Getting started with the STEVAL-PTOOL2V1 compact reference design for medium voltage brushless power tools based on STSPIN32F0252

Introduction

The STEVAL-PTOOL2V1 is a ready-to-use reference design tailored for medium voltage power tools driven by 3-phase brushless motors and supplied from 8S to 15S batteries. It can also effectively be used in other battery-operated applications requiring similar architecture, rating and performance.

The STEVAL-PTOOL2V1 is based on the STSPIN32F0252 motor controller which embeds a 3-phase 250 V gate driver, a Cortex®-M0 STM32 MCU and STL130N8F7 MOSFETs.

The power stage can be populated with any power MOSFET with similar ratings and hosted in a powerFLAT 5x6 package.

The board has a single shunt sensing topology. Field-oriented control (FOC) and sensored or sensorless 6-step control implementation allows driving permanent magnet synchronous motors (PMSMs) and brushless DC (BLDC) motors.

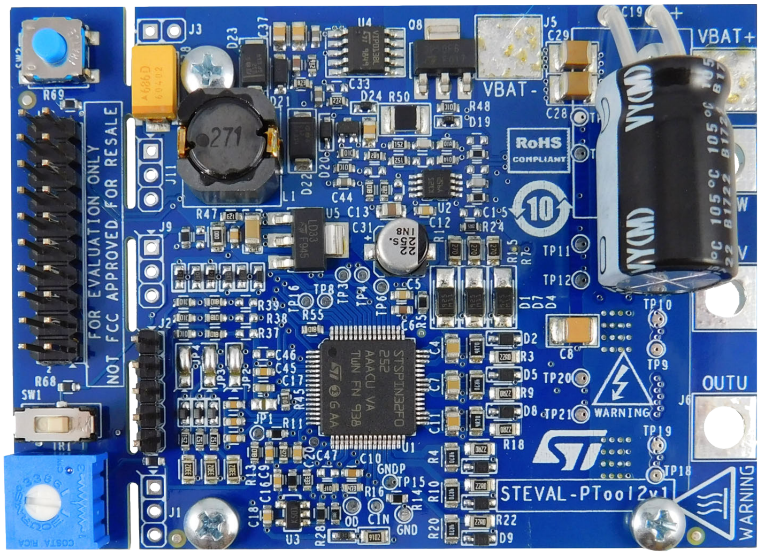
This reference design can deliver up to 19 A of continuous current with very good thermal dissipation performance thanks to the mounted heat-sink. It is compatible with a wide range (from 20 to 72 V_{DC}) input voltage and includes a power supply stage with the VIPER013BLS in buck configuration to generate +12 V and +3.3 V supply voltage required by the application.

The STEVAL-PTOOL2V1 embeds a potentiometer for speed variation and is fully protected from thermal shutdown, undervoltage lockout and overcurrent.

It comes in a compact layout of 80 x 58 mm and includes the STSW-PTOOL2V1 six-step companion firmware that uses the position feedback from Hall effect sensors.

The STSW-PTOOL2V1 firmware can be debugged and configured through an external ST-LINK debugger (ST-LINK/V2-1 or ST-LINK/V3MINI).

Figure 1. STEVAL-PTOOL2V1 evaluation board



1 Getting started

1.1 Safety precautions

Danger:

There is danger of serious personal injury, property damage or death due to electrical shock and burn hazards if the kit or components are improperly used or installed incorrectly.

Warning:

- *The kit is not electrically isolated from the high-voltage supply AC-DC input.*
- *The evaluation board is directly linked to the mains voltage. No insulation is ensured between the accessible parts and the high voltage. All measurement equipment must be isolated from the mains before powering the board.*
- *When using an oscilloscope with the evaluation board, it must be isolated from the AC line. This prevents shock from occurring as a result of touching any single point in the circuit, but does NOT prevent shock when touching two or more points in the circuit.*

Caution: During assembly, testing, and operation, the evaluation board poses several inherent hazards, including bare wires, moving or rotating parts and hot surfaces.

All operations involving transportation, installation, use and maintenance must be performed by skilled technical personnel who is familiar with the installation, use and maintenance of power electronic systems.

Work area safety

- The work area must be clean and tidy
- Do not work alone when boards are powered
- Protect the area against any unauthorized access by putting suitable barriers and signs
- A system architecture that supplies power to the evaluation board must be equipped with additional control and protective devices in accordance with the applicable safety requirements (i.e., compliance with technical equipment and accident prevention rules)

Electrical safety

- Remove power supply from the evaluation board and electrical loads before performing any electrical measurement
- Arrange measurement setup, wiring and configuration paying attention to high voltage sections
- Once the setup is complete, power the board

Danger:

Do not touch the evaluation board when it is powered or immediately after it has been disconnected from the voltage supply as several parts and power terminals containing potentially energized capacitors need time to discharge, and heat-sinks and transformers may still be very hot.

The kit is not electrically isolated from the AC-DC input.

Personal safety

- Always wear suitable personal protective equipment, such as insulating gloves and safety glasses
- Take adequate precautions and install the board preventing accidental touch
- Use protective shields, such as insulating box with interlocks

1.2 Overview

The STEVAL-PTOOL2V1 features:

- 20 to 72 V_{DC} input voltage
- Up to 250 V high voltage rail (limited to 100 V by on-board components)
- Up to 19 Arms output current
- STSPIN32F0252 featuring:
  - 250 V, 1 A 3-phase gate driver
  - Smart shutdown OCP
  - Cortex-M0 STM32
- STL130N8F7 MOSFET power stage with:
  - V_{DS} = 80 V
  - $R_{DS(on)}$ max. = 3.6 mΩ
  - 5x6 PowerFlat package
- Single shunt current sensing for:
  - Sensored or sensorless 6-step algorithm
  - Single shunt vector algorithm
- Digital Hall sensors and encoder input
- Plug-and-play thanks to the six-step firmware with Hall-effect sensor feedback
- Speed regulation through an external trimmer
- Heat-sink for the best power dissipation performance
- Fully protected:
  - Thermal shutdown
  - Undervoltage lockout
  - Overcurrent protection
- Compact footprint (80 x 58 mm)
- Bus voltage sensing
- 12 V V_{CC} and 3.3 V V_{DD} supplies
- Serial wire debug (SWD) port for debugging/programming
- UART TX-RX interface
- Simple user interface with buttons and trimmer
- RoHS compliant

1.3 Hardware and software requirements

To use the STEVAL-PTOOL2V1 board, you need:

- a Windows (XP, Vista, 7, 8 or 10) PC
- ST-LINK debugger/programmer for STM32
- STSW-PTOOL2V1 firmware
- a three-phase brushless or PMSM motor with compatible current and voltage ranges
- External DC power supply

1.4 Evaluation board intended use

The STEVAL-PTOOL2V1 is intended for evaluation purposes only and must not be used for electrical installations or machinery. Technical data and information concerning the power supply conditions should be strictly observed.

