Motor Control Application Kit

For XMC1000 Family

PMSM-LV-15W

PMSM Low Voltage 15W Motor Card

Board User's Manual

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Introduction

This document describes the features and hardware details of the PMSM Low Voltage 15W Motor Card (PMSM-LV-15W) designed to work with Infineon"s XMC1300 CPU Card. This board is part of Infineon's XMC1000 Motor Control Application Kits.

1 Overview

The PMSM Low Voltage 15W Motor Card is an application expansion card of XMC1000 Motor Control. The combination of PMSM Low Voltage 15 W Motor card and XMC1300 boot kit is the best kit to evaluate the motor control capabilities of XMC1300. The main use case for this application card is to demonstrate the various motor control algorithms (e.g. Block commutation with Hall sensor, V/F control, Field Orientation Control) by using XMC1300 device including the toolchain. The focus is safe operation under evaluation conditions. The board is not cost optimized and cannot be seen as reference design.

1.1 Key Features

The PMSM LV15W Card is equipped with the following features

- Connection to XMC1300 CPU Cards via 2x30 pins (0.8mm pitch) SAMTEC HSEC8 connector
- 3 phase low voltage full bridge inverter using Infineon N-channel Dual OptiMOS power transistors
- Gate Driver IC (6EDL04N02PR) with over-current detection circuit (ITRIP)
- Current measurement by using single or triple shunts (amplified)
- Positioning sensing via
    - Hall sensor Interface
    - Quadrature encoder interface for both single ended and differential signals
- Input voltage range: 12V-24V +/- 20%
- Power supply
    - Low drop voltage regulator (5V) for hall sensor power supply
    - Low drop voltage regulator (5V) for XMC1300 power supply
    - Low dropout linear voltage regulator (15V) for MOSFET gate driver power supply
- Maximum DC-link current: 3A & Maximum motor phase current: 3A

1.2 Boot Mode Index (BMI) Configuration

A micronctroller would normally have a few boot mode selection pins that determine its Boot Mode after power on reset. However, the XMC1000 devices from Infineon, is a low pin count device, so the use of a few pins just for Boot-up mode selection is not desirable.

The XMC1100, XMC1200 and XMC1300 bootkit are programmed to User mode with debug enabled (SWD0), so that the application program will start to run after power-up. The selection of the port pin to be used depends on BMI value. If the XMC1000 bootkits are programmed to SWD mode, the specified pin P0.14 and P0.15 are used to communicate.

Referring the schematic connection of PMSM Low Voltage 15W Motor card, the hall sensor interface pin ENCI-POSIF.IN2 is connected to P0.15 at XMC1300 CPU card. Therefore, the XMC1300 CPU card has to be programmed the BMI to SPD mode to avoid using P0.15 as programming pin. After the XMC1300 CPU card BMI has changed, the DIP switch SWCLK on Jlink Debugger on XMC1300 CPU card has to be off. The user code will run after power up and supports debugging using single pin debug protocol.

For more information about how to handle BMI for XMC1000 family, please refer to the XMC1000 Family Tooling Guide.

1.3 Block Diagram

Figure 1 shows the block diagram of the PMSM Low Voltage 15W Motor Card in connection with XMC1300 CPU Card.

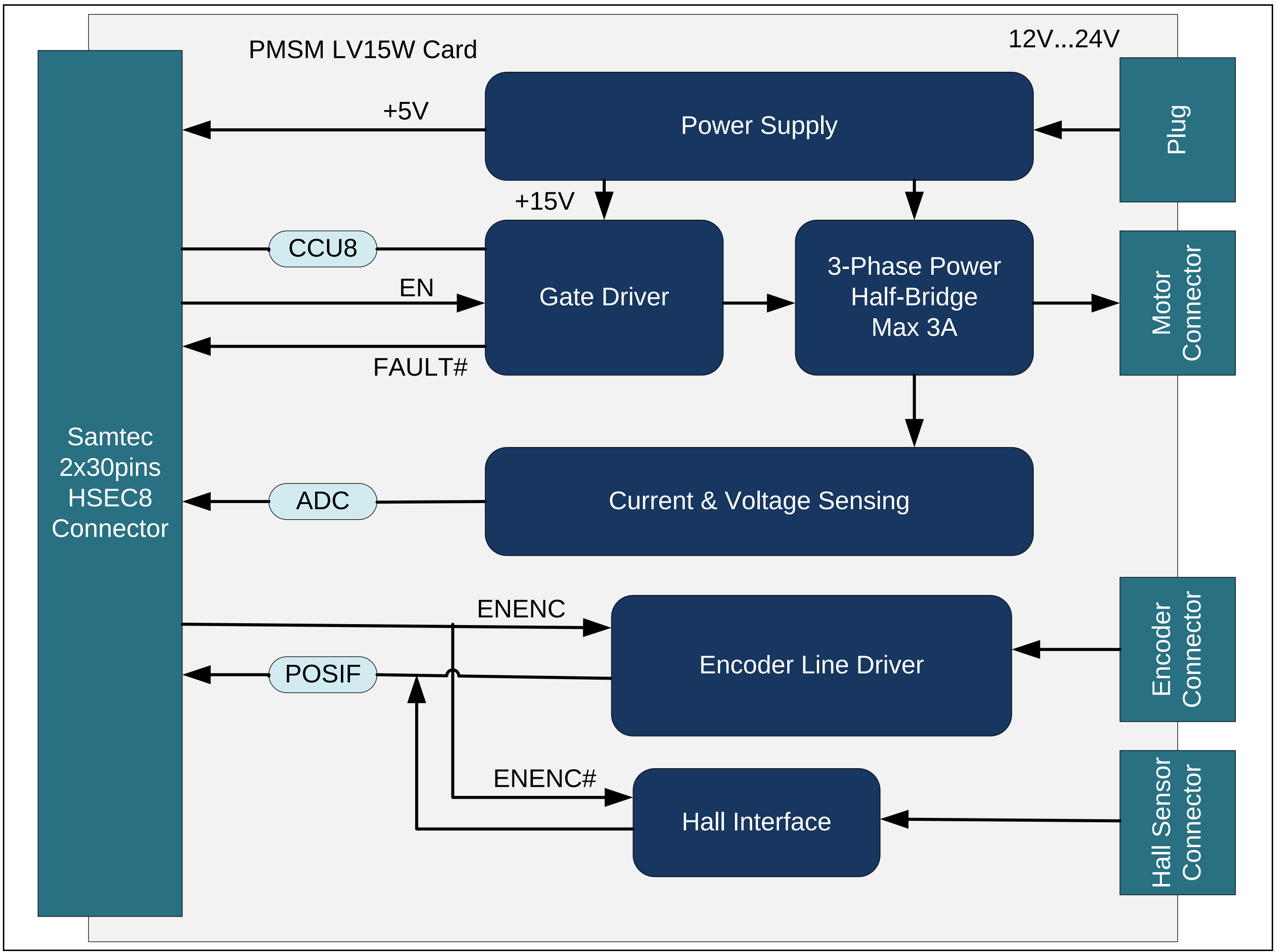


Figure 1 Block Diagram of PMSM Low Voltage 15W Motor Card in connection with XMC1300 CPU Card

2 Hardware Description

The following sections give a detailed description of the hardware and how it can be used.

