5 kW low voltage high current inverter for industrial motor control applications

Introduction

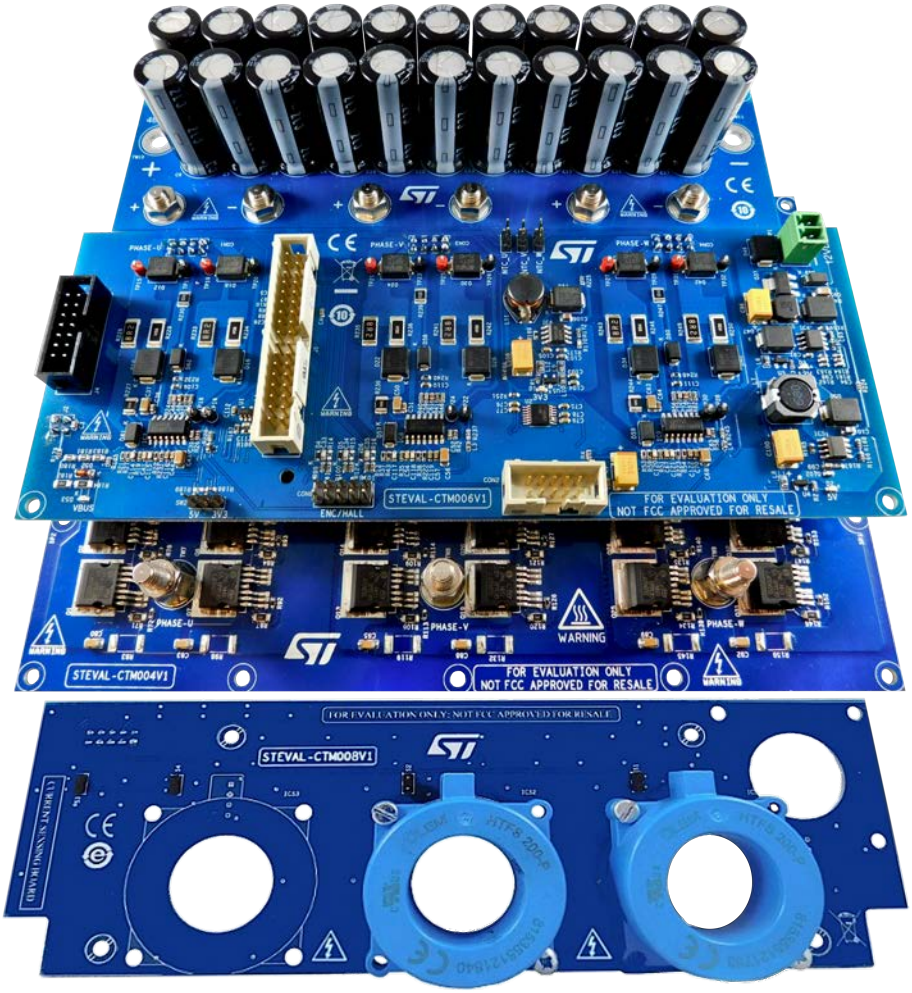
The STEVAL-CTM009V1 evaluation kit for motor control is designed to demonstrate the capabilities of ST Power MOSFETs based on STripFET™ F7 technology. The 100V STripFET™ F7 devices (STH31*N10F7) are ideal for low voltage (up to 48 V), high current applications such as forklifts, golf carts and power tool.

The STEVAL-CTM004V1 power board features an insulated metal substrate (IMS), NTCs for thermal protection and decoupling gate resistors for each power MOSFET. The board mounts ST devices in the H²PAK-6 package.

The driver stage is an STEVAL-CTM006V1 board with L6491 high current capability gate drivers to drive the power MOSFETs and integrated comparator for protections. The driver board includes the ST motor control connector, so you can interface the STEVAL-CTM009V1 with any ST MCU control board suitable for motor control (not included in the kit).

The system also has an STEVAL-CTM005V1 bus link capacitor board and an STEVAL-CTM008V1 current sensing board.

Figure 1. STEVAL-CTM009V1 evaluation kit



1 Evaluation kit features

1.1 Electrical and functional characteristics

The kit features the following main characteristics:

- Power board with insulated metal substrate (IMS) hosting 36 STH310N10F7 or STH315N10F7 power MOSFETS in the H²PAK-6 (6x switch) package, designed also for automotive applications.
- High and low-side, high current capability (L6491) gate driver with integrated comparator for fast protection and smart shutdown functions.
- Maximum power 5 kW at 48 V.
- Isolated current sensing, bus voltage and temperature monitoring.

1.2 Target applications

The STEVAL-CTM009V1 kit is designed for applications involving motor drives for electric traction, such as:

- forklifts
- golf carts
- E-rickshaw

2 Safety and operating instructions

2.1 General terms

All operations involving transportation, installation and use, as well as maintenance, has to be carried out by skilled technical personnel (national accident prevention rules must be observed). For the purpose of these basic safety instructions, "skilled technical personnel" are considered as suitably qualified people who are familiar with the installation, use, and maintenance of power electronic systems.

2.2 Intended use of evaluation kit

This evaluation kit is designed for demonstration purposes only and shall not be used for any commercial purpose. The technical data, as well as information concerning power supply conditions, must be taken from the relevant documentation and strictly observed.

2.3 Evaluation kit setup

- The evaluation kit must be set up in accordance with the specifications and the targeted application.
- The board contains electro-statically sensitive components that are prone to damage through improper use. Electrical components must not be mechanically damaged or destroyed.
- Avoid any contact with other electronic components.
- During the motor driving, converters must be protected against excessive strain. Do not bend or alter the isolating distances any components during transportation or handling.

2.4 Electronic connections

Applicable national accident prevention rules must be followed when working on the main power supply with a motor drive. The electrical installation must be completed in accordance with the appropriate requirements. A system architecture which supplies power to the evaluation board must be equipped with additional control and protective devices in accordance with the applicable safety requirements (e.g., compliance with technical equipment and accident prevention rules).

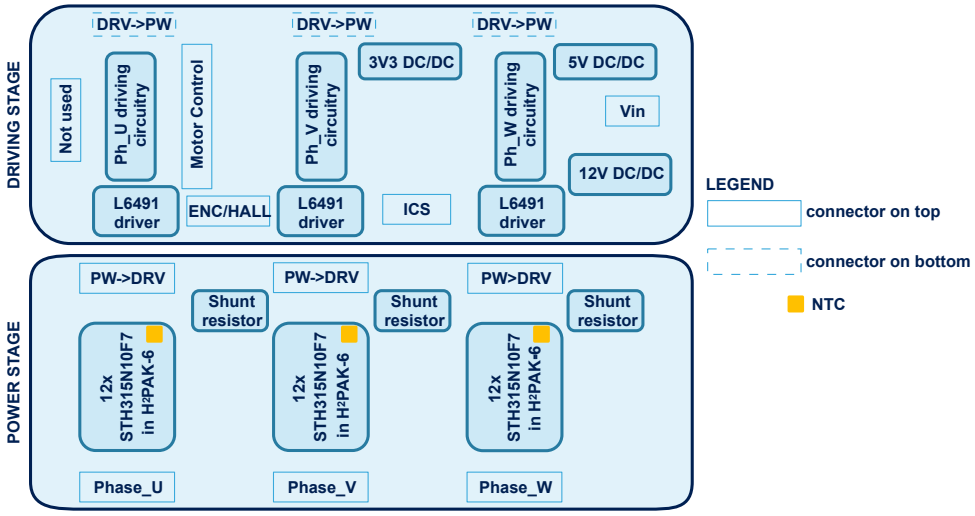
3 Evaluation kit overview

The STEVAL-CTM009V1 evaluation kit is designed to let you evaluate STH31*N10F7 power MOSFETs, which are driven by high and low-side, L6491 high current capability gate drivers. The system includes a bulk capacitor board and a current sensing board.

The STEVAL-CTM009V1 can be interfaced with any ST MCU evaluation board with embedded ST motor control and ST FOC firmware library support.

This kit has been tested with the STEVAL-CTM001V1C (not included in this kit) control board of the STEVAL-HKI001V1 kit), which features an STM32F303RB 32-bit microcontroller.

Figure 2. STEVAL-CTM009V1 block diagram



4 STEVAL-CTM004V1 power board

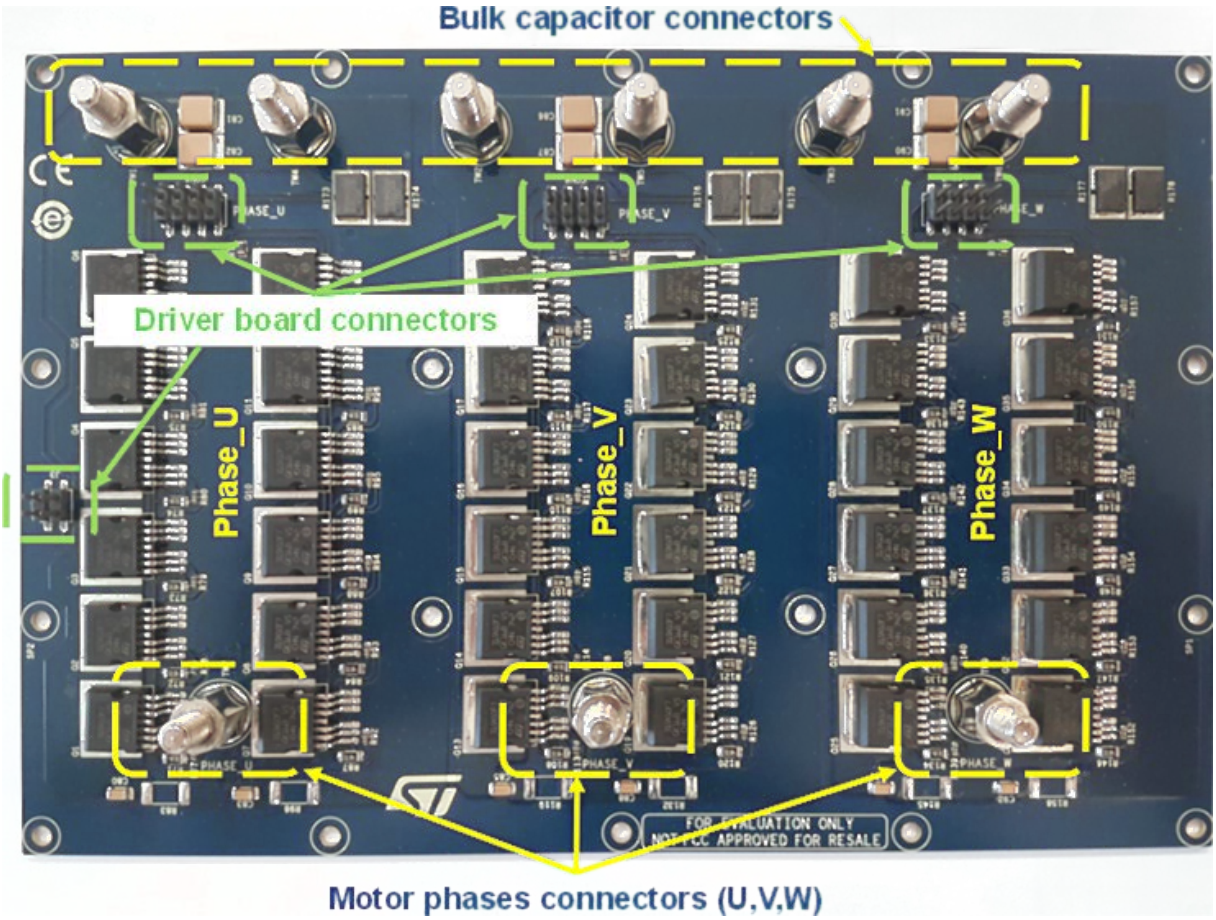
The STEVAL-CTM004V1 power board of the evaluation kit has 36 STH31*N10F7 N-channel Power MOSFETS in the H²PAK-6 package. A gate resistor is placed near each power MOSFET to eliminate parasitic oscillation. A pull-down resistor between the gate and the source of each transistor helps to avoid capacitive coupling driving the transistor and unwanted switch-on when gate is floating. A snubber RC circuit on each switch limits the rate of voltage change during switching transitions to reduce electromagnetic interference (EMI) and losses.

two decoupling capacitors close to the switching power MOSFETs reduce ringing on the VDS and voltage stress on the devices. The capacitors reduce voltage overshoot caused by abrupt current change in the parasitic inductors in the circuit.

