15 W actuator control reference design

User guide

Z8F80902074

About this document

Scope and purpose

This user guide provides instructions for using the reference design, which is designed to evaluate the performance of TLE9934EVW40C MOTIX™ MCU for applications like coolant valve and grill shutter actuator control. Moreover, this user guide provides an overview on the whole system offering for actuator control and extensive technical information on the board.

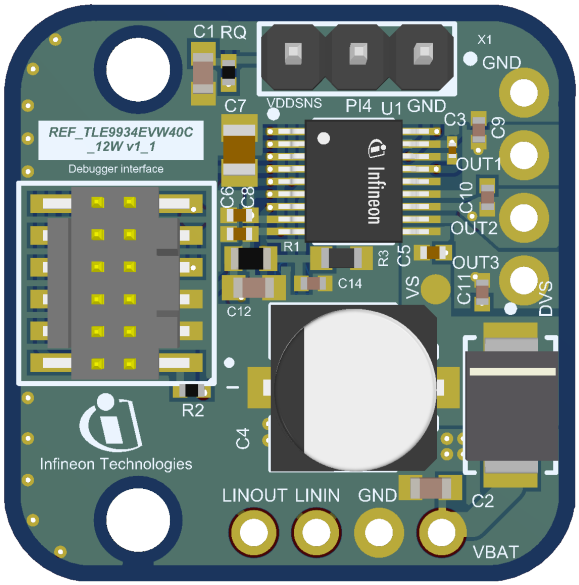

Figure 1 15 W actuator control reference board (REF_Mini_Actuator_15W)

Intended audience

This document is intended for anyone using Infineon's REF_Mini_Actuator_15W reference design.

***Note**: The printed circuit board (PCB) and the auxiliary circuits are NOT optimized for final customer design.*

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Safety precautions

***Note**:* *Note the following warnings regarding the hazards associated with development systems.*

Table 1 **Safety precautions**

	**Warning:** *The DC link potential of this board is up to 1000 V or more. When measuring voltage waveforms by oscilloscope, high voltage differential probes must be used. Failure to do so may result in personal injury or death.*
	**Warning:** *The evaluation or reference board contains DC bus capacitors which take time to discharge after removal of the main supply. Before working on the drive system, wait five minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	**Warning:** *The evaluation or reference board is connected to the grid input during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by oscilloscope. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	**Warning:** *Remove or disconnect power from the drive before you disconnect or reconnect wires, or perform maintenance work. Wait five minutes after removing power to discharge the bus capacitors. Do not attempt to service the drive until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.*
	**Caution:** *The heat sink and device surfaces of the evaluation or reference board may become hot during testing. Hence, necessary precautions are required while handling the board. Failure to comply may cause injury.*
	**Caution:** *Only personnel familiar with the drive, power electronics and associated machinery should plan, install, commission and subsequently service the system. Failure to comply may result in personal injury and/or equipment damage.*
	**Caution:** *The evaluation or reference board contains parts and assemblies sensitive to ESD. Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable* ESD *protection handbooks and guidelines.*
	**Caution:** *A drive that is incorrectly applied or installed can lead to component damage or reduction in product lifetime. Wiring or application errors such as undersizing the motor, supplying an incorrect or inadequate AC supply, or excessive ambient temperatures may result in system malfunction.*
	**Caution:** *The evaluation or reference board is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.*

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1 TLE993x System offering

Infineon's system offering for TLE993x encompasses a range of components that work together to provide a comprehensive solution.

Key Components:

- **Infineon TLE993x evaluation board**: A robust hardware foundation for efficient integration and connectivity with TLE993x and several interfaces
- **Infineon TLE993x evaluation kit**: It is an compact board for evaluation with reduced interface and cost effective
- **15 W actuator control reference design (REF_Mini_Actuator_15W)**: It is a optimized *PCB* for size, thermal and *electromagnetic compatibility (EMC)* performance
- **Coolant valve application software**: An embedded software project for Keil uVision which includes the peripheral driver library and application code
- **MOTIX™ peripheral driver library (PDL)**: The peripheral driver library (PDL) integrates device header files, startup code, and peripheral drivers into a single package. The PDL supports the MOTIX™ and LITIX™ devices (CAT9) family. The drivers abstract the hardware functions into a set of easy-to-use APIs
- **MOTIX™ MCU Device configurator**: A PC tool consisting of a *graphical user interface (GUI)*. It allows to enable and configure device peripherals, such as clocks and pins, as well as standard MCU peripherals
- **MOTIX™ MCU Solution designer**: It is a graphical configuration tool to analyze, debug and tune your motor control application based on Infineon's MOTIX™ motor control stack
- **MOTIX™ MCU Memory analyzer**: The memory analyzer is a tool used for analyzing the memory assignment and statistics, of an ARM linker
- **MOTIX™ MCU BSL tool** : BSL programming tool is the user interface to control the firmware of a *microcontroller unit (MCU)* target via the provided *bootstrap loader (BSL)* commands interactively for MOTIX™ and LITIX™ products
- **Infineon Automotive Power Explorer**: It provides powerful features to decide and find on best fitting products based on integrated calculations and simulations of power dissipation, transient thermal and other essential analysis

2 Introduction

The reference design is based on the latest generation of the MOTIX™ MCU family REF_Mini_Actuator_15W. This integrated solution combines multiple key components, including the *MCU*, power management, gate driver, communication, and MOSFETs, all within a single package. The design of the board has been carefully optimized to achieve a compact size while also ensuring optimal thermal performance and *EMC*.

The reference design can be supplied over input supply interface with 12 V *direct current (DC)*. The board is protected against reverse polarity of the input voltage supply.

The board has a 12 pin connector which could directly be used by Tracebox or it can be used to connect to supplementary board to flash the device with *serial wire debug (SWD)* connector. The power stage output, *local interconnect network (LIN)* auto addressing and sensor interfaces are available on the board.

2 Introduction

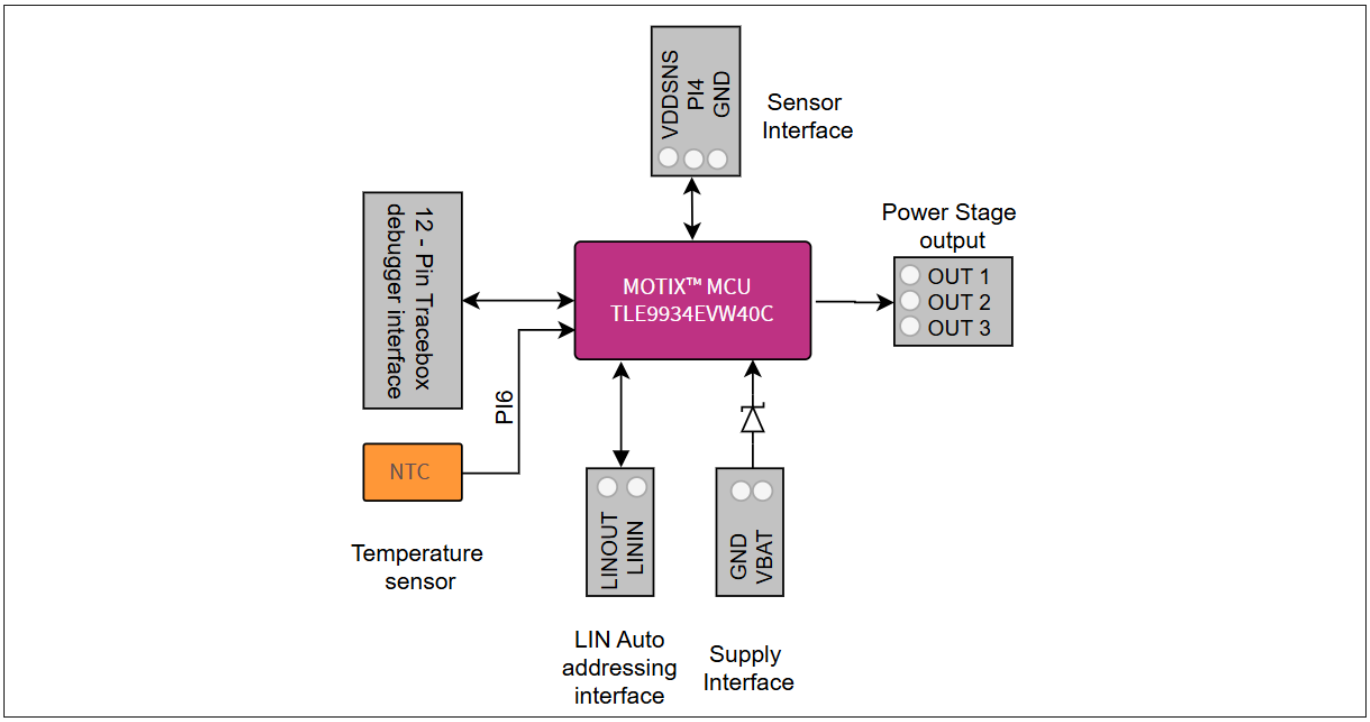

Figure 2 Block diagram

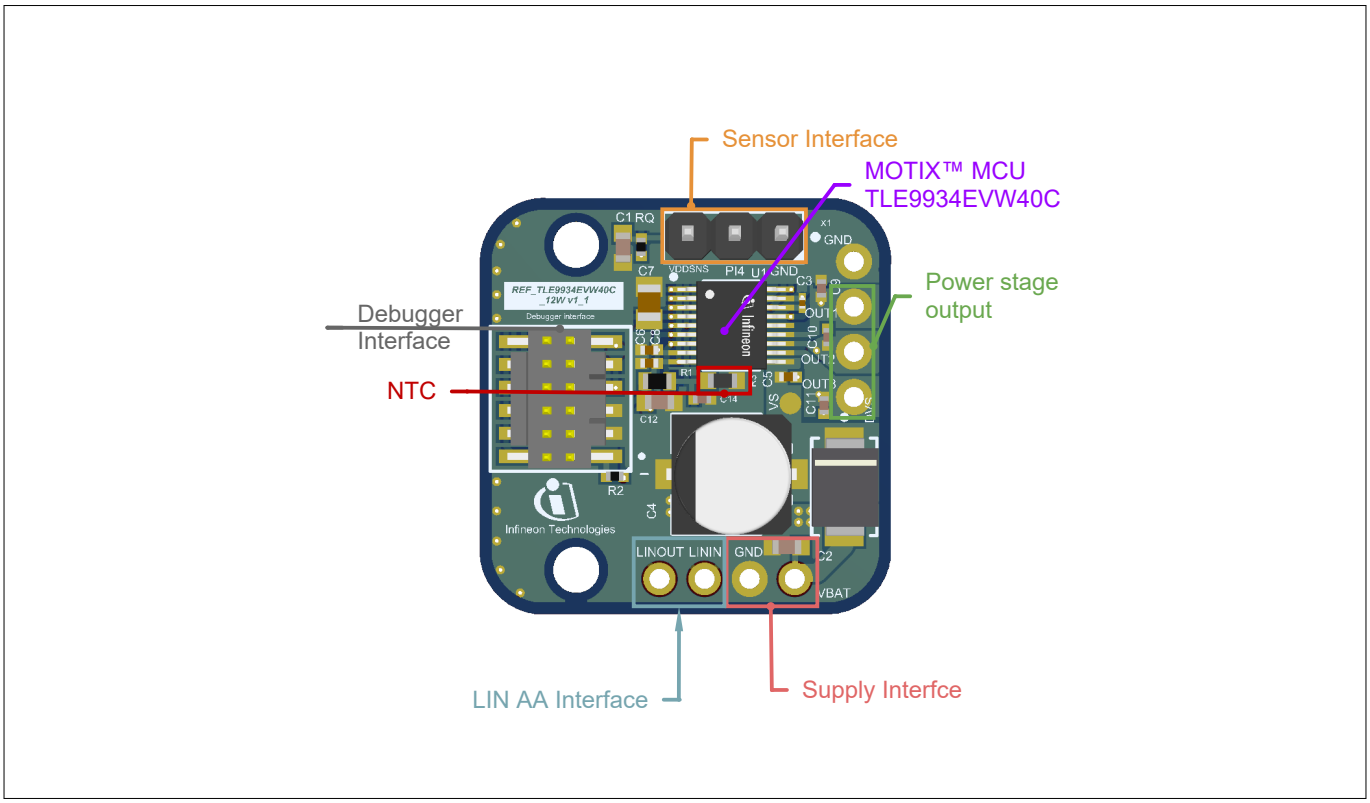

Figure 3 REF_Mini_Actuator_15W reference design

Box delivery content

The coolant valve reference board is delivered together with a supplementary connector board to flash the board using SWD connector, XMC™ link to connect SWD connector to PC and a QR code on the box to access exclusive content for the board, such as *PCB* design files, EMC and thermal performance report.

