ST com SL-PTOOL1V1 Compact Reference Design for Low Voltage Brushless Power tools User Manual

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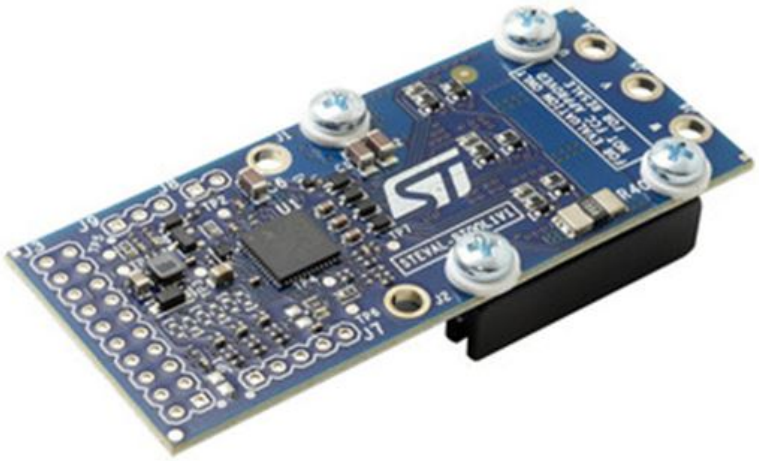


Introduction

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 sensorless and sensored FOC, and can be configured for six-step sensorless control through available BEMF sensing circuitry. The firmware example included in STM32 Motor Control SDK (X-CUBE-MCSDK-Y) uses position feedback from Hall effect sensors, with debugging and programming capability available through the SWD interface and the direct firmware update feature.

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

Getting started

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

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 Arms
- 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 six-step firmware with Hall effect sensor feedback
- Six-steps sensorless control available through dedicated BEMF sensing circuitry and sensorless/sensored Field Oriented Control
- 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

Hardware and software requirements

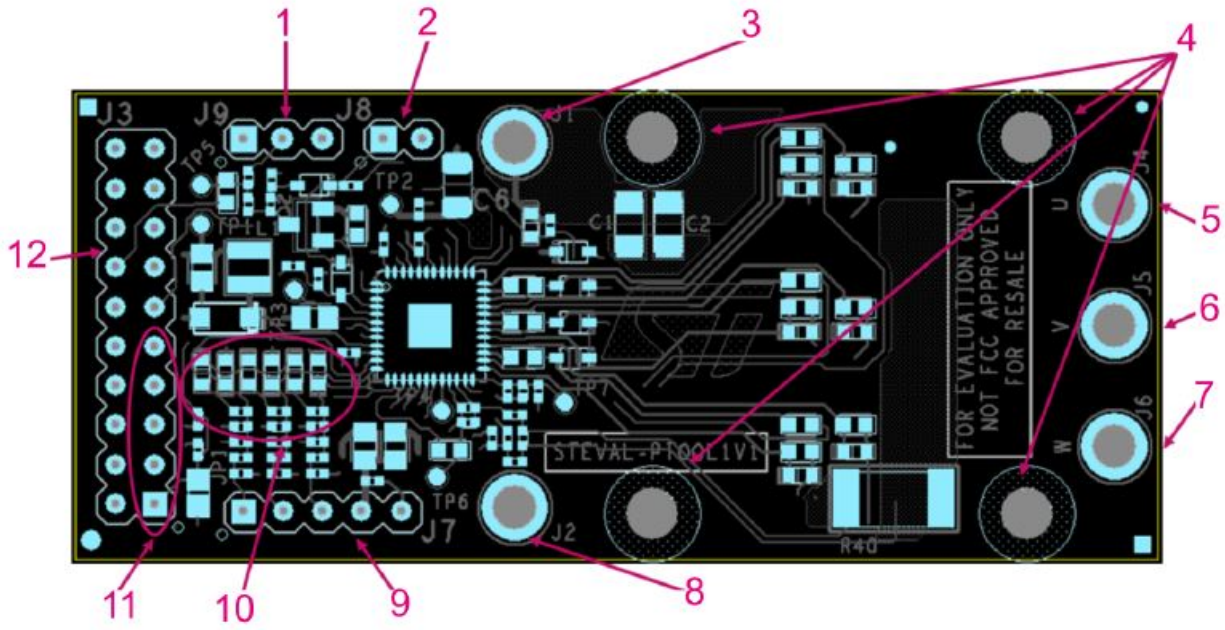
To use the STEVAL-PTOOL1V1 board, you need:

