1 kW BLDC Power Tool Kit User Manual

Application Note

About this document

This Application Note introduces a complete system level solution to drive a BLDC Motor for cordless power tools. It also describes how to quickly get started integrating this demonstration PCB and take advantage of Infineon's SMD technology featuring 40 V OptiMOS™ MOSFETs and XMC1000 series microcontroller.

Scope and purpose

To show the efficiency, present a thermal solution for a power stage with SMD MOSFETs and show how to implement the control with the microcontroller to drive a BLDC motor equipped with 3 hall sensors. This enables the power tool manufacturers to minimize time to market.

Intended audience

Battery driven power tool manufacturers who intend to reduce the system cost and improve the efficiency and increase the power density, which in turn provides longer run time and higher peak power pulse capability.

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1 Overview

Infineon´s Power Tool Kit EVAL_SSO8_1kW_BLDC is as complete system solution implemented with a 3-phase bridge MOSFET power stage and a control PCB featuring Infineon's low cost 32-bit microcontroller XMC1302.

This demonstration unit is specifically designed for cordless power tool application by using simple plug and play system, but it can easily be adopted for any 3-phase brushless DC motor application. Its compact design, optimized thermal performance and a ready to use firmware allows the user to effectively and quickly implement this design.

The source code is also provided which can be modified to implement additional features.

In its original shape the overall PCB measures 90 mm x 36 mm and provides test points to all signals from the microcontroller. This allows the user to monitor the signals of interest. This board can be further split into 3 parts: control PCB, power PCB, and capacitor PCB. These individual PCBs can then be connected via ribbon cable and give users the flexibility to physically insert these boards into practically any power tool.

This demonstration board is more than just a reference design. Its unique layout, cooling concept and utilization of surface mount components will result in the highest power density, reliability, and a low cost product.

Important Notes:

1. **The electrolytic capacitor is provided for filtering, but it is important that the battery wires are kept as short as possible. Otherwise a large ripple current can flow through this capacitor leading to its premature failure. If a power supply with long wires is used, it is recommended to connect in addition a 4700 uF/50 V capacitor as close as possible to the power stage.**
2. **It is also recommended that UART FTDI communication cable is disconnected from the computer USB connector when the demo board is powered up.**

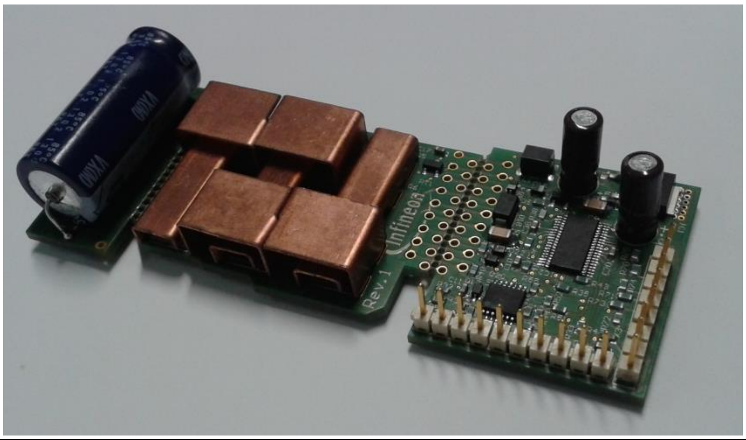


Figure 1 1 kW BLDC Motor Control Power Tool PCB (EVAL_SSO8_1kW_BLDC)

1.1 Key Features

- B6 Inverter for 3-phase BLDC motor
- Nominal voltage 20 V
- Continuous phase current 50 A

- 1 kW output power (Test conditions: 100% duty, 50 A RMS per phase; V_{supply}=20 V @50 A, open frame/ no forced air, 26°C room temperature; resulting in 60°C temperature rise above ambient in 1 min)
- Operation down to 6 V battery supply
- Peak current capability up to 200 A
- Overcurrent detection by measuring $V_{DS,ON}$ across the MOSFET on all 3 phases
- Duty cycle controlled BLDC motors with 3 hall sensors
- 2 parallel MOSFETs BSC010N04LSI in SuperSO8 package – 40 V/1.05 mOhm $R_{DS(ON),max}$ with integrated monolithic Schottky-like diode (low reverse recovery charge (Q_{rr}) and low forward voltage diode drop (V_{SD})
- Low PCB parasitic inductance
- PCB
  - 90 mm x 36 mm overall dimensions
  - Power stage PCB : L=45 mm x W=36 mm x H=10 mm
  - Material - FR4
  - 2 layers, 2oz copper (70 µm)
- Low conduction losses
- Low diode losses, and low reverse recovery charge with an integrated Shottky-like diode (MGD)
- Low voltage overshoot and low ringing
- Accessible signals at the PCB interface
- Good thermal dissipation
- Temperature sensor
- 32-bit XMC motor control optimized microcontroller
- Provides all connections for power tool functions: hall sensors, speed controller pot, motor direction switch, UART communication port, debugger connection
- High efficiency ~99%
- Maximized power density ~ 75 W/cm^3
- Half bridge gate driver 2EDL05N06PF – 0.5 A peak
- Boost converter for gate driver voltage generation – programmed for 12 V (V_boost) but it can be modified for other gate driver voltages

2 Power Tool Kit Package content

The Power Tool Kit includes following items:

- Power Tool demo PCB (programmed and ready to use)
- USB/Serial communication adapter (FTDI Cable)
- USB memory stick including documentation and software
- 2 x 15 cm ribbon cable

Figure 2 Power Tool Package

2.1 PCB

The PCB consists of several building blocks:

- Linear regulator IFX27001TFV50 DC/DC converter stepping down the battery voltage to +5 V for MCU
- Boost circuit used for gate drivers and an Opamp
- Temperature sensor for thermal overload shutdown
- 3-phase full bridge inverter implemented with 2 in parallel Infineon OptiMOS™ Power MOSFETs BSC010N04LSI (I_d=100 A, $R_{DS(on)}$=1.05 mΩ).
- Current measurement by using voltage measurement across the MOSFET when turned ON
- 3 x Half Bridge gate driver with integrated bootstrap diode
- 32-bit XMC1302 microcontroller
- Hall sensors signal input circuitry for BLDC motor commutation
- Serial communication for programming and controlling the MCU
- Connector for a direct access to MCU debug pins
- 10 spare MCU pins which can be configured as input or output pins
- Potentiometer input for speed control
- L/R motor direction switch

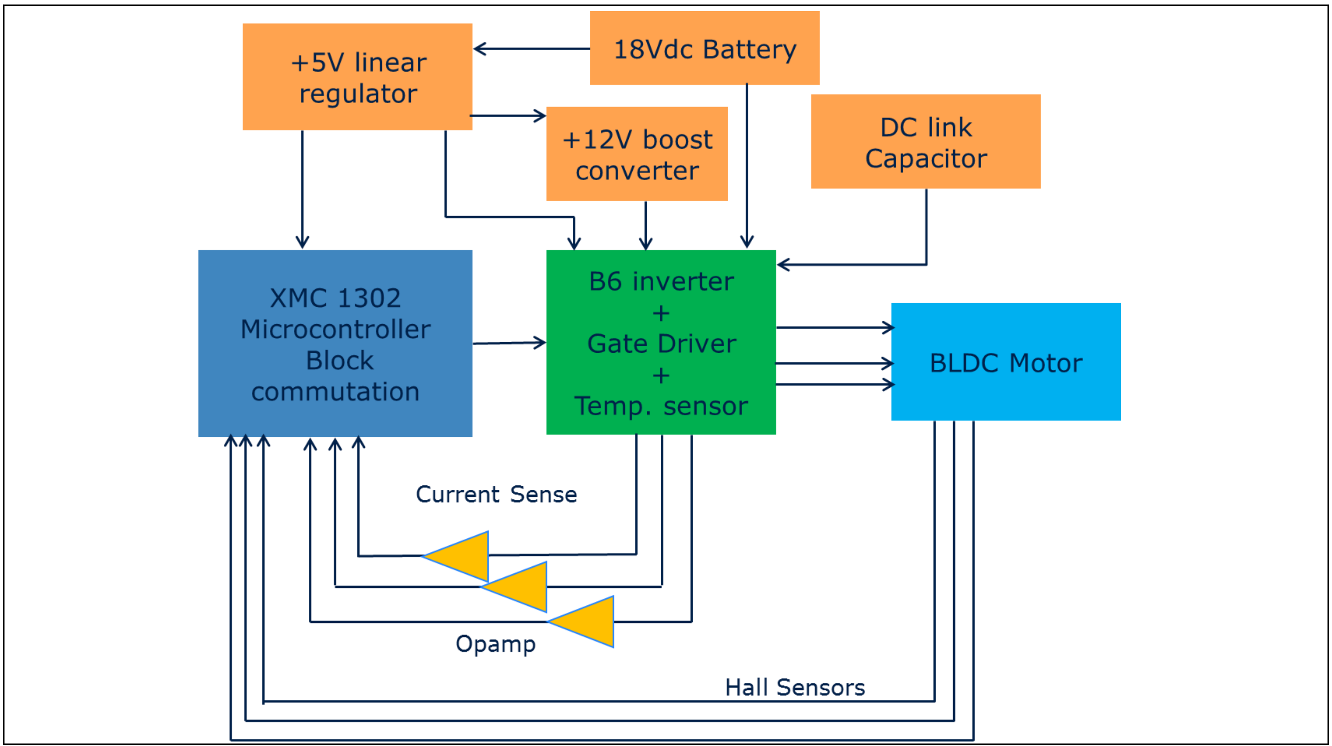
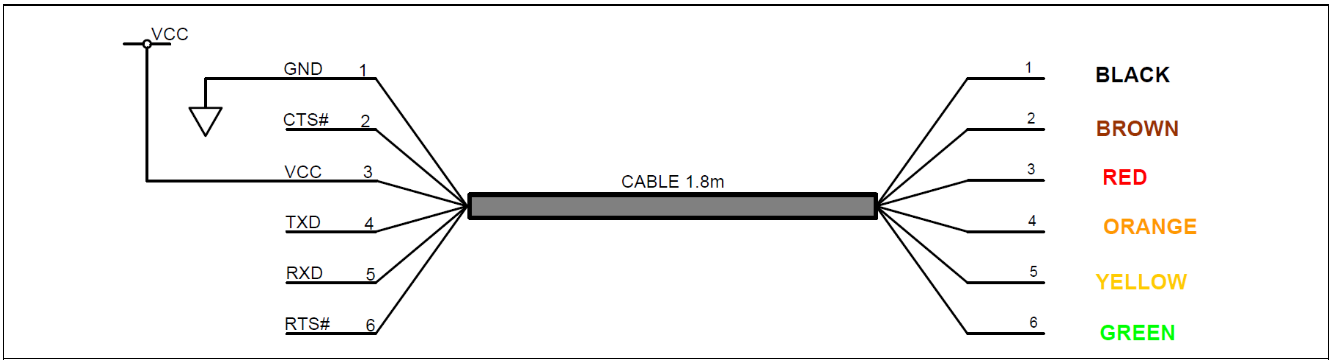


Figure 3 System Block Diagram

2.2 Communication Interface

Communication interface is a link between PC user interface and the board. It was realized with a commercially available cable from FTDI TTL-232R-5V-WE.



Colour	Name	Type	Description
Black	GND	GND	Device ground supply pin.
Brown	CTS#	Input	Clear to Send Control input / Handshake signal.
Red	VCC	Output	+5V output
Orange	TXD	Output	Transmit Asynchronous Data output.
Yellow	RXD	Input	Receive Asynchronous Data input.
Green	RTS#	Output	Request To Send Control Output / Handshake signal.

Figure 4 TTL-232R-5V-WE FTDI Cable Connections

2.3 Dedicated Software for the Onboard 32-bit Microcontroller

The XMC microcontroller is already programmed with dedicated software for power drill application. The following functions are implemented in the software:

- Block commutation for running BLDC motor with voltage control
- Wrong Hall sensor shut down

2.4 BLDC Motor (BLDCM)

The Power Tool Demo Board can run every BLDC motor equipped with 3 hall sensors.

3 Running the Power Tool Kit

In order to run the BLDC motor, the following connections must be made:

1. DC power supply (+20 V, GND)
2. 3 BLDC motor phases (U, V, W)
3. BLDC motor Hall Sensors (+5 V, GND, H1, H2, H3)

3.1 Connecting the board to a BLDC Motor

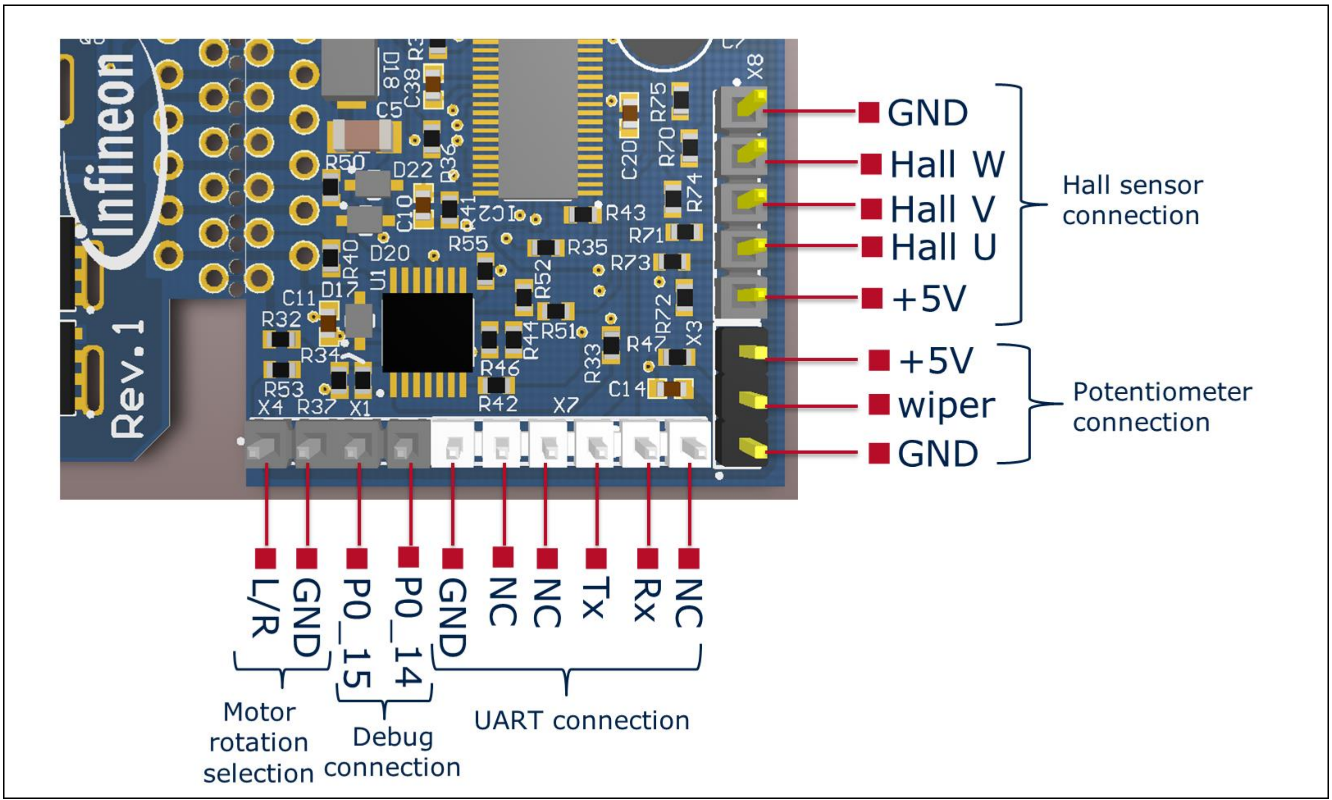


Figure 5 Control Board Connections

Note: Hall sensors must match respective phases, otherwise the inverter will immediately shut down.