3 In detail: REF_Mini_Actuator_15W reference design

3.1 Technical data

Technical data is specified in the table below.

Table 2 Technical data

Parameter	Value
Supply voltage	Specified by design Typ. 13 V (max. 28 V)
Supply current	Max. 1.3* A
Pin ports	5 V
Board size	22 mm x 22 mm
Conducted emission	Class 5 (CISPR25, 150kHz -108 MHz)

3.2 Functional description

3.2.1 Power supply

The board can be powered up with 12 V *DC* supply through the *battery voltage supply (VBAT)* and *ground (GND)* interface. The board has a diode to protect it against the reverse polarity and a buffer cap C4 to mitigate the impact of fast changing currents due to *metal-oxide-semiconductor field-effect transistor (MOSFET)* switching to the main supply. For more information on power supply circuit, refer to Schematic of REF_Mini_Actuator_15W reference design

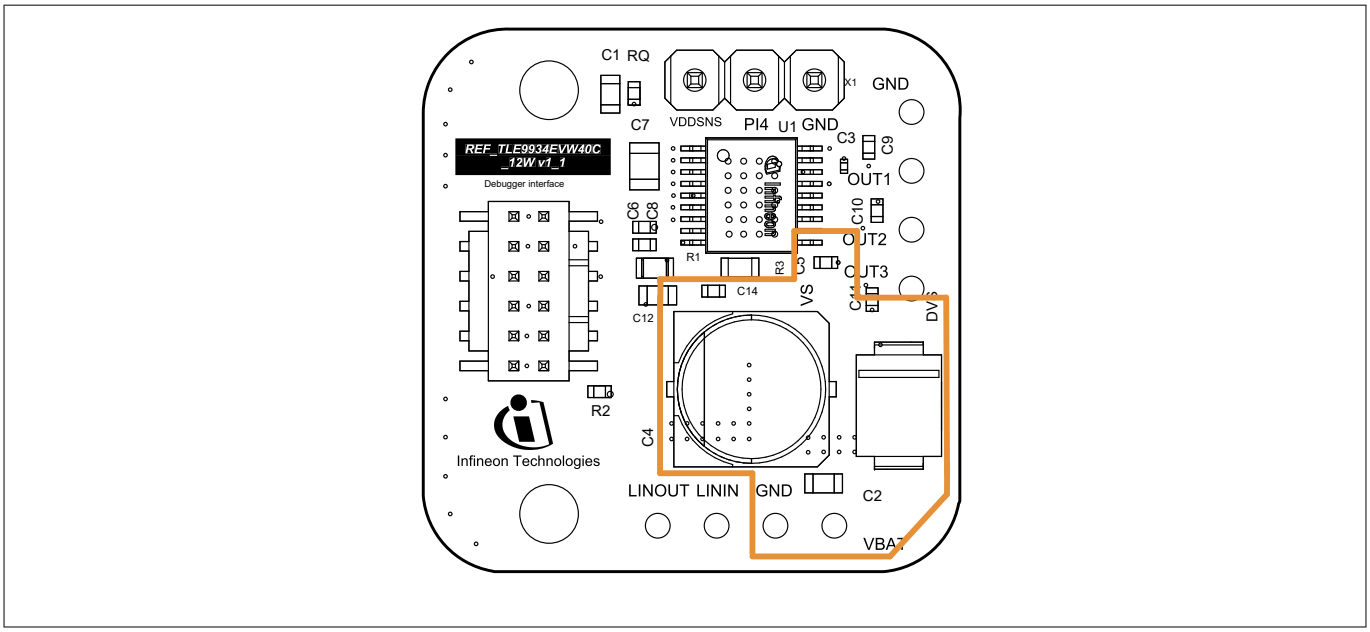

Figure 4 Power supply circuit

3.2.2 Power stage

The integrated power stages of MOTIX™ MCU TLE9934EVW40C are connected to the output interface at OUT1, OUT2 and OUT3 respectively.

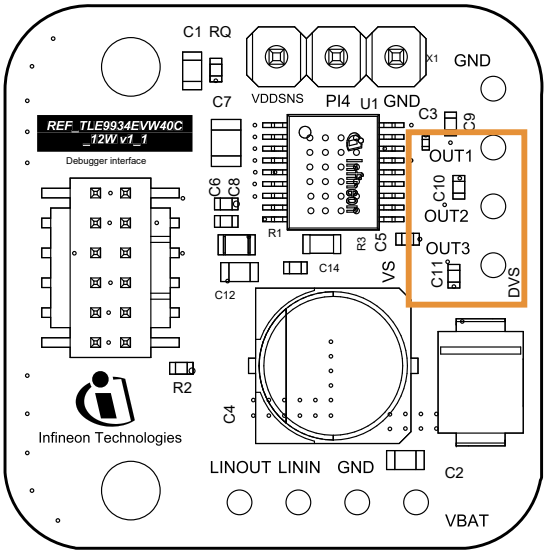

Figure 5 Power stage output

3.2.3 Debugger interface

The board has a 12- pin connector which can directly be used with trace-box to flash the device. To use the *SWD* interface for flashing with 10 pin SWD ARM connector, connect reference board to supplementary connector board using flex cable which is provided in the box.

For more information on 12-pin connector pinout, refer to Schematic of REF_Mini_Actuator_15W reference design

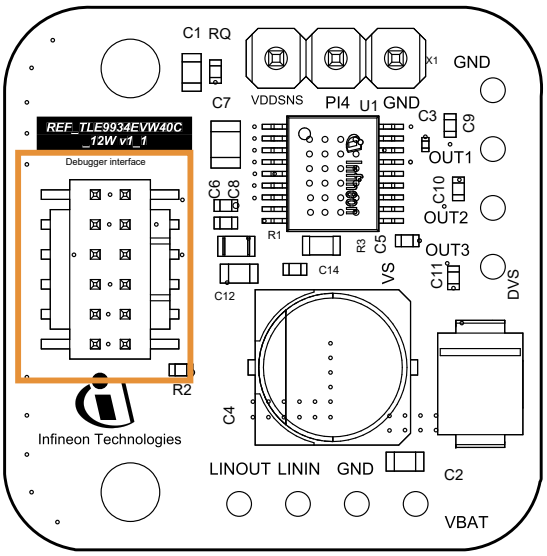

Figure 6 Debugger interface

3.2.4 Test points

All the TLE9934EVW40C device pins can be accessed through test points on the bottom side of the *PCB* as shown in the picture below

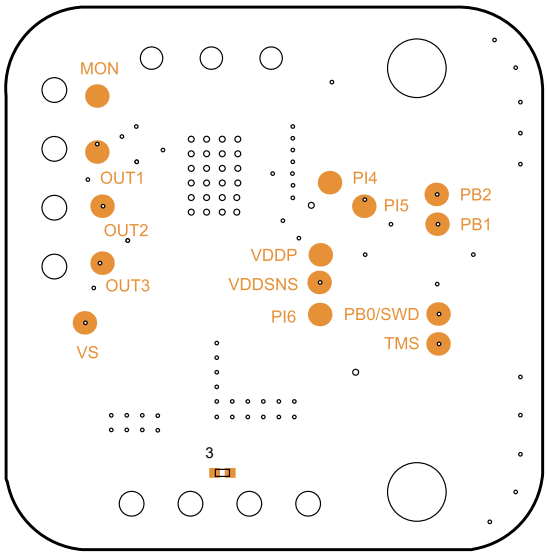

Figure 7 Test points - PCB bottom

3.2.5 LIN Auto-addressing

The integrated *LIN* auto-addressing (AA) transceiver pins of MOTIX™ MCU TLE9934EVW40C are available at through-hole interface as shown in the picture below.

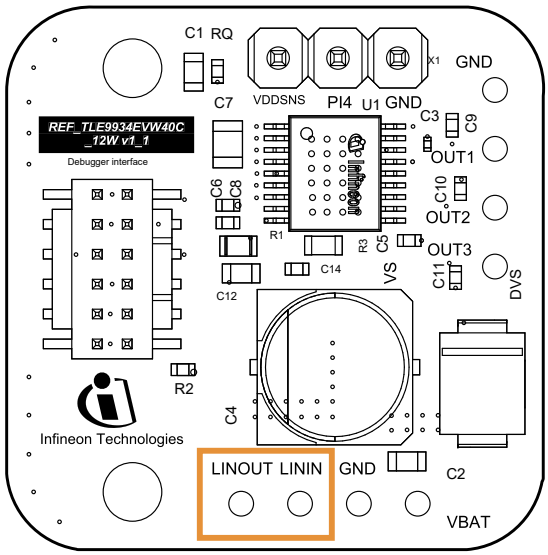

Figure 8 LIN AA interface

3.2.6 Temperature sensor (NTC)

The board is equipped with a temperate sensor *negative temperature coefficient (NTC)*. The analog output of the sensor is connected to the PI6 input pin of the TLE9934EVW40C. For more information, refer to Schematic of REF_Mini_Actuator_15W reference design

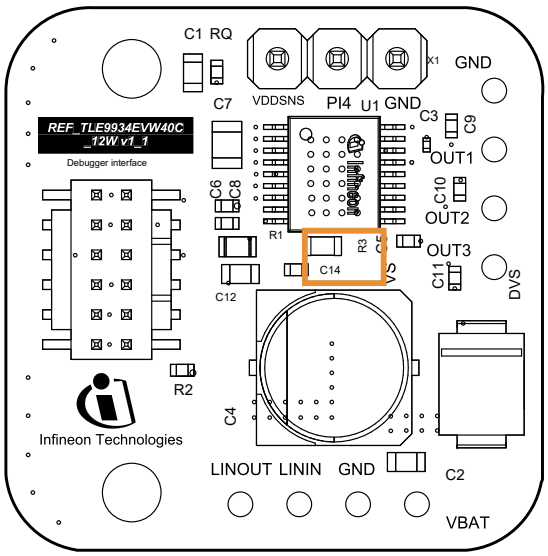

Figure 9 NTC sensor

3.2.7 Hall latch sensor interface

On the reference design an optional three pin interface for the Hall latch sensor is available. The sensor supply pin is connected to VDDSNS of the TLE9934EVW40C, sensor *GND* pin is connected to the ground of the board and sensor output pin the connected to the input pin PI4 of the TLE9934EVW40C. For more information, refer to Schematic of REF_Mini_Actuator_15W reference design

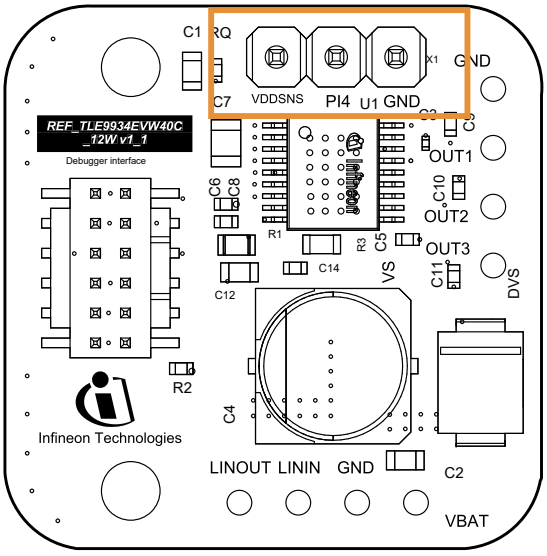

Figure 10 Sensor input terminal

3.2.8 Assembly options

Values for these optional additional placements must be determined depending on the application. The typical components and values can be found in Bill of material evaluation board.