- a Windows (7, 8 or 10) PC
- ST-LINK debugger/programmer for STM32
- the STM32 Motor Control SDK (X-CUBE-MCSDK-Y)
- one of the following IDEs:
  - IAR Embedded Workbench for ARM
  - Keil microcontroller development kit (MDK-ARM-STR)
  - STM32CubeIDE
- a power supply with output voltage between 7 and 45 V (70 mA, max. DC current PCB absorption only in run-mode)

- a three-phase brushless motor in the current and voltage ranges of the power supply and the STSPIN32F0B

Hardware description and configuration

Figure 2. STEVAL-PTOOL1V1 overview



1. Speed regulation trimmer
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

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

Connector	Pin no.	Signal	Remarks
J3	13	PA15	
	14	PA3	Speed regulation trimmer input
	15	PB6	
	16	PC14	
	17	PB7	
	18	PC15	
	19	PB8	
	20	PB9	

Operation mode and sensing topology selection

The STEVAL-PTOOL1V1 supports 6-step sensorless and sensored algorithms.
According to the algorithm used, you can change the board configuration by soldering the missing components as per the table below.

Table 2. Hardware configuration

Driving technique	Hardware changes
Sensorless Voltage mode (see Figure 3)	• BEMF sensing circuitry must be populated • R10, R11 and R12 must be unsoldered
Sensorless Current mode (see Figure 3 and Figure 4)	• BEMF sensing circuitry must be populated • R10, R11 and R12 must be unsoldered • C20 and C21 can be populated to improve current feedback filtering performances • R28 and R38 can be populated to offset or partition current feedback signal
Hall sensors Voltage mode	Default – no change required
Hall sensors Current mode (see Figure 4)	• C20 and C21 can be populated to improve current feedback filtering performances and/or to offset/partition • R28 and R38 can be populated to offset or partition current feedback signal

