AURIX™ TC3xx Motor Control Power Board

TriCore™, TC3xx Family, AURIX™ 32-bit microcontrollers

About this document

Scope and purpose

This application note provides an overview of the 3-phase motor control power board including its main features, key data, pin assignments and mechanical dimensions.

The power board has been designed to operate in various configurations and conditions, such as input voltages and control algorithms.

The hardware is compatible with AURIX™ Application Kit TC3x7 with TFT display, with AURIX™ TC3x7 in LFBGA-292 package.

Attention: ***This power board is intended only for evaluation purposes and is not intended to be an end product. Please always take care of the dead-time settings of the gate driver and always have in mind that power board has no breaking chopper or similar hardware protection to absorb the energy generated during regenerative breaking of a motor. In any case, user should ensure that voltage and current are monitored properly, by software or additional hardware.***

The design of this board originates from the need of a simple and plug-and-play motor drive power board to be used for AURIX™ TC3xx evaluation purposes in motor drive applications.

Intended audience

This document is intended for all technical specialists working with the motor control power board under laboratory conditions.

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1 Introduction

The motor control power board is a part of the KIT_A2G_TC387_MOTORCTR package (eMotor Kit). In order to run a motor, the matching control board is required to interface this power board. The motor control power board is compatible with AURIX™ Application Kit TC3x7 with TFT display, with AURIX™ TC3x7 in LFBGA-292 package [1].

The motor control power board is equipped with all assembly circuits required for sensor based and sensorless based field oriented control (FOC), as well for the block commutation control. It provides low voltage DC connector, three phase output for connecting the motor, and connectors for position sensors such as encoder, resolver and Hall.

An encoder sensor based FOC application example is described in [2]. In this example, three shunts in the ground path are used for phase currents sensing. The DC-link voltage sensing, phase voltage sensing and high-side DC-link current sensing information could be used for monitoring purposes.

As a part of KIT_A2G_TC387_MOTORCTR the motor control power board is available through regular Infineon distribution partners as well as on Infineon's website.

Note: The board is neither cost nor size optimized and does not serve as a reference design.

1.1 Key features

The motor control power board characteristics are:

- All components are SMD and only placed on the top side
- Driving of a three phase PMSM / BLDC (12 V, max. 50 W)
- Sensing of motor position with resolver, encoder or Hall sensors
- Advanced gate driver (TLE9180D-31QK)
- High-side DC-link current sensing
- Low-side DC-link current sensing
- Phase current sensing with two or three shunts in ground path
- Sensing of DC-link voltage
- Sensing of phase voltages
- Configuration / Diagnostic via SPI (TLE9180D-31QK)
- Power board fits perfectly to Application Kit TC3xx with TFT display, with AURIX™ TC3x7 in LFBGA-292 package
- Low power status LED
- PCB dimensions: 100mm x 120mm
- All test points accessible from bottom side

1.2 Block diagram

The block diagram of low voltage motor control power board is shown in Figure 1. This power board includes low power DC connector, control board connectors, low power motor connectors, resolver connector, encoder connector and Hall sensor connector. The auxiliary power supply TLE42744DVD50 is used to provide 5V for an advanced gate driver TLE9180D-31QK and motor positon sensor interfaces. The LED indicates the presence of the generated 5V voltage. The phase current sensing is possible with two or three shunts in the ground path. The low-side DC-link current sensing could be used with slight changes. The TLE9180D-31QK has three integrated current sense amplifiers with programmable gains. The high-side DC-link current sensing is implemented by using a bidirectional, zero-drift, high-speed current-shunt monitor. The DC-link voltage and phase voltage sensing are directly measured using resistive dividers with RC filters and the mounting options for Zener diodes which can be used to protect microcontroller pins. The 3-phase Power Bridge consists of three IPG20N04S4-08A dual N-channel MOSFETs.

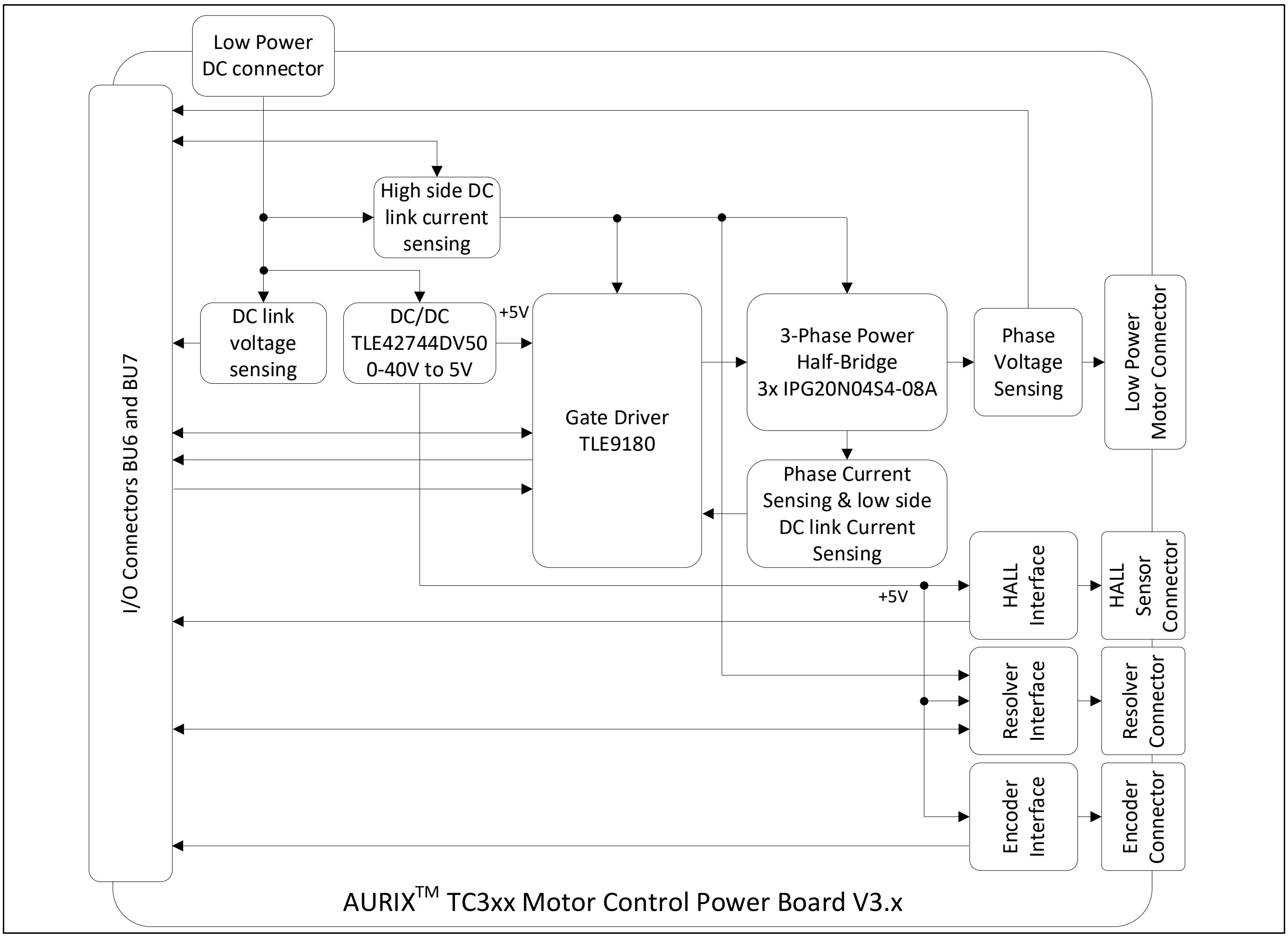

Figure 1 Block diagram of low voltage AURIX™ Motor Control Power Board in connection with AURIX™ TC3xx Application Kit with TFT display

1.3 Placement

The top and the bottom component and test points' placement are shown in Figure 2 and Figure 3, respectively.

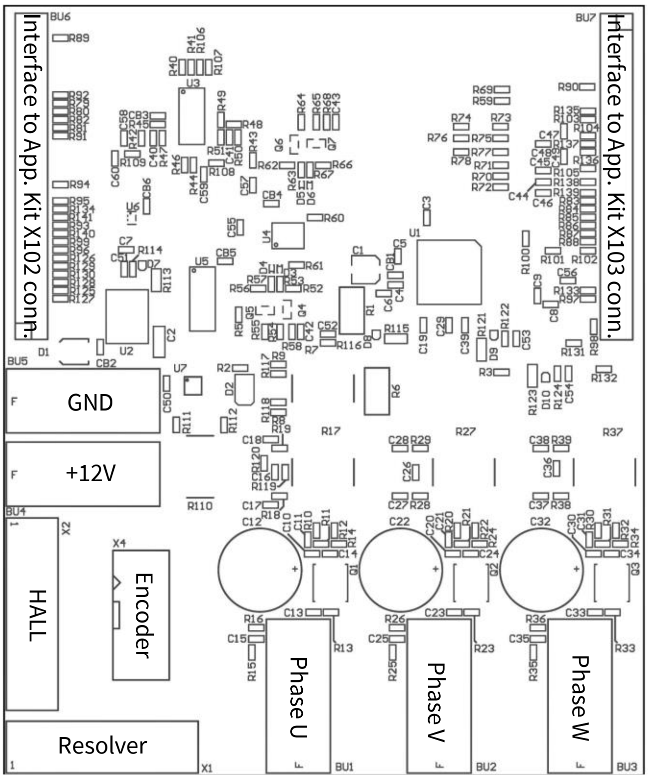

Figure 2 Top placement

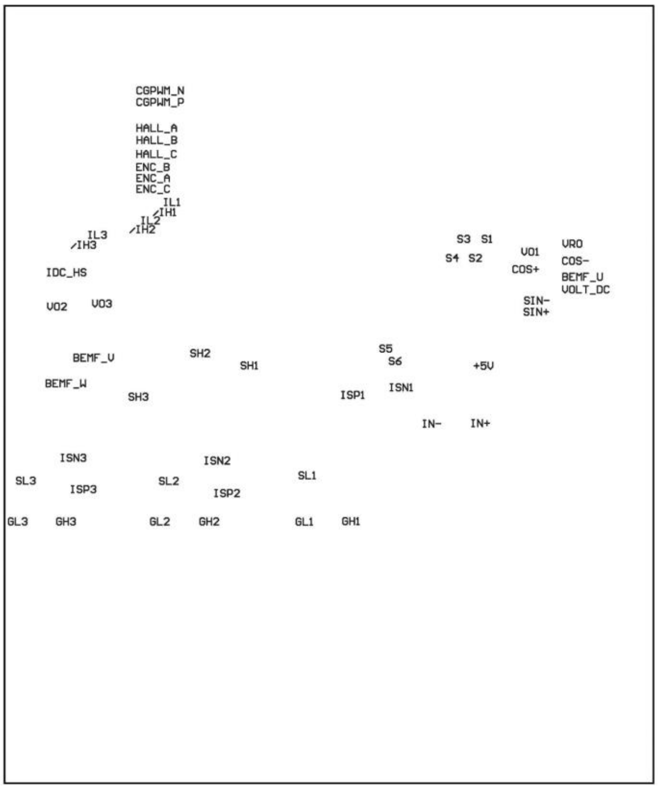

Figure 3 Bottom placement, test points

The mappings between test points and signal names are provided in Table 6, Table 8, Table 10 and Table 11.

