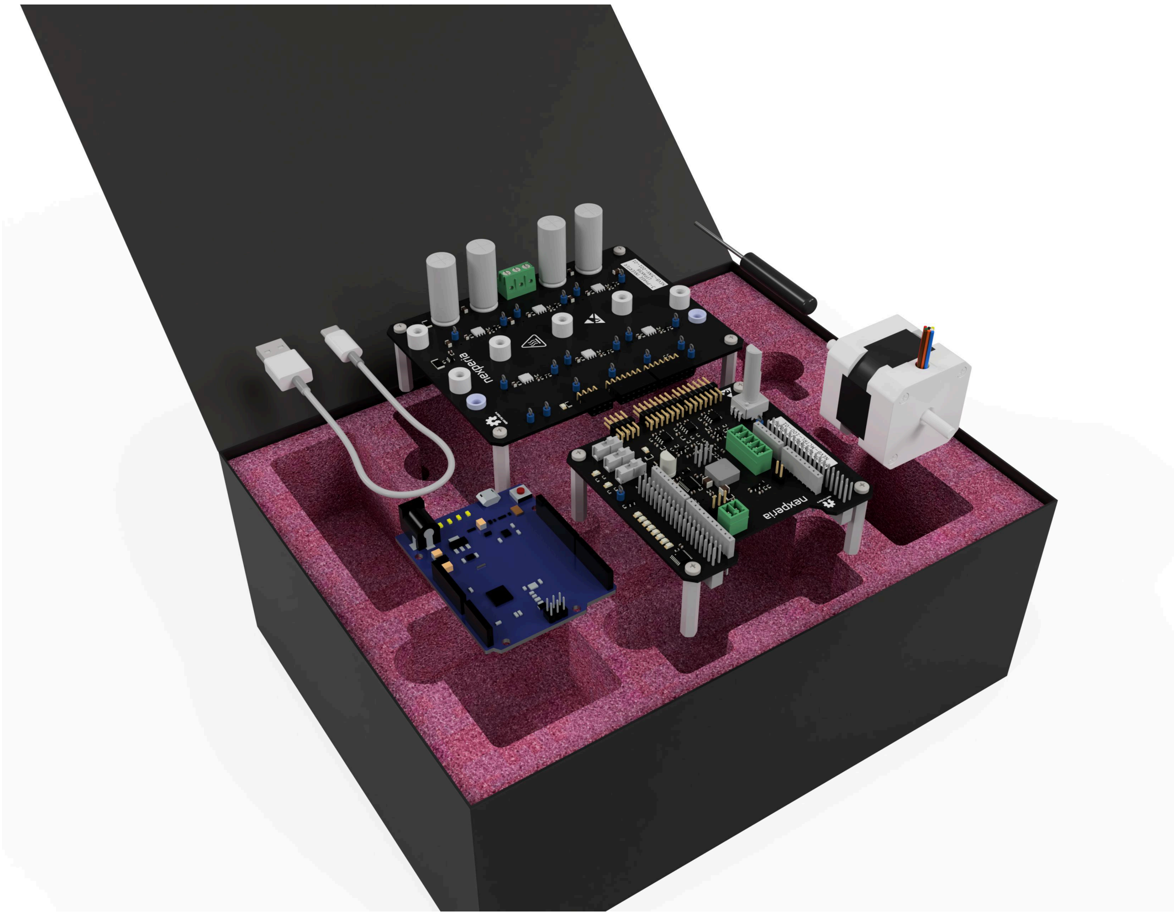
UM90029

Rev. 1.0 — 15 April 2024

User manual

NEVB-MCTRL-100-01-3INV-001-01 motor driver evaluation kit



Abstract: This user manual describes Nexperia's motor driver evaluation kit and details its set-up and use. Design details of the motor controller and 3-phase inverter PCBs are included.

Keywords: NEVB-MCTRL-100-01-3INV-001-01, BLDC, motor controller, 3 phase, H-bridge, LFPAK56

Contents

Date of release: 15 April 2024

1. Introduction

The BLDC motor driver kit provides a full motor drive solution for 12 V - 48 V, 1,000 W, 3-phase BLDC motors. The kit contains PCBs designed for the Nexperia LFPAK56 MOSFET family. Before using the kit users must read the important safety precautions. By using this kit you agree to the terms and conditions of use.

Included in BLDC motor driver kit:

- Motor controller board (NEVB-MCTRL-100-01)
- 3-phase inverter board (NEVB-3INV-001-01)
- Leonardo R3 development board
- USB-A to Micro USB cable
- Flat head screwdriver
- Pluggable terminal block connectors
- M5 pozidriv screws
- 3-phase BLDC motor with Hall-effect sensors (42BLS40-24-01)
- Motor control firmware (for trapezoidal control of BLDC motors using Hall-effect sensors). **Note:** other types of control and motors are supported

Not included in BLDC motor driver kit:

- Bench top power supply with complimentary cables

The modular design of the BLDC motor driver kit allows for different motor controllers, gate drivers, MOSFETs and motors to be used. In addition, each board provides convenient test points for power, motor drive, and sensing signals to aid with development and testing with Nexperia's LFPAK56 MOSFET family.

The motor controller board is designed for the Leonardo R3 and Nucleo development board form factors. The supplementary firmware is compatible with the Leonardo R3 development board or ATMEGA32u4 micro controller to aid in the evaluating of 3-phase BLDC applications. The Leonardo R3 development board, motor controller board, and 3-phase inverter board are shown in Fig. 1.

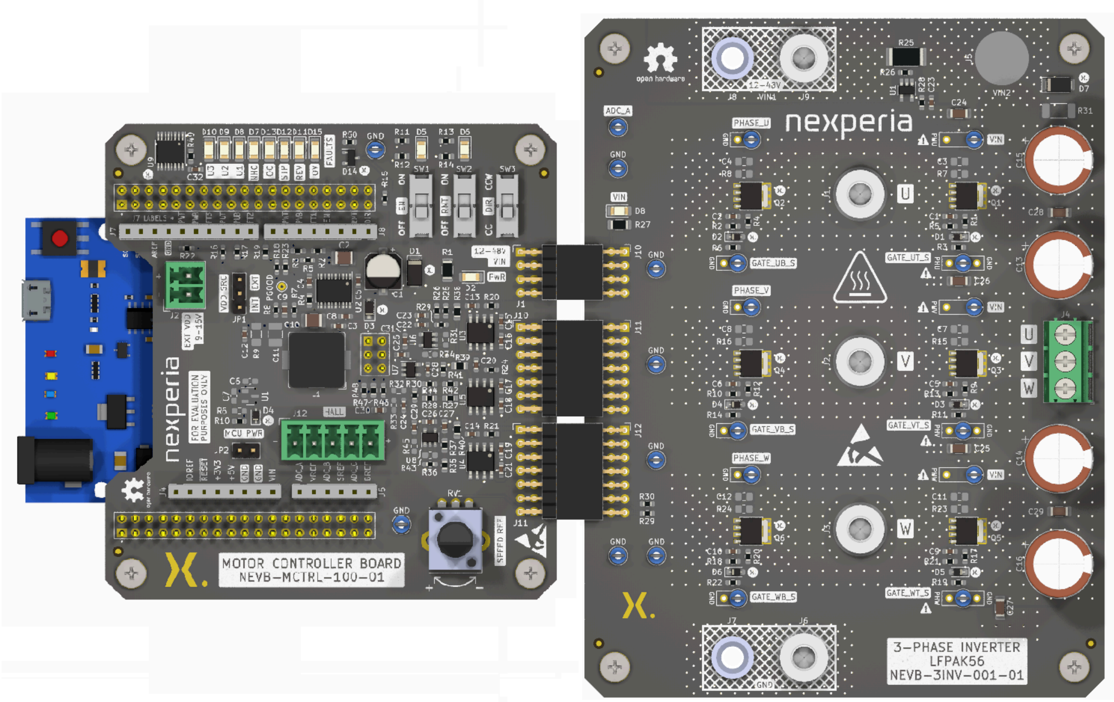


Fig. 1. Leonardo R3 development board, motor controller board and 3-phase inverter board

A simplified block diagram of the motor control kit is shown in Fig. 2.

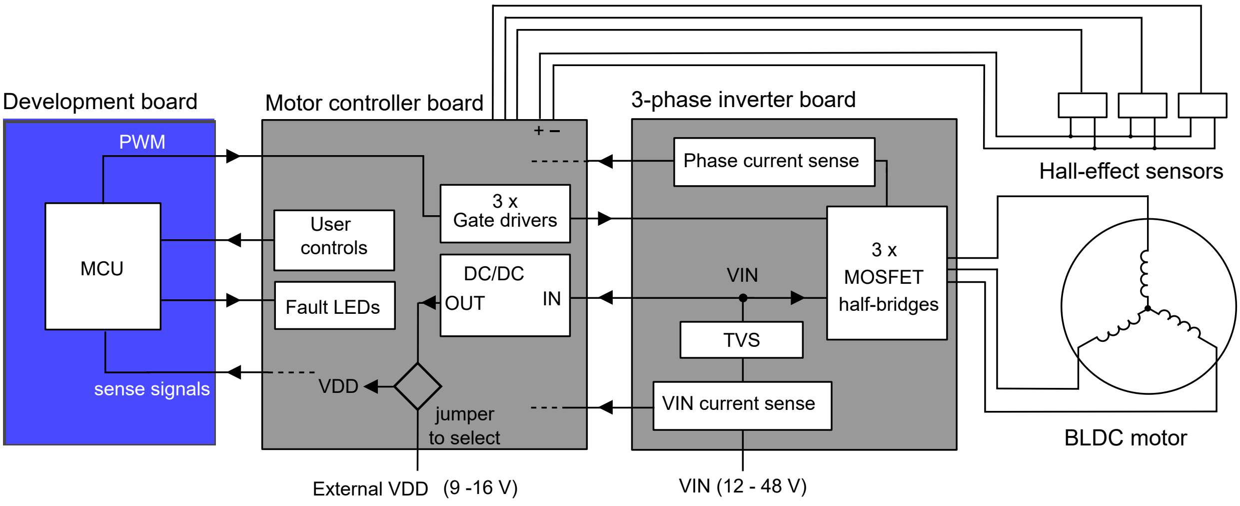


Fig. 2. BLDC motor control kit block diagram

1.1. Motor evaluation kit specifications

The following are the recommended operating conditions for this motor evaluation kit:

- Supported primary input voltage (VIN): 12 V – 48 V[1 2]
- Nominal gate drive voltage: 12 V[3]
- Maximum input power: 1000 W[4]
- MCU development board IO reference voltages: 3.3 V – 5 V
- Maximum junction temperature allowed by default MOSFETs: 175 °C

Supported variations of control methods and motors:

- Sensored (with Hall-effect sensors, absolute and incremental encoders) and sensor-less (with back-EMF zero-crossing detection)
- Trapezoidal and sinusoidal [5]
- Unipolar and bipolar
- Brushless DC (BLDC), Permanent Magnet Synchronous Motors (PMSM) and Brushed DC motors[6]

Note: although all the above are supported, only firmware code for trapezoidal control of BLDC motors using Hall-effect sensors is provided. Users are expected to implement other types of control themselves.