Figure 3. **Sensorless (voltage mode) configuration**

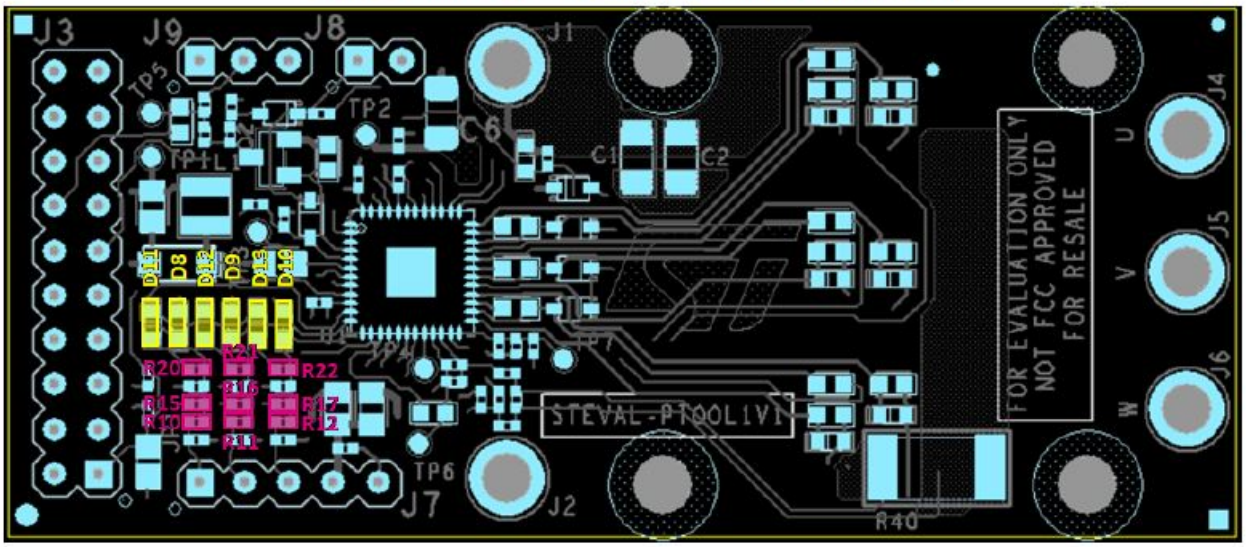
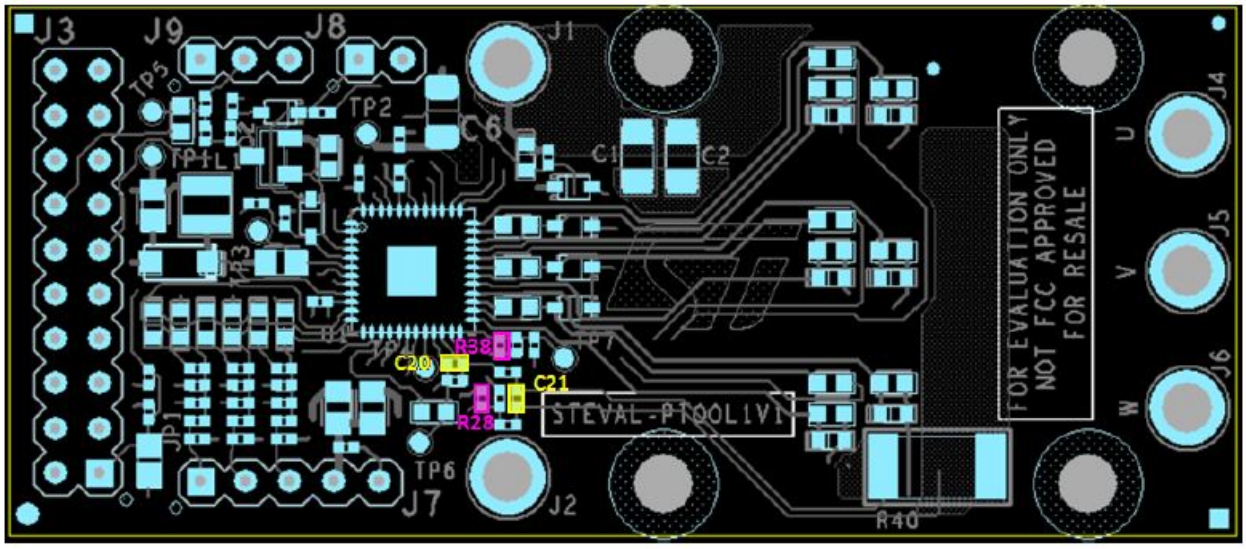


Figure 4. **Sensorless (current mode) configuration**



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.

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

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:

