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Automotive Fuse Circuit Board

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The main goal of the work encompassed in this thesis was to answer a real need for a product from Sensible 4 Oy, which would allow for a faster and easier alternative to troubleshoot issues, while at the same time reducing the physical dimensions of components used and decreasing assembly time.

Briefly, the purpose of this product is to guarantee the safety of autonomous systems installed in manual vehicles and allow the control of the car to be safely switched between manual and autonomous mode.

The board was designed in KiCad and special attention was paid when choosing components to ensure that they were suitable for this application. Specifically, automotive components that met the AEC-Q200 standard were selected.

After a brief period where all project requirements and constraints were established, the design phase was initiated. A few flaws that were identified with the previous practices and components were added to the list of improvements to be implemented.

The selection of components took an unexpected long time, mainly due to the strict requirements for all components, although the lack of experience in this area might have played small role too.

While future improvements were already identified, which would further contribute to a better product, the final product meets all the requirements within the initial constraints and represents an improvement in safety and reliability.

For the aforementioned reasons, the outcome of this project can be regarded a success.

Keywords	PCB, Fuse, Power Distribution, Automotive

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List of Abbreviations

AD	Autonomous Driving.
ADCU	Autonomous Driving Computing Unit.
ADS	Autonomous Driving Software.
DIN	Deutsches Institut für Normung.
FET	Field-Effect Transistor.
LED	Light Emitting Diode.
PCB	Printed Circuit Board.
PWM	Pulse-with Modulation.
S4	Sensible 4 Oy.
SPL	Sound Pressure Level.
SMD	Surface Mount Device.
ZIF	Zero Insertion Force.

1 Introduction

Sensible 4 Oy is a Finnish technology company focused on development of self-driving software that stands out among its competitors for being able to allow vehicle operation in all weather conditions [1]. The company develops full-stack software solutions that allow any vehicle to become autonomous. The unique technology combines software and information from several different sensors to overcome obstacles and achieve optimal performance in various environments and different situations, including snowfall and fog.

To showcase the full-stack autonomous driving software in the best possible way the company created GACHA, the World's first self-driving bus for all weather conditions. Developed by Sensible 4 and designed in cooperation with MUJI, GACHA was made for everyday use for people around the world. It offers smart, safe, and sustainable on-demand transportation all year round. This award-winning autonomous shuttle bus can be fully integrated into existing public transportation systems and is an ideal use-case for last-mile transportation. [2.]

Although GACHA is the most internationally recognized product of Sensible 4 Oy, in the recent years several pilot programs have been deployed, in Finland and neighbour Scandinavian countries, which involved other vehicles that have been retrofitted for autonomous driving.

The process to retrofit an autonomous driving system in a conventional manual driven vehicle requires among others, the installation of extra sensors and actuators. An oversimplified explanation of the process would read: The full-stack software is responsible for processing the data gathered via sensors and control multiple actuators responsible of accelerating, braking, and steering the vehicle with the purpose of achieving autonomous driving. The scope of this project is resultant from the need to be able to electrically isolate these extra sensors and actuators from the vehicle's own systems to guarantee safety in case of a fault with the autonomous driving software (ADS) or hardware. No commercially available options fulfilled all the needs and limitations, hence a custom board had to be design.

2 Project Overview

This project arose from the need of a space saving solution which would also offer a better and faster method to troubleshoot some of the more common issues encountered during the operation of a previous version of the prototype.

A custom PCB was found to the most suitable solution after an extensive research and careful consideration of commercial off-the-shelf available products with similar functions.

Power distribution modules by e.g., Littelfuse, Motec, or Bussman are regarded as quality and proved products in the industry. Yet, no single product from their catalogues satisfied all the requirements and fit the constraints involved in this project.

The combination of more than one available product was considered, which could meet most of needs. However, the presence of unnecessary features, i.e., IP rating or control solutions, and the resultant accumulated price of this type of solution revealed to be forbidding so this option was discarded.

Another possibility studied was to divide the list of needs in smaller pieces: by buying an off-the-shelf product to meet some of the needs and designing a smaller custom PCB to fulfill the rest. Although this solution would in theory be more reliable and less time consuming in the designing phase, the trade-off was the added complexity in wiring due to the increased number of connectors, as well as the size and price of the resultant solution.

One last solution was shortly contemplated, to out-source the design of the custom PCB to a third party. Though, this was quickly disregarded since the team involved was comprised of fully capable and skillful engineers.

The focus of this project is a small but vital piece of a much wider and complex autonomous driving (AD) system solution. The simplified architectural layout, exhibited in figure 1, sheds some light on the important role of this custom PCB.

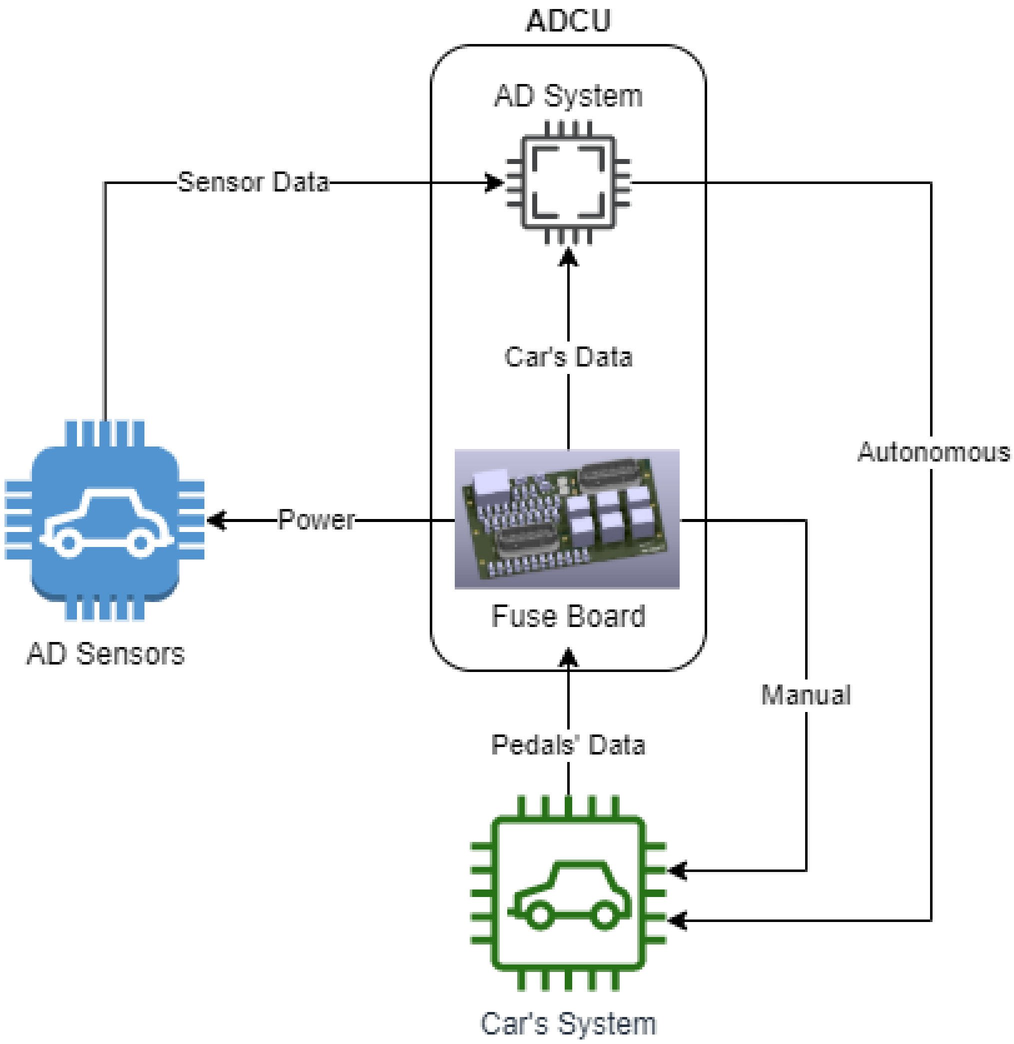

Figure 1. Simplified architectural layout of the AD solution implemented by S4

The power used to supply all AD systems thru the fuse board is coming from a secondary battery installed in parallel with the vehicle's own. A relay guarantees the two batteries are isolated whenever the AD system is shutdown.

2.1 Project Requirements

Safety and reliability were the top concerns for this project for it will play a key role in the operation of an autonomous vehicle where passengers are involved.

The requirements that determined the quality of the final product and satisfaction of the client were:

- Accommodate two different voltages supplies (Main 1 and Main 2)
- Presence of light indicators for fuses status.
- Presence of light indicators for relay status.
- Integration of a sound indicator.
- Implementation of a temperature measuring device.
- Reduction of wiring.
- Reduction of component size.
- Facilitate replacement of fuses and relays.
- Provide spare fuses and relays for possible future features.
- Temperature monitor feature.
- Adequate cover and attachment options.

2.2 Project Constraints

The main constraint for this project was space. The final product was to be installed in an ADCU case among various other large components, so space dictated the maximum dimensions of the PCB. All components used needed to comply with the automotive AEC-Q200 standard to ensure safety and a reliable performance.

3 Component Selection

3.1 Connector

When choosing the connectors, the top considerations were the current rates and suitable number of pins for the application. High priority was then given to automotive connectors due to the rough environment in which they are used and to make sure it would comply with industry standards which include properties like positive locking - to make sure the connector never becomes accidentally loose, or temperature and humidity ratings which are unusual for tabletop uses. Finally, the shape, availability and insertion-release method were then evaluated and compared to reach the final solution.

ZIF connectors, namely the ITT DL series, were briefly a candidate, due to good previous personal experience while working on a motorsport project and to minimize the possible damage to the PCB or connector due to misuse. However, the available options were not suitable either due to current ratings or because the locking mechanism required extra tools.

The best solution found that checked all the requirements was provided by TE Connectivity which is a major and well-known manufacturer with an extensive automotive catalogue of all kinds of parts and components. The connector selected, presented in figure 2, is comprised of two mating sides; the wire-to-board header that is assembled straight to the PCB and the correspondent housing that completes the pair.

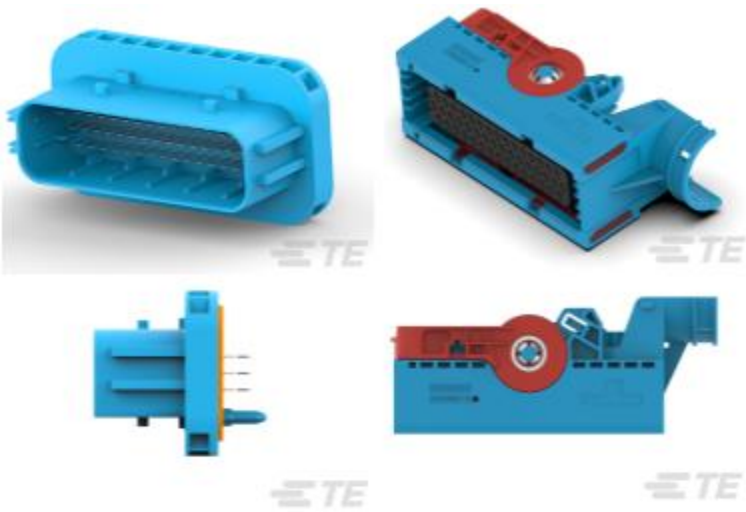

Figure 2. TE Connectivity connector chosen for this application [3]

The mating housing had a particular feature provided by the red latch, shown in figure 2, which works both as positive locking and as an easy-to-remove mechanisms for the connector, avoiding the accidental damage to both connector and PCB and reducing the possibility of mishandling it.

With the objective in mind to eliminate some of the wiring needed between the PCB and the interface with the exterior of the ADCU enclosure, an attempt was made to find a connector that not only fulfilled all the requirements above mentioned but would also be possible to secure directly to the interface panel of the ADCU enclosure. Upon further investigation and debate with some colleagues, that idea was abandoned mainly because the arrangement of the other components inside the enclosure would be an obstacle but also due to the forces exerted on PCB resultant of its weight and normal operation of the vehicle: vibrations and acceleration in different directions.

For the power supply and ground a different connector was needed since the current ratings had to be much higher which resulted in a wire cross section area very large. For simplicity and reliability, a wire-to-board connector was chosen with screwless terminals to minimize the risk of screws being loose as result of vibrations or simple human error.