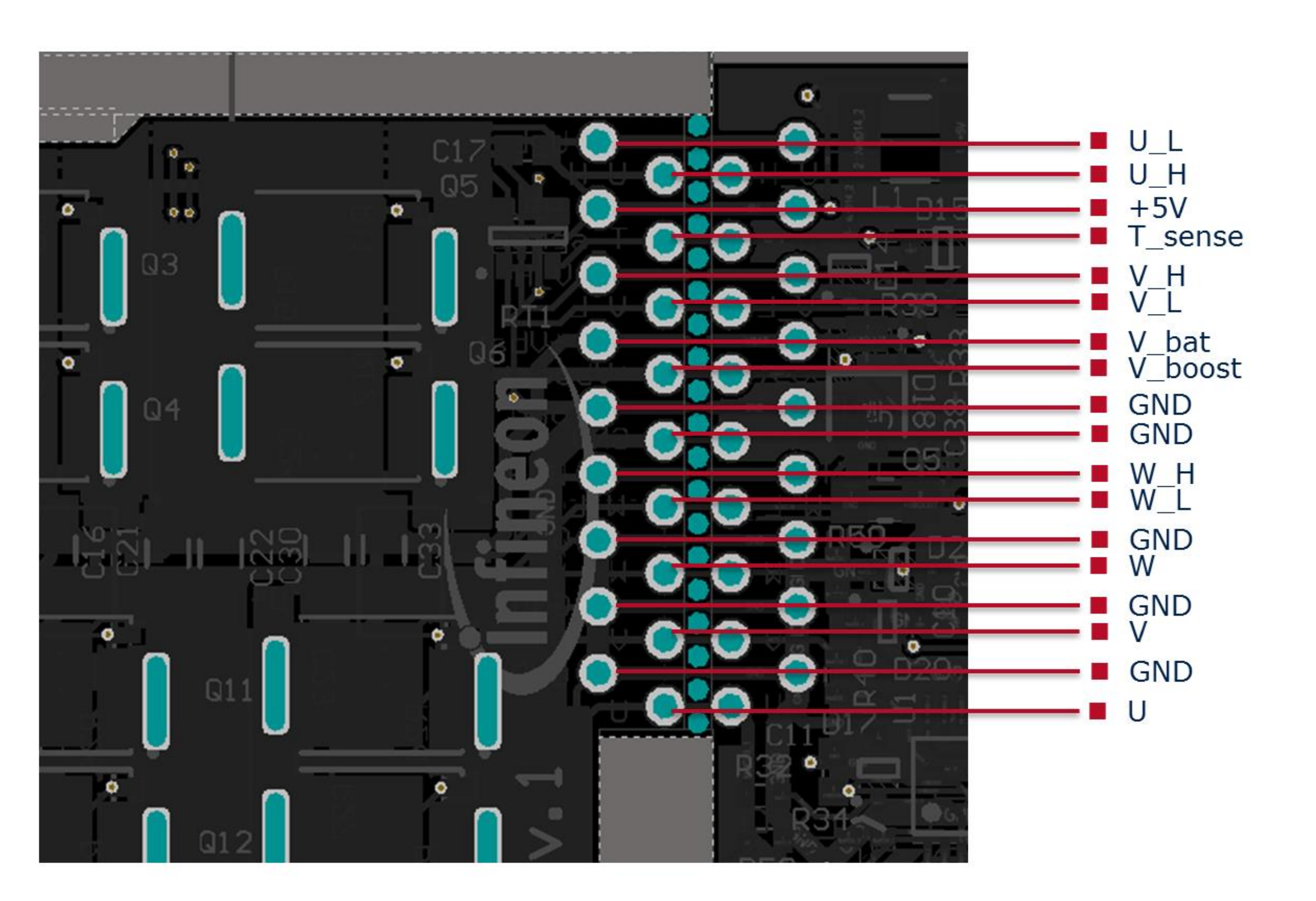


Figure 6 Interface signals between control board and power board

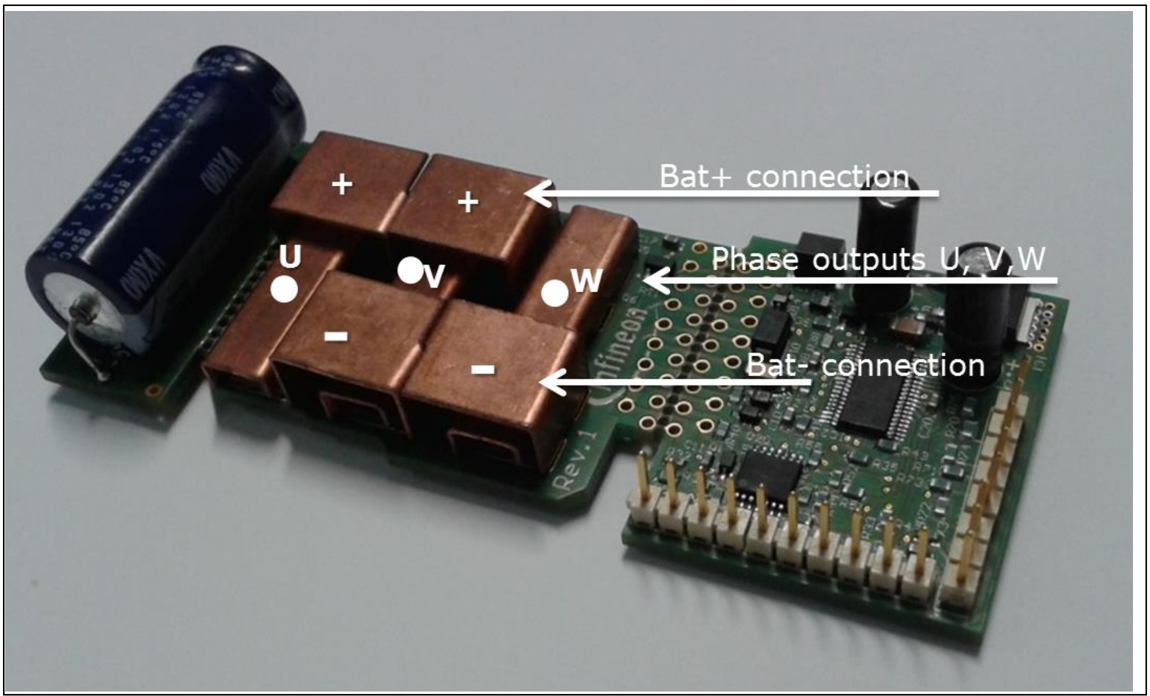


Figure 7 Power Inverter Board Connections

It is recommended that the power connection be made by means of direct soldering to the exposed copper. Since the thermal conductance is very high, use 450°C soldering iron with a large solder tip to effectively transfer the heat to copper parts and solder the connection wires. Ensure that there are no short circuit connections between phase outputs and battery +/- copper plates. See a sample below.

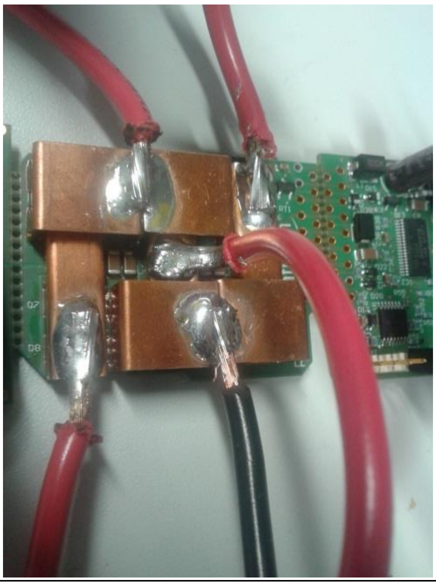


Figure 8 Power Inverter Board Connections

4 Hardware Description

4.1 Power Supply: +5 V and 12 V_boost

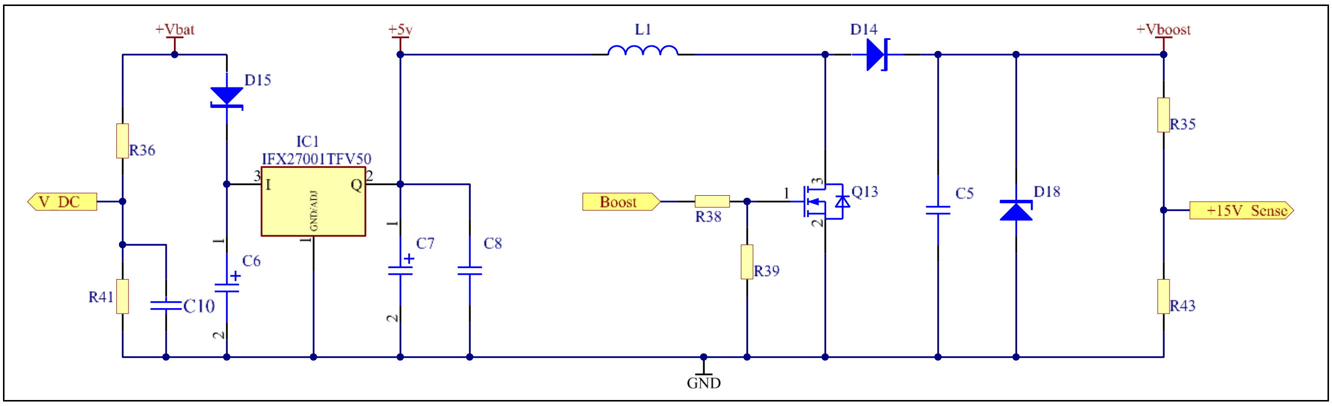


Figure 9 Power Supply Schematic

The system input voltage range is 6-24 V. The supplied voltage is stepped down to +5 V by using a low dropout voltage regulator IFX27001TFV50. This +5 V voltage is used to supply MCU, hall sensors, temperature sensor, and as supply voltage to the boost converter.

The 12 V_boost voltage, which is used for gate drivers 2EDL05N06PF and the LM324 operational amplifier, is generated by the boost converter built around Q13.

4.2 Power Stage

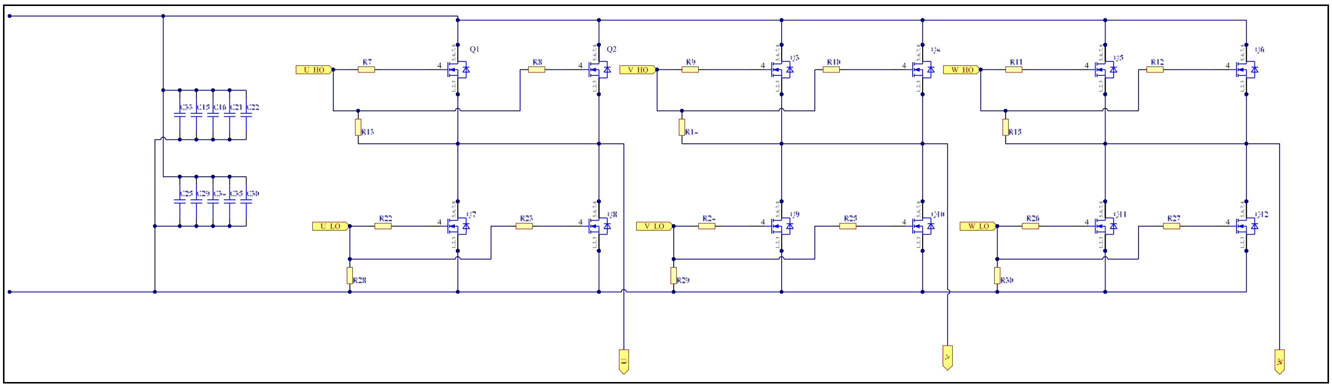


Figure 10 3 Phase Inverter Schematic

The power stage is designed to drive a BLDC motor up to 1 kW using two BSC010N04LSI MOSFETs in parallel. The gate resistors have a value of 100 Ohm which can be further modified depending on desired performance. Higher value of gate resistors will increase switching losses, since the MOSFETs are switching slower, but at the same time, the slower switching will generate lower voltage overshoots and require lower filter capacitors value.

If the gate resistors values are reduced, it is possible to reduce the dead time between high and low side MOSFETs leading to faster switching and lower switching losses, but on the other hand, the parasitic inductance of the battery and the circuit parasitic inductance will have more effect and generate higher voltage overshoot.

Multilayer ceramic caps (10 x 2.2 µF/50 V MLCC) are place on top side of the PCB which will filter out high frequency currents. The number of MLCCs can be further optimized depending on system requirements.

4.3 Current measurement

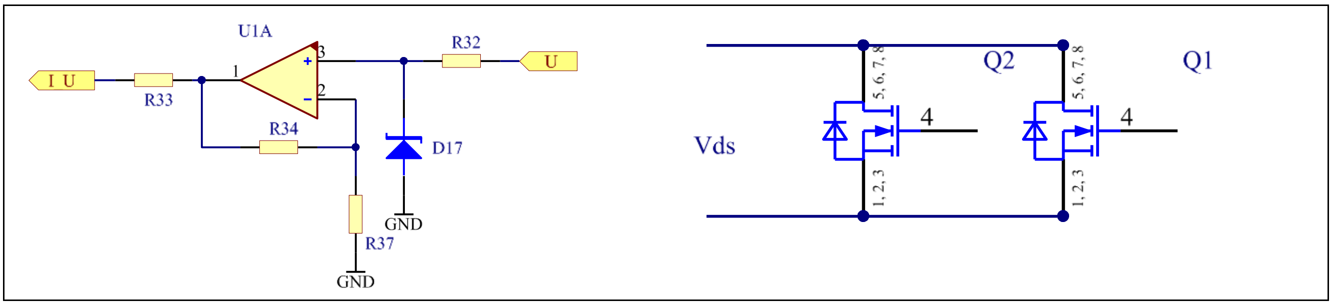


Figure 11 Current Measurements Schematics

The current measurement is implemented by means of measuring the voltage across the Drain-Source of the MOSFET. Since the MOSFET behaves like a resistor when in “ON” state, the voltage across it can be measured and the current through MOSFET can be calculated by using Ohm’s law.

$$I_{ds} = \frac{Vds}{R_{DS(on)}} \qquad [1]$$

Since the $R_{DS(on)}$ is dependent on temperature, we need to compensate for temperature change.

In Figure 12 below (found in datasheet of BSC010N04LSI) we can see $R_{DS(on)}$ dependency of temperature. Two curves provided are for a typical and a maximum initial $R_{DS(on)}$ value.

The software which is included in this package, is assuming a linear $R_{DS(on}$ dependency of temperature (indicated with the red line). The temperature information is obtained from the temperature sensor RT1.

If more accurate current measurements are required, one can create a curve fit formula instead of linear approximation. Also in effort to reduce the measurement error, we can factor out the variation of initial $R_{DS(ON)}$ and op-amp offset by initial calibration.