1.5 Installing the board

- The installation and cooling down of the evaluation board must be in accordance with the specifications and target application
- The motor drive converters must be protected against excessive strain. In particular, components should not be bent or isolating distances altered during transportation or handling
- No contact must be made with other electronic components and contacts
- The evaluation board contains electrostatic sensitive components that could be damaged if used incorrectly

2 Hardware description and configuration

Figure 2. STEVAL-PTOOL2V1 circuitry main blocks - top view

1. SWD, UART, GPIOs
2. Power supply
3. Feedback network
4. STSPIN32F0252

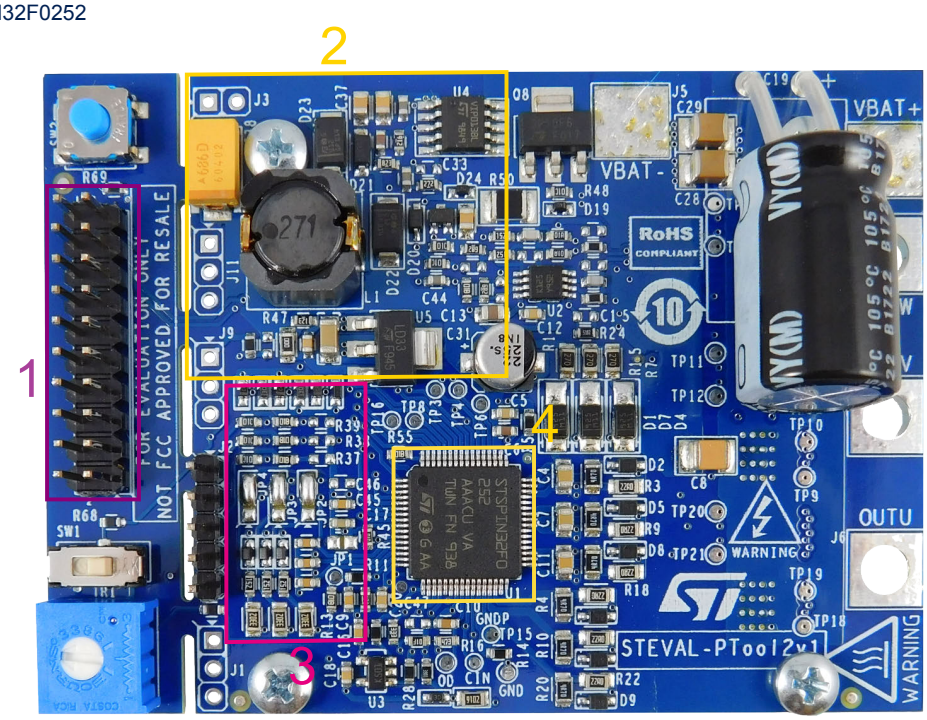


Figure 3. STEVAL-PTOOL2V1 circuitry main blocks - bottom view

1. Power stage
2. Shunt resistor
3. Heat sink mounting hole
4. Heat sink mounting hole
5. Heat sink mounting hole
6. Heat sink mounting hole

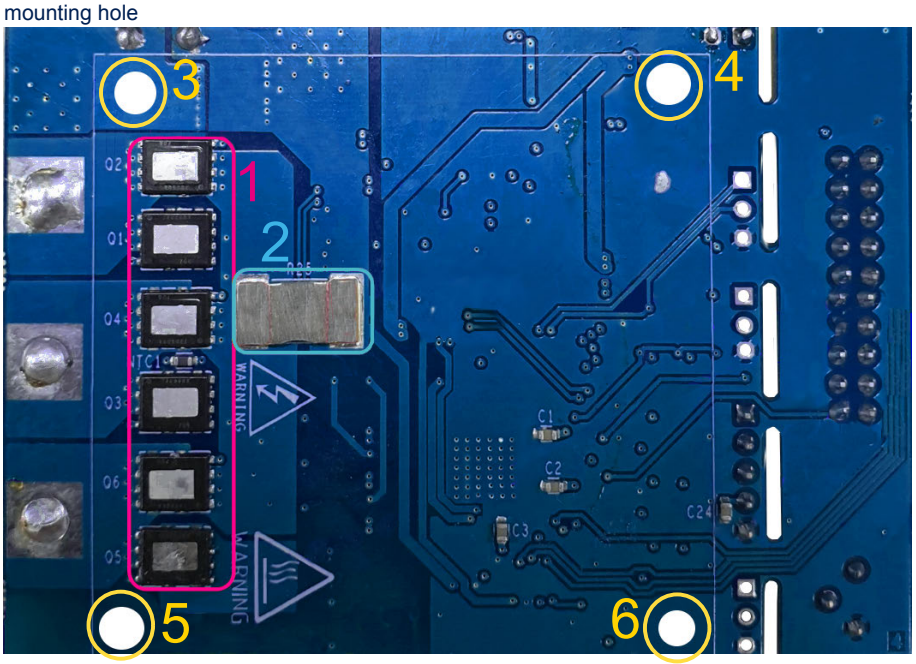


Figure 4. STEVAL-PTOOL2V1 main components and connectors

1. J3 external trigger
2. VBAT-
3. VBAT+
4. J8 W phase
5. J7 V phase
6. J6 U phase
7. J2 Hall encoder connector
8. J1 external speed regulation potentiometer
9. TR1 speed regulation trimmer
10. SW1 spinning direction switch
11. J9 external direction switch
12. J10 UART SWD - GPIO connector
13. J11 SWD connector
14. SW2 trigger button