2 Connector Pin Assignment

2.1 Control board connectors

General information about the connectors used for connection of control board and the power board is described below. For more details about control board pinout check [1].

Figure 4 shows the control board connectors' pinout, BU6 and BU7 (placement shown on Figure 2).

BU6 connected to App. Kit with TFT X102 connector

N.C.	39	40	N.C.
N.C.	37	38	/SOFF
N.C.	35	36	N.C.
N.C.	33	34	N.C.
/ERR	31	32	N.C.
CSN	29	30	CLK_SPI
MOSI	27	28	MISO
N.C.	25	26	ENA
N.C.	23	24	N.C.
N.C.	21	22	N.C.
N.C.	19	20	PFB2
PFB1_Enable	17	18	PFB3
N.C.	15	16	GS0_HS
PFB1	13	14	GS1_HS
VRO	11	12	VO1
COS- (VCC/2)	9	10	COS+
BEMF_U	7	8	VOLT_DC
SIN- (VCC/2)	5	6	SIN+
GND	3	4	GND
VCC_IN	1	2	VEXTA

BU7 connected to App. Kit with TFT X103 connector

VEXTB	2	1	VCC_IN
GND	4	3	GND
N.C.	6	5	N.C.
N.C.	8	7	N.C.
/INH	10	9	N.C.
N.C.	12	11	N.C.
CGPWM_P(Prim.Coil)	14	13	CGPWM_N(Prim.Coil)
HALL A	16	15	N.C.
HALL_C	18	17	HALL_B
ENC_B	20	19	ENC_A
N.C.	22	21	ENC_C
IL1	24	23	N.C.
IL2	26	25	/IH1
IL3	28	27	/IH2
N.C.	30	29	/IH3
N.C.	32	31	N.C.
N.C.	34	33	N.C.
IDC_HS	36	35	BEMF_V
VO3	38	37	N.C.
VO2	40	39	BEMF_W

Figure 4 Control board connectors - Pinout

Table 1 provides the pin assignments of the BU6.

Table 1 Control board connector, BU6

Short name	Description	Pin number
VCC_IN	Supply Input of Application Kit with TFT display (5.5 V÷50 V)	1
VEXTA	Not connected	2
GND	Ground	3
GND	Ground	4
SIN-	Analog signal / Trimmed resolver sensing coil SIN- signal (VCC/2)	5
SIN+	Analog signal / Trimmed resolver sensing coil SIN+ signal	6
BEMF_U	Analog input / Phase voltage U sensing signal	7
VOLT_DC	Analog signal /DC-Link voltage sensing signal	8
COS-	Analog signal / Trimmed resolver sensing coil COS- signal (VCC/2)	9
COS+	Analog signal / Trimmed resolver sensing coil COS+ signal	10
VRO	Analog signal / Reference voltage, used for current sensing	11
VO1	Analog signal / Phase current 1 (U or low side DC-link current)	12
PFB1	Digital signal / Phase voltage feedback 1 (U)	13

Short name	Description	Pin number
GS1_HS	Digital signal / Gain select, high side DC-link current sense	14
GS0_HS	Digital signal / Gain select, high-side DC-link current sense	16
PFB1_Enable	Digital signal / Enable PFB1 monitoring	17
PFB2	TLE9180D-31QK – Digital signal / Phase voltage feedback 1 (V)	18
PFB3	TLE9180D-31QK – Digital signal / Phase voltage feedback 1 (W)	20
/ENA	TLE9180D-31QK – Enable	26
MOSI	TLE9180D-31QK – SPI Master In Slave In	27
MISO	TLE9180D-31QK – SPI Master In Slave Out	28
CSN	TLE9180D-31QK – SPI Chip Select Not	29
CLK_SPI	TLE9180D-31QK – SPI Clock Serial Peripheral Interface	30
/ERR	TLE9180D-31QK – Error not	31
/SOFF	TLE9180D-31QK – Independent save state	38

Table 2 provides the pin assignments of the BU7.

Table 2 Control board connector, BU7

Short name	Description	Pin number
VCC_IN	Supply input of Application Kit with TFT display (5,5V...50V)	1
VEXTB	Not connected	2
GND	Ground	3
GND	Ground	4
/INH	TLE9180D-31QK – Inhibit not (active low)	10
CGPWM_N	Resolver exciting coil signal, negative	13
CGPWM_P	Resolver exciting coil signal, positive	14
HALL A	Hall A signal	16
HALL B	Hall B signal	17
HALL C	Hall C signal	18
ENC_A	Encoder A signal	19
ENC_B	Encoder B signal	20
ENC_C	Encoder top zero signal	21
IL1	PWM Low side 1	24
/IH1	PWM High side 1	25
IL2	PWM Low side 2	26
/IH2	PWM High side 2	27
IL3	PWM Low side 3	28
/IH3	PWM High side 3	29
BEMF_V	Analog input / Phase voltage V sensing signal	35
IDC_HS	Analog input / High-side DC-link current sensing signal	36
VO3	Analog input / Phase current 3 (W)	38
BEMF_W	Analog input / Phase voltage W sensing signal	39

Short name	Description	Pin number
VO2	Analog input / Phase current 2 (V)	40

2.2 Resolver connector

Figure 5 shows the resolver signals connector pinout, X1 (placement shown on Figure 2).

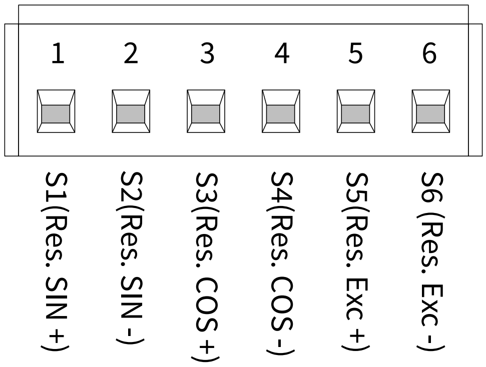

Figure 5 Resolver connector

Table 3 provides the pin assignments of the resolver connector, X1.

Table 3 Resolver signals connector, X1

Short name	Description	Pin number
S1	Resolver sensing coil SIN+ signal	1
S2	Resolver sensing coil SIN- signal	2
S3	Resolver sensing coil COS+ signal	3
S4	Resolver sensing coil COS- signal	4
S5	Resolver exciting coil signal, positive	5
S6	Resolver exciting coil signal, negative	6

2.3 Hall signals connector

Figure 6 shows the Hall signals connector pinout, X2 (placement shown on Figure 2).

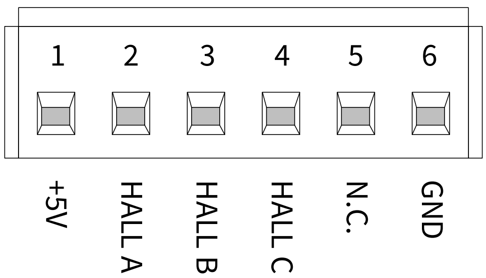

Figure 6 Hall signals connector

Table 4 provides the pin assignments of the resolver connector, X2.

Table 4 **Hall, X2**

Short name	Description	Pin number
5V	Supply of Hall sensor	1
HALLA	Hall sensor A signal	2
HALLB	Hall sensor B signal	3
HALLC	Hall sensor C signal	4
N.C	Not connected	5
GND	Ground	6

2.4 Encoder connector

Figure 7 shows the encoder signals connector pinout, X3 (placement shown on Figure 2).

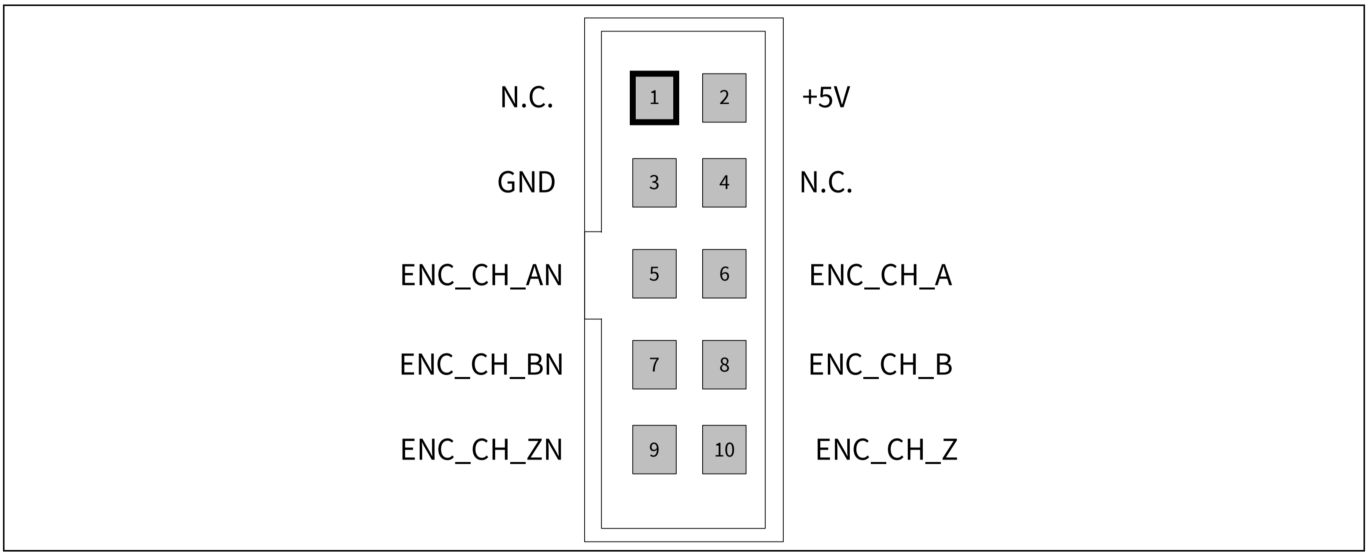

Figure 7 **Encoder connector**

Table 5 provides the pin assignments of the resolver connector, X3.

Table 5 **Encoder, X3**

Short name	Description	Pin number
N.C.	Not connected	1
+5V	Supply of encoder	2
GND	Ground	3
N.C.	Not connected	4
ENC_CH_AN	Neg. Incremental Signal Channel A	5
ENC_CH_A	Incremental Signal Channel A	6
ENC_CH_BN	Neg. Incremental Signal Channel B	7
ENC_CH_B	Incremental Signal Channel B	8
ENC_CH_ZN	Neg. Incremental Signal Channel Z (top 0)	9
ENC_CH_Z	Incremental Signal Channel Z (top 0)	10

3 Schematic and Layout

3.1 Overview

An overview of the board's schematics is shown in Figure 8. Basically, the schematic can be divided into five sub-blocks:

- the advanced gate driver and supply (shown in Figure 9)
- the power stage with current and voltage sensing's (shown in Figure 10)
- resolver interface (shown in Figure 12)
- encoder and hall sensors interface (shown in Figure 14)
- control board connectors (shown in Figure 15)

The external controller board (AURIX™ Application Kit TC3xx with TFT display) has to be connected to the evaluation board by the BU6 and BU7 power board connectors.

