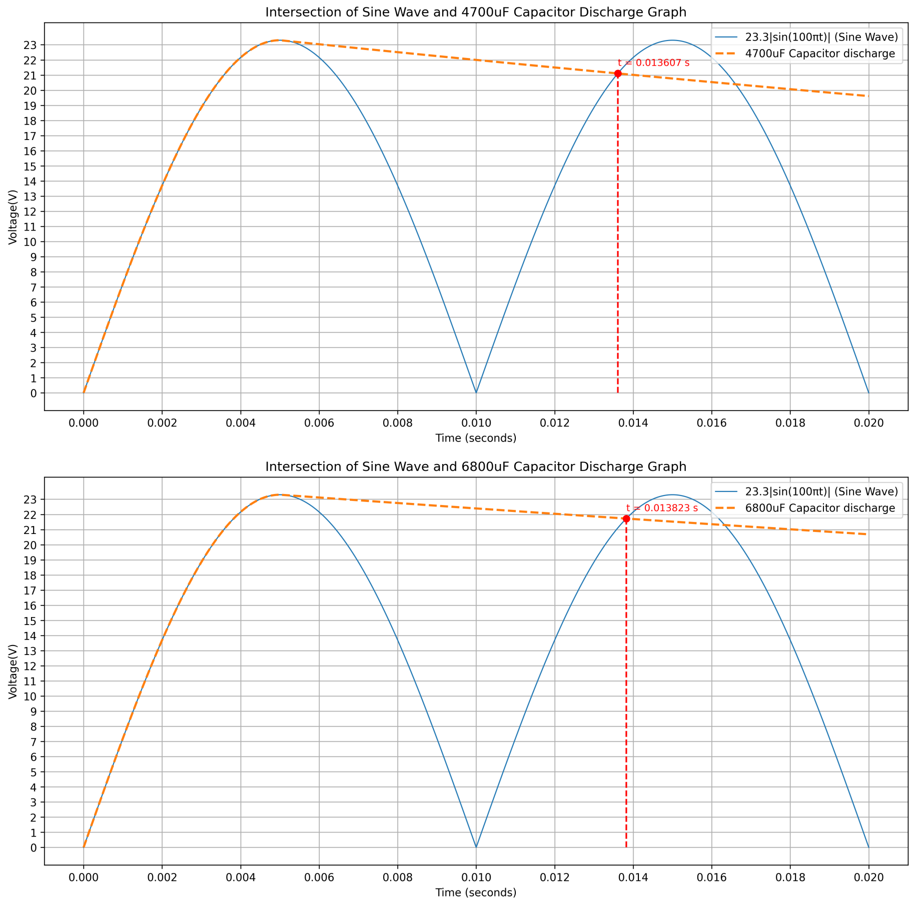

Figure 2.2: Intersection points for the 6800µF and the 4700µF capacitor

From the discharge formula (2.5), it can be inferred that a capacitor with a higher capacitance would perform better because, as the capacitance increases, the time constant (τ=RC) also increases. A larger time constant results in a slower discharge rate, allowing the capacitor to maintain its voltage for a longer duration

The time constant (τ) for discharge when load of 18.5 ohm is connected has been calculated using formula 2.1 (see table 2.2) After deriving the avarage voltage and the maximum voltage, the ripple percentage can be calculated using formula 2.2:

- For 6800μF:

$$Ripple\% = \frac{23.30 - 22.51}{22.51} x100 = 3.5\%$$

- For 4700μF:

$$Ripple\% = \frac{23.30 - 22.20}{22.20} x100 = 4.9\%$$

The 6800 μF capacitor was chosen along with the 4400 ohm resistor because, as inferred from the calculations(see table 2.2), a larger capacitor results in a lower ripple voltage, and offers a good balance between physical size and ripple reduction.

Capacitance(μF)	**Ripple %**	**Discharge Time (ms)**	**Average Voltage**	**τ(ms)**
6800	3.5	8.8	22.51	126
4700	4.9	8.6	22.20	87

Table 2.2

3

Simulations

3.0.1. Circuit design in LTspice

The programme LTSpice was used to simulate the power supply circuit. The simulations include both the 4700µF and 6800µF capacitors with their respective resistors.

