Comfort application reference design

User guide

Z8F80816870

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About this document

Scope and purpose

This reference board design guide provides an overview of the reference design, enabling the reader to design their own reference design. This design guide provides an overview on the whole system offering for automotive comfort application, and extensive technical information on the board.

Intended audience

This document is intended for anyone interested in designing optimized 3-phase *brushless direct current (BLDC)* motor control applications.

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1 Comfort application reference design overview

The REF_COMFORT_APP_DC is a reference design for comfort applications in the power class of 150 W. The board is designed to operate with nominal voltage of 12 V. It features single-shunt current sensing and Hall sensor-based position sensing to enable *brushless DC motor (BLDC motor)* operation.

The reference design is optimized for:

- Electromagnetic compatibility
- Thermal performance
- Space on the board
- Number of components on the board

The board features a MOTIX™MCU, TLE9954EQW40, which consists of an M23 Arm Cortex, PWM generation unit, and gate driver, among other modules. The board incorporates three half-bridge OptiMOS7 MOSFETs in SSO8 package.

1 Comfort application reference design overview

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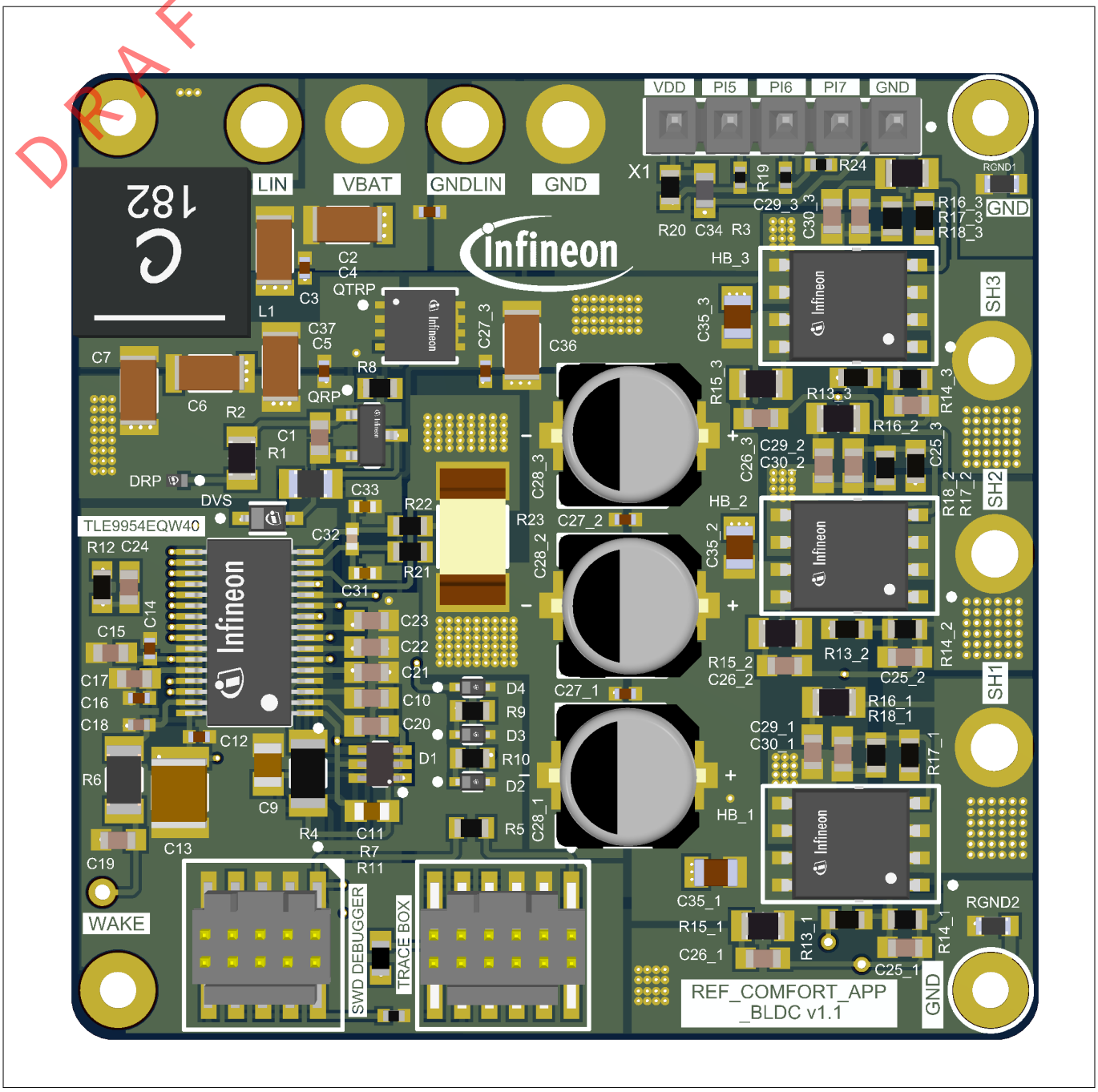


Figure 1 REF_BLDC_COMFORT_APP

Applications	Highlighted design aspects
• Seat control • Window control • 150 W, 12 V sensor-based and sensorless BLDC motor applications	• EMC optimized • Cost optimized • Space optimized • Thermally optimized

Highlighted components

- MOTIX™ MCU TLE9954EQW40
- OptiMOS7 IAUCN04S7N024H
- OptiMOS7 IAUZN04S7N032

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2 System offerings

The table below provides an overview of all the available materials which could be helpful to build your custom solution. For more information see https://www.infineon.com/tle995x.

Table 1 System offerings

Title	Description
TLE995x reference design	REF_COMFORT_APP_BLDC is a reference design developed for 3-phase automotive comfort applications, such as automotive window control and seat position systems. The reference design is optimized in terms of *EMC* and thermal behavior. It includes a dedicated example software as well as support material including layout and schematic files (Altium), EMC tests, thermal analysis, and detailed documentation.
MOTIX™ TLE994x/TLE995x datasheet	This document provides detailed information on TLE995x.
MOTIX™ TLE994x/TLE995x user manual	The user manual describes the functionality of the super-set device of the TLE994x/5x family. For the available functionality (features) of a specific TLE994x/5x derivative (device), refer to the respective datasheet. The various device types are referenced by the collective term TLE994x/5x throughout this manual.
MOTIX™ TLE994x/TLE995x firmware reference manual	This document provides technical information on the *bootROM* firmware features of the TLE994x/5x, as well as technical guidance on how to interact with the device using embedded mechanisms and the user *API* functions. The subsequent sections provide the necessary information for bootROM firmware API handling.
TLE995x hardware design guide	This document provides detailed descriptions of hardware design guidelines for the external components, using the TLE994x/5x devices. This document is to be used in combination with the product datasheet, user manual and firmware reference manual.
TLE994x_995x Evalboard/Evalkit	The TLE994x_995x DUT Board can be used during design in, for evaluation and testing of the MOTIX™ MCU TLE994x and TLE995x family features.
TLE995x PDL	The peripheral driver library (PDL) integrates device header files, startup code, and peripheral drivers into a single package. The drivers abstract the hardware functions into a set of easy-to-use APIs. The PDL reduces the need to understand register usage and bit structures, therefore easing software development for the extensive set of peripherals.
Device configurator	Infineon Device Configurator can be used to update various parameters of TLE995x.
MOTIX™ Solution Designer	MOTIX™ MCU Solution Designer is a tool designed to guide users in developing a motor control application.

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3 System overview

REF_COMFORT_APP_BLDC is a reference design for comfort applications. The design can be used as a reference for other *BLDC* motor applications. The board of the reference design is developed using standard *printed circuit board (PCB)* materials and processes.

The figure below shows an overview of the REF_COMFORT_APP_BLDC. The reference design is supplied with power via the battery terminal connection on the top of the board, as well as a *local interconnect network (LIN)* connection. The reference design contains an input PI filter and a reverse polarity circuit with an OptiMOS™ 7 MOSFET. MOTIX™ MCU TLE9954EQW40 drives 6 OptiMOS™ 7 MOSFETs. The current sensing through the bridge is possible via the shunt located at the center of the board. The position of the motor can be sensed using hall sensors using the connectors available on the top right side of the board. The communication to the microcontroller can be established via the debug connectors at the bottom of the board.

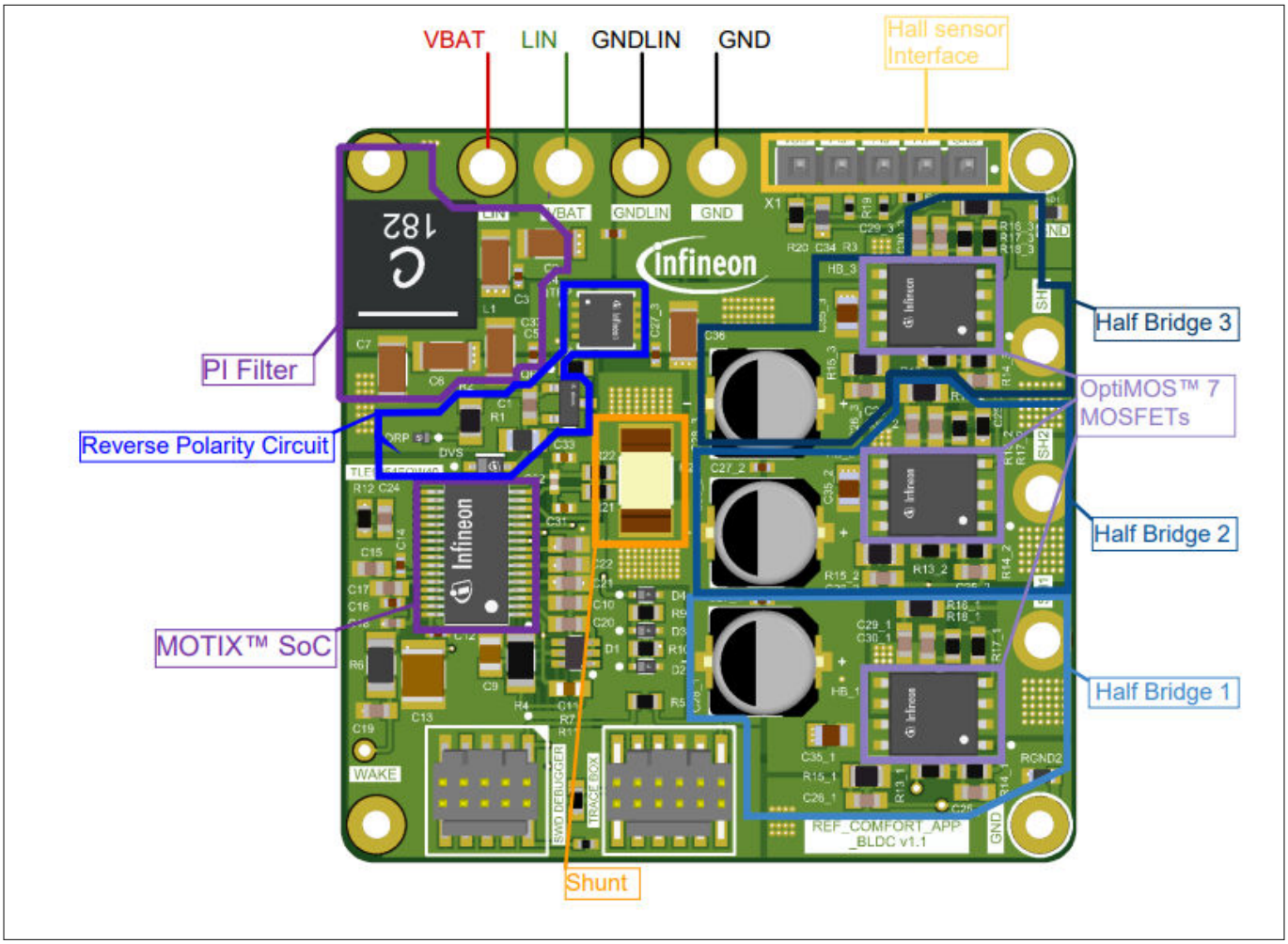


Figure 2 **Figure 2 Overview of the Comfort application reference design**

The next chapter highlights the design specifications that were used as a reference during the design of the board.

3.1 Design specifications

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

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Table 2 Design specifications

Parameter	Symbol	Values			Unit	Comment
		Min.	Typ.	Max.		
System parameters						
Functional input voltage	V_{IN}	9	13.5	24	V	Specified according to specification of comfort applications
Peak input current	I_{IN}	-	-	22	A	Peak current (<10 s)
Nominal input current	I_{IN}	-	12	-	A	Specified by design
LIN interface	V_{BUS}	-40	-	40	V	PRQ-1377
Phase voltage 1, 2, 3	V_{SH}	-8	-	48	V	PRQ-1250
Thermal						
Operating temperature	T_A	-40	25	125	°C	Specified by design
Electromagnetic Compatibility						
Conducted emissions				Class 5		CISPR25, 150 kHz -108 MHz
Mechanical specification						
Dimensions PCB	45 mm x 45 mm x 12 mm (length x width x height)					

3.2 Highlighted products

3.2.1 OptiMOS™ 7 40 V SSO8 HB (PG-TDSON-8-60) MOSFET

The new integrated half-bridge (5mm x 6mm) from Infineon is the cost-efficient package solution for motor drive and body applications. The integrated half-bridge provides the ideal solution for optimized routing in bridge applications, and considerably reduces the *PCB* area. The portfolio provides a wide $R_{DS(on)}$ range from 2.3 mΩ to 5.4 mΩ, and an increased current rating of 60 A. For this design, a $R_{DS(on)}$ of 2.4 mΩ was chosen to optimize performance. For more information about the product, see https://www.infineon.com/cms/en/product/promopages/OptiMOS7_40V/.

Table 3

Product	Maximum $R_{DS(on)}$[mΩ]	I_D (DC current) [A]	I_D (chip limitation) [A]	Q_G typ. [nC]	$V_{GS(th)}$ [Logic/ Normal Level]
IAUCN04S7L023H	2.3	100	133	35	Logic Level
IAUCN04S7N024H	2.4	100	130	27	Normal Level
IAUCN04S7L037H	3.7	87	87	16	Logic Level

(table continues...)

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Table 3 (continued)

Product	Maximum $R_{DS(on)}$[mΩ]	I_D (DC current) [A]	I_D (chip limitation) [A]	Q_G typ. [nC]	$V_{GS(th)}$ [Logic/ Normal Level]
IAUCN04S7N040H	4.0	84	84	13	Normal Level
IAUCN04S7L050H	5.0	64	64	11	Logic Level
IAUCN04S7N054H	5.4	62	62	9	Normal Level

3.2.2 MOTIX™ MCU - 32-bit motor control SoC with integrated 3-phase bridge driver

The MOTIX™ TLE9954EQW40 is a single-chip 3-phase motor driver with an Arm® Cortex®-M23 core and flash memory. It supports field-oriented control (FOC) and complies with ISO 26262 up to ASIL B for safety. Featuring Arm® TrustZone for security, this AEC-Q100 Grade 0 automotive-qualified device is designed for various cost-efficient *BLDC* motor drive applications.

For more information about the product, see https://www.infineon.com/tle995x.

3.2.3 OptiMOS™ 7 40 V S3O8 3x3 with Cu-clip

The reverse polarity protection circuit consists of the S3O8 package, which offers a high current capability of 40 A, with a small footprint of 3.3 x 3.3 mm^2. In combination with Infineon's OptiMOS-7™ 40 V power MOS technology, it is optimized to meet and exceed the energy efficiency and power density requirements of automotive *BLDC* and *half bridge (HB)* applications. Infineon's robust S3O8 leadless package technology, enables you to create very small and efficient system designs with minimal $R_{DS(on)}$, down to 1.2 mΩ. For more information about the product, see https://www.infineon.com/cms/en/product/promopages/new-optimos-7-technology/.

The IAUZN04S7N032 is a high-current, low-$R_{DS(on)}$ power MOSFET in a 3 x 3 mm^2 advanced leadless package, with a Cu-Clip for low package $R_{DS(on)}$ and minimal stray inductance. The IAUZN04S7N032 offers high power density, low conduction losses, and optimized switching behavior, with a reduced form factor compared to traditional leaded packages, which makes it ideal for automotive applications such as power distribution, body control modules, and electric motors.

For more information about the product, see https://www.infineon.com/cms/en/product/promopages/new-optimos-7-technology/.

3.2.4 Infineon Schottky diodes

BAS3010B-03W and BAS70-02L are used within the reverse polarity circuit. The selection of Infineon Schottky diodes are silicon low-barrier N-type devices and are available in various junction diode configurations. The low forward voltage drop and high forward current handling (up to 3 A) makes the Schottky diodes ideal for creating reverse polarity protection, as well as clipping and clamping circuits. More info on diodes can be found here https://www.infineon.com/cms/en/product/small-signal-transistors-diodes/diode/schottky-diodes/.

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4 System design

Related Links

General component selection on page 10
Input filter and reverse polarity protection circuit on page 11
Motor control - MOTIX™ MCU TLE9954EQW40 on page 13
Power stage on page 17
Measurement circuits on page 20

General component selection

General component selection is based on the AEC-Q100 qualification, maximum and minimum temperature rating and voltage rating.

Since the REF_COMFORT_APP_BLDC is designed for automotive applications, the AEC-Q100 qualified components are selected. Whenever possible, the components with maximum and minimum temperature rating of 150°C and -40°C respectively are selected. Due to unavailability and/or high cost, certain components selected have the maximum temperature rating of 125°C.

All the selected components are sized to the appropriate voltage rating, with consideration to heat dissipation. Certain components, such as capacitors, are derated by at least 25% due to unexpected voltage spikes in the system.

The FR 4-layer board has been designed with all the components connected on top side.

The bottom side of the board exhibits tests points for every node on the board. These test points can be used to perform in-circuit testing (ICT).

Table 4 provides an overview of the top and bottom view of the PCB.

4.1 General component selection

General component selection is based on the AEC-Q100 qualification, maximum and minimum temperature rating, and voltage rating.

Since the REF_COMFORT_APP_BLDC is designed for automotive applications, the AEC-Q100 qualified components are selected. Whenever possible, the components with maximum and minimum temperature rating of 150°C and -40°C respectively are selected. Due to unavailability and/or high cost, certain components selected have the maximum temperature rating of 125°C.

All the selected components are sized to the appropriate voltage rating, with consideration to heat dissipation. Certain components, such as the capacitors, are derated by at least 25% due to unexpected voltage spikes in the system.

The FR4 4-layer board has been designed with all the components connected on the top side.

The bottom side of the board exhibits test points for every node on the board. These test points can be used to perform in-circuit testing (ICT).

Table 4 provides an overview of the top and bottom view of the *PCB*.

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Table 4 Top and bottom view of the reference design

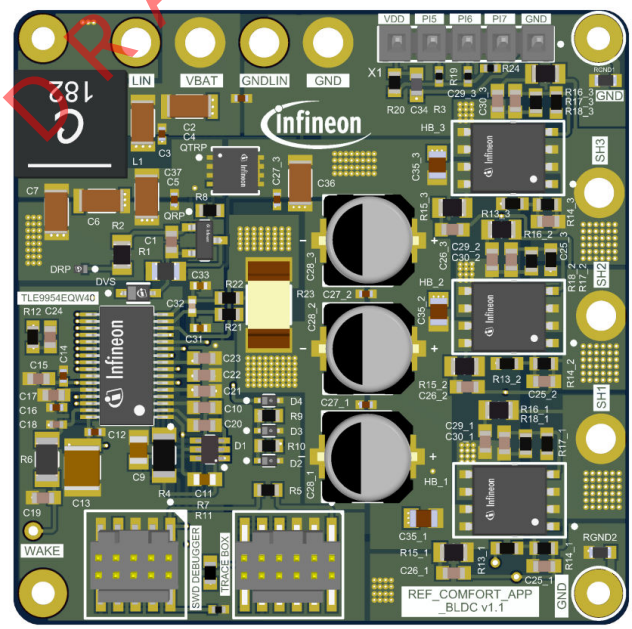


Figure 3 Top view

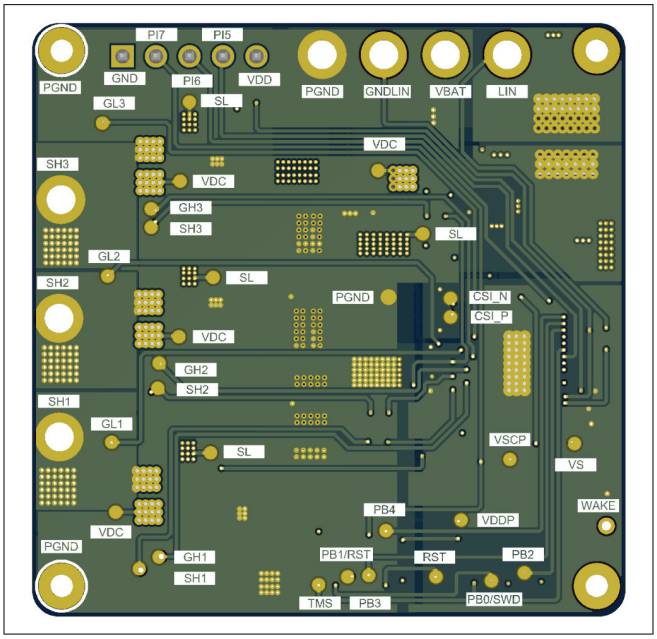


Figure 4 Bottom view

The following chapters offer an overview on component selection of different main blocks of the design.

4.2 Input filter and reverse polarity protection circuit

Figure 5 shows an overview of the input filter and the reverse polarity protection circuit.

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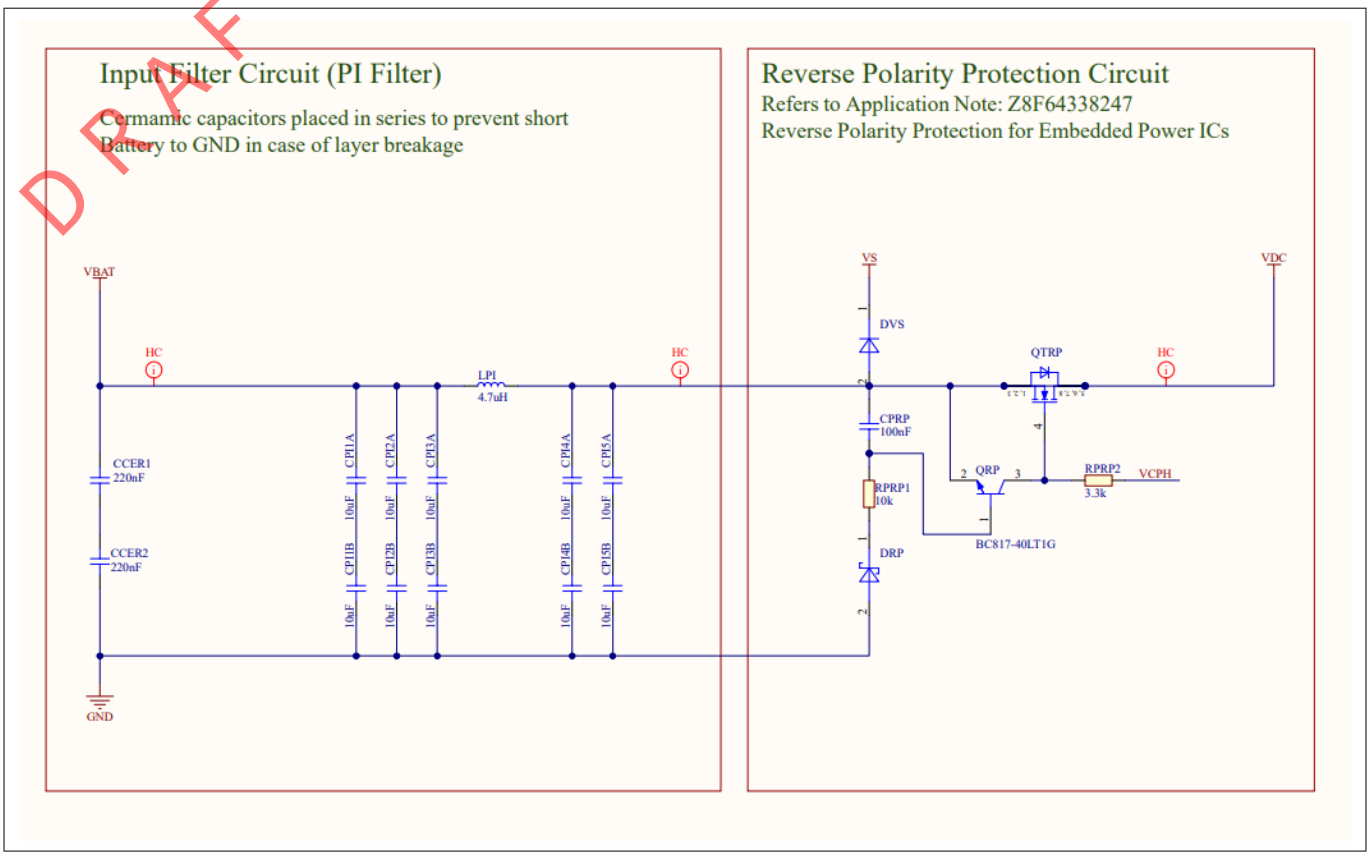


Figure 5 Input filter and reverse polarity protection circuit

The following chapters provide a deeper insight into the component selection of the input filter and the reverse polarity protection circuit.

Related links

Input filter on page 11
Reverse polarity protection circuit on page 12

4.2.1 Input filter

The input filter is in a *BLDC* motor control application to suppress the noise that is generated from the MOSFET switching. In the REF_COMFORT_APP_BLDC , the input filter is implemented in the form of a PI filter. The PI filter is composed of multiple ceramic capacitors around a power inductor to attenuate the noise from the power stage due to the switching of the MOSFETs.

Along with the PI filter, additional capacitor C8 is placed in between *battery voltage supply (VBAT)* and *ground (GND)* terminals to filter high frequency noise.

Below is the component selection of the PI filter:

The calculation of the PI filter was done based on the cut-off frequency of 20 kHz.

$$L \times C = \frac{1}{4 \times \pi^2 \times f_c^2} = \frac{1}{4 \times \pi^2 \times 20\ \text{kHz}^2} = 6.34\ \mu H \times \mu F$$

Assuming 6 capacitors of equal value (CPI1 = CPI2 = CPI3 = CPI4 = CPI5 = CPI6 = y), the total capacitance, C = 6y. Therefore,

$$L \times 6y = 6.34\ \mu H \times \mu F$$

Selecting an available inductor value of L = 4.7 uH, the value of capacitors can be calculated.

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$$y = \frac{6.34\ \mu H \times \mu F}{4.7\ \mu H \times 6} \approx 10\ \mu F$$

Given the DC-link capacitors on the right side of the inductor, the sixth capacitor in the PI filter is not required. Therefore, the PI filter consists of five ceramic capacitors, CPI1-5, with inductor, LP1. Figure 6 shows the PI filter location on the REF_COMFORT_APP_BLDC along with the component placement.

