Getting started with the STEVAL-PTOOL1V1 compact reference design for low voltage brushless power tools based on STSPIN32F0B

Introduction

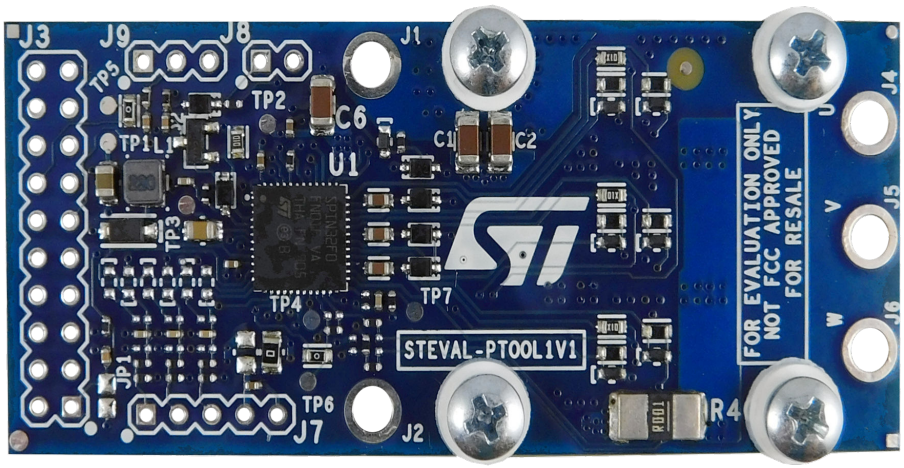
This STEVAL-PTOOL1V1 compact 70 mm x 30 mm reference design board is tailored for low voltage power tools driven by 3-phase brushless motors, supplied by 2S to 6S batteries. The design is based on the STSPIN32F0B controller and STL180N6F7 (or STL220N6F7) power MOSFET.

The board is ready for 6-step driving with Hall-effect sensor feedback, and can be configured for 6-step sensorless control through available with few hardware modifications. The firmware examples included in X-CUBE-MCPKG001 are based on STM32 Motor Control SDK (X-CUBE-MCSDK) enabling all the features of the board, included the low quiescent standby mode.

The board can deliver up to 15 A continuous current, thanks also to the optimal thermal dissipation provided by an embedded heatsink. It embeds a fast power-on circuit that connects and disconnects the battery, allowing standby consumption below 1 µA for extended battery duration. Several protection features are included, such as thermal shutdown, undervoltage lockout, overcurrent protection with programmable threshold and reverse biasing of power stage outputs.

This reference design is predominately intended for power tools, but is very suitable for any battery-powered application involving similar architecture, rating and performance. A potentiometer input for speed variation is available.

Figure 1. STEVAL-PTOOL1V1 reference design



1 Getting started

1.1 Safety precautions

Danger: *Some of the components mounted on the board could reach hazardous temperature during operation.*

Caution: While using the board:

- 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
- Adding a bulk capacitor is highly recommended to prevent a not stabilized power supply or voltage overshoots at power-on which could damage the device

1.2 Overview

The STEVAL-PTOOL1V1 implements a single-shunt topology and features:

- 7 - 45 V motor voltage rating supported
- Recommended for power tools supplied from 2S to 6S batteries
- Output current up to 15 A_{rms}
- STSPIN32F0B advanced 3-phase motor controller tailored for single-shunt applications
- STL180N6F7 60 V, 1.9 mΩ N-channel power MOSFET
- Ultra-low standby current below 1µA thanks to an external turn-on/off trigger
- Heat sink for improved power dissipation
- Extremely compact footprint (70 mm x 30 mm)
- Input connector for Hall effect sensors and encoder
- Plug-and-play capability through 6-step firmware with Hall effect sensor feedback
- Speed regulation through an external trimmer
- Protections: thermal shutdown, UVLO, overcurrent and reverse biasing of power stage outputs
- SWD debug interface and direct firmware update (DFU) via UART

1.3 Hardware and software requirements

To use the STEVAL-PTOOL1V1 board, you need:

