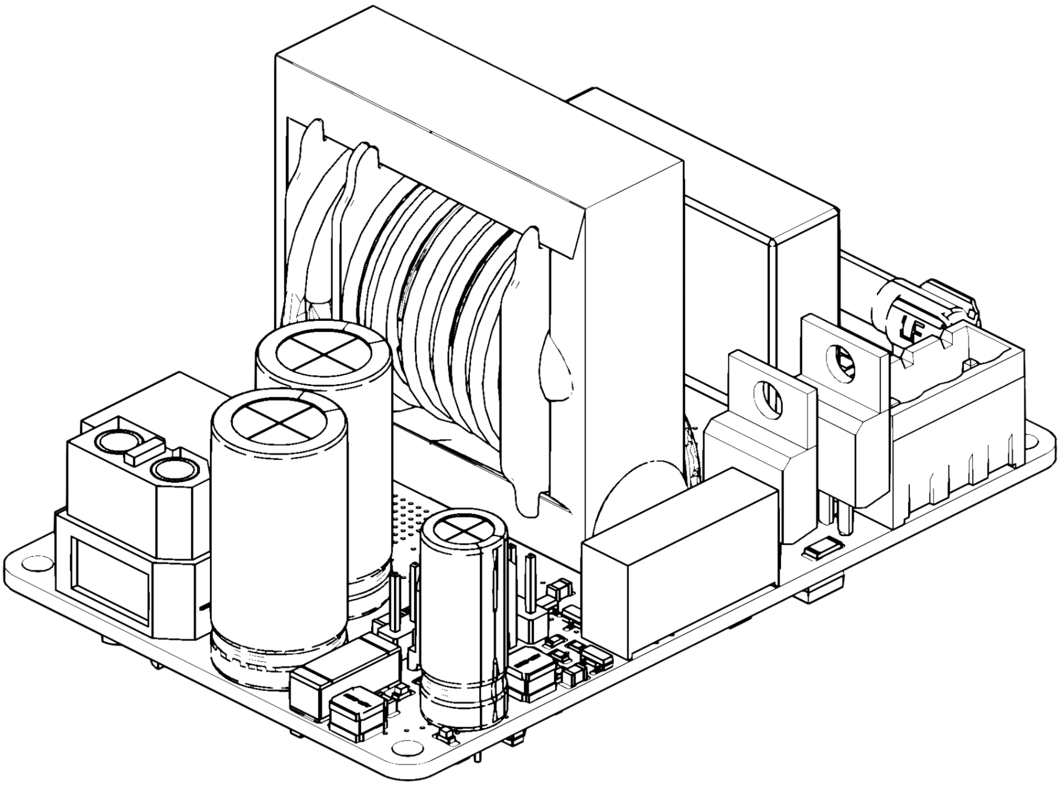
DCDCv9-3

Build Guide



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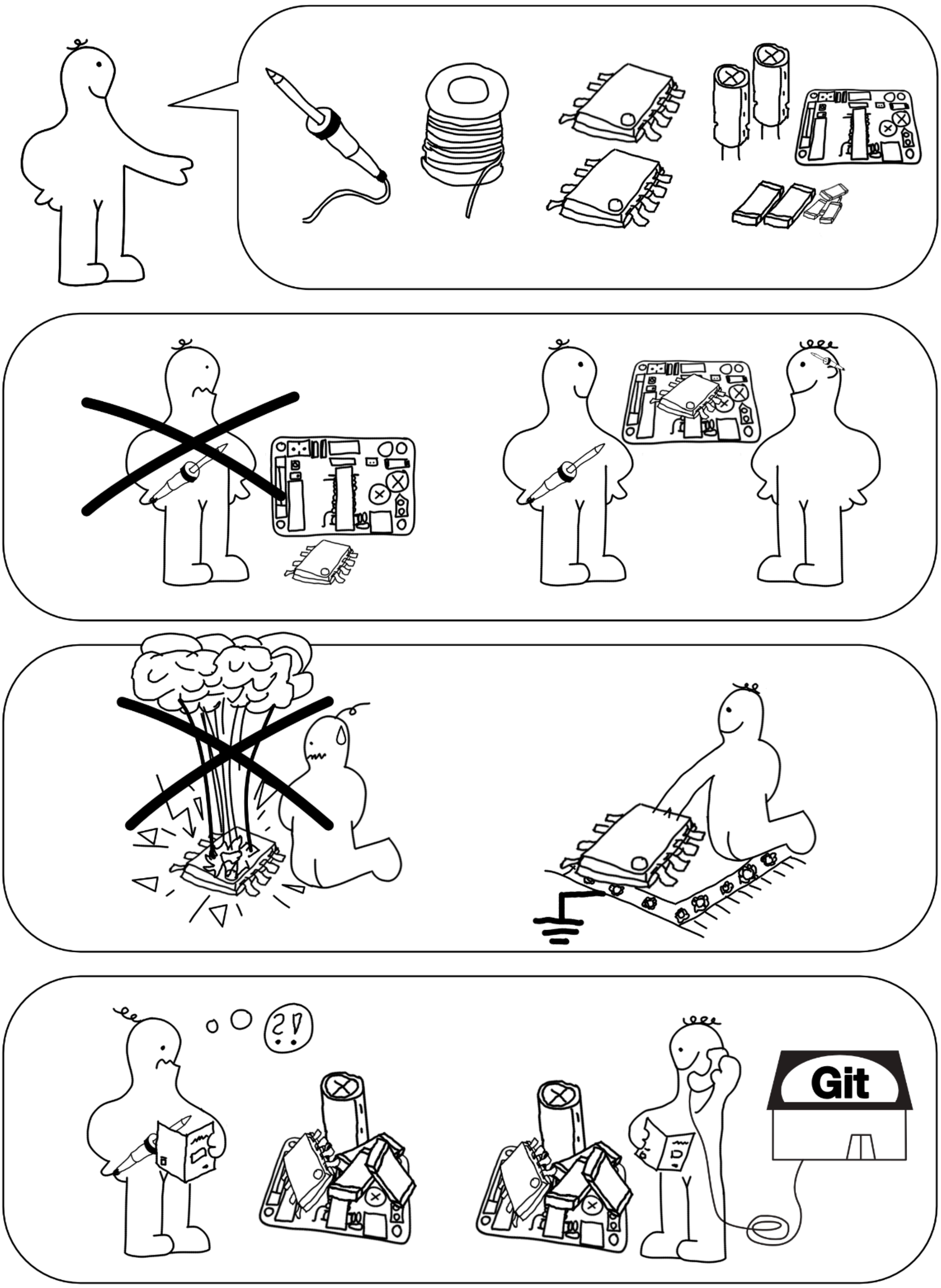
Date:	**01/26/2025**
Manual for hardware:	**v9-3 / v9-3r**
Language:	**English**
License:	**CERN-OHL-W**

GitHub: https://github.com/Rootthecause/DCDC

open source hardware



The instructions shown above are a parody. It is not associated with any particular company or its products. All elements of this guide were created independently and are for entertainment purposes only. It is not possible to call Git! Instead, create a Git [Issue](#).

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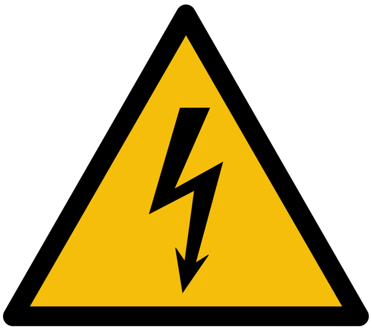
1 Safety instructions

The author is not liable for any damage in connection with this document, nor does he guarantee the functionality or correctness of the circuits and facts described. Reproduction of the circuits is at your own risk. Always apply practical knowledge and critical thinking, as there may be errors in the descriptions and illustrations despite careful preparation. Before commissioning, a risk assessment must be carried out and suitable safety measures taken. Under no circumstances should the device be operated if considerable damage to property or personal injury is possible in the worst-case scenario. The described circuits must not be operated unsupervised and only by qualified personnel. Care must be taken to ensure that unauthorized persons do not make any changes to or switch the setup.

Notice

The author intends to use the described circuits only in a controlled laboratory environment. For use outside this environment, the functionality, safety and compliance with legal requirements (e.g. EMI regulations) must be checked independently by the user.



Attention high voltage!

The project involves working with voltages and currents that can cause life-threatening hazards such as electric shocks, fire, serious injuries and death if handled carelessly. The circuits must only be used with the necessary caution and the appropriate safety precautions. The wearing of personal protective equipment such as insulating gloves, safety goggles and electrically insulating shoes as well as the use of insulated test equipment and power supply units with overvoltage and overcurrent protection is strongly recommended.

After switching on, do not touch any components that are connected to the circuit. Measuring during operation must be carried out with extreme caution, as slipping of the measuring tips can lead to short circuits. Measuring devices should be installed at the points to be measured before operation.

Voltages and currents can be significantly higher than can be expected from calculations or simulations, as they may be based on models that do not replicate reality accurately enough. Due to the way the circuits function, it is also possible that high voltage is present within the circuit, although the voltage supplied is many times lower. Components such as capacitors can be charged with high voltage even after switching off!

Attention hot surfaces!

Some components can reach temperatures above 55 °C. The user must not touch these components during operation or immediately after operation, as high temperatures may be present and cause burns.

1.1 Information on the selection and provision of components

The components were chosen independently and solely on the basis of personal preference and are not tied to a specific manufacturer. Some components (Q10, Q11) were provided free of charge as samples by Infineon as part of Formula Student, but without any expectations or obligations. Apart from this provision, there is no collaboration, sponsorship or other connection between the manufacturers and this project. Should there be any cooperation in the future, this will be communicated transparently.

1.2 Information on AI-generated content

The previous sections have been supplemented with AI-generated content or adopted in a similar form. Some other content in this document has been improved with AI-generated suggestions to clarify safety-related aspects.

1.3 Note on translated content

This document has been translated from the German source file using DeepL. However, the translation has been reviewed and manually edited to ensure accuracy and clarity.

2 Build Guide

Dear interested reader,

This build guide is intended to help you successfully build a DC/DC converter. There should be at least one team member who will take care of the build throughout the season. Experience in SMD soldering with a soldering iron and hot air as well as knowledge of working with high voltage is recommended. The team member should be aware of their responsibility that just one in 500 solder joints can lead to the failure of the DCDC and thus also to the failure of the entire low-voltage system. The author therefore recommends that this project only be considered if the team member has sufficient experience and suitable equipment.
If there are any problems with the replica, please create an issue on GitHub. Private messages about technical problems will not be answered.

Instructions for the instructions
It is advisable to at least skim through the instructions before starting the project in order to roughly estimate the work involved. When assembling, the respective chapter should then be read in full before the work steps are carried out. The instructions are valid for version v9-3r (release), whereby some measurements refer to the tested v9-3 and do not differ from the v9-3r.

2.1 Planning the replica

Before replication, it must be decided whether the PCB is to be ordered empty or pre-assembled. The minimum order quantity from PCB manufacturers is often 5 units. SMD assembly is particularly worthwhile in terms of costs for higher quantities, but the lower effort involved in rebuilding and reduced susceptibility to errors outweigh the costs, even with 5 pieces.

Planning steps

0. Understanding how the converter works
1. Ordering PCB and components (2-4 h, delivery time 1-2 weeks)
2. Obtaining tools, additional materials and measurement technology (individual)
3. Manufacturing of the transformer (1-2 days of which 2-5 hours for SLA printing)
4. Isolation test and measurement of the transformer (1 day)
5. Soldering the components (1-2 days for empty PCB, 80% assembled PCB 2-3 hours)
6. Testing the converter (2-3 days basic tests, 1-2 weeks long-term and field tests)

A total of approx. 1 month should be planned for one person without secondary activities who is rebuilding the converter for the first time. Several people can speed up the assembly process.

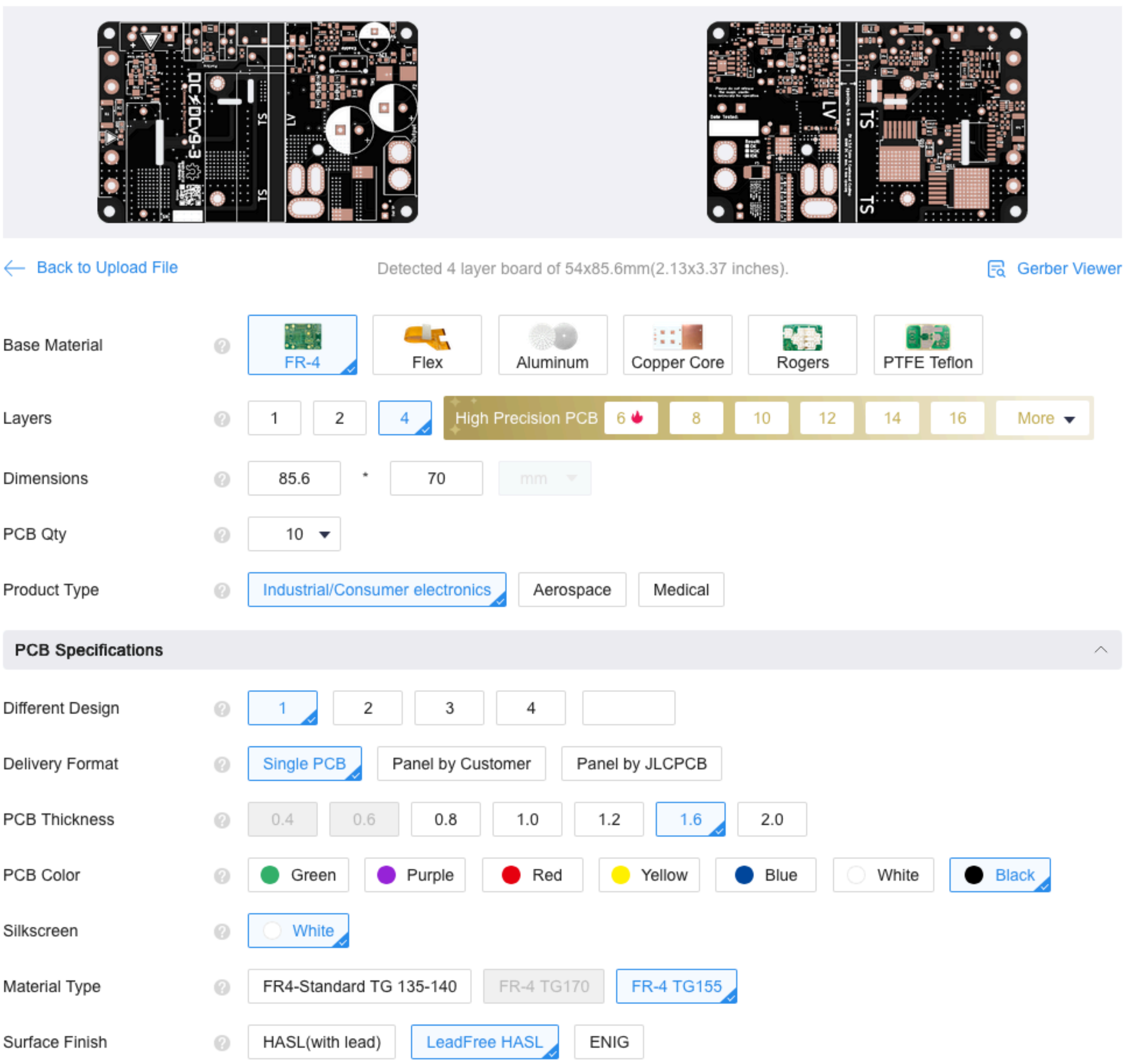
3 Ordering PCBs and components

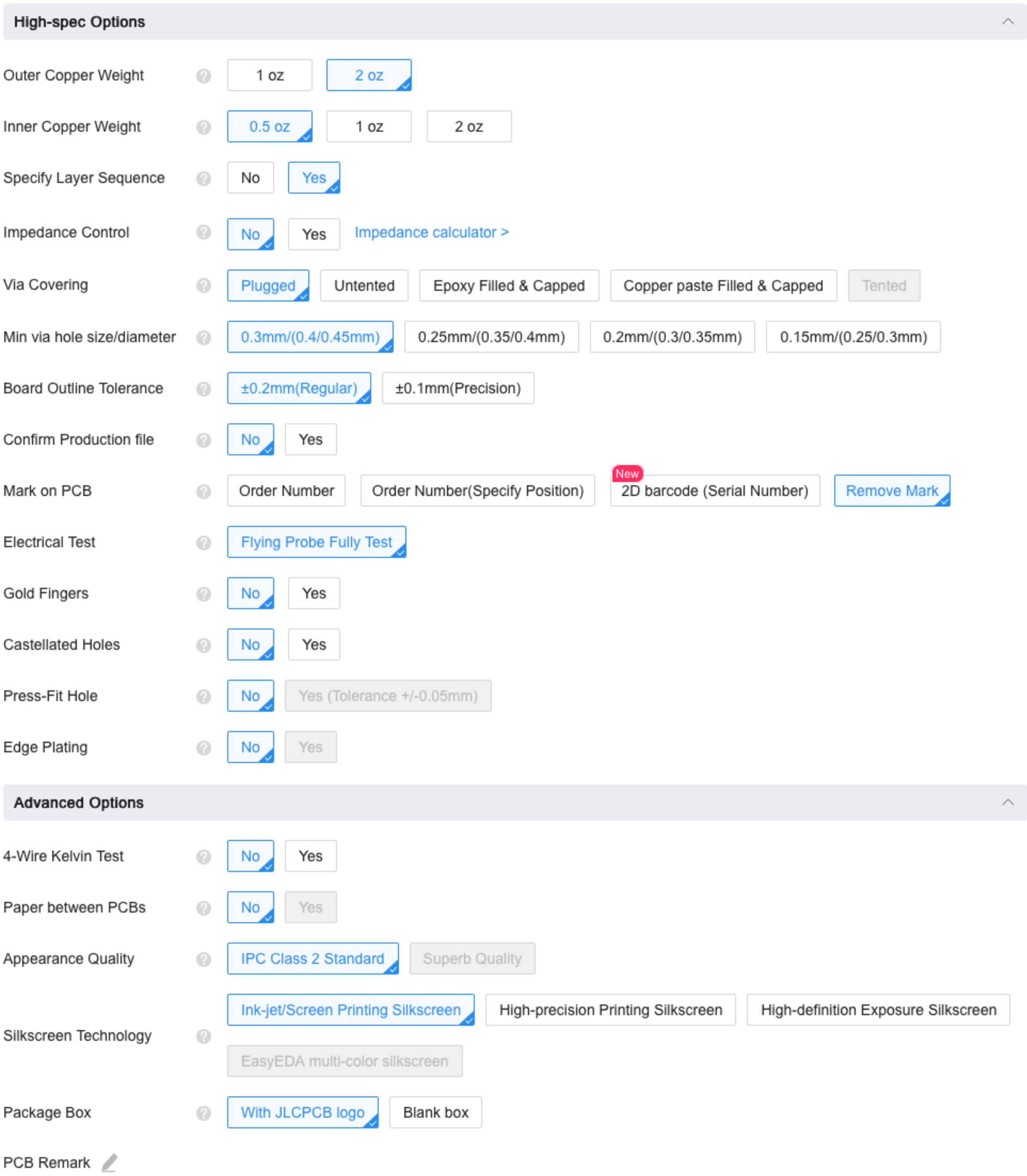
To order the PCB, the Gerber files [`DCDCv9-3r.zip`] must be uploaded from the [`kicad/production`] folder to the website of a PCB manufacturer. If assembly is required, the corresponding service (PCB Assembly) must be selected. The following settings were used to manufacture a PCB including assembly at the manufacturer JLCPCB.

