300W engine cooling fan evaluation board design for 12V application

OptiMOS-6™ 40 V SSO8 MOSFET, TLE9879QXA40 Embedded Power IC

Design Overview

This Reference Design Guide describes a detailed implementation of an automotive engine cooling fan application. The system is controlled by a system on chip microcontroller with integrated MOSFET driver in combination with OptiMOS™-6 leadless MOSFETs.

The design is capable to drive loads up to 300W at a battery voltage of 12 V.

This design guide contains a description of the design, schematics and measurement reports.

Thermal performance information is given and discussed.

Highlighted Components

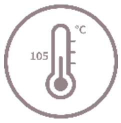
- TLE9879QXA40
- IAUC100N04S6N015, IAUC120N04S6N013

Target Application

- Engine cooling fan
- 300W BLDC Motor for 12 V application

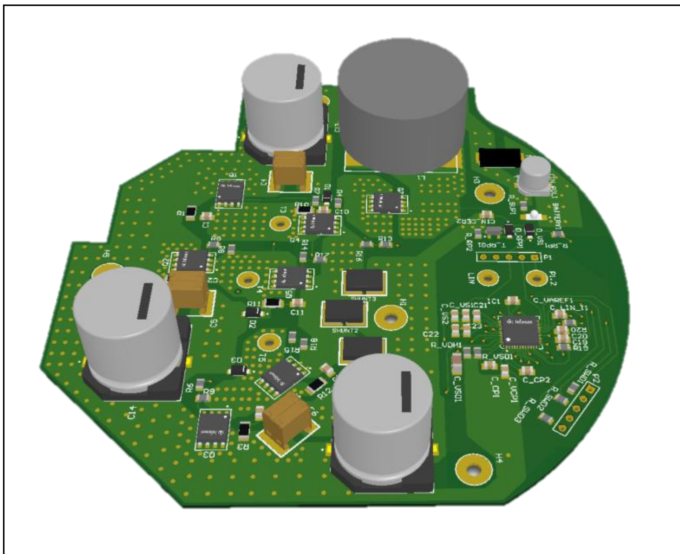
Highlighted Design Aspects

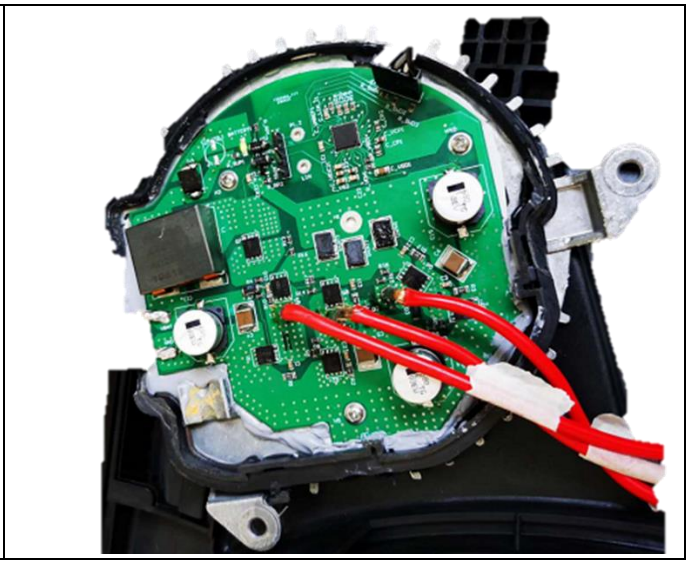
300W functional



Thermally tested

Evaluation Board Design and Assembly Example





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1 System Description

The reference design describes a solution for an engine cooling fan with a power capability. This solution can be used for similar applications with smaller or equal power consumption. The circuit contains an integrated 3-phase motor control solution. The SoC microcontroller is a member of the Embedded Power IC family. It combines an Arm® Cortex®-M3 microcontroller with application specific modules like an integrated 3-phase MOSFET driver, power supply and LIN-transceiver. In combination with the OptiMOS™-6 PG-TDSON-8 (SSO8) MOSFETs the system is optimized for a minimum of PCB size for this power class. The focus of the reference design is to use standard PCB materials and processes.

1.1 Design Specifications

The design specifications are related to the used components and design considerations. They shouldn't differ from the product datasheet values. In case of misalignment, the datasheet values of the products are valid.

Table 1 Design Specifications

Parameter	Symbol	Values			Unit	Comment
		Min.	Typ.	Max.		
System Parameters						
Input voltage	V_{IN}	-0.3	12	40	V	P_1.1.1 (TLE9879QXA40)
Functional input voltage	V_{IN}	8.5	12	15	V	Specified for Design
Output current peak	I_{OUT}	-	-	26	A	Peak current (<10 s), air cooling attached
Output current continous	I_{OUT}	-	15	24	A	Specified for Design
LIN interface	V_{LIN}	-28	12	40	V	P_1.1.7 (TLE9879QXA40)
Phase 1,2,3	V_{SH}	-8.0	12	48	V	P_1.1.11 (TLE9879QXA40)
Thermal						
Operating temperature	T_A	-40	25	105	°C	Specified for Design
Mechanical Specification						
Dimensions	108 mm x 107 mm x 19 mm (W x D x H)					
PCB	1.6mm 4-layer 2 oz Standard FR4					

1.2 Overview

Figure 1 shows the 3D CAD view of the system. The board has seven TDSON-8 MOSFETs, one 3-phase gate driver, and a shunt resistor. All active components, including the seven MOSFETs and one driver IC, are carefully located on the board to distribute the heat over the whole area of the PCB. As passive components, the shunt resistor is an additional heat source. The board is designed to dissipate the heat of the MOSFETs, driver IC and shunt effectively through thermal pad and also through the mounting bolts. As most of the PCB bottom-side does not have any components mounted, it is possible to attach a simple flat heatsink at the bottom of the board. Only the lead of the 5-pin connectors for LIN and debugger has to avoid the contact to the heatsink.

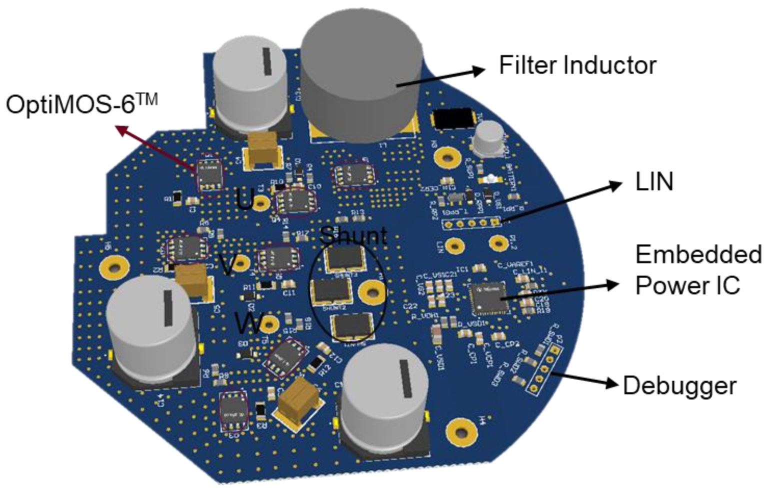


Figure 1 External view of the evaluation board

1.3 Highlighted Products

1.3.1 OptiMOS-6™ 40 V SSO8 (TDSON-8) MOSFET

The SSO8 package offers compact 20mm² footprint size with $R_{DS(on)}$ ranging from 0.8 ~4.4 [mΩ]. Its current rating is up to 3 times bigger than the S3O8 (TSDSON-8) package. In combination with Infineon's OptiMOS-6™ 40 V power MOS technology, TDSON package offers a compact yet powerful solution for automotive 3-phase motor drive up to 400W with 0.6 mΩ Best-In-Class NL product, at Infineon's well known quality level for robust automotive packages.