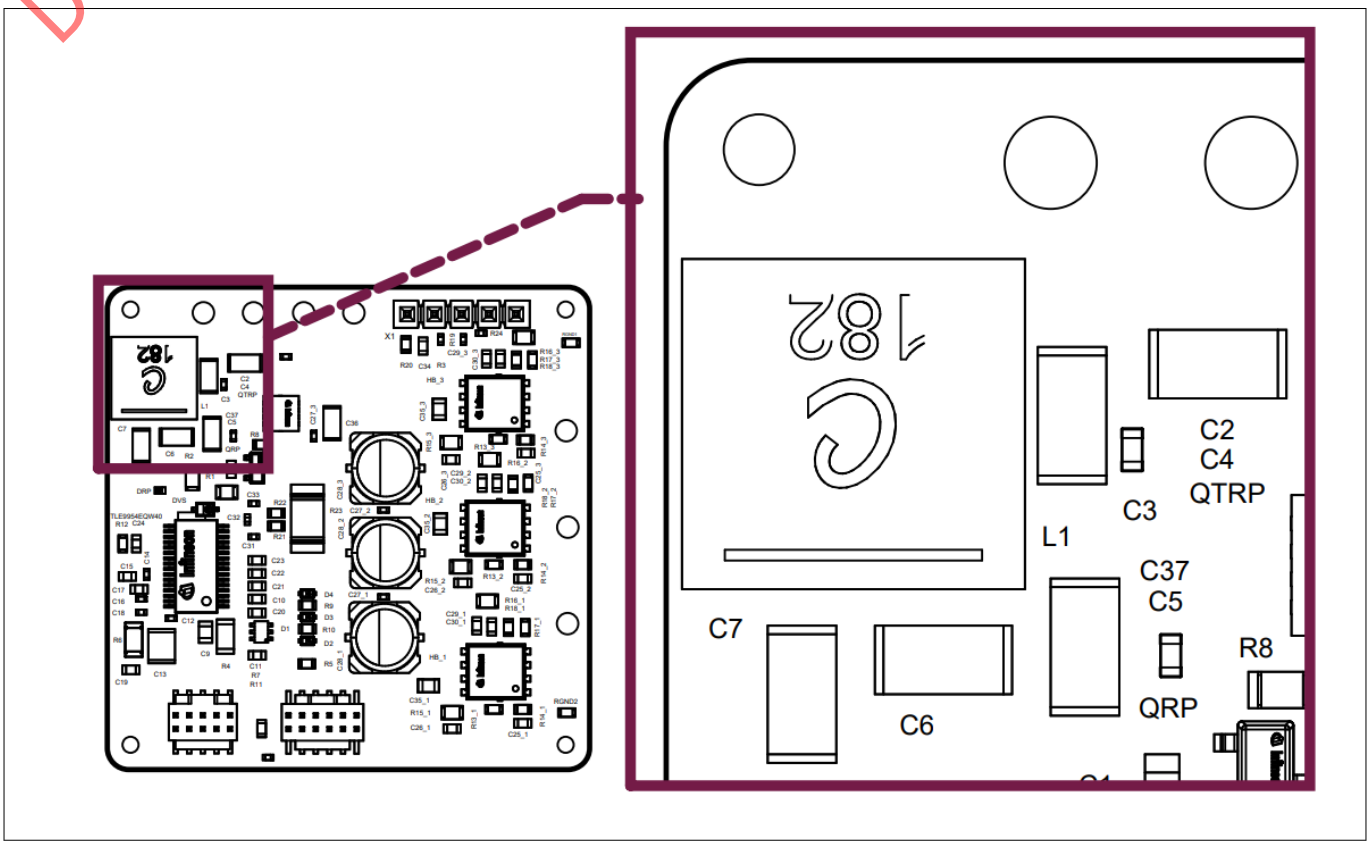


Figure 6 Input filter circuit on REF_COMFORT_APP_BLDC

4.2.2 Reverse polarity protection circuit

If the cables connected to the battery terminals are swapped accidentally, for example during care maintenance, the resulting negative voltage could damage all the connected electrical units. In order to avoid failure due to reversal in battery polarity, the reverse polarity protection circuit plays a precautionary role.

There are several methods of implementing reverse polarity protection. REF_COMFORT_APP_BLDC uses N-channel MOSFET with the help of the charge pump voltage generated by MOTIX™ MCU TLE9954EQW40 to create the reverse polarity protection circuit.

A detailed description of the implementation is in the application note Reverse Polarity Protection for Embedded Power ICs.

Figure 7 shows the location of the reverse polarity protection circuit on the REF_COMFORT_APP_BLDC, along with the components used for the implementation.

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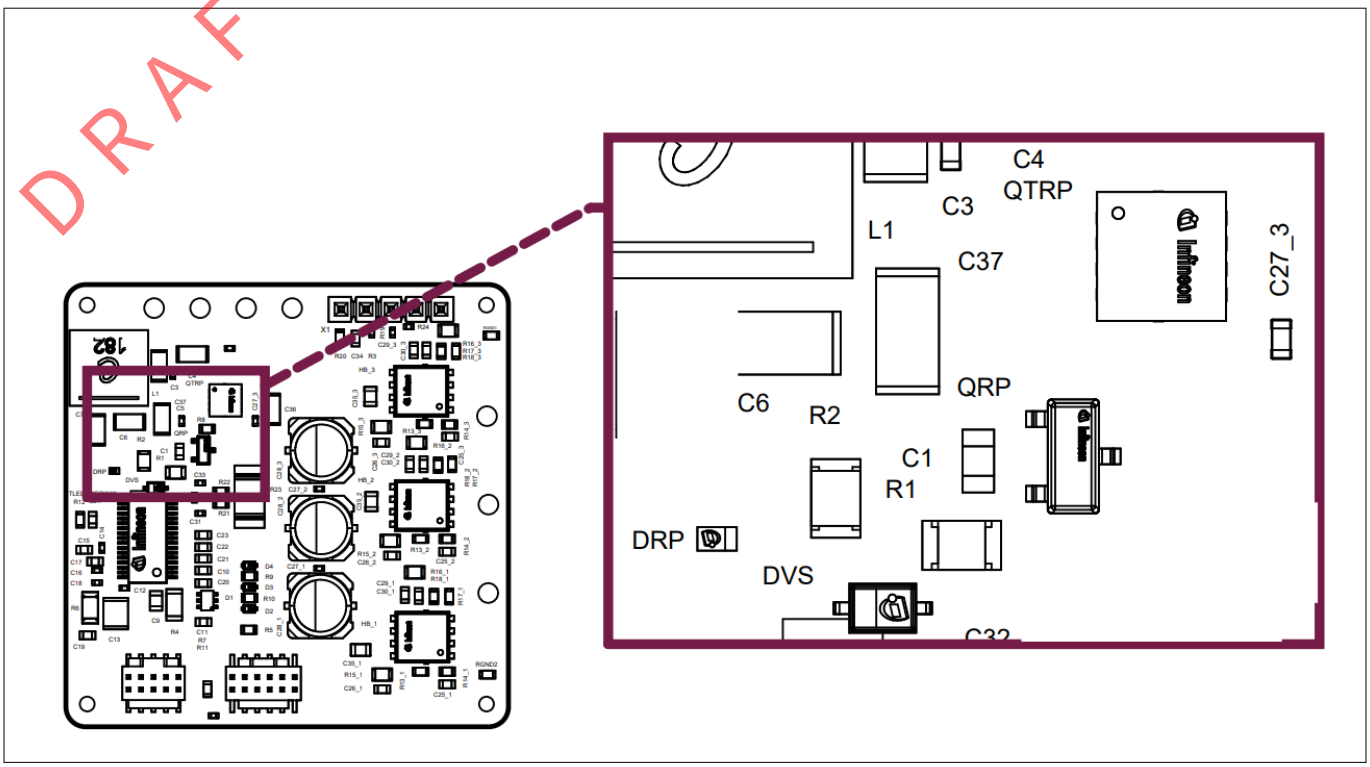


Figure 7 Reverse polarity protection circuit on REF_COMFORT_APP_BLDC

4.3 Motor control - MOTIX™ MCU TLE9954EQW40

Figure 8 shows the interfaces and the external components around the TLE9954EQW40, to enable motor control.

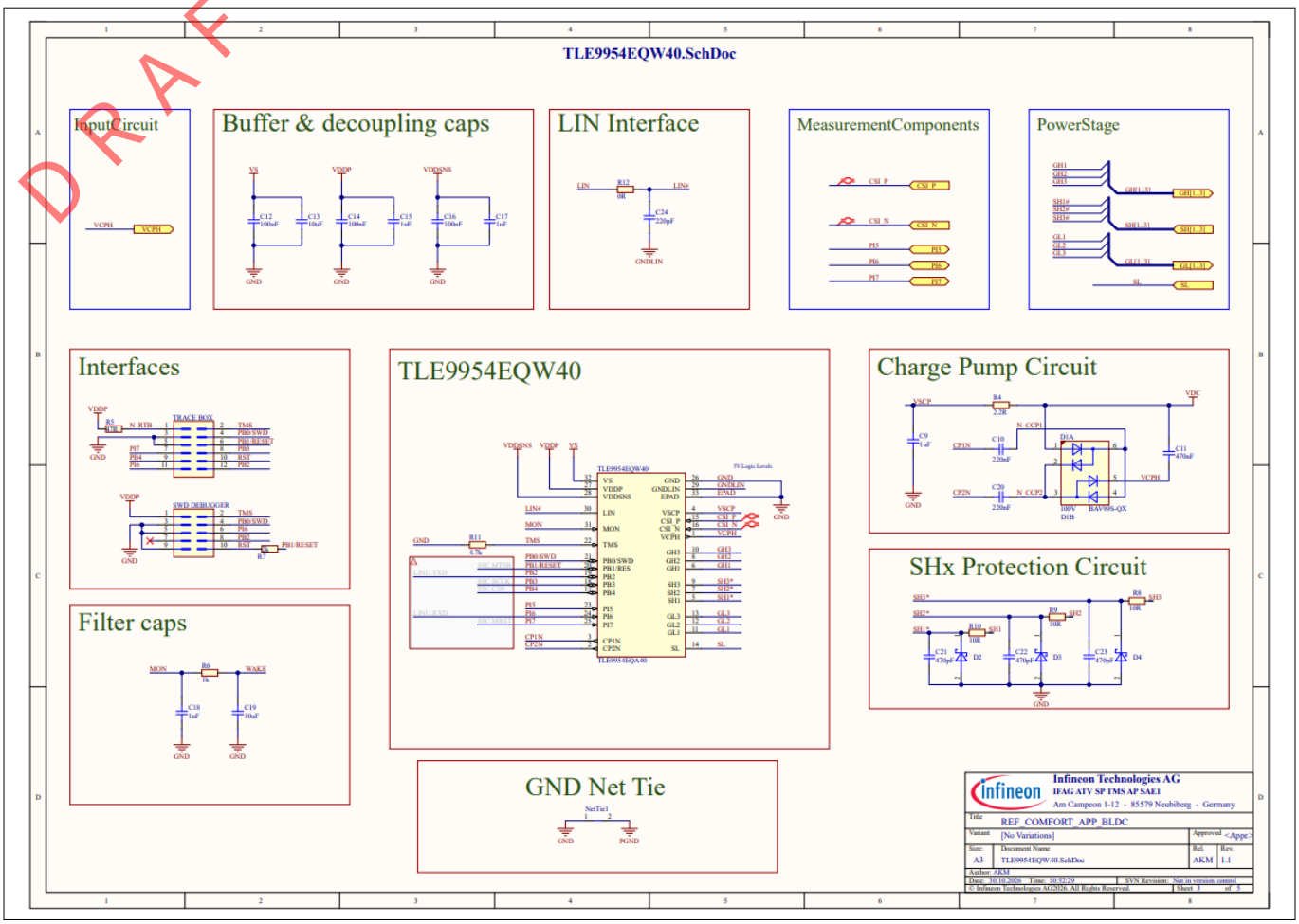


Figure 8 Interfaces and external components for MOTIX™ MCU

Related links

- Interfaces - Debug and Test on page 14
- External components for MOTIX™ MCU TLE9954EQW40 on page 16

4.3.1 Interfaces - Debug and Test

In order to access the debug interface of the microcontroller, the REF_COMFORT_APP_BLDC provides 10-pin *serial wire debug (SWD)* and 12-pin Tracebox interfaces. The 10-pin SWD interface can be used to connect to the device in debug mode. The 12-pin Tracebox connector enables debug connection along with the possibility to stream software variables via *serial peripheral interface (SPI)* to visualize the software variables via Tracebox in real time. For more details on Tracebox, see https://www.infineon.com/cms/en/product/evaluation-boards/moteon-tracebox/.

Figure 9 shows the location of the two debug interfaces.

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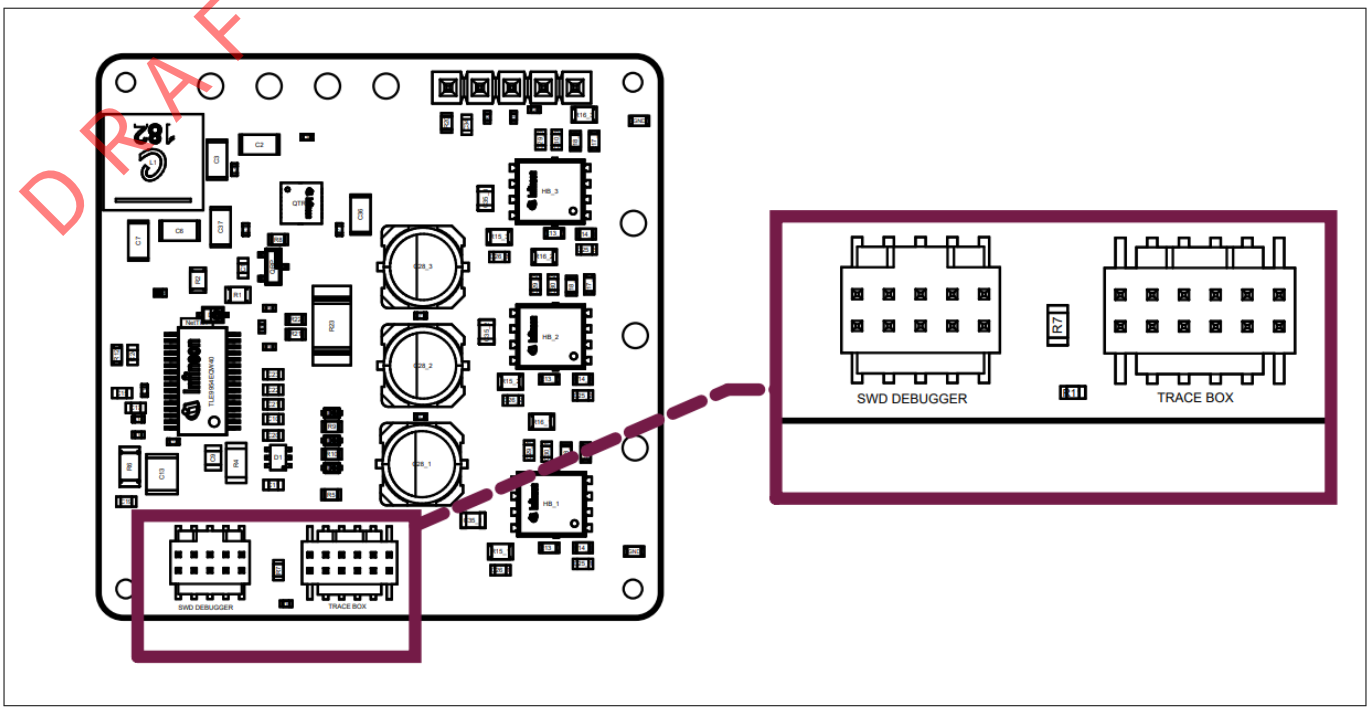


Figure 9 Debug connectors

Additionally, every net is connected to a dedicated test point on the bottom side of the board. 0. Figure 10 provides an overview of the test points and the footprint of the pin header mentioned.

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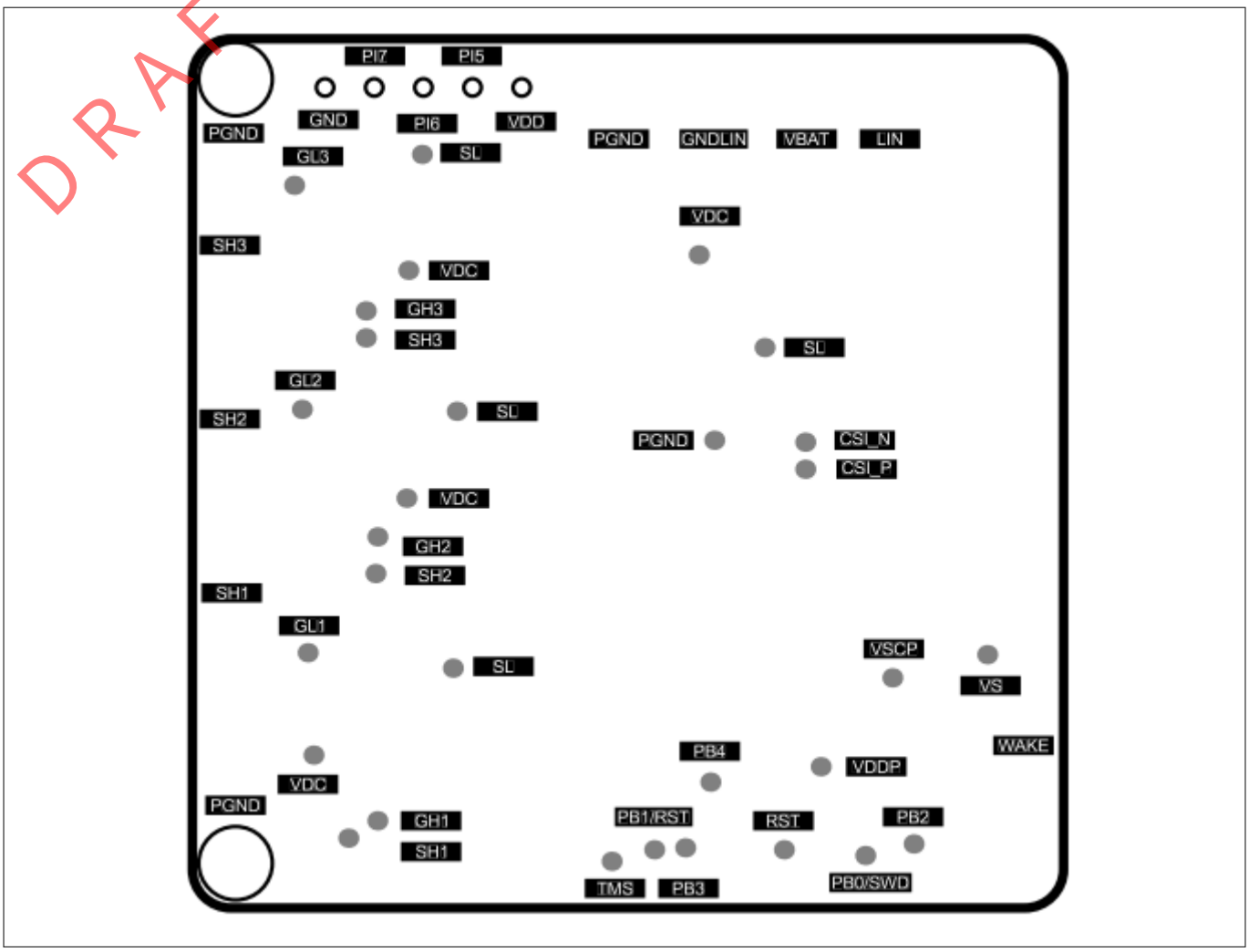


Figure 10 Test points and pin header on the bottom side of the board

4.3.2 External components for MOTIX™ MCU TLE9954EQW40

All the external components should be placed as close as possible to the relevant pins of the TLE9954EQW40 to maximize effectiveness.

The component selection, for all the components surrounding the TLE9954EQW40, is based on the 'TLE994x/5x hardware design guideline'.

Related links

- Decoupling and filter capacitors on page 16
- Charge pump and SHx circuit on page 16

4.3.2.1 Decoupling and filter capacitors

As seen in Figure 1, several buffer and decoupling capacitors are connected to input voltage (VS) and voltage regulators (VDDP and VDDSNS) output of TLE9954EQW40 to stabilize the voltage input and output respectively.

A filter circuit is placed, at the high voltage monitor pin (MON) and LIN pin, to suppress noise. The LIN ground must be kept as standalone as possible to avoid coupling noise from the LIN ground to the digital ground of the device.

The placement of the decoupling and filter components on the REF_COMFORT_APP_BLDC is shown in Figure 11

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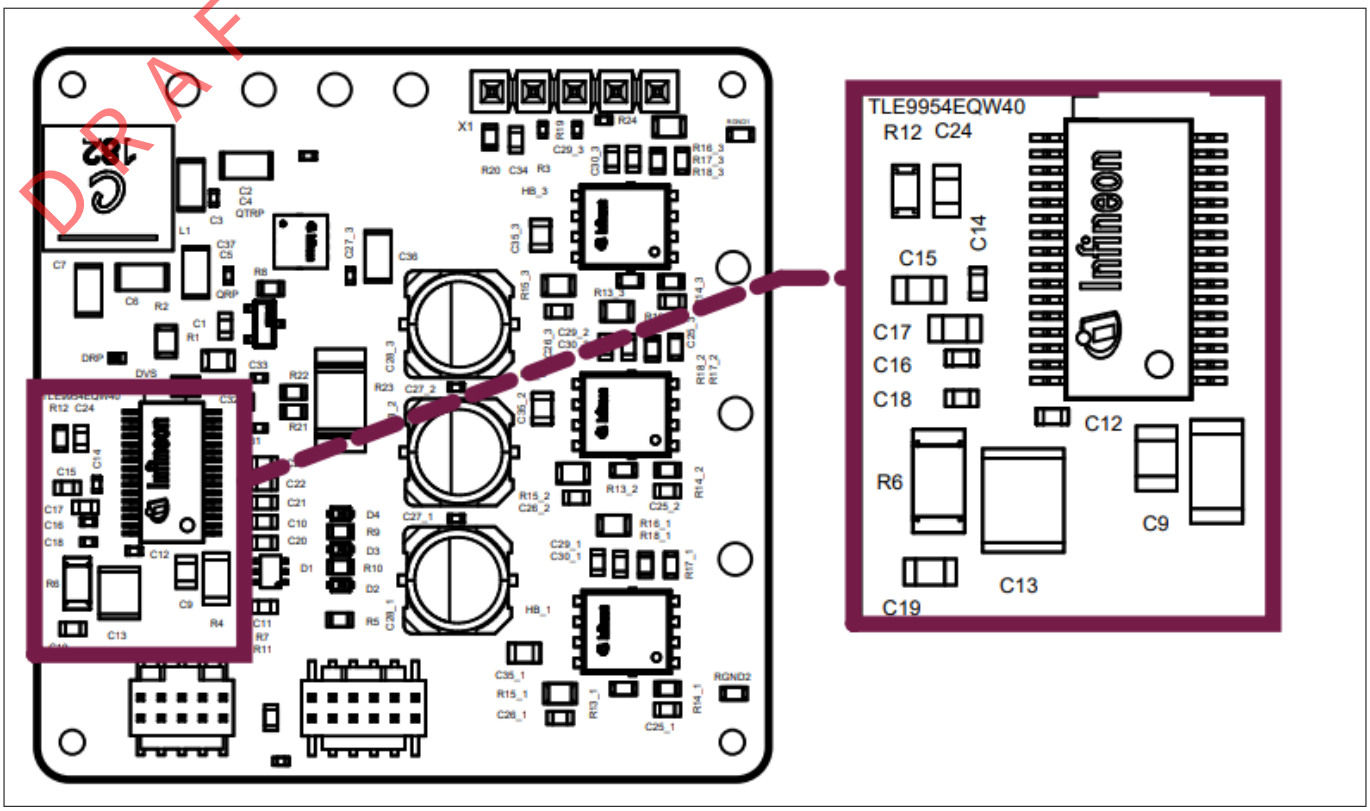


Figure 11 Decoupling and filter capacitors for TLE995x

4.3.2.2 Charge pump and SHx circuit

An external circuit is used to regulate the charge pump voltage. The capacitors at the SHx pin are used to filter the high frequency noise on the pins. Diodes at the SHx pins are not populated by default. However, it is possible to place them to protect the pin from negative voltage spikes, which is done by clamping the pin. Figure 12 shows the charge pump regulation circuit on the left, and the SHx capacitors with the diode placement options on the top right of the zoomed-in part.

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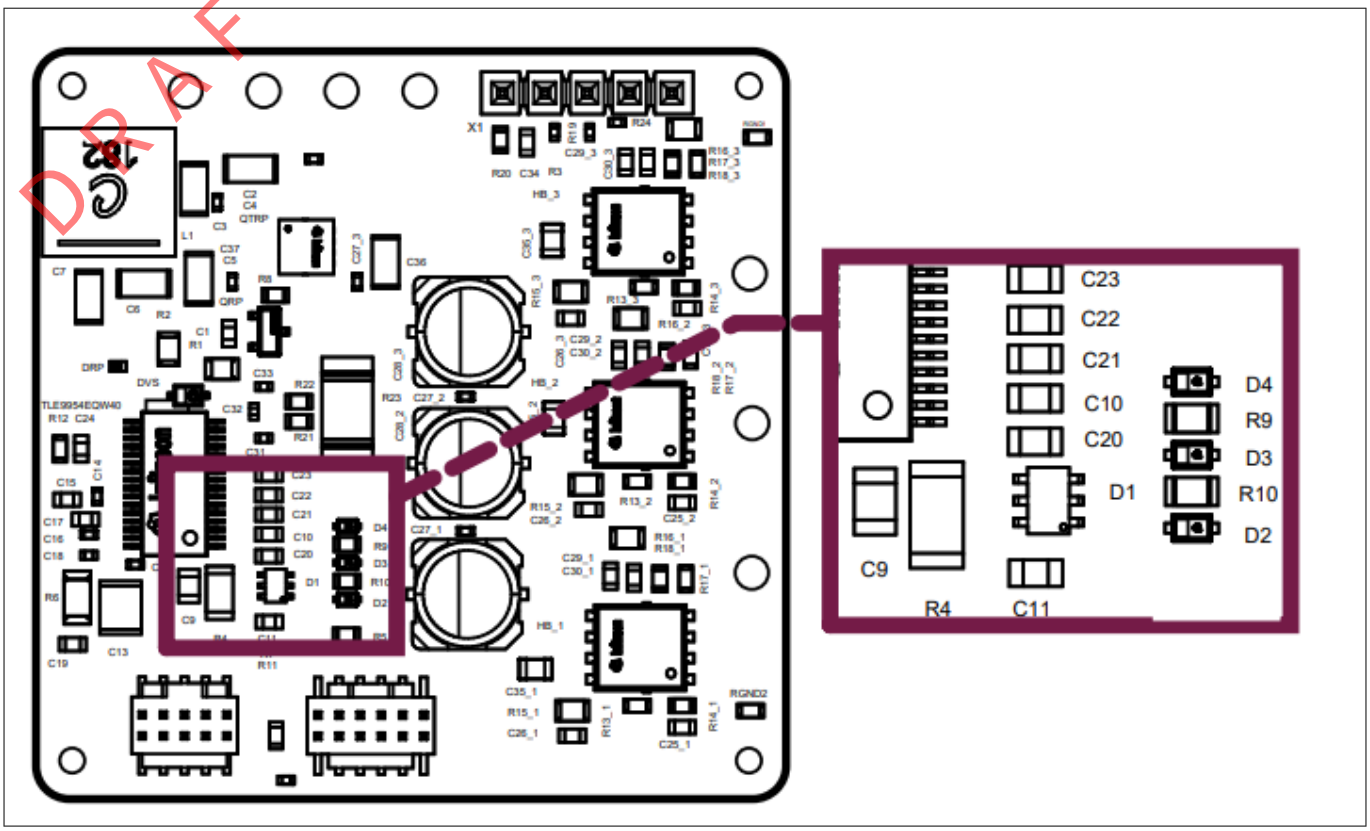


Figure 12 Charge pump circuit and SHx circuit on REF_COMFORT_APP_BLDC

4.4 Power stage

Figure 13 shows the power stage implementation for one half-bridge circuit. All the components of the power stage should be placed as close as possible to the MOSFET. Ensure that the traces from the gate driver, through the gate resistor (if present), to the gate of the MOSFET is as short as possible.

