Safety motor control application kit

User guide

About this document

Scope and purpose

The purpose of this document is to inform customers about setting up and using the Safety Motor Controller Application Kit.

Intended audience

The target audience for this document are electronics engineers or students from related fields.

Reference board/kit

The board contains components embedded on a PCB targetting a motor inverter application for safety-focused applications, including functional software. The board design and component choice are optimized with the requirements of the target application.

Note: Boards do not necessarily meet safety, EMI, quality standards (for example UL, CE) requirements

Important notice

“Evaluation Boards and Reference Boards” shall mean products embedded on a printed circuit board (PCB) for demonstration and/or evaluation purposes, which include, without limitation, demonstration, reference and evaluation boards, kits and design (collectively referred to as “Reference Board”).

Environmental conditions have been considered in the design of the Evaluation Boards and Reference Boards provided by Infineon Technologies. The design of the Evaluation Boards and Reference Boards has been tested by Infineon Technologies only as described in this document. The design is not qualified in terms of safety requirements, manufacturing, and operation over the entire operating temperature range or lifetime.

The Evaluation Boards and Reference Boards provided by Infineon Technologies are subject to functional testing only under typical load conditions. Evaluation Boards and Reference Boards are not subject to the same procedures as regular products regarding returned material analysis (RMA), process change notification (PCN) and product discontinuation (PD).

Evaluation Boards and Reference Boards are not commercialized products, and are solely intended for evaluation and testing purposes. In particular, they shall not be used for reliability testing or production. The Evaluation Boards and Reference Boards may therefore not comply with CE or similar standards (including but not limited to the EMC Directive 2004/EC/108 and the EMC Act) and may not fulfill other requirements of the country in which they are operated by the customer. The customer shall ensure that all Evaluation Boards and Reference Boards will be handled in a way, which is compliant with the relevant requirements and standards of the country in which they are operated.

The Evaluation Boards and Reference Boards as well as the information provided in this document are addressed only to qualified and skilled technical staff, for laboratory usage, and shall be used and managed according to the terms and conditions set forth in this document and in other related documentation supplied with the respective Evaluation Board or Reference Board.

It is the responsibility of the customer’s technical departments to evaluate the suitability of the Evaluation Boards and Reference Boards for the intended application, and to evaluate the completeness and correctness of the information provided in this document with respect to such application.

The customer is obliged to ensure that the use of the Evaluation Boards and Reference Boards does not cause any harm to persons or third-party property.
The Evaluation Boards and Reference Boards and any information in this document is provided "as is" and Infineon Technologies disclaims any warranties, express or implied, including but not limited to warranties of noninfringement of third-party rights and implied warranties of fitness for any purpose, or for merchantability.

Infineon Technologies shall not be responsible for any damages resulting from the use of the Evaluation Boards and Reference Boards and/or from any information provided in this document. The customer is obliged to defend, indemnify, and hold Infineon Technologies harmless from and against any claims or damages arising out of or resulting from any use thereof.

Infineon Technologies reserves the right to modify this document and/or any information provided herein at any time without further notice.

Safety precautions

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

Table 1 Safety precautions

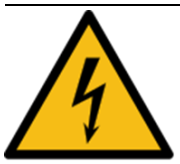
	**Warning**: *The evaluation or reference board contains DC bus capacitors, which take time to discharge after removal of the main supply. Before working on the drive system, wait 5 minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death.*
	**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.*
	**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 electrostatic discharge (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 DC 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.*

Table of contents

About this document **1**
Important notice **2**
Safety precautions **3**
Table of contents **4**
1 The board at a glance **5**
1.1 Scope of supply 7
1.2 Block diagram 7
1.3 Main features 7
1.4 Board parameters and technical data 8
2 Hardware Considerations **9**
2.1 Assembling the power supply cable and connecting it to the board 9
2.2 Description of the functional blocks 16
2.3 Example: design tips 26
3 System design **28**
3.1 Schematics 28
3.2 Layout 29
3.3 Bill of materials 34
3.4 Connector details 35
4 System performance **36**
4.1 Test points 36
Revision history **37**
Disclaimer **37**

1 The board at a glance

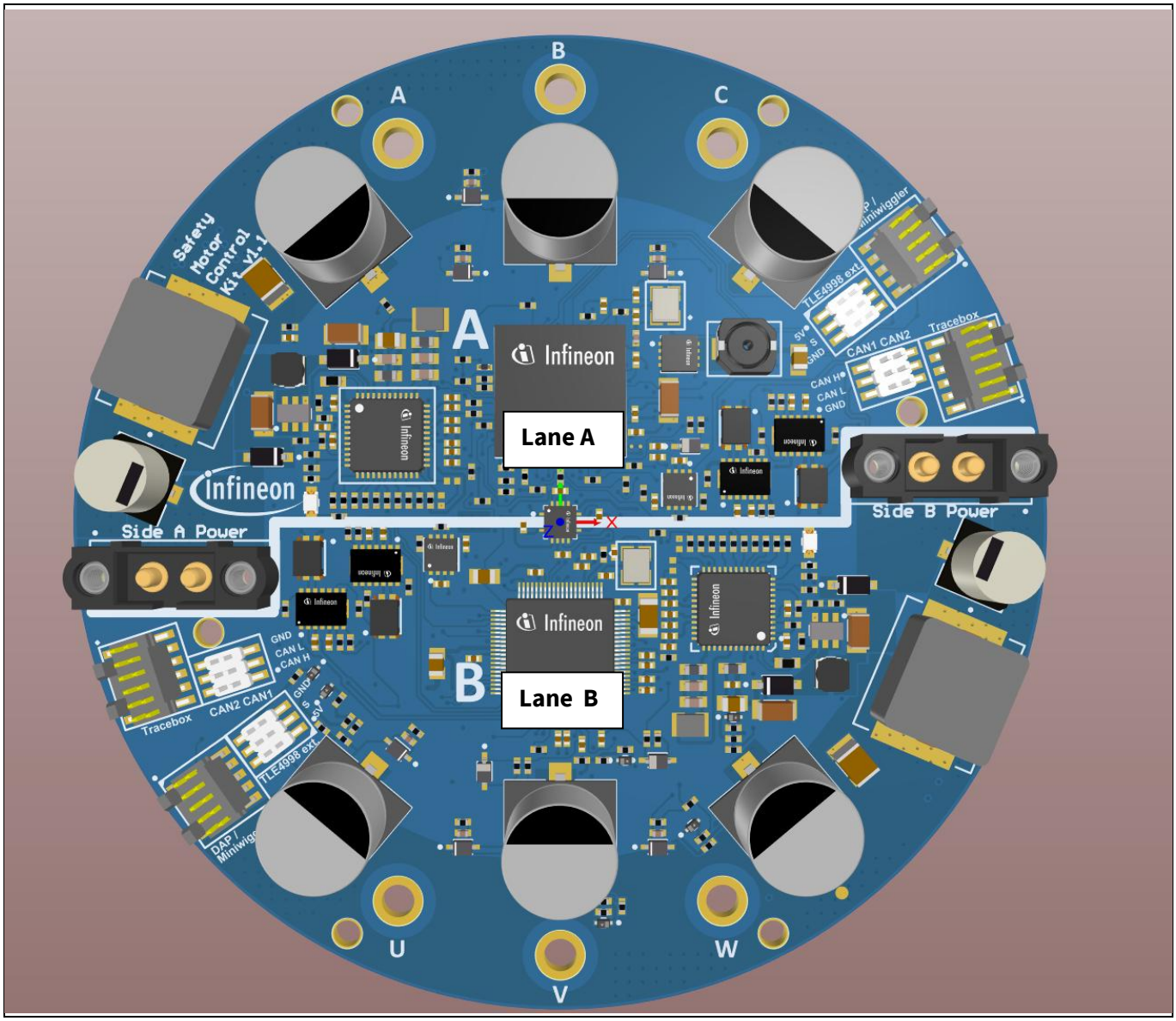


Figure 1 Top side of the board

1 The board at a glance

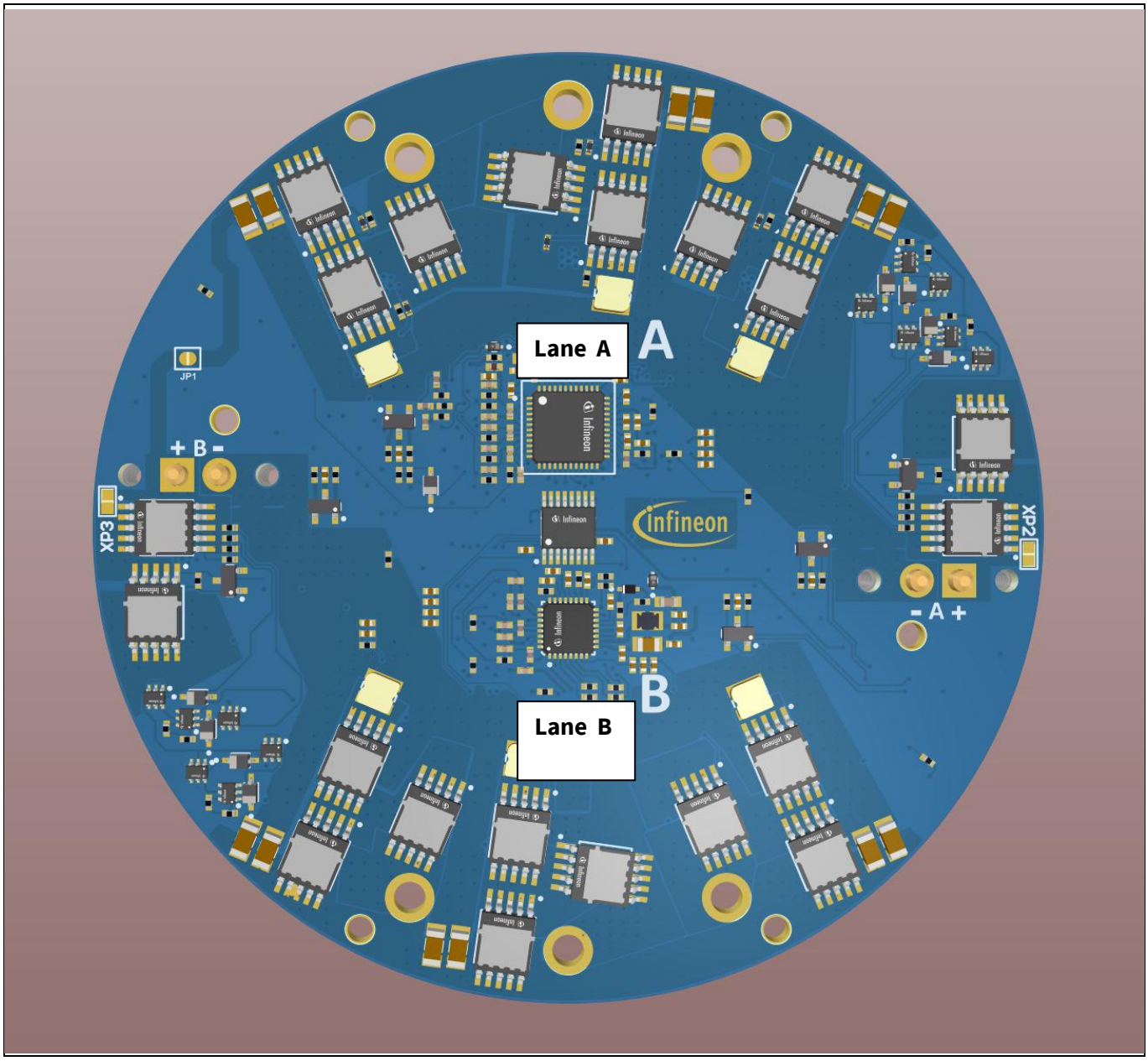


Figure 2 Bottom side of the board

The board is split in two similar halves, which will be refered to as “Lane A” and “Lane B” from here onwards. Each has the very same functional blocks, but implemented with different components to emphasize on the aspect of hardware diversity. Each individual lane is a three phase inverter on its own.

The two inverters can work in parallel to drive a dual three phase motor or a six phase motor simultaneously. Alternatively, there is also the option to use one single lane as the main inverter and use the other one as a backup inverter in case of failure in the primary one.

1.1 Scope of supply

The application kit box contains the board in an ESD bag and a power connector which needs to be assembled by the user. For assembly instructions see chapter 2.1.