Instead of using a transformer, two voltage sources of 24 V (corresponding to $17\,\mathrm{V_{ACrms}} \times \sqrt{2}$) with a frequency of 50 Hz (standard power outlet frequency) were used. A ground connection was placed between the sources to provide ± 24 V on two separate lines.

Figure 3.1 shows the power supply circuit with the 4700µF with the load connected to 1 terminal.

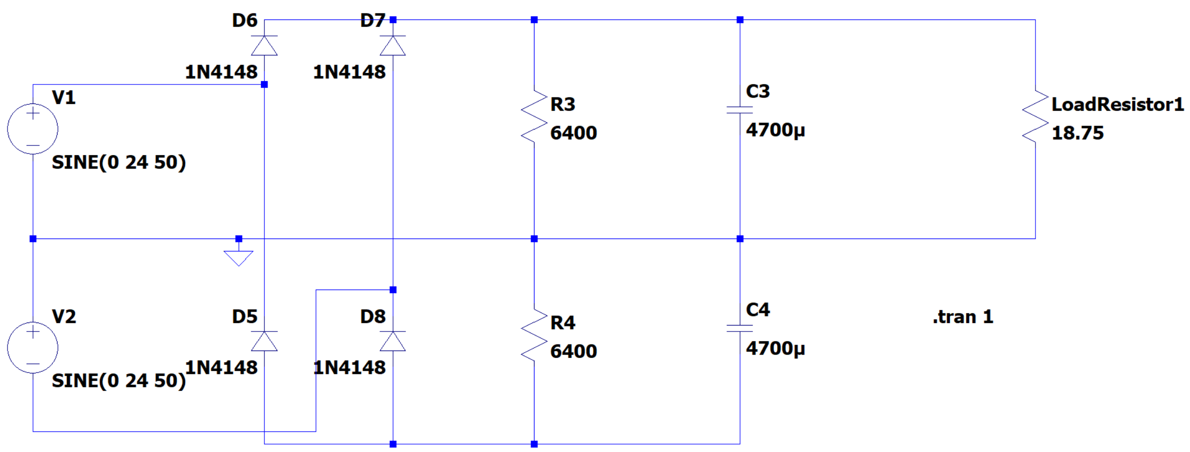

Figure 3.1: LTspice design of the power supply circuit with the 4700µF capacitor

Figure 3.2 shows the power supply circuit with the 6800μF with the load connected to 1 terminal.

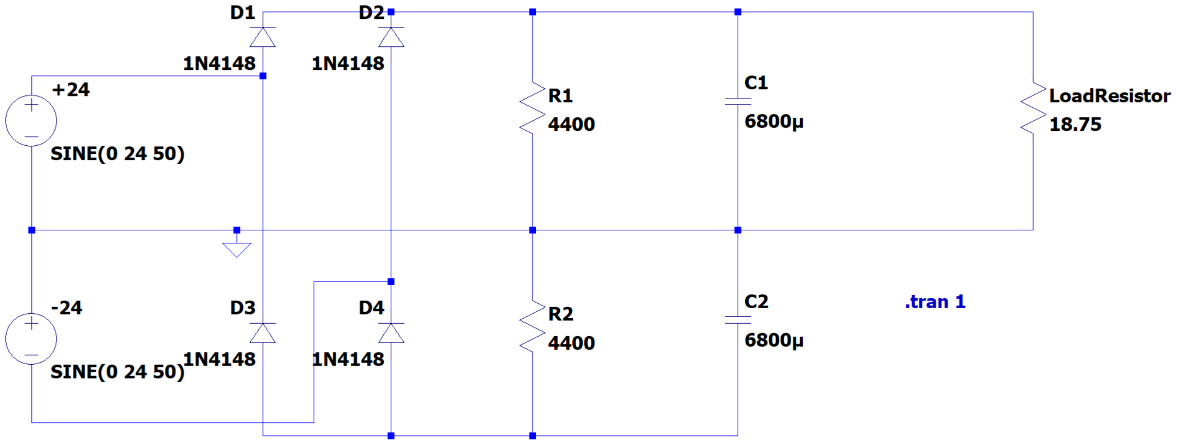

Figure 3.2: LTspice design of the power supply circuit with the 6800μF capacitor

3.0.2. Simulation Results

Figure 3.3 presents the voltage graphs of the simulated circuits, with the red line representing the 4700μF circuit and the blue line corresponding to the 6800μF circuit. As shown in the close-up graph in Figure 3.4, the ripple is significantly reduced on the blue line. This observation aligns with theoretical calculations and justifies the choice of the 6800μF capacitor to construct this circuit.