- a Windows PC
- ST-LINK debugger/programmer for STM32 or equivalent
- STM32 Motor Control SDK (X-CUBE-MCSDK) and STM32CubeMX
- one of the following IDEs:
  - STM32CubeIDE
  - IAR Embedded Workbench for ARM
  - Keil microcontroller development kit
- a power supply with output voltage between 7 and 45 V
- a three-phase brushless motor fitting the current and voltage ranges of the power supply and the STEVAL-PTOOL1V1

2 Hardware description and configuration

Figure 2. **STEVAL-PTOOL1V1 overview**

1. Speed regulation trimmer (NOT MOUNTED)
2. Power-on trigger
3. Positive battery supply
4. Holes for mounting the heatsink
5. Motor phase connector
6. Motor phase connector
7. Motor phase connector
8. Negative battery supply
9. Hall sensor connectors
10. BEMF sensing circuitry
11. SWD interface
12. GPIOs

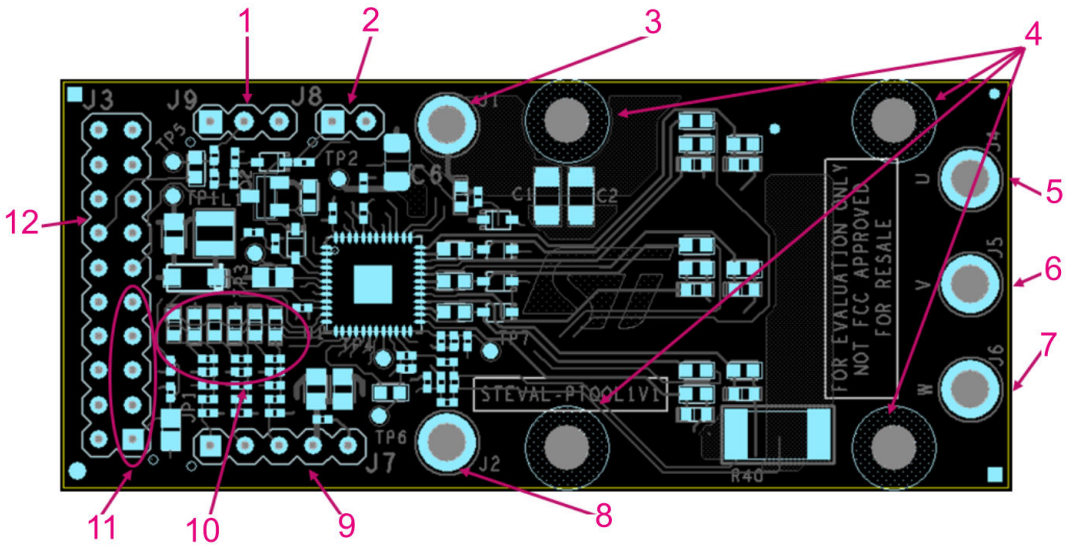


Table 1. **MCU GPIOs mapped on J3 connectors**

Connector	Pin no.	Signal	Remarks
J3	1	NRST	SWD-RESET signal
	2	Ground	
	3	PA13	SWD-CLK signal
	4	PB1	
	5	Ground	SWD-GND signal
	6	PA7	BEMF divider enabler
	7	PA14	SWD-DIO signal
	8	PA6	
	9	VDD	
	10	PA5	
	11	BOOT0	
	12	PA4	Current feedback
	13	PA15	
	14	PA3	Speed regulation trimmer input

Connector	Pin no.	Signal	Remarks
J3	15	PB6	
	16	PC14	
	17	PB7	
	18	PC15	
	19	PB8	
	20	PB9	

2.1 Operation mode and sensing topology selection

The STEVAL-PTOOL1V1 supports by default 6-step algorithm with Hall-effect sensor feedback.

To enable the usage of different algorithms, change the board configuration by soldering the missing components as per the table below.

