Getting started with the low voltage servo drive for multi-axial position control with multi-protocol Ethernet real-time connectivity

Introduction

The STEVAL-ETH001V1 servo drive evaluation board has been developed to address three-phase PMSM applications oriented to multi-axial position control and connectivity.

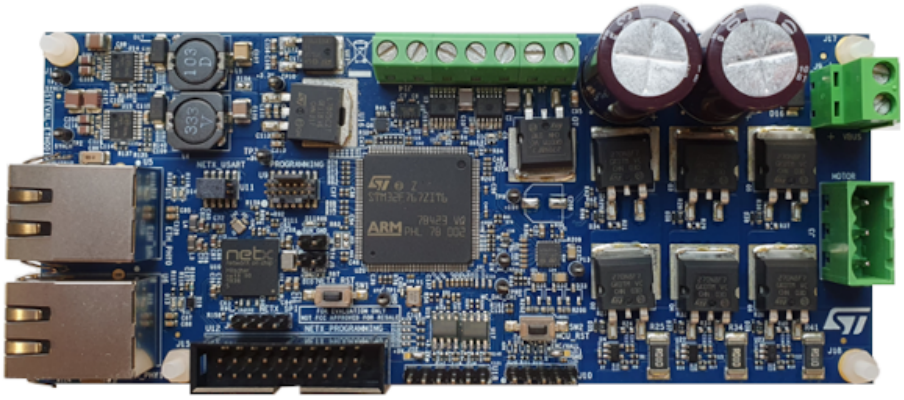
Motor control power stage hosts the STDRIVE101 half bridge gate driver and six STH270N8F7-2 power MOSFETs. The solution allows multi-axial position control for PMSM motor, featuring real-time connectivity with EtherCAT stack available on-board.

Moreover, load actuation and interface based on RS485 are possible using CLT03-2Q3, IPS160H and ST3485EI ICs.

Proper board functionality is supported by a power management unit based on L7987L, L7805CD2T-TR and LD39150DT33-R devices.

The STEVAL-ETH001V1 is equipped with two RJ45 connectors to guarantee daisy-chain connection and a stripline connector to interface via RS485 digital encoder or host unit (i.e., a PC). For a better noise immunity, the PCB is characterized by a 6-layer stack and an insulated track for supply line and ground. A quadrature encoder interface with index is present as well.

Figure 1. STEVAL-ETH001V1 evaluation board



1 Overview

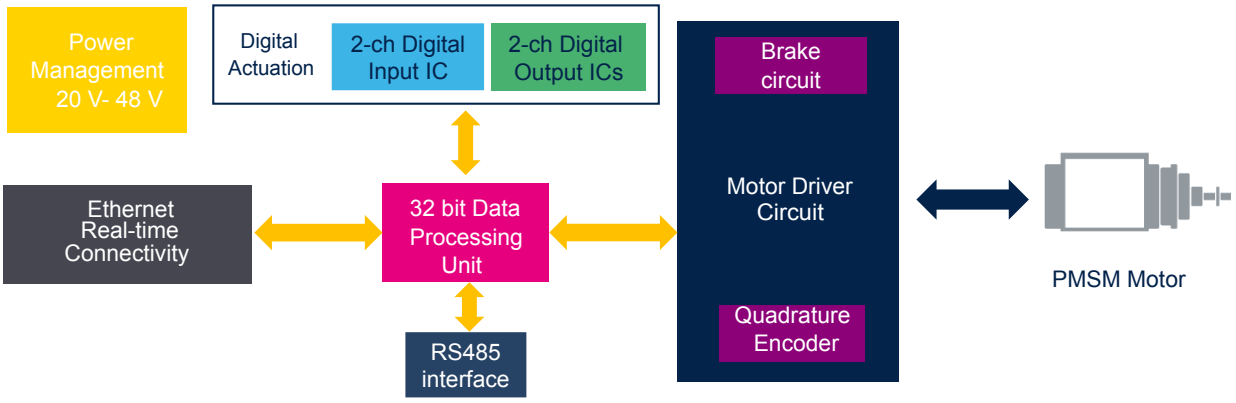
The STEVAL-ETH001V1 has been developed for motor control applications and multi-axial position control in factory automation applications.

The board is characterized by a 6-layer stack structure for a better noise immunity and features:

- Ethernet real-time communication with on-board EtherCAT protocol
- Three-phase motor driver inverter based on STDRIVE101 gate driver and STH270N8F7-2 power MOSFET
- STM32F767ZI microcontroller Arm®32-bit Cortex®-M7
- NETX90 network controller
- Operating supply voltage up to 48 V with a max. overvoltage robustness of 60 V
- Max. power dissipation up to 700 W
- Motor brake dissipative energy circuit
- Digital actuation section for industrial loads
- RS485 interface for digital encoder and host interface
- On-board DC-DC converter and linear regulator

The STEVAL-ETH001V1 has a compact form factor to facilitate engine assembly. The board structure can be schematized as shown below.

Figure 2. Functional block diagram

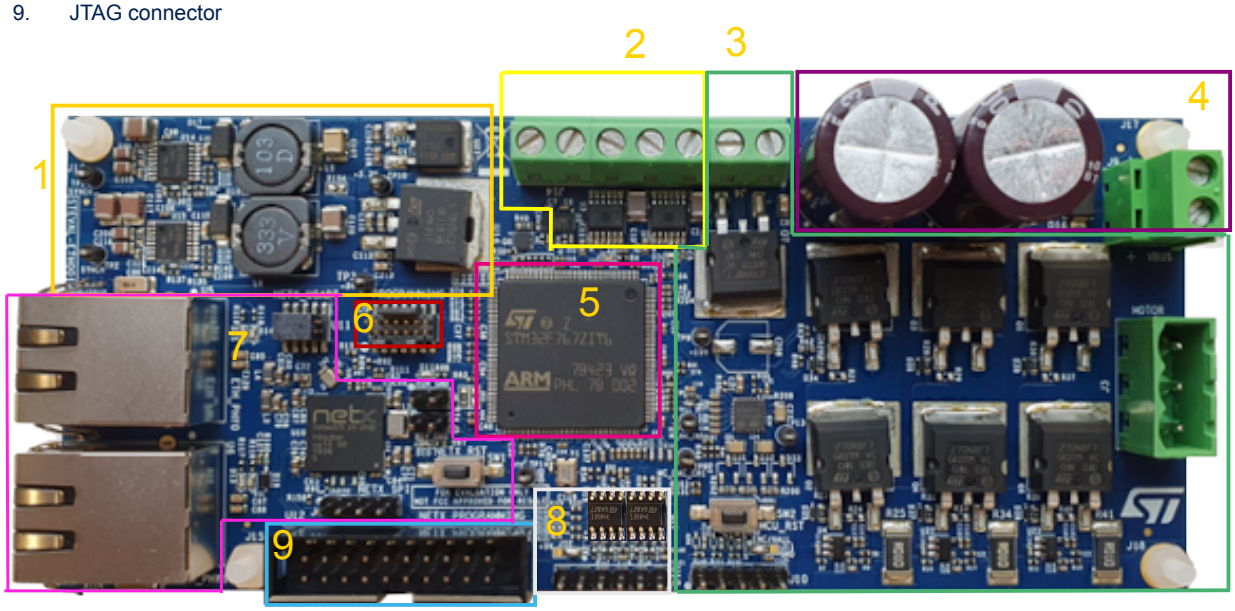


2 Hardware description

2.1 Main blocks

Figure 3. STEVAL-ETH001V1 main blocks

1. Power management
2. Digital actuation
3. Motor driver
4. Supply voltage connection
5. STM32F767ZI MCU
6. SWD connector
7. Ethernet real-time connectivity with NETX90 IC
8. RS485 interface
9. JTAG connector



2.2 Motor driver

The motor driver consists of a three-half bridge with the STH270N8F7-2 power MOSFET driven by the STDRIVE101 gate driver to drive a three-phase motor embedding quadrature encoder to detect the rotor position.

The STDRIVE101 embeds different blocks mainly featuring:

1. Matched propagation delay for all channels
2. Very short propagation delay of 40 ns
3. Integrated bootstrap diodes
4. 12 V LDO linear regulator (50 mA max.)
5. Embedded VDS monitor for each external MOSFET
6. Overcurrent comparator
7. UVLO and thermal shutdown protection
8. Standby mode for low current consumption operation

Motor driving signals are modulated according to the current sensing and speed feedback.

The sensing network has been built using the TSV991ILT operational amplifier which amplifies the voltage signal read by three shunt resistors connected in series to each STH270N8F7-2 power MOSFET low side.

To limit overvoltage during motor active braking operation, the use of an external brake resistor is supported, dissipating the motor avalanche energy. It is suggested to connect two resistors (10 Ω 25 W) in parallel with J4 screw connector.