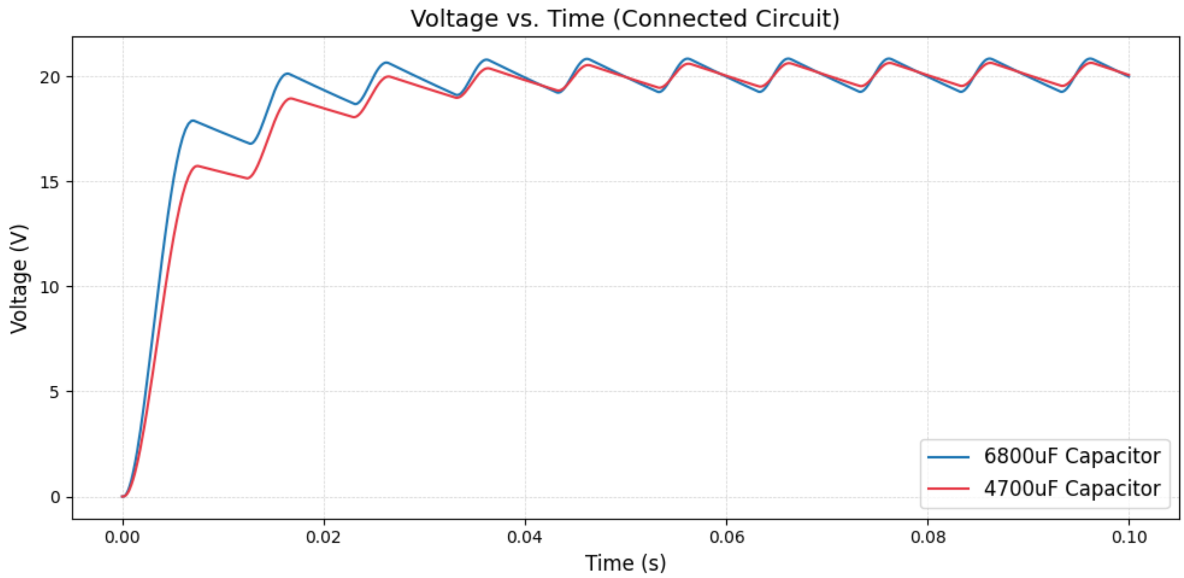

Figure 3.3: Voltage vs. Time graph of both simulated circuits

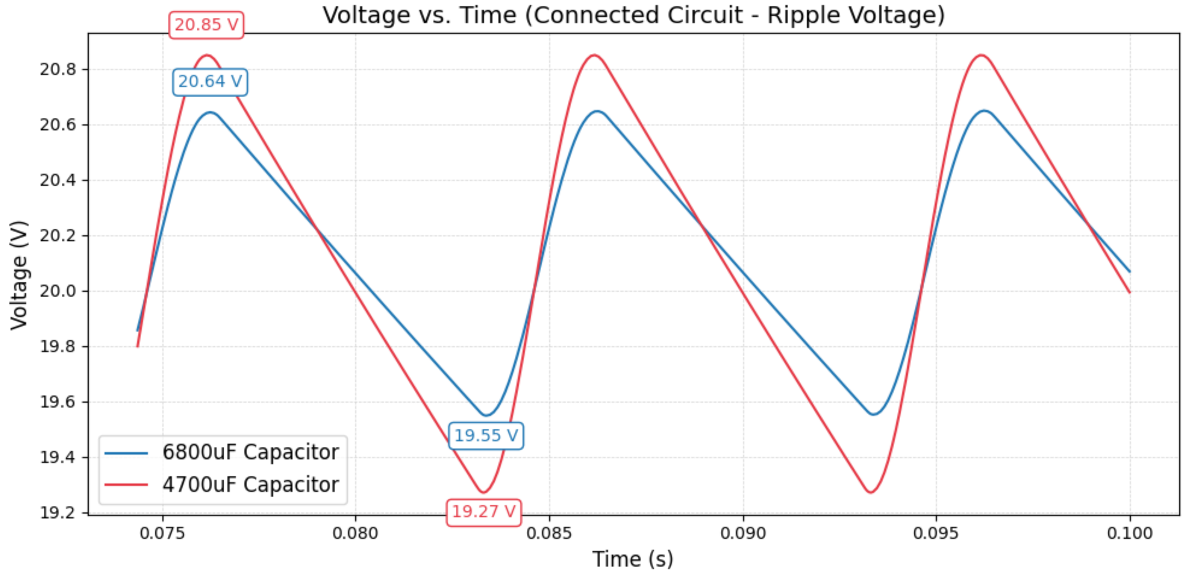

Figure 3.4: Voltage vs. Time graph of both simulated circuits, zoomed to show peaks and dips

From these simulation results, it is possible to calculate the ripple voltage using the ripple voltage formula (2.2):

$$\text{Ripple Voltage 6800μF capacitor} = \left(\frac{20.64 - 20.09}{20.10}\right) \times 100 \tag{3.1}$$

$$= \left(\frac{0.55}{20.10}\right) \times 100 \tag{3.2}$$

Performing the calculation:

$$\approx 2.71\% \tag{3.3}$$

$$\text{Ripple Voltage 4700μF capacitor} = \left(\frac{20.85 - 20.06}{20.06}\right) \times 100 \tag{3.4}$$

$$= \left(\frac{0.79}{20.06}\right) \times 100 \tag{3.5}$$

Performing the calculation:

$$\approx 3.94\% \tag{3.6}$$

In Figure 3.5, the discharge of the circuit with the 6800μF capacitor was modeled, and the resulting voltage versus time plot is shown. As seen in the graph, the