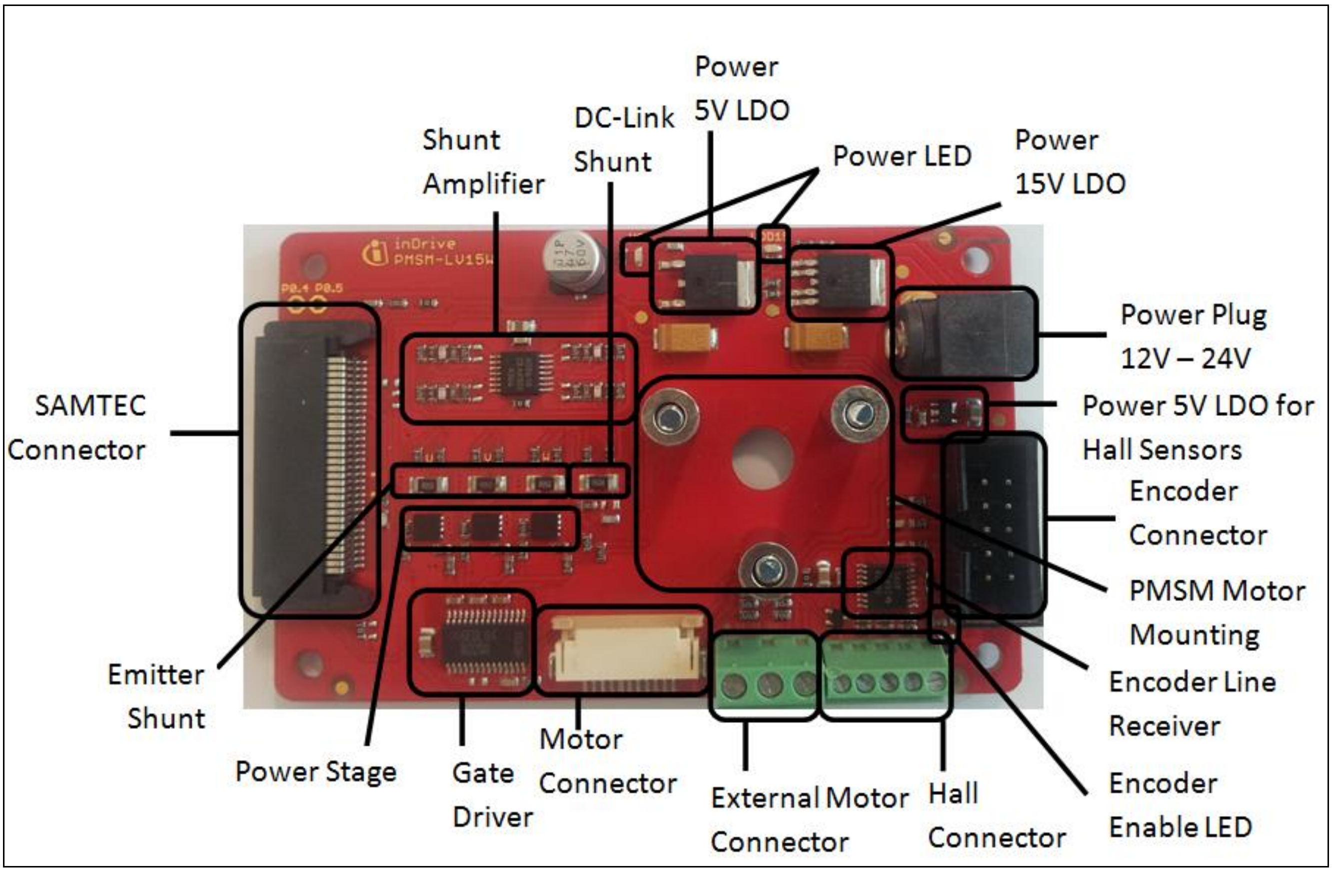


Figure 2 PMSM Low Voltage 15W Motor Card

2.1 Power

The PMSM Low Voltage 15W Motor Card must be supplied by an external DC power supply (12V to 24V) connected to its power jack X201. 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 (24V/1A) delivered with the motor control kit is sufficient to drive the enclosed motor as well as the CPU card. The power supply schematic is shown in Figure 3.

An on-board voltage regulator (IC203) steps down the 24 V input voltage from the power jack to 15 V (VDD15). The input voltage up is regulated to an output voltage 15 V with a precision of $\pm$ 2%. The output voltage can be configured to regulate between 2.5V and 20V. The 5 V supply for hall sensor VDD5 is derived from VDD15 regulated by LDO (IC201). Another LDO voltage regulator generates stable 5 V (VCC) out of VDD15 for microcontroller power supply and operational amplifier.

Two power LEDs indicate the presence of the generated supply voltages.

Table 1 Power LED

LED	Power Rail	Voltage	Note
V202	VDD15	15 V	Must always be "ON"
V201	VCC	5 V	Must always be "ON"

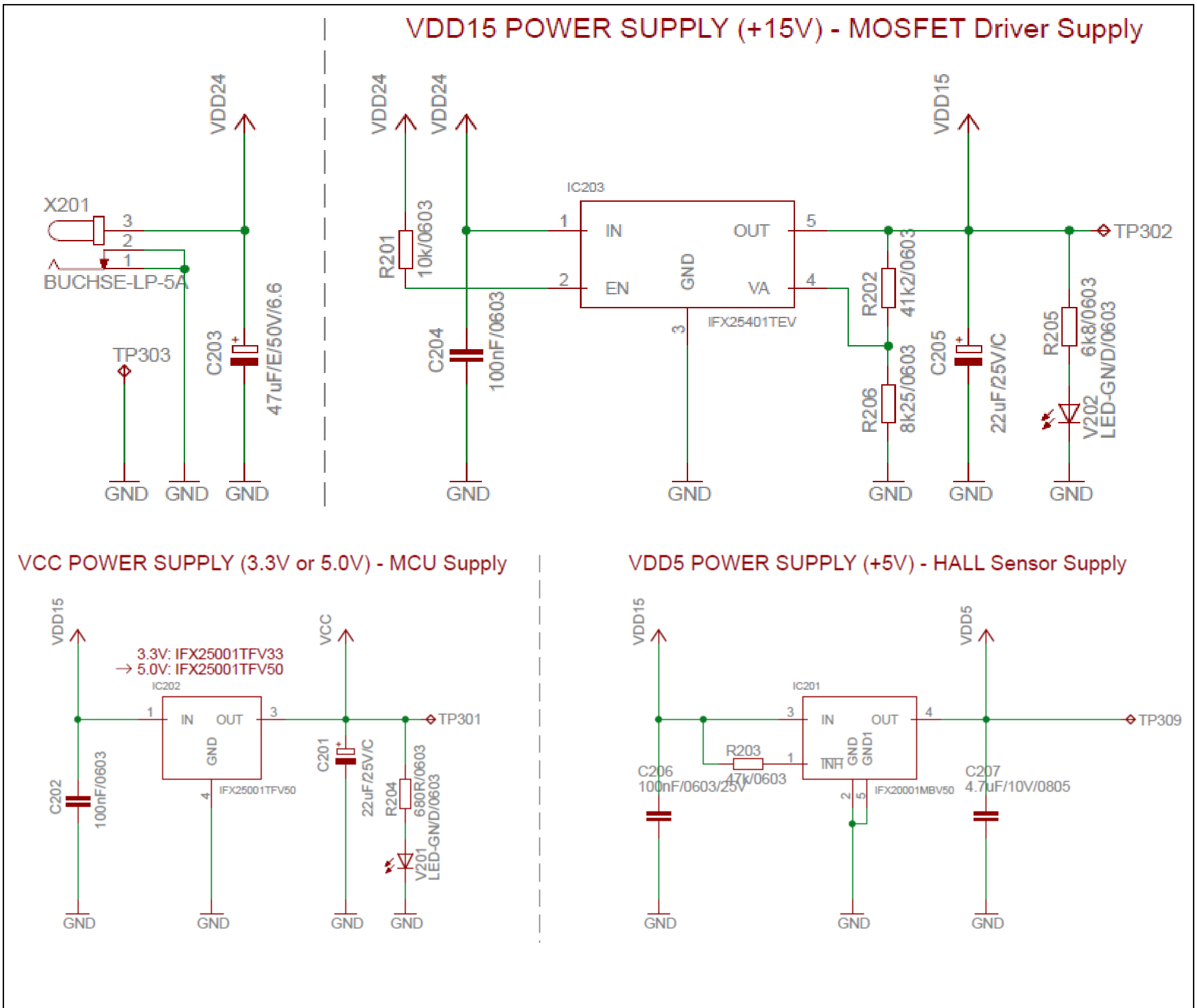


Figure 3 Hardware Connection of Power Supply

Table 1 Power and ground signals connection to the SAMTEC 2x30pins connector

Pin No.	Signal Name	Description
13	VAGND	Analog ground
14	GND	Digital ground
15	VAREF	Analog VDD +5V
16	VDD	Digital VDDP +5V

2.2 SAMTEC 2x30pins connector

The SAMTEC connector of the PMSM Low Voltage 15W Motor Card is the interface to the XMC1000 CPU card e.g. XMC1300 CPU card as shown in Figure 4.

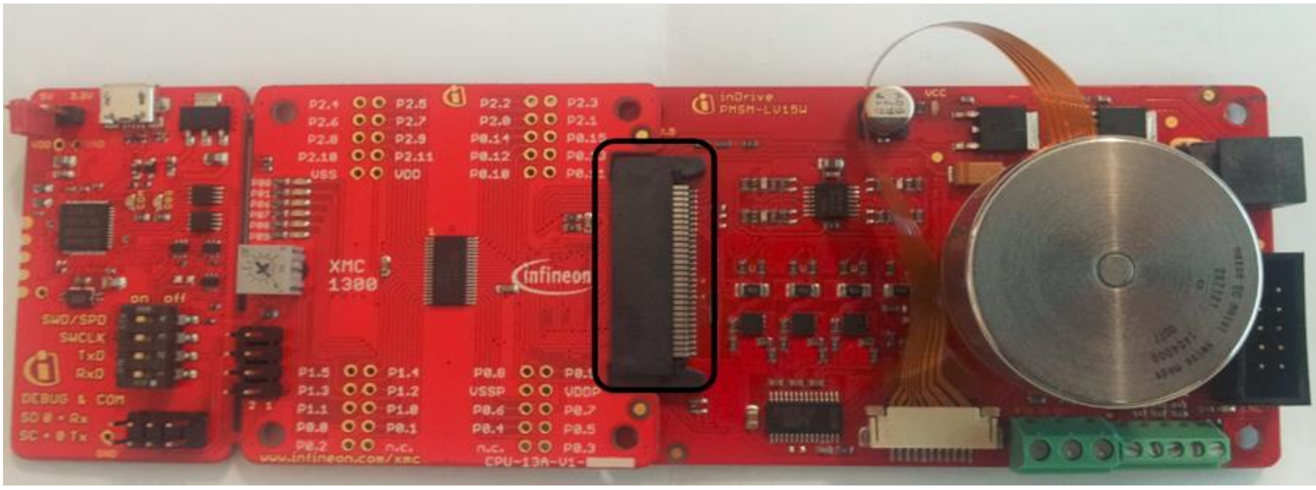


Figure 4 SAMTEC 2x30pins connector to the CPU card

Figure 5 is a view of the signal mapping between the PMSM Low Voltage 15W Motor card SAMTEC 2x30 pins connector and the “XMC1300 CPU card”. It shows in details which pin of the XMC1300 is mapped to which signal on the motor drive card. The inner rows show the general function of the 30 pins of the SAMTEC connector, which is common for all CPU cards. The outer rows show the signals of the PMSM Low Voltage 15W Motor Card.