Figure 4. Power stage

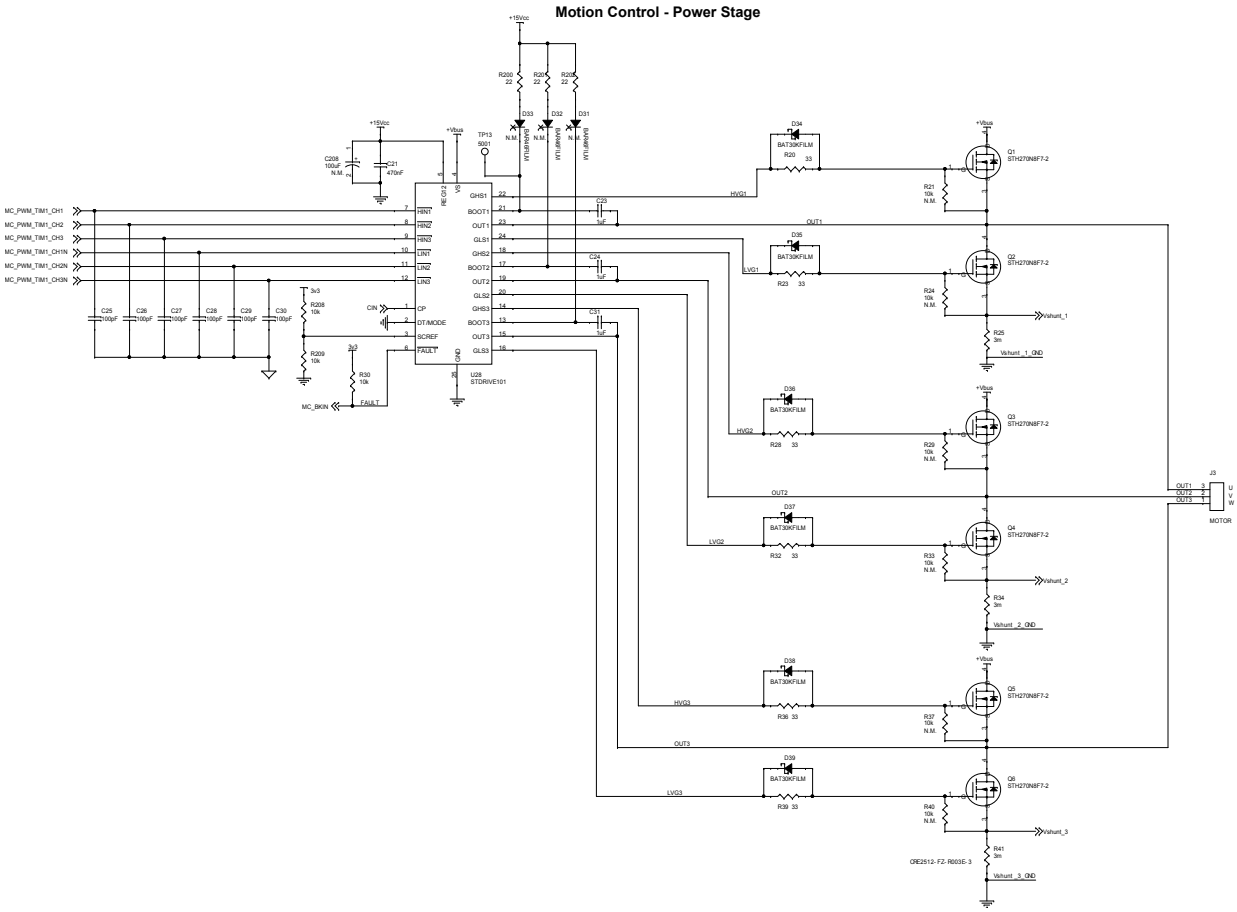


Figure 5. Sensing network

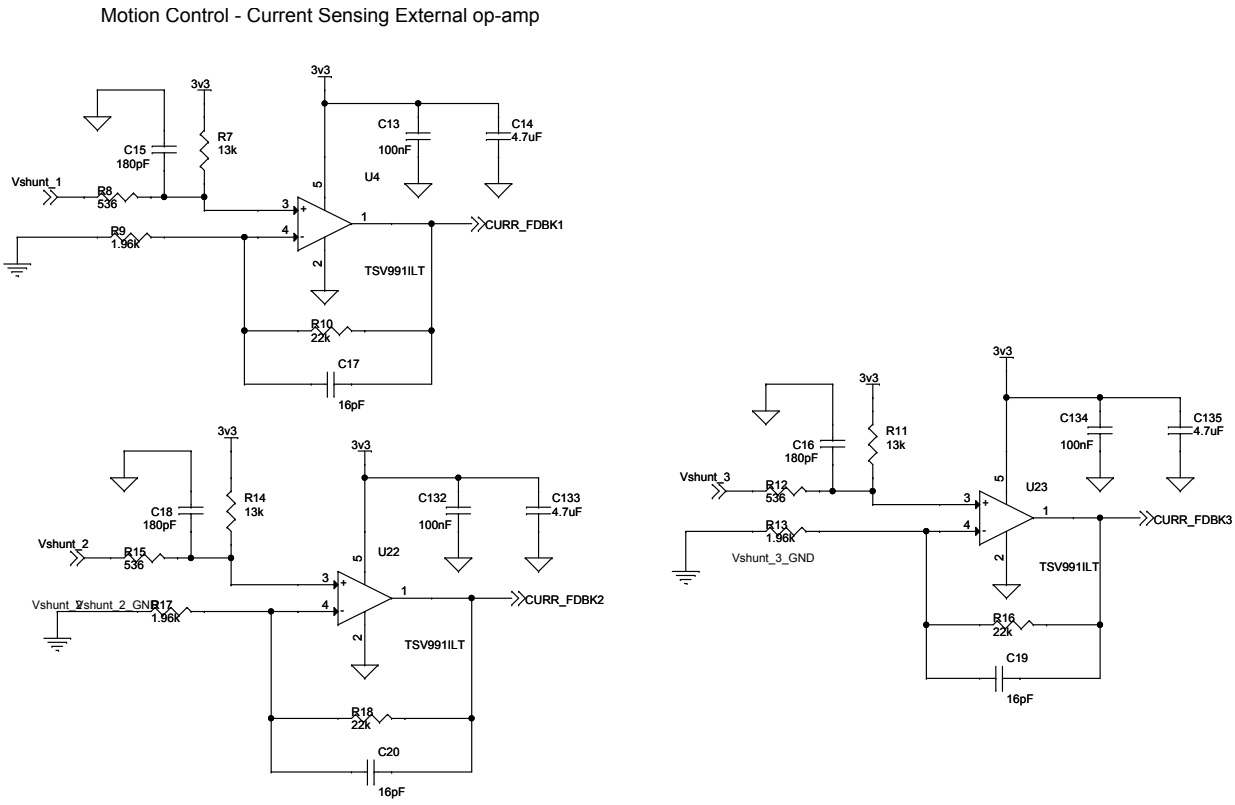
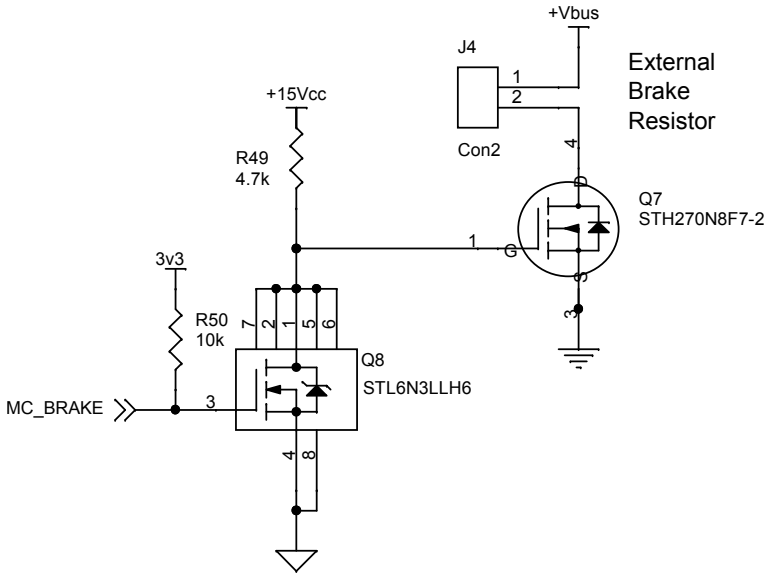


Figure 6. Braking network



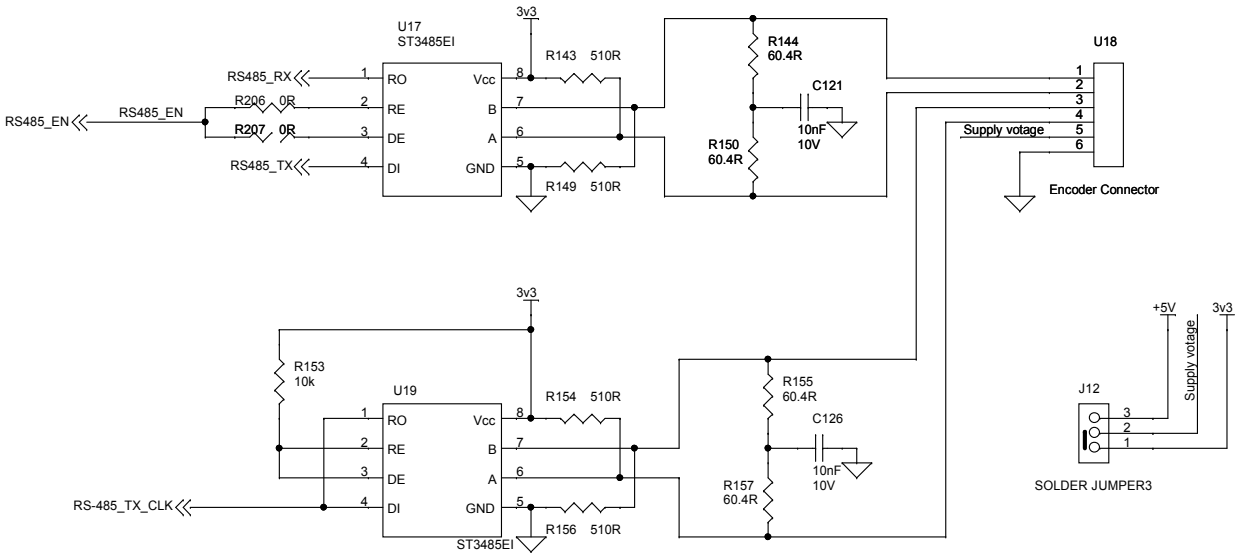
2.3 Serial interface

The on-board RS485 interface connects the digital absolute encoder based on EnDat, BiSS, and SSi, or establishes PC communication using a standard serial terminal.

The interface consists of two RS485 (one for the data and one for the clock) based on ST3485EI.

Using J12 jumper, it is possible to select between 5 V and 3.3 V as supply voltage of the digital absolute encoder connected via U18 connector.

Figure 7. RS485 serial interface



2.4 Digital actuation

The circuit implements an actuation power stage, with two digital input channels and two digital output channels; the digital output allows driving any kind of load (inductive , resistive, and capacitive), guaranteeing a 2.5 A output current.

Thanks to the integrated active clamp on the IPS160H IC, it is possible to manage demagnetization energy without any external component, whereas embedded protection in the intelligent power switch provides robustness against:

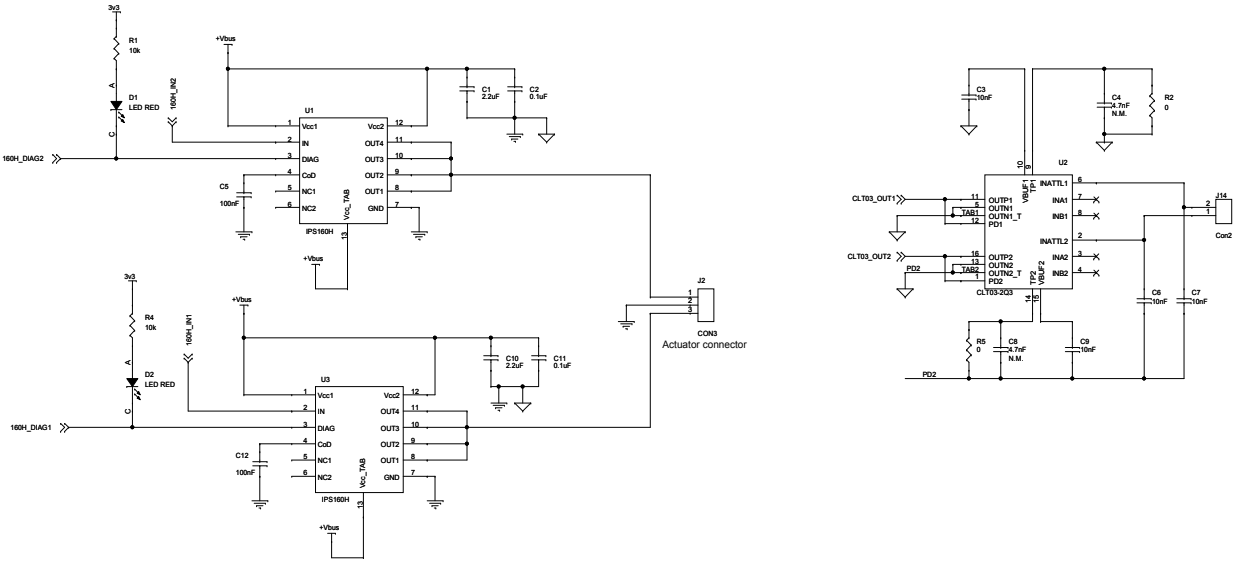
1. cut-off and thermal shut-down
2. overcurrent with 2.6 A minimum threshold
3. undervoltage lock-out
4. Vcc disconnection

The diagnostic feature is also available with a dedicated pin to signal:

1. cut-off intervention
2. thermal shut-down intervention
3. open load in off state

The feedback related to load driving can be implemented using the IC CLT03-2Q3 current limiter; in this case, it is necessary to connect the IPS160H output to the current limiter input stage.

Figure 8. **Digital input/output circuit**



2.5 Power management

The power stage circuit consists of an input stage with 48 V max. operating voltage and 60 V max. overvoltage, embedding two 330µF/100V electrolytic bulk capacitors with Transil protection, and two DC-DC converters in buck configuration to regulate the 3.8 V and the 15 V.

The 3.8 V regulates the 3.3 V with max. output current of 1 A for the digital circuit (i.e. microcontroller, ST3485EI transceiver, NETX90); the 15 V is used, instead, for the STDRIVE101 digital supply and to regulate the 5 V with 200 mA output current supplying the encoder.

Both regulation circuits have been built using the L7987L switching regulator in TSSOP package. Two linear regulators have been inserted in series into the switching regulator to improve the ripple on the regulated low voltage reference (3.3 V and 5 V): in particular, the LD39150DT33-R low drop has been used for the 3.3 V and the L7805CD2T-TR linear regulator has been used for the 5 V.

Figure 9. **DC-DC converter - V_{BUS} to 3.8 V regulation**

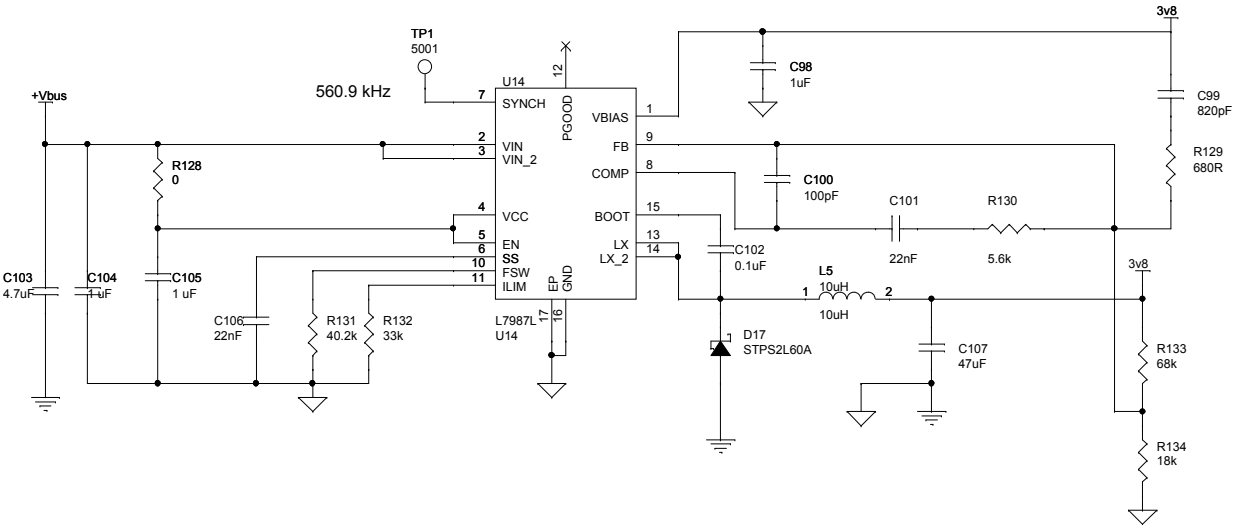


Figure 10. **3.8 and 3 V regulation**

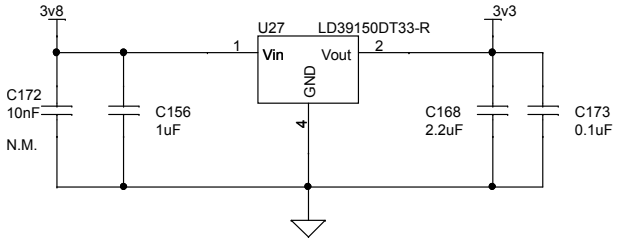


Figure 11. **DC-DC regulation - V_{BUS} to 15 V regulation**

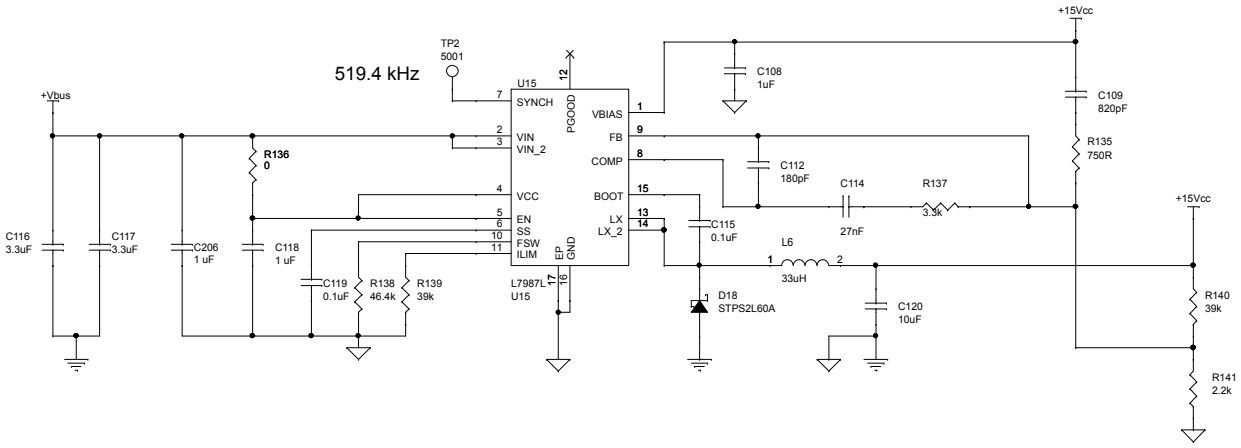
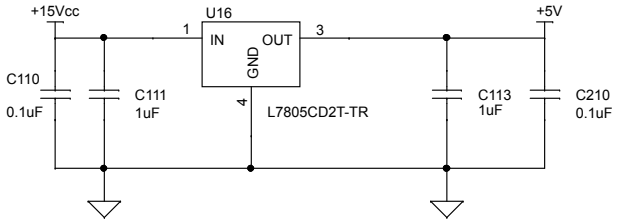


Figure 12. **15 V to 5 V regulation**



2.6 Ethernet real-time connectivity

The connectivity core is the NETX90 multi-protocol SoC which integrates two PHYs with 100 Mbps communication speed, powered by a dual core structure and several peripherals, such as SPI,USART,I^2C, CAN, FMC, ADC and timers.