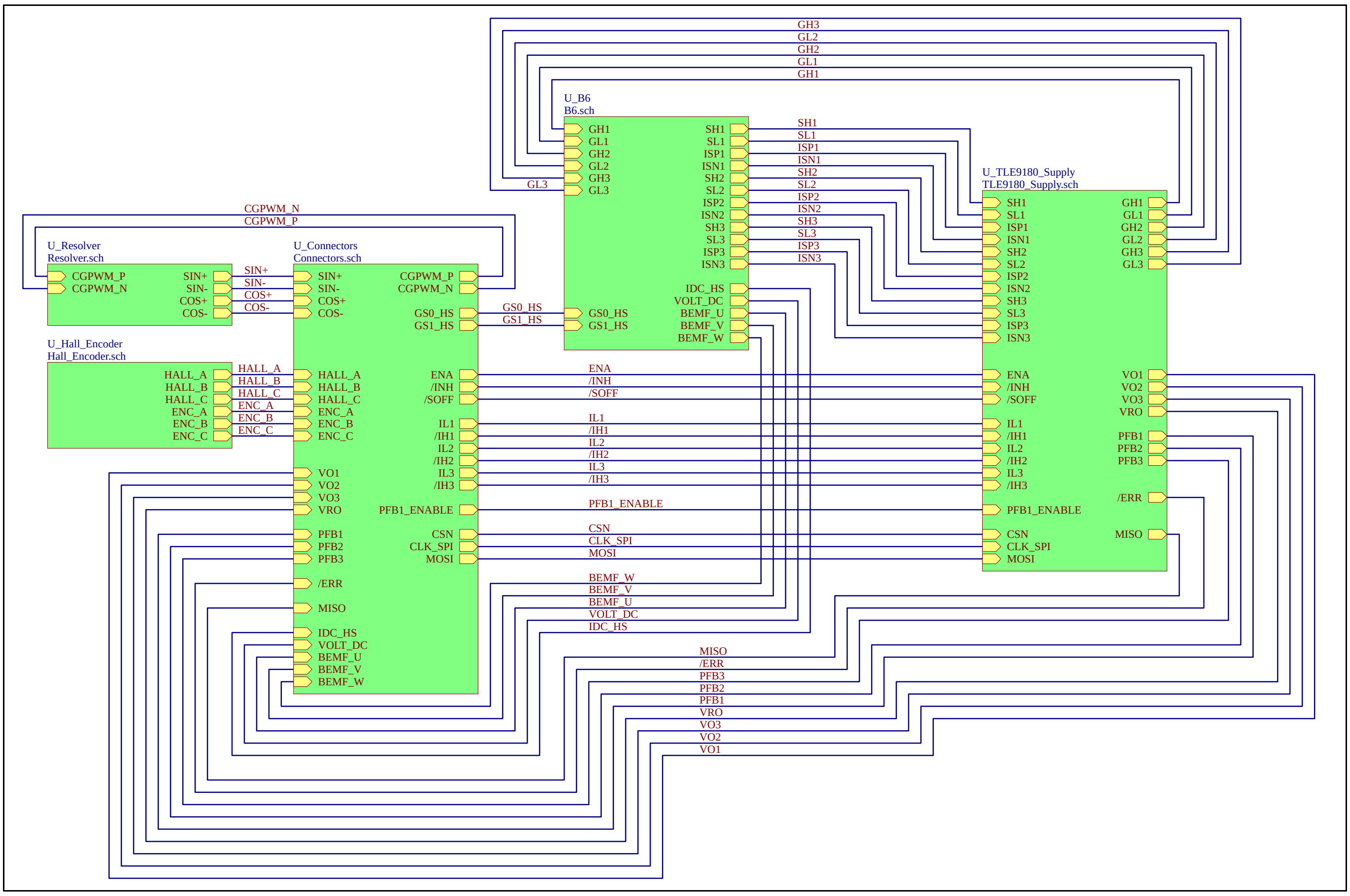

Figure 8 **Schematic: Overview**

3.2 Power supply and three phase gate driver

Figure 9 depicts the schematic of the power supply and three phase gate driver (U_TLE9180_Supply block in Figure 8).

The power board must be supplied by an external DC power supply (from 12 V to 24 V) connected to its power connectors (BU4 and BU5). The power to be delivered by the external power supply depends on the overall load mainly defined by the power consumption of the motor. The power supply unit (12 V / 2 A) delivered with the motor control kit is sufficient to supply the control board and the motor provided with the kit.

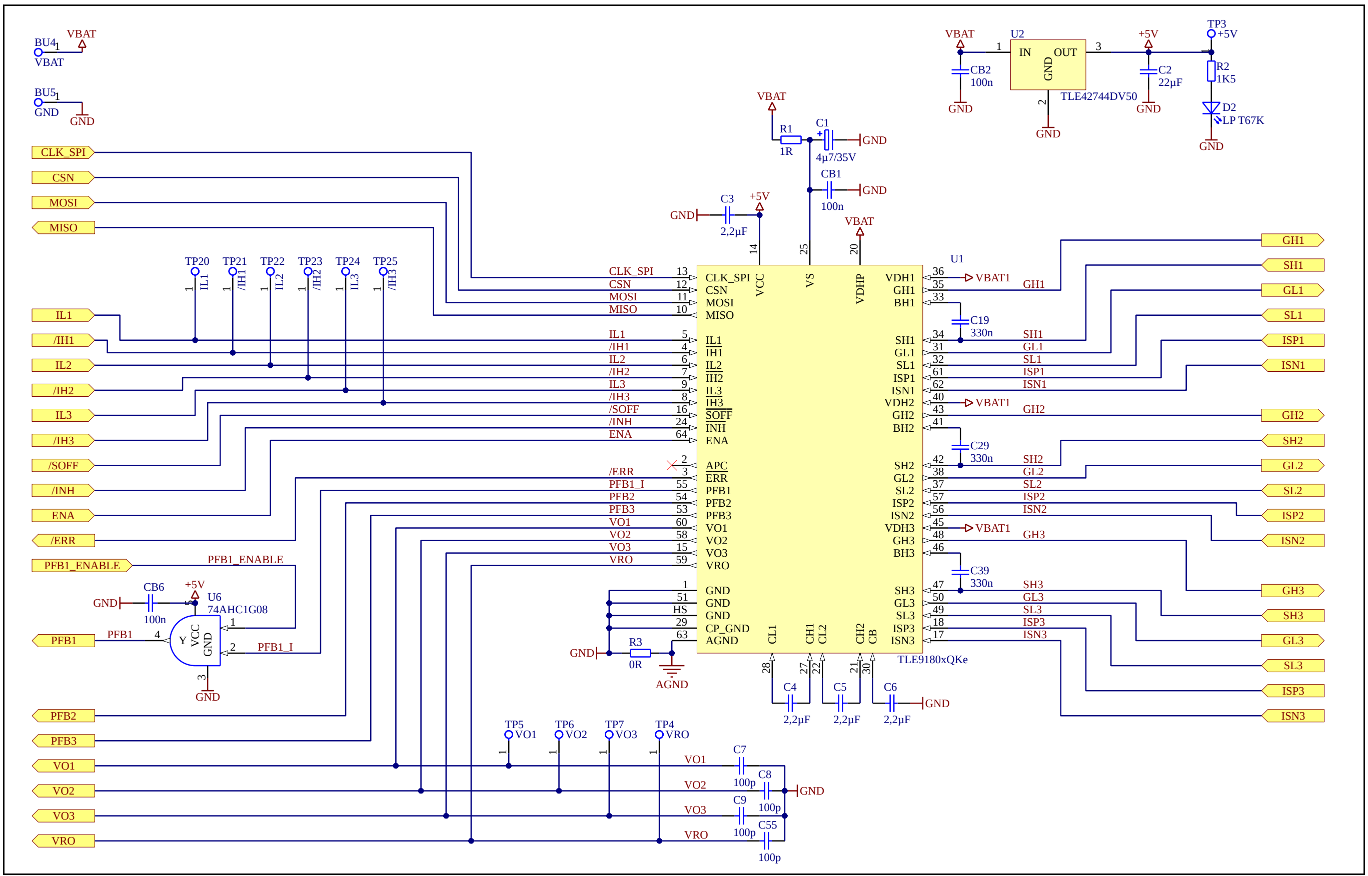

Figure 9 Schematic: Power supply and three phase gate driver

Table 6 provides the list of test points and related signals. Test points placement is of shown on Figure 3.

Table 6 Test points: Power supply and three phase gate driver

Test point	Signal
TP3	+5 V
TP4	VRO, for details see Table 7
TP5	VO1, for details see Table 7
TP6	VO2, for details see Table 7
TP7	VO3, for details see Table 7
TP20	IL1, for details see Table 7
TP21	/IH1, for details see Table 7
TP22	IL2, for details see Table 7
TP23	/IH2, for details see Table 7
TP24	IL3, for details see Table 7
TP25	/IH3, for details see Table 7

3.2.1 Power supply

The 3-phase Bridge Driver IC needs 2 different supply voltages. The 12 V is supplied externally. The 5 V are generated internally via the Infineon TLE 42744D V50. The LED indicates the presence of the generated 5 V voltage. Additionally, TLE 42744D V50 provides 5 V for position sensor circuits, as shown in Figure 9.

The TLE42744 is a monolithic integrated low dropout voltage regulator for load currents up to 400 mA. An input voltage up to 40 V is regulated to $V_{Q,nom}$ = 5 V / 3.3 V with a precision of ±2%. The device is designed for the harsh environment of automotive applications. Therefore it is protected against overload, short circuit and over temperature conditions by the implemented output current limitation and the over temperature shutdown circuit. The TLE42744 can be also used in other applications requiring a stabilized 5 V / 3.3 V voltage. Due to its very low quiescent current the TLE42744 is dedicated for the use in such applications, where power is permanently connected to V_{BAT}.

The power board has to be connected to an external 12 V DC power supply by using BU4 (12 V) and BU5 (GND), as shown in Figure 2.

The maximum power consumption is not specified, but the current should not exceed 3 A.

3.2.2 Three phase gate driver

The TLE9180D-31QK, shown in Figure 9, is an advanced gate driver IC dedicated to control 6 external N-channel MOSFETs forming an inverter for high current 3 phase motor drive application in the automotive sector.

An advanced high voltage technology allows the TLE9180D-31QK to support applications for single and mixed battery systems with battery voltages of 12 V, 24 V and 48 V even within tough automotive environments in combination with high motor currents. Therefore bridge, motor and supply related pins can withstand voltages of up to 90 V. Motor related pins can even withstand negative voltage transients down to -7 V up to -15 V without destruction.

An integrated SPI interface is used to configure the TLE9180D-31QK for the application after power-up. After successful power-up, adjusting parameters, monitoring data, configuration and error registers can be read through SPI interface. Cyclic redundancy check over data and address bits ensures safe communication and data integrity.

Ground related bridge currents can be measured with up to 3 integrated current sense amplifiers. The outputs of the current sense amplifiers support 5 V ADCs and the robust inputs can withstand negative transients down to -10 V without destruction. Low noise, fast settling times and high accuracy are the main features of the integrated current sense amplifiers. Gain and the zero current voltage offset can be adjusted by reconfigurations through SPI. The offset can be calibrated.