Table 2. Hardware configuration

Driving technique	Hardware changes
6-step sensorless (see Figure 4)	• BEMF sensing circuitry must be populated (see Figure 3. BEMF sensing circuitry) • R10, R11 and R12 must be unsoldered
6-step with hall effect sensors	Default – no change required

Figure 3. BEMF sensing circuitry

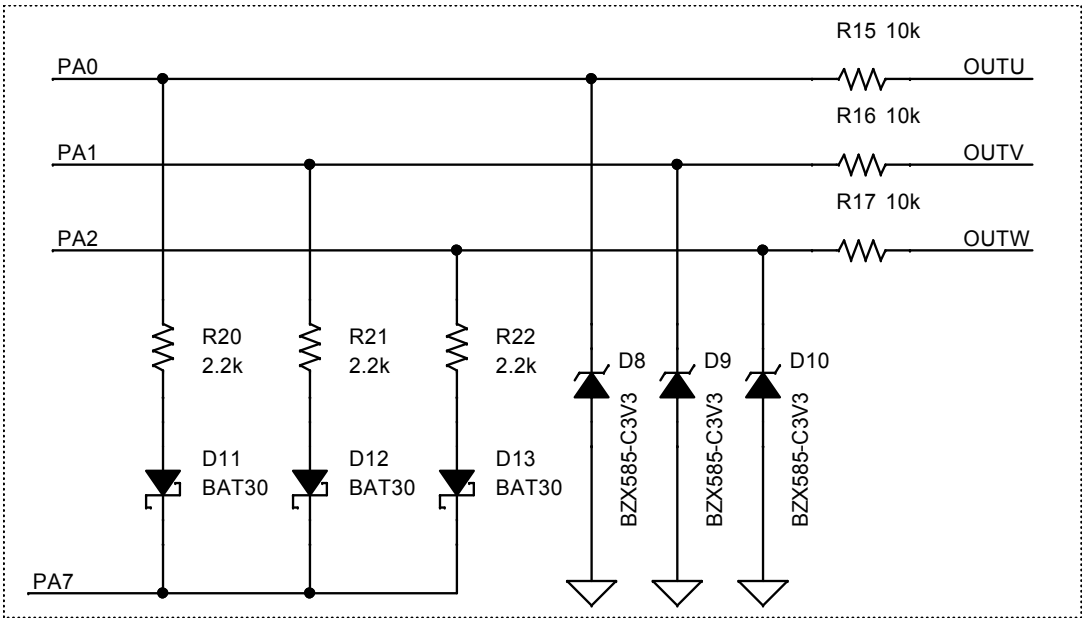
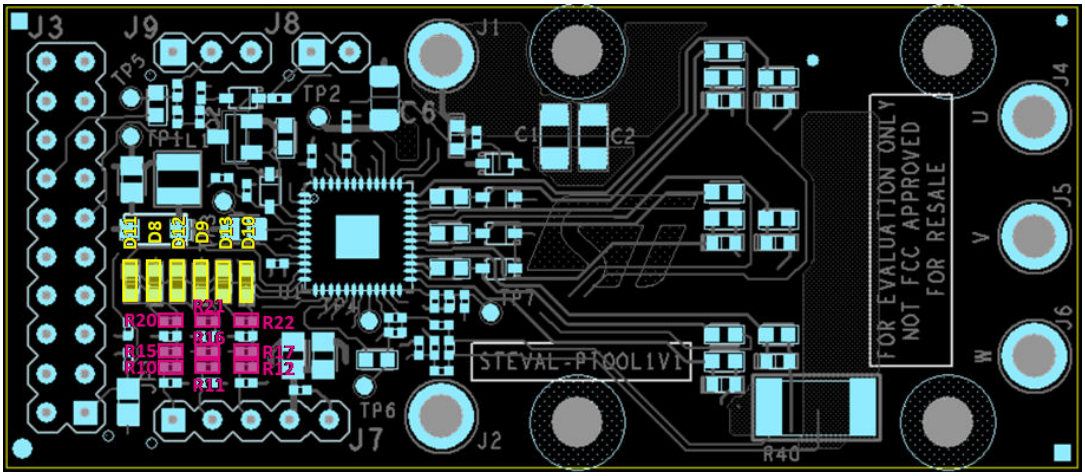


Figure 4. **Sensorless (voltage mode) configuration**



2.2 Current sensing

The STEVAL-PTOOL1V1 board mounts a shunt resistor to sense the current flowing into the motor phases. The resistor is connected to an amplifier integrated in the STSPIN32F0B for signal conditioning before forwarding the sensed value to the integrated comparator. Filtering parameters and gain factor can be changed through R26 and C20. The filtered signal (current feedback) is routed to J3-12.