Essential properties of the circuit board:

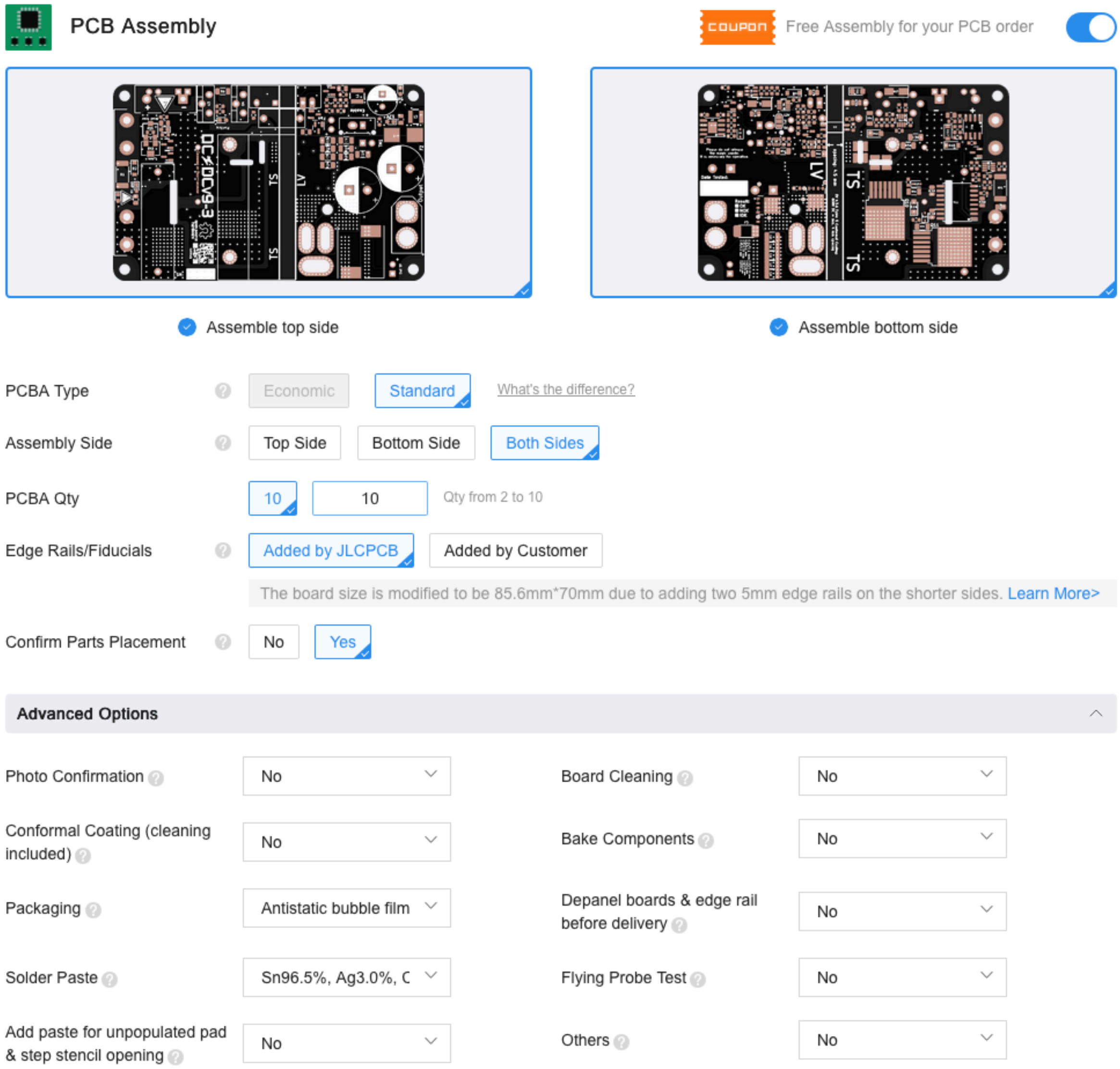
- 4-layer, FR4, thickness: 1.6 mm
- The outer copper layers must have at least 2 OZ copper
- The inner copper layers must have at least 0.5 OZ copper
- TG130 or more
- Solder mask: Black, matt (better heat radiation and thermal image measurement)

Note: The dimensions of the PCB are 85.6 x 54 mm. However, if PCB Assembly is selected, edge rails are required on the shorter outer dimensions - these are added automatically if the corresponding option is selected. The edge rails are provided with a V-cut and can be easily broken off with pliers.





A stencil can be ordered for manual assembly in order to apply solder paste cleanly. However, a good result can also be achieved with a fine syringe for solder paste if experienced.



3.1 PCB Assembly

In the next ordering step, the BOM and CPL (position data positions.csv) for double-sided assembly can be uploaded. If this error message appears, it can be ignored: *"The below parts won't be assembled due to data missing. NT1,NT2 designators don't exist in the BOM file. JP1 designator don't exist in the CPL file."*

Note: Instead of `bom.csv`, [`bom_for_JLC_PCBA.csv`] should be used. It only contains components that JLC has in stock (last checked Jan. 2025). For all components marked with a yellow exclamation mark on the website, the comparison was not exactly possible or there have been changes in stock. These must be updated accordingly with suitable components. The most important criteria for suitable spare parts are

- Same footprint
- same value (resistance, capacitance), same manufacturer number for ICs
- same or higher dielectric strength and rated power (resistance, capacitance)

If no suitable components can be found, they must be ordered for example from Mouser and soldered manually.

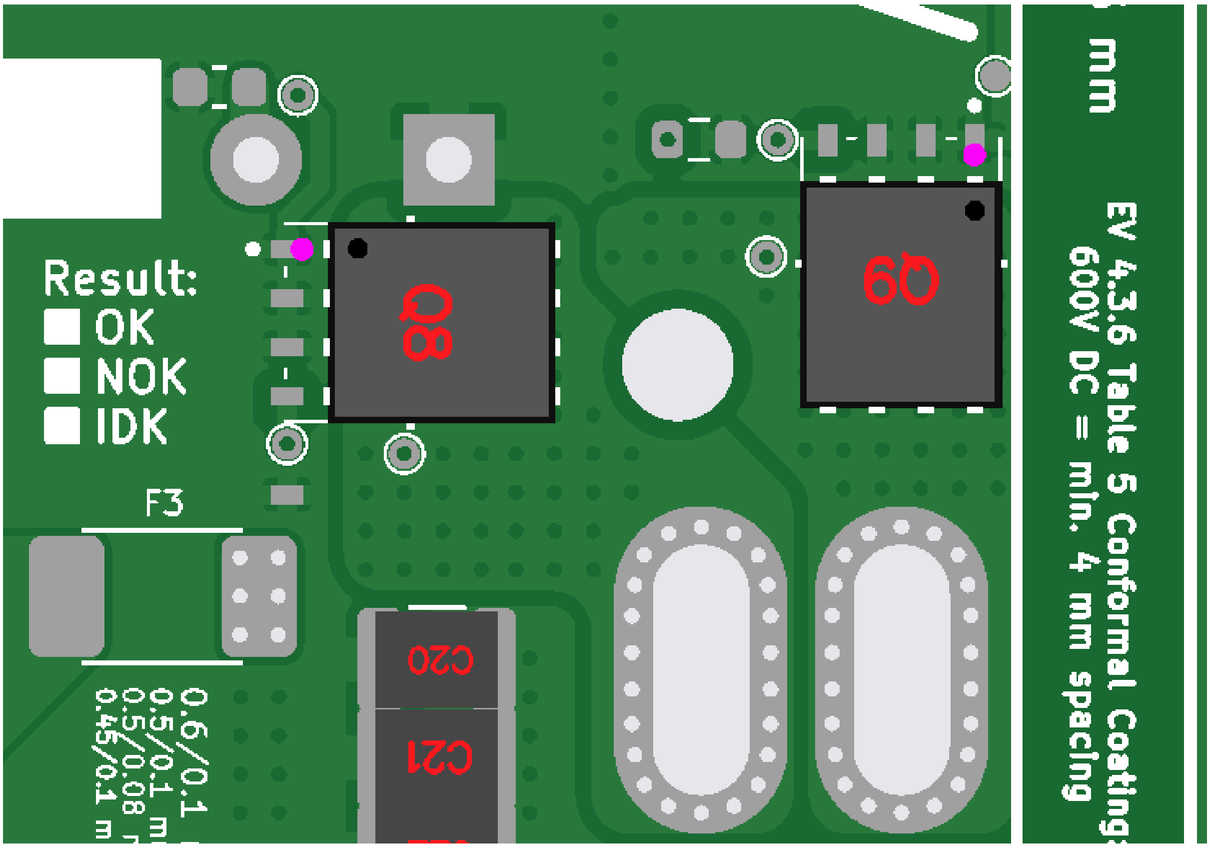
Both Sides Total 43 parts detected | 43 Parts confirmed Complete File Upload BOM/CPL

Uploaded BOM Data				Review Matched Parts					
Top Designator	Bottom Designator	Comment	Footprint	Matched Part Detail	Qty	Source	Lib Type	Total Cost	Select
	C14,C32	100nF	C_0603_1...	CC0603KRX7R9BB104 C14663 50V 100nF X7R ±10% 0603 Multilayer Cer...	20	JLCPCB	Basic	€0.0465	☑
	C15,C40,C41	2.2uF	C_0805_2...	CL21A225KBQNNNE C377773 50V 2.2uF X5R ±10% 0805 Multilayer Cer...	23	JLCPCB	Basic	€0.3209	☑
	C16	1nF	C_0603_1...	CL10B102KB8NNNC C1588 50V 1nF X7R ±10% 0603 Multilayer Cera...	20	JLCPCB	Basic	€0.0523	☑
	C17,C19,C25,C2...	1uF	C_0603_1...	CL10A105KB8NNNC C15849 50V 1uF X5R ±10% 0603 Multilayer Cera...	40	JLCPCB	Basic	€0.1628	☑
	C18,C27,C33,C46	10uF	C_0805_2...	CL21A106KAYNNNE C15850 25V 10uF X5R ±10% 0805 Multilayer Cera...	30	JLCPCB	Basic	€0.2587	☑
	C20,C21,C22,C2...	10uF	C_1210_3...	GRM32ER71J106KA12L C437568 63V 10uF X7R ±10% 1210 Multilayer Cera...	25	JLCPCB	Extended	€8.0354	☑
	C26,C44	22nF	C_0603_1...	CL10B223KB8NNNC C21122 50V 22nF X7R ±10% 0603 Multilayer Cera...	20	JLCPCB	Basic	€0.0640	☑
	C29	47pF	C_0603_1...	CL10C470JB8NNNC C1671 50V 47pF C0G ±5% 0603 Multilayer Cera...	20	JLCPCB	Basic	€0.0698	☑
	C30	10nF	C_0603_1...	0603B103K500NT C57112 50V 10nF X7R ±10% 0603 Multilayer Cera...	20	JLCPCB	Basic	€0.0446	☑
	C39	470pF	C_1206_3...	1206B471K102NT C9189 1kV 470pF X7R ±10% 1206 Multilayer Cer...	20	JLCPCB	Extended	€0.2151	☑
	C42	22uF	C_0805_2...	CL21A226MAQNNNE C45783 25V 22uF X5R ±20% 0805 Multilayer Cera...	20	JLCPCB	Basic	€0.4167	☑

Excerpt from the Matched Parts Review of a PCBA order from JLC. Note: The specified quantity corresponds to the total quantity for all PCBs to be assembled.

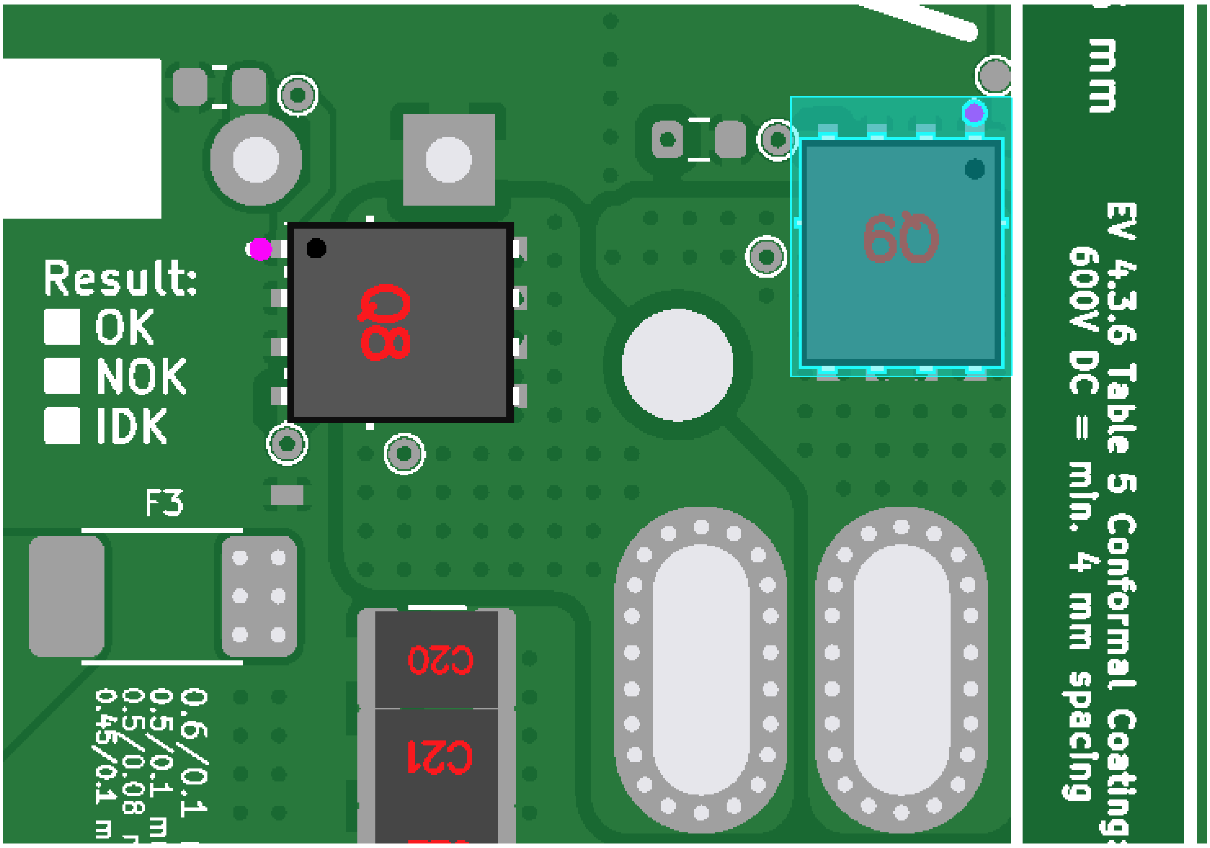
Component Placement

After checking the component assignment, the placement must be checked. The placement of the DCDCv9-3 was OK so far, except for Q8 and Q9 (rear).



Placement Q8 (too far to the right) and Q9 (too far down)

The placement must be corrected by clicking on the component and moving it with the arrow keys.



Placement Q8 and Q9 corrected, Q9 is selected

Some components are shown as chequerboard patterns. These are not available as 3D models from JLC, but do not usually pose a problem for assembly.

The total costs are then displayed. ‘Reserarch\Education\DIY\Entertainment’ and the subcategory ‘DIY - HS Code 902300’ can be selected as the product description (Customs).
After adding to the shopping basket, the shipping carrier must be selected. Depending on the size of the order, not all shipping options are available. For the PCBA, shipping to Germany with FedEx was selected (customs payment online). It is recommended to inform yourself in advance about the shipping companies and the current experience reports with the respective PCB manufacturers.

Future plans
It is currently not possible to order a PCB design from JLC via a public link. This manufacturer therefore only offers the option of configuring all ordering options yourself. The manufacturer PCBWay, on the other hand, offers the option of creating public designs. If time permits, the author reserves the right to publish the DCDC there.

3.2 Ordering the components

If a PCB has been ordered (without assembly), the components must be ordered in the DCDCv9-3_kicad_full_bom. If a PCBA has been ordered (with assembly), the components must be ordered in the DCDCv9-3_Mouser_BOM_for_PCBA.

It is recommended to upload the BOM to Mouser in the ”Shopping cart“ area (assuming the shopping cart is empty). By selecting the appropriate columns (quantity, manufacturer number), the components can be automatically added to the shopping cart. Note: There are components in the BOM that cannot be purchased from Mouser.

4 Obtaining tools, additional materials and measuring equipment

The following tools and materials are required in addition to the PCB and its components for the replica.
The linked products were used by the author as they are relatively budget-friendly. Of course, other products can be used, some of which may be easier to use. If you would like to support the author, you can use the affiliate link ‘Amazon Affiliate’, where the author receives a small commission when a purchase is made. If you do not wish to support the author, please use the ‘Amazon’ link.

Name	Source/URL
SLA printer (FDM printer not permitted!)	any
Resin	https://www.3djake.de/liqcreate/flame-retardant-hdt (UL94-v0) or (cheaper, no UL94-v0) https://www.3djake.de/phrozen/tr300-ultra-high-temp-resin-grau
3M™ Scotch-Weld™ DP100FR	https://www.3mdeutschland.de/3M/de_DE/p/d/b40066500/
120 grit + 400 grit carbide sandpaper (not necessary for N27+N97 core with air gap)	Amazon Affiliate Amazon
Flat surface for grinding (hard plastic, glass or stone) (not necessary for N27+N97 core with air gap)	
Double-sided adhesive tape (for attaching the sandpaper) (not necessary for N27+N97 core with air gap)	
cutting pliers	Amazon Affiliate Amazon
Soldering iron + small and large soldering tips (powerful soldering iron recommended for tinning and soldering the transformer strands)	Amazon Affiliate Amazon
Solder The entire converter can be soldered with a lead-free solder if you have the appropriate experience.	Amazon Affiliate Amazon
Solder paste (+ syringe for application, if not using a stencil), no low-temperature bismuth alloys!	Amazon Affiliate Amazon
Flux (+ syringe for application)	Amazon Affiliate Amazon

Soldering hotplate	Amazon Affiliate Amazon (or something better)
Hot air soldering station	Amazon Affiliate Amazon (or something better, although it works well)
Paper towels (for cleaning)	-
Ultrasonic cleaner for PCB + brush	Amazon Affiliate Amazon
Isopropanol	Amazon Affiliate Amazon
Shrink tubing	Amazon Affiliate Amazon
HF litz wire (see transformer construction for cross-sections and lengths)	Ebay
XT60 plug (1x male, 1x female)	Amazon Affiliate Amazon
LV connection cable	Amazon Affiliate Amazon
Connection cable TH1	Amazon Affiliate Amazon
HV connection cable (min. 85°C rating)	-
Enable switch and Molex-Microfit (male)	Solder/crimp yourself
Conformal Coating (Plastik 70)	Amazon Affiliate Amazon
Fan 30 x 30 x 7 mm, 5V, 5 m3/h (at nominal voltage)	Amazon Affiliate Amazon
Spring clamps (set)	Amazon Affiliate Amazon
Cable ties, small (2.5 to 3 mm wide)	-

4.1 Measurement equipment, voltage sources/power sinks

Name	Source/URL
AC high-voltage source min. 1800 Vrms for isolation test	-
Adjustable DC high voltage source up to 600 V / 2A resp. min. 500 W	e.g. 2x Delta Elektronica SM 400-AR-4 (in series) alternatively 1500 W inverter (isolation) or isolating transformer + DIY PFC

4x multimeters for efficiency measurement or corresponding power meters	e.g. UNI-T UT139C or UT61E+
DC load 24V up to 31.25 A	2x DPS5020 for CV/CC setting Amazon Affiliate Amazon Polylux lamp as load Amazon Affiliate Amazon
LCR meter (sufficient for replication) (an impedance analyzer is recommended for development, e.g. Analog Discovery 2 or 3 with expansion board for impedance measurement)	Analog Discovery 3 Impedanz Analysator
Oscilloscope (either with galvanically isolated inputs or with battery operation)	z.B. Micsig TO3004
High-voltage probe 1:100	Amazon Affiliate Amazon

5 Manufacturing the transformer

The heart of the DC/DC converter is the self-developed ferrite core transformer.