To monitor the temperature of the power board and provide over-temperature protection, three NTCs are placed on the power board near the drain of one power MOSFET for each inverter leg.

The power section also has connectors for the driver board, with CON5 (phase_U), CON6 (phase_V) and CON7 (phase_W) for gate driving and NTC sensing, and J3 for bus voltage. The board also hosts six towers near the bulk capacitor board connection and three towers near the motor connection.

Figure 3. Main blocks of the STEVAL-CTM004V1 power board



4.1 STH315N10F7 N-channel Power MOSFET characteristics

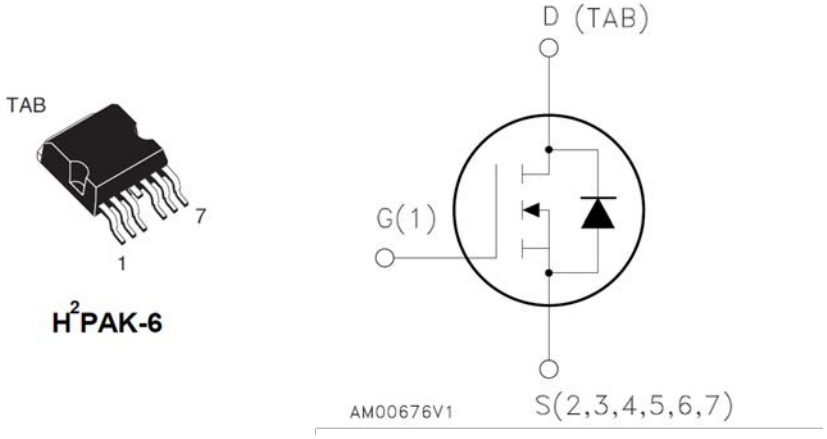
The N-channel Power MOSFETs use STripFET™ F7 technology with an enhanced trench gate structure for very low on-state resistance and reduces internal capacitance and gate charge for faster and more efficient switching.

The STH315N10F7 N-channel Power MOSFET has the following features:

- Designed for automotive applications and AEC-Q101 qualified

- Among the lowest $R_{DS(on)}$ on the market
- Excellent figure of merit (FoM)
- Low C_{rss}/C_{iss} ratio for EMI immunity
- High avalanche ruggedness

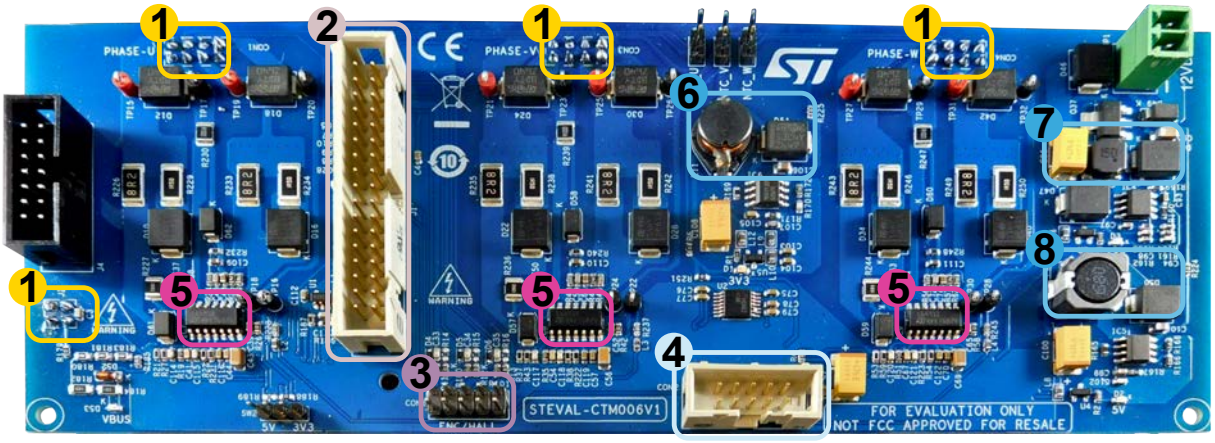
Figure 4. Package and internal schematic diagram



5 Driver board and control board overview

Figure 5. **STEVAL-CTM006V1 driver board functional blocks**

1. connections to power board
2. motor control connector
3. ENC/HALL connector
4. ICS connector
5. L6491 drivers
6 3V3 DC/DC regulation
7. 5V DC/DC regulation
8. 12V DC/DC regulation



5.1 STEVAL-CTM006V1 driver board

5.1.1 Power supply section

The power supply section provides all the voltages necessary for the circuitry. The required input voltage is 8 to 36 V input, which is supplied through connector JP1.

The input voltage is then converted to the following voltage levels:

- +12V for gate driver section (via an A7986 3 A step-down switching regulator)
- +5V and +3.3V for the control board (via an A6902 1 A switch step-down regulator)

5.1.2 Bus voltage monitoring

Bus voltage monitoring is implemented across an input voltage range of 5 to 75 V.

The following table shows the measured input voltage and the corresponding voltage level sent to the ADC input of the STM32 microcontroller unit.

Table 1. **Input voltage bus and input signal to STM32 ADC channel**

Input Voltage	ADC input
48V	2.0V
75V (max value)	3.1V

5.1.3 Temperature monitor

Three NTCs are placed on the power section to provide temperature information, although only one NTC may be chosen at a time. Close one of the three jumpers S1, S2 or S3 to read the temperature near the U, V or W phase, respectively. The microcontroller monitors processed signals to determine the temperature of the driver board and manage any overload or over-temperature conditions.

To protect the hardware from excess temperature, a safe threshold is set in the STM32 FOC SDK software library.

Table 2. **NTC electrical characteristics**

Symbol	Parameter	Test Condition	Min	Typ	Max	Unit
R_{-40}	Resistance	T = -40°C	-	105.7	-	kΩ
R_{25}	Resistance	T = 25°C	-	4.7	-	kΩ
R_{100}	Resistance	T = 100°C	-	0.426	-	kΩ
B	B- constant	T = 25°C to 50°C	-	3500	-	-
T	Operating temp range		-40		125	°C

5.1.4 L6491 gate driver characteristics

The L6491 gate driver has the following main features:

- dV/dt immunity ± 50 V/ns in full temperature range
- Driver current capability: 4 A source/sink
- Switching times 15 ns rise/fall with 1 nF load
- 3.3 V, 5 V TTL/CMOS inputs with hysteresis
- Integrated bootstrap diode
- Comparator for fault protections
- Smart shutdown function
- Adjustable deadtime
- Interlocking function
- Compact and simplified layout
- Bill of material reduction
- Effective fault protection
- Flexible, easy and fast design

For detailed information on the product, see the device datasheet.

Figure 6. **L6491 gate driver pin-out**

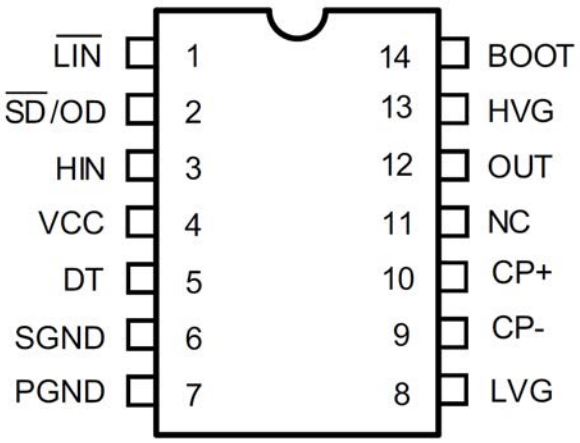


Table 3. **Pin functions of L6491 gate driver**

Pin number	Pin name	Type	Function
1	$\overline{LIN}$	I	Low-side driver logic input (active low)
2	$\overline{SD}$ / OD	I/O	Shutdown logic input (active low)/open-drain comparator output
3	HIN	I	High-side driver logic input (active high)

Pin number	Pin name	Type	Function
4	VCC	P	Lower section supply voltage
5	DT	I	Deadtime setting
6	SGND	P	Signal ground
7	PGND	P	Power ground
8	LVG	O	Low-side driver output
9	CP-	I	Comparator negative input
10	CP+	I	Comparator positive input
11	NC		Not connected
12	OUT	P	High-side (floating) common voltage
13	HVG	O	High-side driver output
14	BOOT	P	Bootstrapped supply voltage

6 STEVAL-CTM005V1 bus link capacitor board

In EV inverter systems, bus link capacitors reduce ripple current and suppress voltage spikes caused by leakage inductance and switching operations. These capacitors provide a low impedance path for the ripple currents caused by output inductance load, the bus voltage and PWM frequency.

The bus link capacitors must sustain a ripple current given by the following formula:

$$\Delta I_{0.5t} = 0.25 \times \frac{V_{bus}}{(f \times L)}$$

Where:

- $\Delta I_{0.5t}$ is the maximum ripple current when duty cycle is 50%
- V_{bus} is the bus voltage
- f is the switching frequency
- L is the load inductance.

For a very low inductance motor (worst case scenario), $\Delta I_{0.5t}$ is about 48 A_{RMS} (V_{bus} = 52 V, f = 8 kHz and L = 12 µH). If we add 10% to $\Delta I_{0.5t}$ and choose electrolytic capacitors with a ripple current of 2.4 A, 22 electrolytic capacitors are required. The resulting capacitance is about 6 mF, leading to a negligible ripple voltage on the bus.

Figure 7. STEVAL-CTM005V1 bus link capacitor board

6.1 STEVAL-CTM008V1 current sensing board

The STEVAL-CTM008V1 current sensing board is a general purpose board for motor control that can read up to three phase motor currents and DC bus currents if four ICS are on-board. The board included in the kit hosts two ICS to read two phase currents.