STSPIN32F0B integrates a comparator for OC detection. When an OC event is triggered, the OC comparator output signals the OC event to the MCU PB12 and PA12 inputs (BKIN and ETR). The comparator internal OC threshold can be set via MCU (PF6 and PF7 ports as per the table below). The corresponding current limit setting depends on the shunt resistor and signal conditioning values, , the table reports the expected thresholds with the default configuration.

Table 3. **OC thresholds**

PF6	PF7	OC threshold [mV]	Default current limit [A]
0	0	N.A.	
0	1	100	20
1	0	250	50
1	1	500	100

2.3 Hall effect sensors and encoder connector

The STEVAL-PTOOL1V1 board interfaces the digital Hall effect sensors or encoder mounted on the motor with the STM32 Nucleo development board through J7 connector.

The connector provides:

- pull-up resistors (R6, R8, R9) for open-drain and open-collector interfacing

Note: Remove the pull-up resistors in case of push-pull outputs (see Figure 5)

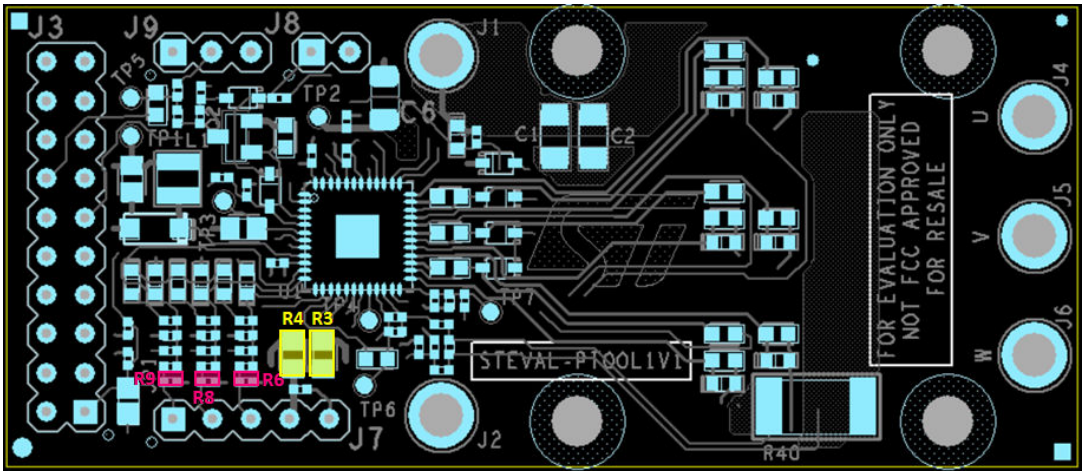
- the encoder/sensor supply is normally connected to the battery voltage but the default setting can be changed by removing R3 and short-circuiting R4 allowing V_{DD} supply (see Figure 5)

Table 4. **J7 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

Pin	Encoder	Hall effect sensor
5	Ground	Ground

Figure 5. **STEVAL-PTOOL1V1 pull-up resistors**



2.4 Speed trimmer

You can connect an external trimmer to J9 connector to provide the MCU with an analog signal used by the firmware as the setting point of the speed control loop.

