UM2647

How to use the 1 kW traction controller reference design for 3-phase BLDC motors for light electric vehicles

Introduction

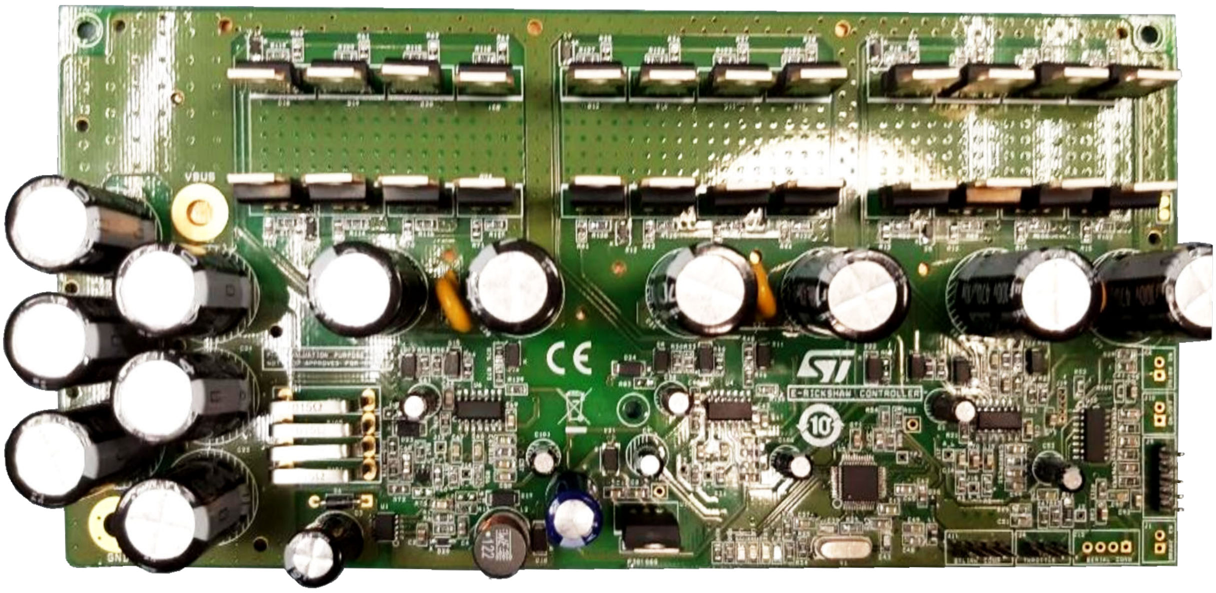
The 1 kW BLDC traction controller is a reference design for low voltage battery powered light electric vehicles running on nominal 48 V_{DC} and 50 A peak current. The wide input voltage range (42-65 V) and combination of hardware and design features deliver a highly responsive and efficient solution with fault diagnostic features that render this drive a highly viable solution across a variety of applications.

The inverter stage in full bridge 3-phase topology includes N-channel Power MOSFETs featuring STripFET F6 trench gate technology, driven by smart L6491 gate driver ICs with embedded comparators ensuringr real time cycle-by-cycle overcurrent protection.

The motor control logic is based on six step commutation in voltage mode, with Hall Sensor feedback for position detection. Detailed instructions are provided for configuring the firmware with an easy-to-use GUI and compiling the binary files for download onto the STM8S microcontroller.

The microcontroller section on the board can accommodate I²C and UART communication protocols for enhanced interfacing and control such as LCD display.

Figure 1. **1 kW light electric vehicle BLDC motor controller**



For further development, ST provides the ST Visual Development (STVD) environment and technical support for customizing and scaling the solution for Industrial and Automotive applications.

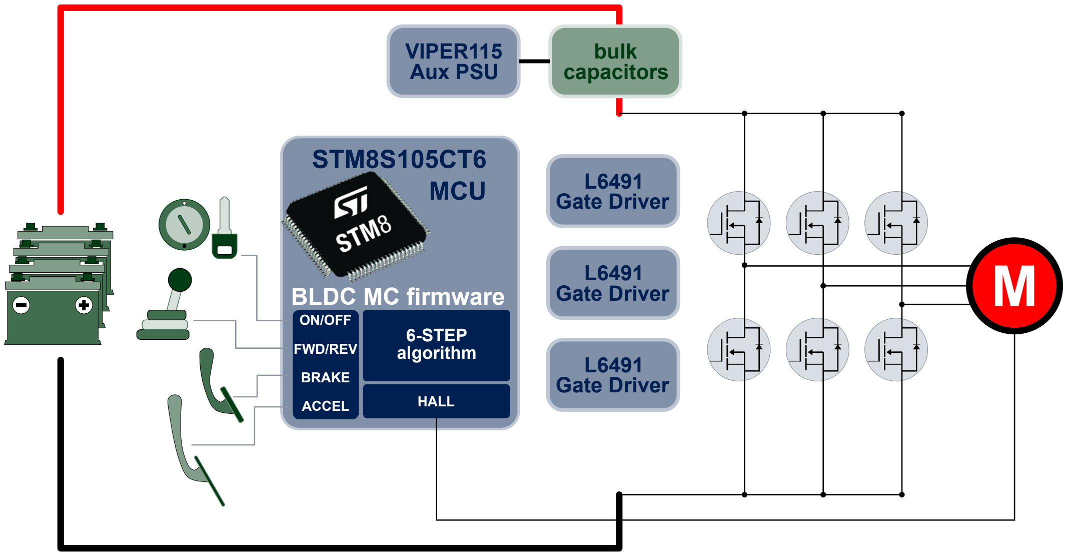
The system has been field tested on an e-Rickshaw, but it is designed for use with any low speed or light electric vehicles.

1 BLDC motor control for light electric vehicles

This BLDC motor control application is based on a 6-step motor control algorithm with motor position feedback information from magnetic field Hall sensors on the motor. The MCU firmware generates PWM signals for the gate drivers to control the power delivered to the 3 phases of the motor and therefore determine motor speed and rotation.

The design includes the necessary mechanisms for the normal inputs expected in a light electric vehicle, including on and off, forward and reverse, a throttle or accelerator, and a brake.

Figure 2. BLDC traction control for light electric vehicles



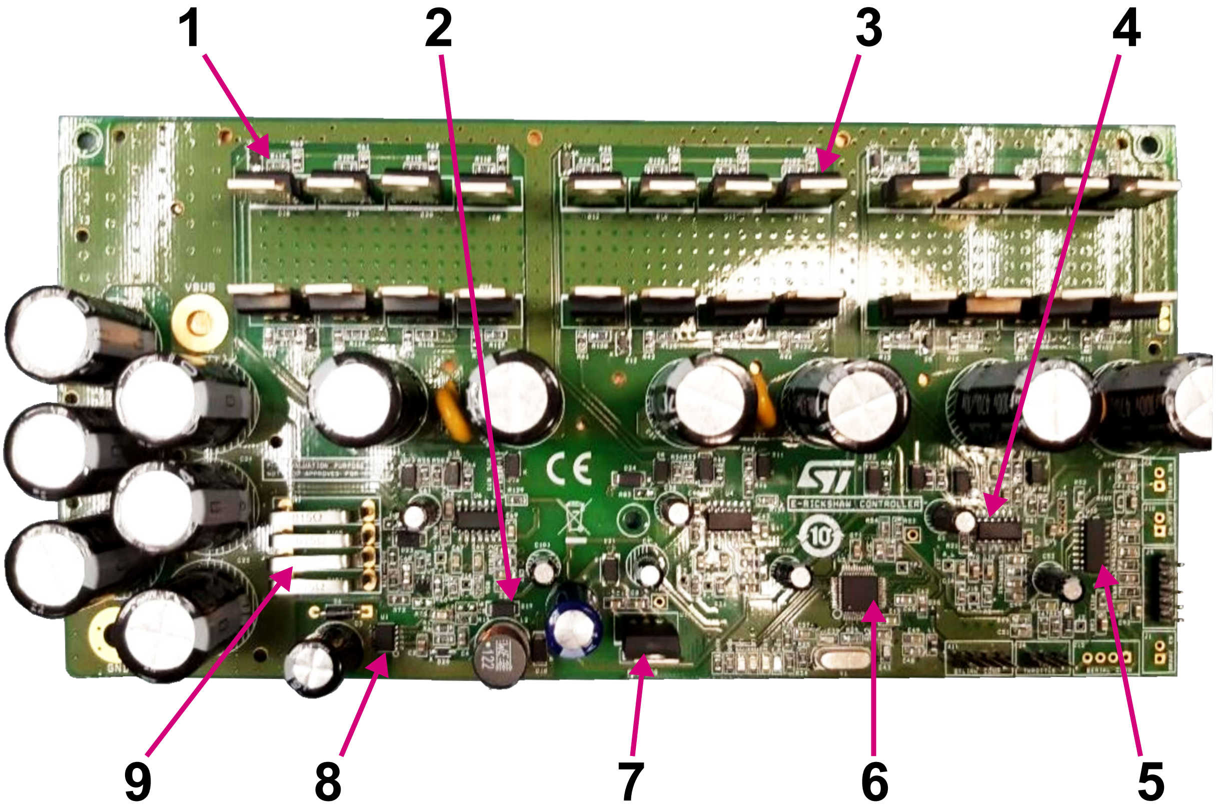
The protection mechanisms included to prevent excess heating and current are also crucial aspects of the design, and the safest and most responsive solutions use hardware elements to monitor thresholds and trigger immediate reactions when limits are exceeded, instead of relying exclusively on MCU responses, which may not intervene quickly enough to avoid damage or injury.

2 Features and functions

- 48 V DC 1 kilowatt design
- Six Step drive commutation topology
- Input Voltage range: 42 V_{DC} to 65 V_{DC}
- Efficiency > 80%
- Compatible with any 5 V throttle
- Compatible with any start wound 48 V 3-phase BLDC motor with Hall sensor feedback
- Protections:
  – Overcurrent, overvoltage and undervoltage protection
  – Option for two levels of ovecurrent protection with different thresholds
  – Speed and position feedback fault detection and protection
- VIPER115LS based auxiliary power supply
- 3 LEDs for fault indication
- Drive ON/OFF switch
- Drive Forward/Reverse switch
- Drive disabled while mechanical brakes are applied
- RoHS compliant

Figure 3. Key components of the evaluation board

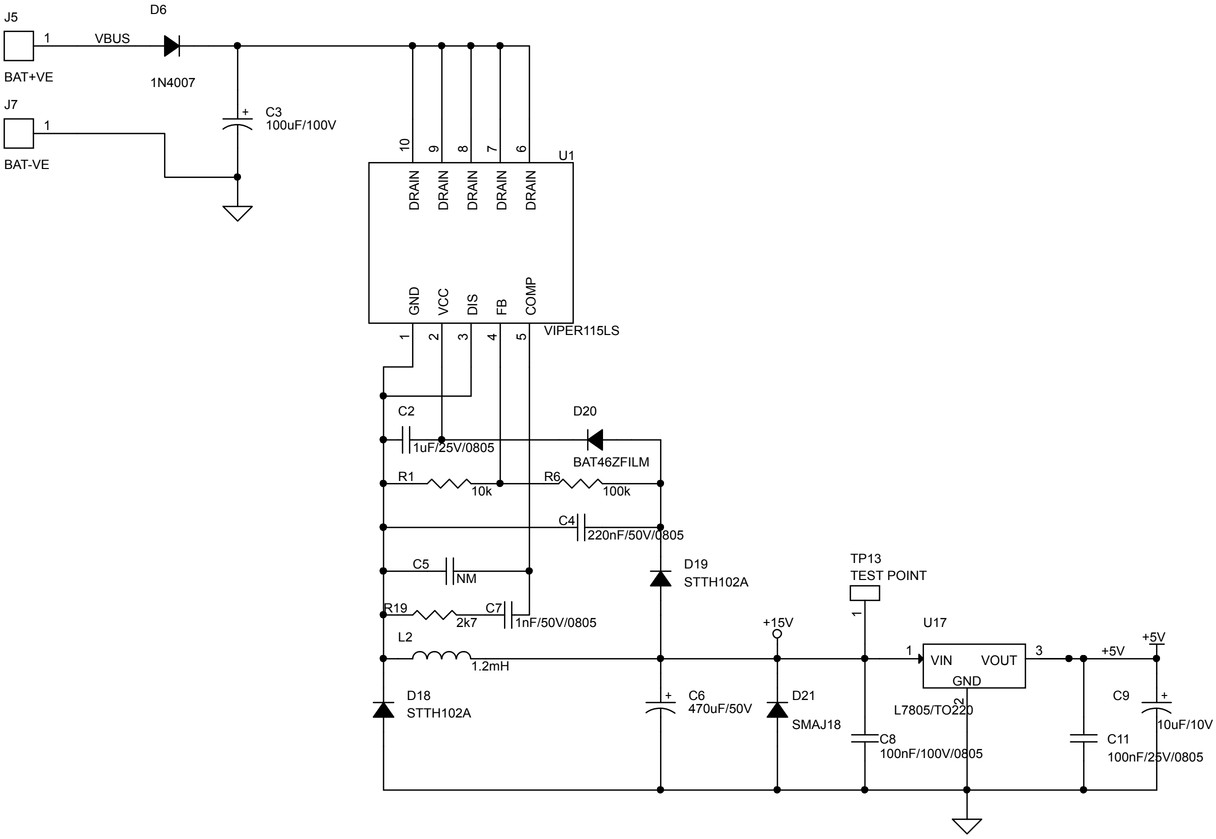
1. STPS1L60RL Schottky diode
2. STTH102A ultrafast recovery diode
3. STP100N8F6 MOSFETs
4. L6491D gate driver
5. M74HC4050 HEX Buffer
6. STM8S105C6T6 microcontroller
7. L7805 voltage regulator
8. VIPER115LS buck converter
9. Metallic shunt resistors



2.1 Auxiliary Power supply with high voltage converter and voltage regulator

The isolated Auxiliary power supply is based on the VIPER115LS high voltage converter operating in primary sensing mode, which generates a 12 V_{DC} voltage from an input battery or power supply voltage range of 35 to 68 V_{DC}. The downstream L7805 voltage regulator provides a further regulated 5 V to the digital controller and hall effect sensors.