voltage approaches zero after approximately 2.5 minutes, which aligns with the predicted behavior and confirms the accuracy of the calculations. This further demonstrates that the system meets the required specifications. To generate this graph, switches were incorporated into the simulated circuit. For detailed information on the circuit including the switches, please refer to Appendix B.

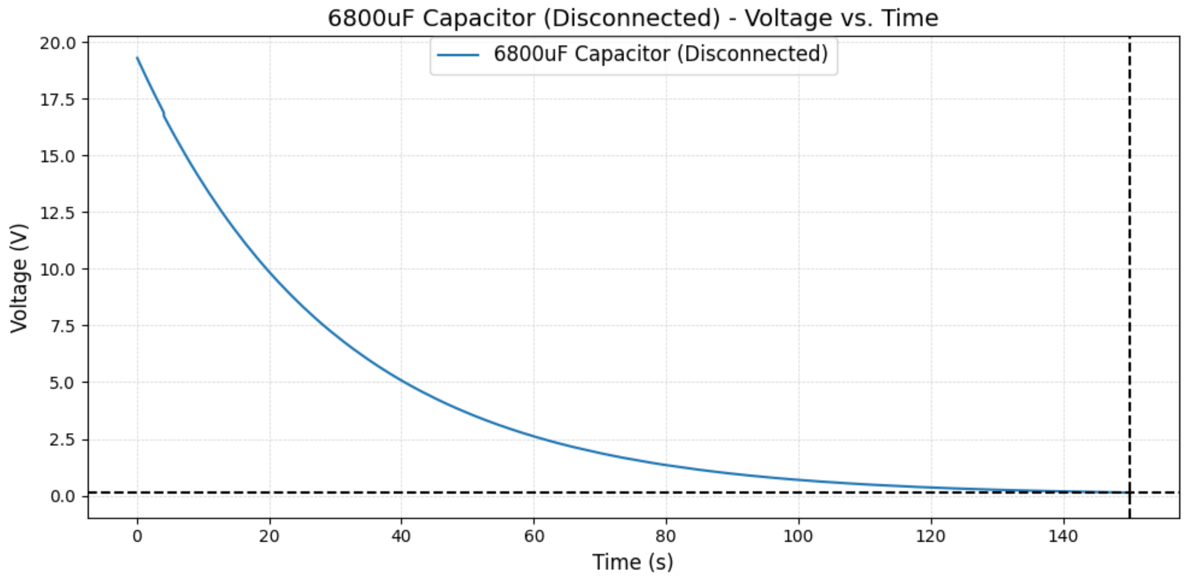

Figure 3.5: Voltage vs. Time plot for the discharge of the circuit with a 6800μF capacitor

3.0.3. Comparison with Theory

Compairing the results to the calculated results in chapter 2, we can see that:

- The average voltage is 20V DC which is in our range
- The ripple frequency is in the desired range
- The capacitor loses 99% of its voltage within 2.5 minutes, which is in the desired range

4 Measurement results

4.0.1. Building of the Circuit

The next step was to construct the circuit following the design and simulations.