1 Ensure that the motor being used is capable of the voltage being used. The motor provided with the kit is designed for 24 V.
2 If operating beyond these conditions, please ensure appropriate measure are taken. For VIN < 12 V, an additional power supply must be provided to J2 to supply the appropriate voltage to the gate driver (and if configured to, the MCU development board). More discussed in Section 4.1 and Section 4.2
3 Alternative gate voltage levels supported, please refer to Section 4.1 and Section 4.2
4 Subject to multiple conditions, including but not limited to the device being used, gate resistance value, switching frequency, motor speed and control method. Higher power can be achieved given appropriate conditions are met.
5 Field Oriented Control (FOC) can be supported if alternative 3-phase inverter board is used that feeds the per phase current into the motor control board.
6 For brushed DC motors, any two phases can be chosen to act as a H-bridge.

1.2. Safety precautions

- **Motor Handling**: Ensure that the motor is securely clamped down and cannot move unexpectedly during operation. This is crucial to prevent any accidents or damage to the system.
- **Operating Ranges**: Verify that the motor's intended operating ranges (voltage, current, speed, etc.) are supported by your setup. Operating the motor outside its specified limits can lead to malfunction or damage.
- **Power Isolation**: Implement appropriate measures to quickly and safely isolate the power to the system if needed. This might include emergency stop mechanisms or easily accessible power switches
- **General Safety**: Always take reasonable safety precautions when handling electronic components. This includes wearing protective gear as necessary, ensuring a tidy and organized workspace, and being cautious of potential electrical hazards.
- **Hot temperatures**: During operation, be aware of the fact that the inverter board with the MOSFETs may reach high temperatures especially for higher powers.
- **ESD Protection**: Utilize grounding methods, such as ESD wrist straps and anti-static mats, to safeguard against electrostatic discharge and prevent potential damage to any electronic components.

WARNING

Ensure safety precautions, including reading the accompanying materials, have been taken for operating the system.

WARNING

Hot Surface.

To prevent burns or injury, avoid touching any exposed surfaces near the MOSFETs while the kit is powered on or immediately after use.

WARNING

ESD sensitive devices.

Recommended for use in ESD-Safe Work Environment and to implement ESD Handling Procedures.

2. Getting started

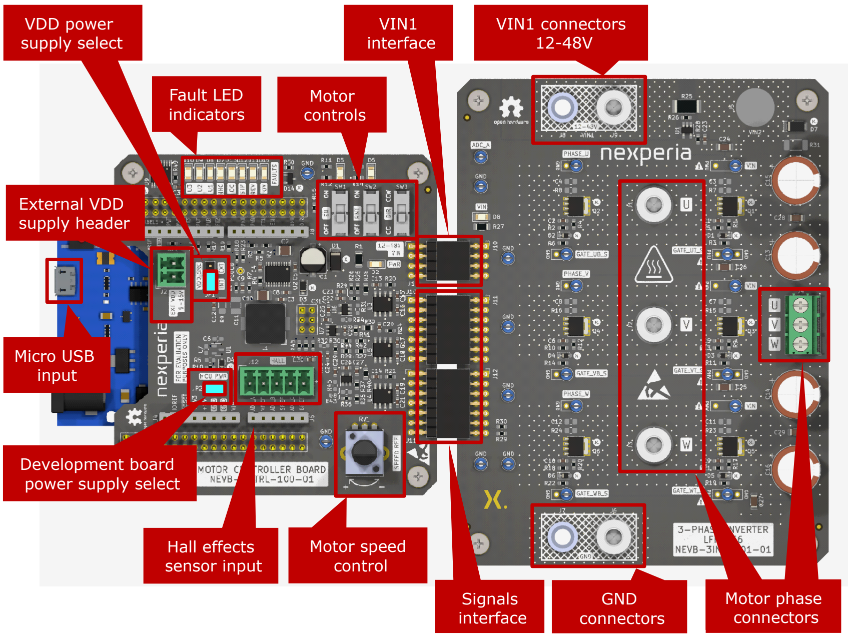
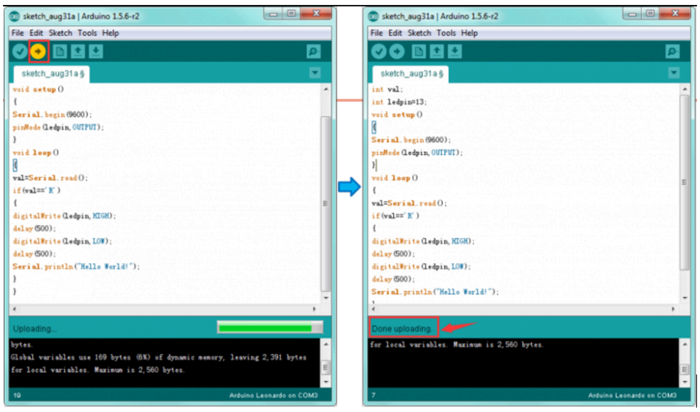


Fig. 3. BLDC motor driver kit overview

To start using the motor driver kit refer to Fig. 3 and the following steps:

1. Review the default jumper positions, motor controls, and motor speed control in Section 5.1 and Section 5.2
2. Connect the Leonardo R3 development board, motor controller board, and the 3-phase inverter board together as shown in Section 5.3
3. Connect the 3-phase BLDC motor phase wires and motor hall wires to BLDC kit as shown in Section 5.4
4. Connect a 24 V power supply to VIN1 and GND, as labeled in Fig. 3 with a current limit of 2.5 A using a banana jack cables
5. The board will come with the firmware for trapezoidal control of BLDC motors using Hall-effect sensors (NEVC-MCTRL-100-t01) with presets configured to work with the motor provided in the kit. To make any changes, please review the entirety of the Software section to download the Arduino™ IDE, import motor control firmware, click upload to run the motor control firmware as shown below:



6. Move SW1 (EN) motor control switch to the ON position (towards the edge of the board), and turn the motor speed control potentiometer clockwise to control the motor speed. **Note**: SW2 (RMT) must be switched to the OFF position on micro controller boot up to allow local control using the motor controls. For details about remote control, please refer to Section 6.5.

3. 3-phase inverter board

The 3-phase inverter board is the power stage of the motor driver kit, see Fig. 4, it features:

- Power supply connections
- High-side current monitoring
- 3 x half-bridge LFPAK56 MOSFET pairs
- Motor phase connections
- Motor controller PCB interface

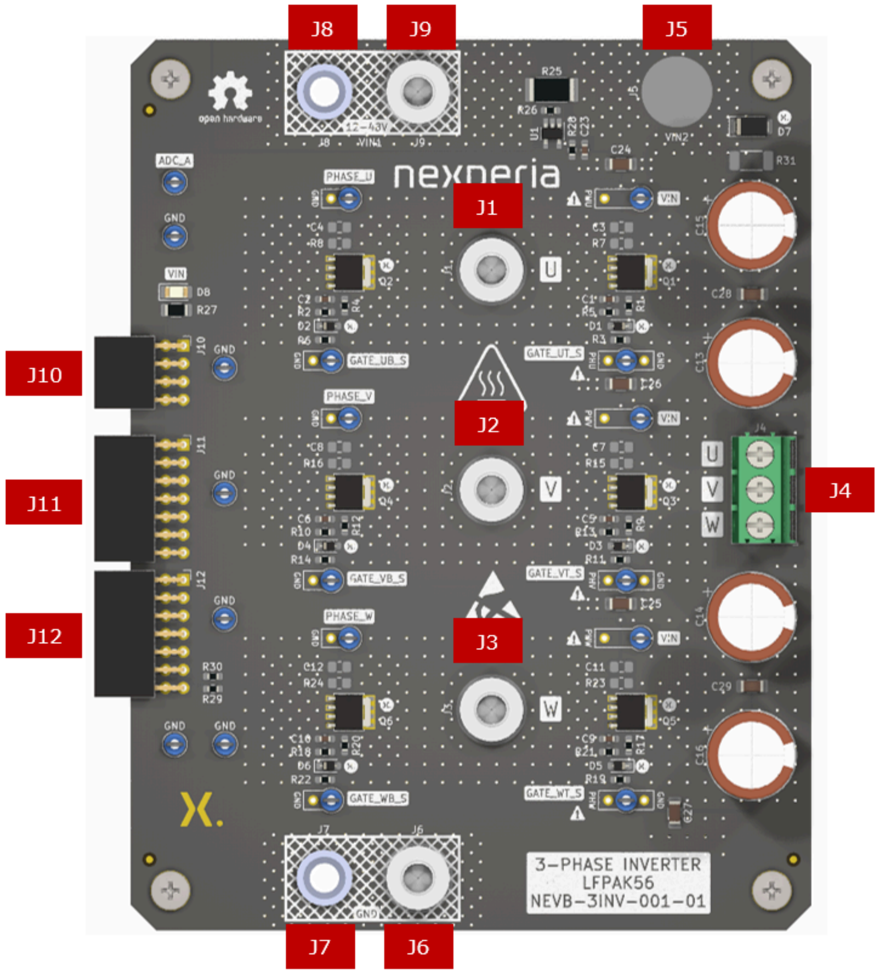


Fig. 4. 3-phase inverter board connector locations

3.1. Power supply and high-side current monitoring

The 3-phase inverter board is designed for an input voltage of 12 V - 48 V during standard operation. There are multiple ways to provide power to the 3-phase inverter board as shown in Table 1:

Table 1. 3-phase inverter board; supply locations

Location	Description
+VIN connections	
J8	The banana jack connector labeled VIN1
J9	Threaded screw terminal labeled VIN1
J5	Un-populated threaded screw connector which is the VIN net, this bypasses current sensing
GND (current return path) connections	
J7	The banana jack connector labeled GND
J6	Threaded screw connector labeled GND

High-side current monitoring

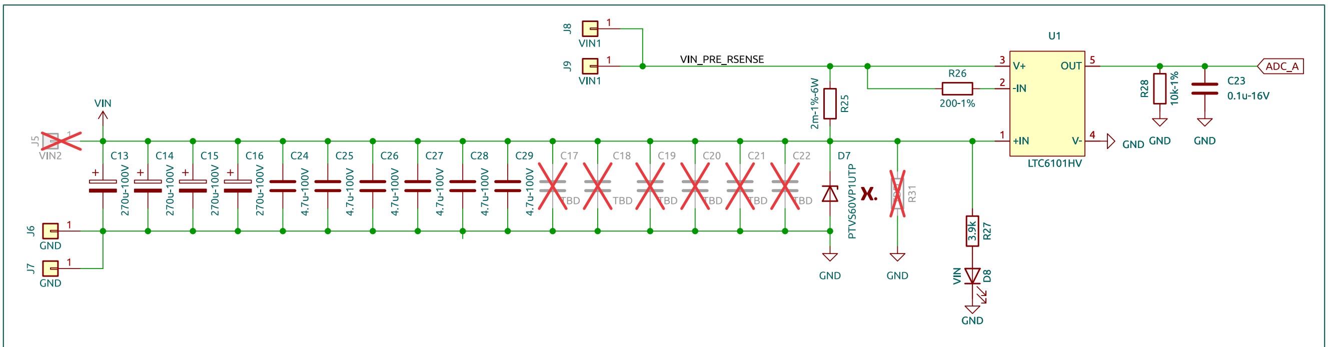


Fig. 5. 3-phase inverter board; high-side current monitoring

Fig. 5 shows the high-side current monitoring circuit. U1 (LTC6101HV) is a high-side current monitor IC that senses current into the 3-phase inverter board though a 2 mΩ shunt resistor. The ratio of R28 to R26 determine the gate of the current monitoring circuit and is by default 50 for the values used in the design. This is adequate to allow current sensing up to 50 A, however, the downside to the large range is lower accuracy for applications with lower current requirements. It is best to optimize the gain by changing R28 to provide the maximum accuracy dependent on the required maximum current.

