UM3257

User manual

Getting started with the EVLDRIVE101-HPD compact circular reference design based on STDRIVE101 for high-current brushless motors

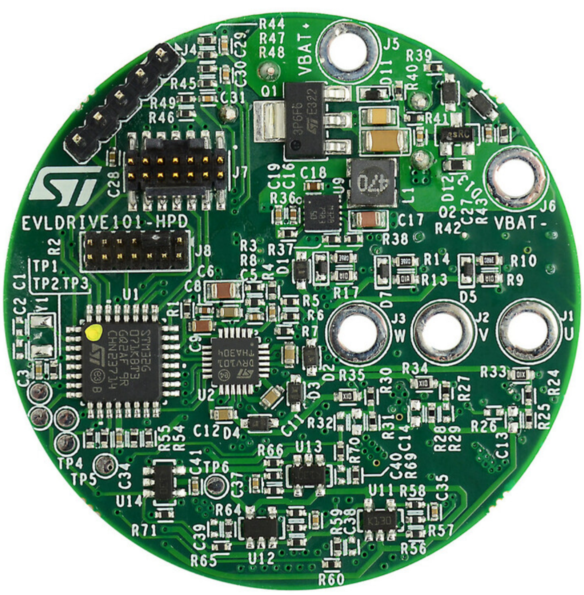
Introduction

The EVLDRIVE101-HPD is a three-phase extremely compact inverter for brushless motors based on the STDRIVE101 device in conjunction with the STM32G071KB microcontroller. The board is a ready-to-use and flexible solution ideal for battery-powered three-phase applications requiring high output currents.

It implements both three-shunt and single-shunt topologies and includes the following features:

- Operative voltage from 18 V to 52 V
- Output current up to 15 Arms
- Low consumption mode cutting the battery supply to the control stage
- Current limiter with adjustable reference
- VDS monitoring, undervoltage lockout, overcurrent, and protection against reverse biasing from power stage outputs
- Back-EMF (BEMF) sensing circuitry
- Input connector for encoder or Hall-effect based sensors
- Bus voltage monitoring and temperature monitoring
- 5 spare GPIOs
- STDC14 debug connector and direct firmware update through UART

Figure 1. **EVLDRIVE101-HPD reference design board**



1 Safety precautions

Warning: *Some of the components mounted on the board could reach hazardous temperatures during operation.*

When using the board, follow these precautions:

- Do not touch the components or the heatsink.
- Do not cover the board.
- Do not put the board in contact with flammable materials or with materials releasing smoke when heated.
- After operation, allow the board to cool down before touching it.

2 Hardware and software requirements

To use the board, the following software and hardware are required:

- A Windows PC
- An STLINK debugger/programmer for STM32 or equivalent
- A 6-step or FOC firmware generated with the X-CUBE-MCSDK .
- An IDE chosen among the IAR Embedded Workbench for Arm (IAR-EWARM), Keil® microcontroller development kit (MDK-ARM-STM32), and STM32CubeIDE (STM32CubeIDE)
- A power supply with an output voltage between 18 V and 52 V
- A three-phase brushless motor fitting the current and voltage ranges of both the power supply and the board

3 Getting started

To start your project with the board:

1. Connect the brushless motor phases to J1, J2, and J3
2. Supply the board through J5 (positive) and J6 (ground)
3. Download the compiled code through the SWD interface connecting the STLINK programmer to J7 (STDC14 connector)

Note: To program the MCU, the control circuitry must be supplied shorting the pin 5 of J8 to ground (that is, trigger switch closed). See Section 4.6 Turn-on/off circuitry for further details.

4 Hardware description and configuration

The ratings of the board are listed in Table 1 and Figure 2 shows the position of the connectors of the board.

Table 1. EVLDRIVE101-HPD specifications

Parameter		Value
Input voltage	Nominal	From 18 V to 52 V
Output current	Peak	21.15 A
	Continuous (1)	15 A $_{rms}$
Output power	Continuous (1)	750 W

1. *Actual continuous current may be limited by ambient temperature and thermal dissipation.*