Diagnostic coverage and redundancy have increased steadily in recent years in automotive drive applications. Therefore the TLE9180D-31QK offers a wide range of diagnostic features, such as monitoring of power supply voltages and system parameters. A testability of safety relevant supervision functions has been integrated. The failure behavior, the threshold voltages and the filter times of the supervisions of the device are adjustable by using SPI.

The TLE9180D-31QK is integrated in a

- VQFN48 7*7 package with an exposed pad
- LQFP64 package with an exposed pad

Due to its exposed pad the gate driver IC provides an excellent thermal characteristic.

Table 7 provides an overview of TLE9180D-31QK used pins in motor control power board. For more information about pin functionalities and expected signals, see [4].

Table 7 TLE9180D-31QK – Used pins

Short name	Description
/ERR	Error signal (active low)

Short name	Description
/IH1	Input for high-side switch 1 (active low)
IL1	Input for low-side switch 1 (active high)
IL2	Input for low-side switch 2 (active high)
/IH2	Input for high-side switch 2(active low)
/IH3	Input for high-side switch 3 (active low)
IL3	Input for low-side switch 3 (active high)
MISO	SPI Master In, Slave Out
MOSI	SPI Master Out, Slave In
CSN	SPI Chip Select
CLK_SPI	SPI clock input
VCC	Power supply for digital I/O pins and input for VCC monitoring
/SOFF	Independent safe state switch off (active low)
VDH	Connection to drain of high-side switches for short circuit detection; Supply for CP2
CH2	+ Terminal for pump capacitor of charge pump 2
CL2	- Terminal for pump capacitor of charge pump 2
/INH	Inhibit pin (active low)
VS	Voltage supply
CH1	+ Terminal for pump capacitor of charge pump 1
CL1	- Terminal for pump capacitor of charge pump 1
CP_GND	Charge pump GND
CB	Buffer capacitor for charge pump 1
GL1	Output to gate low-side switch 1
SL1	Connection to source low-side switch 1
BH1	Bootstrap pin for + terminal of bootstrap capacitor CBS1
SH1	Connection to source high-side switch 1
GH1	Output to gate high-side switch 1
SL2	Connection to source low-side switch 2
GL2	Output to gate low-side switch 2
BH2	Bootstrap pin for + terminal of bootstrap capacitor CBS2
SH2	Connection to source high-side switch 2
GH2	Output to gate high-side switch 2
BH3	Bootstrap pin for + terminal of bootstrap capacitor CBS3
SH3	Connection to source high-side switch 3
GH3	Output to gate high-side switch 3
SL3	Connection to source low-side switch 3
GL3	Output to gate low-side switch 3
GND	GND

Short name	Description
PFB3	Phase feedback of motor connection phase 3
PFB2	Phase feedback of motor connection phase 2
PFB1	Phase feedback of motor connection phase 1
VRO	Output of reference voltage of differential amplifier
VO3	Output of differential 3 amplifier for shunt signal amplification
VO2	Output of differential 2 amplifier for shunt signal amplification
VO1	Output of differential 1 amplifier for shunt signal amplification
ISP	+ Input of differential amplifier for shunt signal amplification
ISN	- Input of differential amplifier for shunt signal amplification
AGND	Analog ground especially for the current sense differential amplifier
ENA	Enable pin (active high)

3.3 Power Bridge, current and voltage sensing

Figure 10 depicts the schematic of the Power Bridge, current and voltage sensing (U_B6 block in Figure 8).

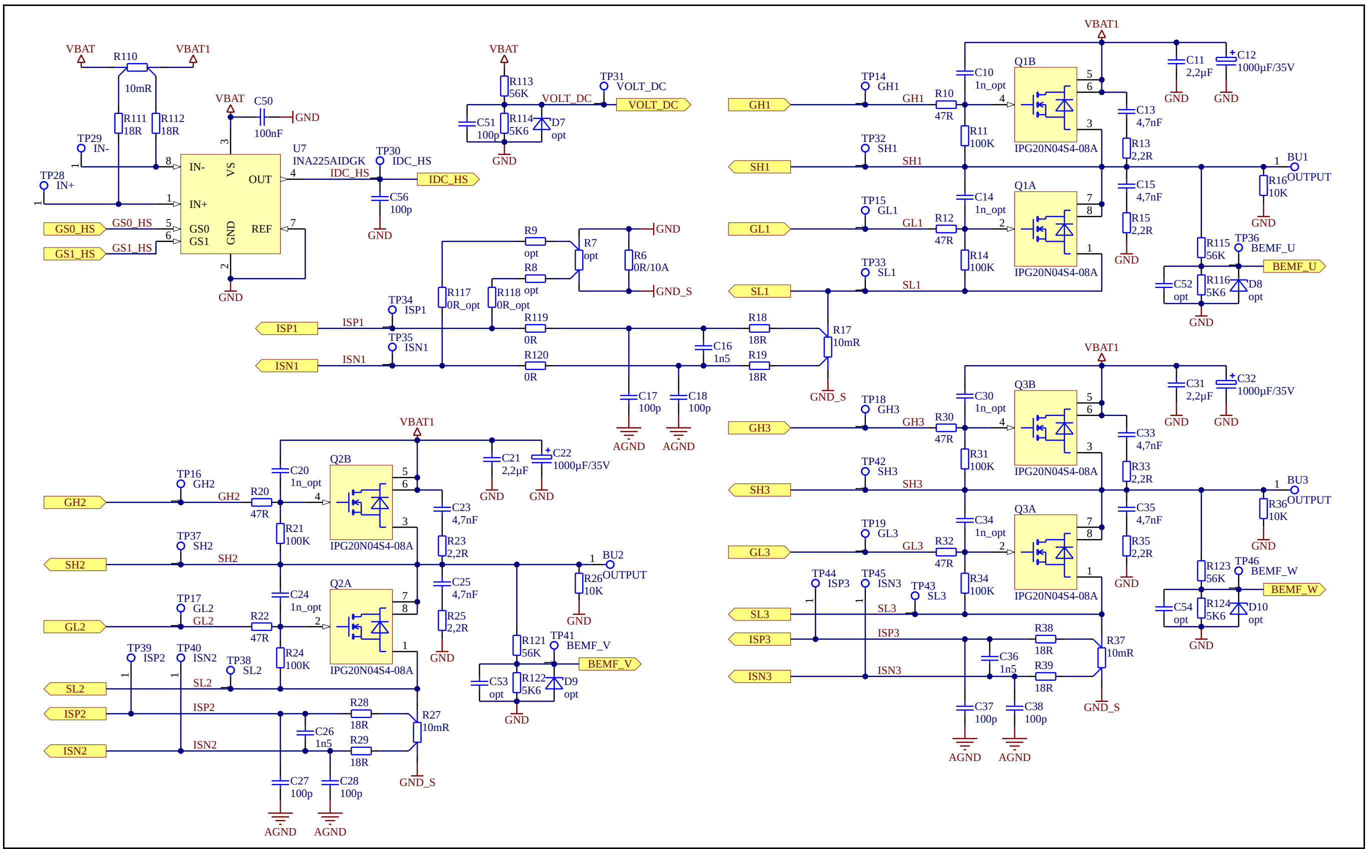

Figure 10 Schematic: Power Bridge, current and voltage sensing

Table 8 provides the list of test points and related signals of schematic shown on Figure 10. Test points placement is of shown on Figure 3.

Table 8 Test points: Power Bridge, current and voltage sensing

Test point	Signal
TP14	GH1, for details see Table 7
TP15	GL1, for details see Table 7
TP16	GH2, for details see Table 7
TP17	GL2, for details see Table 7
TP18	GH3, for details see Table 7
TP19	GL3, for details see Table 7
TP28	INA225AIDGK IN+, connected to supply side of high-side DC-link shunt resistor
TP29	INA225AIDGK IN-, connected to load side of high-side DC-link shunt resistor
TP30	IDC_HS, for details see 3.3.3
TP31	VOLT_DC, for details see 3.3.2
TP32	SH1, for details see Table 7
TP33	SL1, for details see Table 7
TP34	ISP1, for details see Table 7
TP35	ISN1, for details see Table 7
TP36	BEMF_U, for details see 3.3.5
TP37	SH2, for details see Table 7
TP38	SL2, for details see Table 7
TP39	ISP2, for details see Table 7
TP40	ISN2, for details see Table 7
TP41	BEMF_V, for details see 3.3.5
TP42	SH3, for details see Table 7
TP43	SL3, for details see Table 7
TP44	ISP3, for details see Table 7
TP45	ISN3, for details see Table 7
TP46	BEMF_W, for details see 3.3.5

3.3.1 Power Bridge

For the Power Bridge, three dual N-channel MOSFETs IPG20N04S4-08A in a smart PG-TDSON-8-10 package have been selected, as shown in Figure 10.

Summary of features:

- Dual N-channel Normal Level - Enhancement mode
- AEC Q101 qualified
- MSL1 up to 260°C peak reflow
- 175°C operating temperature
- Green Product (RoHS compliant)
- 100% Avalanche tested
- Feasible for automatic optical inspection (AOI)

Benefits:

- Dual Super S08 can replace multiple DPAKs for significant PCB area savings and system level cost reduction
- Bond wire is 200 µm for up to 20 A current
- Larger source lead frame connection for wire bonding
- Same thermal and electrical performance as a DPAK with the same die size
- Exposed pad provides excellent thermal transfer (varies with die size)
- Two N-Channel MOSFETs in one package with 2 isolated lead frames

3.3.2 DC-link voltage sensing

The DC-link voltage is directly measured using resistive divider at the power board low power supply connection, as shown in Figure 10. The DC-link voltage signal is available at VOLT_DC pin of the control board signal connector BU6, as shown in Figure 4. The DC-link voltage signal could be used in motor control software for over and under voltage protection or for the compensation of the DC-Link voltage in the motor control loop.

$$\mathrm{VOLT\_DC} = \mathrm{VBAT} \cdot \frac{R113}{R114 + R113} \tag{Eq. 1}$$

$$\text{@12V power supply voltage: } \mathrm{VOLT\_DC} = 12\,V \cdot \frac{5.6kOhm}{5.6kOhm + 56kOhm} = 1.09\,V$$

$$\text{@24V power supply voltage: } \mathrm{VOLT\_DC} = 24\,V \cdot \frac{5.6kOhm}{5.6kOhm + 56kOhm} = 2.18\,V$$

A free soldering pad for a 5.1 V Zener diode is available and pin voltage can be clamped to protect the microcontroller pin. Consider that the Zener diode might have considerable capacitive behavior.

3.3.3 High-side DC-link current sensing

The voltage across the high-side DC-link shunt resistor is fed into the INA225AIDGK inputs IN- and IN+, as shown in Figure 10. The INA225AIDGK, bidirectional current-shunt monitor, has programmable gain levels [6]. The high-side DC-link current sensing signal is available at IDC_HS pin of the control board signal connector BU7, while the gain selection pins GS0 and GS1 are available at control board signal connector BU7, as shown in Figure 4. The DC-link current sensing could be used in motor control software for monitoring, three phase current reconstruction or other purposes.