The PMSM Low Voltage 15W Motor Card provides 5 functional groups of signals (marked by color code) at its pins of the SAMTEC connector:

- The encoder and hall sensor signals (ENCA, ENCB, ENCI): pin 43, 45 and 47
- Control and TRAP signals (ENENC#, ENPOW, FAULT#, P0.4, P0.5): pin 37, 39, 41, 25 and 27
- Voltage and current measurement signals: (UU, UV, UZ, AMP_IW...) located from pin 1 to 9
- PWM signals for the 3 phase power stage (HIN1#, LIN1#, HIN2…): pin 17, 19, 29, 31, 33 and 35

XMC1300 Boot Kit XMC Pin	XMC1300 Boot Kit XMC Function	SAMTEC Connector Function (PMSM Low Voltage 15 W Motor Card)	SAMTEC Connector Pin	SAMTEC Connector Pin	SAMTEC Connector Function (PMSM Low Voltage 15 W Motor Card)	XMC1300 Boot Kit XMC Function	XMC1300 Boot Kit XMC Pin
P2.11	SH0.IN3	AMP_IU	2	1	UU	SH0.IN5	P2.0
P2.10	SH0.IN4	AMP_IV	4	3	UV	SH0.IN6	P2.1
P2.9	SH0.IN2	AMP_IW	6	5	UW	SH0.IN7	P2.2
P2.8	SH0.IN1	AGND	8	7	UZ	SH1.IN5	P2.3
P2.7	SH1.IN1	SH1-1	10	9	IAVG	SH1.IN6	P2.4
P2.6	SH0.IN0	AGND	12	11	RESERVED (POT)	SH1.IN7	P2.5
GND	VSSP	GND	14	13	AGND	VAGND	AGND
VDDP	VDDP	VCC	16	15	VDD	VDDP	VAREF
P0.8		nc	18	17	HIN1	CCU8.OUT00	P0.0
P0.9		nc	20	19	LIN1	CCU8.OUT01	P0.1
P0.10		nc	22	21	HIN3	CCU8.OUT02	P0.2
P0.11		nc	24	23	LIN3	CCU8.OUT03	P0.3
P0.12		nc	26	25	P0.4	CCU8.OUT13	P0.4
P0.13		nc	28	27	P0.5	CCU8.OUT12	P0.5
P0.14		nc	30	29	LIN2	CCU8.OUT11	P0.6
P0.15		nc	32	31	HIN2	CCU8.OUT10	P0.7
P1.5		TP305	34	33	HIN3	CCU8.OUT20	P0.8
P0.9		nc	36	35	LIN3	CCU8.OUT21	P0.9
P0.10		nc	38	37	ENENC	CCU8.OUT22	P0.10
P1.4		TP306	40	39	ENPOW	CCU8.OUT23	P0.11
P1.3		nc	42	41	FAULT#	CCU8.OUT33	P0.12
P1.2		nc	44	43	ENCA-POSIF.IN0	POSIF0.IN0B	P0.13
P1.1		nc	46	45	ENCB-POSIF.IN1	POSIF0.IN1A	P1.1
P1.0		nc	48	47	ENCI-POSIF.IN2	POSIF0.IN2B	P0.15
P2.0	-	nc	50	49	nc	-	P1.0
P2.1	-	nc	52	51	nc	-	P1.1
P1.1	-	nc	54	53	nc	-	P1.2
P0.0	-	nc	56	55	nc	-	P1.3
P0.6	-	nc	58	57	nc	-	P0.8
P0.7	-	nc	60	59	nc	-	P0.9

Figure 5 Pin Mapping to XMC1300 CPU card with 2x30 pins SAMTEC Connector on PMSM Low Voltage 15W Motor Card

2.3 Gate Driver and Power Stage

The power stage consists of three half-bridges using Infineon's Dual N-channel OptiMOS™ power transistors. They are selected for a safe operation area with huge headroom, hence no cooling is needed when using at norminal current of 7.5 Ampere.

The gate driver (6EDL04N02PR) is Infineon's 2nd generation full bridge driver to control power devices like MOS-transistors or IGBTs in 3-phase systems. The gate driver offers several protection features like under-voltage lockout, signal interlocking of every phase to prevent cross-conduction and overcurrent detection. Therefore, the current signal of the DC-link reference is measured in order to recognize overcurrent or halfbridge short circuit events. A shunt resistor generates a voltage drop. A small RC-filter for attenuating voltage spikes is recommended. Such spikes may be generated by parasitic elements in the practical layout.

In an error situation a FAULT# signal is generated and must be handled by the microcontroller. The FAULT# signal changes to low state if an over-current condition has been detected by the ITRIP circuit. The ITRIP current level is measured as the amplified voltage drop over the DC-link shunt (see Figure 6). The minimum input voltage level to trigger an over-current event is specified at 375mV.

$$I_{trip} = \frac{V}{RS104}$$

$$I_{trip} = \frac{375\ mV}{50\ m\Omega}$$

$$I_{trip} = 7.5\ A$$

The external circuit at pin RCIN defines the overcurrent recovery of the drive system. This circuit consist of a single capacitor C_{RCin} according to Figure 6. There is also the option for a path to the supply voltage Vcc via resistorR_{RCin}. The fault-clear time t_{FLTCLR} is dependent on the re-charging of C_{RCin}, because the system recovers, when the threshold of the integrated Schmitt-trigger.

The datasheet specifies the typical fault clear time t_{FLTCLR} = 1.9 ms which the current source needs to charge an external capacitor of 1nF without pull up resistor. This parameter can be scaled linearly to any other capacitor value and results immediately in the according fault clear time. This means with 22nF capacitor will realize a fault clear time of 22 * 1.9 ms = 41.8 ms.

The microcontroller must provide the PWM signals (LIN1/2/3, HIN1/2/3) for the high-side and low-side switches. The PWM signals must be generated high-active.

The gate driver must be enabled via signal ENPOW.

A phase current measurement is provided via shunt resistors

a) Single shunt (50 mΩ) in the DC-link path and/or
b) Triple shunt (50 mΩ) in the low-side path

The resistance of the shunts limits the system behaviour and may not fit to the low-ohmic power transistors. This is intended as the main purpose of this board is to proof SW algorithms and methods over a wide range.

