Easy-Automotive Modules

Application Note

HV to LV DC/DC-Converter Evaluation Kit with Easy Automotive Module

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08-2012	1.1	T. Reiter	Updated Schematics to Rev2.2 Board

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1 Introduction

The Evaluation Kit *"EASYKIT DCDC"* was developed to support customers during their first steps in designing applications with the Easy Automotive H-Bridge power module. This Easy Module contains HighSpeed IGBT3 and Rapid Diode and is e.g. well suited for HV to LV DC/DC-converters in phase shift full bridge zero voltage transition (ZVT) DC/DC-converters up to 100 kHz and 3 kW. Such a phase shifted converter system is demonstrated in the Evaluation Kit and gives the customers important information about the specific characteristics of this HighSpeed IGBT Technology in this particular application.

The application note contains general information about the operation of phase shift full bridge ZVT DC/DC converters, schematics as well as detailed experimental results from the Evaluation Kit. The information is intended to enable the customers to re-use and modify the Evaluation Kit design for their own specific requirements.

1.1 Safety Warning for Evaluation KIT

Please read and understand the manual and the following safety warnings.

The design operates with unprotected high voltages. Therefore, the Evaluation Kit may only be handled by persons with sufficient electrical engineering training and experience. The customer assumes all responsibility and liability for its correct handling and/or use of the Evaluation Kit and undertakes to indemnify and hold Infineon Technologies harmless from any third party claim in connection with or arising out of the use and/or handling of the Evaluation Kit by the customer.

The Evaluation Kit is a sample to be used by the customer solely for the purpose of evaluation and testing. It is not a commercialized product and shall not be used for series production.. The Evaluation Kit is thus not intended to meet any automotive qualifications. Due to the purpose of the system, it is not subjected to the same procedures regarding Returned Material Analysis (RMA), Process Change Notification (PCN) and Product Withdraw (PWD) as regular products. See Legal Disclaimer and Warnings for further restrictions on Infineon Technologies warranty and liability.

European legislation in relation to inter alia the restriction of hazardous substances (RoHS), waste from electrical and electronic equipment (WEEE), electromagnetic compatibility, as well as duties to comply with CE, FCC or UL standards do not apply to the Evaluation Kit and the Evaluation Kit may not fulfill such requirements..

1.2 How to Order the Evaluation Kit

The Evaluation Kit has Infineon Technologies Sales Product Number and can be ordered via Infineon Sales Partners. **EASYKIT DCDC** Order Number: **SP000635950**

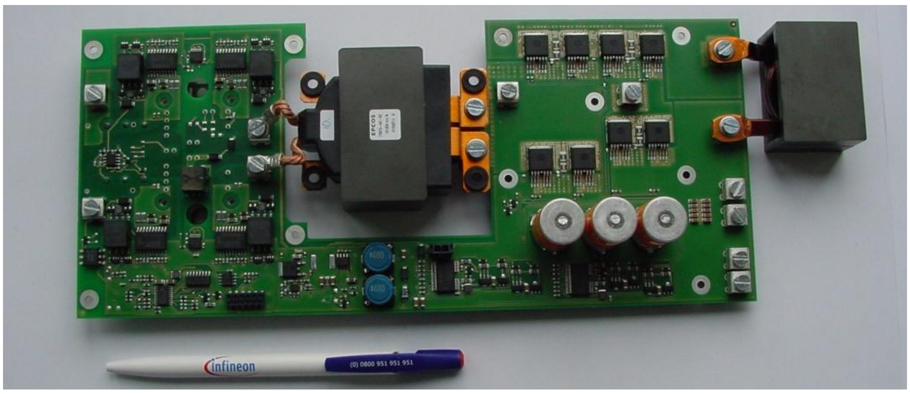


Figure 1 Picture of the "EASYKIT DCDC" Evaluation Kit.

2 Quick Start Guide

Before operating this Evaluation Kit two steps are necessary:

1. Mount system on a cooling plate
2. Connect aux supply, HV supply and LV load

Please read the following instructions carefully in order to prevent damage on the Evaluation Kit.

2.1 Mount System on a Cooling Plate

The power module can be attached directly on a cooling plate with a 50 um thick applied thermal grease (e.g. Fischer WLP). Detailed information on the mounting of the Easy Automotive Module can be found in [2].

The LV secondary side PCB area has to handle high currents up to 170 A and has to be cooled. The PCB is designed with thermal vias in the areas of the synchronous rectifier MOSFETs. A mounting on a cooling plate via a gap pad is recommended (e.g. Bergquist GapPad VO Ultra Soft 0.5mm or Kunze Ku-TCS50 0.5mm). Please take care that the pins of the connectors and capacitors do not generate a short circuit to the cooling plate.

Please note that it is also required to cool the transformer windings as well as the core if the Evaluation Kit should run continuously at high load currents. Please contact Epcos/TDK for more information about mounting and cooling of the passive components.

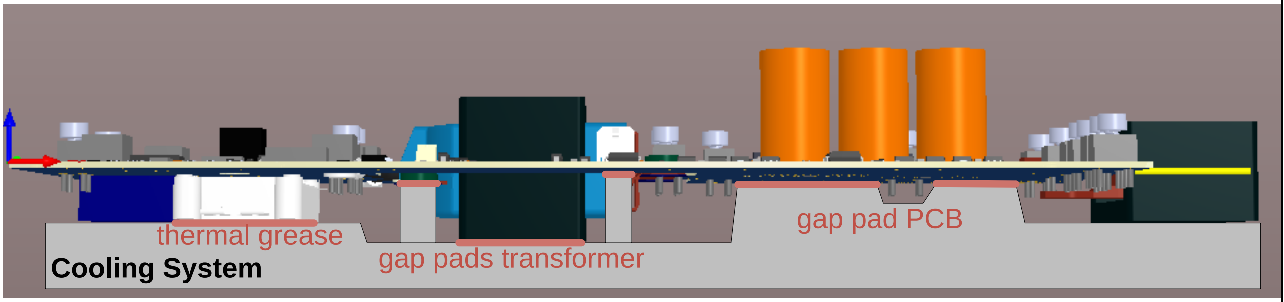


Figure 2 Recommended mounting concept of the Evaluation Kit. The module is mounted with standard thermal grease on the cooling system. The transformer core, windings as well as PCB area, where the secondary side MOSFETs are located, are connected via gap pads to the cooling system.

A 3D file of a flat cooling plate according to Figure 2 can be requested from Infineon. The flat cooling plate can than be mounted easily e.g. on a water cooling system or the design files can be used as a starting point for a customer specific cooling system.

For short term operation tests, it is also possible to operate the Evaluation Kit with active cooling of the power module only. The LV secondary side as well as the transformer is cooled from the intrinsic thermal capacitances only. Please take note that such an operation has certain risks as the design is not protected against any overtemperature events and thus it is only recommended for very experienced developers.

The experimental results of Figure 3 with 45K delta T after running at 100A just 30s make clear that operation at high output current will be possible only for some seconds if the secondary side is cooled with free convection only!

