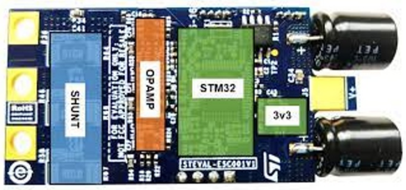


ST UM2197 Electronic Speed Controller for BLDC and PMSM Three Phase Brushless Motor User Manual

UM2197
User manual
life. augmented

Contents

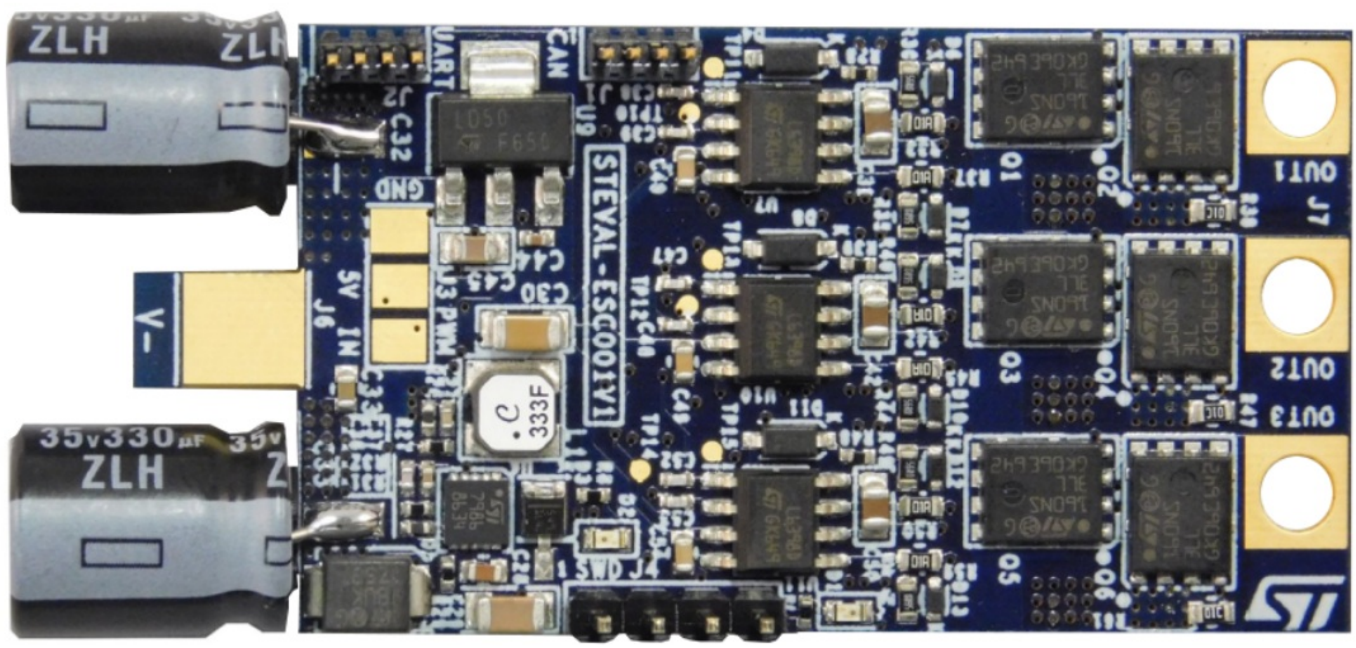
UM2197 Electronic Speed Controller for BLDC and PMSM Three Phase Brushless Motor

Electronic speed controller for BLDC and PMSM three-phase brushless motor

Introduction

The STEVAL-ESC001V1 reference design for electronic speed controllers (ESC) for drones fits the entry-level commercial drone designs and drives any three-phase brushless (or PMSM) motor running off 6S LiPo battery packs, or any equivalent DC supply, up to 30 A peak current.
The STEVAL-ESC001V1 lets you spin a motor and its propeller in minutes thanks to STM32 Motor Control Software Development Kit (MCSDK) with the ST Motor profiler (X-CUBE-MCSDK). It implements a sensorless field-oriented controlled (FOC) algorithm with 3-shunt current reading, speed control, and full active braking.
The reference design board can accept commands from a flight control unit through PWM signals; other communication bus interfaces like UART, CAN, and I²C are also available. The reference embeds a battery eliminator circuit working at 5 V, an NTC sensor for temperature measurement, and circuitry for overcurrent/overvoltage protection (OCP/OVP). The compact form factor and current capability render this reference design suitable for electronic speed controllers on small and light unmanned aerial vehicles like professional drones. The X-CUBE-MCSDK software package lets you refine your electronic speed controller design.
They act on the FOC parameters embedded in the STM32 and experiment with the ST motor profiler to retrieve rapidly the motor parameters. The ST sensorless FOC algorithm ensures longer flight times and optimal dynamic performance. The STEVAL-ESC001V1 is designed around the highly efficient, low Rdson STripFET F7 power MOSFETs, the high-performance STM32F303CBT7 microcontroller with Arm ® ® Cortex -M4 core, and the L6398 drivers.

Figure 1. STEVE-ESC001V1 evaluation board



Main features

- Complete reference design for electronic speed controller implementing a sensorless FOC algorithm
- Designed for drones with a 6S pack of LiPo batteries or systems with an equivalent suitable DC supply
- ESC ready for communication with any standard flight control unit (FCU): PWM or CAN
- Temperature overheating protection
- Nominal operating voltage range: 3S-6S Li-Po battery DC voltage level (11.1 to 22.2 V)
- Maximum RMS output current: 20 Arms
- Output peak current: 30 A
- Battery eliminator circuit (BEC): 5 V/0.5 A for an external receiver or FCU
- Example project available on STM32 motor control software development kit (X-CUBE-MCSDK)

- Supported by ST motor control software SDK and ST motor profiler
- Compact PCB design: 29.1 x 58 mm
- Further target applications:
  – motor driving for RC vehicles: electric cars, helicopters, trucks, etc.
  – any three-phase BLDC or PMSM motor application
- RoHS and WEEE compliant

Target application

Motor driving for remote control vehicles, UAV drones, electrical cars, boats, etc.

Figure 2. STEVE-ESC001V1 target applications

Description

The STEVAL-ESC001V1 electronic speed controller (ESC) evaluation board drives a single three-phase brushless motor with very high performance in sensorless mode (without a position sensor). It is designed to provide fast and efficient propulsion for remote control applications like electric cars, boats, and drones and is capable of low and very high-speed regulation and strong dynamic response under different load conditions.
An external signal via a communication bus between the board and a generic central unit sets the speed regulation reference and another signal reports the status of the system, including faults, which the central unit can use to trigger corrective events..
The same 6Step (or trapezoidal) control algorithm (often with no shunt resistors) drives the many different ESCs offering various motor currents, sizes,s, and input voltages for remote control applications. A more sophisticated control algorithm is used in the STEVAL-ESC001V1, based on field-oriented control (FOC); it features:

- better torque control
- motor current regulation in case of fast load change
- vibration reduction
- active braking function
- better efficiency
- noise reduction
- a real-time monitor of the rotor speed
- energy recovery during the deceleration

The typical system architecture pictured below shows individual ESC boards connected to single brushless motors in a quadcopter system. An external Li-Po battery powers the four boards and a wired bus carries communication between each board and an external unit such as a flight control board.