Table 9 provides the gain select settings based on voltage levels applied to GS0 and GS1.

Table 9 High-side DC-link current sensing amplifier gain select settings

Gain	GS0	GS1
25 V/V	GND	GND
50 V/V	GND	V_S
100 V/V	V_S	GND
200 V/V	V_S	V_S

Shunt resistor is selected to be 10 mΩ ±1%, 3W.

3.3.4 Three phase and low-side DC-link current sensing

The motor control power board is designed based on three phase current sensing, while for low-side DC-link current sensing it needs hardware changes. The voltage across the three phase shunt resistors is fed into the TLE9180D-31QK shunt positive and negative inputs (ISPx and ISNx, where x = 1, 2, 3), as shown in Figure 10. The TLE9180D-31QK has 3 integrated current sense amplifiers (CSA). The outputs of the current sense amplifiers feed ADCs with an analog range from 0 V to 5 V. The offsets and gains of current sense amplifiers are programmable by using SPI [4]. Following gains of current sense amplifiers are possible:

- 83.19
- 38.13
- 34.45 (default)
- 30.18
- 26.90
- 23.35
- 19.56
- 15.71

The DC output voltage at the outputs of the CSAs (VOx, x = 1, 2, 3) for zero differential input voltage is defined by the output of the reference buffer at Voltage Reference Output (VRO) pin. Therefore, positive and negative currents through the shunt resistor can be amplified by the CSAs and thus measured by the ADC of microcontroller. Three different VRO voltages can be set at the reference buffer RB. Each of the three VRO voltage settings can be fine-tuned.

VRO output voltage levels:

- 0.5 V
- 1.65 V
- 2.5 V

Additionally, VRO output voltage level can be trimmed, see [4].

Shunt resistors are selected to be 10 mΩ ±1%, 3 W.

In case of using the low-side DC-link current sensing, following guideline shall be followed:

- Remove the 10 mΩ resistors R17, R27 and R37
- Assemble R17, R27 and R37 resistors with 0 Ω resistors
- Remove R6 resistor
- Assemble R7 with 10 mΩ ±1%, 3 W resistor
- Remove R119 and R120 resistors

Note: *If additional capacitors are needed, instead of removing resistors R119 and R120, the resistors R18 and R19 shall be removed.*

Note: *If the CSA is not used the input pins ISPx and ISNx of the CSA shall be connected to GND and the output pins VRO and VOx shall be left open. Additionally, the supplies of the not used CSA shall be turned off via SPI [4].*

3.3.5 Phase voltages sensing

The phase voltage is directly measured using resistive dividers at the phases, as shown in Figure 10. The phase voltage sensing signals are available at BEMF_U, BEMF_V, BEMF_W pins of the control board signal connectors BU6 and BU7, as shown in Figure 4.

$$\mathrm{BEMF\_U} = \mathrm{U} \cdot \frac{R116}{R116 + R115} \qquad \text{Eq. 2}$$

$$\text{@12V phase voltage: BEMF\_U} = 12V \cdot \frac{5.6kOhm}{5.6kOhm + 56kOhm} = 1.09V$$

$$\text{@24V phase voltage: BEMF\_U} = 24V \cdot \frac{5.6kOhm}{5.6kOhm + 56kOhm} = 2.18V$$

Phase voltage sensing is available for sensorless BLDC scalar control using 6-step modulation scheme as well as for various other scopes.

A free soldering pad for a 5.1 V Zener diode is available and pin voltage can be clamped to protect the microcontroller pin. Consider that the Zener diode might have considerable capacitive behavior.

3.4 Resolver interface

Resolvers are absolute angle transducers that are mounted on the motor shaft to get the motor's absolute angular position. Resolvers are often used for angle sensing in noisy environments, due to their rugged construction and their ability to reject common-mode noise. Resolver applications, shown on Figure 11, determine the rotation angle by evaluating the induced signals from two orthogonally placed coils, SIN and COS. These coils are excited by the magnetic field of a third coil. Their amplitudes are modulated with the sine and cosine magnitudes corresponding to the current resolver position.

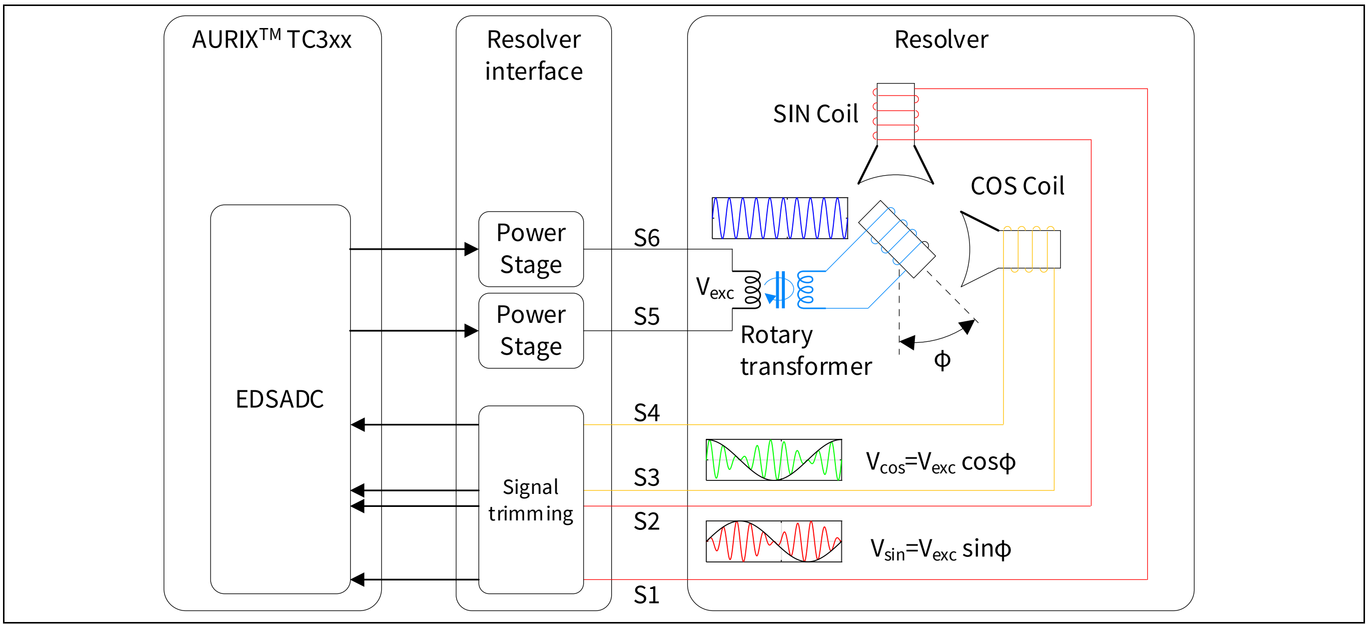

Figure 11 Resolver application

Figure 12 shows the schematic of the resolver interface that provides sinusoidal resolver excitation and adapts the sine and cosine signals to fit AURIX™ Enhanced Delta-Sigma to Digital Converter (EDSADC) module input voltage range (U_Resolver block in Figure 8).

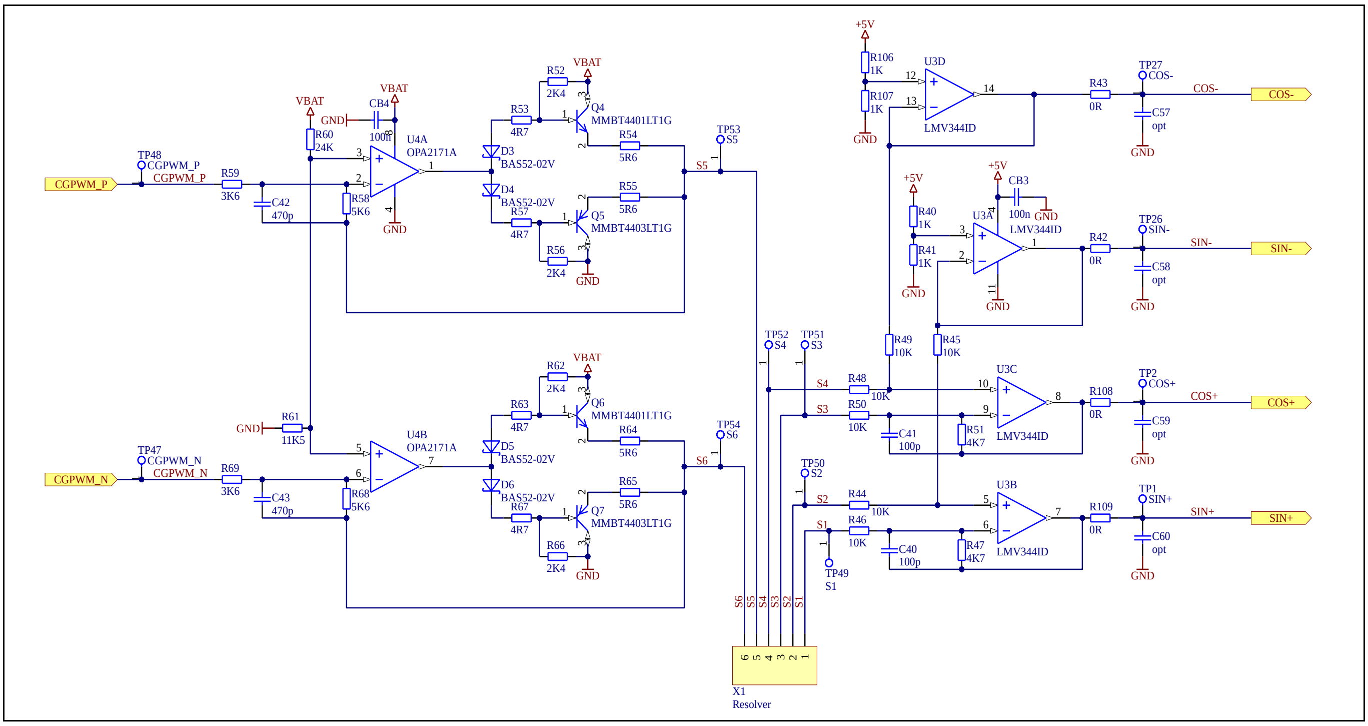

Figure 12 Schematic: Resolver interface

Table 10 provides the list of test points and related signals of schematic shown on Figure 12. Test points placement is of shown on Figure 3.