Figure 4. STDES-EVT001V1 auxiliary power supply schematic



RELATED LINKS

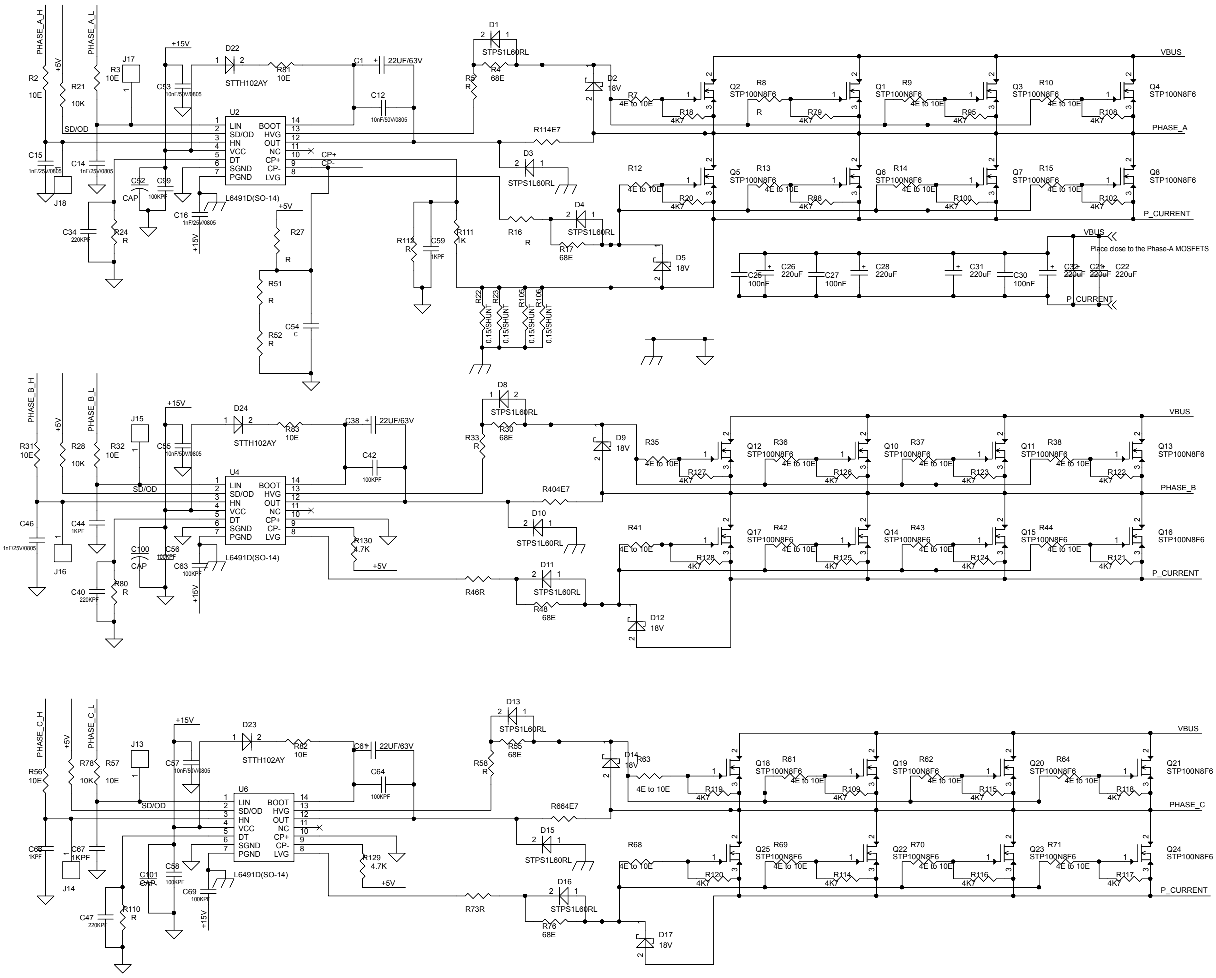
For more information on VIPER115LS high voltage converters, visit the product page on the ST website

You can download the full schematics from the product page on the ST website

2.2 Power converter in 3-phase inverter topology

The power converter is based on 3-phase inverter topology, with four STP100N8F6 N-Channel Power MOSFETs connected in parallel forming the switches of the 3-phase full bridge. A capacitor bank is included to improve the power transfer response during switching. The motor torque is proportional to the throttle input, which is set by the user to act on the duty cycle of the PWM signals.

Figure 5. STDES-EVT001V1 power converter schematic



RELATED LINKS

For more information on STP100N8F6 N-Channel Power MOSFETs, visit the product page on the ST website

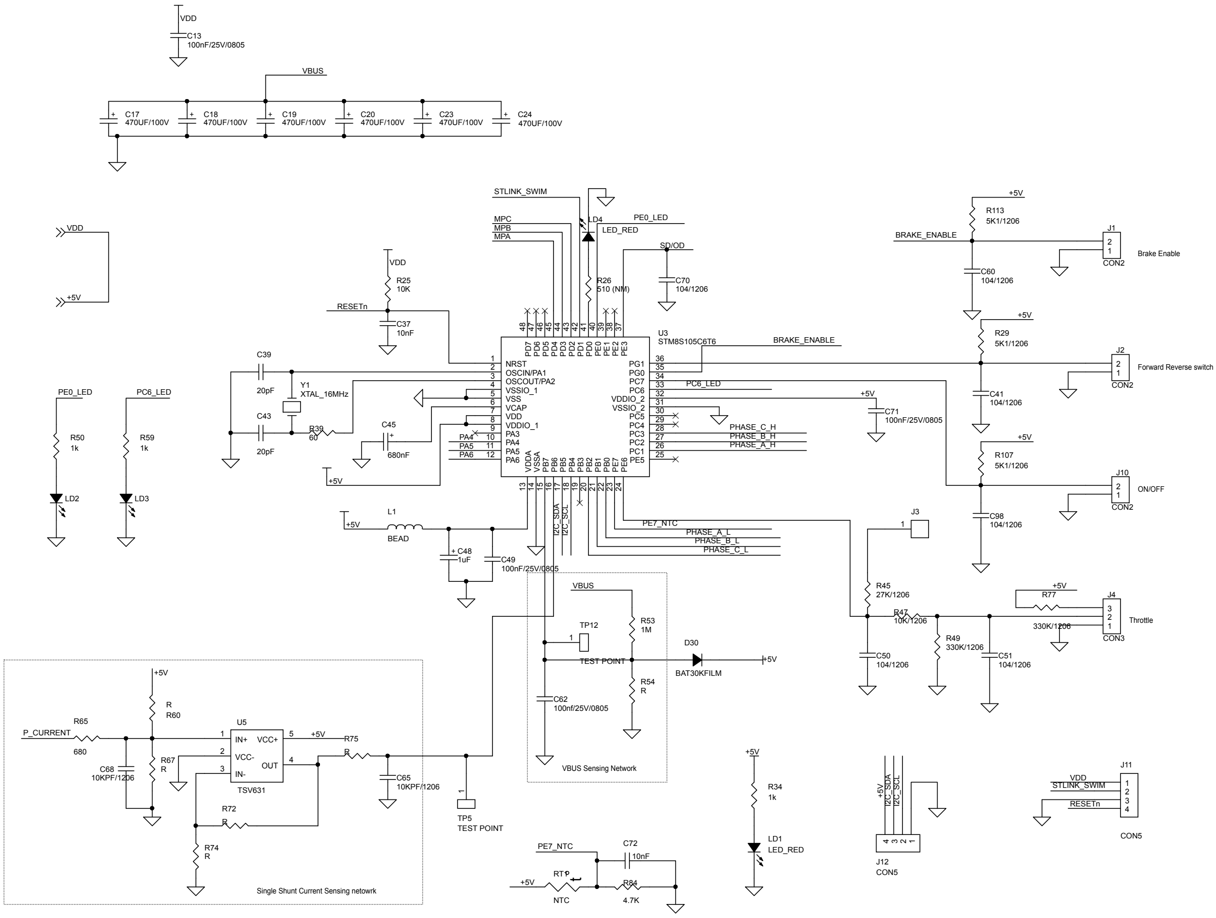
You can download the full schematics from the product page on the ST website

2.3 Control block with STM8S microcontroller

The control block consists of the STM8S105C6 microcontroller and the signal conditioning circuits. The main parameter inputs for this stage are user commands such as the on-off and forward-reverse switches, and brake enable. Hall sensor signals from the motor provide rotor position feedback information to the microcontroller running the 6-step drive algorithm.

The voltage, current and temperature in the power stage are sensed through conditioning circuits to ensure the system remains within safety limits, and further protection logic can be programmed into the MCU in addition to current thresholds and stoppage durations controlled by hardware.

Figure 6. STDES-EVT001V1 control unit schematic



RELATED LINKS

For more information on STM8S105C6 microcontroller, visit the product page on the ST website

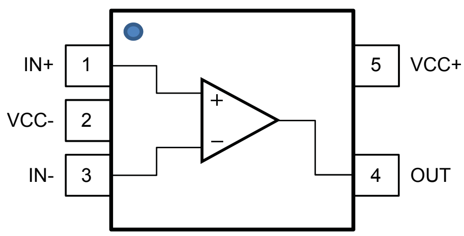
You can download the full schematics from the product page on the ST website

For more information on the STM8 BLDC Motor control library, visit the relevant page on the ST website

2.3.1 TSV631 Op-Amp

The TSV631 Operational Amplifier in this design provides current sensing with overcurrent protection. These devices feature a very low input bias current and a low offset voltage, making them ideal for applications that require precision.

Figure 7. Pin connections for TSV631



The 880 kHz, 5 V CMOS operational amplifier supports rail-to-rail input and output, and is used here as a non-inverting amplifier. The output of the inverter can be used to monitor for overcurrent events. The threshold current limit used here is different to the one used for cycle-by-cycle current limitation/shutdown used in the gate driver IC.

The output of the non-inverting amplifier is interfaced with the microcontroller pin, which can be configured as an analog input to enable continuous current monitoring or perhaps an adaptive algorithm.