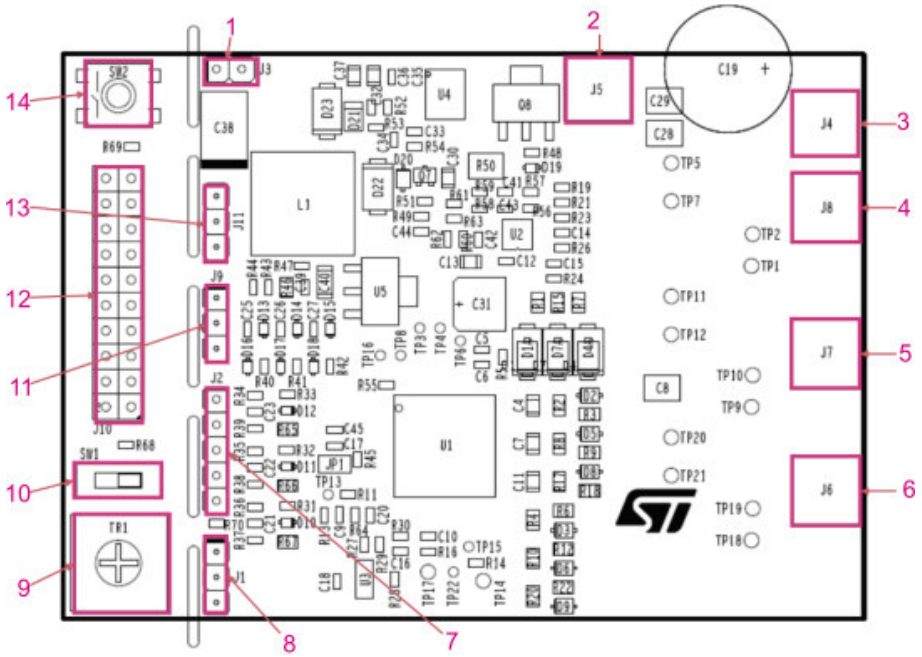


Table 1. Jumper settings

Jumper	Permitted configurations	Default condition
JP1	External reset (connected through soldering pads)	OPEN
JP2	Selection PA0 connected to BEMF phase U (1-2 CLOSED) or Hall 1 (2-3 CLOSED)	(2-3 CLOSED)
JP3	Selection PA1 connected to BEMF phase V (1-2 CLOSED) or Hall 2 (2-3 CLOSED)	(2-3 CLOSED)
JP4	Selection PA2 connected to BEMF phase W (1-2 CLOSED) or Hall 3 (2-3 CLOSED)	(2-3 CLOSED)

Table 2. Connectors and test points

Name	Pin	Label	Description
J1	1-2-3	J1	External potentiometer connector (remove R70 if used)
J2	1	A+/H1	Hall/encoder sensor connector
	2	B+/H2	
	3	Z+/H3	
	4	VDD	Hall sensor/encoder supply
	5	GND	
J3	1-2	J3	External trigger switch
J4	1	VBAT+	Battery positive terminal
J5	1	VBAT-	Battery negative terminal
J6	1	OUT U	3-phase BLDC motor phases connections
J7	1	OUT V	
J8	1	OUT W	
J9	1-2-3	J9	External direction switch connector (remove R68 if used)
J10	1	J10	NRST – MCU reset
	2		GND
	3		SWDIO – MCU debug IO port
	4		PB1 MCU GPIO
	5		GND
	6		PB0 MCU GPIO
	7		SWCLK – MCU debug clock port
	8		VBUS_fdbk (PA7) – Battery supply MCU monitor
	9		VDD – MCU supply
	10		CURRENT_REF (PA6) – current reference for 6-step current mode control
	11		PA15 MCU GPIO
	12		Curr_fdbk (PA5) – shunt current MCU sensing
	13		PB3 MCU GPIO
	14		Temp_fdbk (PA4) – Power bridge MCU monitor
	15		UART1_TX (PB6) – MCU uart transmit
	16		PA3 MCU GPIO – Speed set point MCU monitor
	17		UART1_RX (PB7) – MCU UART receive
	18		PF1 MCU GPIO
	19		BOOT0 – MCU bootloader selector
	20		PB8 MCU GPIO
J11	1	SWD IO	Auxiliary connector for SWD mode debugging/programming
	2	SWD CLK	
	3	GND	

Table 3. **Test points**

Name	Pin	Label	Description
TP1	-	TP1	W phase high side gate
TP2	-	OUT3	W phase
TP3	-	TP3	RES3
TP4	-	TP4	RES2
TP5	-	TP5	W phase low side gate
TP6	-	TP6	RES1
TP7	-	TP7	SENSE
TP8	-	TP8	PB4 MCU GPIO
TP9	-	TP9	V phase high side gate
TP10	-	TP10	V phase
TP11	-	TP11	V phase low side gate
TP12	-	TP12	SENSE
TP13	-	TP13	Speed set point
TP14	-	GND	GND – signal ground
TP15	-	PGND	PGND – power ground
TP16	-	TP16	PB5 GPIO
TP17	-	OD	OD – Smart SD Open Drain output, unlatch and restart input
TP18	-	TP18	U phase high side gate
TP19	-	TP19	U phase
TP20	-	TP20	U phase low side gate
TP21	-	TP21	SENSE
TP22	-	TP22	CIN – comparator positive input

3 How to use the board

Step 1. Check the jumper position according to the target configuration (see Section 2 Hardware description and configuration).

Step 2. Connect the motor phases to J6, J7 and J8 pads on the basis of the motor phase sequence.

Step 3. Supply the board through DC J4 (VBAT+) and J5 (VBAT-) pads.

Step 4. Develop your application using the STSW-PTOOL2V1 firmware example package as starting point.

3.1 Sensorless mode

To configure the STEVAL-PTOOL2V1 evaluation board for 6-step sensorless mode, BEMF network components (R65, R66, R67) have to be mounted and the BEMF detection network must be enabled.

You have to set jumpers as follows:

- JP2 pins 1-2: closed, PA0 connected to BEMF phase U
- JP3 pins 1-2: closed, PA1 connected to BEMF phase V
- JP4 pins 1-2: closed, PA2 connected to BEMF phase W

4 Hall/encoder motor speed sensor

The STEVAL-PTOOL2V1 evaluation board supports the digital Hall and quadrature encoder sensors for motor position feedback.

Sensors can be connected to the STSPIN32F0252 through J2 connector as listed in the following table.

Table 4. Hall/encoder sensors and J2 connections

Name	Pin	Description
Hall1/A+	1	Hall sensor 1/encoder out A+
Hall2/B+	2	Hall sensor 2/encoder out B+
Hall3/Z+	3	Hall sensor 3/encoder Zero feedback
VHALL	4	Sensor supply voltage (default VDD)
GND	5	Ground

A protection resistor of 1 kΩ is mounted in series with sensor outputs.