This sensing feature determines motor currents for digital control based on FOC algorithms. The sensors provide high accuracy, with 4 mV/A over a temperature range of -40 °C to +105 °C and a nominal current of 200 A_{RMS}.

The internal reference voltage of the ICSs (according to their V_{CC}) is generally used, but the reference voltage can be overdriven by providing an external reference voltage through the J1 connector. A female to female flat cable is used to connect CON2 on the driver board with J1 on the current sensing board.

The signals from the sensors center around 1.65 V (average value at zero current).

Figure 8. **STEVAL-CTM008V1 current sensing board**

7 How to set up the system

Follow the steps below to set up the evaluation kit.

Step 1. Mount the STEVAL-CTM004V1 power board heatsink.
Use standard thermal interface material or a graphite sheet for high thermal conductivity

Step 2. Connect the STEVAL-CTM004V1 power board with the STEVAL-CTM006V1 driver board.
- use connectors CON5, CON6, CON7 and J3 on the STEVAL-CTM004V1 power board
- use connectors CON1, CON3, CON4 and J2 on the STEVAL-CTM006V1 driver board

Step 3. Connect the control board:
- If you use the STEVAL-CTM001V1C control board (not included in the kit):
  - use connectors J1 and J4 on the STEVAL-CTM006V1 driver board
  - use connectors CON3 and CON1 on the STEVAL-CTM001V1C control board.
- If you use a control board that is not the STEVAL-CTM001V1C:
  - Use connector J1 on the driver board.

Step 4. Mount the STEVAL-CTM005V1 bus link capacitor board on the STEVAL-CTM004V1 power board

Step 5. Set up the STEVAL-CTM001V1C control board (optional, if present).
- close jumper SW5 in the default position (indicated near the switch)
- connect ST-LINK to the CON14 connector
- connect the USB to serial converter to the P2 with a serial cable DB9 female to female

Step 6. Set up the STEVAL-CTM006V1 driver board.
- close jumper S1, S2 or S3 to read one of the three NTCs on the power stage
- connect a 12 V DC power supply to the JP1 connector and turn on the power supply

Step 7. Connect the flat cable between CON2 on the STEVAL-CTM006V1 driver board and J1 on the STEVAL-CTM008V1 current sensing board.

Step 8. Connect a 48 V_{DC} power supply to the STEVAL-CTM006V1 driver board.

Step 9. Connect the phase motor cables to the STEVAL-CTM004V1 power board.

7.1 Connectors

In addition to the connector used for the supply voltage, the driving board has connectors to plug it to the power board and the control board, and to receive external signals.

- Connector for supply voltage: provided at JP1 (8 to 36 V).
- Connectors to the power board:
  - CON1, CON3 and CON4: for power MOSFET driving and NTC sensing.
  - J2: connector for DC bus voltage sensing (fpr undervoltage and overvoltage protection).
- Connectors to the control board
  - J1: motor control connector, including signals like fault management, bus voltage monitoring, power board temperature sensing and current sensing.
  - J4: connector used for mechanical robustness when a control board (e.g., STEVAL-CTM001V1C, not included in kit) is plugged but not electrically connected.
- Connectors for external signals
  - CON8 (ENC/HALL connector): to receive external signals from Encoder/Hall sensors and provides +3V3 or +5V supply voltages.
  - CON2 (CURRENT SENSING connector): to receive current signals from the external current sensor board and provide a +5V supply voltage.

Figure 9. **Current sensing connector (CON2 on driver board)**

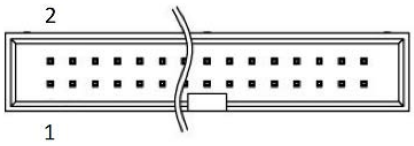


Table 4. **Current sensing connector pinout**

Pin number	Pin name / Function
1	Ground
2	ADC_U
3	Ground
4	ADC_V
5	Ground
6	ADC_W
7	Ground
8	Not Connected
9	Ground
10	Vcc_ICS

Figure 10. **34-pin motor control connector (J1 on the driver board)**

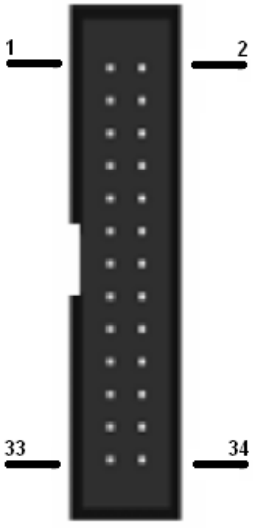


Table 5. **Motor control connector pinout**

Pin number	Pin name / Function	Pin number	Pin name / Function
1	FAULT	18	Ground
2	Ground	19	ADC_W
3	PWM_U_H	20	Ground
4	Ground	21	Not connected

Pin number	Pin name / Function	Pin number	Pin name / Function
5	PWM_U_L	22	Not connected
6	Ground	23	Not connected
7	PWM_V_H	24	Not connected
8	Ground	25	5V
9	PWM_V_L	26	Heatsink temperature signal
10	Ground	27	Not connected
11	PWM_W_H	28	3.3V
12	Ground	29	Not connected
13	PWM_W_L	30	Ground
14	Bus voltage monitoring	31	Enc A/H1
15	ADC_U	32	Ground
16	Ground	33	Enc B/H2
17	ADC_V	34	Enc Z/H3

7.2 Signal LEDs

Table 6. LEDs Indicators on board

Name	Color	Description	Location
D1	RED	3V3	STEVAL-CTM006V1
D2	RED	5V	STEVAL-CTM006V1
D3	RED	12V	STEVAL-CTM006V1
D53	RED	48V	STEVAL-CTM004V1

7.3 Push buttons

Table 7. Push buttons

Name	Description	Location
SW6	STM32 microcontroller reset	Control Board
SW7	User push-button	Control Board

8 Firmware for STM32 PMSM FOC SDK

This evaluation kit is compatible with latest X-CUBE-MCSDK - STM32 FOC firmware library, please visit the X-CUBE-MCSDK web page on www.st.com for information and installation instructions.

8.1 Firmware for STM32 PMSM FOC SDK

You can use the ST Motor control workbench to customize the STM32 FOC library (installed together with the X-CUBE-MCSDK package). The required parameters for the power stage of the STEVAL-CTM009V1 are given in the following table.

Parameter	Value	Unit
Inrush current limiter	disabled	-
Dissipative brake	disabled	-
Bus voltage sensing	Enabled	-
R1 (Bus voltage sensing)	63.9	kΩ
R2 (Bus voltage sensing)	2.7	kΩ
Min. rated voltage	36	V
Max. rated voltage	60	V
Nominal voltage	48	V
Temperature sensing	Enabled	-
V0	761	mV
T0	25	°C
ΔV/ΔT	21	mV/°C
Max. working temperature on sensor	125	°C
Current sensing	Enabled	-
Current reading topology	Two insulated current sensors	-
ICS gain	0.004	V/A
Overcurrent protection	disabled	-
Power switches - switching frequency	12 (can be changed according the requirements)	kHz
Power switches - dead-time	2 (can be changed according the requirements)	µs
U,V,W driver High side driving signal polarity	Active high	-
U,V,W driver Low side driving signal Complemented from high side	disabled	-
U,V,W driver Low side driving signal Polarity	Active low	-

Parameter	Value	Unit
U,V,W driver Force same values for U, V, W driver	enabled	-
U,V,W driver Use STGAP1S gap drive	disabled	-

9 Experimental measurements

The experimental results were obtained by testing the system at maximum power rating.

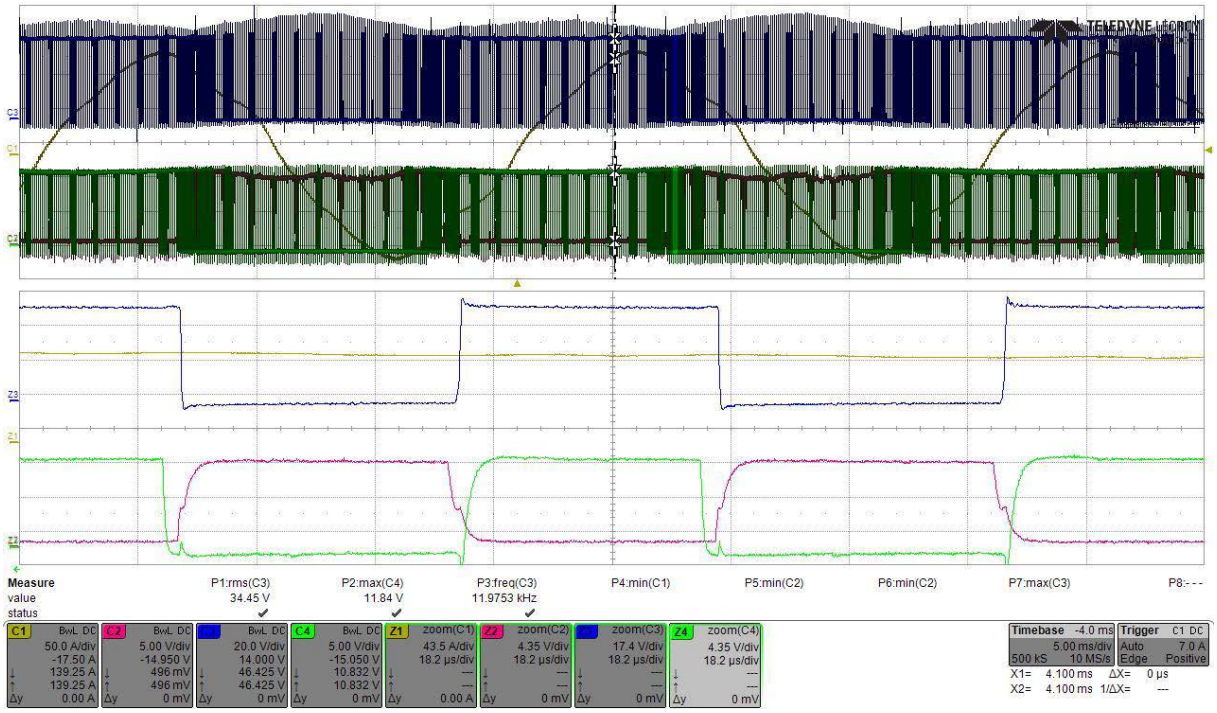
The power board was mounted with a heatsink (manuf.: ABL Components; manuf. order code: 159AB2000B; Rth: 0.36 °C/W; dimensions: 200x160x40mm, or equivalent), using a thermal interface material with high thermal conductivity (1300 W/mK) to form a natural convection cooling system.

A 48 V bus voltage was applied to drive a PMSM connected to a brake dynamometer.

The system was set at 5 kW output power to monitor the behavior of V_{GS}, V_{DS}, phase current and device temperatures measured by an infrared thermo-camera.