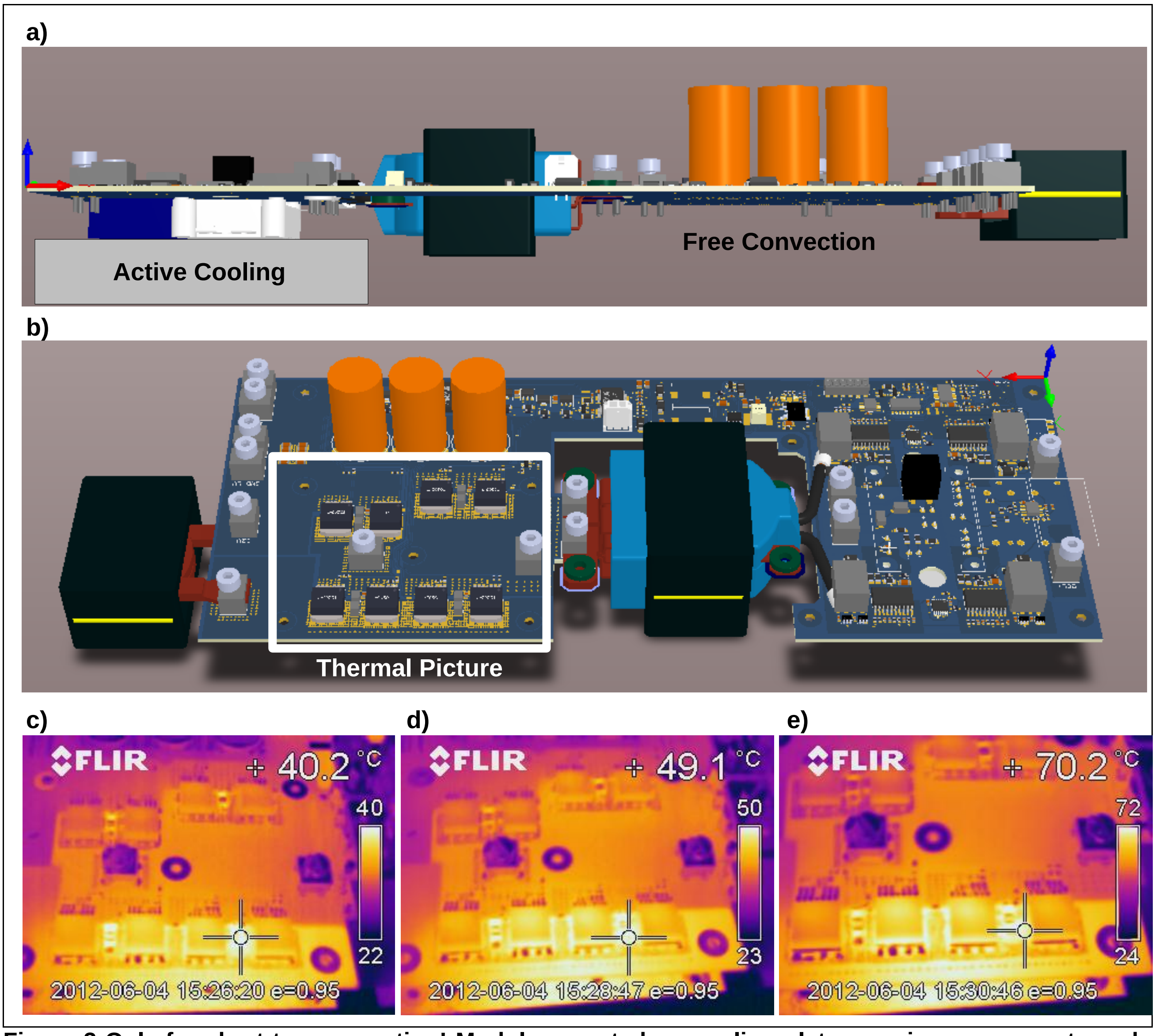


Figure 3 Only for short term operation! Module mounted on cooling plate, passive components and secondary side PCB area in free convection (a). Illustrated window of the thermal picture (b). Thermal picture at 20°C room temperature after running 30 seconds at 50A/700W (c), 75A/1050W (d), and 100A/1.4kW output load (e).

2.2 Connect Supplies and Load

The Evaluation KIT has to be connected to a high voltage source (<350V, 20A) an auxillary supply (8..18V/1A) as well as a load (electric controlled or passive) with minimum 20V and up to 170A.

Please take note that only the aux supply is reverse polarity protected up to -20V. The power terminals for the <350V DCL supply as well as the the 14V load are not protected against reverse polarity events. Thus the correct polarization according to Figure 4 is required.

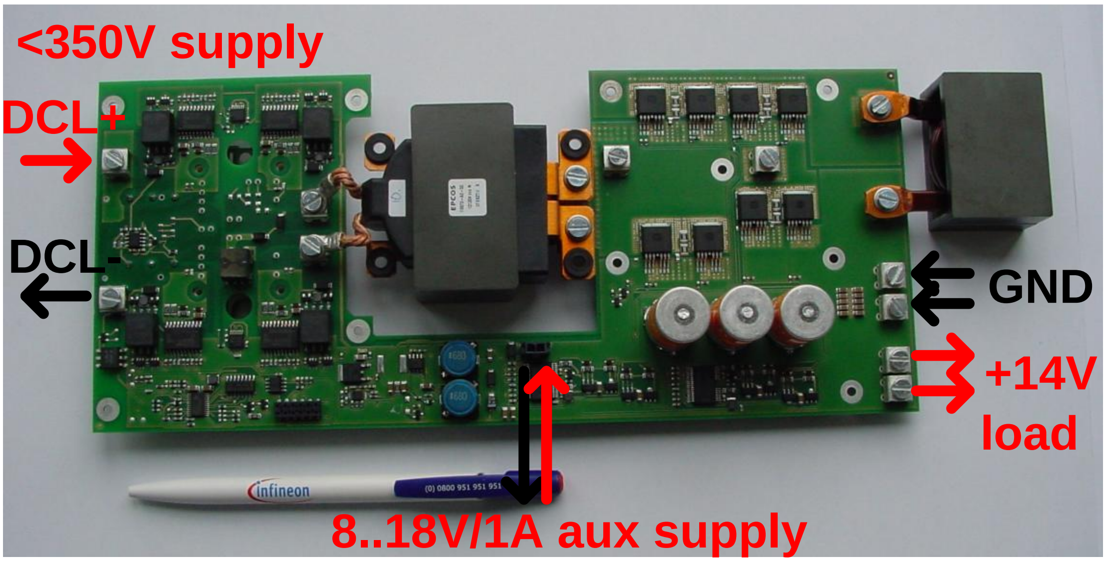


Figure 4 Supply and load connections to operate the Evaluation Kit.

2.3 Recommended Test Setup and Equipment

Minimum to operate the Evaluation Kit:

- 400V 20A DC source
- 20V 1A DC source
- 40V >=170A DC electronic load
- Cooler plate, thermal grease, gap pads (see section 2.1)

For investigations on the switching behavior additional:

- 4 channel scope (min. 100Mhz)
- Differential probes (capable for measuring 650V)
- Rogowski current probe (e.g. CWT1)

For investigations on the efficiency additional:

- 3 channel power analyzer
  OR
- 10mΩ 3W precision shunt
- 0.25mΩ precision shunt or 200A compensated current transducer
- 4 V-Meter with milli-volt rage

3 Feature Description

3.1 Key Features

- Full Bridge Phase Shift Converter with Synchronous Rectification (see Figure 5)
- 100 kHz Switching Frequency with HighSpeed IGBT3 and Rapid Diode
- Wide Input Voltage Range (160 V…350 V with 9:1 transformer)
- Output currents up to 170 A @14 V (limit of secondary side)
- High efficiency up to 93% incl. all aux supplies
- High efficiency over wide load and temp conditions e.g. >90% @160 V from 150 W to 2.3 kW
- Low system BOM (e.g. no resonating inductance, no active components in sec side snubber,…)

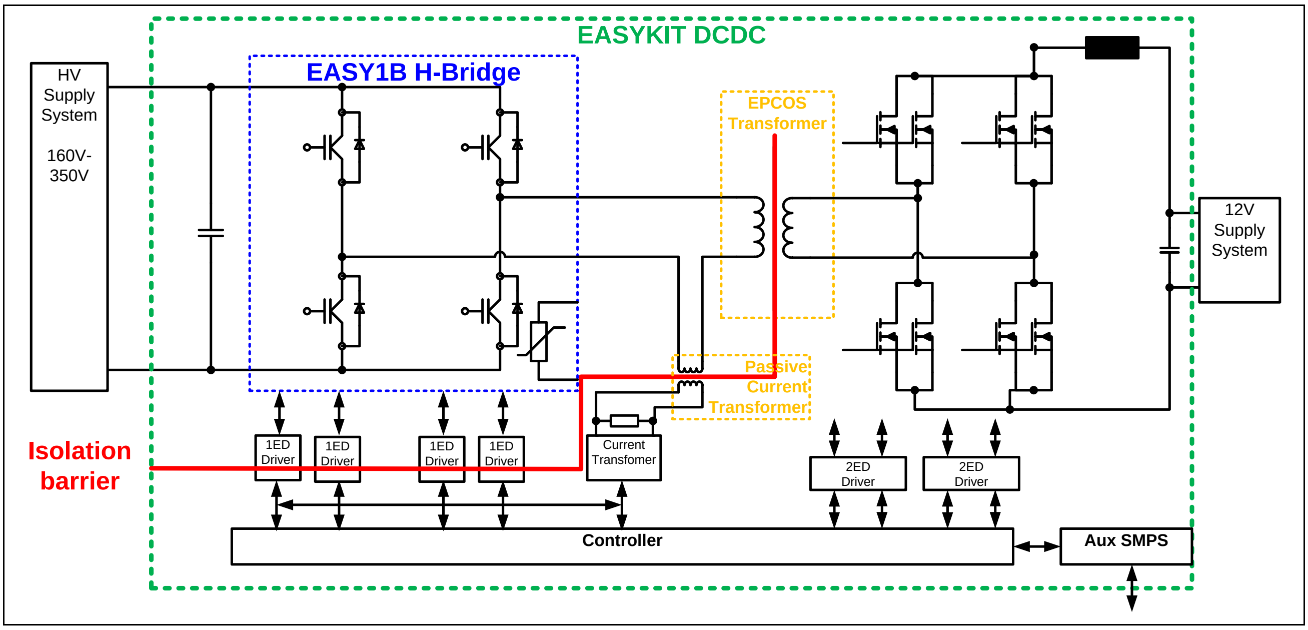


Figure 5 Topology of the EASYKIT DCDC Evaluation Kit.

3.2 Protection Features

The protection features in this Evaluation KIT are very limited. This allows easier adoptions to different requirements. Please take note that testing beyond maximum rating may lead to device failures and thus is not recommended. Infineon will not take any liability for failures on the Evaluation KIT as well as damage on lab equipments.

The design is not protected against:

- X Overtemperature (HV and LV side)
- X Overvoltage (HV and LV side)
- X Reverse energy flow (Energy transfer from LV to HV)*
- X Reverse polarity on power connectors
- X Short circuit (still in evaluation)

**the power stage is suitable for reverse energy transfer but the control can cause wrong PWM patterns, which can lead to failure of sync rectifier MOSFETs as well as the HighSpeed IGBT Module.*

Following protection features are implemented and activated:

- Gate Driver Undervoltage Lockout (UVLO)
- Gate Driver not Ready event locks all other Channels to avoid transformer saturation
- Overcurrent redundant in peak current mode control and emergency turn-off
- Aux supply short circuit and overcurrent with self restart (hiccup mode)

3.3 Key Components BOM

Part	Description	Manufacturer	Status
F4-50R07W1H3_B11A	Easy 1B Automotive H-bridge with HighSpeed IGBT3 and Rapid Diode 650V	Infineon	In development
1ED020I12FA	EiceDriver™ 2A Single Channel Gate Driver	Infineon	Productive
IPB180N08S4-02	80V 2.2mΩ OptiMOS™ in TO263-7	Infineon	In development
2ED020I12FA	EiceDriver™ 2A Dual Channel Gate Driver	Infineon	Productive
CRS Capacitor	PressFIT Ceramic Ripple Suppressor Vmax=450V; Ceff=10uF	TDK/Epcos	*
T6973	3kW Phase Shift ZVT Transformer 9:1	TDK/Epcos	*
T7509	SMD Gate Driver Supply Transformers 1:1.1 5mm clearance/creepage	TDK/Epcos	*
T7078	SMD Current Sense Transformer 1:100 5mm clearance/creepage	TDK/Epcos	*
T7921-51	Output Choke 2.1uH, Isat=170A	TDK/Epcos	*

* For status and datasheets of the passive TDK/Epcos components please ask design-solutions@epcos.com.