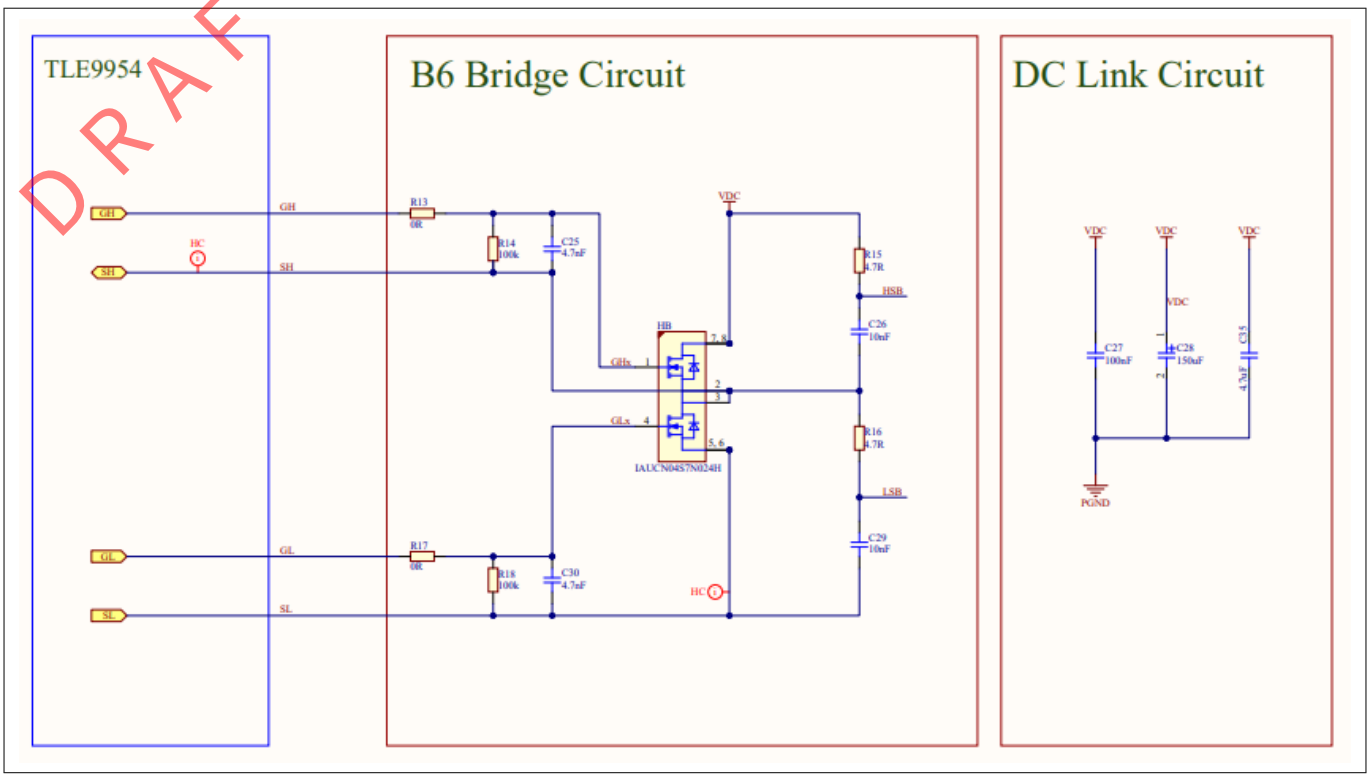


Figure 13 Power stage circuit

As seen in Figure 13, the gate capacitance and snubbers are not populated in the circuit due to adequate performance. However, the option to place them is provided.

Figure 14 zooms in on half-bridge 1 by highlighting the related components.

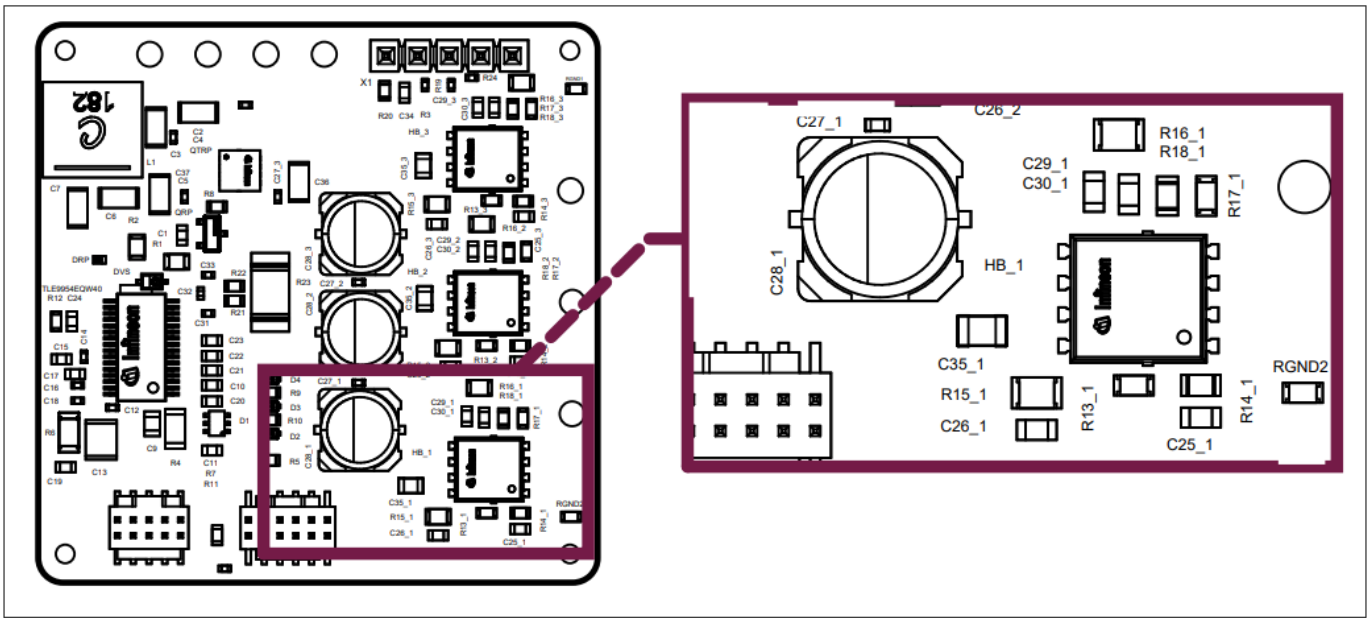


Figure 14 Half-bridge 1 on REF_COMFORT_APP_BLDC

Figure 15 zooms in on the power stage consisting of all three half-bridges. The three squares on the right, at the edge of the board, highlight the phase connectors to phases 3, 2, 1 from top to bottom.

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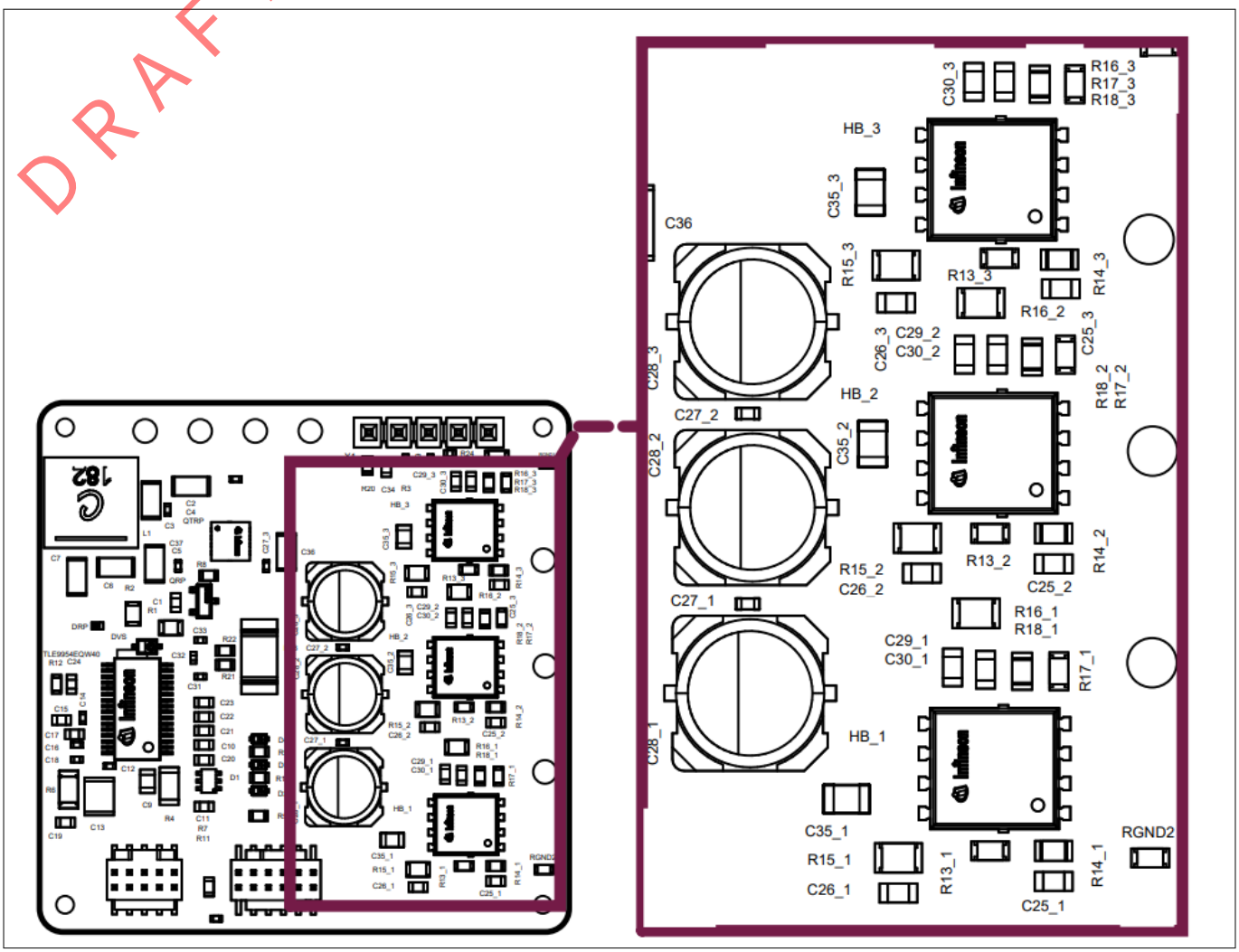


Figure 15 Power stage on REF_COMFORT_APP_BLDC

Related links

- DC-link capacitor sizing on page 19
- Snubbers on page 20
- External components for half-bridge MOSFETs on page 20

4.4.1 DC-link capacitor sizing

The value of the DC-link capacitors depends on the *pulse-width modulation (PWM)* frequency and current used to control the *BLDC* motor. The switching of the MOSFETs generates a voltage ripple on the motor supply, resulting in RMS current in DC-link capacitors.

Assuming a permanent-magnet AC machine (with near unity power factor), the worst-case current stress estimation with the output current ($I_{out,\,rms}$) is given by:

$$I_{C,rms} \approx {}^{1}\!/\!_{\sqrt{2}} \cdot I_{Out,rms} \cdot$$

Targeting the peak-to-peak voltage ripple (V_{ripple}) of the capacitor within 1 V, at 18 A_{rms} output current ($I_{out,\,rms}$) the required capacitance is given by:

$$C_{DC-link} = I_{C,rms} \times \frac{1}{f_{PWM} \cdot V_{ripple}} = \frac{1}{\sqrt{2}} \times 18A \times \frac{1}{20kHz} = 636\mu F$$

Therefore, in this design, a 220 µF electrolytic capacitor is used for each leg of the bridge, for a total of 660 µF.

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Three ceramic capacitors of 220 nF are used to suppress high frequency noise.

4.4.2 Snubbers

As shown in Figure 1, a RC snubber between the drain and source of the low-side MOSFET can be used to suppress voltage transients at the motor terminals. However, they are not populated on the reference design due to adequate performance. Snubbers must not be placed if the rotor position detection depends on the BEMF signal processing, because the RC circuit slows detection of the BEMF signal.

The following chapter shows that the *electromagnetic compatibility (EMC)* performance of CISPR class 5 can be achieved without the snubbers. However, the option to place the snubbers is provided.

4.4.3 External components for half-bridge MOSFETs

External resistors, R_{gs}, are placed between the gate and source of both high- and low-side MOSFETs. This resistor functions as a pull down resistor that reduces the probability of false turn ON of the MOSFET.

With reference to Figure 1, note that gate resistors, $R_{GH/GL}$ of 0 Ω are placed. This resistor can be eliminated, and the gate driver signals from the TLE9954EQW40 can be directly routed to the gate of the MOSFET to enable operation. However, an option to populate the resistor with other resistance values is provided by populating a 0 Ω placeholder. Additionally, gate-source capacitors, $C_{GSH/GSL}$ are not placed to reduce the number of components.

4.5 Measurement circuits

Figure 16 shows the two measurement components used in the REF_COMFORT_APP_BLDC. On the left is the shunt measurement circuit, and on the right is the hall sensor interface.

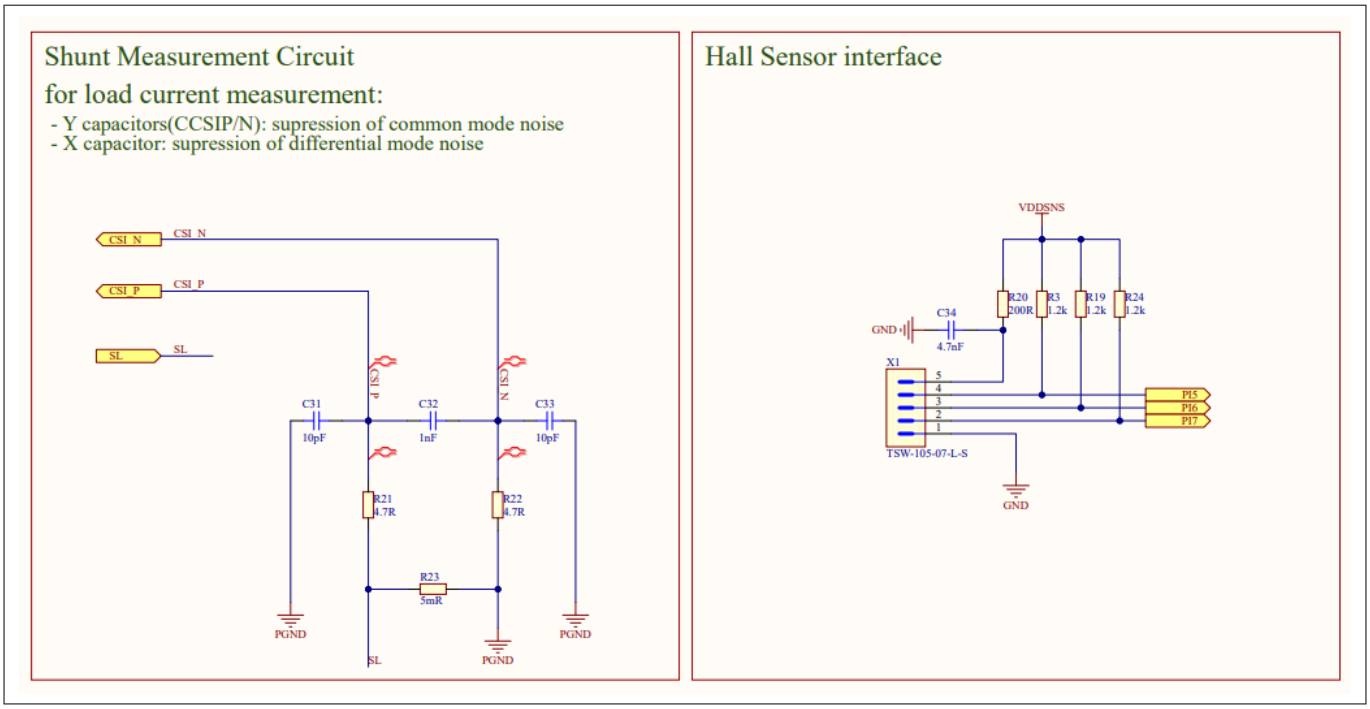


Figure 16 Measurement components

Related links

- Shunt measurement circuit on page 21
- Shunt resistor selection on page 21
- Hall Sensor interface on page 22

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4.5.1 Shunt measurement circuit

The shunt measurement circuit consists of a shunt resistor to measure the current flowing through the power stage. A RC filter circuit is used to filter out measurement noise and must be placed close the shunt resistor. Figure 17 shows the location of the shunt resistor and the RC filter on the REF_COMFORT_APP_BLDC .

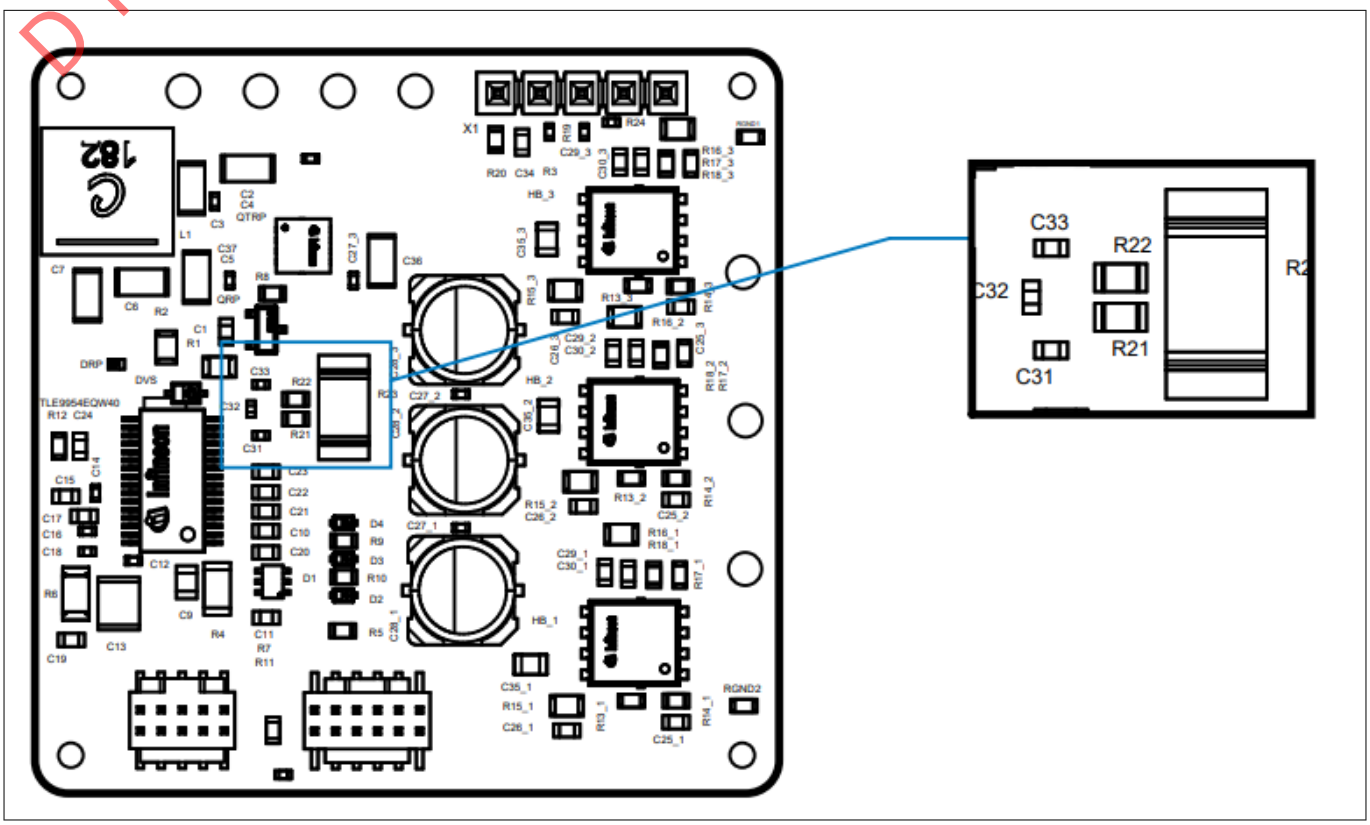


Figure 17 Shunt resistor and RC filter on REF_COMFORT_APP_BLDC

4.5.2 Shunt resistor selection

When selecting a shunt resistor, several parameters must be considered:

- Resistance
- Tolerance
- Stray inductance
- Temperature coefficient
- Wattage
- Derating
- Form factor
- Environmental robustness

The voltage measured by the *current-sense amplifier (CSA)* is described by the following equation:

$$V_{CSA} = V_{CSA_OFF} + Gain \times R_{shunt} \times I_{motor}$$

The maximum and minimum possible values of the shunt resistor were calculated to determine the value of the shunt resistor.

The maximum possible value of shunt resistor is dictated by the limited linear input range of the current sense amplifier. The maximum motor current is shown by the equation below:

$$R_{shunt(max)} = \frac{V_{CSA(max)} - V_{CSA_OFF}}{Gain_{CSA} \times I_{motor(max)}}$$

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Based on the design specification, $I_{motor(max)}$ = 20 A.

The current sense amplifier in the TLE9954EQW40 offers various gain settings to amplify the measured voltage, enabling current measurement over a wider range. These gain settings are as follows G = {11.34, 14.65, 20.65, 25.1, 35.1, 50.1}.

Calculating for maximum and minimum gain settings, we have the following results:

$$R_{shunt(max)} = \frac{3.5V - 0.5V}{\{11.34, 50.1\} \times 20A} = \{13m\Omega, 2.9m\Omega\}$$

With the lowest gain setting, the maximum value of the shunt resistor results in 13 mΩ. Whereas, with the highest gain setting, the maximum value of shunt resistor results in 2.9 mΩ.

The minimum possible value of the shunt resistor depends on the ADC12 resolution. The resolution of ADC12 plays a key role in measuring the smallest change in current possible.

$$V_{LSB} = \frac{4.04V}{2^{12} - 1} = 0.99mV$$

Hence,

$$R_{shunt(min)} = \frac{V_{LSB}}{Gain \times \Delta I_{min}} = \frac{0.99mV}{\{11.31, 50.1\} \times 30mA} = \{2.9m\Omega, 0.66m\Omega\}$$

With the lowest gain setting, the minimum value of the shunt resistor results in 2.9 mΩ. Whereas, with the highest gain setting, the minimum value of shunt resistor results in 0.66 mΩ.

Therefore, taking the lowest minimum value and the highest maximum value of the shunt resistor while considering variable gain settings, the optimal range for shunt resistor values is defined below:

$$R_{shunt(min)} < R_{shunt} < R_{shunt(max)}$$

$$0.66m\Omega < R_{shunt} < 13m\Omega$$

Higher shunt resistance results in higher losses through the shunt resistor, however lower resistance values affect the accuracy of the measurement. Therefore, considering the availability of the shunt resistance values, shunt resistance of 5 mΩ is selected to strike a balance between the two extremes.

Power dissipation of the shunt resistor makes up a huge portion of the overall power consumption. A shunt resistor of 2.5 W/5 mΩ is selected for the reference design. Considering the power derating down to 15% of 2.5 W at 155°C, the maximum power of the shunt resistor at 155°C is 0.375 W. According to the resistor specification, the resistance is expected to rise by 50 ppm/K, giving a total shunt resistance equal to ((155-25)°C x 50 ppm/K =) 5.0065 mΩ. Therefore, the power dissipation at 12 A_{rms} current is: (12 A)^2 x 5.0065 mΩ = 0.721 W.

Low switching losses, low *electromagnetic interference (EMI)* noise, and stable MOSFET switching can be ensured if the DC-link loop inductance is as low as possible. Therefore, the lower the stray inductance of the shunt resistor, the better the performance for high-speed switching applications. Combining all the design features, such as low-inductance shunt, small DC-link layout loop, and close placement of the DC-link ceramic capacitor, the stray inductance of the DC-link loop was measured to be 0.32 µH at 10 kHz with test level 0.1 V_{rms}.

4.5.3 Hall Sensor interface

The Hall sensor interface circuit consists of three signal conditioning resistors , one for each Hall channel, to ensure stable and robust Hall signal levels. An RC filter is used on the Hall sensor supply to reduce noise coupling from the power stage and improve measurement reliability. The filter components should be placed close to the Hall connector/interface entry point. Figure 18 shows the placement of the hall sensor interface.

4 System design

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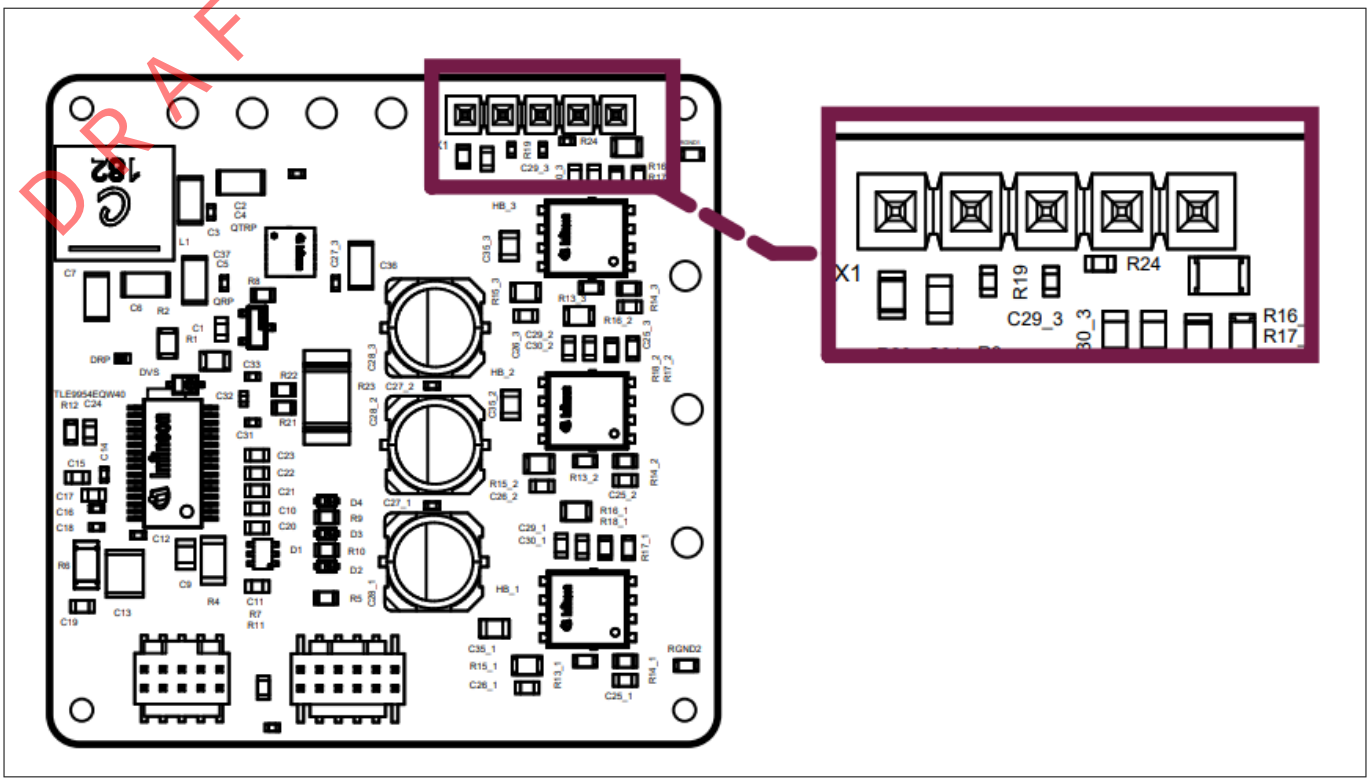


Figure 18 Hall sensor interface circuit on REF_COMFORT_APP_BLDC

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5 Placement and layout

The placement of the components on the reference design is constrained by the 45 x 45 mm board size to optimize space utilization As seen in , the placement of the components on the board is dictated by the phase connectors of the motor.