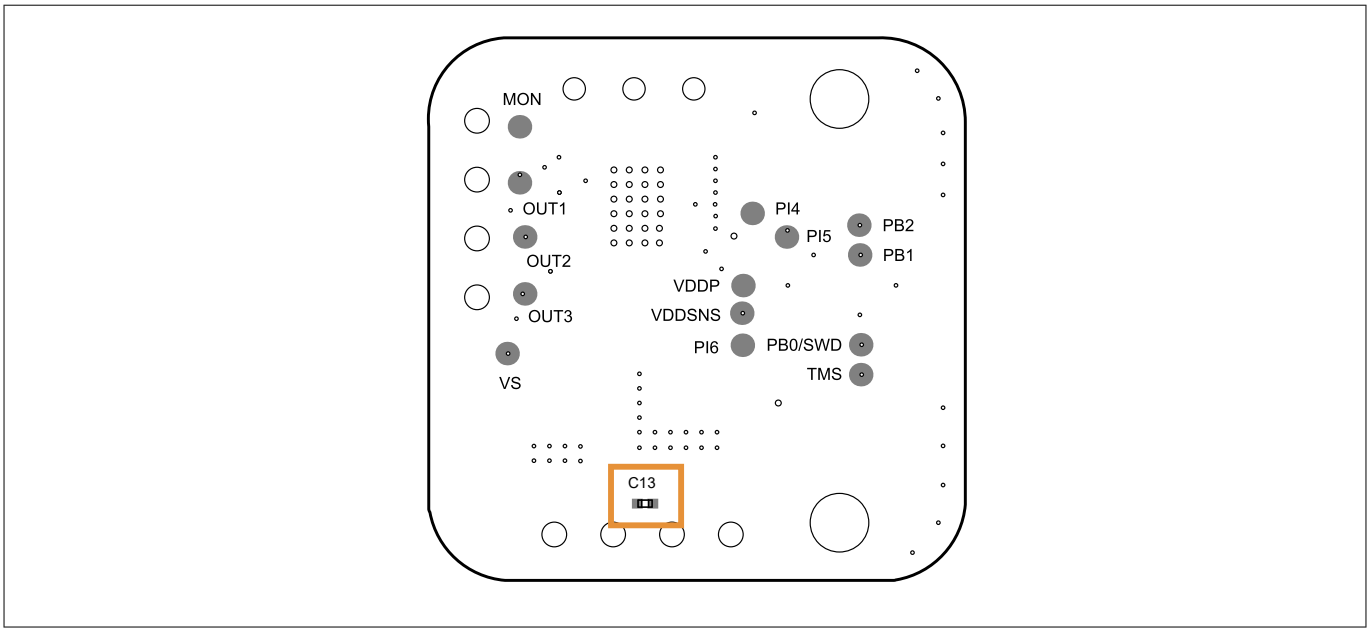

Figure 11 Assembly options

Table 3 Additional placement

Designator	Description
C13	Optional filter capacitor at *LIN*

4 Hardware design guide

4.1 General component selection

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

Since the 15 W actuator control reference board (REF_Mini_Actuator_15W) is designed for automotive applications, 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 the heat dissipation. Certain components such as the capacitors are derated by at least 25% due to unexpected voltage spikes in the system.

The FR4 2-layer board has been meticulously designed with all the components connected on the top side to allow for optimized cooling.

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)*. The figure below shows an overview of the top and bottom side of the *PCB*.

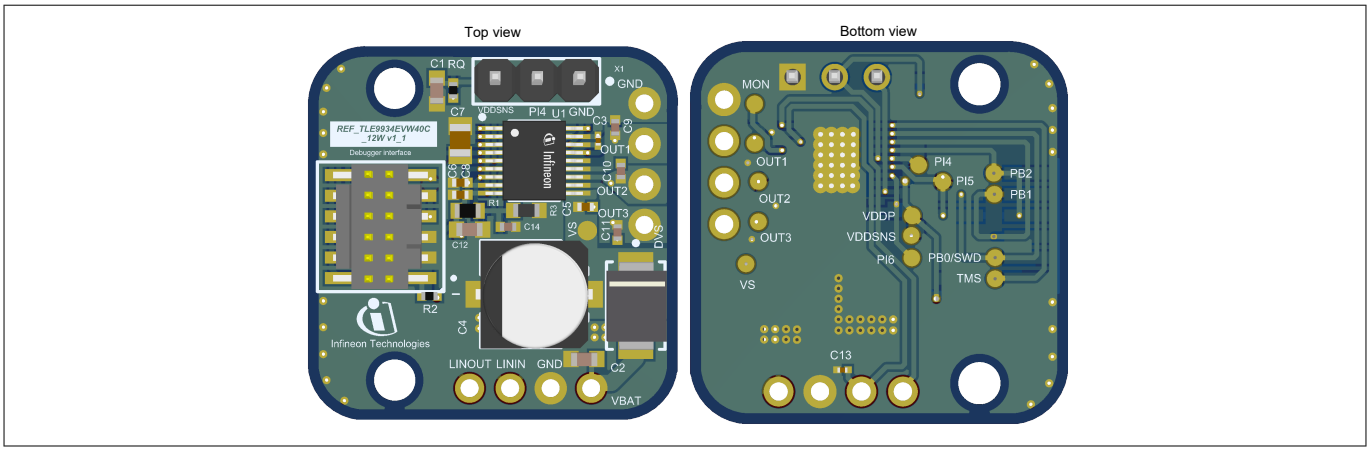

Figure 12 15 W actuator control reference board views

4.2 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. The 15 W actuator control reference board uses D_VS diode to realize the reverse polarity protection circuit.

The figure below exhibits the location of the reverse polarity protection circuit on the 15 W actuator control reference board along with the components used for the implementation.

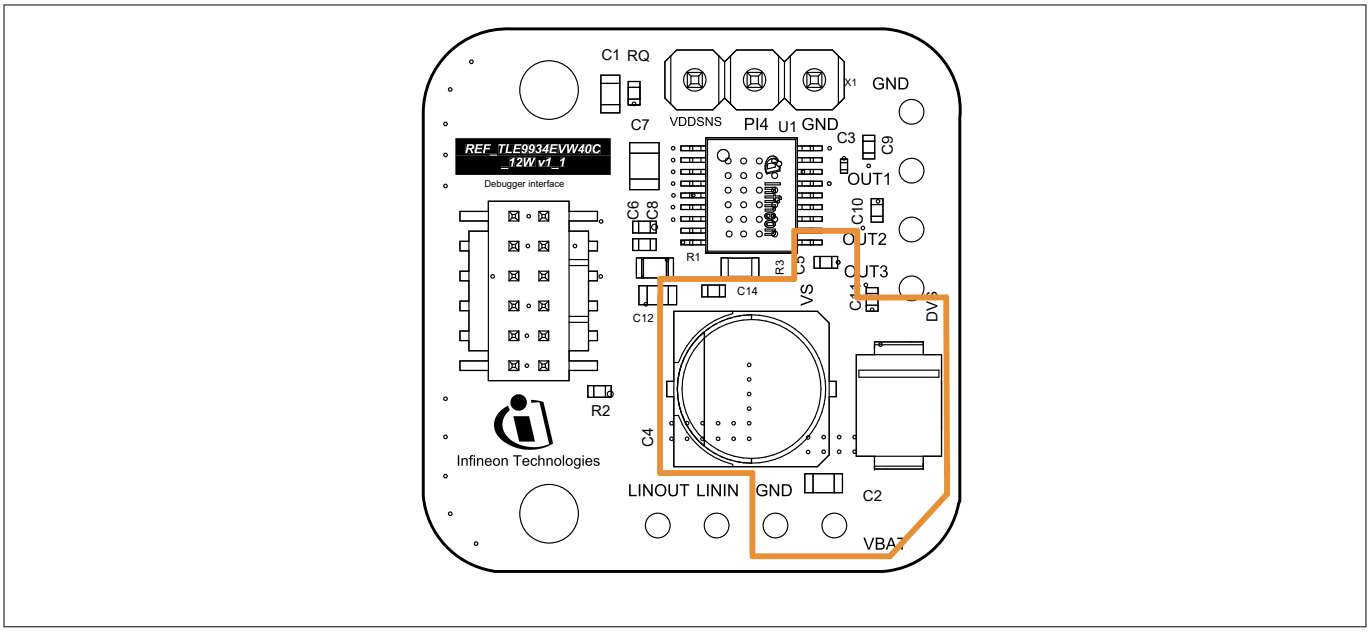

Figure 13 15 W actuator control reference board reverse polarity protection

4.3 External components

All the external components should be placed as close to the relevant pins of devices as possible for maximum effectiveness.

The component selection for all the components surrounding devices are based on the hardware design guideline of the TLE9934EVW40C device

4.4 Decoupling and filter capacitors

Several buffer and decoupling capacitors are connected to input voltage (*voltage supply (VS)*) and voltage regulators (VDDP and VDDSNS) output of device to stabilize the input and output voltage respectively.

Moreover, a filter circuit is placed for *LIN* pin to suppress noise. It is important to ensure that the LIN ground is kept as standalone as possible to avoid coupling noise from LIN ground to the digital ground of the device.

4.5 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 loads. 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 *alternating current (AC)* machine (with near unity power factor), the worst-case current stress estimation with the output current ($I_{out,\ rms}$) is given by:

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

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

$$C_{DC\ -\ link} = I_{C,\ rms} \times \frac{1}{f_{PWM} \ \cdot \ V_{ripple}} \ = \ \frac{1}{\sqrt{2}} \ \times \ 1A \ \times \ \frac{1}{20kHz} \ = 35\mu F$$

Therefore, considering the capacitance dependency on voltage level and degradation, in this design, a 68 µF electrolytic capacitor is used for the bridge. Moreover, optional three ceramic capacitors are used to suppress high frequency noise.

4.6 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:

- 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 Diode to the *DC* link cap and the integrated half-bridges.

The current to the motor primarily flows through the top layer of the PCB. However, the return current flows through the bottom layer below the top layer. Via stitching from top layer to the layer below allows the return current to flow directly without any current loops towards supply ground.