4 Function Description and Measurement Results

4.1 Function Principle of Phase Shift ZVT Converter

The phase shift ZVT converter operates at a fixed switching frequency and achieves, in an ideal operation, a lossless turn-on (zero voltage transition) due to intrinsic and optional external parasitic elements. In following only intrinsic elements are considered as it is implemented in the Evaluation Kit. How parasitic elements can help to avoid switching losses will be more understandable after a brief review of the switching states of the converter (see Figure 6).

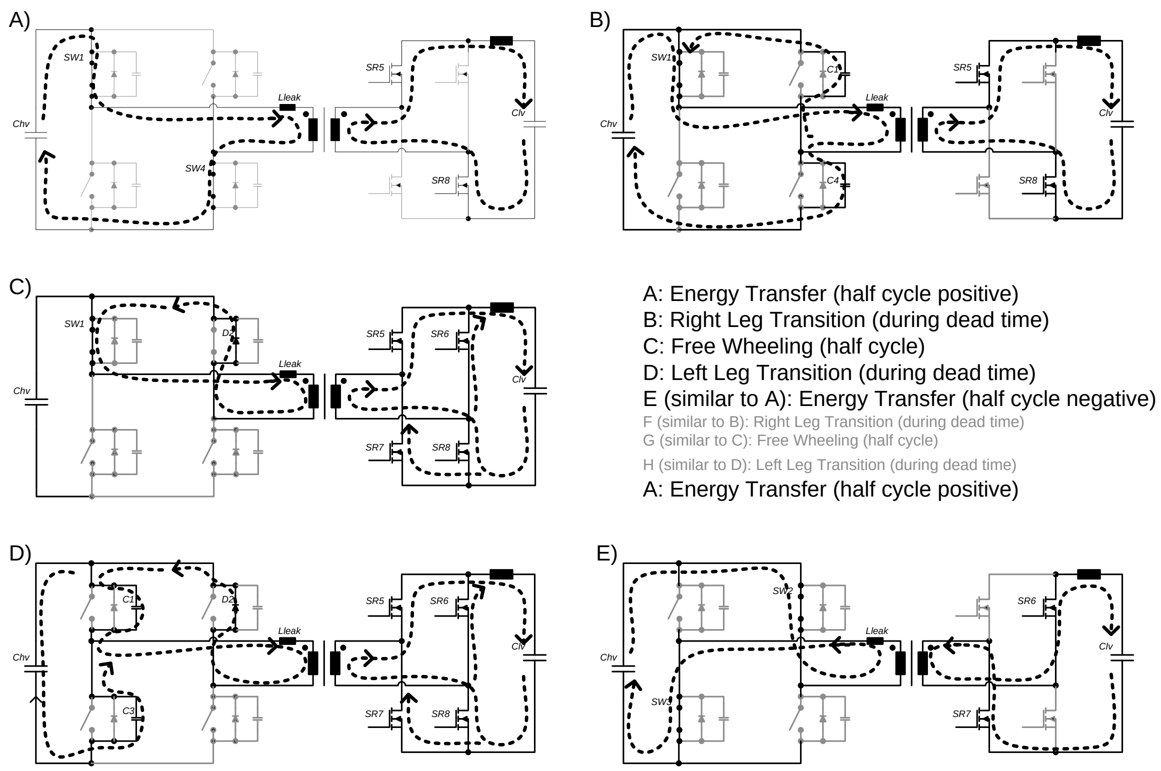


Figure 6 Phase shift ZVT full-bridge DC/DC-converter topology with active H-bridge rectification. State A to H shows the current flow in half of a switching period.

A) Energy Transfer (half cycle positive)

The diagonal switches in the H-bridge are turned-on and energy from HV side is transferred via the transformer to the LV side. The transformer is magnetized in positive direction and the leakage inductance of the transformer (or optional an external Lres) is charged.

B) Right/Leading Leg Transition (during dead time)

After the energy transfer phase the right low-side switch is “hard” turned-off. The voltage across the switch is not changing immediately, as the output capacitances of the switches in the right leg clamps it. However, the parasitic capacitances of both low- and high-side switch are charged/discharged by the stored energy in the leakage inductance of the transformer. The ZVT condition is achieved if the stored energy in the leakage inductance is higher than the required energy to charge/discharge the capacitors.

C) Freewheeling (half cycle)

If the leakage inductance had enough stored energy the diode of the right high-side switch (D2) conducts. Otherwise, the switch (SW2) turn-on without ZVT, which is the case for light load conditions. During the freewheeling, the transformer windings on primary and secondary side are shorted.

D) Left/Trailing Leg Transition (during dead time)

Before entering the next energy transfer phase, the left leg transition is required. The left high-side switch is turned-off. Similar to the right leg transition, the parasitic capacitances clamps again the voltage slope. The parasitic capacitances of both switches are charged/discharged, respectively.

E) Energy Transfer (half cycle positive)

If the leakage inductance had enough stored energy to charge/discharge the parasitic capacitances of the left leg switches, the left low-side switch can turn-on at zero-voltage and the second half of the energy transfer phase starts (similar to state A). In this state the transformer is magnetized in the negative direction.

The states F, G, H are similar to the explained states B, C, D but in reverse current direction in view of the transformer.

The corresponding current waveform on the primary side of the transformer (and thus leakage inductance) as well as the gate signals for the HV switches are shown in Figure 7.
Each half bridge leg is driven by a quasi-complementary 50% PWM pulse pattern. In this example the right leg is phase-shifted to the left leg, which is in this topology the duty cycle command.
The resulting half cycles (T/2) with this gate driving pattern can be clearly seen. The result is that the transformer, filter inductor, HV and LV capacitor is driven at two times of the switching frequency. The leakage inductance, which was required to achieve ZVT, limits the current slope when the transformer is switched from positive to negative cycle and vice versa. During this state the transformer is not transferring energy to the output. Consequently, the leakage inductance causes a “loss of duty cycle” (D_{Loss}) at each half cycle.

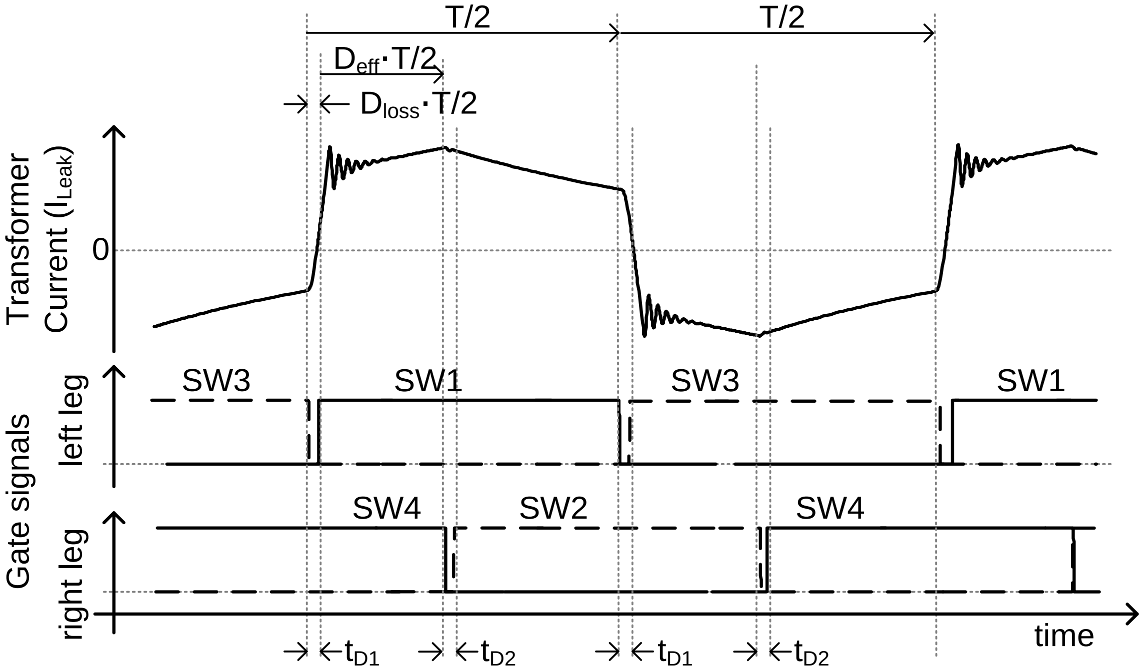


Figure 7 Current waveform of the transformer primary side with the corresponding gate control signals of the 4 HV switches. Each half bridge leg is driven by constant 50% duty cycle. The phase shift of the right leg is here the duty cycle command for the converter energy transfer. The leakage inductance of the transformer leads to a loss of duty cycle (D_{loss}).

The dead times are not only required to a avoid shoot through. As explained before, the parasitic capacitance has to be charged before the corresponding switch is turned-on. At “too short” dead times the converter generate hard switching conditions and will cause additional turn-on power losses.