Figure 2. Board overview

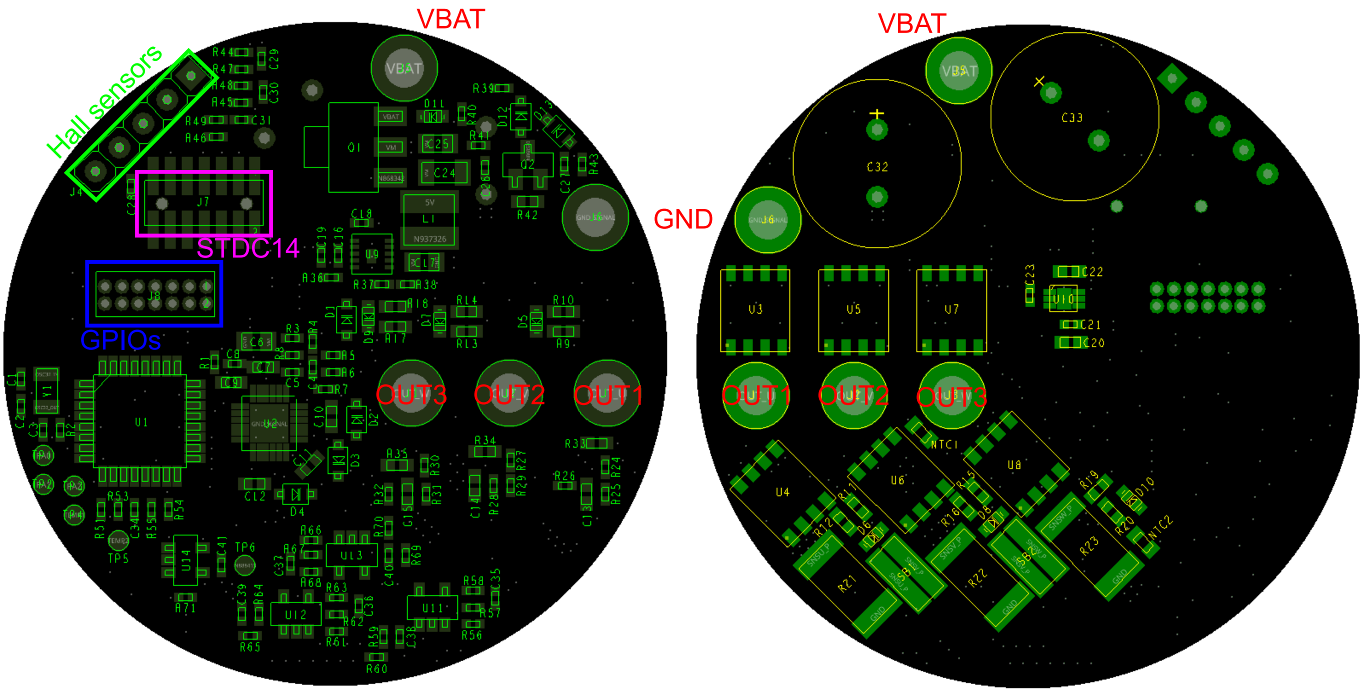


Table 2 lists the MCU GPIOs mapped on the J8 connectors.

Table 2. J8 pinouts

Connector	Pin	Signal	Remarks
J8	1	5 V	5 V supply
	2	3.3 V	3.3 V supply
	3	Ground	
	4	Ground	
	5	Input trigger switch	Connect to ground to supply the control circuitry
	6	Not connected	
	7	PA6	Optional potentiometer input 1 (ADC channel 6)
	8	PA12	Current limiter comparator output

Connector	Pin	Signal	Remarks
J8	9	PB2	Optional potentiometer input 2 (ADC channel 10)
	10	PB4	Current limiter reference
	11	PB8	Reserved GPIO for keep-alive circuit
	12	PB9	
	13	PB7	USART_RX
	14	PB6	USART_TX

4.1 Operation modes

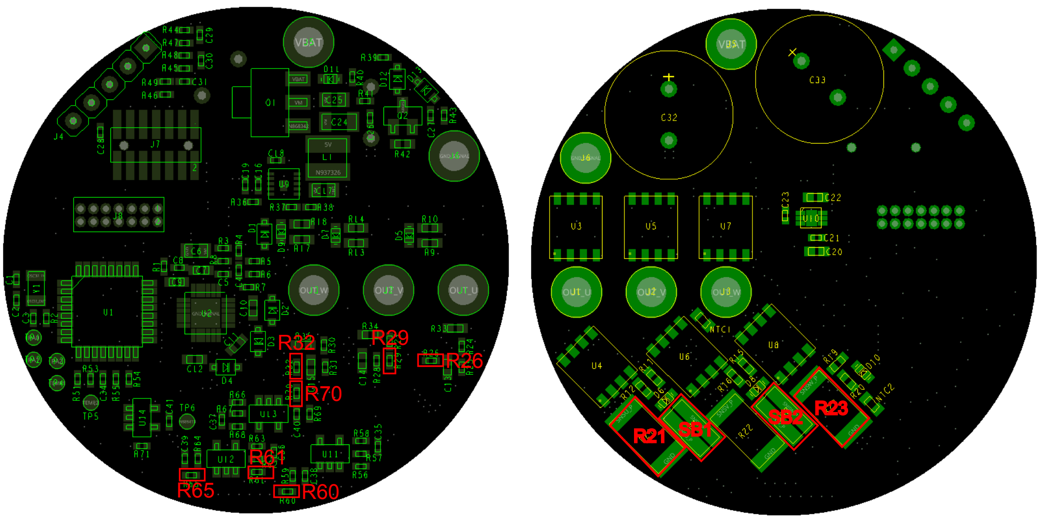
The EVLDRIVE101-HPD supports FOC and 6-step algorithms, both sensor-less and sensored.

According to the algorithm, the hardware configuration of the board must be modified as indicated in Table 3 and shown in Figure 3.

Table 3. **EVLDRIVE101-HPD configuration**

Operation mode	Hardware changes
FOC *Three shunts*	• Default – no changes are required
FOC *Single shunt*	• SB1 and SB2 short-circuited • It is recommended to unsolder R21 and R23 to maintain proper correspondence between shunt signal and op amp gain
6-STEP Sensor-less Voltage-mode	• Remove R60, R65, and R70 • Short R26, R29, and R32
6-STEP Hall-sensors Voltage-mode	• Default – no changes are required
6-STEP Hall-sensors Current-mode	• Remove R61 • SB1 and SB2 short-circuited • It is recommended to unsolder R21 and R23 to maintain proper correspondence between shunt signal and op amp gain