Figure 3. System structure overview

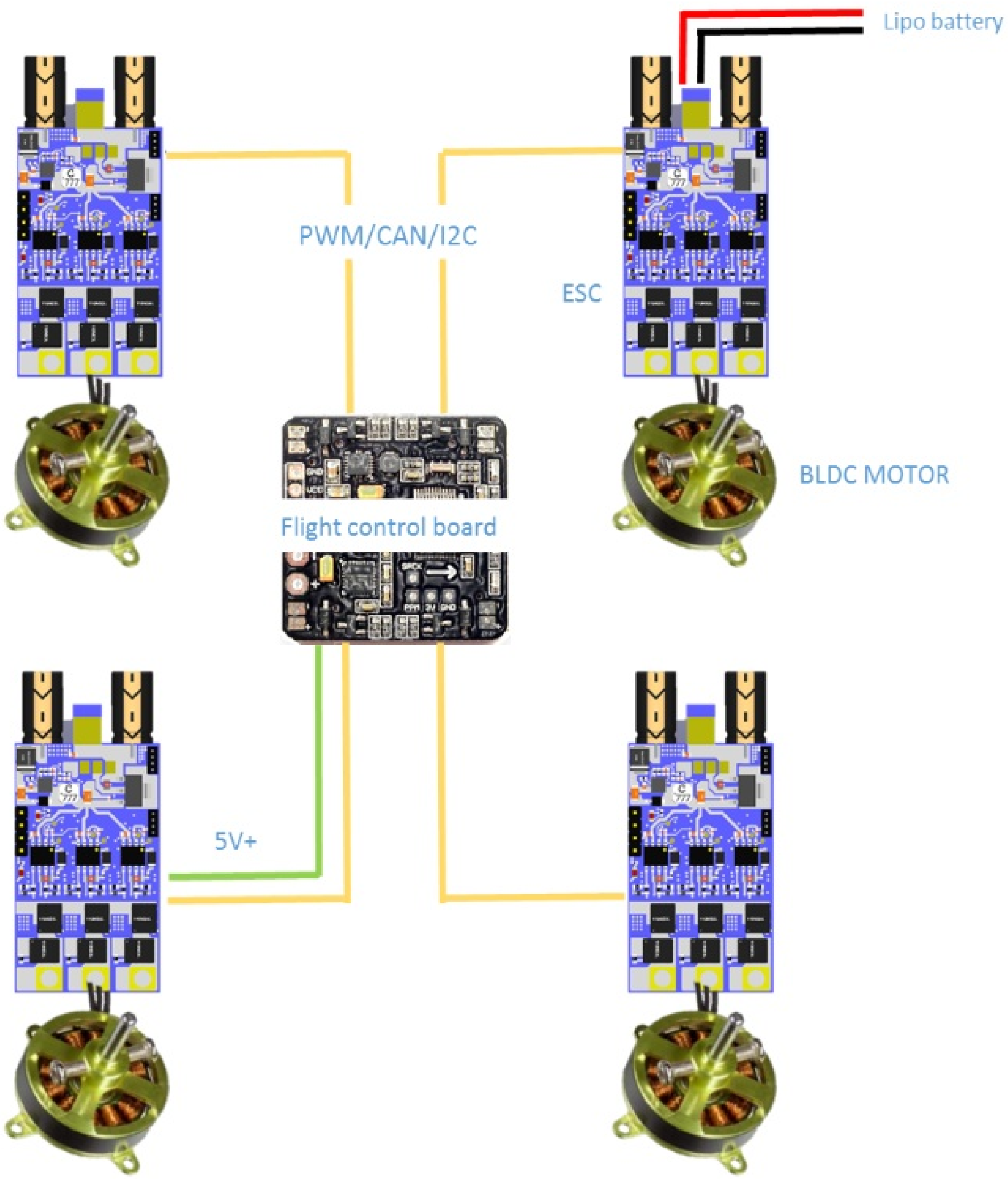
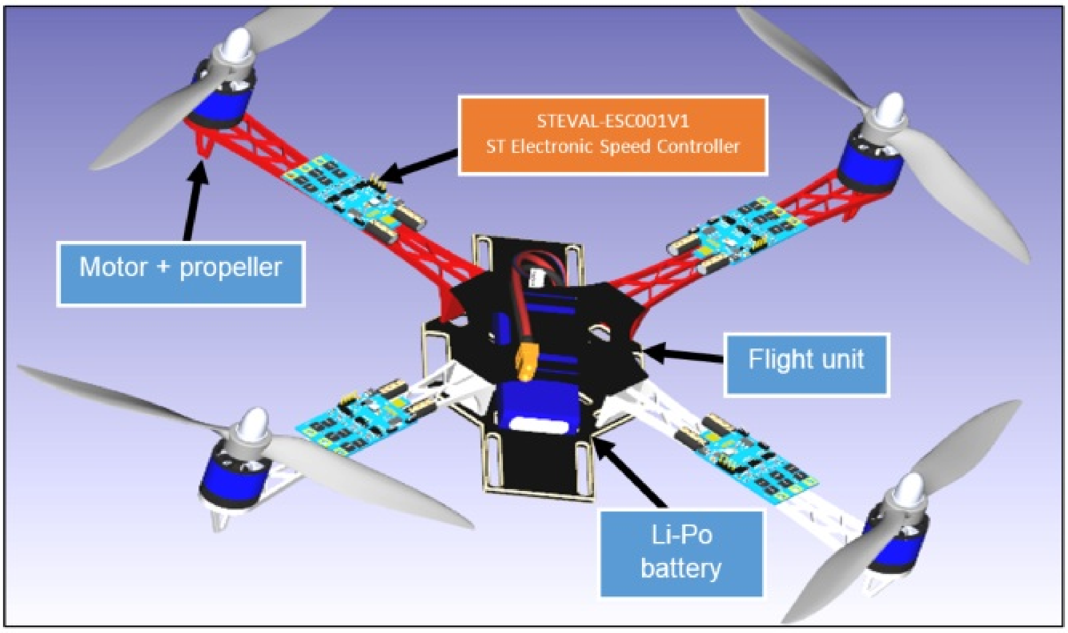


Figure 4. Typical quadcopter architecture

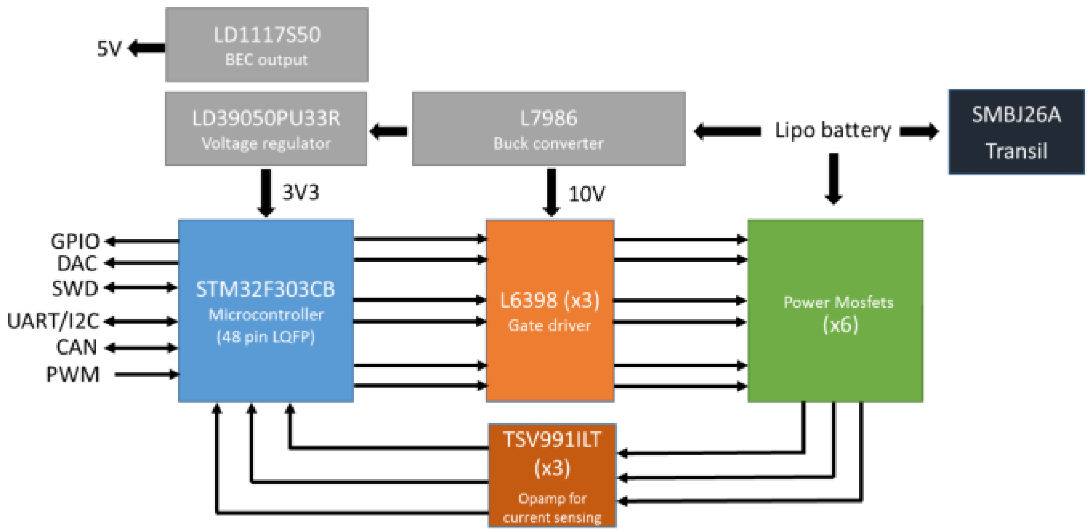


The on-board I²C, UART, PWM, and CAN communication protocols provide maximum flexibility, and a DC-DC converter with a 5 V output connector (BEC) can supply an external control unit or sensor board.

2.1 STEVAL-ESC001V1 hardware overview

The STEVAL-ESC001V1 power and control platform is based on the ST componentry illustrated below.