Table 2 Automotive SSO8 MOSFET with 40 V OptiMOS-6™

Package	Silicon Technology	Product	Max $R_{DS(on)}$ [mΩ]
SSO8 (TDSON-8)	OptiMOS™-6	IAUC120N04S6L005	0.5
		IAUC120N04S6N006	0.6
		IAUC120N04S6L008	0.8
		IAUC120N04S6N008	0.8
		IAUC120N04S6N009	0.9
		IAUC120N04S6L009	0.9
		IAUC120N04S6N010	1.0
		IAUC120N04S6L012	1.2
		IAUC120N04S6N013	1.3
		IAUC100N04S6L014	1.4
		IAUC100N04S6N015	1.5
		IAUC100N04S6L020	2.0
		IAUC100N04S6N022	2.2
		IAUC100N04S6L025	2.5
		IAUC100N04S6N028	2.8
		IAUC80N04S6L032	3.2
		IAUC80N04S6N036	3.6
		IAUC60N04S6L039	3.9
		IAUC60N04S6N044	4.4

1.3.2 3-Phase Bridge Driver IC with Integrated Arm® Cortex®-M3

The TLE987x family addresses a wide range of smart 3-phase brushless DC motor control applications such as auxiliary pumps and fans. It provides an unmatched level of integration and system cost to optimize the target application segments. In addition, it offers scalability in terms of flash memory sizes and MCU system clock frequency supporting a wide range of motor control algorithms, either sensor-based or sensor-less. For more information about the product, please visit Infineon web-page linked below.

- www.infineon.com/tle987x

Table 3 Product Family of 3-Phase Bridge Driver IC with Integrated Arm® Cortex®-M3

Grade	Product	Flash	RAM	Frequency	Interface	Tjmax
Grade-0	TLE9873QXW40	48 kByte	3 kByte	40 MHz	PWM + LIN	175 °C
	TLE9877QXW40	64 kByte	6 kByte	40 MHz	PWM + LIN	175 °C
	TLE9879QXW40	128 kByte	6 kByte	40 MHz	PWM + LIN	175 °C
Grade-1	TLE9871QXA20	36 kByte	3 kByte	24 MHz	PWM	150 °C
	TLE9877QXA20	64 kByte	6 kByte	24 MHz	PWM + LIN	150 °C
	TLE9877QXA40	64 kByte	6 kByte	40 MHz	PWM + LIN	150 °C
	TLE9879-2QXA40	128 kByte	6 kByte	40 MHz	PWM + LIN	150 °C
	TLE9879QXA40	128 kByte	6 kByte	40 MHz	PWM + LIN	150 °C

2 Getting Started

2.1 Toolchain Installation

In order to get the board ready and running, the software shown in Table 4 shall be installed.

The µVision software is a development tool provided by Arm® Keil®. With code length limitation, the shareware version of the µVision is still able to edit, compile and debug. The Infineon Config Wizard is a tool for configuring peripherals of the Embedded Power IC. The tool can be called from the pull-down menu of the µVision and helps users changing parameters from its user interface and then generates the software code accordingly. Infineon provides standard motor drive software codes for the Embedded Power IC. It can be downloaded from the Pack Installer within the µVision.

Table 4 Software Toolchain Installation Guide

Steps	Company	Description
STEP1 Download and Install **Keil® µVision5**	Arm® Keil®	• Arm® Keil® µVision is an integrated development environment which consists of code editor, compiler and debugger. • To learn how to use Arm® Keil® µVision 5, check out our video "**Get your motor spinning**".
STEP2 Download Config Wizard	Infineon Technologies	• Infineon provides the Config Wizard free of charge, which is designed for configuration of chip modules. Config Wizard supports easy configuring of Embedded Power IC peripherals. • Config Wizard can be installed via the Infineon Toolbox. If you don´t have the Infineon Toolbox yet, please go to **Infineon Toolbox** and enjoy the release management for updates.
STEP3 Download and Install **Segger J-Link Driver**	SEGGER	• SEGGER J-Link is a widely used driver for "on-board" or "stand-alone" debugger.
STEP4 Download the SDK via µVision5 Pack Installer	Infineon Technologies	• The Embedded Power Software Development Kit (SDK) is a low level driver library which can be downloaded within Keil® µVision via the "Pack Installer"

For the toolchain installation and free motor drive software, please check below link.
www.infineon.com/embedded-power
For more information about the tool chain installation steps, watch our video.
Toolchain Installation for Embedded Power ICs / TLE98xx

2.1.1 Configuration

Open a motor drive code project in µVision5 and go to "Tools" and open "Config Wizard". From there, setup the parameters of motor, speed/current controller and the peripherals of TLE987x. As the Embedded Power IC has a current-source gate driving scheme, the switching speed is not controlled by gate resistors, but by the "Gate Charge/Discharge" parameters in the BDRV tap of the peripherals. For more details about the configuration, please visit the Infineon website of Embedded Power ICs.

3 System Design

The evaluation board design is an automotive 3-phase motor controller for 12 V automotive applications. Target application is an engine cooling fan within the engine compartment with a power of up to 300W with the housing exposed to the air flow. The functional blocks of the system are shown in Figure 1. The two main active components are:

- *3-Phase Bridge Driver IC with Integrated Arm® Cortex® -M3 (TLE9879QXA40)*
- OptiMOS-6™ MOSFET in SSO8 package (*IAUC120N04S6N015, IAUC120N04S6N013*)

OptiMOS-6™ is the newest generation of Infineon's low voltage MOSFET silicon technology. Combined with the compact Super-SO8 (SSO8) package, the product is a good fit for motor drive under 400W within the engine compartment, with small form factor and quality for automotive applications. The TLE987x is an Embedded Power IC, combining a 3-phase bridge driver with a 32-bit Arm® Cortex® M3 core and peripherals such as timer modules, ADCs, double stage charge pump, voltage regulators, external sensor supply, RAM, flash memory and LIN communication module. This Embedded Power IC is equipped with many popular functions, requiring just a few passive components nearby, with the capability to perform advanced motor control, such as sensorless FOC with current-controlled gate driving.