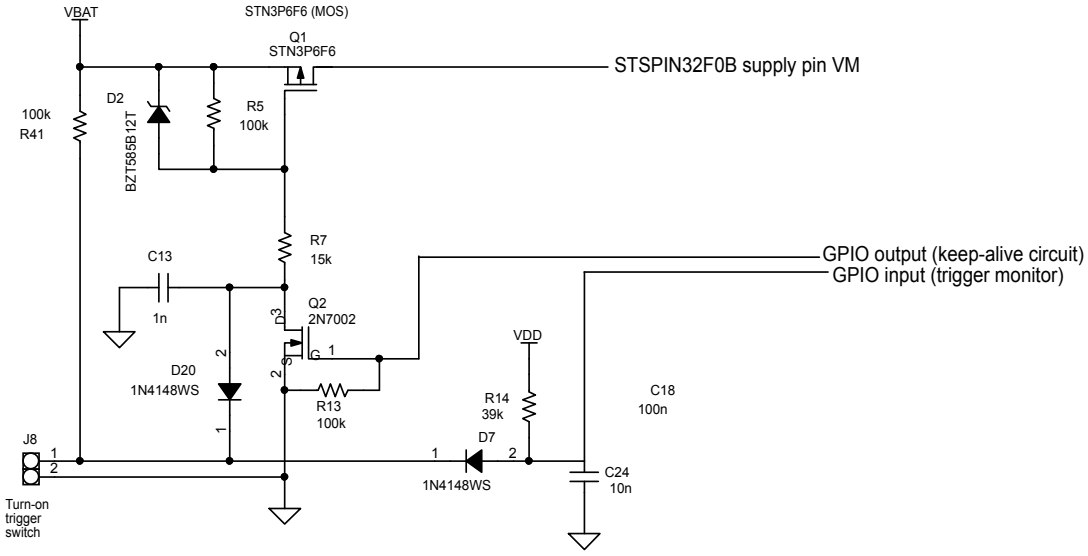
The voltage ranges from 0 to 3.3 V (V_{DD}) and increases by rotating the trimmer in clockwise direction.

2.5 Turn on/off circuitry

An external switch allows you to properly connect or disconnect the MCU and the battery, reducing the quiescent consumption to the lowest level. As soon as the switch is closed, the motor can be driven as required by the control algorithm.

The schematic section below shows the turn on/off trigger circuitry. By closing the trigger switch, the Q1 PMOS gate is forced low, connecting the battery to the control circuitry.

Figure 6. **Turn on/off trigger circuitry**



2.5.1 Keep-alive circuit

As soon as the Q1 PMOS connects the battery to the STSPIN32F0B and the VM rises above the turn on threshold, the power-up sequence starts and the integrated buck regulator performs the soft-start ramp supplying the MCU.

When the MCU is operative, you can keep the PMOS closed using Q2 NMOS which acts as an MCU driven switch parallel to the external trigger switch. Thus, the firmware takes control of the connection between the battery and the STSPIN32F0B allowing the code to perform a safe switch-off (for example, by braking the motor).

Note: Set the GPIO output (PF0) at MCU initialization.

2.5.2 External trigger status detection

While the STSPIN32F0B is supplied by the keep-alive circuit, the actual status of the external trigger switch must be constantly monitored to execute the shutdown sequence when it is released.

The monitoring GPIO (PF1) is connected to the switch through D2 diode. As long as the switch is closed, the GPIO is forced low through D2. Releasing the switch, D2 turns off and the GPIO is pulled up by the resistor.

An interrupt to trigger the braking and stop the motor should be set on the rising edge of PF1.

2.5.3 Protection against reverse biasing from power stage outputs

The battery is always connected to the power stage while the control side is disconnected through the Q1 PMOS switch. Thus, the voltage of the power stage output (V_{OUT}) 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 reverse biasing by the diodes between each output and the VM supply (D3, D4, D5 and D7).

3 How to use the board

Step 1. Check the mounting options according to the desired operation mode (see Section 2.1: Operation mode and sensing topology selection).

Step 2. Connect an external trigger switch to J8.

If needed, connect an external trimmer (recommended value 10k) to J9 to vary the motor speed.

Step 3. Supply the board through J1 (positive) and J2 (ground).