3.2 Fuse

The fuse type selection was quite simple and straight forward due to the options in the existing market for automotive industry.

In the end, when choosing the type, the decision was between either mini or regular blade fuses since these are the most widely available and easy to replace. Due to space constraints the mini version was favoured, represented in figure 3.

A further analysis was necessary to make sure that the fuse was the best option and offered adequate protection.

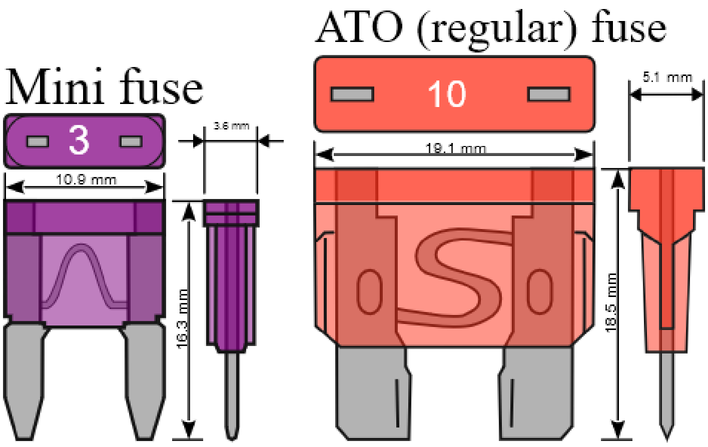

Figure 3. Blade fuse size considered for the application [4]

However, when picking the adequate ratings, the choice was not as straight forward since there were five different, fuse specific, parameters to consider: voltage rating, interrupting rating, time-current characteristics, current rating, and transient overcurrent [5]. Furthermore, application specific considerations like wire gauge or trace width matching and voltage drop across terminals had to be contemplated. Lastly, in scope of this particular project, the fuse holder was to be considered when making the final decision.

The mini blade fuses withstood scrutiny even after all parameters were analysed in depth and worst-case scenarios were accounted for, especially the temperature derating and melting-current curves.

Although the regular size has a faster response when compared to the mini size, evident by comparing figure 4 and figure 5, the difference was deemed negligible and overweighted by the physical size of both options and respective matching holders.

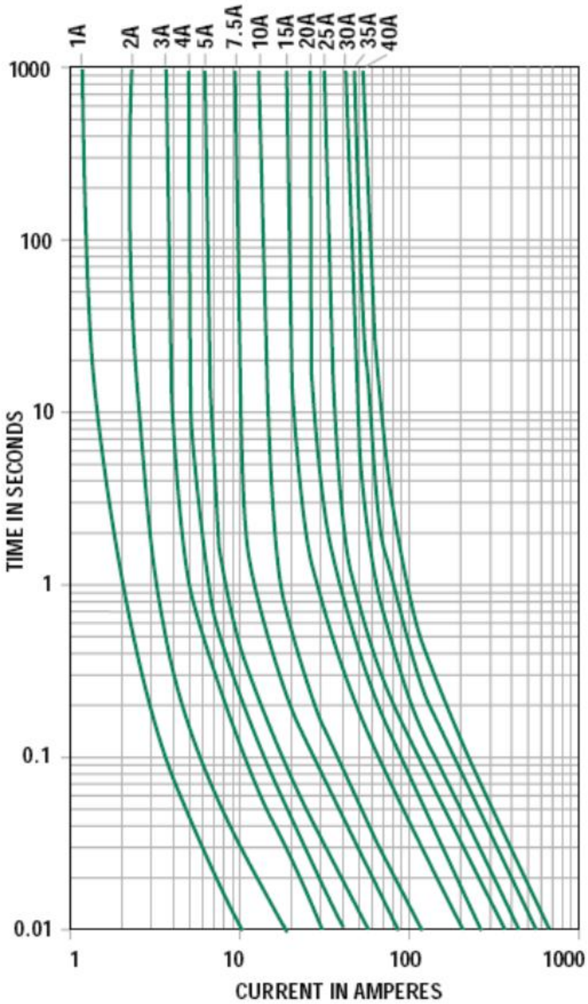

Figure 4. Characteristic average melting-current curve for regular blade fuse [6]

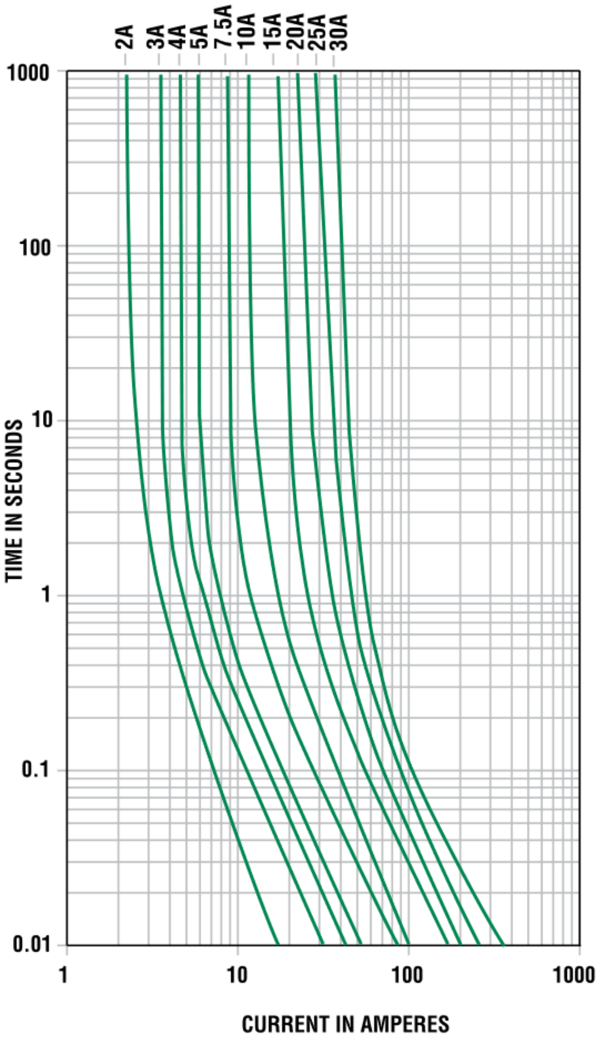

Figure 5. Characteristic average melting-current curve for mini blade fuse [7]

The fuse holder chosen was a thru-hole component instead of SMD to avoid mechanic damage when removing and inserting fuses. SMD option would pose the risks of pads lifting or even getting ripped off due when replacing fuses or in case of misuse.

3.3 Relay

The choice of relay was the most time-consuming task among all component choices. Due to lack of automotive options that satisfied the requirements the components chosen were industrial grade components – the next best alternative for our purposes.

While there are several types of relays, currently these are mainly divided by the principle of operation, either electromechanical, solid state or a combination of both (hybrid), and further sub grouped by contact configuration, listed in figure 6.

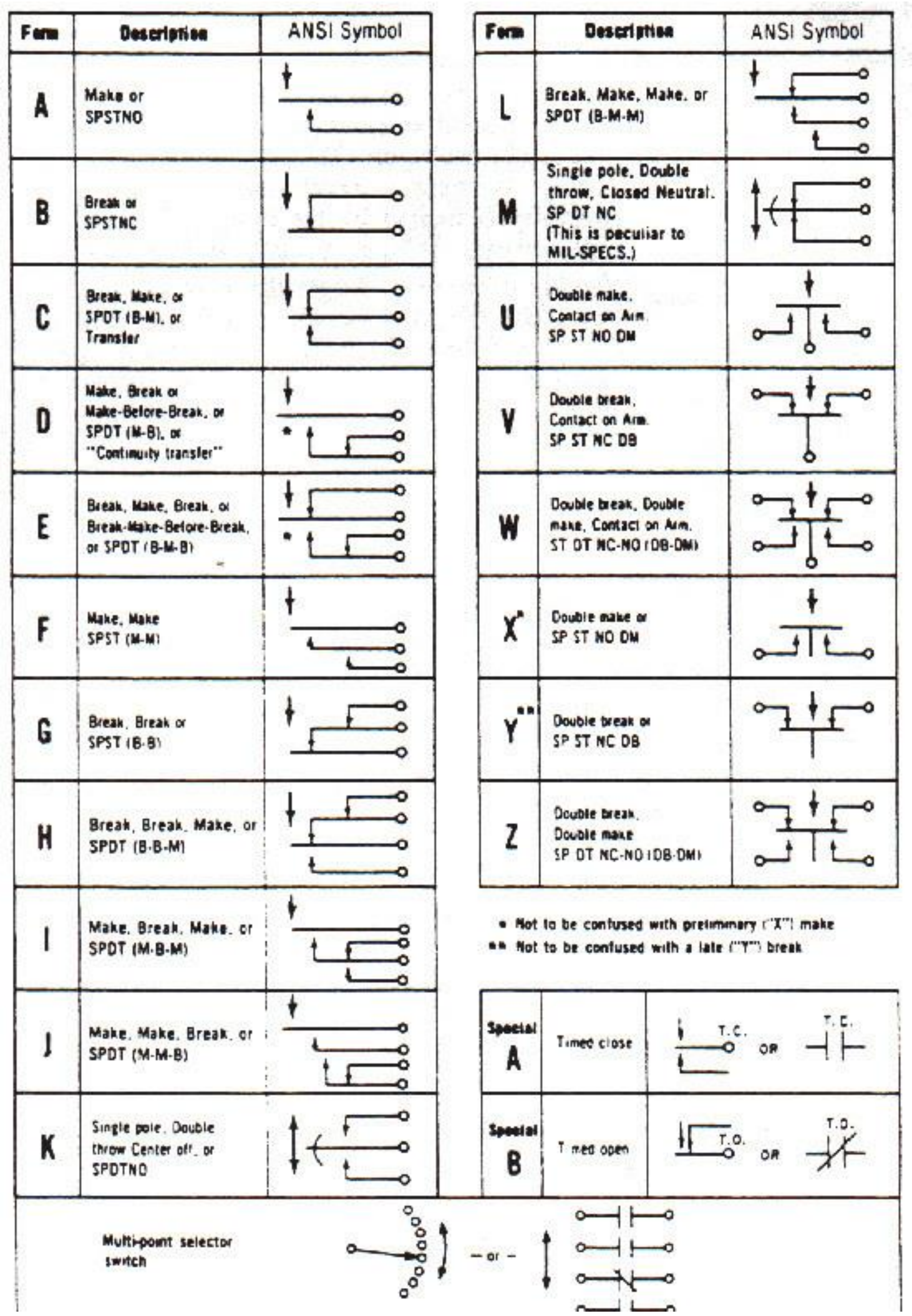

Figure 6. Contact configurations of relays [8]

The main function of the relays in this project was to implement a hardware isolation between the vehicle's own systems and the company's installed autonomous systems, allowing a safe disengagement of the autonomous driving which did not rely only on software. For that purpose, various signals were switched between autonomous and manual driving modes, most of them having the same trigger.

Another factor of major importance, that made the choice so arduous, was serviceability. The option to replace relays without the need of specialized tools and in a relatively quick and safe manner determined that only socketable versions were a real option for this application.

The final choice was a 4 Form C type Miniature Relay PT from Schrack and respective PCB mounted socket, observed in figure 7, which allowed up to 4 signals to be controlled at the same time with a single trigger, increasing reliability as delays on the switching of redundant signals could lead to false error and conflicts in the vehicle's systems while saving some space in the process.

Figure 7. Miniature Relay PT570012 diagram, relay body and PCB mounted socket [9]

All the original vehicle's systems were connected via the normally closed position of the contact configuration so that in case of failure the control of the vehicle would always revert to the manufacturer's settings.

3.4 Buzzer

The buzzer played a crucial role in this project since it was the most obvious and only audio signal used to inform the vehicle's operator that the systems were switched between autonomous and manual modes and vice-versa. From the feedback received, after the first prototype that was used in the field, there was a clear need for the ability to adjust the sound level. Furthermore, upon design review, the lack of a spare buzzer and a way to monitor the state of these components was a critical flaw that needed fixing.

When choosing the buzzer, the main concern was to make sure it was loud enough for the operator to be aware of it. An important consideration was the fact that the PCB would be installed inside an enclosure used in an environment where the base noise level can be quite high, mainly due to traffic and the vehicle's radio usage.