Communication peripherals (such as SPI and FMC) manage the communication between the controller and the MCU (feature implemented by dedicated libraries that have been developed by the controller manufacturer).

Other peripherals, such as EnDat2.2 , BiSS and SSi, interface the controller with the encoder in motor control applications (the related libraries are not implemented at the moment).

The network controller for this application solution is programmed with the EtherCAT protocol, enabling a communication with low latency and low jitter between master node and slave node.

The protocol stack and the firmware library for STM32 have been developed in demo version by the controller manufacturer (Hilscher) and are integrated into the application and middleware layers of the STEVAL-ETH001V1 evaluation board.

Daisy-chain communication can be implemented thanks to the two on-board RJ45 connectors.

Figure 13. **RJ45 Ethernet connectors**

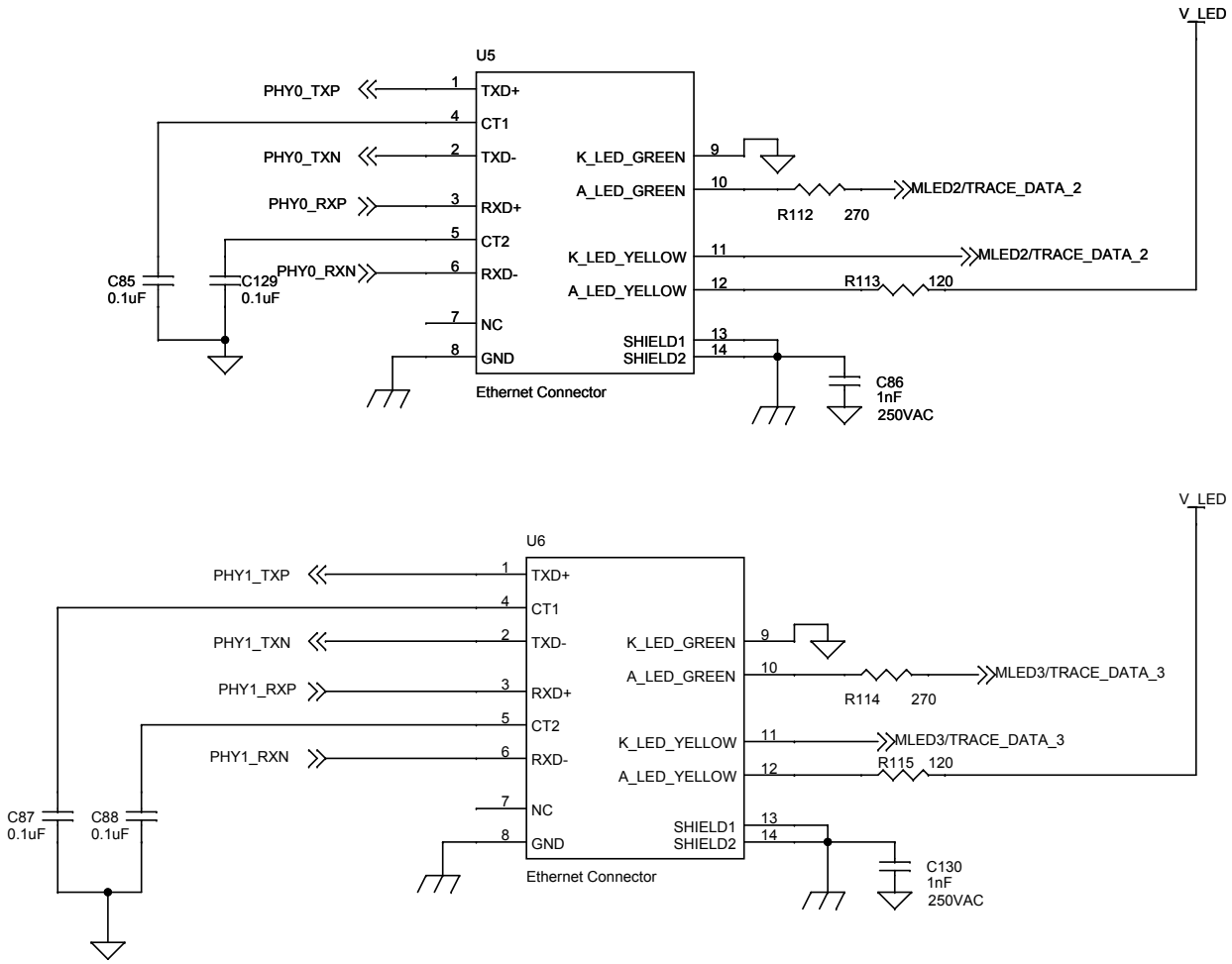


Figure 14. **Communication status LEDs**

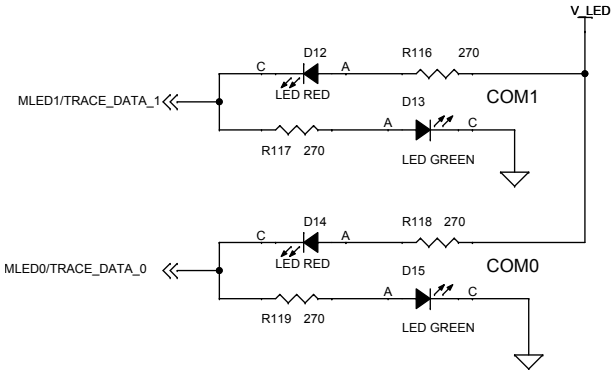
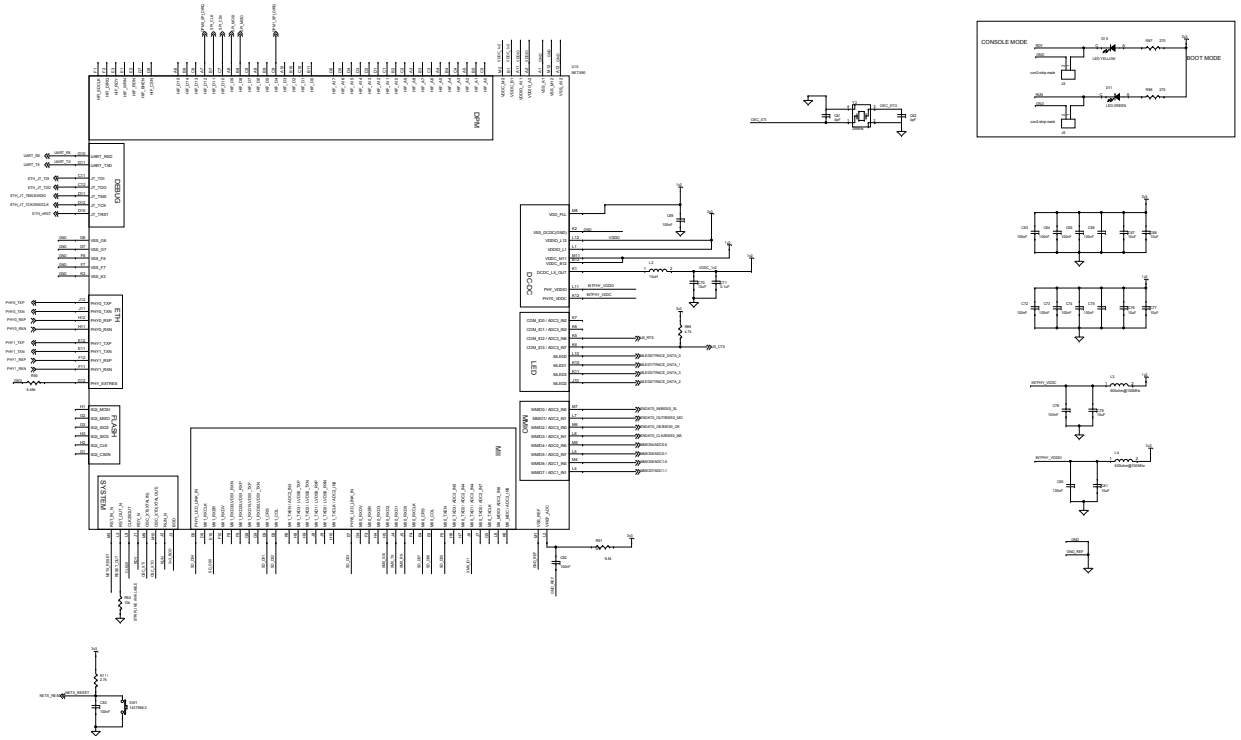


Figure 15. **NETX90 device**



3 Using the STEVAL-ETH001V1 evaluation board

The STEVAL-ETH001V1 evaluation board can be used in several factory automation applications, such as industrial connectivity, actuation and motion control.

32-bit data processing powered by STM32F767ZI and real-time communication using NETX90 network controller connected through four-wire SPI communication with MCU allows PMSM motor driving via remote control.

The solution also integrates two DC-DC converters powered by the L7987L switching converter in buck configuration.

These converters have been designed to provide 3.8 V and 15 V reference voltages when the input voltage works in the range of 20-48 V; moreover, post regulation circuits have been designed to obtain the 3.3 V for the MCU and connectivity and the 5 V for the quadrature encoder.

The hardware is supported by a firmware package based on STM32Cube architecture, consisting of:

- Application layer
- Drivers layer with BSP/CMSIS and HAL library
- Middleware layer

The firmware solution embeds the EtherCAT protocol and a motor control library to handle, respectively, data packet exchange between master and slave and perform the position control according to the data received from the master unit. Data consists of commands to be executed by the motor and the data angle used to set the desired rotor position in a fixed time period; these data type are exchanged using the process data channel of the protocol stack (for further details, refer to UM2808 freely available at www.st.com).

To ensure the correct time frame on the bus, a scheduler has been implemented with a dedicated timer, fixing a time period of 1 ms, for a cyclic check on new data available on the data channel.

As expected by the protocol, a daisy-chain configuration can be implemented to connect more than one sensor node to the same network (see Figure 16). In this case, the master generates a common frame with the data to be addressed to all EtherCAT slaves (ECS) and each node identifies its own frame by verifying only the MAC address reported in the frame: if the MAC is correctly identified, data are stored, whereas the other part of the frame continues forwarding to the other nodes (see Figure 17).

Motion control driving has been implemented by setting the motor control parameters at application level, on the basis of the electrical characteristics of the PMSM motor series S160-2B305.