For the resistor, to meet the discharge time requirement, a resistance value of 4400 Ω was needed. The closest available resistor in the lab was 4700 Ω, which was selected for the design. While this resistor slightly increases the discharge time beyond the 2.5-minute mark, the difference is negligible. Additionally, using a higher resistance reduces the internal load, thus lowering power waste, minimizing thermal losses, and preventing overheating. This also ensures that the circuit can provide a slightly higher sustained voltage. In this case, these benefits outweighed the minor increase in discharge time.

For the capacitor, as proven to be better in the theory and simulations, the 6700μF capacitor was used.

Figure 4.1 has the fully built circuit with the components soldered on.

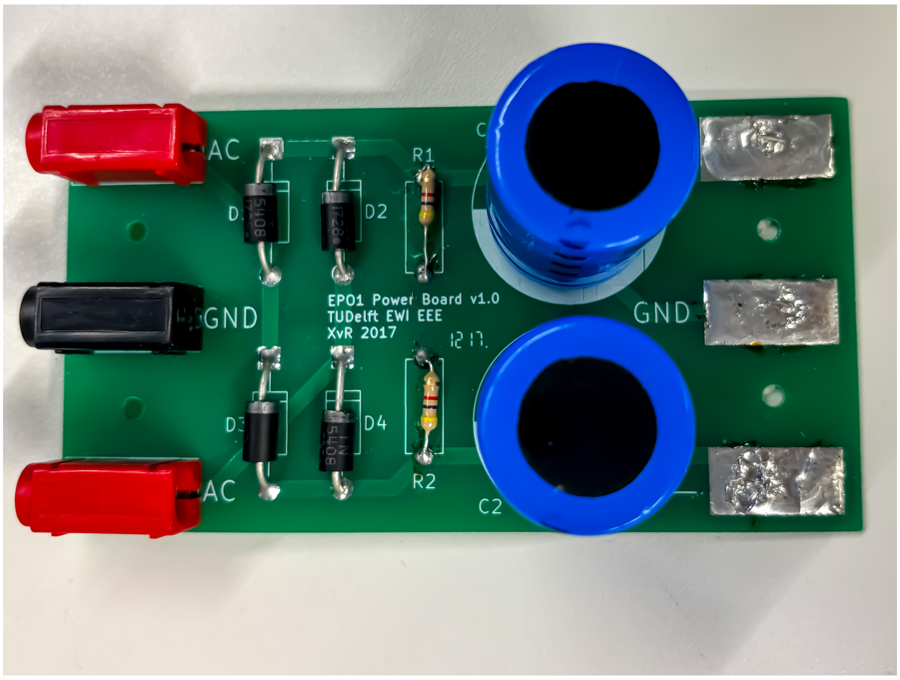

Figure 4.1: Fully built power supply circuit

4.0.2. Multimeter and Oscilloscope Measurements

Several values were measured using the multimeter provided including loaded and unloaded, single and double channel voltages. These are present in the table 4.1 below:

Output Current (A)	**Loaded Voltage(V) Single Channel**	**Loaded Voltage(V) Double Channel**	**Unloaded Voltage(V) Single Channel**	**Unloaded Voltage(V) Double Channel**
1.0	20.1	40.2	23.3	46.4

Table 4.1: Power supply lab measurements

In addition to this, voltage measurements were also taken from the oscilloscope. The figure 4.2 shows the voltage on 1 power supply channel, whereas Figure 4.3 shows the dual channel output. As it can be seen, from the values the ripple voltage can be calculated again, using formula 2.2:

$$Ripple\% = \frac{21.3 - 20.6}{20.6} x100 = \%3.4 \tag{4.1}$$

Which is well within the required range.