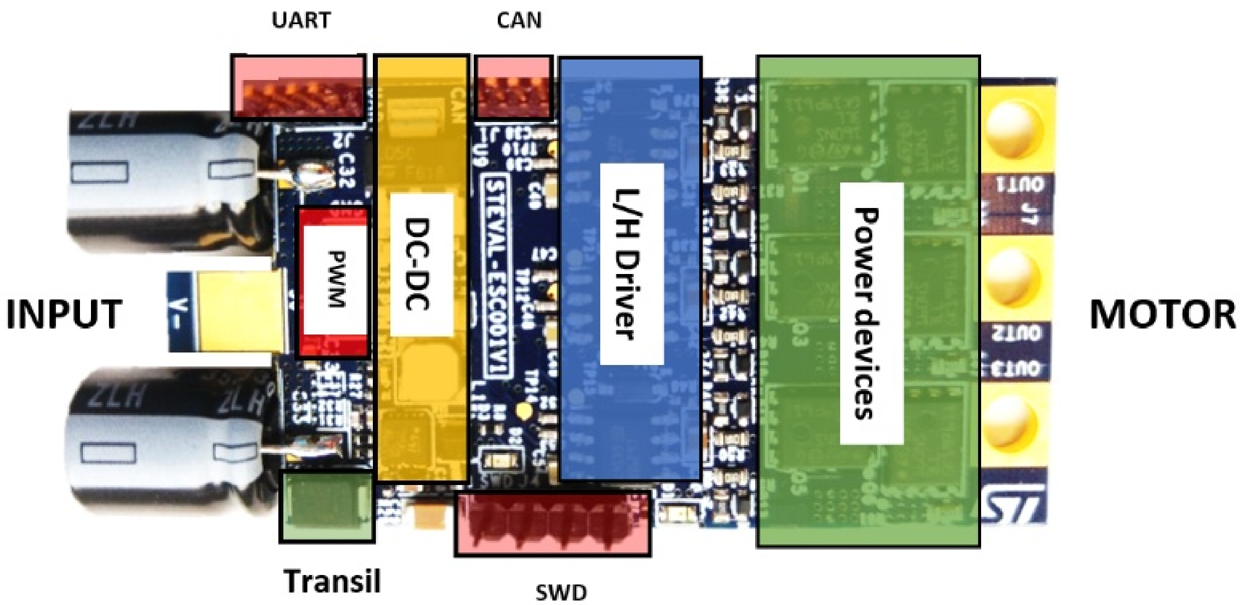
Figure 5. STEVAL-ESC001V1 block diagram



2.1.1 STEVAL-ESC001V1 top side components

The inverter section is formed by the L6398 gate driver and the STL160N4F7 and the Power MOSFETs.

Figure 6. Top side features



L6398 high voltage high and low-side driver

The L6398 is a high voltage device manufactured with the BCD™ "offline" technology. It is a single-chip half-bridge gate driver for the N-channel power MOSFET or IGBT.

The high-side (floating) section is designed to stand a voltage rail up to 600 V. The logic inputs are CMOS/TTL compatible down to 3.3 V for the easy interfacing microcontroller/DSP. Key features:

- High voltage rail up to 600 V
- DV/DT immunity ±50 V/ns in the full temperature range
- Driver current capability:
  – 290 mA source
  – 430 mA sink
- Switching times 75/35 ns rise/fall with 1 nF load
- 3.3 V, 5 V TTL/CMOS input comparators with hysteresis
- Integrated bootstrap diode
- Fixed 320 ns deadtime
- Interlocking function
- Compact and simplified layout
- Bill of material reduction
- Flexible, easy, and fast design

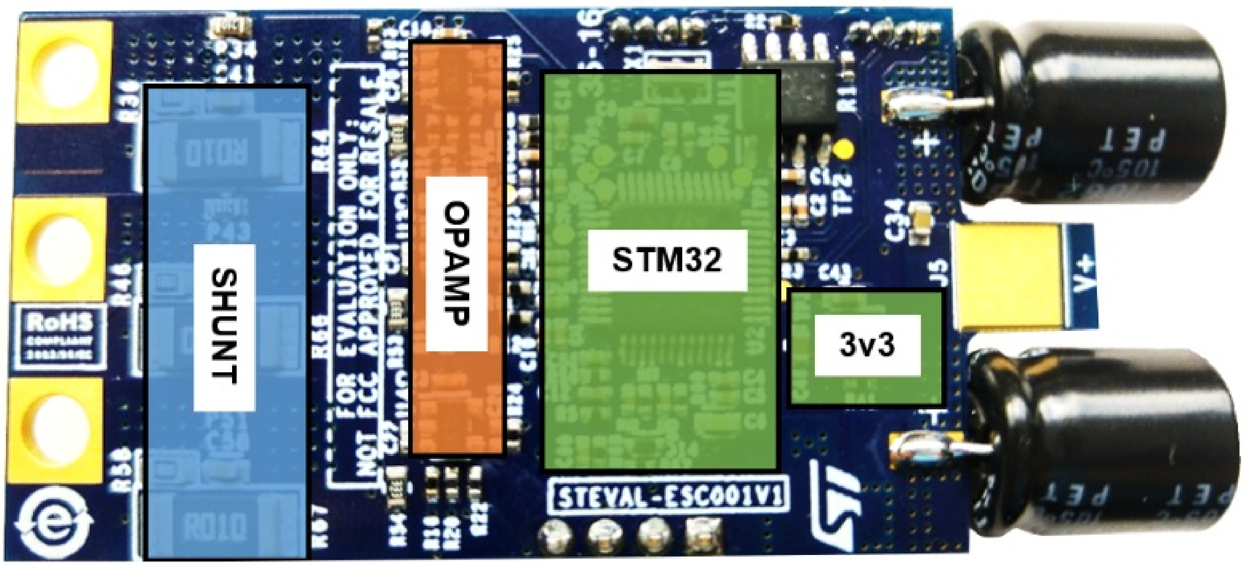
STL160N4F7 160 A STripFET™ F7 Power MOSFETs
This N-channel Power MOSFET uses STripFET™ F7 technology with an enhanced trench gate structure that results in very low on-state resistance, while also reducing internal capacitance and gate charge for faster and more efficient switching.

L7986, LD1117S50, and LD39050PU33R
These devices provide the appropriate voltage for gate driving, BEC output, and MCU power.

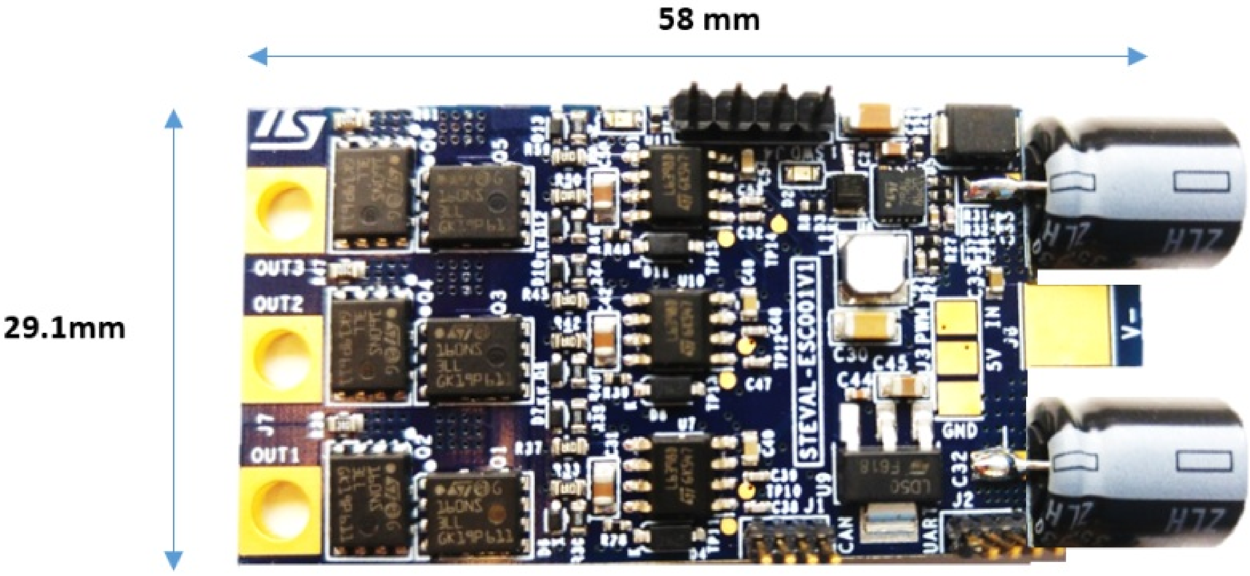
2.1.2 STEVAL-ESC001V1 bottom side components
The bottom side componentry is mainly for the digital section; featuring an STM32F303 microcontroller for three-shunt sensorless FOC control in an LQFP 48-pin package.