As the current monitoring circuit cannot be used up to 50 A with the default current sense resistor, if the user wishes to use the current shunt monitor, voltage must be applied at VIN1. For higher currents or to bypass the current shunt monitoring circuit, apply voltage through the VIN (or VIN2) net, applying voltage through the VIN (or VIN2) net will bypass the current shunt monitoring circuit. The output of U2 is taken to the interface connector which is covered in Section 3.3.

The 3-phase inverter board includes four 270 µF aluminum electrolytic capacitors and six 4.7 uF ceramic capacitors for VIN, with additional footprints to accommodate more on the bottom of the board if required. There is also a Nexperia TVS, PTVS60VP1UTP, (D7) which, with a 60 V standoff voltage, provides over-voltage protection.

Note: there is a common GND or return path shared by the entirety of the 3-phase inverter PCB and has no intended method of separation. As a result, individual phase current monitoring is not supported. However, the motor controller board supports up to three current monitoring signals and a different version of this board could be used which accommodates multiple phase current monitoring sensors, if required.

3.2. Half-bridge MOSFETs

The 3-phase inverter PCB includes 6 NextPower 100 V, 4.3 mOhm, 120 A, N-channel MOSFETs (PSMN3R9-100YSF) in the LFPAK56E package, arranged as 3 half-bridges. These half-bridges are used to drive the 3 phases of a Brushless DC motor. Each phase contains a high-side

MOSFET and a low-side MOSFET, see Fig. 6. The outputs of the half-bridges are referred to as Phase U, Phase V and Phase W, see Table 2.

Table 2. Half-bridge MOSFET designations

Phase	Location	Designator
Phase U	High-side	Q1
	Low-side	Q2
Phase V	High-side	Q3
	Low-side	Q4
Phase W	High-side	Q5
	Low-side	Q6

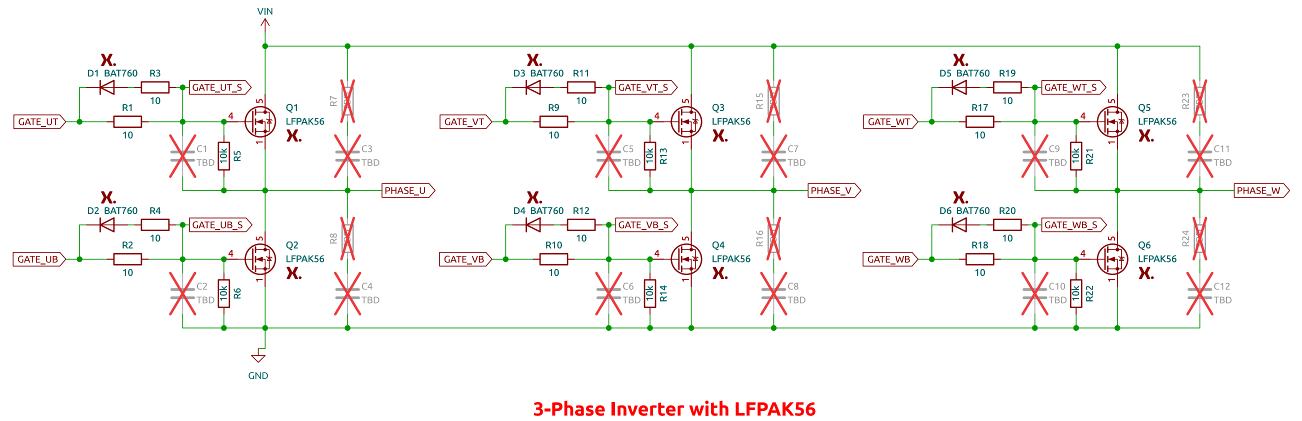


Fig. 6. Half-bridge MOSFET pairs

Each MOSFET uses a universal PCB footprint that will accept most 5 mm x 6 mm package power MOSFETs. If using packages other than LFPAK56 or LFPAK56E, please ensure pin-out is compatible.

There are resistors connected from gate to source for each MOSFET. These resistors act as protection to establish a known relationship between gate and source to prevent unwanted turn-on. They are R5, R13, and R21 for the high-side MOSFETs and R6, R14, and R22 for the low-side MOSFETs.

The unpopulated series R and C between the drain and source of each MOSFET are RC snubbers. RC snubbers suppress high-frequency oscillations associated with reverse recovery effects in power semiconductor applications. R7 and C3, R15 and C7, R23 and C11 are the high-side RC snubbers. In addition, R8 and C4, R16 and C8, and R23 and C12 for the low-side RC snubbers. Information for designing and calculating optimal RC snubber values can be found in the MOSFET & GaN FET Application Handbook.

There are unpopulated capacitors between the gate and source of each MOSFET. These capacitors give the designer the option to increase the rise and fall times for each MOSFET, which makes each MOSFET switch states slower. These values can be tuned in combination with the gate resistors discussed in the Section 4.2.

Each phase leads to terminal block (J4), as shown in Fig. 7, and screw top connectors (J1, J2, and J3 for phase U, V, and W; respectively). This is the intended area to connect the motor.

Note: take note of motor phase wire and the labeled phase node: PHASE_U, PHASE_V or PHASE_W. This connection is very important for motors with integrated sensor, where the phase and position sensor must be correlated.

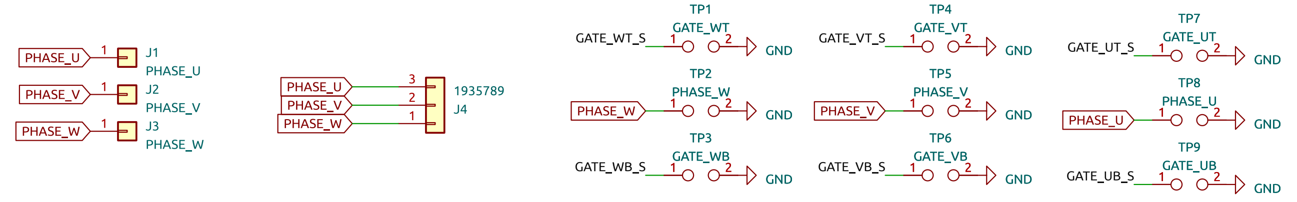


Fig. 7. Motor phase terminal block

3.3. Interface Connector

The interface connector (J11 and J12) is the signal interface between the 3-phase inverter board and the controller board, see Fig. 8. As a result, most MOSFET gate, and drain or source connections are used as IOs or monitoring. In addition, the 3-phase inverter board current consumption and IO reference voltage are also connected.

There is a main supply voltage interface connector (J10) for VIN that is used to power the motor controller board. This will go to the Buck converter stage on the motor controller board described in Section 4.1.

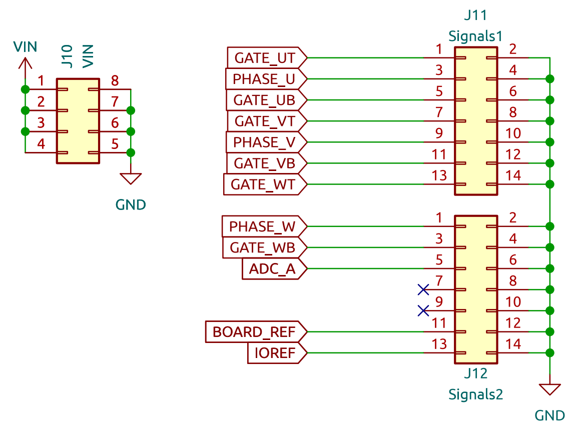


Fig. 8. Interface connector

Table 3. J10 / J11 / J12 VIN interface connectors

Net name	Pin number	Description
J10		
VIN	1 - 4	Main input supply voltage (VIN) that supplies the motor controller board
GND	5 - 8	Return path of the main input supply voltage (GND) from the motor controller board
J11		
GATE_UT	1	High side gate voltage for phase U
PHASE_U	3	Switch node or motor phase voltage of phase U
GATE_UB	5	Low side gate voltage for phase U
GATE_VT	7	High side gate voltage for phase V
PHASE_V	9	Switch node or motor phase voltage of phase V
GATE_VB	11	Low side gate voltage for phase V
GATE_WT	13	High side gate voltage for phase W
GND	2, 4, 6, 8, 10, 12, 14	GND or return path

Net name	Pin number	Description
J12		
PHASE_W	1	Switch node or motor phase voltage of phase W
GATE_WB	3	Low side gate voltage for phase W
CURRENT	5	Output voltage from high-side current monitor
NA	7, 9	Not used
BOARD_REF	11	Voltage derived from IOREF that is sensed by development board
IOREF	13	IO reference voltage provided from development board
GND	2, 4, 6, 8, 10, 12, 14	GND or return path

3.4. Probing signals

There are test points available to probe most signals on the board which have been designed to allow use with different probe types and tips. By default, they are populated with loop terminal for convenient probing using probes with hook tips, as show in Fig. 9.

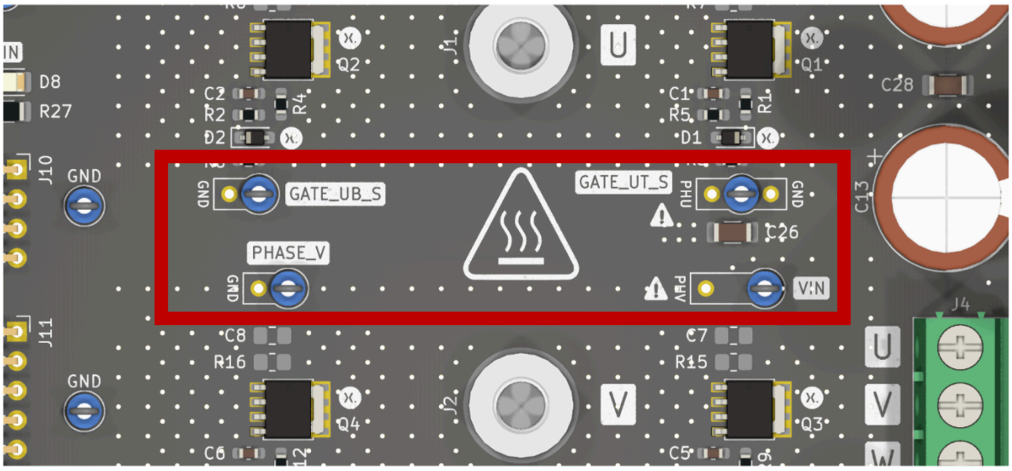


Fig. 9. 3-phase inverter board with loop terminals populated for test points

Alternatively, they can be left empty and used with probes with ground springs for better signal integrity as shown in Fig. 10, or be populated with 2.54 mm and 5.08 mm pin headers for use with differential probes as in Fig. 11.