Figure 8. Voltage gain and phase vs. frequency at V_{CC} = 5 V

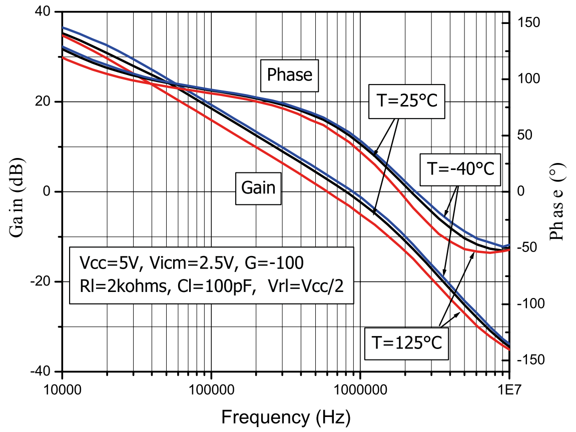
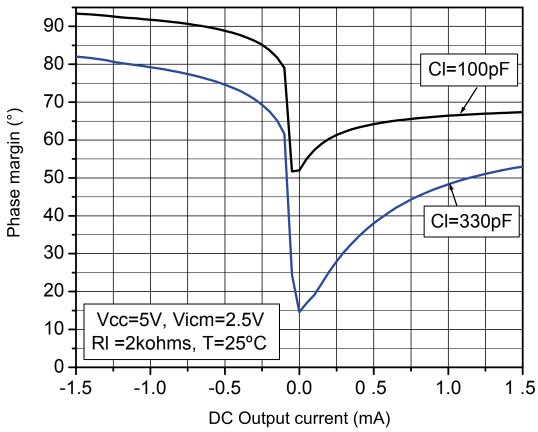


Figure 9. Phase margin vs. output current at V_{CC} = 5 V



RELATED LINKS

For more information on TSV631 Op-Amps, visit the product page on the ST website

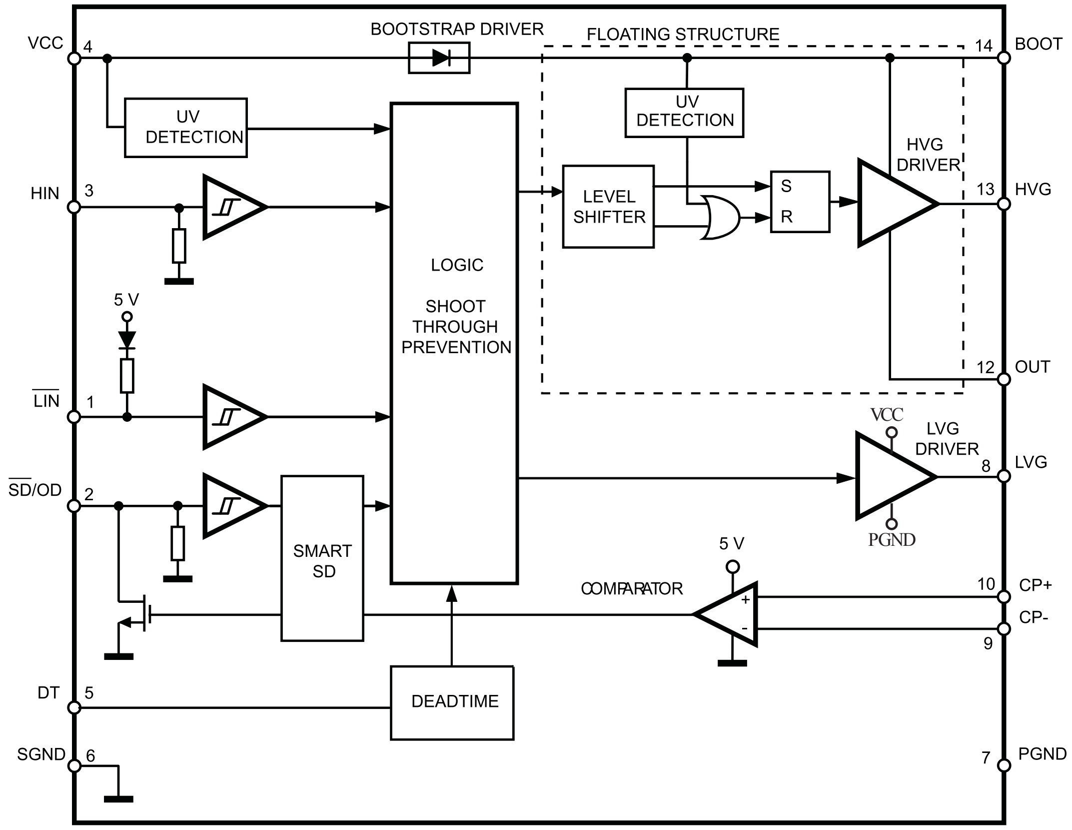
2.3.2 L6491D high voltage high and low-side gate driver

The L6491D half-bridge gate drivers that control the Power MOSFETs in the 3-phase bridge feature embedded comparators for fault (current) sensing functionality.

The comparator input is connected to an external shunt resistor for simple overcurrent detection function. The output signal of the comparator is fed to an integrated MOSFET with the open-drain output available on pin 2, shared with the SD input. When the comparator triggers, the device is set in shutdown state and both its outputs are set to low level, leaving the half bridge in 3-state.

The triggered gate driver also signals the other gate drivers to shut down, thereby providing comprehensive cycle by cycle overcurrent protection without the latencies introduced by equivalent microcontroller interventions.

Figure 10. L6491 block diagram



RELATED LINKS

For more information on L6491D half-bridge gate drivers, visit the product page on the ST website

3 Motor control software

The BLDC traction control firmware is based on the STM8 BLDC Motor control library with additional user interface and other application-specific functions. The ST Visual Development (STVD) environment allows developers to further customize the firmware with additional behavior and functionality.

RELATED LINKS

For more information on the STM8 BLDC Motor control library, visit the relevant page on the ST website

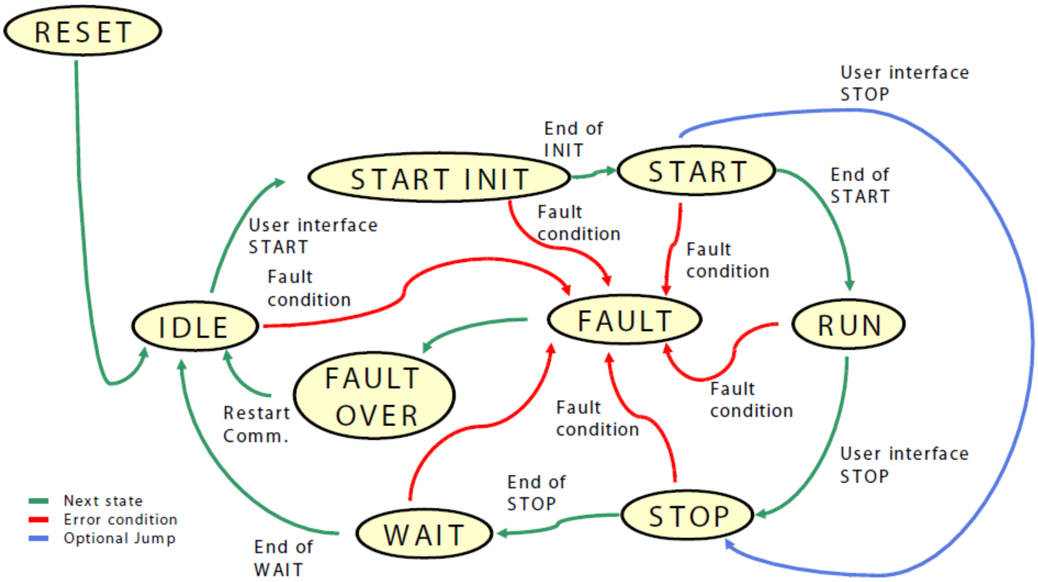
For more information on the visual development environment for STM8 firmware, visit the relevant page on the ST website

3.1 Application State machine

The motor control firmware logic is governed by the state machine that is implemented in the MC_StateMachine.c module and consists of the following states: Reset, Idle, Start init, Start, Run, Stop, Wait, Fault and Fault over.

Each state machine function makes calls to associated drive functions, user interface interaction functions, and error check functions, and executes actions on the basis of the outputs of these functions.

Figure 11. Motor control state machine



- Reset: the system enters the Reset state after a main reset event; it is used for general initialization of the system.
- Idle*: the motor is stopped and the system waits for a startup event.
- Start init: is executed whenever the motor is restarted; it is used for specific initialization.
- Start*: the motor ramps up.
- Run*: is entered at the end of the start phase to maintain normal system operation; the user can interact with the system, change parameters in real-time, or issue a stop command.
- Stop: is entered when a stop command is issued.
- Wait*: is entered when the motor is stopped; it remains in this state until the conditions for a new restart are satisfied.
- Fault*: is entered when an error condition occurs; it remains in this state for as long as the fault condition persists.

- Fault over*: is entered when the fault condition is cleared; the system remains in Fault-over state to indicate which error occurred, and waits for a user action.

Note: The states marked with an asterisk continue to run until an event occurs (user action or fault condition).

Each state represents the execution of a corresponding function, while the next state is determined by one of the following values that the function in the current state returns:

- State remain: no change in the state is required by the state machine function.
- Next state: the state machine progresses to the next step in its natural flow (for example, Idle → Init start → Start → Run); natural flow is represented by green lines in Figure 11.
- Optional jump: a user action causes the state machine to move to a step that is not part of its natural flow (for example Start → Stop); optional jumps are represented by blue lines in Figure 11.
- Error condition: a fault condition occurred (for example, Startup failed, overtemperature); error conditions are represented by red lines in Figure 11.

4 STM8S motor control firmware library builder

The STM8 MC FW builder allows the development of specific motor control firmware configuration files through an interactive GUI. The files are then compiled in the ST Visual Development (STVD) environment with the COSMIC C toolchains, ready for download onto the STM8S microcontroller.

RELATED LINKS

For more information on the STM8 BLDC Motor control library, visit the relevant page on the ST website

For more information on the visual development environment for STM8 firmware, visit the relevant page on the ST website

4.1 How to configure the Motor section

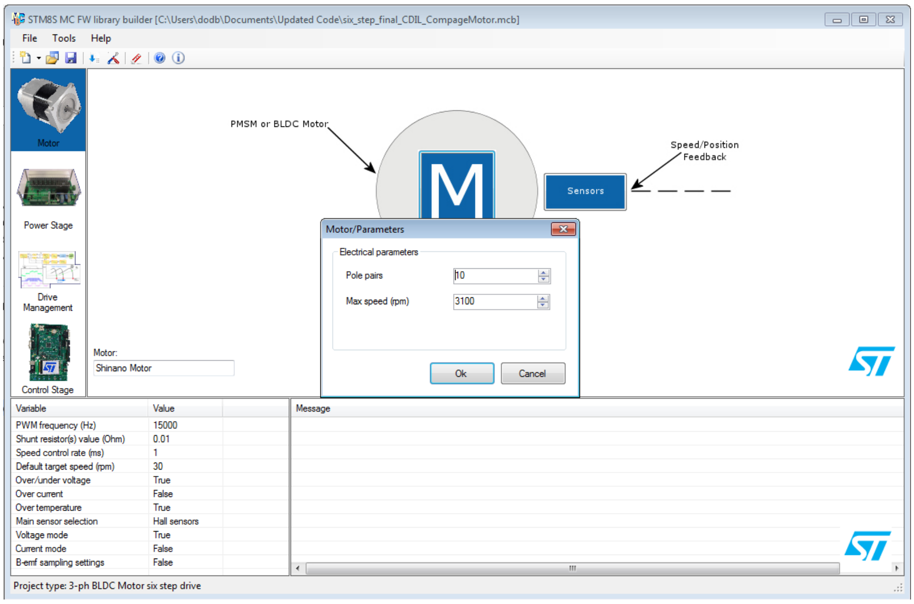
Before you begin, you must install and run the STSW-STM8042 Motor Control Library Builder on your PC and create a new project for 3-phase BLDC Motor six step drive.

A new window appears with several areas related to the functional blocks of motor control.

Step 1. Select the [**Motor**] tile in the left panel.