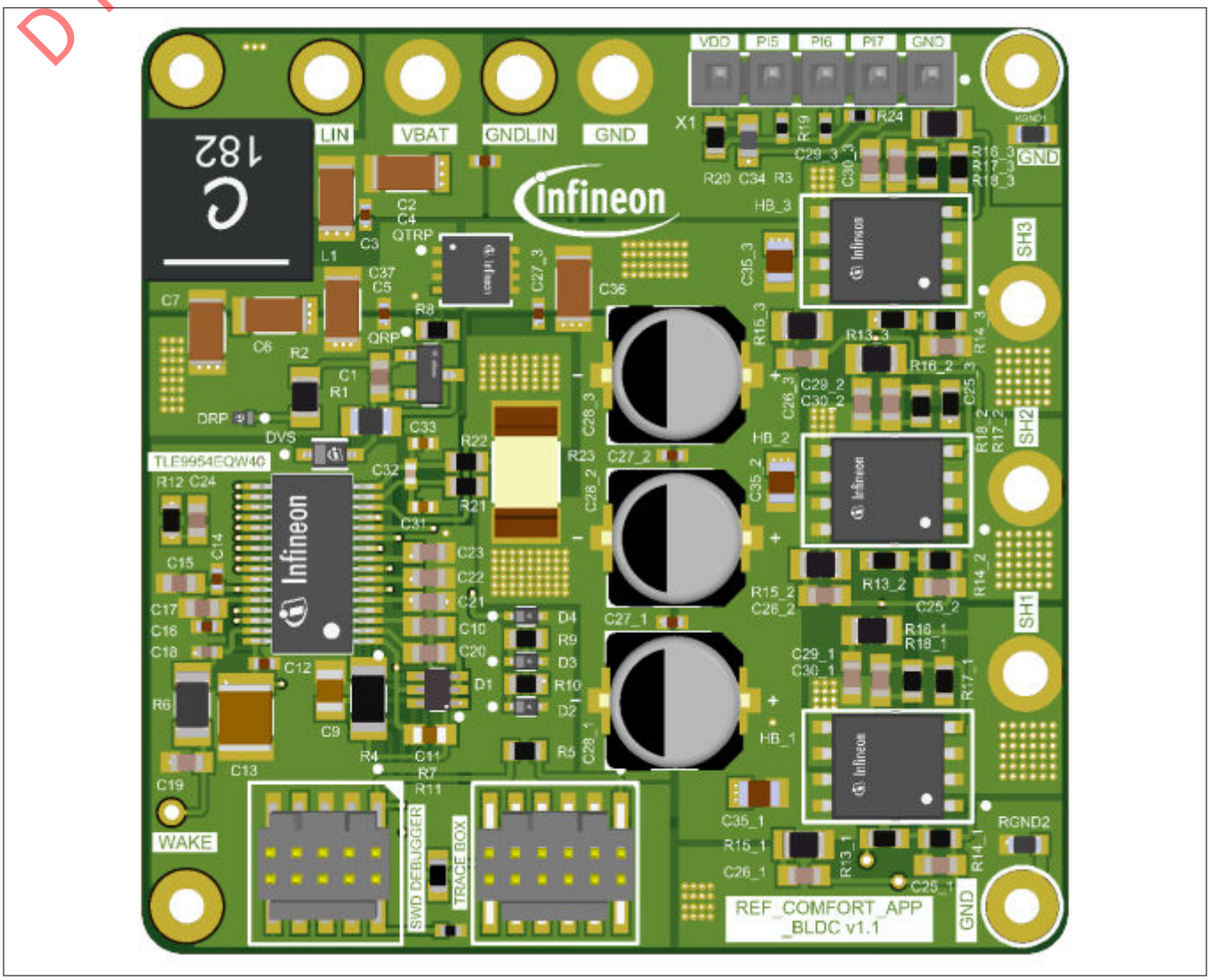


Figure 19 REF_COMFORT_APP_BLDC

Related links

- Component placement on page 25
- Layout and current flow on page 25

5.1 Component placement

With reference to Figure 1, the motor phase connectors (phases 1, 2 and 3) are placed at the location of circle pads on the right side of the *PCB* respectively. Therefore, the MOSFETs are placed as close as possible to the phase connectors to ensure the shortest current path. As mentioned in the previous chapter, the DC-link capacitors (electrolytic and ceramic) including the external MOSFET components must be placed as close to the MOSFETs are possible to ensure optimal performance.

The connection to the battery terminal is found on the top of the reference design. Therefore, the PI filter is placed close to the battery connector pad to ensure that all of the noise generated through MOSFET switching passes to the PI filter before exiting through the *GND* of the battery.

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The shunt resistor is placed in close proximity to the power stage to ensure small current loops. In theory, the shunt should be positioned symmetrically with respect to all phases. However, due to the geometry and space constraints, the best compromise was chosen.

After having populated the power stage, PI filter, and shunt circuits, the microcontroller circuit was placed. All the buffer and decoupling caps are placed as close to the pins of the microcontroller as possible to ensure optimized performance. SWD debug connector and Tracebox debug connector are placed at the bottom of the board for easy accessibility. Refer to Figure 1 for reference.

5.2 Layout and current flow

Thermal and *EMC* performance of the reference design is dependent on the current flow in the *PCB*. Therefore, the following aspects have been taken into account:

- Separate digital and analog supply and ground to avoid noise coupling
- Keep current loops small to reduce stray inductance
- Avoid thermal choke points

In the reference design, the current is intended to flow from the battery terminal to reverse polarity protection MOSFET through the PI filter capacitors and inductors to the DC-link caps and the high-sides of all three half-bridges.

If the high-side switches of phase 1 and phase 2 and the low-side switch of phase 3 are turned ON, the current flows from the supply line to phase 1 and phase 2 and then back out to the supply via phase 3. This is the configuration that is visualized in the two figures below.

Table 5 Current flow to/from the motor & microcontroller

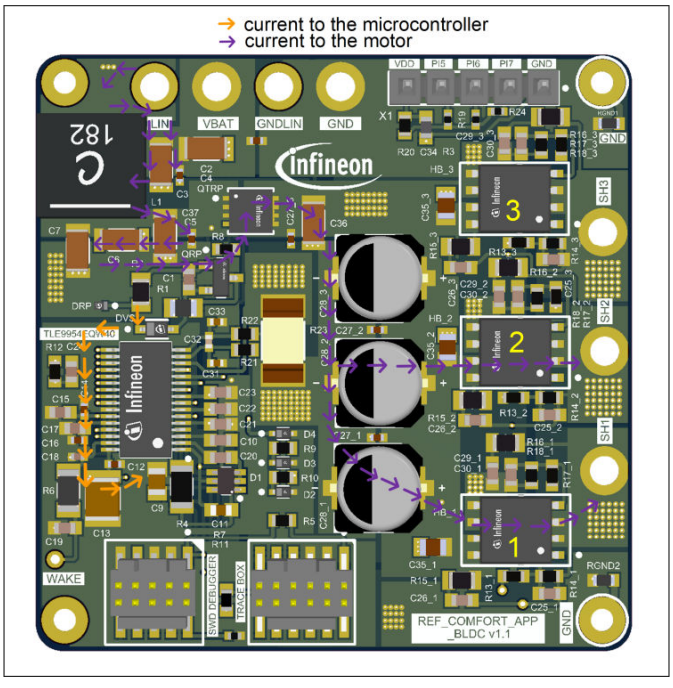


Figure 20 Current flow in to the motor & microcontroller

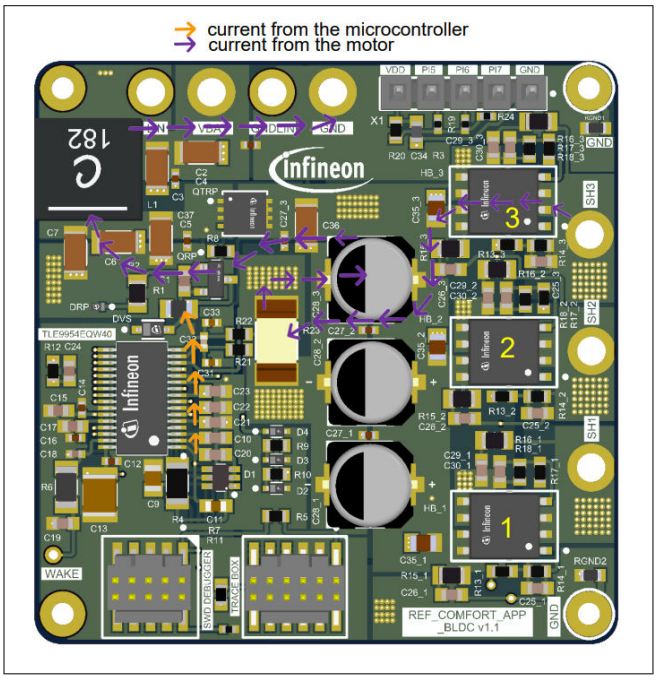


Figure 21 Current flow out from the motor & microcontroller

The current to the motor primarily flows through the top layer of the PCB. However, the return current flows through the second layer below the top layer. Through stitching from the top layer to the layer below, the return current is allowed to flow directly to the shunt resistor.

5 Placement and layout

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The current then passes through the shunt resistor and via the PI filter to return to the negative terminal of the battery connector. The return current must flow back through the DC-link capacitors and the output filtering capacitors of the PI filter to remove any common-mode noise that could be coupled back on the supply line over input capacitors of the PI filter.

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6 System performance

The following chapter details the analysis of the performance and characteristics of the reference design. The test was conducted by attaching the water pump to the an emulated water circuit with a water tank setup. For all the tests performed, the test setup, conditions, and results were documented.

The default test configuration is assumed to be the following, unless mentioned otherwise:

- Electrical power = ~ 150 W
- Battery voltage = 13 V
- Nominal speed = 3600 rpm

Related Links

- System test setup on page 27
- MOSFET switching characteristics on page 30
- Thermal behavior on page 33
- EMC on page 36

6.1 System test setup

The reference design, REF_COMFORT_APP_BLDC, drives an automotive *BLDC* motor. The motor is directly connected to a comfort application system constituting of different mechanical linkages and actuators. The system is configured to emulate the load of an automotive comfort application cycle.

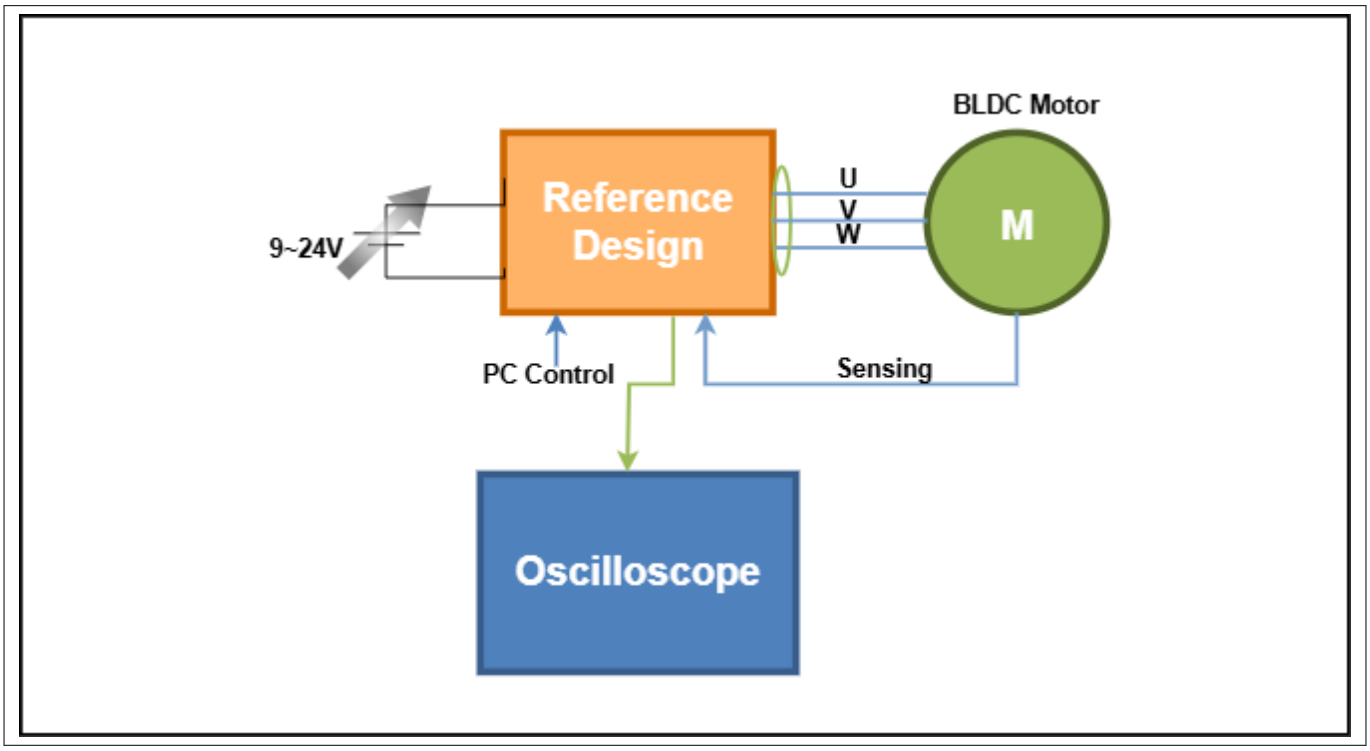


Figure 22 Test setup block diagram

Related links

- Gate Driver Setup on page 27
- Field Oriented Control (FOC) Setup on page 28

6.1.1 Gate Driver Setup

The bridge driver of the TLE995x offers several protection mechanisms such as:

- Programmable cross current protection time

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- Shoot-through protection
- Safe switch-OFF in case of faults
- Adjustable short-circuit detection in ON and OFF state

The bridge driver is capable of driving the output stages with a programmable gate current profile. It is possible to configure the gate driver charging profile with the help of gate current sequencer. The sequencer can be configured for active high- and low-side MOSFETs to fine tune the switching behavior of the MOSFET. For more information on the various settings and configurations, refer to the MOTIX™ TLE994x/5x user manual.

Figure 23 shows the bridge driver configuration in Device Configurator tuned for the particular application. The MOSFETs were configured to a switching speed of approximately 200 ns, while ensuring minimized power dissipation.

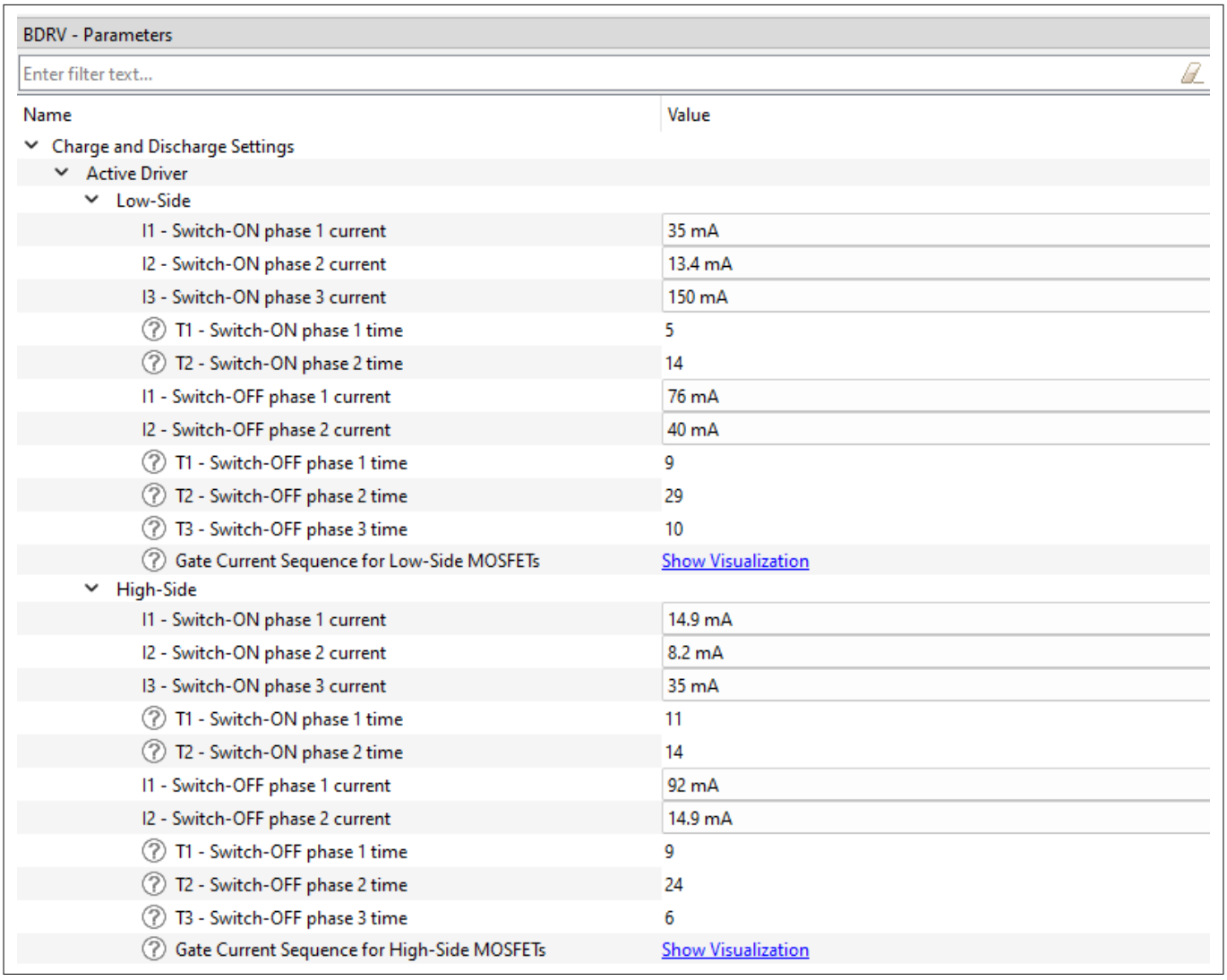


Figure 23 Gate driver parameters configuration

6.1.2 Field Oriented Control (FOC) Setup

In order to acquire an overview and configure the software parameters, refer to "User interface overview" section by clicking on the help button of Infineon MOTIX™ MCU Solution Designer as shown in the figure below.

6 System performance

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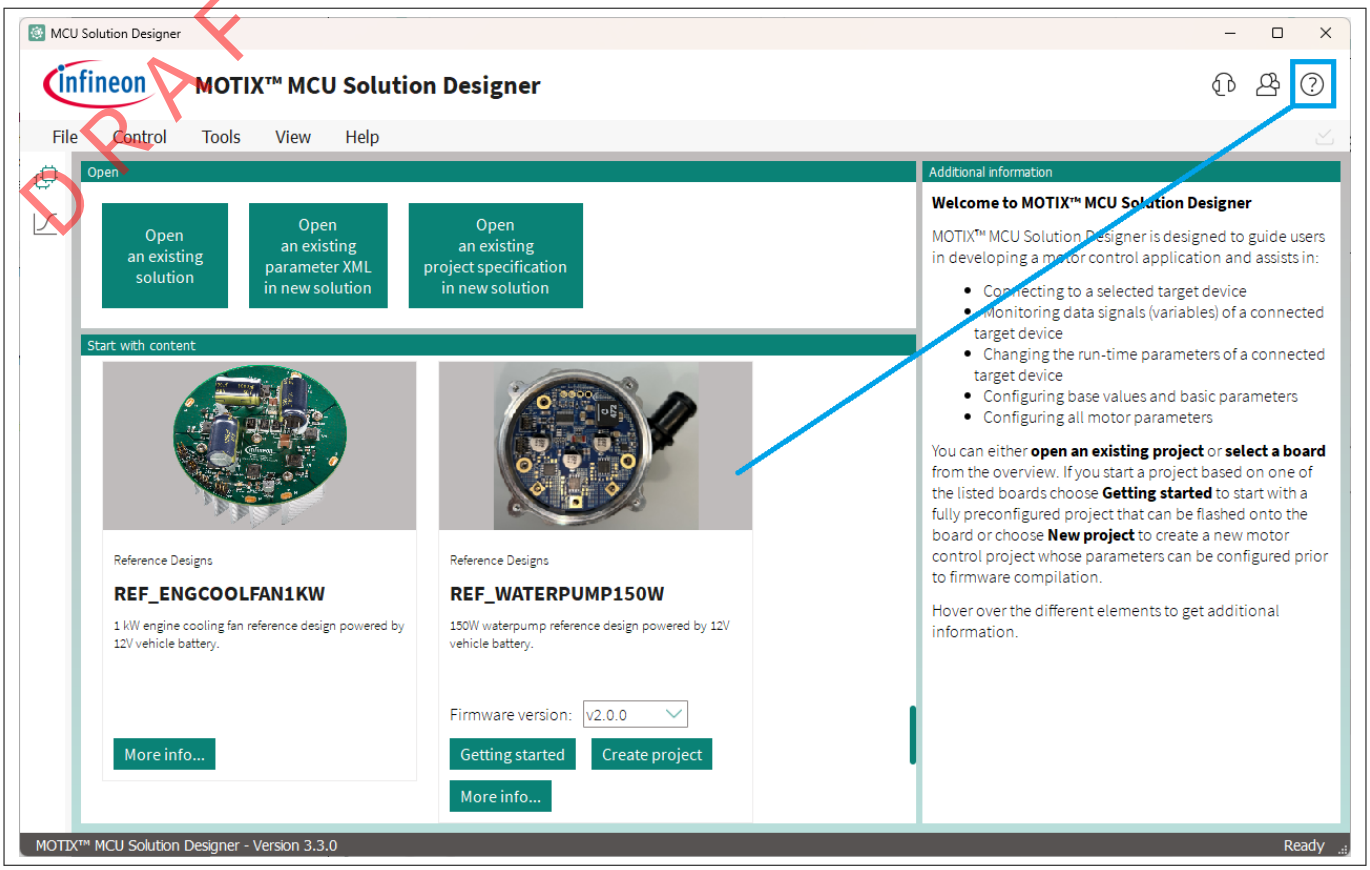


Figure 24 MOTIX™ MCU Solution Designer user interface

In order to setup the software, the parameters of the motor are required to be determined. These parameters can be updated into the Infineon MOTIX™ MCU Solution Designer. The figure below shows the mentioned parameters in the project configurations menu.

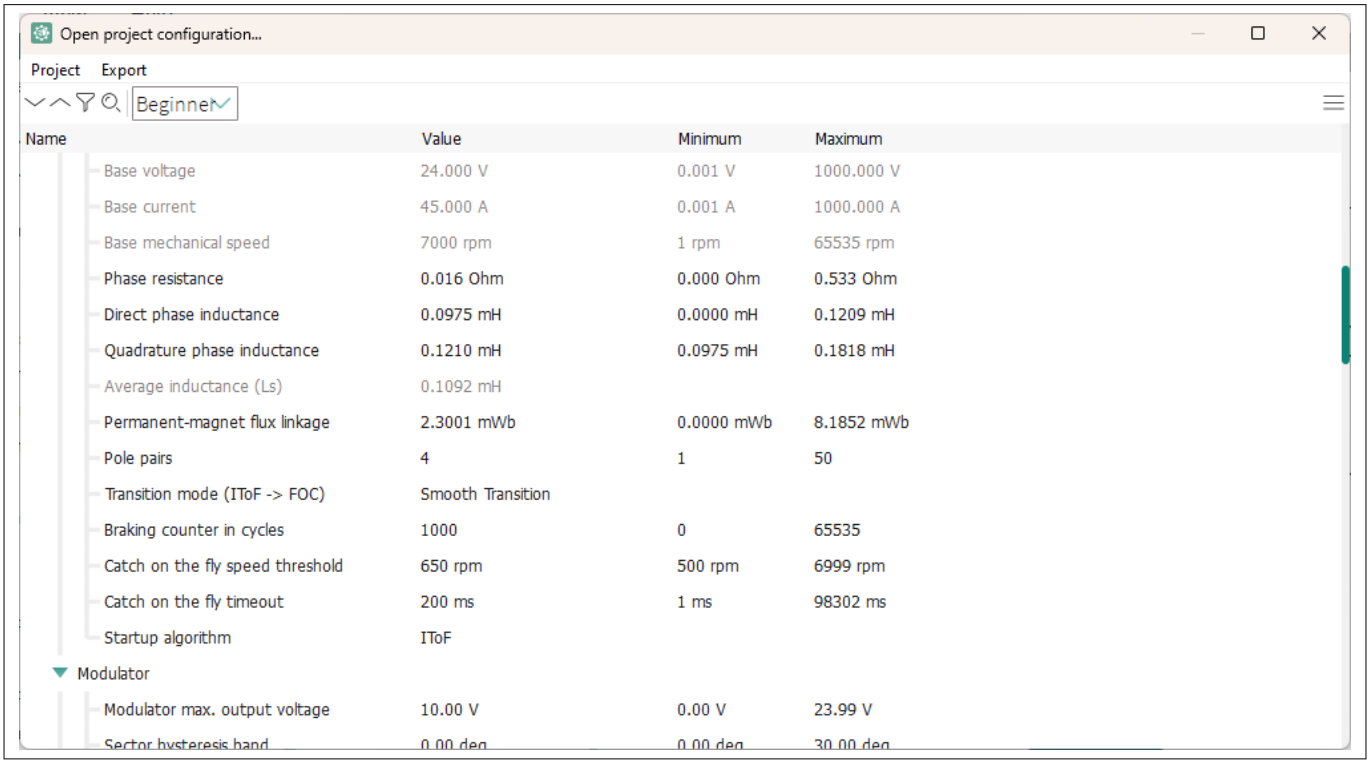


Figure 25 Motor parameter setting in the MOTIX™ MCU Solution Designer

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Based on the provided inputs such as the motor parameters, the system base voltage and current, the shunt resistance, and the MOSFET switching timings, the tool configures the relevant software program, which can then be compiled into an execution file.

Advanced settings such as the gains of the PI controllers, ramp up rate, start-up current, start-up algorithm, FOC mode selection etc. can all be configured in the project configurations settings.