Some signals allow reference signals other than ground e.g. in Fig. 11, GATE_UT_S can be referenced to either PHU or GND.

These are denoted using the  symbol.

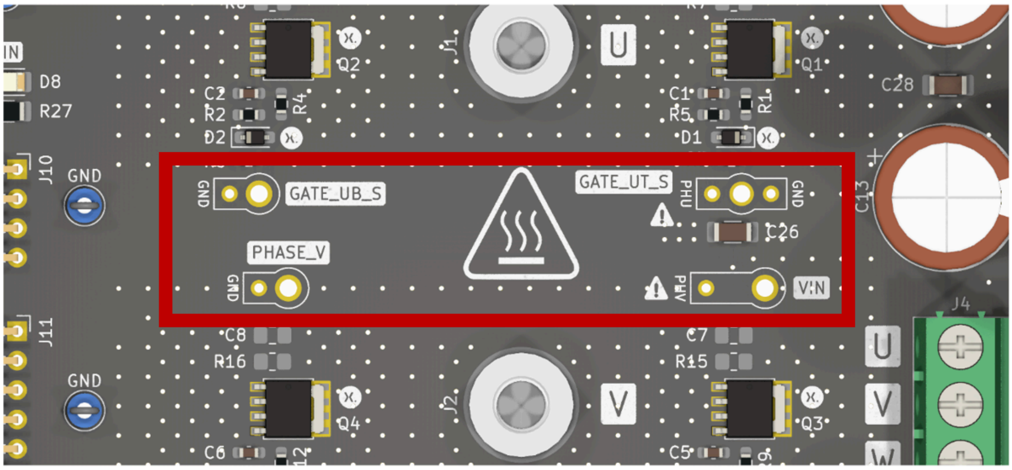


Fig. 10. 3-phase inverter board with no components populated for test points

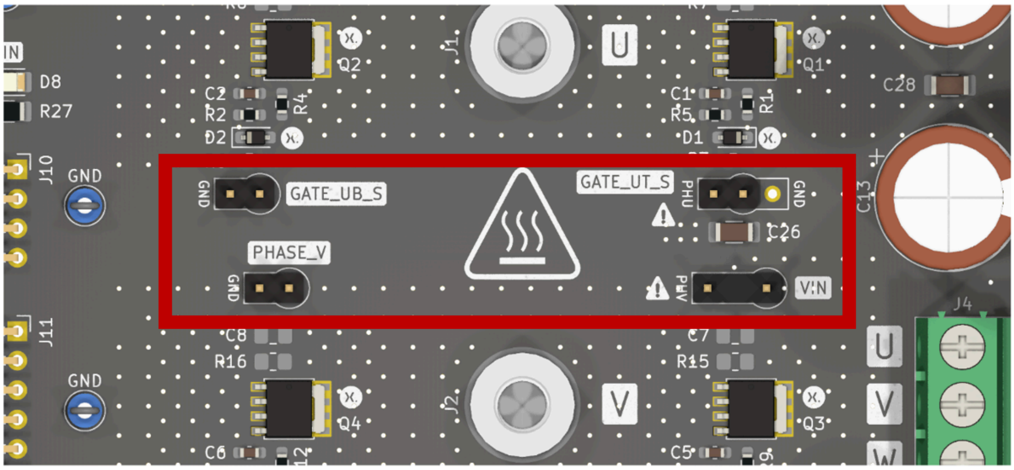


Fig. 11. 3-phase inverter board with 2.54 mm and 5.08 mm pin headers populated for test points

Warning: Test points with the ⚠ symbol are to be referenced on the board to signals other than common ground. These are meant to be used with differential probes. Do not connect the return path for any passive probes to the reference signal here as this can lead to equipment damage.

4. Motor controller board

The motor controller board connects to the development board and to the 3-phase inverter board, see Fig. 12, it features:

- DC-to-DC converter to generate VDD
- Gate driver for MOSFETs
- Position sensor inputs
- Development board or microcontroller board connections
- Interface signals to the 3-phase inverter board
- Back-emf zero-crossing detection circuit
- User motor control inputs
- MUX, fault and over-voltage indicator LEDs

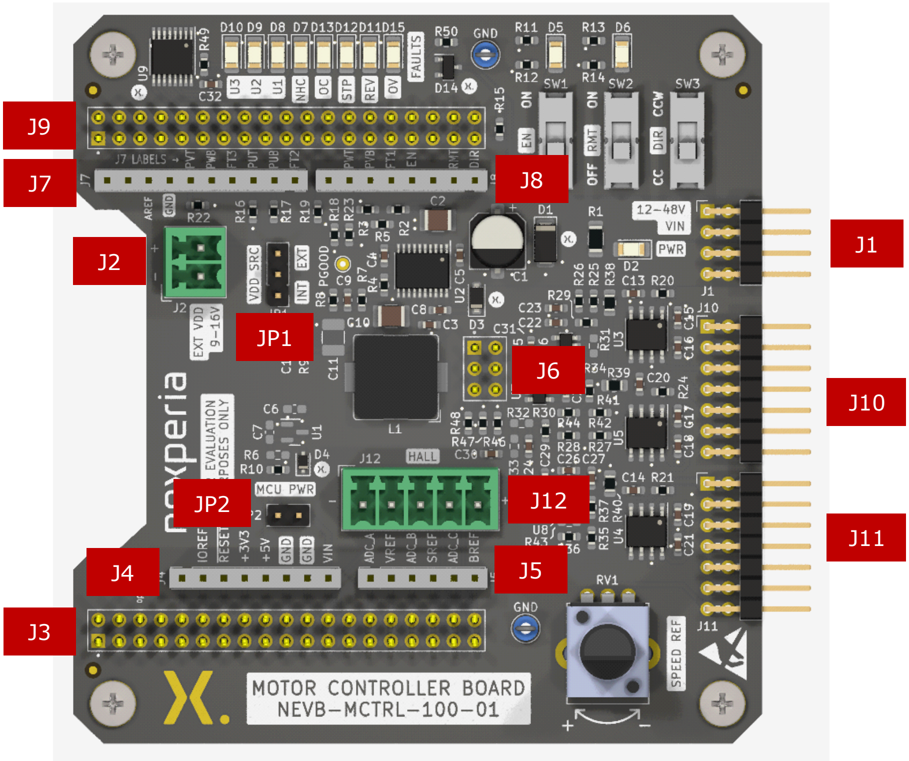


Fig. 12. Motor controller board connector locations

4.1. DC-to-DC converter to generate VDD

The controller board has an on-board DC-to-DC step-down buck regulator that will supply power for the entire controller board, and for development board if selected, see Fig. 13. The input to the DC-to-DC regulator is supplied through the VIN connection (J1) from the 3-phase inverter board, which is discussed in Section 3.3. VIN is routed to the LT8630, which is a current mode PWM step-down DC-to-DC converter with internal synchronous switches that provide current for output loads up to 0.6 A.

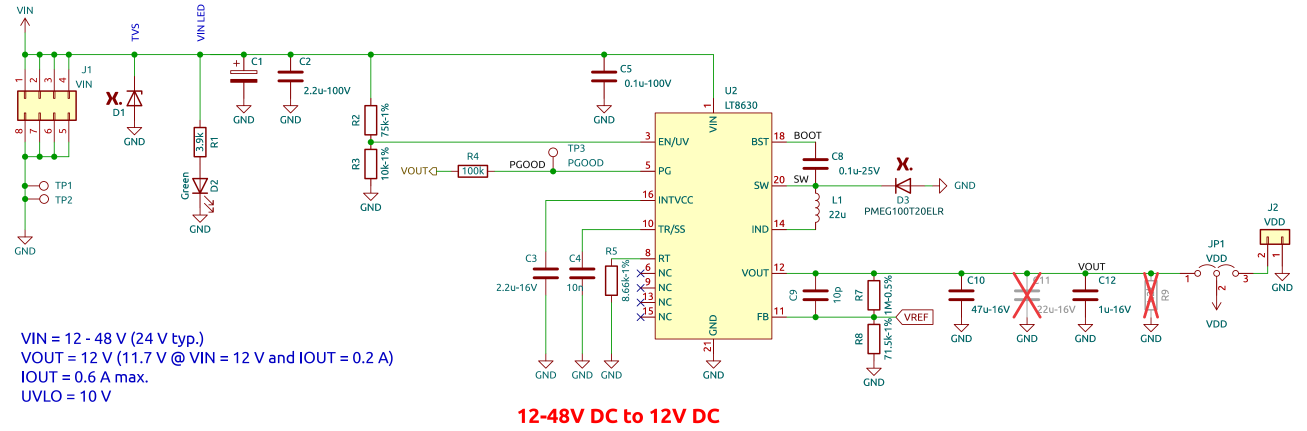
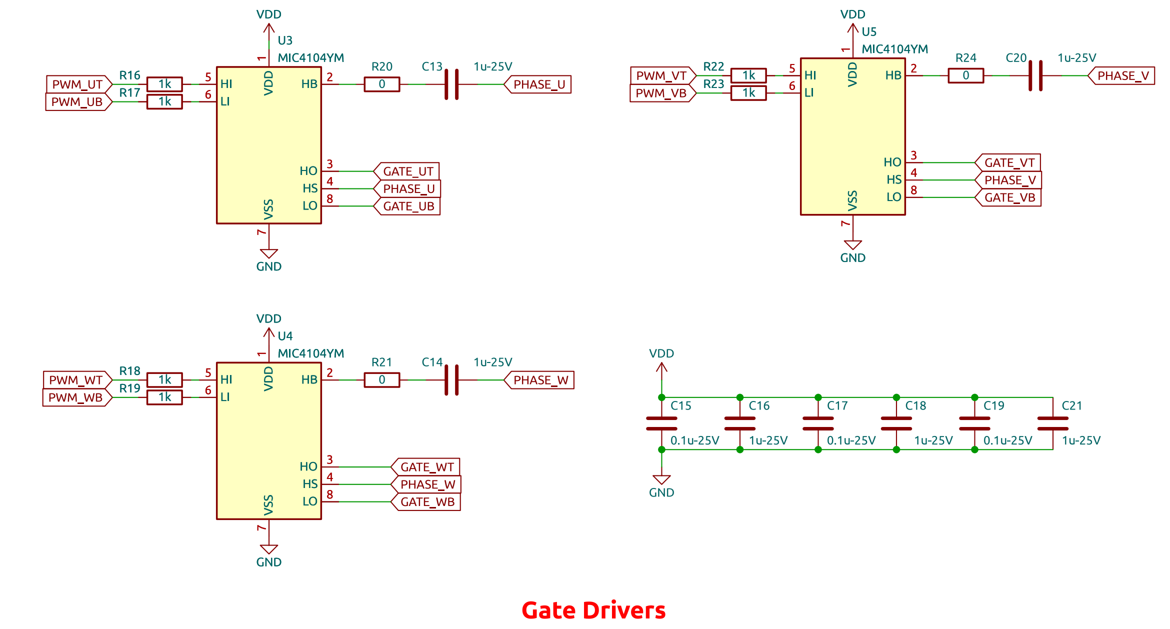


Fig. 13. DC-to-DC step-down regulator

Note: if VIN is less than 12 V an external supply is required and JP1 should be set to position 2 - 3, so connector J2 is used to supply VDD from an external source, instead of the DC-to-DC converter. VDD must be 9 - 16 V, but can be extended to 5.5 - 16 V if using an alternative gate driver, see Fig. 14.