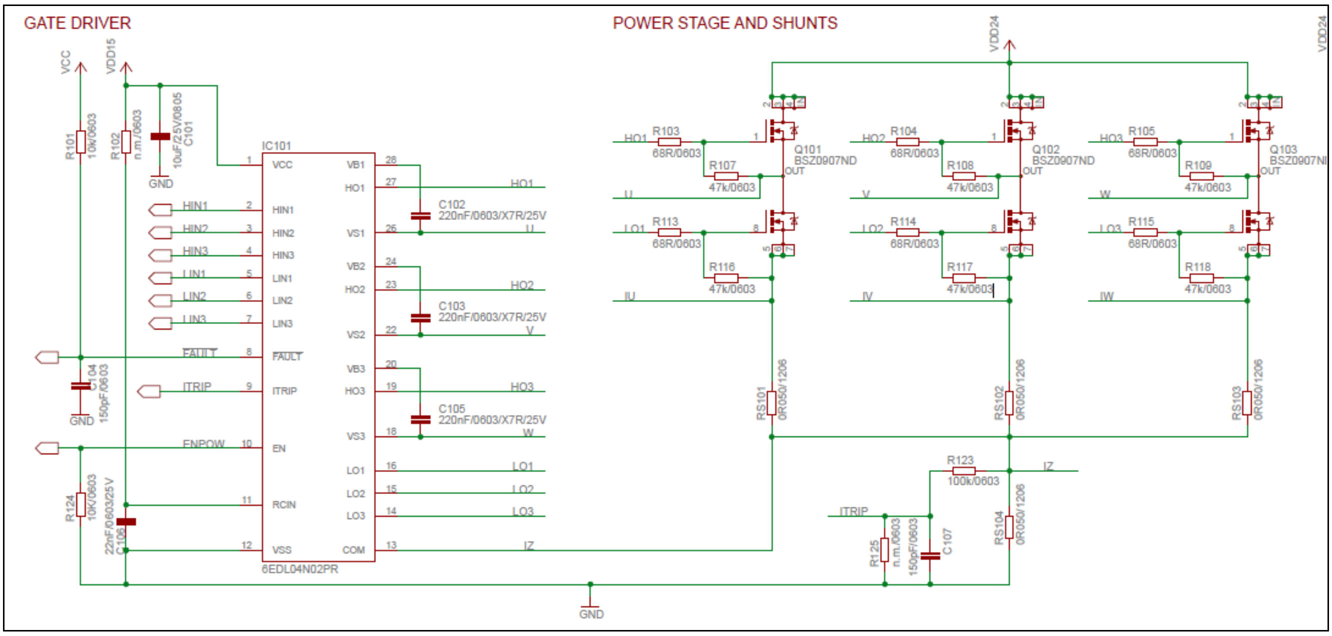


Figure 6 Hardware connection of the Date Driver and Power Stage

Table 2 shows the connection of the Gate Driver signals to the SAMTEC 2x30pins connector.

Table 2 Gate Driver signals connection to the SAMTEC 2x30pins Connector

Pin No.	Signal Name	Description
19	FAULT#	This signal indicates over-current and under-voltage (low active)
25	ENPOW	High level enables the power stage (high active)
27	HIN1	High-side logic input 1 (high-active)
29	LIN1	Low-side logic input 1 (high-active)
31	HIN2	High-side logic input 2 (high-active)
33	LIN2	Low-side logic input 2 (high-active)
35	HIN3	High-side logic input 3 (high-active)
37	LIN3	Low-side logic input 3 (high-active)

2.4 Voltage and Current Measurements

The phase current measurement is illustrated on the top side of Figure 8; the right side shows the voltage divider for the voltage measurement.

2.4.1 Phase Current Measurement

The current measurement can be done via a single shunt (signal IZ) in the DC-link path or via triple shunts (IU, IV, IW) at the low side. In both cases the measurement is dimensioned for the following requirements:

Motor power range up to 15W which leads to a nominal DC-link current of about 0.625 A. The phase current range is -3 A to +3 A. The output of the operational amplifier (AMP_IU, AMP_IV, AMP_IW, and AMP_IZ) is available at the PMSM Low Voltage 15 W Motor card connector and connected to ADC input channels of the XMC1000 microcontroller. The DC offset voltage level is about 2.5V at the ouput of the Op -Amps when there is no current flow through the shunts.

In order to get Op-Amp DC offset, AC gain, and DC link maximum current, the calculation can be done as below:

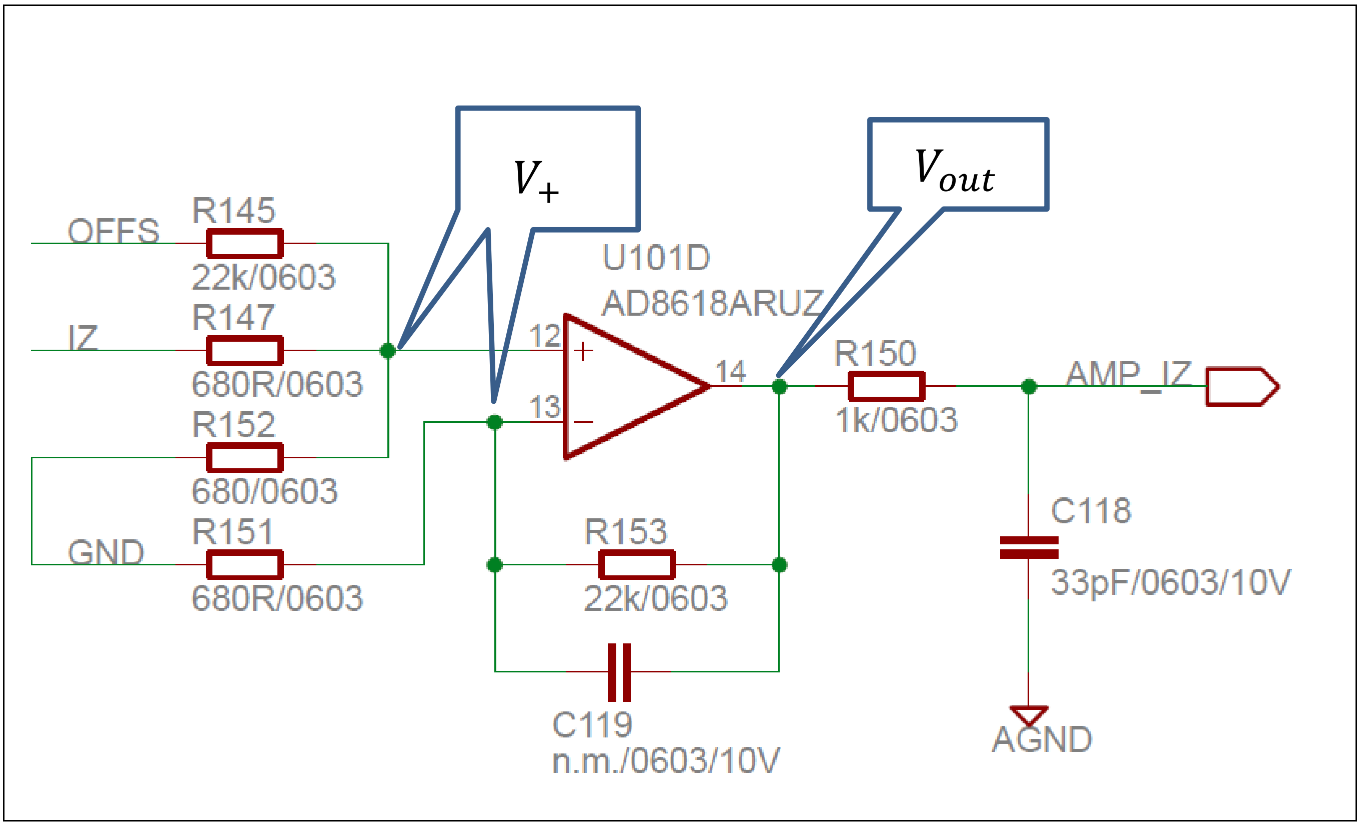


Figure 7 Hardware Circuit Op-Amp of DC Link Current Sensing

To get the Op-Amp DC offset:

$$\frac{OFFS - V_+}{R145} + \frac{IZ - V_+}{R147} + \frac{-V_+}{R151} = 0$$

$$\frac{V_{out} - V_+}{R153} - \frac{V_+}{R152} = 0$$

$$V_{out} = \frac{R153 + R152}{R152} \cdot V_+$$

$$V_{out} = \underbrace{\frac{R153 + R152}{R152} \cdot \frac{1}{1 + R145\left(\frac{R147 + R151}{R147\,R151}\right)} \cdot OFFS}_{\text{Op-Amp DC Offset}} + \underbrace{\frac{R153 + R152}{R152} \cdot \frac{1}{\frac{R147}{R145}\left(\frac{R147 + R151}{R151}\right)}}_{\text{AC Gain}} \cdot IZ$$

Op-Amp DC Offset AC Gain

By substituting all the resistor value into the formula, the Op-Amp DC offset with 2.5V is generated. The AC gain of the operation amplifier is set to 16.4, which leads to DC link phase current range of 0V @ -3 A and 5V @ +3 A. The DC-Link shunt resistor is 50 mΩ.