There are two main types of audio transducers, piezo and magnetic buzzers. Both have advantages and disadvantages and the choice of one over the other usually depends on the application. While the piezo transducers can be used in a much wider voltage range at lower currents, 3~250 V @ 15~30 mA; magnetic are generally rated for up to 16 V and required 30~100 mA to perform optimally. Piezo transducers are typically rated for higher frequencies and can produce higher sound pressure levels when compare to its counterpart.

Sound pressure level (SPL), denoted as L_p and represented in decibels (dB), measures the effective pressure of sound relative to a reference value in a logarithmic scale. It is calculated using equation 1:

$$L_p = 20\ \log_{10}\left(\frac{p}{p_0}\right)\ dB \quad (1)$$

Where:

- p is the root mean square sound pressure
- p_0 is the reference sound pressure used, commonly p_0 = 20 µPa in air, which is considered the threshold of a normal human listener for a sound frequency of 1 kHz.

Upon comparing the SPL of different day-to-day activities, as shown in table 1, it was decided that the buzzer chosen should be able to produce a sound pressure level between 80 and 90 dB to be effectively used as a critical indicator and be considered loud enough.

Table 1. Comparison of different SPL's [10]

Sound Source	Sound Pressure [Pa]	Sound Pressure Level at 1 m [dB]
Rifle	200	140
Threshold of pain	20	120
Pneumatic hammer	2	100
Street traffic	0.2	80
Talking	0.02	60
Library	0.002	40
Night at quiet rural area	0.0002	20
Threshold of hearing	20×10^{-6}	0

Although it was theoretically possible to use an audio indicator which includes the driving circuitry for the transducer, in practice, the controller used could not supply the adequate current to drive it. Instead, a driverless transducer was chosen and the required circuitry, demonstrated in figure 8, was designed and implemented to match the requirements.

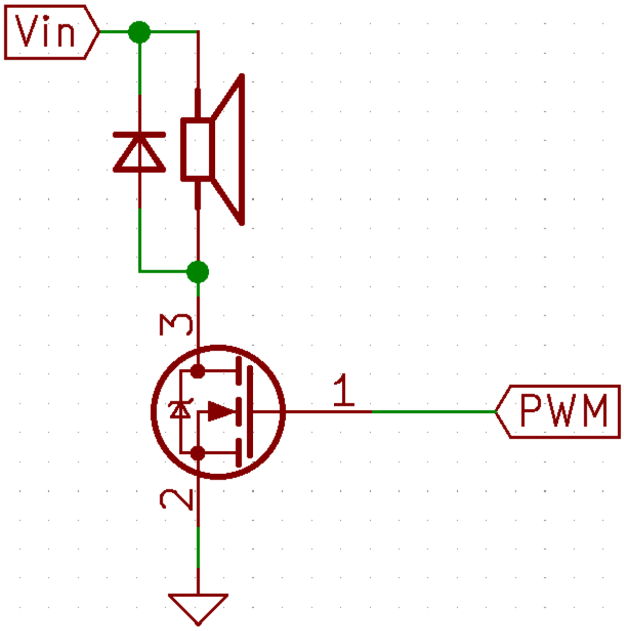

Figure 8. Audio transducer circuitry example

The final choice was a magnetic buzzer transducer able to produce an SPL of 90 dB @ 12 V when measured at 10 cm. Although 90 dB might be considered quite loud for an audio signal inside a quiet vehicle parked in a garage, it was necessary to account for the worst-case scenario where the audio device was installed inside an enclosure while the vehicle was being driven in a busy road, with windows down and radio playing.

3.5 Temperature Sensor

The TMP236AQDBZRQ1 analogue temperature sensor by Texas Instruments was selected by the client but to be integrated in this project the datasheet was consulted to double check the suitability (ratings and standards) of this component, follow the manufacturer guidelines and account for the possible necessary external circuitry for proper performance. For redundancy, two sensors were installed in the PCB.

3.6 Other Components

The imperial size 1206 was preferred when picking capacitors, resistors, and LEDs, because it was deemed a good trade-off between footprint size and ease to solder in case maintenance or replacement was necessary.

The picked LEDs were green because they indicated that the correspondent component was being powered and working properly. For the FET chosen, the widely used SOT-23 package was preferred over other available packages, mainly due to size. Once again, all previous components met the required standards for automotive use.

3.7 Enclosure and Attachment

Due to the exposed leads of the thru-hole components and pads of the SMD ones, there was a need to design and manufacture a protective cover for the PCB to avoid short circuits. This cover should be designed in a way that also provides some support to alleviate the mechanical stress of inserting and removing fuses, relays, and connectors. Finally, the whole board and cover needed to be secured inside the ADCU box in a way that would withstand the normal operation of the vehicle. Both the design and manufacturing of cover and attachments were executed, under close collaboration, by a colleague with suitable knowledge and experience.

4 Calculations

4.1 LED Serial Resistor Value

A serial resistor was needed for each LED that was used as status indicator. The chosen LED had a voltage drop of 3.2 V and a current of 20 mA was necessary for optimal performance. The power supply was the vehicle's battery with range 11 – 14 V, depending on the charge left and if the vehicle's alternator that is responsible for charging the battery is active or not. With this data and using Ohm's Law, equation 2, it was possible to calculate the resistor value.

$$V = I * R \qquad (2)$$

To ensure that the current was never over 20 mA, the calculations were made using assuming that the voltage source was 14 V, equation 3.

$$R = \frac{14\,V - 3.2\,V}{20\,mA} = 540\,\Omega \qquad (3)$$

The closest, immediately higher, standard value of a E24 series resistor corresponded to 560 Ω, with a 5% tolerance, good enough as no better alternative was found at a similar price point.

Equation 4 was used to calculate the power dissipated by the resistor.

$$P = R * I^2 \Rightarrow P = 560\,\Omega * (20\,mA)^2 = 224\,mW \qquad (4)$$

The ¼ W or 250 mW resistor would be adequate to this application. Although equation 4 has a small error since the current is no longer 20 mA but 19.3 mA, due to bigger value resistor used, the difference is irrelevant since the voltage source is not constant.

4.2 Buzzer Serial Resistor Value

Similarly, the buzzer required a serial resistor to limit the current to 30 mA, Ohm's Law was used to determine the adequate resistor value, equation 5.

$$R = \frac{14\,V}{30\,mA} = 467\,\Omega \qquad (5)$$

The closest, immediately higher, standard value of a E24 series resistor was 470 Ω, with a 5% tolerance, good enough as no better option was found for a similar price.

Equation 6 was used to calculate the power dissipated by the resistor.

$$P = R * I^2 \Rightarrow P = 470\,\Omega * (30\,mA)^2 = 423\,mW \qquad (6)$$

In this case the 250 mW rated resistor is no longer suitable, one with at least ½ W rating must be used.

4.3 PCB Trace Widths

The fuses to be used on the final product had different ratings depending on the device or equipment being protected. The calculations of the specific fuse ratings according to each device, wire length and respective cross-section was outside the scope of this project, instead, a list with the required fuses was provided to determine all trace dimensions, table 2.

Table 2. Total number of fuses to be implemented with respective ratings and power supply.

	Power Supply									
	Main 1					Main 2				
Fuse rating [A]	2	3	5	(2)	(3)	2	5	15	30	(3)
Total number	17	6	3	2	2	1	2	1	1	2

The fuse ratings in between parenthesis in table 2 represent the spare fuses.

Using the general equation 7 from the IPC-2221B [11], available as a calculator in KiCad, the trace widths were calculated.

$$I = 0.048 * \Delta T^{0.44} * (W * H)^{0.725} \quad (7)$$

Where:

- I = maximum current in amperes
- ΔT = temperature rise above ambient in degrees Celsius
- W, H = width and thickness of trace in mils

The thickness of the traces was determined by the ounce of copper per feet square (oz/ft^2) of the PCB layer. In order to keep the traces relatively thin without increasing the price of boards by a lot, the option of having 2 oz/ft^2 was selected when the PCB were ordered, corresponding to a trace thickness of 2.688 mils.

The temperature rise allowed was slightly dependent on the environment in which the vehicle would be operating. Though, since all vehicles used were equipped with air conditioning, it was safe to assume that the ambient temperature would be set at around 21 degrees Celsius which permit a rise of about 30 degrees Celsius before any significant derating of fuses [5].

The last parameter required to calculate the width was the maximum current in amperes. To make sure the fuse would trigger before any trace was damaged, the width was calculated for the respective rating plus five amperes, which resulted in added safety at the cost of oversized traces. Table 3 summarizes the resultant trace widths to be used on the layout of the board.

Table 3. Trace width calculation results and real widths used on the PCB

Fuse rating [A]	2	3	5	15
I (equation 7) [A]	7	8	10	20
Calculated width [mils]	38	45	62	161
Trace width used [mils]	35	50	100	160

To note that the pins of the connector used were rated for 23 A and not 30 A but it was already accounted for upon selection since the device that is being protected by this fuse used two pins for supply. Hence, it was also possible and convenient to use two pins of the PCB connector to stay under the maximum allowed current per pin. The width calculations for this were done as a two times 15 A instead of a trace width for 30 A.

5 Measurements and Tests

After the selection and necessary calculations, a few of the components were ordered so as to validate the choices made.

To test the LED, a lead was soldered to each of the poles of the component since it was impossible to use alligator clip connectors due to its size. A protoboard was then used to wire the resistor of the calculated value in series and the power supply, demonstrated in figure 9.

Figure 9. LED test setup

Power was supplied to the LED for about one hour while being monitored for any changes in brightness, possible burn out and the current used.

The test ran smoothly and without a noteworthy event.

During the buzzer test, an Arduino was used as a PWM generator due to the lack of a bench wave generator device and for the simplicity of coding compared to the controller that would represent the real-case use. Also, the flyback diode was left out during this test because the bench power supply can handle inductive loads.

Once again, a protoboard was utilized to connect all the necessary components and wires, as shown in figure 10.

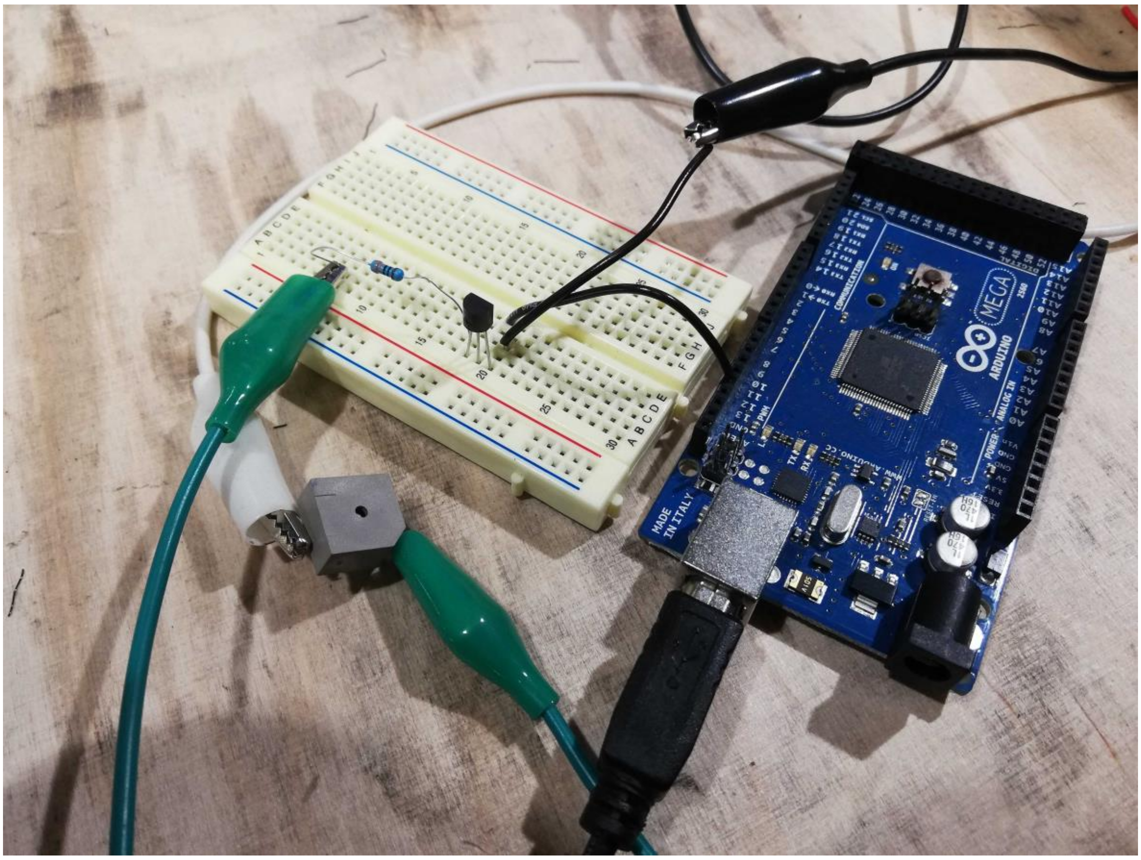

Figure 10. Buzzer test setup

The test encompassed several steps due to the main three variables that could affect the SPL produced by the buzzer during the real case use in the vehicle: voltage, frequency, and duty cycle.