1.2 Block diagram

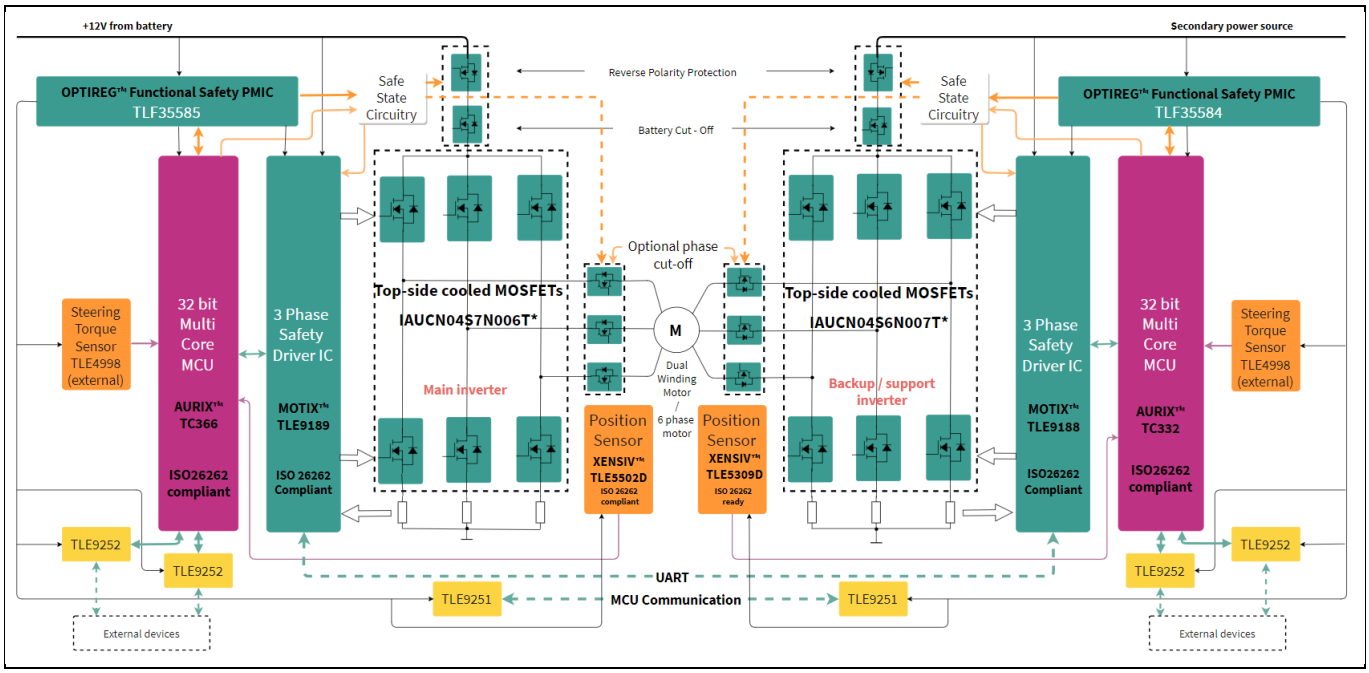


Figure 3 Circuit block diagram

1.3 Main features

- Dual three phase inverter stage with topside cooled MOSFETS
- Fail operational design
- Redundant safety features for safe state triggering
- External torque sensor (i.e. TLE4998) interface
- Angle position detection
- Phase cutoff circuitry
- Dual CAN communication (2x transceivers on each lane) for external devices

1.4 Board parameters and technical data

Table 1 Parameter

Parameter	Symbol	Conditions	Value	Unit
Supply voltage (individual or common)	V_S	Regular operation	12	V
Continuous phase current	I_{ph}		10	A rms
Operating temperature	Top	Heatsink mounted, driving motor with I_{ph} in a well ventilated ambient	≤ 50	°C
Maximum supply voltage (individual or common)	V_{SMax}	Regular operation	16.5	V
Minimum supply voltage (individual or common)	V_{SMin}	Regular operation	9	V

2 Hardware Considerations

2.1 Assembling the power supply cable and connecting it to the board

Some preparation is required to commission the board.

The power supply inputs for the board consist of two Harwin M80-5000000M1-02-PM1-00-000 connectors:



Figure 4 On-board power connector

One female power connector (Harwin M80-4000000F1-02-325-00-000) is provided within the application kit. It has to be soldered to an individual power cable that can then be connected to different power sources, such as laboratory bench power supplies or 12 V batteries. It is highly recommended that, if an unregulated power supply such as a battery pack is used, some form of overcurrent protection (i.e. fast acting fuse) is used in series with the board.



Figure 5 Off-board female power supply connector

In order to solder the power cable correctly to the connector, the user must pay careful attention to the connector pinout. It is highly recommended that color coded power cables are used, with the convention that a red cable should be used for the positive side of the supply and a black cable should be used for the negative side.

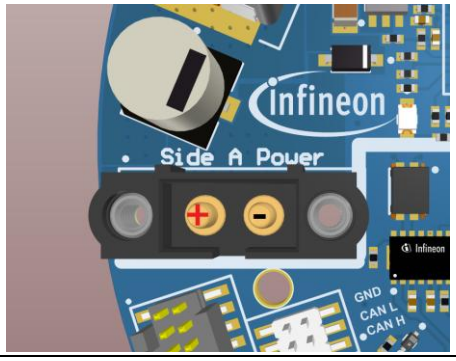


Figure 6 Lane A power connector polarity

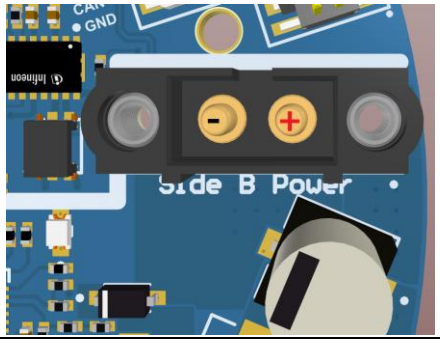


Figure 7 Lane B power connector polarity

If in doubt, a user can always take a look at the backside of the board where the polarity is marked directly on the pcb:

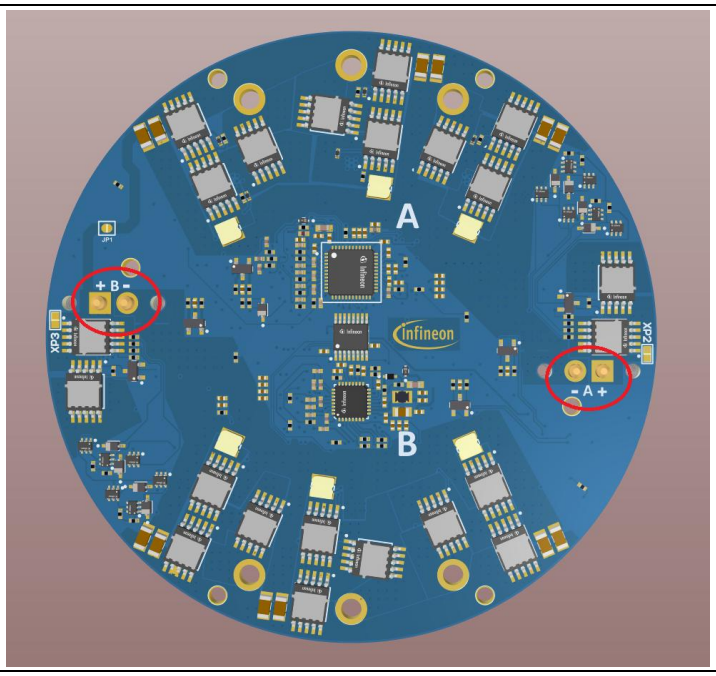


Figure 8 Polarity markers on the bottom side of the board

It is highly recommended that properly sized conductors are used. For small electrical loads, typically under 10 A, a pair of banana connectors with cables made from regular 1mm² stranded copper conductors is recommended.

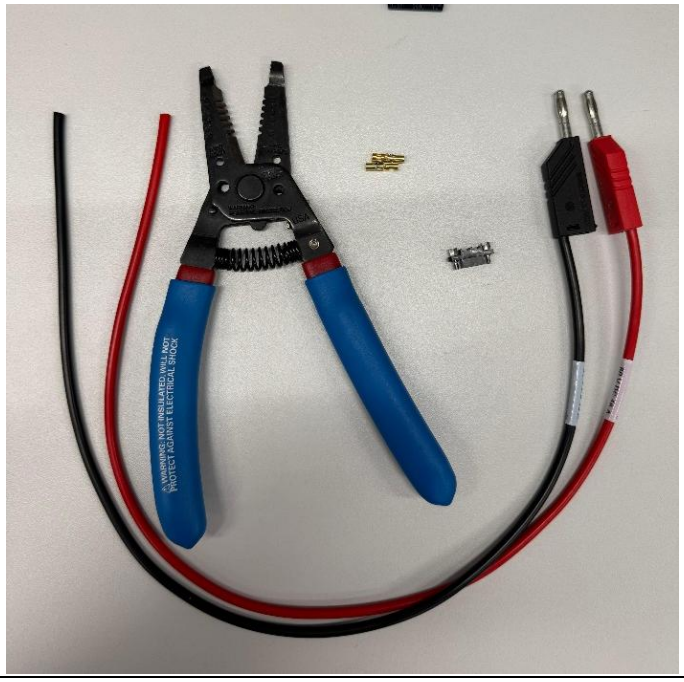


Figure 9 Banana cables, stripping tool and connector kit

After cutting the cables to length, stripping about 5 mm of the insulation is required. The stripped cables must then be inserted in each terminal as such:



Figure 10 Stripped cable inside connector pin

Prior to soldering the cable in place, it is highly recommended that some soldering flux is applied so that the soldering alloy makes proper contact between the cable and pin.



Figure 11 Soldering the cable

Solder the cable by adding a generous amount of alloy. Apply soldering alloy to the point where it can be seen up to the insulation of the cable.

Next, let the pin cool down until it is safe to touch by hand and prepare heatshrink tubing to insulate each pin. Note that, while it is not mandatory, it is highly recommended that some form of insulation between the two pins is used, since they are placed very close together and the exposed sections of the cables can easily be accidentally bent together, resulting in a short circuit on the power supply side.

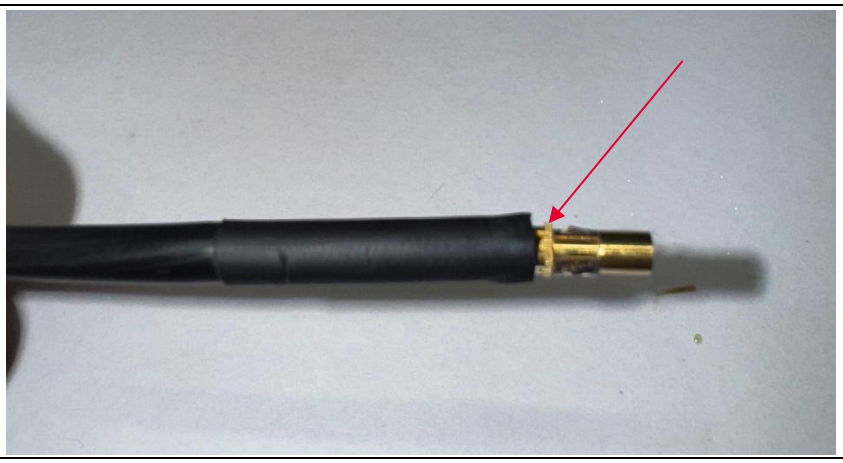


Figure 12 Adding heatshrink tubing to the cable

When adding the heatshrink, it is important that it does not cover the square portion of the pin. Failing to do so will result in the pin not locking inside the connector housing.

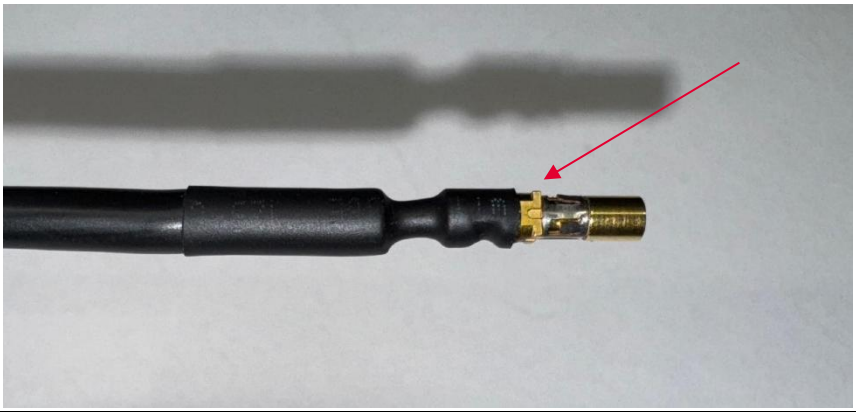


Figure 13 Cable with contracted heatshrink

Next, the pins must be inserted into the connectors. They have to be pressed all the way in until a click can be heard, which means that they have been securely locked into place. To avoid any potential errors about where each pin goes, the empty connector can be placed on the board to ensure that the polarity is correct. The keyway of the connector prevents it from being inserted the wrong way. Note that the housing should not be plugged into the board when inserting the pin in order to make the process easier.