In a calibration process, it is advisable to set a known current on the power supply and cycle through all 3 phases. The readings on microcontroller A/D inputs can be then correlated with this current (suggested range ~10 A). The provided demonstration board is not calibrated.

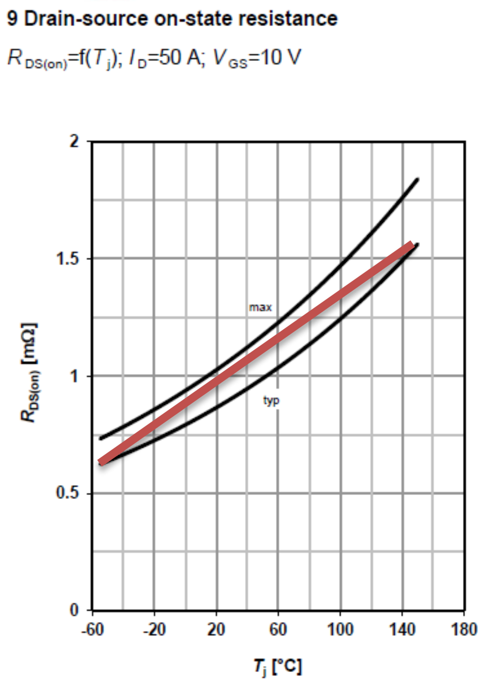


Figure 12 $R_{DS(on)}$ dependency of temperature for BSC010N04LSI

From the graph above (typical curve), we can see that with increased temperature $R_{DS,(on)}$ is increasing. For example if the temperature rises from 25°C to 100°C, the $R_{DS,(on)}$ will change from 0.8 mOhm to 1.25 mOhm. In order to compensate for temperature change we can calculate the $R_{DS(on),hot}$ as

$$R_{DS(on),hot} = R_{DS(on),cold} * (1 + \alpha(T_{hot} - T_{cold})) \quad [2]$$

where α is a temperature coefficient.

Since we have 2 MOSFETs in parallel and assuming a typical $R_{DS(on)}$=0.9 mOhm at 25°C, and T_j=100°C we can estimate the $R_{DS(on),hot}$:

$$R_{DS(on),hot} = \frac{0.9\ mOhm}{2} * \left(1 + \frac{0{,}45\ mOhm}{100°C}(100°C - 25°C)\right) = 0.60\ mOhm \quad [3]$$

The current is calculated as

$$I_{phase} = \frac{V_{DS}}{R_{DS(on),hot}} \quad [4]$$

Since the measured V_{DS} signal is small due to very low $R_{DS(on)}$ (0.6 mOhm), an op-amp is used to amplify this signal. The op-amp amplification is set to 30 V/V.

The current information is used to detect overload condition and shut down the inverter.

4.4 Gate Drivers

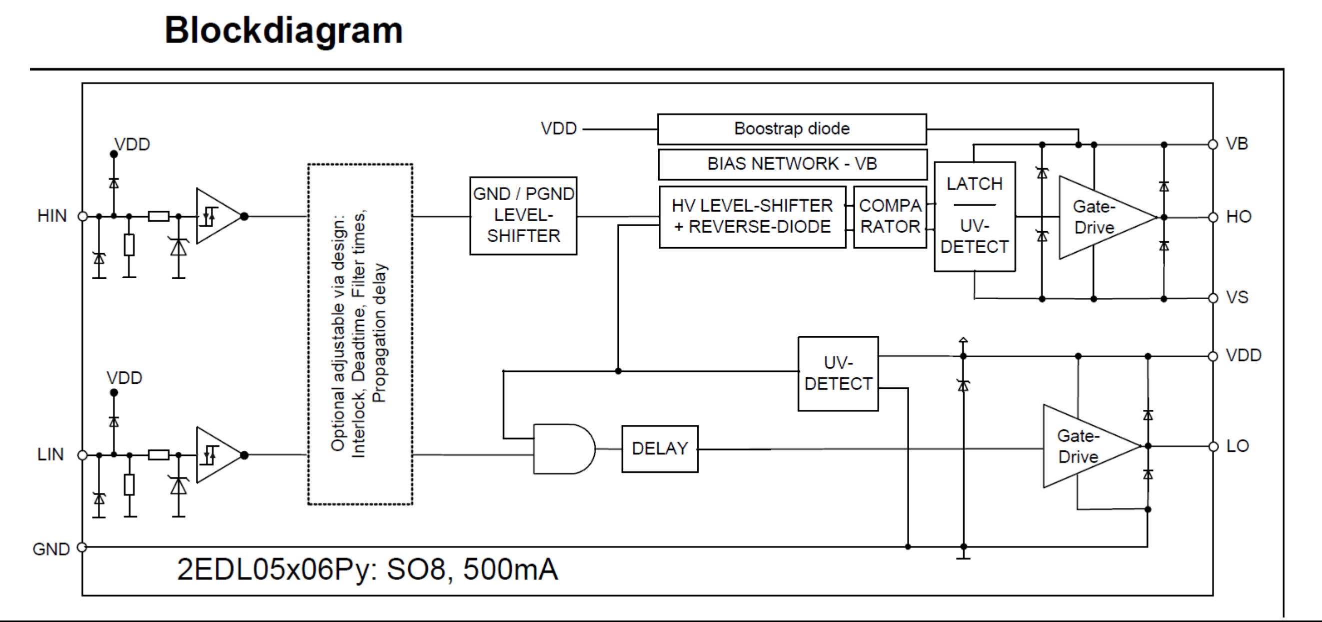


Figure 13 Single Gate Driver Block Diagram

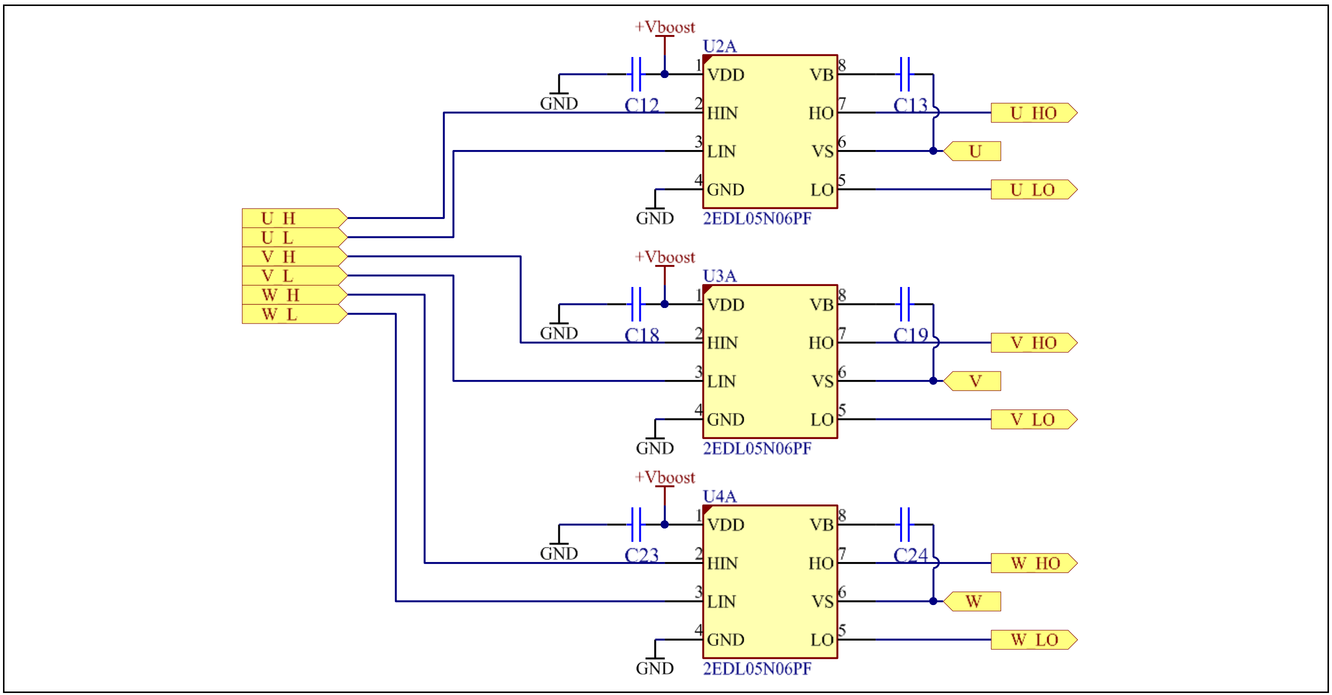


Figure 14 Schematic of a 3-Phase Gate Driver Circuit

4.4.1 Gate driver 2EDL05N06PF features

This demonstration board is using three 2EDL05N06PF Half Bridge gate drivers with integrated bootstrap diode.

Main features

- Output current 500 mA
- Thin-film-SOI-technology
- Insensitivity of the bridge output to negative transient voltages up to -50 V given by SOI-technology
- Ultrafast bootstrap diode
- Maximum blocking voltage +600 V
- Individual control circuits for both outputs
- Filtered detection of under voltage supply
- All inputs clamped by diodes
- Off line gate clamping function
- Asymmetric under voltage lockout thresholds for high side and low side
- Qualified according to JEDEC1 (high temperature stress tests for 1000 h) for target applications

4.5 Microcontroller

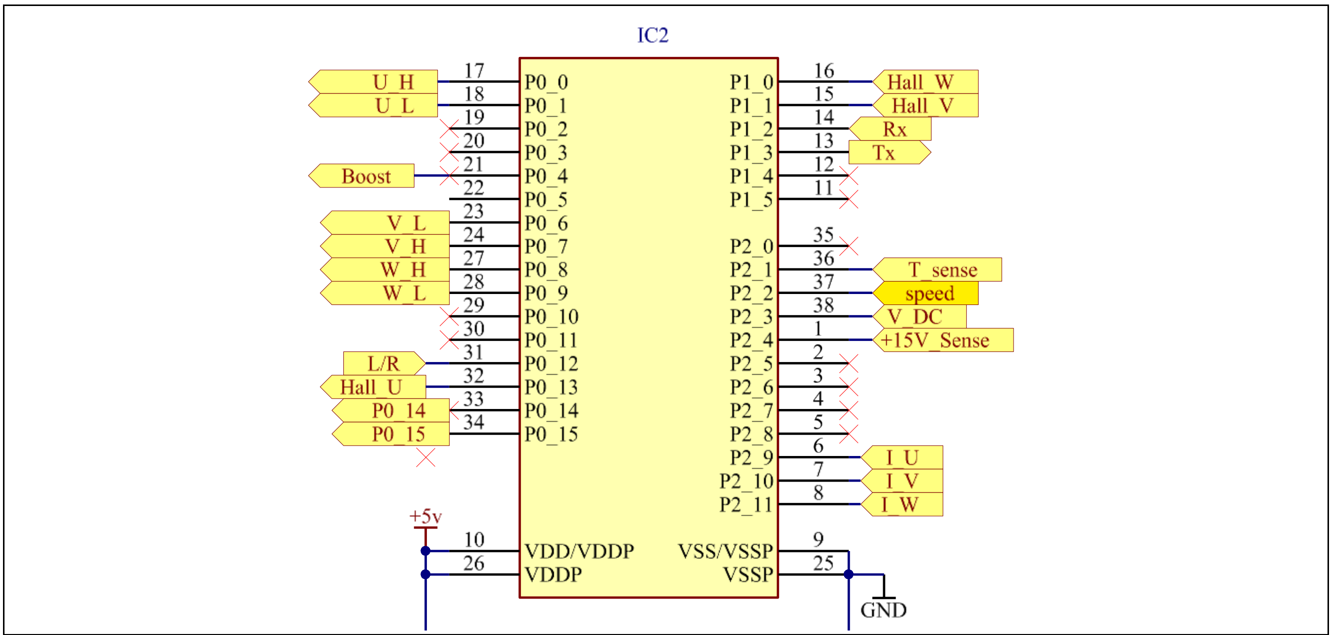
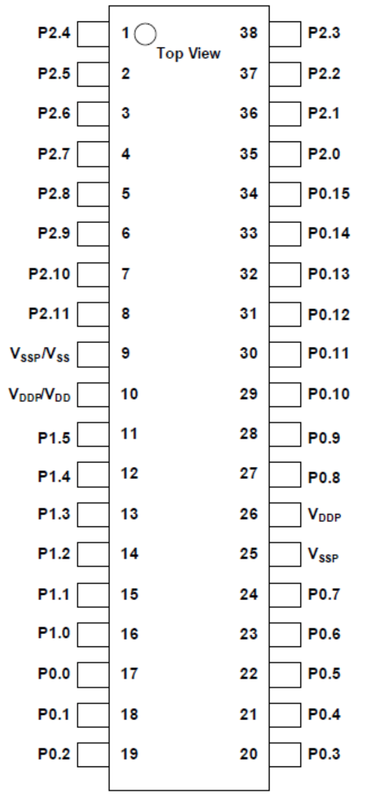


Figure 15 XMC1302 Microcontroller schematic

The XMC1300 devices are members of the XMC1000 family of microcontrollers based on the ARM® Cortex™-M0 processor core. The XMC1300 series is suitable for the real-time control needs of the BLDC motor.

It also controls all input and output signals necessary for the power tool operation.