Assuming the V_{out} of the operation amplifier is 5 V,

$$AC\ Gain = \frac{V_{out} - V_{DC\ offset}}{V_{in}}$$

$$V_{in} = \frac{5\,V - 2.5\,V}{16.4}$$

$$I_{in} = \frac{(5\,V - 2.5\,V)}{16.4} \cdot \frac{1}{R_{DC-link\ shunt}}$$

$$I_{in},\ DC\ link\ maximum\ current = 3A$$

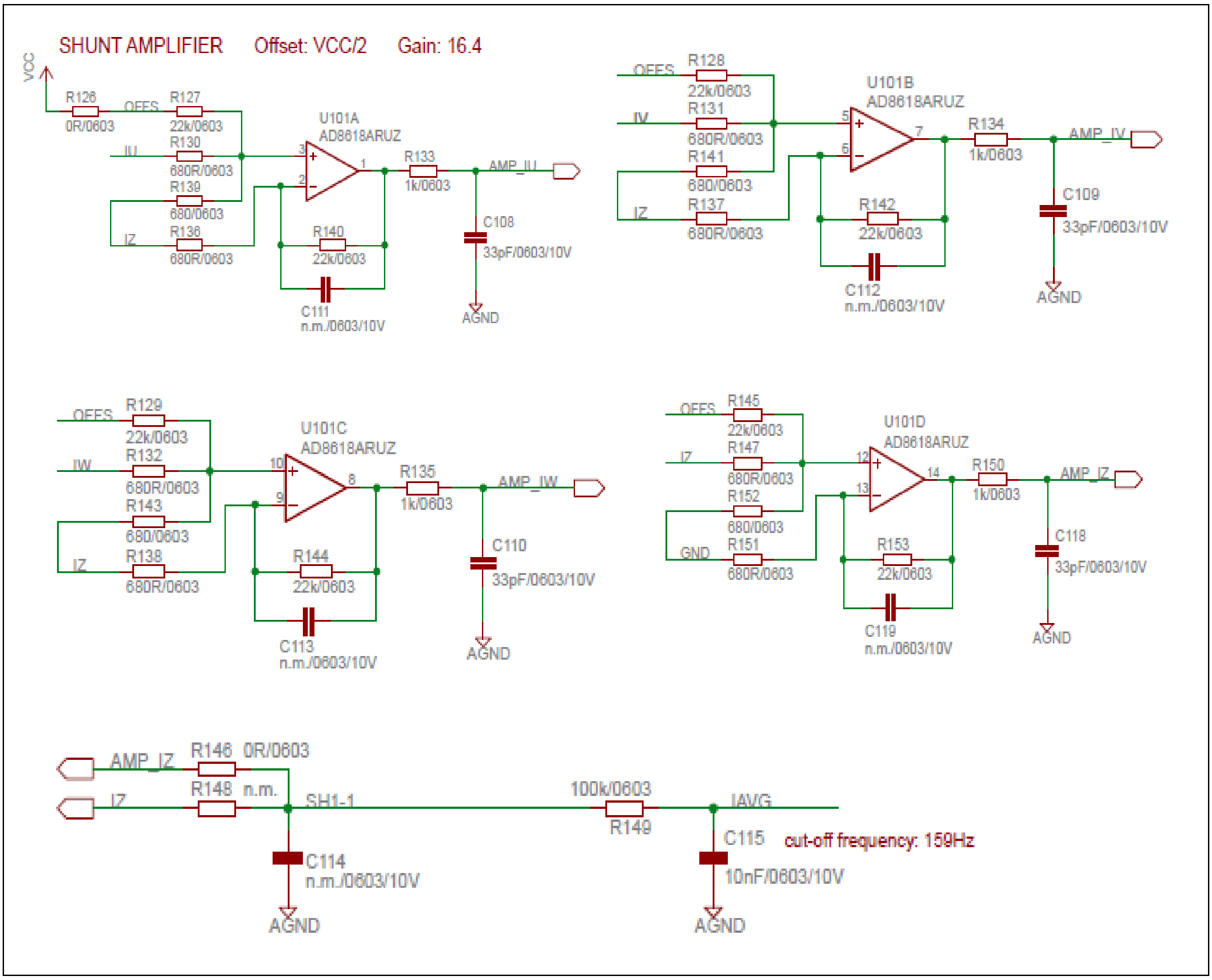


Figure 8 Hardware Connection of Shunt Amplifier

The IAVG is the average current measurement of DC-link after low pass RC filter.

To get 159Hz cutoff frequency:

$$f_{cutoff} = \frac{1}{2\pi R_{149} C_{115}}$$

2.4.2 Phase Voltage Measurement

The phase voltage is directly measured using resistive dividers at the phases (signals UZ, UU, UV, and UW). The divider is dimensioned to divide the measured voltage UZ, UU, UV, UW by factor 10.21. The formula to calculate the phase voltage U_{PHx} from the measured voltage U_x is:

$$U_{PHx} = 10.21 \times U_x$$

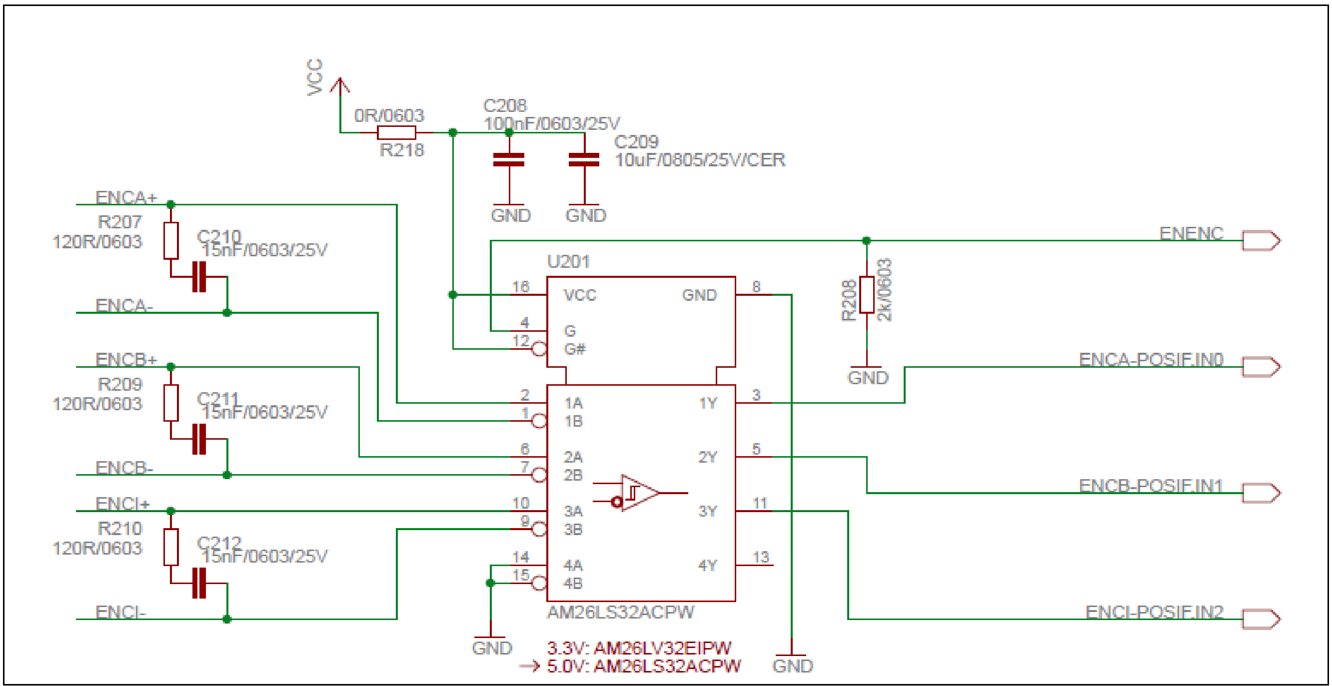
Table 3 summarizes all the voltage and current signals available at SAMTEC connector.

Table 3 Voltage and Current signals at the SAMTEC Connector

Pin No.	Signal Name	Description
2	AMP_IU	Amplified shunt voltage output representing the current of phase U
4	AMP_IV	Amplified shunt voltage output representing the current of phase V
6	AMP_IW	Amplified shunt voltage output representing the current of phase W
9	IAVG	Amplified shunt voltage output representing the DC-link current after filter
10	SH1-1	Shunt voltage output representing the DC-link current
1	UU	Divided voltage output of phase U (divided by 10.21)
3	UV	Divided voltage output of phase V (divided by 10.21)
5	UW	Divided voltage output of phase W (divided by 10.21)
7	UZ	Divided DC-link voltage (divided by 10.21)

2.5 Encoder and Hall Interface

A quadrature encoder can be used for detecting the actual rotor position. There are single-ended and differential encoders, the board supports both types. For the differential types an encoder line receiver is required as the microcontroller needs single ended signals.



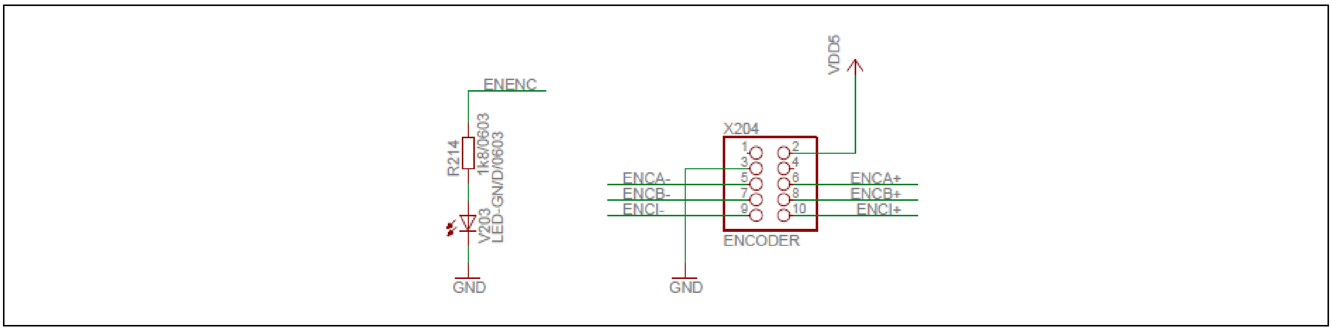


Figure 9 Encoder Line Driver and Connector for differential encoder signals

The differential signals from the encoder (ENCA +/-, ENCB +/-, ENCI +/-) must be connected to the 10-pin encoder connector X204 (Figure 9). The Encoder Line Driver must be enabled by the signal ENENC (set to 1).