For sensors requiring external pull-up, three 10 kΩ resistors are already mounted on the output lines and connected to VDD voltage.

Set jumper resistors (R43 and R44) to configure the power supply for sensor supply voltage as follows:

- R44 mounted, R43 unmounted → Hall sensors powered by VDD (3.3 V)
- R44 unmounted, R43 mounted → Hall sensors powered by VCC (12 V)

The STSPIN32F0252 MCU can decode Hall/encoder sensor outputs by configuring jumpers as follows:

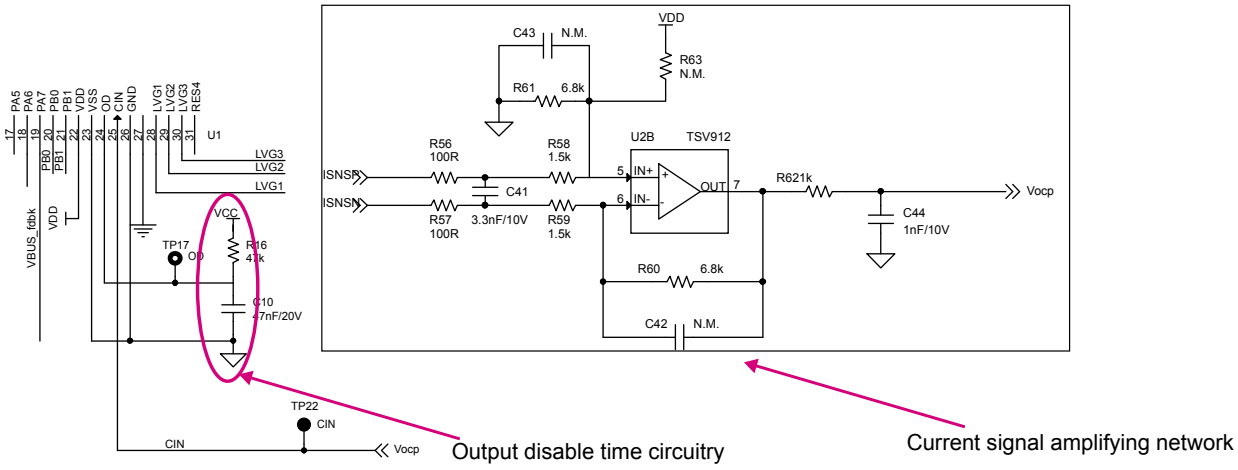
- JP2 pins 2-3: closed, PA0 connected to Hall1
- JP3 pins 2-3: closed, PA1 connected to Hall2
- JP4 pins 2-3: closed, PA2 connected to Hall3

5 Overcurrent detection and current sensing measurement

The STEVAL-PTOOL2V1 evaluation board implements overcurrent protection based on the STSPIN32F0252 integrated comparator.

The single shunt resistor measures the load current bringing the voltage signal associated to the load current and amplified by U2B OpAmp to CIN pin (TP22). When the phase peak current exceeds the selected threshold, the integrated comparator is triggered and all power switches are disabled until the current falls below the threshold and the output disable time expires.

Figure 5. Current sensing and disable time circuitry



By default, the STEVAL-PTOOL2V1 evaluation board overcurrent threshold is set to I_{OC_typ} = 36 A and the restart time after fault detection is ~735 µs.

Overcurrent threshold can be modified by changing the amplifying circuit gain and offset, according to the following formulas:

$$I_{OCtyp} = V_{REFtyp} \cdot \frac{1}{5R_{SHUNT} \cdot Ra \cdot G} - VDD \cdot \frac{R_b}{R_{SHUNT} \cdot Ra} \quad (1)$$

Where, based on default values:

V_{REF_typ} = 460 mV, VDD = 3.3 V, R_{SHUNT} = R25 = 3 mΩ and

$$Ra = \frac{R63//R61}{R56 + R58 + R63//R61} = 0.81(R63 \rightarrow +\infty) \quad (2)$$

$$Rb = \frac{(R58 + R56)//R61}{R63 + [(R58 + R56)//R61]} = 0\Big(R63 \rightarrow +\infty\Big)G = 1 + \frac{R60}{R58 + R56} = 5.25 \quad (3)$$

Therefore:

$$I_{OCtyp} \cong 36\ A$$

The output disable time can be monitored on OD pin (TP17) and is determined by the time required to recharge C10 capacitor up to V_{SSDh} threshold, according to:

V_{SSDh} = 3.8 V, V_{SSDl} = 0.56 V, V_{OD} = VCC =12 V

$$T_2 \cong C10 \cdot R16 \cdot 1n\left(\frac{V_{SSDl} - V_{OD}}{V_{SSDh} - V_{OD}}\right) \quad (4)$$

6 Bus voltage circuit

The STEVAL-PTOOL2V1 evaluation board provides the bus voltage sensing. This signal is set through voltage dividers (R71 and R72) from motor supply voltage (VBAT) and sent to PA7 GPIO (ADC channel 7) of the embedded MCU. The default voltage divider is set to 24.3.

7 Hardware user interface

The STEVAL-PTOOL2V1 board provides a hardware user interface which consists of:

- a trimmer (TR1) to set the target speed
- SW1 switch to set motor spin direction
- SW2 switch to turn the board power supply on or off, thus reducing static consumption to 0 A via Q8 P-channel MOSFET. If a continuous power supply is needed, for example, to load the firmware onto the MCU, short J3 connector pins.