XMC1300 PG-TSSOP-38 Pin Configuration (top view)

Figure 16 XMC1302 Microcontroller Pin out

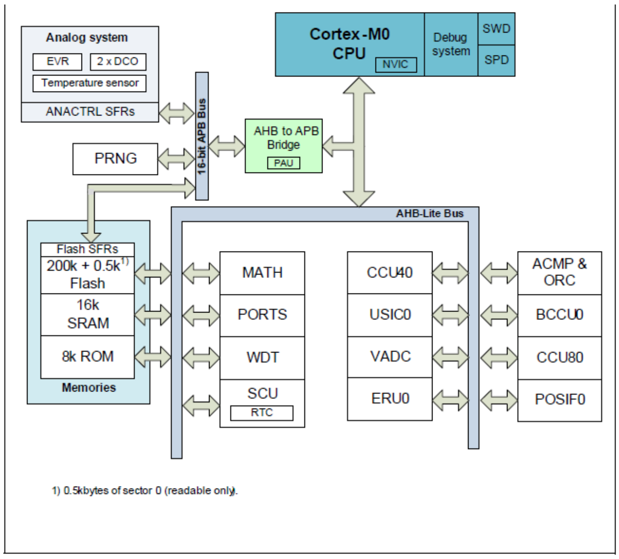


Figure 1 System Block Diagram

Figure 17 XMC1302 Microcontroller Block Diagram

4.5.1 XMC Microcontroller features

CPU Subsystem

- CPU Core
  - High Performance 32-bit ARM® Cortex™-M0 CPU
  - Most of 16-bit Thumb instruction set
  - Subset of 32-bit Thumb2 instruction set
  - High code density with 32-bit performance
  - Single cycle 32-bit hardware multiplier
  - System timer (SysTick) for Operating System support
  - Ultra low power consumption
- Nested Vectored Interrupt Controller (NVIC)
- Event Request Unit (ERU) for programmable processing of external and internal service requests
- MATH Co-processor (MATH), consists of a CORDIC unit for trigonometric calculation and a division unit

On-Chip Memories

- 8 kbytes on-chip ROM
- 16 kbytes on-chip high-speed SRAM
- 200 kbytes on-chip Flash program and data memory

Communication Peripherals

- Two Universal Serial Interface Channels (USIC), usable as UART, double-SPI, quad-SPI, IIC, IIS and LIN interfaces

Analog Frontend Peripherals

- 12 A/D Converters, includes 2 sample and hold stages and a fast 12-bit analog to digital converter with adjustable gain
- 8 channels of out of range comparators (ORC)
- 3 fast analog comparators (ACMP)
- Temperature Sensor (TSE)

Industrial Control Peripherals

- Capture/Compare Units 4 (CCU4) for use as general purpose timers
- Capture/Compare Units 8 (CCU8) for motor control and power conversion
- Position Interfaces (POSIF) for hall and quadrature encoders and motor positioning
- Brightness and Color Control Unit (BCCU), for LED color and dimming application

System Control

- Window Watchdog Timer (WDT) for safety sensitive applications
- Real Time Clock module with alarm support (RTC)
- System Control Unit (SCU) for system configuration and control
- Pseudo random number generator (PRNG), provides random data with fast generation times

Input/Output Lines With Individual Bit Controllability

- Tri-stated in input mode
- Push/pull or open drain output mode
- Configurable pad hysteresis

Debug System

- Access through the standard ARM serial wire debug (SWD) or the single pin debug
- (SPD) interface
- A breakpoint unit (BPU) supporting up to 4 hardware breakpoints
- A watchpoint unit (DWT) supporting up to 2 watchpoints

4.6 Hall Sensors Digital Inputs

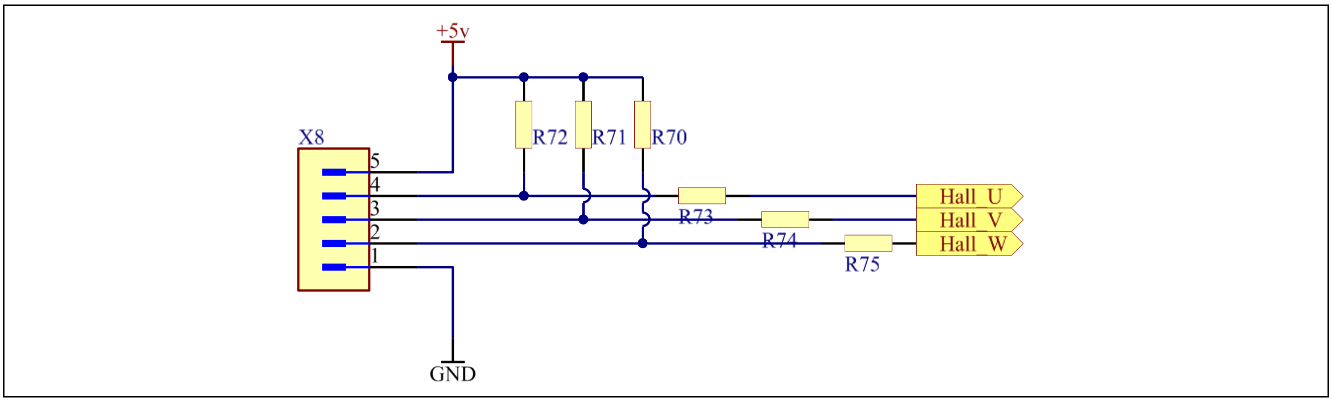


Figure 18 Hall Sensor Input Schematic

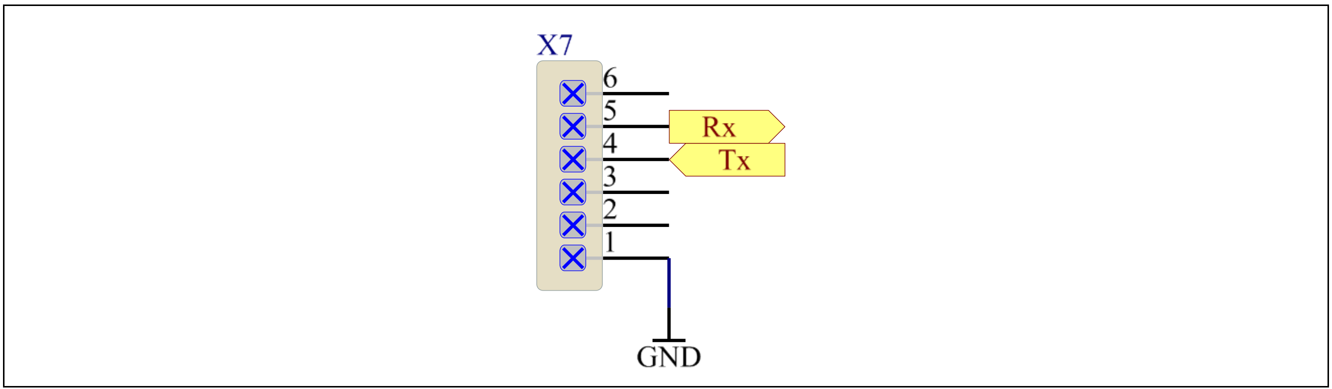


Figure 19 Communication Port Schematic

Table 1 Communication Port Pin Out

Connector X7 Pin Number	Name	TTL-232R-5V-WE FTDI cable connection
5	Receive Input (Rx)	Yellow - RXD
4	Transmit Output (Tx)	Orange - TXD
1	Ground (GND)	Black - GND

4.7 Free MCU pins

Since one of the objectives of this reference board is to create a very compact design, the MCU free pins are directly accessible at the PCB bottom side.

Free MCU pins are : #2,3,4,5,11,12,19,29,30,35

5 PCB

5.1 Schematic

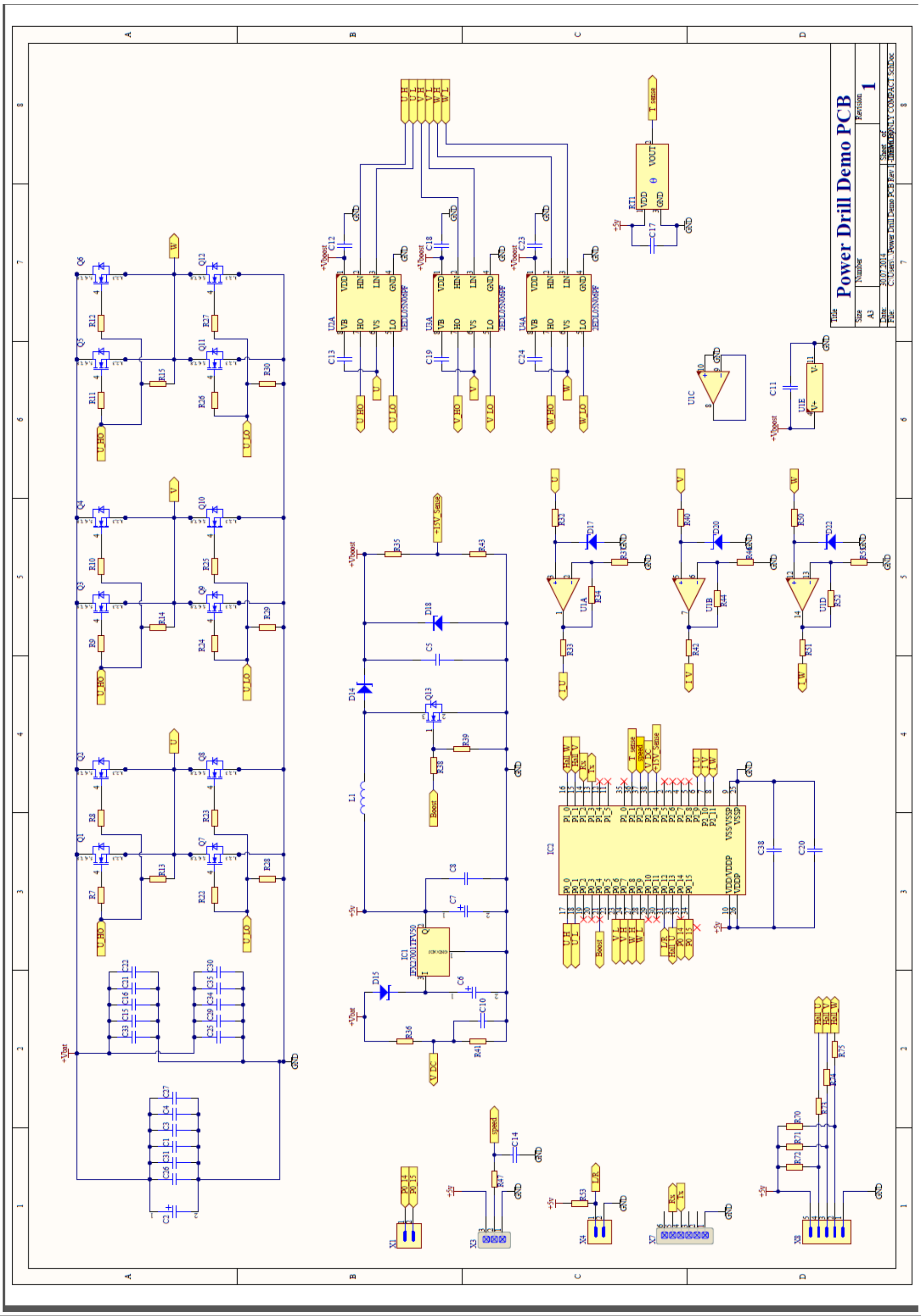


Figure 20 Complete Schematic

5.2 Layout and Placement

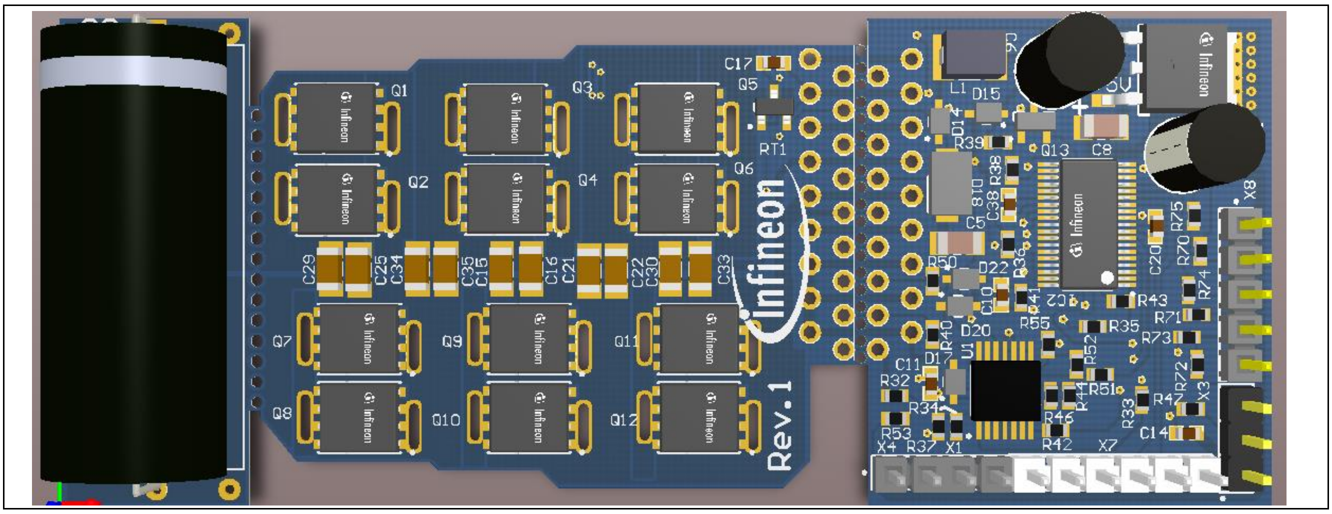


Figure 21 PCB Top (90 mm x 36 mm)