In case of using a single ended encoder or a hall sensor the signals must be applied to the connector X203 and the encoder line receiver must be disabled by setting the signal ENENC to low level (default). The signal ENENC controls the transistor to enable/disable the supply to the hall interface as shown in Figure 10.

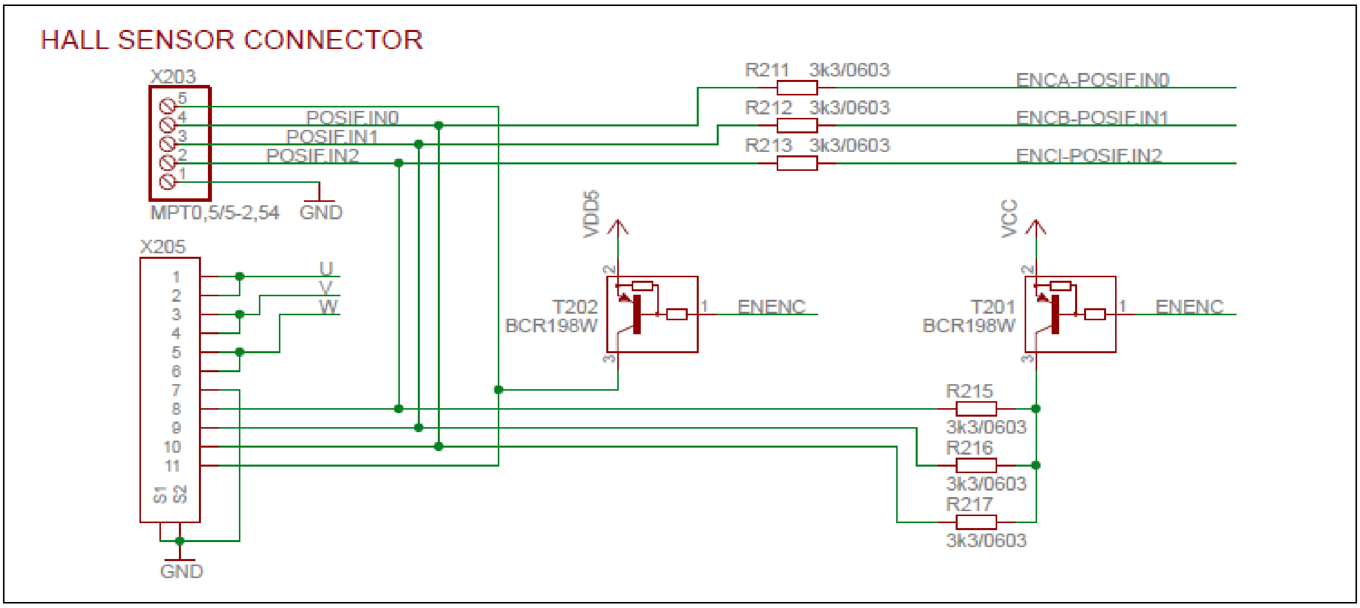


Figure 10 Hall Sensor Connector Interface

Table 4 summarizes all the encoder/hall sensors signals available at the SAMTEC connector

Table 4 Encoder / hall signals at the SAMTEC connector

Pin No.	Signal Name	Description
37	ENENC	Enable signal for encoder line receiver (active high)
43	POSIF.IN0	Encoder Channel A / Hall Channel A
45	POSIF.IN1	Encoder Channel B / Hall Channel B
49	POSIF.IN2	Encoder Channel I / Hall Channel C

2.6 PMSM Motor

In this section, the technical data of the motor can be found.

Please refer directly to Maxon Motor internet page http://www.maxonmotor.com/ for the latest information about this ECflat motor with part number 267121.

Motor Data			267121 / 226006
	Values at nominal voltage		
1	Nominal voltage	V	24
2	No load speed	rpm	4530
3	No load current	mA	36.9
4	Nominal speed	rpm	2760
5	Nominal torque (max. continuous torque)	mNm	25.5
6	Nominal current (max. continuous current)	A	0.5
7	Stall torque	mNm	85.8
8	Starting current	A	1.75
9	Max. efficiency	%	74
	Characteristics		
10	Terminal resistance phase to phase	Ω	13.7
11	Terminal inductance phase to phase	mH	7.73
12	Torque constant	mNm/A	49
13	Speed constant	rpm/V	195
14	Speed/torque gradient	rpm/mNm	54.5
15	Mechanical time constant	ms	20
16	Rotor inertia	gcm²	35

Connection	with Hall sensors
Pin 1	V_{Hall} 3.5…24 VDC
Pin 2	Hall sensor 3
Pin 3	Hall sensor 1
Pin 4	Hall sensor 2
Pin 5	GND
Pin 6	Motor winding 3
Pin 7	Motor winding 2
Pin 8	Motor winding 1