4.2. Gate driver for MOSFETs

The motor controller board contains the gate drivers used to switch the MOSFETs on the 3-phase inverter board. The inputs to the gate drivers are Pulse Width Modulation (PWM) signals that come from the MCU. Each gate driver controls the high-side (PWM_xT) and low-side (PWM_xB) MOSFETs for each phase.



Gate driver IC options:

MIC4104YM for TTL logic, 9 - 16 V supply voltage, 2 A source / 2 A sink

MIC4103YM for CMOS logic, 9 - 16 V supply voltage, 3 A source / 2 A sink

MIC4605-1YM for TTL logic, 5.5 - 16 V supply voltage, 1 A source / 1 A sink

Fig. 14. Gate driver circuit

4.3. Position sensor inputs

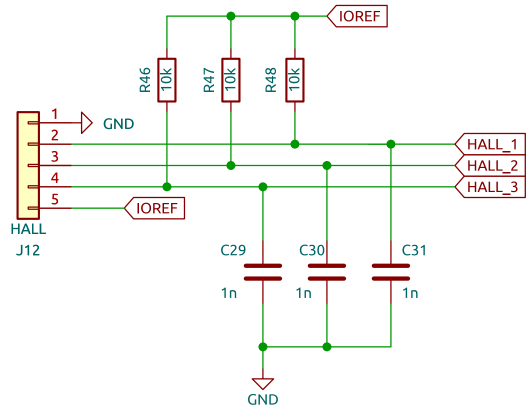


Fig. 15. Hall-effect sensor input connections

The motor controller board can work with different types of position sensors; seeTable 4:

- Hall-effect sensors, with 3 output signals
- Incremental encoders, with 2 output signals
- Any encoder that supports SPI

Note: The firmware provided only supports sensor-ed control with Hall-effect sensors.

Table 4. Hall-effect input connector; J12

Pin name	Pin number	Description
GND	1	Return path or GND for position sensor
HALL_1	2	Hall-effects: Input Hall-effect signal that correlates with phase U. Incremental encoder: Input either quadrature outputs A or B. SPI supported sensor: Connect SPI Clock (SCK) signal [1].
HALL_2	3	Hall-effects: Input Hall-effect signal that correlates with phase V. Incremental encoder: Input either quadrature outputs A or B. SPI supported sensor: Connect SPI Master out Slave in (MOSI) signal [1].
HALL_3	4	Hall-effects: Input Hall-effect signal that correlates with phase W. Incremental encoder: Input either quadrature outputs A or B. SPI supported sensor: Connect SPI Master in Slave out (MISO) signal [1].
IOREF	5	Supply voltage for Hall-effect sensors. 5 V typical and is sourced from the development board.

[1] Chip select (CS) pin must be chosen any available pins from J3 - J9. This pin is not available on the position sensor input connector, J11. Reset pin can be used from J3, J4 or J6.

4.4. Development board (microcontroller) connections

J3 and J9 can be used to extend support to other microcontroller boards.

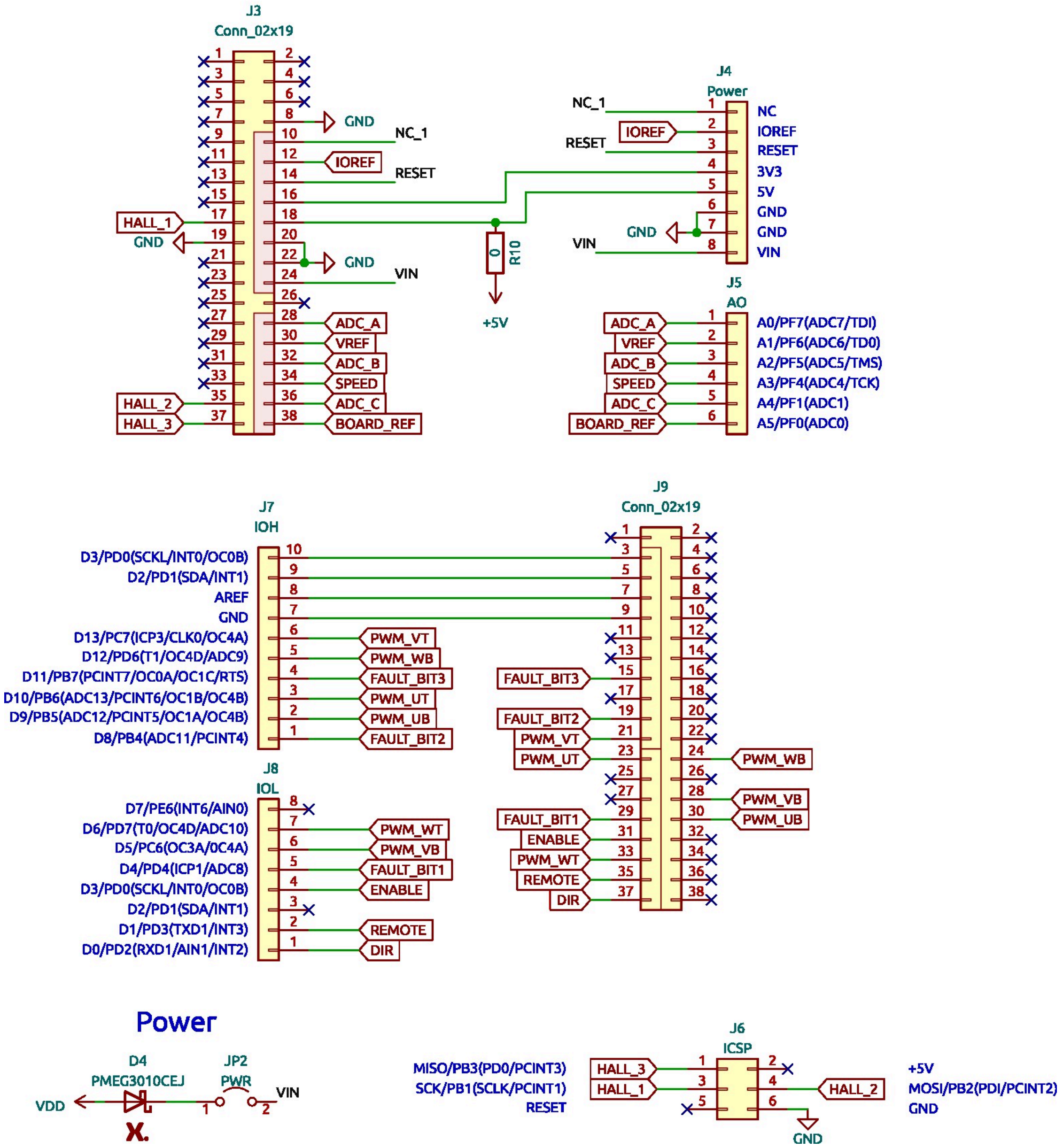


Fig. 16. Connections to development board (e.g. Leonardo R3 development board)

Table 5 lists the power connections (J4) between the motor controller board and the development board (e.g. Leonardo R3 development board).

Table 5. Development board power connector; J4

Pin name	Pin number	Description
NC_1	1	This signal is connected to J3[10] and is not used
IOREF	2	IOREF is sourced from the development board and is 5 V by default for the Leonardo R3 development board
$\overline{\text{RESET}}$	3	$\overline{\text{RESET}}$ is a digital IO that can be used to send a reset signal
3V3	4	3V3 sourced from the development board and is 3.3 V by default. 3.3 V is not used
5V	5	5V is sourced from the development board and is 5 V board by default. 5V can be used to source the +5V net
GND	6, 7	GND is the return path or GND for the development board
VIN	8	VIN is MCU_VIN and is usually supplied from VDD. See D4 and JP2 in Fig. 16

Table 6 lists the ADC signal connections (J5) between the motor controller board and the development board (e.g. Leonardo R3 development board).

Table 6. Development board ADC signal connector; J5 (AO)

Net name	Pin number	Description
ADC_A	1	ADC_A is an ADC analog input on the development board and is used as the current sense input for the 3-phase inverter board (NEVB-3INV-001-01)
VREF	2	VREF is the reference voltage on the buck DC-to-DC converter, and fed to an ADC input on the development board
ADC_B	3	ADC_B is an ADC analog input on the development board and is not used
SPEED	4	SPEED is the output of the motor speed control potentiometer (RV1)
ADC_C	5	ADC_C is an ADC analog input on the development board and is not used
BOARD_REF	6	BOARD_REF is an ADC analog input on the development board. The signal is derived on the 3-phase inverter board

Table 7 lists the fault status and MOSFET gate driver (PWM) signal connections (J7) between the motor controller board and the development board (e.g. Leonardo R3 development board).

Table 7. Development board fault status and MOSFET gate driver signal connector; J7 (IOH)

Net name	Pin number	Description
FAULT_BIT2	1	FAULT_BIT2 is a digital output on the development board to the MUX
PWM_UB	2	PWM_UB is the low-side MOSFET (PWM) gate signal for phase U
PWM_UT	3	PWM_UT is the high-side MOSFET (PWM) gate signal for phase U
FAULT_BIT3	4	FAULT_BIT3 is a digital output on the development board to the MUX
PWM_WB	5	PWM_WB is the low-side MOSFET (PWM) gate signal for phase W
PWM_VT	6	PWM_VT is the high-side MOSFET (PWM) gate signal for phase V
-	7	This GND is connected to J9 [9] and is not used
AREF	8	This signal is connected to J9 [7] and not used
D2/PD1(SDA/INT1)	9	This signal is connected to J9 [5] and is not used
D3/PD0(SCKL/ INT0/OC0B)	10	This signal is connected to J9 [3] and is not used

Table 8 lists the further connections (J7) between the motor controller board and the development board (e.g. Leonardo R3 development board).