Figure 3. **Components identification in the layout**

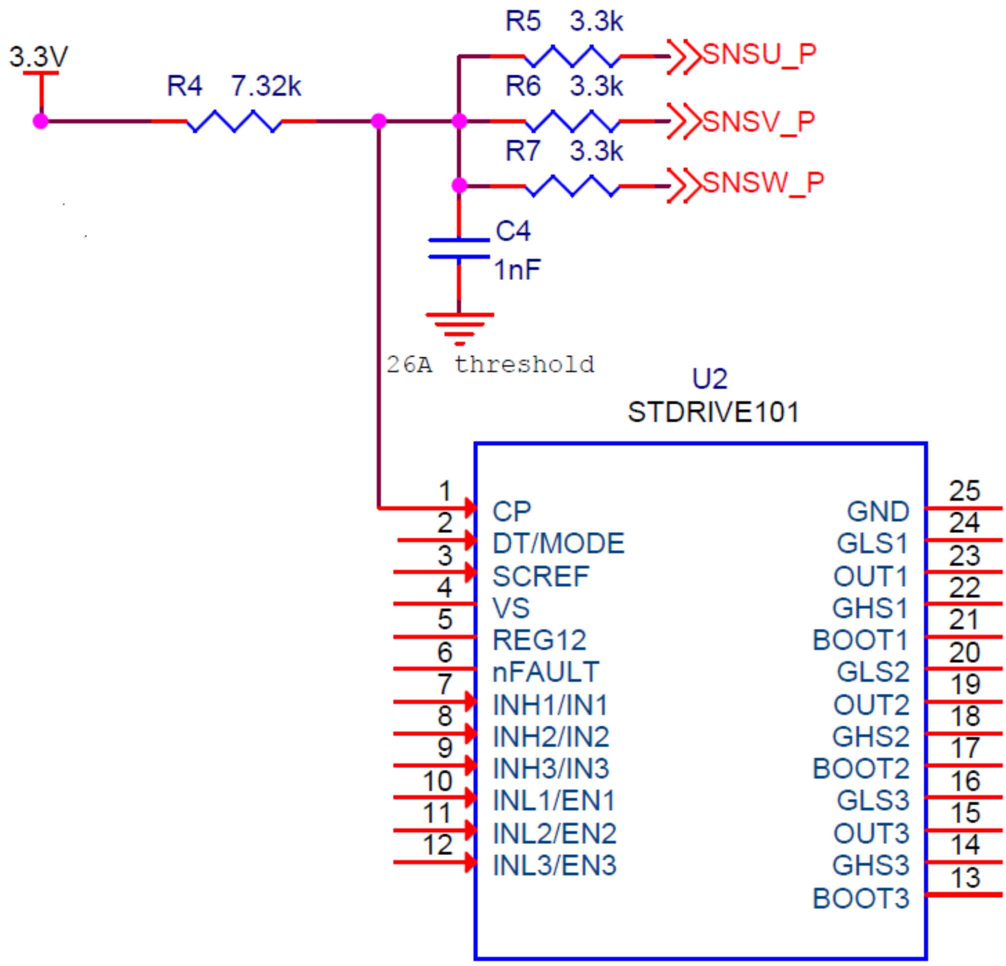


4.2 Current sensing

The board mounts three shunt resistors to sense the current flowing into the motor phases. Each resistor is connected to an amplifier for signal conditioning before forwarding the sensed value to the ADC. Filtering parameters and the gain factor may be changed thanks to R59, R64, R69 and C38, C39, C40.

The STDRIVE101 integrates a comparator for overcurrent (OC) detection: its intervention is set changing the value of R4, R5, R6, and R7 (see Figure 4) according to Eq. (1).

Figure 4. Overcurrent detection circuitry



Equation 1

$$OC_{th} = \frac{3 \times V_{REF} - R_{net} \times (V_{DD} - V_{REF})}{R_{shunt}} \quad (1)$$

Where

$R_{net} = \frac{R5}{R4} = \frac{R6}{R4} = \frac{R7}{R4}$

$V_{REF} = 0.505V$

The default threshold is set to 25.5 A.

4.3 Hall-effect sensors and encoder connector

The board allows motors with digital Hall-effect sensors or encoders to be interfaced with the board through connector J4.

The connector provides:

- Pull-up resistors (R44, R45, R46) for open-drain and open-collector interfacing. It is always recommended to remove the pull-up resistors in case of push-pull outputs (see Figure 5)
- 5 V supply generated by the voltage regulator integrated on the board

Table 4. J4 pinout

Pin	Encoder	Hall-effect sensor
1	A+	Hall 1
2	B+	Hall 2
3	Z	Hall 3
4	Encoder power supply	Sensor power supply
5	Ground	Ground

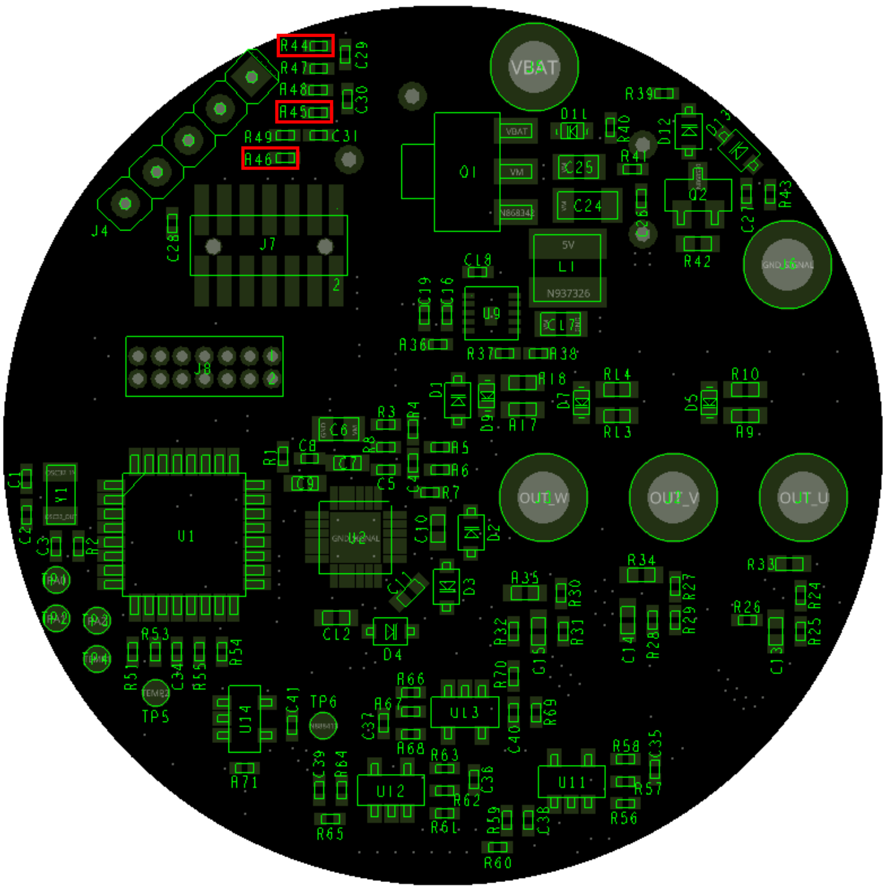


Figure 5. R44, R45, and R46 identification on the layout

4.4 BEMF sensing network

As shown in Figure 6, the board integrates a BEMF sensing network to allow sensor-less driving mode with a 6-step algorithm. Phase voltage V_{OUT} is divided according to Eq. (2) before ADC conversion.