Table 10 Test points: Resolver interface

Test point	Signal
TP1	SIN+, for details see Table 1
TP2	COS+, for details see Table 1
TP26	SIN-, for details see Table 1
TP27	COS-, for details see Table 1
TP47	CGPWM_N, for details see Table 2
TP48	CGPWM_P, for details see Table 2
TP49	S1, for details see Table 3
TP50	S2, for details see Table 3
TP51	S3, for details see Table 3
TP52	S4, for details see Table 3
TP53	S5, for details see Table 3
TP54	S6, for details see Table 3

Resolver sine excitation signal (carrier), generated within EDSADC module, is provided as a differential signal on AURIX™ device pins CGPWMp and CGPWMn [3]. The carrier signal is first filtered by means of RC stage (F_{cp} for signal CGPWMp and F_{cn} for signal CGPWMn) and then amplified by means of inverting amplifier (U4A for signal CGPWMp with Ratio$_p$ and Offset$_p$, while U4B for signal CGPWMn with Ratio$_n$ and Offset$_n$) – to tune the signals with respect to gain and offset. To reach required power ratings needed for excitation of typical resolver external amplification circuit, implemented as a push-pull stage (bipolar transistor Q4/Q5 for S5 and Q6/Q7 for

S6), is provided to increase resolver excitation circuit current driving capabilities – in this design up to 1A can be driven. The diodes D3/D4 and D5/D6 set the quiescent current in the output stage Q4/Q5 and Q6/Q7, respectively. The resistors R52/R56 and R62/R66 set the quiescent current in the intermediate buffer stage at output of the operation amplifiers U4A and U4B. The maximum out current is set by resistors R54/R55 and R64/R65 for the CGPWMp and CGPWMn, respectively.

$$F_{cp} = \frac{1}{2\pi \times C42 \times R58} \tag{Eq. 3}$$

$$F_{cn} = \frac{1}{2\pi \times C43 \times R68} \tag{Eq. 4}$$

$$\mathrm{Ratio}_p = -\frac{\mathrm{R58}}{\mathrm{R59}} \tag{Eq. 5}$$

$$\mathrm{Offset}_p = \mathrm{VBAT} \times \frac{R61}{R60 + R61} \tag{Eq. 6}$$

$$\mathrm{Ratio}_n: -\frac{\mathrm{R68}}{\mathrm{R69}} \tag{Eq. 7}$$

$$\mathrm{Offset}_n = \mathrm{VBAT} \times \frac{R61}{R60+R61} \tag{Eq. 8}$$

The sine and cosine signals from resolver are trimmed with 4-channel operational amplifier (U3) to fit within EDSADC range of AURIX™ TC3xx device. The channels U3A and U3D are used to define common mode voltages (Offset_{cos-} ,Offset_{sin-}) for resolver negative sine and cosine coils signals. The channels U3B and U3C are the scaled down filtered signals (F_{csin+},F_{ccos+}) of resolver positive sine and cosine coils signals.

$$\mathrm{Offset}_{cos-} = \mathrm{VCC} \times \frac{R107}{R107 + R108} \tag{Eq. 9}$$

$$\mathrm{Offset}_{sin-} = \mathrm{VCC} \times \frac{R41}{R40 + R41} \tag{Eq. 10}$$

$$F_{csin+} = \frac{1}{2\pi \times C40 \times R47} \tag{Eq. 11}$$

$$F_{ccos+} = \frac{1}{2\pi \times C41 \times R51} \tag{Eq. 12}$$

Note: *In case of using resolver interface, the capacitor C122 at AURIX™ Application Kit TC3x7 with TFT display needs to be removed.*

3.5 Encoder and Hall sensor interface

An incremental encoder contains LED emitters, integrated circuits with light detectors and output circuitry. A disk with a markings pattern on its surface rotates between the emitter and detector IC, thus allowing and blocking the light of the emitter from reaching the detector IC. The outputs of the detector IC could be single-ended and differential signals. There are three output signals. Two of them provide a square wave signal with a 90 degree phase shift. The third one generates once per revolution a short pulse for synchronization.

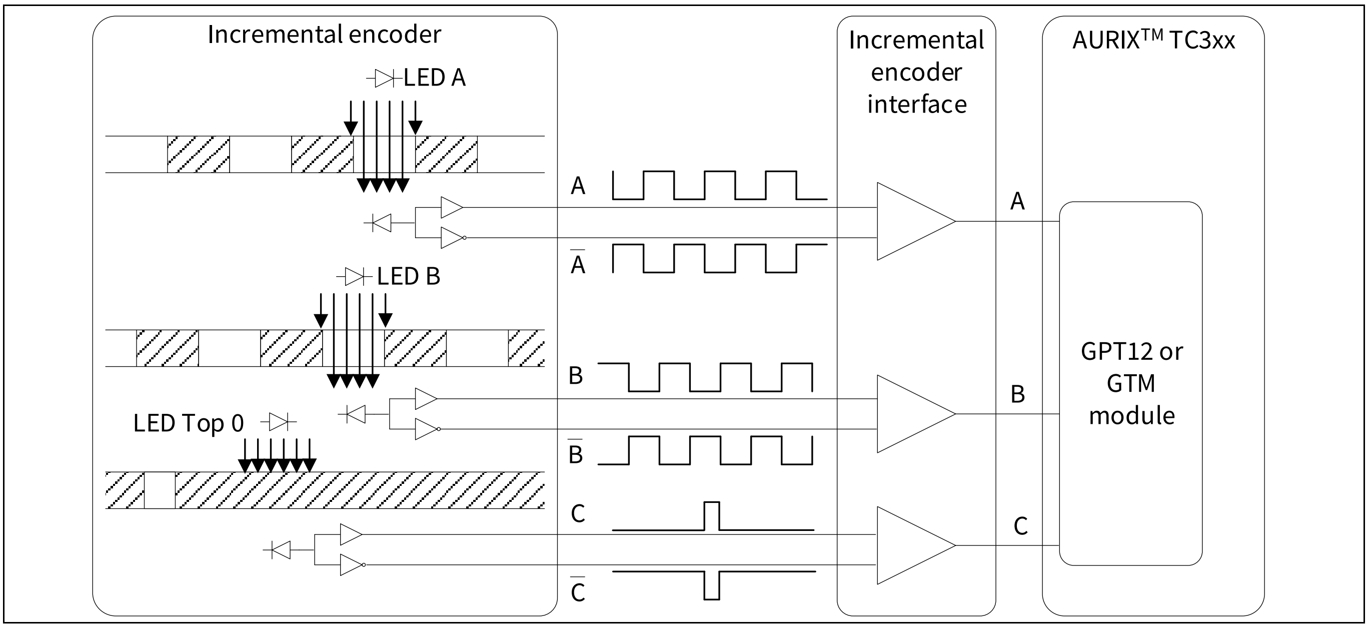

Figure 13 Encoder application

Figure 14 shows the schematic of the encoder and Hall sensor interface (U_Hall_Encoder block in Figure 8).

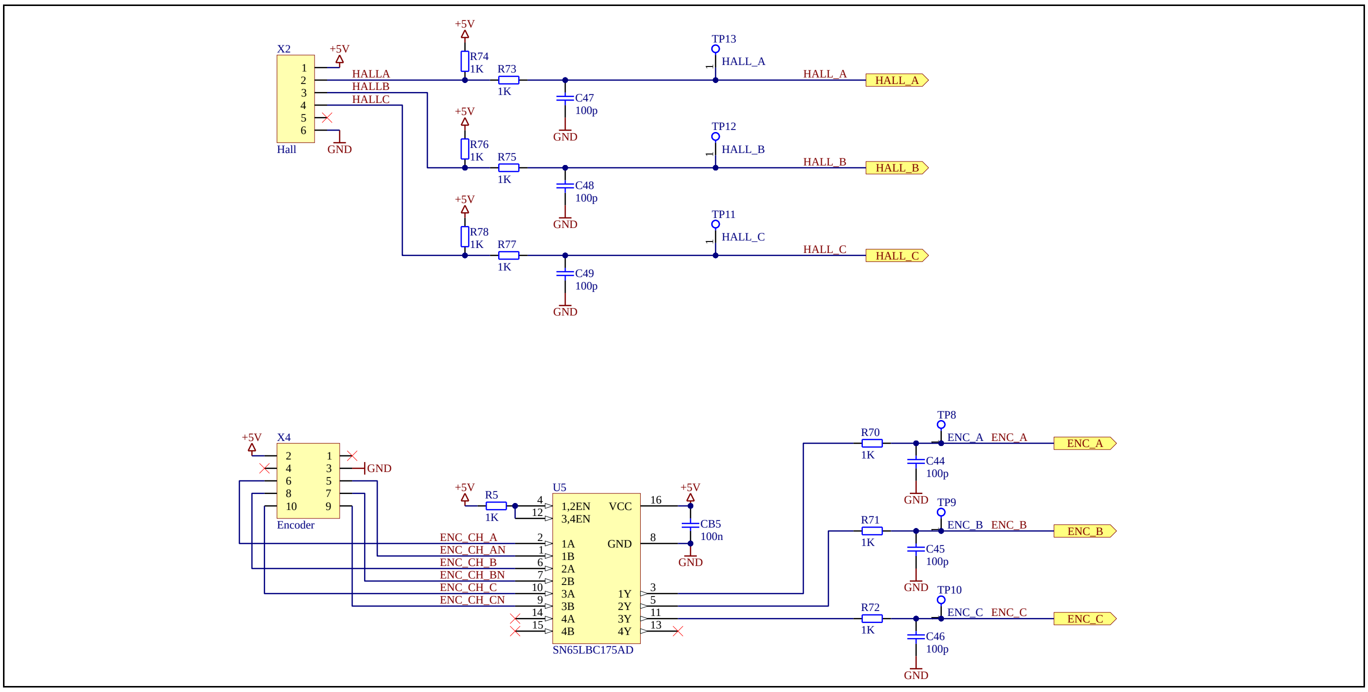

Figure 14 Schematic: Encoder and Hall sensors interface

Table 11 provides the list of test points and related signals of schematic shown on Figure 14. Test points placement is of shown on Figure 3.

Table 11 Test points: Encoder and Hall sensors interface

Test point	Signal
TP8	ENC_A, for details see Table 2
TP9	ENC_B, for details see Table 2
TP10	ENC_C, for details see Table 2
TP11	HALL_C, for details see Table 2
TP12	HALL_B, for details see Table 2
TP13	HALL_A, for details see Table 2

The encoder interface connector provides a differential input which is transformed into single ended signals by an interface IC as the microcontroller needs single ended signals. The differential signals from the encoder (ENCA +/-, ENCB +/-, ENCZ +/-) must be connected to the 10-pin encoder connector X4 (Figure 7).

In case of using a Hall sensor the signals must be attached to the connector X2 (Figure 6). Next to the Hall signals that are pulled up to 5 V, the 5 V Hall sensor supply and GND connections are also available.

3.6 Control board connectors

Figure 15 shows the control board connectors. The power board is compatible with AURIX™ Application Kit TC3xx with TFT display (U_Connectors block in Figure 8).