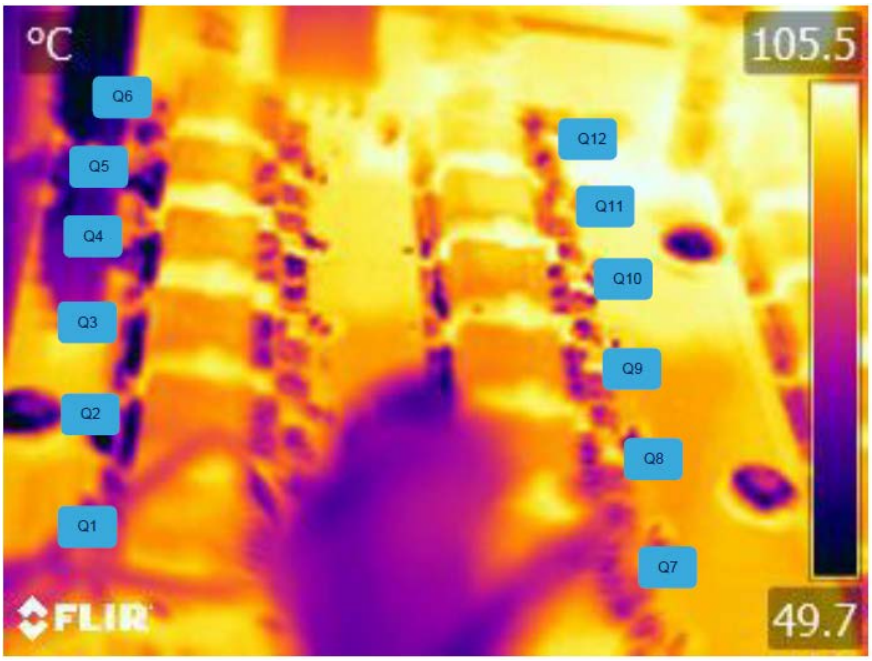
Ch1: Ids; Ch2: Vgs HS; Ch3: Vds HS; Ch4: Vgs LS

Figure 11. Measured waveforms



The figure below shows the temperature of phase U devices after 40 minutes of continuous operation at full power. The devices operated in safe conditions and the temperature did not exceed the absolute max ratings. The maximum measured temperature is about 105 °C.

Figure 12. **Measured temperatures of U_phase Power MOSFETs**



The following table shows the MOSFET maximum, minimum and average temperature values.

Table 8. **Measured case temperatures of the STH315N10F7 power MOSFETs**

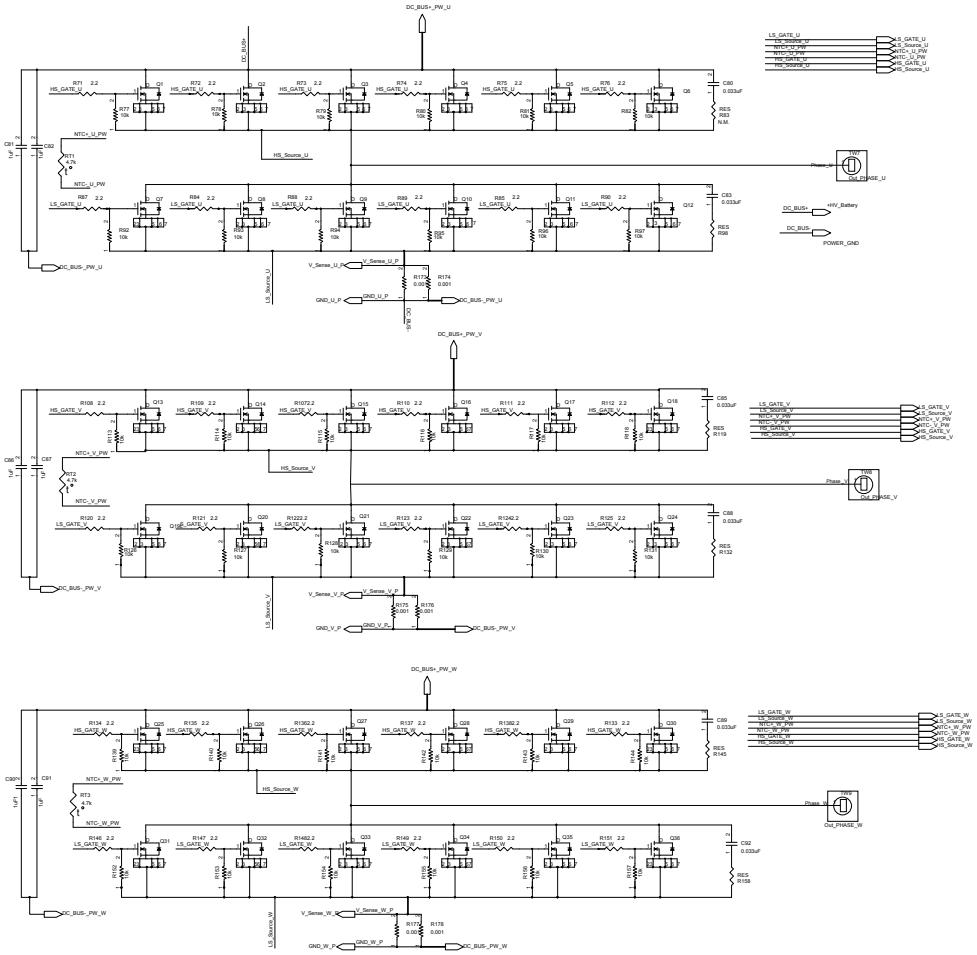
Case Temperature [°C]	High Side Uphase devices						Low Side Uphase devices					
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
max.	99.5	99.8	100.4	101.2	102.4	101.5	98.5	101.9	103.4	104.5	104.3	104.9
min.	85.9	81.1	91.9	91.9	87.9	93.3	NA (1)	NA(1)	88.6	90.1	94.9	103.5
Average	94.6	91.6	98.8	96.2	96.7	97.4	NA(1)	NA(1)	94.5	96.7	99.9	101.9