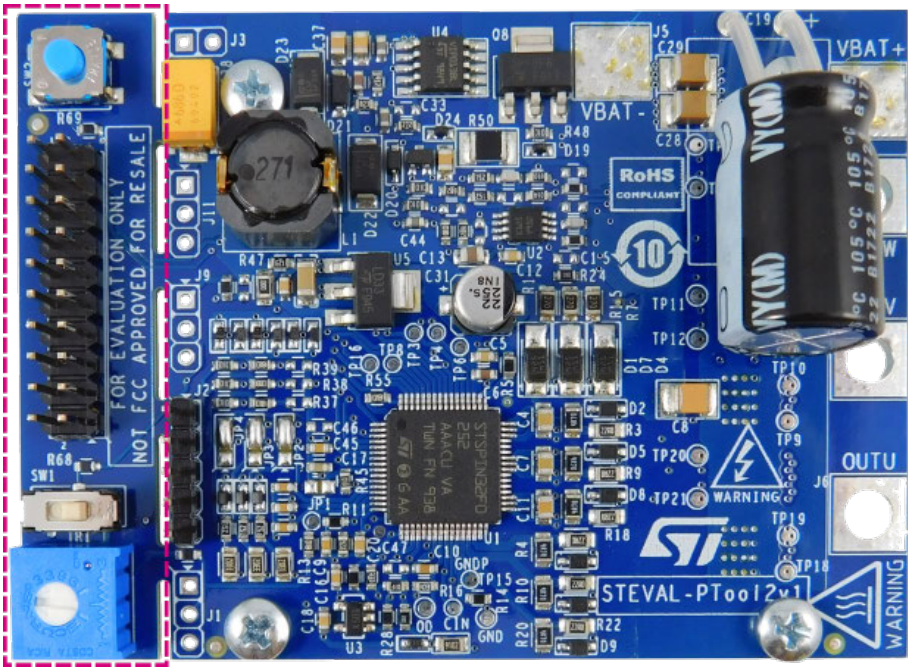
All above mentioned interfaces can be replaced by external inputs.

7.1 Detachable interface

If the on-board hardware user interface (SW1, SW2 and TR1) are not used, it is possible to detach the interface section by breaking the PCB along the slot holes.

You can still program or debug STSPIN32F0252 by connecting an external ST-LINK/V2-1 to J11 SWD connector.

Figure 6. STEVAL-PTOOL2V1 detachable section



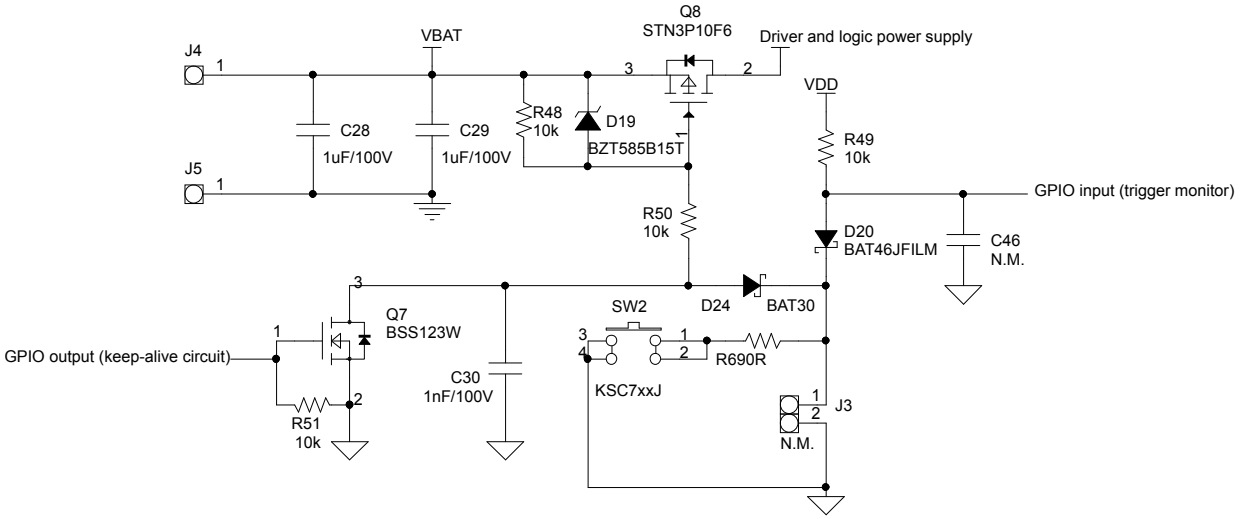
7.2 Turn on/off circuitry

The board offers the possibility of connecting or disconnecting the battery to the circuitry via an external switch (J3), to reduce the quiescent consumption to a very low level.

As soon as the switch is closed, the motor can be driven as required by the control algorithm.

By closing the trigger switch, the Q8 PMOS gate is forced low, connecting the battery to the control circuitry.

Figure 7. Turn on/off trigger circuitry



7.2.1 Keep-alive circuit

As soon as the Q8 PMOS connects the battery to the buck regulator, the power-up sequence starts, and V_{CC} and V_{DD} are provided to the STSPIN32F0252 driver and MCU, respectively.

When the MCU is operative, the PMOS can be kept turned on using Q7 NMOS, which acts as an MCU driven switch in parallel with the external trigger switch. Thus, the firmware takes control of the connection between the battery and the STSPIN32F0252 allowing the code to perform a safe switch-off (for example, by applying a brake sequence to the motor).

Note: Set the GPIO output (PC14) HIGH at MCU initialization.

7.2.2 External trigger status detection

While the STSPIN32F0252 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 (PC15) is connected to the switch through D20 diode. As long as the switch is closed, the GPIO is forced low through D20. Releasing the switch, D20 is no more polarized and the GPIO is pulled up by R49 resistor. Therefore, setting an interrupt on the rising edge of PC15 allows detecting the trigger release and stop the motor.

8 Debug

The STEVAL-PTOOL2V1 evaluation board can be connected to an external ST-LINK/V2-1 debugger/programmer which features:

- USB software re-enumeration
- Virtual COM port interface on USB connected to the STSPIN32F0252 (UART1) PB6/PB7 pins
- Mass storage interface on USB

The power supply for ST-LINK/V2-1 is provided by the host PC.

The MCU programming/debugging phase can be performed through the serial wire interface available on J10 or J11 connectors.