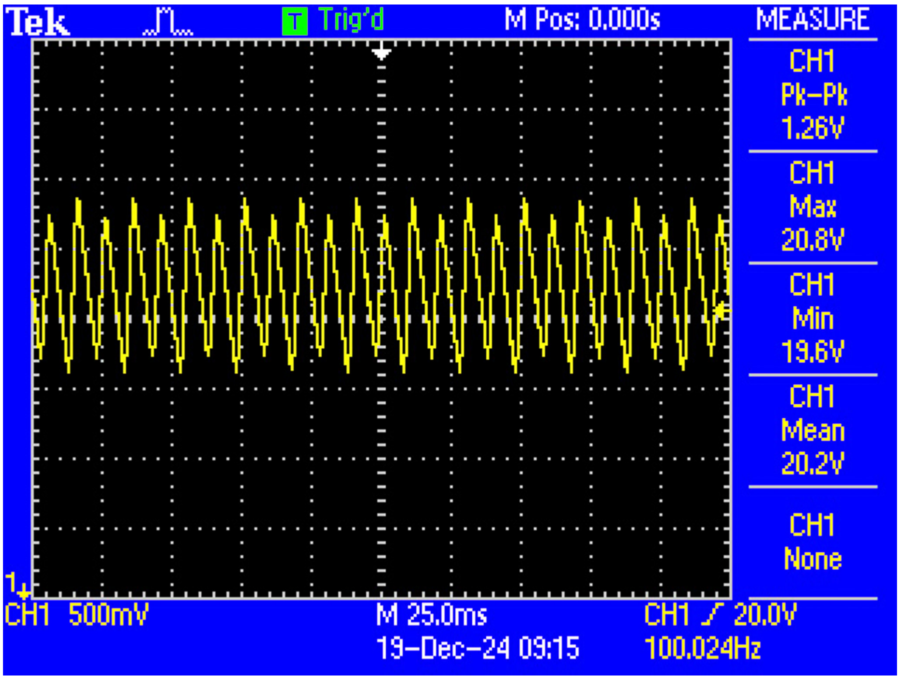

Figure 4.2: Voltage Graph of the Single Channel Output of the Power Supply

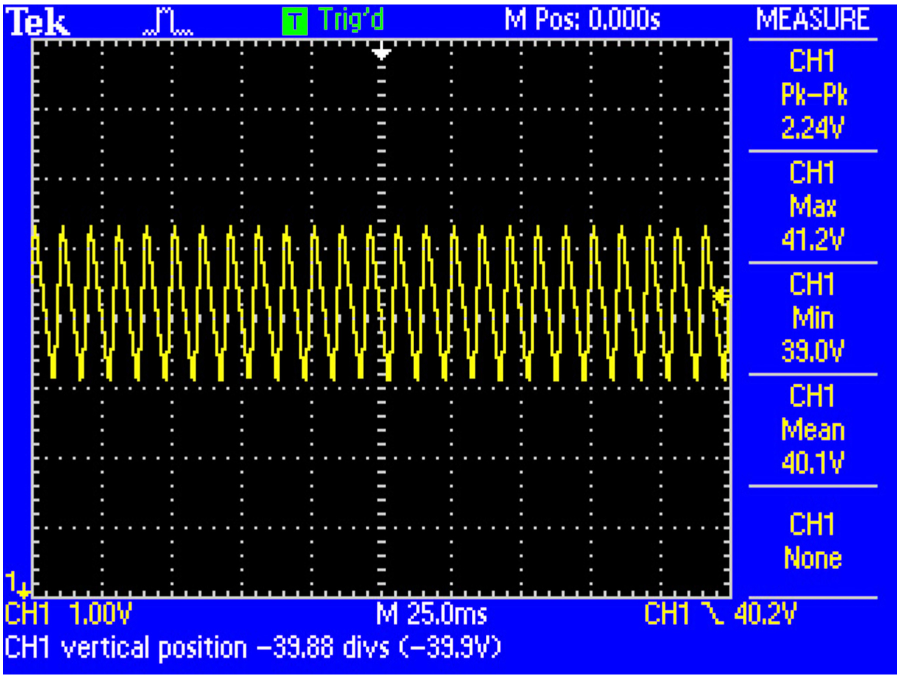

Figure 4.3: Voltage Graph of the Dual Channel Output of the Power Supply

Figure 4.4 shows the discharge of the power supply circuit. After ensuring the capacitors were fully charged, the circuit was disconnected. The graph ends after 2,5 minutes, at which point the capacitor has lost more than 99% of its total voltage.