1. *Not measured due to an obstacle along the measurement line*

10 STEVAL-CTM0091V1 kit schematic diagrams

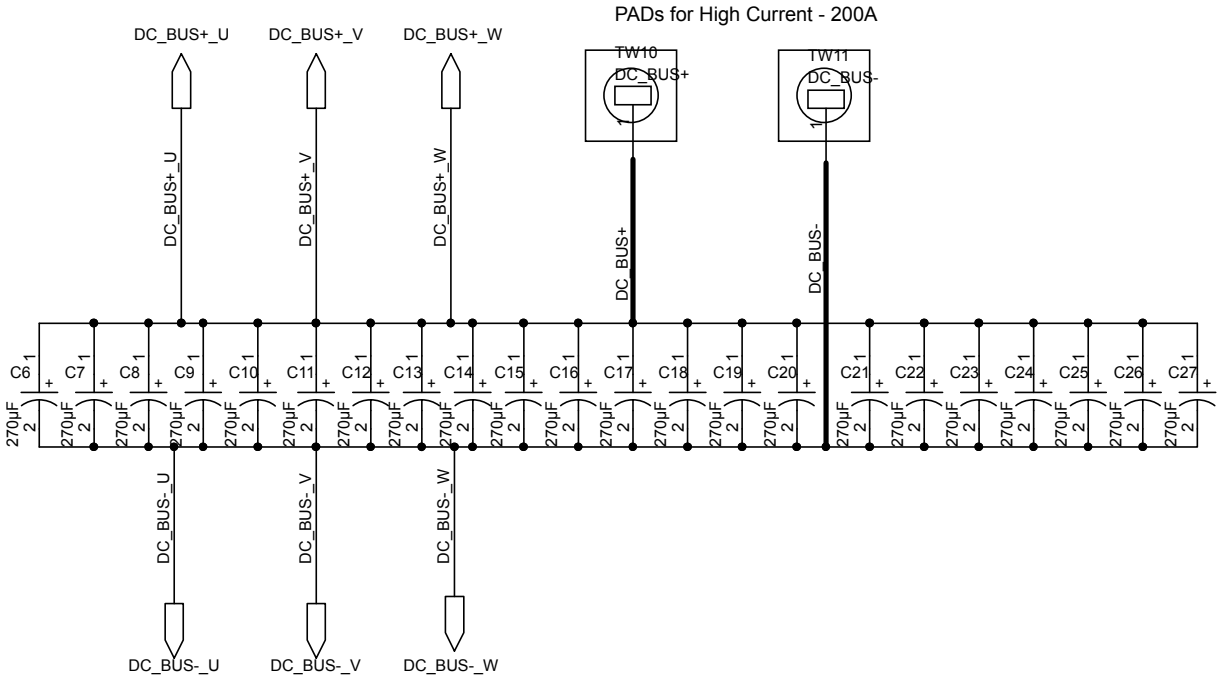
10.1 STEVAL-CTM004V1 schematic diagram

Figure 13. **STEVAL-CTM004V1 power board schematic**



10.2 STEVAL-CTM005V1 schematic diagram

Figure 14. STEVAL-CTM005V1 capacitor board schematic



10.3 STEVAL-CTM006V1 schematic diagrams

Figure 15. STEVAL-CTM006V1 driver board schematic - main

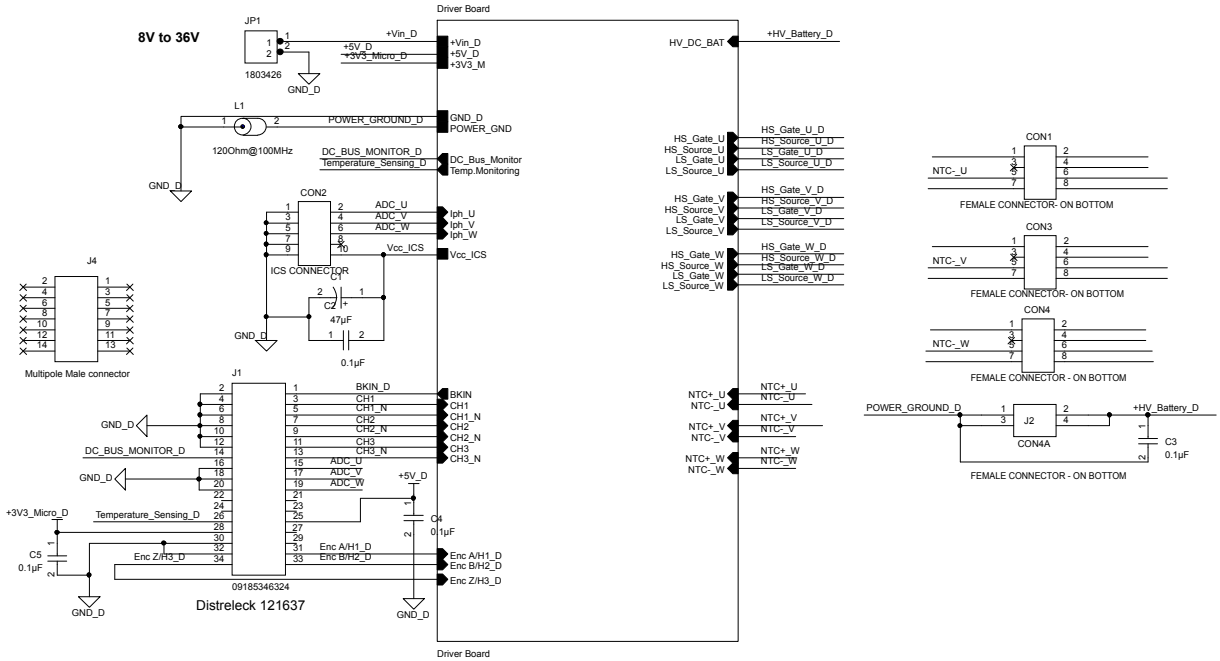


Figure 16. **STEVAL-CTM006V1 driver board schematic - sensing**

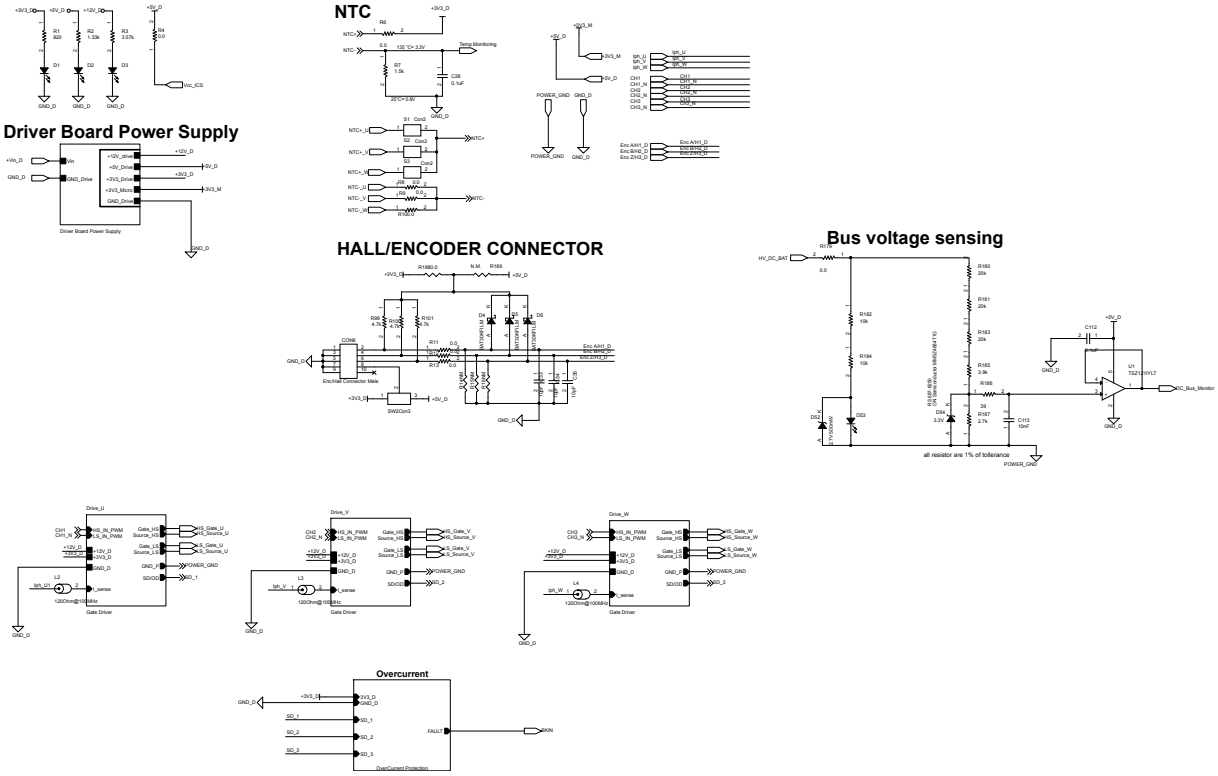


Figure 17. STEVAL-CTM006V1 driver board schematic - gate drivers

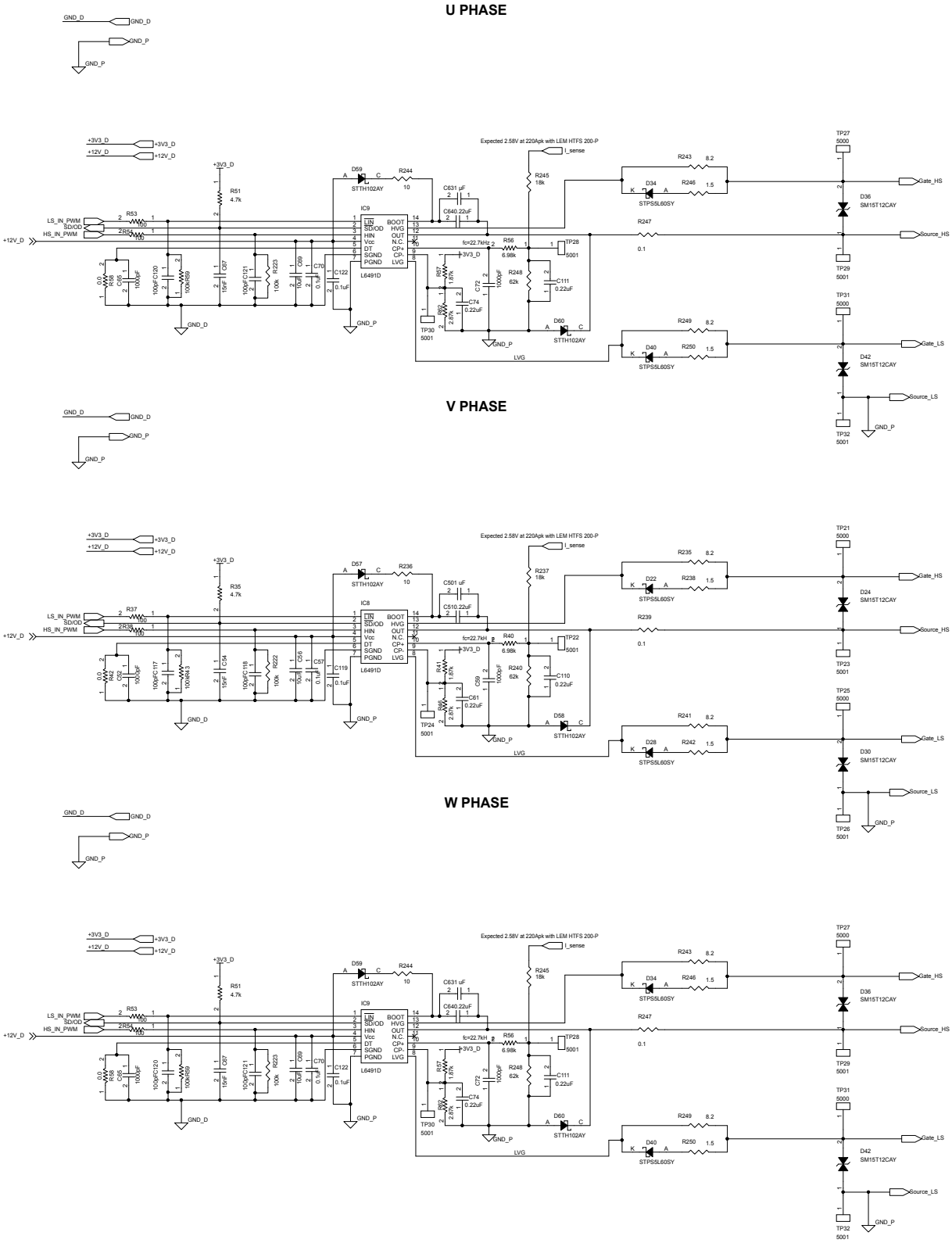


Figure 18. **STEVAL-CTM006V1 driver board schematic - overcurrent protection**

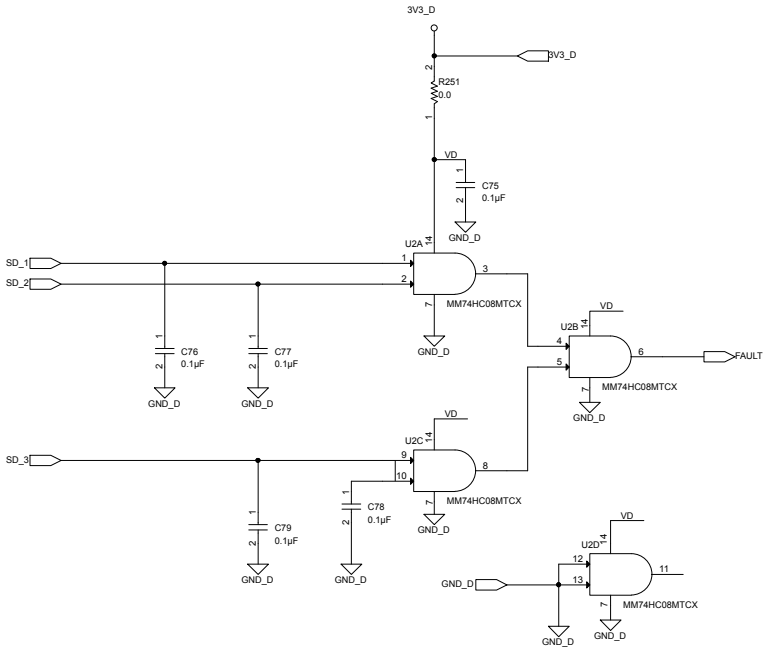
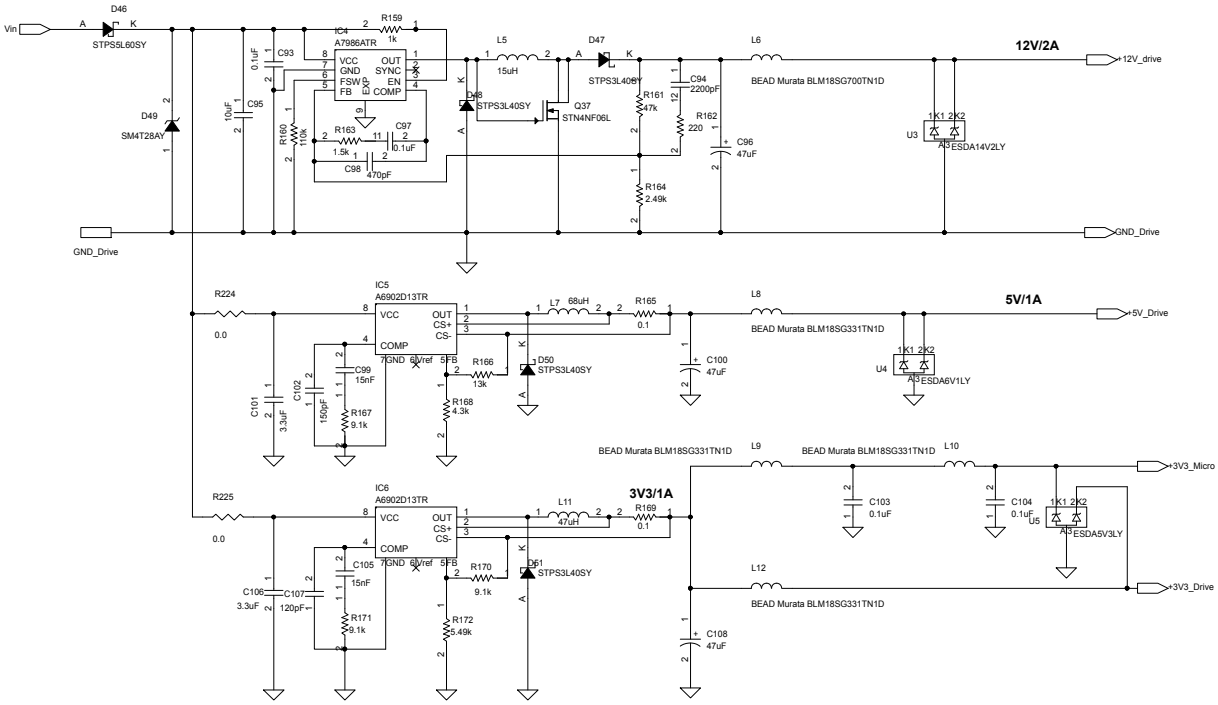
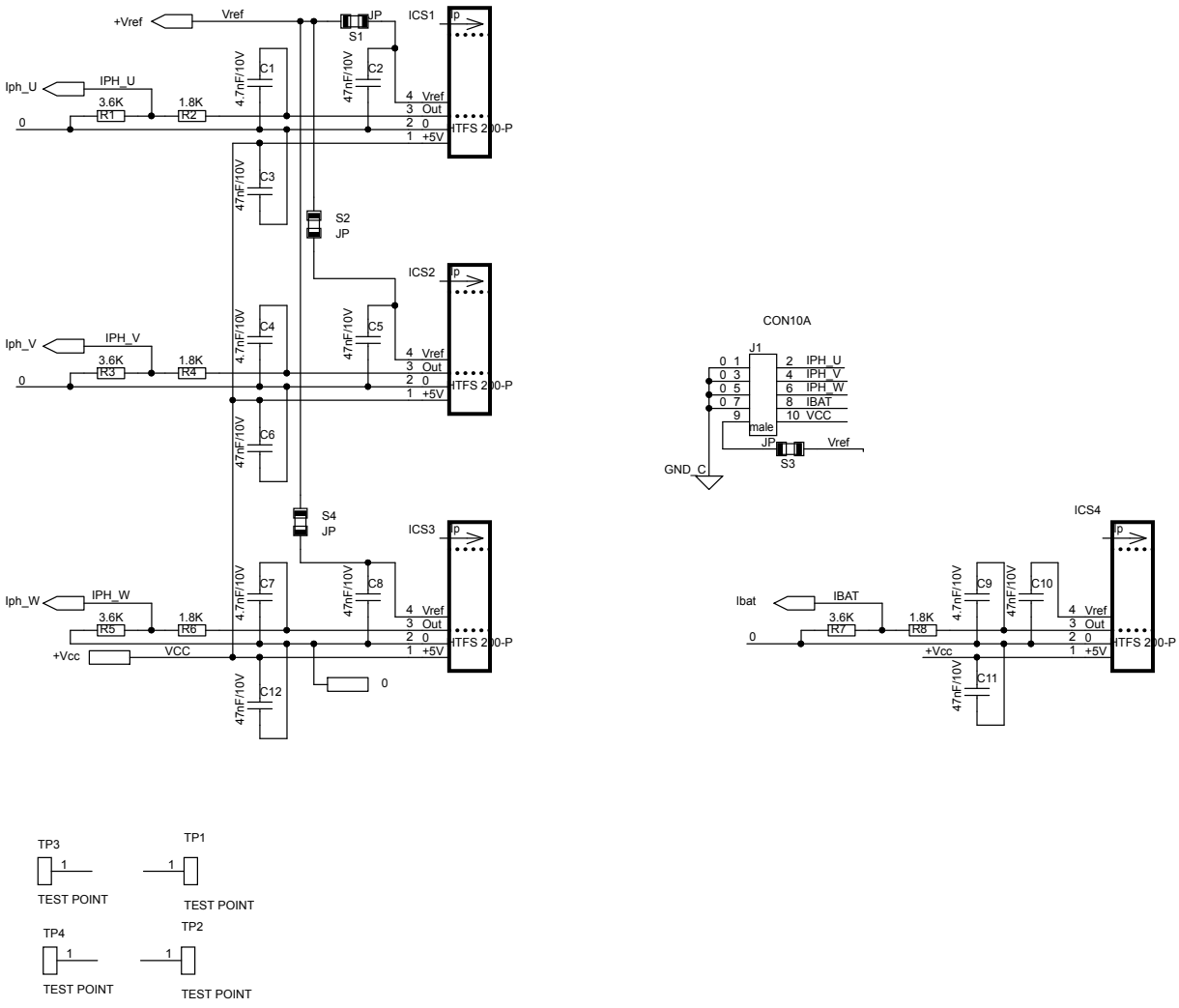


Figure 19. **STEVAL-CTM006V1 driver board schematic - power supply**



10.4 STEVAL-CTM008V1 schematic diagram

Figure 20. **STEVAL-CTM008V1 current sensing board schematic**



11 STEVAL-CTM009V1 bill of materials

Table 9. STEVAL-CTM009V1 evaluation kit bill of materials

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	1	-	STEVAL-CTM004V1	Power board	ST	not available separately
2	1	-	STEVAL-CTM005V1	Capacitor board	ST	not available separately
3	1	-	STEVAL-CTM006V1	Driver board	ST	not available separately
4	1	-	STEVAL-CTM008V1	Current sensing board	ST	not available separately

11.1 STEVAL-CTM004V1 bill of materials

Table 10. STEVAL-CTM004V1 power board bill of materials

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	6	C80, C83, C85, C88, C89, C92	0.033uF 1206 (3216 Metric) 250V	CAP CER 0.033UF 250V X7R 1206	TDK Corporation	CGA5L3X7R2E333M160AA
2	6	C81, C82, C86, C87, C90, C91	1uF 2220 (5750 Metric) 250V	CAP CER 1UF 250V X7R 2220	TDK Corporation	CGA9N3X7R2E105K230KA
3	3	CON5, CON6, CON7	CON8 StripMale2X4SMD	Double Strip Line Male SMD 2X4 Pitch 2, 54	Molex. LLC	0015912080
4	1	J3	CON4A StripMale2X2SMD	double Strip Line male smd 2X2 Pitch 2, 54mm	Molex. LLC	0015912040
5	36	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12, Q13, Q14, Q15, Q16, Q17, Q18, Q19, Q20, Q21, Q22, Q23, Q24, Q25, Q26, Q27, Q28, Q29, Q30, Q31, Q32, Q33, Q34, Q35, Q36	100V 180A	N-Ch Power MOSFET H²PAK-6	ST	STH310N15F7-6 STH315N10F7-6

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
6	36	R71, R72, R73, R74, R75, R76, R84, R85, R87, R88, R89, R90, R107, R108, R109, R110, R111, R112, R120, R121, R122, R123, R124, R125, R133, R134, R135, R136, R137, R138, R146, R147, R148, R149, R150, R151	2.2 1206 (3216 Metric) 1/4	-	-	-