9 Schematic diagrams

Figure 8. **STEVAL-PTOOL2V1 circuit schematic (1 of 2)**

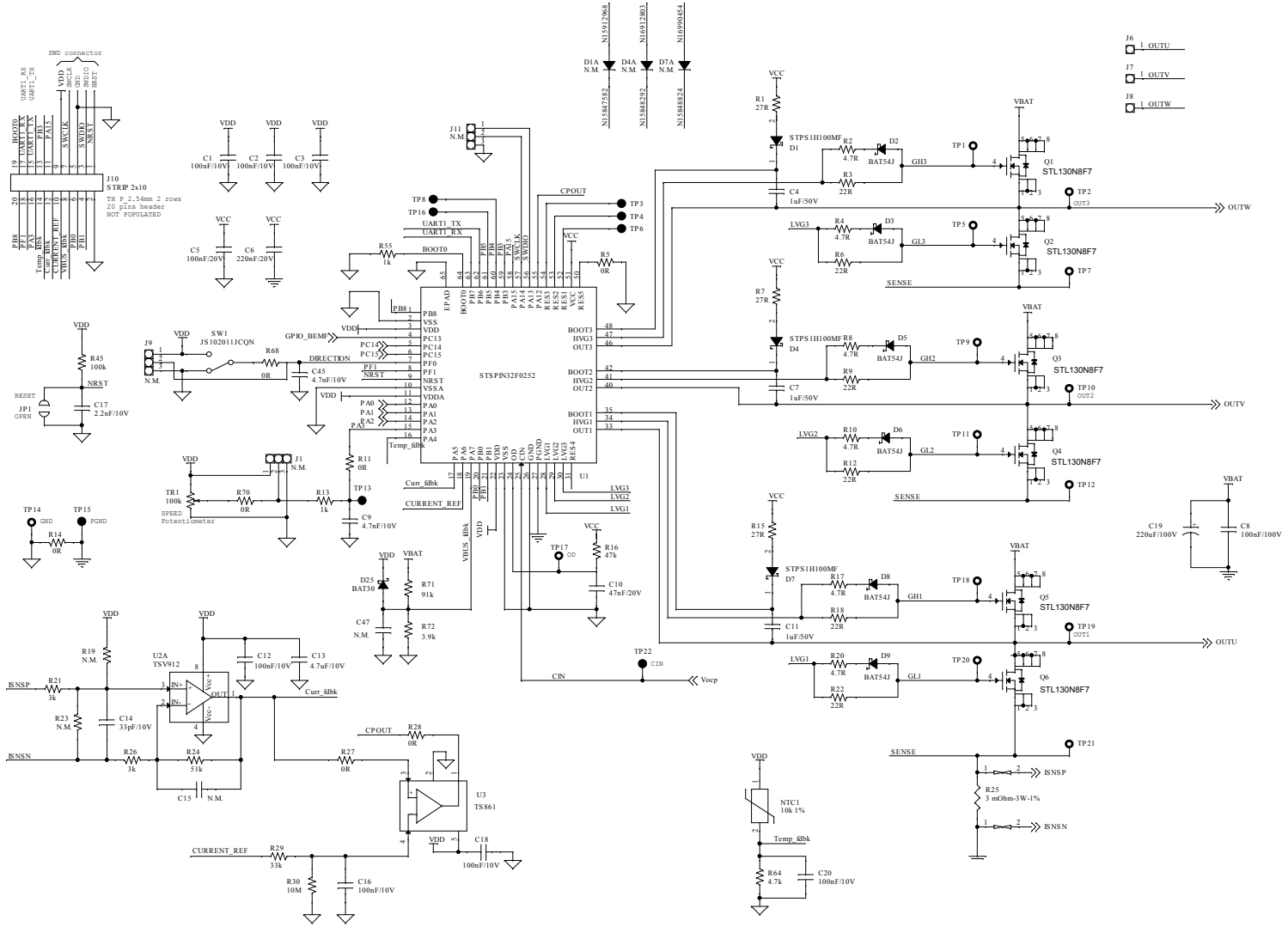
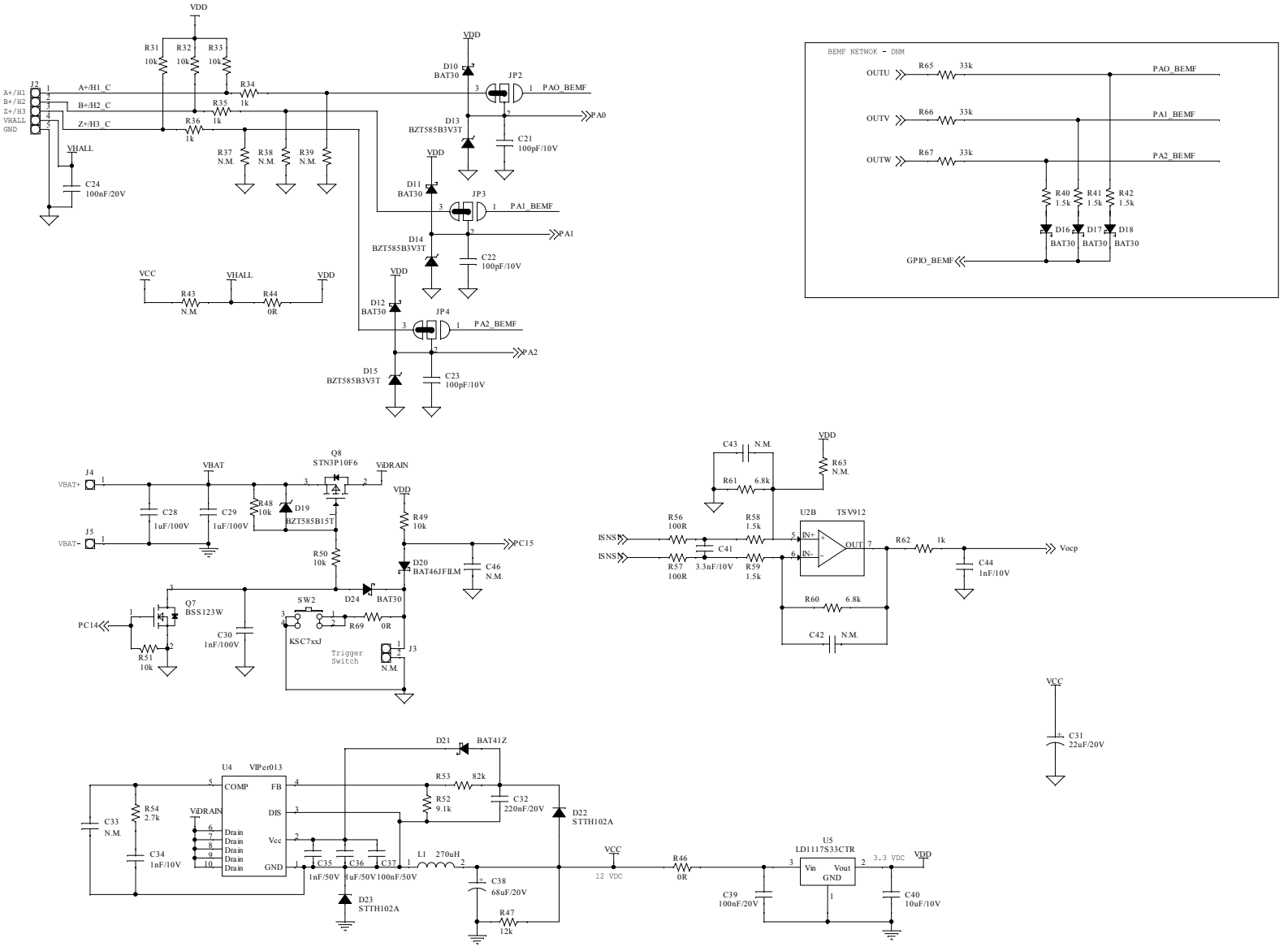