Figure 16. **Daisy-chain architecture**

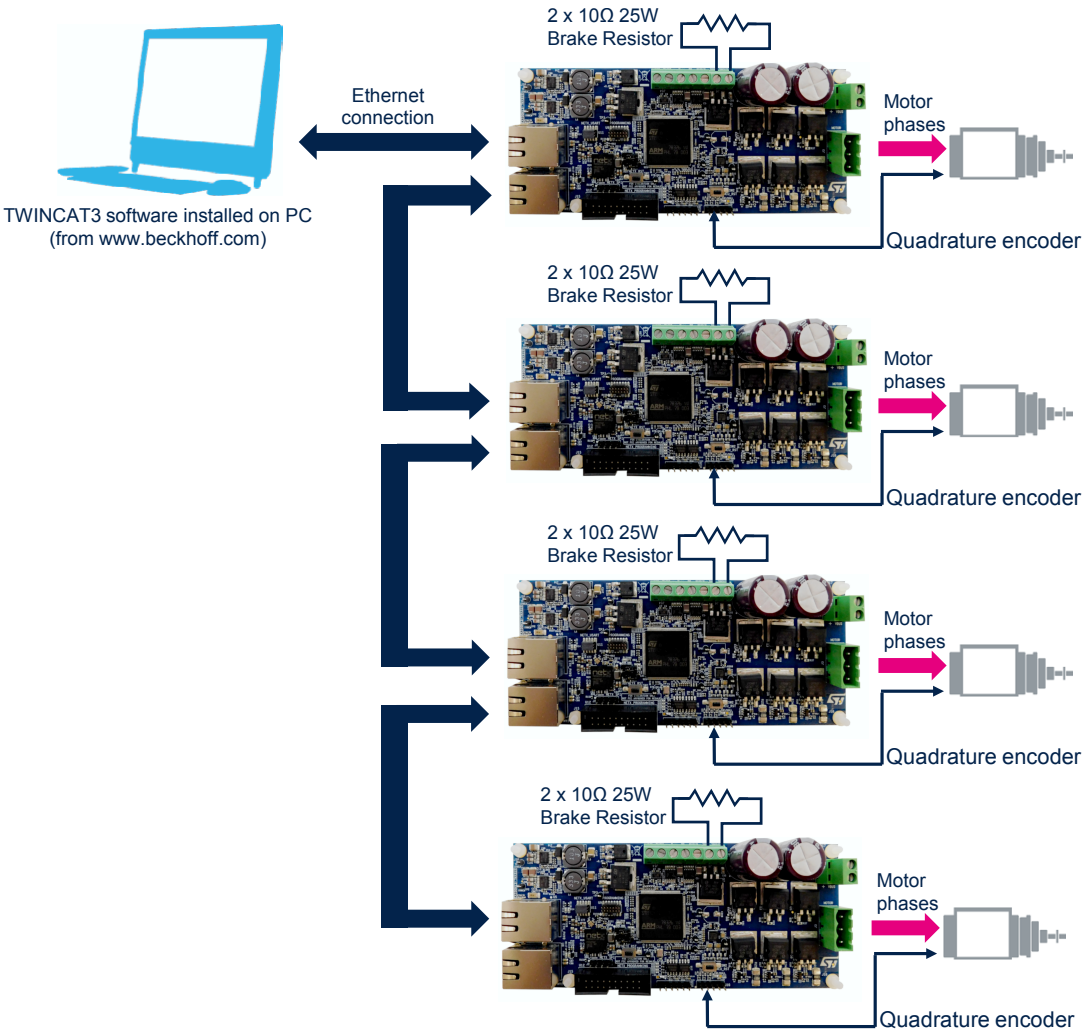
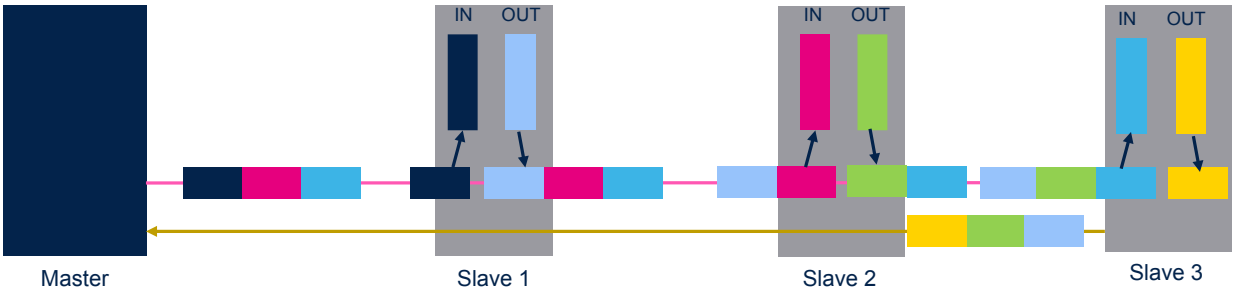


Figure 17. **Daisy-chain EtherCAT data flow representation**

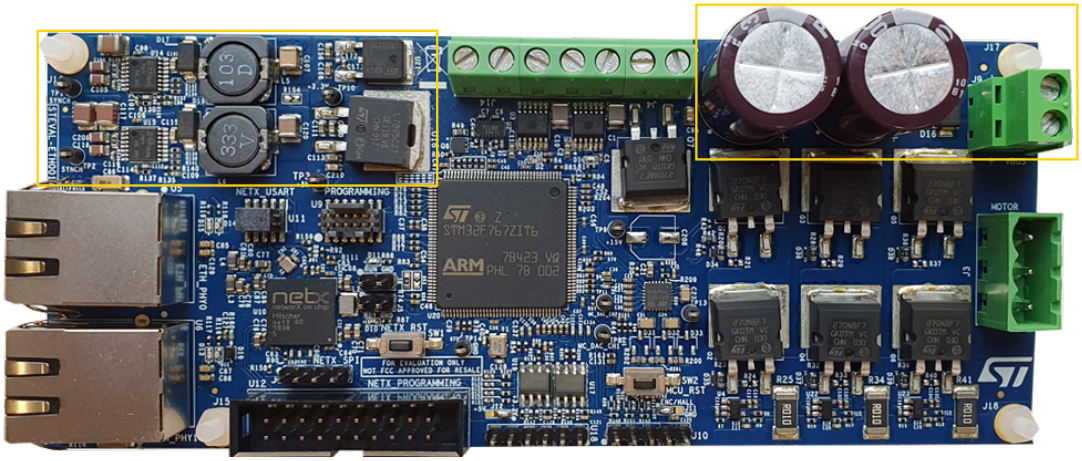


Load actuation and input signal detection (i.e., 0-24 V proximity sensor) are allowed by the actuation circuit. It is powered by the IPS160H intelligent power switch and the CLT03-2Q3 current limiter (to this aim, a set of routines has been implemented in the firmware application layer).

3.1 Power supply connection

The operating main supply voltage is in the range of 20-48 V.

Figure 18. Main supply connection (highlighted in yellow)

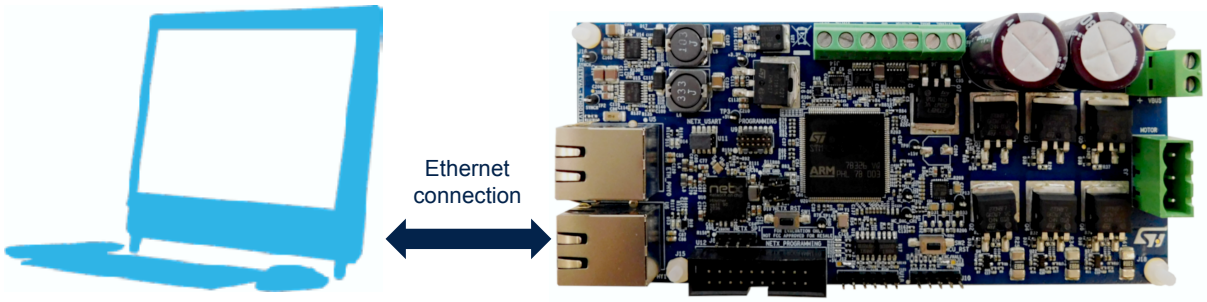


The input DC voltage has to be connected to J9 connector. When the board is powered, the 15 V, 3.3 V and 5 V voltages are generated and the green LED (close to NETX90, D11) switches on.

3.2 Ethernet real-time connectivity

Connectivity is managed by the NETX90 network controller. Once the STEVAL-ETH001V1 evaluation board is powered, add it to the network through an EtherCAT master (implemented with a software tool or hardware) and an Ethernet cable using RJ45 connector as shown in the figure below.

Figure 19. STEVAL-ETH001V1 connection example with hardware EtherCAT master



TWINCAT3 software installed on PC
(from www.beckhoff.com)

The green LED close to RJ45 connector starts blinking when a scan procedure through the master EtherCAT is performed. The LED remains always ON if the communication has been properly established.

3.3 Digital actuation connection

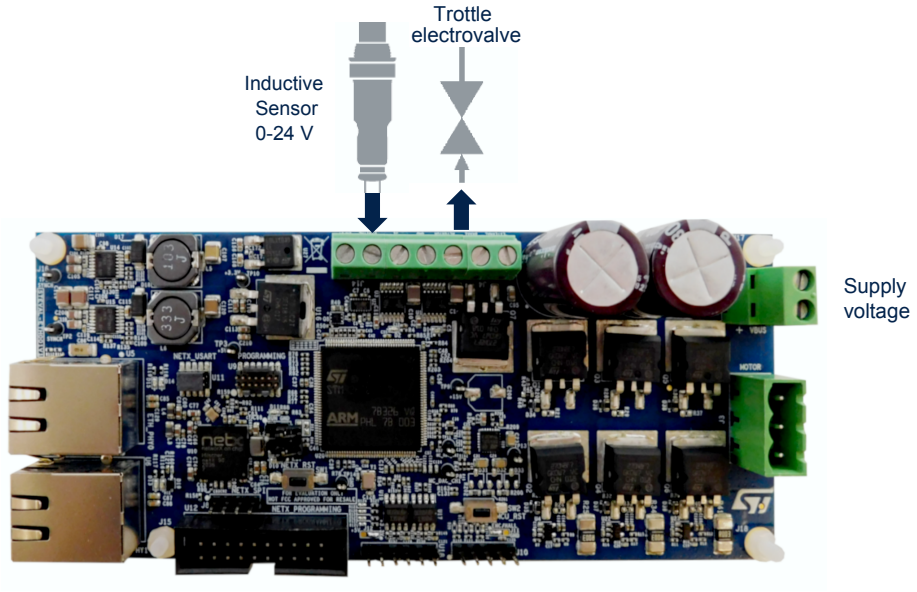
This section consists of CLT03-2Q3 dual channel digital input and IPS160H single channel digital output.

The digital output stage can drive resistive, capacitive and inductive loads with a max. output capability of 2.5 A per channel and a maximum operating voltage of 48 V; the input stage can be used to read sensor signals (0-24 V) or for feedback signalization related to the digital output status (as the operating voltage is 48 V, the feedback to the CLT03-2Q3 has to be scaled according to the maximum input voltage reported in the datasheet).

Load actuation and feedback detection can be enabled via J2 (three ways) and J14 (two ways) screw connectors.

The picture below shows a connection example of a proximity sensor with feedback in the range of 0-24 V and an electrovalve (a generic load can be used as well) as load on the actuation stage.

Figure 20. Digital actuation



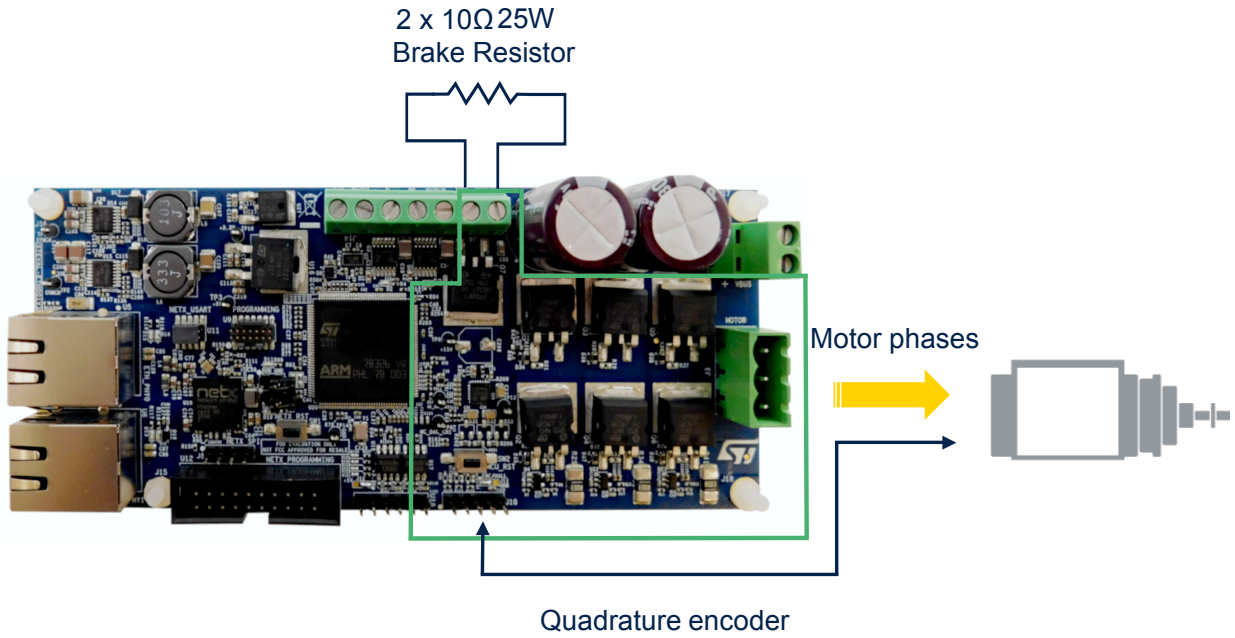
3.4 Motor driver connection

This circuit consists of the STDRIVE101 gate driver, the STH270N8F7-2 N-channel power MOSFET and the conditioning circuit based on TSV991ILT.

Motor driving is performed by connecting the motor phases to J3 connector to provide the right PWM modulation to run the motor, and the quadrature encoder to J10 connector to detect the rotor position.

The power stage also includes a small circuit with a power MOSFET activated by the microcontroller to discharge the demagnetization energy during the deceleration phase, through external 2x10 Ω, 25 W resistors connected in parallel with J4.

Figure 21. Motor driver

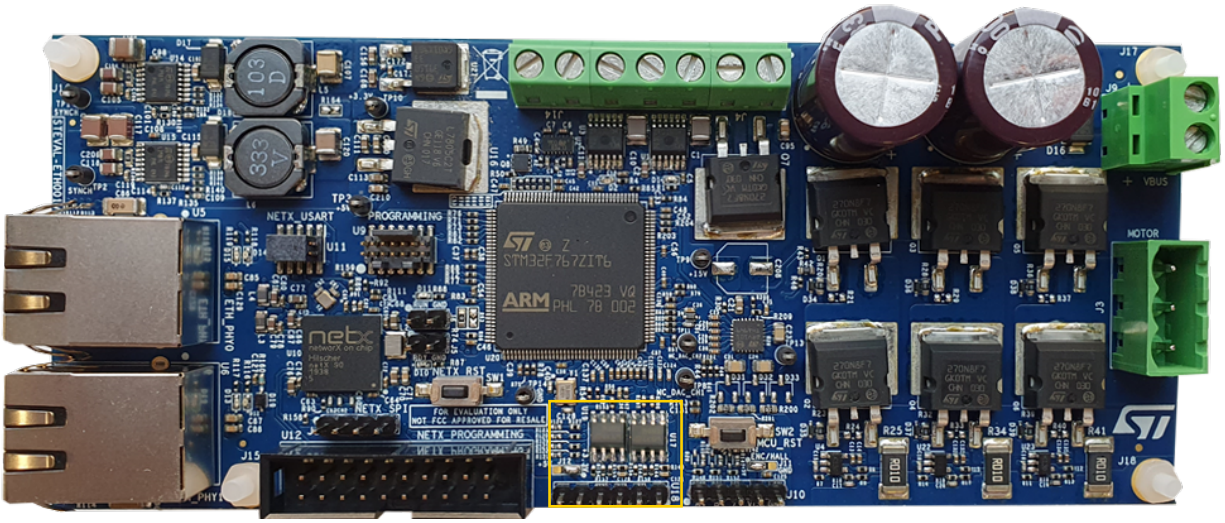


3.5 RS485 interface connection

The RS485 interface is available on-board to connect the sensor encoder supporting digital protocols (EnDat, BiSS and SSi) or connect the board to the host unit. The physical layer is based on ST3485EI.