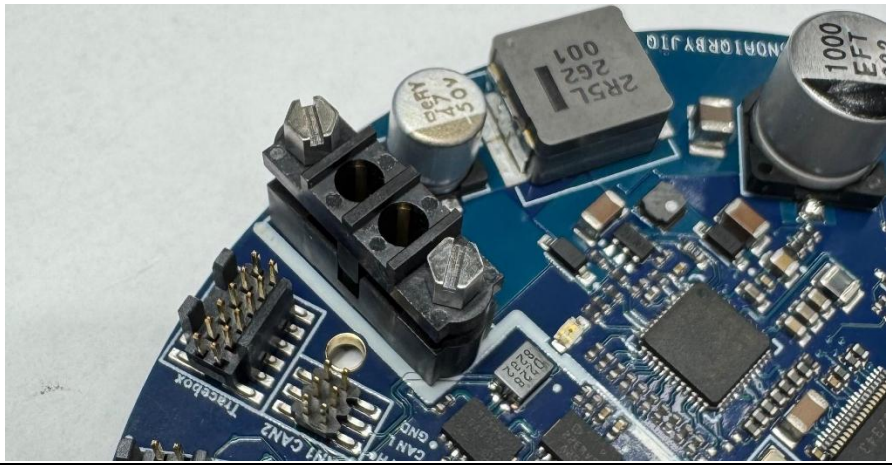


Figure 14 Empty connector placed into the pcb socket

After inserting the pins into the connectors, gently try to tug the cable out of the connector to check if it is securely attached.

When screwing the assembled connector in place, one must pay attention to progressively and alternatively tighten each screw. Screwing one bolt to the end and then moving to the other could damage the connector or result in improper electrical contact.

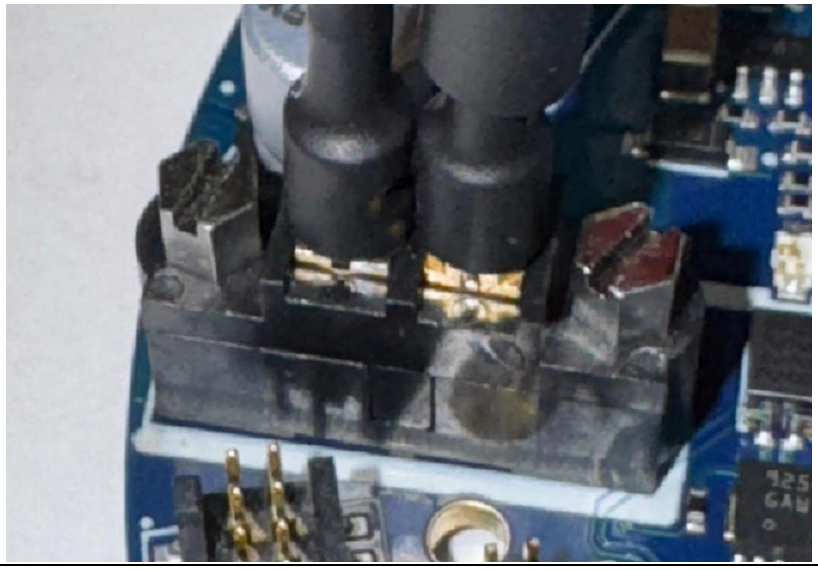


Figure 15 Correctly bolted connector

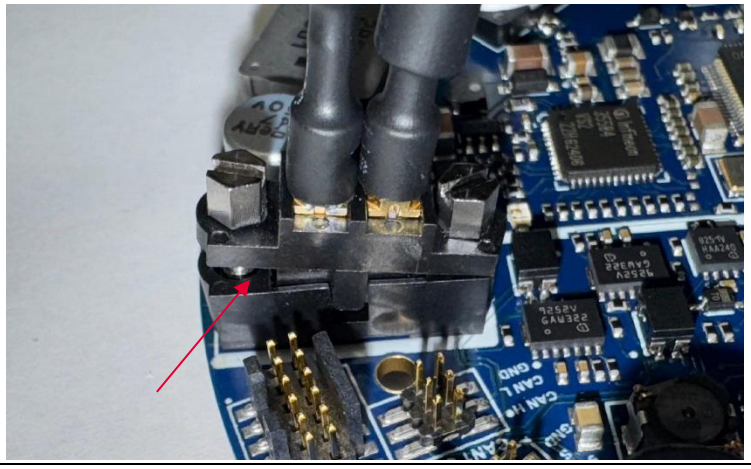


Figure 16 Incorrectly bolted connector

For intensive load operation such as driving a motor coupled to a mechanical load, a heatsink and thermal conductive pad must be used to cool down the power MOSFETs. A dedicated heatsink (doubling as a holder) has been designed for the board, the mechanical production files are available on the Infineon Developer Center page of the project, upon board registration.

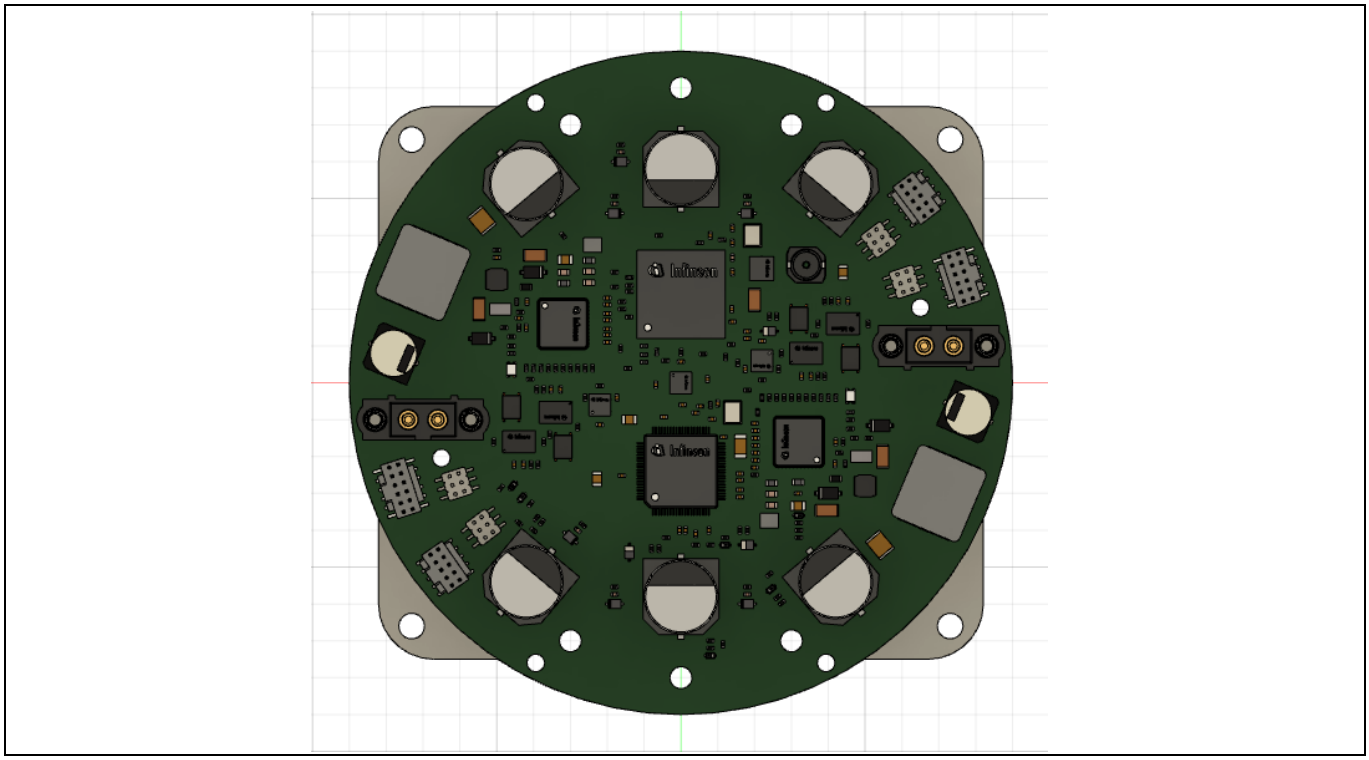


Figure 17 Board and custom heatsink

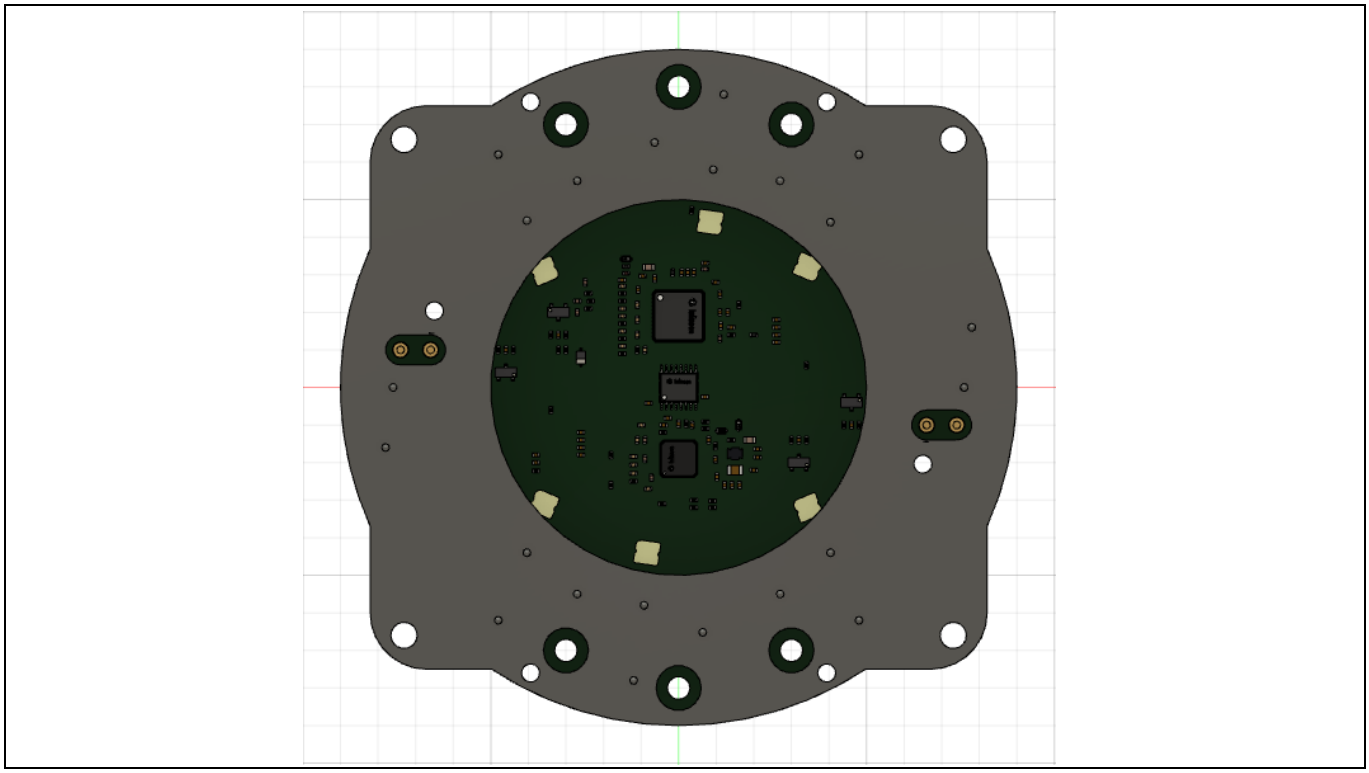


Figure 18 Board and custom heatsink

The advantage of using this type of heatsink design is given by the circular cutout on the bottom side, which grants access to the resistors that can be used as test points for relevant signals.

It is necessary to use plastic fasteners (M2 bolts and nuts) for mounting the board on a heatsink to prevent the risk of shortcircuit or damaging the board. It is mandatory to use an electrically insulating, thermally conductive pad to avoid short circuiting the inverter stage MOSFETs drain terminals together regardless of which type of heatsink is used.

If a custom heatsink is made, it is highly recommended to use standoffs between it and the PCB in order to prevent applying to much torque on the PCB/transistors.

2.2 Description of the functional blocks

The main functional blocks of the board are:

- PMICs
- Microcontrollers and their peripherals (angle sensors, CAN transceivers)
- Gate drivers
- Power stages
- Safety circuitry

Each of the two lanes of the board contains the same functional blocks, though implemented with different components.

Table 2 Main components of the application kit

Functional component name	Lane A	Lane B
Microcontroller	SAK-TC366DP-64F300S AA	SAK-TC332LP-32F300F
CAN transciever	2 x TLE9252VLC 1 X TLE9251VLE	2 x TLE9252VLC 1 X TLE9251VLE
PMIC	TLF35585QVS02	TLF35584QVVS2
Gate driver	TLE9189QVW	TLE9188QV
Power stage MOSFETs	IAUCN04S7N006T	IAUCN04S6N007T
Safety circuitry	2N7002DW	2N7002DW
Angle sensor	TLE5502D S0002	TLE5309D E2211

Take a brief look at what each functional block represents and how they work. Please keep in mind that this section is meant to work as a short introduction to the purpose and capabilities of each component and is not meant to provide extensive details. For that, please refer to the individual components' application technical datasheetand/or application manuals.

PMIC

The functional safety PMIC (power management integrated circuit) is one of the crucial functional blocks of the board. It is the powerhouse of the board, providing the 3.3 V and 5 V required by the sensitive integrated circuits. It offers two 5 V tracker outputs for precision circuitry, such as the steering angle sensors present on the board, alongside a 3.3 V LDO for microcontroller core supply, and a 5 V LDO aimed for peripherals such as CAN transceivers.