Equation 2

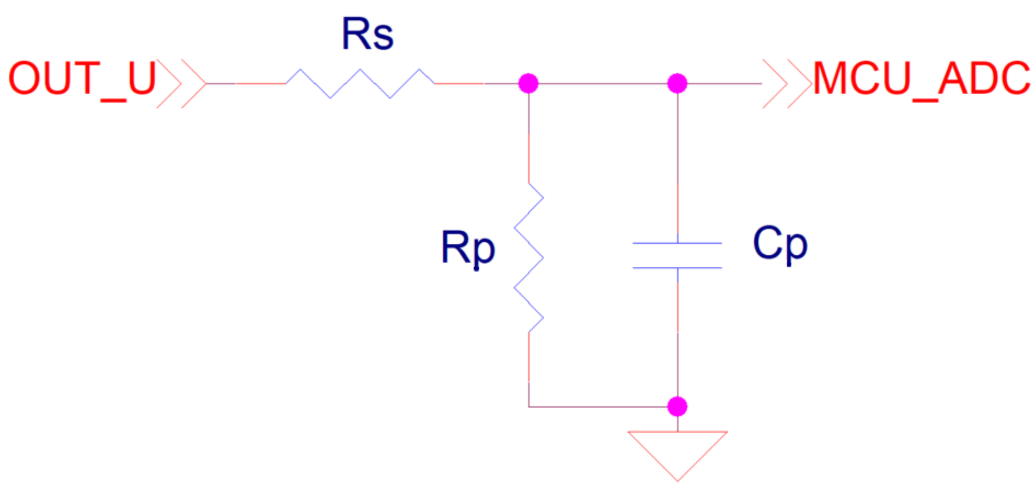
$$\frac{V_{ADC}}{V_{OUT}} = \frac{R25}{R24 + R25} = \frac{R28}{R27 + R28} = \frac{R31}{R30 + R31} \quad (2)$$

Note: It is advised that V_{ADC} does not exceed V_{DD} to prevent GPIO damaging.

On the other hand, the user should be aware that implementing a V_{ADC} / V_{OUT} ratio much lower than needed, the BEMF signal may be too low and the control not robust enough. The recommended value is:

$$\frac{Rp}{Rs + Rp} = \frac{0.95\ X\ VDD}{BusVoltage[V]}$$

Figure 6. **BEMF sensing network**

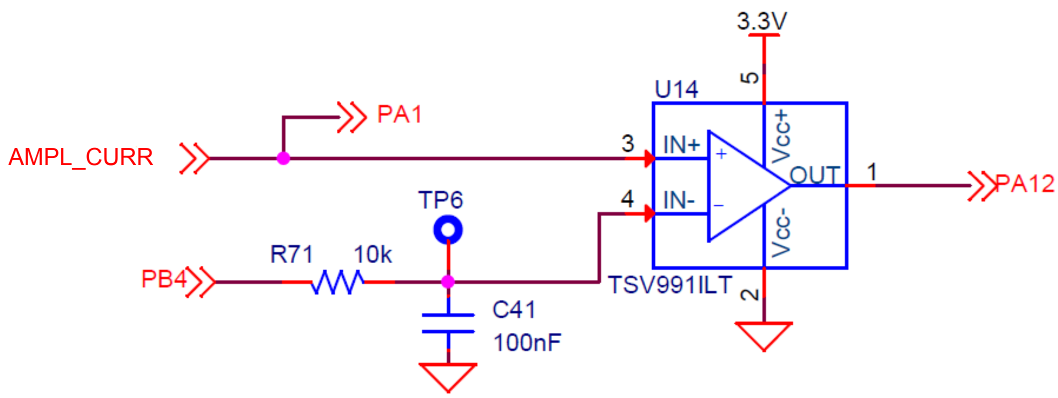


4.5 Current limiter

The board integrates a current limiter to allow current driving mode with a 6-step algorithm and motors with Hall sensors. Configuring the board in single-shunt topology, the amplified current signal is compared to the reference (PB4) generated by a filtered PWM signal. The schematic is shown in Section 4.5.

The current limiting feature is not available with 6-step sensor-less driving mode.