4.2 Efficiency

The measured efficiency is shown in Figure 8. At light load conditions, constant losses (auxiliary power supply, core losses etc.) are dominant and cause low efficiency. Their impact on the efficiency is relatively low at higher output power. On the other hand, the resistive losses become then more dominant as these losses are proportional to the square of RMS output current

The highest efficiency is reached at partial load, where the best balance of different losses relatively to the output power is achieved. The highest measured efficiency was 92.5% (at Vin = 160V and Iload = 50A). At a wide range of load currents from ~30A to full load, efficiency higher than 90% is achieved. The efficiency is very high taken into account that the power module was designed for best cost/performance ratio. For highest possible efficiency the HighSpeed IGBT should be replaced by the leading CoolMOS technology with lowest Rdson.

Efficiency curves in Figure 8 are shifted to lower values when the input voltage of the converter is increased. This is caused by the lower phase shift (duty cycle) and longer freewheeling period followed by increased losses. In the design process, transformer turn ratio is determined by the maximum allowed duty cycle (minimum input voltage) and because of the wide range of input voltages, duty cycle is considerably shorter at the maximum input voltages. If the transformer turn ratio would be adapted for other input voltage range, a higher efficiency at high input voltages can be achieved.

Due to the controller functionality (light load efficiency management), synchronous rectifier control is starting at load current of approximately 12 A output load. Up to this current only body diodes are conducting.

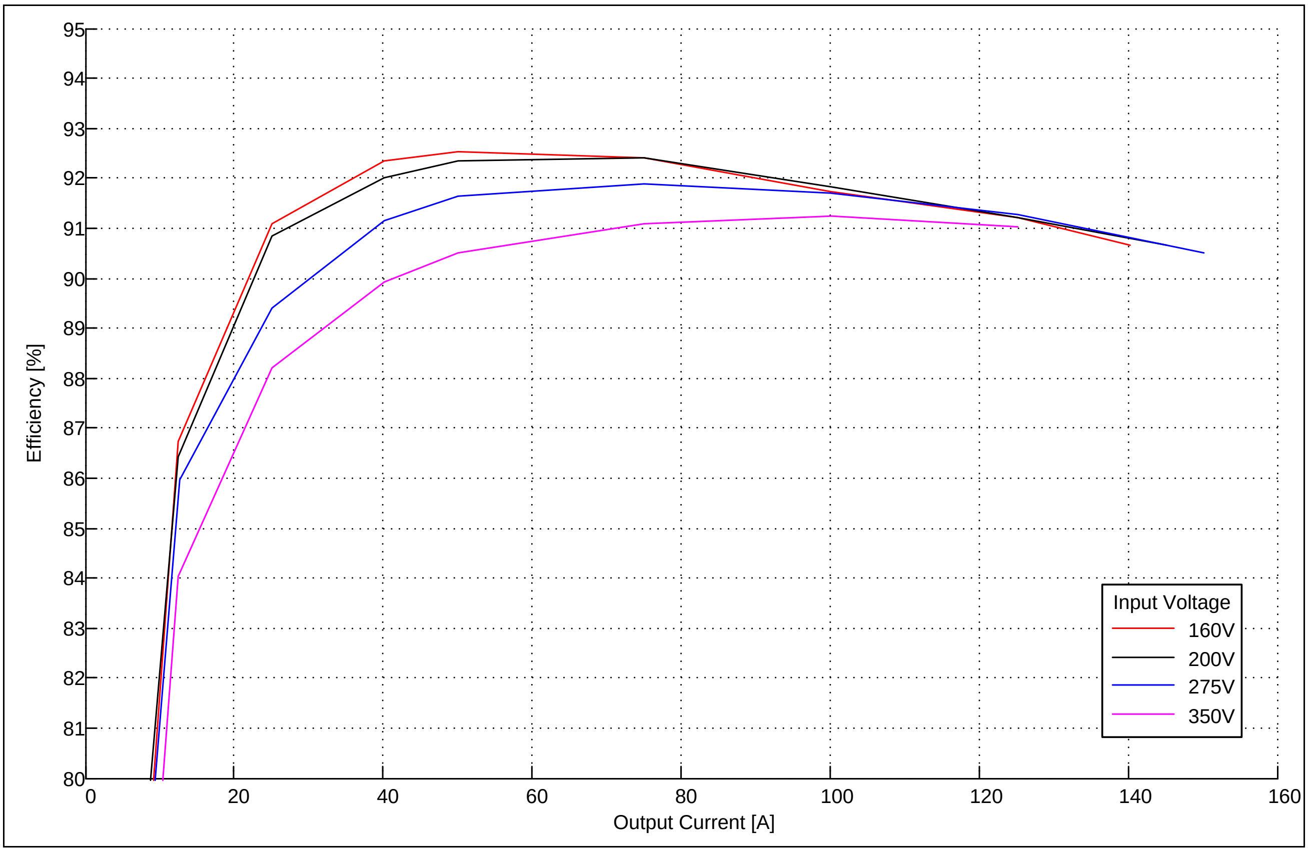
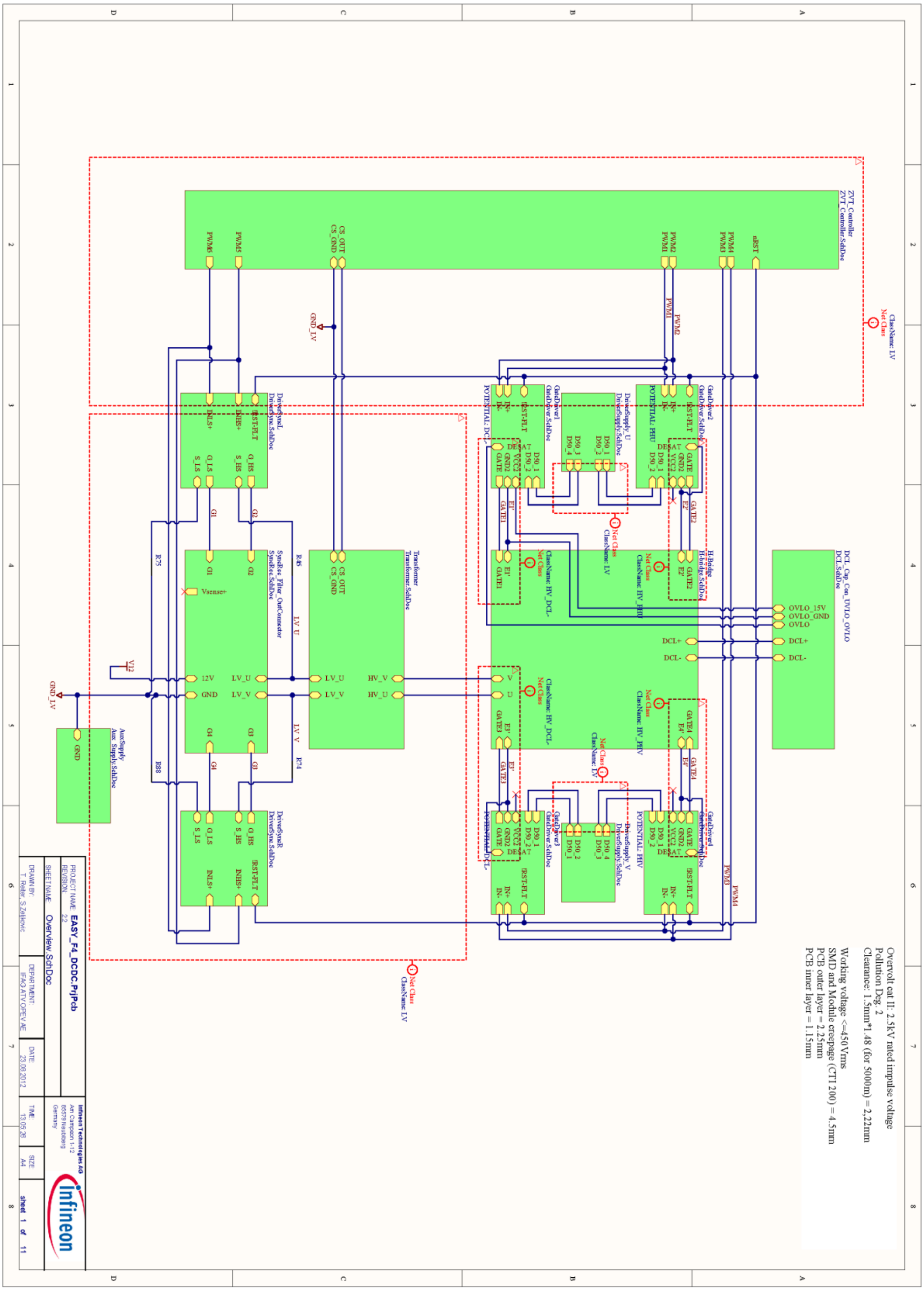