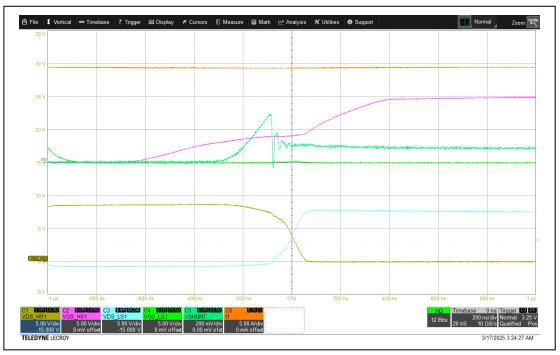
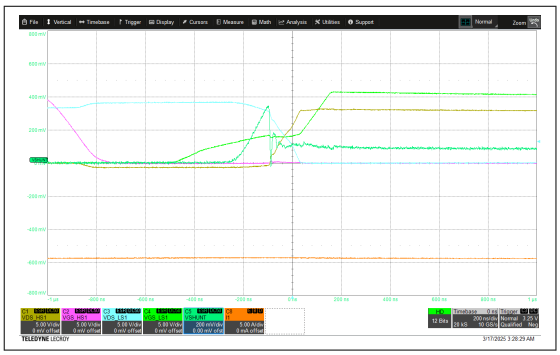
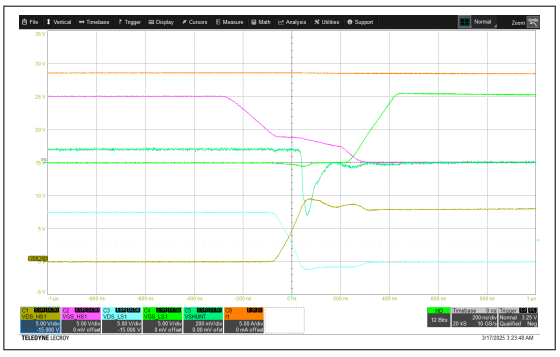
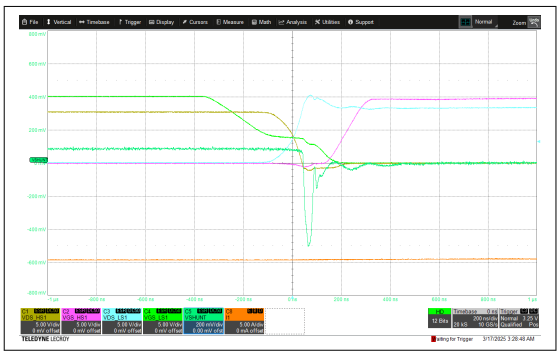
For more information on getting started with the software, getting the motor parameters, or configuring the parameters in MOTIX™ Solution Designer, refer to the software user guide.

6.2 MOSFET switching characteristics

The gate driver switching behavior needs to be configured in order to ensure that the MOSFETs are switching according to the desired switching behavior, while avoiding the ringing to keep electromagnetic emissions to a minimum.

The following figures show the switching of a HS1 and LS1 for different operating voltage levels.

Table 6 MOSFET switching at various voltage levels

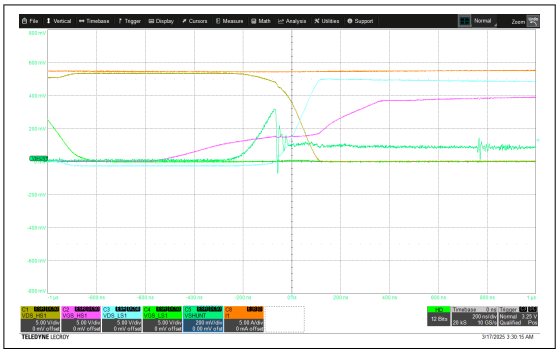
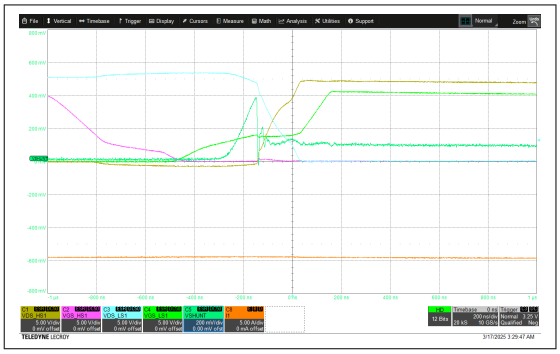
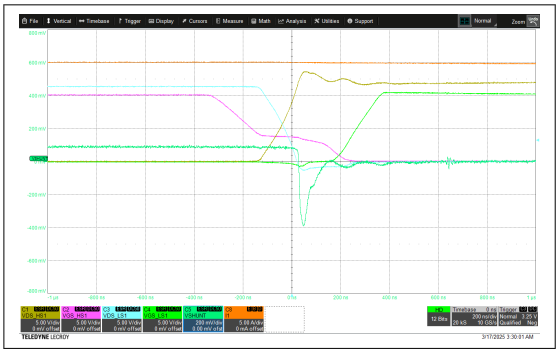
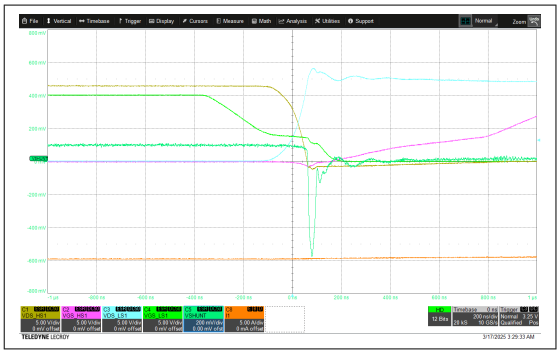
Operating condition	HS1	LS1
V = 8 V, I = 12 A, P = 135 W		
	Figure 26 Turn on HS1	**Figure 28 Turn on LS1**
		
	Figure 27 Turn off HS1	**Figure 29 Turn off LS1**

(table continues...)

6 System performance

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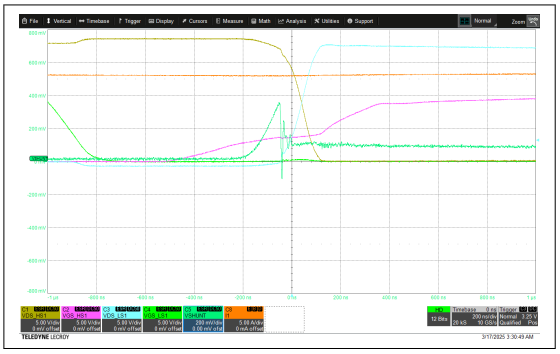
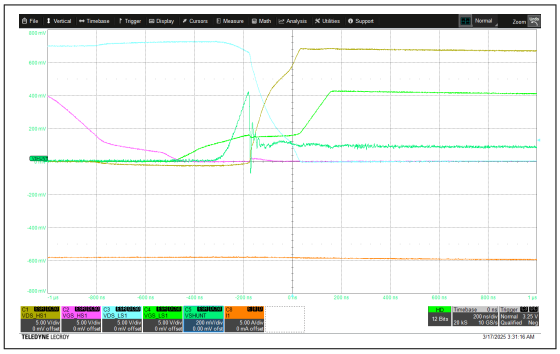
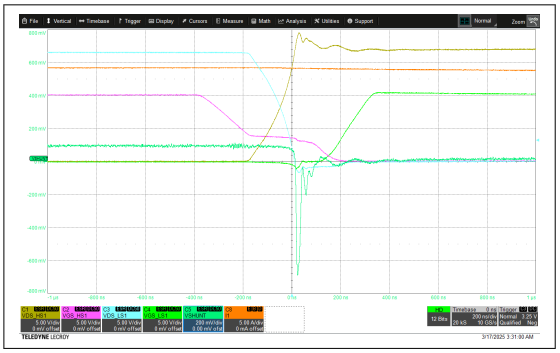
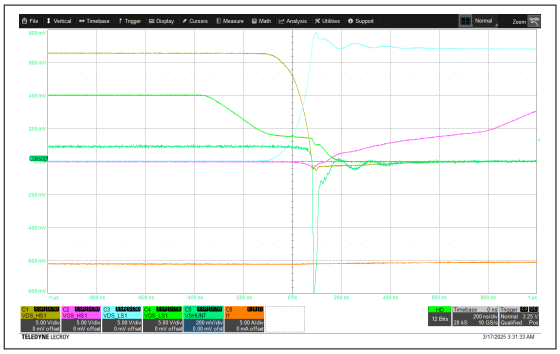
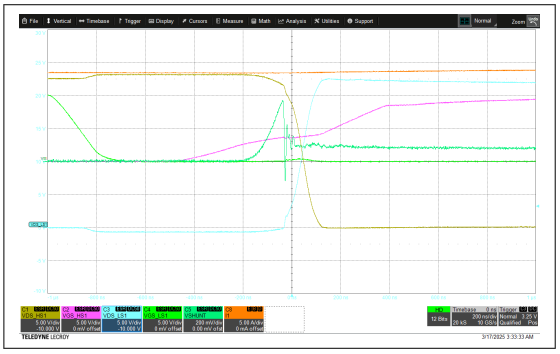
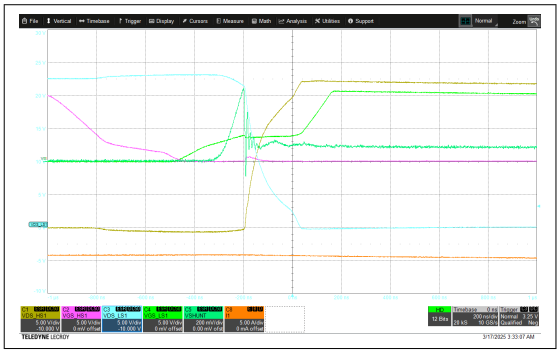
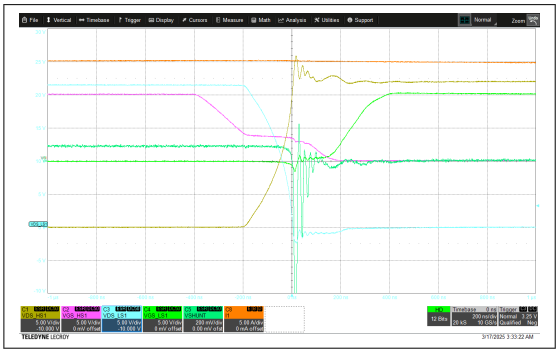
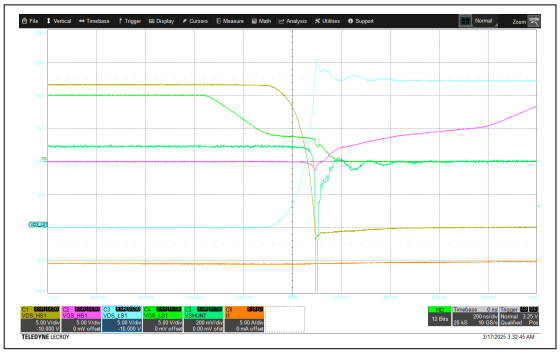
Table 6 (continued) MOSFET switching at various voltage levels

Operating condition	HS1	LS1
V = 13 V, I = 11 A, P = 135 W		
	Figure 30 Turn on HS1	**Figure 32 Turn on LS1**
		
	Figure 31 Turn off HS1	**Figure 33 Turn off LS1**

(table continues...)

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Table 6 (continued) MOSFET switching at various voltage levels

Operating condition	HS1	LS1
V = 18 V, I = 7.5 A, P = 135 W	 **Figure 34 Turn on HS1**	 **Figure 36 Turn on LS1**
	 **Figure 35 Turn off HS1**	 **Figure 37 Turn off LS1**
V = 24 V, I = 5.8 A, P = 135 W	 **Figure 38 Turn on HS1**	 **Figure 40 Turn on LS1**
	 **Figure 39 Turn off HS1**	 **Figure 41 Turn off LS1**

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The gate driver was configured to switch the MOSFETs within approximately 200 ns. With reference to the figures above, a rise in voltage across the shunt is explained by the rapid change in current (di/dt) and the inductance of the shunt resistor. The ringing at the end of the switching period exhibits the reverse recovery behavior of the diode.

6.3 Thermal behavior

6.3.1 Water cycles in thermal management

The thermal performance of a water pump *electronic control unit (ECU)* in an automotive thermal management system is essential due to high operating temperature conditions. Since the water pump is a part of an automotive thermal management system, the part is exposed to varying temperature ranges spanning from -40°C to 85°C.

Therefore, it is important to understand the thermal energy dissipated by the active components to understand the thermal performance and reliability of the reference design in application scenarios.

6.3.2 Thermal testing test setup

In order to evaluate the heat generated by the active components on the reference design, a thermal camera was used to capture the temperature profile of the key active components at a room temperature of 25°C . The reference design was coupled onto the pump in the water circuit via a metal adapter plate to keep the phase contacts as short as possible. Before measuring any data, the reference design was spray-painted black to eliminate any reflective surfaces which can skew the temperature measurement, to get a uniform emission coefficient over the total surface.

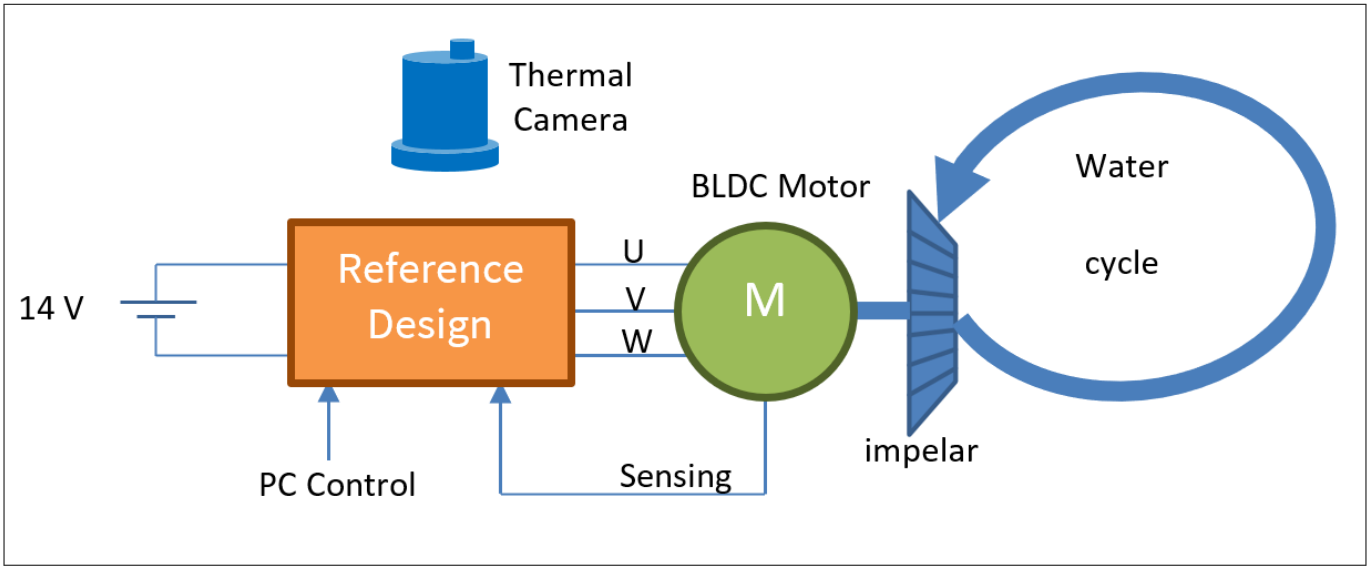


Figure 42 Thermal testing test setup block diagram

6.3.3 Self-heating of components

The power dissipation on the reference design is due to various components on the *PCB*. TLE995EQA40, the MOSFETs, and the shunt resistor are the major source of heat dissipation on the reference design.

- TLE9954EQW40: The operation of the charge pump, analog and digital logic, and gate drivers dissipates some power from TLE9954EQW40. This power dissipation depends on the supply voltage and the connected MOSFETs
- MOSFETS: Switching and conduction losses of MOSFETs result in power dissipation from the half-bridge MOSFETs package. These losses are defined by the supply voltage, load current, and the switching speed
- Shunt resistor: Current flow through the shunt resistor causes thermal losses in the resistor. The losses are determined by the amount of load current flowing through the resistor

6 System performance

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Table 7 Thermal dissipation test conditions

Power (W)	Supply voltage (V)	Input current (A)	Speed (rpm)
55	13	4.2	2400
100	13	7.7	2900
156	13	12	3300

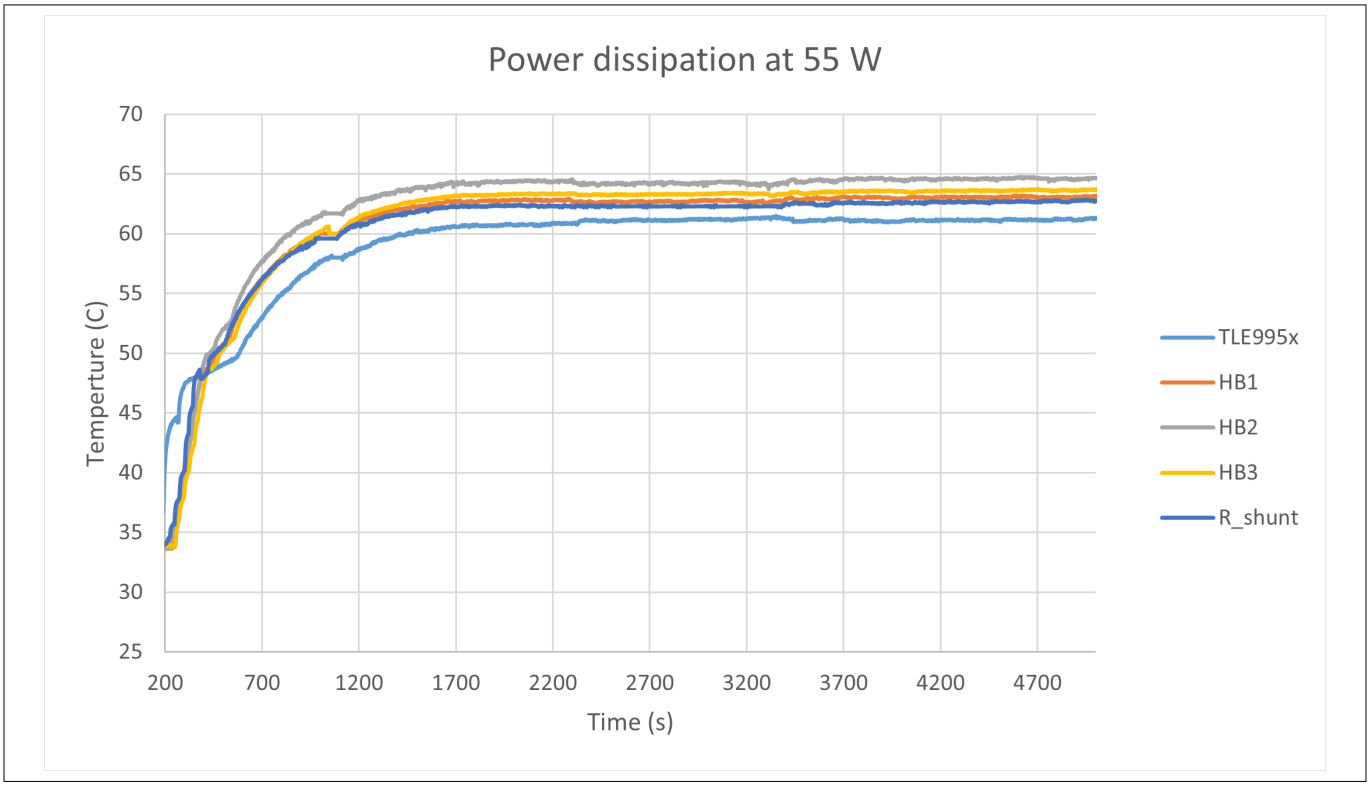


Figure 43 Thermal dissipation at 55 W

6 System performance

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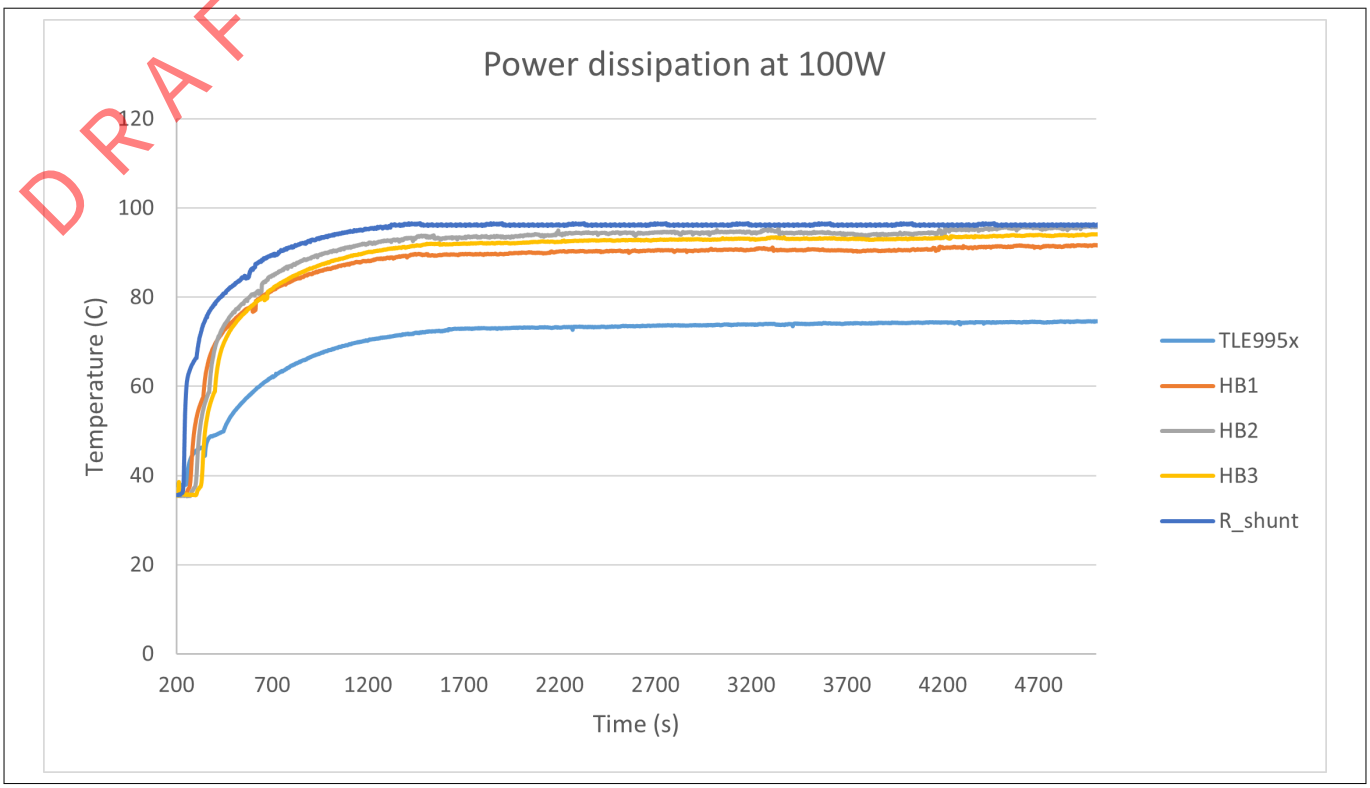


Figure 44 Thermal dissipation at 100 W

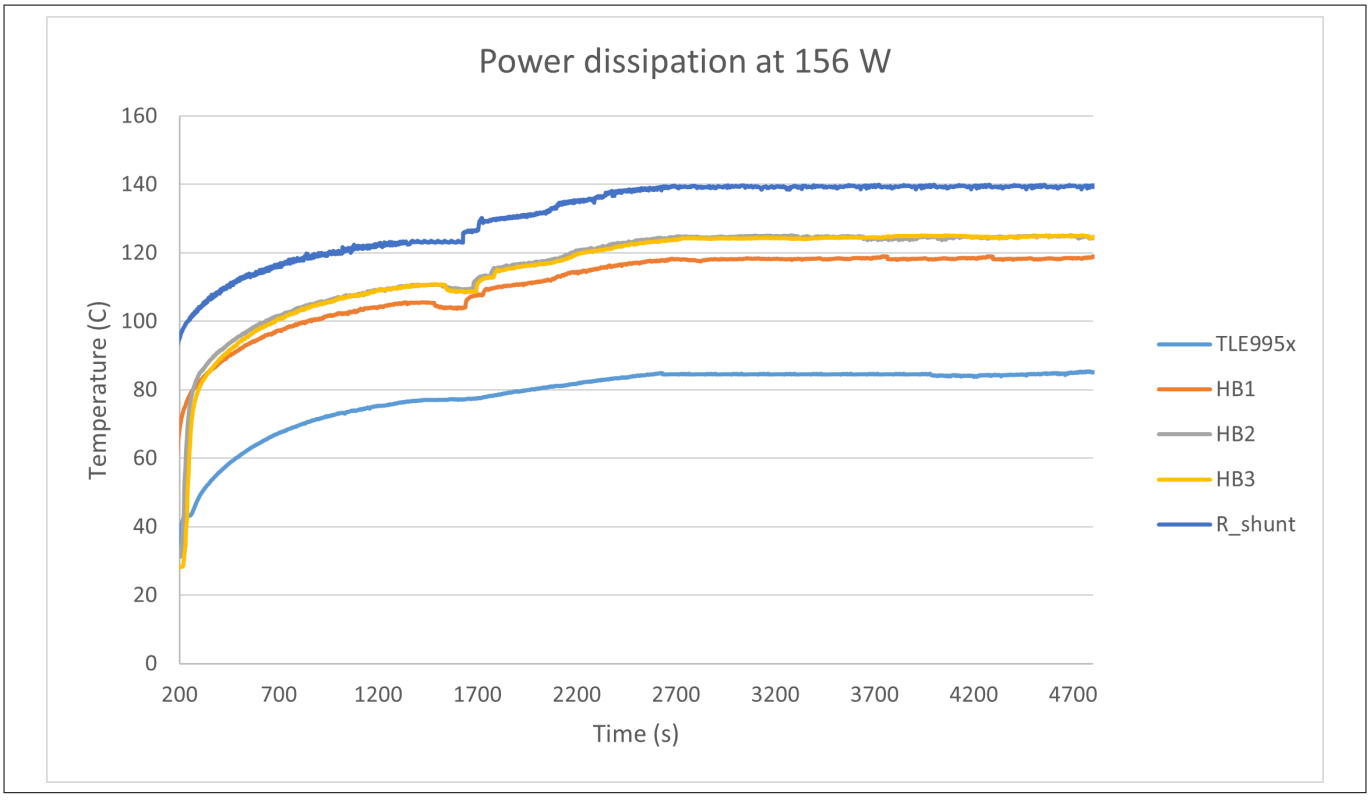


Figure 45 Thermal dissipation at 156 W

The temperature rise follows a smooth pattern. The slight jumps in the measurements, in particular for power dissipation at 156 W around 1700 s, are due to a discrepancy in the measurement setup and can be ignored.

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6.3.4 Self-heating conclusion

The figures in the previous chapter, show that the heat dissipation from TLE9954EQW40, HB1-3, and the resistor increases as the power through the reference design increases. However, after a certain amount of time a steady state temperature of the components was achieved.

In the test performed, the reference design *PCB* was coupled via a metal adapter plate to the pump housing to have access to the phase connectors. In order to reduce the heat dissipation by the components, the PCB can be directly coupled to the pump housing as all the components are populated only on the top side.

Additionally, the cooling body mounted on top of the pump can be installed to further increase the cooling effect as shown on the right in Figure 46. In order to perform the temperature measurements, it was essential to have visual access to the components on board as shown on the left in Figure 46. Therefore, the accompanying cooling body mounted on the top of the pump was removed. Additionally, the temperature of the shunt resistor could be reduced by using a shunt resistor with a lower resistance.

In conclusion, several cooling strategies could help in cooling the PCB and reduce the overall temperature of the components.