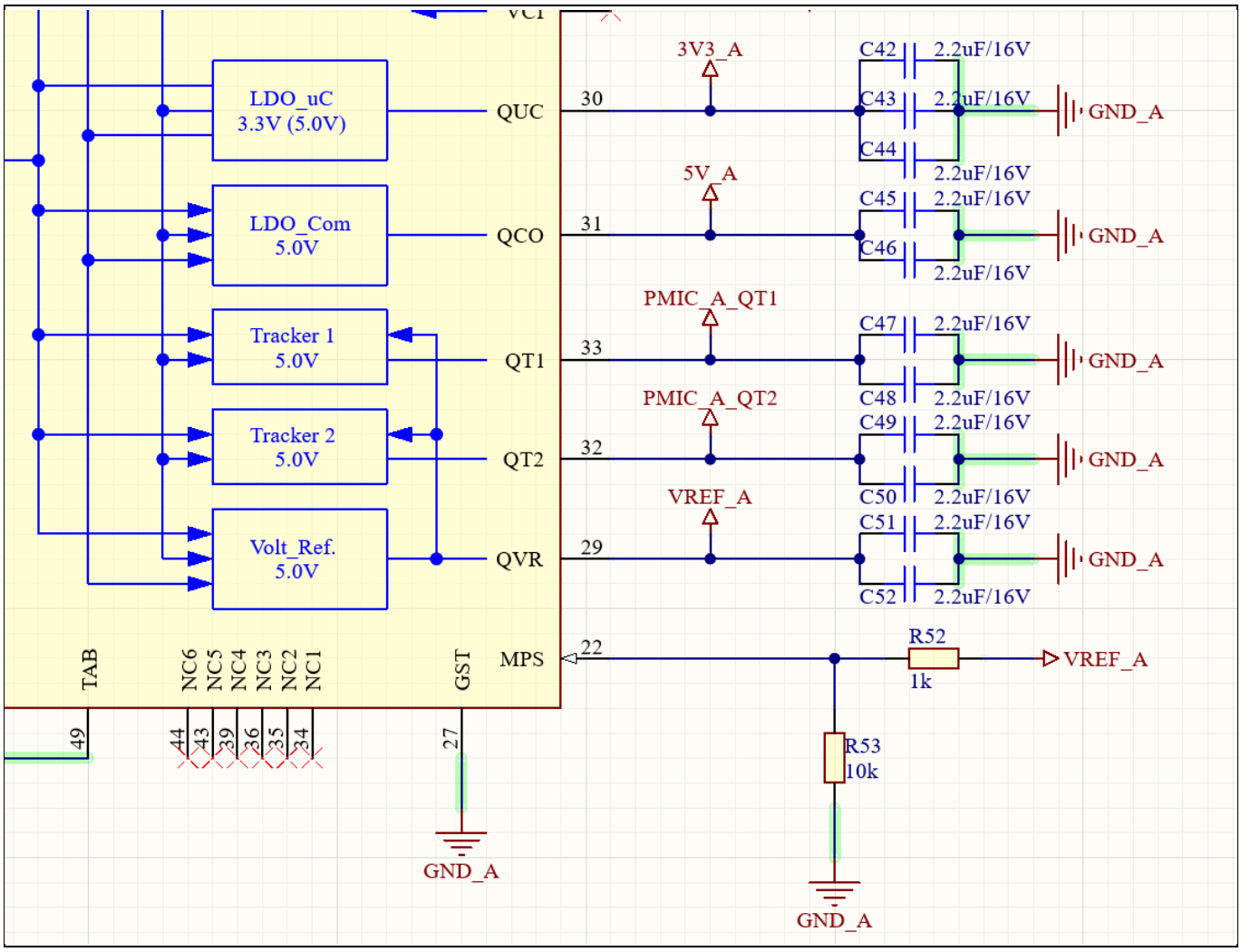


Figure 19 PMIC output supplies

It features a configurable time-based and functional watchdog, error pin monitoring and voltage monitoring for supervision functionality to maximize fail-operation capabilities.

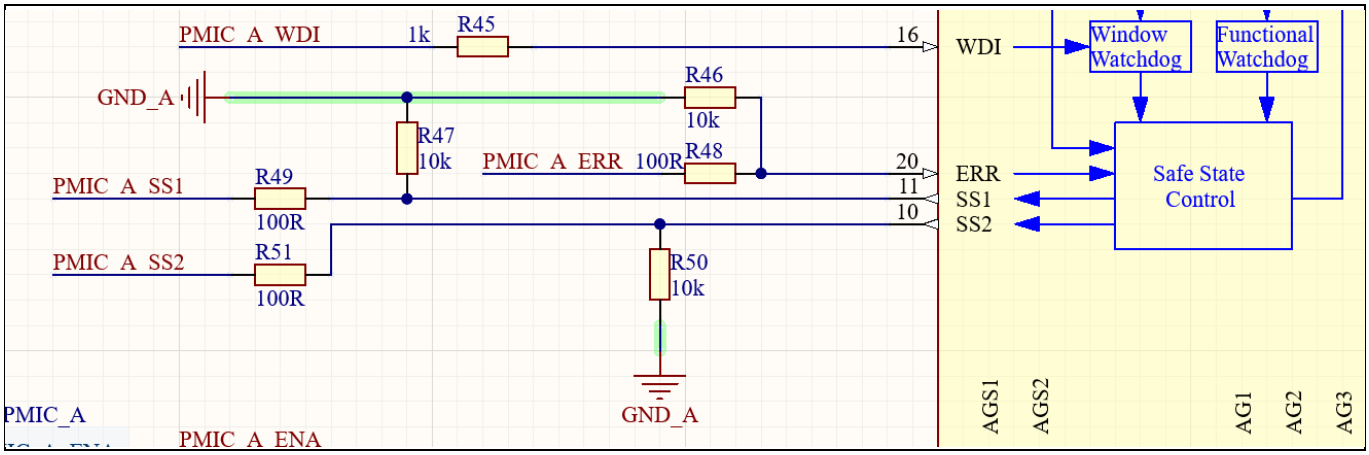


Figure 20 PMIC safety-related pins

Additionally, the PMIC includes specialized functional blocks – one boost converter acting as a preregulator and one intermediary buck converter to step down the intermediate voltage which is then fed into LDOs.

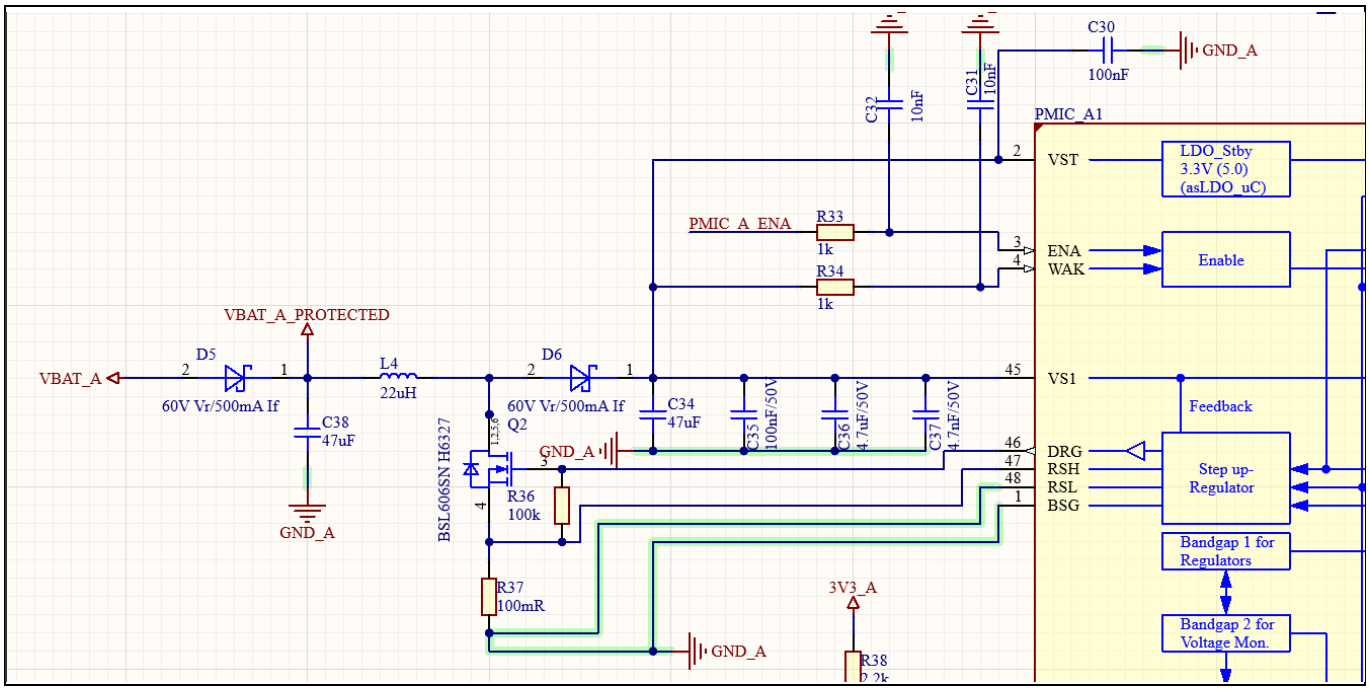


Figure 21 PMIC input step up regulator

Precise control of the input step up regulator is achieved with the help of R37, which acts as a current sense resistor.

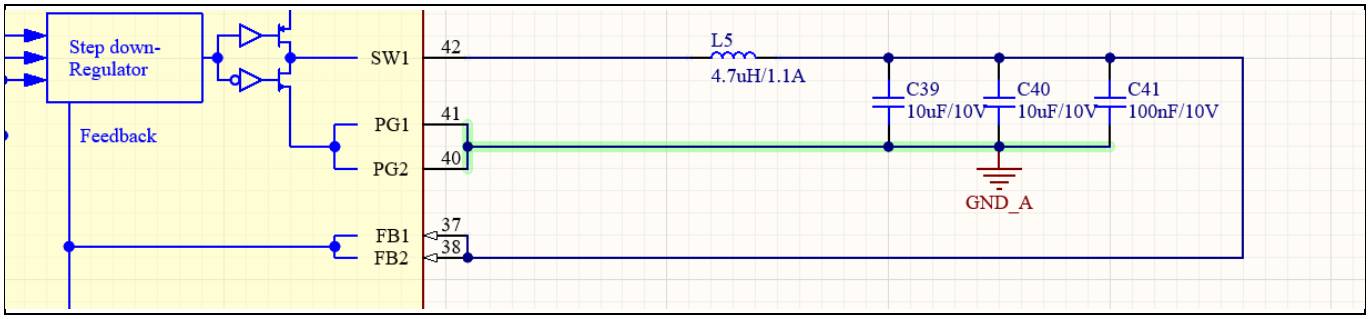


Figure 22 PMIC intermediate step down regulator and feedback loop

The two PMICs present on the board are very similar in terms of functionality, as the TLF35585 is a direct successor to the TLF35584.

Microcontrollers

Both lanes of the board are running on AURIX™ TC3. For lane B, TC332 was chosen as a cost efficient solution, while trading off some functionalities and pins that may not be relevant for the application. Lane A is equipped with TC366, which is a more capable unit in terms of processing power and features such as ADC inputs, digital pins, etc, with a great potential for upscaling and future-proofing with the disadvantage of an increased cost.

The two microcontrollers communicate between each other via dedicated CAN transceivers only. The two lanes can communicate as standalone ECUs via CAN in a more traditional automotive fashion, with the alternate option of using UART over CAN.