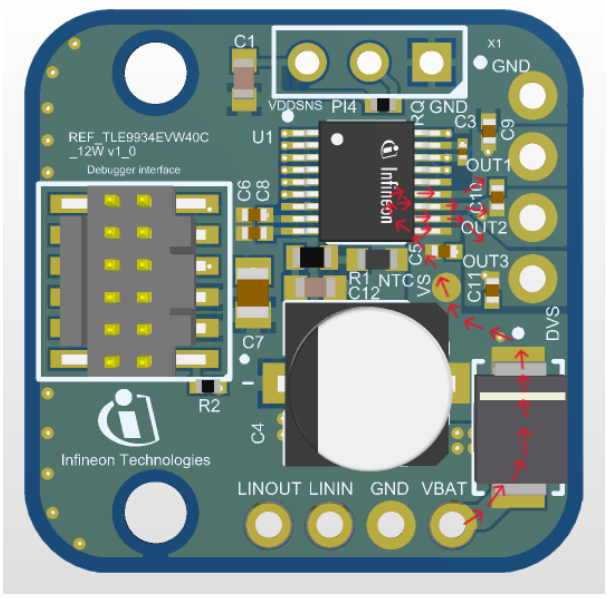

Figure 14 Supply current flow

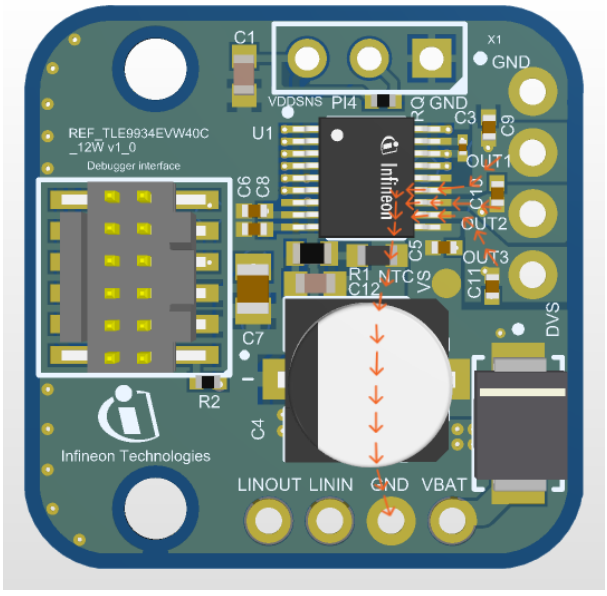

Figure 15 Return current flow

5 System performance

5.1 EMC tests

Test Setup

The measurements were performed in a semi-anechoic *EMC* chamber. The EMC level limits are compliant to CISPR25 class 5. Test setup conditions are defined in the table below.

Table 4 EMC test setup condition

Parameter/Peripheral	Description
Input voltage	13.5 V
PI Filter	No
MCU core frequency	40 MHz
Slew rate	50V/us
Load	Coolant valve, grill shutter
Speed	2000 RPM
Cable length between OUTx of board and load	• **Coolant valve:** 20cm • **Grill Shutter:** 30cm
Software	BEMF based 6-step block commutation
Setup mode	• **Init mode:** Device is active without any operation • **Application mode:** Complete application is running with 6 Step BEMF based block commutation

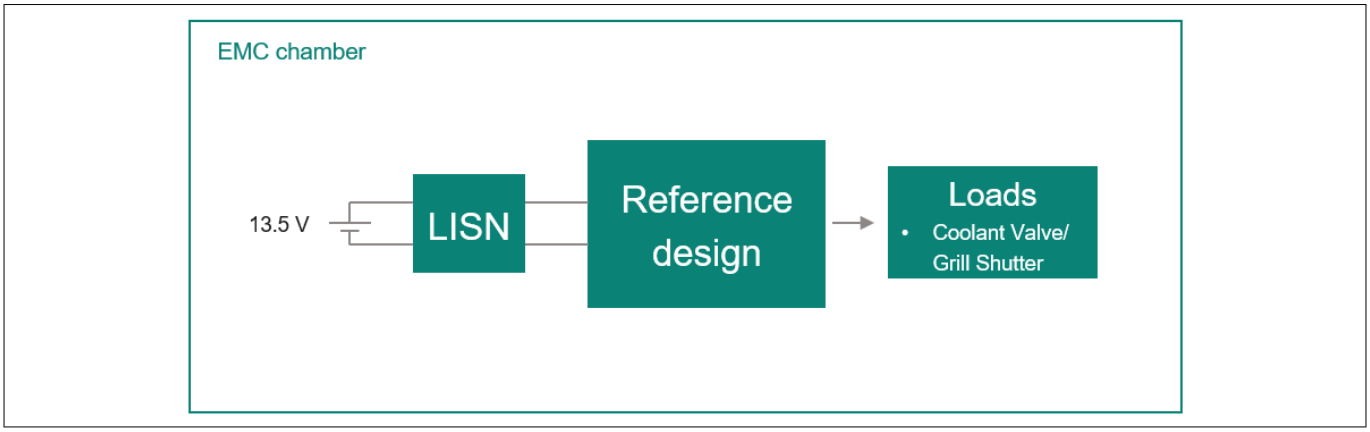

Figure 16 EMC chamber tests setup

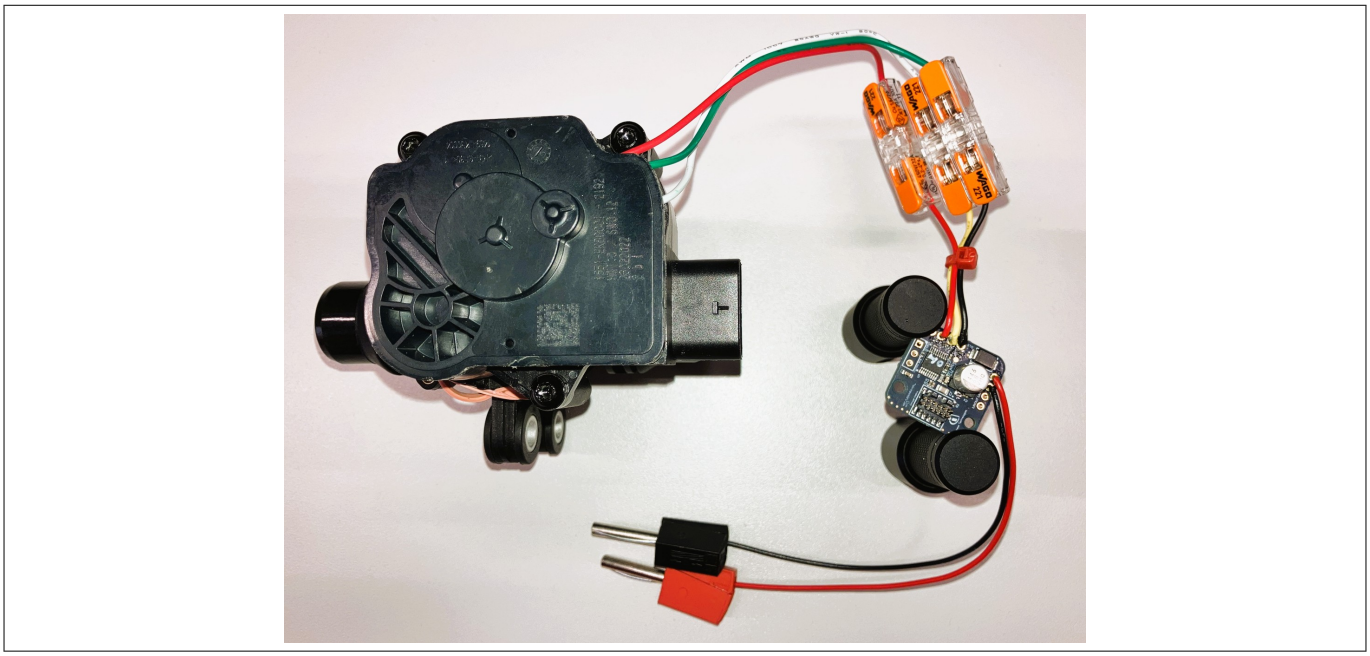

Figure 17 Coolant valve EMC test hardware setup

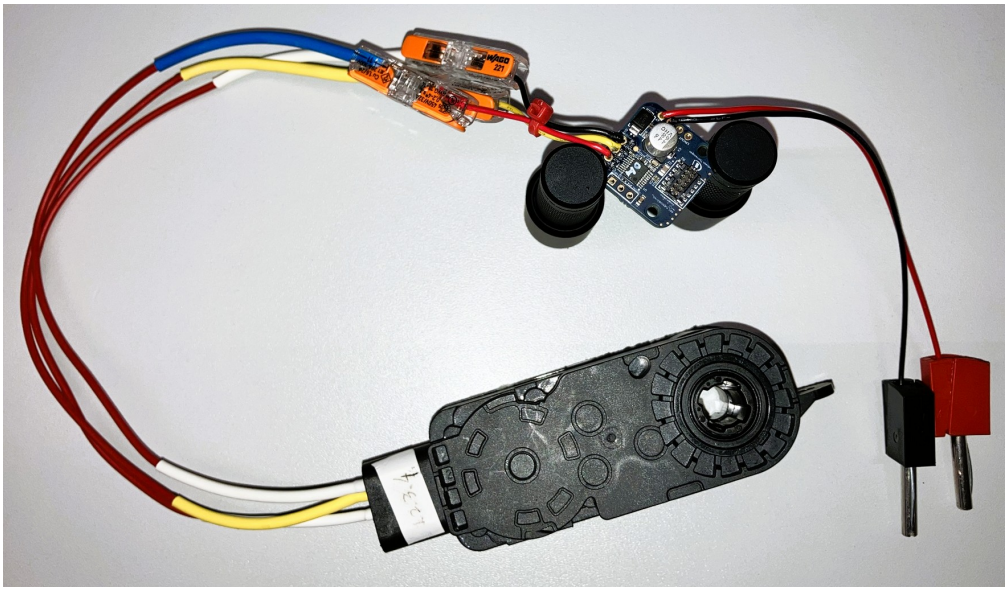

Figure 18 Grill Shutter EMC test hardware setup

Results

The EMC results were taken with two different loads, coolant valve and grill shutter, both loads have a different cable length between the OUTx of board and load terminal. Different cable length were selected to show the impact of the setup on EMC performance

Results without filter capacitors

The first result are taken with coolant valve and grill shutter without additional filter capacitor placed at input between *VS* to ground and OUTx to ground.

- In Figure 19 and Figure 20, we can see that there is a high emission in frequency range 4-12 MHz and followed by harmonics of that frequency, this noise is mainly coming from the fundamental digital and analog block of the device such as oscillator to generate the clock, bridge driver, *serial peripheral interface (SPI)* etc.
- In Figure 19 and Figure 20, we can also see the high emission in frequency range 12 - 120 MHz, it combines the noise coming from the measurement setup and harmonics of the lower frequency noise
- Remember that we have difference of cable length between OUTx to motor terminal for both loads and this impact we can see in the result. At high frequency, the noise for grill shutter in Figure 20 is bit shifted away from the 100 MHz, this is due to the fact of bit higher inductance, more antenna effect etc.