The voltage was varied between 11 and 14 volts in one-volt intervals to represent the different state of charge of the vehicle's battery during normal use. As expected, this variable had no effect in the SPL produced by buzzer selected since the electromagnetic element contained it is driven by current and not voltage.

By varying the duty cycle between 25% and 75% the tone of the audio signal was slightly affected. However, the change was so nuanced that this variable was not considered important when driving the buzzer.

The remaining variable to be tested was the frequency, the device's datasheet indicated both the lower and upper limit, 2000 Hz and 2800 Hz respectively. During this test, it became clear that frequency was the main factor that controlled the SPL of the device; by significantly affecting the pitch of the produced audio signal, the perceived "loudness" was as well affected.

To test the selected temperature sensor its datasheet was consulted, and instructions followed regarding pinout. Similarly, to the LED, leads had to soldered to the component pins to allow a good and reliable connection, pictured in figure 11. These leads might have affected the results obtained since they were a piece of copper wire which is a good heat conductor.

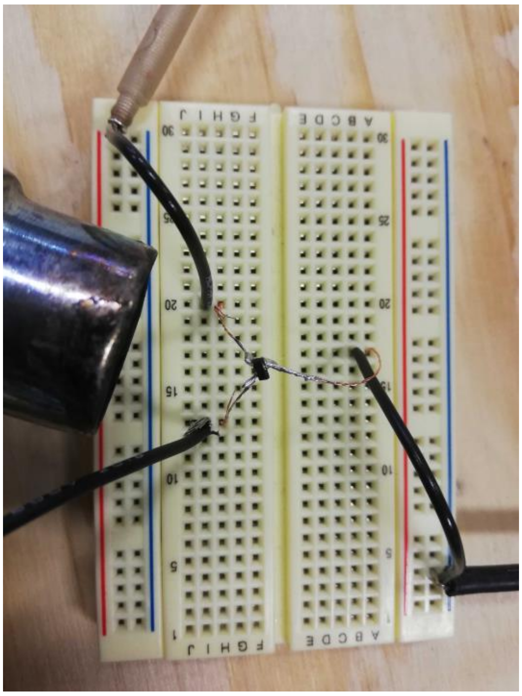

Figure 11. Enhanced view of the protoboard setup used for testing the temperature sensor

The nozzle present in figure 11 and 12 belonged to a heat gun which temperature could be adjust from 50 to 210 degrees Celsius in 10-degree intervals. Although its accuracy was not to be heavily relied upon, it was a decent tool to gather some data.

Figure 12. Temperature sensor test setup

The testing setup, shown on figure 12, included a PicoScope Automotive and respective software used to record the data presented in figure 13.

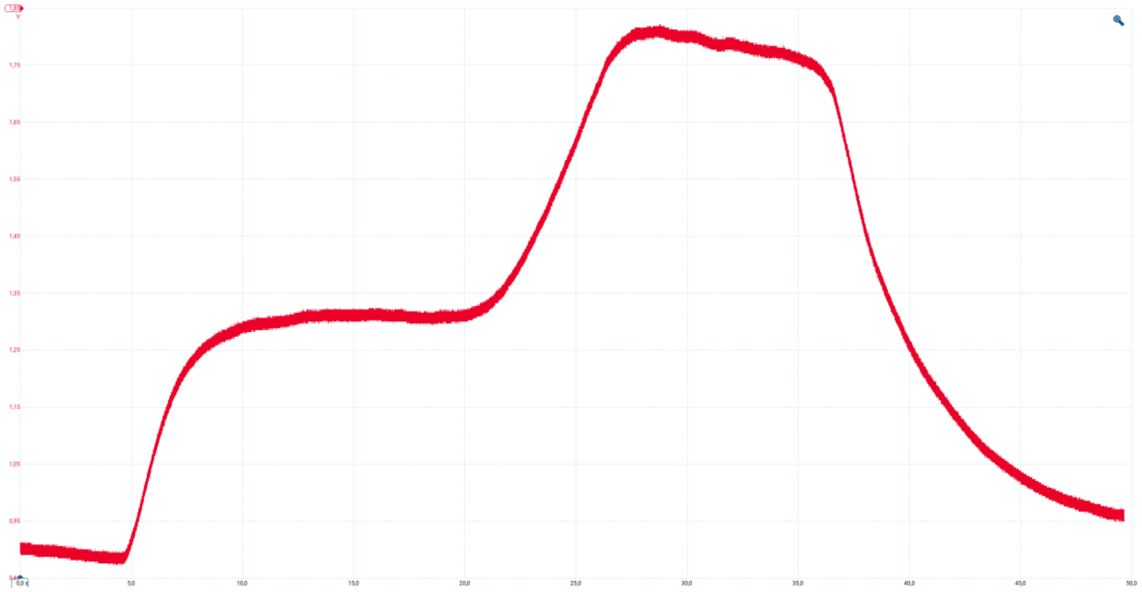

Figure 13. Measurement of voltage output of temperature sensor. Volts on the Y-axis in 0.1 V intervals from 0.85 V to 1.85 V; and time in five-second intervals in the X-axis.

The data presented in figure 13 was obtained by recording the initial ambient temperature for five seconds, then using the heat gun set at 50 degrees Celsius to warm up the device and after 15 seconds when it seemed stabilized the temperature was them changed to 90 degrees Celsius. Another 15 seconds were given and finally the heat gun was disabled, and the temperature sensor was allowed to cool off.

This data, when accounting for setup and measurement conditions, is in line with the numbers consulted on the device's datasheet.

6 Schematic

To design the schematic a free software was used - KiCad 5.1.9. Although not as full of features as some other paid software, the fact that previous experience with KiCad had been acquired and that it was already being used by the company for other projects made the software selection easy.

The following section presents some of the key schematics in detail along with the decisions behind them. The full schematic can be found in appendix 1.

6.1 Fuse

For the implementation of the indicator status light of the fuse a simple circuitry as shown in figure 14 was used.

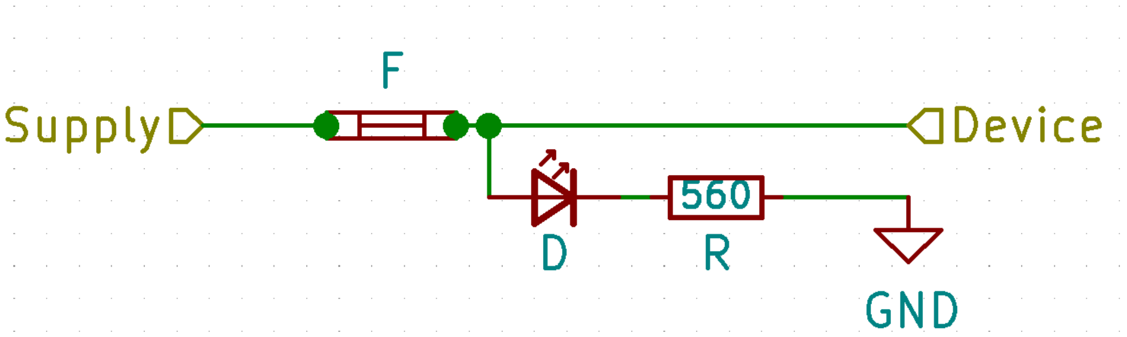

Figure 14. Fuse with status light schematic

The status light was not to be an absolute and definitive troubleshoot feature but more of a starting point and a quick way to hint if the fuse had been blown or not.

A problem with power supply, a broken LED or a broken resistor would be undistinguishable from a blown fuse at first glance. Yet, the fact that the LED is OFF makes it easier to first check if the fuse needs replacing before proceeding with further steps to find the root of the problem.

6.2 Buzzer

When analysing the schematic present in figure 15, the diode in parallel with the buzzer serves to eliminate flyback. Because the magnetic buzzer constitutes an inductive load it will create a sudden voltage spike when the supply current is suddenly reduced or interrupted, to avoid possible damage due to this spike, a flyback diode is used.

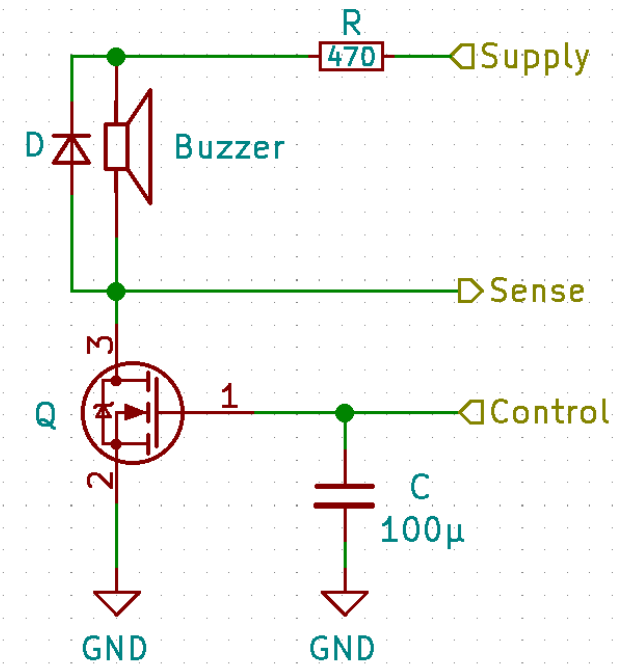

Figure 15. Buzzer schematic

The capacitor in the previous schematic is required as per datasheet of the controller used to switch the N-Channel MOSFET, that drives the buzzer.

Since there was a need to ensure that the buzzer was working correctly the solution found was to monitor the output of the buzzer (Sense), this signal will work as a feedback that the controlled can compare to the PWM signal (Control) being output, allowing for some basic check on the status of the buzzer and the possibility to switch to the backup audio indicator in case of failure.

6.3 Pedals' Relays

As mentioned in section 3.3, relays were used to switch between autonomous and manual drive regarding the control of accelerator and brake.

Figure 16 shows how that is achieved by controlling the output of four signals, two throttle pedal signals (TPS) and two brake pedal signals (BPS), with a single trigger that controls relays K5 and K6.