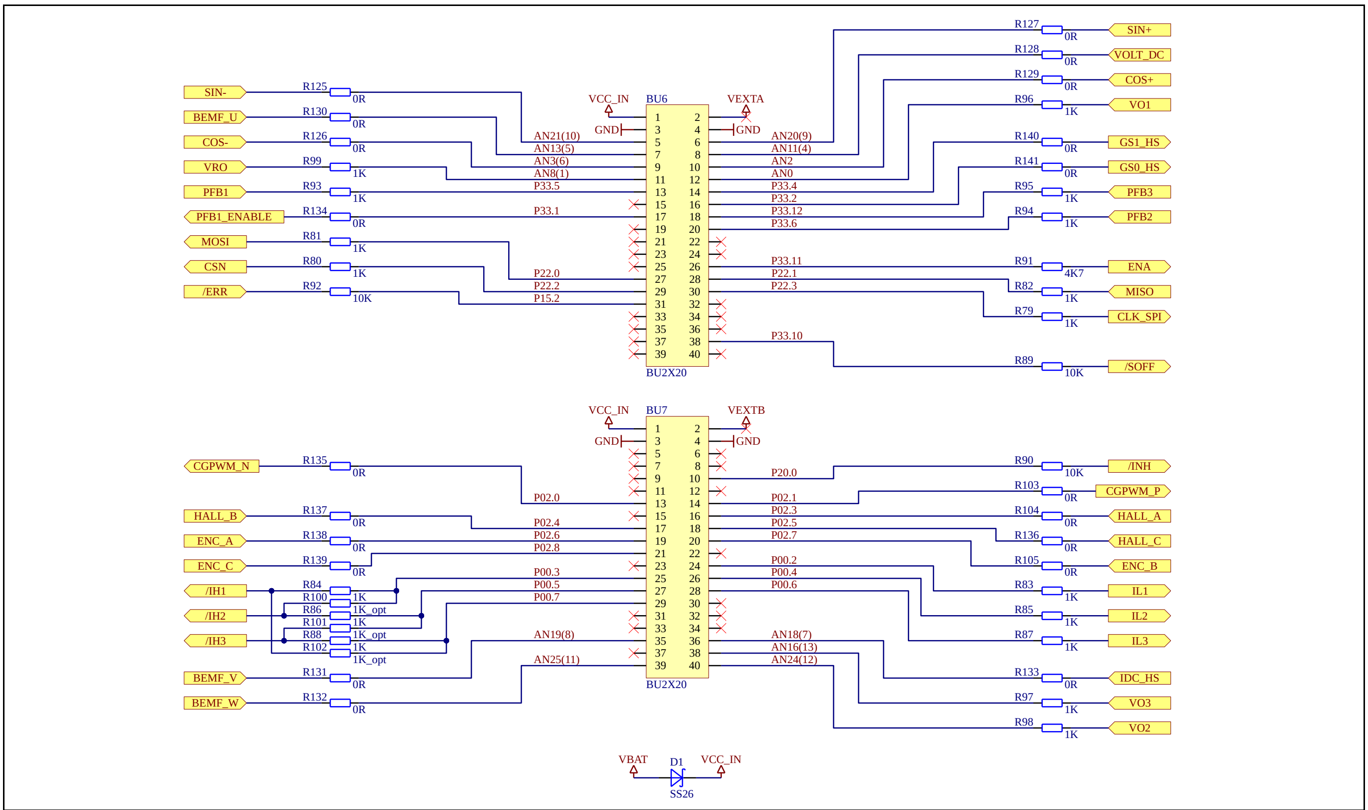

Figure 15 Schematic: Control board connectors

Following tables shows used pins of control board AURIX™ Application Kit TC387 with TFT display. The power board connector BU6 will be connected with the X102 connector of AURIX™ Application Kit TC387 with TFT display, while BU7 with X103. The pin numbering matches (e.g. BU6 Pin 1 == X102 Pin 1, BU7 Pin1 == X103 Pin 1).

Table 12 AURIX™ Application Kit TC387 with TFT display, pins used for phase currents sensing or low-side DC-link current sensing

AURIX™ TC387 Name	AURIX™ TC387 Pin	AURIX™ TC387 Direction	Signal of power board
AN0	T10	Analog input	V01
AN24/P40.0	W2	Analog input	V02
AN16	W5	Analog input	V03
AN8	W8	Analog input	VR0

Table 13 AURIX™ Application Kit TC387 with TFT display, pins used for resolver interface

AURIX™ TC387 Name	AURIX™ TC387 Pin	AURIX™ TC387 Direction	Signal of power board
AN20	Y3	Analog input	SIN+
AN21	Y2	Analog input	SIN-
AN2	W9	Analog input	COS+
AN3	U9	Analog input	COS-
P02.0	B1	Output	CGPWMN
P02.1	C2	Output	CGPWMP

Table 14 AURIX™ Application Kit TC387 with TFT display, pins used for phase voltage sensing

AURIX™ TC387 Name	AURIX™ TC387 Pin	AURIX™ TC387 Direction	Signal of power board
AN13	W6	Analog input	BEMF_U
AN19/P40.12	W3	Analog input	BEMF_V
AN25/P40.1	W1	Analog input	BEMF_W

Table 15 AURIX™ Application Kit TC387 with TFT display, pins used for high-side DC-link current sensing and DC-link voltage sensing

AURIX™ TC387 Name	AURIX™ TC387 Pin	AURIX™ TC387 Direction	Signal of power board
AN18/P40.11	W4	Analog input	IDC_HS
AN11	W7	Analog input	VOLT_DC
P33.2	W11	Output	GS0_HS
P33.4	W12	Output	GS1_HS

Table 16 AURIX™ Application Kit TC387 with TFT display, pins used for general purpose input or output pins related to TLE9180D

AURIX™ TC387 Name	AURIX™ TC387 Pin	AURIX™ TC387 Direction	Signal of power board
P33.5	Y12	Input	PFB1
P33.6	W13	Input	PFB2
P33.12	W16	Input	PFB3
P33.10	W15	Output	/SOFF
P33.11	Y15	Output	ENA
P20.0	H20	Output	/INH
P15.2	C19	Input	/ERR
P33.1	Y10	Output	PFB1_ENABLE

Table 17 AURIX™ Application Kit TC387 with TFT display, pins used for TLE9180D SPI

AURIX™ TC387 Name	AURIX™ TC387 Pin	AURIX™ TC387 Direction	Signal of power board
P22.0	P20	Output	MOSI
P22.1	P19	Input	MISO
P22.2	R20	Output	CSN
P22.3	R19	Output	CLK_SPI

Table 18 AURIX™ Application Kit TC387 with TFT display, pins used for PWM generation

AURIX™ TC387 Name	AURIX™ TC387 Pin	AURIX™ TC387 Direction	Signal of power board
P00.2	H1	Output	IL1
P00.3	H2	Output	/IH1
P00.4	J1	Output	IL2
P00.5	J2	Output	/IH2
P00.6	J4	Output	IL3
P00.7	K1	Output	/IH3

Table 19 AURIX™ Application Kit TC387 with TFT display, pins used for encoder interface

AURIX™ TC387 Name	AURIX™ TC387 Pin	AURIX™ TC387 Direction	Signal of power board
P02.6	E1	Input	ENC_A
P02.7	F2	Input	ENC_B
P02.8	F1	Input	ENC_C

Table 20 AURIX™ Application Kit TC387 with TFT display, pins used for Hall sensor interface

AURIX™ TC387 Name	AURIX™ TC387 Pin	AURIX™ TC387 Direction	Signal of power board
P02.3	D2	Input	HALL_A
P02.4	D1	Input	HALL_B
P02.5	E2	Input	HALL_C

3.7 PCB Layout

The layout of this board is especially designed for evaluation purposes. Consequently, it has test points and is not necessarily suited for continuous operation at full load. The PCB has four electrical layers with 70 µm copper. The size is 100 mm x 120 mm. The PCB thickness is 1.6 mm. For more details on the layout design and the latest Gerber-files, contact our technical support team.

Schematic and Layout

Figure 16 illustrates the top assembly print of the power board.

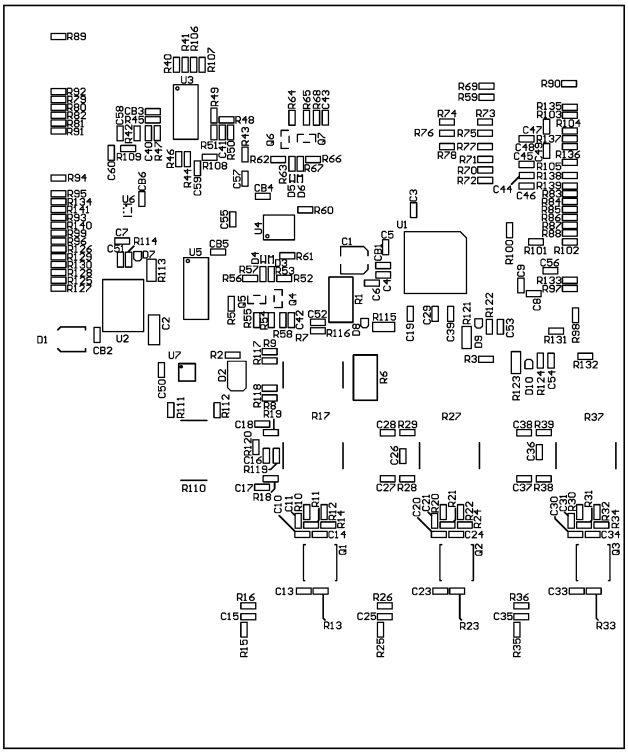

Figure 16 Top overlay print of the power board

Figure 17 illustrates the bottom assembly print of the power board.

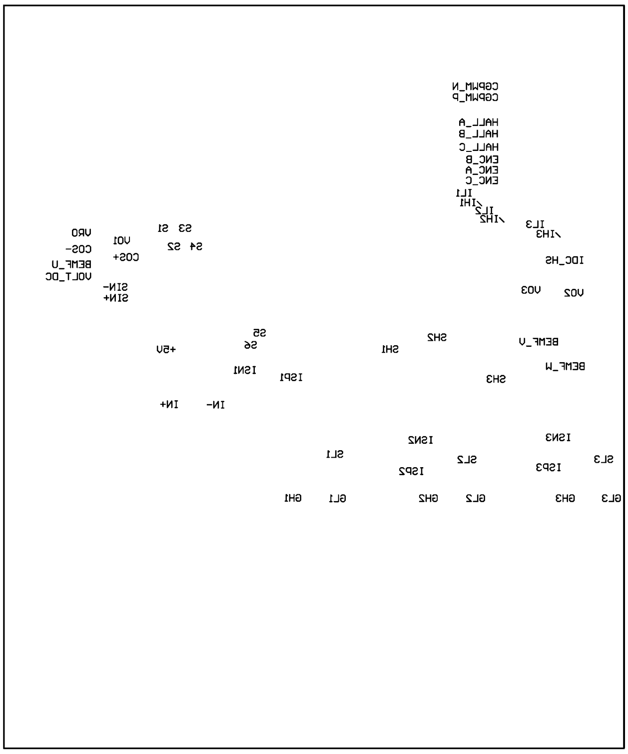

Figure 17 Bottom overlay print of the power board

Figure 18 illustrates the dimensions of the PCB.