Table 8. Development board motor direction and MOSFET gate driver signal connector; J8 (IOL)

Net name	Pin number	Description
DIR	1	DIR is a digital input used to control the rotor motion direction
REMOTE	2	REMOTE is a digital input used to enable remote software control
-	3	No connection
ENABLE	4	ENABLE is a digital input used to allow the motor to start communication
FAULT_BIT1	5	FAULT_BIT1 is a digital output on the development board to the MUX
PWM_VB	6	PWM_VB is the low-side MOSFET, PWM gate signal for phase V
PWM_WT	7	PWM_WT is the high-side MOSFET, PWM gate signal for phase W
-	8	No connection

Table 9 and Table 10 lists the further connections (J3 and J9) between the motor controller board and alternative MCU development boards compatible with the Nucleo form factor.

Table 9. Connection for alternative MCU development boards (e.g. Nucleo); J3

Net name	Pin number	Description
-	1 - 7, 9, 11, 13, 15, 21, 23, 25 - 27, 29, 31, 33	No connection
GND	8	GND is the return path, negative supply, or GND
NC_1	10	This signal is connected to J4[1] and is not used
IOREF	12	IOREF is sourced from the development board and is 5 V by default
RESET	14	RESET is a digital IO that can be used to send a RESET signal
3V3	16	3V3 sourced from the development board and 3.3 V by default. 3V3 is not used
HALL_1	17	Input Hall-effect sensor that correlates with phase U
5V	18	5V is sourced from the development board and is 5V board by default. 5V can be used to source the +5V net
GND	19, 20, 22	GND is the return path, negative supply, or GND
VIN	24	VIN is MCU_VIN and is usually supplied from VDD. See D4 and JP2 in Fig. 16
ADC_A	28	ADC_A is an ADC analog input on the development board. It is not used
VREF	30	VREF is the reference voltage on the Buck DC-to-DC converter. It is fed to an ADC input on the development board
ADC_B	32	ADC_B is an ADC analog input on the development board. It is not used
SPEED	34	SPEED is the output of the motor speed control potentiometer (RV1)
HALL_2	35	Input Hall-effect sensor that correlates with phase V
ADC_C	36	ADC_C is an ADC analog input on the development board. It is not used
HALL_3	37	Input Hall-effect sensor that correlates with phase W
BOARD_REF	38	BOARD_REF is an ADC analog input on the development board. The signal is derived on the 3-phase inverter board

Table 10. Connection for alternative MCU development boards (e.g. Nucleo); J9

Net name	Pin number	Description
-	1, 2, 4, 6, 8, 10 -14, 16 - 18, 20, 22, 25 - 27, 32, 34, 36, 38	This connection is not used
D3/PD0(SCKL/ INT0/OC0B)	3	This signal is connected to J7[10] and is not used
D2/PD1(SDA/INT1)	5	This signal is connected to J7[9] and is not used
AREF	7	This signal is connected to J7[8] and is not used
-	9	This GND is connected to J7[7] and is not used
FAULT_BIT3	15	FAULT_BIT3 is a digital output on the development board to the MUX
FAULT_BIT2	19	FAULT_BIT2 is a digital output on the development board to the MUX
PWM_VT	21	PWM_VT is the high side MOSFET, PWM gate signal for Phase V
PWM_UT	23	PWM_UT is the high-side MOSFET, PWM gate signal for phase U
PWM_WB	24	PWM_WB is the low-side MOSFET, PWM gate signal for phase W
PWM_VB	28	PWM_VB is the low-side MOSFET, PWM gate signal for phase V
FAULT_BIT1	29	FAULT_BIT1 is a digital output on the development board to the MUX
PWM_UB	30	PWM_UB is the low-side MOSFET, PWM gate signal for phase U
ENABLE	31	ENABLE is a digital input used to allow the motor to start communication
PWM_WT	33	PWM_WT is the high-side MOSFET, PWM gate signal for phase W
REMOTE	35	REMOTE is a digital input used to enable remote software control
DIR	37	DIR is a digital input used to control the rotor motion direction

4.5. Interface signals to the 3-phase inverter board

The interface connectors (J10 and J11) are the signal interface between the 3-phase inverter board and the controller board, see Section 4.5. As a result, most MOSFET gate, and drain or source connections are used as IO or monitoring. In addition, 3-phase inverter board current consumption and IO reference voltage are connected as well.

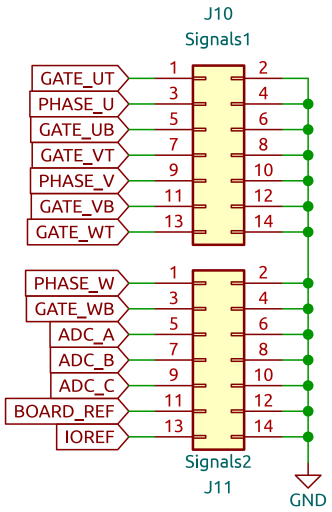


Fig. 17. Interface signals to the 3-phase inverter board

Table 11. interface connectors; J10 and J11

Net name	Pin number	Description
J10		
GATE_UT	1	High-side gate voltage for phase U
PHASE_U	3	Switch node or motor phase voltage of phase U
GATE_UB	5	Low-side gate voltage for phase U
GATE_VT	7	Low-side gate voltage for phase V
PHASE_V	9	Switch node or motor phase voltage of phase V
GATE_VB	11	Low-side gate voltage for phase V
GATE_WT	13	High-side gate voltage for phase W
GND	2, 4, 6, 8, 10, 12, 14	GND or return path
J11		
PHASE_W	1	Switch node or motor phase voltage of phase U
GATE_WB	3	Low-side gate voltage for phase U
CURRENT	5	Output voltage from high-side current monitor
-	7 - 9	Not used
BOARD_REF	11	Voltage derived from IOREF that is sensed by development board
IOREF	13	IO reference voltage provided from development board
GND	2, 4, 6, 8, 10, 12, 14	GND or return path

4.6. Back-EMF zero-crossing detection circuit

The BLDC back-EMF zero-crossing detection circuit uses a voltage divider for each phase voltage to step down the motor's back-EMF, see Fig. 18, which is then fed to a comparator. The reference voltage for each phase comparator is measured by creating a virtual center tap or neutral. Each block has RC filtering to clean up the signals. This allows the user to develop sensor-less motor control algorithms.

To use the detection circuit:

- R33, R34 and R45 must be shorted. The position sensor input, J12, can no longer be used to connect any sensors in this configuration.
- Adjust any values for the components in the voltage divider or RC filter to fit the target application.
- Implement the firmware for sensor-less motor control.

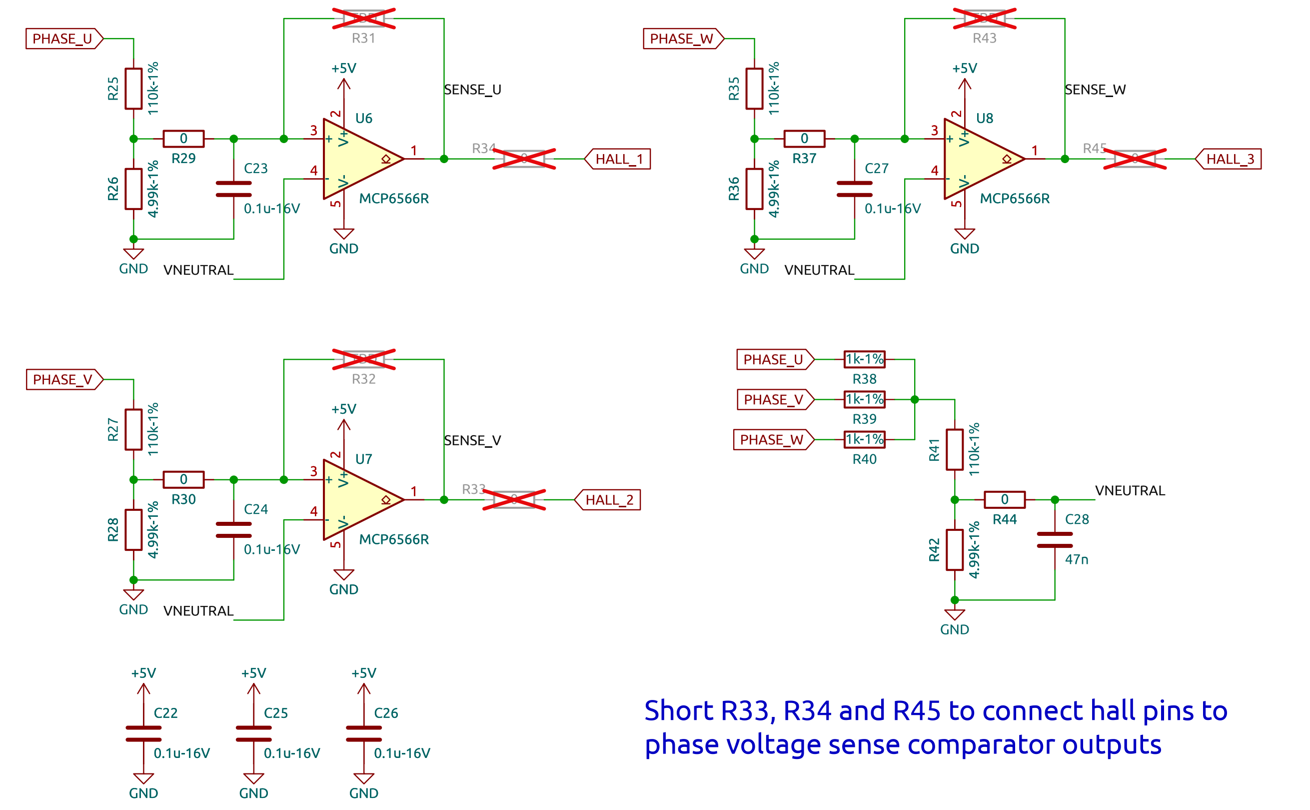


Fig. 18. Phase voltage sense circuit

4.7. Motor control board user inputs

The motor controller board supports 4 user inputs, see Fig. 19,:

- **SPEED** - motor speed, controlled via RV1
- **ENABLE** - motor enable, selected via SW1
- **REMOTE** - remote software control, enabled via SW2
- **DIR** - motor direction control, selected via SW3

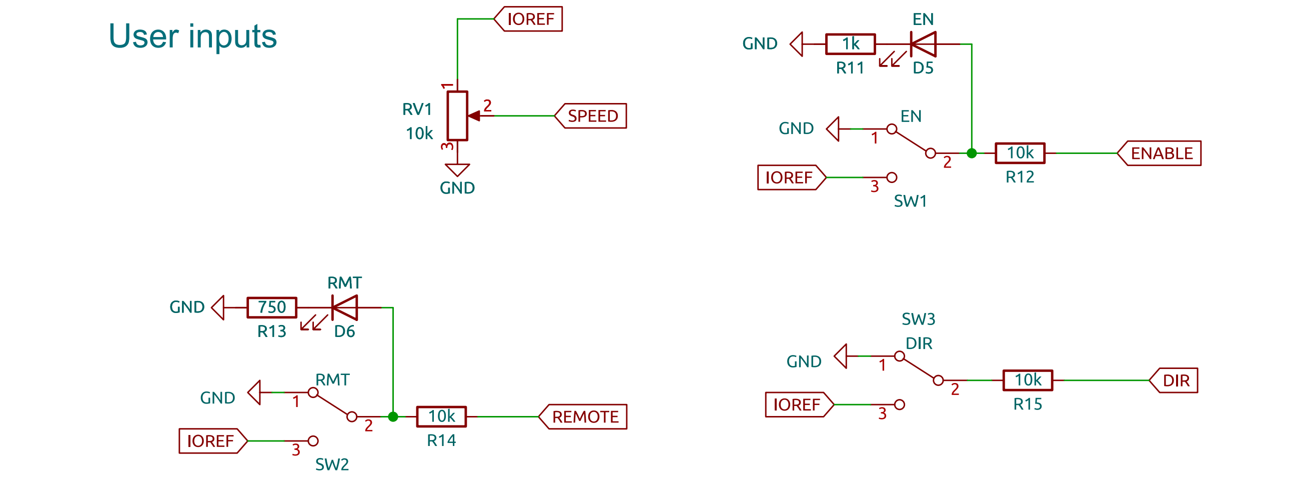


Fig. 19. Motor control board user inputs

4.8. MUX, fault and over-voltage LEDs

The motor controller board includes LEDs to indicate fault conditions, see Fig. 20.