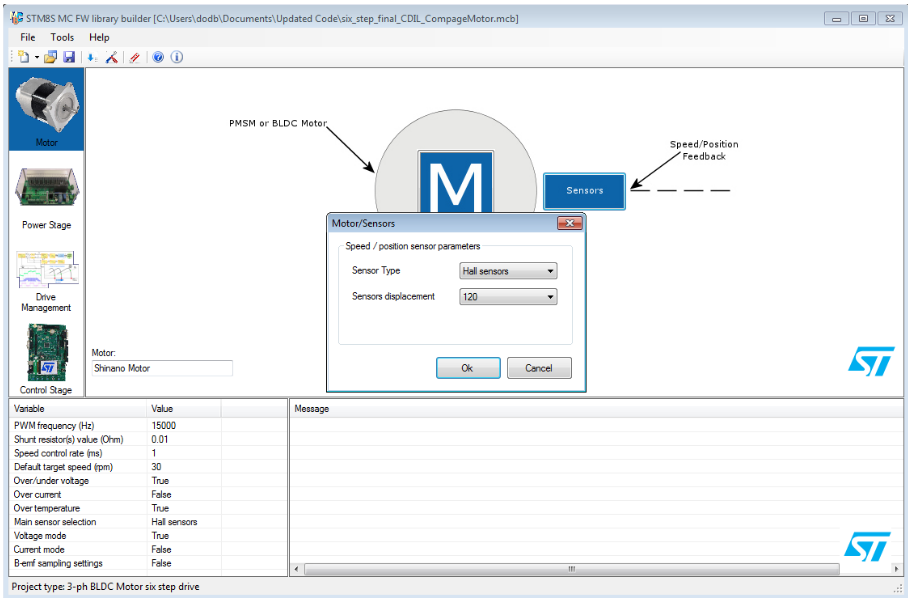
Step 2. Click on the M block (PMSM or BLDC Motor), input your [**Pole pairs**] and [**Max. speed (rpn)**] parameters and press [**Ok**].

Figure 12. **MC FW builder GUI, Motor electrical parameters**



Step 3. Click on the [**Sensors**] block, and set the [**Sensor Type**] to Hall sensors and [**Sensors displacement**] to 120 and press [**Ok**].

Figure 13. MC FW builder GUI, Motor sensor parameters

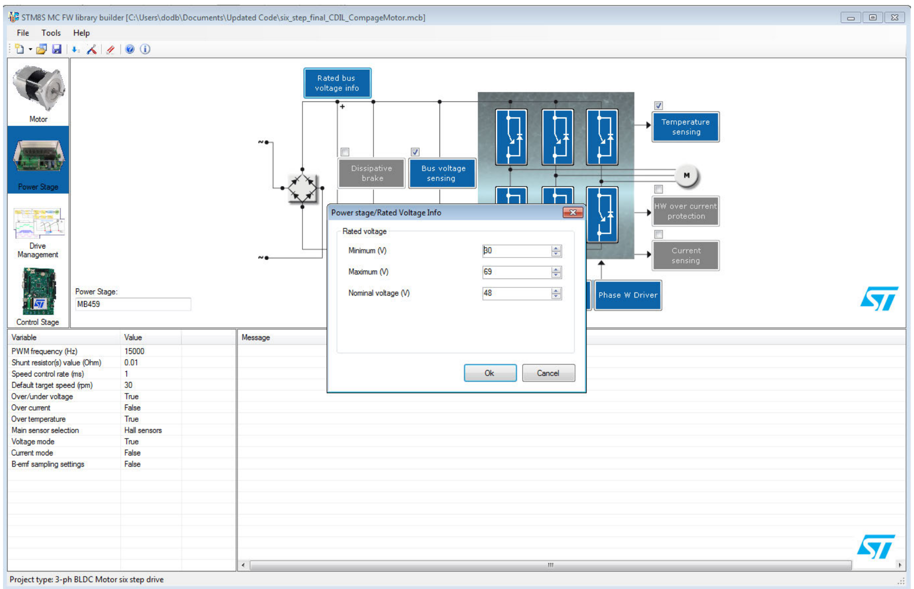


4.2 How to configure the Power Stage section

Step 1. Select the [**Power Stage**] tile in the left panel.

Step 2. Click on the [**Rated bus voltage info**] box and enter the appropriate values shown in the following figure.

Figure 14. MC FW builder GUI, power stage voltage parameters



Step 3. Check the [**Bus voltage sensing**] box to enable it and enter the appropriate values shown in the figure below.

The Bus voltage sensing tile changes form grey to blue when it is enabled.

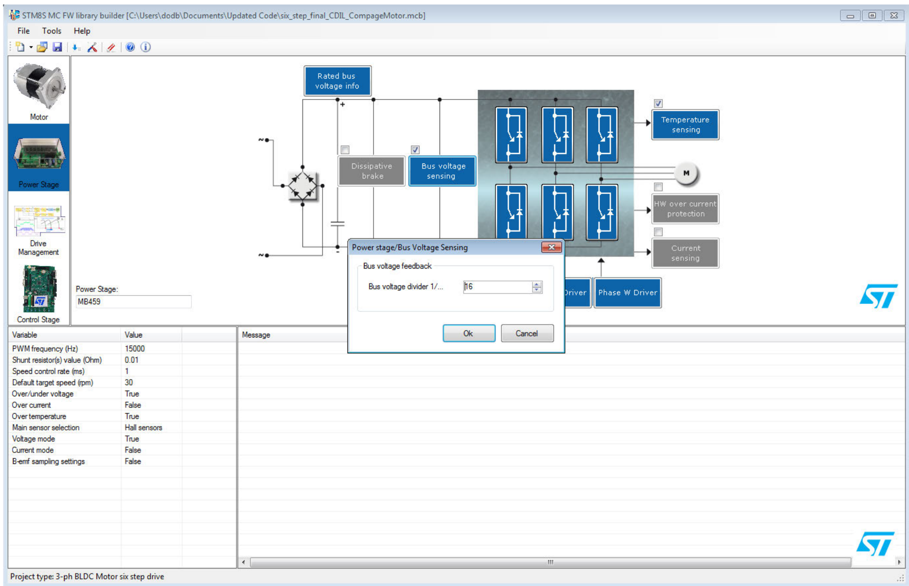


Figure 15. MC FW builder GUI, power stage voltage sensing parameters

Step 4. Check the [**Temperature sensing**] box to enable it and enter the appropriate values shown in the figure below.

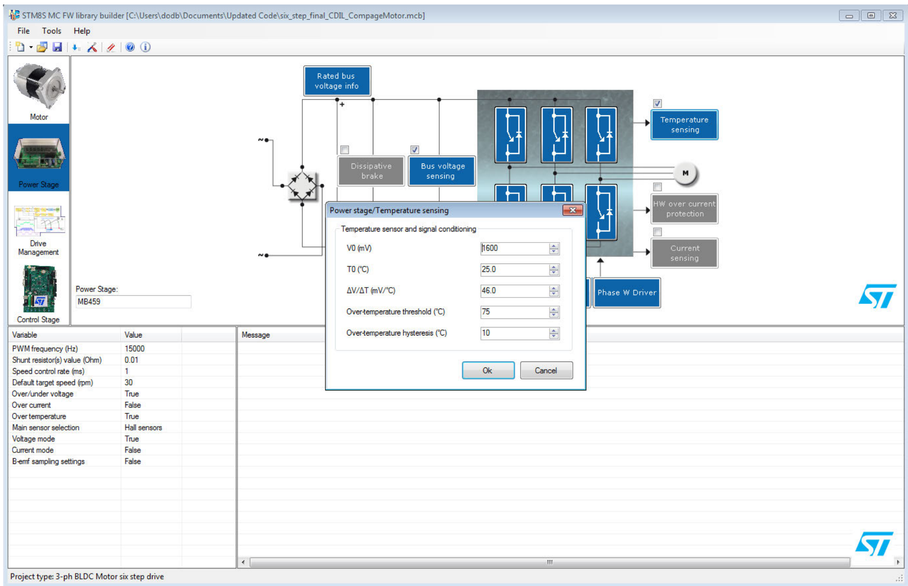
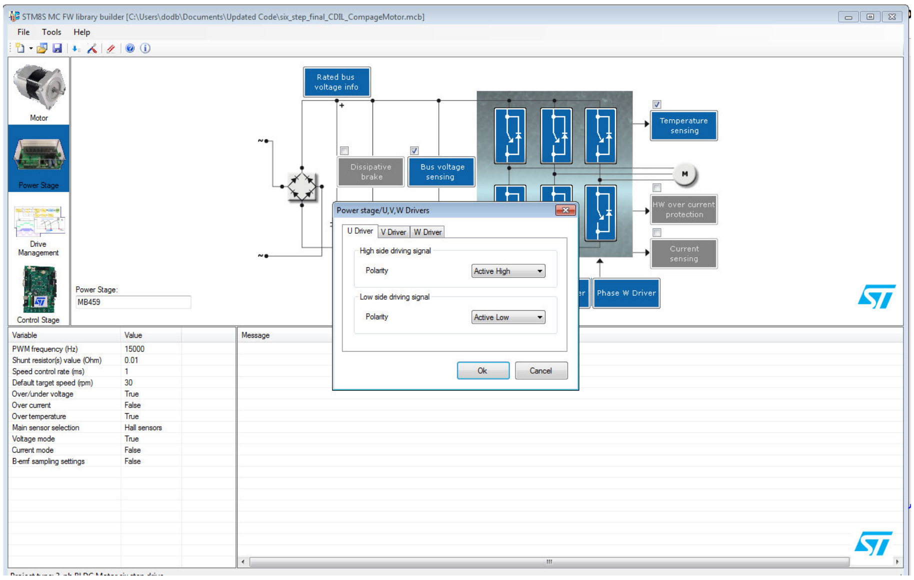


Figure 16. MC FW builder GUI, power stage temperature sensing parameters

Step 5. Click on [**Phase U Driver**], [**Phase V Driver**], and [**Phase W Driver**] blocks and set High side driving signal [**Polarity**] to Active High and Low side driving signal [**Polarity**] to Active Low in each block.

Figure 17. MC FW builder GUI, power stage driver parameters

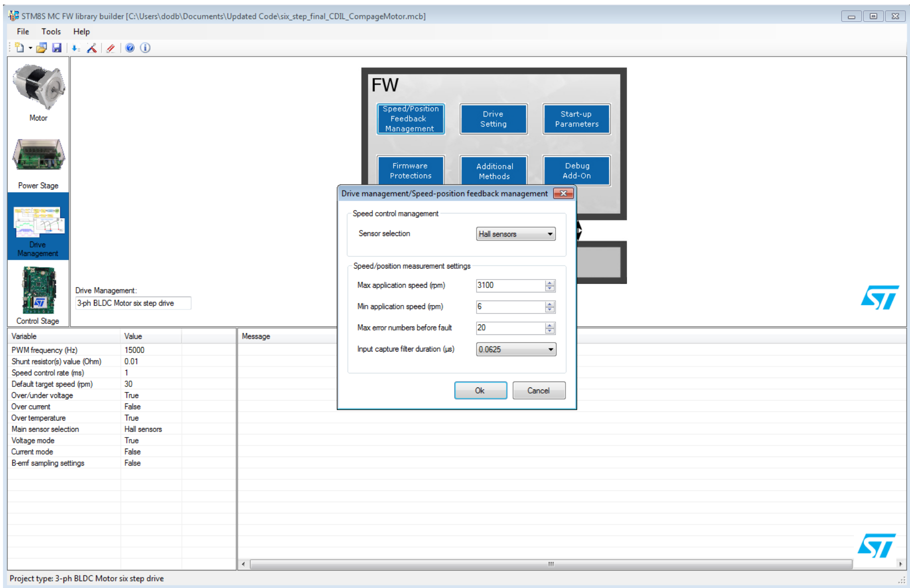


4.3 How to configure the Drive Management section

Step 1. Select the [**Drive Management**] tile in the left panel.

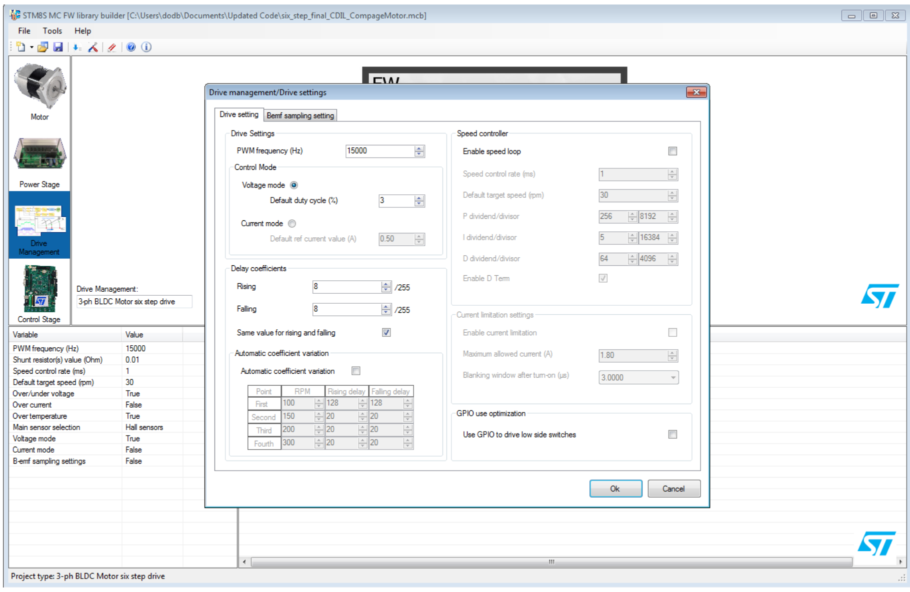
Step 2. Select the [**Speed/Position Feedback Management**] box and enter the appropriate values shown in the figure below.