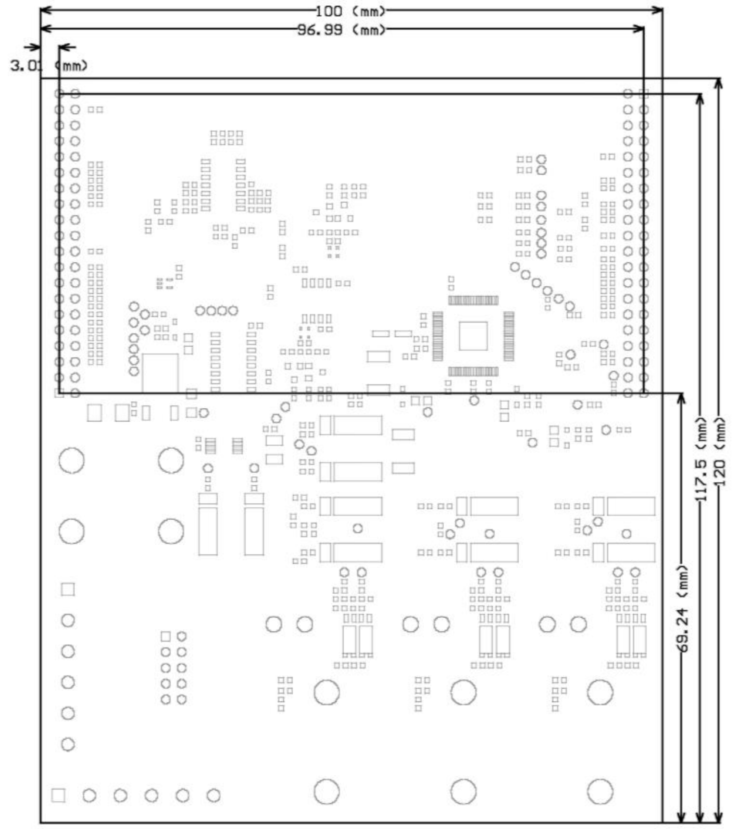

Figure 18 Dimensions of the power board

The top layer routing of the PCB is provided in Figure 19.

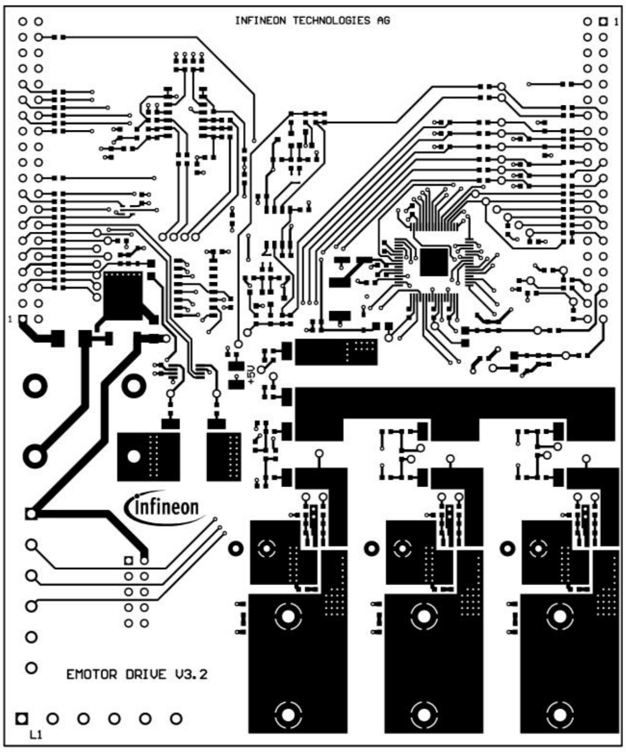

Figure 19 Top layer routing of the power board

Figure 20 illustrates the bottom layer routing of the PCB.

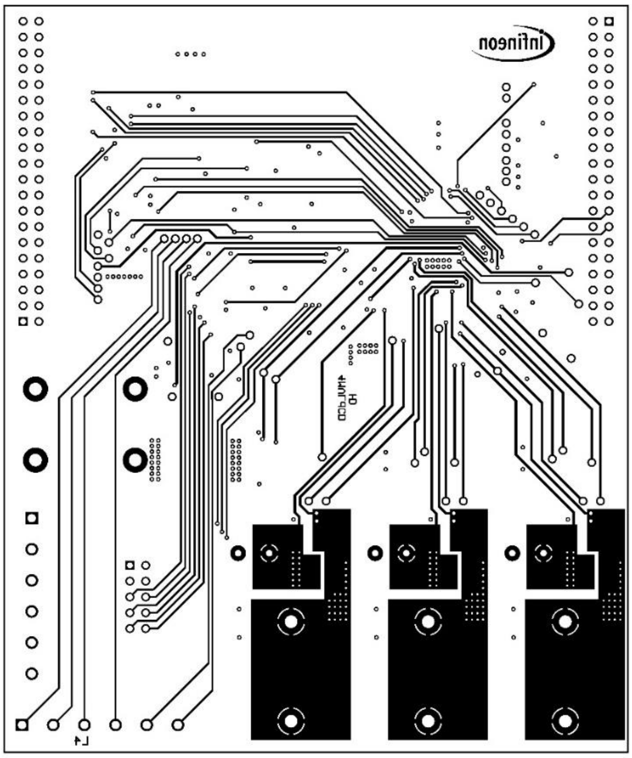

Figure 20 Bottom layer routing of the power board

4 Bill of Materials

Table 21 provides the complete bill of materials of the motor control power board.

Table 21 Bill of materials

No.	Qty	Part description	Designator
1	2	Multicomp PCB Socket A-2.107-B (black)	BU1, BU5
2	2	Multicomp PCB Socket A-2.107-R (red)	BU2, BU4
3	1	Multicomp PCB Socket A-2.107-Y (yellow)	BU3
4	1	Capacitor SMD; 4µ7/35V; FROLYT – 4	C1
5	1	Capacitor SMD min. 6,3V; ESR < 3R; 22µF; 1206	C2
6	7	Capacitor SMD; 2,2µF; 603	C3, C4, C5, C6, C11, C21, C31
7	20	Capacitor SMD; 100p; 603	C7, C8, C9, C17, C18, C27, C28, C37, C38, C40, C41, C44, C45, C46, C47, C48, C49, C51, C55, C56
8	6	Capacitor SMD; 1 nF (not mounted); 603	C10, C14, C20, C24, C30, C34
9	3	Capacitor 1000 µF/35 V RS108-35V-RL13x14 71; RAD5-13	C12, C22, C32
10	6	Capacitor SMD; 4,7 nF; 603	C13, C15, C23, C25, C33, C35
11	3	Capacitor SMD; 1,5 nF; 603	C16, C26, C36
12	3	Capacitor SMD; 330 nF; 603	C19, C29, C39
13	2	Capacitor SMD; 470 pF; 603	C42, C43
14	1	Capacitor SMD; 100 nF; 603	C50
15	9	Capacitor SMD, Resistor SMD; (not mounted); 603	C52, C53, C54, C57, C58, C59, C60, R8, R9
16	6	Capacitor SMD; 100 nF; 603	CB1, CB2, CB3, CB4, CB5, CB6
17	1	Schottky Diode SMD; SS26; DO214-AA	D1
18	1	LED PLCC2 2mA green; LP T67K; LED-TOP	D2
19	4	Schottky Diode SMD; BAS52-02V; SC79	D3, D4, D5, D6
20	4	Zehner MM3Z5V1ST1G; (not mounted); SOD323	D7, D8, D9, D10
21	3	OptiMOS-T2 Power Transistor; IPG20N04S4-08A; TDSON-8-10	Q1, Q2, Q3
22	2	NPN Transistor SMD; MMBT4401LT1G; SOT23	Q4, Q6
23	2	PNP Transistor SMD; MMBT4403LT1G; SOT23	Q5, Q7
24	1	Resistor SMD; RC2512JK-071; 1R; 2512	R1
25	1	Resistor SMD; 1K5; 603	R2
26	27	Resistor SMD; 0R; 603	R3, R42, R43, R103, R104, R105, R108, R109, R119, R120, R125, R126, R127, R128, R129, R130, R131, R132, R133, R134, R135, R136, R137, R138, R139, R140, R141

No.	Qty	Part description	Designator
27	31	Resistor SMD, Resistor SMD 0.1%; 1K; 603	R5, R40, R41, R70, R71, R72, R73, R74, R75, R76, R77, R78, R79, R80, R81, R82, R83, R84, R85, R86, R87, R88, R93, R94, R95, R96, R97, R98, R99, R106, R107
28	1	Resistor SMD; RC2512JK-070; 0R/10A; 2512	R6
29	1	Resistor; (not mounted) WSL3637	R7
30	6	Resistor SMD; 47R; 603	R10, R12, R20, R22, R30, R32
31	6	Resistor SMD; 100K; 603	R11, R14, R21, R24, R31, R34
32	6	Resistor SMD; 2,2R; 603	R13, R15, R23, R25, R33, R35
33	12	Resistor SMD; 10K; 603	R16, R26, R36, R44, R45, R46, R48, R49, R50, R89, R90, R92
34	4	Shunt; 10mR; WSL3637	R17, R27, R37, R110
35	8	Resistor SMD; 18R; 603	R18, R19, R28, R29, R38, R39, R111, R112
36	3	Resistor SMD; 4K7; 603	R47, R51, R91
37	4	Resistor SMD; 2K4; 603	R52, R56, R62, R66
38	4	Resistor SMD; 4R7; 603	R53, R57, R63, R67
39	4	Resistor SMD; 0,1%; 5R6; 603	R54, R55, R64, R65
40	6	Resistor SMD; 0,1%; 5K6; 603	R58, R68, R114, R116, R122, R124
41	2	Resistor SMD; 0,1%; 3K6; 603	R59, R69
42	1	Resistor SMD; 0,1%; 24K; 603	R60
43	1	Resistor SMD; 0,1%; 11K5; 603	R61
44	3	Resistor SMD; 1K; (not mounted); 603	R100, R101, R102
45	4	Resistor SMD; 56K; 805	R113, R115, R121, R123
46	2	Resistor SMD; 0K; (not mounted); 603	R117, R118
47	54	Testpoints	TP1 – TP54
48	1	3-Phase Bridge Driver IC; TLE9180xQKe; LQFP64-18	U1
49	1	5V Power regulator; TLE42744DV50; TO252-3	U2
50	1	High-Slew-Rate, Single-supply 4 Operational Amplifiers; LMV344ID; SO14-150	U3
51	1	Dual General Purpose Operational Amplifiers, 36V, Single Supply; OPA2171A; SO8-150	U4
52	1	Quadruple RS-485 Diff. Line Receivers; SN65LBC175AD; SO16-150	U5

No.	Qty	Part description	Designator
53	1	Single AND Gate; 74AHC1G08; SOT353	U6
54	1	Programmable-Gain, Voltage-Output, Bidirectional, Zero-Drift Series, Current-Shunt Monitor; INA225AIDGK; MSOP8	U7
55	1	Res. Phoenix Contact; MKDSN 1,5/ 6;	X1
56	1	Hall Phoenix Contact; MKDSN 1,5/ 6;	X2
57	1	Pin header 2x5, RM 2.54mm, with tub e.g. Multicomp series MC9A12; HDR2X5-TUB	X4

5 References

[1] Application Kit User Manual, revision 1.0

[2] AP32540 PMSM FOC motor control using AURIX TC3xx, revision 1.0

[3] User Manual AURIX™ TC3xx, revision 1.5

[4] Datasheet of TLE9180D-31QK, revision 1.0

[5] Datasheet of IPG20N04S4-08A, revision 1.0

[6] Datasheet of INA225, Texas Instruments

Revision history

Document version	Date of release	Description of changes
v1.0	2020-08-17	Initial version.

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