STM32F303xB 32-bit ARM Cortex-M4 MCU with 128 Kbytes Flash and 72 MHz CPU
The family of microcontrollers is based on the high-performance ARM ® ®Cortex -M4 32-bit RISC core plus FPU operating at 72 MHz max and embedded memory protection unit (MPU).

Figure 7. Bottom side features



2.1.3 Board dimensions (29.1 x 58 mm)
Figure 8. STEVE-ESC001V1 board dimensions (not including capacitors)



2.2 Communication, programming, and command interfaces

The STEVAL-ESC001V1 features these communication interfaces:

- CAN port (J1): comes with an onboard transceiver; the J1 connector includes 3V3 and GND pins.
- UART/I²C port (J2): normally used for serial communication between the ESC board and a PC; ST MC Workbench can be connected with the STM32, adding an external circuit (requires USB/RS232 converter-3v3 level)

  Figure 9. UART TX/RX (3v3 level)

- **PWM signal input (J3):** connects with an external board (e.g., flight control unit), to receive commands; the signal level (at 3v3) sets the motor speed according to the Ton duration (i.e., 1060 µs for min. speed and 1860 µs for max. speed). Other pins are for GND and a +5Vdc power line to supply an external board
- **SWD debug port (J4):** provides the SWD connection between the STM32 and ST-LINK programmer; other pins like 3V3 and GND are available.

2.3 STM32 pinout for motor control

Table 1. Main STM32 pinout for motor control

Pin	Default	Signal
1	VBA	3V3
2	PC13/TAMP/RTC	TP4
3	PC14	N.C.
4	PC15	N.C.

5	PF0/OSC-IN	OSC 8Mhz
6	PF1/OSC-OUT	OSC 8Mhz
7	NRST	RESET
8	VSSA/VREF-	GND
9	VDDA/VREF+	3V3
10	PA0-WKUP	Curr_fdbk1
11	PA1	Curr_fdbk2
12	PA2	Curr_fdbk3
13	PA3	Temperature feedback
14	PA4	VREF, DAC1, TP8
15	PA5	DAC2, TP9
16	PA6	N.C.
17	PA7	Vshunt_1_filtered
18	PB0	Vshunt_2_filtered
19	PB1	TIM1_CH3N
20	PB2	STATUS
21	PB10	N.C.
22	PB11	Vshunt_3_filtered
23	VSS1	GND
24	VDD1	3V3
25	PB12	PHASE_1
26	PB13	VBUS
27	PB14	PHASE_2
28	PB15	PHASE_3
29	PA8	TIM1_CH1
30	PA9	TIM1_CH2
31	PA10	TIM1_CH3
32	PA11	TIM1_CH1N
33	PA12	TIM1_CH2N
34	PA13	STUDIO
35	VSS2	GND
36	VDD2	3V3
37	PA14	SWCLK

38	PA15	INPUT
39	PB3	N.C.
40	PB4	TP3
41	PB5	N.C.
42	PB6	USART1_TX/I2C1_SCL
43	PB7	USART1_RX/I2C1_SDA
44	BOOT0	BOOT0

Pin	Default	Signal
45	PB8	CAN_RX
46	PB9	CAN_TX
47	VSS	
48	VDD	

Table 2. Input/output terminals

Screw Terminal	Function
J5/J6	Li-Po battery power input (3S-6S)
J7	3-PH Motor connector

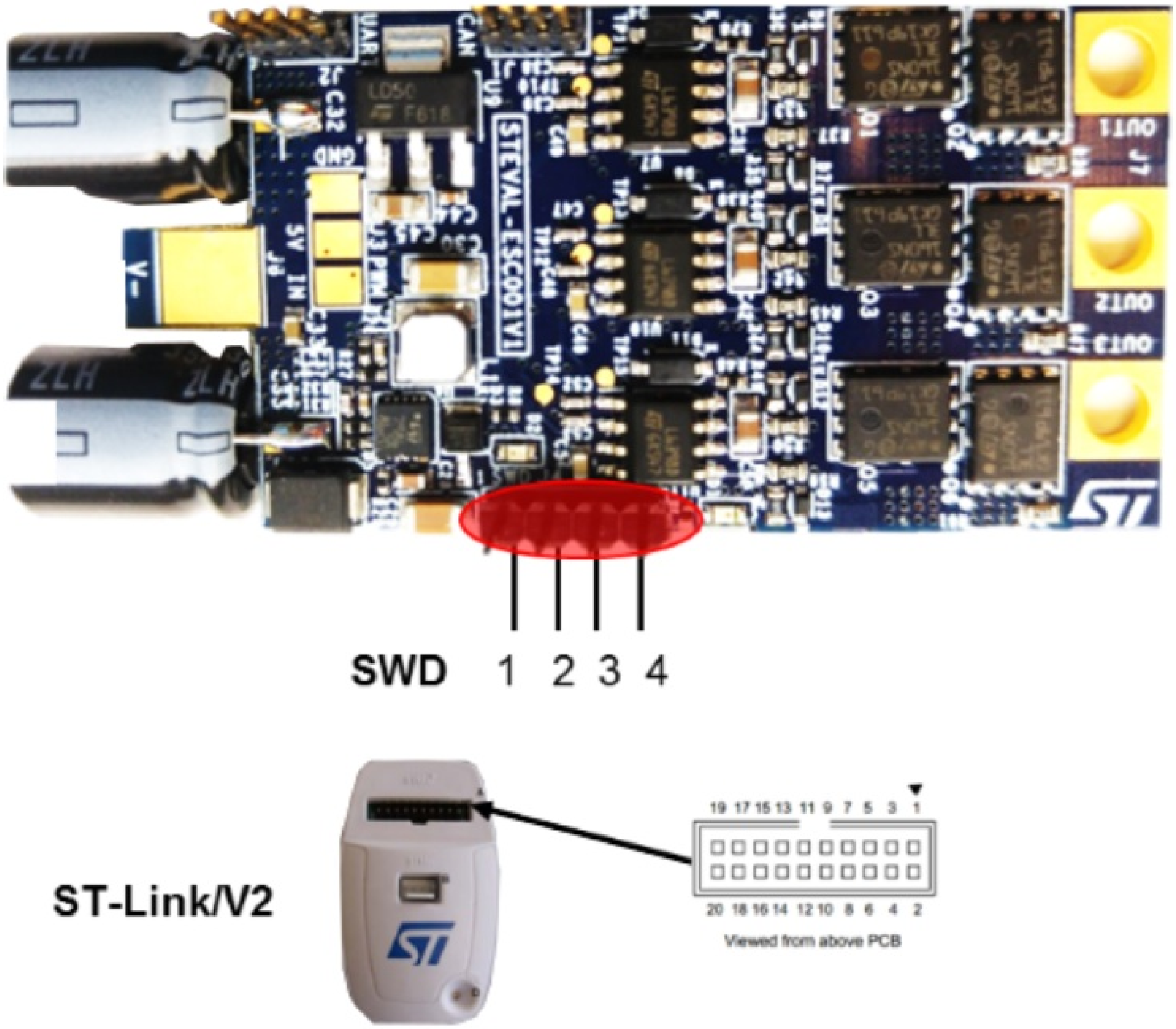
Initializing and using the STEVAL-ESC001V1 ESC board

Step 1. Connect the ST-LINK/V2 programmer to the J4 connector on the board.