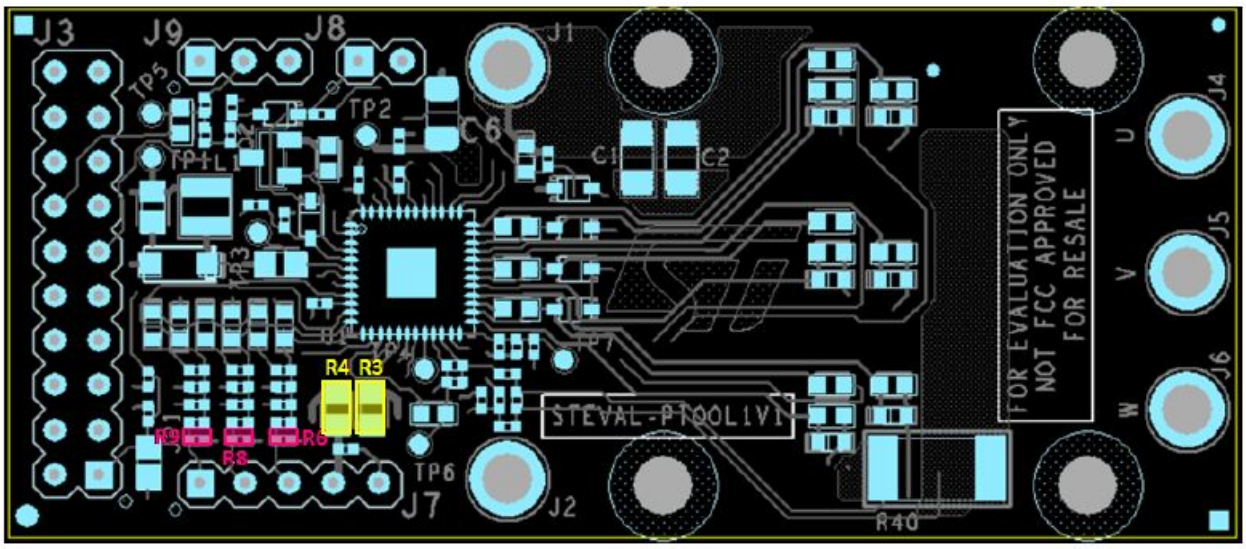
- pull-up resistors (R6, R8, R9) for open-drain and open-collector interfacing
  Remove the pull-up resistors in case of push-pull outputs (see Figure 5)
- the encoder/sensor supply is normally connected to the battery voltage but the default setting can be changed by removing R3 and short-circuiting R4 allowing VDD 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

Pin	Encoder	Hall effect sensor
4	Encoder power supply	Sensor power supply
5	Ground	Ground

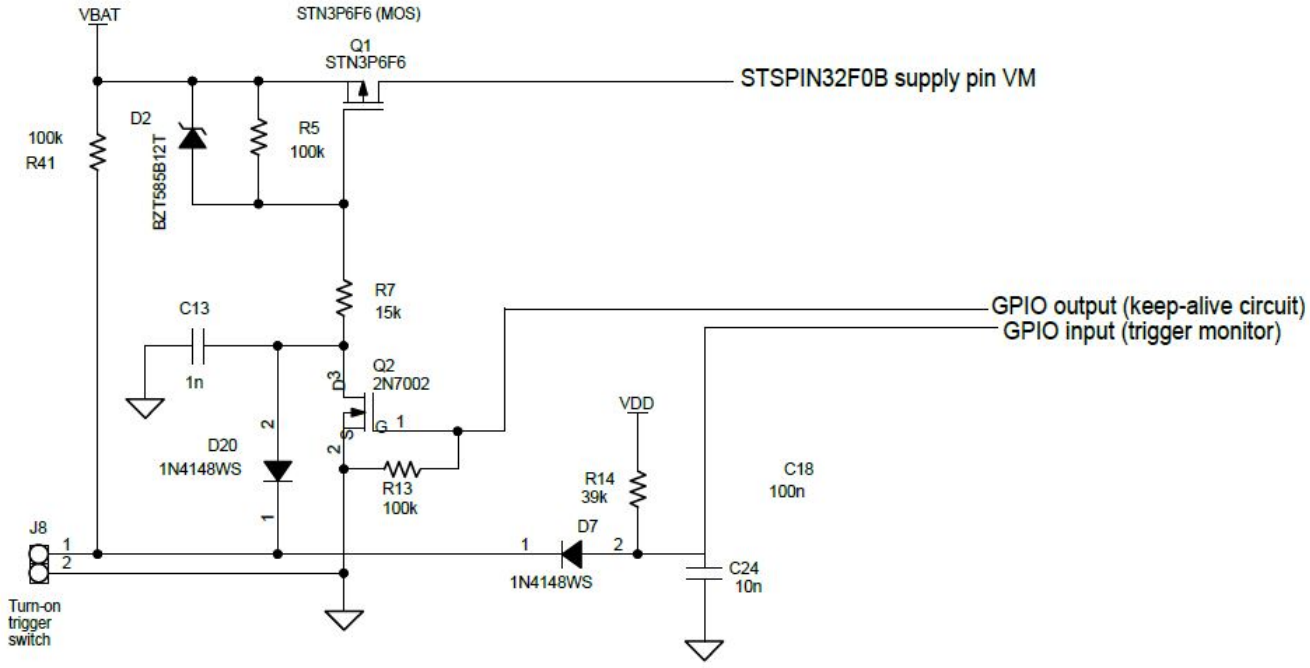
Figure 5. **STEVAL-PTOOL1V1 pull-up resistors**



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 (VDD) and increases by rotating the trimmer in clockwise direction.