Figure 9. STEVAL-PTOOL2V1 circuit schematic (2 of 2)



10 Bill of materials

Table 5. **STEVAL-PTOOL2V1 bill of materials**

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
1	7	C1, C2, C3, C12, C16, C18, C20	100 nF/10 V/X7R 0603	SMT Ceramic Capacitor	Wurth Elektronik	885012206020 or equivalent
2	4	C4, C7, C11, C36	1 µF/50 V/X5R 0805	SMT ceramic capacitor	Wurth Elektronik	885012207103 or equivalent
3	3	C5, C24, C39	100 nF/20 V/X7R 0603	SMT Ceramic Capacitor	Wurth Elektronik	885012206071 or equivalent
4	2	C6, C32	220 nF/20 V/X7R 0603	SMT ceramic capacitor	Wurth Elektronik	885012206073 or equivalent
5	1	C8	100 nF/100 V 1210	SMT Ceramic Capacitor	TDK	CGA6M3X7R2E104M200AE or equivalent
6	2	C9, C45	4.7 nF/10 V 0603	SMT Ceramic Capacitor	Wurth Elektronik	885012206012 or equivalent
7	1	C10	47 nF/20 V/X7R 0603	SMT Ceramic Capacitor	Wurth Elektronik	885012206069 or equivalent
8	1	C13	4.7 µF/10 V/ X7R0805	SMT Ceramic Capacitor	Wurth Elektronik	885012207025 or equivalent
9	1	C14	33 pF/10 V/NPO 0603	SMT Ceramic Capacitor	Wurth Elektronik	885012006005 or equivalent
10	6	C15, C33, C42, C43, C46, C47	N.M. 0603	SMT ceramic capacitor (not mounted)	Any	
11	1	C17	2.2 nF/10 V/X7R 0603	SMT Ceramic Capacitor	Wurth Elektronik	885012206010 or Equivalent
12	1	C19	220 µF/100 V Diam. 12.5mm p. 5mm 100V	THT Electrolytic Capacitor	Panasonic	EEUFS2A221B or equivalent
13	3	C21, C22, C23	100pF/10V/ X7R0603	SMT Ceramic Capacitor	Wurth Elektronik	885012206003 or equivalent
14	2	C28, C29	1 µF/100V 1210	SMT ceramic capacitor	KEMET	C1210C105K1RACAUTO
15	1	C30	1nF/100V/X7R 0805	SMT ceramic capacitor	Wurth Elektronik	885012207116 or equivalent
16	1	C31	22 µF/20V 5x5.4 mm 20V	SMT Aluminum Elect. Capacitor	Wurth Elektronik	865090442004 or equivalent
17	1	C34	1nF/10V/X7R 0603	SMT ceramic capacitor	Wurth Elektronik	885012206008 or equivalent
18	1	C35	1 nF/50 V/X7R 0603	SMT ceramic capacitor	Wurth Elektronik	885012206083 or equivalent
19	1	C37	100 nF/50 V/ X7R0805	SMT ceramic capacitor	Wurth Elektronik	885012207098 or equivalent
20	1	C38	68 µF/20 V D / E 20V	Low ESR series of robust MnO2 solid electrolyte capacitors	AVX	TPS Series or equivalent
21	1	C40	10 µF/10 V/X7R 1206	SMT Ceramic Capacitor	Wurth Elektronik	885012208018 or equivalent

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
22	1	C41	3.3 nF/10 V/X7R 0603	SMT ceramic capacitor	Wurth Elektronik	885012206011 or equivalent
23	1	C44	1 nF/10 V/NPO 0603	SMT ceramic capacitor		
24	3	D1, D4, D7	STPS1H100MF STmite flat (DO222-AA)	High voltage power Schottky rectifier	ST	STPS1H100MF
			N.M. SMA	High efficiency ultrafast diode (not mounted)	ST	STTH102A
25	2	D22, D23	STTH102A SMA	High efficiency ultrafast diode	ST	STTH102A
26	6	D2, D3, D5, D6, D8, D9	BAT54J SOD-323	40 V, 300 mA Small signal Schottky SMT Diode	ST	BAT54JFILM
27	8	D10, D11, D12, D16, D17, D18, D24, D25	BAT30 SOD-523	30 V, 300 mA small signal Schottky SMT diode	ST	BAT30KFILM
28	3	D13, D14, D15	BZT585B3V3T SOD523	Surface mount precision Zener diode	Diodes Incorporated	BZX585B3V3T or equivalent
29	1	D19	BZT585B15T SOD523	Surface mount precision Zener diode	Diodes Incorporated	BZT585B15T or equivalent
30	1	D20	BAT46JFILM SOD-323	100 V, 150 mA small signal Schottky diode	ST	BAT46JFILM
31	1	D21	BAT41Z SOD-123	100 V, 200 mA low capacitance small signal Schottky diode	ST	BAT41ZFILM
32	1	JP1	OPEN Soldering pads	SMT jumper	Any	
33	3	JP2, JP3, JP4	CLOSE 2-3 Soldering pads	SMT jumper	Any	
34	3	J1, J9, J11	N.M. 1x3 pins	Strip connector 3 pos, 2.54 mm (not mounted)	Wurth Elektronik	61300311121 or equivalent
35	1	J2	STRIP 1x5 1x5 pins	Strip connector 5 pos, 2.54 mm	Wurth Elektronik	61300511121 or equivalent
36	1	J3	N.M. 1x2 pins	Strip connector 2 pos, 2.54 mm (not mounted)	Wurth Elektronik	61300211121 or equivalent
37	2	J4, J5	N.M. Dim. 6.2x6.5 mm	Solder Pad (not mounted)	Any	
38	3	J6, J7, J8	N.M. Dim. 6.2x6.5 mm	Solder Pad (not mounted)	Any	
39	1	J10	STRIP 2x10 2x10 pins	Strip connector 2x10, pitch 2.54 mm	Wurth Elektronik	61302021121 or Equivalent
40	1	L1	270uH	Wire Wound Ferrite Inductor for Power Lines	Murata or Wurth Elektronik	#B966BS-271M=P3 or Equivalent or 744776227