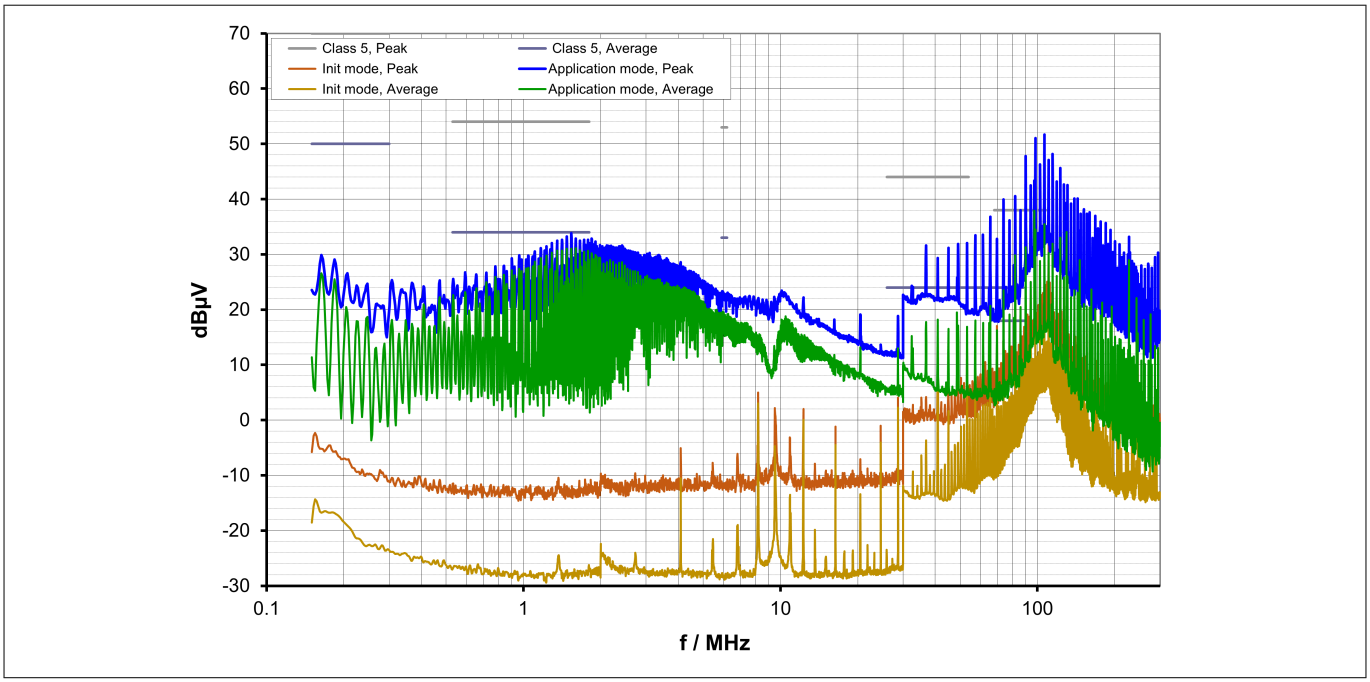

Figure 19 EMC result, Valve, reference design without caps at OUTx - GND and input Vs cap

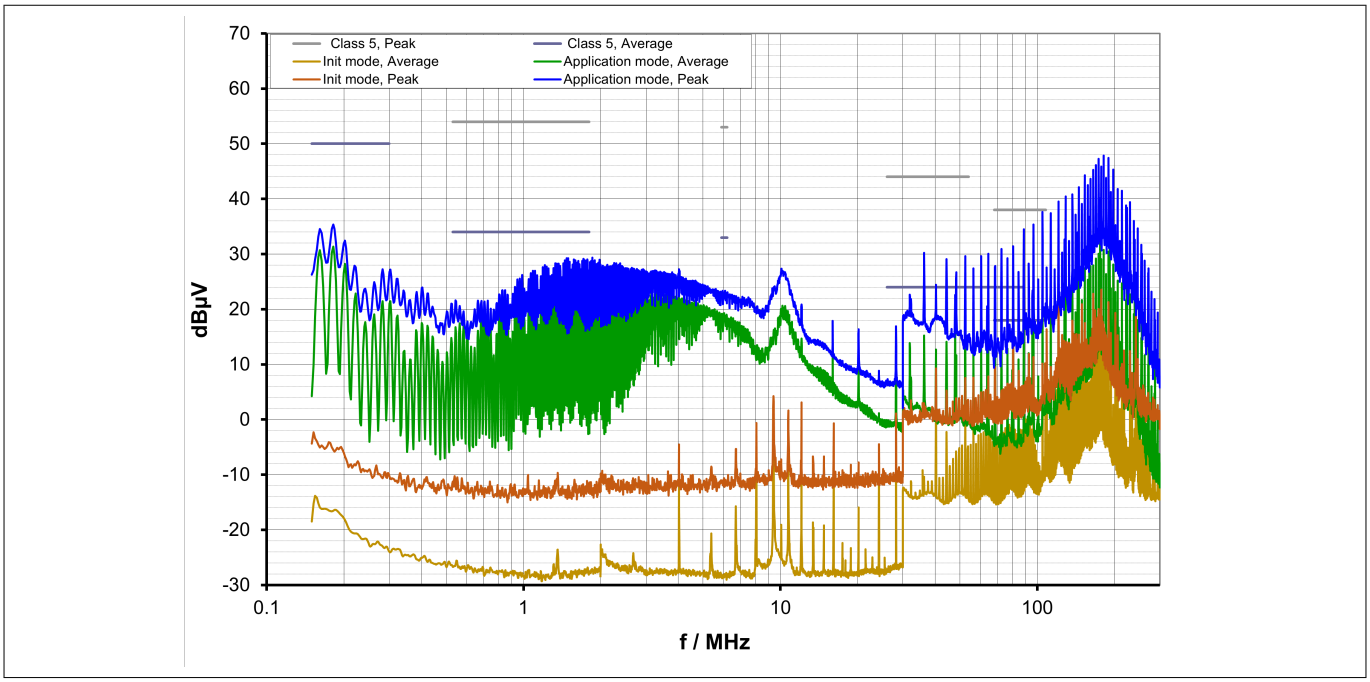

Figure 20 EMC result, Grill shutter, reference design without caps at OUTx - GND and input Vs cap

Results with filter capacitors

Now, there are two filter capacitors included on the board:

1. **100nF** : Capacitor between VS and ground at the input to reduce the emission in lower frequency range cased by fundamental blocks of the device
2. **1nF**: Capacitor between OUTx and ground close to the OUTx terminal at *PCB* to reduce the noise at high frequency range coming form the setup

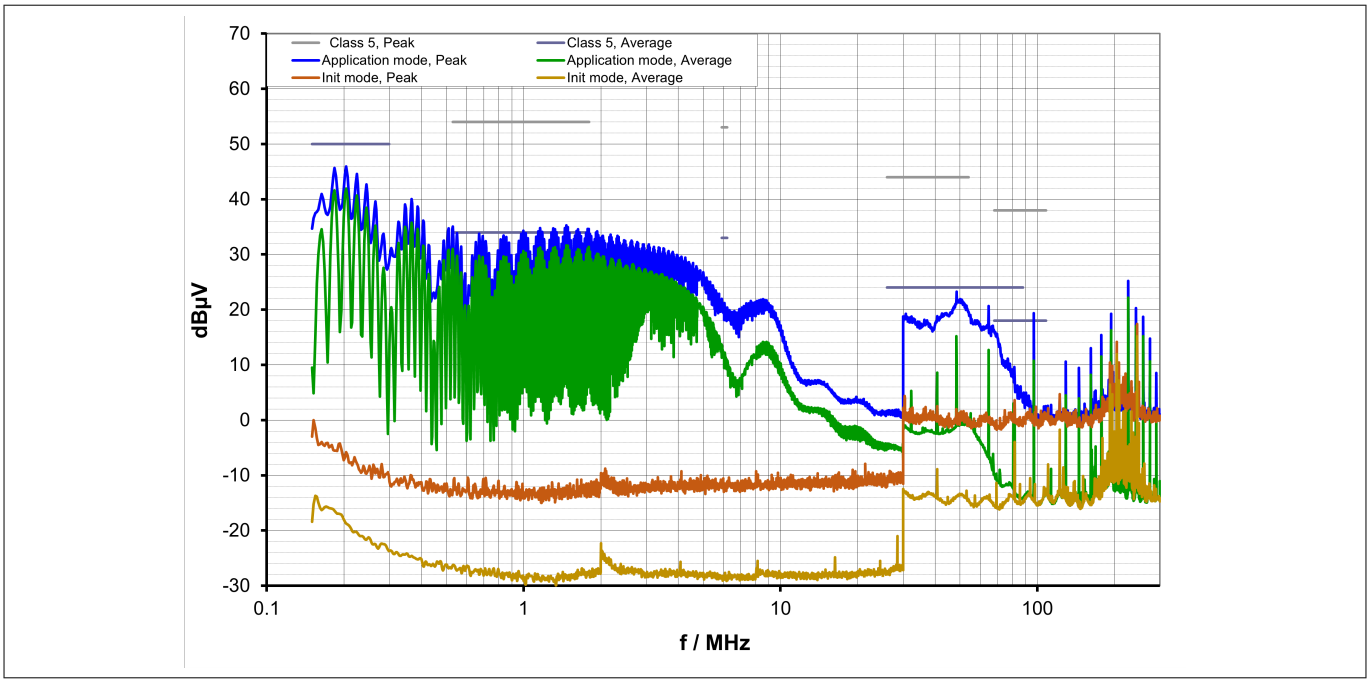

Figure 21 **EMC result, Valve, reference design with 1nF caps at OUTx - GND and 100nF input cap**

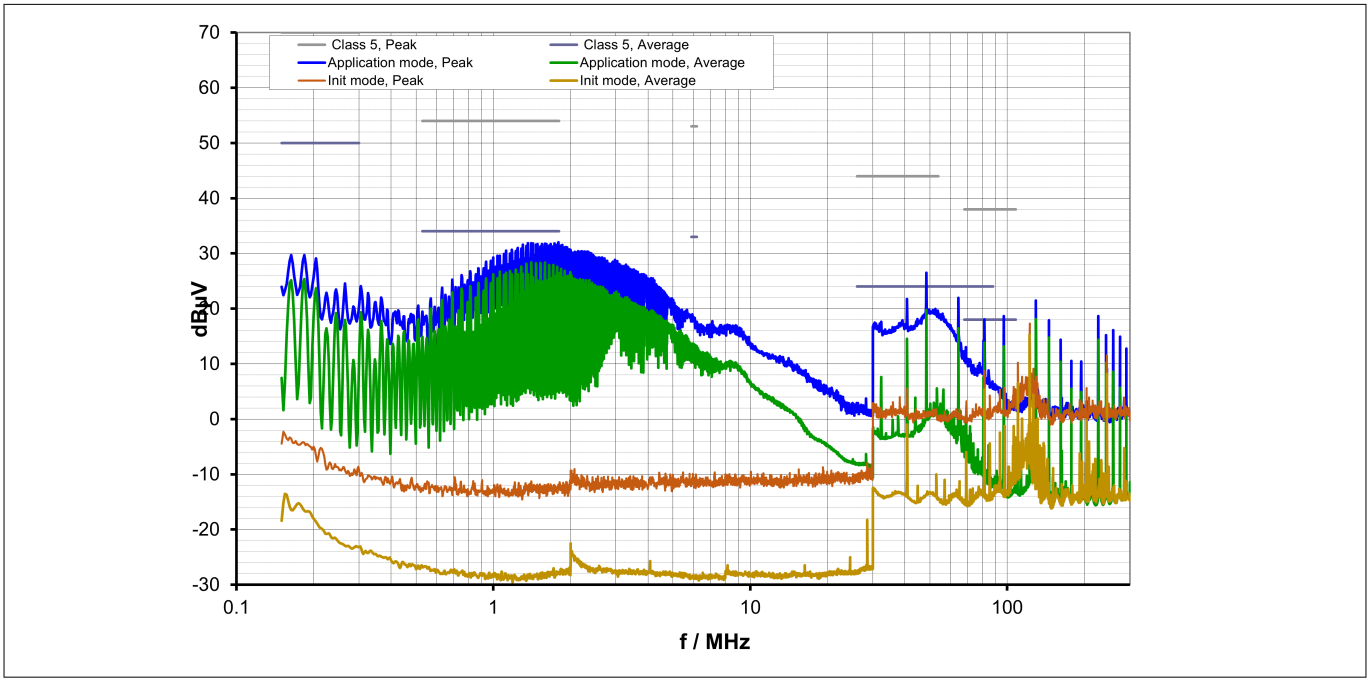

Figure 22 **EMC result, Grill Shutter , reference design with 1nF caps at OUTx - GND and 100nF input cap**

By introducing these capacitors we can see in Figure 21 and Figure 22 that the noise has significantly reduced. At low frequency, noise is completely removed from both setups and important thing to observe at high frequency is that noise coming form the both setup has a different peak due to the fact of different cable length, at the output. The following points need to be considered for the individual design, application and setup condition:

- 100 nF caps is necessary irrespective of the application for the fundamental blocks

- Capacitor between OUTx to *GND* highly depend on the setup. If the board is mounted directly at the motor terminal without any additional cable in between, it might be that this capacitor is not required or if length is higher different value is required, this needs to be checked for individual setups
- If BEMF based motor control technique is used to drive the load, the capacitor needs to be selected carefully, oversized capacitor may damp out the back-EMF signals

5.2 Thermal test

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 power dissipation on the reference design is due to various components on the *PCB*. TLE9934EVW40C and the reverse polarity protection diode are the major source of heat dissipation on the reference design.