Two ST3485EI ICs in SO8 package manage the communication; in particular, U17 is used for data, U19 is used for clock (in case of digital encoder). To connect the sensor encoder to the board, use U18 connector.

Figure 22. RS485 interface

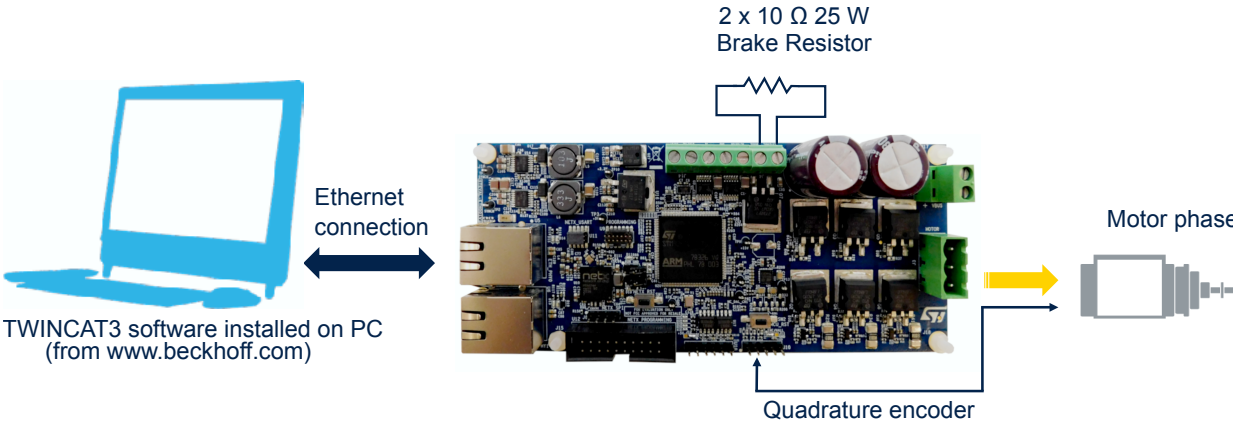


3.6 Application example

The application example allows the user to build an EtherCAT network with a master node implemented using TwinCAT software tool and a slave node implemented using the STEVAL-ETH001V1.

Once the hardware has been assembled by following the guidelines described in the previous paragraphs, it is necessary to flash the code available in the STSW-ETHDRV01V1 firmware package, use TwinCAT to open the project available in the Utilities folder and run the application. UM2808, freely available at www.st.com, describes how the application runs.

Figure 23. Example of connection



4 Schematic diagrams

Figure 24. STEVAL-ETH001V1 circuit schematic (1 of 10)

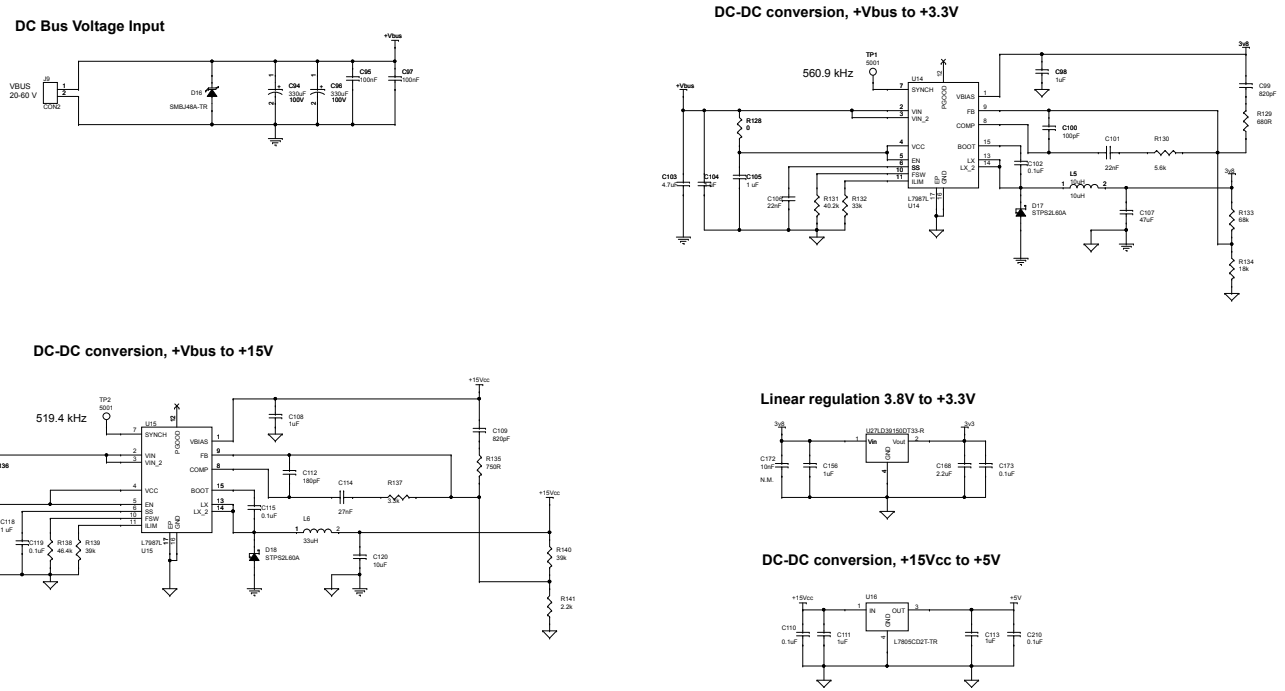


Figure 25. **STEVAL-ETH001V1 circuit schematic (2 of 10)**

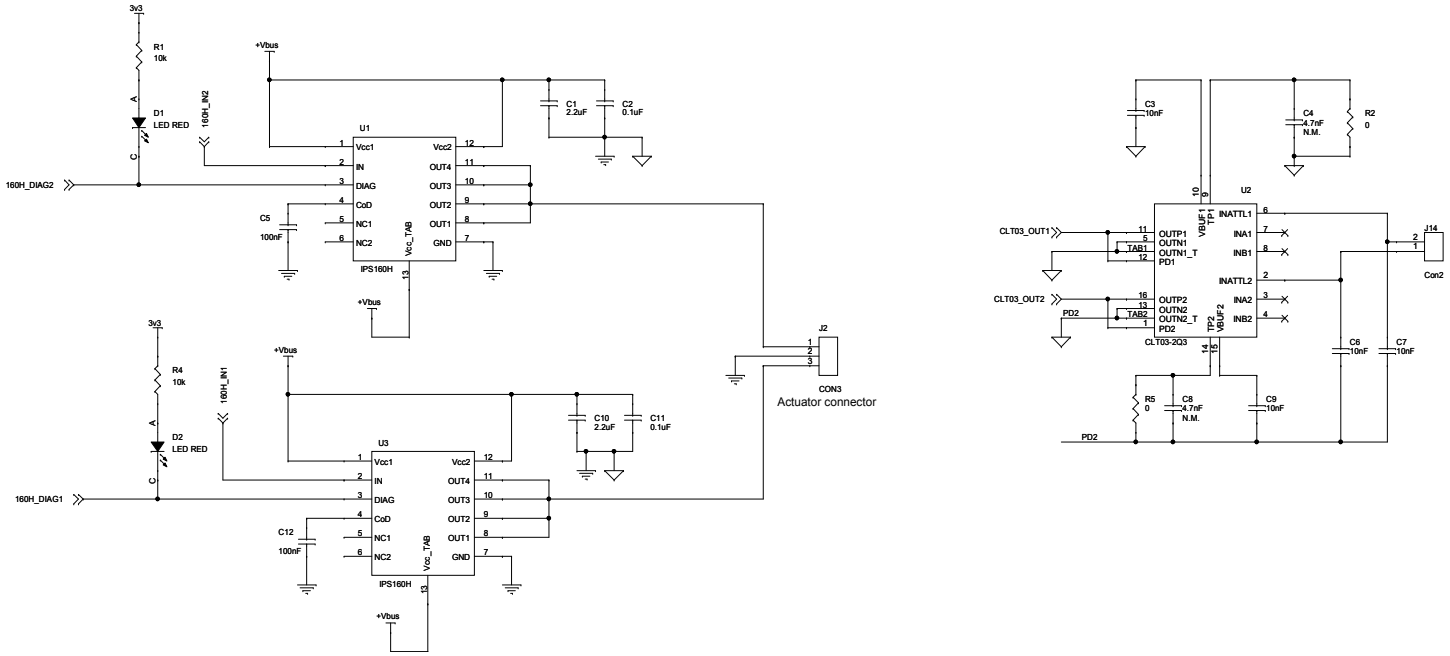


Figure 26. STEVAL-ETH001V1 circuit schematic (3 of 10)

Motion Control - Current Sensing External op-amp

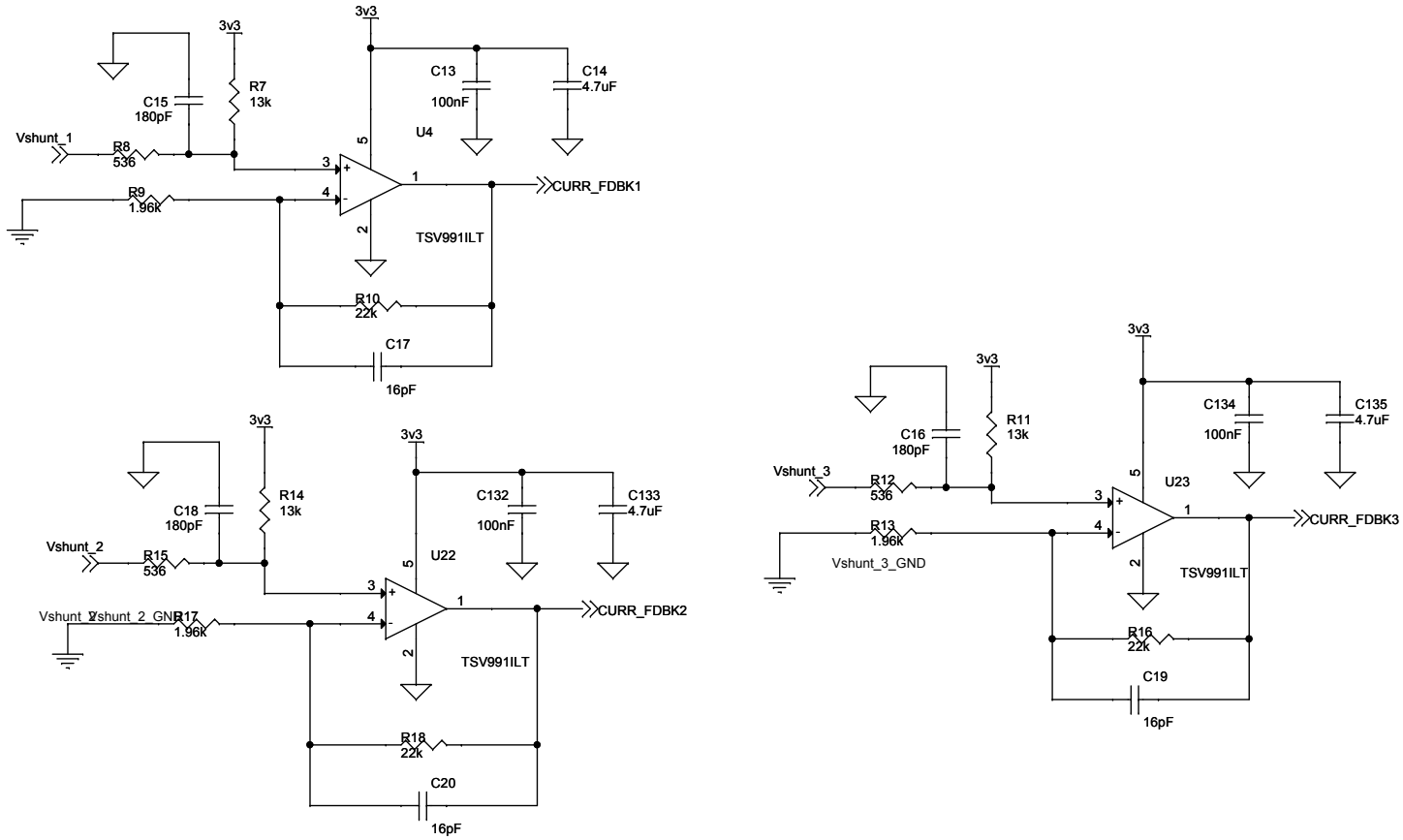


Figure 27. STEVAL-ETH001V1 circuit schematic (4 of 10)