Table 3. Relationship between the STEVAL board SWD pinout and SWD on ST-Link/V2 programmer

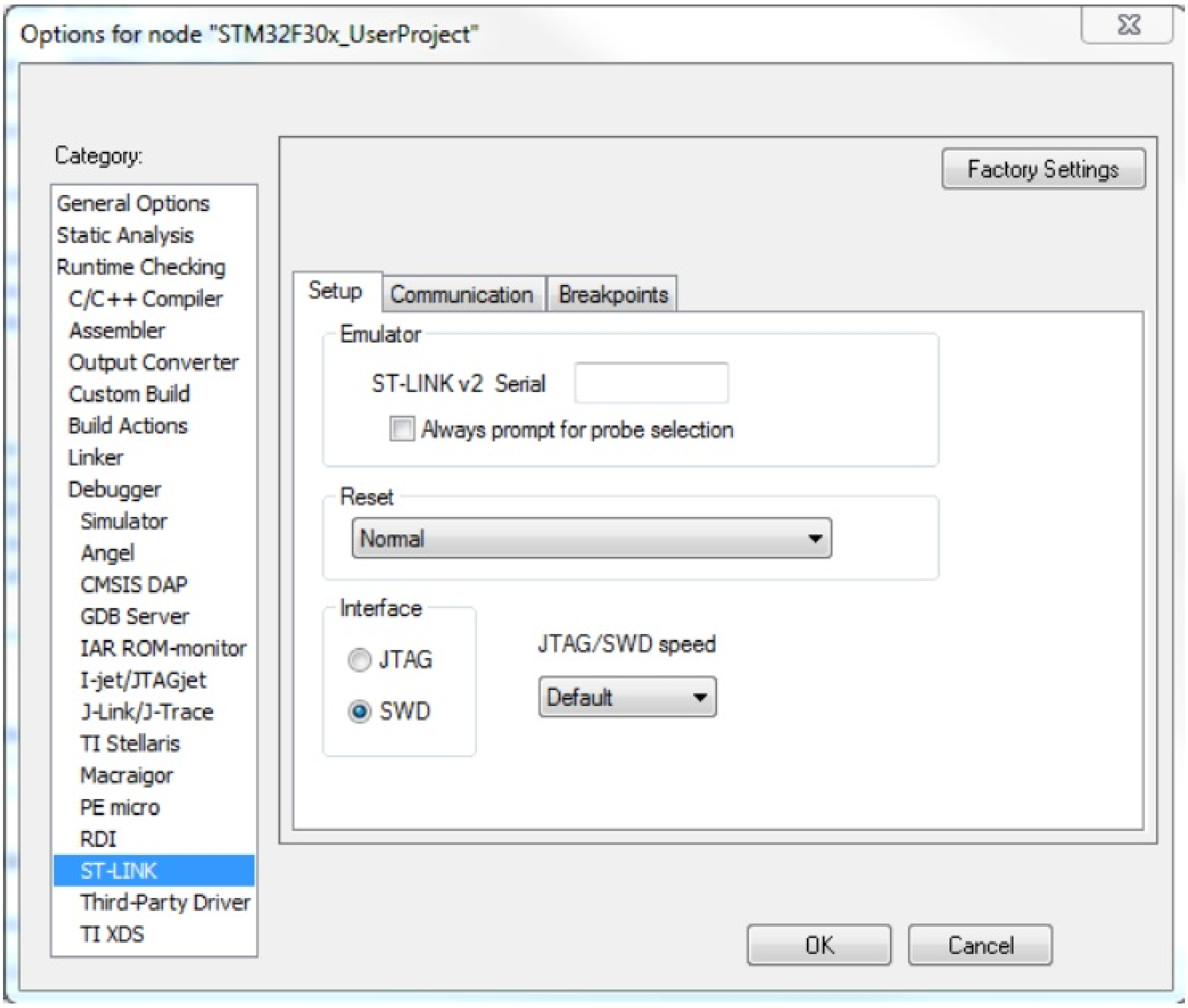
Pin no. in STLINK	ST-LINK/V2	ST-LINK/V2 function	Target connection	Pin no. in STEVALESC001V1 (J4 connector)
1	connector	Target VCC	(SWD)	1
2	VAPE	Target VCC	MCU VDD	1
6	VAPE			4
7	GND	SW IO	STUDIO	3
9		SW CLK	SWCLK	2

Figure 10. STEVAL-ESC001V1 connection for MCU programming



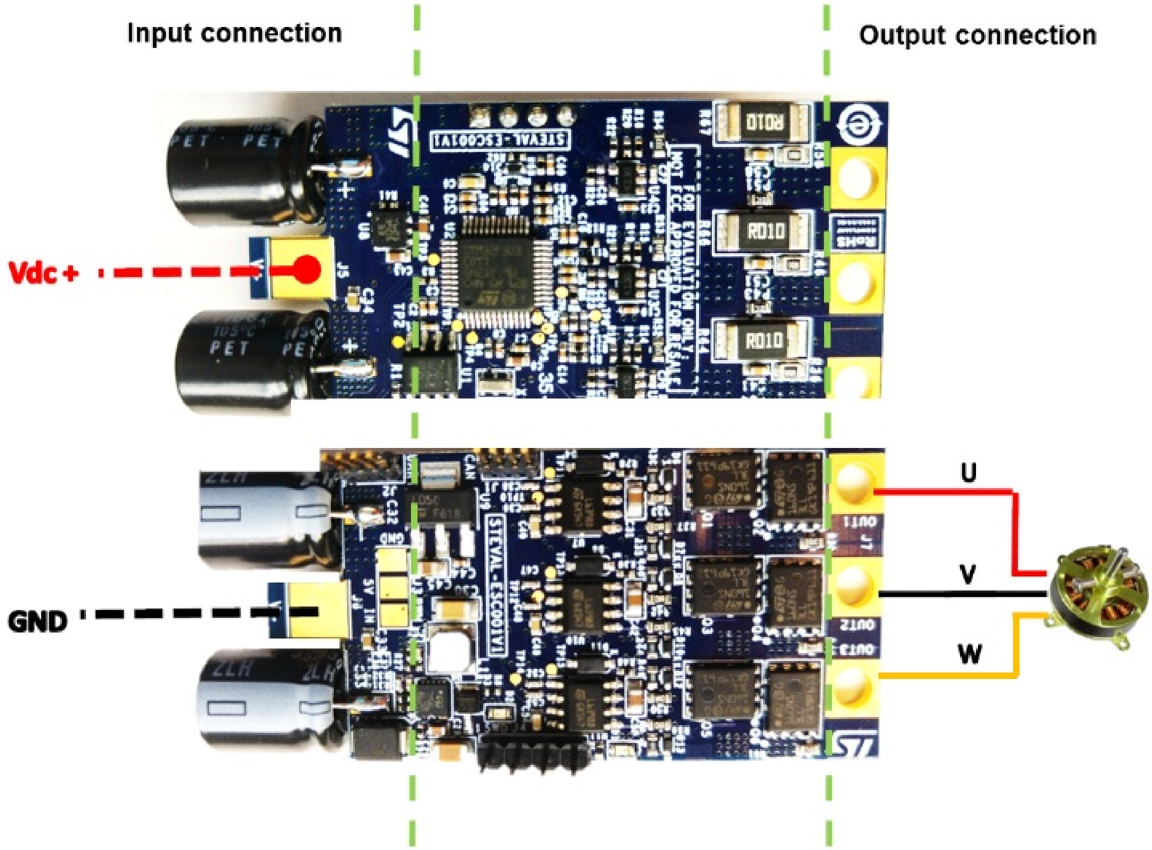
Step 2. Set the SWD interface in the IDE tool.

Figure 11. Sample SWD configuration on the IAR tool



Step 3. Solder the three motor wires U, V, and W at the motor connector with no particular color sequence. As shown in Figure 12. STEVAL-ESC001V1 input/output connection, the right side is for the motor connection with three pads provided for soldering.
Step 4. Solder the PWM input at the J3 connector. The INPUT pin level must not exceed 3V3.