Table 5 Thermal test setup condition

Parameter/Peripheral	Description
Input voltage	13 V
Motor speed	3500 rpm
MCU core frequency	40 MHz
Slew rate	50 V/us
Load	Motor test bench

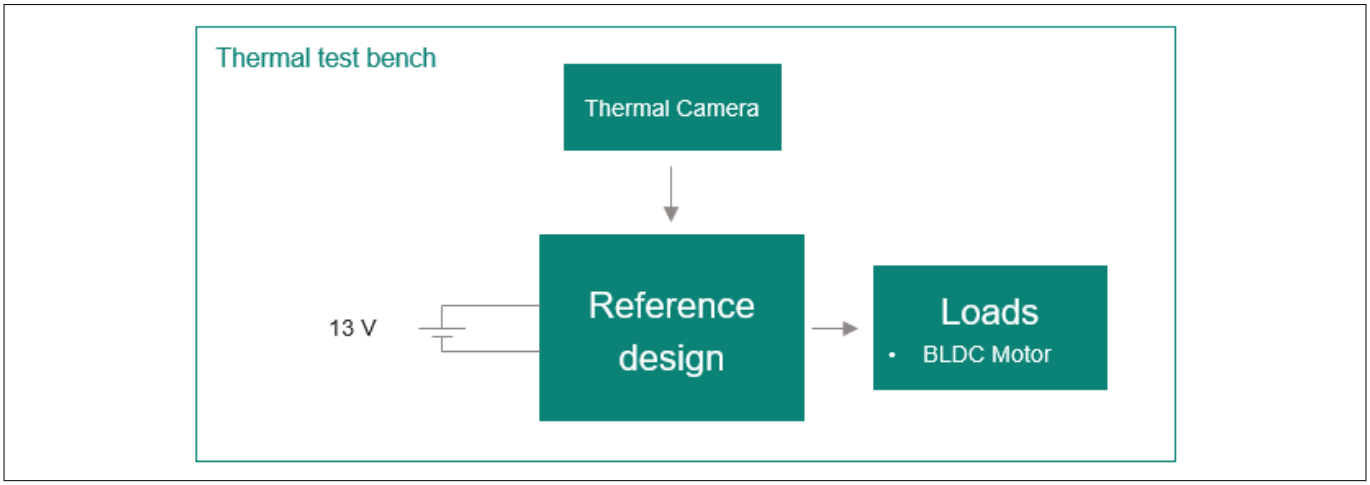

Figure 23 Thermal tests hardware setup block diagram

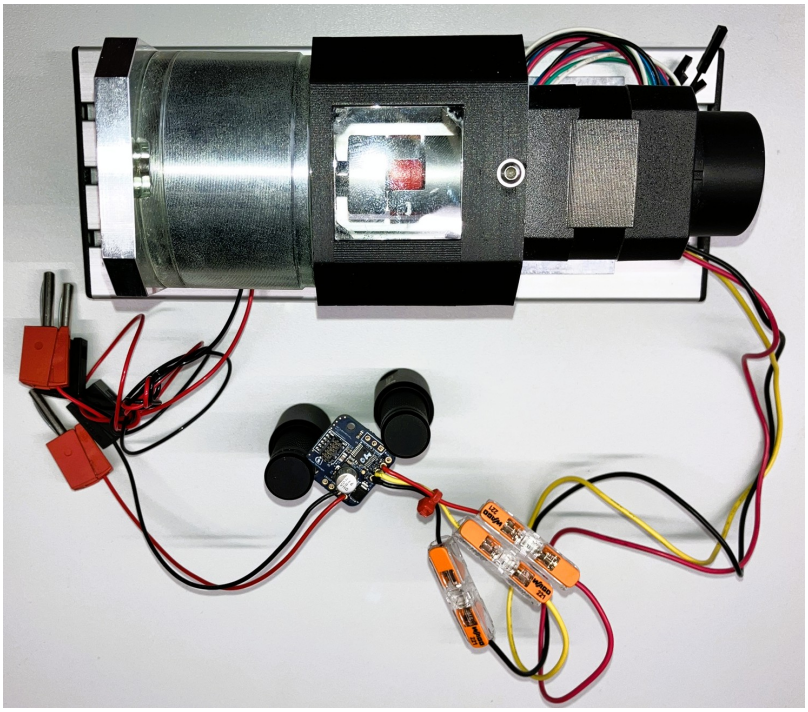

Figure 24 Thermal tests hardware setup

Results

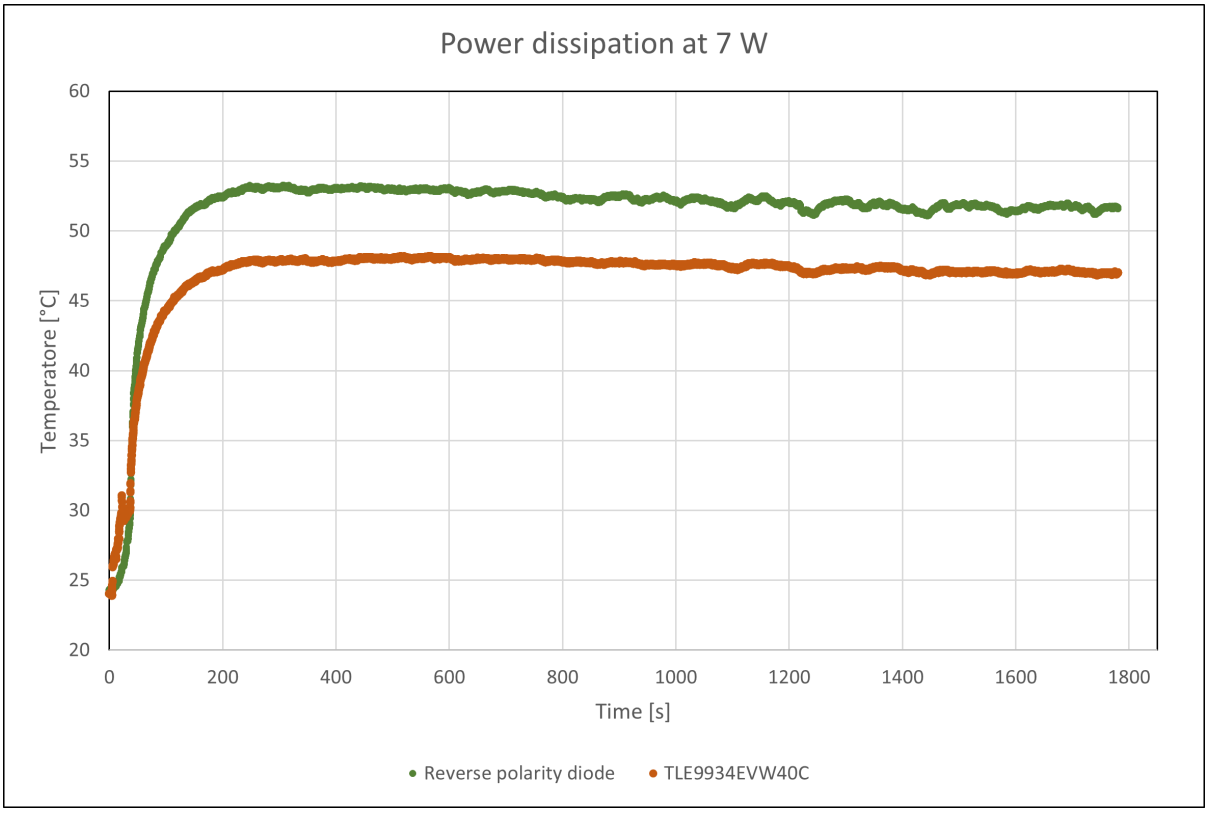

Figure 25 Temperature change at 7 W power dissipation

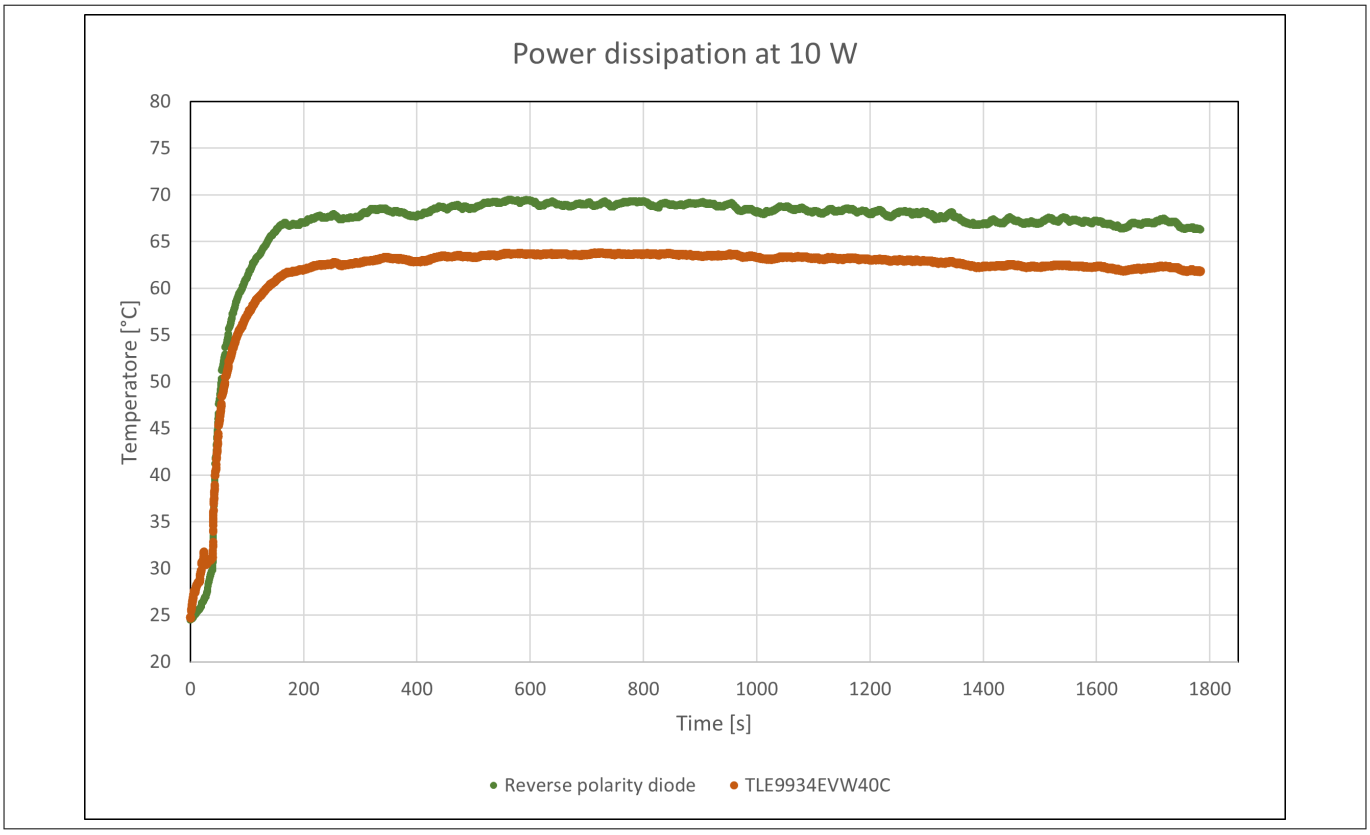

Figure 26 Temperature change at 10 W power dissipation

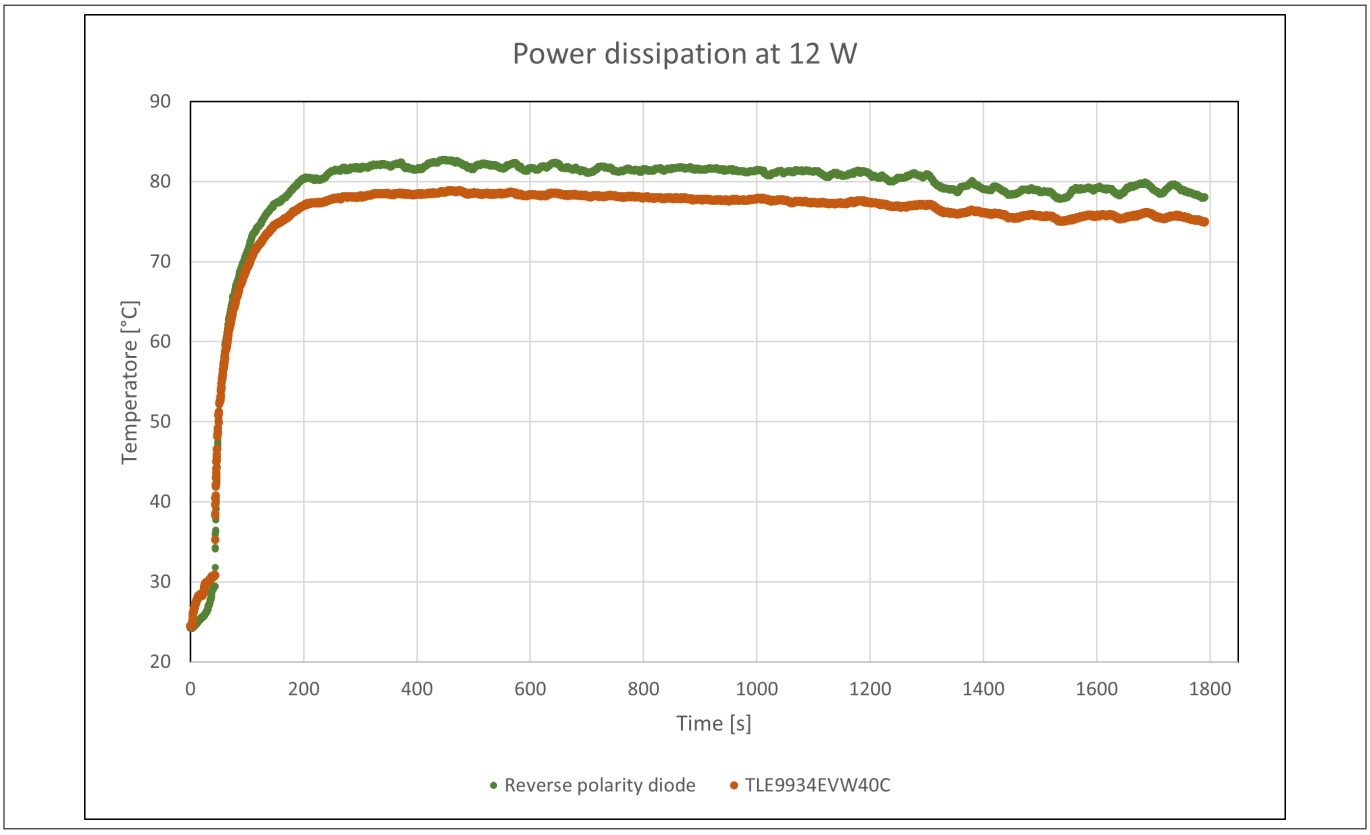

Figure 27 Temperature change at 12W power dissipation

5 System performance

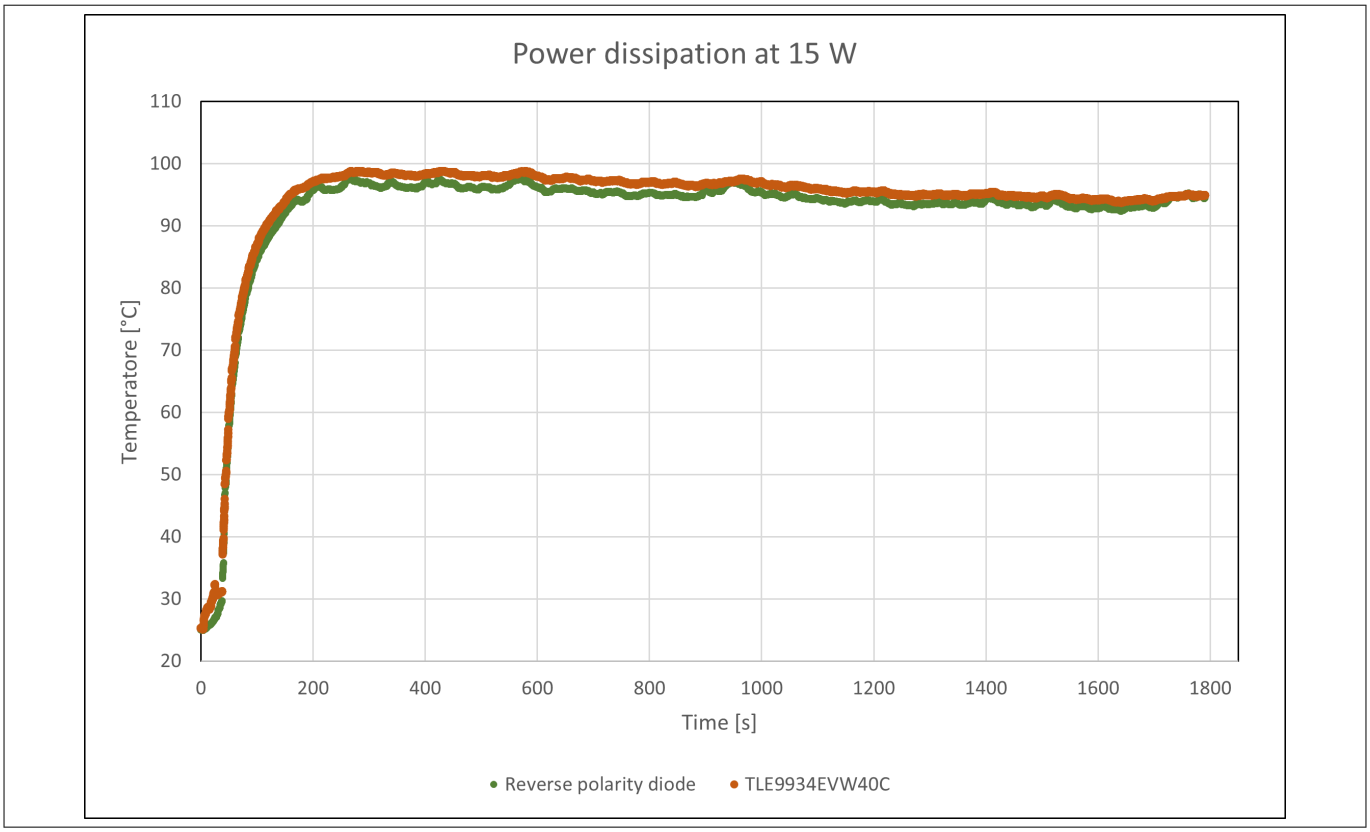

Figure 28 Temperature change at 15W power dissipation

6 Design files

6.1 Schematic of REF_Mini_Actuator_15W reference design

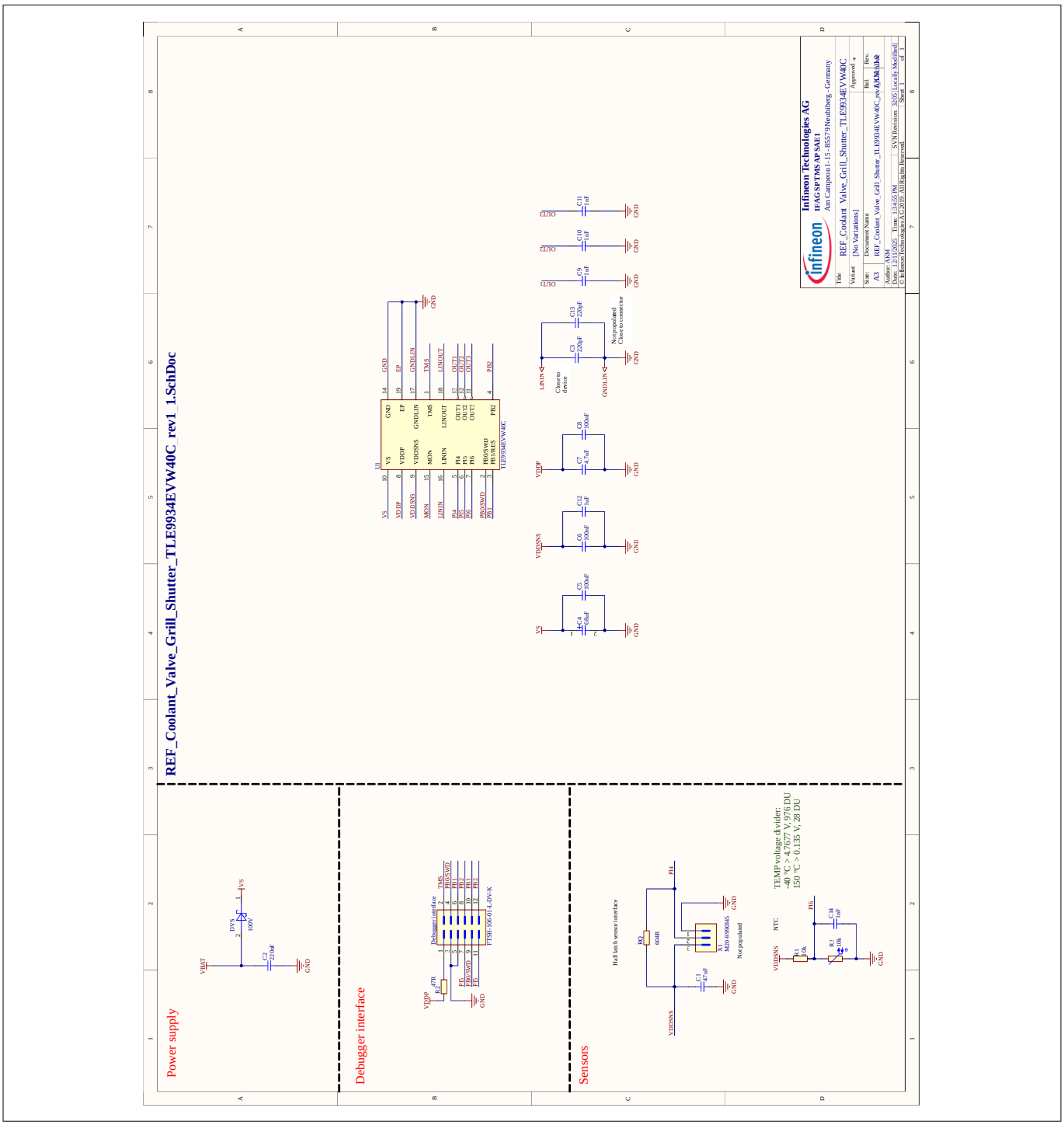

Figure 29 Schematic of REF_Mini_Actuator_15W reference design

6.2 Layout of REF_Mini_Actuator_15W reference design

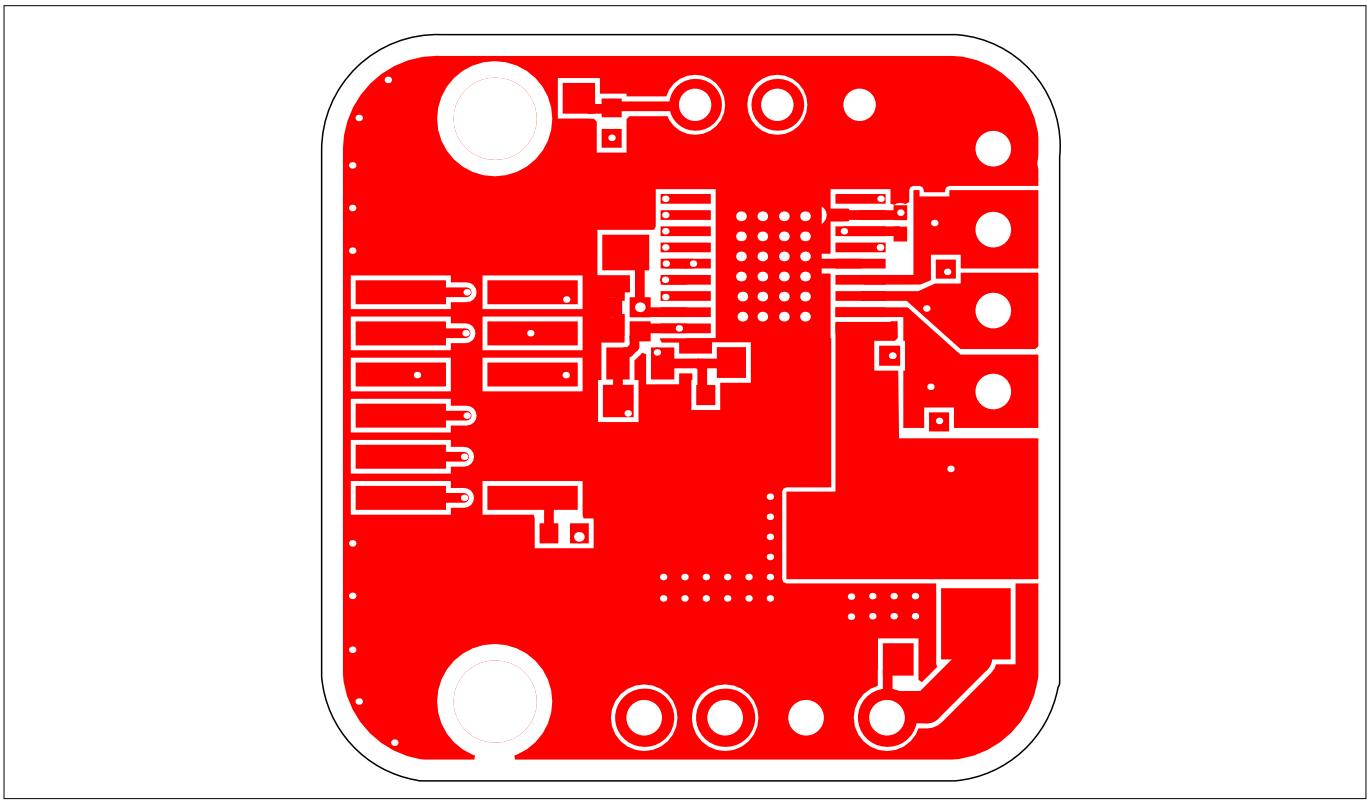

Figure 30 Layout of REF_Mini_Actuator_15W reference design -Top

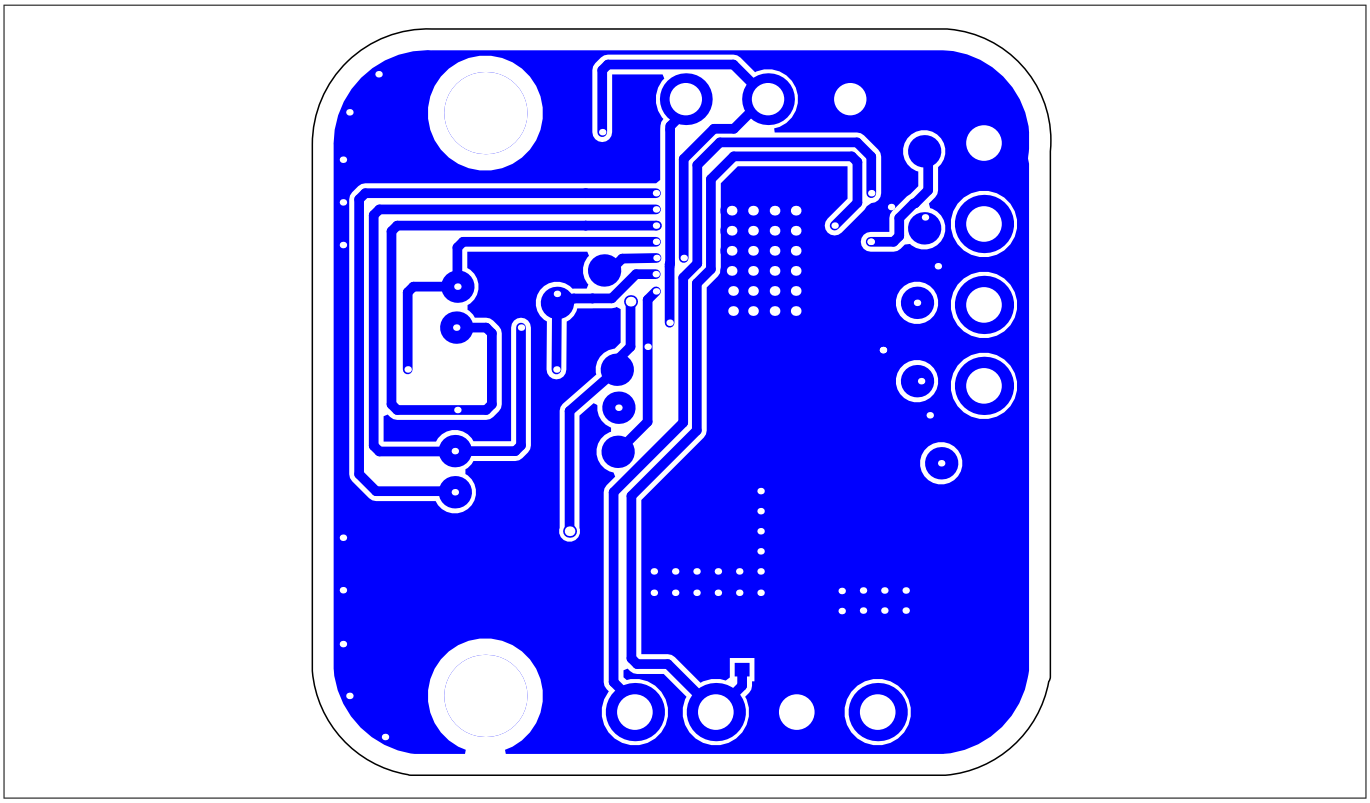

Figure 31 Layout of REF_Mini_Actuator_15W reference design - Bottom

6.3 Bill of materials of REF_Mini_Actuator_15W reference design

Designator	Value	Description	Manufacturer Order Number	Manufacturer
C1	47nF	CAP / CERA / 47nF / 25V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	GCM188R71E473KA37	MuRata
C2	220nF	CAP / CERA / 220nF / 50V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	GCM188R71H224KA64	MuRata
C3	220pF	CAP / CERA / 220pF / 25V / 10% / X7R (EIA) / -55°C to 125°C / 0201(0603) / SMD / -	GCM033R71E221KA03	MuRata