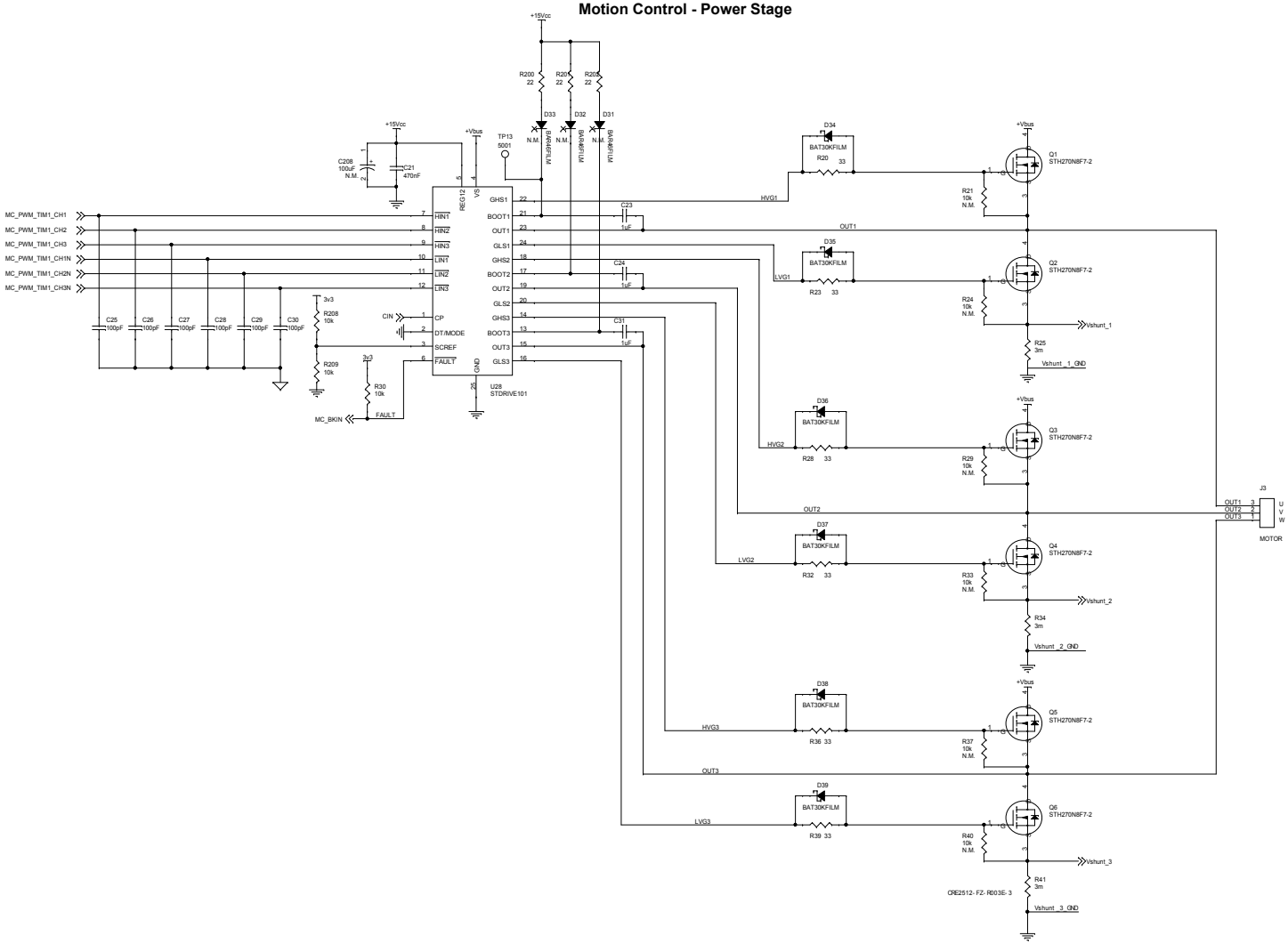
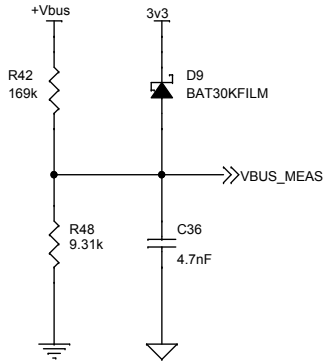
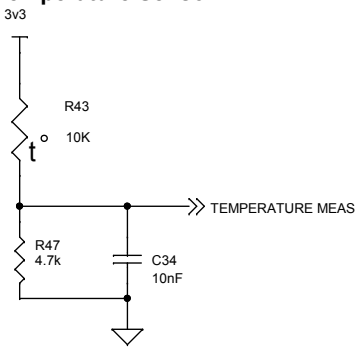


Figure 28. **STEVAL-ETH001V1 circuit schematic (5 of 10)**

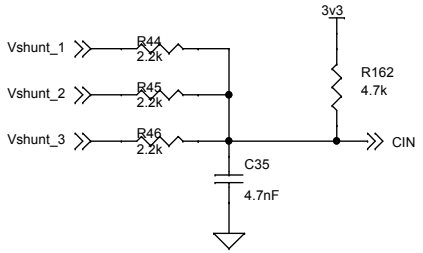
Bus Voltage Sensing



Temperature Sensor



Over Current Protection



Brake Motor Network for over voltage energy dissipation

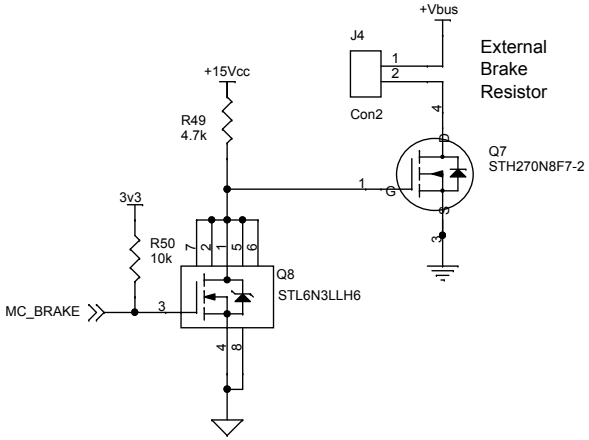
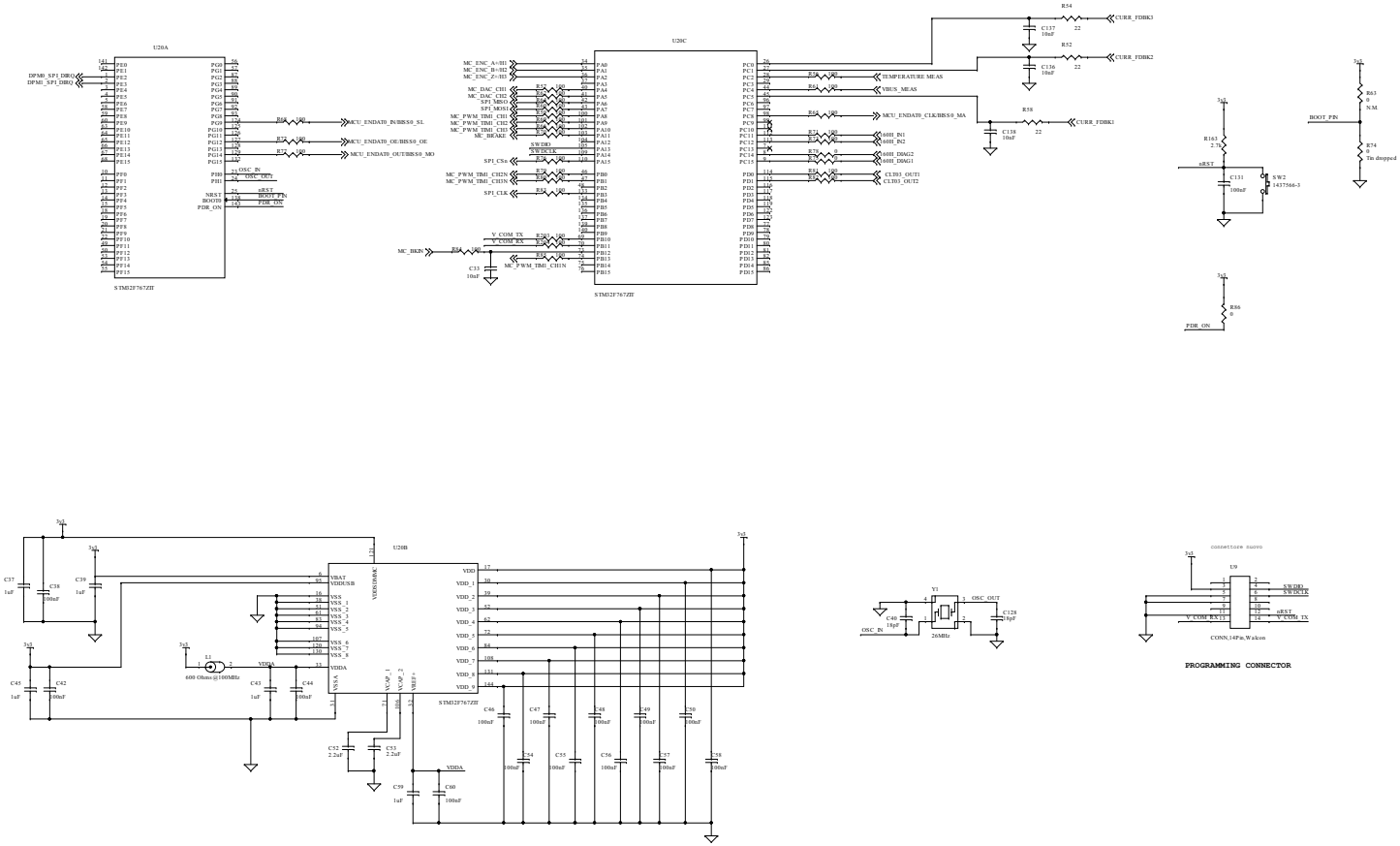


Figure 29. STEVAL-ETH001V1 circuit schematic (6 of 10)



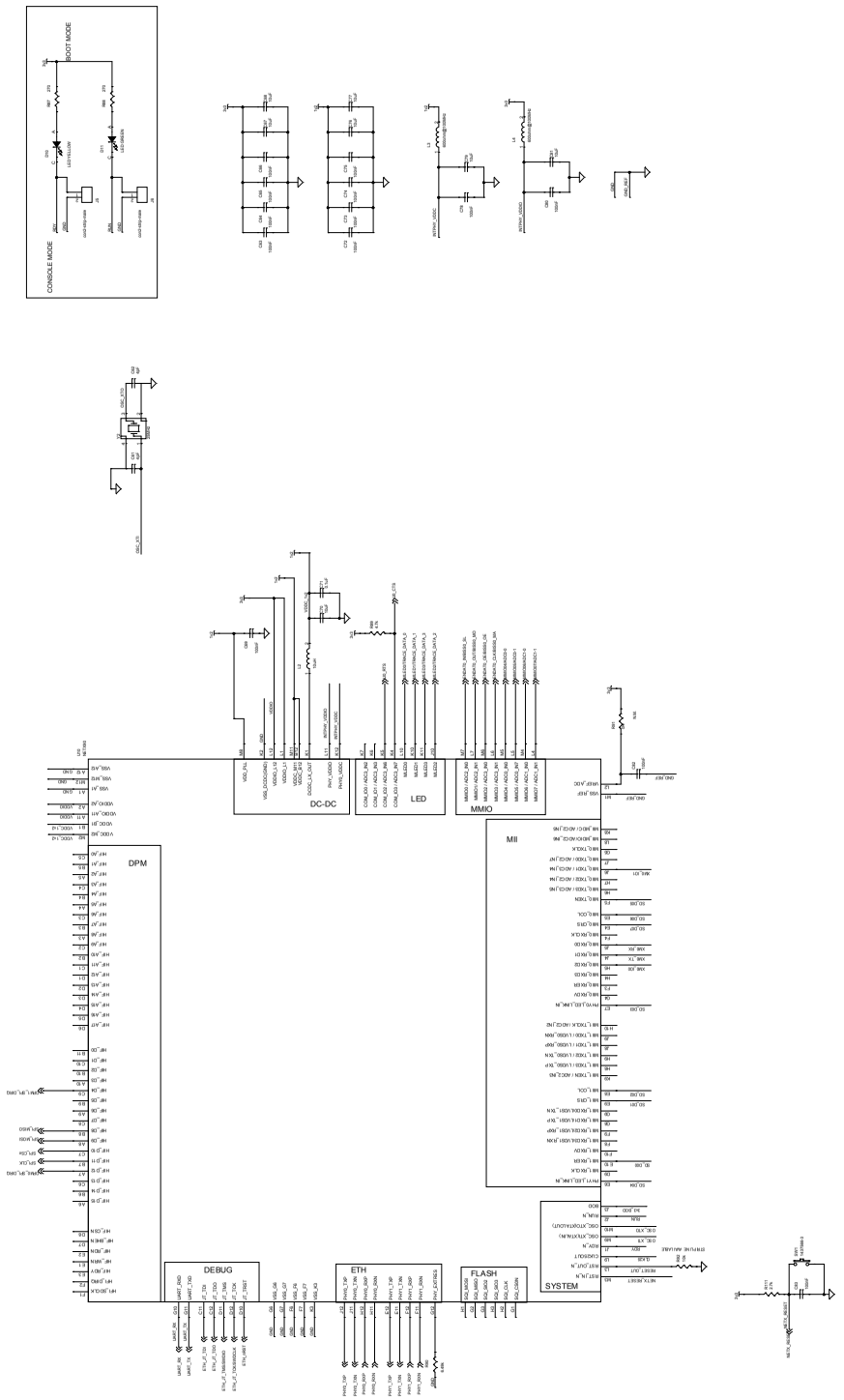


Figure 30. STEVAL-ETH001V1 circuit schematic (7 of 10)

Figure 31. STEVAL-ETH001V1 circuit schematic (8 of 10)