7	36	R77, R78, R79, R80, R81, R82, R92, R93, R94, R95, R96, R97, R113, R114, R115, R116, R117, R118, R126, R127, R128, R129, R130, R131, R139, R140, R141, R142, R143, R144, R152, R153, R154, R155, R156, R157	10k 0603 (1608 Metric) 1/10w	RES SMD 10K OHM 1% 1/10W 0603	Yageo	RC0603FR-0710KL
8	6	R83, R98, R119, R132, R145, R158	NM	-	-	-
9	6	R173, R174, R175, R176, R177, R178	0.001 2818 7W	RES SMD 0.001 OHM 1% 7W 2818	Vishay Dale	WSHM28181L000FEA
10	3	RT1, RT2, RT3	4.7k 0805 (2012 Metric)	NTC THERMISTOR 4.7K OHM 5% 0805	Murata Electronics North America	NCP21XM472J03RA
11	9	TW1, TW2, TW3, TW4, TW5, TW6, TW7, TW8, TW9, TW10, TW11	Hexagonal Tower M5x10mm	Male-Femal M5X10	RS PRO	806-6632
12	2	SP1, SP2	M3x10mm	Standoff, Steel, M3, Hex Male-Female, 10 mm, WA-SSTIE Series	Wurth Electronic	971 100 351
13	18	conic head screw M3X8mm	M3x8mm	Machine Screw with flat + spring lock washer	Farnell	2494539
14	9+9+9	-	M5	Nut + Washer + shakeproof	RS	483-0546 + 482-7720 + 526-833

11.2 STEVAL-CTM005V1 bill of materials

Table 11. STEVAL-CTM005V1 capacitor board bill of materials

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
15	22	C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27	270µF Radial, Can 100V ±20%	CAP ALUM	Rubycon	100ZLJ270M12.5X30

11.3 STEVAL-CTM006V1 bill of materials

Table 12. STEVAL-CTM006V1 driver board bill of materials

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	2	C1, C96	47µF 25V ±10%	CAP TANT 2917	AVX Corporation	TAJD476K025RNJ
2	2	C2, C4	0.1µF 25V ±10%	CAP, Ceramic, SMD, 0603	Kemet	C0603C104K3RAC
3	19	C3, C5, C28, C44, C57, C70, C75, C76, C77, C78, C79, C93, C97, C103, C104, C112, C116, C119, C122	0.1µF 50V ±10%	CAP CER X7R 0603	KEMET	C0603C104K5RACTU
4	1	C33	10pF 50V ±10%	CAP CER X7R 0603	Murata Electronics North America	GRM188R71H103KA01D
5	2	C34, C35	10pF 50V ±0.5pF	CAP CER 10PF 50V C0G 0603	TDK Corporation	CGA3E2C0G1H100D080AD
6	3	C37, C50, C63	1 µF 50V ±10%	CAP CER JB 1206	TDK Corporation	C3216JB1H105K160AA
7	9	C38, C48, C51, C61, C64, C74, C109, C110, C111	0.22µF 50V ±10%	CAP CER X7R 0603	TDK Corporation	CGA3E3X7R1H224K080AD
8	6	C39, C46, C52, C59, C65, C72	1000pF 50V ±10%	CAP CER X7R 0603	AVX Corporation	06035C102KAT2A
9	5	C41, C54, C67, C99, C105	15nF 50V ±10%	CAP CER X7R 0603	Murata Electronics North America	GRM188R71H153KA01D
10	4	C43, C56, C69, C95	10µF 50V ±20%	CAP CER X5R 1206	TDK Corporation	CGA5L3X5R1H106M160AB
11	1	C94	2200pF 50V ±10%	CAP CER X7R 0603	TDK Corporation	CGA3E2X7R1H222K080AD
12	1	C98	470pF 50V ±5%	CAP CER C0G 0603	TDK Corporation	CGA3E2C0G1H471J080AD
13	2	C100, C108	47µF 10V ±10%	CAP TANT 2917	AVX Corporation	TAJD476K010RNJ