Step 5. Connect the STEVAL-ESC001V1 with a Li-Po battery (or DC power supply: min 3S – max 6S) with the right polarity and turn it ON. The input connector has two large pads for soldering: the top layer for GND and the bottom for Vdc+. A transit device prevents damage in case of reverse polarity.



Step 6. Verify if the green led is turned on.
Step 7. Open ST ST Motor Control Workbench.

Figure 13. ST MC Workbench

Step 8. Follow the instructions included in the readme file to compile/upload the example project.

Schematic diagrams

Figure 14. STEVAL-ESC001V1 circuit schematic (1 of 4)

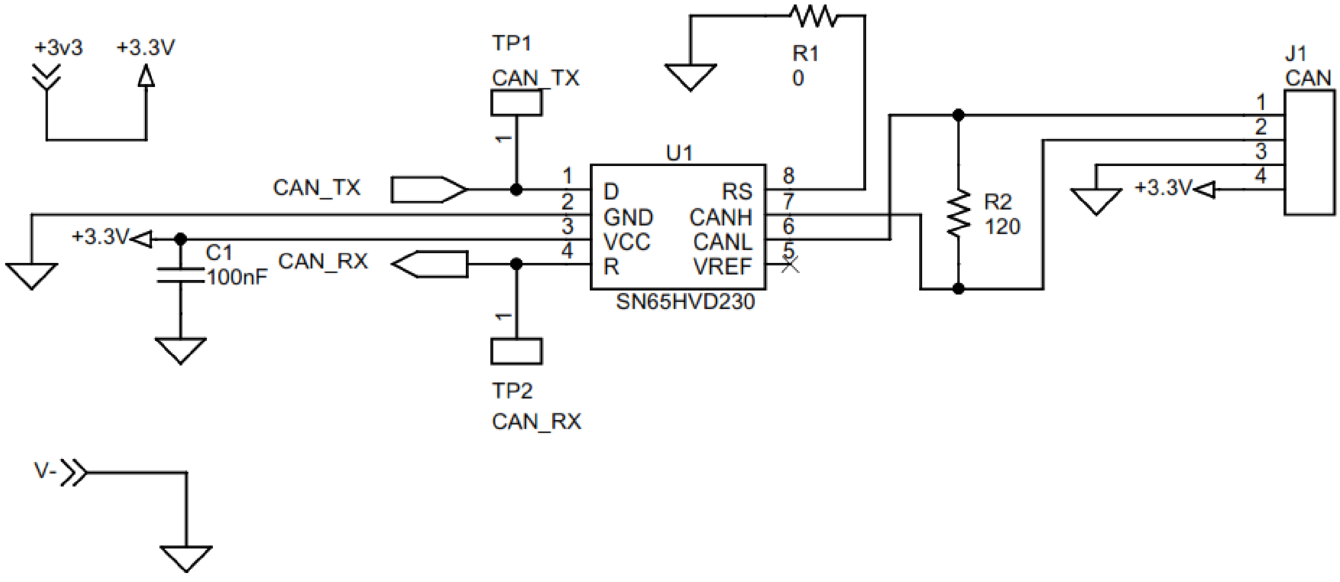


Figure 15. STEVAL-ESC001V1 circuit schematic (2 of 4)

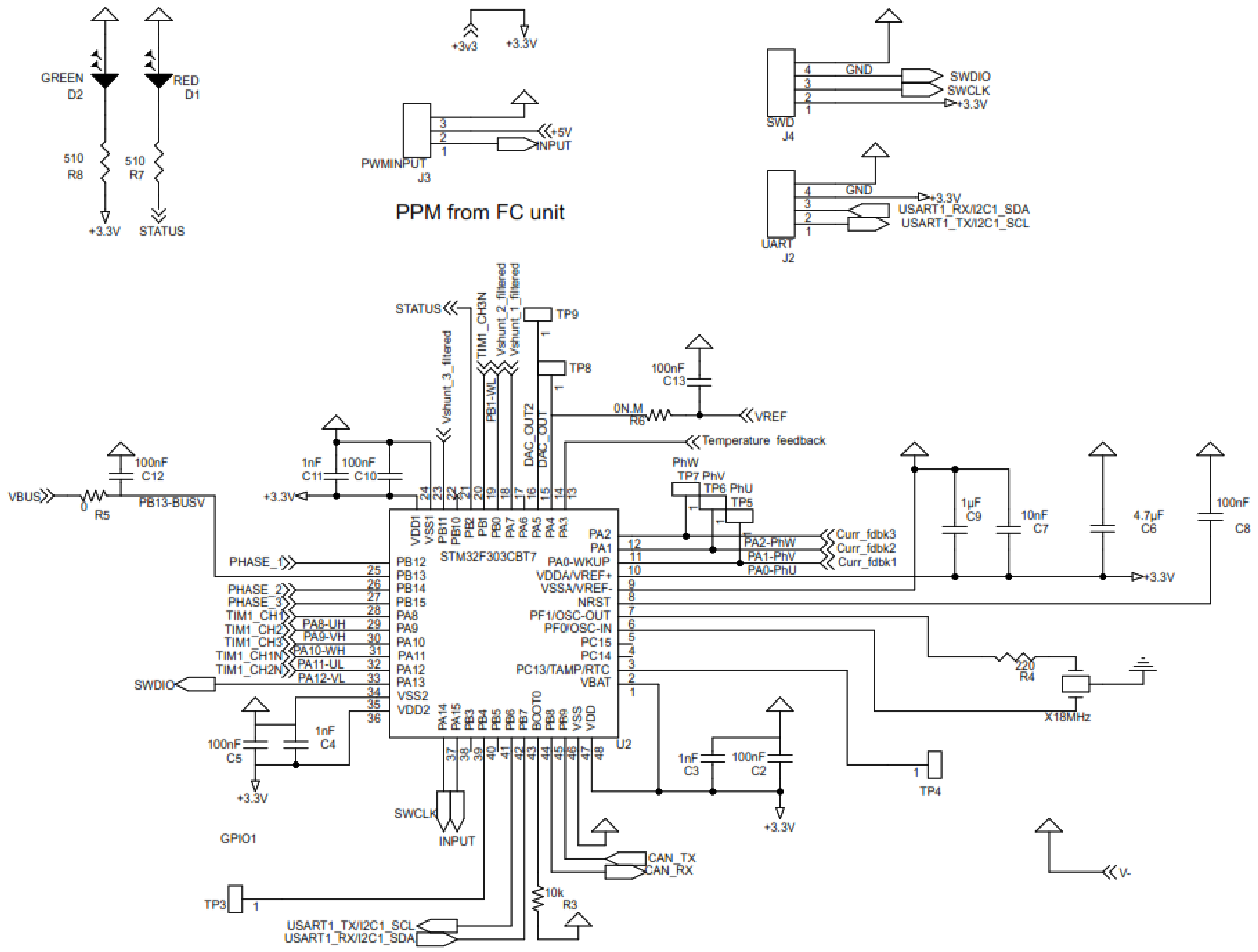


Figure 16. STEVAL-ESC001V1 circuit schematic (3 of 4)