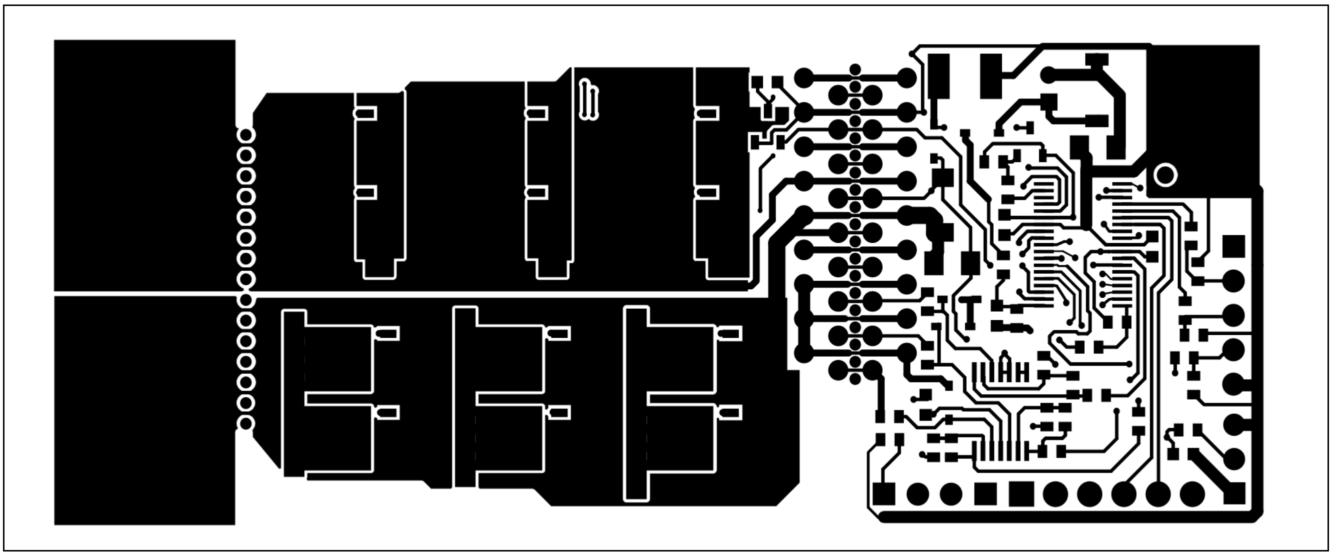


Figure 22 Gerber File - Copper Top

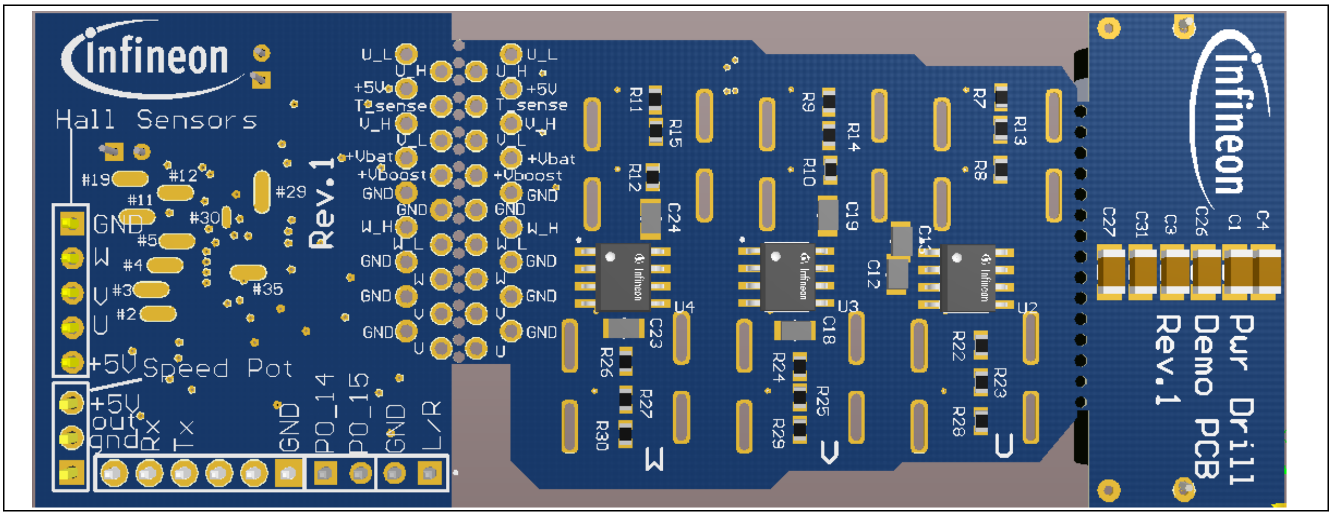


Figure 23 PCB Bottom

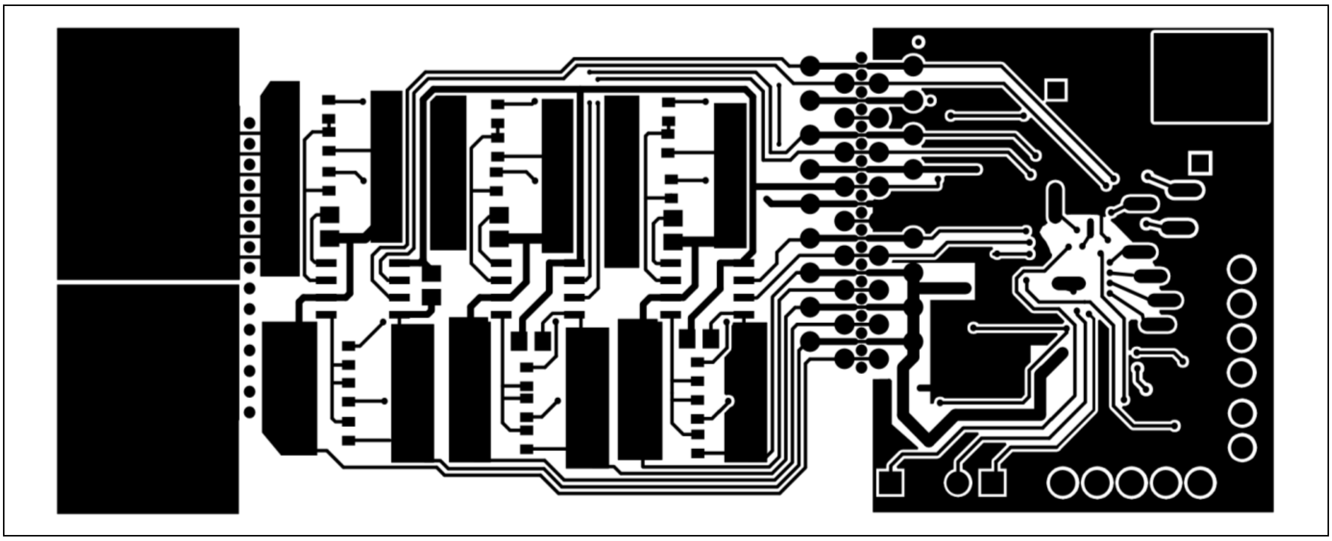


Figure 24 Gerber file - Copper Bottom

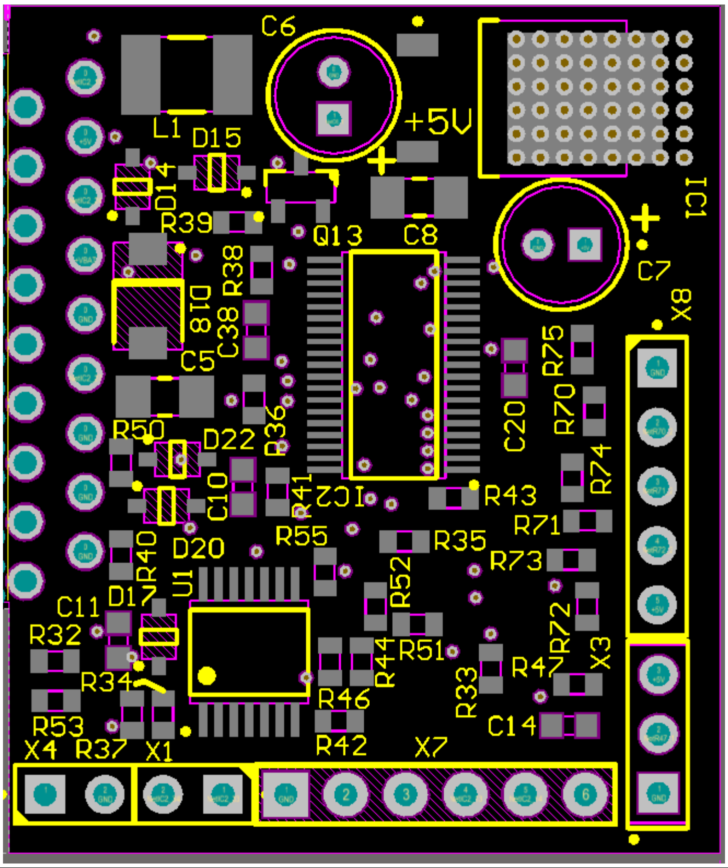


Figure 25 Top Overlay – Control PCB

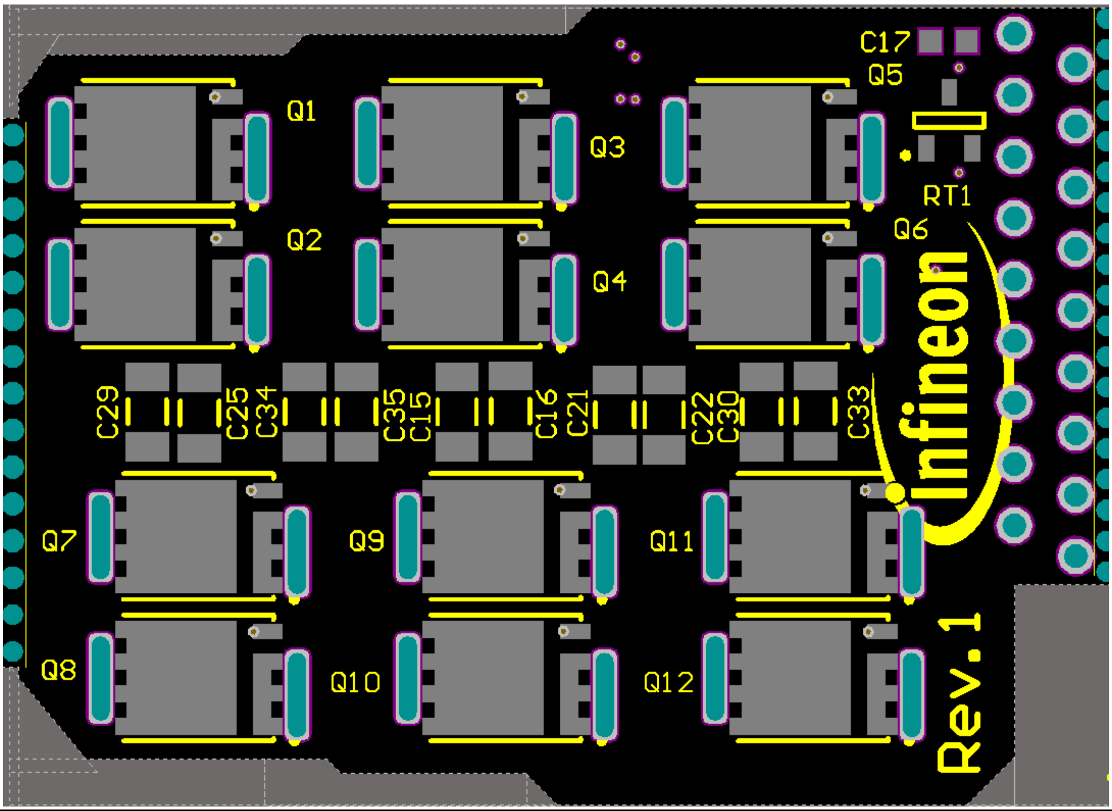


Figure 26 Top Overlay – Power PCB

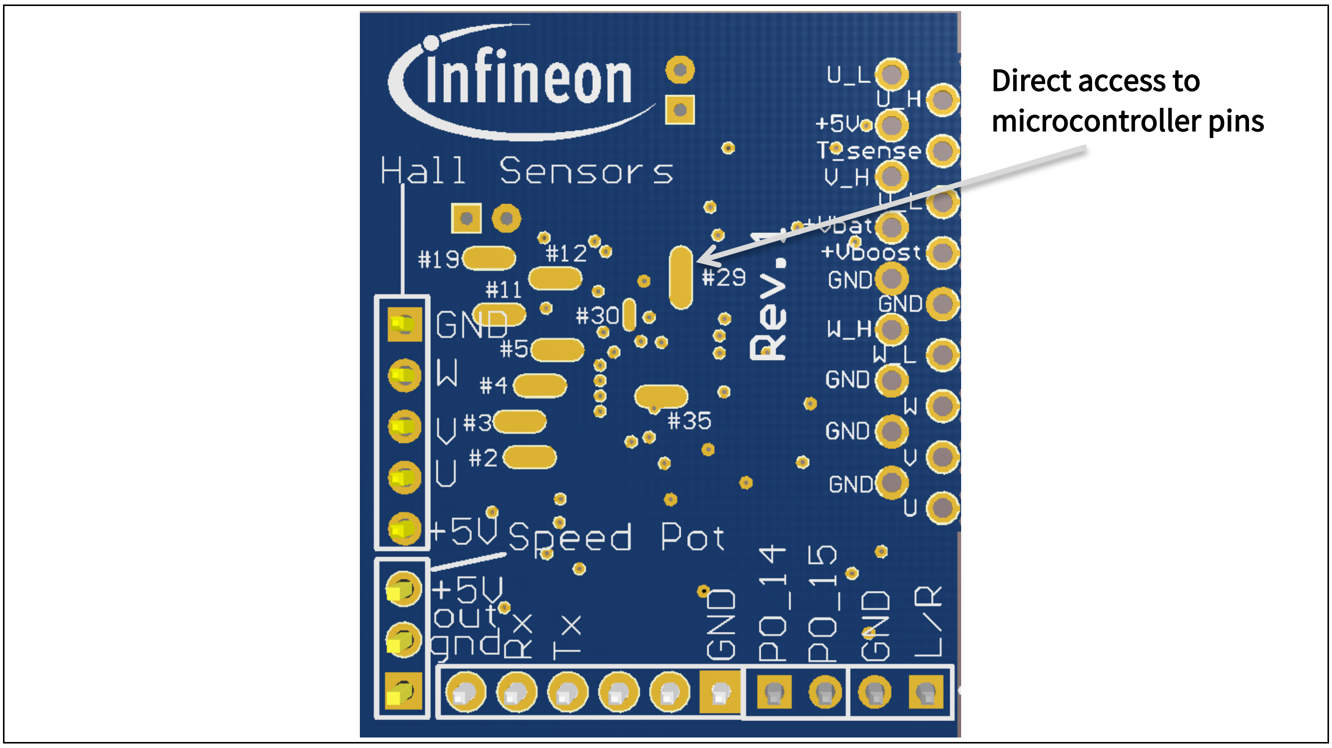


Figure 27 Bottom Overlay – Control PCB

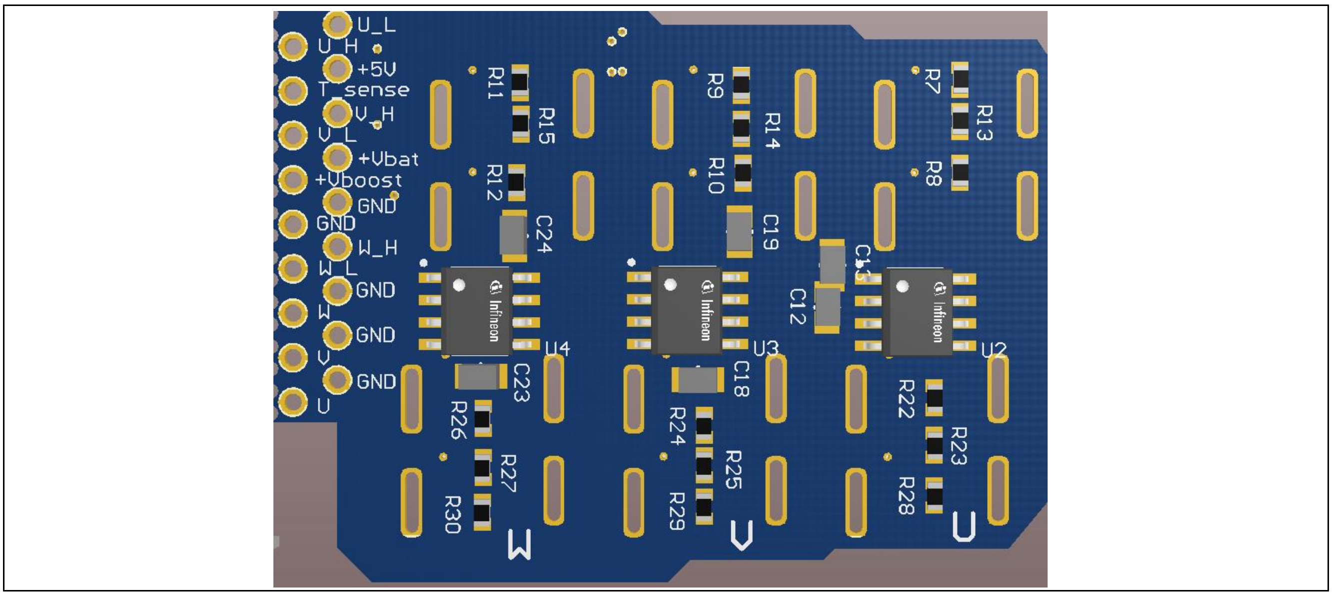


Figure 28 Bottom Overlay – Power PCB

5.3 PCB production

During the PCB production it is important to establish a good connection between the MOSFET and the PCB copper plane. This will ensure a good heat transfer to the copper plates. This demonstration board is produced with the solder profile shown below. The results are displayed in x-ray pictures which indicate an acceptable voids rate of approximetely 5-10%.