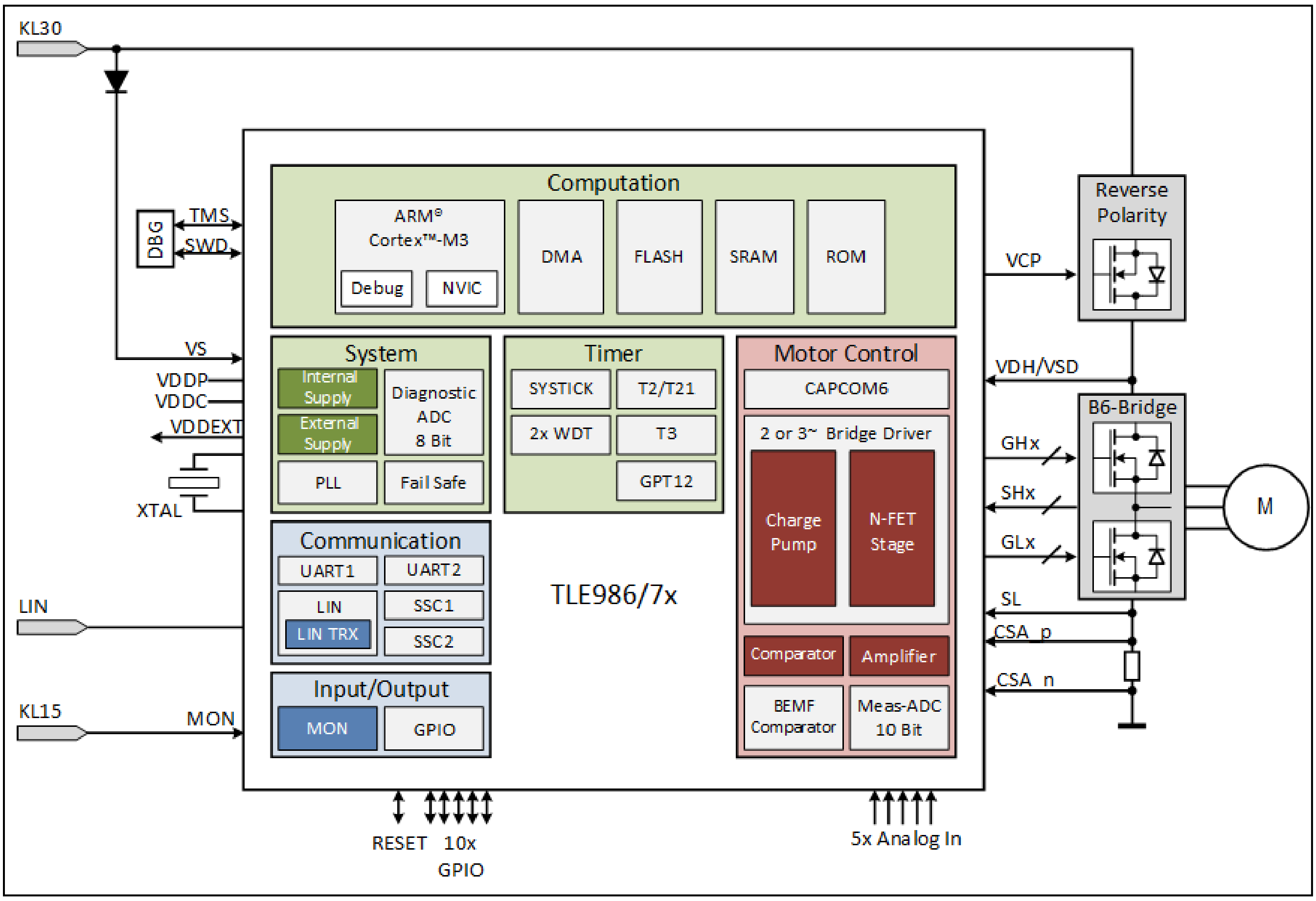


Figure 2 System block diagram

3.1 Electrical Design and Components

3.1.1 DC-link Electrolytic Capacitor

Document [4] shows a simple analytical expression for the current stress on the DC-link capacitor. For the case where the inverter controls a permanent-magnet AC machine (with near unity power factor), the worst-case current-stress estimation, used as a basis for the capacitor dimensioning, is given by $I_{C,rms} \approx {}^{1}/_{\sqrt{2}} \cdot I_{Out,rms}$. Targeting the voltage ripple of the capacitor within 1 V, at 28 A rms output current, a total capacitance of 850 µF is required. In this design, a 1000 µF electrolytic capacitor is used for each leg of the bridge.

3.1.2 Shunt Resistor

The resistance, temperature coefficient, wattage, derating, form-factor, stray-inductance and environmental robustness are the main features to consider when choosing a shunt resistor. As shown in the Table 5, the maximum value of the differential input voltage of the operational amplifier is given by the expression 1.5 / G, where G is the selected gain of the currente sense amplifier. Therefore, the value of the shunt resistor can be determined considering the targeted maximum shunt current. In this evaluation design, the differential gain is set to 10, resulting in the maximum differential input voltage of 150 mV. With three 10 W, 9 mΩ shunts in parallel, the maximum shunt current is equal to: I_shunt_max = (150 mV/3 mΩ) = 50 A. And the maximum power rating of the shunt is 5.4 W at 155 °C, considering the specified 88% derating.

Table 5 Differential Input Voltage Range of the Operational Amplifier of TLE9879QXW40

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Differental gain (uncalibrated)	G	9.5 19 38 57	10 20 30 40	10.5 21 42 63		Gain settings GAIN<1:0> 00 01 10 11
Differential input operating voltage range OP2 - OP1	VIX	-1.5 / G	-	1.5 / G	V	G is the gain specified

Considering the resistance tolerance and temperature dependency, the max resistance of the shunt at 155°C is expected to be 3.11 mΩ. Thus, the power dissipation at 28 A rms current is: $(28\ A)^2$ x 3.11 mΩ ≈ 2.44 W. The total area of the shunt resistor is 20.5 mm x 9 mm = 184.5 mm^2.

3.1.3 Snubber

The value of the RC snubber is based on Cornell Dubilier application guide [5], chosen by double pulse switching test. The 1 Ω, 15 nF RC snubber is combined with 35 V, 100 µF DC-link ceramic capacitor. The 1000 µF electrolytic capacitor works as a DC-link filter for each leg of the bridge. The power dissipation of the snubber has been calculated and verified at 18 V / 20 kHz switching frequency.

4 System Performance

This chapter shows the performance and characteristics of the evaluation design, driving an engine cooling fan in the lab.

4.1 Motoring Test Setup

The setup is designed for 300W engine cooling fan, supplied by 8.5 V ~ 15 V power source. Its startup duty-cycle is 12% and maximum speed is 3500 rpm.

Table 6 Parameters of ECF Motor

Parameter	Value	Unit
Phase Resistance	0.005	Ω
Phase Inductance	170	µH
Pole Pairs	4	
Maximum Speed	3500	rpm

4.1.1 Motor Parameter Setup

The parameters of the pump-motor are entered into the Config Wizard, as shown in Figure 3. Then the Config Wizard configures the relevant software code, which will be compiled into an execution file by µVision. This is an essential step to read the back-EMF properly, as the feedback of the control.