For internal comparator

OCP circuit

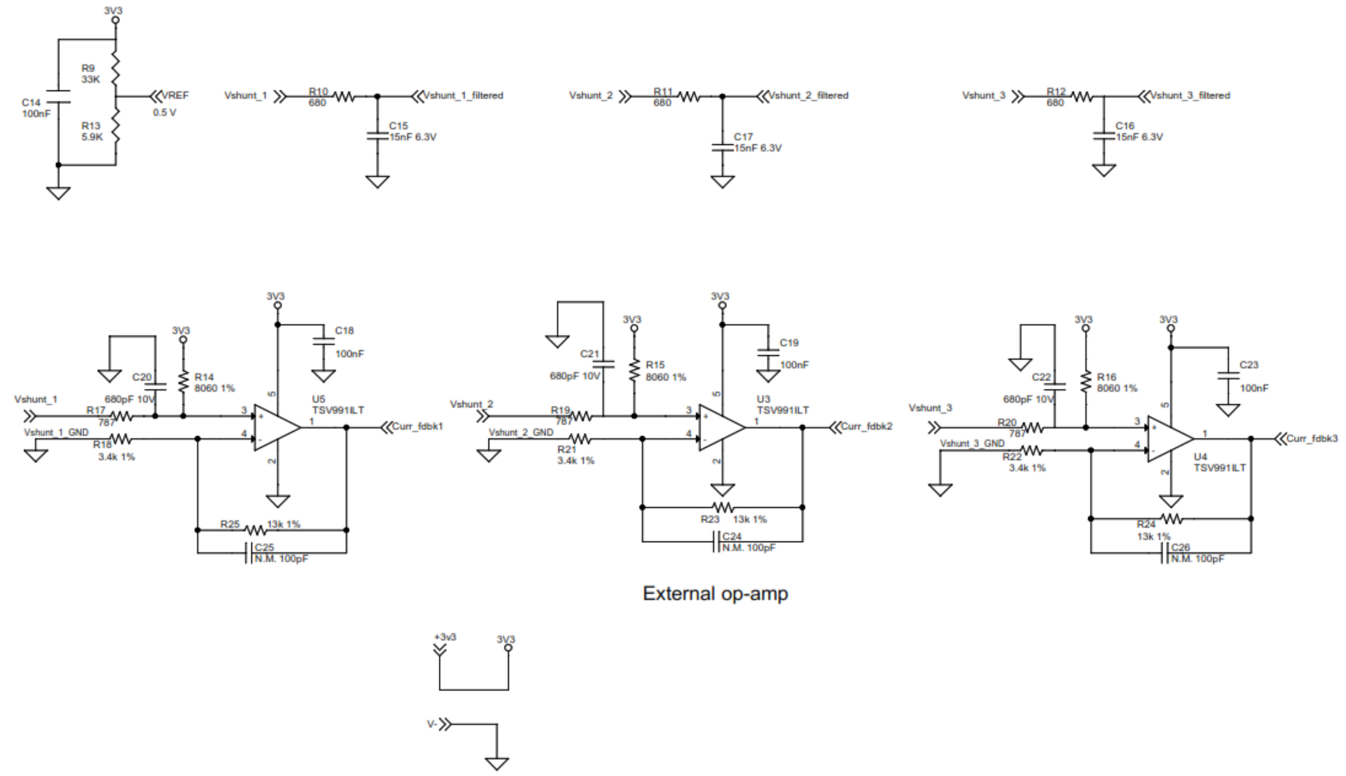
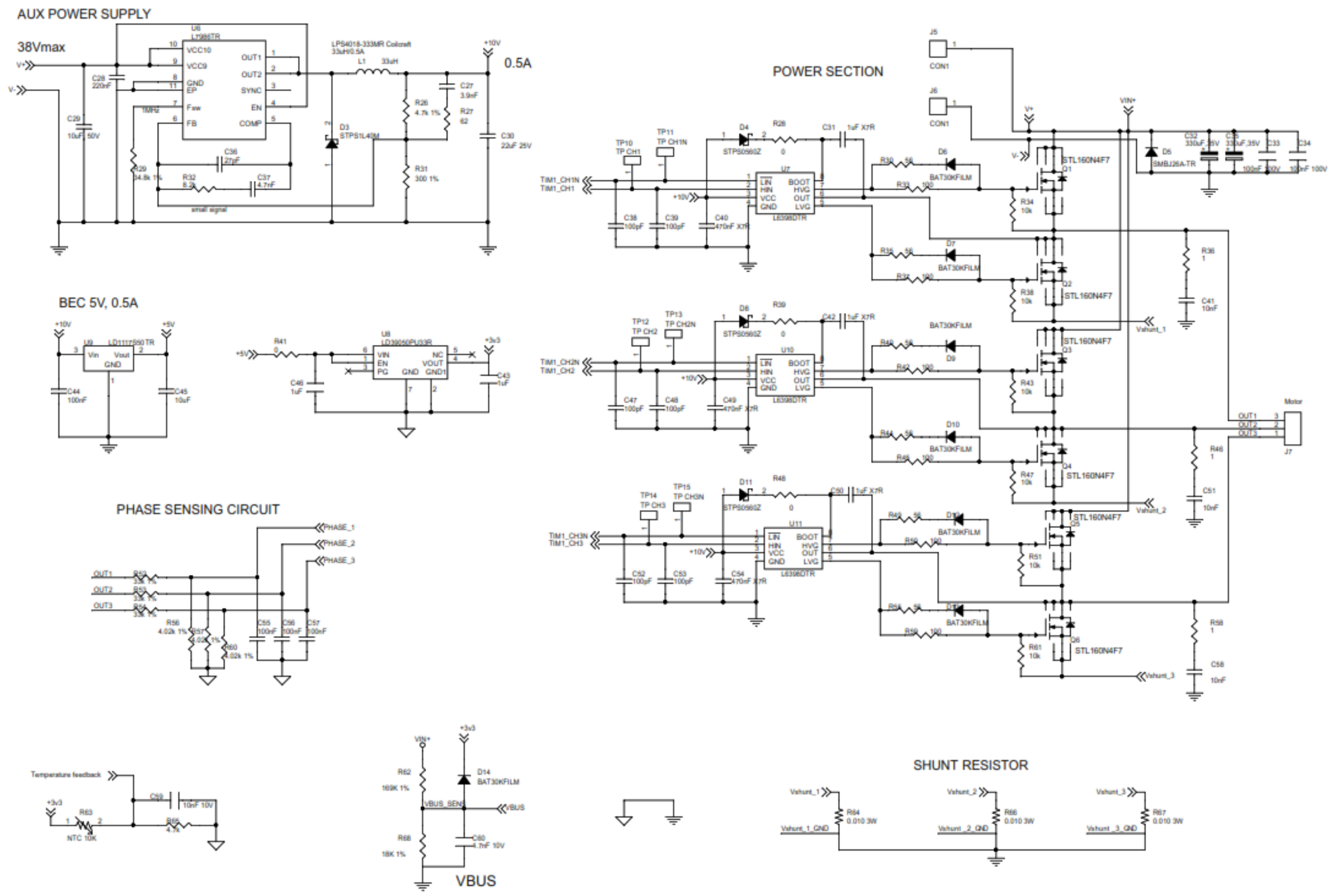


Figure 17. STEVAL-ESC001V1 circuit schematic (4 of 4)



Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code

1	15	C1, C2, C5, C8, C10 C12, C13, C14, C18 C19, C23, C44, C55 C56, C57	100 nF 25 V ±10% X7R	Ceramic capacitor	any	
2	3	C3, C4, C11	1 nF 50 V ±10% X7R	Ceramic capacitor	any	
3	1	C6	4.7 µF 10 V ±10% X5R	Ceramic capacitor	Murata	GRM188R61A475KE15D
4	2	C7, C59	10 nF 50 V ±10% X7R	Ceramic capacitor	any	
5	3	C9, C43, C46	1 µF 16 V ±10% X7R	Ceramic capacitor	TDK	C1608X7R1C105K080AC
6	3	C15, C16, C17	15 nF 10 V ±10% X7R	Ceramic capacitor	any	
7	3	C20, C21, C22	680 pF 10 V ±5% C0G	Ceramic capacitor	any	
8	3	C24, C25, C26	100 pF ±0%	Capacitors (not		
9	1	C27	3.9 nF 50 V ±10% X7R	Ceramic capacitor	any	
10	1	C28	220 nF 50 V ±10% X7R	Ceramic capacitor	any	
11	1	C29	10 µF 50 V ±10% X5R	Ceramic capacitor	any	
12	1	C30	1 µF X7R 50 V ±10%	Ceramic capacitor	any	
13	3	C31, C42, C50	330 µF,35 V ±20%	Ceramic capacitor	any	
14	2	C32, C35	100 nF 100 V ±10% X7R	Electrolytic capacitor	Rubycon	35ZLH330MEFC10X12.5
15	2	C33, C34	27 pF 50 V ±5% C0G	Ceramic capacitor	any	
16	1	C36	4.7 nF 16 V ±10% X7R	Ceramic capacitor	any	
17	2	C37, C60	100 pF 16 V ±10% X7R	Ceramic capacitor	any	