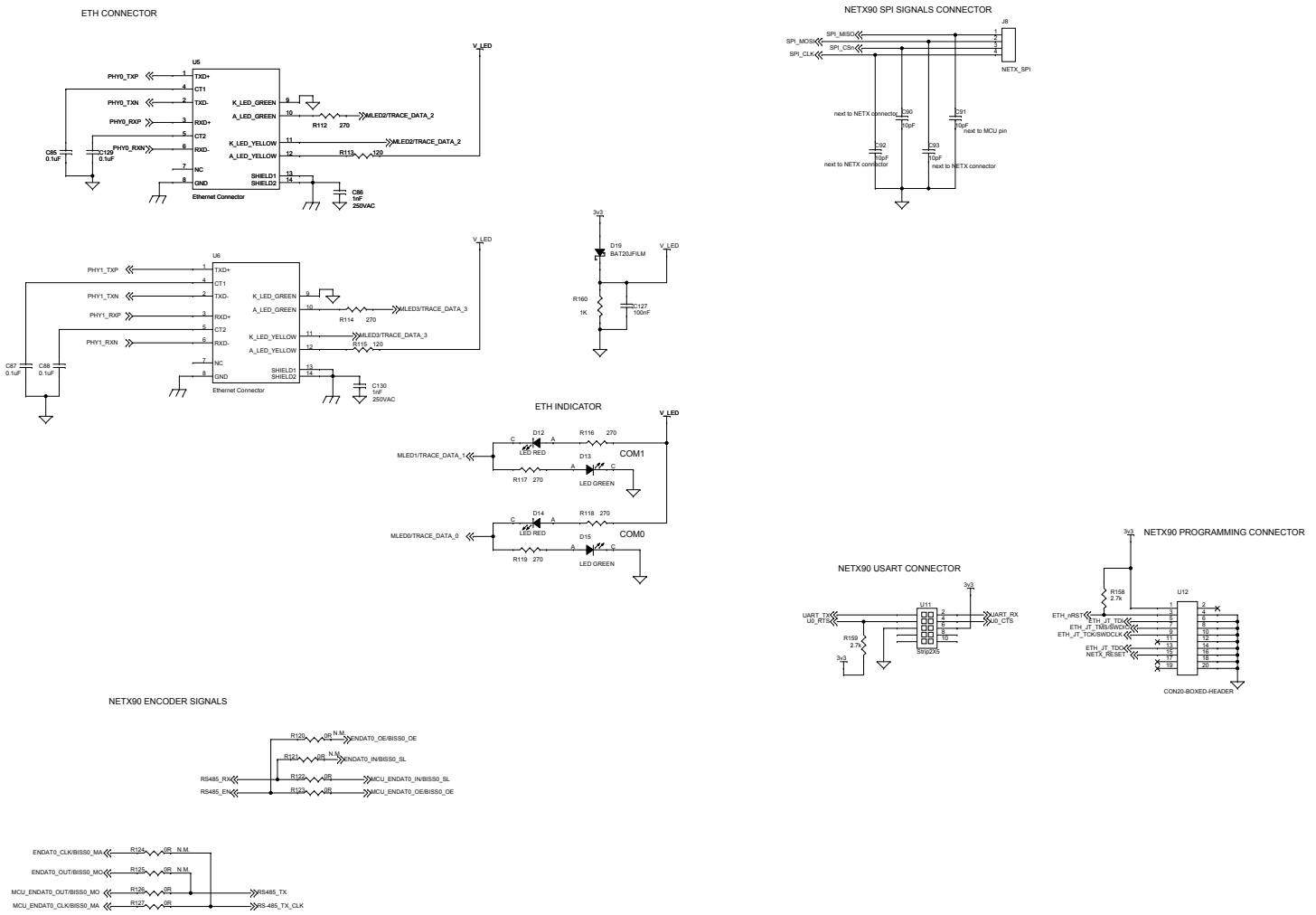


Figure 32. **STEVAL-ETH001V1 circuit schematic (9 of 10)**

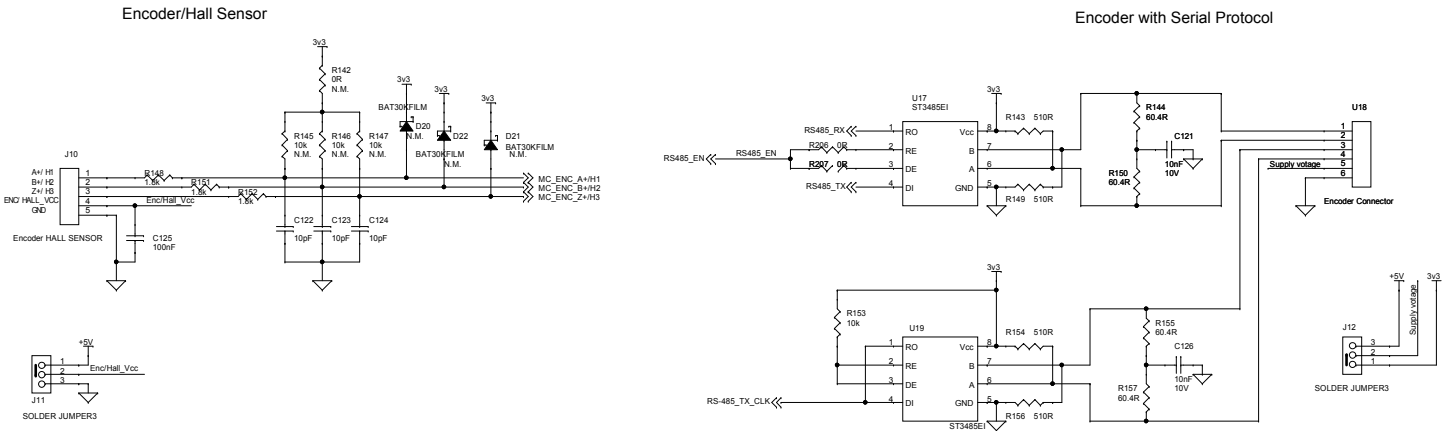
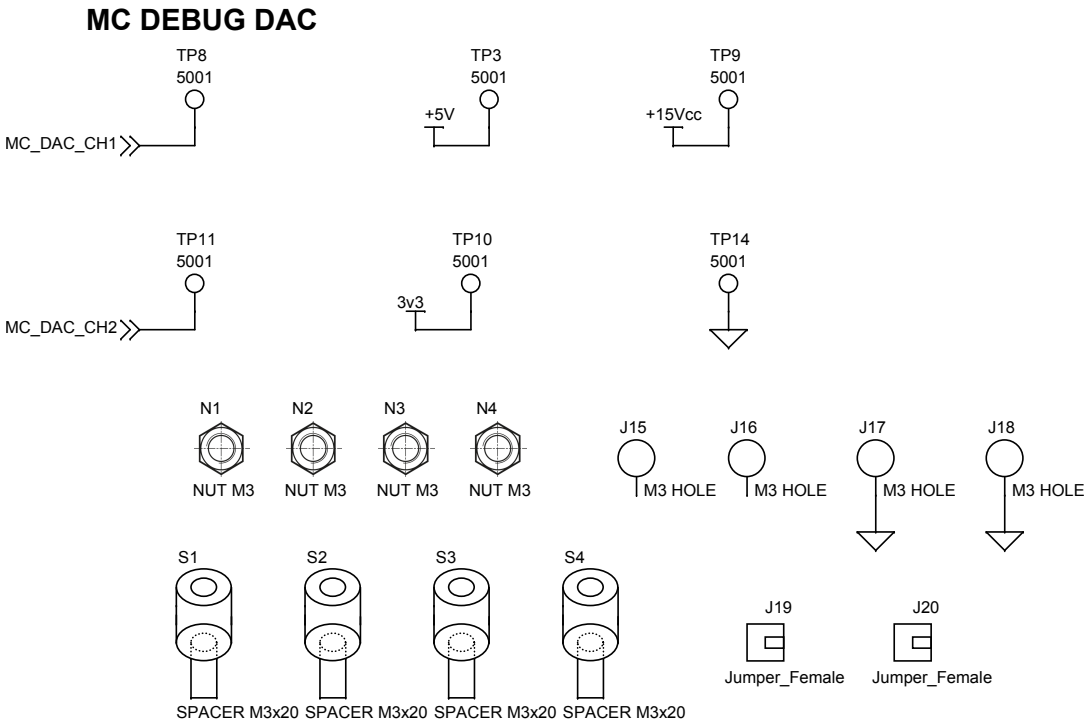


Figure 33. **STEVAL-ETH001V1 circuit schematic (10 of 10)**



5 Bill of materials

Table 1. **STEVAL-ETH001V1 bill of materials**

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
1	2	C1 C10	2.2 µF 1210 (3225 Metric) 100 V ±10% X7R	Ceramic capacitors	KEMET	C1210C225K1RACTU
2	2	C2 C11	0.1 µF 0603 (1608 Metric) 100 V ±10% X7R	Ceramic capacitors	TDK Corporation	CGA3E3X7S2A104K080AB
3	4	C3 C6 C7 C9	10 nF 0402 (1005 Metric) 25 V ±10% SMD	Ceramic capacitors	Yageo	CC0402KRX7R9BB103
4	2	C4 C8	4.7 nF 0402 (1005 Metric) 25 V ±10% SMD	Ceramic capacitors (not mounted)	Any	
5	31	C5 C12 C38 C42 C44 C46 C47 C48 C49 C50 C54 C55 C56 C57 C58 C60 C63 C64 C65 C66 C69 C72 C73 C74 C75 C78 C80 C82 C83 C127 C131	100 nF 0402 (1005 Metric) 16 V ±10% X7R	Ceramic capacitors	Murata Electronics North America	GRM155R71C104KA88J
6	4	C13 C125 C132 C134	100 nF 0402 (1005 Metric) 25 V ±10% SMD	Ceramic capacitors	Murata Electronics	GRM155R61E104KA87D
7	3	C14 C133 C135	4.7 µF 0402 (1005 Metric) 10 V ±10% SMD	Ceramic capacitors	TDK	C1005X5R1A475M050BC
8	3	C15 C16 C18	180 pF 0402 (1005 Metric) 25 V ±10% SMD	Ceramic capacitors	AVX	04025A181JAT2A
9	3	C17 C19 C20	16 pF 0402 (1005 Metric) 25 V ±10% SMD	Ceramic capacitors	Murata Electronics	GRM1555C1H160JA01D
10	1	C21	470 nF 0603 (1608 Metric) 25 V ±10%	Ceramic capacitor	Wurth Electronics Inc.	885012206075
11	3	C23 C24 C31	1 µF 0805 (2012 Metric) 50 V ±10% X7R	Ceramic capacitors	AVX	08055C105KAT2A
12	6	C25 C26 C27 C28 C29 C30	100 pF 0402 (1005 Metric) 25 V ±10% X7R	Ceramic capacitors	Wurth Electronics Inc.	885012205038
13	5	C33 C34 C136 C137 C138	10 nF 0402 (1005 Metric) 25 V ±10% X7R	Ceramic capacitors	Yageo	CC0402KRX7R9BB103

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
14	2	C35 C36	4.7 nF 0402 (1005 Metric) 16 V ±10% SMD	Ceramic capacitors	Murata Electronics North America	GRM15XR71C472KA86D
15	7	C37 C39 C43 C45 C59 C98 C108	1 uF 0402 (1005 Metric) 25 V ±10% X5R	Ceramic capacitors	Murata Electronics North America	GRM155R61E105KA12D
16	2	C40 C128	18 pF 0402 (1005 Metric) 50 V ±5% C0G/NPO	Ceramic capacitors	Yageo	CC0402JRNPO9BN180
17	2	C52 C53	2.2 µF 0402 (1005 Metric) 10 V ±20% X5R	Ceramic capacitors	Wurth Electronics Inc.	885012105013
18	2	C61 C62	4 pF 0402 (1005 Metric) 10 V ±5% C0G SMD	Ceramic capacitors	TDK	C1005C0G1H040C050BA
19	7	C67 C68 C70 C76 C77 C79 C81	10 µF 0603 (1608 Metric) 6.3 V ±20% X5R	Ceramic capacitors	TDK Corporation	C1608X5R0J106M080AB
20	7	C71 C85 C87 C88 C102 C115 C129	0.1 µF 0603 (1608 Metric) 16 V ±10% X7R	Ceramic capacitors	Wurth Electronics Inc.	885012206046
21	2	C86 C130	1 nF 1808 250 V_{AC} ±10% X7R	Ceramic capacitors	Murata Electronics North America	GA342QR7GD102KW01L
22	4	C90 C91 C92 C93	10 pF 0402 (1005 Metric) 10 V ±5% C0G/NP0	Ceramic capacitors	Wurth Electronics Inc.	885012005007
23	2	C94 C96	330 µF Radial,16x25mm 100 V ±20%	Electrolytic capacitors	Nichicon	UPW2A331MHD
24	2	C95 C97	100 nF 0805 (2012 Metric) 100 V ±10% X7R	Ceramic capacitors	Wurth Electronics Inc.	885012207128
25	2	C99 C109	820 pF 0402 (1005 Metric) 50 V ±5%	Ceramic capacitors	TDK	CGA2B2C0G1H821J050BA
26	1	C100	100 pF 0402 (1005 Metric) 10 V ±5% C0G/NP0	Ceramic capacitor	Wurth Electronics Inc.	885012005013
27	2	C101 C106	22 nF 0402 (1005 metric) 25V 10%X7R	Ceramic capacitors	Wurth Electronics Inc.	885012205052
28	1	C103	4.7 µF 1210 (3225 Metric) 100 V ±10% X7R	Ceramic capacitor	Samsung Electro-Mechanics	CL32B475KCVZW6E
29	4	C104 C105 C118 C206	1 µF 0805 (2012 Metric) 100 V ±10%	Ceramic capacitors	TDK Corporation	C2012X7S2A105K125AB
30	1	C107	47 µF 1210 (3225 Metric) 16 V ±10%	Ceramic capacitor	Murata Electronics North America	GRM32ER61C476KE15K