Figure 18. MC FW builder GUI, drive management speed/position parameters



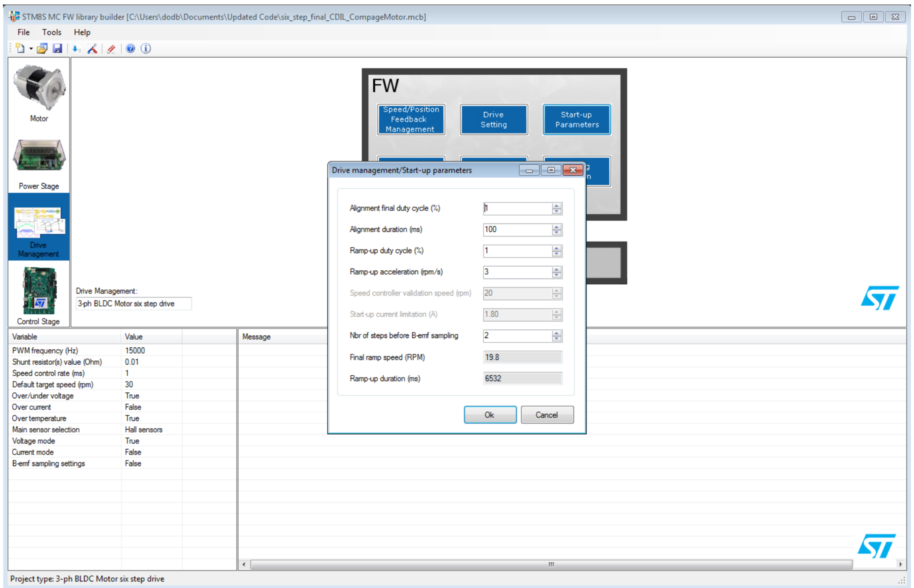
Step 3. Select the [**Drive Setting**] box and enter the appropriate values shown in the figure below.

Figure 19. MC FW builder GUI, drive management drive parameters



Step 4. Select the [**Start-up Parameters**] box and enter the appropriate values shown in the figure below.

Figure 20. MC FW builder GUI, drive management start-up parameters

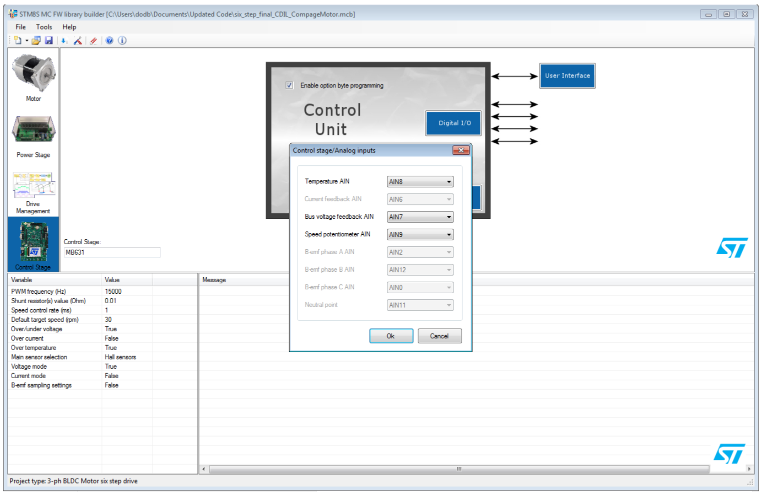


4.4 How to configure the Control Stage section

Step 1. Select the [**Control Stage**] tile in the left panel.

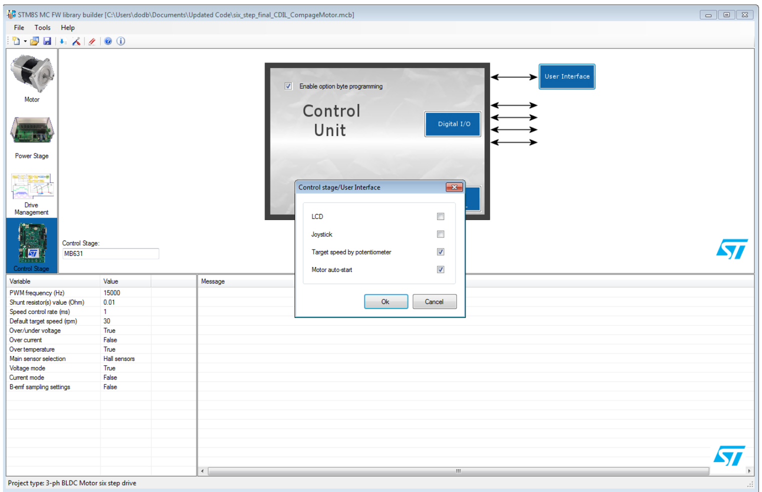
Step 2. Select the [**Analog inputs**] box and verify the pin allocations against those shown in the figure below.

Figure 21. MC FW builder GUI, control stage analog input parameters



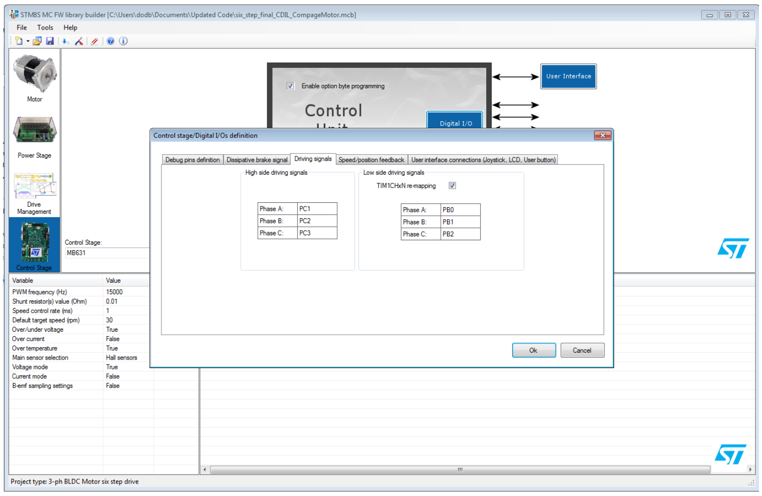
Step 3. Select the [**User Interface**] box and enable the functions shown in the figure below.

Figure 22. MC FW builder GUI, control stage user interface parameters



Step 4. Select the [**Digital I/O**] box and re-map the timers as shown in the figure below.

Figure 23. MC FW builder GUI, control stage driving signal timer re-mapping

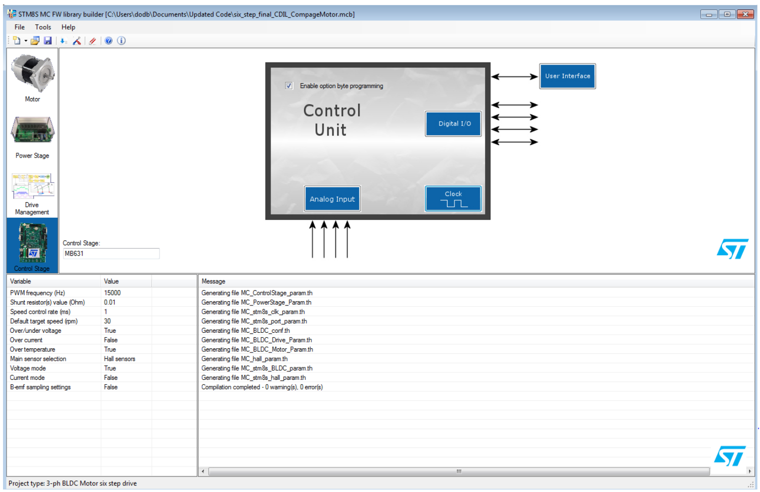


Step 5. Select the [**Clock**] box and set the clock to 16 MHz.

Step 6. Select the [**Options**] icon from the toolbar menu and set the path where the generated code should be saved.

Step 7. Click on the [**Compile**] icon from the toolbar menu to your initialized firmware code.
Successful compilation is confirmed in the Message panel below the main window.

Figure 24. MC FW builder GUI, code generation success confirmation

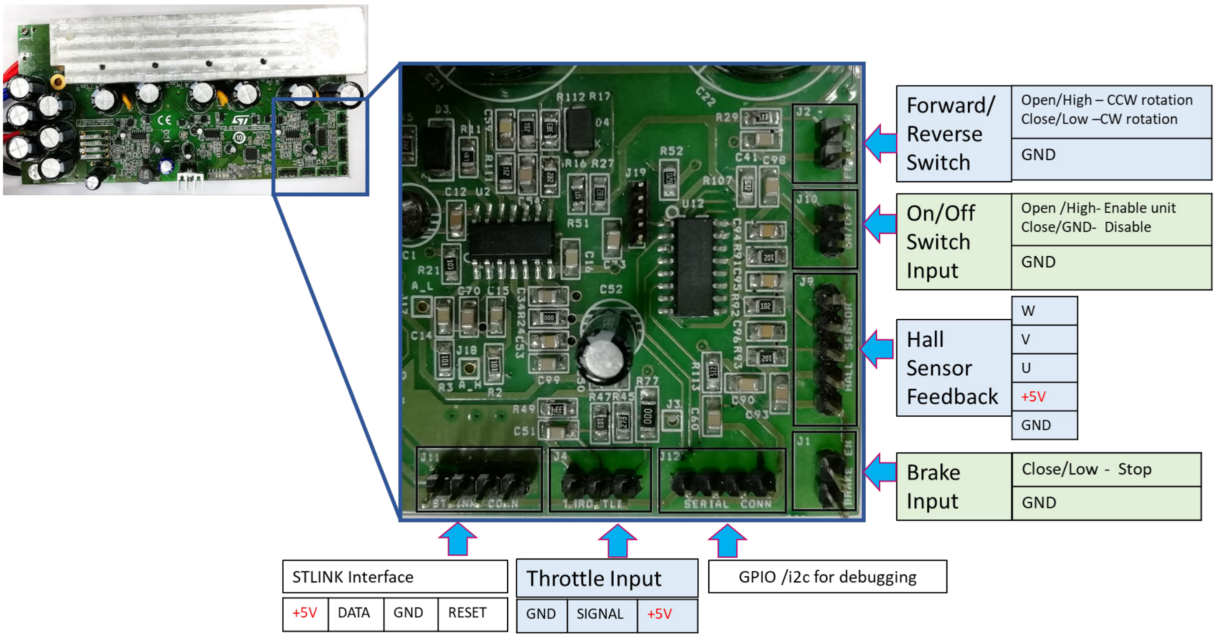


4.5 Application-specific firmware functionality

4.5.1 Control inputs from user

The throttle input is detected via an A/D converter. Typically, the minimum maximum voltage is 5 V, which corresponds to maximum duty cycle, while the minimum voltage level can be calibrated to match the Throttle used. Brake and Direction are digital inputs to the MCU.

Figure 25. STEVAL-EVT001V1 reference design control and debug interfaces



4.5.2 Hall effect sensor signal conditioning

The signals from Hall sensors are processed in the firmware to eliminate false notches which might appear due to cogging/vibration under light load, especially in lab testing conditions.

4.5.3 Fault LED indications

Input voltage, power converter heatsink temperature and overcurrent events are monitored in firmware and signaled by three Fault status LEDs.

Note: During startup, all LEDS blink to indicate normal operation.

Table 1. Fault LED Indications

Fault	LED1	LED2	LED3
Under Voltage	OFF	OFF	ON
Over Voltage	OFF	OFF	Blink
Over Current	OFF	ON	OFF
Over Temperature	ON	OFF	OFF
Over Temperature with Over Voltage	ON	OFF	Blink
Over Temperature with Under Voltage	ON	OFF	ON
Over Voltage with Over Current	OFF	ON	Blink
Under Voltage with Over Current	OFF	ON	ON
Hall Signal Fault (Not Valid State)	Toggle in sequence	Toggle in sequence	Toggle in sequence

5 How to set up and run the 1 kW traction control hardware

This procedure presumes that have already generated the BLDC motor control firmware with 6-step drive algorithm and loaded it onto the STM8S microcontroller.