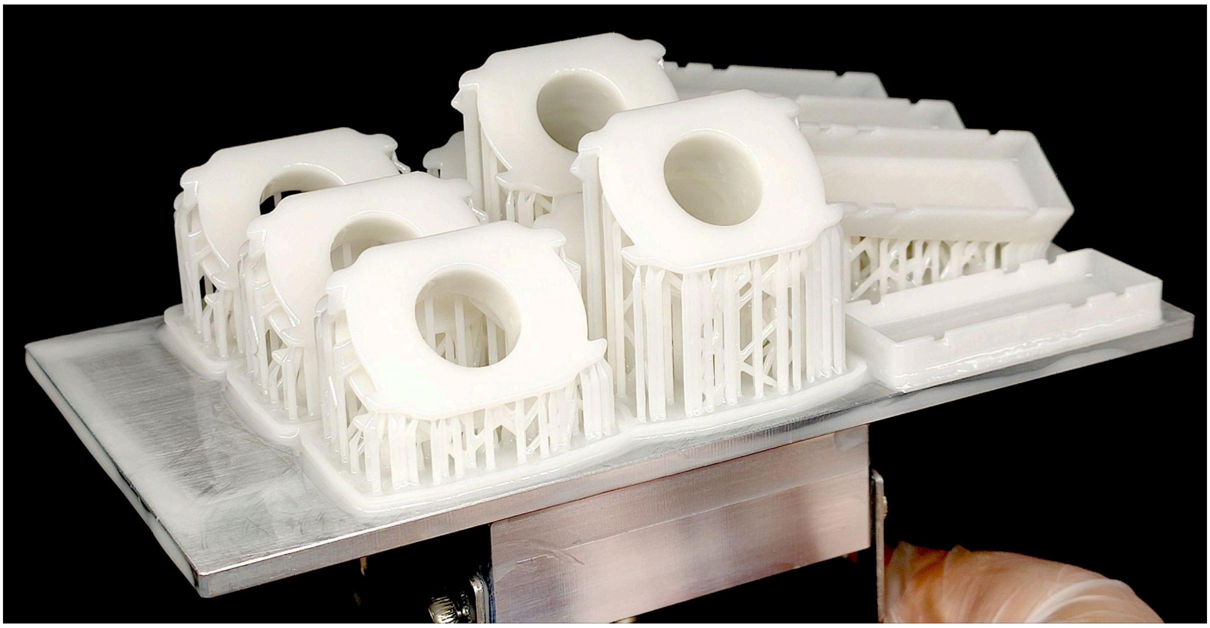
For the **ETD39** transformer is required:

- 1800 mm 120 x 0.1 mm HF litz wire for 28 windings (primary)
- 165 mm 600 x 0.071 mm for 2 windings (secondary winding 1 inside)
- 185 mm 600 x 0.071 mm for 2 windings (secondary winding 2 outside)
- SLA-printed coil holders (Prim, Sek, Isolator)
- Ferrite core halves (size ETD39):
    - 1x N27 with 1.0 mm air gap Prod. no.: B66363G1000X127
    - 1x N97 without air gap Prod. no.: B66363G0000X197

Core halves with air gap (right half), coil holder prim (left) sec (right) and isolator (bottom)

5.1 Notes on SLA printing

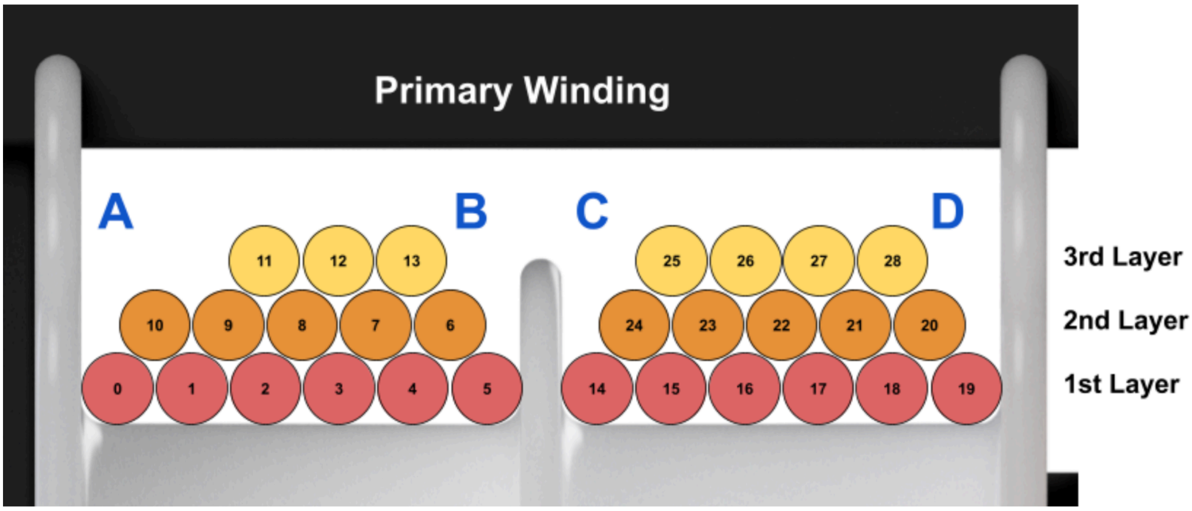
- Visually check that all pixels are functional for LCD or DLP SLA printing
- The models should be aligned so that the center cylinder (around which the coil is wound) has no external support structure in order to obtain a smooth surface and not to damage the isolation of the conductors.
- Holders must under no circumstances have holes, cracks, contamination or delamination.
- Models can break with sharp edges under mechanical stress, so care must be taken when handling them. Even small drops can lead to breakage.
- The necessary safety regulations for handling SLA printers and the UV resin must be observed and consumables and material residues must be disposed of properly.
- The prints must be cured with UV light in accordance with the manufacturer's instructions
- After completion, check that the prints can be easily attached onto the core halves and that there is a slight gap when joining the two core halves with the prints. This is required as the holders expand slightly when the transformer heats up. If the holders do not fit on the core halves, make shrinkage adjustments in the print settings. If there is a gap between the core halves when joining them together, check the thickness of the flat end plates (coil formers). If it is more than 1.0 mm, grinding is permitted, provided this is done before the isolation test.
- Broken “hooks” (“thorns” “ears”) on the prints are permissible if the anti-twist protection on the ferrite cores is ensured (alternatively: gluing).

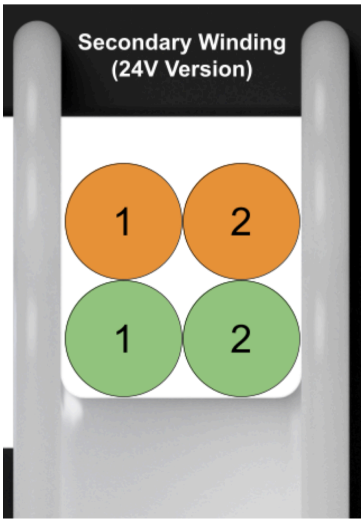


SLA print of the ETD39 coil holder with support structure after printing

5.2 How to wind

The winding direction (clockwise or counterclockwise) of the primary coil does not matter as long as it always remains the same on the coil. The holder of the primary coil has a separator in the middle to stabilize the three layers and to gain additional insulation distance. The arrangement shown was chosen to achieve a compromise between winding capacity, insulation voltage between the windings and complexity of the winding. It is a mixture of U-winding and sectional winding.



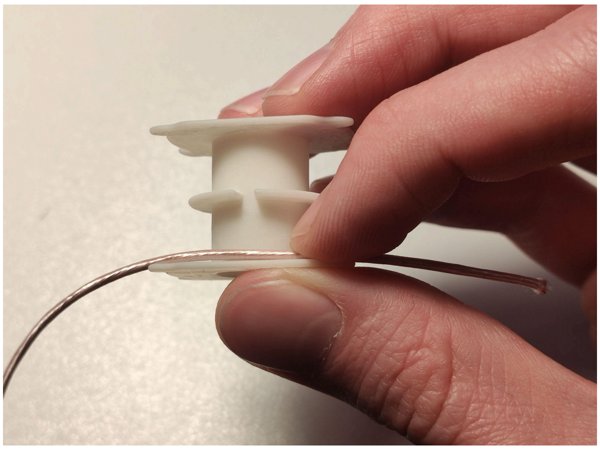
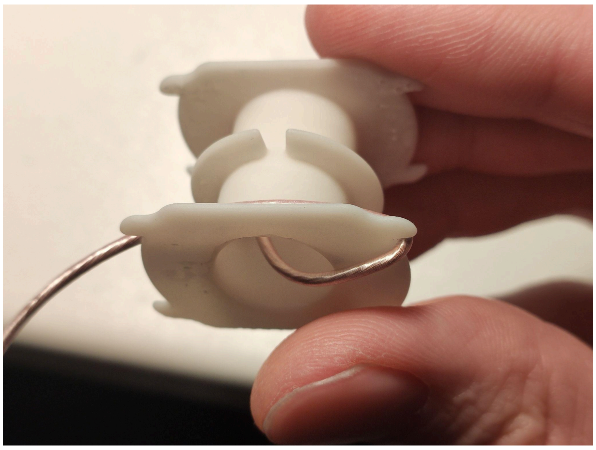
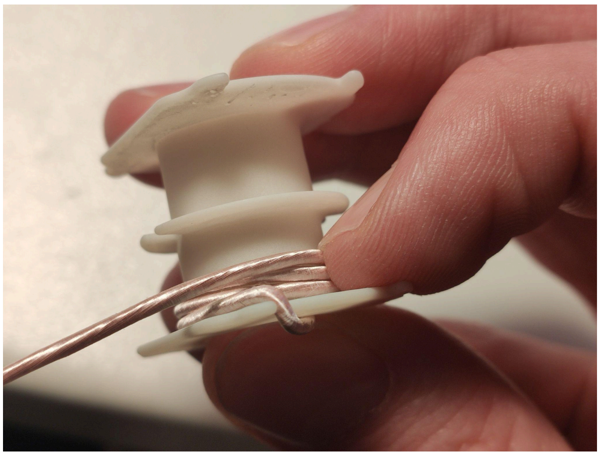
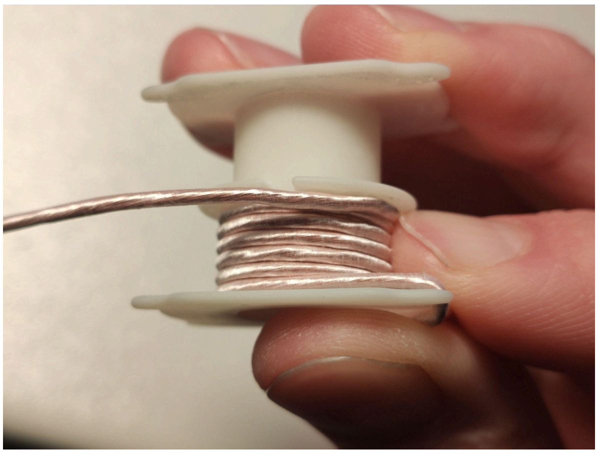
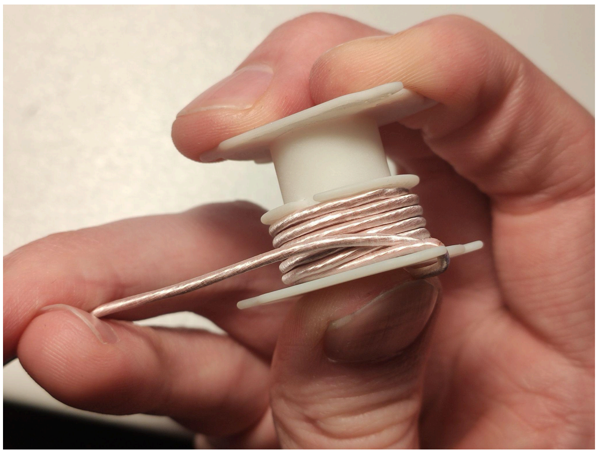
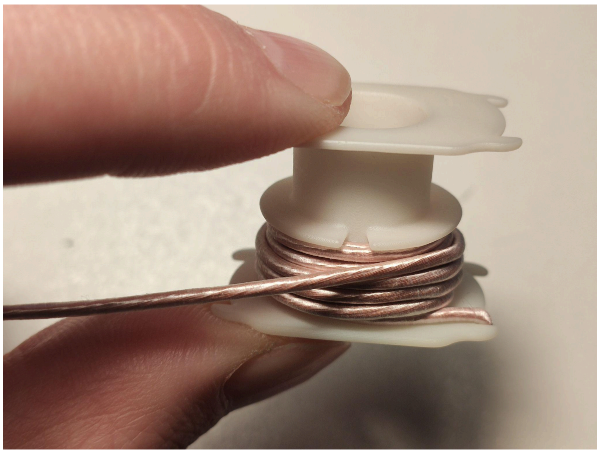


Tip: A black permanent marker or short piece of heat shrink tubing can be used to distinguish the ends of the same secondary winding.

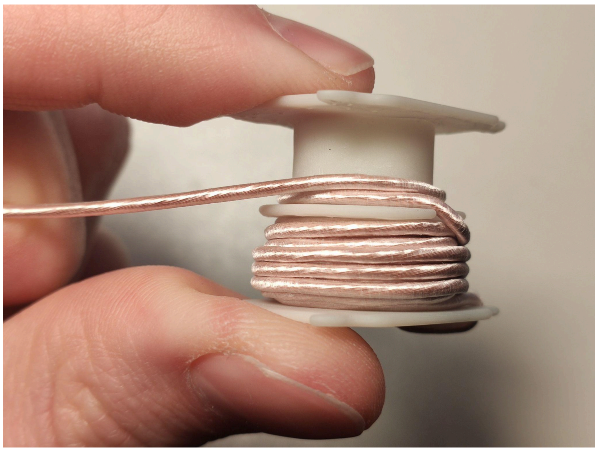
The winding direction is irrelevant for both the primary winding and the secondary winding. However, when connecting the secondary winding, it is important to ensure that the windings generate opposite voltages. It is recommended that both secondary windings are wound in the same direction.

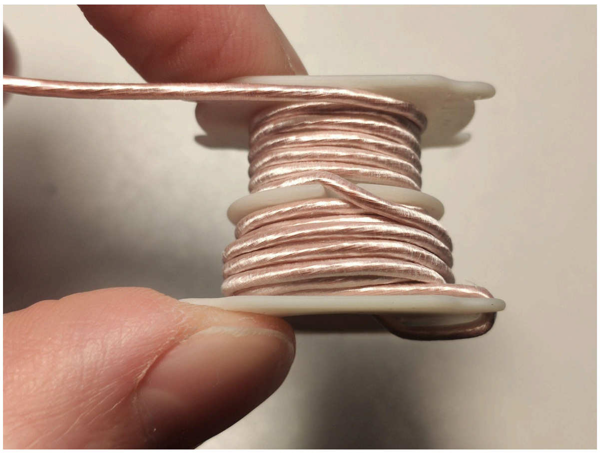
5.3 Winding the primary winding

About 3 cm of the HF litz wire is folded behind one of the hooks. The protruding piece is bent into the coil holder during winding and pressed against the holder with a finger during winding. The windings are then wrapped around the coil holder according to the winding diagram above. Make sure that the HF litz wire is applied tightly in order to achieve a clean and space-saving winding. The last turn of the first layer may be wound onto the next layer before it is completely enclosed due to the limited space available.

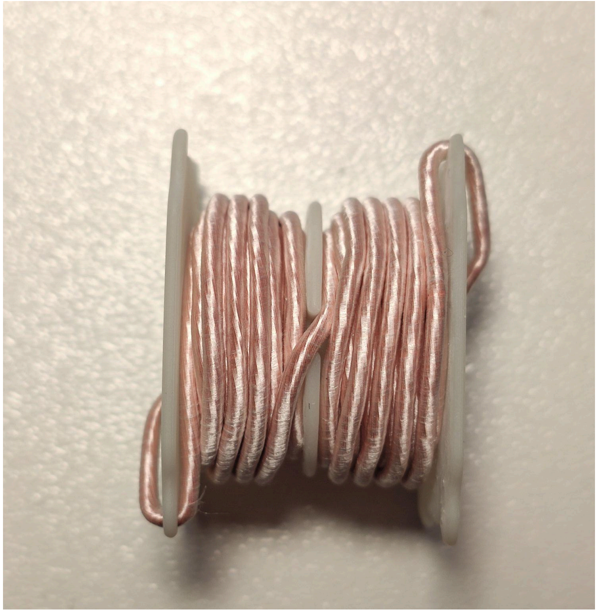







After the first half has been wound, the second half is wound in the same way as the first half, but the last layer has one more turn.





After the last turn, the end of the HF litz wire can be bent over another hook. Up to this point, the entire process does not require any adhesives. Then apply some 2-component adhesive to the top left and bottom right to fix the windings in place.