Figure 11 EC 32 flat 32 mm, brushless 15 Watt Motor Specification

2.6.1 Motor Operating Range

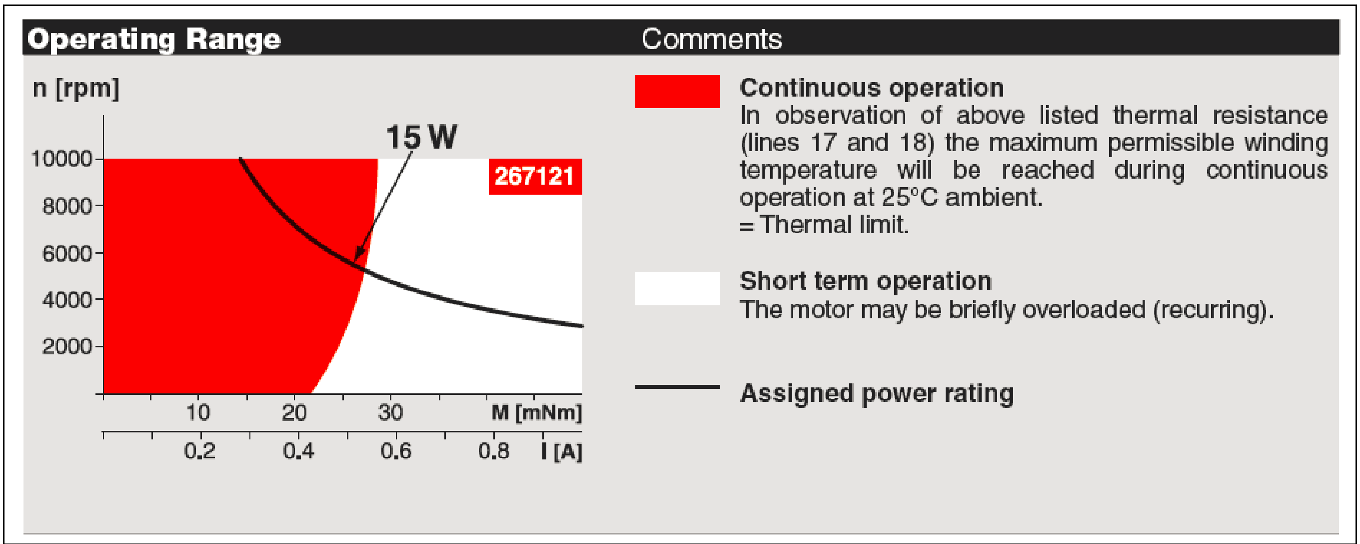


Figure 12 Motor Operating Range

2.6.2 Geometry

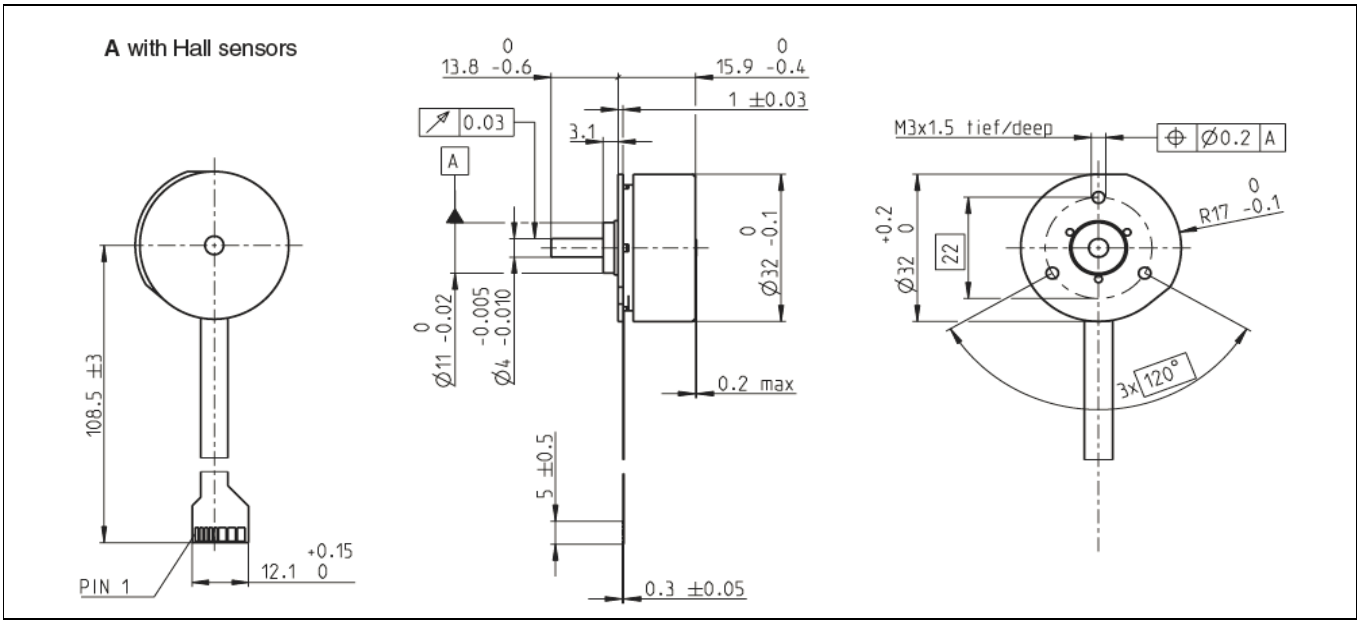


Figure 13 Motor Geometry

3 Production Data

3.1 Schematics

This chapter contains the schematics for the PMSM Low Voltage 15W Motor Card:

- Figure 14: SAMTEC Connector, Power Supply, Encoder Line Driver and Connector, Hall Sensor Connector
- Figure 15: Gate Driver, Power Stage, Shunt Amplifier, Motor Connector

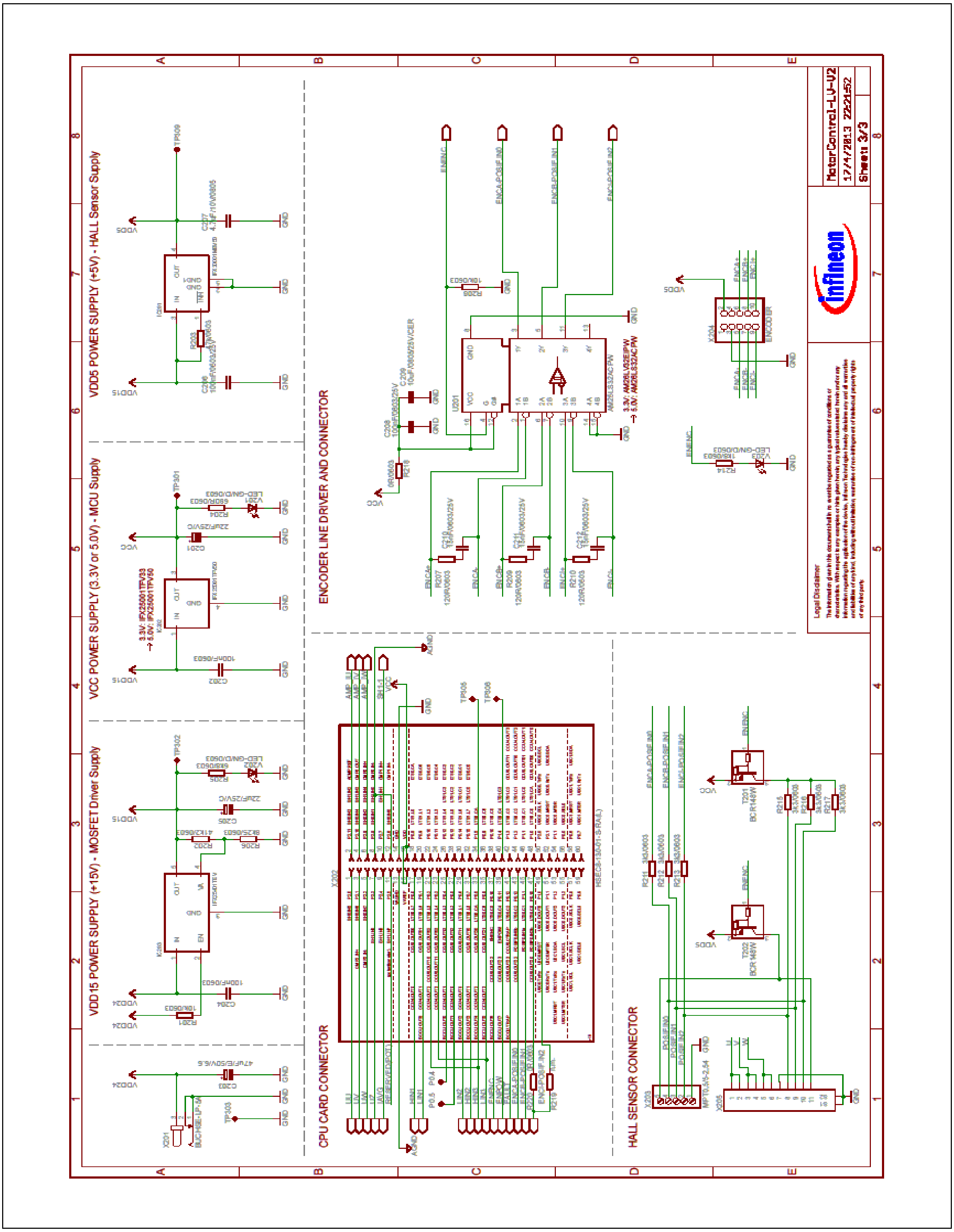


Figure 14 Schematic of SAMTEC Connector, Power Supply, Encoder Line Driver and Connector, Hall Sensor Connector

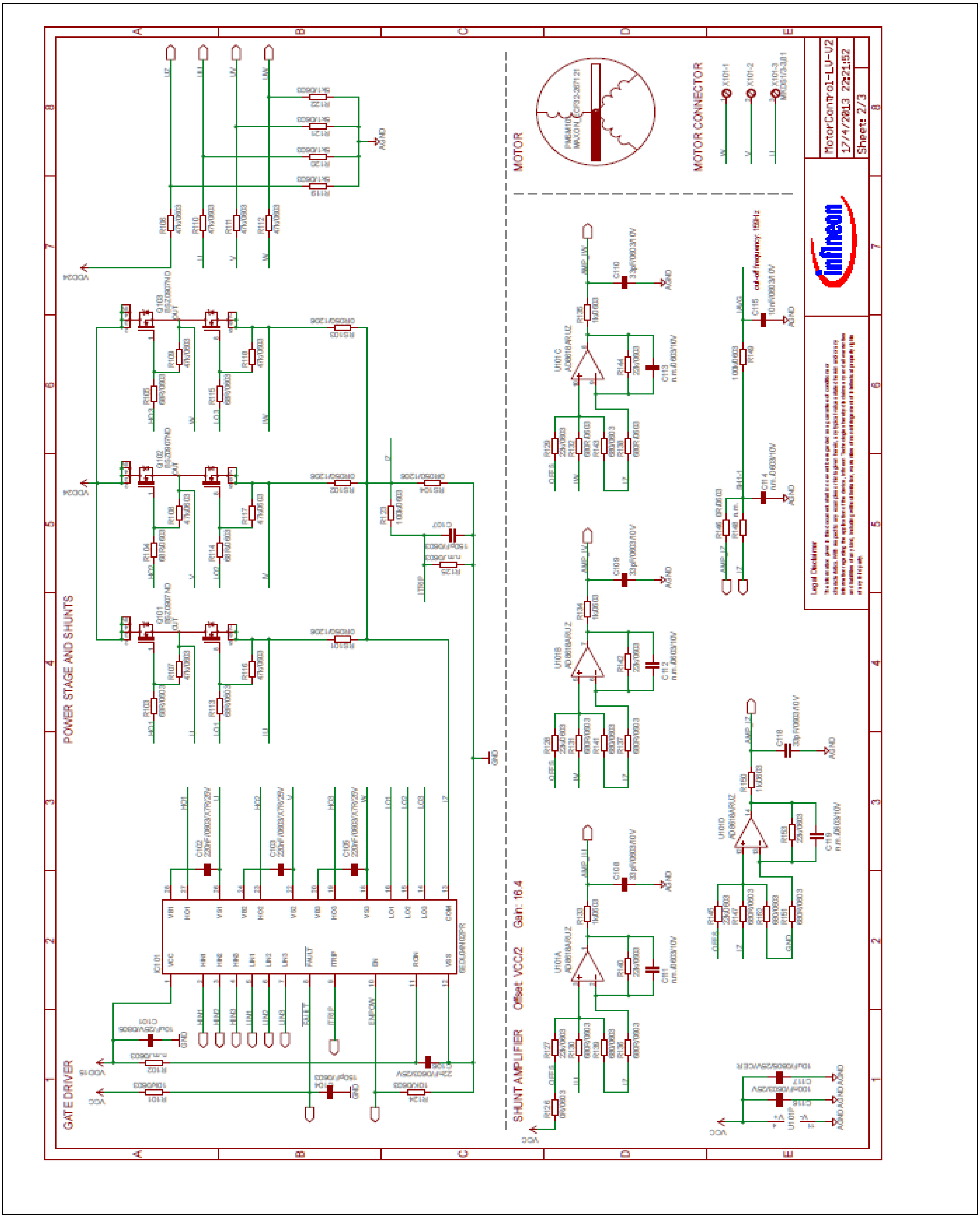


Figure 15 Schematic of Gate Driver, Power Stage, Shunt Amplifier, Motor Connector