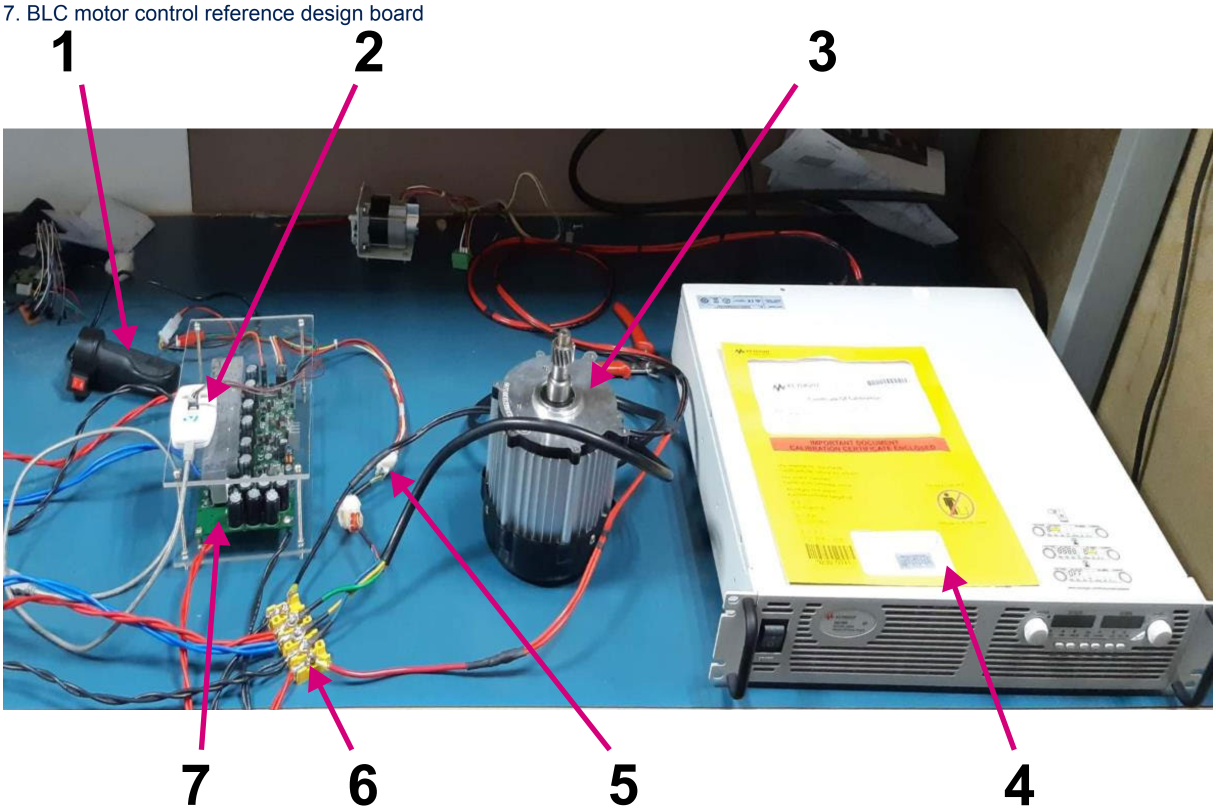
The figure below shows a traction control setup with our 1 kW reference design, a BLDC motor with Hall sensors, an appropriate DC power supply and a potentiometer for throttle control.

Caution: A suitable heat sink along thermally conductive casing is also required for field testing and deployment, basing the overall thermal resistance of the heat sinking scheme on ambient conditions and duty cycle.

The system is designed for 48 V_{DC} input voltage; do not supply above 50 V.

Figure 26. 1 kW traction control hardware setup

1. Throttle (accelerator)
2. ST-LINK programmer/debugger
3. BLDC motor
4. DC power supply
5. Hall sensor signal from motor to drive
6. Motor terminals and bus voltage connector
7. BLC motor control reference design board



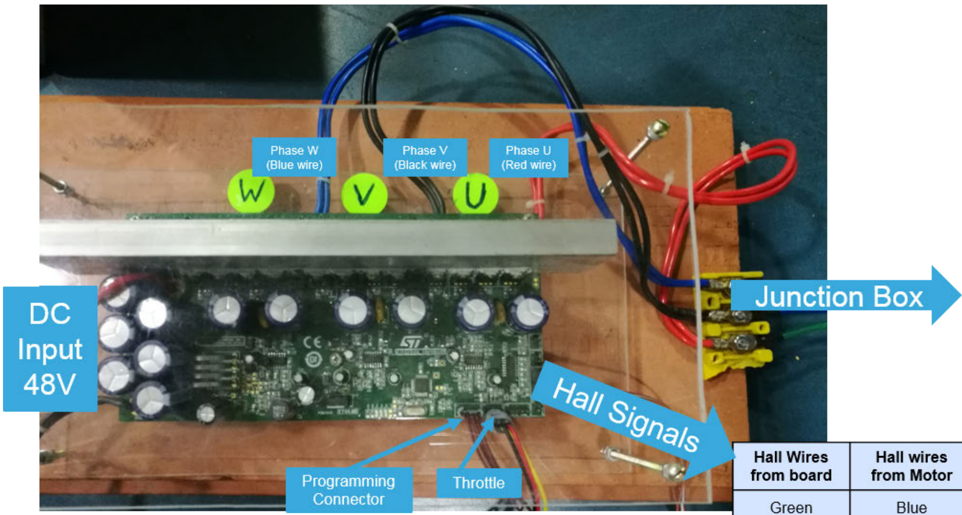
Step 1. Connect the phase U, V and W motor terminals to the output connector of the board.

Step 2. Connect the DC supply to the input connector.
Check the polarity (red is positive, black is ground).

Step 3. Connect the Hall sensor signal from the motor to connector J9 of board (5-pin Connector).

Step 4. Connect Throttle (accelerator) to connector J4 of board (3-pin connector)

Figure 27. Installation of the board



Board output	Motor Wires
Phase U (RED)	Green
Phase V (BLACK)	Blue
Phase W (BLUE)	Yellow

Hall Wires from board	Hall wires from Motor
Green	Blue
Blue	Green
Yellow	Yellow

Step 5. Set the DC power supply to 48 V and overcurrent rating to 22 A.

Step 6. Check all the connections before switching on the supply.

Step 7. Switch ON the power supply to the board.

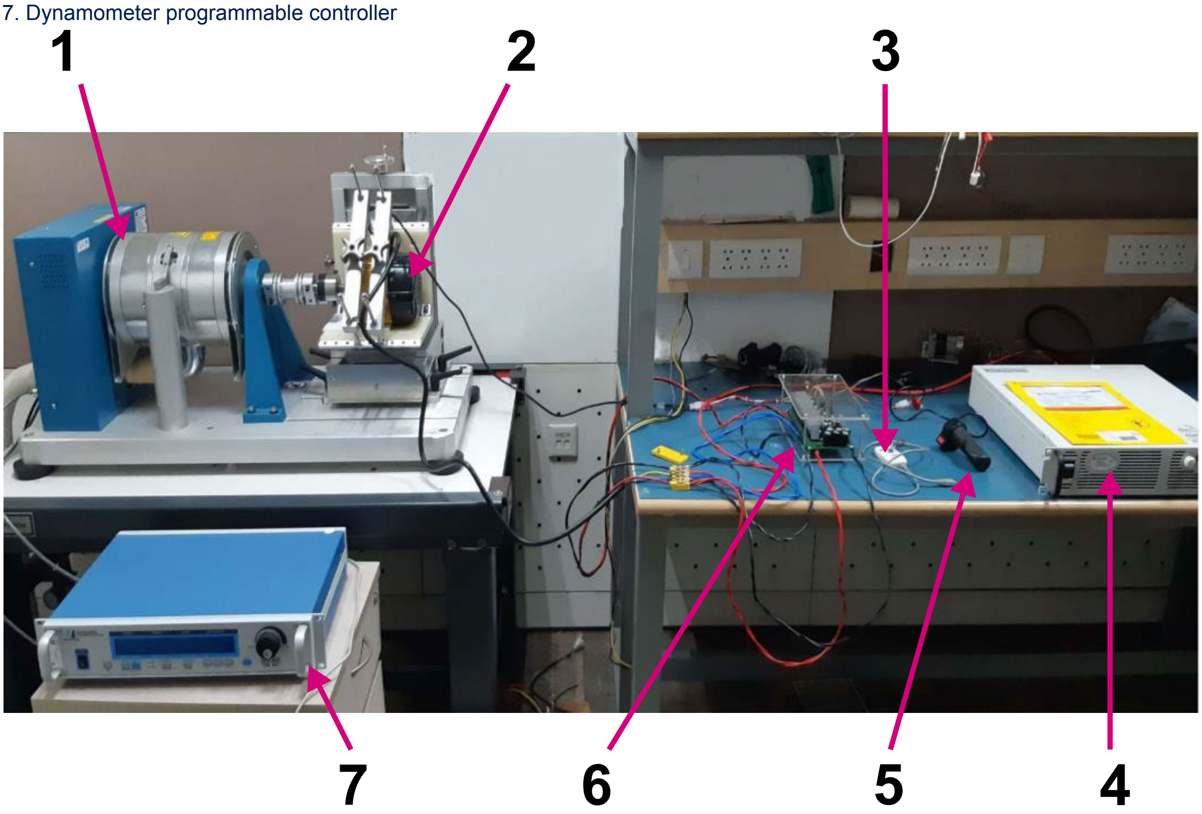
Step 8. Change the position of throttle to control the speed of the motor.

6 Lab setup

The following figure shows the testing setup used to evaluate the performance of the 1 kW BLDC motor control reference design under different load conditions.

Figure 28. 1 kW BLDC motor control reference design

1. Hysteresis dynamometer to load the motor
2. BLDC motor
3. ST-LINK programmer/debugger
4. DC power supply
5. Throttle (accelerator)
6. BLDC motor control reference design
7. Dynamometer programmable controller



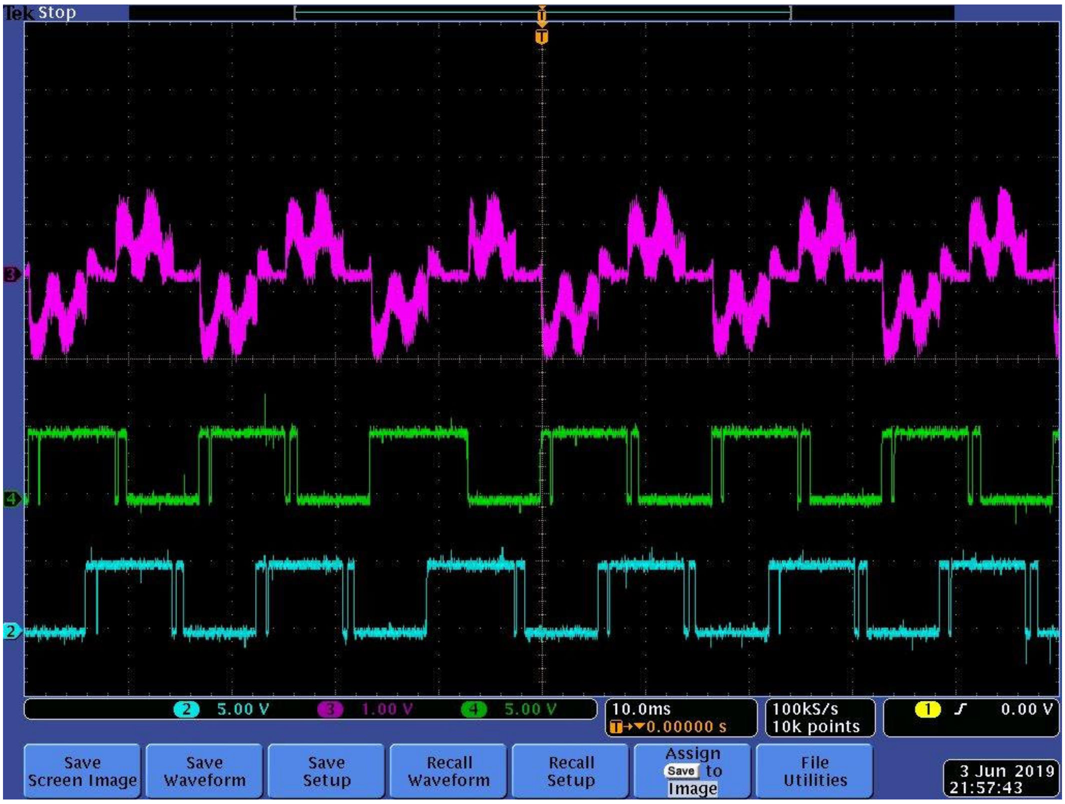
6.1 Load test at 0.5 Nm

Table 2. Test conditions for 0.5 Nm load test (V_{IN} = 48 V)