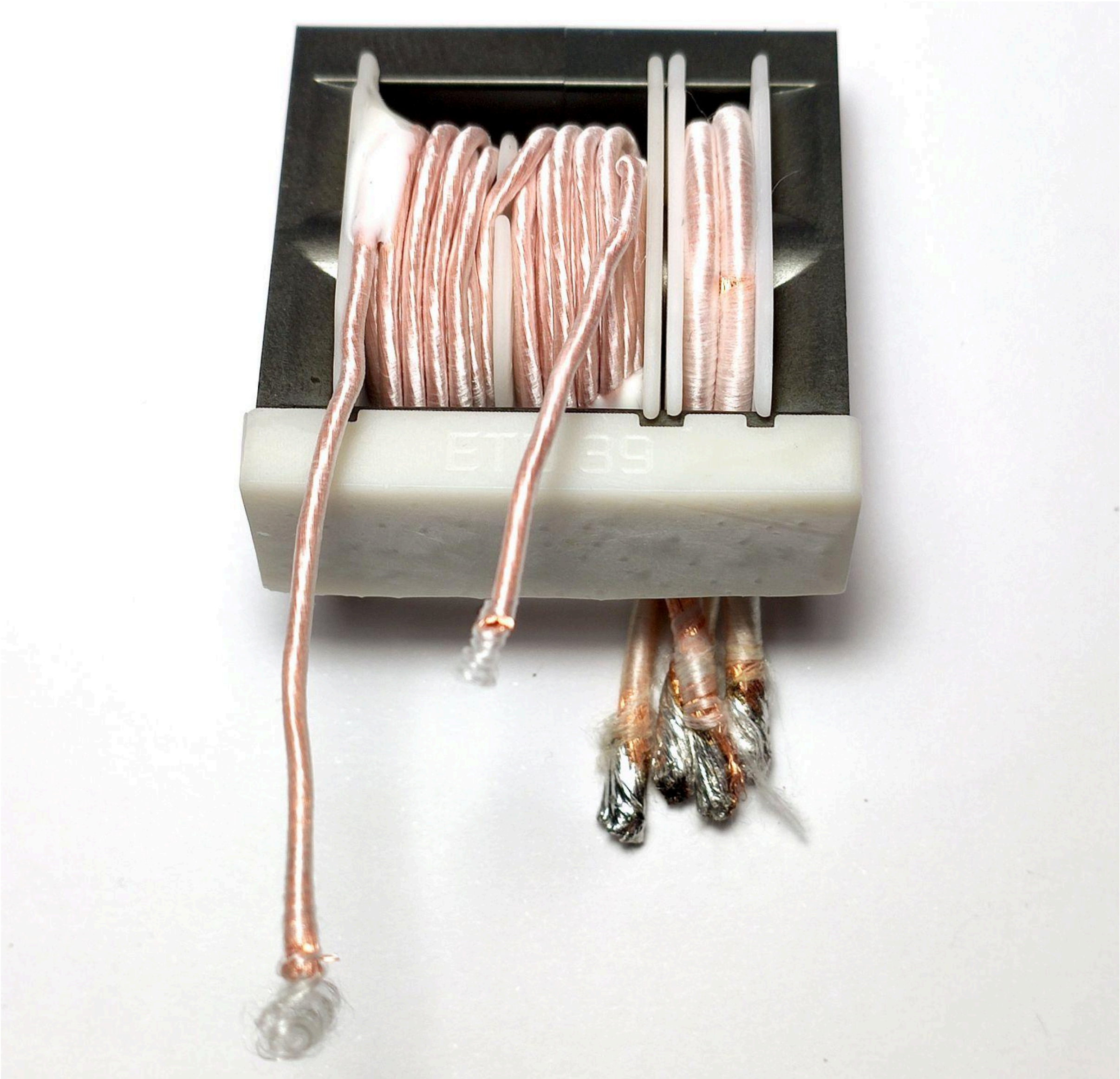


Pro-tips:

- *If you have received too many sticky notes as a promotional gift, you can use them to stir 2K adhesive on them.*
- *Leftover PTFE tubes from a Bowden 3D printer can be used to stir the 2K adhesive. Once cured, it can be easily removed from the tube and reused (does not stick to PTFE).*
- *Hot air (e.g. from a soldering station) can be used to heat the 2K adhesive. Heating removes the air bubbles in the 2K adhesive and reduces the viscosity. This results in a beautiful surface, even if the epoxy resin is already curing.*
- *By placing the PTFE tube in the rest of the 2K adhesive, you have a good reference of how hard the epoxy is on the transformer without having to touch it.*

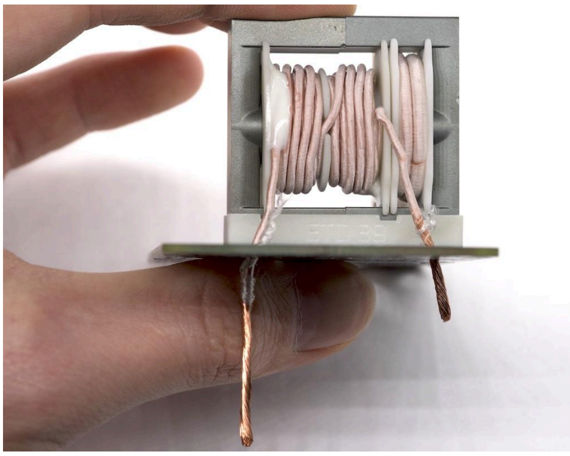
5.4 Winding the secondary winding

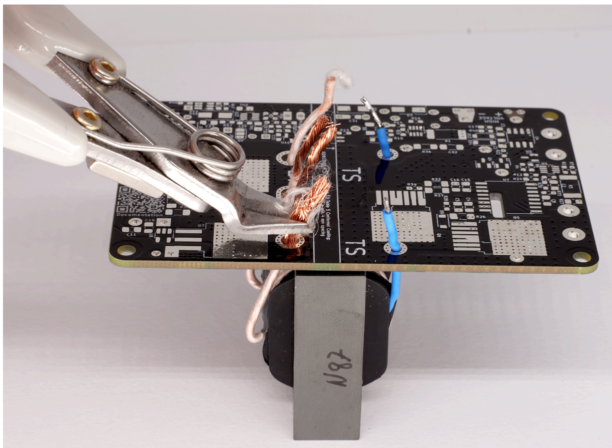
The shorter HF litz wire is first applied with two windings. The longer HF litz wire is then wound onto the existing windings in the same winding direction. Gluing the secondary windings is not necessary, but can be helpful during installation.



5.5 Tinning the ends

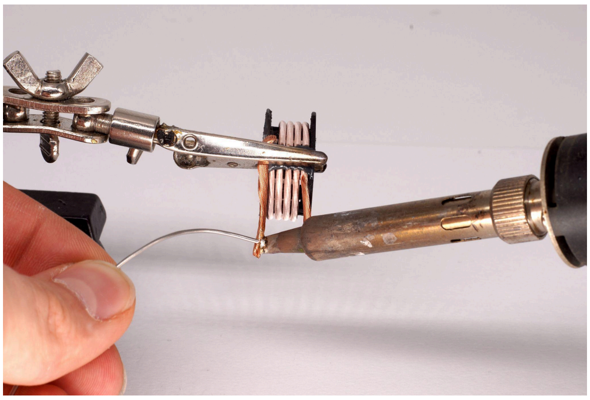
Before tinning, the ends of the windings must be shortened to a suitable length. To do this, it is recommended to insert the transformer into a circuit board and use a pair of pliers to shorten the ends to an excess length of approx. 5 mm.

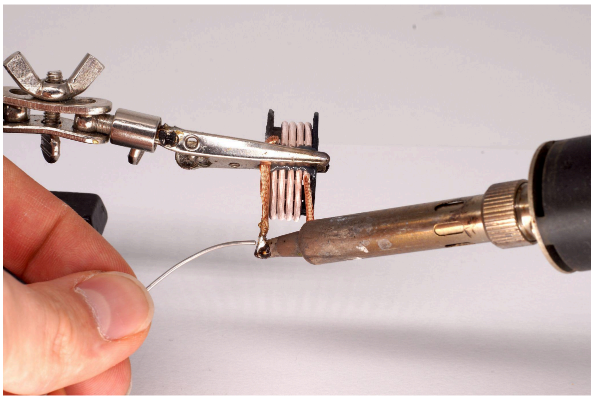


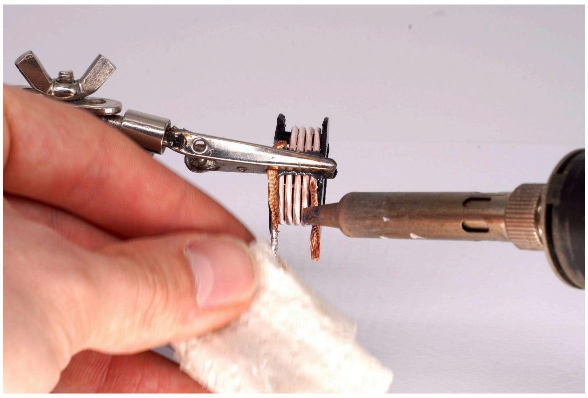


Note: The picture on the right and the one below show an older version of the DCDC.

The silk wrapping must be shortened by approx. 10 mm at the ends. The ends of the primary winding must be isolated with shrink tubing. Otherwise, shrink tubing can be used to prevent fraying. The ends of the windings can be tinned at 400 °C, whereby additional flux is helpful. Care must be taken to ensure that all strands are fully tinned and that there are no major residues of enamel on the ends. The ends are cleaned by wiping them with paper towels. The matching video `Transformer tinning.mp4` is located in the `transformer` folder.



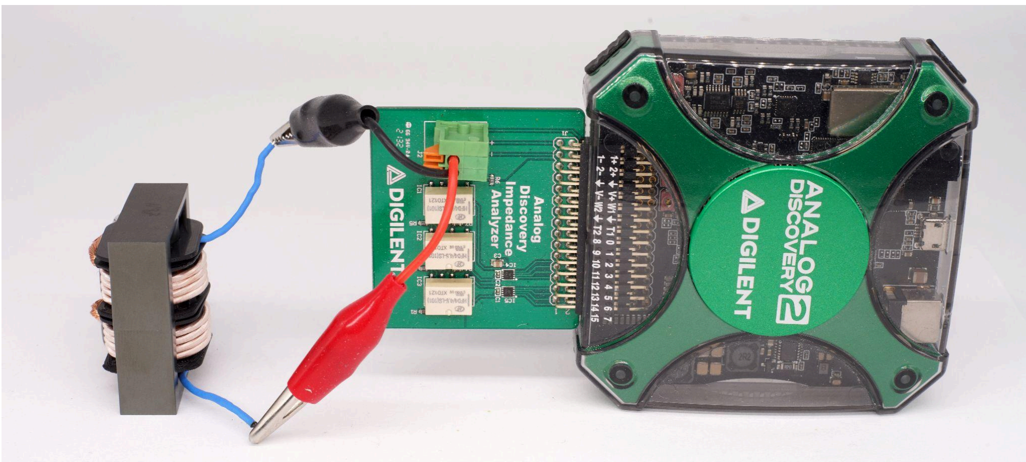




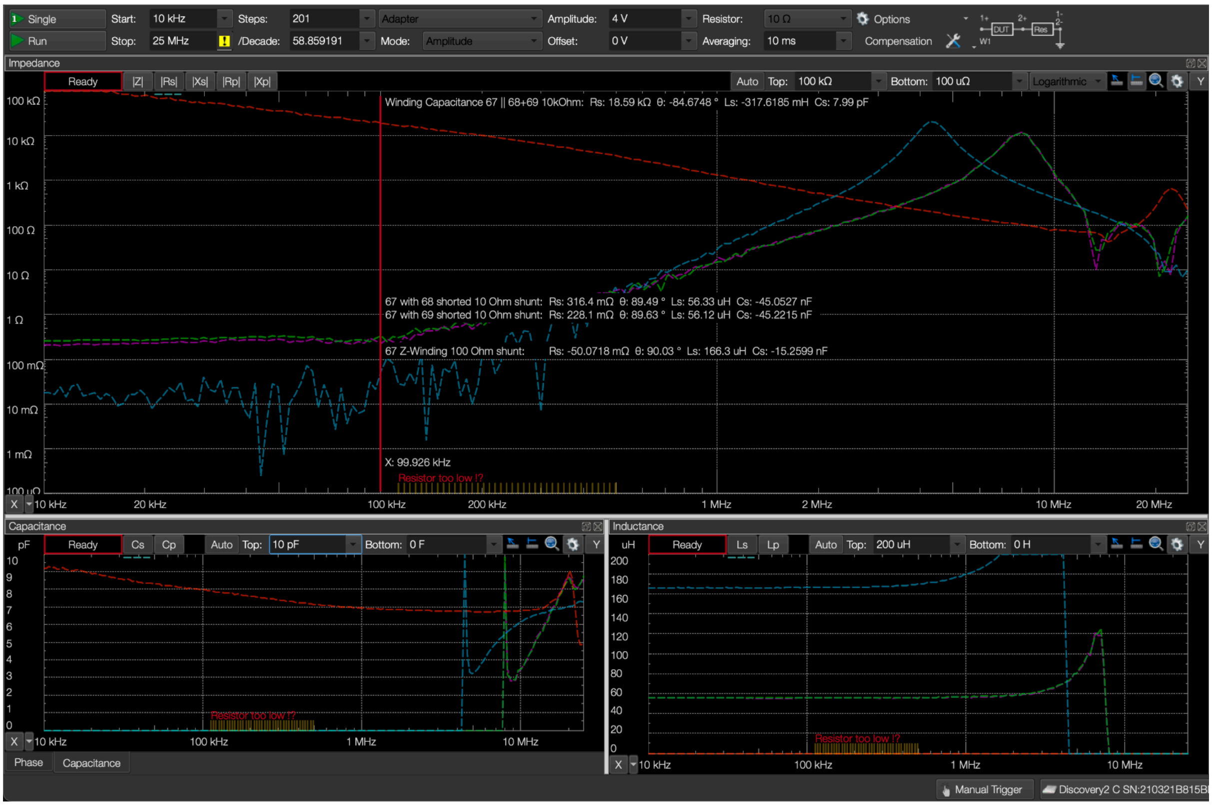
In the final step, the finished windings are placed on the two core halves as shown. The primary winding on the N97 core, the secondary windings on the N27 core with air gap. It should be possible to insert the windings without applying force (see notes on SLA printing). Coat the outer legs of the ferrite core with a thin layer of 2K adhesive. The two halves are then brought together with the coils and pressed together using a spring clamp (medium size, 4.5 cm clamping opening) under slight force. Screw clamps are not permitted as the force is difficult to adjust and can cause the cores to break (no force can be transferred through the air gap in the center leg). The core halves should be as flush as possible at the top and bottom, although slight differences in size are common. The isolator should not be glued to the core halves due to the different coefficients of thermal expansion, as this may lead to stress cracks.

6 Measurement of the transformer

An Analog Discovery 2 with the Impedance Analyzer extension was used to measure the transformer. However, an ordinary LRC meter is sufficient for the replica.



Note: The picture shows an older version of the DCDC transformer.



Measurement of the frequency-dependent resistance and inductance of the transformer.
Blue: Primary coil W1 resistance vs. frequency, secondary coils open
Green: Primary coil W1 resistance vs. frequency, secondary coil W2 short-circuited
Purple: Primary coil W1 resistance vs. frequency, secondary coil W3 short-circuited
Red: capacitance measurement between the primary coil W1 and the secondary coils W2+W3

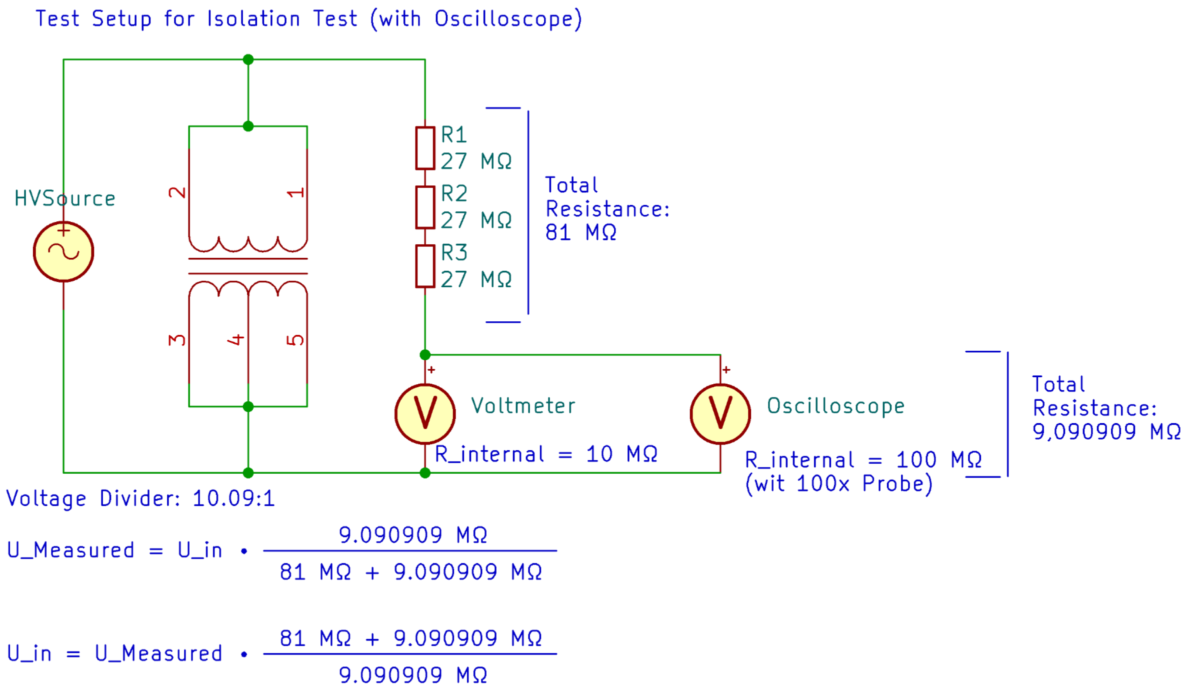
The following parameters were determined for the DCDCv9-3 transformer at a measurement frequency of 100 kHz. A measurement between 10 kHz and 300 kHz is also possible with a small deviation. The inductance and leakage inductance of W1 should not deviate by more than ± 5 %. The designators W1, W2 and W3 stand for the primary winding and the two secondary windings.

Modul	Parameter		Typ.	Unit
Inductance W1	100 kHz 4 Vpp sine, AD2 Shunt = 10 Ω		166.3	µH
Stray inductance W1	100 kHz 4 Vpp sine, AD2 Shunt = 10 Ω	W2 short circuit	56.32	µH
		W3 short circuit	56.11	µH
Inductance	100 kHz 4 Vpp sine AD2 Shunt = 10 Ω	W2 open	1.057	µH
		W3 open	1.014	µH
Stray inductance		W2 open, W1 short circuit	0.3557	µH
		W3 open, W1 short circuit	0.3496	µH

Other parameters such as saturation current are only of interest for development and should also be similar if the above parameters are observed. There is no requirement to check these values.

6.1 Isolation test

The Formula Student regulations require an isolation strength of three times the maximum battery voltage as an AC RMS value for one minute. In this case, the battery voltage is a maximum of 600 V, so the insulation voltage must be at least 1800 V AC RMS. Although the rules do not specify a test frequency, 50 Hz is common. All resistors used are high-voltage resistors from the GH 84 series. Any suitable resistors can be used to measure the high voltage, as long as the voltage divider does not exceed the maximum input voltage of the voltmeter and the entire voltage divider does not place a heavy load on the source.



The breakdown detection was recorded both with an oscilloscope by triggering on short voltage dips and acoustically or by electromagnetic interference on the microphone for the video recording. In addition to the isolation test, a further recording was made to verify the functionality of the measuring equipment used. The video recordings serve as proof that the isolation test was passed and can be found in the Scrutineering Support Presentation.

If all transformer tests have been passed, the transformer can be installed as the second last component (Cstart1 as the last) on the PCB. The transformer including isolator is attached to the PCB via its terminals. Ensure that there is as little clearance as possible between the transformer and the PCB. There are currently no plans to secure the isolator to the PCB to prevent it from vibrating, but this could be done using double-sided adhesive tape or flexible adhesive. However, bonding should not be carried out until after the performance tests at the earliest, as removing it in the event of a fault could damage the circuit board. However, it is conceivable that the transformer itself can still be removed, as it is only inserted into the isolator.

It is advisable to apply a layer of Kapton adhesive tape under the isolator on the circuit board to ensure isolation of the core halves between HV and LV in the event of the isolator breaking.

7 Soldering the components

Note: The lithium capacitor is only inserted after initial operation!