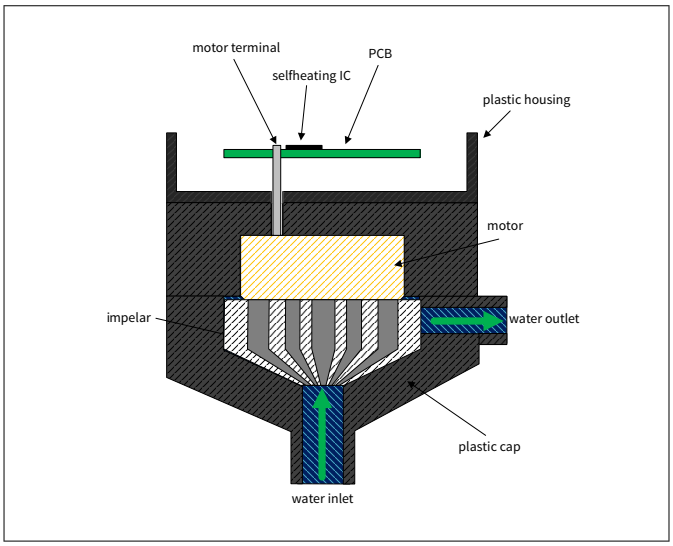


Figure 46 Test setup without the top mount

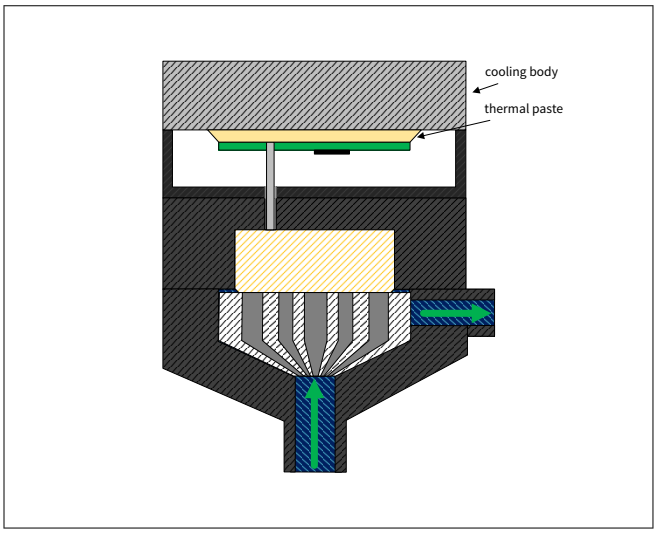


Figure 47 Assembly with top cooling mount on the pump

6.4 EMC

6.4.1 EMC test setup

The measurement setup is described in Figure 48. The water cycle setup was placed in a semi-anechoic *EMC* chamber to perform the measurements. The EMC level limits are compliant to CISPR25 class 5.

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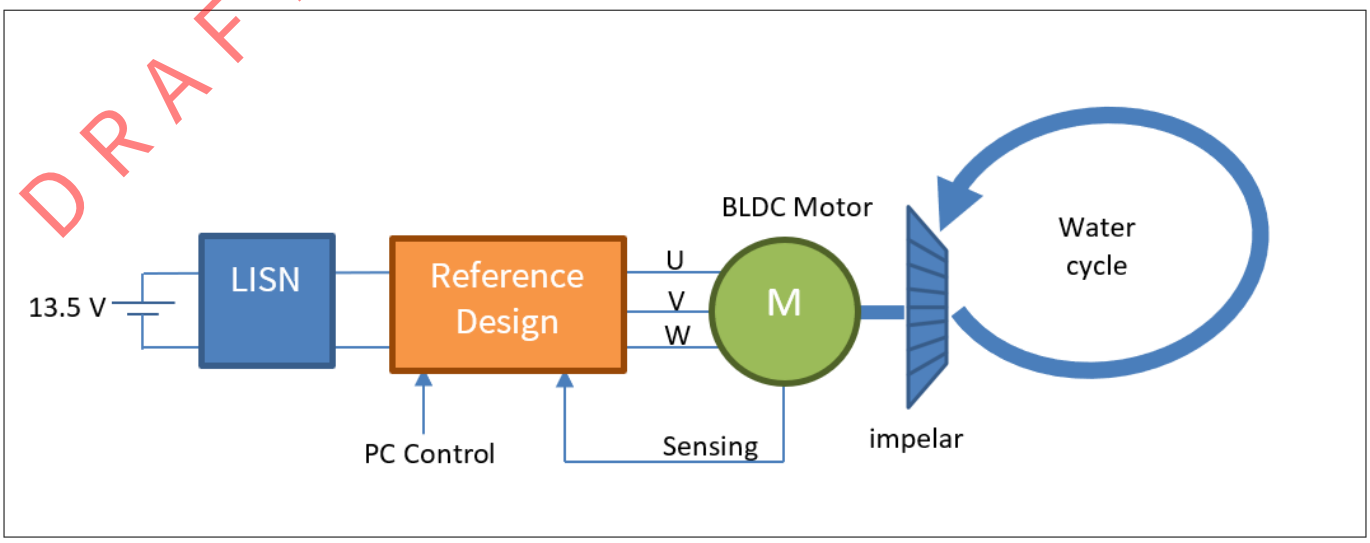


Figure 48 EMC test setup block diagram

6.4.2 Conducted emission with microcontroller in ON-state

In this condition, the reference design is supplied with 14 V and the microcontroller of the TLE9954EQW40 executes the flashed program without controlling the motor. The peak (PK) and average (AV) curves show the conducted emissions while the MOSFET bridge driver and charge pump are disabled. The measurement results are shown in Figure 49.

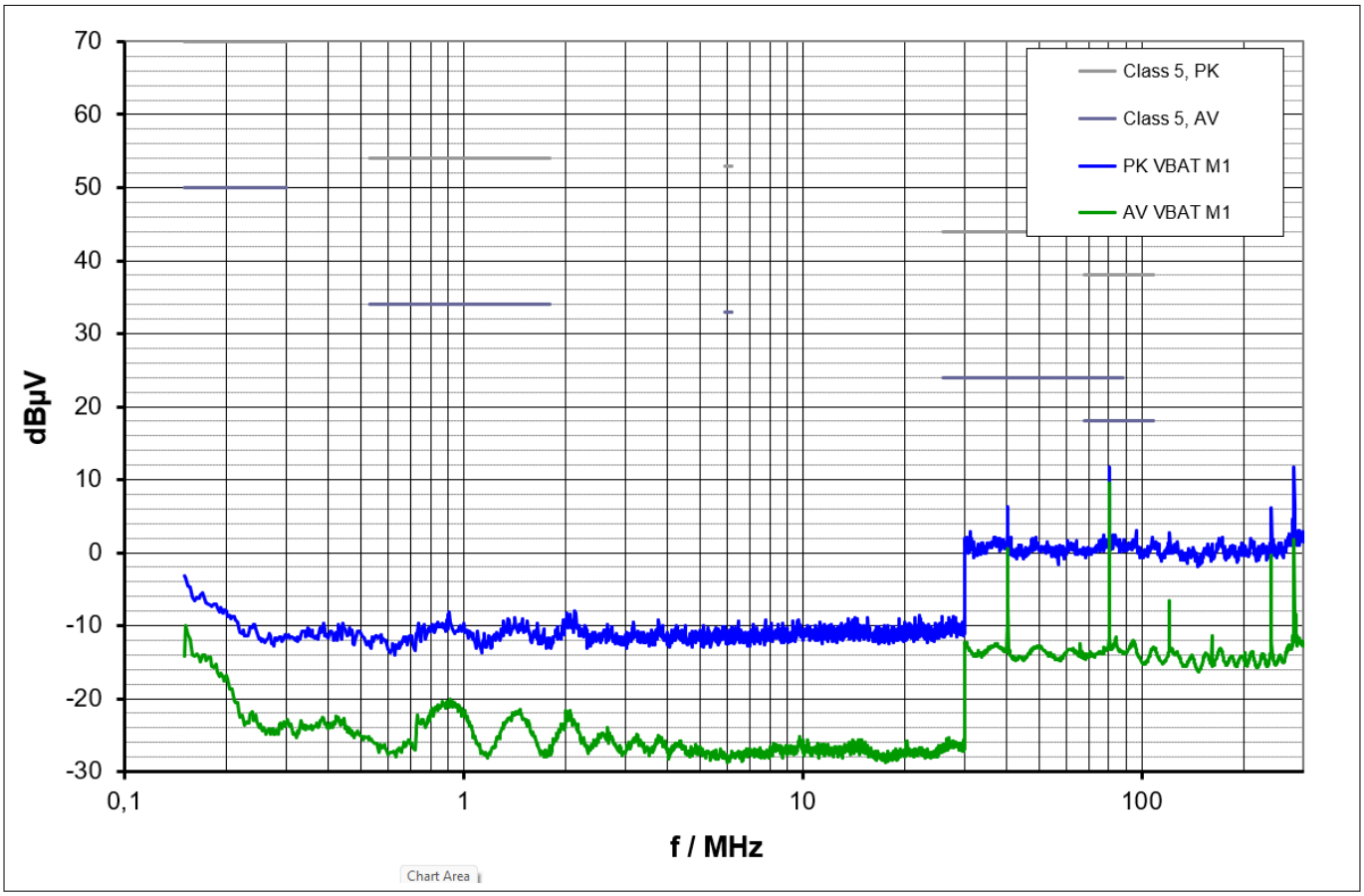


Figure 49 Conducted emissions measurement on VBAT line with motor and charge pump off

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6.4.3 Conducted emission with system in on-state

The reference design is powered with 14 V on the *VBAT* line, and the microcontroller of the TLE9954EQ140 executes the flashed program. The MOSFET bridge driver and the charge pump are enabled. The measurement is performed for the following load conditions: 49 W, 72.5 W and 154 W. The figures below show the emissions which are below the CISPR class 5 limits.

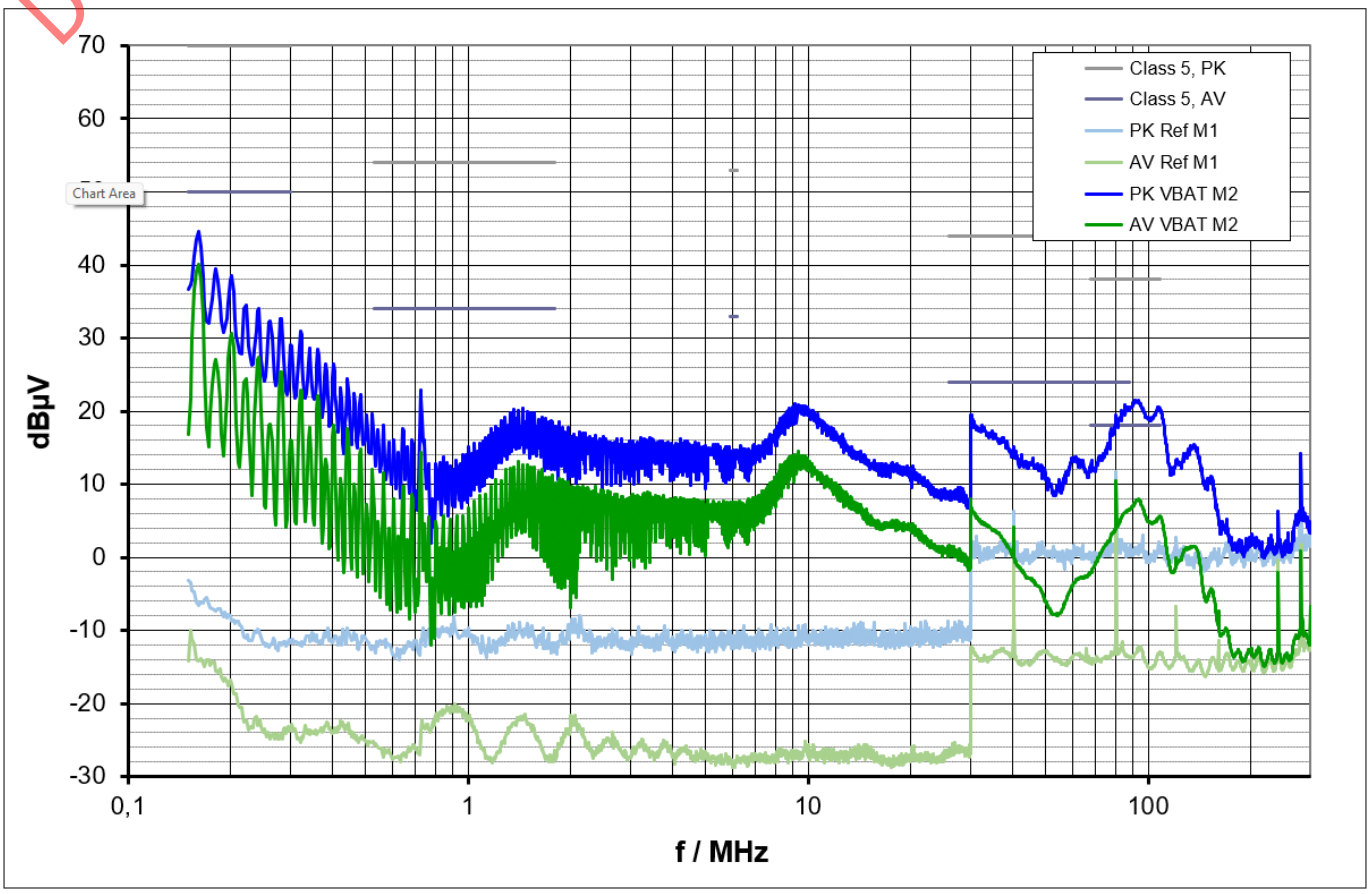


Figure 50 Conducted emissions measurement on VBAT line at 49 W

6 System performance

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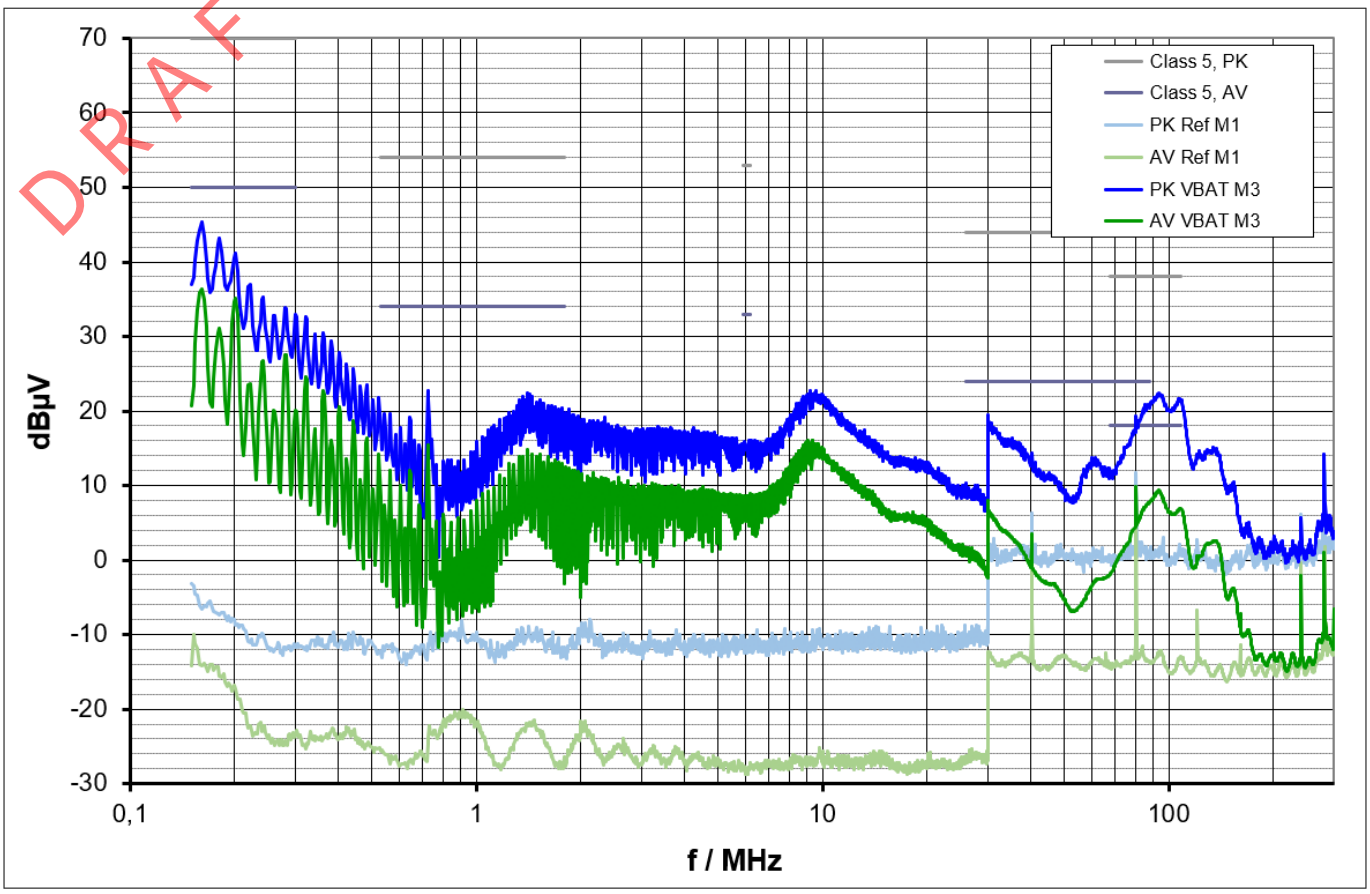


Figure 51 Conducted emissions measurement on VBAT line at 72.5 W

6 System performance

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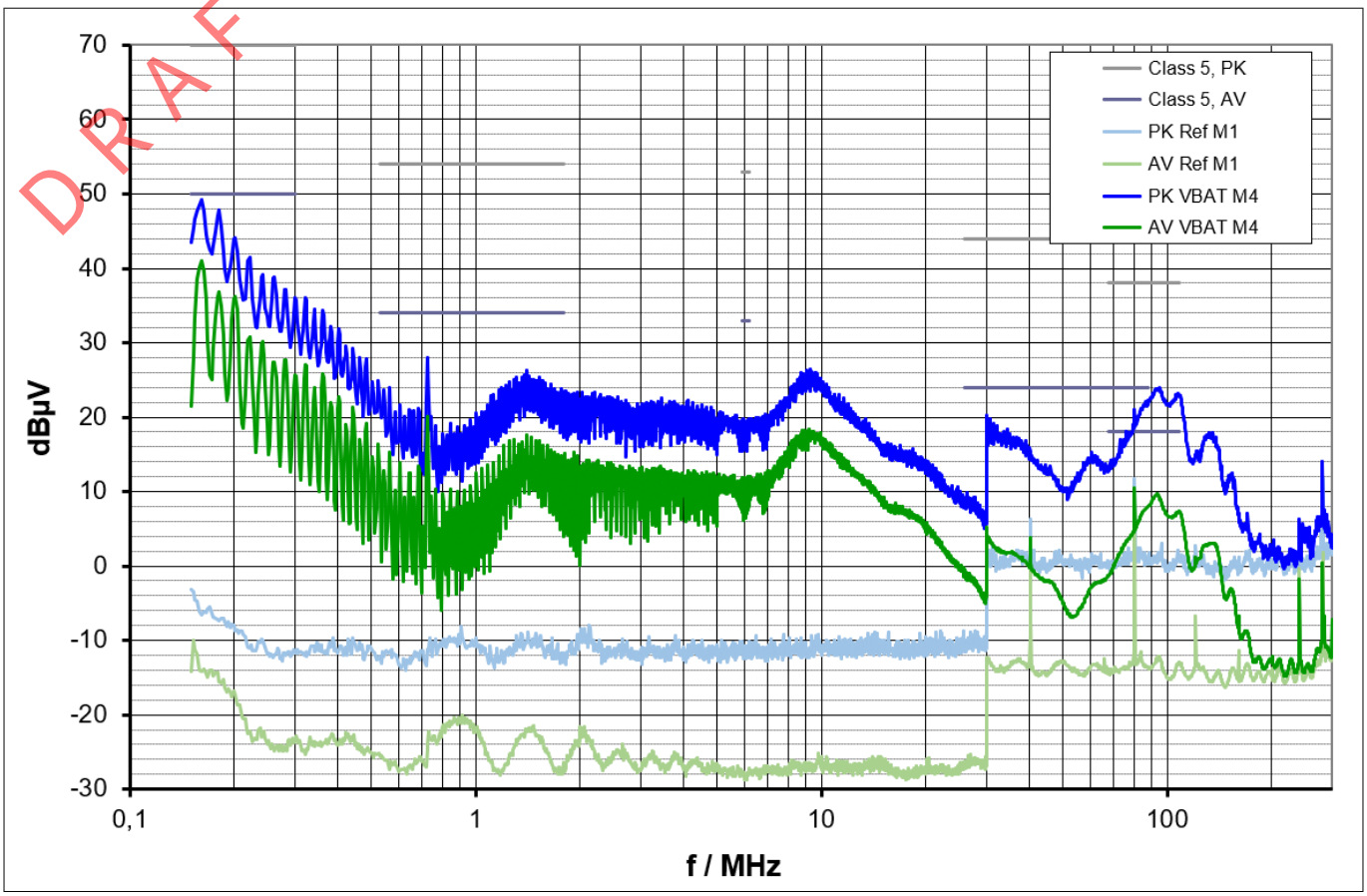


Figure 52 Conducted emissions measurement on VBAT line at 154 W

6 System performance

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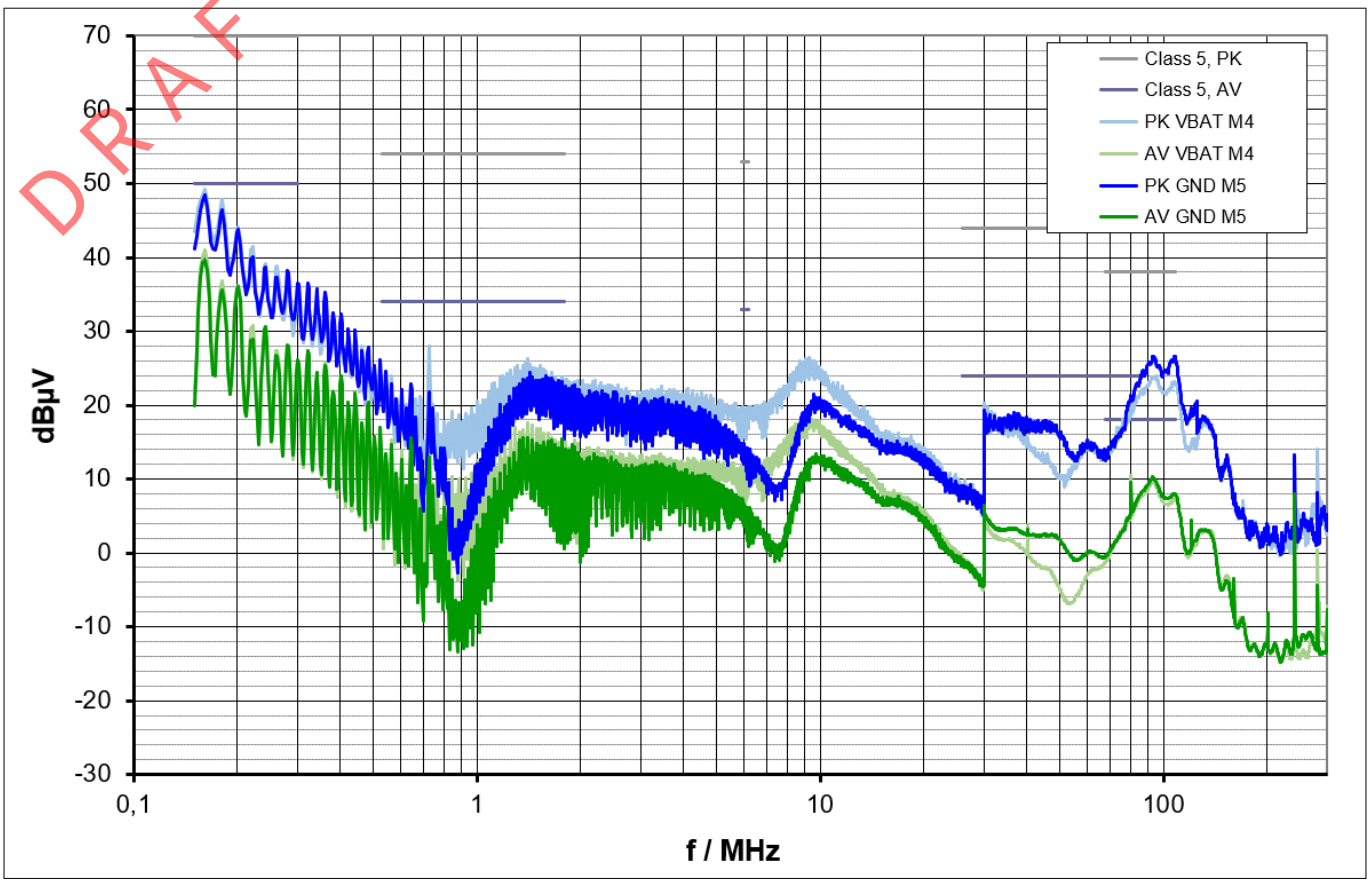


Figure 53 Conducted emissions measurement on GND line at 154 W

In conclusion, the input Pi filter is effective in the lower frequency ranges, and the slew rate is efficiently controlled by the bridge driver resulting in emissions below CISPR class 5 limits.