The main highlights of the microcontrollers present on the board are:

- **TC332**
  - 1x TriCore™ running at 300 MHz
  - 2 MB flash with ECC protection
  - 248 KB SRAM with ECC protection
  - 16x DMA channels
  - Redundant and diverse timer modules (GTM, CCU6, GPT12)
  - 1x FlexRay, 8x CAN FD, 12x ASCLIN, 4x QSPI, 6x SENT, 1x I^2S emulation
  - eVita full HSM (ECC256 and SHA2)
  - TQFP 80 package
  - ISO26262 ASIL-D support
  - AUTOSAR 4.2 support
  - 3.3 V supply voltage (5 V option available as well)
  - Temperature range: -40°C to 150°C
  - Best-in-class performance enabling ASIL-D designs
  - Upward and downward scalability to the rest of the AURIX™ TC3xx family
- **TC366**
  - 2x TriCore™ running at 300 MHz
  - Supporting floating point and fix point with all cores
  - 4 MB flash with ECC protection
  - 672 KB SRAM with ECC protection
  - 64x DMA channels
  - Redundant and diverse timer modules (GTM, CCU6, GPT12)
  - 100 Mbit Ethernet capability (not present on the board)
  - 1x FlexRay, 8x CAN FD, 12x ASCLIN, 4x QSPI, 10x SENT, 1x I^2S emulation, 2x PSI5, 1x PSI5S
  - eVita full HSM (ECC256 and SHA2)
  - BGA 180 package
  - ISO26262 ASIL-D support
  - AUTOSAR 4.2 support
  - 3.3 V supply voltage (5 V option available as well)
  - Temperature range: -40°C to 150°C

- Standby mode controller
- Best-in-class performance enabling ASIL-D designs
- Scalable upwards and downwards with the rest of the AURIX™ TC3xx family
- A/B swap software update over the air support

Gate drivers

Two individual gate drivers are present on the board, with fundamentally different operating principles:

- **Lane B: TLE9188**
  - It has the advantage of being controlled via SPI only, making it a valuable choice where space is at a premium
  - One fundamental difference from the TLE9189 is that the highside/lowside MOSFET on/off control is not done via dedicated IHN/ILN pins. Instead, this gate driver is controlled via SPI only. Thus, it is advantageous in terms of the number of required microcontroller pins and occupied surface area
  - It relies on a boost converter to provide the required voltage for gate turn on, as it can be seen in the schematic below. C_{HSS} is the output capacitor of the boost converter, storing part of the electrical charge required to turn on the power stage MOSFETs' gates

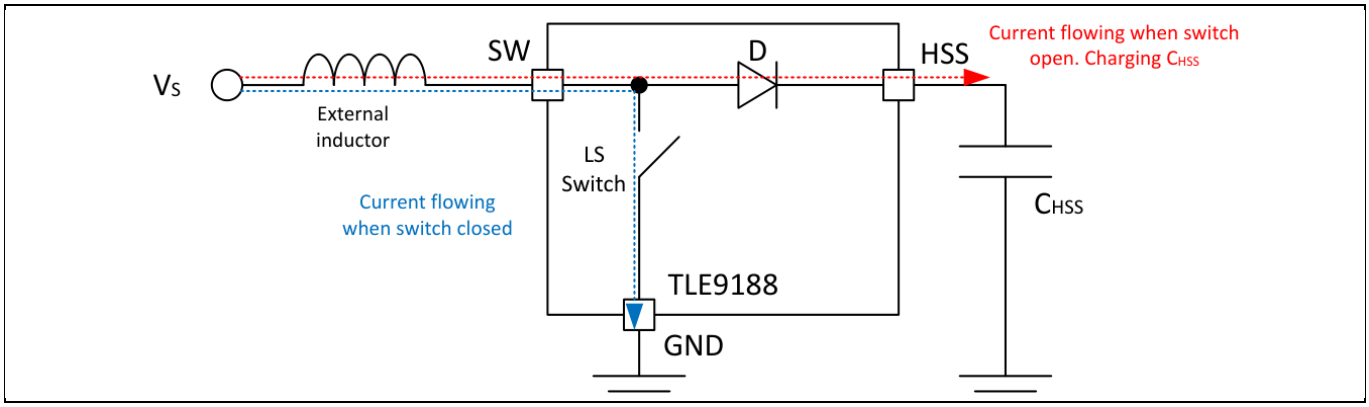


Figure 23 Basic operation of the TLE9188 boost converter

- Individual phase current sensing is performed via dedicated shunt resistors and signal filtering is achieved with the help of resistors and capacitors

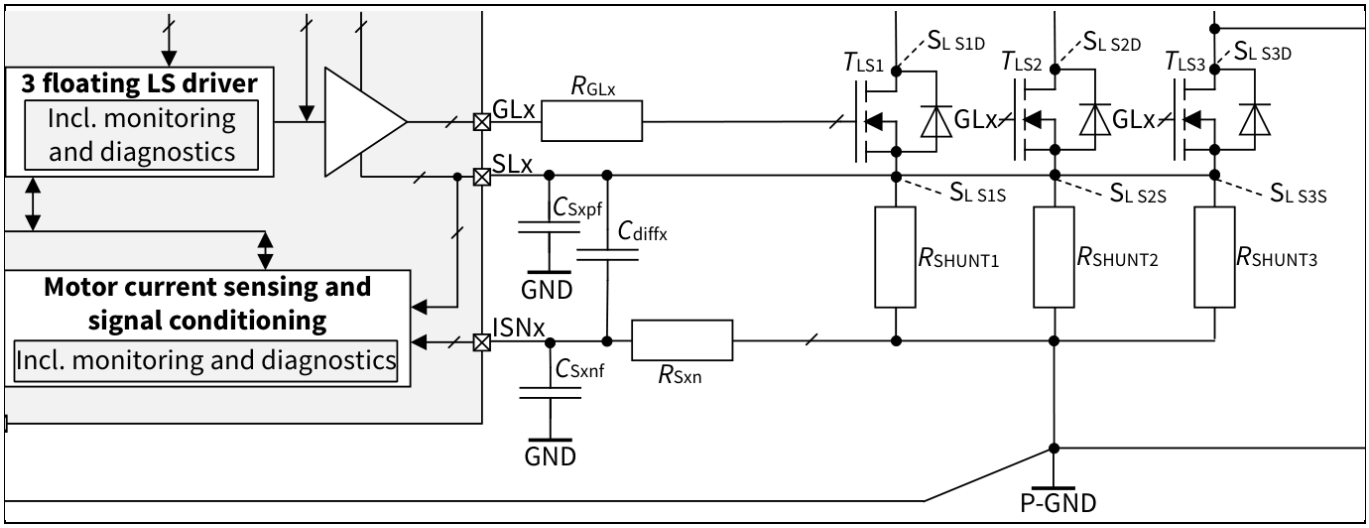


Figure 24 TLE9188 individual phase current sensing circuitry

- There is one particular design choice that the reader must keep in mind. A simple form of MOSFET switching speed control was implemented passively – resistors and diodes were placed between the TLE9188 GLx/GHx pins and the actual gate pins of the transistors to achieve on-time/off-time commutation control

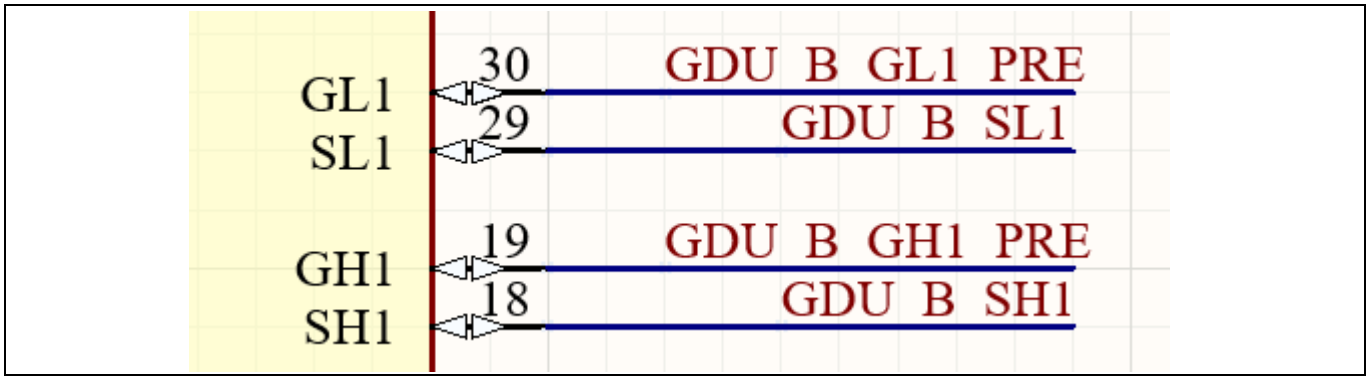


Figure 25 TLE9188 GHx and GLx pins and designated nets

The same naming scheme is repeated for each of the three inverter stage phase half-bridges.

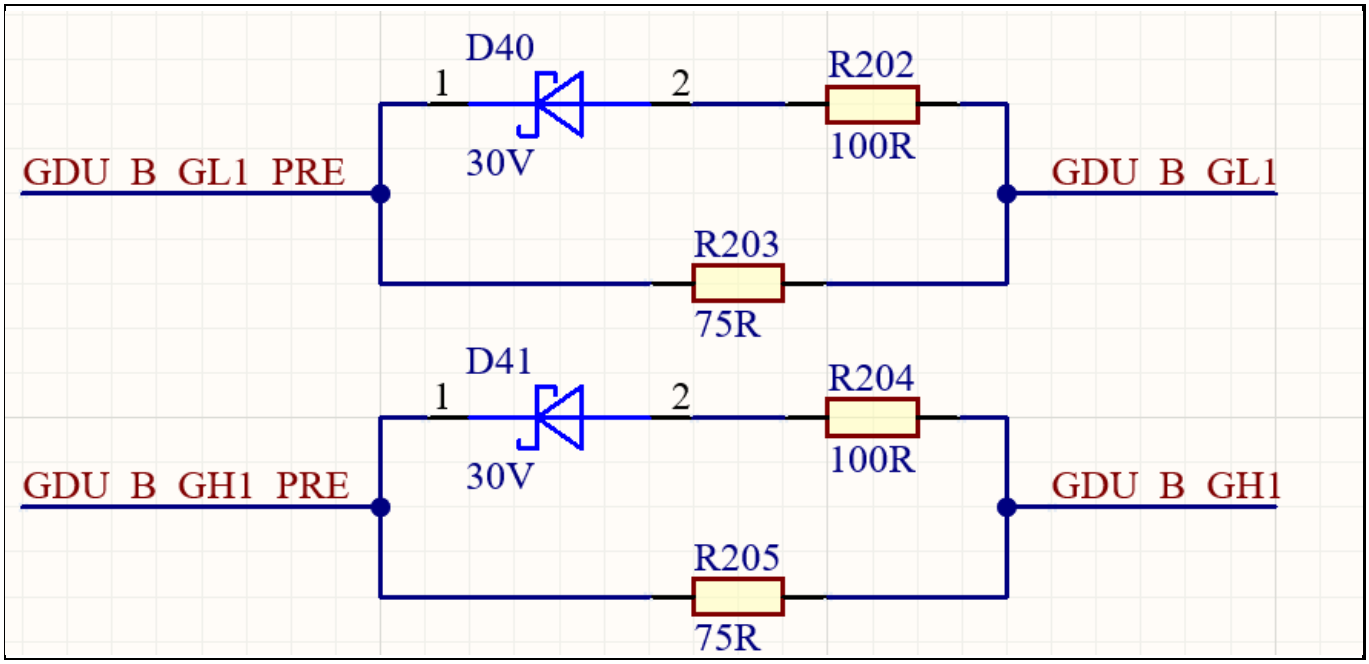


Figure 26 Lane B MOSFET gate switching speed control circuitry

The same naming scheme and adjancent component placement is repeated for each of the three inverter stage phase half-bridges.

Adding these auxiliary components is recommended due to the nature of the gate driver, which is a push-pull type driver.

To determine the values for the two resistors, the following initial conditions were set:

Table 3 Initial conditions for calculating the gate resistors' values

Parameter name	Value	Mentions
Transistor model	IAUCN04S6N007T	Present on lane B
Assumed Miller plateau voltage (V_{Miller})	4 V	Estimated from MOSFET datasheet
Push-pull stage output voltage (V_{DRV_OUT})	11 V	Estimated from gate driver datasheet
Desired time for switching time Miller plateau (t_{Miller})	200 ns	Application specific/ arbitrarily chosen
MOSFET gate-drain charge (Q_{GD})	19 nC	From MOSFET datasheet

The value of the two resistors was calculated by using the following logic:

$$I_{GateMillerON} = \frac{Q_{GD}}{t_{Miller}} = \frac{19\,nC}{200\,ns} = 95\text{ mA}$$

Equation 1 Calculating the switch on commutation current

From the current value we can determine the switch on commutation resistor value

$$R_{ON} = \frac{V_{DRV_{OUT}} - V_{Miller}}{I_{GateMillerON}} = \frac{11-4(V)}{0.095(A)} = \text{approx. } 74\ \Omega$$

Equation 2 Calculating the switch on resistor value

Though the desired value is 74 Ω, a 75 Ω resistor was chosen instead as it is a more commonly commercially available value.

However, using a single resistor for both on and off commutation does not work, due to the asymmetry between V_{Miller} and V_{DRV_OUT}. The switch off commutation current to the Miller plateau voltage can be calculated as well:

$$I_{GateMillerOff} = \frac{(4-0)(V)}{75\ \Omega} = \text{approx. } 54\ \text{mA}$$

Equation 3 Calculating the switch off commutation current with a 75 Ω gate resistor

With that current value we can furthermore determine the off time commutation duration by dividing the same Q_{GD} charge by the current:

$$t_{Miller_{off}} = \frac{19(nC)}{0.054(A)} = 351\ \text{ns}$$

Equation 4 Calculating the switch off time with a 75 Ω gate resistor

To compensate the imbalance between the on and off commutation time, the secondary resistor and diode are used (D40 and R202 from the figure above, for example).

We are aiming for a switch on/off time of 200 ns, as stated above, which translates to a gate current of 95 mA, as calculated above, so the value for the target turnoff resistence value can be calculated as:

$$R_{OFF'} = \frac{V_{Miller}-0}{0.095(A)} = \frac{4(V)}{0.095(A)} = 42\ \Omega$$

Equation 5 Calculating the value for the switch off resistance

In the calculated value above, the voltage drop across the diode is approximated to zero. However, for large gate switch off currents and/or undersized or closely matched diodes, the voltage drop across the diode can be significant and it makes sense to take it into account when calculating the resistor values.