Figure 7. **Current limiter schematic**

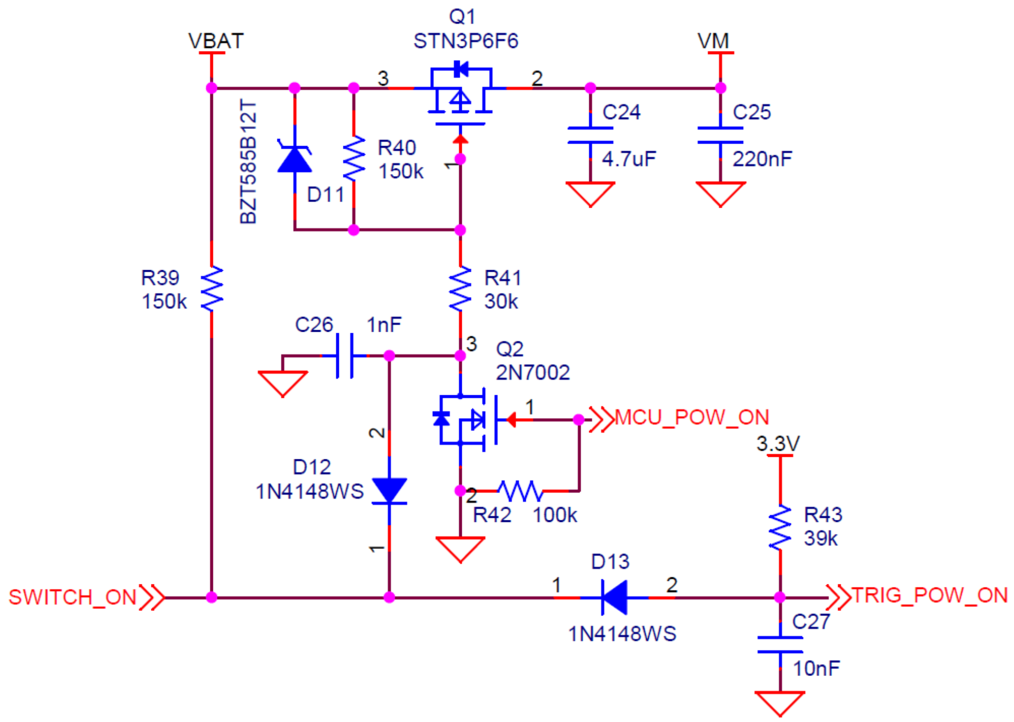


4.6 Turn-on/off circuitry

An external switch placed between pin 5 of J8 and ground (pin 3 of J8) allows to connect and disconnect the control circuitry to the battery reducing the quiescent consumption to the lowest possible level.

The schematic in Figure 8 shows the turn-on trigger circuitry. At power-up, Q1 PMOS is open and the battery is disconnected from the control circuitry. Closing the switch, the gate of the Q1 PMOS is forced low connecting the battery to the control circuitry.

Figure 8. Turn-on trigger circuitry



4.6.1 Keep-alive circuit

As soon as the Q1 PMOS connects the battery to the STM32G071KB, the MCU keeps the Q1 PMOS closed using the Q2 NMOS. In fact, it acts as an MCU driven switch in parallel to the external trigger switch.

In this way, the firmware takes control of the connection between the battery and the control circuitry, allowing the code to perform a safe switch-off, for example, braking the motor.

It is recommended to set the GPIO output controlling Q2 gate (PB8) at the very beginning of the MCU initialization.

4.6.2 Detection of the status of the external trigger

A dedicated circuit allows the monitoring of the actual status of the external trigger switch.

The monitoring GPIO (PB5) is connected to the switch through the D13 diode. As long as the switch is closed, it forces the GPIO low through D13. Releasing the switch, D13 turns off and the GPIO returns high thanks to a pull-up resistor.

When the MCU detects the opening of the switch, the braking and stopping procedure of the motor is started.

4.6.3 Protection against reverse biasing from power stage outputs

As shown in the schematic diagram of Section 6, Figure 9, the battery is always connected to the power stage while the Q1 PMOS switch connects and disconnects the control circuitry. In this way, the voltage of the power stage outputs (VOUT) can be higher than the control logic supply (VM) violating the AMR limit of the gate driving circuitry: $V_{OUT,max} = VM + 2\ V$.

The device is protected against this condition by means of the diodes between each output and the VM supply (D1, D2, D3, and D4).

5 Bill of materials

Table 5. EVLDRIVE101-HPD bill of materials

Item	Qty	Ref.	Part/value	Description	Manufact.	Order code
1	5	CI,C2,C38,C39,C40	NM	SMT ceramic capacitor		
2	7	C3,C19,C21,C23,C28,C34,C41	100 nF	SMT ceramic capacitor		
3	5	C4,C26, C35,C36,C37	1n	SMT ceramic capacitor		
4	2	C5,C27	10n	SMT ceramic capacitor		
5	2	C6,C17	1uF	SMT ceramic capacitor		
6	1	C7	100n	SMT ceramic capacitor		
7	1	C8	220 nF	SMT ceramic capacitor		
8	1	C9	4.7uF	SMT ceramic capacitor		
9	5	C10,C11,C12,C20,C22	1uF	SMT ceramic capacitor		
10	3	C13,C14,C15	NM	SMT ceramic capacitor		
11	1	C16	470 nF	SMT ceramic capacitor		
12	1	C18	2.2uF	SMT ceramic capacitor		
13	1	C24	4.7 u	SMT ceramic capacitor		
14	1	C25	220n	SMT ceramic capacitor		
15	3	C29,C30,C31	2.2 nF	SMT ceramic capacitor		
16	2	C32,C33	220 u	Through hole aluminum elect. capacitor	Panasonic	ECA2AM221
17	6	D1,D2,D3,D4,D12,D13	1N4148WS	Small signal fast switching diode	Vishay	1N4148WS-E3-08 / -E3-18 or equivalent
18	6	D5,D6,D7,D8,D9,D10	BAT30	Small signal Schottky diode	STMicroelectronics	BAT30KFILM
19	1	D11	BZT585B12T	SMD precision Zener diode	Diodes Incorporated	BZT585B12T or equivalent
20	5	J1,J2,J3,J5,J6	pad200hole118_11			
21	1	J4	STRIP 1x5	Strip connector 5 poles, 2.54 mm		
22	1	J7	STDC14	Connector header SMD 14POS 1.27 mm	Samtec	FTSH-107-01-L-DV-K-A