Input Current(A)	Input Power(W)	Dynamometer Display Mechanical Power(W)	Speed (RPM)	Torque (Nm)	Mechanical Power Calculated(W)	Efficiency (%)	Direction
1.85	88.8	47.7	912	0.5	47.75469169	53.78	Forward

Figure 29. **Current waveform with Hall Sensor Signal at Phase A and B taken at 0.5 Nm torque load**

(3) Phase current
(4) H1 - Phase A Hall Sensor Signal
(2) H2 - Phase B Hall Sensor Signal



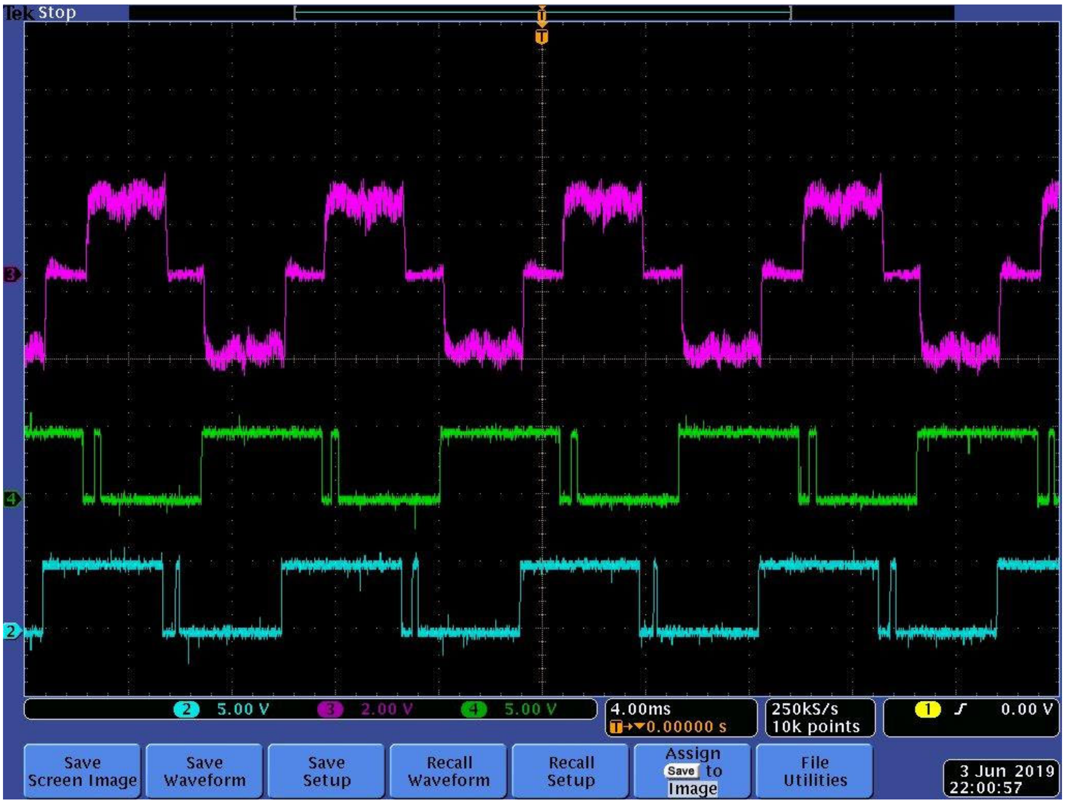
6.2 Load test at 3.0 Nm

Table 3. **Test conditions for 3.0 Nm load test (V_{IN} = 48 V)**

Input Current(A)	Input Power(W)	Dynamometer Display Mechanical Power(W)	Speed (RPM)	Torque (Nm)	Mechanical Power Calculated (W)	Efficiency (%)	Direction
13.22	634.56	511.36	1628	3	511.477882	80.60354924	Forward

Figure 30. Current waveform with Hall Sensor Signal at Phase A and B taken at 3.0 Nm torque load

(3) Phase current
(4) H1 - Phase A Hall Sensor Signal
(2) H2 - Phase B Hall Sensor Signal



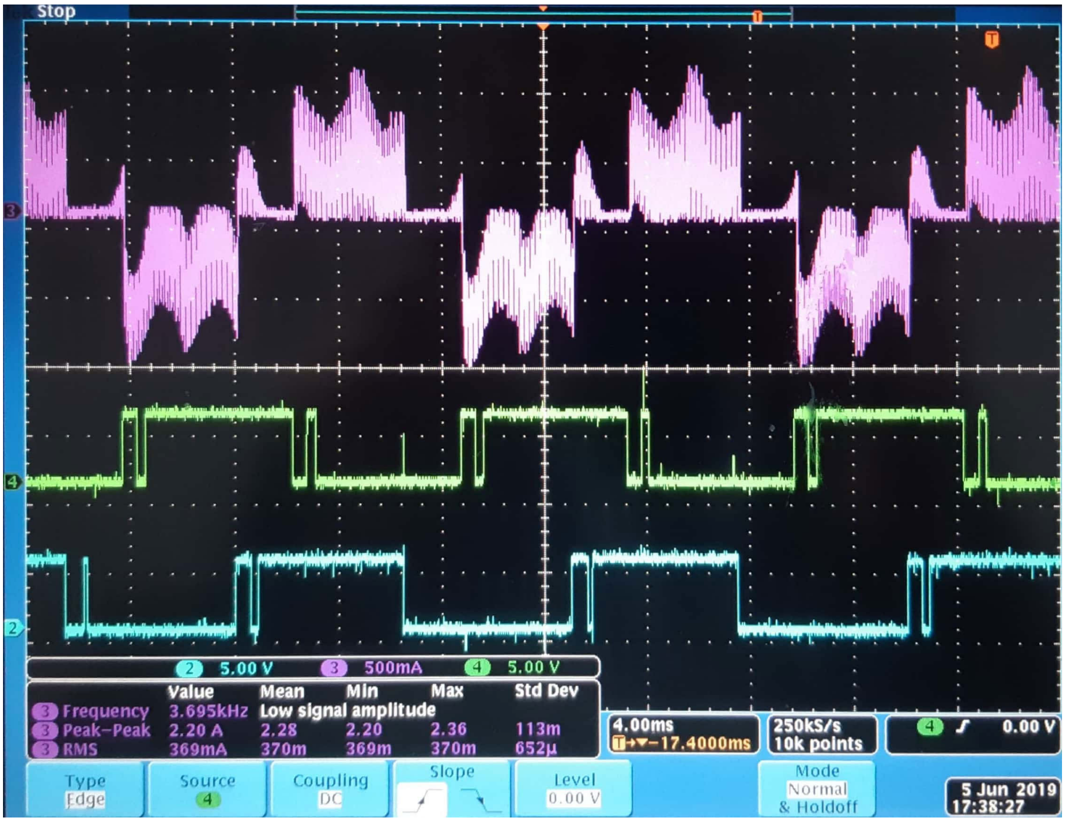
6.3 Test at no load

Table 4. Test conditions for no load (V_{IN} = 48 V)

Input Current(A)	Input Power(W)	Speed (RPM)
1.95	93.6	1222

Figure 31. Current waveform with Hall Sensor Signal at Phase A and B taken at No load

(3) Phase current
(4) H1 - Phase A Hall Sensor Signal
(2) H2 - Phase B Hall Sensor Signal



6.4 Performance graphs

The following performance graphs are derived from the measurements taken from performance testing of the traction control system at 0.5 Nm, 3.0 Nm and no load conditions from a nominal 48 V power supply voltage.