C4	68uF	CAP / ELCO / 68uF / 35V / 20% / Aluminiumelectrolytic / -55°C to 125°C / 6.60mm L X 6.60mm W X 8.00mm H / SMD / -	HHXC350ARA680MF80G	Nippon Chemi-Con
C5, C6, C8	100nF	CAP / CERA / 100nF / 50V / 10% / X7R (EIA) / -55°C to 125°C / 0402(1005) / SMD / -	GCM155R71H104KE02	MuRata
C7	4.7uF	CAP / CERA / 4.7uF / 16V / 10% / X7R (EIA) / -55°C to 125°C / 0805(2012) / SMD / -	GCM21BR71C475KA73	MuRata
C9, C10, C11, C14	1nF	Multilayer ceramic chip capacitor 0.001uF 50V C0G 5%	CGA2B2NP01H102J050BA	TDK Corporation
C12	1uF	CAP / CERA / 1uF / 25V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	GCM188R71E105KA64	MuRata
C13	220pF	CAP / CERA / 220pF / 25V / 10% / X7R (EIA) / -55°C to 125°C / 0201(0603) / SMD / -	GCM033R71E221KA03	MuRata
Debugger interface	FTSH-106-01-L-DV-K	Connector Header Surface Mount 12 position 0.050 (1.27mm)	FTSH-106-01-L-DV-K	Samtec
DVS	100V	High Voltage Surface-Mount Schottky Rectifier, VRRM 100V	SS2H10-E3/52T	Vishay
R1	10k	RES / STD / 10k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603 / SMD / -	CRCW060310K0FK	Vishay
R2	47R	RES / STD / 47R / 63mW / 1% / 100ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	CRCW040247R0FK	Vishay
R3	10k	Resistor; Single; Negative Temperature Coefficient; 2 Pins	ERTJ1VG103FM	Panasonic
RQ	604R	RES / STD / 604R / 63mW / 1% / 100ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	CRCW0402604RFK	Vishay
U1	TLE9934EVW40C	TLE993xEQW40C	TLE993xEQW40C	Infineon Technologies
X1	M20-9990345	Header, 3Pins, 2.54mm Pitch, Single Row	M20-9990345	Harwin

Glossary

AC

alternating current (AC)

BSL

bootstrap loader (BSL)

A small program or routine that is responsible for initializing the system and loading the main operating system or application into the memory of the target device during the system boot-up process.