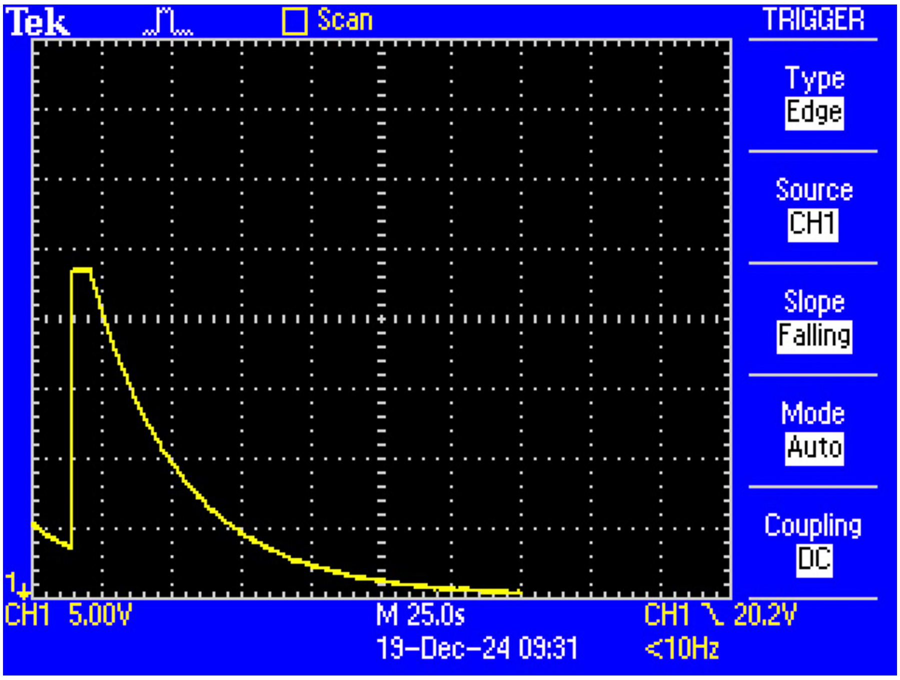

Figure 4.4: Discharge of the circuit after disconnecting from the power source and load

4.0.3. Discrepancies

The theoretical calculations and methodology did not account for the possible inaccuracies of the components available in the lab.

As inferred from the data points, the voltage output of the circuit slightly exceeded the specified requirement of ±17–20 V DC. However, after consulting with the op-amp subgroup and verifying the specifications of the powered component, it was confirmed that the device operates within a range of ±10 to ±47 V DC. Although this is not ideal, since the excess voltage could result in slightly higher heat output and potentially impact the speaker's performance over time, the deviation from the expected values is minimal and does not pose significant concerns for the circuit's functionality.

While small deviations in the measured results were observed, they were anticipated. Despite these minor discrepancies, the circuit performs as expected and aligns with the simulated results.

4.0.4. Findings

- Both the unloaded and the voltage were slightly higher than the requirements but as explained in subsection discrepancies, this will not cause a problem with the rest of the circuit
- The ripple is well within the expected range of 5%
- The discharge time of the capacitor is within 2.5 minutes

5

Conclusions

This report provided a comprehensive analysis of the design, simulation, and construction of a power supply system, detailing its functionality and the processes involved. The circuit demonstrated an unloaded voltage of 23.3 V DC and, under a 1 A load, a voltage of 20.2 V with a ripple of 5%. The findings emphasized the importance of capacitor size, with higher capacitance proving more effective. Additionally, a 4,400-ohm resistor was identified as suitable for achieving a 2.5-minute discharge time for a 6,800 μF capacitor. The results of simulations and measurements closely aligned with theoretical expectations, with minor deviations that are negligible. Overall, the circuit fulfills the specified requirements and operates as intended.

Bibliography

[1] G.J.M. Janssen et al. *EE Quarter 2 Student Manual Integrated Project 1 (IP-1) EE1L1 “Booming Bass (Sound) System” Year 2024-2025*.