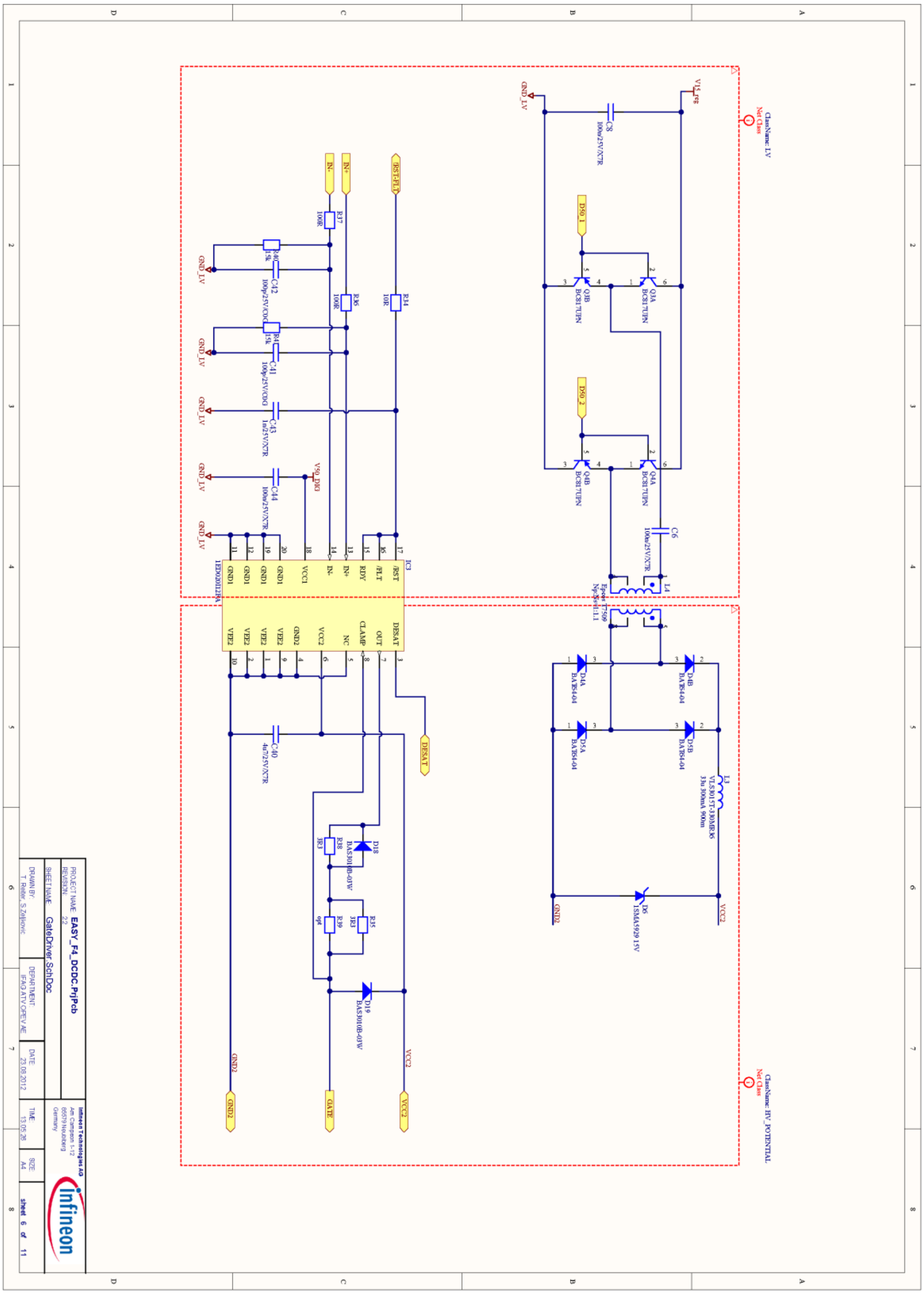
Figure 8 Efficiency incl. all aux power supplies at V_{LV}=14V output voltage and 85°C cooling plate temperature under the Easy Automotive power module.