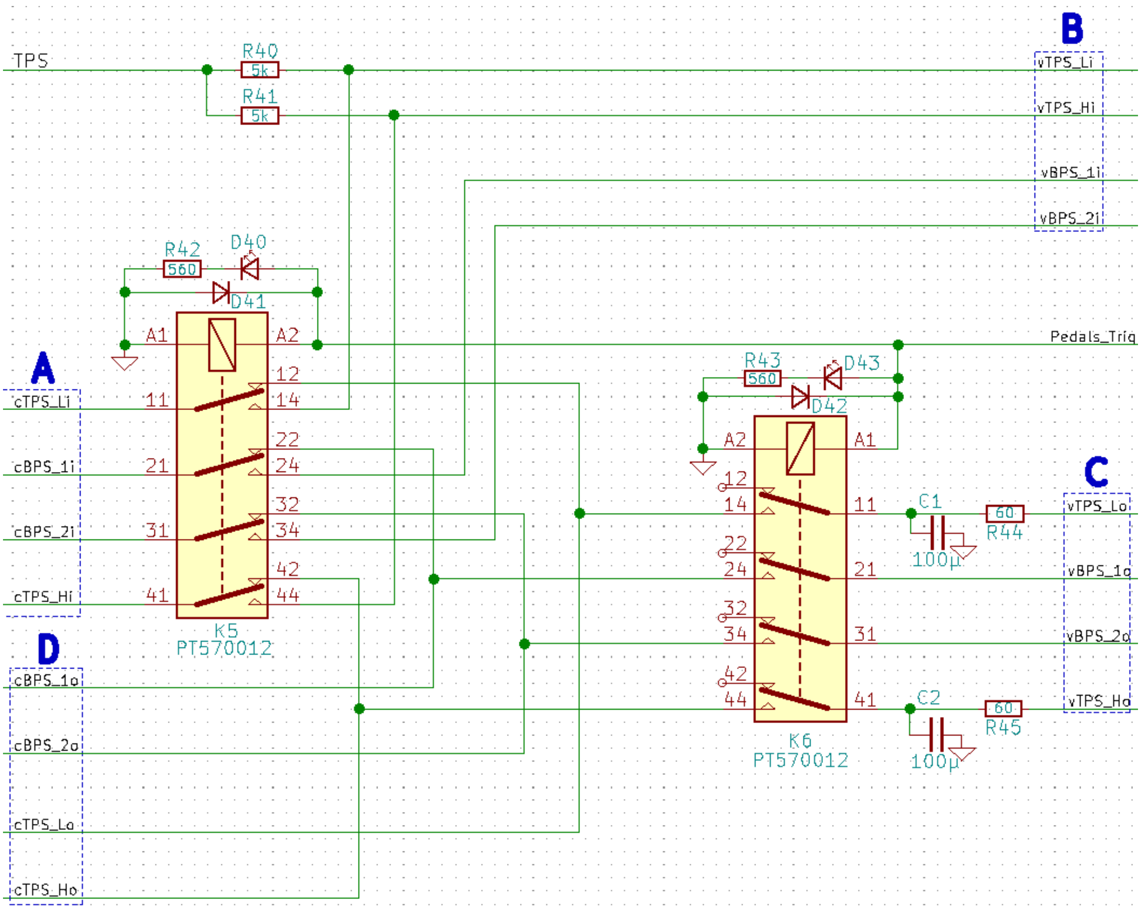

Figure 16. Control of signals from throttle and brake pedals

In summary, signals marked A are prevenient from the pedals of the vehicle and will be passed onto D when in manual mode (relays deactivated). But, when in autonomous mode (relays active) signals C are originated from a controller and are the ones being passed onto D to control the vehicle, during this mode the pedals signals A are also being monitored by the same controller through B in case the driver wants to bypass the autonomous commands.

For the same reasons stated in the previous section, the relays required a flyback diode in parallel with the coil (D41 and D42).

The LEDs provide an easy diagnose tool to indicate the status of the relay, although ideally connected to one of the contacts instead of in parallel with the coil, in this situation it was not possible since all contacts were being use, as demonstrated in figure 16. Consequently, this LED will only indicate if the coil is energized or not, rather than the position of the contacts.

The 5 kΩ resistors (R40 and R41) were determined necessary pull-ups when reverse-engineering the throttle pedal signals.

Finally, the low pass RC filters formed by the pairs R44 & C1 and R45 & C2 were proved necessary when noise issues were encountered in the first iteration of the prototype.

6.4 Handbrake Control

The handbrake control is also done with 2 relays, the same way as described in previous section for the signals from both pedals.

7 Layout

After the schematic was finished and re-checked the next step was to create the necessary footprints of the selected components.

Although KiCad's library includes a vast number of components besides the most standard packages, a choice was made to create all the footprints for all the components to guarantee that no mistakes were made.

Due to the dimension's constraints, the most time-consuming task was to figure out the arrangement of the PCB components in such a small board. Via the involvement in the planning and arrangement of all other devices inside the ADCU box and extensive discussions about all decision made, it is believed that smartest disposition of the board components was reached as demonstrated in figure 17.

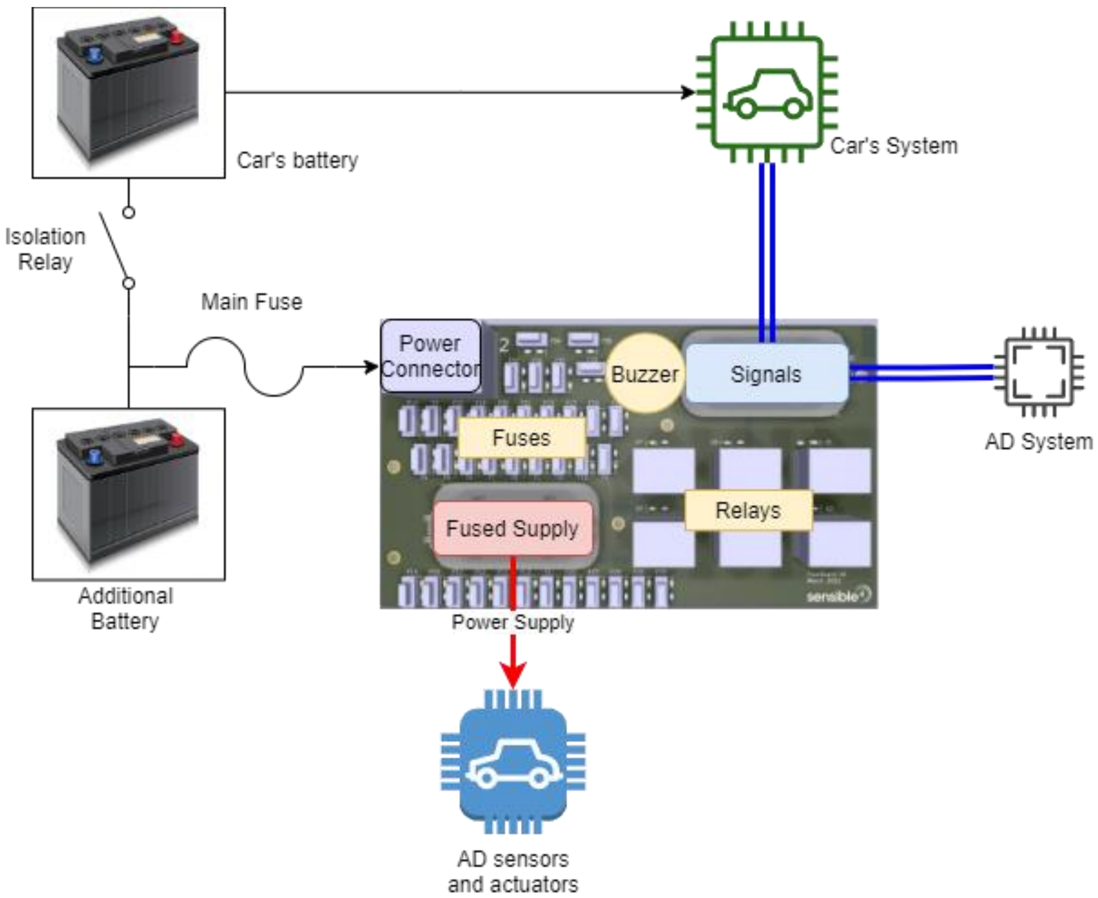

Figure 17. Diagram of components and respective function

For correct dimensions of components and landing patterns not only the datasheets of all components were consulted but also the manufacturing capabilities and tolerances of the PCB manufacturer [12].

A four-layer approach was reasoned best due to the high current at the board input. All traces were routed in the external layers, which were subsequently filled with grounded copper. As for the internal layers, one of them was used for power and the other an additional ground layer. A numbering technique at the corner of the PCB was used to confirm all layers where present upon receiving the final product from the manufacturer, demonstrated in figure 18, where the green outline represents a keep out for all copper layers and the number are copper from each of the correspondent layers.

Figure 18. Layer numbering for post-inspection

Although some of the thru-hole components had ground pins that would confirm the connection between ground layers, stitching vias were still as a good practice.

The final layout and bill of materials can be consulted in appendix 2 and appendix 3 respectively.

8 Conclusion

The initial objective was to design a board that fulfilled very specific requirements while obeying strict limitations with the aim of replacing a plethora of large DIN rail mounted components, with excessive connections and complex wiring, in order to improve safety, reliability and manufacturability.

The final product represents the culmination of numerous weeks of methodical work, and different iterations for various improvements; it is believed that it meets all requirements set and it will have a return on the time and resources invested during the next few months when it starts to be used after thorough bench testing.

Besides the implementation of redundancy for some critical functions and the very important addition of status LEDs to all fuses and relays and, all connections and terminals that were previously spread across nearly 50 components, distributed all over the ADCU, will now be grouped neatly into three connectors, simplifying the manufacturing process and reducing drastically the wiring involve. Lastly, the volume occupied by the board inside the ADCU is nearly half of the solution previously used.

Unfortunately, due to some setbacks it was not possible to have the final product in hand at the time of completion of this thesis. Nonetheless, thanks to the detailed work and peer review to which the different phases of this project were subjected to, quality and conformity are substantiated.

On future iterations of this PCB a couple of features could be implemented which, although not critical, would provide more information that could be used to troubleshoot eventual upcoming issues.

A humidity sensor would be a possible good addition to monitor the ambient inside the ADCU and a current monitor could provide valuable data to validate the theoretical calculations and the information gathered from the different datasheets of the devices and equipment being fused through this circuit board. Also, an attempt should be made to place all components on a single side of the board to reduce costs of assembly and facilitate visual inspection as well as bench testing.

9 References

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Appendix 1. Fuse Circuit Board Complete Schematic

In this section the full schematic design in Kicad is presented. Figure 1-1 contains all the connectors and fuses with status LEDs as well as all the sub sheets for different systems in the figures 1-2, 1-3, 1-4 and 1-5.

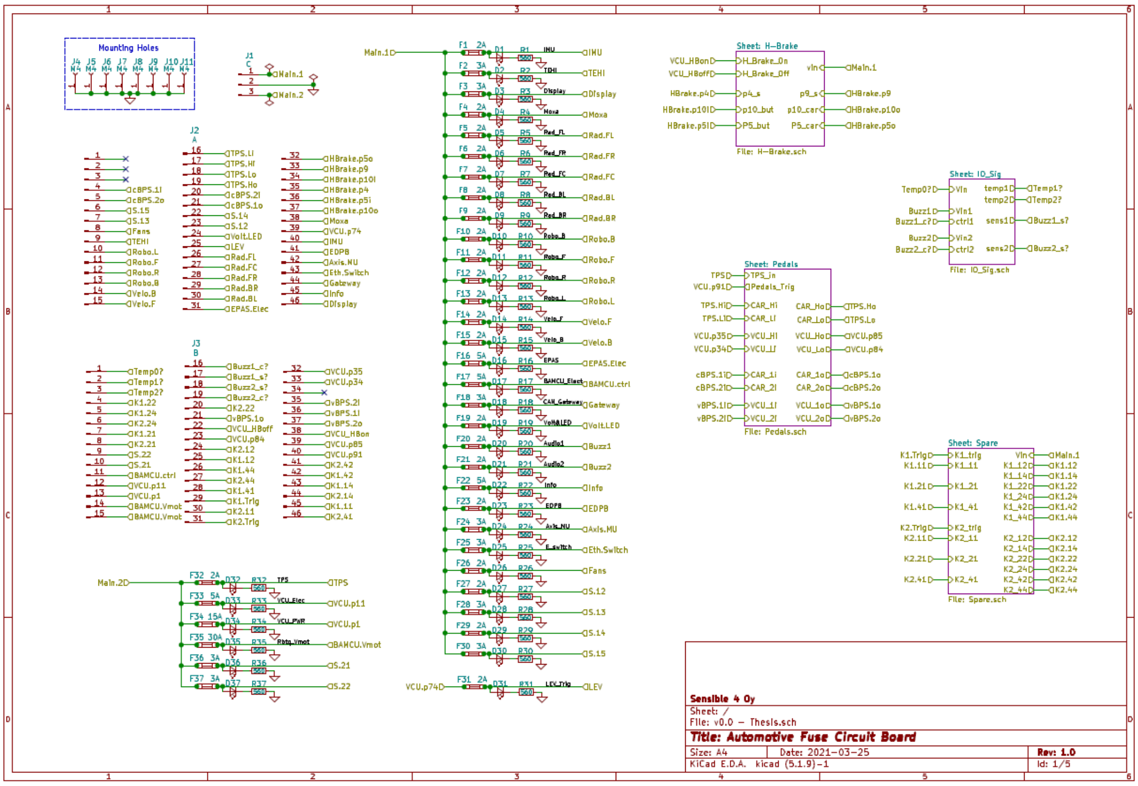

Figure 1-1. Full schematic with sub sheets.