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
14	2	C101, C106	3.3µF 50V ±10%	CAP CER X5R 0805	TDK Corporation	C2012X5R1H335K125 AB
15	1	C102	150pF 100V ±5%	CAP CER C0G 0603	TDK Corporation	CGA3E2C0G2A151J0 80AD
16	1	C107	120pF 50V ±5%	CAP CER C0G 0603	TDK Corporation	CGA3E2C0G1H121J0 80AD
17	1	C113	10nF 50V ±10%	CAP CER X7R 0603	Murata Electronics North America	GRM188R71H103KA0 1D
18	6	C114, C115, C117, C118, C120, C121	100pF 50V ±5%	CAP CER C0G/NP0 0603	Murata Electronics North America	GRM1885C1H101JA0 1D
19	3	CON1, CON3, CON4	CON8	Double Strip Line Female 2X4 Pitch 2,54	Sullins Connector Solution	PPTC042LFBN-RC
20	1	CON2	ICS CONNECTOR	-	HARTING	09185106324
21	1	CON8	Enc/Hall Connector Male	Double Strip Line Female 2X4 Pitch 2,54	Sullins Connector Solution	PPTC042LFBN-RC
22	4	D1, D2, D3, D53	1.6mmX0.8mm,3 0mA, 1.8V	DIO, Rectangle, Flat Top Red,	KINGBRIGHT	KP-1608SRC-PRV
23	3	D4, D5, D6	30V 300mA	DIODE SCHOTTKY SOD523	ST	BAT30KFILM
24	7	D10, D16, D22, D28, D34, D40, D46	60V 5A	DIODE SCHOTTKY SMC	ST	STPS5L60SY
25	6	D12, D18, D24, D30, D36, D42	10.2VWM 21.7VC	TVS DIODE SMC	ST	SM15T12CAY
26	4	D47, D48, D50, D51	40V 3A	DIODE SCHOTTKY SMC	ST	STPS3L40SY
27	1	D49	400 W	Automotive Transil	ST	SM4T28AY
28	1	D52	2.7V 500mW	DIODE ZENER SOD80	Vishay Semiconducto r Diodes Division	TZMB2V7-GS08
29	1	D54	3.3V 500mW	DIODE ZENER SOD123	ON Semiconducto r	MMSZ4684T1G
30	6	D57, D58, D59, D60, D61, D62	200V 1A	DIODE GEN PURP SMA	ST	STTH102AY
31	1	IC4	3A	IC REG BUCK ADJ 8HSOP	ST	A7986ATR
32	2	IC5, IC6	1A	IC REG BUCK ADJ 8SOIC	ST	A6902D13TR
33	3	IC7, IC8, IC9	4A	IC GATE DVR HIGH/LOW 14SOIC	ST	L6491DTR
34	1	J1	34POS	CONN HEADER T/H	HARTING	09185346324
35	1	J2	CON4A 2X2 Pitch 2.54mm	double Strip Line female	Sullins Connector Solution	PPTC022LFBN-RC

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
36	1	J4	Multipole Male	Connector	Sullins Connector Solution	SFH11-PBPC-D07-ST-BK
37	1	JP1	2-position vert 3.81mm	TERM BLOCK HDR	Phoenix Contact	1803426
38	4	L1, L2, L3, L4	120Ω @ 100MHz	FERRITE BEAD 0603 1LN	Wurth Electronics Inc.	742792625
39	1	L5	15µH 1.45A 125 MΩ ±20%	FIXED IND	Wurth Electronics Inc.	74404063150
40	1	L6	70Ω	FERRITE BEAD 0603 1LN	Murata Electronics North America	BLM18SG700TN1D
41	1	L7	68µH 1.9A 132 MΩ ±20%	FIXED IND SMD	Wurth Electronics Inc.	7447714680
42	4	L8, L9, L10, L12	330 Ω	FERRITE BEAD 0603 1LN	Murata Electronics North America	BLM18SG331TN1D
43	1	L11	47µH 1.8A 190 MΩ ±10%	FIXED IND SMD	Wurth Electronics Inc.	74456147
44	1	Q37	60V 4A	MOSFET N-CH SOT-223	ST	STN4NF06L
45	1	R1	820Ω 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-07820RL
46	1	R2	1.33k 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-071K33L
47	1	R3	3.57k 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-073K57L
48	16	R4, R6, R8, R9, R10, R11, R12, R13, R26, R42, R58, R179, R188, R224, R225, R251	0.0Ω 1/10W	RES SMD JUMPER 0603	Yageo	RC0603JR-070RL
49	2	R7, R163	1.5kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-071K5L
50	3	R14, R15, R16	NM	-	Any	-
51	6	R19, R35, R51, R99, R100, R101	4.7kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-074K7L
52	6	R21, R22, R37, R38, R53, R54	100Ω 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-07100RP
53	3	R24, R40, R56	6.98kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-076K98L
54	3	R25, R41, R57	1.87kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-071K87L
55	3	R27, R43, R59	100kΩ 1/10W ±5%	RES SMD 0603	Yageo	RC0603JR-07100KL
56	3	R30, R46, R62	2.87kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-072K87L

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
57	1	R159	1kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-071KL
58	1	R160	110kΩ 1/10W ±5%	RES SMD 0603	Yageo	RC0603JR-07110KL
59	1	R161	47kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-0747KL
60	1	R162	220Ω 1/10W ±1%	RES SMD0603	Yageo	RC0603FR-07220RL
61	1	R164	2.49kΩ 1/10W ±1%	RES SMD 0603	Stackpole Electronics Inc.	RMCF0603FT2K49
62	2	R165, R169	0.1Ω 1/3W ±1%	RES SMD 0603	Panasonic Electronic Components	ERJ-3BWFR100V
63	1	R166	13kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-0713KL
64	3	R167, R170, R171	9.1kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-079K1L
65	1	R168	4.3kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-074K3L
66	1	R172	5.49Ω 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-075K49L
67	3	R180, R181, R183	20kΩ 1/8W ±1%	RES SMD0805	Yageo	RC0805FR-0720KL
68	2	R182, R184	10kΩ 1/4W ±1%	RES SMD 1206	Yageo	RC1206FR-0710KL
69	1	R185	3.9kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-073K9L
70	1	R186	39Ω 1/10W ±1%	RES SMD 0603	Panasonic Electronic Components	ERJ-3EKF39R0V
71	1	R187	2.7kΩ 1/10W ±1%	RES SMD 0603	Yageo	RC0603FR-072K7L
72	1	R189	N.M. ±1%	-	Any	-
73	3	R222, R223, R231	100k ±1%	-	Any	-
74	6	R226, R233, R235, R241, R243, R249	8.2 ±1%	-	Any	-
75	3	R227, R236, R244	10Ω 1/2W ±1%	RES SMD 1210	Stackpole Electronics Inc.	RMCF1210FT10R0
76	3	R228, R237, R245	18k ±1%	-	Any	-
77	6	R229, R234, R238, R242, R246, R250	1.5 ±1%	-	Any	-
78	3	R230, R239, R247	0.1 ±1%	-	Any	-
79	3	R232, R240, R248	62k ±1%	-	Any	-
80	3	S1, S2, S3	Con2	CONN HEADER 2POS VERT T/H	Amphenol FCI	77311-118-02LF

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
81	1	SW2	Con3	SIL VERTICAL PC TAIL PIN HEADER	Harwin Inc.	M20-9990345
82	6	TP15, TP19, TP21, TP25, TP27, TP31	5000	TEST POINT PC MINI .040"D RED	Keystone Electronics	5000
83	12	TP16, TP17, TP18, TP20, TP22, TP23, TP24, TP26, TP28, TP29, TP30, TP32	5001	TEST POINT PC MINI .040"D BLACK	Keystone Electronics	5001
84	1	U1	400KHZ	IC OPAMP ZRO-DRFT SOT23-5	ST	TSZ121IYLT
85	1	U2		IC GATE AND 4CH 2-INP 14-TSSOP	Fairchild/ON Semiconductor	MM74HC08MTCX
86	1	U3	12VWM 21VC	TVS DIODE SOT23-3L	ST	ESDA14V2LY
87	1	U4	5.2VWM 16VC	TVS DIODE SOT23-3L	ST	ESDA6V1LY
88	1	U5	3VWM 19VC	TVS DIODE SOT23-3L	ST	ESDA5V3LY