$R_{OFF'}$ is the equivalent resistance obtained from R_{ON} and the resistor that we need to calculate, R_{OFF}. For that, the formula for parallel resistors is applied.

$$R_{OFF'} = (R_{OFF} || R_{ON}) = \frac{R_{OFF} * R_{ON}}{R_{OFF} + R_{ON}}$$

Equation 6 Mathematical expression for $R_{OFF'}$

From the equation above, we can mathematically determine that:

$$R_{OFF} = \frac{R_{OFF'} * R_{ON}}{R_{ON} - R_{OFF'}} = \frac{42*74}{74-42} = 97\ \Omega$$

Equation 7 Calculating R_{OFF}

The closest easily available resistor value was chosen, 100 Ω.

- **Lane A: TLE9189**
    - It relies on a charge pump to provide the required voltage for gate turn on. In contrast to the TLE9188, the TLE9189 has dedicated IHx and ILx pins to control each individual highside/lowside MOSFET
    - An initial configuration via SPI is still required for the gate driver to enter regular operation
    - In terms of hardware implementation, a very simple approach was chosen, very similar to the example application circuit in the TLE9189 user manual
    - In contrast to lane B, where the TLE9188 is a push-pull type gate driver, there is no need for gate turn on/off control circuitry due to the fact that the TLE9189 allows for configurable turn on/off gate currents

The two gate drivers share some safety features such as dedicated hardware safety turnoff (SOFF_N pin) and built-in safety mechanisms such as cross current detection, short circuit detection, etc.

They are great choices for field oriented control due to their ability to sample individual phase currents accurately.

Power MOSFETs

Two types of power MOSFETs are present on the board. Lane A relies on **OptiMOS™7** (IAUCN04S7N006T) while lane B uses **OptiMOS™6** (IAUCN04S6N007T).

At first glance, the two generations of OptiMOS™ look the same, due to the fact that they share the same package - SSO10T.

Fundamentally, one of the more notable differences between the two consists of the RDS(on) parameter – 0.62 mΩ for IAUCN04S7N006T and 0.75 mΩ for IAUCN04S6N007T. In terms of dynamic characteristics, for the sake of the current application, the two MOSFETs have very similar dynamic characteristics.

The SSO10T package, as the “-T” termination suggests, is a topside cooled package. This aspect can be very favorable in the case of electronic power steering (EPS), steering-by-wire applications, as in practice this allows a more convenient placement of the components and improved cooling capabilities.

With topside cooled MOSFETs, the option to use the mechanical casing of the motor/inverter as a cooling surface becomes even more viable. Test results showed that the SSO10T 5x8 package offers between 20%-50% better power capability than the comparable industry standard SSO8 5x6 bottom side cooled package.

For more details regarding the SSO10T package advantages and real-life application considerations, users can explore the dedicated product page on the Infineon website.

Safety circuitry

The safety circuitry of the board consists of a combination of small signal MOSFETs which take up the role of conditioning the activation/deactivation of the power switch MOSFETs (which control the connection between

the main power supply and the inverter stage). The safety circuitry acts based on safety-related signals, such as the safe state outputs of the PMICs and also separated control signals from the individual AURIX™ devices.

Functionally speaking, the safety circuitry works like a multiple input, multiple output AND gate between the PMIC SS1 signal and the individual control signals (general power switch control, individual phase cutoff circuitry).

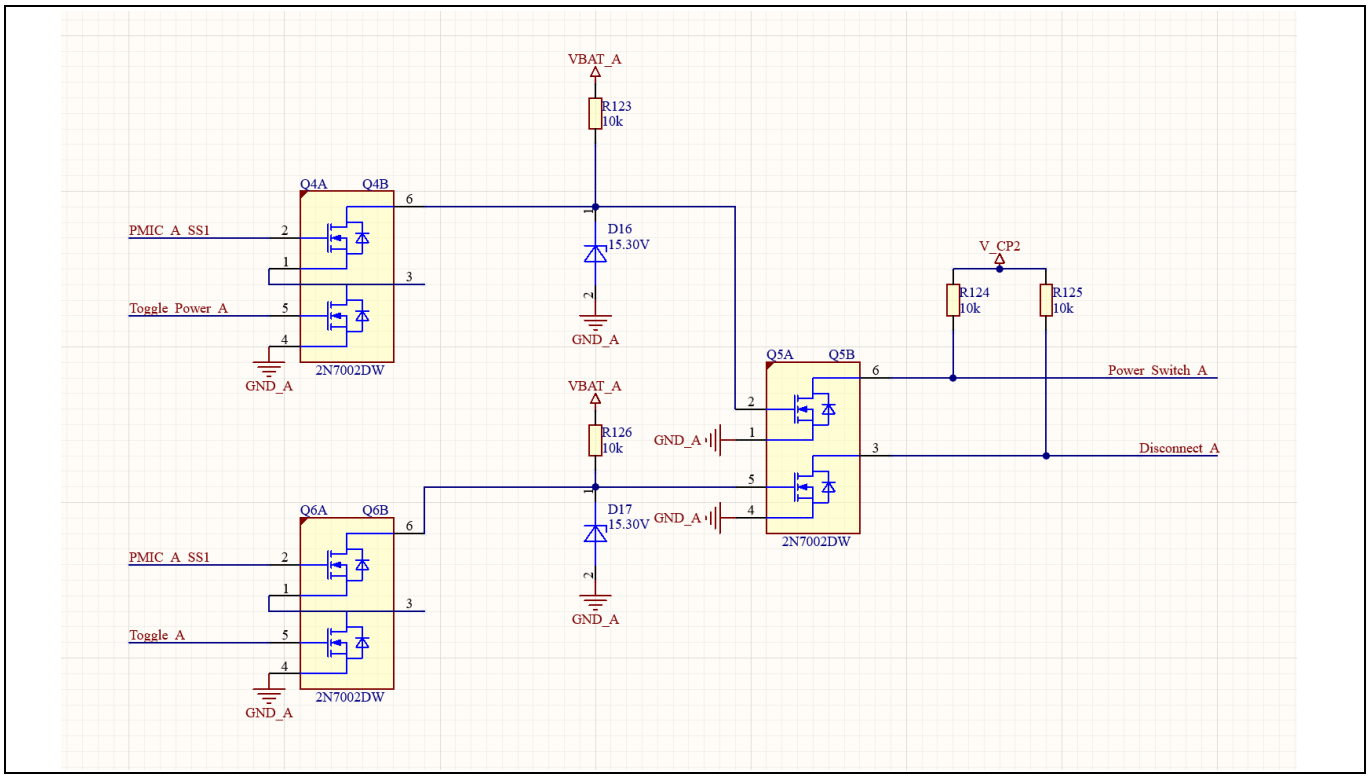


Figure 27 Example of safety circuitry block on lane A

The hardware setup from the image above is repeated in the same fashion for all of the phase disconnects present on the board (Disconnect A/B/C/U/V/W).

Table 4 Safety circuitry truth table

PMIC_A_SS1	Toggle_Power_A	Toggle_A	Power_Switch_A	Disconnect_A
0	0	0	0	0
0	0	1	0	0
0	1	0	0	0
0	1	1	0	0
1	0	0	0	0
1	0	1	0	1
1	1	0	1	0
1	1	1	1	1

The logic is the following:
The default state is defined with signals “Power_Switch_A”, “Disconnect_A”, “Disconnect_B”, and “Disconnect_C” disabled, so that there is no possibility for motor torque to be applied accidentally.
In order for the board to function correctly, the aforementioned signals must be enabled via software. The purpose of the phase disconnect MOSFETs (and dedicated control signals) is to have the option to enable/disable individual motor phases to demonstrate fail-operational functionality. For example in the event that one motor phase is shorted to ground, it can be deactivated selectively so that the remaining two phases (on one of the two lanes) can still work normally to output motor torque so that steering operation will not be lost.
Finally, the PMIC_A_SS1 is a dedicated safe state signal that must be high for the board to enter normal operation mode in case a safe state event is triggered.
A safe state event is defined as when it is mandatory for the board to stop driving the motor due to a detected problem triggered by the safe state control logic.

Angle sensors

The board is equipped with two sensors to detect angular position of the rotor of the electric motor. This is necessary to efficiently control the motor commutation, particularly for highly sensitive applications that require accurate position control, such as electronic power steering. Two different sensors are used. Lane A uses a TLE5502, which is a tunneling magneto resistance (TMR) sensor, in a dual-die configuration. Lane B uses a TLE5309D which includes two individual sensors – one based on anisotropic magnetoresistance (AMR) and one based on giant magnetoresistance (GMR).

Each of the two lanes can determine rotor position, and, for extra redundancy, the individually determined position (out of four sensors and two microcontrollers) can be compared via software to improve accuracy or troubleshooting.

2.3 Example: design tips

The proposed design is a generic example of a safety motor controller. Since it can be used in various applications such as electronic power steering, electro-mechanical braking and others, there is a lot of room for optimizing the circuit for application specific requirements.

Generally speaking, the architecture could be reused as it is, replacing the individual components with alternatives from Infineon. Each building block – microcontroller, gate driver, power stage, etc. can be selectively improved for better performance, cost, size, etc.

One of the goals of developing the safety motor control application kit was to show two implementation versions – Lane A uses newer or more complex components. One example that is visible right away can be noticed with the microcontrollers – The TC366 on Lane A, though it has a total of 180 pins, occupies slightly less area than the TC332 on lane B, which has 80 pins. This is mainly due to the convenience offered by the LFBGA180 package.

However, if not all of the functions/processing power offered on the TC366 are relevant/necessary or if the space savings are not that relevant, then choosing the TC332 might make more sense for certain particular designs, especially cost-efficient designs.

Such examples can be found all across the board. One strikingly similar example can be seen with the gate drivers – though in the end they achieve the same purpose, the gate driver on lane A, TLE9189 is larger due to the fact that it has more pins, since it has dedicated input controllers for each highside/lowside MOSFET in the inverter stage. However, the TLE9188 on lane B is smaller due to the fact that it is controlled via SPI, which means there is no need to allocate as many control pins on the microcontroller side.

To make a proper decision, a hardware designer would have to take a thorough look at the Infineon product portfolio and put in balance the factors of cost, size and complexity.

3 System design

3.1 Schematics

In terms of schematic design, the project follows a typical tree-like structure. To follow that, look at the main schematic page, “Main.SchDoc”:

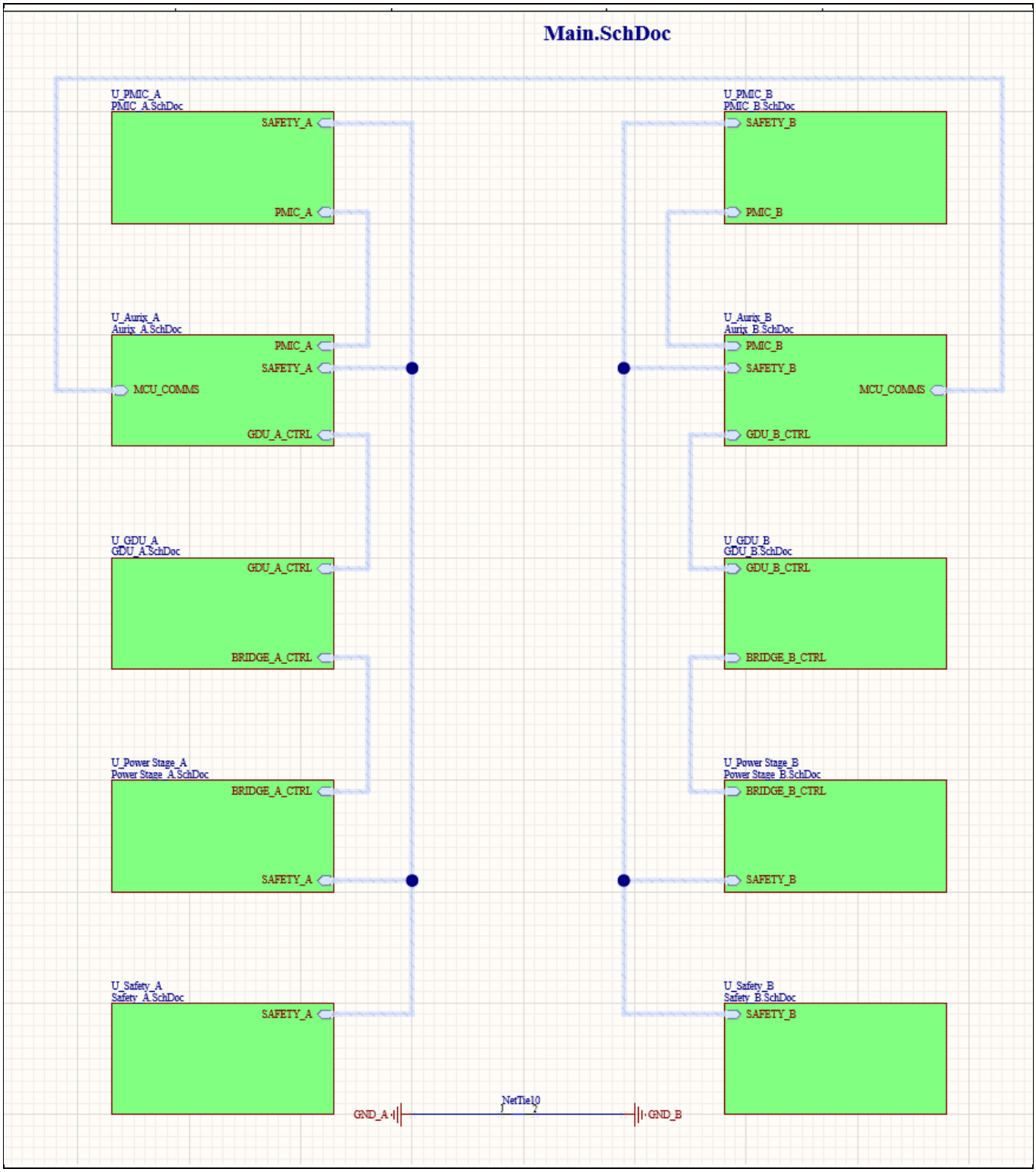


Figure 28 Main schematic page

The schematic page above shows the relationship between the individual schematic pages. To view the individual schematic page contents within Altium Designer, press ctrl+double click on each element to open the desired page.