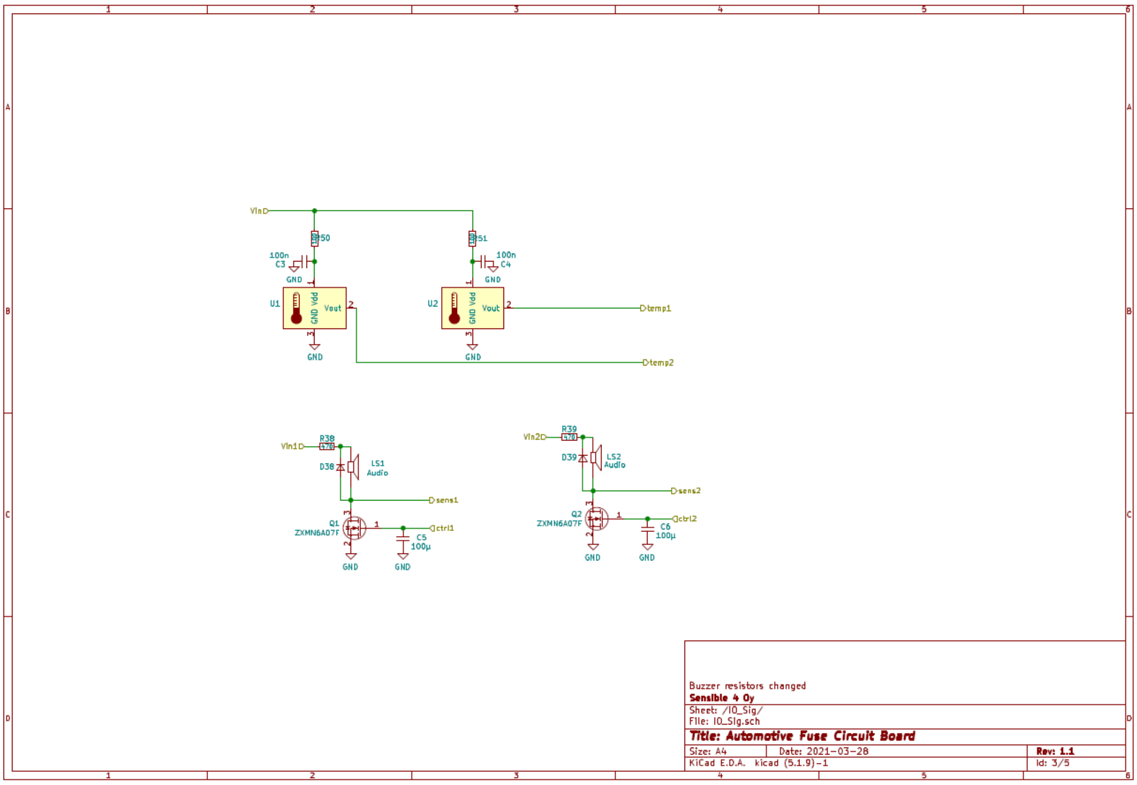

Figure 1-2. Buzzer and temperature sensor schematics

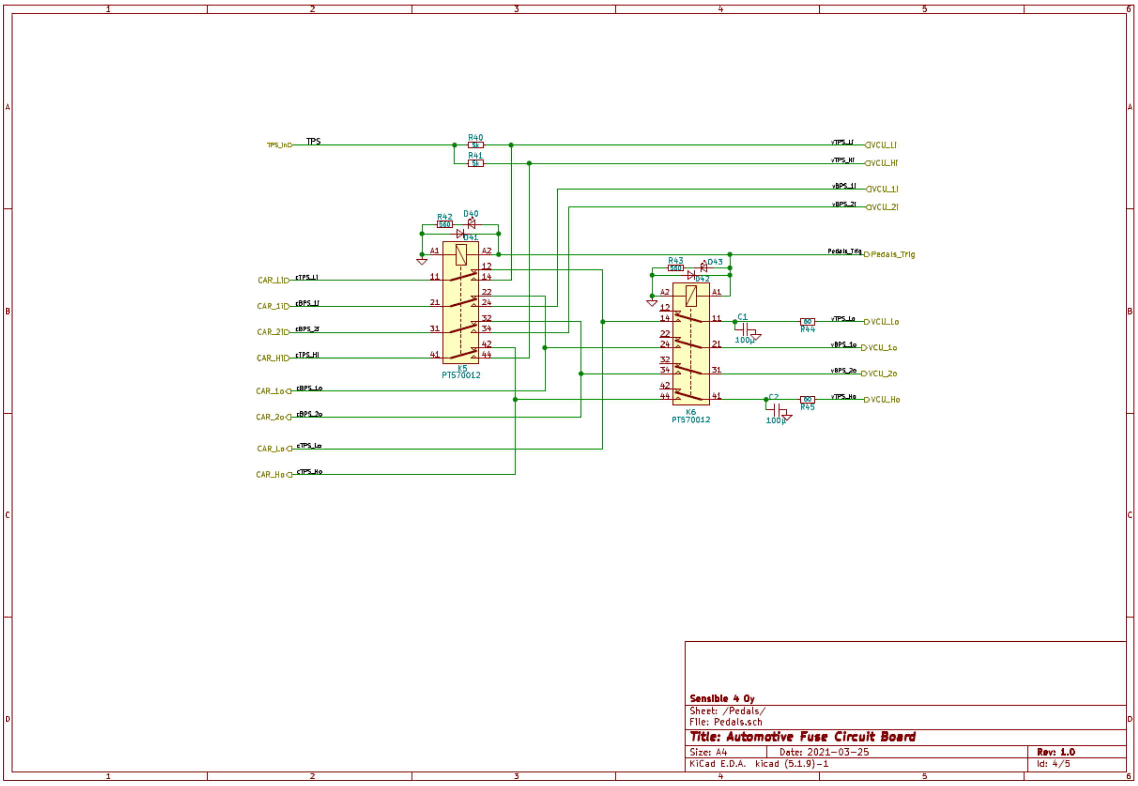

Figure 1-3. Schematic for handling signals from throttle and brake pedals

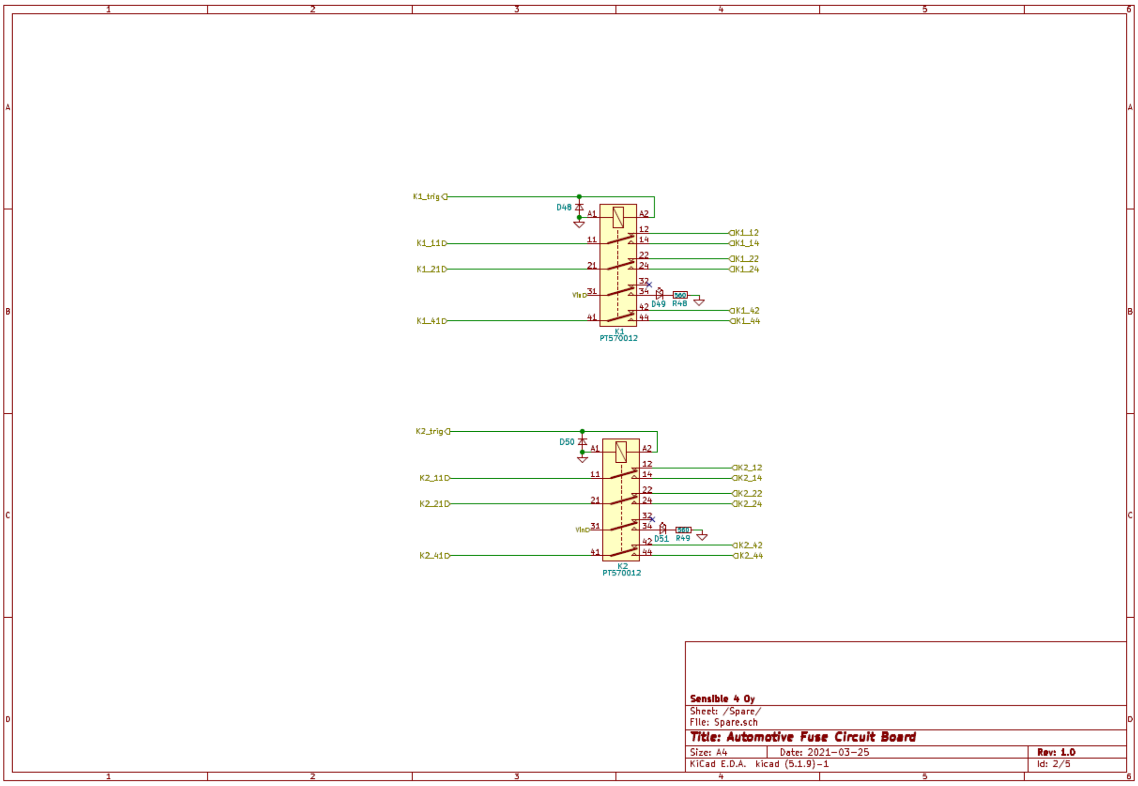

Figure 1-4. Schematic for spare relays

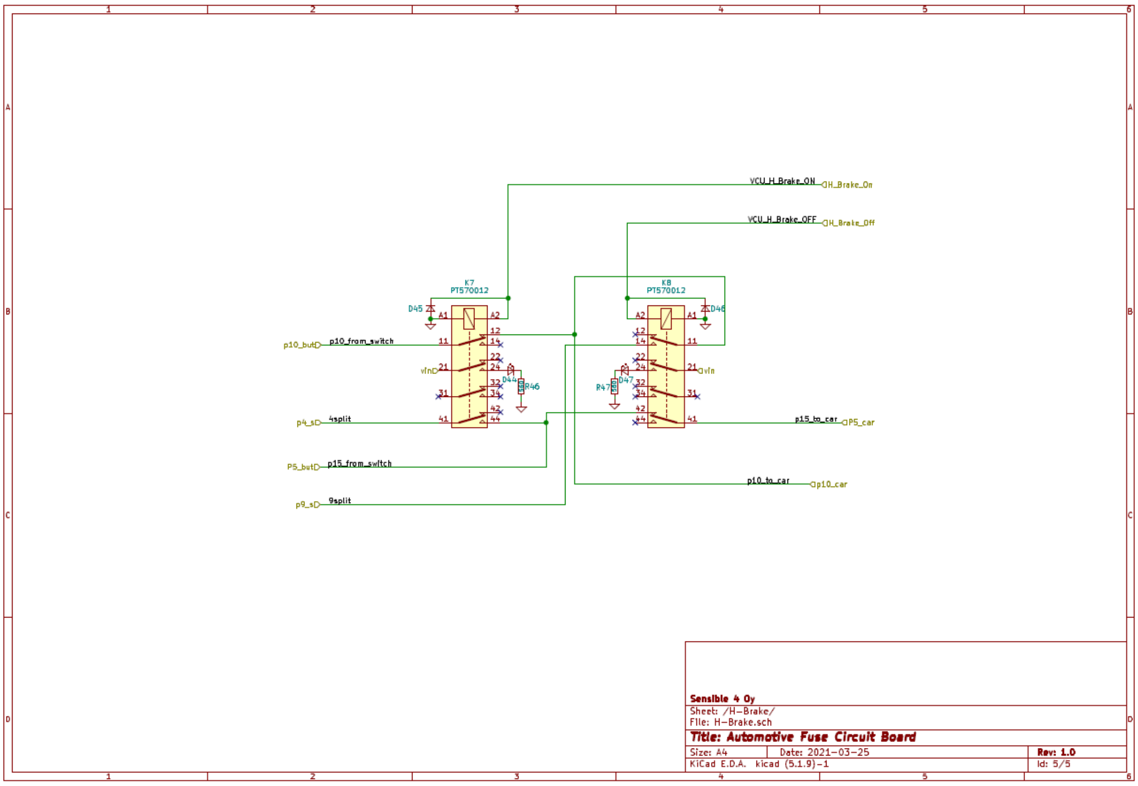

Figure 1-5. Schematic for handbrake signal

Appendix 2. Fuse Circuit Board Layout and 3D rendering

In this section the full layout design in Kicad is presented. Figure 2-1, 2-2, 2-3, 2-4 correspond to the 4 copper layers.

In figures 2-5 and 2-6 the copper pour was hidden for a better assessment of the traces in the top and bottom layers.

Finally, a 3-dimensional rendering of the finished board with all the components assemble can be consulted in figures 2-7 and 2-8.