5 Schematics

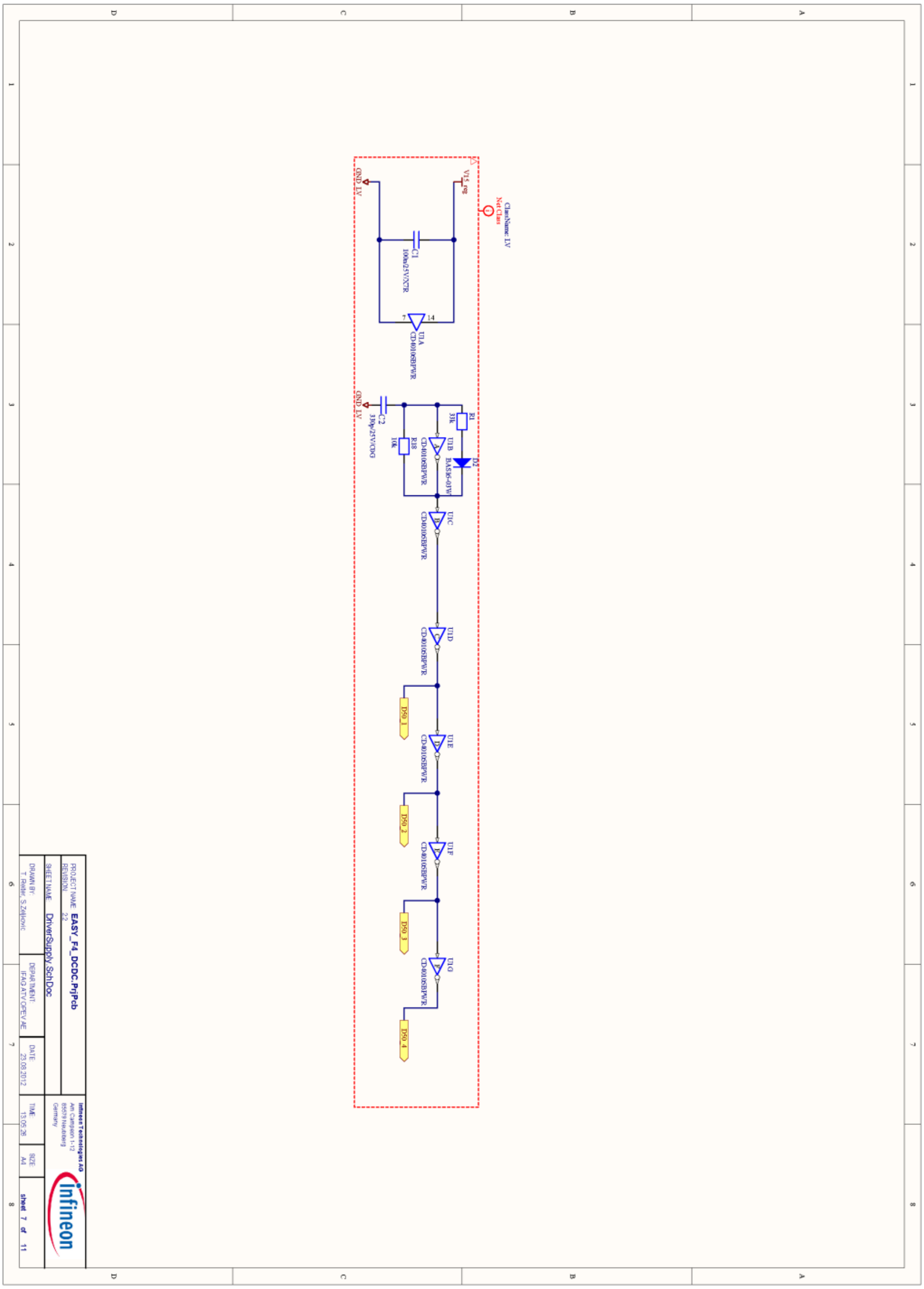
5.1 Overview



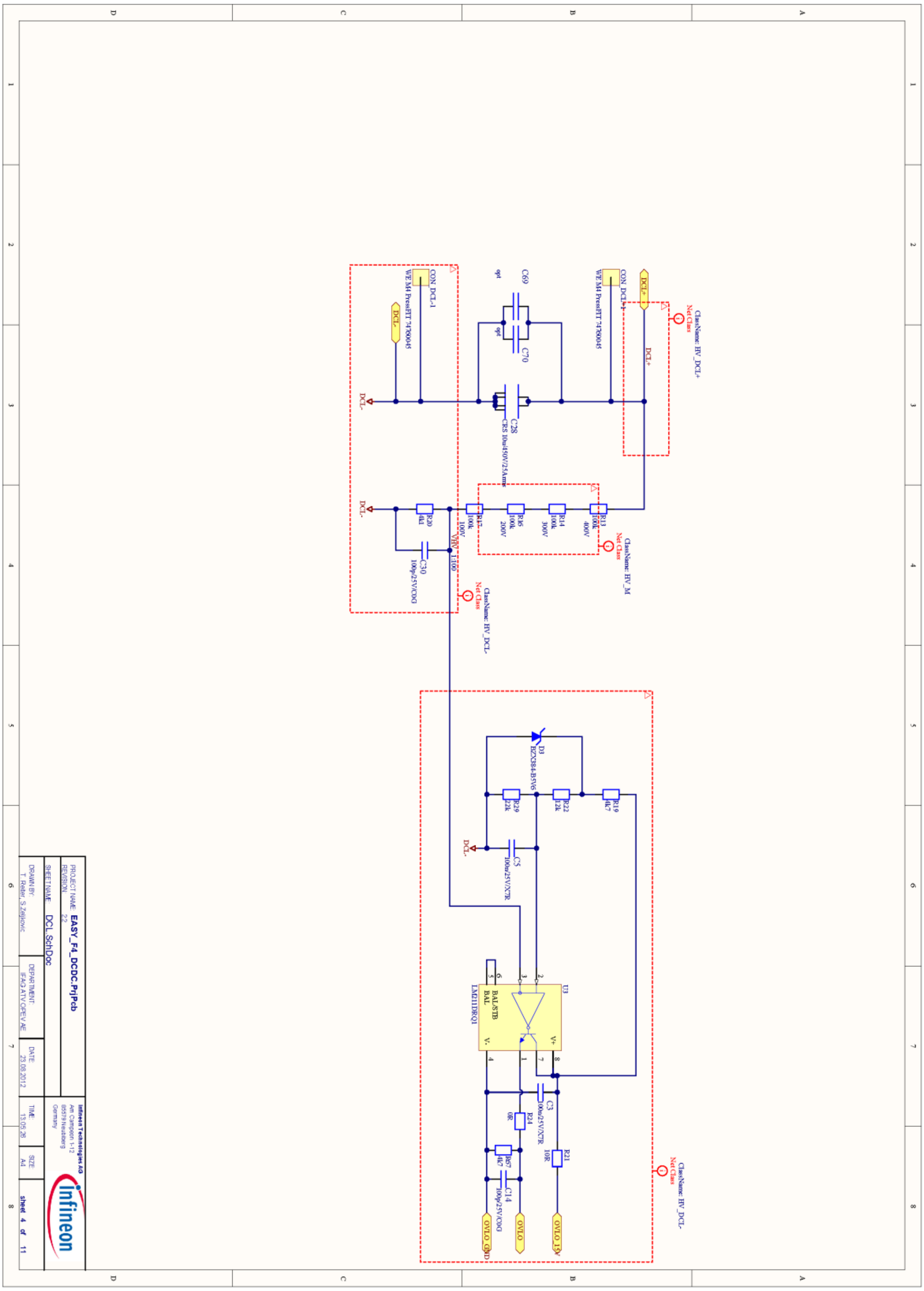
5.2 Gate Driver IGBT



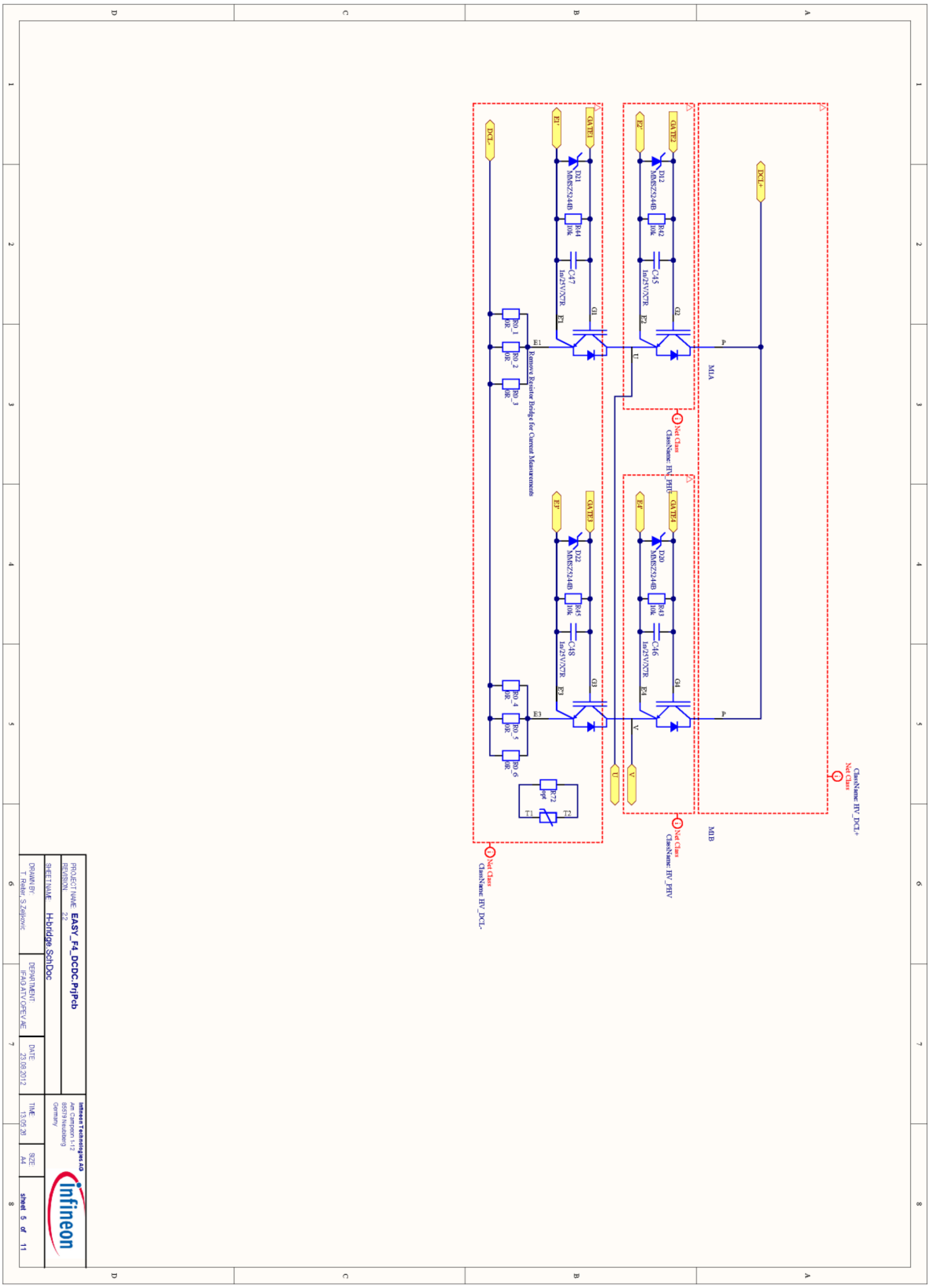
5.3 Oscillator



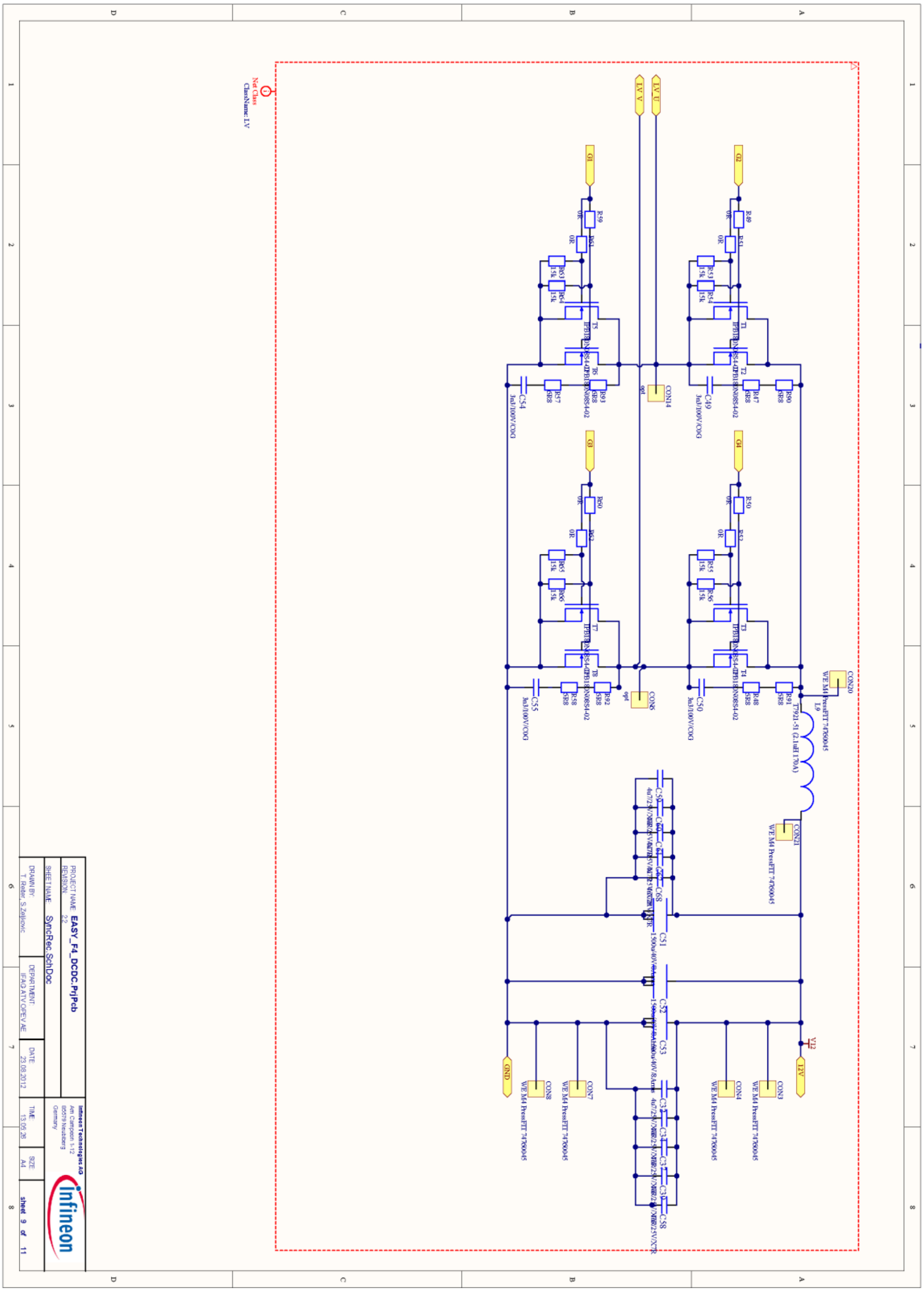
5.4 DCL capacitor



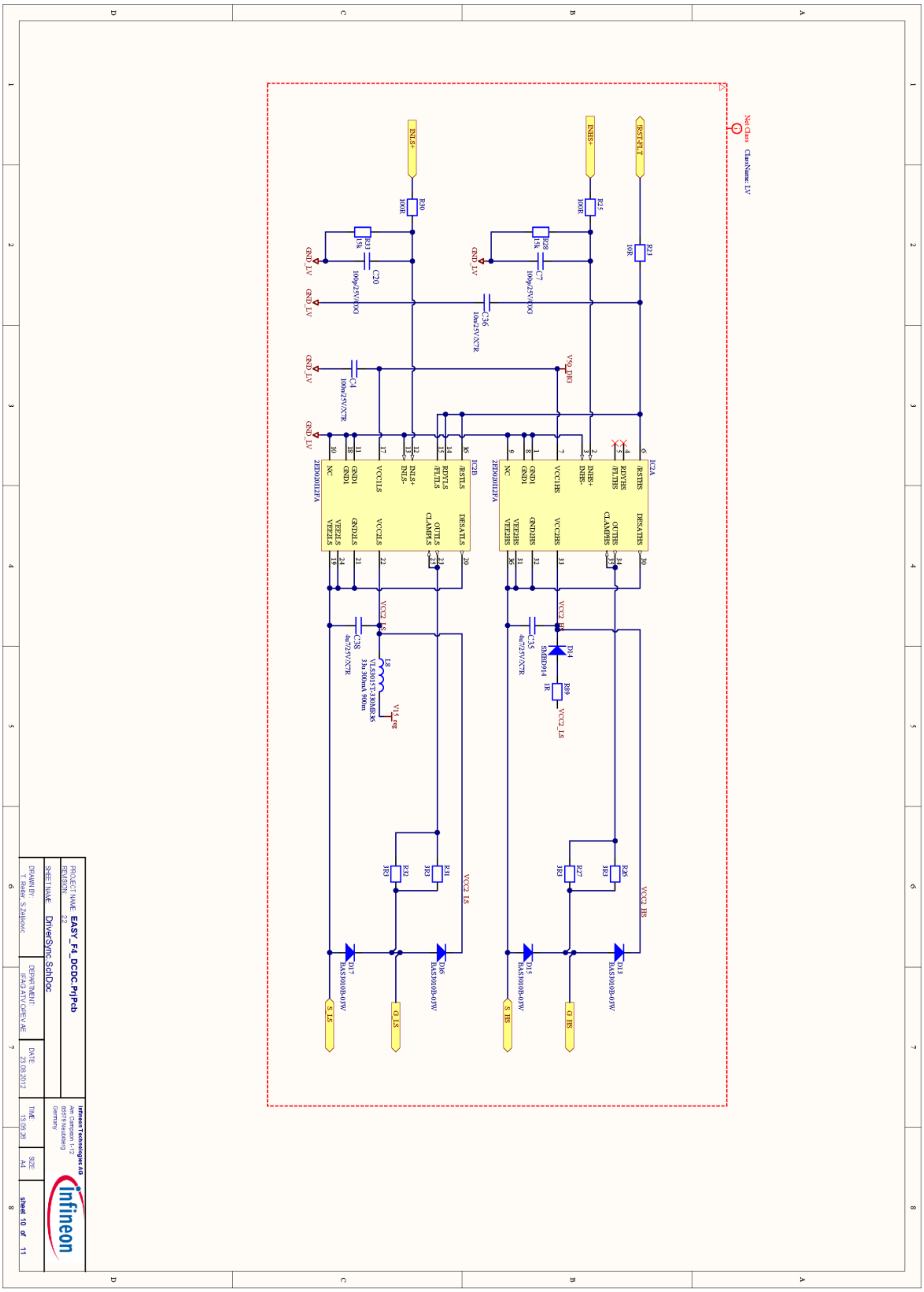
5.5 H-Bridge IGBT



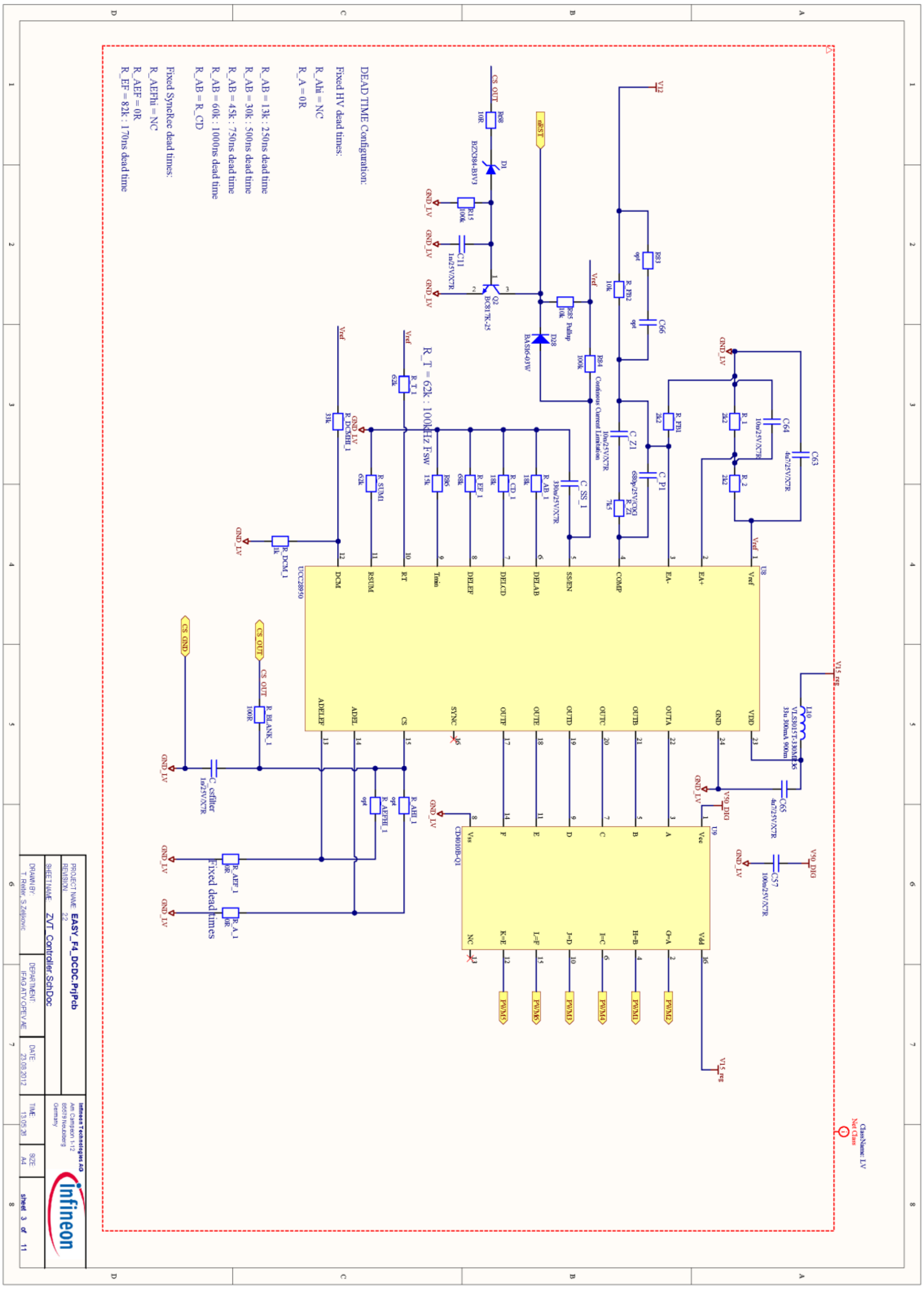