The schematic is split into the main functional blocks – microcontrollers, PMICs, gate drivers, power stage, safety circuitry, with separate sheets for the functional blocks on lane A and slane B of the board.

There are some additional components such as angle sensors and CAN transceivers bundled with the microcontroller schematics, within the “Aurix_A” and “Aurix_B” schematic pages, in order to avoid creating too many individual schematic pages.

3.2 Layout

Numerous aspects were taken into account when designing the board. The following is an insight into the main technical considerations.

First of all, the choice to make the board round shaped originates from the fact that safety-related motors are typically round, dual three phase or six phase motors, with phase connectors diametrically opposed. Additionally, it is mechanically simpler to have the board and motors aligned centrally this way. This is also rather advantageous for applications that require precise motor rotor position sensing, such as traditional power steering or steering by wire. Therefore, it also makes sense to have the angle sensors in the middle of the board, where the motor shaft would typically be located. It is worth noting that, in real-life applications, there is always the option to have the steering angle/torque sensors remotely from the control/inverter board. Such sensors are typically refered to as “satellite” units.

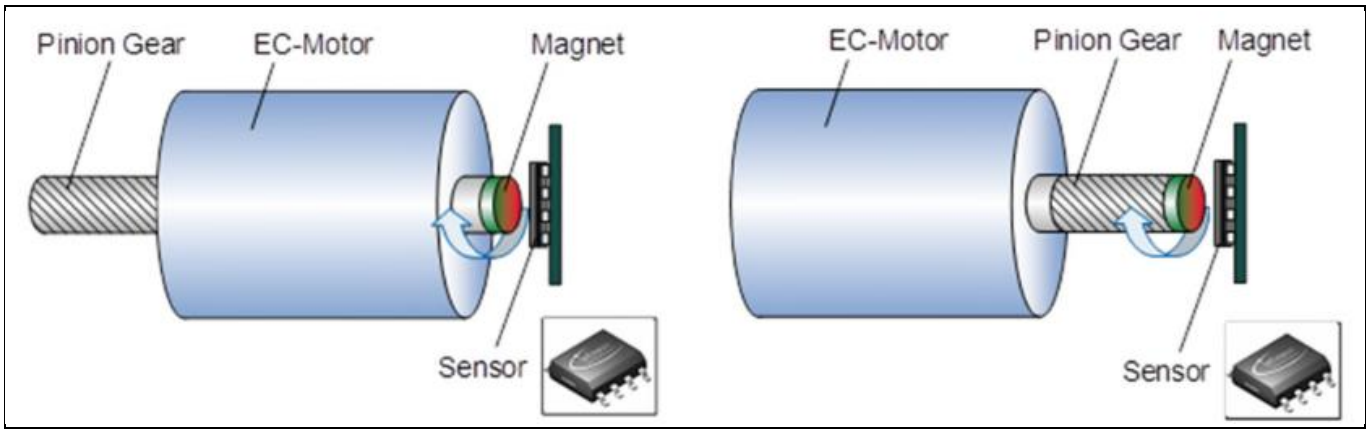


Figure 29 Typical angle sensor/PCB orientation versus steering motor

One angle sensor is placed on the top side (TLE5502) and another one on the bottom side of the board (TLE5309) for two independent readouts.

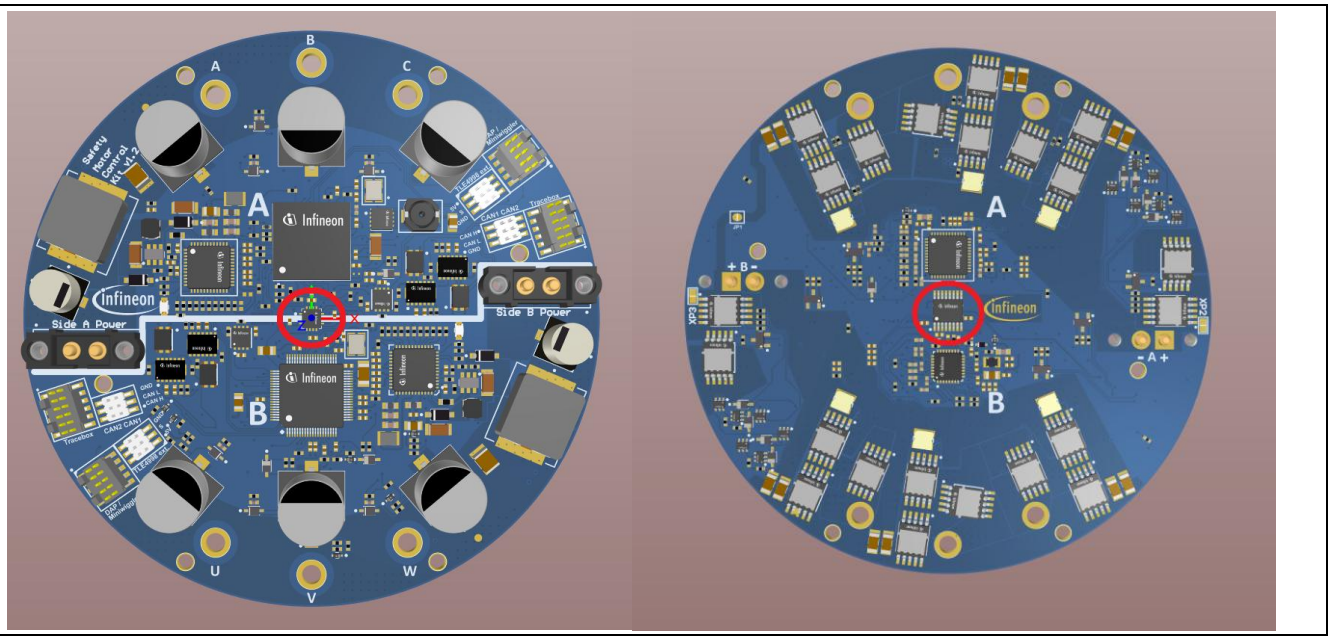


Figure 30 Angle sensors present on the board, top side and bottom side

The idea of placing the inverter stage components towards the outer side was chosen in order to keep the high current path away from the angle sensors, which, in return, can improve the signal to noise ratio.

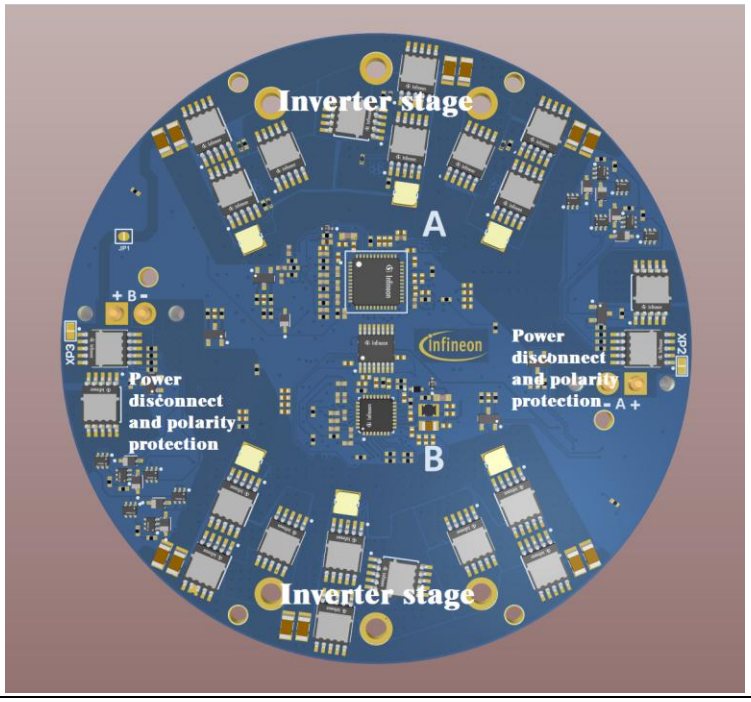


Figure 31 Power stage components distribution

The layout for the individual phase bridges was optimized to mitigate the effects of switching on the high current copper tracks.

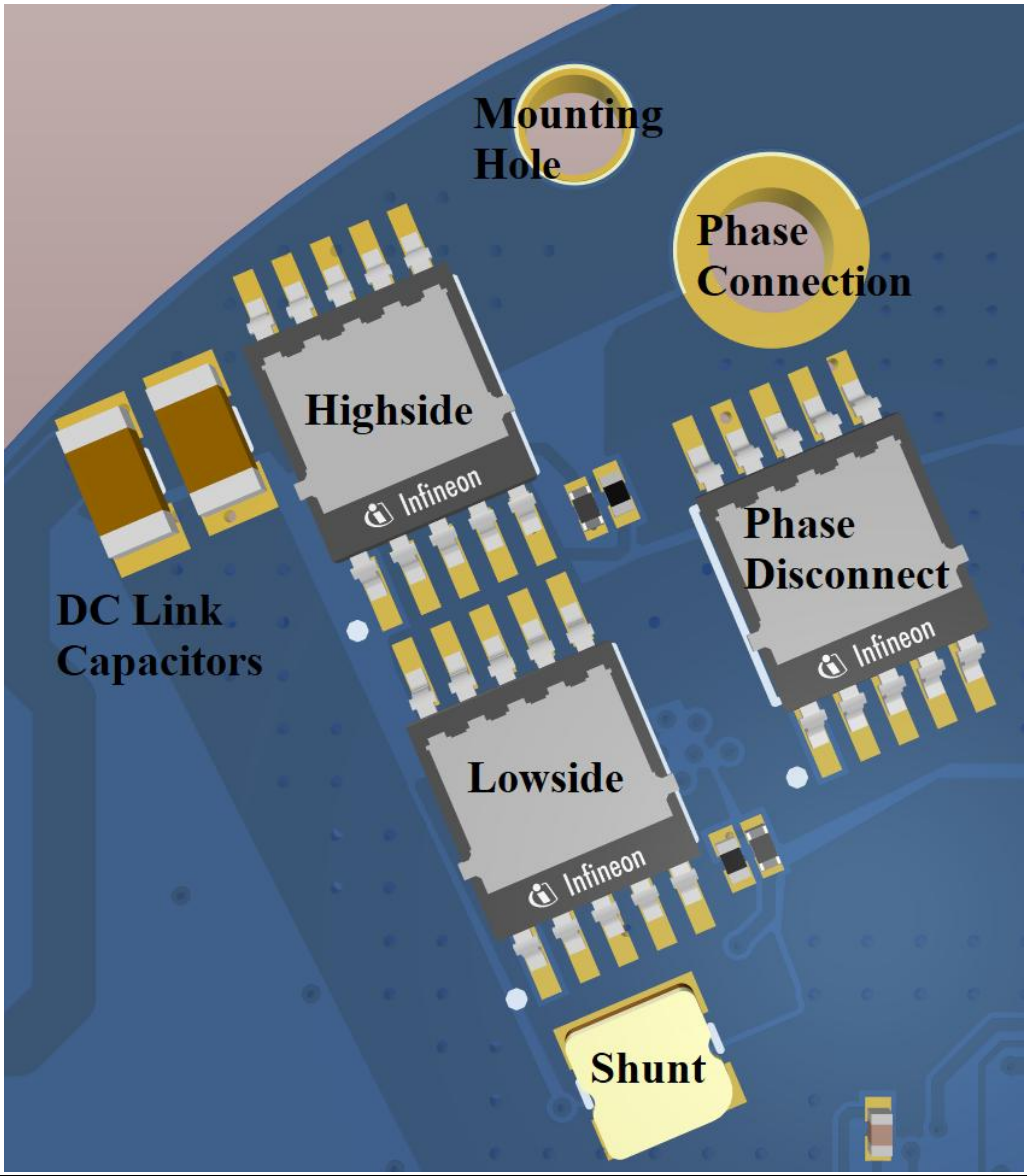


Figure 32 Inverter phase setup

Each of the six phases on the board is driven by the exact same setup, with the mention that there is an extra electrolytic capacitor on the top side of the board (for each half bridge).