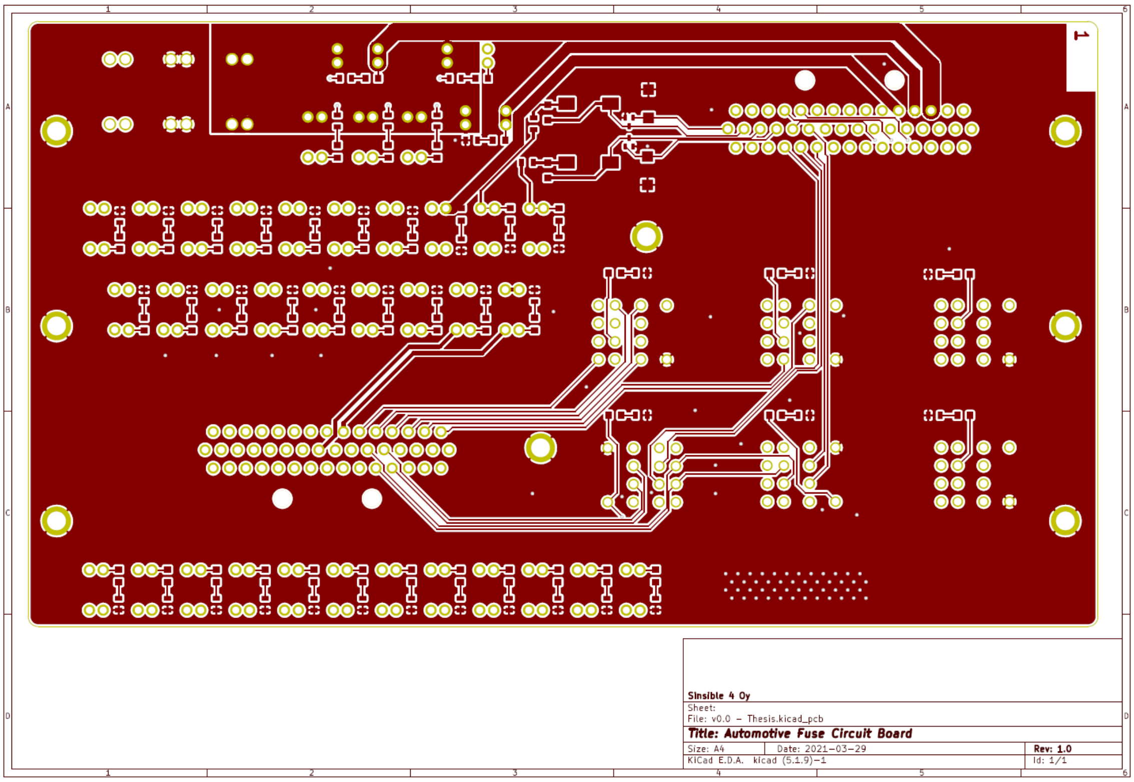

Figure 2-1. Top copper layer (ground)

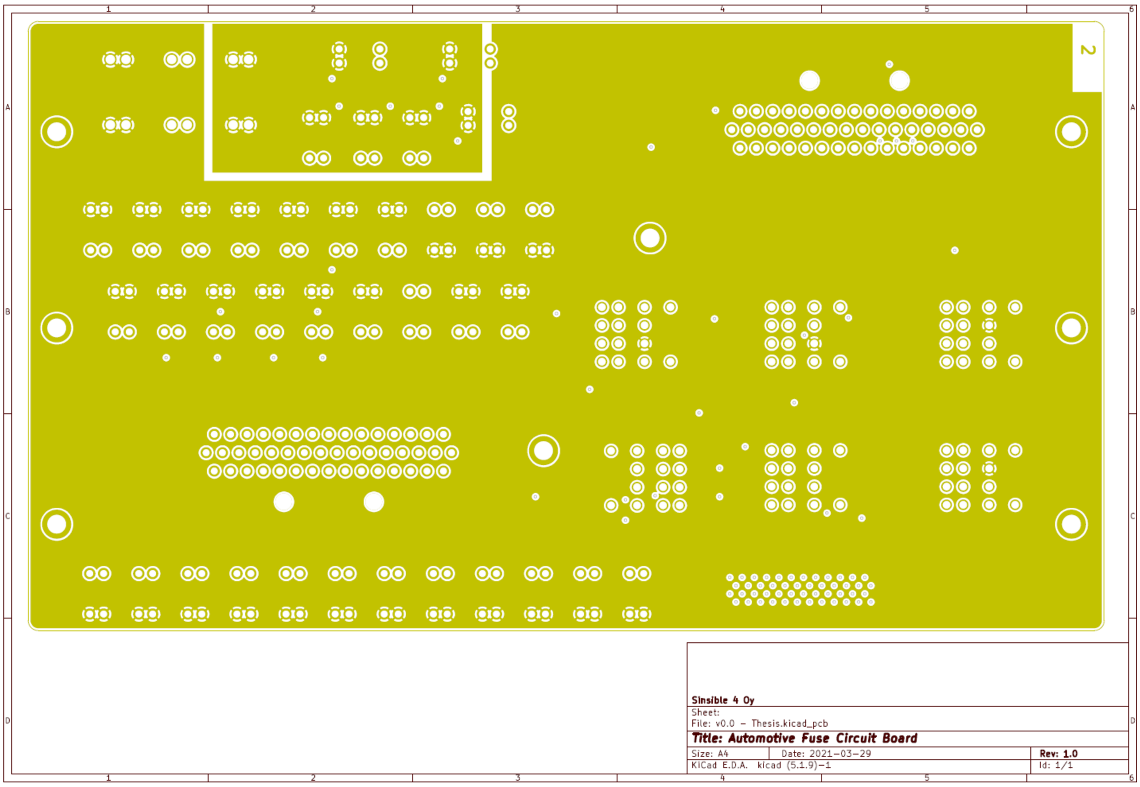

Figure 2-2. Inner copper layer (power supply)

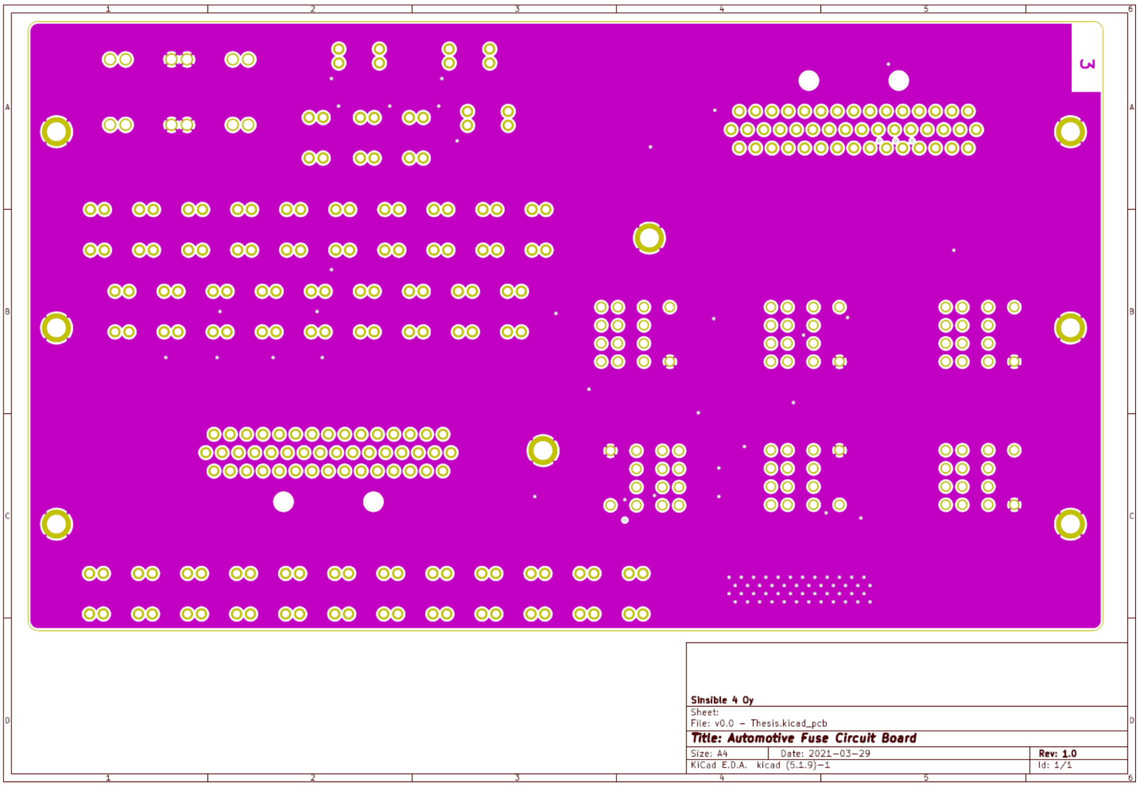

Figure 2-3. Inner copper layer (ground)

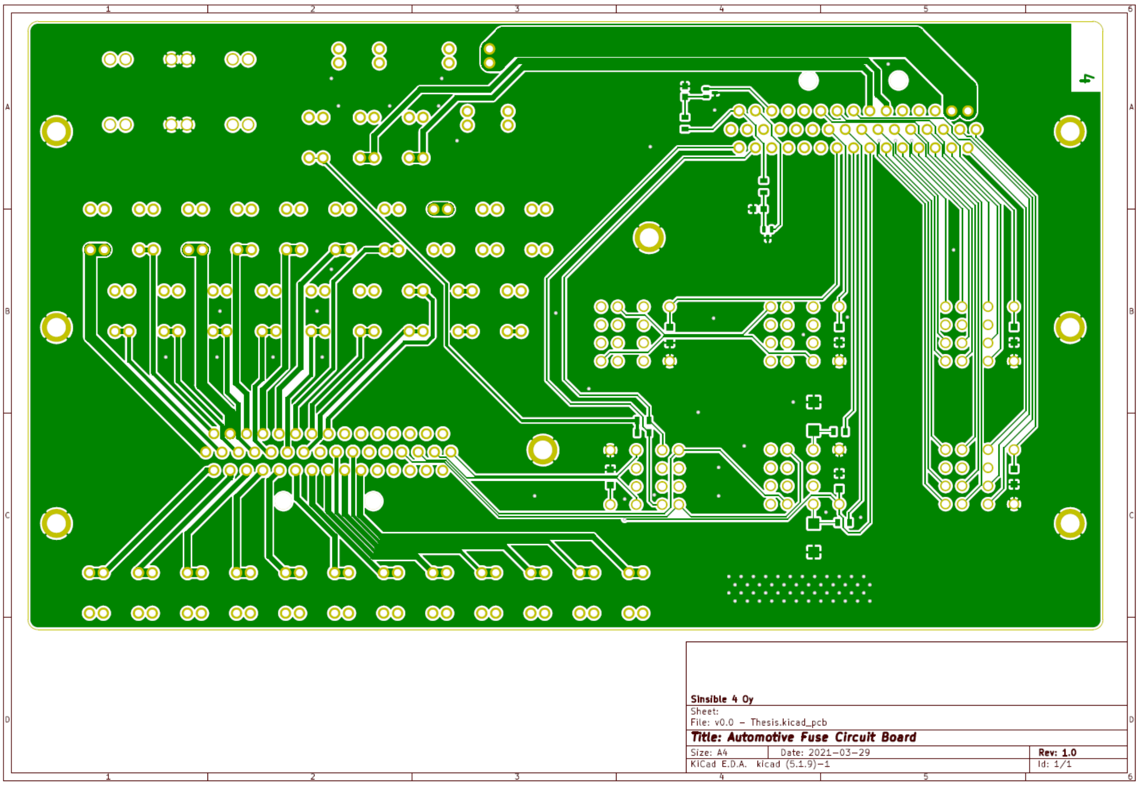

Figure 2-4. Bottom copper layer (ground)