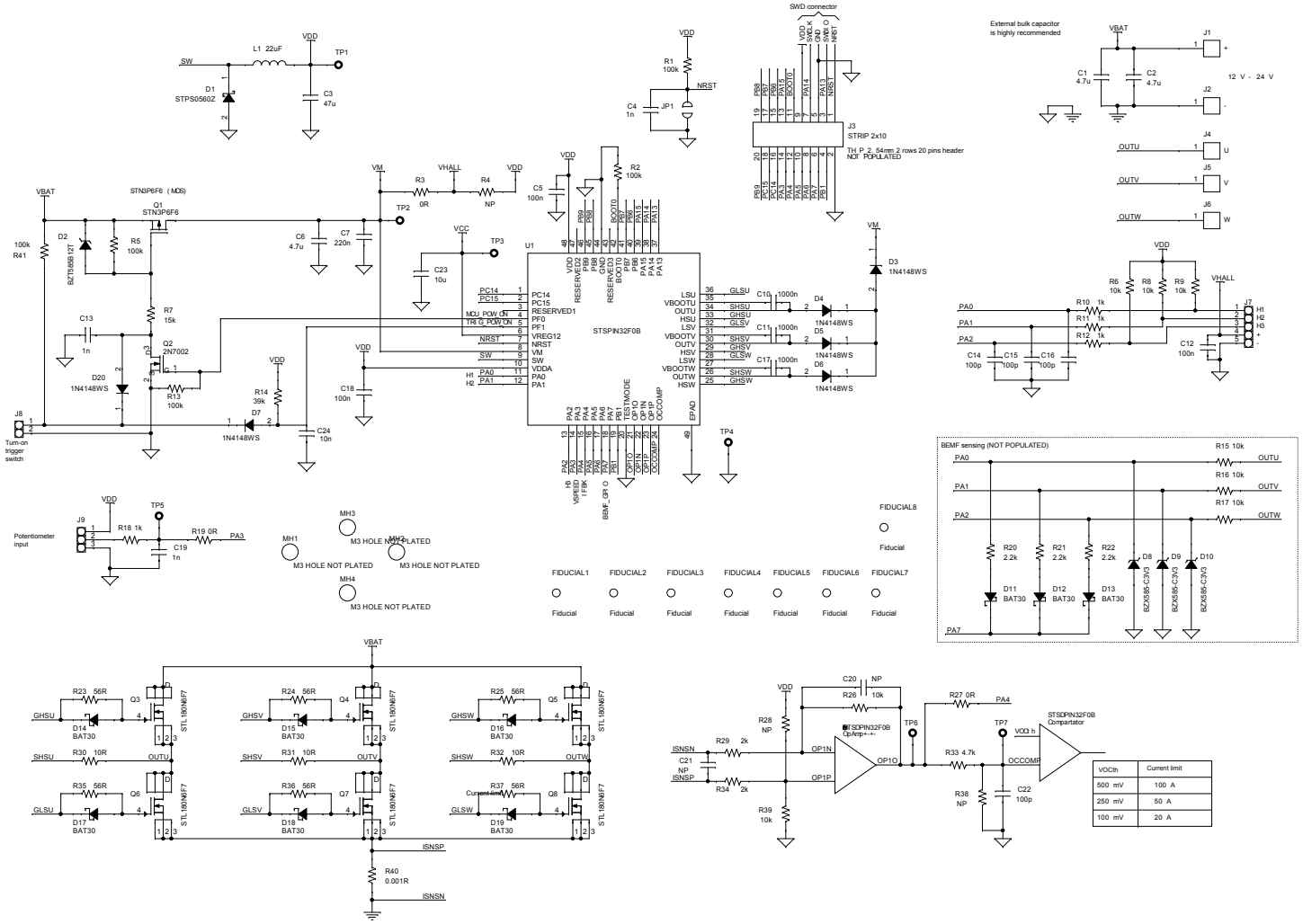
Step 4. Download the pre-compiled code through the SWD interface.

Step 5. Connect the brushless motor phases to J4, J5 and J6. If available, connect the Hall sensors to J7. Be sure that motor phases (U, V and W) and Hall sensors signals (H1, H2 and H3) are properly connected as reported in the board schematics and motor supplier documentation.

Step 6. Develop your application using the firmware example included in X-CUBE-MCPKG001 as starting point.