18	6	C38, C39, C47	470 nF 25 V ±10% X7R	Ceramic capacitor	any	
19	3	C40, C49, C54	10 nF 100 V ±10% X7R	Ceramic capacitor	any	
20	3	C41, C51, C58	10 µF 25 V ±10% X7R	Ceramic capacitor	any	GRM21BR61E106KA73L
21	1	C45	10 µF 25 V ±10% X7R	Ceramic capacitor	Murata	LTST-C193KRKT-5A
22	1	D1		Red LED	Lite-on	LTST-C193KGKT-5A
23	1	D2		Red LED	Lite-on	
24	1	D3	40 V 1 A	Low drop power Schottky diode	ST	STPS1L40M
25	3	D4, D8, D11	60V/0.5A	Power Schottky diode	ST	STPS0560Z
26	1	D5		Trans	ST	SMBJ26A-TR
27	7	D6, D7, D9, D10 D12, D13, D14	30V, 0.3A	Schottky diode	ST	BAT30KFILM
28	2	J1, J2		CAN, UART: 4 WAYS STRIP LINE – MALE 1.27mm	any	
29	1	J3		PWM INPUT: 3 way wires welding	any	
30	1	J4		SWD: 4-way strip line – male 2.54mm		
31	2	J5, J6		CON1 – Input power connector: 1-way wire welding		
32	1	J7		Motor Connector: 3way wire welding		
33	1	L1	33 µH 0.5 A	Power inductor	Coilcraft	LPS4018-333MRB

34	6	Q1, Q2, Q3 Q4, Q5, Q6	30 V, 160 A 40 V, 160 A	Power MOSFETs	ST	STL160NS3LLH7 STL160N4F7
35	6	R1, R5, R28 R39, R41, R48	0 62.5 mW ±5%	SMD resistor	any	
36	1	R2	120 62.5 mW ±5%	SMD resistor	any	
37	1	R3	10 k 62.5 mW ±5% S	SMD resistor	any	
38	1	R4	220 62.5 mW ±5%	SMD resistor	any	
39	1	R6	62.5 mW ±5%	SMD resistor	any	
40	2	R2 R2	510 62.5 mW ±5%	SMD resistor	any	
41	1	R9	33 K 62.5 mW ±5%	SMD resistor	any	
42	3	R10, R11, R12	680 62.5 mW ±5%	SMD resistor	any	
43	1		5.9 K 62.5 mW ±5%	SMD resistor	any	
44	3	R14, R15, R16	8.06 k 62.5 mW ±1%	SMD resistor	Panasonic	CRCW04028K06FKED
45	3	R17, R19, R20	787 62.5 mW ±1%	SMD resistor	Panasonic	ERJ2RKF7870X
46	3	R18, R21, R22	4 k 62.5 mW ±1%	SMD resistor	any	ERJ2RKF3401X
47	2	R23, R24, R25	13 k 62.5 mW ±1%	SMD resistor	any	
48	1	R26	4.7 k 62.5 mW ±1%	SMD resistor	any	
49	1	R65	4.7 k 62.5 mW ±5%	SMD resistor	any	
50	1	R27	4.7 k 62.5 mW ±5%	SMD resistor	any	
51	6	R29	62 62.5 mW ±1%	SMD resistor	any	

52	1	R30, R35, R40 R44, R49, R55	34.8 k 62.5 mW ±1%	SMD resistor	any	
53	1	R31	56 0.1 W ±5%	SMD resistor	any	
55	6	R32	300 62.5 mW ±1%	SMD resistor	any	
56	6	R33, R37, R42 R45, R50, R59	8.2 k 62.5 mW ±1%	SMD resistor	any	
57	3	R34, R38, R43 R47, R51, R61	100 0.1 W ±5 %	SMD resistor	any	
58	3	R36, R46, R58	10 k 0.1 W ±5 %	SMD resistor	any	
59	1	R52, R53, R54	4.02 k 62.5 m W ±1%	SMD resistor	any	
60	1	R56, R57, R60	169 K 62.5 m W ±1%	SMD resistor	any	
61	1	R63	NTC 10 K ±1%	NTC Thermistor	TDK	NTCG103JF103F
62	3	R64, R66, R67	0.01 3 W ±1%	10 mOhm shunt resistor	Bourns KOA Speer	CRA2512-FZ-R01 0ELF TLR3APDTE10L0 F50
63	1	R68	18 K 62.5 mW ±1%	SMD resistor	any	
64	1	TP1, TP2, TP3, TP 4 TP5, TP6, TP7, T P8 TP9, TP10, TP1 1 TP12, TP13, TP1 4 TP15	SMD PAD 1 mm ±0%	Test point	any	
65	1	U1		CAN transceiver	TI	SN65HVD230D
66	1	U2		32bit MCU	ST	STM32F303CBT7
67	1	U3, U4, U5		Rail-to-rail input/ output 20 MHz G BP operational ampli fiers	ST	TSV991ILT

68	3	U6		3 A step-down switching regulat or	ST	L7986TR
69	1	U7, U10, U11		High voltage high and low-side driv er	ST	L6398D
70	3	U8		Low drop voltage regulator	ST	LD39050PU33R
71	1	U9		Low drop voltage regulator	ST	LD1117S50TR
72	1	X1		Resonators 8 Mh z	Murata	CSTCE8M00G55-R0

Revision history

Table 5. Document revision history

Date	Version	Changes
7-Apr-2017	1	Initial release.
13-Nov- 2018	2	Updated Introduction and Section 5 Bill of materials. Added references to STL16 0N4F7.
10-Nov-2021	3	Updated Introduction, Section 1 Main features, and Section 3 Initializing and usin g the STEVALESC001V1 ESC board.

Documents / Resources

ST UM2197 Electronic Speed Controller for BLDC and PMSM Three Phase Brushless Motor [pdf] User Manual
UM2197, Electronic Speed Controller for BLDC and PMSM Three Phase Brushless Motor, UM 2197 Electronic Speed Controller for BLDC and PMSM Three Phase Brushless Motor

References

- STMicroelectronics: Our technology starts with you
- STMicroelectronics Trademark List - STMicroelectronics
- BAT30 - 30 V, 300 mA SMD General purpose Signal Schottky Diode - STMicroelectronics
- L6398 - High voltage high and low-side driver - STMicroelectronics
- L7986 - 3 A step-down switching regulator - STMicroelectronics
- LD1117 - Adjustable and fixed low drop positive voltage regulator - STMicroelectronics
- LD39050 - 500 mA low quiescent current and low noise voltage regulator - STMicroelectronics
- STEVAL-ESC001V1 - Electronic speed controller reference design for drones - STMicroelectronics
- STL160N4F7 - N-channel 40 V, 2.1 mOhm typ., 120 A STripFET F7 Power MOSFET in a PowerFLAT 5x6 package - STMicroelectronics
- STM32F303CB - Mainstream Mixed signals MCUs Arm Cortex-M4 core with DSP and FPU, 128 Kbytes of Flash memory, 72 MHz CPU, MPU, CCM, 12-bit ADC 5 MSPS, PGA, comparators - STMicroelectronics
- STPS0560Z - 60 V, 0.5 A Power Schottky Rectifier - STMicroelectronics
- STPS1L40M - 40 V, 1 A STmite Low Drop Power Schottky Rectifier - STMicroelectronics
- TSV991 - Wide-bandwidth (20MHz) rail to rail input/output 5V CMOS Op-Amp, single - STMicroelectronics
- X-CUBE-MCSDK - STM32 Motor Control Software Development Kit (MCSDK) - STMicroelectronics