5.6 Synchronous Rectifier



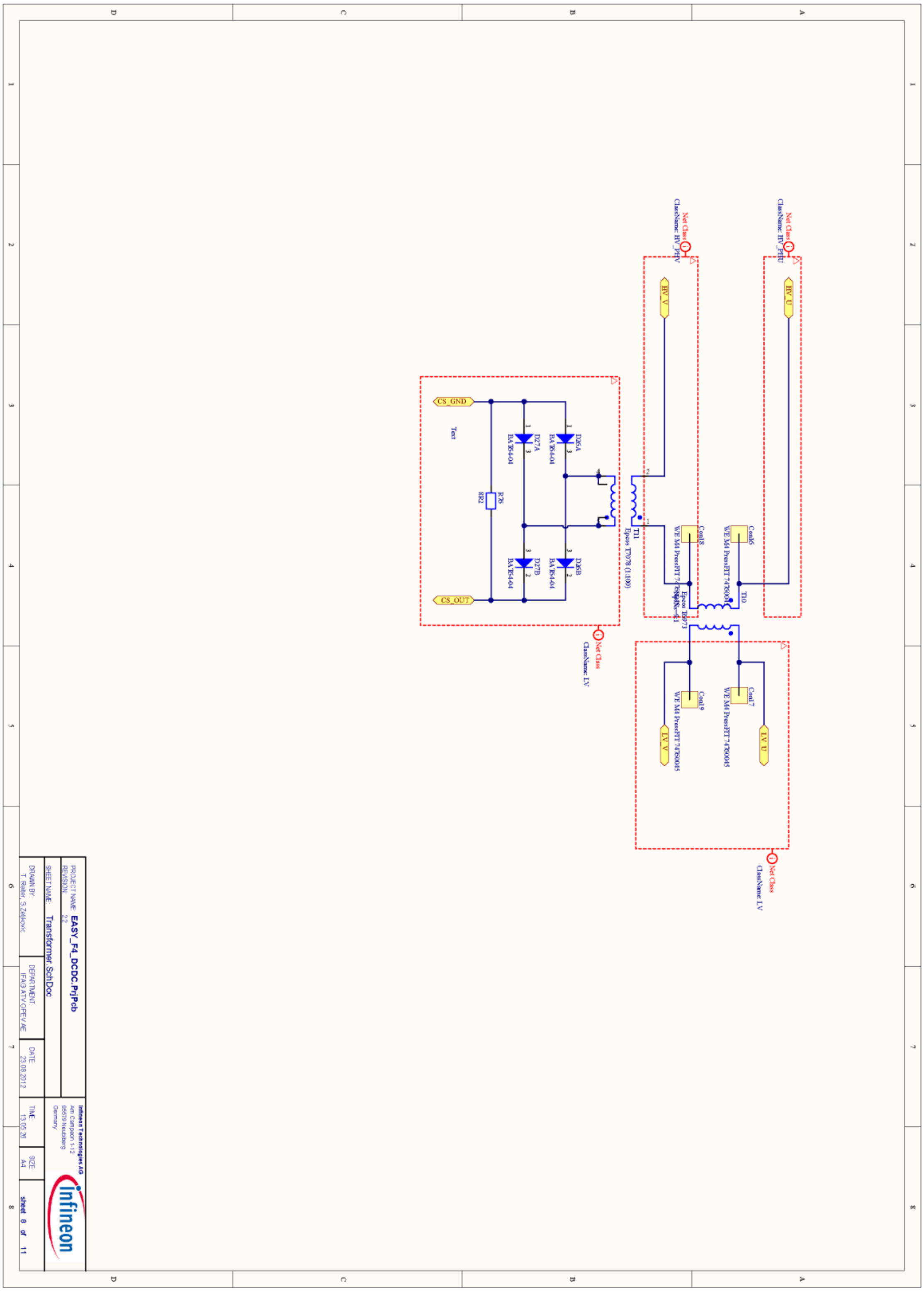
5.7 Gate Driver Synchronous Rectifier



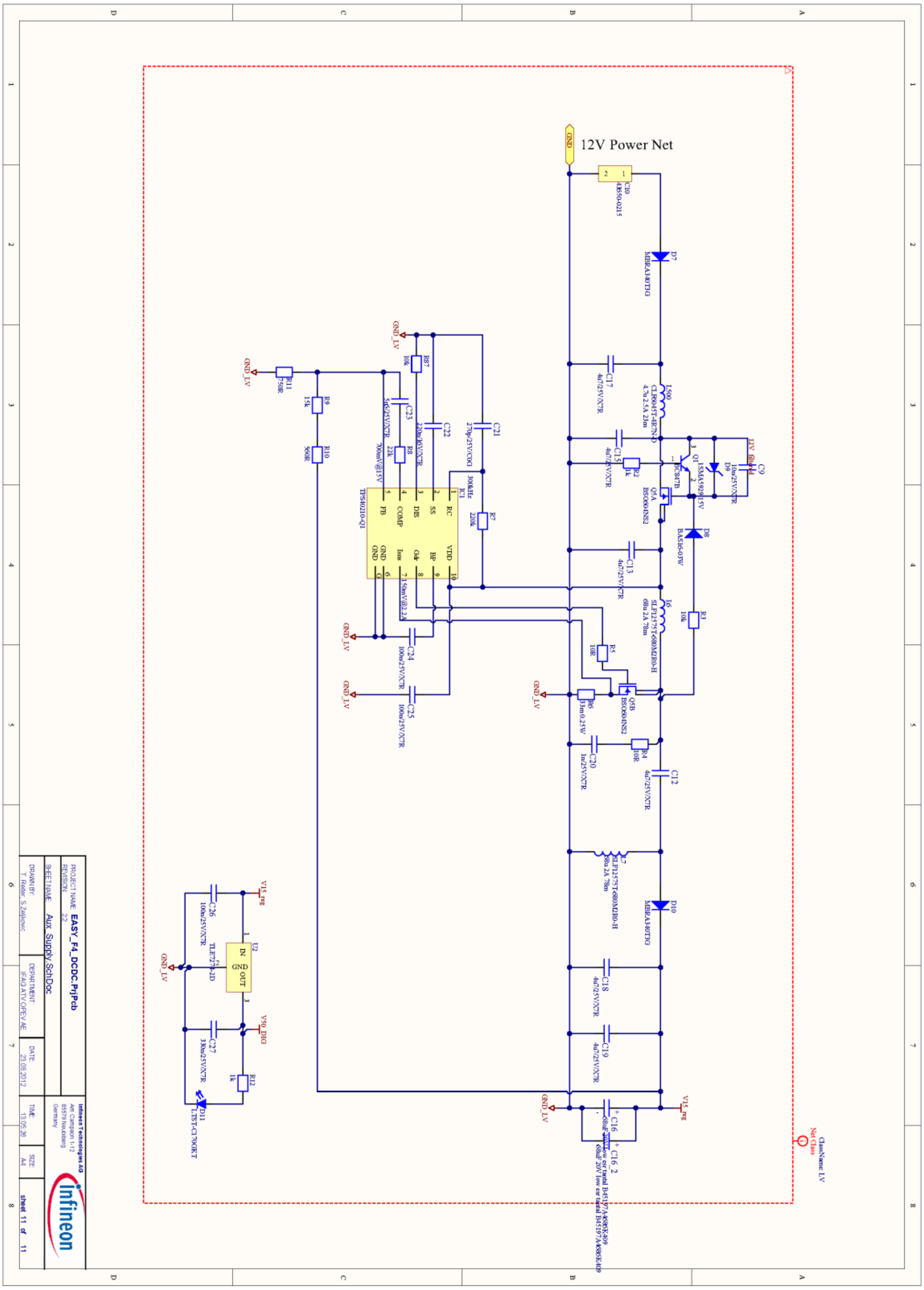
5.8 ZVT Controller



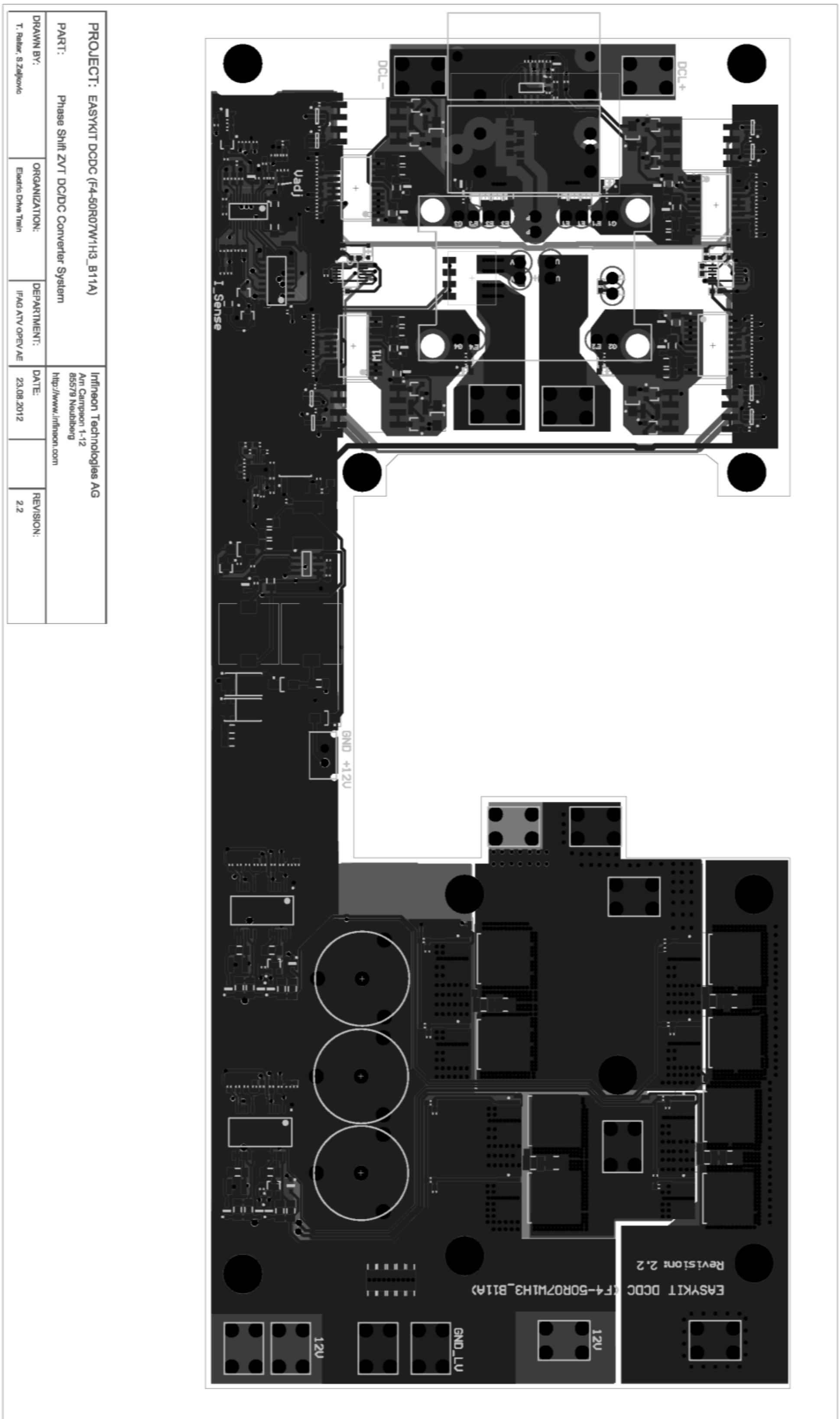
5.9 Transformer



5.10 Aux Supply



5.11 Assembly and Layout



6 References

The referenced application notes can be found at http://www.infineon.com
Direct link to the Easy Automotive site:
http://www.infineon.com/autoeasy

[1] Infineon Application Note AN2010-09, "Explanation of Technical Information".
[2] Infineon Application Note AN2009-01, "Easy PressFIT Assembly Instructions".
[3] Infineon Application Note AN2011-11, "Explanation for Traceability of the Easy Automotive Modules".

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