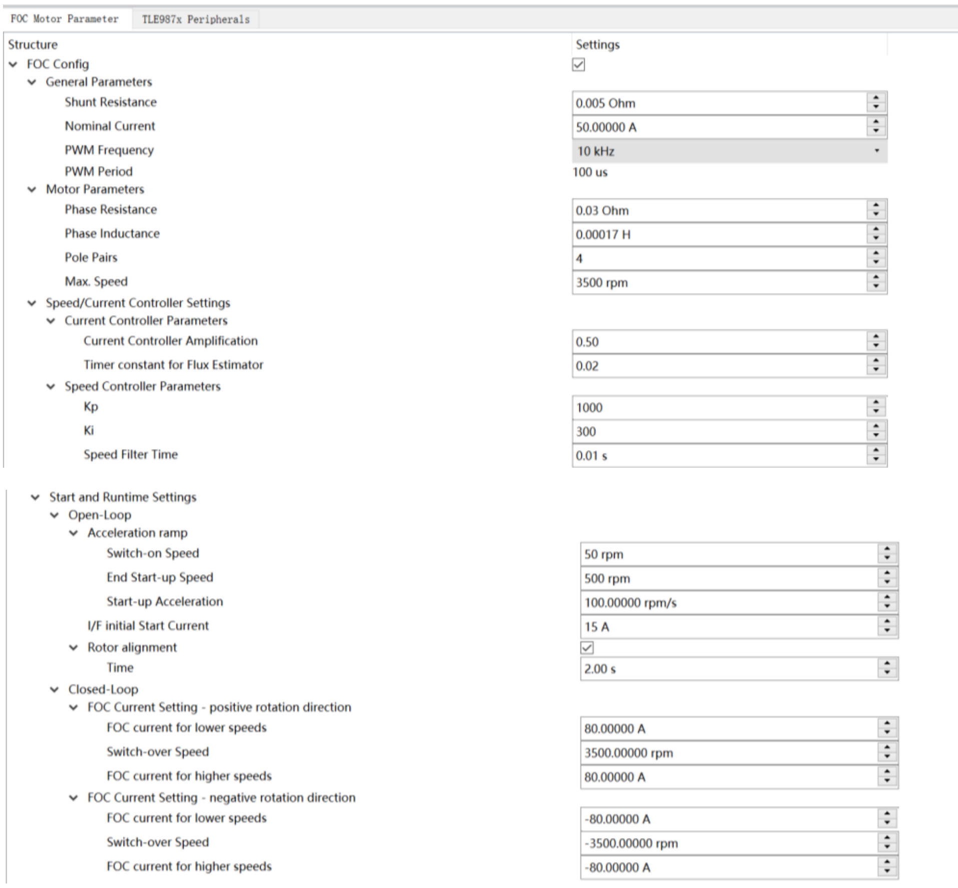


Figure 3 Motor parameter setting of Config Wizard

4.1.2 Gate-drive Setup

The gate driver stage of TLE987x has sophisticated function sets and protection schemes. It has an overcurrent detection and a shutdown feature, adjustable cross conduction protection, supply voltage (VSD) monitoring including adjustable over- and undervoltage shutdown, VDS comparators for short circuit detection in on- and off-state and open-load detection feature in MOSFET off-state, to name a few. Taking a look at the bridge driver parameters setup, the Config Wizard has a 'TLE987x Peripherals' tap, where the user can configure the setting of each function module. Under this, In the BDRV tap, bridge driver parameters such as charge pump, diagnosis and gate charge/discharge can be configured. The MOSFET switching speed is determined by the parameters under 'Gate Charge/Discharge'. Here the user can select the charge/discharge current range. The pull-down menu offers two different ranges, 0 ~ 150 mA or 0 ~ 300 mA. This range is broken down to 31 steps, by which the effective charge/discharge current is determined. By changing these parameters, the gate driving current capacity can be tuned in order to have desired switching speed. Furthermore, the 'Charge Sequencer' and the 'Discharge Sequencer' enables fine tuning of the driving current level over four consecutive time periods, DRV_ON_I_1 ~ DRV_ON_I_4 or DRV_OFF_I_1 ~ DRV_OFF_I_4. In this way, the dynamic characteristics of the MOSFET switching can be fine tuned to fit the application use. For more details, please refer to Chapter 5 of 'TLE986x_TLE987x Bridge Driver Application Note'. The example of the bridge driver setup in the Config Wizard is shown in Figure 4.

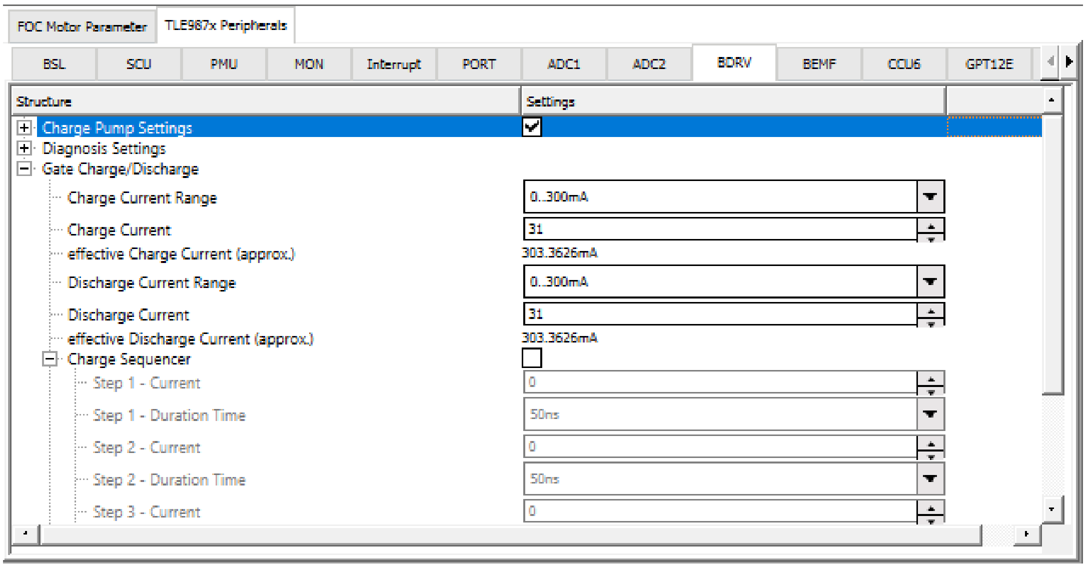


Figure 4 Bridge driver setting of Config Wizard

4.2 Electrical Test Result

4.2.1 Motoring Characteristics

Waveforms during the motor start-up is shown in Figure 5. After aligning rotor position for about 2.4 seconds, the motor accelerates to 500 RPM by open-loop control with the rate of 100 RPM/sec. Once the speed reaches to 500 RPM, the FOC algorithm takes over the speed control accelerating the motor up to the target speed. The electrical angle during the start-up is shown in Figure 6.

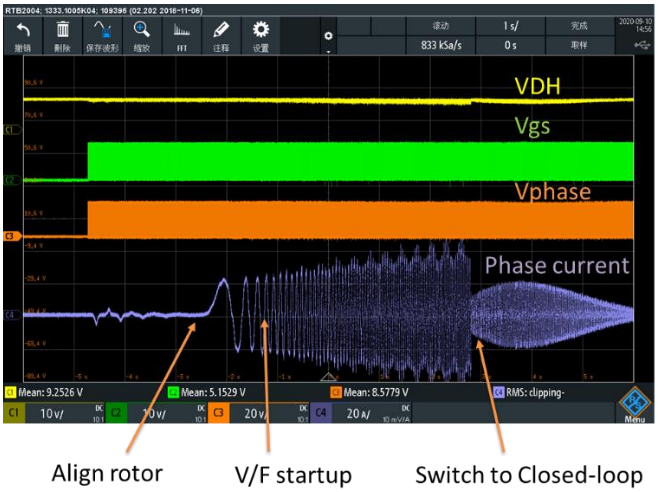


Figure 5 Motor start-up waveform

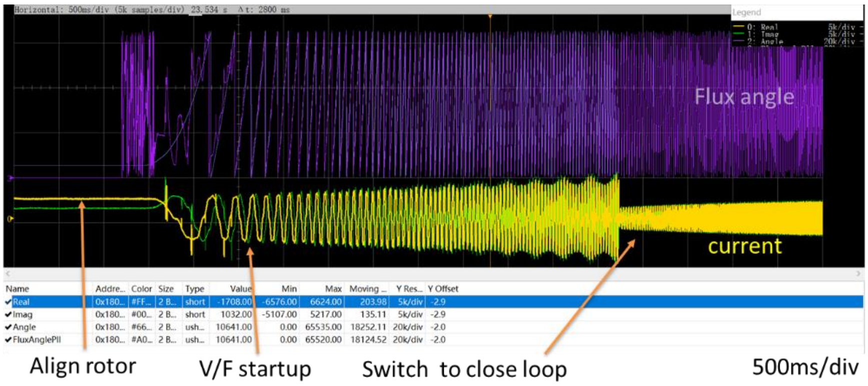


Figure 6 Electrical angle and phase current during start-up

At 3000 RPM operation with 15 Vdc supply, the DC-link voltage and the phase current is measured in Figure 7. The RMS value of the phase current is about 24 Arms and the DC-link voltage ripple is about 1 V. As the maximum motor speed is limited by the motor Back-EMF, the supply voltage is increased to 15 V to achieve higher speed.