DC

direct current (DC)

One-directional flow of electric charge. An electrochemical cell is a prime example of DC power. Direct current may flow through a conductor such as a wire, but can also flow through semiconductors, insulators, or even through a vacuum as in electron or ion beams. The electric current flows in a constant direction, distinguishing it from alternating current (AC).

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.

ESD

electrostatic discharge (ESD)

A sudden and momentary flow of electric current between two electrically charged objects caused by contact, an electrical short or dielectric breakdown.

GND

ground (GND)

GUI

graphical user interface (GUI)

An interface that enables users to interact with electronic devices through icons and visual indicators.

ICT

in-circuit testing (ICT)
An example of white box testing where an electrical probe tests a populated printed circuit board (PCB), checking for shorts, opens, resistance, capacitance, and other basic quantities which will show whether the assembly was correctly fabricated.

LIN

local interconnect network (LIN)

MCU

microcontroller unit (MCU)

A small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals.

Glossary

MOSFET

metal-oxide-semiconductor field-effect transistor (MOSFET)

NTC

negative temperature coefficient (NTC)

A term used in thermistors to describe how resistance decreases as temperature increases.

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)

VS

voltage supply (VS)

Revision history

Document version	Date of release	Description of changes
Rev. 1.00	2026-03-03	• Initial document release

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