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**



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

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.

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 (VOUT) can be higher than the control logic supply (VM) violating the AMR limit of the gate driving circuitry (VOUT 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).

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.

As an option, you can connect an external trimmer to J9 to vary the motor speed.

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

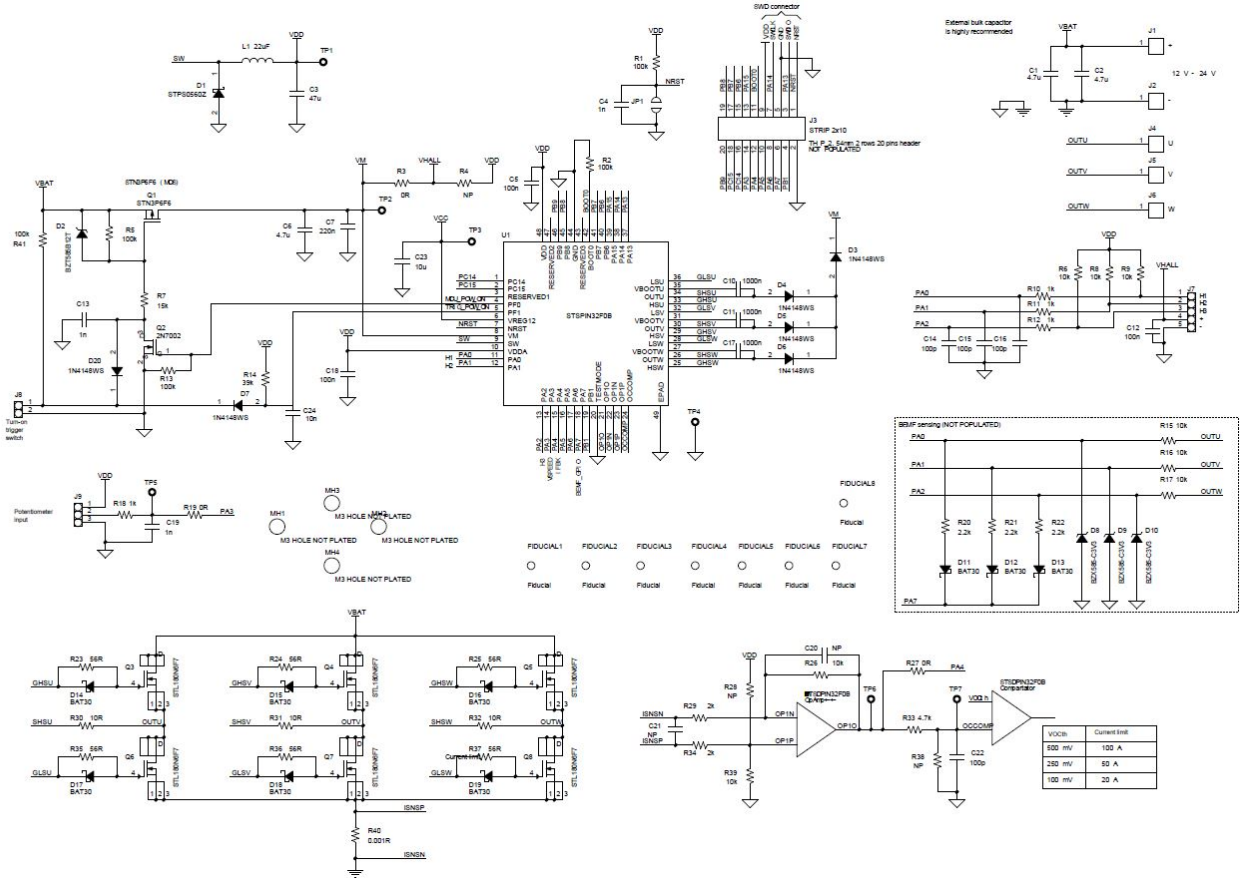
Step 4. Download the pre-compiled code through the SWD interface.