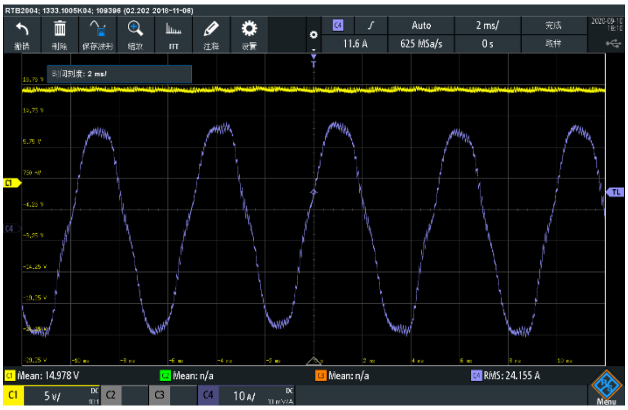
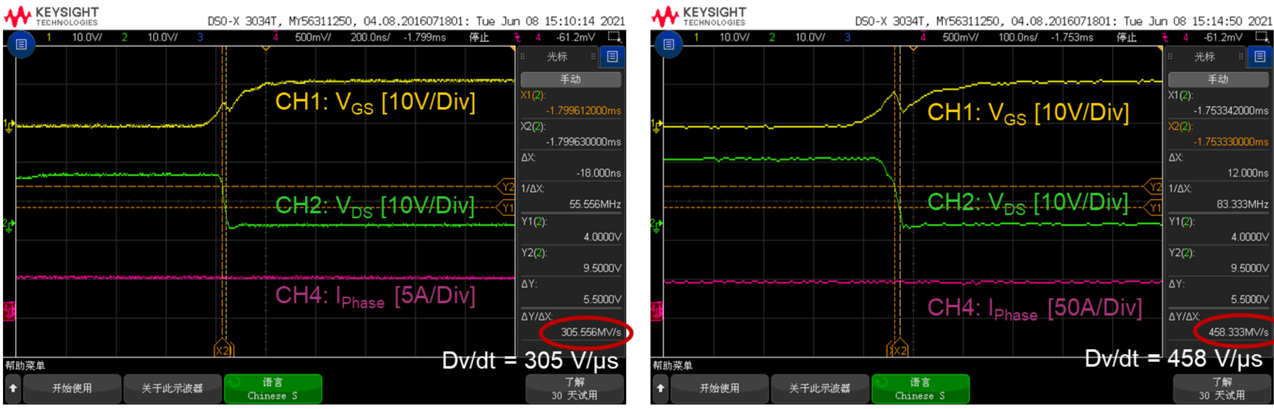


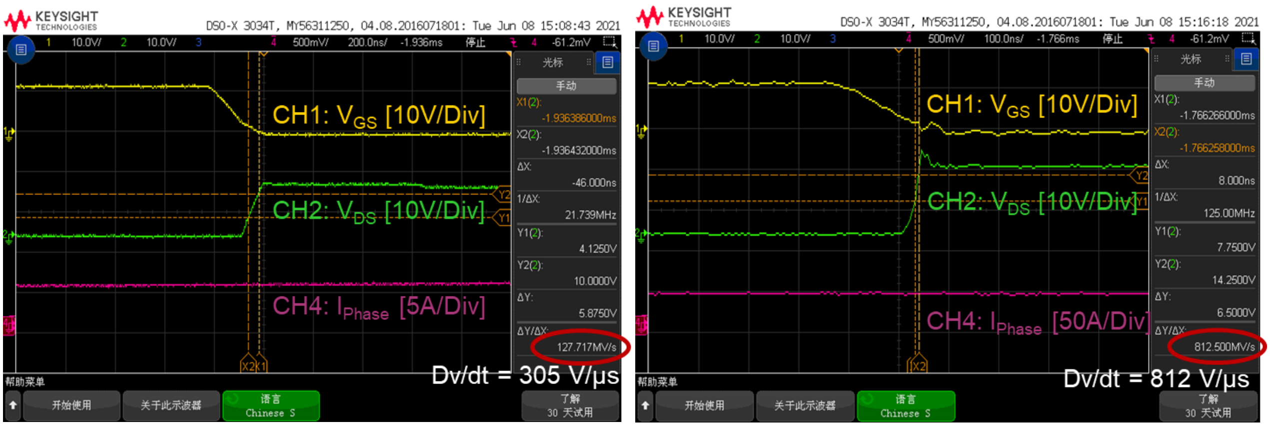
Figure 7 Phase current at 15Vdc and 3000 RPM

Figure 8 and Figure 9 shows the switching waveform of Q5. Measured dV/dt of the Vds is shown in the each waveforms that are captured at different voltage and current. The switching speed can be easily adjusted at the software setting without changing physical gate resistance. Please find more details of the gate drive parameter setting of TLE9879QXA at "TLE987x_TLE987x Bridge Driver Application Note". [2]



(a) $12V_{DC}$, 5A (b) $15.8V_{DC}$, 50A

Figure 8 MOSFET turn-on dv/dt



(a) $12V_{DC}$, 5A (b) $15.8V_{DC}$, 50A

Figure 9 MOSFET turn-off dv/dt

4.3 Thermal Behavior

4.3.1 Housing Assembly for Thermal Test

The housing of an after-market engine cooling fan is assembled in order to perform thermal test. Thermal pad and the PCB are mounted on the housing by three screws as shown in Figure 10. Thermal pad with 1mm thickness and 3.6 W/mK thermal conductivity is used in between the PCB and housing. The PCB is mounted on the heatsink with three of M3 screws to provide close contact between PCB, thermal pad and housing. For the testing purpose, additional thermal grease is used to fill the gaps at some of the locations that are caused by the after-market housing surface design. But, as for the evaluation board, there is no component at the bottom of the board. And having a simple flat surface of the housing is possible. The setup was placed in room temperature for the thermal tests.

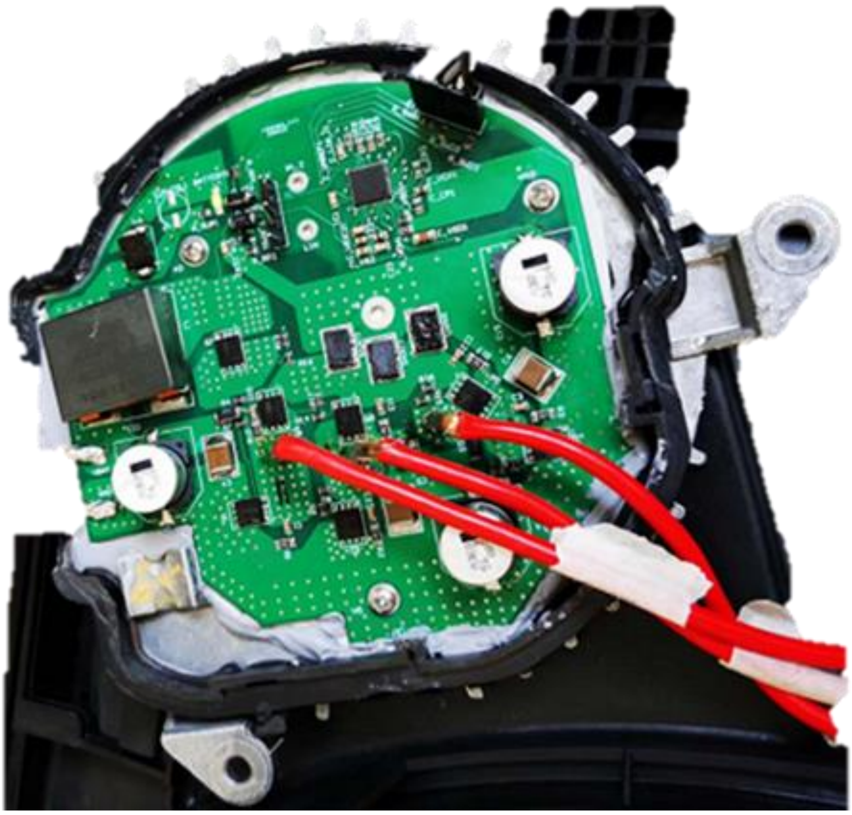
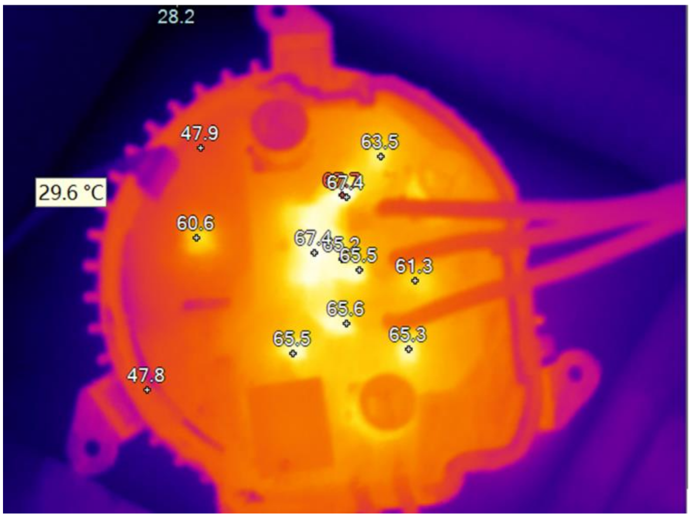