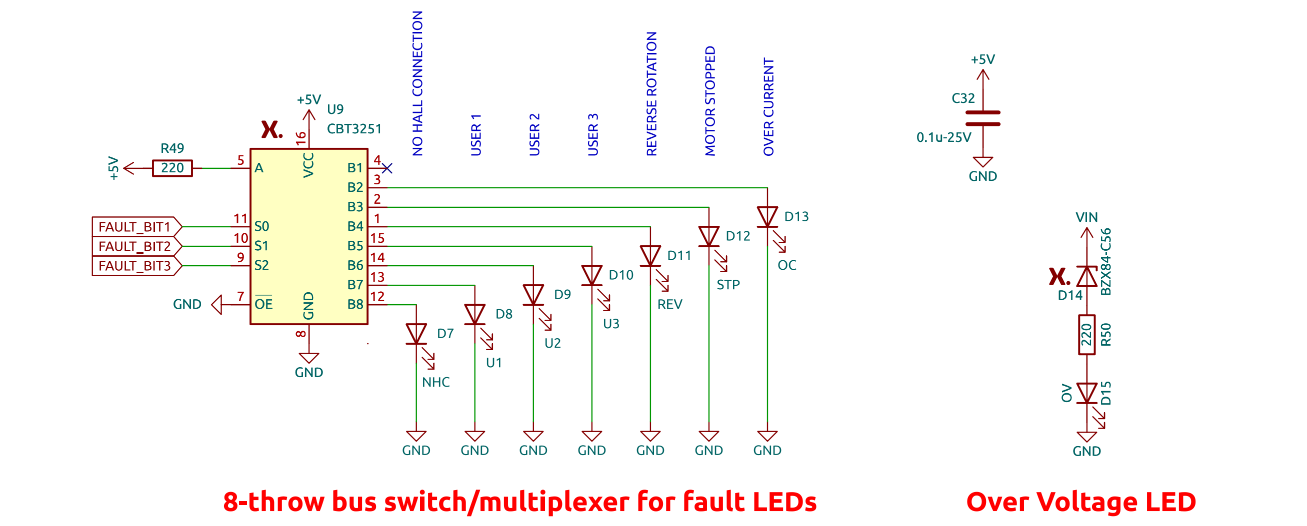


Fig. 20. MUX, fault LEDs, and over-voltage LEDs

Fault bits 1, 2, and 3 are inputs to a Nexperia multiplexer IC (MUX), CBT3251, The multiplexer switches the +5 V supply to activate LEDs, D7 to D13, according to the input bits. These bits control the following fault indicator LEDs as shown in Table 12:

Table 12. Fault status LEDs

Fault	Fault bits (b3b2b1)	Description
-	000	Not connected, not a valid state
Over-current (D13)	001	Current warning limit in software has been exceeded by current sense on 3-phase inverter board. If User LEDs 1-3 are also on, current error limit has been exceeded and system has shutdown (latching)
Motor stopped (D12)	010	Motor has stopped rotating, usually from stall
Reverse rotation (D11)	011	Motor is spinning in reverse compared to intended direction
User LED 3 (D10)	100	User defineable fault LEDs which can be used to show custom error codes. If all User LEDs are on, it indicated a system shutdown (latching) due to a major error
User LED 2 (D9)	101	
User LED 1 (D8)	110	
No Hall-effect sensor	111	There is a missing Hall-effect sensor connection on the motor controller board

Over-voltage of VIN is indicated by D15.

5. Default settings

The default configuration of the BLDC kit is listed below:

- VIN = 24 V
- Motor current limit = 2.5 A
- The buck converter input voltage is supplied by the 3-phase inverter board
- Main supply for the motor controller board, VDD, is controlled by the output of the buck converter
- The motor controller board supplies power to the development board via MCU_VIN
- Hall-effect sensor power is supplied from the development board through IOREF

5.1. Default jumper settings

There are 2 jumpers fitted on the motor control board by default, (see Fig. 21):

- **JP1** - jumper fitted to pins 1 and 2. This selects the main supply for the motor controller board, VDD, to be controlled by the output of the buck converter (INT)
- **JP2** - jumper fitted. This selects the main supply for the development board, MCU_VIN, to be supplied by the motor controller board.

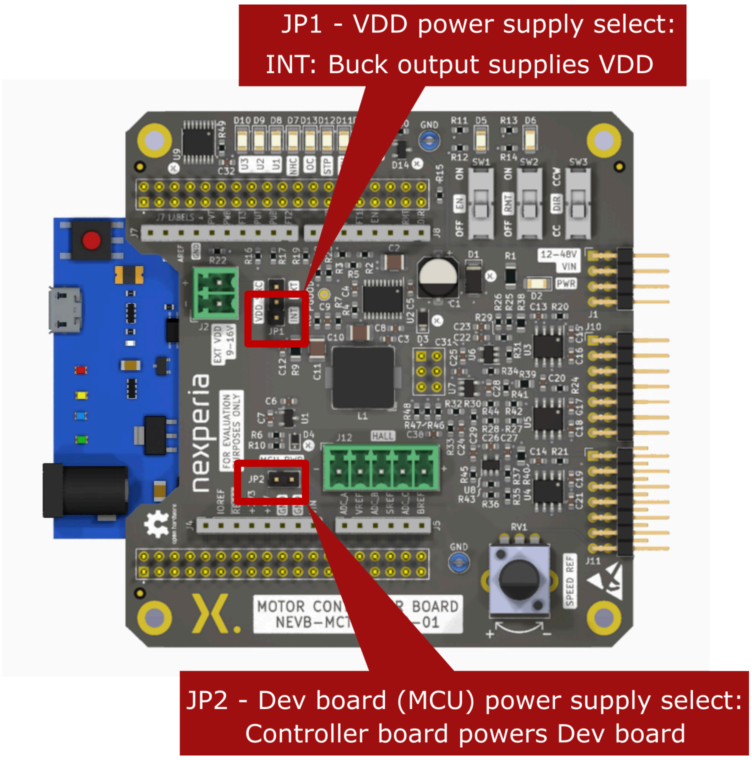


Fig. 21. Motor control board; default jumper positions

For further details see Section 4.1 and Section 4.4.

5.2. Default motor controls

There are 4 default controls settings on the motor control board, 3 switches and 1 potentiometer, (see Fig. 22):

- **SW1** - Motor Enable (EN), between 2 and 3, toward the center of the board. In this position the motor is disabled
- **SW2** - Remote select (RMT), between 2 and 3, toward the center of the board. In this position remote software control is disabled
- **SW3** - Direction (DIR), between 2 and 3, toward the center of the board. In this position the rotor will spin clockwise (CC)
- **RV1** - Motor Control (SPEED REF), RV1 rotated fully anti-clockwise. In this position, the speed of the motor will be 0.

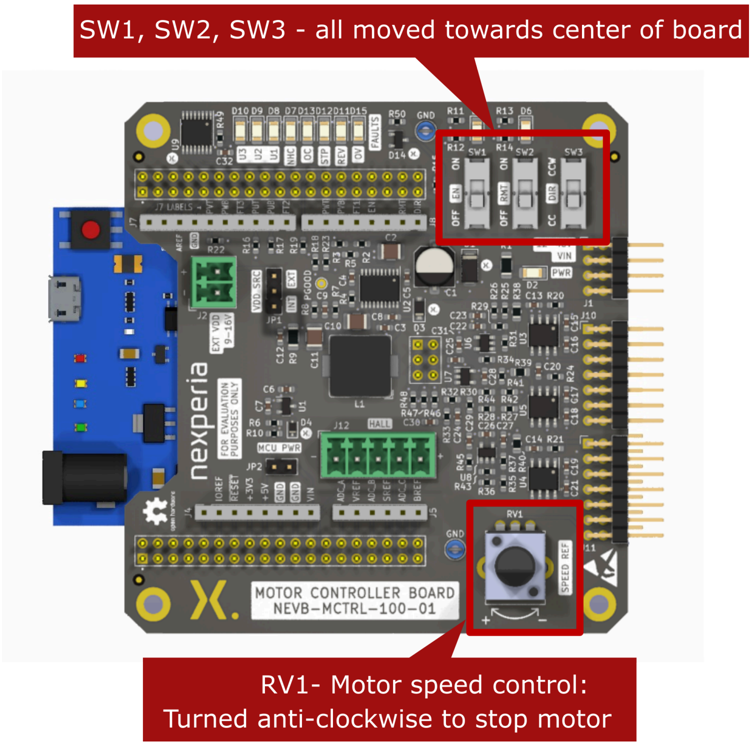


Fig. 22. Default motor controls and speed control position

More information about these controls can be found in Section 4.7.

5.3. Connecting the BLDC kit

Fig. 23 shows the motor controller board, Leonardo R3 development board and 3-phase inverter board connected together. It is recommended to have the development board underneath the motor controller board. Double check the configuration and ensure that the Micro USB connector is exposed.

Table 13 lists the power and data connections between the motor controller board and the 3-phase inverter board. The receptacles and plugs only allow these boards to connect in one specific orientation.