If a user is interested in measuring the control signals of each MOSFET, the gate-source differential measurement can be probed on each transistor at the following points:

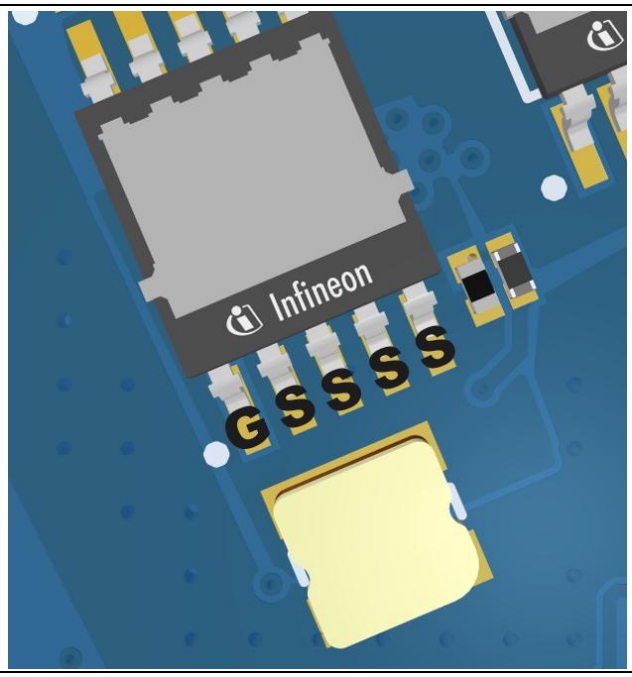


Figure 33 MOSFET probing points

It can be observed that the pin next to the white dot is the gate pin, while the neighboring ones are all source pins.

This is true for all the topside cooled MOSFETs present on the board as they all share the same package.

It is important that the ceramic capacitors are placed next to the highside/lowside MOSFETs to minimize the current loops. Minimizing the length of copper tracks between the pi filter/DC link capacitors and the switching MOSFETs helps decrease the stray inductance, which, in return, minimizes voltage spikes when driving the motor.

The voltage spikes are a result of stray inductances in the motor current path combined with high currents. Since we want to maximize motor current carrying capabilities, we minimize the stray inductances as much as possible to improve performance. One very simple rule of thumb for this is to place all of the components in the motor current path as close together as possible to minimize the physical distance, which in return minimizes the stray inductance.

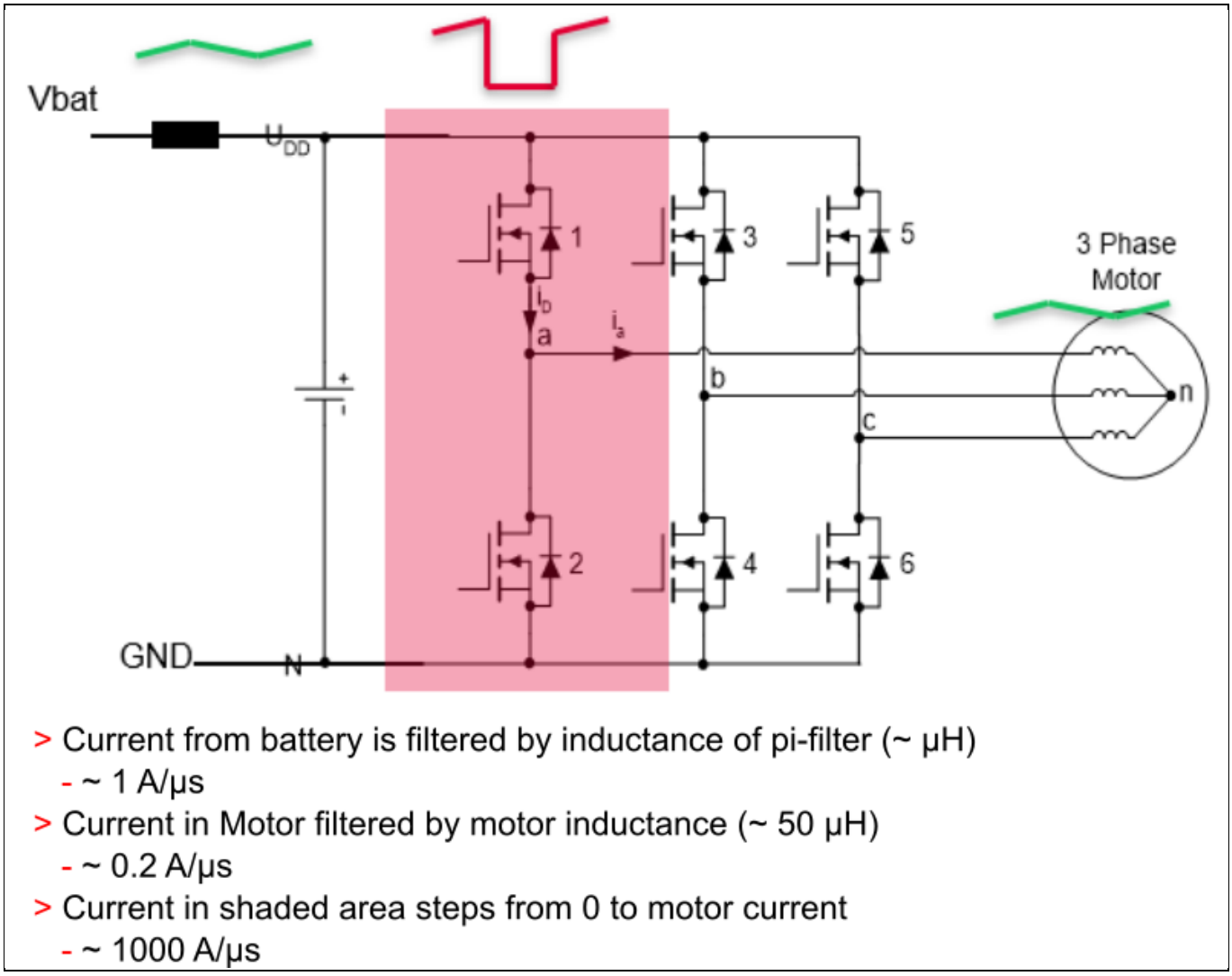


Figure 34 Brief explaination for why it is relevant to reduce parasitic inductances

The high current polygons are spread throughout multiple layers. Generally speaking, it is a good practice to use via stitching for such polygons to decrease stray inductance, track resistance, and decrease capacitive coupling.

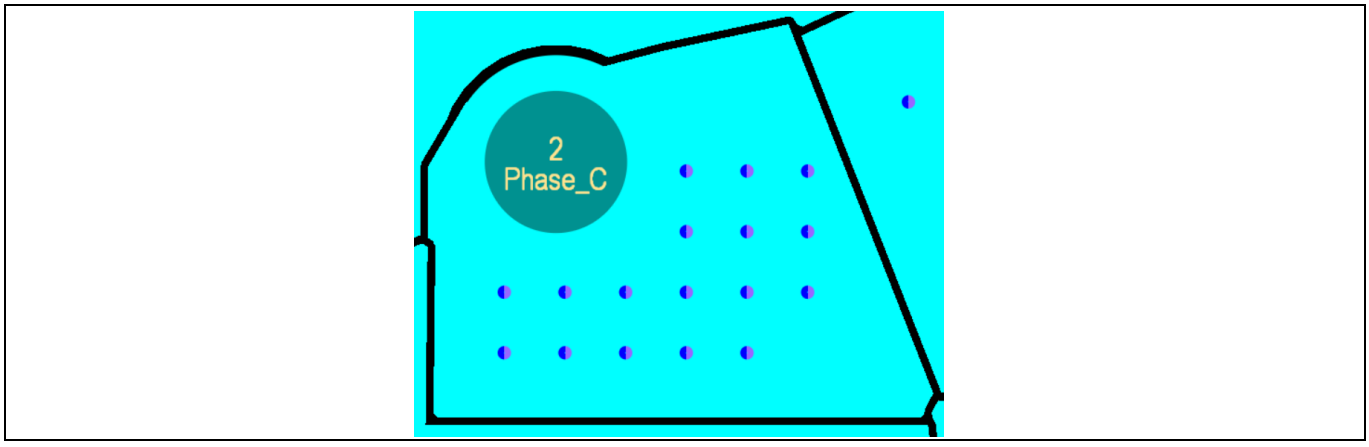


Figure 35 Power polygon via stitching example

For switching tracks it is highly recommended to route the individual MOSFET gate/source track pairs close together, in a similar fashion to a differential pair and use adequately sized copper tracks for the gate switch on/off currents.

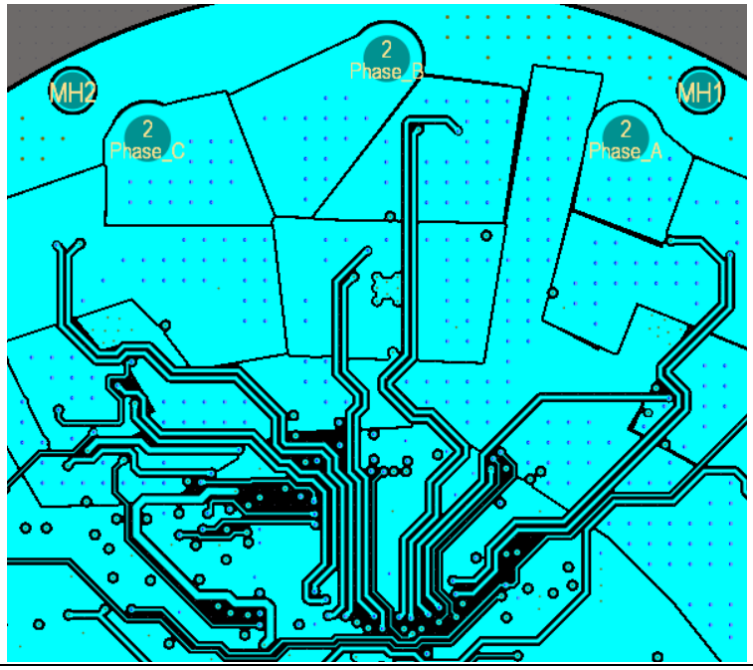


Figure 36 Gate/source tracks routing example on lane A

In the image shown above it can be observed that some tracks cut through some power polygons (only on this specific layer). Though at first glance it might seem pointless to keep the power polygons. For this design it was decided to keep even the ones that are disconnected in an attempt to spread heat evenly throughout the board while also increasing thermal mass.

Another aspect worth mentioning in regards to board design is the fact that symmetry was a key design aspect, both horizontally and vertically, in order to obtain similar electrical characteristics on both lanes and to make navigating the board simpler. Becoming familiar with one lane means becoming familiar with both.

3.3 Bill of materials

The complete bill of materials can be found alongside other relevant documentation within the Infineon Developer Center (IDC), after registering the serial number of a purchased board into the “New project” tab. The product page can be found here.

3.4 Connector details

Table 5 Connectors

PIN	Label	Function
Lane A SWD Communication pins	X1	Moteon Tracebox standardized connector
Lane A CAN Communication pins	XA1	External CAN communication x 2
Lane A SWD Communication pins	X2	Infineon DAP standardized connector
Lane A External torque sensor connection	XBT2	External TLE4998 connector
Lane A VBAT_A, GND_A	X3	Lane A power supply connector
Lane B SWD Communication pins	X4	Moteon Tracebox standardized connector
Lane B CAN Communication pins	XB1	External CAN communication x 2
Lane B SWD Communication pins	X5	Infineon DAP standardized connector
Lane B External torque sensor connection	XBT1	External TLE4998 connector
Lane B VBAT_B, GND_B	X6	Lane B power supply connector

4 System performance

4.1 Test points

For probing particular signals on the board, it is mandatory that the user registers their board and is then granted access to the design files, which can be used to indicate where to probe for each signal. Board registration can be performed on the dedicated portal.

Revision history

Document revision	Date	Description of changes
1.01	28.11.2025	Initial version

Trademarks
All referenced product or service names and trademarks are the property of their respective owners.

Edition 2025-11-28

Published by

Infineon Technologies AG

81726 Munich, Germany

© 2025 Infineon Technologies AG. All Rights Reserved.

Do you have a question about this document?

Email: erratum@infineon.com

Document reference

2025-11-28

Warnings

Due to technical requirements products may contain dangerous substances. For information on the types in question please contact your nearest Infineon Technologies office.

Except as otherwise explicitly approved by Infineon Technologies in a written document signed by authorized representatives of Infineon Technologies, Infineon Technologies' products may not be used in any applications where a failure of the product or any consequences of the use thereof can reasonably be expected to result in personal injury.