11.4 STEVAL-CTM008V1 bill of materials

Table 13. STEVAL-CTM008V1 sensing board bill of materials

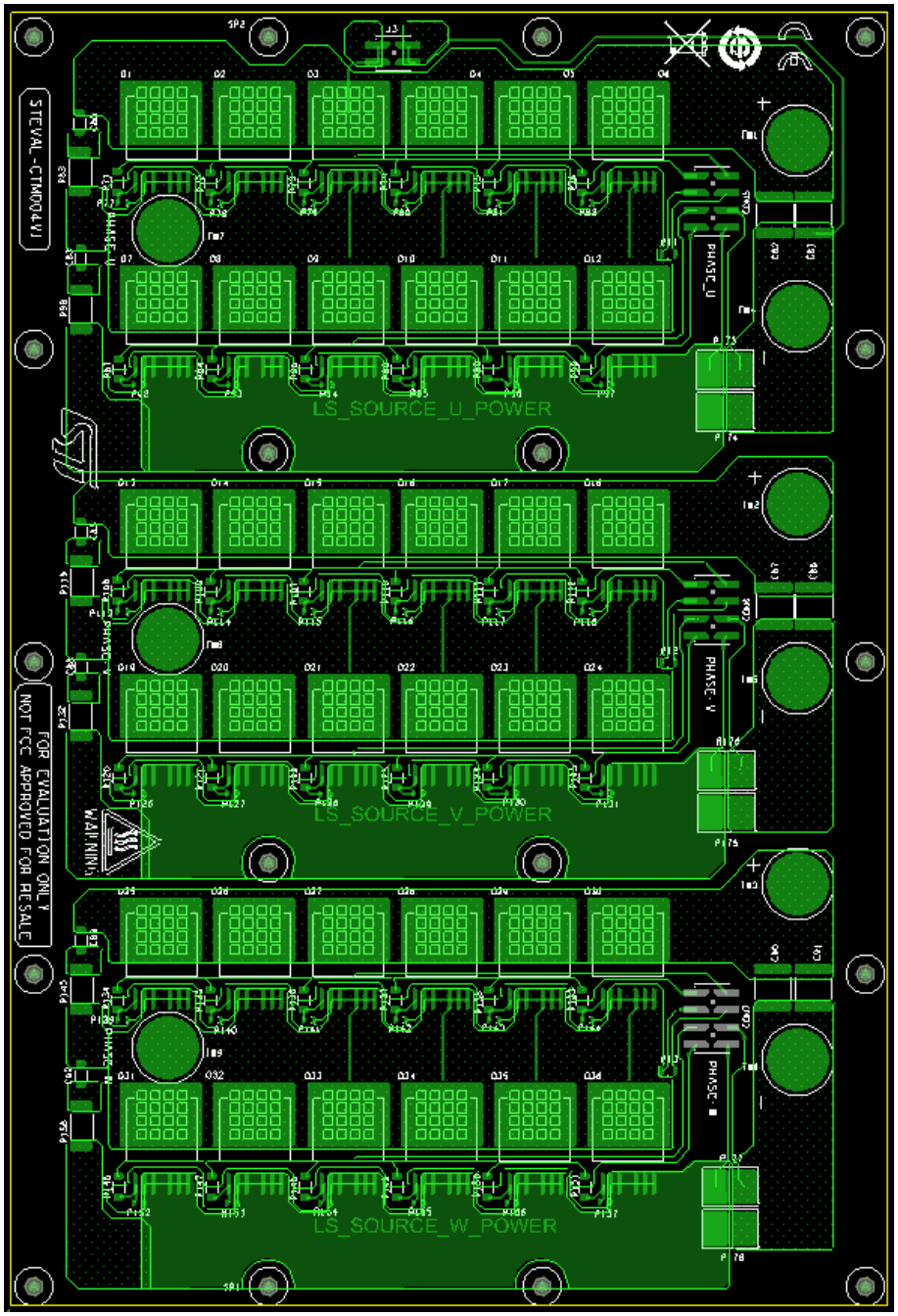
Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	4	C1,C4,C7,C9 ANY	4.7nF , smc0603, 25 V, 10 %	CAP CER X7R 0603	any	-
2	8	C2,C3,C5,C6,C8 ,C10,C11,C12 ANY	47nF, 25 V, 10 %	CAP CER X7R 0603	any	-
3	2	ICS1,ICS2	CURRENT SENSOR HALL 200A V	trasdulemHTFS400 P	LEM	HTFS 200-P
4	1	ICS3 (NM)	CURRENT SENSOR HALL 200A V	trasdulemHTFS400 P	LEM	HTFS 200-P
5	1	ICS4 (NM)	CURRENT SENSOR HALL 200A V	trasdulemHTFS400 P	LEM	HTFS 200-P
6	4	TP1,TP2,TP3,TP 4	M3X20mm Male_Femal, mthole3	hex spacer	richco	htsb-m3-20-5-2
7	1	J1	10X2 pitch 2,54mm, ampmode10	Connector male	Wurth_Elektronik	61201021621
8	4	R1,R3,R5,R7 ANY	3.6kΩ 1/10W 1 %	RES SMD 0603	any	-
9	4	R2,R4,R6,R8 ANY	1.8kΩ, 1/10W 1 %	RES SMD 0603	any	-

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
10	1	Flat cable	150mm	10 Position Cable Assembly Rectangular Socket to Socket	Harwin Inc.	M50-9100542
11	4	S1,S2,S3,S4 ANY	2X2,54 mm + Jumper, siptm2002	Strip line male	any	-

12 PCB layouts

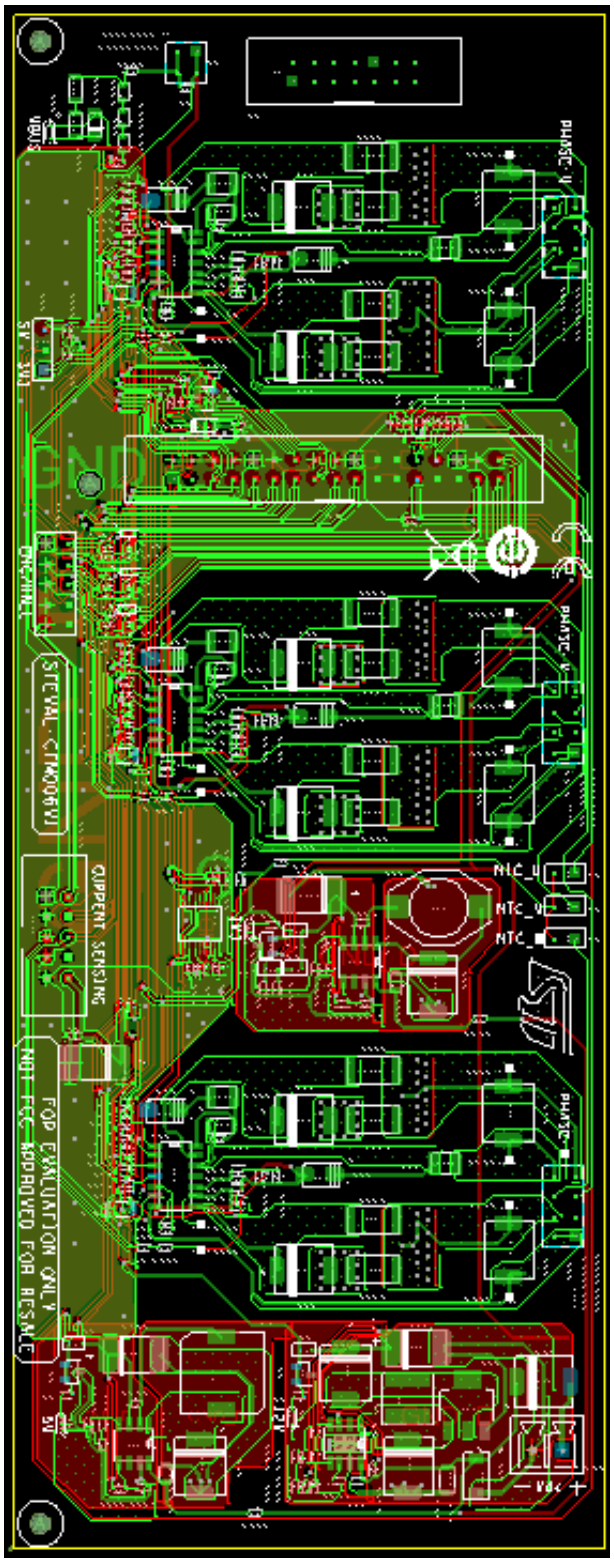
The STEVAL-CTM004V1 power board is built on an IMS mono layer with a copper thickness of 175 µm. The board is designed for optimal thermal management under high current conditions.

Figure 21. STEVAL-CTM004V1 power board layout



The STEVAL-CTM006V1 driver board is a 2-layer PCB, thickness 1.6 mm and copper thickness 70 µm.

Figure 22. **STEVAL-CTM006V1 driver board layout**



Revision history

Table 14. **Document revision history**

Date	Version	Changes
04-Oct-2018	1	Initial release.

Contents

1 **Evaluation kit features** 2
1.1 Electrical and functional characteristics 2
1.2 Target applications 2
2 **Safety and operating instructions** 3
2.1 General terms 3
2.2 Intended use of evaluation kit 3
2.3 Evaluation kit setup 3
2.4 Electronic connections 3
3 **Evaluation kit overview** 4
4 **STEVAL-CTM004V1 power board** 5
4.1 STH315N10F7 N-channel Power MOSFET characteristics 5
5 **Driver board and control board overview** 7
5.1 STEVAL-CTM006V1 driver board 7
5.1.1 Power supply section 7
5.1.2 Bus voltage monitoring 7
5.1.3 Temperature monitor 7
5.1.4 L6491 gate driver characteristics 8
6 **STEVAL-CTM005V1 bus link capacitor board** 10
6.1 STEVAL-CTM008V1 current sensing board 10
7 **How to set up the system** 12
7.1 Connectors 12
7.2 Signal LEDs 14
7.3 Push buttons 14
8 **Firmware for STM32 PMSM FOC SDK** 15
8.1 Firmware for STM32 PMSM FOC SDK 15
9 **Experimental measurements** 17
10 **STEVAL-CTM0091V1 kit schematic diagrams** 19
10.1 STEVAL-CTM004V1 schematic diagram 19
10.2 STEVAL-CTM005V1 schematic diagram 19

10.3 STEVAL-CTM006V1 schematic diagrams 20
10.4 STEVAL-CTM008V1 schematic diagram 23
11 STEVAL-CTM009V1 kit bill of materials 25
11.1 STEVAL-CTM004V1 bill of materials 25
11.2 STEVAL-CTM005V1 bill of materials 26
11.3 STEVAL-CTM006V1 bill of materials 27
11.4 STEVAL-CTM008V1 bill of materials 31
12 PCB layouts 33
Revision history 35

List of figures

Figure 1. STEVAL-CTM009V1 evaluation kit . . . 1
Figure 2. STEVAL-CTM009V1 block diagram . . . 4
Figure 3. Main blocks of the STEVAL-CTM004V1 power board . . . 5
Figure 4. Package and internal schematic diagram . . . 6
Figure 5. STEVAL-CTM006V1 driver board functional blocks . . . 7
Figure 6. L6491 gate driver pin-out . . . 8
Figure 7. STEVAL-CTM005V1 bus link capacitor board . . . 10
Figure 8. STEVAL-CTM008V1 current sensing board . . . 11
Figure 9. Current sensing connector (CON2 on driver board) . . . 13
Figure 10. 34-pin motor control connector (J1 on the driver board) . . . 13
Figure 11. Measured waveforms . . . 17
Figure 12. Measured temperatures of U_phase Power MOSFETs . . . 18
Figure 13. STEVAL-CTM004V1 power board schematic . . . 19
Figure 14. STEVAL-CTM005V1 capacitor board schematic . . . 20
Figure 15. STEVAL-CTM006V1 driver board schematic - main . . . 20
Figure 16. STEVAL-CTM006V1 driver board schematic - sensing . . . 21
Figure 17. STEVAL-CTM006V1 driver board schematic - gate drivers . . . 22
Figure 18. STEVAL-CTM006V1 driver board schematic - overcurrent protection . . . 23
Figure 19. STEVAL-CTM006V1 driver board schematic - power supply . . . 23
Figure 20. STEVAL-CTM008V1 current sensing board schematic . . . 24
Figure 21. STEVAL-CTM004V1 power board layout . . . 33
Figure 22. STEVAL-CTM006V1 driver board layout . . . 34

List of tables

Table 1. Input voltage bus and input signal to STM32 ADC channel . . . 7
Table 2. NTC electrical characteristics . . . 8
Table 3. Pin functions of L6491 gate driver . . . 8
Table 4. Current sensing connector pinout . . . 13
Table 5. Motor control connector pinout . . . 13
Table 6. LEDs Indicators on board . . . 14
Table 7. Push buttons . . . 14
Table 8. Measured case temperatures of the STH315N10F7 power MOSFETs . . . 18
Table 9. STEVAL-CTM009V1 evaluation kit bill of materials . . . 25
Table 10. STEVAL-CTM004V1 power board bill of materials . . . 25
Table 11. STEVAL-CTM005V1 capacitor board bill of materials . . . 27
Table 12. STEVAL-CTM006V1 driver board bill of materials . . . 27
Table 13. STEVAL-CTM008V1 sensing board bill of materials . . . 31
Table 14. Document revision history . . . 35