Item	Qty	Ref.	Part/value	Description	Manufact.	Order code
23	1	J8	STRIP 2x7	Strip connector 7x2 poles, 1.27 mm		NP
24	1	L1	47uH	Inductor, shielded, 47 uH, 580 mA, SMD	Wurth Elektronik	744031470
25	2	NTC1, NTC2	10k	NTC thermistor	Vishay	NTCS0603E3103FMT
26	1	Q1	STN3P6F6	P-channel -60 V, 0.13 Ohm, -3 A STripFET F6 power MOSFET	STMicroelectronics Diodes Incorporated	STNP6F6 DMP6023LE-13
27	1	Q2	2N7002	N-channel 60 V, 7.5 Ohm MOSFET	Diodes Inc.	2N7002 or equivalent
28	2	R1,R43	39k	SMT resistor		
29	4	R2,R36,R37,R38	100k	SMT resistor		
30	1	R3	22k	SMT resistor		
31	1	R4	7.32k	SMT resistor		
32	3	R5,R6,R7	3.3k	SMT resistor		
33	5	R8,R59,R64,R69,R71	10k	SMT resistor		
34	6	R9,R11,R13,R15,R17,R19	100	SMT resistor		
35	6	R10,R12,R14, R16,R18,R20	39	SMT resistor		
36	3	R21,R22,R23	0.01	SMT resistor	Bourns	CRA2512-FZ-R010ELF
37	3	R24,R27,R30	68k	SMT resistor		
38	3	R25,R28,R31	4.3k	SMT resistor		
39	3	R26,R29,R32	NM	SMT resistor		
40	3	R33,R34,R35	10 R	SMT resistor		
41	2	R39,R40	150k	SMT resistor		
42	1	R41	30k	SMT resistor		
43	1	R42	100k	SMT resistor		
44	6	R44,R45,R46, R47,R48,R49	1k	SMT resistor		
45	2	R51,R53	910	SMT resistor		
46	1	R54	91k	SMT resistor		
47	1	R55	5.6k	SMT resistor		
48	3	R56,R61,R66	20k	SMT resistor		
49	6	R57,R58,R62, R63,R67,R68	1.4k	SMT resistor		
50	3	R60,R65,R70	0R	SMT resistor		
51	2	SB1,SB2	SOLDER_JUMPER1x3	Jumper		
52	6	TP1,TP2,TP3,TP4,TP5,TP6	TP-Pad diam1_5mm	Test point - Pad 1.5 mm diameter		

Item	Qty	Ref.	Part/value	Description	Manufact.	Order code
53	1	U1	STM32G071KBT3	Microcontroller Arm Cortex-M0+ MCU, 128 KB flash, 36 KB RAM, 64 MHz CPU	STMicroelectronics	STM32G071KBT3
54	1	U2	STDRIVE101	Three-phase gate driver	STMicroelectronics	STDRIVE101
55	6	U3,U4,U5,U6,U7,U8	STL220N6F7	N-channel 60 V, 1.2 mO typ., 120 A STripFET F7 power MOSFET	STMicroelectronics	STL220N6F7
56	1	U9	L7983PU50R	60 V 300 mA synchronous step-down switching regulator	STMicroelectronics	L7983PU50R
57	1	U10	LDL112PU33R	1.2 A low quiescent current LDO	STMicroelectronics	LDL112PU33R
58	4	U11,U12,U13,U14	TSV991ILT	Wide-bandwidth (20 MHz) rail to rail input/output 5 V CMOS op amp	STMicroelectronics	TSV991ILT
59	1	Y1	NM	Crystal 32.768 kHz 12.5 PF SMD	NDK	NX3215SA-32.768K-STD-MUA-8
60	1			Jumper 2 poles 1.27 mm	Wurth Elektromik	622002115121