For the following section, it is recommended to open the HTML BOM (ibom) in the `kicad/production` folder with a browser. Depending on whether an unassembled PCB or PCB with assembly (PCBA) is present, the correspondingly named iBom can be opened.

7.1 Wireless clip-on installation

If the DCDC is mounted on a carrier board, J5 must be installed on the rear and J1 is omitted. J3, J6 and J7 are installed as 2.54 mm pin headers on the rear side. The length of the pin header must be selected with the distance or spacers to the board below. Exposed HV potentials must be isolated to prevent accidental contact. For the positions of the connections to the carrier board below, it is recommended to either use the dimensions in KiCAD (Layer User.Drawings) or to import the board as a footprint into the project of the carrier board. A footprint has not yet been created. *Data donation possible :)*

7.2 Sequence

The author recommends soldering the components on the back first. You can follow the order as in the iBom (alphabetically by reference designator). Afterwards, the SMD components on the front side should be soldered, followed by the THT components in order of height.

7.3 SMD components

Both classic soldering with solder and soldering iron as well as using solder paste and hot air as well as a hot plate or reflow oven are possible. However, some components can hardly be soldered without solder paste and the application of heat over a large surface:

- Q8, Q9, Q10, Q11
- U3, U5, U8
- C34-37 must be soldered with slow and even application of heat, otherwise cracks may occur in the dielectric: Cracking Problems in Low-Voltage Chip Ceramic Capacitors

Using a hot plate when soldering with hot air can help to successfully solder large SMD components or pads with high thermal conductivity. Additional flux is recommended for both solder paste and lead-free solder.

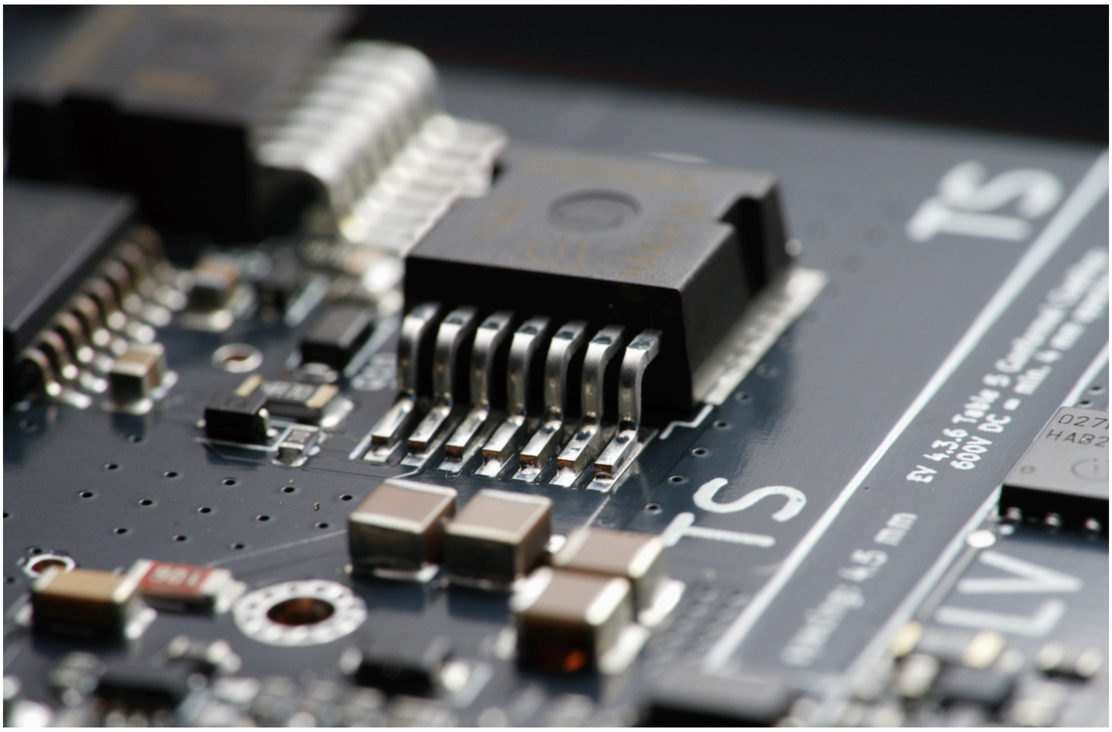
For manual assembly, a stencil helps to apply the solder paste cleanly. With a fine syringe for the solder paste, a good result can also be achieved without a stencil.

7.4 THT components

- XT60 connector (J5): Solder with a large soldering tip for max. 5-10 sec. at 400 - 450 °C. Otherwise it will take too long at a lower temperature and the plug will start to deform.
- C11, C13 at 400 - 450 °C for 2-5 sec.
- T1 (especially the secondary windings) require 400 - 450 °C and soldering times of 10-20 sec.

7.5 Cleaning

After soldering, flux residues can be removed with a soft brush and isopropanol. The author would like to point out that the use of ultrasonic cleaners can damage sensitive components such as ceramic capacitors and should therefore be used at your own risk. No damage was found with previous converters in the cleaner used by the author. Cleaning can be carried out using PCB cleaner. Depending on the manufacturer, the use of isopropanol in the ultrasonic cleaner is not permitted due to the risk of fire. If isopropanol is nevertheless used, it is also at your own risk. The HV fuse must be removed before immersion. After cleaning, thorough drying in a suitable oven (or, if necessary, on an isolated printing plate of a 3D printer) is necessary. A temperature of 70 °C with a drying time of 2 hours can be used. Sufficient ventilation of the heating chamber must be ensured to prevent the accumulation of explosive gases or moisture.



Soldering result with manually applied solder paste after cleaning

In the final step, the PCB must be checked visually (magnifying glass recommended) for solder bridges, tin balls and adequate amounts of solder as well as a well-formed meniscus at the component connections and any defects must be corrected. In addition, photos can be taken for your own documentation. With lead-free solders, the absence of a shiny surface is not a clear criterion for a cold solder joint.

7.6 Conformal Coating

In order to meet the insulation requirements of the Formula Student rules and regulations (EV 4.3.6), it is necessary to coat the converter with an isolating varnish. Plastic 70” was used for this purpose. The manufacturer's instruction manual states:

- Spray distance: 20 to 30 cm
- Surfaces should be free of grease, flux and dirt

- After application, clean the spray nozzle by spraying empty (overhead)
- Touch dry after approx. 20 min

Before applying the insulation coating, all connection connectors (HV input, LV output, fan connection J2, J8) and the RV1 and RV2 potentiometers must be masked. It is advisable to hang the converter from one of the four mounting holes using a wire hook and to apply the conformal coating thoroughly from all sides so that it drips off.
It is suspected that the conformal coating may have a slight negative effect on heat dissipation. According to the interpretation of the FS rules (Rules 2025 v1.0 EV 4.3.6), it would only be necessary to apply conformal coating to the area between the TS and LV so that heat-radiating components could remain free. However, this measure should be seen as a last resort and additional fans should be installed instead. The conformal coating is solderable and can be removed with isopropanol.

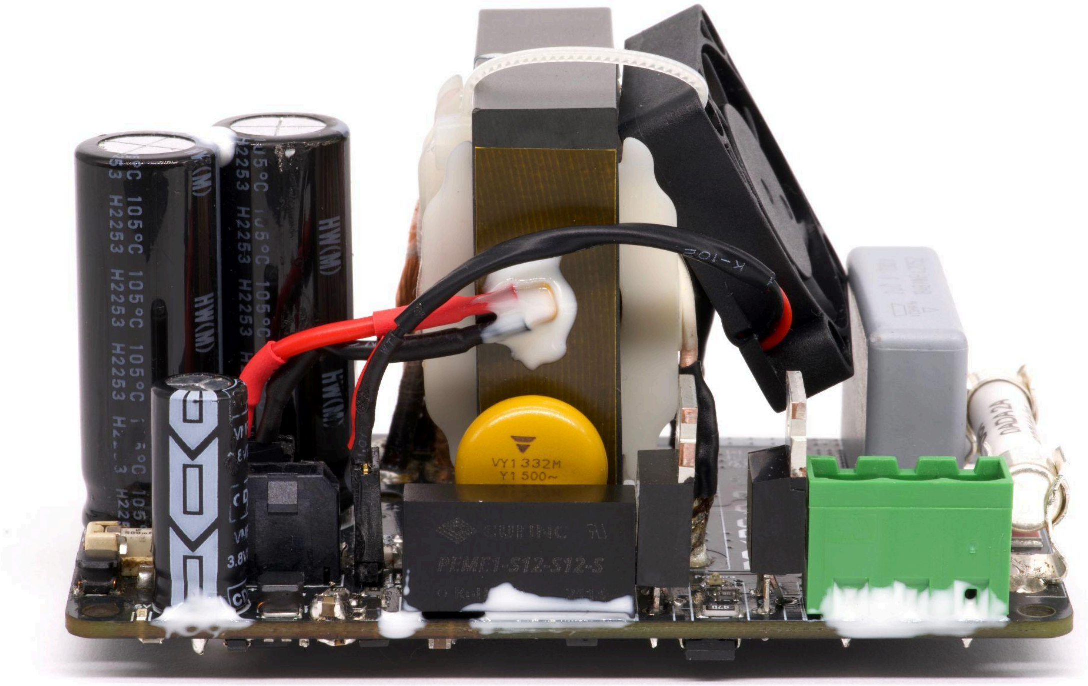
7.7 Fan and temperature sensor

A model with the dimensions 30 x 30 x 8 mm and 5 V nominal voltage was used as the fan (see component list). The supply voltage can be selected between 3.7 V and 12 V using a solder jumper (JP1) on the back. For this purpose, a connection is made with sufficient tin between the middle pad and the outer pad corresponding to the voltage (see labeling). Under no circumstances should all three pads be connected to each other!

The fan connection cables were shortened to a length of approx. 50 - 60 mm and shrink-wrapped with heat-shrink tubing, as neither the isolation voltage nor the temperature rating are known. The cables can then either be soldered directly into the pads of J2 or implemented as a pluggable connection with 2.54 mm pin headers (male + female).

The sticker with the type name on the fan must be removed and covered with a round piece of Kapton for isolation. The fan can then be attached to the upper leg of the transformer on the HV side with a small cable tie in the outlet direction (see next page).

As the terminal legs of the TH1 temperature sensor are too short and not insulated, they are shortened to approx. 5 mm and soldered together with approx. 35 mm of connecting cable. They can then either be soldered directly into the pads of J8 or designed as a pluggable connection with a 2.54 mm pin header (male + female). The temperature sensor has no polarity and is attached to a layer of Kapton on the side of the transformer core using suitable 2K adhesive.



7.8 Miscellaneous

Some components are more susceptible to vibrations during use in the Formula Student vehicle due to their design and assembly. The following components can be reinforced against vibrations with a some 2K adhesive:

- Cstart1 on the PCB
- J1 on the PCB
- U1 on the PCB
- C11 and C13 together at the top end

To switch on the DCDC in test operation, a short enable switch with a Molex Microfit connector can be used:

The HV connector plug can be used in an angled (284051-2) or straight version (282809-2)).

8 Testing the converter

8.1 Initial operation

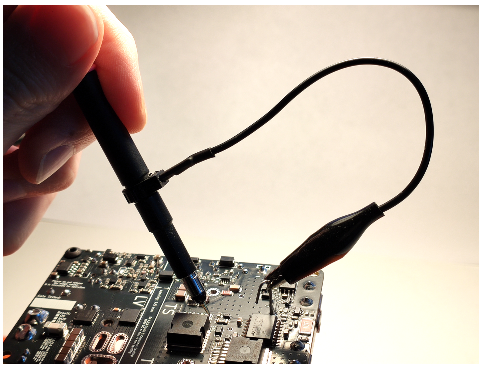
All components except Cstart1 are now soldered.

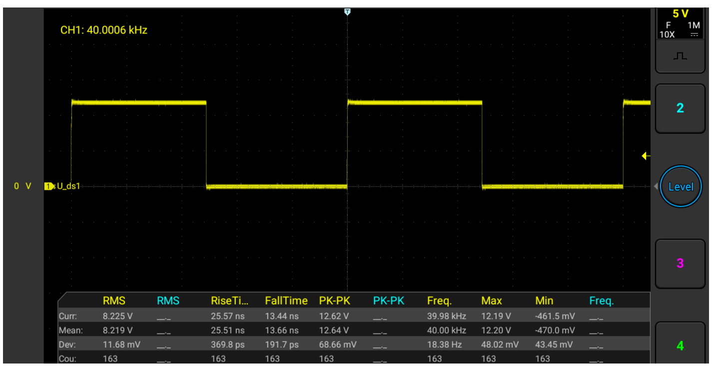
It must be checked:

- Are the HB and SR FETs between the drain source and gate source high-impedance (resistance measurement with a multimeter, resistance should be in the MΩ range)?
  → If not, there is probably a tin bridge between contacts or possibly on the driver.
  → Re-solder with plenty of flux, remove excess solder if necessary.
- Note: U5 and U8 have two orientation points, making it easy to confuse the alignment.

8.2 Initial test (without HV at input)

- Set a constant current of 100 mA and 0 V on the Lab power supply (output OFF) → connect to the 24 V output of the DCDC
- Slowly increase the voltage on the laboratory power supply (output ON) to 24 V
  → A voltage of between 3.6 and 3.8 V should be present at the pads of Cstart1 and the 5 V LED should light up.
- Switch on the DCDC with an enable switch.
  → Approx. 12 to 12.5 V should be present between pads 1 and 2 of U1 and the 12 V and Pwr LEDs should light up. The input current at 24 V should be between 20 and 30 mA
- Inserting the lithium capacitor: Special care must be taken when inserting the capacitor, as the capacitor (Cstart1) is charged between 2.5 V and 3.8 V. DO NOT SHORT CIRCUIT BOTH CONTACTS WHEN TRIMMING THE CONNECTIONS!
- Remove R61 to deactivate UVP/OVP (important for initial tests)
- Note: For HV measurements, C1 pin 1 is recommended as the ground point (solder a small wire or similar here).
- Check whether square-wave signals are present, measured against ground:
  - U12 pins 5 and 8
  - Q10 and Q11 pin 1 (gate)





Example measurement at the gate of Q10. The frequency may be different depending on RV2 setting

→ A low voltage (e.g. 10 V / 100 mA) can now be applied to the HV input. A square wave with the applied voltage should now be present between T1 pin 1 and C1 pin 1.

If these tests are successful, the first adjustments can be made.

8.3 Troubleshooting

The following table can be used as a guide in the event of problems.

Fault	Cause	Solution
DCDC cannot be switched on, no LEDs light up	Discharged start capacitor. Measure the voltage of the enable supply line to ground. Must be > 2.5 V. otherwise Boost converter may be broken	By applying a voltage between 5V and 24V to LV-Out, the start capacitor can be recharged via the internal buck converter. Replace boost converter IC if necessary.
DCDC cannot be switched on, 5V LED does not light up when recharging via output	Check LV fuse, possibly buck converter overloaded or broken.	Replace fuse and/or buck converter IC. Remove Fuse before continuity test!
Precharge LED continuously on	DC link is permanently drained or precharge defective. Measure the resistance of components in the DC link (e.g. half-bridge FETs). Check resistance R6 for the correct value.	Replace half-bridge FETs or precharge FETs/OPV/R6 if necessary
Orange HV LED does not light up		
Orange HV LED lights up continuously, even if DCDC = Disabled	Precharge defective.	replace Precharge FETs
PWR LED does not light up	Precharge not completed or the 12V supply after D11 is overloaded.	Replace half-bridge FETs or precharge FETs/OPV/R6 if necessary. Check for overheating components.
D3 does not light up	HV input voltage below the UVP threshold value or HV fuse is blown due to overload. If the HV Fuse is blown, check resistance of the half-bridge FETs before replacement. They might be defective.	Increase voltage above the UVP threshold value or adjust UVP threshold value if necessary. Replace HV fuse if blown.
LEDs light up normally, but no voltage at the output	output fuse blown due to overload	Replace output fuse if blown.
Only 12V LED lights up	Overtemperature protection active	Allow to cool down for 10 seconds. If a restart is not possible, the fault lies elsewhere.
Output voltage Oscillates in the lower Hz range	Overcurrent protection active. Load may have been switched on too early.	Switch off the converter immediately and check the loads for too high currents!

If none of the errors mentioned apply to a particular problem, the author asks to create an Issue on GitHub to expand the list. Random problems that are caused by soldering errors, for example, are not listed. Many errors can be found by measuring with a multimeter or an oscilloscope. A thermal imaging camera is recommended for quick troubleshooting.

8.4 Test Set-up

The following measurement setup is used for numerous measurements.

At the HV input:

- Voltage source 0 - 600 V / 0 - 2 A
- Multimeter for voltage measurement
- Multimeter for current measurement

→ The multimeters are connected voltage-based, i.e. voltage measurement behind the current meter, followed by the DCDC.

On the LV output:

- Power sink 24 V / max. 0 - 31.25 A
- Multimeter for voltage measurement (connected via measuring points J4)
- Multimeter for current measurement (or measurement of the current via a suitable shunt)
- Laboratory power supply unit for charging the start capacitor (suitable for 5-24 V)

On the DCDC with oscilloscope:

- A) Voltage measurement via Cres (HV! Only suitable if differential HV probes up to 600 V are available or oscilloscope has isolated measurement inputs)
- B) Current measurement (insulated current measuring coil) via a transformer cable. The measured values of both measurement methods (A/B) can be approximately converted into each other, so it is not necessary to measure both. However, the current measurement may be more suitable for understanding the actual load on the transformer.
- Voltage measurement via drain source and gate source on one of the SR MOSFETs (Q8 or Q9)
- Measurements via C1 (HV!) to check the precharge
- HV input and LV output for ripple voltage measurements

Measurement methods A or B are always relevant for all oscilloscope measurements, as they can also be used to determine the switching frequency. With a multi-channel oscilloscope, several measurements can of course be carried out simultaneously. However, attention must always be paid to the existing potential differences and sufficient isolation. In addition, depending on the measurement, signals from one measurement can interfere with other measurements. If in doubt, it is preferable to carry out only one oscilloscope measurement at a time.

Other measurements:

- Room temperature (for insulation measurement also humidity)
- Thermal imaging camera (highly recommended!), alternatively: IR thermometer (less accurate)

8.5 General notes on the measurements/tests

- Always test with a low load first and work up slowly (low voltage, low power → increase power, increase voltage)
- If problems occur at low loads, resolve them early if possible, as they can be much more severe at high loads (e.g. power loss) and can lead to the premature destruction of components
- For tests that involve the risk of component destruction, perform them as late as possible to cover the majority of relevant tests
- Thermal equilibrium: After starting, the converter is allowed to warm up for approx. 10 minutes without load. The transformer in particular reduces its losses during heating. After a change (≤ 100 W) in the output load, wait 30-120 seconds until the measured values and temperatures are constant. A current meter at the input with a time curve helps to detect a constant current consumption more quickly. For large load changes (full load → idle), wait at least 5 minutes.

8.6 Measurement list

The following table, including explanations, is available in the DCDCv9-3 Table in the `Measurements Table example` spreadsheet. It contains all the important values that should be recorded during a measurement, e.g. resonance test or performance test.