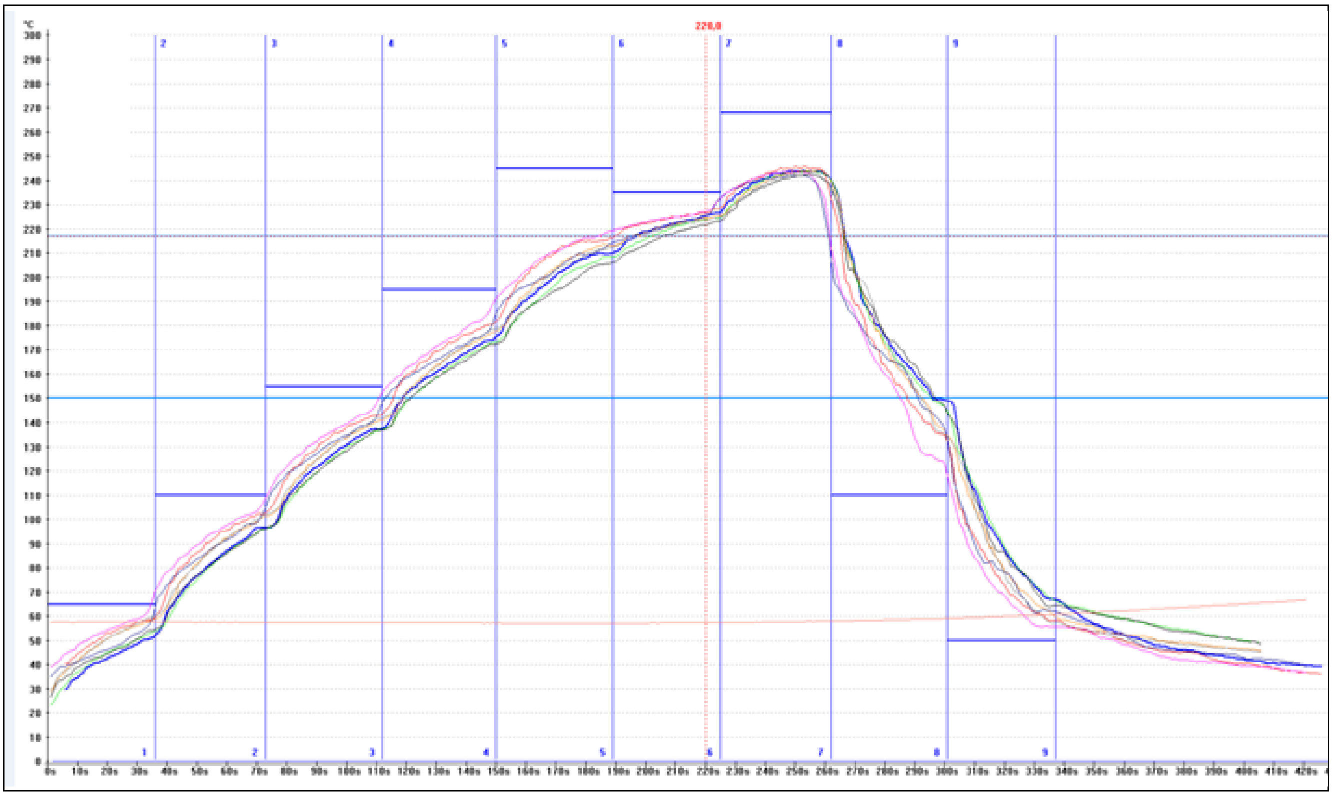


Figure 29 Solder Profile – temperature versus time; Solder Paste type 3: Indium 8.9 Pb-Free

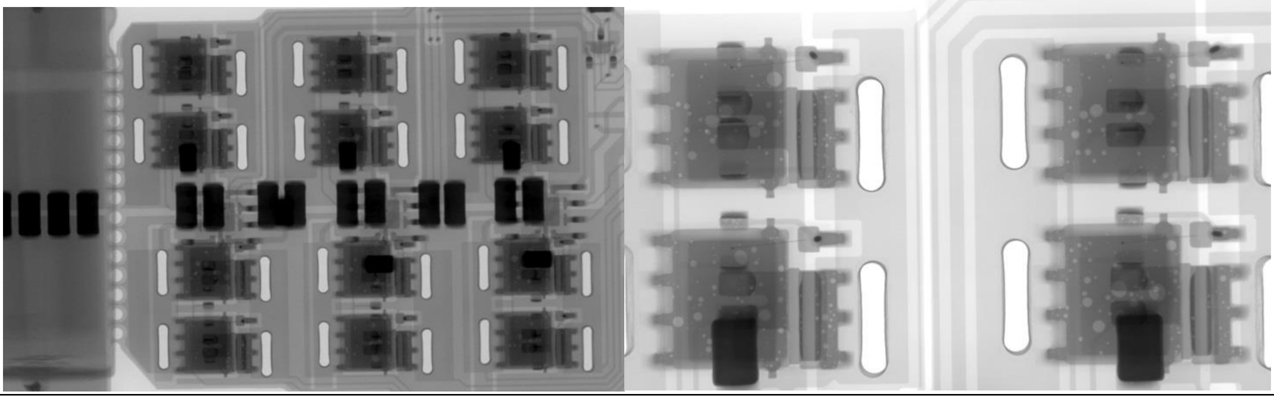


Figure 30 X-ray showing voids distribution of a complete power stage (left); zoomed (right)

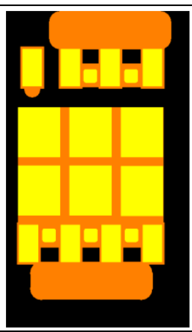


Figure 31 Stencil patterns (yellow color); Stencil thickness 120 µm

5.4 Bill of Material

Table 2 BOM

Quantity	Designator	Manufacturer	Manufacturer Part Number	Description	Footprint
12	C33,15,16,21, 22,25,29,34,3 5,30,8,5	Murata	GRM31MR71E2 25KA93L	MURATA - GRM31MR71E225KA93L - Capacitor, 1206, 2.2uF, 25V	1206
6	C1, C3, C4, C26, C27, C31	Murata	GRM31MR71E2 25KA93L	MURATA - GRM31MR71E225KA93L - Capacitor, 1206, 2.2uF, 25V	1206
1	C2	NICHICON	TVX1V102MCD	NICHICON - TVX1V102MCD – Capacitor, 1000uF, 35V	13 mm x 31.5 mm Axial
6	C12, C13, C18, C19, C23, C24	TDK	C2012X7R1E10 5K125AB	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0805 1 uF 25volts X7R 10%	805
2	C6, C7	United Chemi-Con	EKMGG350ELL 100ME	Aluminum Electrolytic Capa-citors - Leaded 35 V 10uF 5X11	5x11 mm
6	C10, C11, C14, C17, C20, C38	Kemet	C0603C104K5R ACTU	Multilayer Ceramic Capacitors MLCC - SMD/SMT 50volts 0.1uF X7R 10%	603
2	D14, D15	Infineon Technologies	BAT 165 E6327	Schottky Diodes & Rectifiers Med-Power AF 750 mA Schottky Diode 40 V	SOD-323
3	D17, D20, D22	ON SEMICONDUCT OR	MM3Z5V1T1G	ZENER DIODE, 200 mW, 5.1 V	SOD-323
1	D18	ON SEMICONDUCT OR	1SMA5931BT3 G	Zener Diodes 18 V 1.5 W	DO214AC
1	IC1	Infineon Technologies	IFX27001TFV50	LDO Voltage Regulators Linear Voltage Regulator	PG-TO-252-3
1	IC2	Infineon Technologies	XMC1302-T038X0200_AA	XMC1302 ARM® Cortex™-M0 32-bit Microcontroller	SOP50P64 0X120-38N
1	L1	Bourns	CM453232-820KL	Fixed Inductors 82uH 10% Wirewound	1812
12	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12	Infineon Technologies	BSC010N04LSI ATMA1	MOSFET 40 V 1.05 mOhm 100 A	PG-TDSON-8 FL
1	Q13	Infineon Technologies	BSS670S2LH63 27XT	N-Channel Small Signal MOSFET 55 V/650 mOhm	PG-SOT-23
12	R7,8,9,10,11,	KOA	RK73H1JTTD1	Thick Film Resistors - SMD 1/10	603

PCB

Quantity	Designator	Manufacturer	Manufacturer Part Number	Description	Footprint
	12,22,23,24,25,26,27		000F	watts 100 Ohm 1%	
3	R37,R46,R55	KOA	RK73H1JTTD7501F	Thick Film Resistors - SMD 1/10 watt 7.5 kOhm 1%	603
7	R39,50,40,43,32,53,47	KOA	RK73H1JTTD1002F	Thick Film Resistors - SMD 1/10 watts 10 kOhm 1%	603
3	R73,R74,R75	KOA	RK73H1JTTD1500F	Thick Film Resistors - SMD 1/10 watts 150 Ohm 1%	603
6	R33,42,51,70,71,72	KOA	RK73H1JTTD2201F	Thick Film Resistors - SMD 1/10 watt 2.2 kOhm 1%	603
1	R38	KOA	RK73H1JTTD1601F	Thick Film Resistors - SMD 1/10 watt 1.6 kOhm 1%	603
3	R34,44,52	KOA	RK73H1JTTD2203F	Thick Film Resistors - SMD 1/10 watt 220 kOhm 1%	603
1	R35	KOA	RK73H1JTTD3302F	Thick Film Resistors - SMD 1/10 watt 33 kOhm 1%	603
1	R41	KOA	RK73H1JTTD2002F	Thick Film Resistors - SMD 1/10 watt 20 kOhm 1%	603
6	R36,13,14,15,28,29,30	KOA	RK73H1JTTD1003F	Thick Film Resistors - SMD 1/10 watt 100 kOhm 1%	603
1	R36	KOA	RK73H1JTTD1003F	Thick Film Resistors - SMD 1/10 watt 100 kOhm 1%	603
1	RT1	Microchip Technology	MCP9700T-E/TT	Board Mount Temperature Sensors Lin Active Therm 10 mV / C	SOT-23-3
1	U1	Texas Instruments	LM324PWR	Operational Amplifiers Quad GP Opamp	TSSOP-14
3	U2, U3, U4	Infineon	2EDL05N06PF	EiceDRIVER™ high voltage gate driver IC	SOIC127P600X175-8N-2
3		Dulling Elektro & Metal GmBH	9015_006	Copper plate U-Teil 6	custom made
4		Dulling Elektro & Metal GmBH	9015_007	Copper plate U -Teil 7	custom made
2	X1, X4	Samtec Inc	HTSW-102-07-L-S	CONN HEADER 2POS .100" T/H GOLD	vertical, single row
1	X3	Samtec Inc	HTSW-103-07-G-S	CONN HEADER 3POS .100" T/H GOLD	vertical, single row
1	X7	Samtec Inc	HTSW-106-07-G-S	CONN HEADER 6POS .1" T/H GOLD	vertical, single row
1	X8	Samtec Inc	HTSW-105-07-G-S	CONN HEADER 5POS .100" T/H GLD	vertical, single row

6 Software

6.1 Overview

The motor control software is based on a voltage control block commutation algorithm of the BLDC motor. The microcontroller reads 3 hall switch patterns in order to determine the correct switching sequence for the phase commutation. Other input variables such as phase current, temperature, supply voltage, and a wrong hall pattern sequence are also being monitored by the microcontroller. According to their values, the microcontroller takes an action and controls the power inverter stage accordingly.

This demonstration board is already programmed with dedicated software for cordless power drill and is ready for use.

6.2 Features

- Unipolar Block Commutation with active rectification
- Overcurrent shut down
- Over temperature shut down
- Wrong hall pattern shut down
- Motor soft start
- Monitoring input DC voltage
- Programmable boost converter

6.2.1 Unipolar Block Commutation with active rectification

In a unipolar voltage control, while the low side switch (LS) is ON, the PWM pulses are applied to the high sided switch (HS). In addition, the Synch_FET is turned ON when the body diode of the Synch_FET is conducting. In this way the diode losses are minimized. The dead time between HS and LS MOSFETs should be set depending on turn-on and turn-off time of the HS which is directly related to the value of the gate resistors. In this particular example the dead time is set to 2 µs (using R_g=100 Ohm).

The Figure 32 below shows active components while energizing phases U and V, and Figure 32/Figure 33 shows control signals for commutation of all 3 phases.

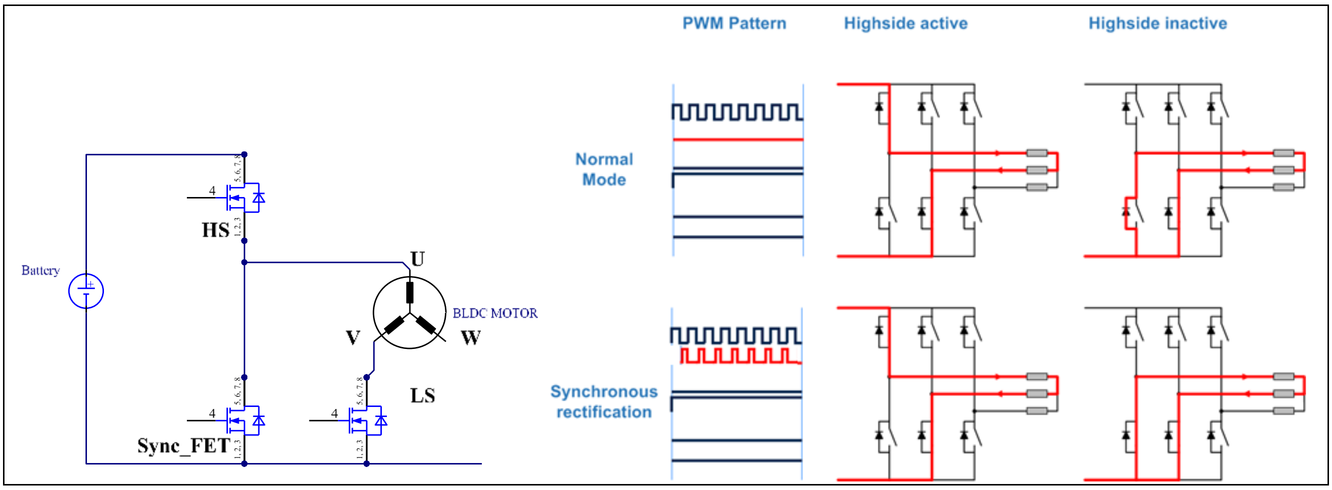


Figure 32 Unipolar voltage switching with synchronous rectification for a single phase

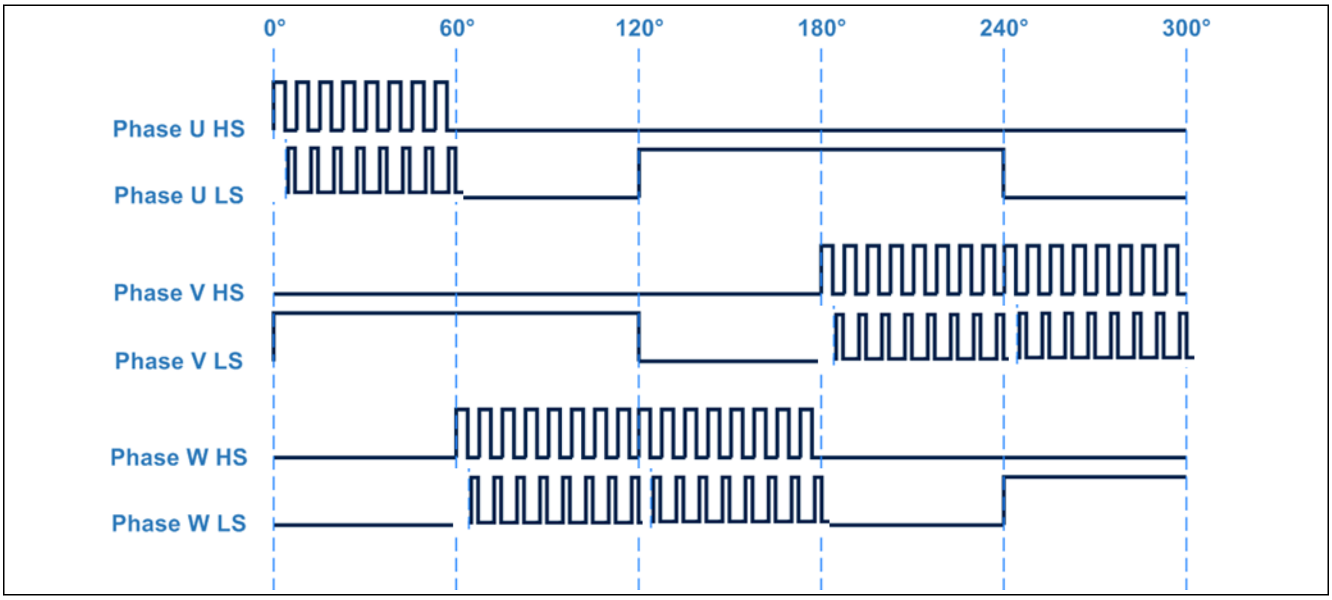


Figure 33 Unipolar voltage switching with synchronous rectification for all 3 phases

6.2.2 Overcurrent shut down

Each phase current is monitored by measuring and amplifying the drain-source voltage of the low side MOSFET during its ON state. This voltage is evaluated and temperature compensated by XMC microcontroller (refer to $R_{DS(on)}$ vs. temperature diagram). The current threshold is set to 150 A. If the phase current exceeds 150 A, the inverter will shut down and stay in de-energized state until the next power cycle.