3.2 Components Placement and Geometry

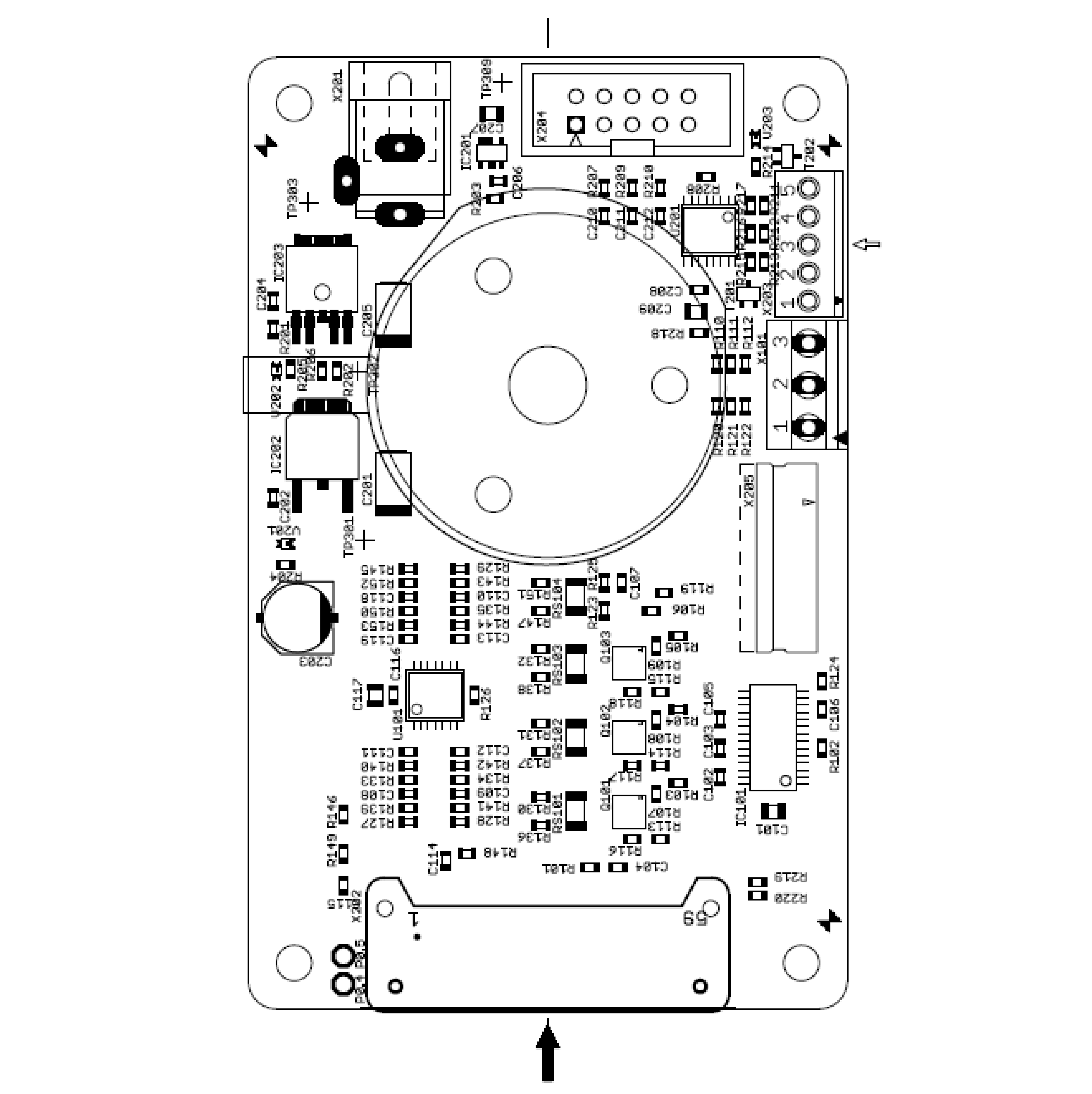


Figure 16 PMSM Low Voltage 15W Motor Card layout and geometry

3.3 Bill of Materials

The list of material is valid for a certain assembly version for the PMSM Low Voltage 15W Motor Card. This version is stated in the header of the Table 5.

Table 5 PMSM Low Voltage 15W Motor Card BOM

No.	Qty	Value	Device	Reference Designator
1	1	HSEC8-130-01-L-RA	HSEC8 socket, SAMTEC	X202
2	1	MKDS1/2-3,81	3.81mm pitch, 2 way, Phoenix	X101
3	1	MPT0, 5/5-2, 54	PC terminal block	X203
4	1	52207-11	Molex Connector	X205
5	1	BUCHSE-LP-5A/SPC4007	Connector Jack	X201
6	1	PAK100/2500-10	Connector	X204
7	5	no ass./0603/10V	Capacitor	C111, C112, C113, C114, C119
8	1	4.7uF/10V/0805	Capacitor	C207
9	1	47uF/50V/6.6	Electrolytic capacitor	C203
10	4	33pF/10V/0603	Capacitor	C108, C109, C110, C118
11	1	10nF/10V/0603	Capacitor	C115
12	1	22nF/25V/0603	Capacitor	C106
13	3	220nF/25V/0603	Capacitor	C102, C103, C105
14	5	100nF/0603	Capacitor	C202, C204, C116, C206, C208
15	3	10uF/25V/0805	Capacitor	C117, C209, C101
16	2	150pF/0603	Capacitor	C104, C107
17	3	15nF/25V/0603	Capacitor	C210, C211, C212
18	2	22uF/25V	Capacitor	C201, C205
19	4	0R/0603	Resistor	R126, R146, R218, R220
20	4	no ass./0603	Resistor	R148, R219, R102, R125
21	4	0R050/1206	Resistor	RS101, RS102, RS103, RS104
22	6	68R/0603	Resistor	R103, R104, R105, R113, R114, R115
23	3	120R/0603	Resistor	R207, R209, R210
24	4	1KR/0603	Resistor	R133, R134, R135, R150
25	1	1K8R/0603	Resistor	R214
26	1	2KR/0603	Resistor	R208
27	6	3K3R/0603	Resistor	R211, R212, R213, R215, R216, R217
28	4	5K1R/0603	Resistor	R119, R120, R121, R122
29	1	6K8R/0603	Resistor	R205
30	1	8K25R/0603	Resistor	R206
31	3	10KR/0603	Resistor	R101, R124, R201
32	8	22K/0603	Resistor	R127, R128, R129, R140, R142, R144, R145, R153
33	1	41K2R/0603	Resistor	R202
34	11	47KR/0603	Resistor	R106, R107, R108, R109, R110, R111, R112, R116, R117, R118, R203
35	2	100KR/0603	Resistor	R123, R149

No.	Qty	Value	Device	Reference Designator
36	3	BSZ0907ND	MOSFET	Q101, Q102, Q103
37	2	BCR198W	Transistor	T201, T202
38	1	6EDL04N02PR	Gate Driver	IC101
39	1	AD8618ARUZ	Operational Amplifier	U101
40	1	AM26LS32ACPW	Quadrature Line Driver	U201
41	1	IFX20001MBV59	Voltage Regulator	IC201
42	1	IFX25001TFV50	Voltage Regulator	IC202
43	1	IFX25401TEV	Voltage Regulator	IC203
44	3	LED-GRN/0603	LED	V201, V202, V203
45	1	ECF32-267121	Maxon Motor	PMSM101
46	3	Farnell 1419294	Screw	
47	3	Farnell 1466915	Spacer	
48	4	Transparent (D7.9mm, H2.2mm)	Support	
49	1	230VAC, 24VDC, 1A	Power Supply	
50	7	No assembly	Test Pad	P0.4, P0.5, TP305, TP306, TP301, TP302, TP309, TP303

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