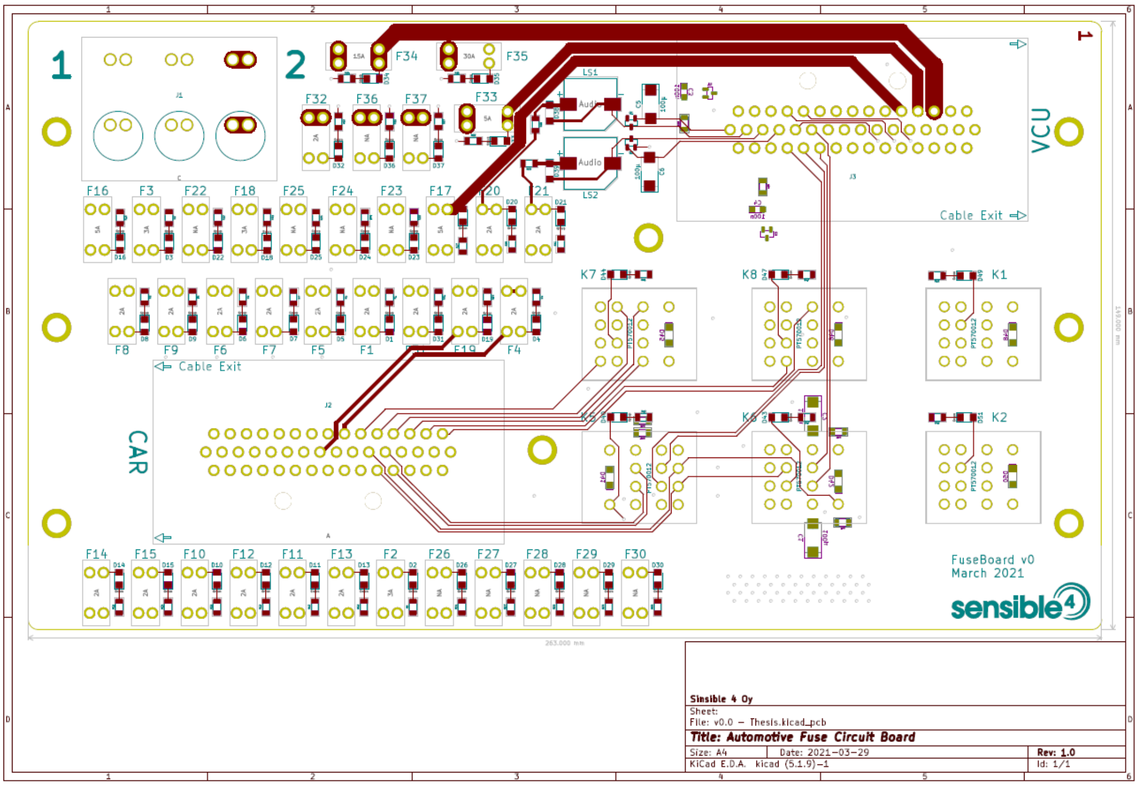

Figure 2-5. Top layer traces

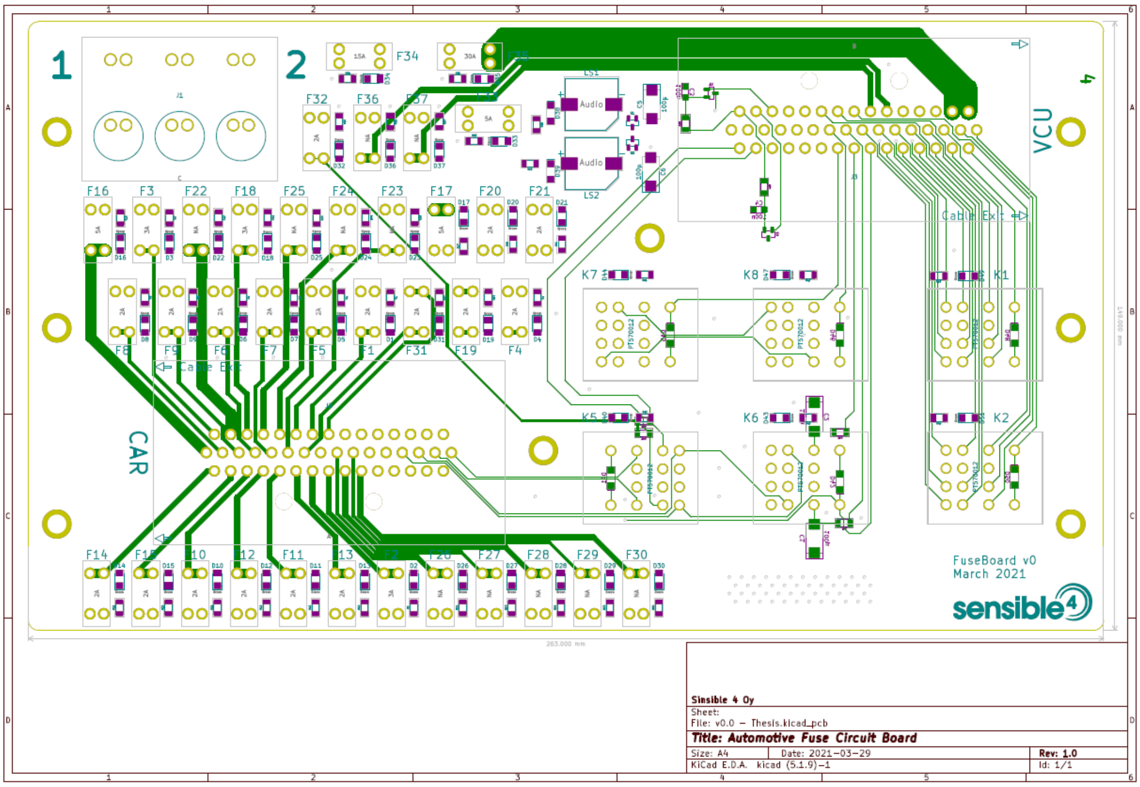

Figure 2-6. Bottom layer traces

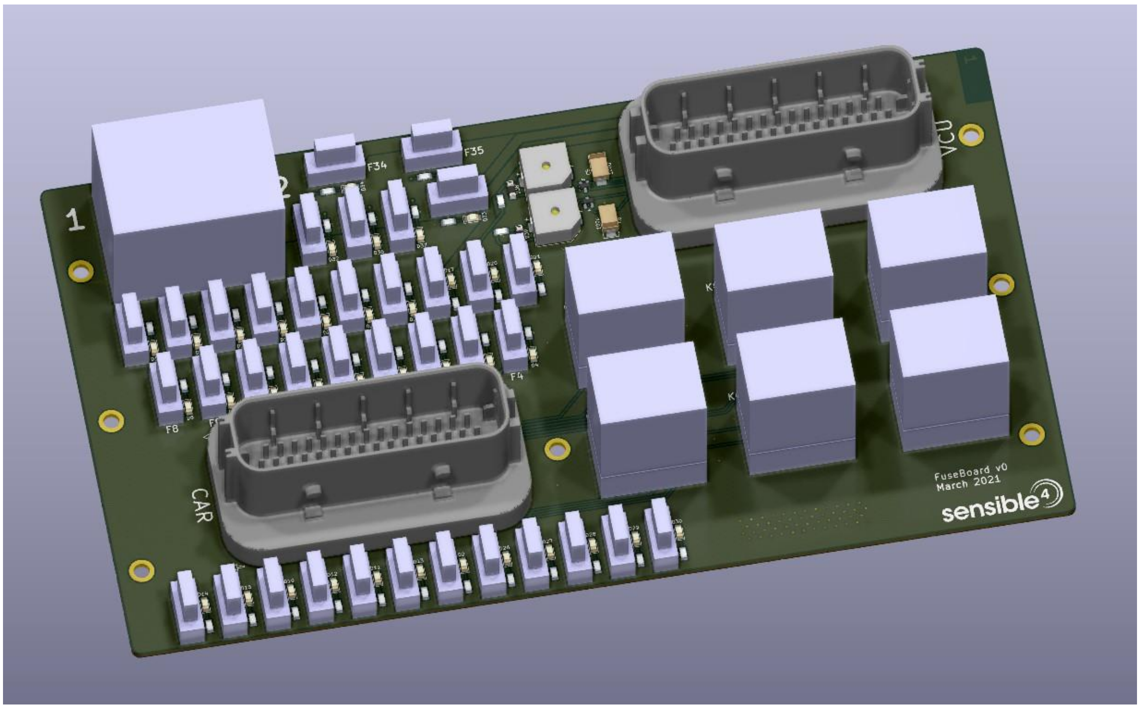

Figure 2-7. Rendering of the top layer with all components assembled

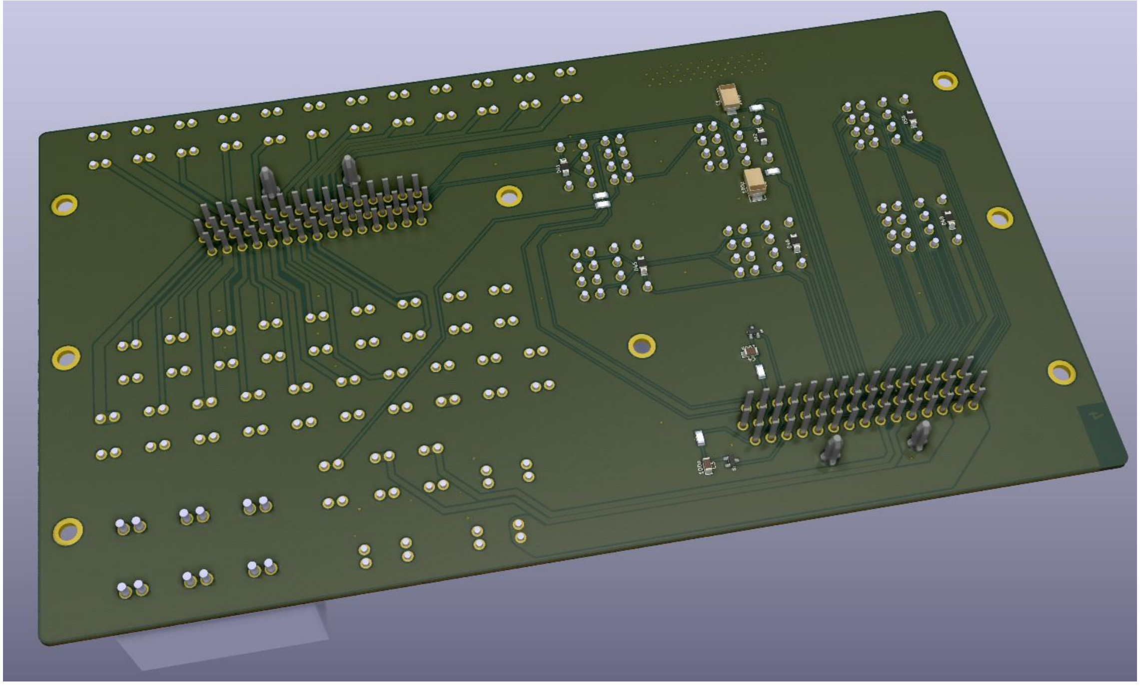

Figure 2-7. Rendering of the top layer with all components assembled

Appendix 3. Fuse Circuit Board Bill of Materials

The complete bill of materials of the components to be soldered onto the PCB can be consulted on table 3-1. The actual fuses, relays and mating connectors are not included since these are not soldered to the board.

Table 3-1. Bill of materials

Designator	Qty	Manufacturer	Mfg Part #	Description	Package
C1, C2, C5, C6	4	AVX	TAJD107K016TNJV	100µ	2917
C3, C4	2	AVX	THJA104K035RJN	100n	1206
D1 - D37, D40, D43, D44, D47, D49	43	Würth Elektronik	150120GS75000	Green LED	1206
D38, D39, D41, D42, D45, D46, D48, D50	8	Comchip Technology	ACGRAT105L-HF	Flyback diode	2010
F1- F37	37	Keystone Electronics	3568	Fuse Holder	
J1	1	Phoenix Contact	1845357	Power Connector	
J2, J3	2	TE Connectivity	3-2331102-1	49-pin Connector	
K1, K2, K5, K6, K7, K8	6	TE Connectivity	27E023	Relay Socket	
LS1, LS2	2	CUI Devices	CT-1212CL-SMT-TR	Buzzer	
Q1, Q2	2	Diodes Incorporated	ZXMN6A07FQTA	N-Mosfet	SOT23
R1 - R37	43	TE Connectivity	CRGCQ1206F560R	560	1206
R38, R39	2	Vishay Dale	RCS1206470RFKEA	470	1206
R40, R41	2	KOA Speer Electronics, Inc.	RK73H2BTTD4991F	5k	1206
R44, R45	2	Yageo	AC1206FR-0760R4L	60	1206
R50, R51	2	KOA Speer Electronics, Inc.	RK73H2BTTD1000F	100	1206
U1, U2	2	Texas Instruments	TMP236AQDBZRQ1	Temp. Sensor	SOT23