6.2.3 Overtemperature shut down

The temperature sensor is placed in vicinity of high side MOSFET of W-phase. When temperature of 80°C is reached the inverter will shut down until the temperature sensor cools down to 50°C. When 50°C is reached, the inverter will automatically turn ON again and resume the operation.

6.2.4 Wrong hall pattern shut down

If the hall patterns do not match the expected sequence (wrong connection), the power stage will shut down to prevent the MOSFET overstress. Each time this condition is encountered, the unit needs to be reset.

6.2.5 Motor soft start

In order to prevent high inrush current, the motor control regulates the rate of duty cycle i.e. voltage increment applied to the motor.

6.2.6 Monitoring input DC voltage

The input DC voltage is monitored by the XMC microcontroller A/D input which reads the voltage across the resistive voltage divider connected across the battery terminals. The operating voltage range is 6-24 V.

6.2.7 Programmable boost converter

The boost converter regulates the gate driver voltage to 12 V. The XMC microcontroller A/D input reads the boost voltage and regulates it accordingly. The boost converter output voltage of 12 V is also used for Opamp voltage supply.

6.2.8 Asymmetric Authentication Feature

XMC1302 support Infineon's Asymmetric Authentication Solution ORIGA™. The authentication chip normally will be embedded in the battery and it can be used to detect and authenticate genuine batteries before charging or operating the tool. ORIGA™ single wire interface (SWI) can be connected to P0.15 and this device can operate in 2 wire mode (SWI and GND). The complete host code is already integrated in the XMC1302 library (would require recompilation with compiler directive). If this feature is implemented, the motor will not start in the event of authentication failure. This authentication feature benefits the user by providing safe reliable operating and charging environment.

For ORIGA™ hardware and more information, please visit http://www.infineon.com/origa

7 XMC microcontroller development platform DAVE™

Further Information:
http://www.infineon.com/dave

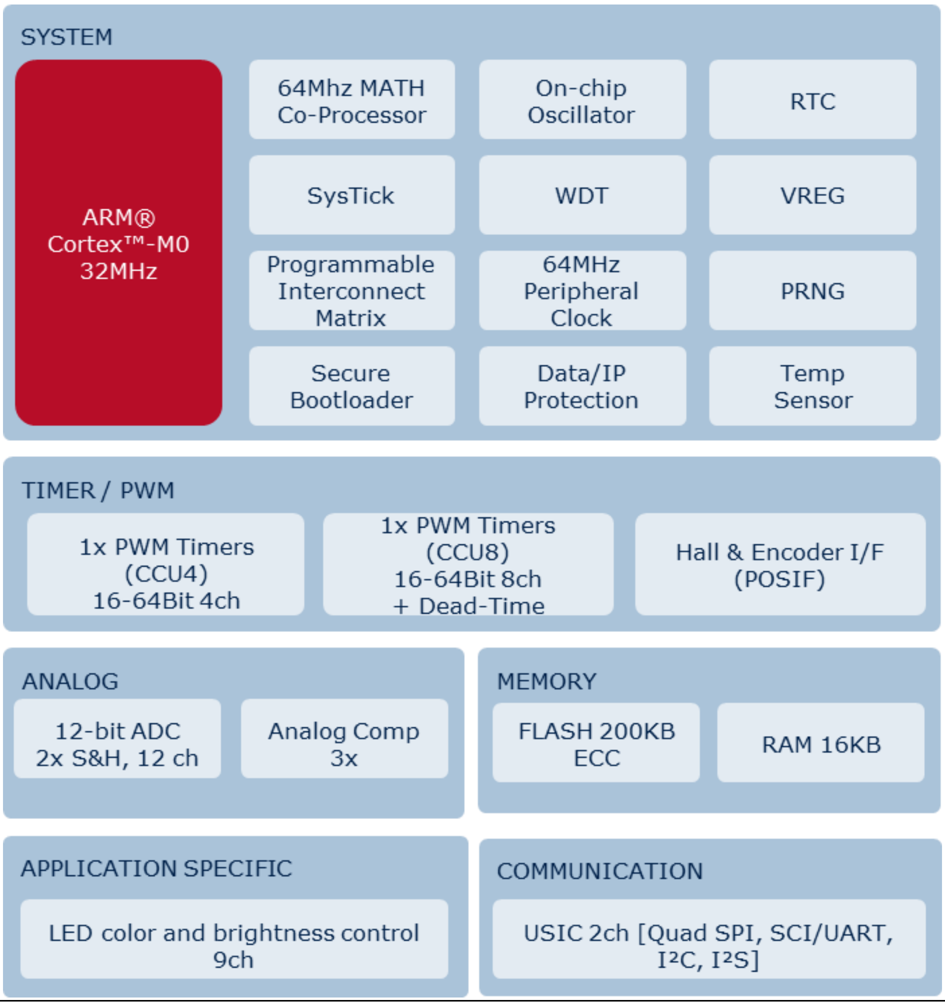


Figure 34 Block diagram of XMC microcontroller

DAVE™ software is a free development platform which reduces software development time for XMC microcontrollers. It includes a complete free tool chain including a GNU compiler, debugger, and a data visualization tool.

DAVE™ Apps are application components for a wide range of use which makes it easy to fully utilize flexible peripherals. A resource solver ensures conflict free mapping of chip resources.

8 Test Results

8.1 Efficiency measurement

For the efficiency measurement following setup is used:

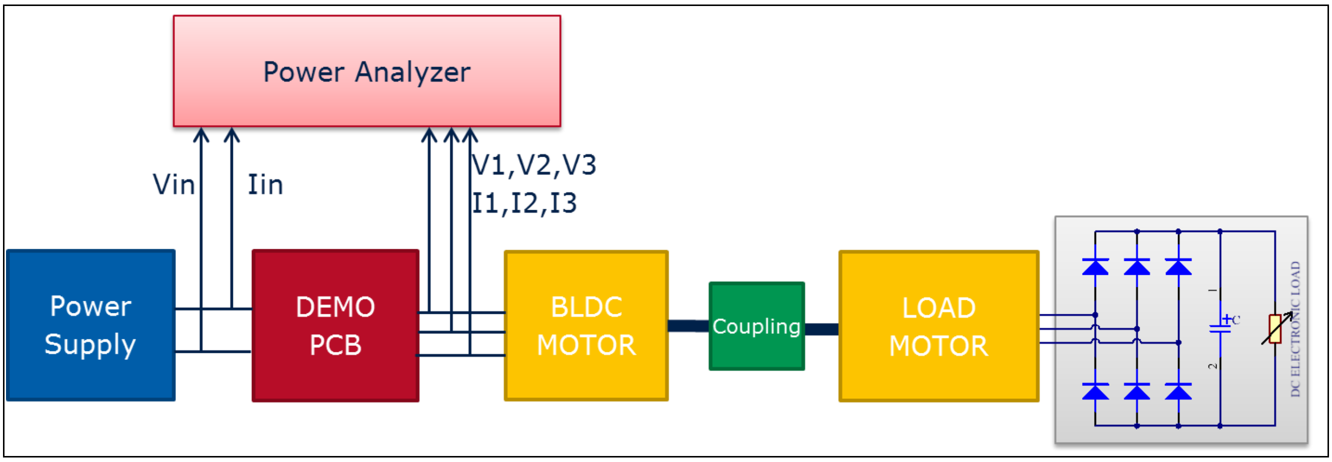


Figure 35 Measurement Setup

Test setup description:

A regulated power supply is used to provide the voltage to the demo board. The supplied current and voltage is fed to the power analyzer. At the output of the DEMO PCB, all 3 phase voltages and currents are fed to the power analyzer.

In order to apply the load, another LOAD BLDC motor is used to break the BLDC MOTOR. These two motors are interconnected with a mechanical coupling. When the BLDC motor spins, the load motor acts as a generator and induces voltage which is rectified with a 3 phase diode bridge. This output voltage is further filtered with a DC link cap. A DC electronic load is connected at the output of the 3 phase diode bridge. By applying different setting on the electronic load, different loading conditions can be achieved.

In effort to improve the efficiency of the power stage, Infineon has developed a MOSFET with integrated monolithic Schottky-like diode which reduces the diode forward voltage drop losses and also diode reverse recovery losses. In order to show the benefits of this technology, two equivalent measurements are performed.

The Table 3 shows the measurements without the Schottky-like diode, and the Table 4 shows the measurements with the Schottky-like diode.

The details of measurements are shown below.

Table 3 Efficiency measurement with BSC010N04LS in block commutated BLDC motor drive

Input Power [W]	Output Power [W]	Efficiency [%]	Power Losses [W]
833	825	**99.0**	8.0
968	953	**98.5**	15.0
1099	1076	**97.9**	23.0
1172	1142	**97.4**	30.0

Table 4 Efficiency measurement with BSC010N04LSI in block commutated BLDC motor drive

Input Power [W]	Output Power [W]	Efficiency [%]	Power Losses [W]
832.24	825.83	**99.2**	6.4
975.34	962.56	**98.7**	12.8
1100.6	1080.81	**98.2**	19.8
1229.3	1202.63	**97.8**	26.7

The table below shows the difference in power loss between BSC010N04LS and BSC010N04LSI.

Table 5 Efficiency summary of BSC010N04LS vs. BSC010N04LSI

Output Power [W]	Δ Power Losses [W]	Efficiency Gain [%]
825	1.6	0.2
953	2.2	0.2
1076	3.2	0.3

Figure 36 Phase voltage (yellow trace) and phase current (green trace) waveforms

The temperature measurements are performed on BSC010N04LSI and BSC010N04LS with the infrared camera.

As previous efficiency tables indicates, we expect a longer run time with the MOSFET with integrated monolithic Schottky-like diode BSC010N04LSI.

Test conditions: full power; 100% duty, I_{phase}=50 A(rms), V_{bat}=20 V , no forced air, room temperature;