Figure 10 Housing assembly

4.3.2 Thermal Image

Figure 11 is an example of a thermal image from the fan test setup. The image was taken from the test run of the fan at 15.8 V, 24 Adc test condition. The system was in room-temperature. MOSFETs, TLE9879 and the shunt resistor are the major components that dissipate power and increase system temperature. The temperature of those components are within the same range at this operating condition. The reverse protection MOSFET, Q7 usually has higher power dissipation at maximum current range. Thus, having lower Rds(on) on this MOSFET,

compared to bridge MOSFETs is generally recommended. With 1.3 mΩ product, the temperature of Q7 is within the same range of other MOSFETs.



Device	Temp(°C)
TLE9879	60.6
Q1	65.3
Q2	61.3
Q3	63.5
Q4	65.6
Q5	65.5
Q6	67.4
Q7	65.5
Shunt	67.4
Mounting bolt	47.8
Housing	47.9

Figure 11 Thermal image showing the temperature reading point

4.3.3 Temperature Profile

Figure 12 is the temperature profile of the components shown in Figure 11. The temperature of the bridge MOSFETs shows 60~68°C at 24 A input current. This translated to 145~153°C mold temperature at 110°C ambient. And the system still can run at its max overload conditions (26Adc) during short period of times. The temperature difference between the hottest MOSFET and the housing is about 20°C. The temperature of TLE9879 gate driver is lower than MOSFETs and increasing less than MOSFETs. Even in higher current condition, the gate driver temperature does not increase as much as MOSFETs, because the direct self heating of the driver is mainly from its internal power regulators and charge pumps, which is much less than indirect heating from the MOSFETs nearby.

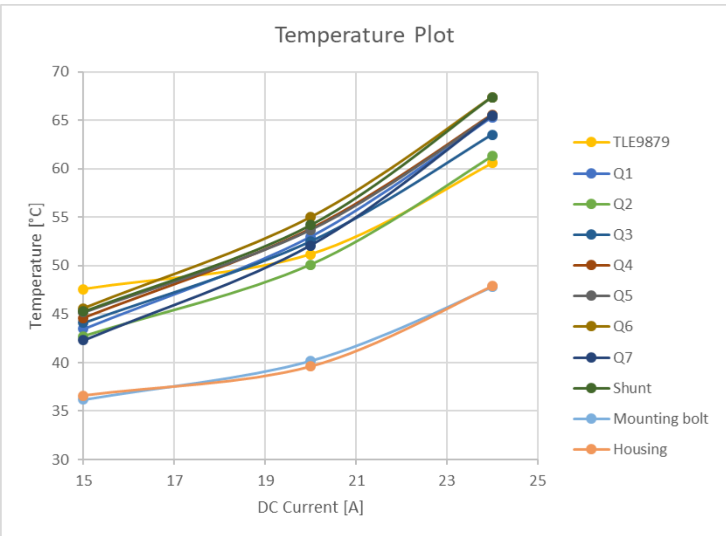
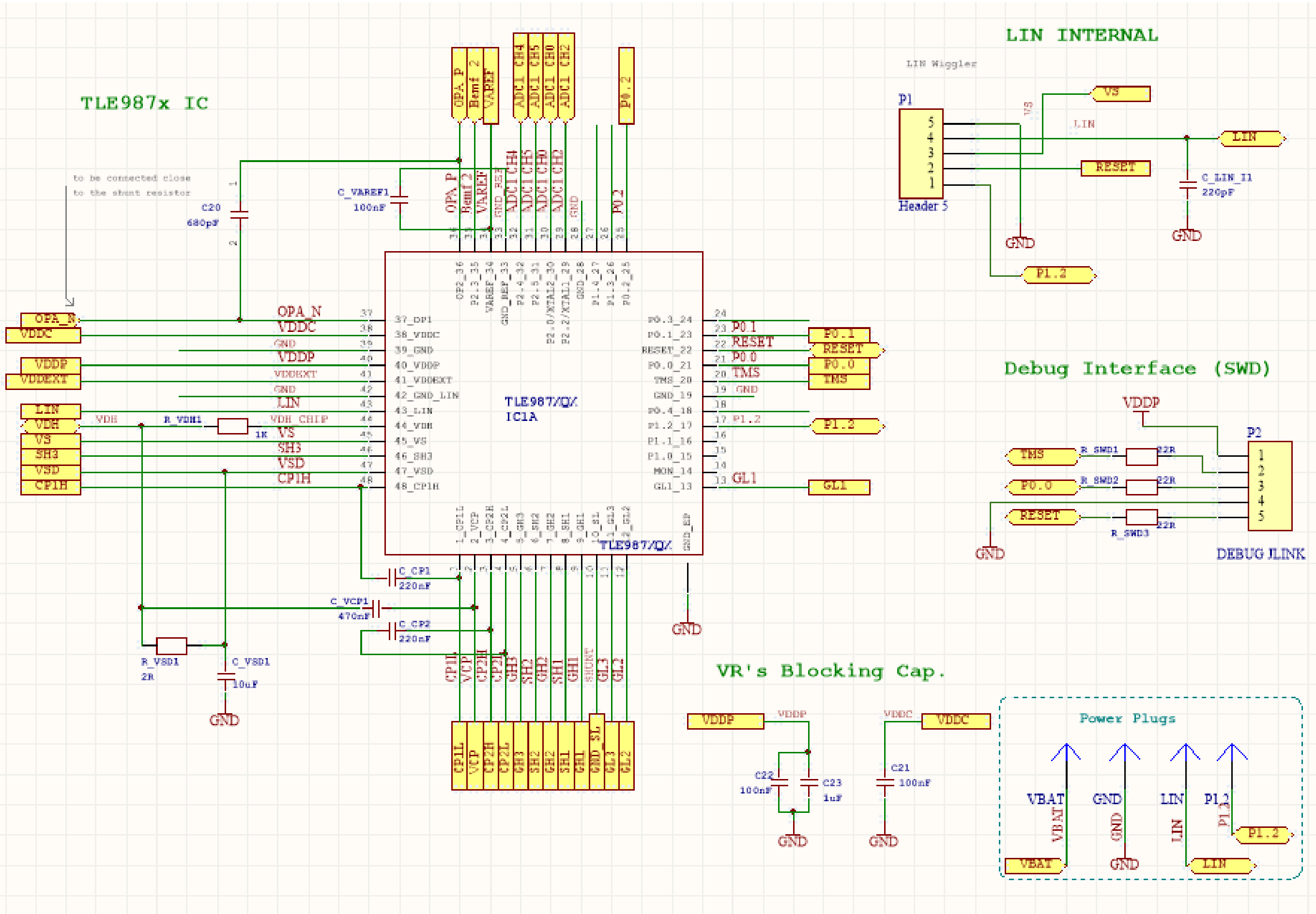
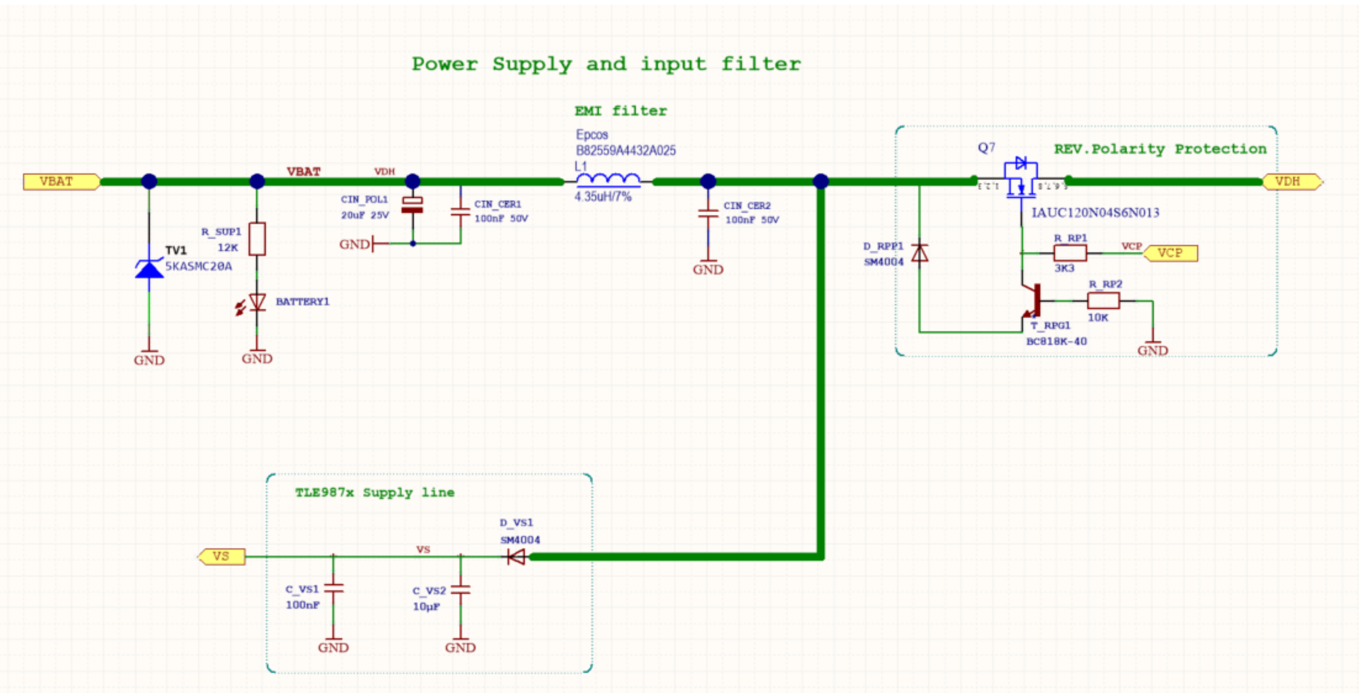