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7 Project collaterals

7.1 Schematics

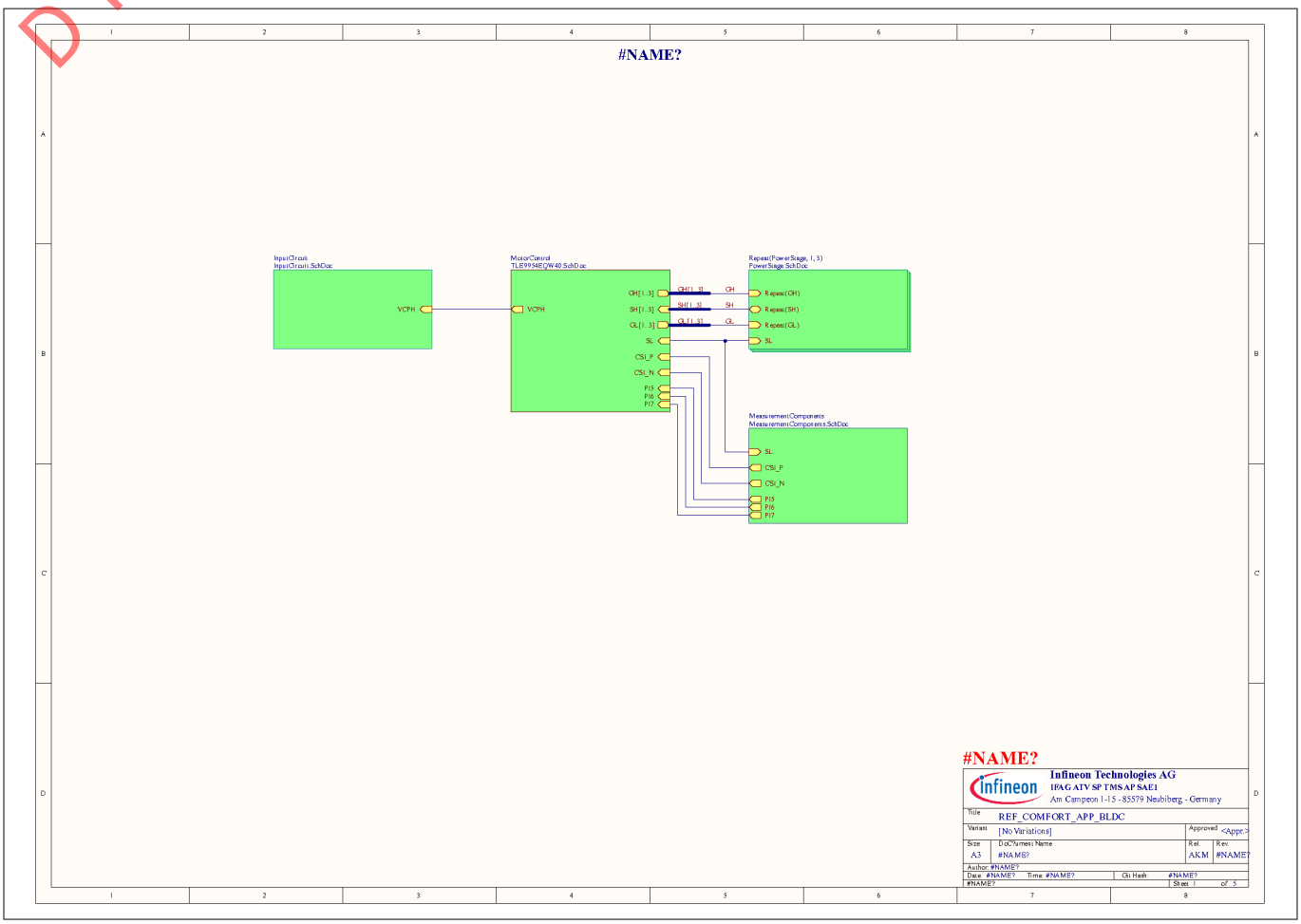


Figure 54 REF_COMFORT_APP Overview

7 Project collaterals

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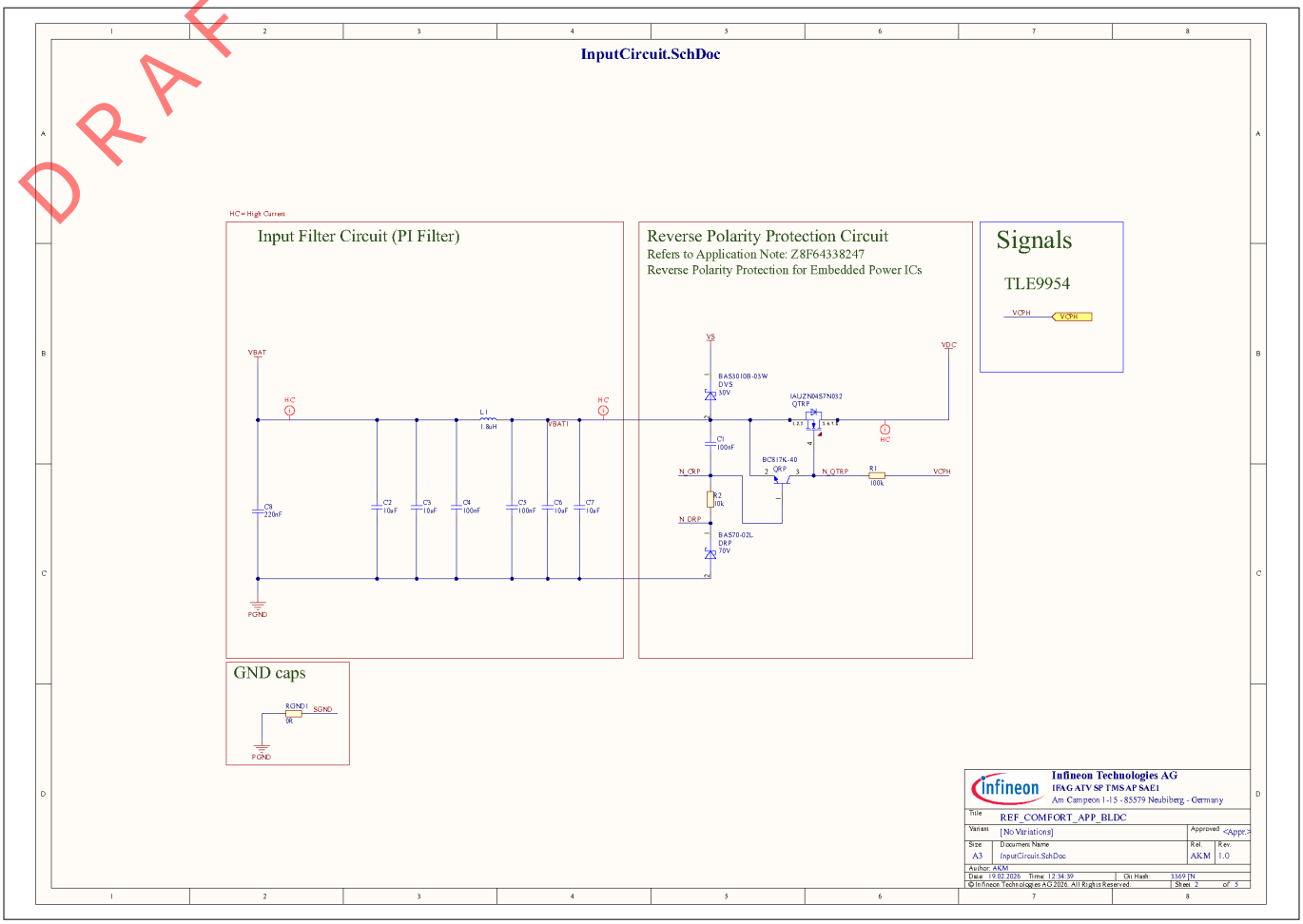
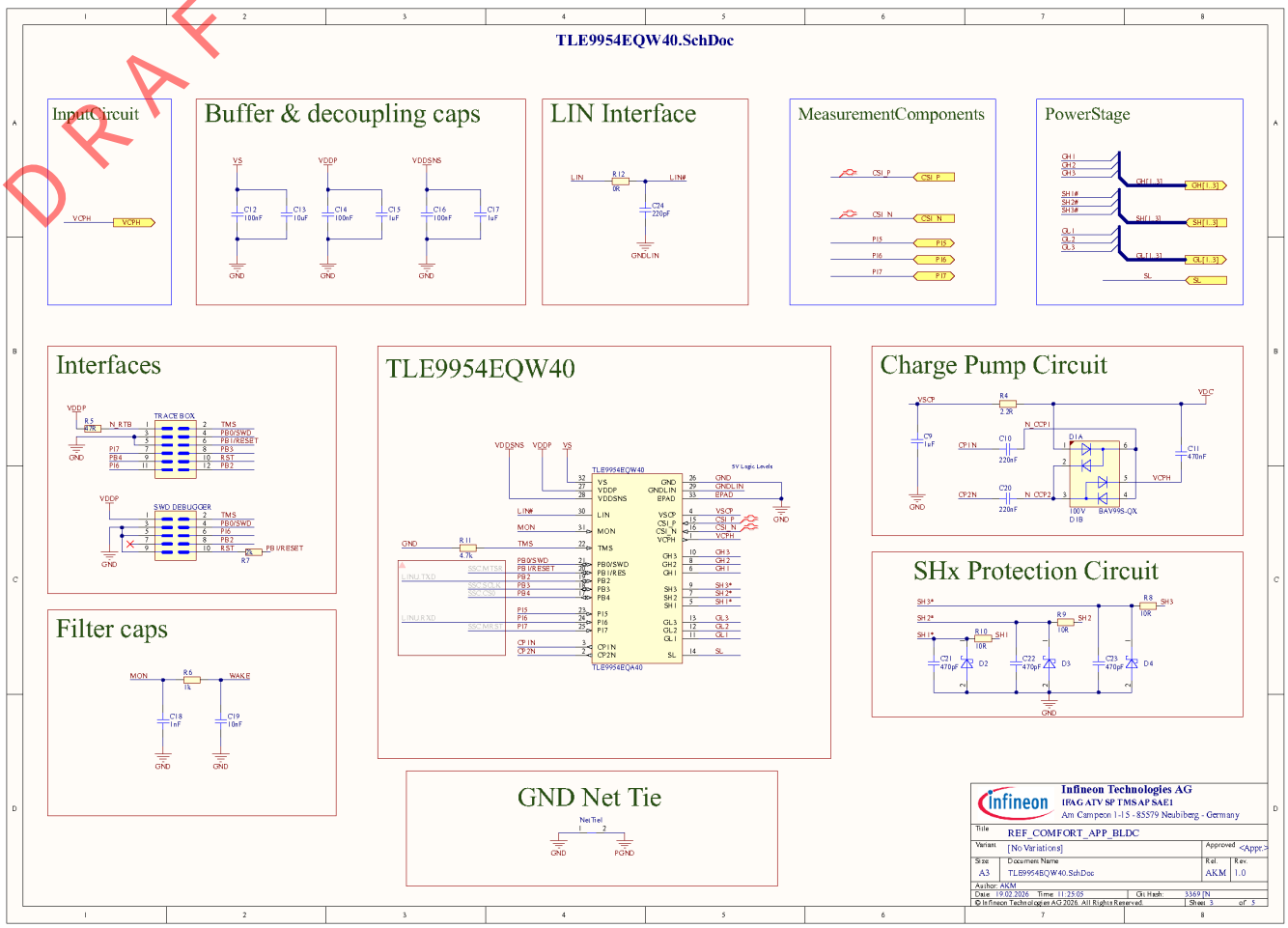


Figure 55 Input circuit

Figure 56 Motor control

7 Project collaterals



7 Project collaterals

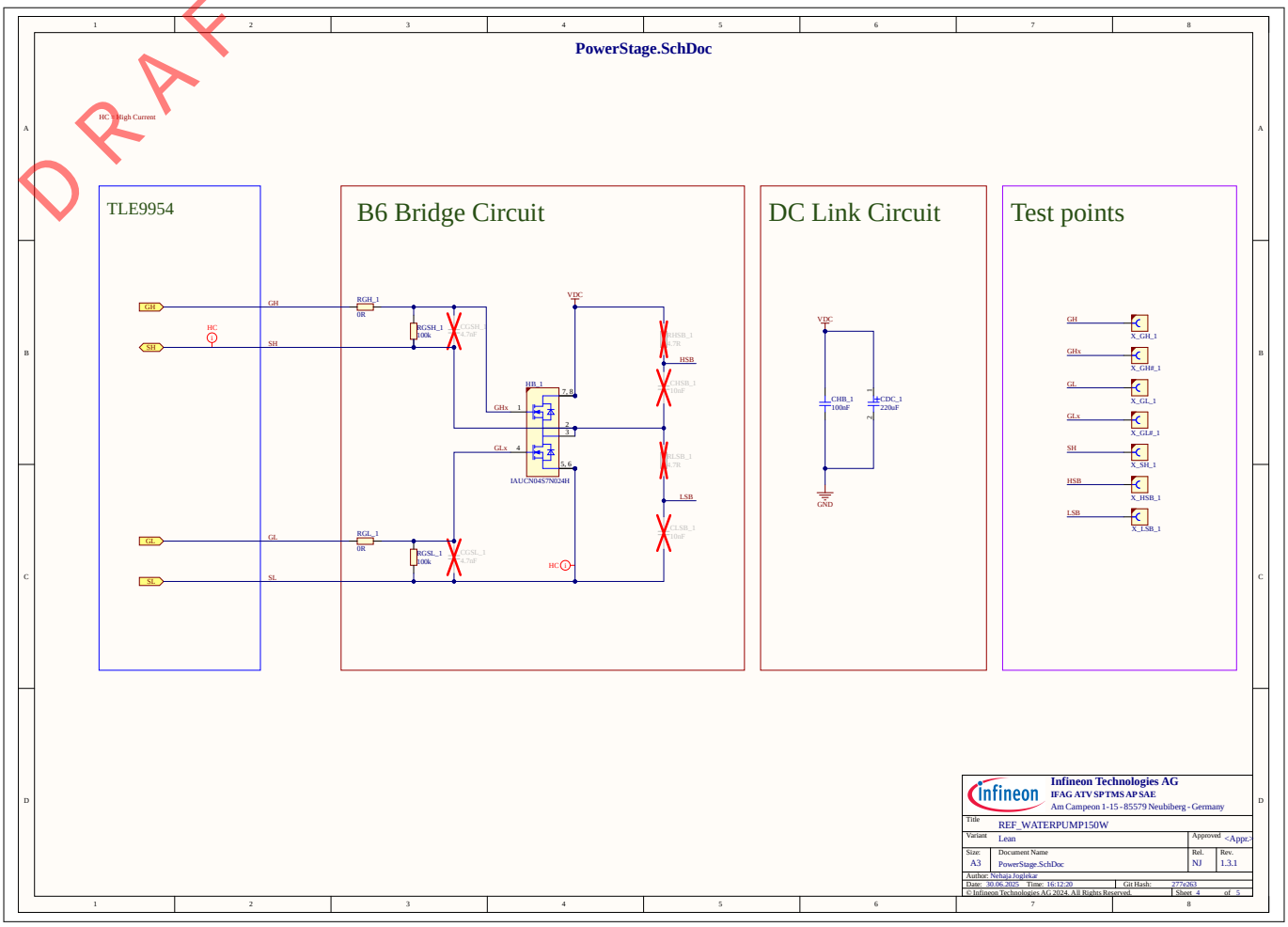


Figure 57 Power stage - half bridge 1

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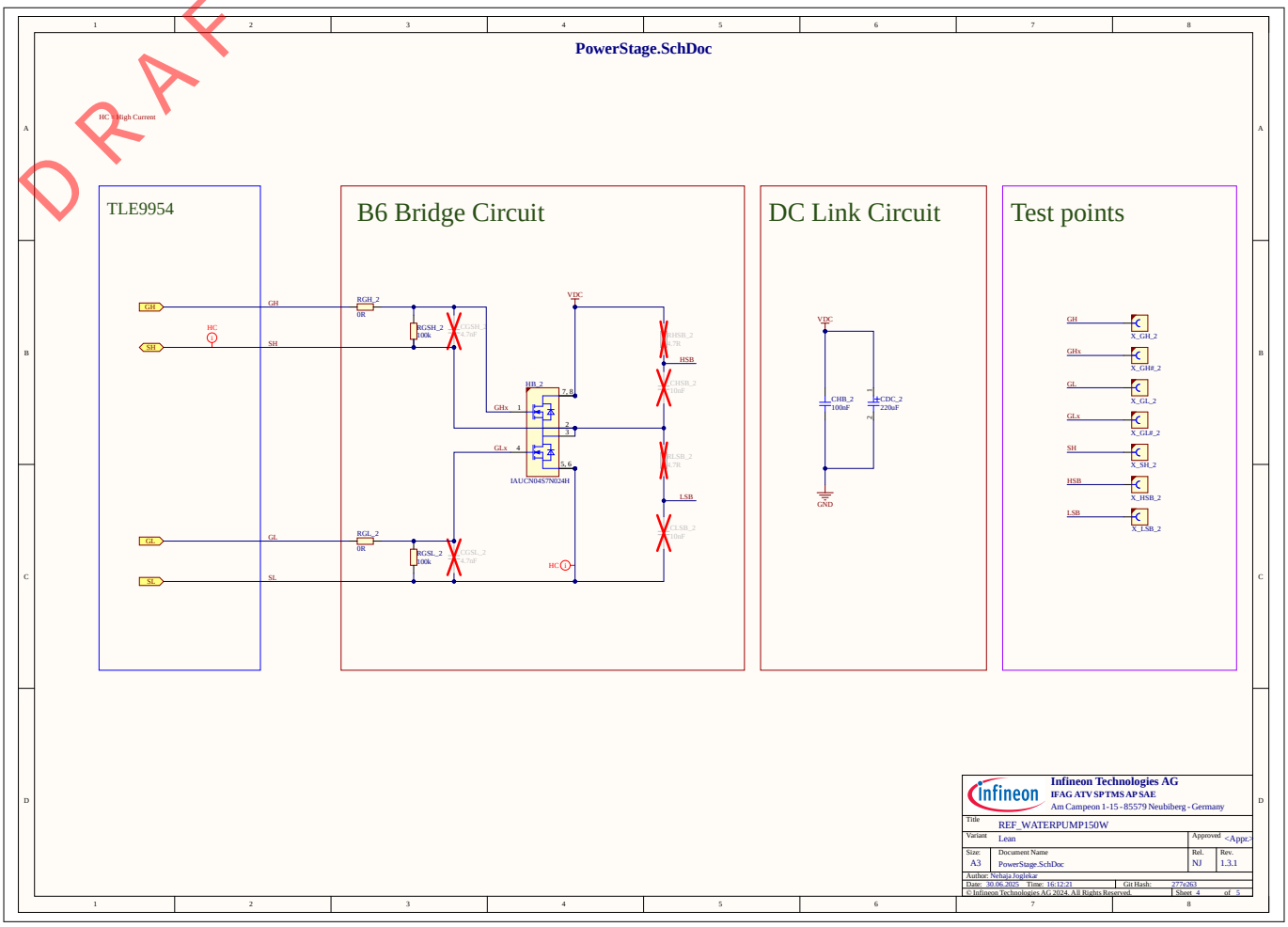


Figure 58 Power stage - half bridge 2

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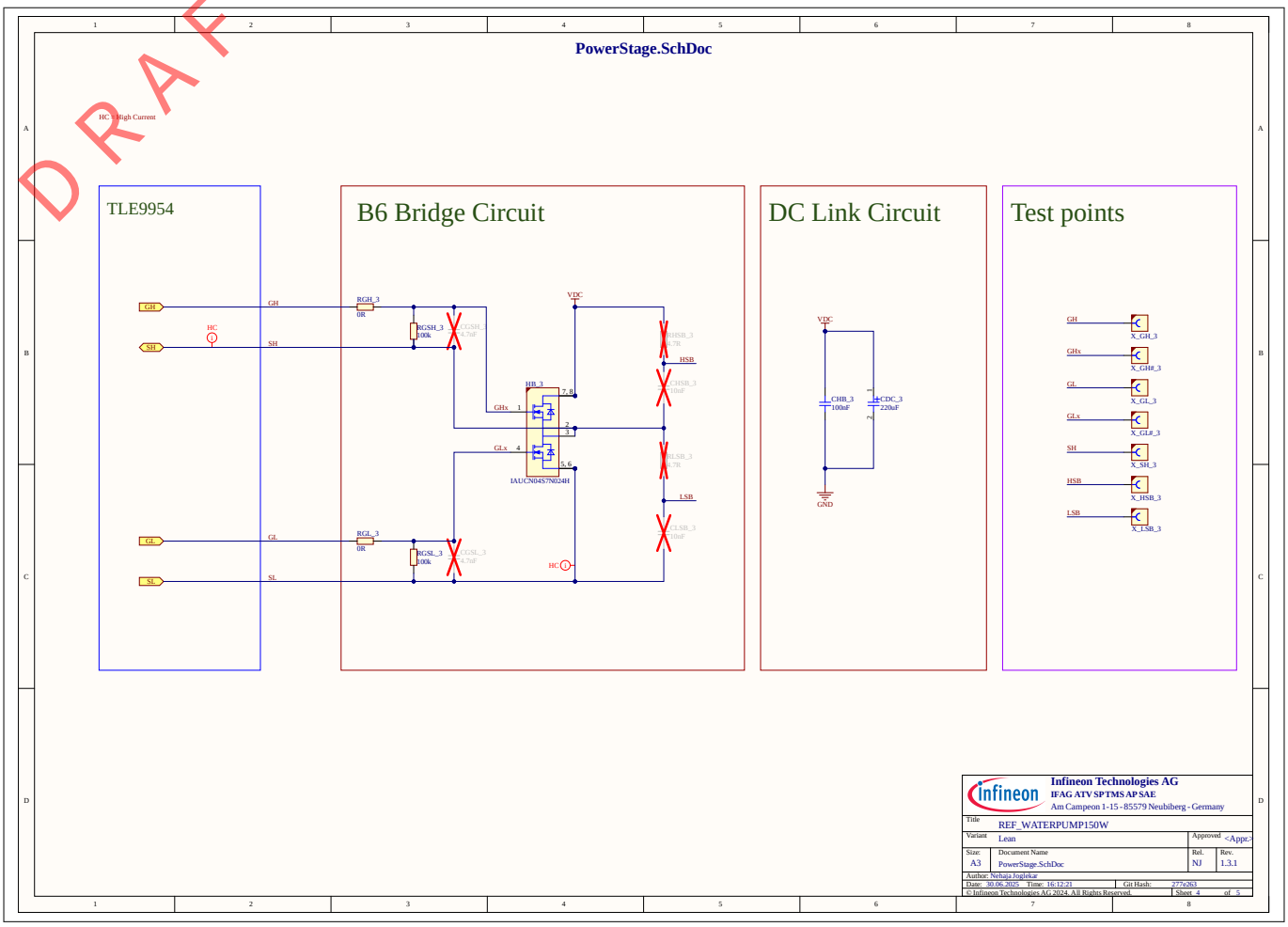
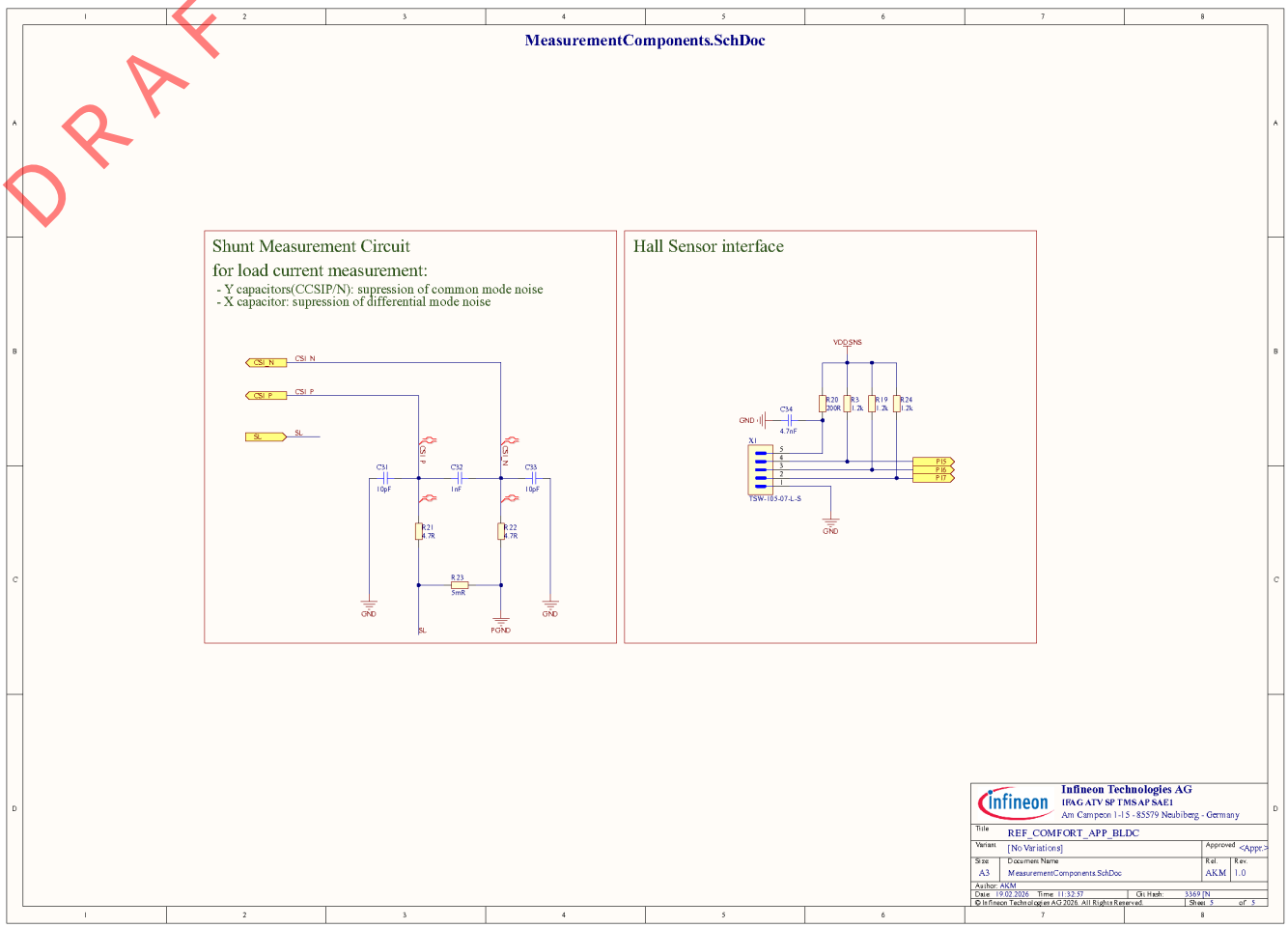


Figure 59 Power stage - half bridge 3

Figure 60 Measurement components

7 Project collaterals

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7.2 Bill of materials

Table 8 Bill of materials

Designator	Value	Description	Quantity	Manufacturer order number	Automotive qualified	Fitted
C_T, CMON2	10nF	CAP/CERA/ 10nF/50V/10% / X7R (EIA) / -55°C to 125°C/ 0603(1608) / SMD / -	2	CAPC1608X90N, 06035C103K4Z2A	AEC Q200	Fitted
CCER1, CCER2, CCP1, CCP2	220nF	CAP/CERA/ 220nF/50V/10% / X7R (EIA) / -55°C to 125°C/ 0603(1608) / SMD / -	4	GCM188R71H224KA64	AEC Q200	Fitted
CCSI	1nF	CAP/ CERA/1nF/50V/5% / C0G (EIA) / NP0 / -55°C to 125°C/ 0402(1005) / SMD / -	1	C0402C102J5GACAUTO	AEC Q200	Fitted
CCSIN, CCSIP	10pF	CAP/CERA/ 10pF/50V/5% / C0G (EIA) / NP0 / -55°C to 125°C/ 0402(1005) / SMD / -	2	GCM1555C1H100JA16	AEC Q200	Fitted
CDC_1, CDC_2, CDC_3	220uF	CAP/ELCO/ 220uF/35V/20% / Aluminum electrolytic / -40°C to 125°C/ 8.30mm L X 8.30mm W X 10.50mm H/SMD / -	3	EEETC1V221UP	AEC Q200	Fitted
CGSH_1, CGSH_2, CGSH_3, CGSL_1, CGSL_2, CGSL_3	4.7nF	CAP/CERA/ 4.7nF/25V/10% / X7R (EIA) / -55°C to 125°C/ 0603(1608) / SMD / -	0	GCM188R71E472KA37	AEC Q200	Not Fitted

(table continues...)