4 Schematic diagrams

Figure 7. **STEVAL-PTOOL1V1 schematic diagram**



5 Bill of materials

Table 5. **STEVAL-PTOOL1V1 bill of materials**

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
1	2	C1, C2	4.7µF Size 1206 50 V	SMT ceramic capacitor	Kemet	C1206C475K5PACTU
2	1	C3	47 µF Size 0805 6.3 V	SMT ceramic capacitor	Kemet	C0805C476M9PACTU
3	2	C4, C19	1 nF Size 0402 6.3 V	SMT ceramic capacitor	Murata	GRM155R61H102KA01D
4	2	C5, C18	100 nF Size 0402 6.3 V	SMT ceramic capacitor	Murata	GCM155R71C104KA55D
5	1	C6	4.7 µF Size 1206 50 V	SMT ceramic capacitor	Kemet	C1206C475K5PACTU
6	1	C7	220 nF Size 0402 50 V	SMT ceramic capacitor	Taiyo Yuden	UMK105BJ224KV-F
7	3	C10, C11, C17	1000 n Size 0603 16 V	SMT ceramic capacitor	TDK	C1608X7R1C105K080AC
8	1	C12	100 n Size 0402 16 V	SMT ceramic capacitor	Murata	GCM155R71C104KA55D
9	1	C13	1 n Size 0402 3.6 V	SMT ceramic capacitor	Murata	GRM155R61H102KA01D
10	4	C14, C15, C16, C22	100 p Size 0402 6.3 V	SMT ceramic capacitor	MULTICOMP	MC0402B101K250CT
11	2	C20, C21	Size 0402 6.3 V	SMT ceramic capacitor (not mounted)	Any	
12	1	C23	10 µ Size 0805 16 V	SMT ceramic capacitor	Murata	GRM21BR61C106KE15L
13	1	C24	10 n Size 0402 6.3 V	SMT ceramic capacitor	Wurth Elektronik	885012205012
14	1	D1	STPS0560Z SOD-123	Schottky Rectifier	ST	STPS0560Z
15	1	D2	BZT585B12T SOD523	SMD Precision Zener Diode	Diodes Incorporated	BZT585B12T-7
16	5	D3, D4, D5, D6, D7	1N4148WS SOD-323F	Small Signal Fast Switching Diode	Vishay	1N4148WS-E3-08
17	3	D8, D9, D10	BZX585-C3V3 SOD-523 3.3 V	3.3 V Zener Diode 300mW (not mounted)	Nexperia	BZX585-C3V3 or equivalent (NP)
18	3	D11, D12, D13	BAT30KFILM SOD-523 30 V	Small Signal Schottky Diode (not mounted)	ST	BAT30KFILM
19	6	D14, D15, D16, D17, D18, D19	BAT30KFILM SOD-523 30 V	Small Signal Schottky Diode	ST	BAT30KFILM
	1	D20	IN4148WS SOD-323 75V	General purpose diode	Vishay	1N4148WS-E3-08
20	1	JP1		SMT jumper	Any	
21	5	J1, J2, J4, J5, J6	Plated Hole 3 mm	Jumpers	Any	

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
22	1	J3	STRIP 2x10 2x10 pins	Strip connector 10x2 poles, 2.54 mm (not mounted)	Any	
23	1	J7	STRIP 1x5 1x5 pins	Strip connector 5 poles, 2.54 mm (not mounted)	Any	
24	1	J8	STRIP 1x2 1x2 pins	Strip connector 2 poles, 2.54 mm (not mounted)	Any	
25	1	J9	STRIP 1x3 1x3 pins	Strip connector 3 poles, 2.54 mm (not mounted)	Any	
26	1	L1	22 µF, 580 mA, SMD 3 x 1.5 mm	Inductor	Bourns	SRN3015-220M
27	1	Q1	STN3P6F6 SOT-223	P-channel -60 V, 0.13 Ohm, -3 A STripFET F6 Power MOSFET	ST	STN3P6F6
28	1	Q2	2N7002 SOT-23	N-channel 60 V, 7.5 Ohm MOSFET	ST	2N7002
29	6	Q3, Q4, Q5, Q6, Q7, Q8	STL180N6F7	N-channel 60 V, 1.9 mOhm, 120 A STripFET F7 Power MOSFET	ST	STL180N6F7
			STL180N6F7	N-channel 60 V, 0.0012 Ohm typ., 260 A STripFET F7 Power MOSFET		STL220N6F7
30	2	R1, R2	100 k Size 0402 1/16W 5 %	SMT resistor	Panasonic	ERJ2RKF1003X
31	1	R3	0 R Size 0805 0.1 W 5 %	SMT resistor	Yageo	RC0805JR-070RL
32	1	R4	Size 0805 0.1 W 5 %	SMT resistor (not mounted)	Any	
33	2	R5, R41	100 k Size 0402 1/16 W 5 %	SMT resistor	Panasonic	ERJ2RKF1003X
34	3	R6, R8, R9	10 k Size 0402 1/16 W 5 %	SMT resistor	Panasonic	ERJ2RKF1002X
35	1	R7	15 k Size 0402 1/16 W 5 %	SMT resistor	Vishay	CRCW040215K0FKED
36	3	R10, R11, R12	1 k Size 0402 1/16 W 5 %	SMT resistor	Panasonic	ERJ2GEJ102X
37	1	R13	100 k Size 0603 1/16W 5 %	SMT resistor	TE Connectivity	CRG0603F100K
38	1	R14	39k Size 0402 1/16W 5 %	SMT resistor	Vishay	CRCW040239K0FKED
39	3	R15, R16, R17	10 k Size 0402 0.1 W 5 %	SMT resistor (not mounted)	Any	