Title:	Test No.	Date	Transformer	Core Material	C_res [nF]	HB MOS R_Gate	Air Gap µm	SR R_gate	SR_fet	Roomtemp	Fan	C_Load		R41	R39	C30	R37	C26	C29	R38/29 min_Ton	33 min							
Initial Test v9-3	300	8.11.24	67+68+69	N97+N27_1AG	4 x 5.6 nF C0G	4R7	1000,0	4R7	BSC027N06LS5ATMA1	21,1°C	no	4400 uF + 1410 µF (DPS5020)		1k	1k	10 nF	47k	22 nF	47 pF	1k	10k							
comments	**F min kHz**	**LV set V**	**Deadtime °**	**HV_IN V**	**HV_IN mA**	**LV_OUT V**	**SHUNT mV**	**F_sw kHz**	**I_prim mA RMS**	**U_RMS Cr_B meas**	**U_RMS Cr calc**	**LV OUT mA**	**HV IN P W**	**LV OUT P W**	**Power loss W**	**Efficiency**	**Gain 28:2**	**Temp after min**	**HS FET**	**LS FET**	**C_res (C0G)**	**outer Rect FET**	**inner Rect FET**	**Trafo prim**	**Trafo Sec**	**Trafo Core**	**snub max. Temp**	**Neutral suface**
f_res, OCP, R60 100k / C44 22 nF response Value: 132,4 Vrms / 652,4 Vpp	80,2	24,1	135°	5,36	1098	18,5	0	80,2	2490	212,8	220,5	5,617	5,89	0,10	5,78	1,77 %	96,64											
	83	24,1	135°	35,03	217	21	0	83,0	2739	224,8	234,4	5,617	7,60	0,12	7,48	1,55 %	16,79	2	46	46	49	34	37	58	42	60	43	22,4
	80,2	24,1	135°	42,04	180	21,41	0	83,5	2785	230,4	236,9	5,617	7,57	0,12	7,45	1,59 %	14,26											
f_res, R60 82k → no OCP triggered	80,2	24,1	135°	6,465	1210	22,7	0	80,3	3007	254,7	266,0	5,617	7,82	0,13	7,70	1,63 %	98,31	3	51	50	56	41	44	71	47	70	47	25
	80,2	24,1	135°	5,858	1288	22,7	0	79,9	3045	259,1	270,7	5,617	7,55	0,13	7,42	1,69 %	108,50											
	81,7	24,1	135°	49,99	245	24,1	0	83,6	3099	259,0	263,4	5,617	12,25	0,14	12,11	1,11 %	13,50	5	47	47	49	32	35	58	41	58		22,6
Oszi Ripple Measurement: 1,140 Vrms, 3,14 Vpp (ringing ignored), ringing on current: 10 MHz, dead time has no influence	81,7	24,1	**135°**	50,06	190	24,1	0	83,5	3099	358,9	263,7	5,617	9,51	0,14	9,38	1,42 %	13,48											
	81,7	24,1	135°	50,036	230	24,1	0,24	83,5	3100	262,1	263,9	103,166	11,51	2,49	9,02	21,60 %	13,49											
	81,7	24,1	135°	49,983	257	24,1	0,37	83,5	3130	263,2	266,5	156,004	12,85	3,76	9,09	29,27 %	13,50											
slight whine (rk)	81,7	24,1	135°	49,84	335	24,1	0,77	83,5	3130	262,2	266,5	318,576	16,70	7,68	9,02	45,98 %	13,54											
more whine (rk)	81,7	24,1	135°	49,63	471	24,1	1,45	83,4	3130	262,9	266,6	594,931	23,38	14,34	9,04	61,34 %	13,60	2	59	59	64	45	51	85	55	83	52	24
slight whine (rk)	81,7	24,1	135°	49,41	758	24,1	2,81	83,1	3246	273,5	277,6	1147,569	37,45	27,66	9,80	73,84 %	13,66	2	60	61	63	51	57	87	59	87	56	24
silence, ripple: 0,94 Vrms	81,7	24,1	135°	49,34	1024	24,1	4,17	83,0	3278	276,3	280,7	1700,113	50,52	40,97	9,55	81,10 %	13,68											
OVL, ripple: 0,673 Vrms	81,7	24,1	135°	49,32	1057	14,81	7,7	81,7	2395	201,1	208,4	3133,851	52,13	46,41	5,72	89,03 %	8,41	5	55	55	60	54	61	73	58	72	58	23,8

8.7 Checklist

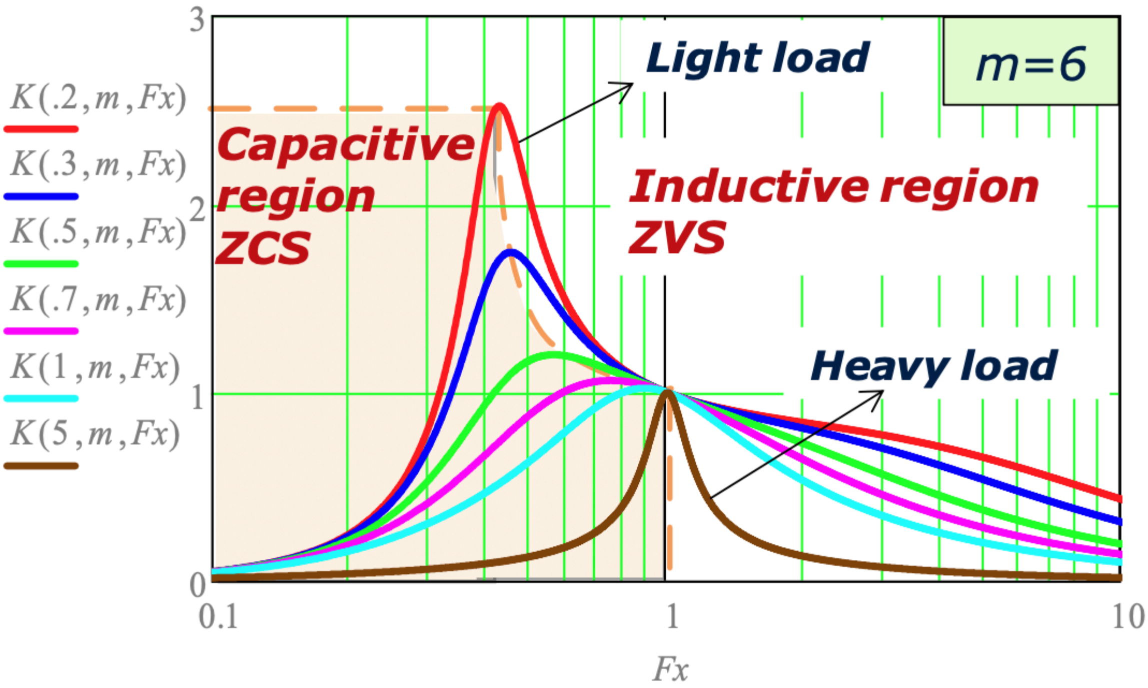
The following list contains all the important measured values that must be determined for each replica. The list can also be found in the `DCDCv9-3 Table` in the `essential Checklist empty` worksheet and can be compared with the `essential Checklist` worksheet. If major deviations are found, the replica must be checked for errors.

Module	Parameter	Value	Unit	Date	Status
Start-up Cap Supply	Charging Voltage (with C_{start1}), DCDC = Disabled		V		☐
Start-up Cap Supply	Input current with fully charged capacitor, $24V_{in}$, Enabled		mA		☐
Start-up Cap Supply	Discharge Current (DCDC = Enabled) no HV, Cap @ 3,75 V		mA		☐
Start-up Cap Supply	Discharge Current (DCDC = Enabled) 600 V		mA		☐
Start-up Cap Supply	Hold-Up time, DCDC = Enabled, no HV,		s		☐
LV Voltage LV Side Voltage	U_{in} = 0 V, DCDC = Enabled, IDLE, 12.2 V		V		☐
LV Voltage 9 V LDO	U_{in} = 0 V, DCDC = Enabled, IDLE, 12.2 V, 20,1°C RT		V		☐
LV Voltage, HV Side	U_{in} = 0 V, DCDC = Enabled, IDLE, 12.2 V		V		☐
LV Voltage, HV Side after D11	U_{in} = 0 V, DCDC = Enabled, IDLE, 12.2 V		V		☐
LV Voltage, HV Side after D14	U_{in} = 0 V, DCDC = Enabled, IDLE, 12.2 V		V		☐
Input Current, Turned ON, above UVP	400 V, 21°C RT, no Fan, dead time = 80°		mA		☐
Input Current, Turned ON, above UVP	500 V, 21°C RT, no Fan, dead time = 80°		mA		☐
Input Current, Turned ON, above UVP	600 V, 21°C RT, no Fan, dead time = 80°		mA		☐
Oscillator	Soft Startup with C34 = 22uF/1k frequency		kHz		☐
Oscillator	frequency min. recommended		kHz		☐
Voltage Regulation	output Voltage, 25°C RT		V		☐
Voltage Regulation	minimum HV input for 24 V Output, set by f_{min} = 94 kHz		V		☐
UVP	enable, 1.7 MΩ		V		☐
UVP	disable, 1.7 MΩ		V		☐
OVP	enable, 543 kΩ		V		☐
OVP	disable, 543 kΩ		V		☐

Module	Parameter	Value	Unit	Date	Status
Overtemperature enable	U6 = TL072 R35 = 330 kΩ, R36 = 4.7 kΩ C28 = 100 nF, C48 = 10 nF		°C		☐
Overtemperature disable	U6 = TL072 R35 = 330 kΩ, R36 = 4.7 kΩ C28 = 100 nF, C48 = 10 nF		°C		☐
Fan control turn-on	U6 = TL072 R31 = 4.7 kΩ, R18 = 470 kΩ		°C		☐
Fan control turn-off	U6 = TL072 R31 = 4.7 kΩ, R18 = 470 kΩ		°C		☐
Fan control Sensor Loss	Fan behavior				☐
Hotbox Test, SR Temperature after 30 min	converter inside a box with T_{amb} = 60 °C must be able to deliver P_{out} = 500 W at V_{in} = 500 V for 30 minutes, restarted after 5 seconds must be possible		°C		☐
Inductance W1	100 kHz 4 Vpp sine, N27+N97		µH		☐
Leakage Inductance W1	W2 short, 100 kHz 4 Vpp Sine, AD2 = 10 Ω, N27+N97		µH		☐
Leakage Inductance W1	W3 short, 100 kHz 4 Vpp Sine, AD2 = 10 Ω, N27+N97		µH		☐
Inductance W2	100 kHz 4 Vpp Sine, AD2 = 10 Ω, N27+N97		µH		☐
Inductance W3	100 kHz 4 Vpp Sine, AD2 = 10 Ω, N27+N97		µH		☐
Leakage Inductance W2	100 kHz 4 Vpp Sine, AD2 = 10 Ω, N27+N97		µH		☐
Leakage Inductance W3	100 kHz 4 Vpp Sine, AD2 = 10 Ω, N27+N97		µH		☐
Isolation	1 minute AC, 50 Hz, no Isolation breakdown		V_{RMS}		☐

8.8 Minimum switching frequency (Fmin or potentiometer RV2)

The switching frequency must always be above the resonant frequency to avoid operating in the capacitive range (switching losses due to hard switching). As can be seen in the following diagram, the limit (orange dashed line) is load-dependent. For the first tests, however, Fmin can be set without load.



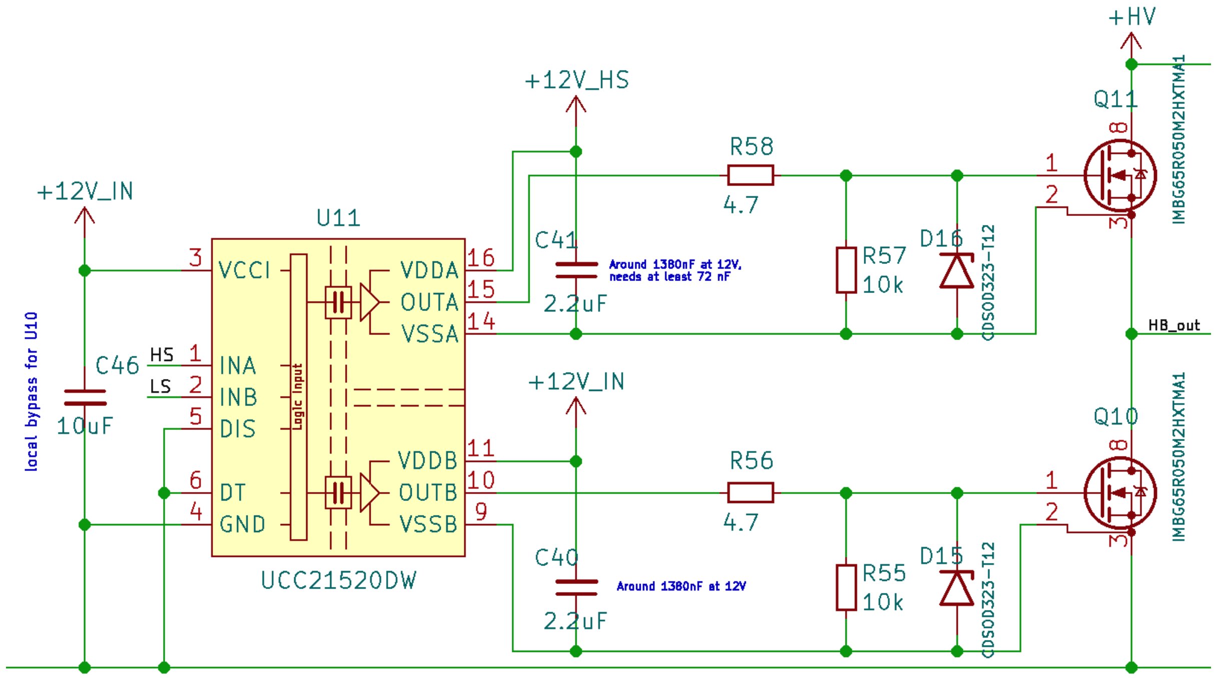
Gain vs. switching frequency (normalized), Infineon Design Note, page 6, V1.0 March. 2013

Caution! Despite the low input voltage, over 300 V can be applied to the transformer and Cres due to the resonant circuit! The transformer can become hotter than 60 °C. The adjustment screwdriver must be insulated! If an output voltage of over 25 V is reached, there is a fault in the control loop and must be resolved before further testing! If a “clicking” sound is heard several times per second, an overcurrent is present in the resonant circuit. The input voltage must be reduced!

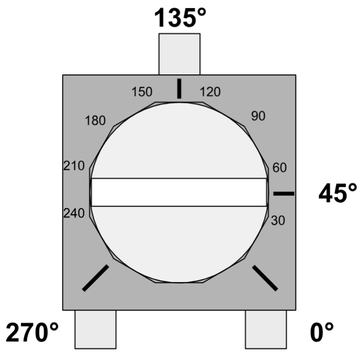
To set Fmin, the resonant frequency of the resonant circuit must first be determined. To do this, connect 5 V to 15 V with a 1.5 A current limit to the HV input and adjust the potentiometer Fmin (RV2) with a trimming screwdriver so that the voltage at the output is maximized.
If 24 V is reached at the output, the input voltage must be reduced so that the output voltage is below 24 V, e.g. 20 V in order to prevent the control circuit from intervening above 24 V. Fmin must then be set again so that the output voltage is maximum but below the control voltage (24 V). This process must be repeated until the frequency with the maximum output voltage at minimum input voltage has been found (resonant frequency without load). All measured values (currents, voltages, switching frequency) should then be entered in the measurement table. In the author's setup, the resonant frequency was 80.2 kHz. Fmin must then be set so that it is approx. 2-5 kHz above the resonance frequency. Turning the potentiometer anticlockwise increases the minimum switching frequency.

Note: If Fmin is too close to the resonance frequency, the resonance capacitors (C34-37) may be destroyed at input voltages above 15 V. If problems with C34-37 occur permanently, remove them and install C3 instead (observe the note in the circuit diagram). For later tests from Vin ≥ 200 V, Fmin must be set so that 24 V is just reached at the output with 180 V at the input. In the author's setup, this frequency was approx. 94 kHz. The calc sheet from Onsemi recommends Fmin = 93 kHz based on the maximum gain under full load. It is possible that the frequency deviates by a few kHz due to tolerances in the replica. In the event of larger deviations, check that the core halves are flush together (a 1.0 mm air gap only in the middle leg) and that the number of primary windings is correct.

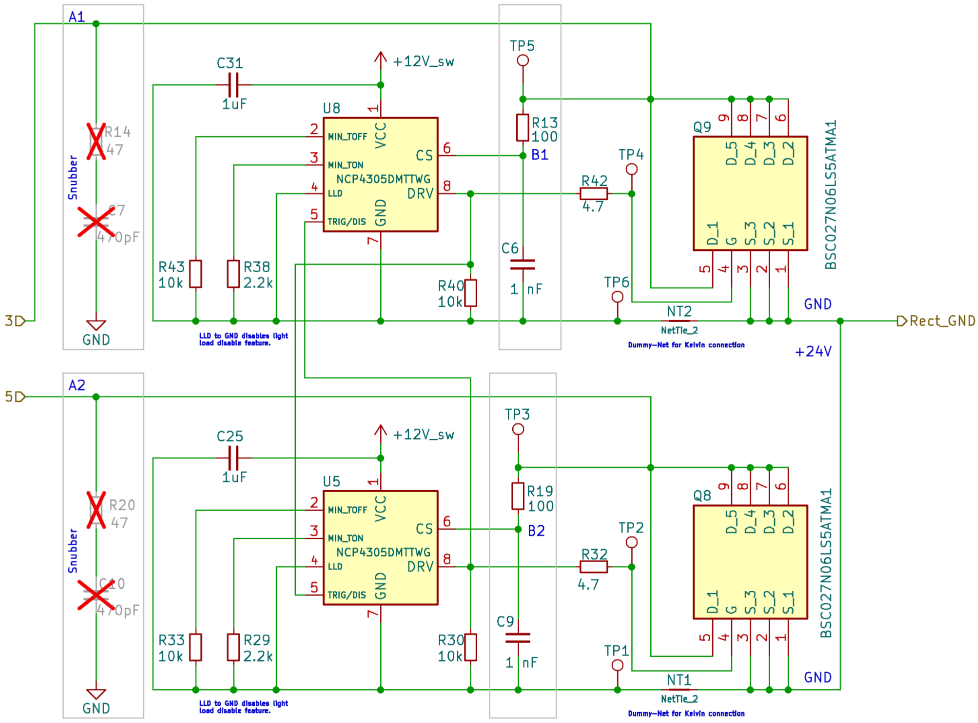
8.9 Dead time (dead time resp. potentiometer RV1)



The two MOSFETs of the half bridge (Q10/Q11) switch on and off alternately. However, as they always have a short delay before switching on and off, some dead time must be added so that they are not both on at the same time (short circuit). Ideally, the dead time is only as short as necessary, as the current from the resonant circuit flows through the body diodes of the MOSFETs during the dead time (losses due to voltage drop). In practice, the dead time can be set so that the efficiency is at its highest. If the input voltage and load at the output are sufficiently constant, it is sufficient to measure the current at the input and ensure that it is minimal. For initial tests, this can be set at 100 V at the input and without load. Later, the setting should be repeated at 600 V, as the switching frequency is highest here. A position of the dead time potentiometer approx. 80° away from the minimum (CCW) (approx. 3 kΩ) has so far been determined as the optimum in the entire voltage and load range.
Clockwise rotation reduces the dead time. From 0° to approx. 60° from the minimum position, the dead time does not change, as the controller has a minimum dead time of 120 ns.