Figure 12 Measured Temperature versus Input Current.

5 Project Collaterals

5.1 Schematics





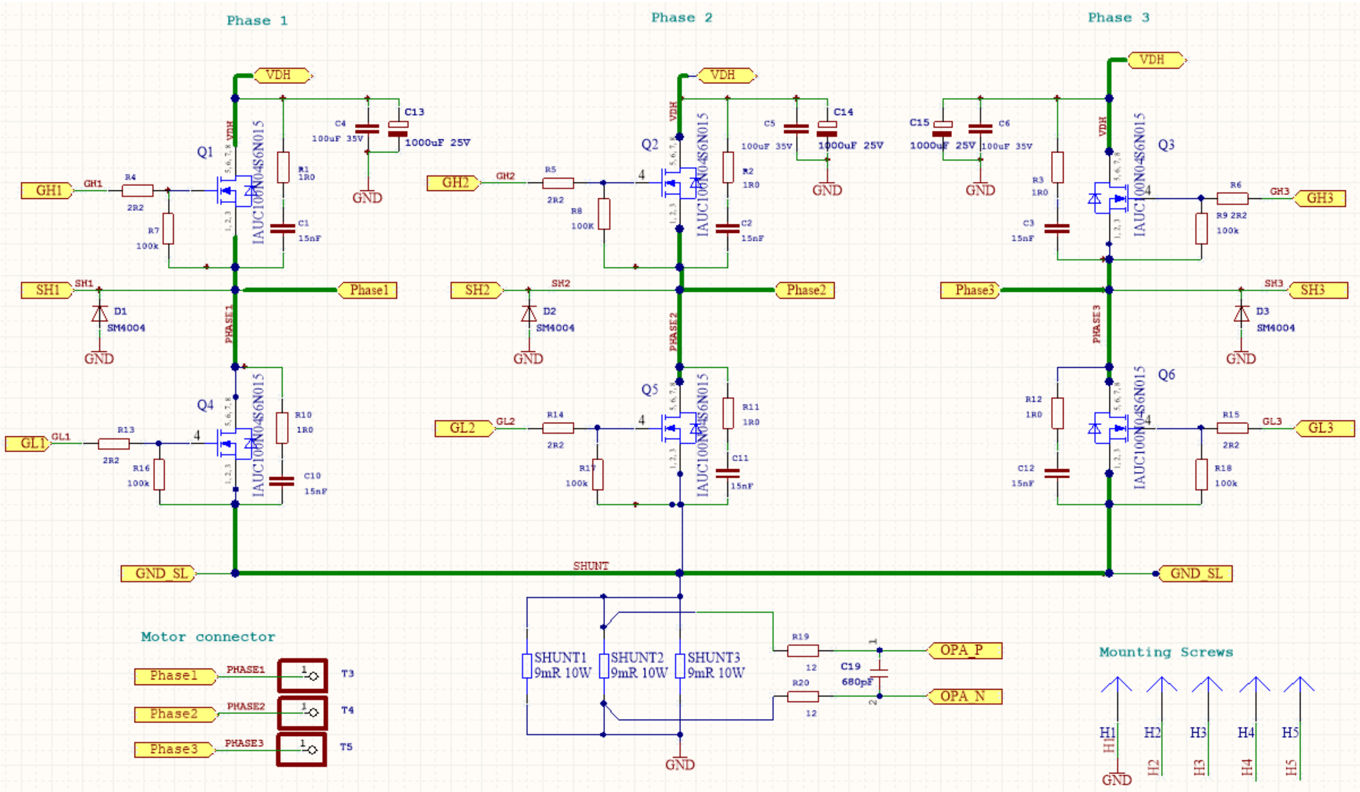


Figure 13 Circuit Schematics

5.2 Bill of Material

Table 7 Bill of material

	Designator	Value	Description	Quantity
1	BATTERY1	LEDSMT1206	LED	1
2	C1, C2, C3, C10, C11, C12	15nF		6
3	C4, C5, C6	100uF 35V		3
4	C13, C14, C15	1000uF 25V	Panasonic，EEVTD1E102UM	3
5	C19, C20	680pF		2
6	C21, C22, C_VAREF1, C_VS1	100nF		4
7	C23	1uF		1
8	C_CP1, C_CP2	220nF		2
9	C_LIN_I1	220pF		1
10	C_VCP1	470nF		1
11	C_VS2	10µF		1
12	C_VSD1	10uF		1
13	CIN_CER2	100nF 50V		1
14	CIN_POL1	20uF 50V	Panasonic，EEETG1H220P,ϕ8	1
15	D1, D2, D3, D_RPP1, D_VS1	SM4004	DIODE	5
16	GND, LIN, P1.2, VBAT	Screw hole	Plug	4
17	H1, H3, H4, H5	Screw hole	Plug	4
18	IC1	TLE9879QXA40	Infineon Epower	1
19	L1	B82559A4432A025	SMT Power Inductor, EPCOS	1
20	P1	Header 5	Header, 5-Pin	1
21	P2	DEBUG JLINK	Header, 5-Pin	1
22	Q1, Q2, Q3,Q4, Q5, Q6	IAUC100N04S6N015		6
23	Q7	IAUC120N04S6N013		1
24	R1, R2, R3, R10, R11, R12	1R0		6
25	R4, R5, R6, R13, R14, R15	2R2		6
26	R7, R8, R9, R16, R17, R18	100k		6
27	R19, R20	12R0		2
28	R_RP1	3K3		1
29	R_RP2	10K		1
30	R_SUP1	12K		1
31	R_SWD1, R_SWD2, R_SWD3	22R		3
32	R_VDH1	1K		1
33	R_VSD1	2R		1
34	SHUNT1, SHUNT2, SHUNT3	WSHP2818R0100	9mR 10W	3
35	T3, T4, T5		Soler Pad Terminal	3
36	T_RPG1	BC818K-40	NPN Transistror BF959	1
37	TV1	5KASMC20A	TVS	1

5.3 Layout Printing

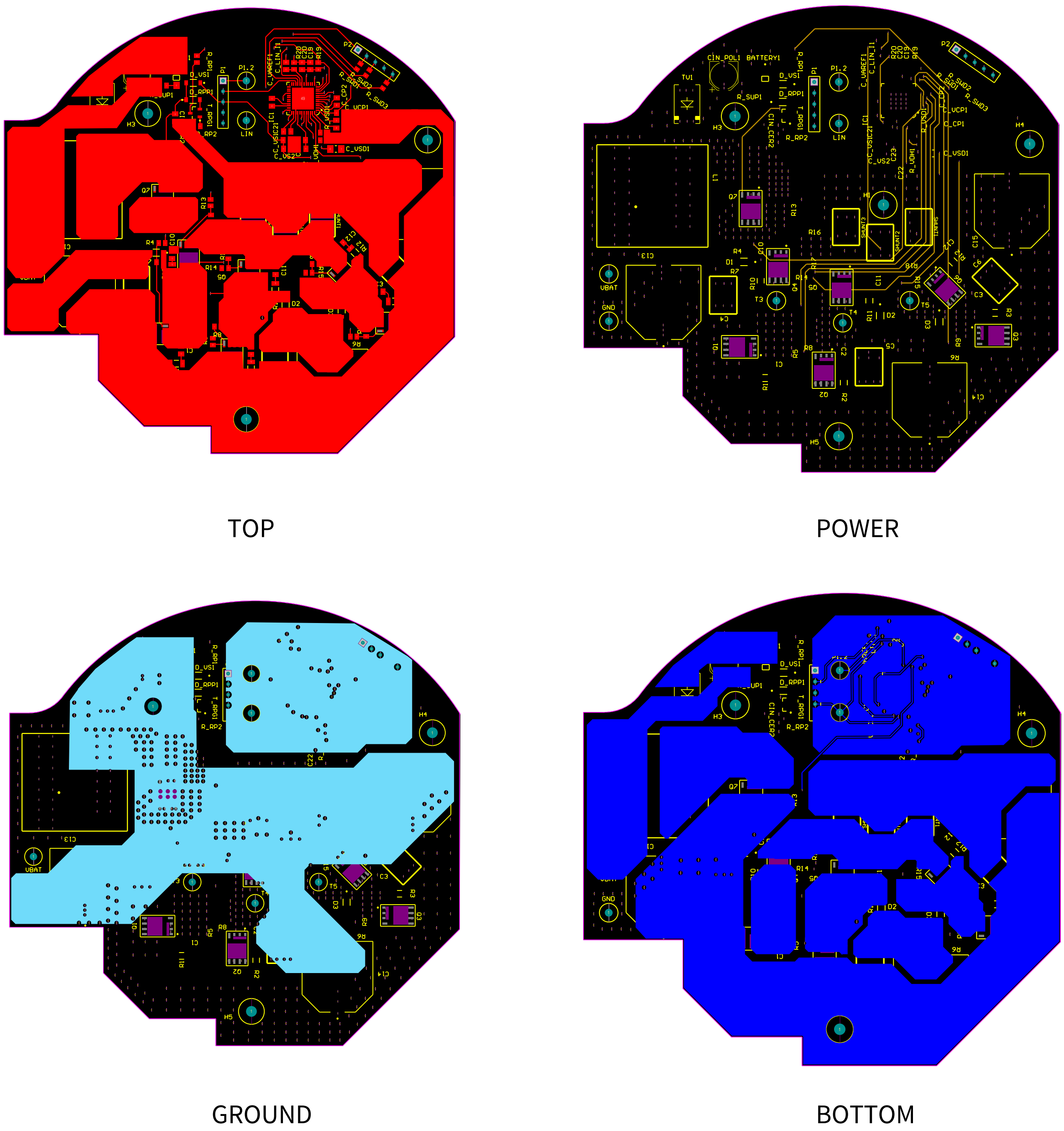


Figure 14 PCB layout printing of 4 Copper layers

6 Abbreviations and definitions

Table 8 Abbreviations

Abbreviation	Definition
ECF	Engine Cooling Fan
LIN	Local Interconnect Network
FOC	Field Oriented Control
MI	Modulation Index
RBP	Reverse Battery Protection
ECU	Electrical Control Unit