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
31	2	C110 C210	0.1 µF 0603 (1608 Metric) 50 V ±10%	Ceramic capacitors	Wurth Electronics Inc.	885012206095
32	2	C111 C113	1 µF 0603 (1608 Metric) 50 V ±10% X5R	Ceramic capacitor	Samsung Electro-Mechanics America, Inc.	CL10A105KB8NNNC
33	1	C112	180 pF 0402 (1005 Metric) 50 V ±10%	Ceramic capacitor	AVX	04025A181JAT2A
34	1	C114	27 nF 0402 (1005 Metric) 10 V ±10%	Ceramic capacitor	AVX	0402ZC273KAT2A
35	2	C116 C117	3.3 µF 1210 (3225 Metric) 100 V ±10%	Ceramic capacitors	TDK Corporation	C3225X7S2A335K200AE
36	1	C119	0.1 µF 0402 (1005 Metric) 25 V ±20%	Ceramic capacitor	Wurth Electronics Inc.	885012105018
37	1	C120	10 µF 1210 (3225 Metric) 35 V ±10%	Ceramic capacitor	Murata Electronics North America	GRM32ER6YA106KA12L
38	2	C121 C126	10 nF 0402 (1005 Metric) 10 V ±10%	Ceramic capacitors	Yageo	CC0402KRX7R9BB103
39	3	C122 C123 C124	10 pF 0402 (1005 Metric) 25 V ±10%	Ceramic capacitors	Murata Electronics	GRM1555C1E100JA01D
40	1	C156	1 µF 0603 (1608 Metric) 16 V ±10%	Ceramic capacitor	Samsung Electro-Mechanics	CL10A105KB8NNNC
41	1	C168	2.2 µF 0603 (1608 Metric) 25 V ±10%	Ceramic capacitor	Murata Electronics	GRM188B31E225KA12D
42	1	C172	10 nF 0402 (1005 Metric) 16 V ±10%	Ceramic capacitor	Wurth Electronics Inc.	885012205031
43	1	C173	0.1 µF 0402 (1005 Metric) 16 V ±10%	Ceramic capacitor	Wurth Electronics Inc.	885012205037
44	1	C208	100 µF Radial, Can - SMD 20%	Ceramic capacitor (not mounted)	Nichicon	UWT1E101MCL1GS
45	4	D1 D2 D12 D14	0402 (1005 Metric) 20 mA	Red LED	Wurth Electronics Inc.	150040RS73240
46	7	D9 D34 D35 D36 D37 D38 D39	SC-79, SOD-523 530 mV @ 300 mA 300 mA (DC)	General purpose signal Schottky diodes	ST	BAT30KFILM
47	1	D10	0402 (1005 Metric) 20 mA	Yellow LED	Wurth Electronics Inc.	150040AS73220
48	3	D11 D13 D15	0402 (1005 Metric) 20 mA	Green LED	Wurth Electronics Inc.	150040VS73240

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
49	1	D16	SMBJ48A-TR DO-214AA, SMB 600W	600 W TVS in SMB	ST	SMBJ48A-TR
50	2	D17 D18	DO-214AC, SMA 2A	Low drop power Schottky rectifier	ST	STPS2L60A
51	1	D19	SC-76, SOD-323 1A	General purpose signal Schottky diode	ST	BAT20JFILM
52	3	D20 D21 D22	SC-79, SOD-523 530 mV @ 300 mA 300 mA (DC)	General purpose signal Schottky diode (not mounted)	ST	BAT30KFILM
53	3	D31 D32 D33	TO-236-3, SC-59, SOT-23-3 1 V @ 250 mA 150 mA (DC)	General purpose signal Schottky diode (not mounted)	ST	BAR46FILM
54	1	J2	CON3	Terminal block	Phoenix Contact	1729131
55	1	J3		Motor terminal block	Wurth Electronics Inc.	691311500103
56	2	J4 J14	Con2	Connector	Phoenix Contact	1729128
57	2	J5 J6	con2-strip-male	Connector header	AMTEK	PH1S25-140GB6.0/3.0L
58	1	J8	NETX_SPI	Connector header	AMTEK	PH1S25-140GB6.0/3.0L
59	1	J9	CON2	Terminal block	Wurth Electronics Inc.	691253510002
60	1	J10		Encoder Hall sensor connector header	AMTEK	PH1S25-140GB6.0/3.0L
61	2	J11 J12	SOLDER JUMPER3 0603 (3pin drop)	Tin drop jumpers	Loctite	C 511 99C 5C
62	2	J19 J20	Jumper_Female	Micro shunt jumpers	AMTEK	MJ1B-BGB-L
63	1	L1	600 Ohms@100MHz 0402 (1005 Metric)	Tiny multilayer suppression bead	Wurth Electronics Inc.	74269241601
64	1	L2	10 µH 1008 (2520 metric) 600 mA ±20%	Fixed inductor	Wurth Electronics Inc.	74438323100
65	2	L3 L4	600 ohm@100 MHz 0805 (2012 Metric)	Ferrite beads	Wurth Electronics Inc.	742792040

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
66	1	L5	10 µH 4.05 A ±30%	Fixed inductor	Coilcraft	MSS1038-103NLB
67	1	L6	33 µH 2.3 A ±20%	Fixed inductor	Coilcraft	MSS1038-333MLB
68	4	N1 N2 N3 N4	NUT M3	Nuts	Duratool	111003
69	7	Q1 Q2 Q3 Q4 Q5 Q6 Q7	TO-263-3, D²Pak (2 leads + tab) Variant 80 V 180 A	StripFET F7 power MOSFETs	ST	STH270N8F7-2
70	1	Q8	6-Power WDFN	StripFET H6 power MOSFET	ST	STL6N3LLH6
71	8	R1 R4 R30 R50 R92 R153 R208 R209	10 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Yageo	RC0402FR-0710KL
72	2	R2 R5	0 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Yageo	RC0402JR-070RL
73	3	R7 R11 R14	13 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Vishay	CRCW040213K0FKED
74	3	R8 R12 R15	536 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Panasonic	ERJ-2RKF5360X
75	3	R9 R13 R17	1.96 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Vishay	CRCW04021K96FKED
76	3	R10 R16 R18	22 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Vishay	CRCW040222K0FKEDC
77	6	R20 R23 R28 R32 R36 R39	33 0603 (1608 Metric) 0.1 W, 1/10 W ±1%	Chip resistors	Vishay	CRCW060333R0FKEA
78	6	R21 R24 R29 R33 R37 R40	10 k 0603 (1608 Metric) 0.1 W, 1/10 W ±5%	Chip resistors (not mounted)	Any	
79	3	R25 R34 R41	3 mOhm 2512 (6432 Metric) 3 W ±1%	Resistors	Bourns Inc.	CRE2512-FZ-R003E-3
80	1	R42	169 k 0603 (1608 Metric) 0.1 W, 1/10 W ±1%	Resistor	Vishay	CRCW0603169KFKEA
81	1	R43	10 K 0402 (1005 metric) 100 mW	Thermistor	TDK Corporation	NTCG103JF103FT1
82	3	R44 R45 R46	2.2 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Vishay	CRCW04022K20FKED
83	3	R47 R89 R162	4.7 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Panasonic	ERJ2GEJ472X

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
84	1	R48	9.31k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Vishay	CRCW04029K31FKED
85	1	R49	4.7k 0603 (1608 Metric) 0.1 W, 1/10 W ±1%	Chip resistors	TE Connectivity	CRG0603F4K7
86	3	R52 R54 R58	22 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Vishay	CRCW040222R0FKED
87	26	R56 R57 R59 R60 R61 R62 R64 R65 R66 R68 R69 R70 R71 R72 R73 R76 R77 R79 R80 R81 R82 R83 R84 R85 R203 R204	100 0402 (1005 Metric) 0.063 W, 1/16 W ±5%	Resistors	Yageo	RC0402FR-07100R
88	1	R63	0 0603	Jumper (not mounted)	Panasonic	ERJ-3GEY0R00V
89	1	R74	0 0603	Jumper	Panasonic	ERJ-3GEY0R00V
90	3	R75 R78 R86	0 0402 (1005 Metric) 0.063 W, 1/16 W ±5%	Resistors	Yageo	RC0402JR-070RL
91	8	R87 R88 R112 R114 R116 R117 R118 R119	270 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Yageo	RC0402FR-07270RL
92	1	R90	6.49 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Resistor	Yageo	RC0402FR-076K49L
93	1	R91	0R 0402 (1005 Metric) 0.063 W, 1/16 W ±5%	Resistor (not mounted)	Yageo	RC0402JR-070RL
94	4	R111 R158 R159 R163	2.7 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Resistors	Yageo	RC0402FR-072K7L
95	2	R113 R115	120 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Resistors	Yageo	RC0402FR-07120RL
96	4	R120 R121 R124 R125	0 R 0402 (1005 Metric) 0.063 W, 1/16 W ±5%	Chip resistors	Yageo	RC0402JR-070RL
97	4	R122 R123 R126 R127	0 R 0402 (1005 Metric) 0.063 W, 1/16 W ±5%	Chip resistors	Yageo	RC0402JR-070RL
98	2	R128 R136	0 0603 (1608 Metric) 0.1 W, 1/10 W Jumper	Resistors	Panasonic Electronic Components	ERJ-3GEY0R00V

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
99	1	R129	680 R 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Resistor	Vishay	CRCW0402680RFKED
100	1	R130	5.6 k 0402 (1005 Metric) 0.063 W, 1/16 W ±5%	Resistor	Vishay	CRCW04025K60FKEDHP
101	1	R131	40.2 k 0402 (1005 Metric) 0.1 W, 1/10 W ±1%	Resistor	Panasonic Electronic Components	ERJ-2RKF4022X
102	1	R132	33 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistor	TE Connectivity	CRG0402F33K
103	1	R133	68 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistor	Panasonic	ERJ2RKF6802X
104	1	R134	18 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Resistor	Yageo	RC0402FR-0718KL
105	1	R135	750 R 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Resistor	Vishay	CRCW0402750RFKED
106	1	R137	3.3 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Resistor	Vishay	CRCW04023K30FKED
107	1	R138	46.4 k 0402 (1005 Metric) 0.1 W, 1/10 W ±1%	Resistor	Panasonic Electronic Components	ERJ-2RKF4642X
108	2	R139 R140	39 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Resistors	Vishay	CRCW040239K0FKED
109	1	R141	2.2 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Resistor	Vishay	CRCW04022K20FKED
110	1	R142	0 R 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistor	Yageo	RC0402JR-070RL
111	4	R143 R149 R154 R156	510 R 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Vishay	CRCW0402510RFKED
112	4	R144 R150 R155 R157	60.4 R 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Resistors	Stackpole Electronics Inc	RMCF0402FT60R4
113	3	R145 R146 R147	10 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors (not mounted)	Yageo	RC0402FR-0710KL
114	3	R148 R151 R152	1.8 k 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistors	Vishay	CRCW04021K80FKEDHP
115	1	R160	1 K 0402 (1005 Metric) 0.063 W, 1/16 W ±1%	Chip resistor	Vishay	CRCW04021K00FKED

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
116	3	R200 R201 R202	22 0603 (1608 Metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-0722RL
117	2	R206 R207	0 R 0402 (1005 Metric) 0.063 W, 1/16 W ±5%	Resistors	Yageo	RC0402JR-070RL
118	4	S1 S2 S3 S4	SPACER M3x20 + Nuts	Spacer and nuts	Keystone Electronics	25505 + 4688
119	2	SW1 SW2	1437566-3 6.00 mm x 3.50mm	Tactile switches	TE Connectivity ALCOSWITCH Switches	1437566-3
120	9	TP1 TP2 TP3 TP8 TP9 TP10 TP11 TP13 TP14	5001 0.100" x 0.180" (2.54 mm x 4.57 mm)	Test points	Keystone Electronics	5001
121	2	U1 U3	PowerSSO12 Exposed Pad	Intelligent power switch	ST	IPS160H
122	1	U2		Self powered digital input current limiter	ST	CLT03-2Q3
123	3	U4 U22 U23	SC-74A, SOT-753	IC OPAMP GP 20MHZ RRO SOT23-5	ST	TSV991ILT
124	2	U5 U6	Ethernet Connector	Modular connectors/ Ethernet connectors port RJ45 THT with LED	Wurth Electronics Inc.	615008185221
125	1	U9	CONN,14Pin,Wa Icon	Connector header	Samtec Inc.	FTSH-107-01-L-DV-K
126	1	U10	NETX90 10x10	Highly integrated industrial Ethernet node	Hilscher	NETX90
127	1	U11	Strip2X5	Low profile terminal	Samtec Inc.	FTS-105-01-L-DV-P
128	1	U12	CON20-BOXED-HEADER	Connector header	AMTEK	BH1S-20GB00A-L
129	2	U14 U15	16-TSSOP (0.173", 4.40mm Width) Exposed Pad	Asynchronou s step-down switching regulator	ST	L7987LTR
130	1	U16	TO-263-3, D²Pak (2 Leads + Tab), TO-263AB	Positive voltage regulator IC	ST	L7805CD2T-TR
131	2	U17 U19		RS-485 transceiver	ST	ST3485EIDT
132	1	U18		Encoder connector header	AMTEK	PH1S25-140GB6.0/3.0L

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
133	1	U20	144-LQFP	Arm Cortex-M7 MCU	ST	STM32F767ZIT6
134	1	U27	TO-252-3, DPak, SC-63	Ultra low drop BicMOS voltage regulator	ST	LD39150DT33-R
135	1	U28	24-VFQFN exposed Pad (4 mmX4 mm, pitch 0.5 mm)	Triple half-bridge gate driver	ST	STDRIVE101
136	1	Y1	26 MHz 4-SMD, No Lead (3.20mmx2.50mm)	Crystal	IQD Frequency Products	LFXTAL059643REEL
137	1	Y2	25MHz 4-SMD (2.00mm x 1.60mm)	Crystal	Abracon LLC	ABM11W-25.0000MHZ-4-D1X-T3

Revision history

Table 2. **Document revision history**

Date	Version	Changes
23-Apr-2021	1	Initial release.

Contents

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