8.10 Active rectification (SR driver)



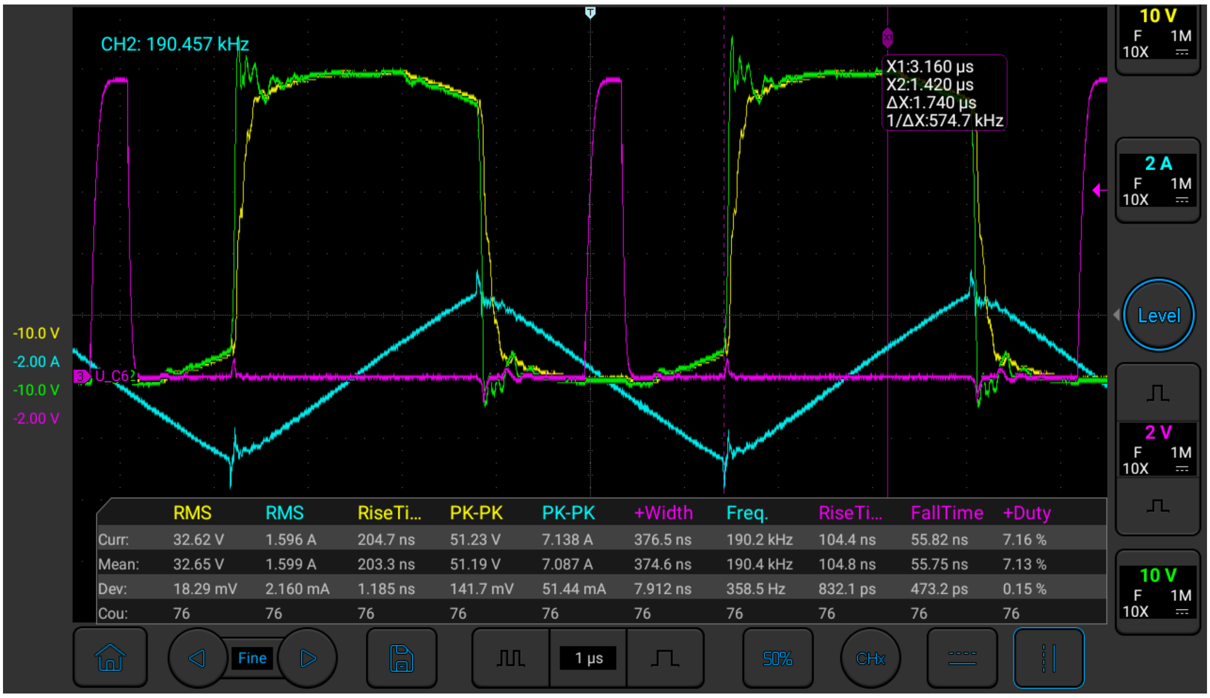
For later performance tests, it must be checked whether the SR drivers are working properly. If not, the MOSFETs (Q8/Q9) may overheat, as rectification will otherwise take place via the body diode (high voltage drop).

Test parameters: Vin = 50 V to 100 V, Vout = 12 V to 24 V, Pout = 0 W to 50 W

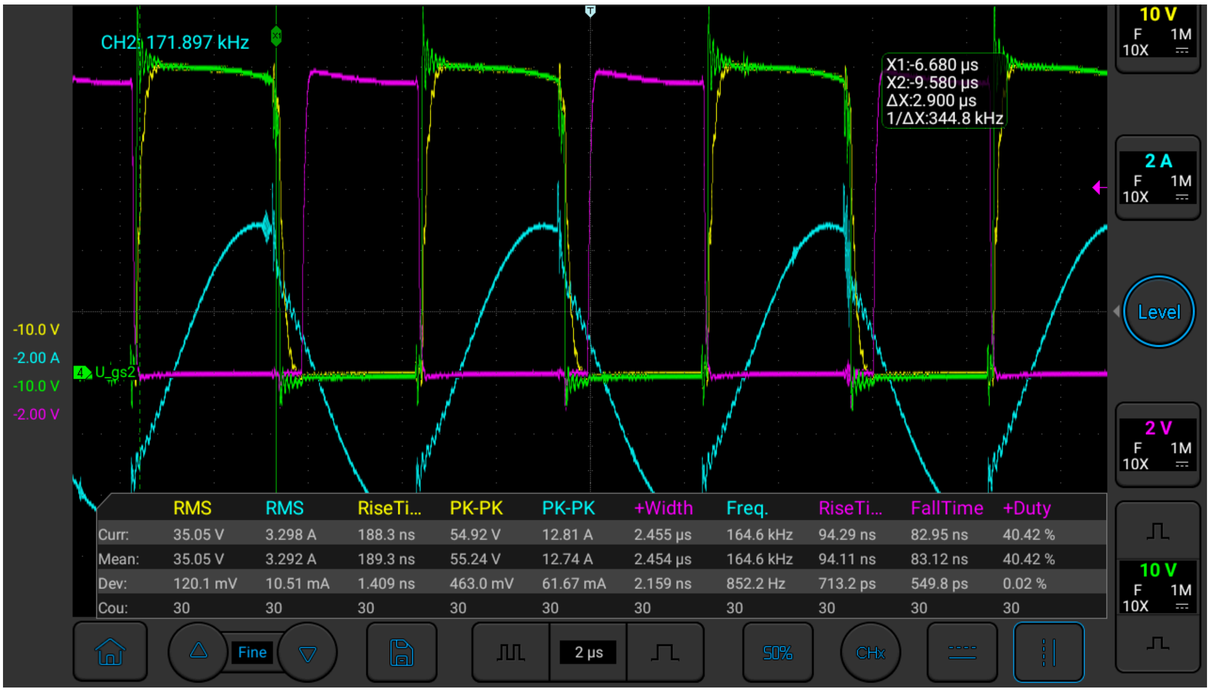
An oscilloscope with at least two measurement channels is recommended for checking. Measurements are taken between the drain source (TP3 and TP1) and gate source (TP2 and TP1) using a ground spring directly on the converter. The load at the output is then increased and the behavior of the gate-source voltage is observed (see oscillograms below).

Note: As the output voltage is probably below the regulation voltage (24 V) due to the low input voltage, a reduction in the output voltage is to be expected when the load is increased.

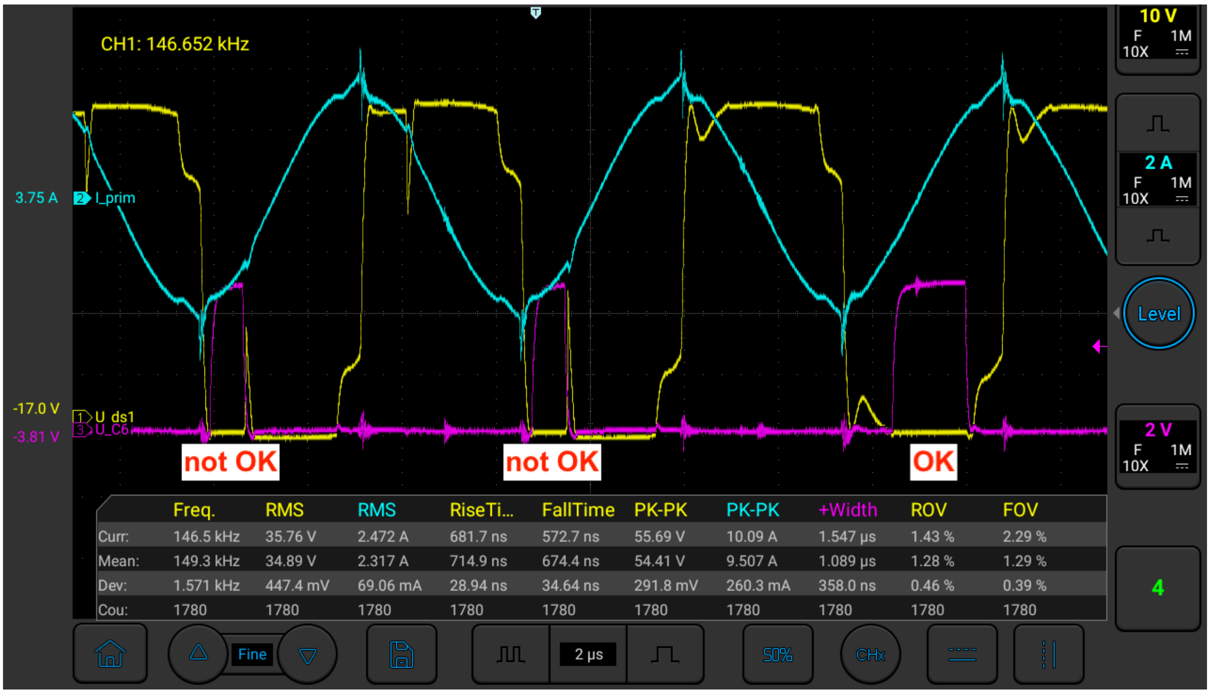
Repeat the measurement for the other rectification. A measurement via crocodile clips or similar instead of a ground spring via the GND of the converter is possible, but may cause interference (not as relevant for checking as for development).



Screenshot: Active rectification with low load (600 V input voltage)
Purple: Gate-source signal, green: Drain-source signal, yellow: Drain-source signal after low-pass, cyan: Transformer primary current (current measuring coil)



Screenshot: Active rectification at high load (600 V input voltage)
Purple: Gate-source signal, green: Drain-source signal, yellow: Drain-source signal after low-pass, cyan: Transformer primary current (current measuring coil)



Screenshot: Example of faulty active rectification at low load. Purple: Gate-source signal, yellow: Drain-source signal, cyan: Transformer primary current (current measuring coil). Here, the leakage inductance of the transformer and parasitic capacitances cause an oscillating circuit to oscillate. This leads to an overshoot when the current sign changes in the drain-source voltage, causing the drivers to switch the gate on and off too early. More information on how active rectification works can be found in the chapter “Active rectification with NCP4305” in the documentation.

8.11 UVP/OVP Adjustment

The undervoltage and overvoltage cut-off are set via fixed voltage dividers. By default, they are set to approx. 200 V UVP and 610 V OVP with approx. 10 V hysteresis. Depending on the supply source, however, it may be useful to adjust the threshold values, for example to prevent deep discharge of the HV battery if the DCDC converter is accidentally forgotten.

$$V_{ref} = 3.3V$$

$$V_{UVPenable} = V_{ref} \cdot \frac{R71 + (R67 + R68)||R62}{(R67 + R68)||R62}$$

$$V_{OVPenable} = V_{ref} \cdot \frac{R1 + (R65 + R66)||R69}{(R65 + R66)||R69}$$

For an UVP of approx. 200 V, R67 = 100 kΩ and R68 = 1.6 MΩ were used
For an UVP of approx. 400 V, R67 = 820 kΩ and R68 = 22k can be used

The corresponding simulation [DCDCv9-3r_OVP__UVP.asc]() is located in the `ltspice` folder.

8.12 Performance test

Since the converter should ultimately be able to convert high power from the high-voltage source into a lower output voltage as efficiently as possible, the power test with efficiency measurement (and temperature measurement) is the most important measurement. *You don't necessarily want to start a fire...*

Previous tests have shown that the following power losses occur during operation:

Power loss	Note
up to approx. 10 W	Power loss without load, no fan required
10 W - 13 W	up to approx. 300 W load, no fan required at room temperature
13 W - 20 W	up to approx. 500 W load, fan required, limit for continuous output
20 W - 25 W	up to approx. 750 W load, fan required, only short-term operation (a few minutes)

The aim is to keep the temperatures of all components below their permissible limits. Even if, for example, the SR MOSFETs could withstand temperatures of up to 150 °C and the HF litz wire up to 155 °C, a lower temperature is more efficient. A further goal is to achieve temperatures below 100 °C for all components at 500 W continuous power. Originally, the aim was also to achieve this continuous power output purely passively, i.e. without fan cooling, but this became increasingly difficult as the design was scaled down. Of course, the performance can be increased with a large fan and the installation of heat sinks, but this would compete with the compactness of the system. At maximum load, temperatures of the SR MOSFETs of up to approx. 120 °C are acceptable for short periods. Above this temperature, the overtemperature cut-out should kick in (check beforehand that it is working correctly!).

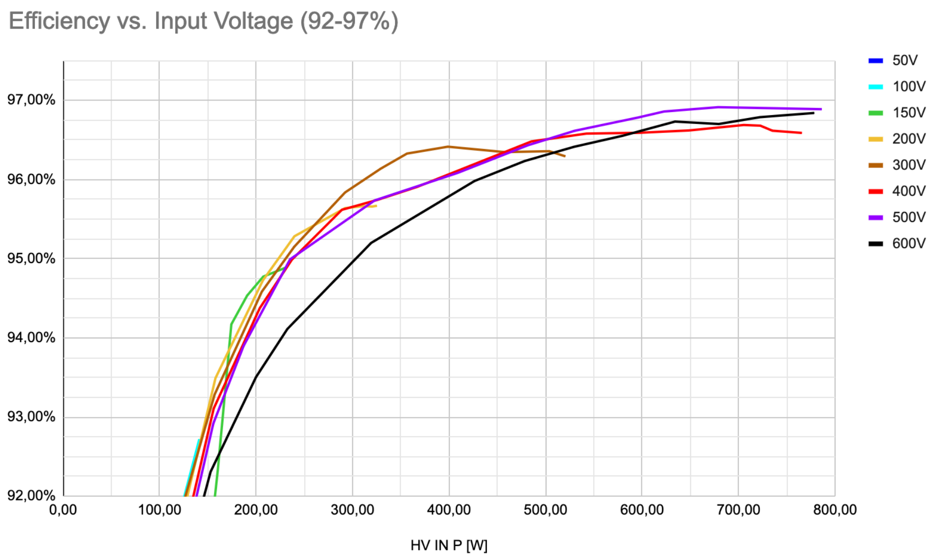
Side fact: The secondary windings are so massive that they also serve as heat sinks for the SR FETs and vice versa. It is therefore sufficient to install the fan only on the transformer in order to cool the SR-FETs as well.

The following voltages/power ratings are preferably tested for the power measurements

Voltage	Output power / remark
5 - 15 V	No power, suitable for setting the minimum switching frequency
50 V	max. 40 W
100 V	max. 130 W
150 V	max. 220 W
200 V (Observe note on Fmin!)	max. 300 W
300 V (Observe note on Fmin!)	max. 500 W
400 V (Observe note on Fmin!)	max. 750 W
500 V (Observe note on Fmin!)	max. 750 W
600 V (Observe note on Fmin!)	max. 750 W

The power levels are also set in steps, with a finer resolution for efficiency measurement at low load than at high load.

e.g. 0 W, 1 W, 2 W, 5 W, 10 W, 20 W, 50 W, 100 W, 150 W, 200 W, 300 W, 400 W, 500 W, 600 W, 750 W. Depending on the aim of the measurement, it may also make sense to select larger or smaller intervals in order to save time. For the first tests, however, it is recommended to record as many measuring points as possible in order to have reference measured values for comparison later on in the event of improvements, but also to slowly feel your way forward to determine which power and voltages are permissible without components overheating. A measurement with 15 load values for a voltage range can easily take an hour, including 2 to 5 complete measurements of the component temperatures.



First efficiency measurement of the v9-3, time required approx. 7 hours, 114 measurement rows

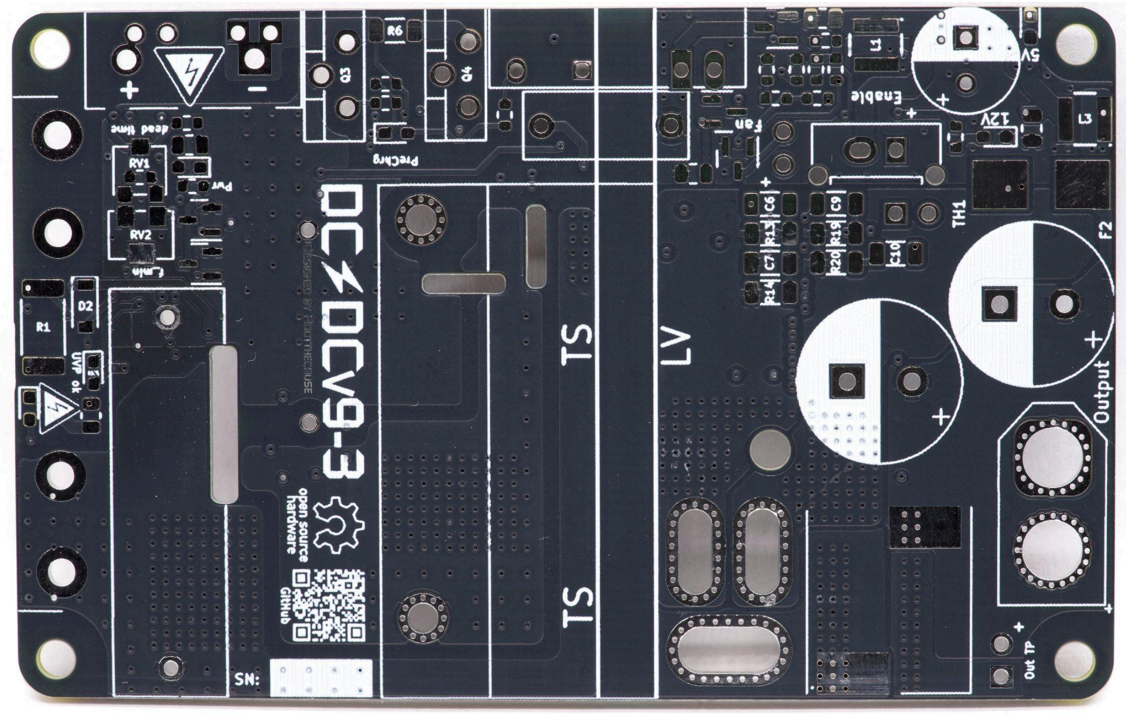
9 Component costs

The following costs refer to the replica of a converter.
Note: 15 PCBs of which 10 PBCA were ordered (the unpopulated boards serve as viewing samples). The prices were calculated for the DCDCv9-3 in the period indicated and may vary depending on VAT, sources of supply and market developments.