A

Appendix

A.1. Calculating the Minimum voltage

Using the values obtained from figure 2.2 and discharge formula:

$$V = V_0 e^{\frac{-t}{\tau}} \tag{A.1}$$

A.1.1. For 6800μF

$$t = 0.0138 - 0.005 = 8.82x10^{-3}s \tag{A.2}$$

$$V = 23.3e^{\frac{-8.82x10^{-3}}{126x10^{-3}}} = 21.7V \tag{A.3}$$

A.1.2. For 4700μF

$$t = 0.0136 - 0.005 = 8.86x10^{-3}s \tag{A.4}$$

$$V = 23.3e^{\frac{-8.86x10^{-3}}{87x10^{-3}}} = 21.1V \tag{A.5}$$

A.2. Calculating the Average Voltage

These calculations were carried out by, first subtracting the minimum voltage from the peak voltage to find the peak-to-peak voltage.

The peak-to-peak voltage is then divided by two to, and the halved value is subtracted from the maximum voltage value to find the midpoint.

A.2.1. For 6800μF

$$peak - to - peak = 23.3 - 21.7 = 1.6 \tag{A.6}$$

$$1.6/2 = 0.8 \tag{A.7}$$

$$V_{average} = 23.3 - 0.8 = 22.5V \tag{A.8}$$

A.2.2. For 4700μF

$$peak - to - peak = 23.3 - 21.1 = 2.2V \tag{A.9}$$

$$2.2/2 = 1.1V \tag{A.10}$$

$$V_{average} = 23.3 - 1.1 = 22.2V \tag{A.11}$$

B
Appendix

Figure illustrates the same circuit simulated in Chapter 3, now including three voltage-activated switches. These switches disconnect the power supply and the load from the circuit after 1 ms of operation, enabling measurements to be taken after disconnection. This setup verifies that the chosen resistor effectively discharges the capacitor within 2.5 minutes

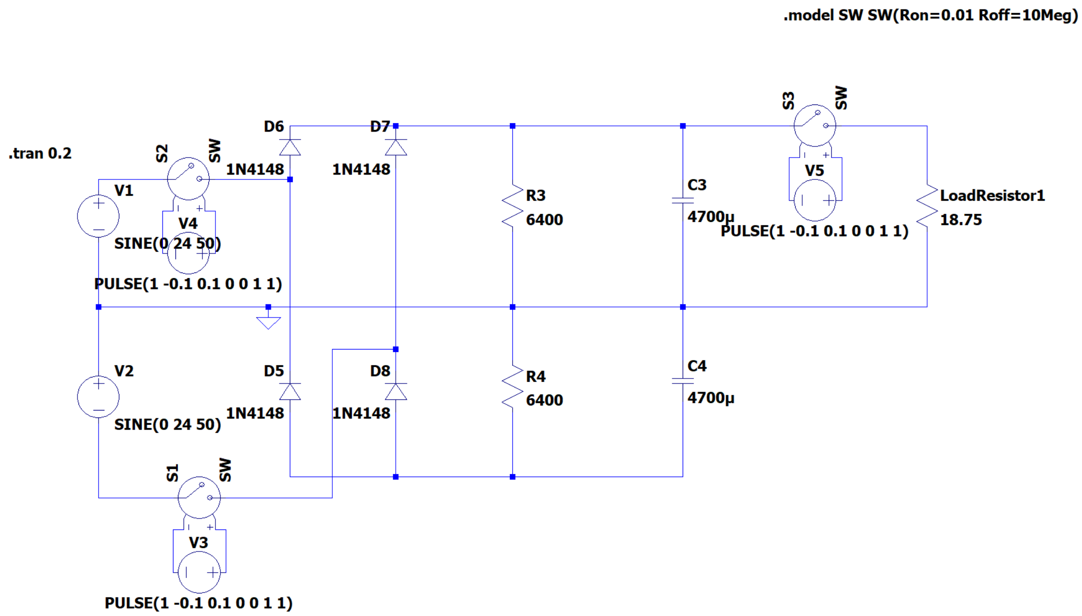

Figure B.1: The simulated circuit with switches, to be able to observe the discharge time