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
40	1	R18	1 k Size 0402 1/16W 5 %	SMT resistor	Panasonic	ERJ2GEJ102X
41	1	R19	0 R Size 0603 1/16W 5 %	SMT resistor	Panasonic	ERJ3GEY0R00V
42	3	R20, R21, R22	2.2 k Size 0402 0.1 W 5 %	SMT resistor (not mounted)	Any	
43	6	R23, R24, R25, R35, R36, R37	56 R Size 0603 0.1 W 5 %	SMT resistor	Vishay	CRCW060356R0FKEA
44	2	R26, R39	10 k Size 0402 1/16 W 1 %	SMT resistor	Panasonic	ERJ2RKF1002X
45	1	R27	0 R Size 0603 0.1 W 5 %	SMT resistor	Panasonic	ERJ3GEY0R00V
46	2	R28, R38	Size 0402 1/16 W 1 %	SMT resistor (not mounted)	Any	
47	2	R29, R34	2 k Size 0402 1/16 W 1 %	SMT resistor	Panasonic	ERJ2RKF2001X
48	3	R30, R31, R32	10 R Size 0603 0.1 W 5 %	SMT resistor	Vishay	CRCW060310R0FKEA
49	1	R33	4.7 k Size 0402 1/16 W 1 %	SMT resistor	Panasonic	ERJ2GEJ472X
50	1	R40	0.001R Size 2512 3 W 1 %	SMT resistor	Bourns	CRE2512-FZ-R001E-3 or equivalent
51	7	TP1, TP2, TP3, TP4, TP5, TP6, TP7	TP-SMD-diam1_27mm copper pad	SMD pad	Any	
52	1	U1	STSPIN32F0B VFQFPN48 7x7x1mm	Advanced single shunt BLDC controller with embedded STM32 MCU	ST	STSPIN32F0B
53	1		3386W-1-503LF	Potentiometer, 50Kohm, through hole, 3386 trimpot series	Bourns	3386W-1-503LF
54	1		Heatsink-29x29x8 mm	Heatsink-29x29x8 mm	Fischer Elektronik	ICK SMD E 29 SA
55	1	PCB	30x70x1.55mm 30x70x1.55mm	4 layer FR4-PCB cu Thikness 70micron, inner 35micron	Any	
56	4		3x8mm 3x8mm	Vite metrica cilindrica M3 RS PRO, in Acciaio, 8mm	Wurth	00463 8
57	4		7X3.2X0.5mm 7X3.2X0.5mm	Nylon 6/6 UL94-V2	STEAB	5021/1
58	1		3.2 W/m*K 150x150x0.5 mm self-adhesive	Thermal interface sheet	R.S. Pro	707-4645

Revision history

Table 6. **Document revision history**

Date	Version	Changes
02-Oct-2020	1	Initial release.
14-Jan-2021	2	Updated Section 1.1 Safety precautions, Section 3 How to use the board and Section 4 Schematic diagrams.
03-Aug-2021	3	Updated Introduction, Hardware and software requirements and How to use the board.
11-Nov-2021	4	Updated Section 4: Schematic diagrams.
06-Apr-2023	5	Updated Introduction and Section 3: How to use the board.
15-Mar-2024	6	Updated Section Introduction, Section 1.2: Overview, Section 1.3: Hardware and software requirements, Section 2.1: Operation mode and sensing topology selection, Section 2.2: Current sensing and Section 3: How to use the board.

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