6 Schematic diagram

Figure 9. EVLDRIVE101-HPD schematic: STM32G071 and STDRIVE101

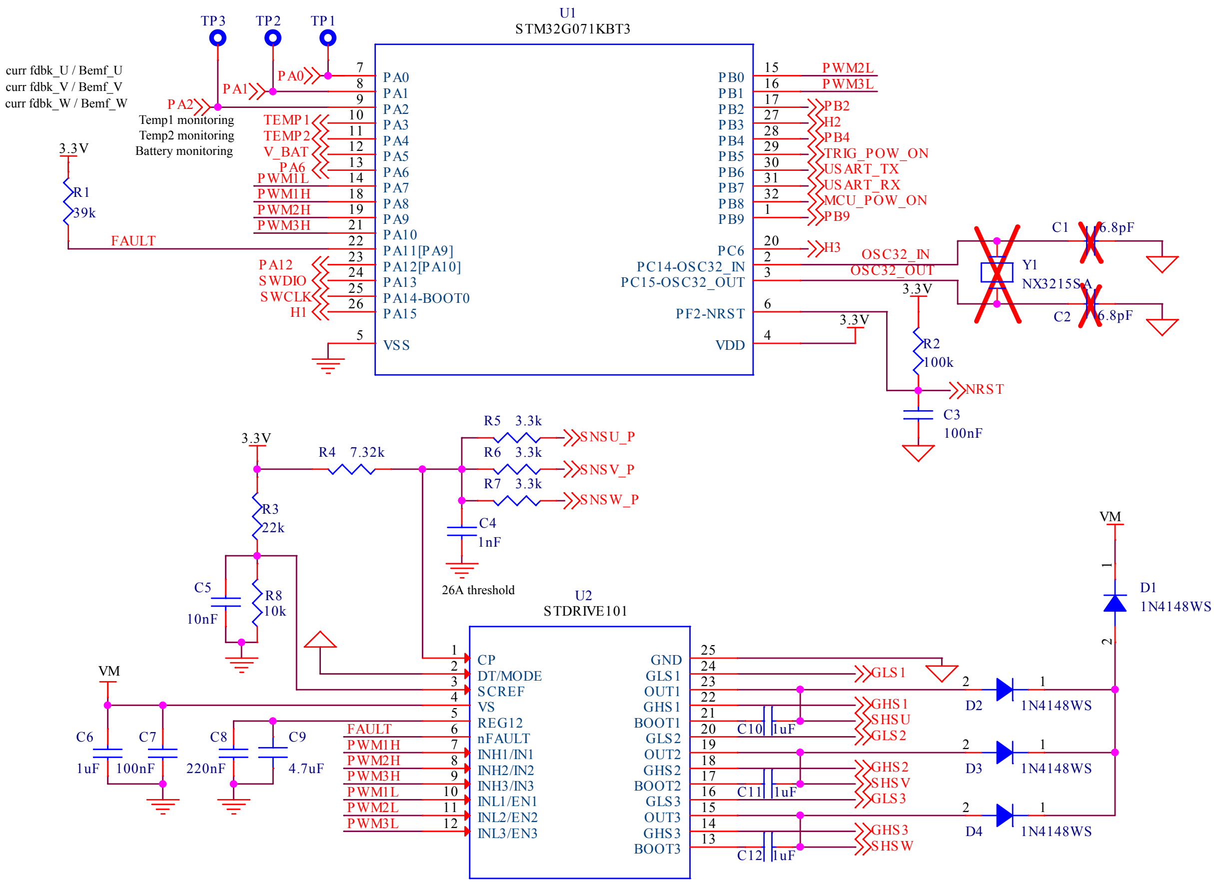


Figure 10. **EVLDRIVE101-HPD schematic: power stage**

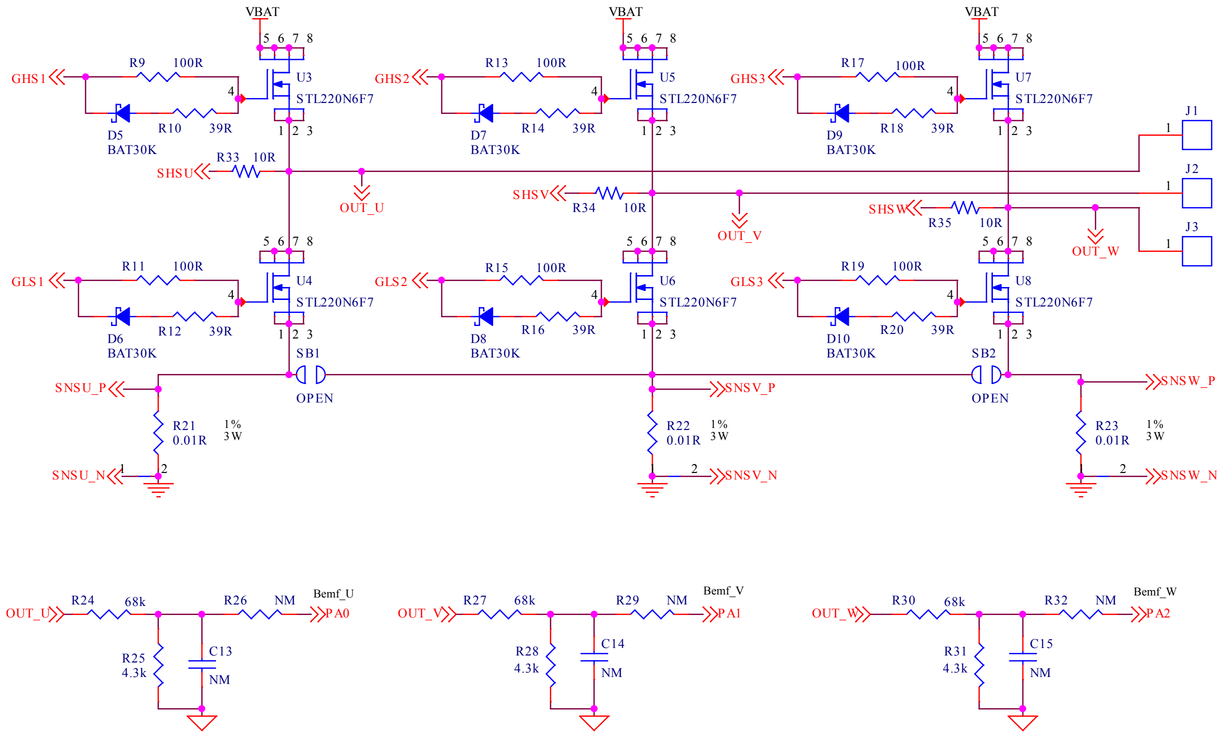


Figure 11. **EVLDRIVE101-HPD schematic: power supply conversion**

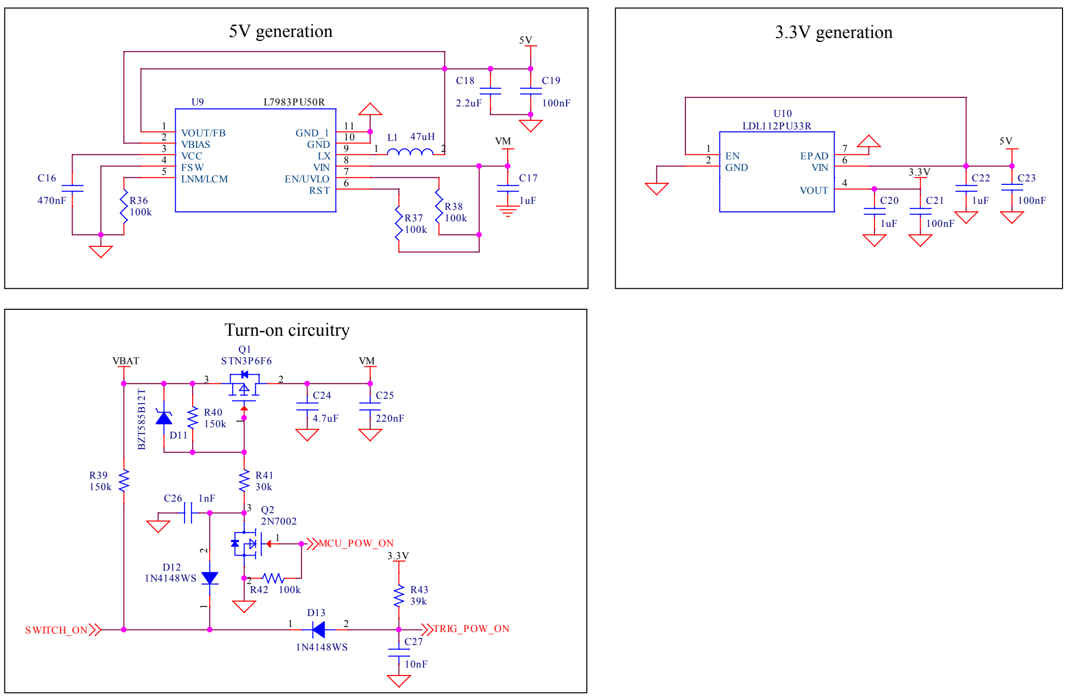