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
41	1	NTC1	10 k ±1% 0603	NTC Thermistor	Murata	NCP18XH103F03RB or Equivalent
42	2	Net1, Net2	N.M.	(not mounted)	Any	
43	6	Q1, Q2, Q3, Q4, Q5, Q6	STL130N8F7	N-channel 80 V, 3.0 mOhm typ., 120 A STripFET F7 power MOSFET	ST	STL130N8F7
			STL130N8F7	Automotive-grade N-channel 80 V, 3.15 mOhm typ., 130 A STripFET F7 Power MOSFET		STL135N8F7AG
44	1	Q7	BSS123W SOT-323	SIPMOS small signal transistor	DIODES incorporated	BSS123W-7-F or equivalent
45	1	Q8	STN3P10F6 SOT-223	P-channel -100 V, 0.136 O typ., -3 A STripFET F6 Power MOSFET	ST	STN3P10F6
46	3	R1, R7, R15	27 R 0805	SMT resistor	Any	
47	6	R2, R4, R8, R10, R17, R20	4.7 R 0805	SMT Resistor	Any	
48	6	R3, R6, R9, R12, R18, R22	22 R 0805	SMT Resistor	Any	
49	1	R5	0 R 0603	SMT Resistor	Any	
50	8	R11, R14, R27, R28, R44, R68, R69, R70	0 R 0603	SMT resistor	Any	
51	6	R13, R34, R35, R36, R55, R62	1 k 0603	SMT resistor	Any	
52	1	R16	47 k 0603	SMT Resistor	Any	
53	7	R19, R23, R37, R38, R39, R43, R63	N.M. 0603	SMT resistor (not mounted)	Any	
54	2	R21, R26	3 k 0603	SMT Resistor	Any	
55	1	R24	51 k 0603	SMT Resistor	Any	
56	1	R25	3 mOhm-3 W ±1% 2512	Power Metal Strip Resistors, Very High Power (to 3 W), Low Value	Vishay	WSLP25123L000FEA or equivalent
57	1	R29	33 k 0603	SMT Resistor	Any	
58	1	R30	10 M 0603	SMT Resistor	Any	
59	6	R31, R32, R33, R48, R49, R51	10 k 0603	SMT resistor	Any	

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
60	5	R40, R41, R42, R58, R59	1.5 k 0603	SMT resistor	Any	
61	1	R45	100 k 0603	SMT resistor	Any	
62	1	R46	0 R 0805	SMT resistor	Any	
63	1	R47	12 k 0603	SMT resistor	Any	
64	1	R50	10 k 1210	SMT resistor	Any	
65	1	R52	9.1 k 0603	SMT resistor	Any	
66	1	R53	82 k 0603	SMT resistor	Any	
67	1	R54	2.7 k 0603	SMT resistor	Any	
68	2	R56, R57	100 R 0603	SMT resistor	Any	
69	2	R60, R61	6.8 k 0603	SMT resistor	Any	
70	1	R64	4.7 k 0603	SMT Resistor	Any	
71	3	R65, R66, R67	33 k 0805	SMT resistor	Any	
72	1	R71	91 k 0805	SMT resistor	Any	
73	1	R72	3.9 k 0603	SMT resistor	Any	
74	1	SW1	JS102011JCQN	SMT sub-miniature slide switches	C&K	JS102011JCQN or equivalent
75	1	SW2	KSC7xxJ	KSC series sealed tactile switch for SMT	C&K	KSC701J LFS / LFG or equivalent
76	14	TP1, TP2, TP5, TP7, TP9, TP10, TP11, TP12, TP14, TP17, TP18, TP19, TP20, TP21	N.M. Copper pad	50 mils SMD pad (not mounted)	Any	
77	3	TP3, TP8, TP16	N.M. Copper Pad	Test point - PCB 1 mm diameter (not mounted)	Any	
78	1	TP4	N.M. Copper Pad	Test point - PCB 1 mm diameter (not mounted)	Any	
79	1	TP6	N.M. Copper Pad	Test point - PCB 1 mm diameter (not mounted)	Any	
80	1	TP13	N.M. Copper Pad	Test point - PCB 1 mm diameter (not mounted)	Any	
81	1	TP15	N.M. Copper Pad	Test point - PCB 1 mm diameter (not mounted)	Any	
82	1	TP22	N.M. Copper Pad	Test point - PCB 1 mm diameter (not mounted)	Any	
83	1	TR1	100 k 3386P	Trimming potentiometer	Bourns	3386P-1-104-LF or Equivalent

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
84	1	U1	STSPIN32F0252 TQFP64-10x10x 1.0	250 V three-phase controller with ARM Cortex MCU-1 A capability	ST	STSPIN32F0252TR
85	1	U2	TSV912 MiniSO8	Dual rail-to-rail input/output 8 MHz operational amplifiers	ST	TSV912IST / TSV912IYST
86	1	U3	TS861 SOT23-5	Rail-to-rail micropower BiCMOS comparators	ST	TS861
87	1	U4	VIPer013 SSOP10	Energy saving off-line high voltage converter	ST	VIPER013BLS/ VIPER013BTR
88	1	U5	LD1117S33CTR SOT-223	800 mA, 3.3 V adjustable and fixed low drop positive voltage regulator	ST	LD1117S33CTR
89	4		M3x10mm	M3 conical head screw	Any	
90	4		M3 Nut	M3 nut	Any	
91	4		sp. 1.19 mm	Flat washers	Keystone	3162 or equivalent
92	1		54x54x10 mm	Heat sink	ATS	ATS-CPX054054010-125-C2-R0 or equivalent
93	1		diam. 1.6 (0.8) 36 mm	Shrink tube	Any	
94	1		40x50mm 40x50mm thickness.0, 5 mm.	Thermal interface sheet, 3.2 W/m·K, 150x150 mm	Any	
95	1		56.5x80 mm	PCB	Any	

Revision history

Table 6. **Document revision history**

Date	Version	Changes
02-Oct-2020	1	Initial release.
10-Feb-2022	2	Updated Section 10 Bill of materials.

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