Step 5. Connect the brushless motor phases to J4, J5 and J6.

Step 6. Develop your application using the firmware example included in STM32 Motor Control SDK (X-CUBEMCSDK- Y) as starting point.

Schematic diagrams

Figure 7. STEVAL-PTOOL1V1 schematic diagram



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 75 V	General purpose diode	Vishay	1N4148WS-E3-08

20	1	JP1		SMT jumper	Any	
21	5	J1, J2, J4, J 5, J6	Plated Hole 3 mm	Jumpers	Any	

Item	**Q.ty**	**Ref.**	**Part/Value**	**Description**	**Manufacturer**	**Order code**
22	1	J3	STRIP 2×10 2×10 pins	Strip connector 10× 2 poles, 2.54 mm (not mounted)	Any	
23	1	J7	STRIP 1×5 1×5 pins	Strip connector 5 poles, 2.54 m m (not mounte d)	Any	
24	1	J8	STRIP 1×2 1×2 pins	Strip connector 2 poles, 2.54 m m (not mounte d)	Any	
25	1	J9	STRIP 1×3 1×3 pins	Strip connector 3 poles, 2.54 m m (not mounte d)	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 08 05 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 04 02 1/16 W 5 %	SMT resistor	Panasonic	ERJ2RKF1002X
35	1	R7	15 k Size 04 02 1/16 W 5 %	SMT resistor	Vishay	CRCW040215K0FKED
36	3	R10, R11, R 12	1 k Size 040 2 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 VFQFPN 48 7x7x1mm	Advanced single shunt BLDC controller with embedded STM32 MCU	ST	**STSPIN32F0B**
53	1		3386W-1-503L F	Potentiometer, 50Kohm, through hole, 3386 trimpot series	Bourns	3386W-1-503LF
54	1		Heatsink-29×29×8 mm	Heatsink-29x29x 8 mm	Fischer Elektronik	ICK SMD E 29 SA
55	1	PCB	30x70x1.55 m m 30x70x1.55 m m	4 layer FR4-PCB cu Thiknes s 70micron, inner 35micron	Any	
56	4		3x8mm 3x8 mm	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**.

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Documents / Resources

	ST com SL-PTOOL1V1 Compact Reference Design for Low Voltage Brushless Power tools [pdf] User Manual SL-PTOOL1V1, Compact Reference Design for Low Voltage Brushless Power tools, Compact Reference Design, SL-PTOOL1V1, Reference Design

References

- STMicroelectronics: Our technology starts with you
- STMicroelectronics Trademark List - STMicroelectronics
- BAT30 - 30 V, 300 mA SMD General purpose Signal Schottky Diode - STMicroelectronics
- ST-LINK/V2 - ST-LINK/V2 in-circuit debugger/programmer for STM8 and STM32 - STMicroelectronics
- STEVAL-PTOOL1V1 - Compact reference design for low voltage brushless power tools based on STSPIN32F0B - STMicroelectronics
- STL180N6F7 - N-channel 60 V, 1.9 mOhm typ., 120 A STripFET F7 Power MOSFET in a PowerFLAT 5x6 package - STMicroelectronics
- STL220N6F7 - N-channel 60 V, 0.0012 Ohm typ., 120 A STripFET F7 Power MOSFET in a PowerFLAT 5x6 package - STMicroelectronics
- STM32CubeIDE - Integrated Development Environment for STM32 - STMicroelectronics
- STN3P6F6 - P-channel -60 V, 0.13 Ohm typ., -3 A STripFET F6 Power MOSFET in a SOT-223 package - STMicroelectronics
- STPS0560Z - 60 V, 0.5 A Power Schottky Rectifier - STMicroelectronics
- STSPIN32F0B - Advanced single shunt BLDC controller with embedded STM32 MCU - STMicroelectronics
- X-CUBE-MCSDK - STM32 Motor Control Software Development Kit (MCSDK) - STMicroelectronics
- STM32 Nucleo Boards - STMicroelectronics