Figure 12. EVLDRIVE101-HPD schematic: inputs and outputs

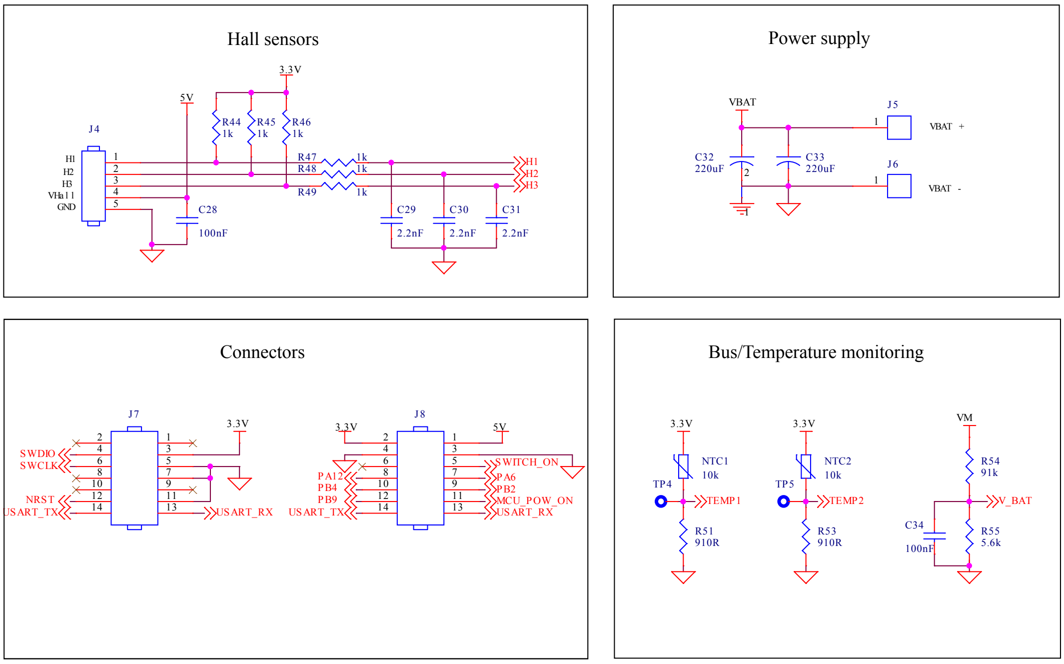
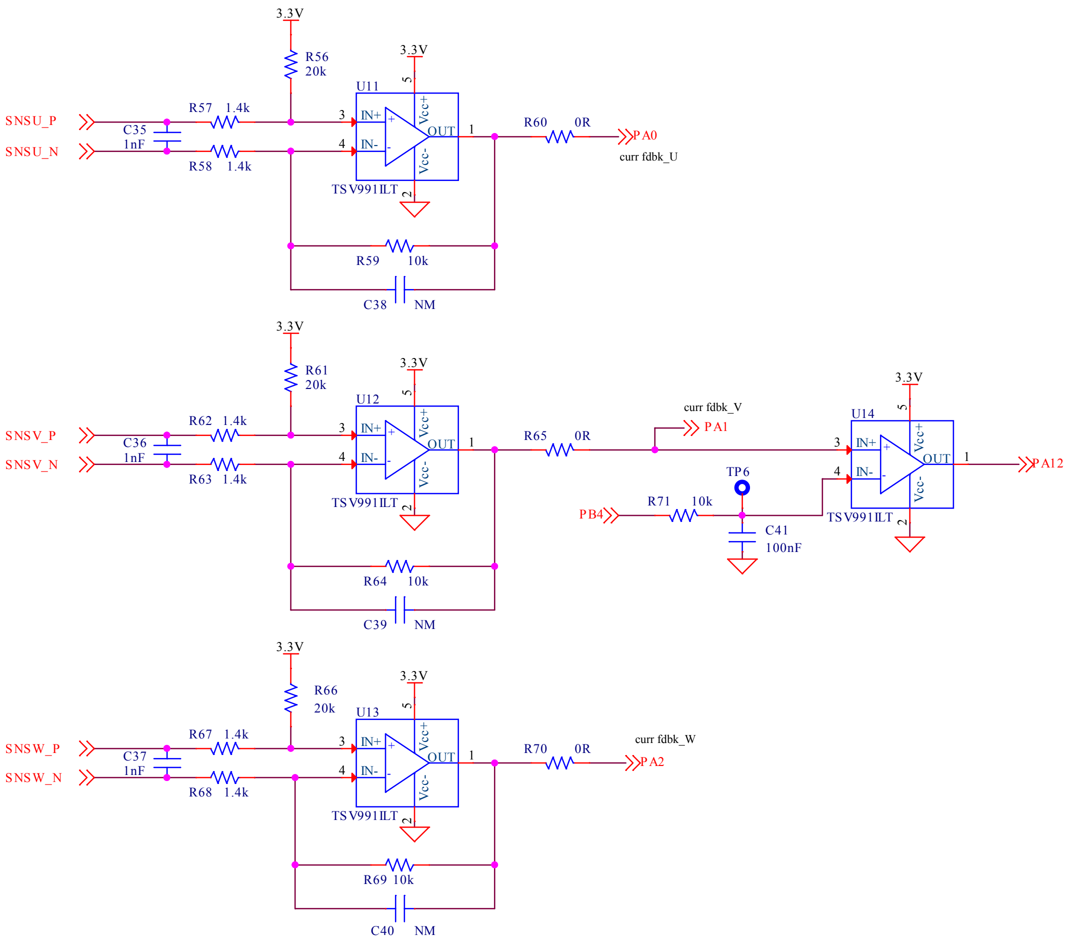


Figure 13. EVLDRIVE101-HPD schematic: current sensing



Revision history

Table 6. **Document revision history**

Date	Version	Changes
11-Dec-2023	1	Initial release.
25-Mar-2024	1	Updated title.

Contents

List of tables

List of figures