Figure 32. Speed vs torque

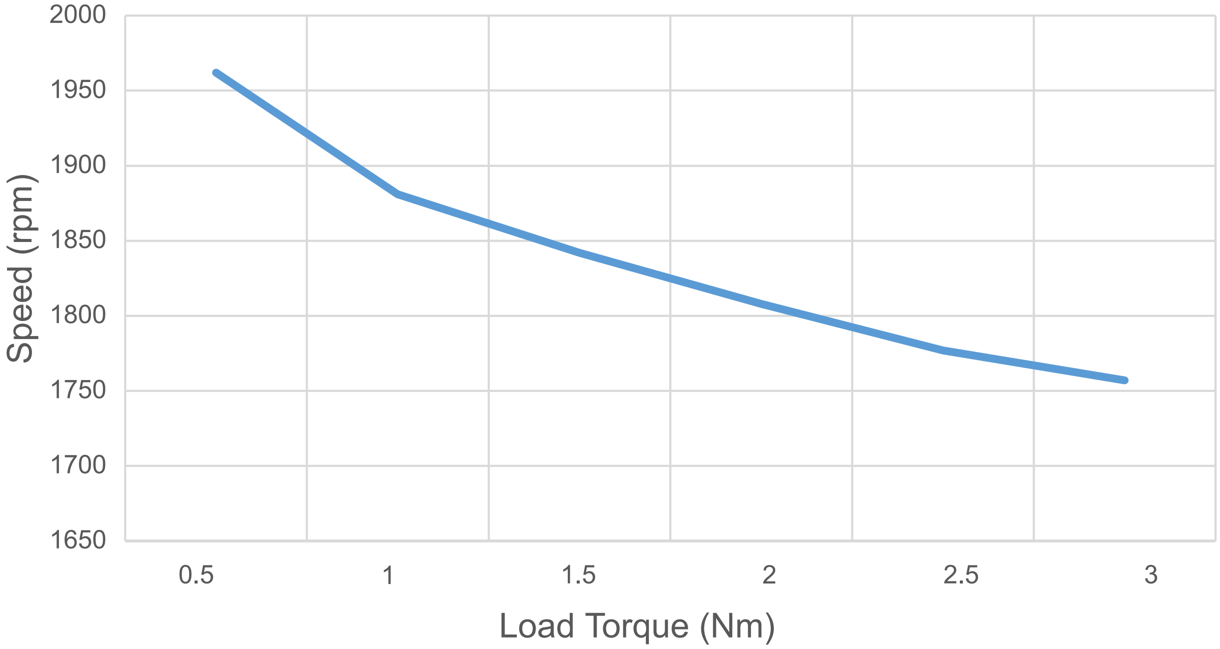


Figure 33. Load torque vs efficiency

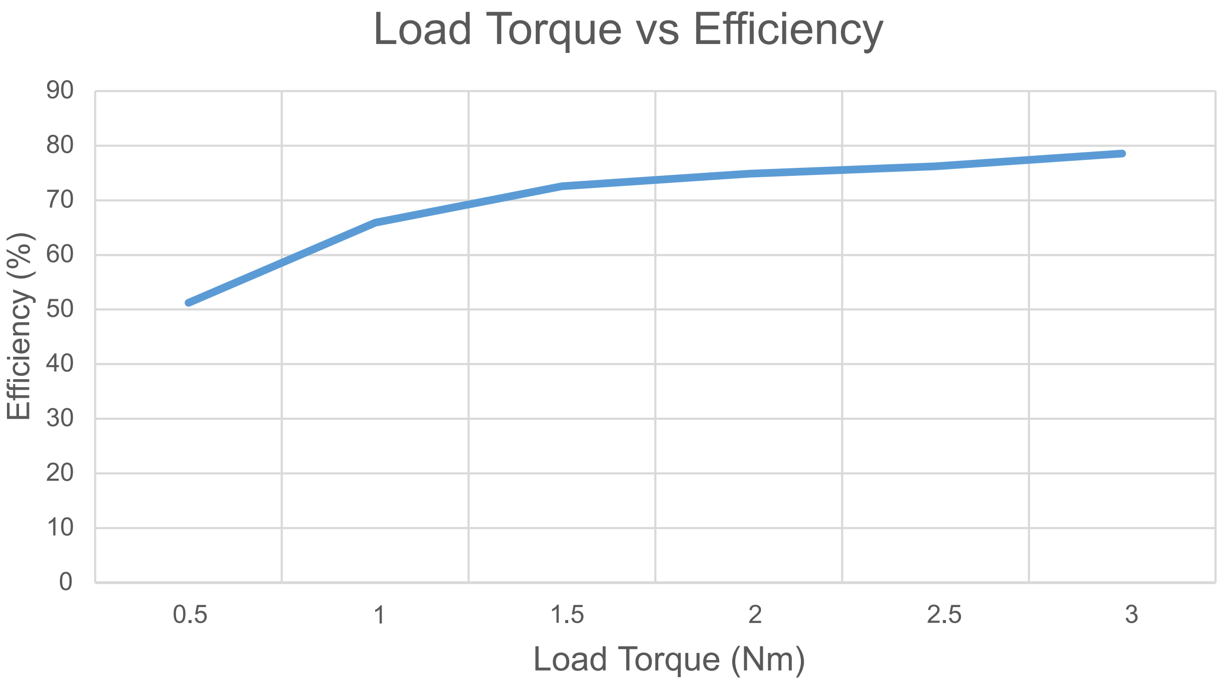
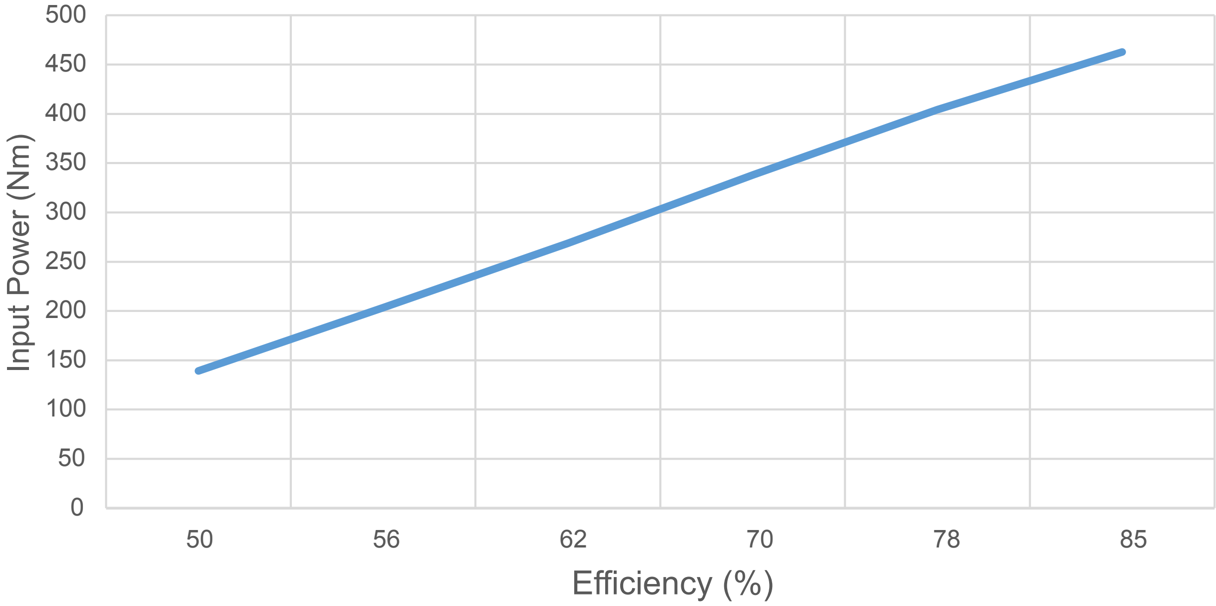


Figure 34. Input power vs efficiency



7 Bill of materials

Table 5. STDES-EVT001V1 bill of materials

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	3	C1, C38, C61	22µF, 63V, ±20%	Electrolytic capacitor, 5mm dia, 2mm pitch, Through Hole	Panasonic Electronics	ECA-1JM220
2	1	C2	1µF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KKX7R8BB105
3	1	C3	100µF, 100V, ±20%	Electrolytic capacitor, 10mm dia, 5mm pitch Through Hole	Nichicon	UVR2A101MPD
4	1	C4	220nF, 50V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KKX7R9BB224
5	1	C5	(not mounted)	SMD0805	-	-
6	1	C6	470µF, 25V, ±20%	Electrolytic capacitor, 10mm dia, 5mm pitch Through hole	Panasonic Electronics	ECA-1EM471
7	1	C7	1nF, 50V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KRX7R9BB102
8	1	C8	100nF, 100V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KKX7R0BB104
9	1	C9	10µF, 16v, ±20%	Electrolytic capacitor, 8mm dia, 3.5mm pitch, Through Hole	Nichicon	USH1C100MPD
10	3	C11, C49, C71	100nF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KRX7R8BB104
11	4	C12, C53, C55, C57	10nF, 50V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KRX7R9BB103
12	3	C13, C62, C73	100nF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KRX7R8BB104
13	11	C14, C15, C16, C44, C46, C59, C66, C67, C94, C95, C96	1nF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KRX7R8BB102
14	12	C17, C18, C19, C20, C21, C22, C23, C24, C26, C28, C31, C32	470µF, 100V, ±20%	Electrolytic capacitor, 16mm dia, 7.5mm pitch, Through hole	Panasonic Electronics	ECA-2AHG471
15	3	C25, C27, C30	2.2nF, 760VAC, 500VAC, ±20%	Safety Ceramic Disc Capacitors, Through Hole	Vishay	VY1222M37Y5VQ63V0
16	3	C34, C40, C47	220nF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KRX7R8BB224
17	2	C37, C72	10nF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KRX7R8BB103
18	2	C39, C43	20pF, 25V, ±5%	Ceramic Capacitor, SMD0805	AVX	08053A200JAT2A

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
19	6	C41, C50, C51, C60, C70, C98	100nF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KRX7R8BB104
20	7	C42, C56, C58, C63, C64, C69, C99	100nF, 50V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KKX7R9BB104
21	1	C45	680nF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KKX7R8BB684
22	1	C48	1µF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KKX7R8BB105
23	3	C52, C100, C101	1µF, 50V, ±20%	Electrolytic capacitor, 5mm dia, 2mm pitch, Through hole	Wurth Electronics	860010672005
24	1	C54	100nF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KRX7R8BB104
25	1	C65	10nF, 25V, ±10%	Ceramic Capacitor, SMD0805	Yageo	AC0805KRX7R8BB103
26	1	C68	10nF, 50V, ±10%	Ceramic Capacitor, SMD1206	Wurth Electronics	885012208081
27	2	C90, C93	100nf, 25V, ±10%	Ceramic Capacitor, SMD0805	Wurth Electronics	885012207072
28	9	D1, D3, D4, D8, D10, D11, D13, D15, D16	1.0 Amp, 60 V	Schottky Diodes & Rectifiers , SMA	ST	STPS1L60A
29	6	D2, D5, D9, D12, D14, D17	18V, 18V/ 500MW, ±5%	Zener Diode, SOD-123	ON Semiconductor	MMSZ5248BT1G
30	1	D6	1000V 1A	Rectifier , Through hole	ON Semiconductor	1N4007RLG
31	2	D18, D19	200V 1A	Ultrafast Recovery Diode, SMA	ST	STTH102A
32	1	D20	100 V, 150 mA	General Purpose Signal Schottky Diode, SOD-123	ST	BAT46ZFILM
33	1	D21	18V	TVS Diodes, SMA	ST	SMAJ18A-TR
34	3	D22, D23, D24	200V 1A	Ultrafast Diode, SMA	ST	STTH102AY
35	1	D30	30V, 300mA	General Purpose Schottky Diodes, SOD-523	ST	BAT30KFILM
36	3	J1, J2, J10	CON2, connector	Header and Wires, 2 Pins Through hole	Molex	22-28-4033
37	7	J3, J13, J14, J15, J16, J17, J18	15V_+VE	Header and Wires, 1 Pin each Through hole	Molex	22-28-4033
38	1	J4	CON3	Header and Wires, 3 Pins Through hole	Molex	22-28-4033
39	1	J5	BAT+VE	VBUS (marked on Board)	-	-
40	1	J7	BAT-VE	GND (marked on board)	-	-

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
41	3	J9, J11, J12	CON5, connector	Header and Wires, 5 Pins Through hole	Molex	22-28-4033
42	4	LD1, LD2, LD3, LD4	LED_RED, 1.7V	LED Indicator, SMD0805	Stanley Electric	BR1112H-TR
43	1	L1	BEAD, 150MA 360 MΩ, ±10%	Fixed inductor 10µh, SMD0805	Taiyo Yuden	LBR2012T100K
44	1	L2	1.2mH, 750mA, ±10%	Fixed inductor 1.2mh, 5 mm pitch Through hole	Wurth Electronics	7447480122
45	24	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q10, Q11, Q12, Q13, Q14, Q15, Q16, Q17, Q18, Q19, Q20, Q21, Q22, Q23, Q24, Q25	STP100N8F6, 80 V, 100 A	N-channel Power MOSFET, TO-220 Through hole	ST	STP100N8F6
46	1	RT1	10kΩ NTC	NTC Thermistor	EPOCS/TDK	B57703M103G40
47	6	R1, R47, R21, R25, R28, R78	10K, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT10K0
48	6	R2, R3, R31, R32, R56, R57	100E, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT100R
49	6	R4, R17, R30, R48, R55, R76	3R3, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT3R30
50	6	R5, R16, R33, R46, R58, R73	2R2, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT2R20
51	2	R6, R53	100k, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT100K
52	27	R7, R8, R9, R10, R11, R12, R13, R14, R15, R35, R36, R37, R38, R40, R41, R42, R43, R44, R61, R62, R63, R64, R66, R68, R69, R70, R71	4R7, 250mW, ±1%	Thick Film, SMD0805	Stackpole Electronics	RNCP0805FTD4R70
53	3	R24, R80, R110	0R, 125mW	Thick Film, SMD0805	TE Connectivity	CRG0805ZR
54	24	R18, R20, R79, R88, R95, R100, R102, R108, R109, R114, R115, R116, R117, R118, R119, R120, R121, R122, R123, R124, R125, R126, R127, R128	4K7, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT4K70
55	1	R19	2k7, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT2K70

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
56	4	R22, R23, R105, R106	0.015/SHUNT, 3W, ±1%	Metal Element Current Sensing Resistors, Through hole	TT Electronics	OAR3R015FLF
57	1	R27	1K8, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT1K80
58	4	R29, R72, R107, R113	5K1, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT5K10
59	9	R26, R34, R50, R59, R74, R75, R81, R82, R83	1K, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT1K00
60	4	R39, R60, R65, R67	680, 250mW, ±0.5%	Thick Film, SMD0805	Panasonic Electronics	ERJ-PB6D6800V
61	1	R45	27K, 250mW, ±5%	Thick Film, SMD0805	Panasonic Electronics	ERJ-T06J273V
62	1	R49	330K, 250mW, ±5%	Thick Film, SMD0805	Stackpole Electronics	RPC0805JT330K
63	1	R51	120E, 250mW, ±5%	Thick Film, SMD0805	Panasonic Electronics	ERJ-T06J121V
64	1	R52	82E, 250mW, ±5%	Thick Film, SMD0805	Panasonic Electronics	ERJ-T06J820V
65	1	R77	0E, 250mW	Thick Film, SMD1206	Yageo	RC1206FR-070RL
66	1	R54	6K8, 250mW, ±0.5%	Thick Film, SMD0805	Panasonic Electronics	ERJ-PB6D6801V
67	6	R84, R91, R92, R93, R129, R130	4.7K, 250mW, ±0.5%	Thick Film, SMD0805	Panasonic Electronics	ERJ-PB6D4701V
68	2	R111, R112	1.5K, 250mW, ±5%	Thick Film, SMD0805	Panasonic Electronics	ERJ-T06J152V
69	6	TP1, TP2, TP4, TP5, TP12, TP13	TEST POINT	-	-	-
70	1	U1	VIPER115LS, 30V, 1.25mA	AC/DC Converters, SSOP 10	ST	VIPER115LS
71	3	U2, U4, U6	4A	Half-Bridge Gate Driver, SO-14	ST	L6491D
72	1	U3	STM8S105C6T6, 2.95-5.5V	8-bit MCU, LQFP 48 7x7x1.4	ST	STM8S105C6T6
73	1	U5	TSV631, 60 µA at 5 V	Operational Amplifiers - Op Amps 60uA , SOT23-5L	ST	TSV631ILT
74	1	U12	74HC4050D/SO16, 15V	Buffers & Line Drivers, SO16	Nexperia	74HC4050D
75	1	U17	L7805/TO220, 1.5A	Linear Voltage Regulators, TO-220	ST	L7805
76	1	Y1	XTAL_16MHz	Crystal Oscillator, HC-49/S Through Hole	TXC Corporation	AS-16.000MAHK-B

Revision history

Table 6. **Document revision history**

Date	Version	Changes
04-Nov-2019	1	Initial release.

Contents

List of figures

List of tables