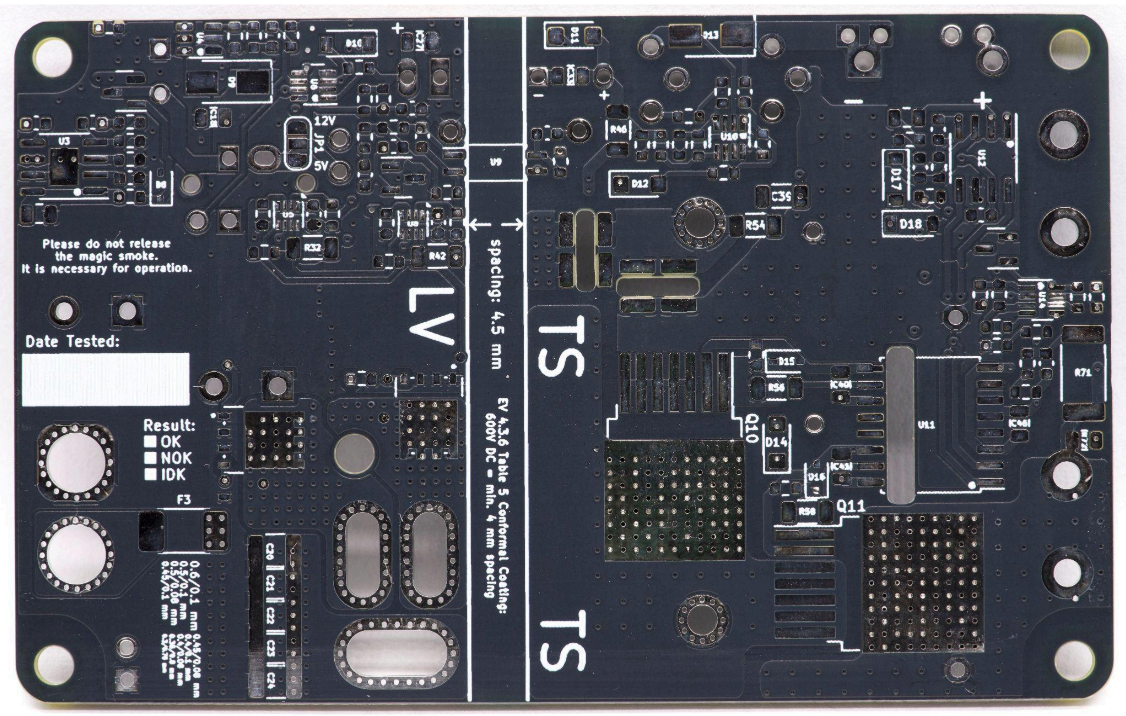
Object	Total costs incl. VAT.	Price Date
PCB (with 15 pieces ordered)	5,16 €	Okt. 2024
Assembly incl. components (with 10 pieces ordered)	23,63 €	Okt. 2024
PCB shipping (with 15 pieces ordered)	3,36 €	Okt. 2024
PCB Customs (with 15 pieces ordered)	1,19 €	Okt. 2024
Mouser order for remaining components per PCBA without quantity discount (with quantity discount from 10 pieces)	94,06 € (74,46€)	Jan. 2025
XT60 male + female connector	0,80 €	Jan. 2025
5 V Fan	3,00 €	Jan. 2025
SLA Resin Flame Retardant HDT 250 ml (used 11ml)	2,51 €	Jan. 2025
HF Litz wire (180 cm Prim. + 35 cm Sec.)	4,96 €	Okt. 2024
Total cost (with Mouser quantity discount from 10 pieces)	138,67 € (119,07€)	

10 Picture gallery

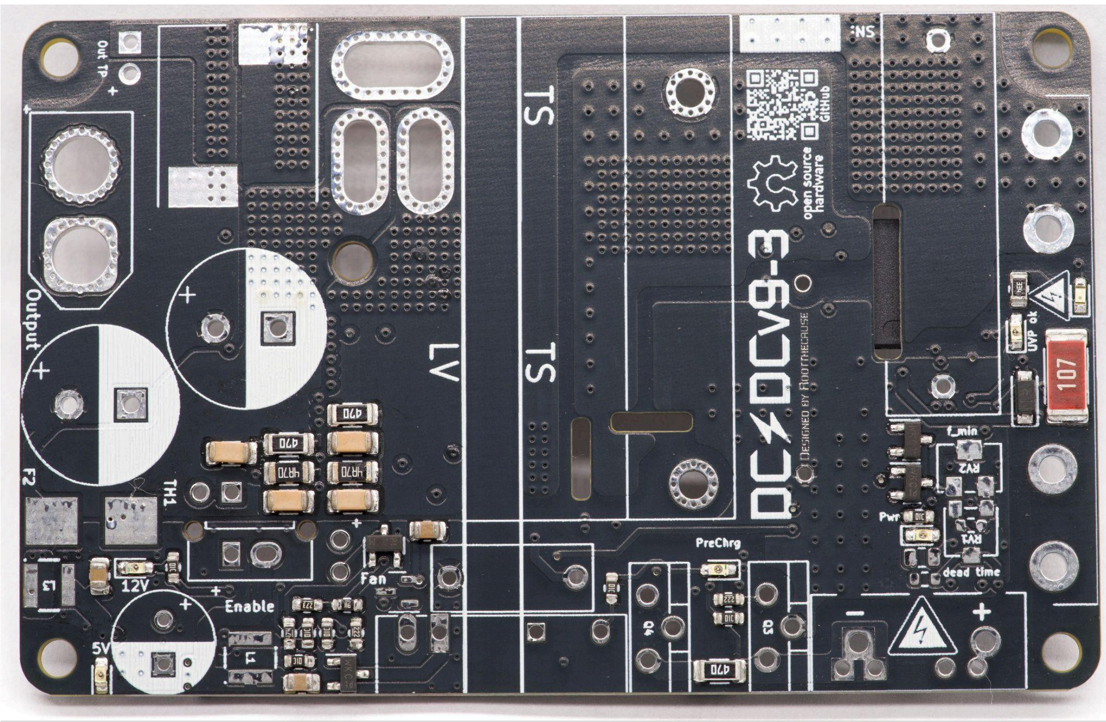
The following pictures show the DCDCv9-3 and serve as orientation for the reproduction. The release version DCDCv9-3r has small changes on the back, such as additional capacitors and snubbers. On the front, the HV input connector has been rotated by 180° (wave pattern inwards). As the pictures were taken after the tests, some components have signs of wear.



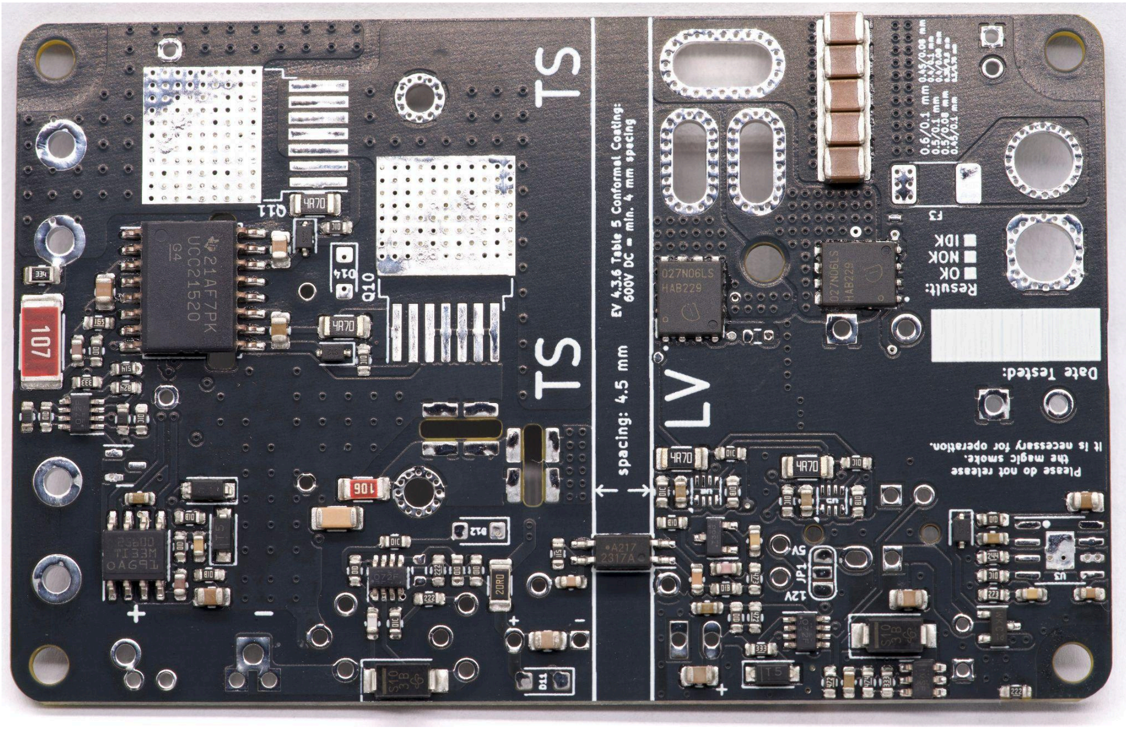
DCDCv9-3 PCB front, empty



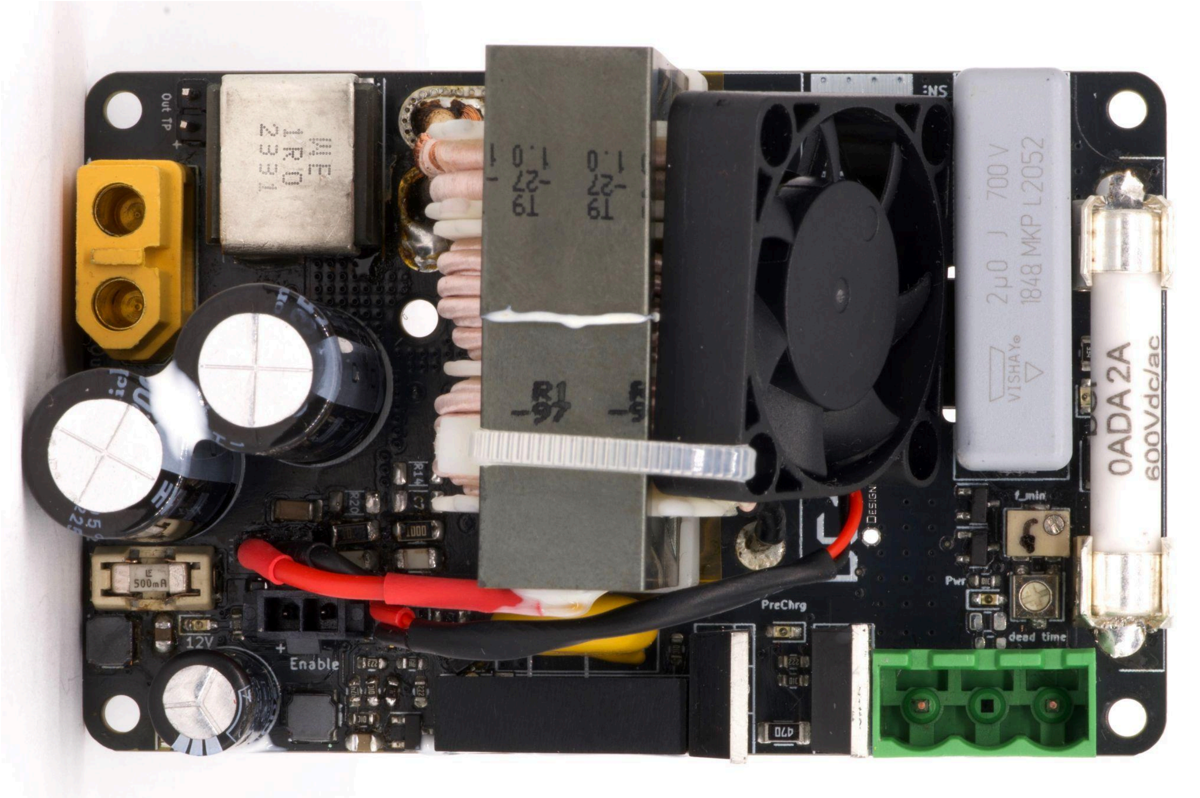
DCDCv9-3 PCB rear, empty



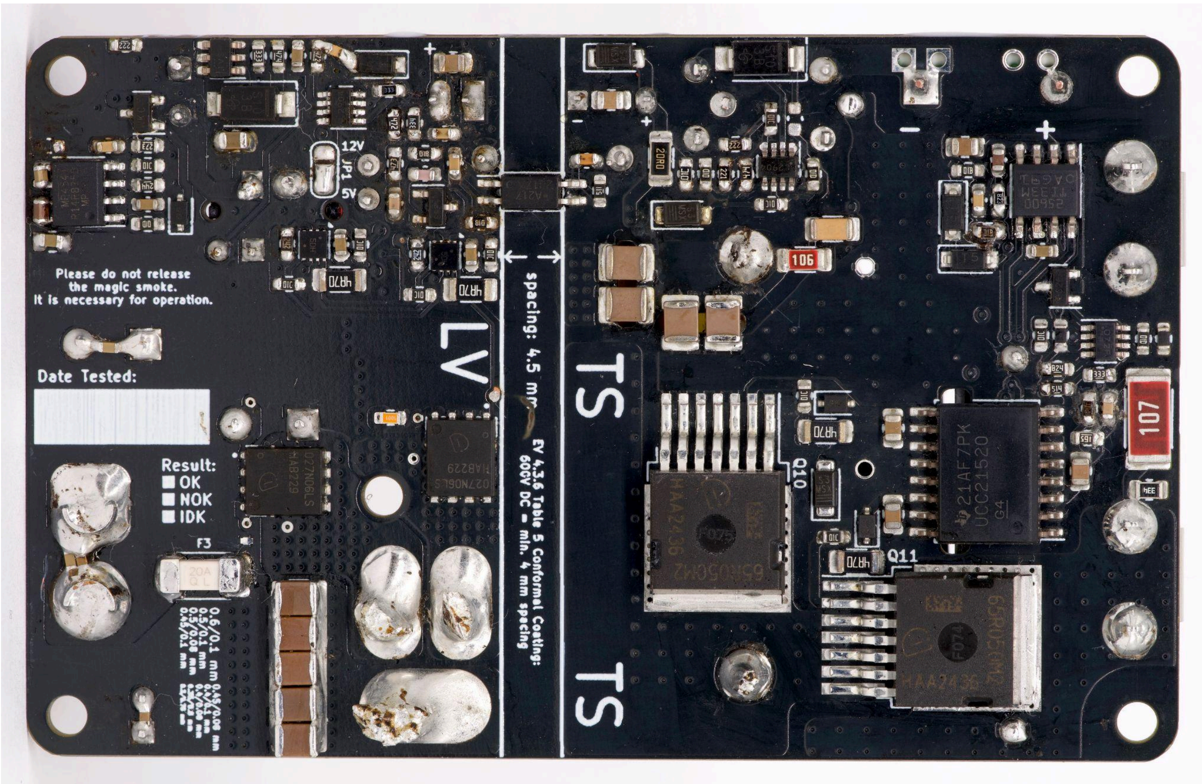
DCDCv9-3 PCBA front, with assembly



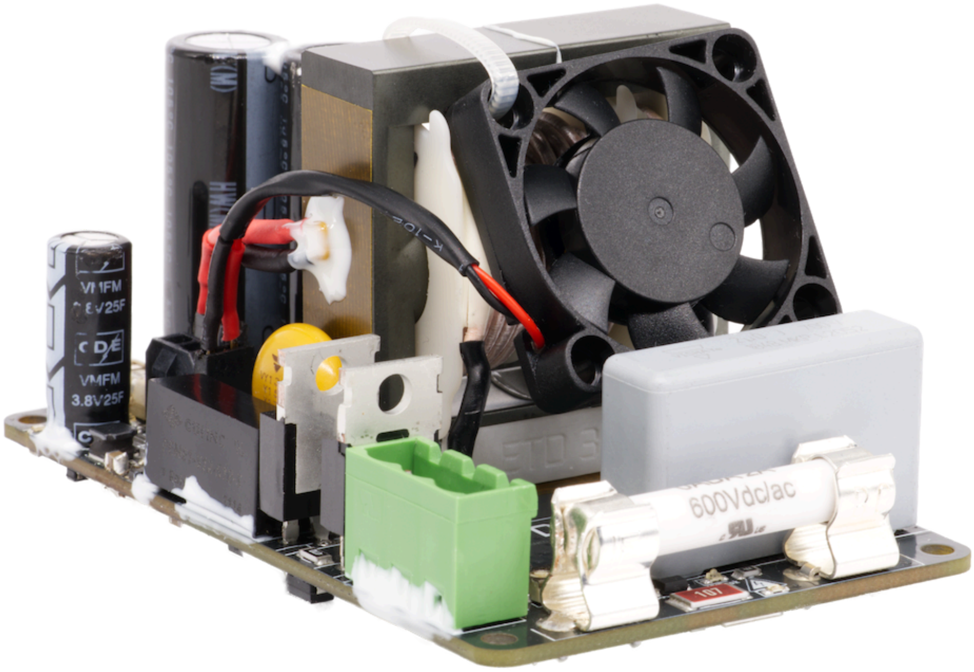
DCDCv9-3 PCBA rear panel, with assembly



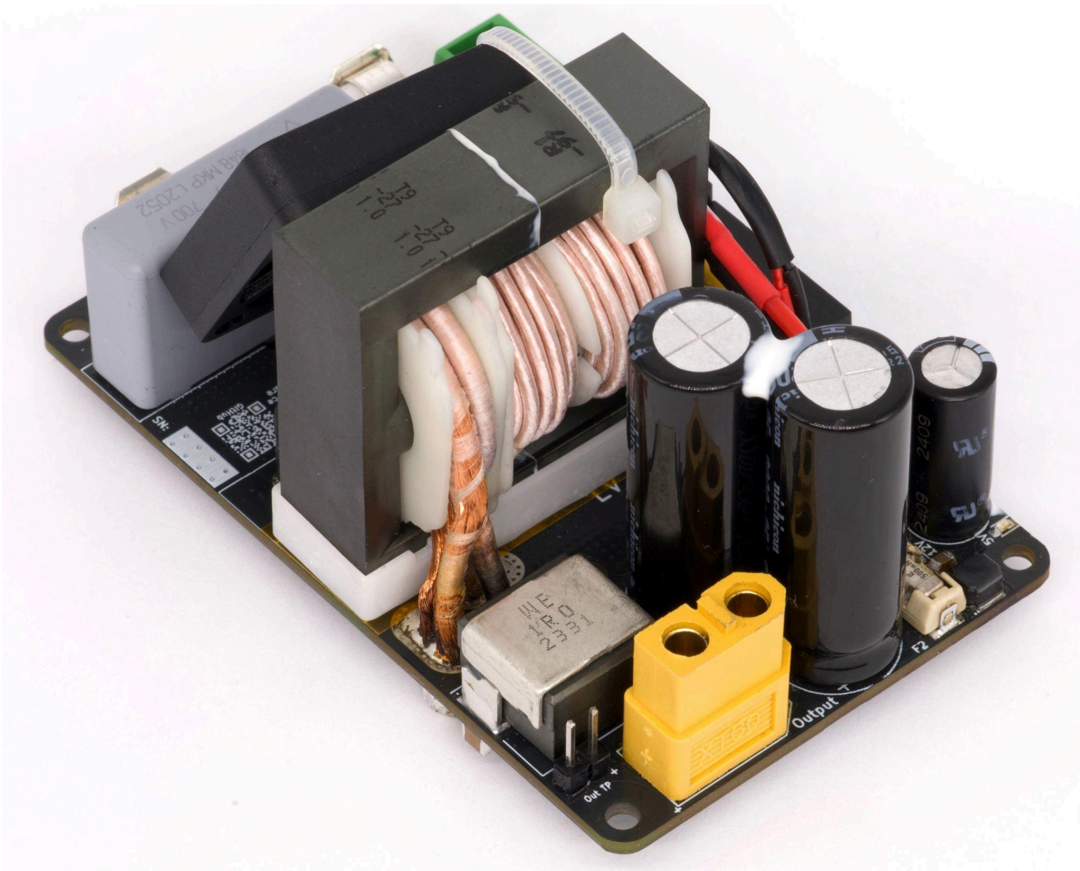
DCDCv9-3 PCB front side, complete assembly



DCDCv9-3 PCB rear side, complete assembly



DCDCv9-3 HV side view



DCDCv9-3 LV side view

Thank you for reading! If you have any questions, criticism or ideas for improving the documentation, the author is happy to receive feedback :)