7 Project collaterals

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Table 8 (continued) Bill of materials

Designator	Value	Description	Quantity	Manufacturer order number	Automotive qualified	Fitted
CHB_1, CHB_2, CHB_3	100nF	CAP/CERA/ 100nF/50V/10 % / X8R (EIA) / -55°C to 150°C/ 0805(2012) / SMD / -	3	GCM21BR91H 104KA37	AEC Q200	Fitted
CHSB_1, CHSB_2, CHSB_3, CLSB_1, CLSB_2, CLSB_3	10nF	CAP/CERA/ 10nF/50V/10% / X7R (EIA) / -55°C to 125°C/ 0603(1608) / SMD / -	0	06035C103K4 Z2A	AEC Q200	Not Fitted
CLIN	220pF	CAP/CERA/ 220pF/50V/5% / C0G (EIA) / NP0 / -55°C to 125°C/ 0603(1608) / SMD / -	1	CGA3E2C0G1 H221J080AA	AEC Q200	Fitted
CMON1	1nF	CAP/ CERA/1nF/50V /5% / C0G (EIA) / NP0 / -55°C to 150°C/ 0402(1005) / SMD / -	1	CGA2B2NP01 H102J050BA	AEC Q200	Fitted
CPI1, CPI2, CPI3, CPI4, CPI5, CVS2	10uF	CAP/CERA/ 10uF/50V/10% / X7S (EIA) / -55°C to 125°C/ 1210(3225) / SMD / -	6	GCM32EC71H 106KA03	AEC Q200	Fitted
CRP	100nF	CAP/CERA/ 100nF/50V/10 % / X8R (EIA) / -55°C to 150°C/ 0603(1608) / SMD / -	1	CGA3E3X8R1H 104K080AB	AEC Q200	Fitted

(table continues...)

7 Project collaterals

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Table 8 (continued) Bill of materials

Designator	Value	Description	Quantity	Manufacturer order number	Automotive qualified	Fitted
CSH1, CSH2, CSH3	470pF	CAP/CERA/ 470pF/50V/2% / C0G (EIA) / NP0 / -55°C to 125°C/ 0603(1608) / SMD / -	3	GCM1885C1H 471GA16	AEC Q200	Fitted
CVCPH	470nF	CAP/CERA/ 470nF/50V/10 % / X7R (EIA) / -55°C to 125°C/ 0603(1608) / SMD / -	1	CGA3E3X7R1H 474K080AE	AEC Q200	Fitted
CVDDP1, CVS1, CVSNS1	100nF	CAP/CERA/ 100nF/50V/10 % / X7R (EIA) / -55°C to 125°C/ 0402(1005) / SMD / -	3	CGA2B3X7R1H 104K050BB	AEC Q200	Fitted
CVDDP2, CVSNS2	1uF	CAP/ CERA/1uF/16V /10% / X7R (EIA) / -55°C to 125°C/ 0603(1608) / SMD / -	2	CGA3E1X7R1C 105K080AC	AEC Q200	Fitted
CVSCP	1uF	CAP/ CERA/1uF/50V /10% / X7R (EIA) / -55°C to 125°C/ 0805(2012) / SMD / -	1	GCM21BR71H 105KA03	AEC Q200	Fitted
DCP	100V	High Speed Switching Diode, 100V, 200mA	1	BAV99S-QX	AEC Q101	Fitted
DRP	70V	Silicon Schottky Diode	1	BAS70-02L	AEC Q101	Fitted
DSH1, DSH2, DSH3	45V	Silicon Schottky Diode	0	BAS52-02V	AEC Q101	Not Fitted

(table continues...)

7 Project collaterals

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Table 8 (continued) Bill of materials

Designator	Value	Description	Quantity	Manufacturer order number	Automotive qualified	Fitted
DVS	30V	Medium Power AF Schottky Diode	1	BAS3010B-03W	AEC Q101	Fitted
HB_1, HB_2, HB_3	IAUCN04S7N024H	Power Transistor Dual N-Channel Enhancement, Pin 1 Gate, 2 Source, 3 Drain, 4 Gate, 5 Source, 6 Source, 7 Drain, 8 Drain, 8 Pins	3	IAUCN04S7N024H	AEC Q101	Fitted
LPI	4.7uH	IND/STD/ 4.7uH/ 25.4A/20% / -40°C to 125°C/ 5.2mR/SMD/ Inductor, 2 pin, 10.00mm L X 11.30mm W X 10.00mm H/SMD / -	1	XAL1010-472MED	AEC Q200	Fitted

(table continues...)

7 Project collaterals

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Table 8 (continued) Bill of materials

Designator	Value	Description	Quantity	Manufacturer order number	Automotive qualified	Fitted
PB0/SWD, X_CCP1, X_CCP2, X_CER, X_CP1N, X_CP2N, X_CRP, X_CSI_N, X_CSI_P, X_DGND, X_DRP, X_GH_1, X_GH_2, X_GH_3, X_GH#_1, X_GH#_2, X_GH#_3, X_GL_1, X_GL_2, X_GL_3, X_GL#_1, X_GL#_2, X_GL#_3, X_GNDLIN, X_HSB_1, X_HSB_2, X_HSB_3, X_LIN, X_LIN#, X_LSB_1, X_LSB_2, X_LSB_3, X_MON, X_PB1, X_PB2, X_PB3, X_PB4, X_PGND, X_PI5, X_PI6, X_PI7, X_QTRP, X_RST, X_RTB, X_SH1#, X_SH2#, X_SH3#, X_SH_1, X_SH_2, X_SH_3, X_SL, X_TMS, X_VBAT, X_VBAT1, X_VCPH, X_VDC, X_VDDP, X_VS, X_VSCP,	-	Test pad, SMD, 1.0 mm	61	-	No	Fitted

(table continues...)

7 Project collaterals

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Table 8 (continued) Bill of materials

Designator	Value	Description	Quantity	Manufacturer order number	Automotive qualified	Fitted
X_VSNS, X_WAKE						
QRP	BC817K-40	NPN Silicon AF Transistor	1	BC817K-40	AEC Q101	Fitted
QTRP	IAUZN04S7N032	Insulated-Gate Field-Effect Transistor (IGFET), N-Channel, Enhancement, Body Diode, Pin 1 Source, 2 Source, 3 Source, 4 Gate, 5 Drain, 6 Drain, 7 Drain, 8 Drain, 8 Pins	1	IAUZN04S7N032	AEC Q101	Fitted
R_T	10k	RES/NTC/10k/100mW/1% / - / -40°C to 150°C/ 0603/SMD / -	1	ERTJ1VG103FM	AEC Q200	Fitted
R_T1	10k	RES/STD/10k/100mW/1% / 100ppm/K / -55°C to 155°C/ 0603/SMD / -	1	CRCW060310K0FK	AEC Q200	Fitted
RCSI_N, RCSI_P	4.7R	RES/STD/ 4.7R/ 100mW/1% / 100ppm/K / -55°C to 155°C/ 0603(1608) / SMD / -	2	CRCW06034R70FK	AEC Q200	Fitted
RGH_1, RGH_2, RGH_3, RGL_1, RGL_2, RGL_3, RGND, RLIN, RSH1, RSH2, RSH3	0R	RES/STD/0R/ 100mW/0R/ 0ppm/K / -55°C to 155°C/ 0603(1608) / SMD / -	11	AC0603JR-070RL, RC0603JR-070RL	AEC Q200	Fitted

(table continues...)

7 Project collaterals

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Table 8 (continued) Bill of materials

Designator	Value	Description	Quantity	Manufacturer order number	Automotive qualified	Fitted
RGSH_1, RGSH_2, RGSH_3, RGSL_1, RGSL_2, RGSL_3	100k	RES/STD/ 100k/ 100mW/1% / 100ppm/K / -55°C to 155°C/ 0603(1608) / SMD / -	6	CRCW0603100KFK	AEC Q200	Fitted
RHSB_1, RHSB_2, RHSB_3, RLSB_1, RLSB_2, RLSB_3	4.7R	RES/STD/ 4.7R/ 125mW/1% / 100ppm/K / -55°C to 155°C/ 0805(2012) / SMD / -	0	CRCW08054R70FK	AEC Q200	Not Fitted
RMON	1k	RES/STD/1k/ 250mW/1% / 100ppm/K / -55°C to 155°C/ 1206(3216) / SMD / -	1	MCR18EZPF1001	AEC Q200	Fitted
RRP1	10k	RES/STD/10k/ 125mW/1% / 100ppm/K / -55°C to 155°C/ 0805(2012) / SMD / -	1	CRCW080510K0FK	AEC Q200	Fitted
RRP2	100k	RES/STD/ 100k/125mW/ 0.1% / 25ppm/K / -55°C to 155°C/ 0805(2012) / SMD / -	1	ERA6AEB104V	AEC Q200	Fitted
RRST	2k	RES / - / 2k/ 100mW/1% / 100ppm/K / - / 0603(1608) / SMD / -	1	ERJ3EKF2001V	AEC Q200	Fitted

(table continues...)

7 Project collaterals

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Table 8 (continued) Bill of materials

Designator	Value	Description	Quantity	Manufacturer order number	Automotive qualified	Fitted
Rshunt	5mR	RES/STD/5mR /2.5W/1% / 50ppm/K / -65°C to 170°C/ 6.35mm L X 3.05mm W X 0.81mm H/SMD / -	1	BVT-I-R005-1.0	AEC Q200	Fitted
RTB	47R	RES/STD/47R/ 100mW/1% / 100ppm/K / -55°C to 155°C/ 0603(1608) / SMD / -	1	CRCW060347R0FK	AEC Q200	Fitted
RTMS	4.7k	RES/STD/ 4.7k/ 63mW/1% / 100ppm/K / -55°C to 155°C/ 0402(1005) / SMD / -	1	CRCW04024K70FK	AEC Q200	Fitted
RVSCP	2.2R	RES/STD/ 2.2R/ 250mW/1% / 100ppm/K / -55°C to 155°C/ 1206(3216) / SMD / -	1	CRCW12062R20FK	AEC Q200	Fitted
SWD DEBUGGER	FTSH-105-01-L-DV-K	SMT Micro Header, 1.27mm pitch, 10 pin, vertical, double row, keying shroud,DAP	1	FTSH-105-01-L-DV-K	No	Fitted
TRACEBOX DEBUGGER	FTSH-106-01-L-DV-K	Connector Header Surface Mount 12 position 0.050 (1.27mm)	1	FTSH-106-01-L-DV-K	No	Fitted

(table continues...)

7 Project collaterals

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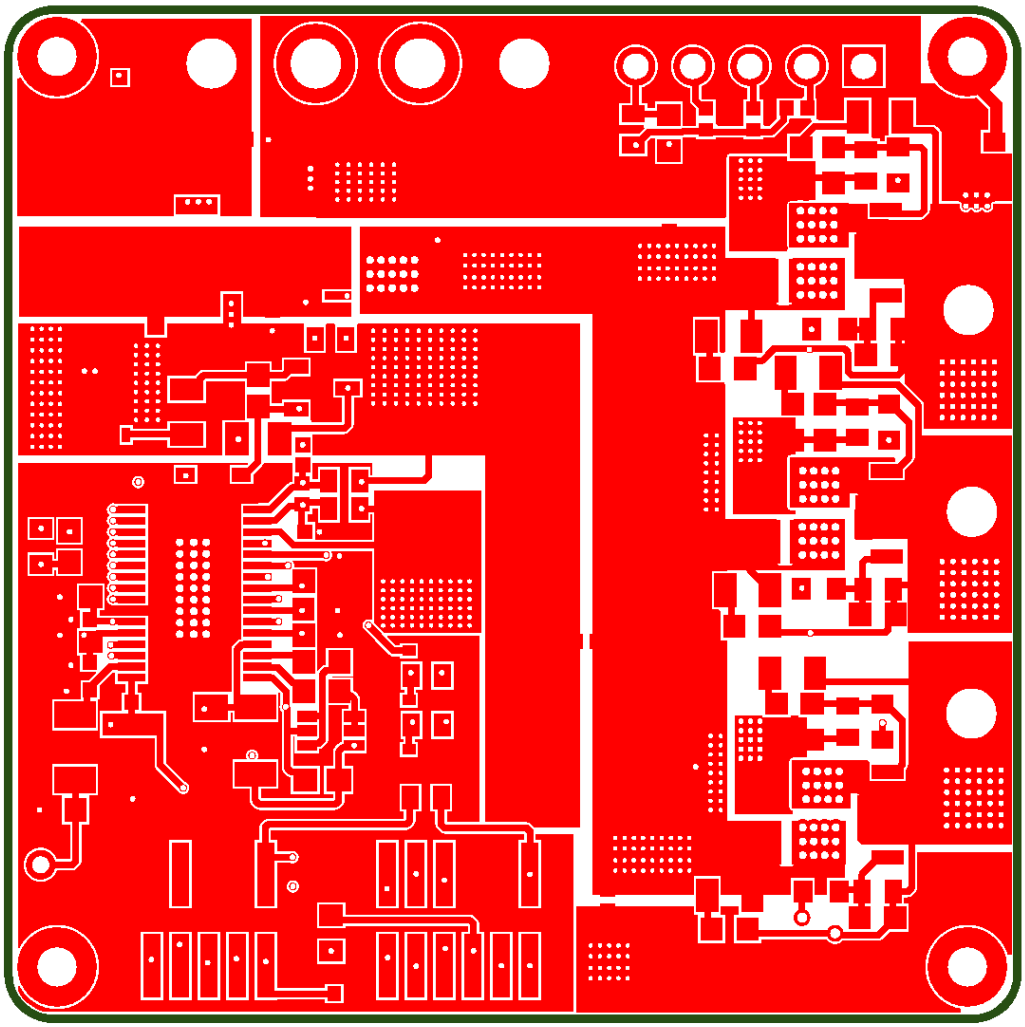
Table 8 (continued) Bill of materials

Designator	Value	Description	Quantity	Manufacturer order number	Automotive qualified	Fitted
U1	TLE9954EQW40	Microcontroller with LIN and NFET Driver for BLDC application	1	TLE9954EQW40	AEC Q100	Fitted
X_SIG	TSM-110-01-F-SV	SMT .025 SQ Post Header, 2.54mm pitch, 10-pin, vertical, single row	0	TSM-110-01-F-SV	No	Not Fitted

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7.3 Layout

Figure 61 Top Layer



7 Project collaterals

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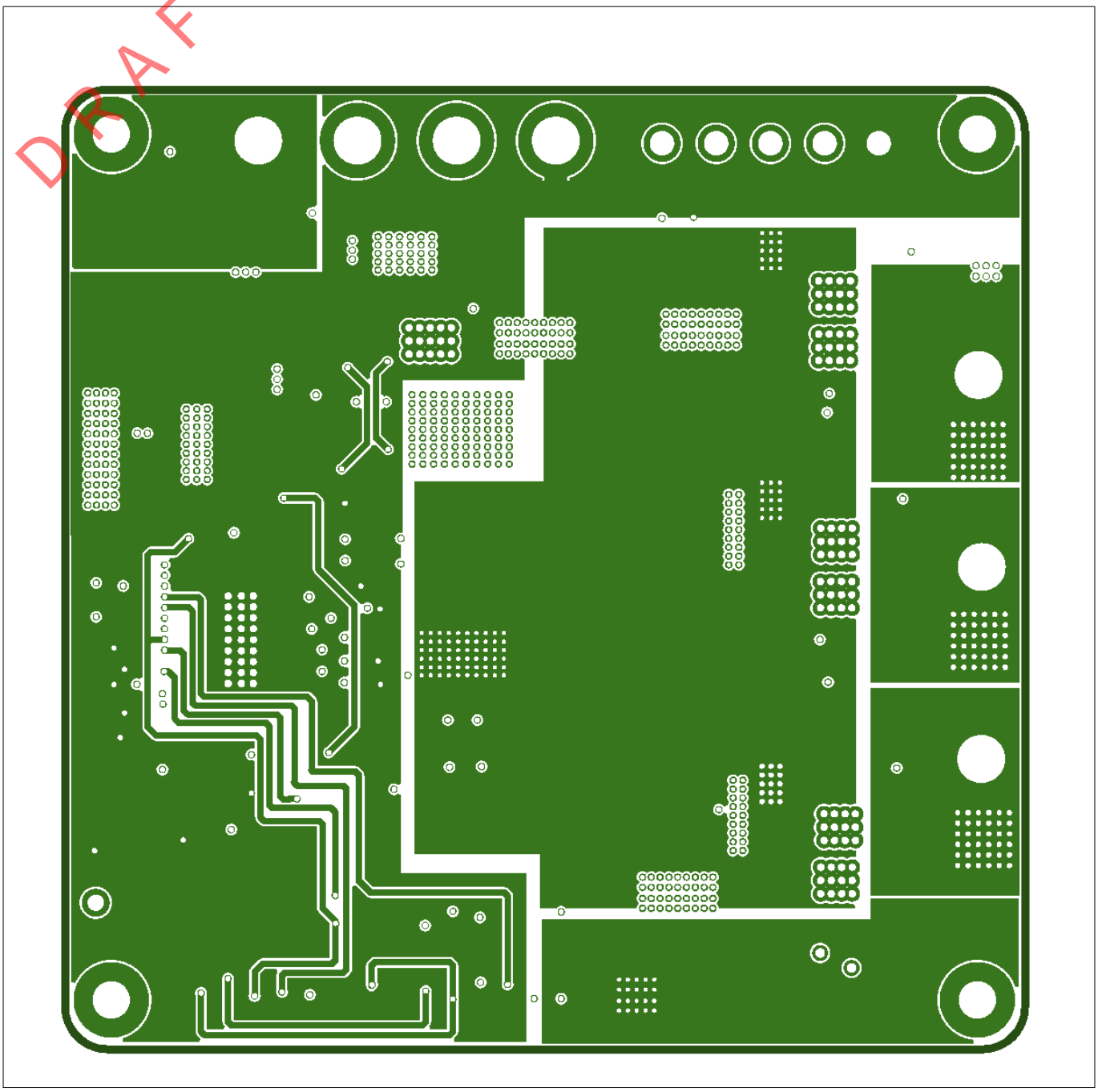


Figure 62 Power Layer

7 Project collaterals

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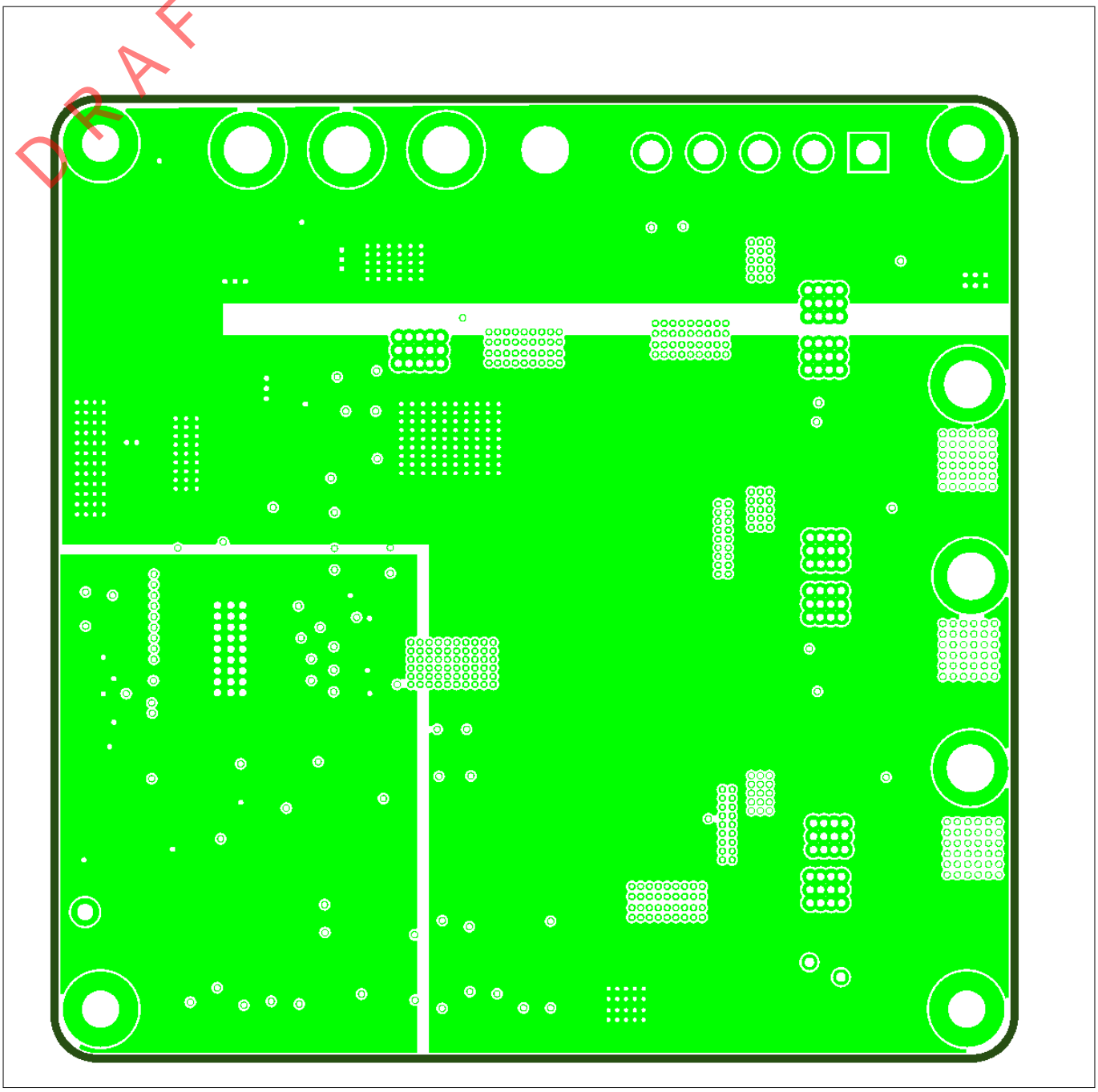


Figure 63 Ground Layer

7 Project collaterals

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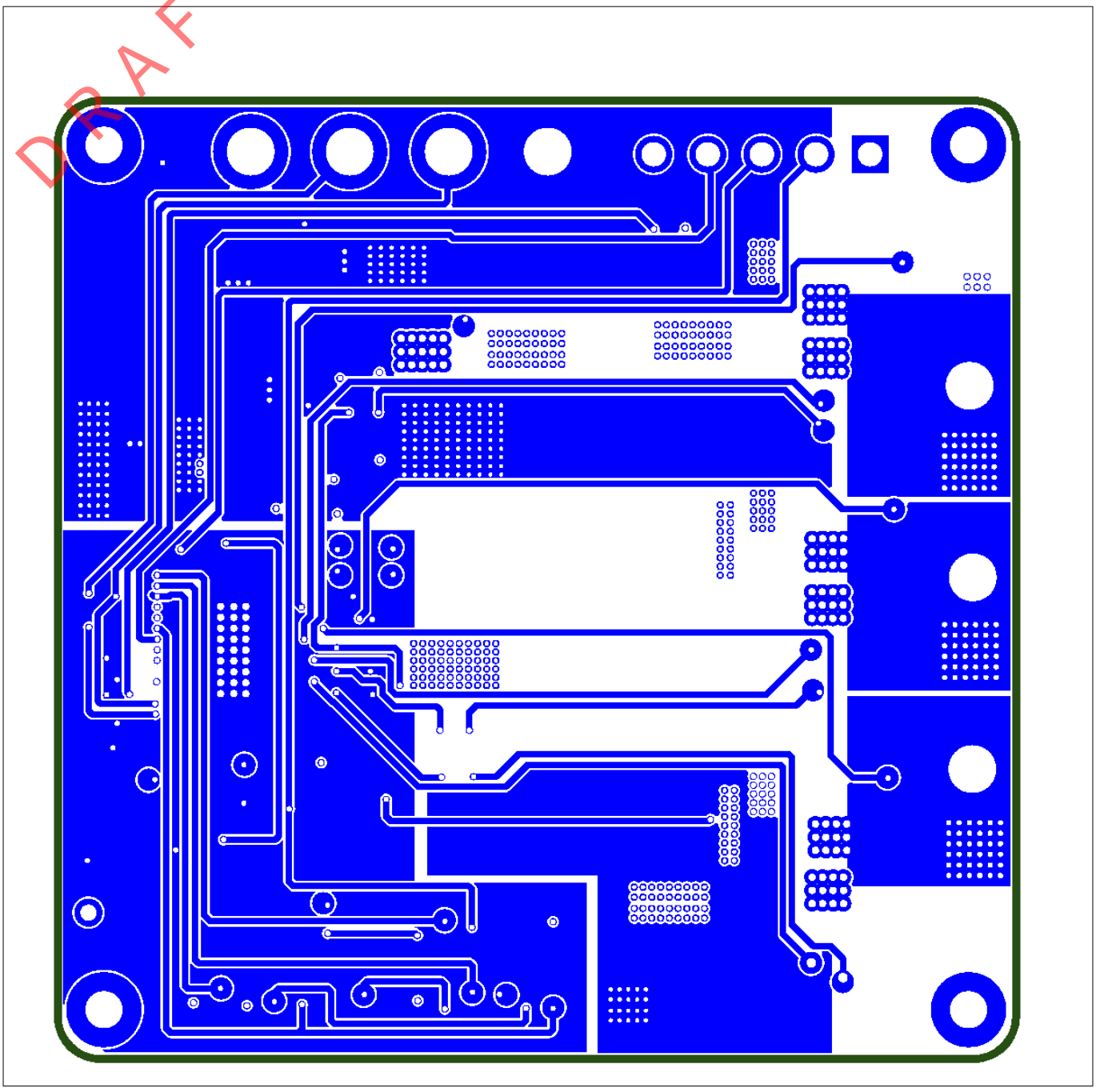


Figure 64 Bottom Layer

References

[1] *Infineon: Reverse Polarity Protection for Embedded Power ICs*https://www.infineon.com/dgdl/Infineon-Reverse_Polarity_Protection-ApplicationNotes-v01_00-EN.pdf?fileId=5546d46267c74c9a01684be08bf45dfb&da=t

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Glossary

API

application programming interface (API)

A set of defined rules that enables various software components to communicate with each other.

BLDC motor

brushless DC motor (BLDC motor)

A synchronous motor using a direct current electric power supply.

BLDC

brushless direct current (BLDC)

bootROM

boot code in ROM (bootROM)

The location of boot code.

CSA

current-sense amplifier (CSA)

Special-purpose amplifiers that output a voltage proportional to the current flowing in a power rail. They utilize a "current-sense resistor" to convert the load current in the power rail to a small voltage, which is then amplified by the current-sense amplifiers.

ECU

electronic control unit (ECU)

An embedded system in automotive electronics that controls one or more of the electrical systems or subsystems in a car or other motor vehicle.

EMC

electromagnetic compatibility (EMC)

The ability of electrical equipment and systems to function acceptably in their electromagnetic environment, by limiting the unintentional generation, propagation and reception of electromagnetic energy which may cause unwanted effects such as electromagnetic interference (EMI) or even physical damage in operational equipment.

EMI

electromagnetic interference (EMI)

A disturbance generated by an external source that affects an electrical circuit by electromagnetic induction, electrostatic coupling, or conduction.

GND

ground (GND)

HB

half bridge (HB)

A type of power electronic circuit that uses two switches in a serial connection, unlike an H-bridge or full bridge, which uses four switches.

LIN

local interconnect network (LIN)

Glossary

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PCB

printed circuit board (PCB)

A board that mechanically supports and electrically connects electronic components using conductive tracks, pads, and other features etched from copper sheets laminated onto a non-conductive substrate.

PWM

pulse-width modulation (PWM)

A technique to encode an analog value into the duty cycle of a pulsing signal with arbitrary amplitude.

SPI

serial peripheral interface (SPI)

A synchronous serial communication interface specification used for inter-chip communication, primarily in embedded systems.

SWD

serial wire debug (SWD)

A communication interface and protocol used for debugging and programming embedded systems, particularly microcontrollers and other integrated circuits.

VBAT

battery voltage supply (VBAT)

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Revision history

Document version	Date of release	Description of changes
Rev. 1.00	2025-07-10	• Initial document release

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Edition 2026-mm-dd

Published by

Infineon Technologies AG

81726 Munich, Germany

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Document reference
IFX-dqi1770962078325

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