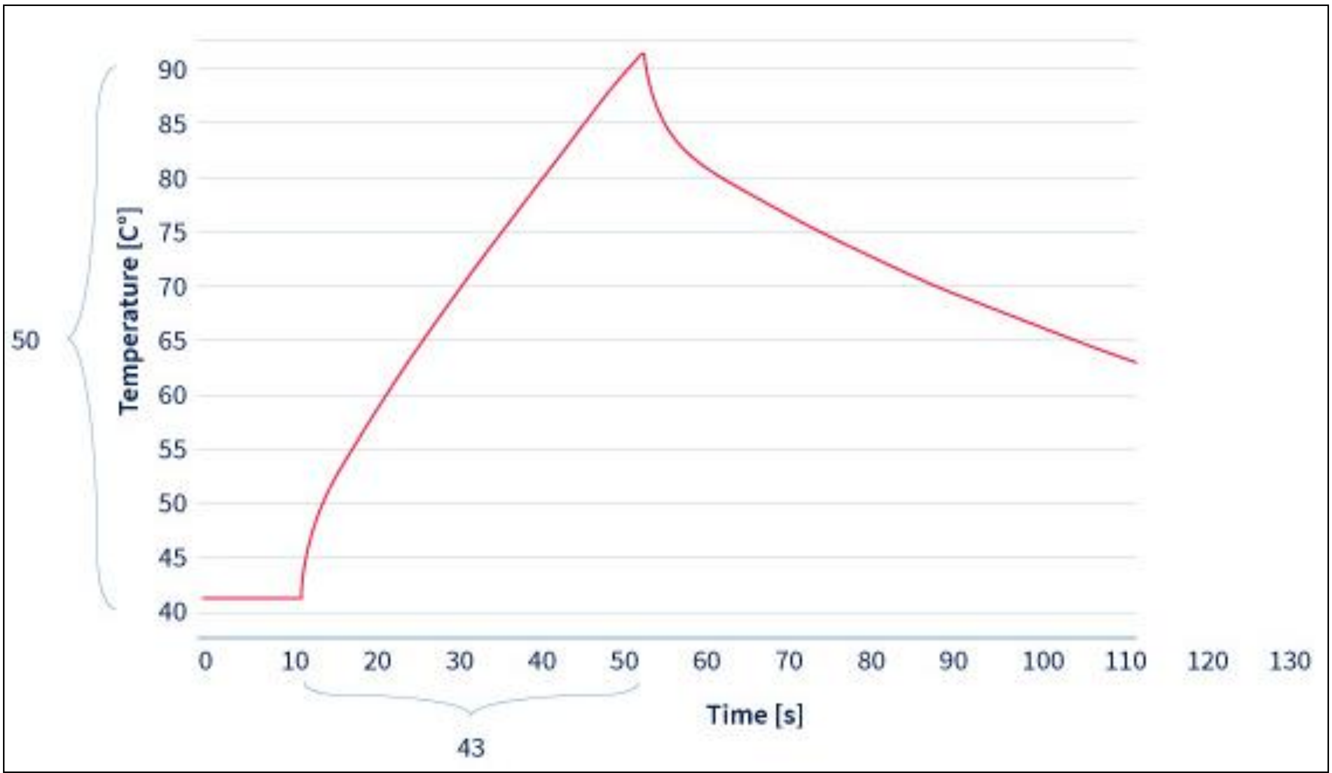


Figure 37 Temperature rise at full power with BSC010N04LSI

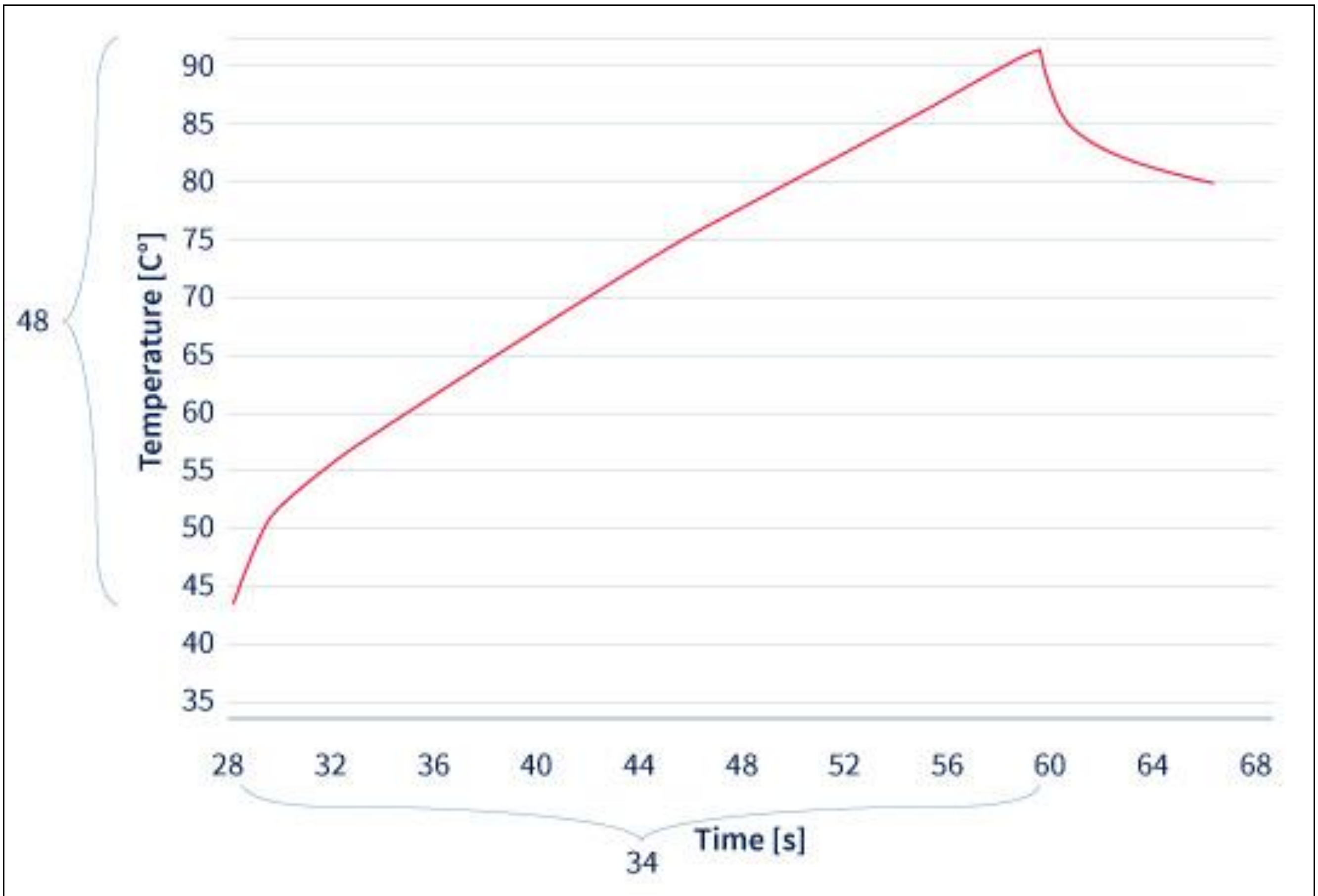


Figure 38 Temperature rise at full power with BSC010N04LS

8.1.1 Determining the Z_{th}

8.1.2 Z_{th} of the complete power inverter stage including copper elements

As mentioned in earlier chapter, it is essential to establish a good thermal connection between the MOSFET and the PCB. This ensures a good thermal connection between a MOSFET and cooling copper plates.

In order to determine how a system behaves thermally, we refer to a Z_{th} diagram.

The Z_{th} diagram provides the information of how much power we are able to dissipate for a specified duration and what will be the resultant temperature of the MOSFET at the end of power pulse.

The Z_{th} diagram below is shown for this system.

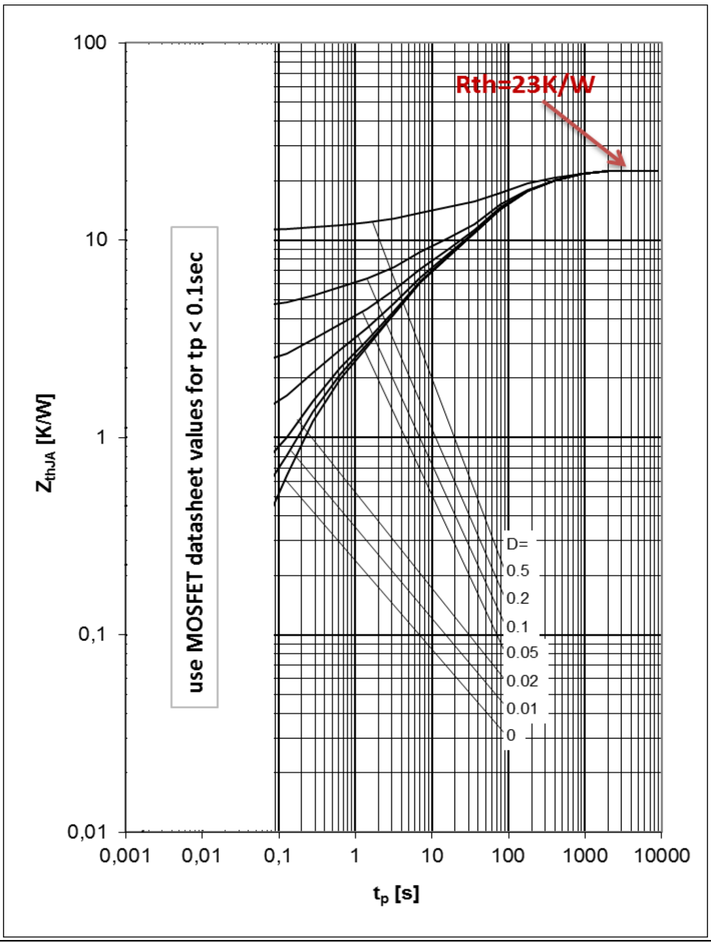


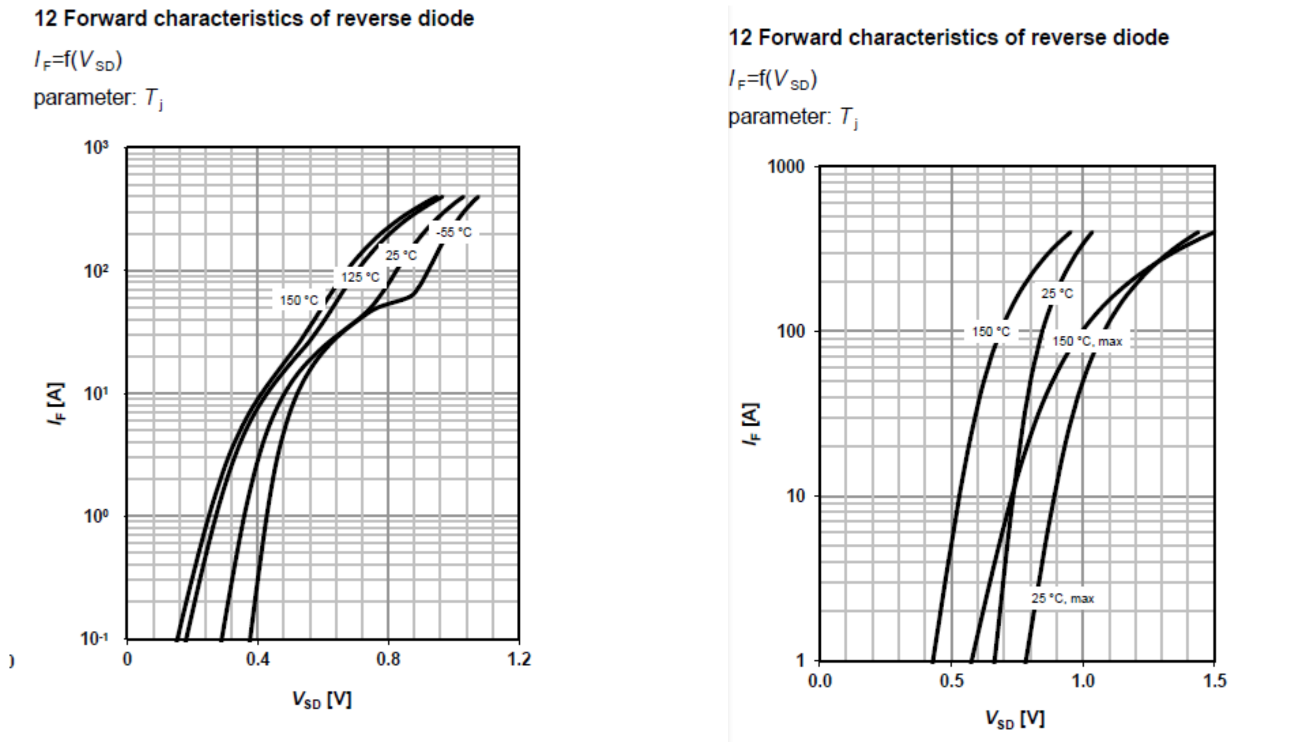
Figure 39 Z_{th} diagram of the power inverter

Note: The Z_{th} diagram above should not be confused with the MOSFET Z_{th} diagram. For power pulses less than 0.1 s, please refer to MOSFET data sheet Z_{th} diagram.

9 Properties of integrated Schottky-like diode

The efficiency measurements and the temperature graphs show that the BSC010N04LSI has about 20% power loss reduction or 20% longer running time as compared to BSC010N04LS under the same loading conditions. This efficiency gain is due to integrated monolithic Schottky-like diode.

If we take a closer look at the diode forward voltage graph, we can see that the BSC010N04LSI diode has a lower forward voltage drop, and also lower recovery charge which account for higher efficiency.



BSC010N04LSI BSC010N04LS

Figure 40 Forward characteristics of reverse diode for BSC010N04LSI and BSC010N04LS

The positive effect of the integrated Schottky-like diode has also some drawbacks.

Some of the parameters of interest are: Leakage current, $R_{DS(on)}$, and avalanche capability.

The summary is shown in the table below.

Table 6 Comparison of parameters of interest for BSC010N04LS and BSC010N04LSI

Parameter	Description	Test conditions	BSC010N04LS	BSC010N04LSI
I_{DSS}	Zero gate voltage drain current	V_{GS}=0, V_{DS}=32 V, T_j=25°C	1 mA	500 mA
$R_{DS(on),max}$	Drain-source on-state resistance	V_{GS}=10 V, I_D=50 A	1.00 mOhm	1.05 mOhm
E_{AS}	Avalanche energy, single pulse	I_D=50 A, R_{GS}=25 Ohm	330 mJ	230 mJ

Nevertheless, in power tool application the advantage of integrated diode outweighs its drawbacks.

Leakage current:

In most designs the relevance of leakage current, which is important for a stand by operation, is minimized since the power trigger switch separates battery from the circuit and the stand by current is virtually reduced to zero. In the ON state during normal operation this leakage current is negligible compared to the load current.

The leakage current is greatly reduced at lower voltages.

For BSC010N04LSI at 10 V, the voltage which a MOSFET will experience in a half bridge configuration connected to 20 V source, is 5 µA.

The leakage current increases with the temperature. The leakage current graph as a function of applied voltage and temperature is given below.

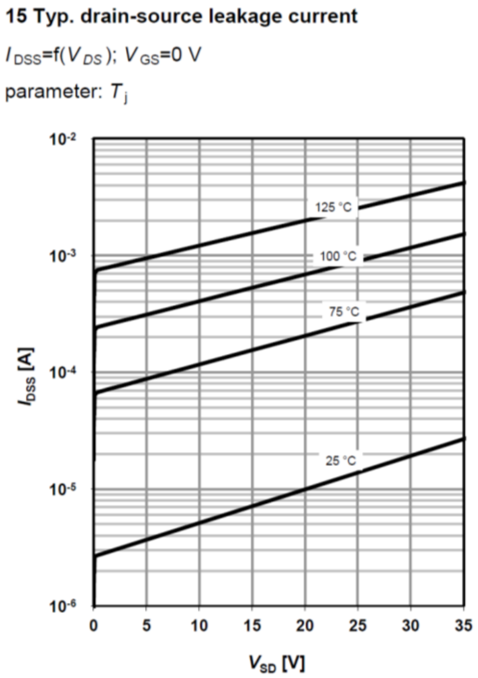


Figure 41 Leakage current versus Drain-Source voltage

$R_{DS(on)}$:

In case of BSC010N04LSI, the $R_{DS(on)}$ is increased by 5% which increases conduction losses. Nevertheless, despite the slightly increased conduction losses, the power loss reduction due to integrated monolithic Schottky-like diode is greater.

Avalanche:

The avalanche rating of a MOSFET becomes important only if the breakdown voltage $V_{(BR)DSS}$ is exceeded. This demonstration board has very low voltage overshoot due to low reverse recovery charge Q_{rr} of the integrated monolithic Schottky-like diode, and a low PCB layout parasitic inductance.

It is not recommended to exceed the maximum breakdown voltage $V_{(BR)DSS}$ of a MOSFET at any time. The avalanche energy contained in a voltage overshoot is difficult to quantify, thus it present a risk to exceed the maximum avalanche E_{AS} rating of a MOSFET if the $V_{(BR)DSS}$ is exceeded.

10 Conclusion

The presented demonstration board provides a plug and play solution for driving BLDC motors in cordless power tool applications. The optimized size allows a quick integration in cordless power drills. With Infineon developed dedicated software, and a free software development platform DAVE™, the user is able to integrate additional functions.

The generated Z_{th} diagram for the inverter power stage allows the designer to determine the MOSFET temperature for a given condition. This can be very useful especially for motor start up and locked rotor conditions.

It was shown that in BLDC motor power inverter, the body diode plays a key role. The power loss and temperature measurements show an improvement of up to 20% of BSC010N04LSI MOSFET with integrated Schottky-like diode.

The Infineon's patented Schottky-like diode MOSFET technology, enables the tool manufacturers to implement their solution with a cost effective packages such as SuperSO8 and achieve more motor torque, higher current operation, and up to 20% saving in power losses which is directly proportional to longer operation time in the application.

11 Accessories

11.1 ORIGA™ Authentication

This demonstration board can in addition be equipped with an authentication hardware and software which ensures usage of OEM batteries only.

For more information and implementation of the ORIGA™ go to http://www.infineon.com/origa

12 Useful material and links

- DAVE™ - Free Development Platform for Code Generation:
  http://www.infineon.com/dave
- OptiMOS™ 40V/60V Webpage:
  http://www.infineon.com/optimos5-40v60v
- Product Brief OptiMOS™ 40V/60V:
  http://www.infineon.com/dgdl/Infineon+-+Product+Brief+-+Power+MOSFETs+-+OptiMOS+5+40V+and+60V.pdf?folderId=db3a304314dca38901154c20869c1b30&fileId=db3a3043353fdc16013543568a1731a7
- Video OptiMOS™ 5 40V/60V
  http://www.edge-cdn.net/index.php?ct=1353&vid=163276&setlang=en
- ORIGA™ – Battery Authentication - Webpage
  http://www.infienon.com/origa
- XMC 1000 Webpage
  http://www.infineon.com/xmc1000
- EiceDRIVER™ Compact Webpage
  http://www.infineon.com/eicedriver-compact

Revision History

Major changes since the last revision

Page or Reference	Description of change
--	First Release

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