PWM	Pulse Width Modulation
PCB	Printed Circuit Board
EMC	Electromagnetic Compatibility
IC	Integrated Circuit
DC	Direct Current
ESR	Equivalent Series Resistance
DUT	Device under test
BDRV	Bridge Driver Module of Embedded Power IC

7 Reference documents

This document should be read in conjunction with the following documents:

[1] TLE9879QXA40 datasheet, Infineon Technologies AG, https://www.infineon.com/dgdl/Infineon-TLE9879QXA40-DS-v01_00-EN.pdf?fileId=5546d4625a888733015a89d10a283f20

[2] TLE987x_TLE987x Bridge Driver Application Note, 2018-12, Infineon Technologies AG, Rev 1.02 https://www.infineon.com/dgdl/Infineon-TLE987x_TLE986x-BDRV-ApplicationNotes-v01_02-EN.pdf?fileId=5546d46267c74c9a0167cbe1686a191d

[3] TLE987x User Manual, 2020-10, Infineon Technologies AG, Rev 1.5.3 https://www.infineon.com/dgdl/Infineon-TLE9879QXA40-UserManual-v15_03-EN.pdf?fileId=5546d4624e24005f014e52ca1628452c

[4] IAUC120N04S6N013 datasheet, Infineon Technologies AG, https://www.infineon.com/dgdl/Infineon-IAUC120N04S6N013-DataSheet-v01_00-EN.pdf?fileId=5546d4626afcd350016b1ca3ea611222

[5] IAUC100N04S6N015 datasheet, Infineon Technologies AG, https://www.infineon.com/dgdl/Infineon-IAUC100N04S6N015-DataSheet-v01_00-EN.pdf?fileId=5546d4626afcd350016b1ca3da54121e

[6] Analytical calculation of the RMS current stress on the DC-link capacitor of voltage-PWM converter systems, 2006-07, IEE Proc.-Electr. Power Appl., Vol. 153, No.4.

Revision history

Major changes since the last revision

Date	Version	Description
28-06-2021	V0.7	Initial version

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Edition 28-Jun-2021

Published by

Infineon Technologies AG

81726 Munich, Germany

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Document reference