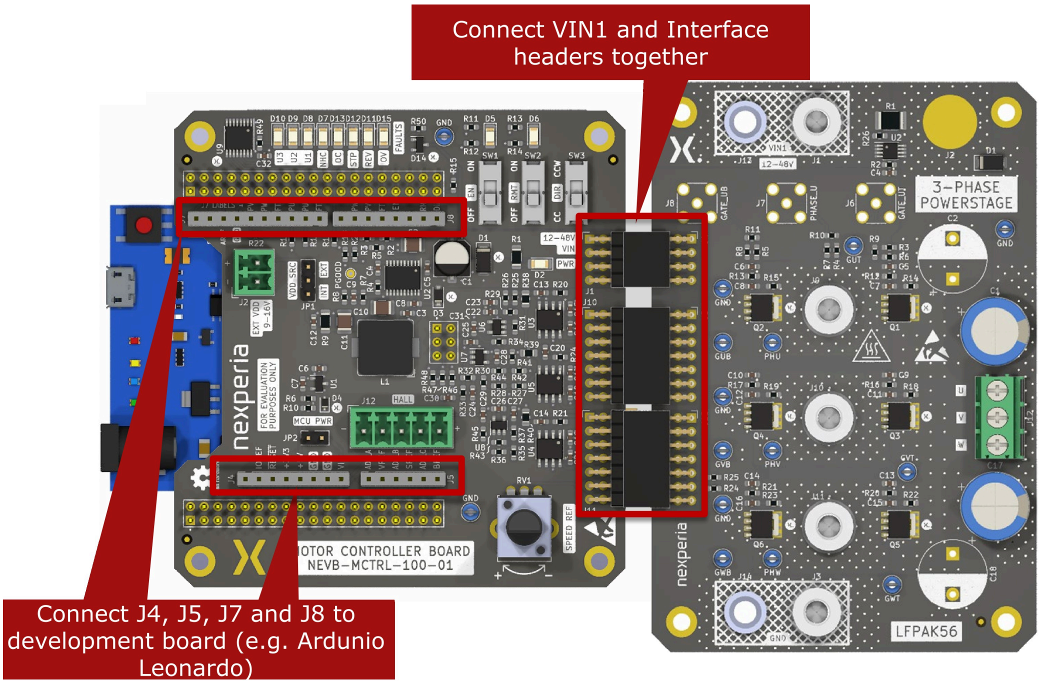


Fig. 23. Connecting the BLDC kit boards

Table 13. Motor controller to 3-phase inverter board interface connectors

Motor controller board (plug)	3-phase inverter board (receptacle)	Description
J1 (VIN1)	J10 (VIN)	This is the main power supply from the 3-phase inverter board that supplies the motor controller board
J10 (Signals1)	J11 (Signals1)	These connectors hold most of the half-bridge gate and phase voltage signals
J11 (Signals2)	J12 (Signals2)	This connects hold the sensing signals, reference voltages, and some phase W signals

More information about these headers can be found in Section 3.3, Section 4.4, and Section 4.5.

5.4. Connecting the 3-phase BLDC motor

The 3-phase BLDC motor, 42BLS40-24-01, provided in the kit has 8 wires. These wires correlate to the Hall-effect sensors and motor phases; see Fig. 24. Prior to connecting the wires:

- Install the 5 x 1 plug connector provided in the kit into J12 for the Hall-effect sensor wire inputs
- Obtain the flat head screwdriver from the kit

The recommended location to connect the motor phase wires is terminal block J11.

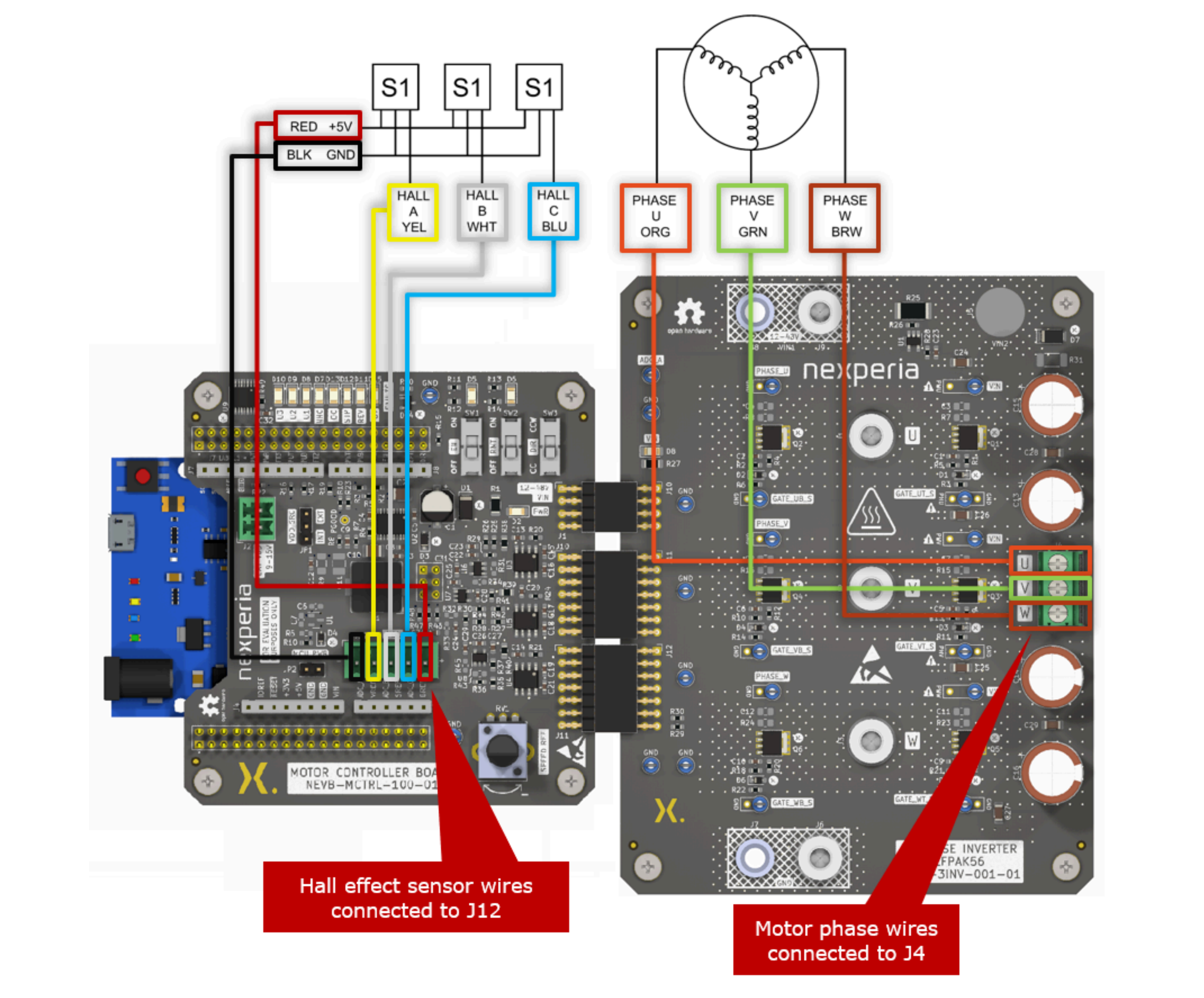


Fig. 24. Hall sensor and motor phase wire connections

5.5. Default motor controller board voltages

Table 14 lists the nominal power supply voltages upon successful power up:

Table 14. Default motor controller board voltages

Voltage supply	Probe Location	Nominal voltage
VOUT	Pin 1 of JP1	12 V
VDD	Pin 2 of JP1	12 V
VIN_MCU	Pin 2 of JP2	VDD
IOREF	Pin 12 of J3 / Pin 2 of J4	5 V
+5V	Pin 18 of J3 / Pin 5 of J4	5 V
BOARD_REF (BREF)	Pin 18 of J3 / Pin 6 of J5	1 V
PGOOD	PGOOD	VDD

6. BLDC kit software

The firmware provided with this kit allows trapezoidal control of Brushless DC (BLDC) motors using Hall-effect sensors specifically using the Leonardo R3 development board or the ATMEGA 32u4 microcontroller, which is a platform widely recognized under the Arduino™ Leonardo nomenclature.

The firmware code is set up to be used with the Arduino IDE v1 or v2 and alternatively Microsoft Visual Studio Code with the Arduino extension installed. To learn more about the Leonardo hardware and software tools, go to Arduino's getting started page.

The latest version of the firmware for trapezoidal control of BLDC motors using Hall-effect sensors (NEVC-MCTRL-100-t01), is pre-uploaded to the Leonardo R3 development board provided with the kit. Firmware version NEVC-MCTRL-100-t01-1.0.0 comes with the following features:

- Trapezoidal control of Brushless DC (BLDC) motors using Hall-effect sensors
- Unipolar PWM
- Control MOSFET switching frequencies from 7,813 Hz to 100,000 Hz (can be overridden to extend upper limit)
- Control dead-time from 350 ns to 1875 ns. (can be overridden to extend lower limit)
- Control duty cycle (0.01 – 0.31 % depending on frequency) directly while in open loop mode or control speed in closed loop mode.
- PID controller for closed loop control
- Soft start for open loop mode (not required for closed loop)
- Two turn off methods: braking and coasting
- Emulate hall as a debugging tool (not to be driven)
- Reverse rotation detection
- Motor stopped detection
- Missing Hall-effect sensor connectors detection
- Over current detection
- Remote operation with SCPI (Standard Control of Programmable Instruments) support

For a complete description of the firmware code refer to the extensive code documentation which is provided with the firmware code.

When running the code (with the motor provided in the kit) for the first time, you do not have to modify any parameters unless other parameters are preferred. To make any changes, head to the "To do" section of the code documentation to see the list of recommended changes.

6.1. Arduino™ software installation

To install the Arduino™ IDE V1 or V2:

- Get the latest version of the IDE for your computer from Arduino’s download page.
- Follow the instructions in the installation guide: V1 (Windows), V1 (Linux), V2 (Windows/Linux/MacOS).
- The drivers should be automatically installed alongside the IDE. If still facing issues in Windows, please refer to this driver installation guide.

6.2. Setting up the project

6.2.1. Connecting and selecting the development board

This section details the connection of the Leonardo R3 development board and selecting it in the Arduino™ IDE, Arduino™ IDE V1 is used.

- Connect the Leonardo R3 development board to your computer using the USB cable. The power LED should go on. **Note:** For any new board which has not been flashed before, it is best to upload the firmware code while it is unplugged from the motor controller board. This prevents unexpected issues due to IO conflicts.
- Open the Arduino™ IDE.
- Click the “Tools -> Board”, then select the correct board: “Arduino Leonardo”
- Click the “Tools -> Port”, then select the correct port for the Leonardo R3 development board.

The IDE is now configured to work with the Leonardo R3 development board provided.

6.2.2. Importing the project and uploading the code

- Download and extract the source code for the firmware. Navigate to folder “main” within the project and open “main.ino”.
- Follow the *to do* section of the code documentation to make any changes to meet the system requirements. The default configuration is set to work with the motor provided.
- Click the verify button to check the errors. If compiling successfully, the message "Done compiling." will appear in the status bar.
- Click the “Upload” button to upload the code. If the upload is successful, the message "Done uploading." will appear in the status bar.

The firmware has now been uploaded and available to be used. After ensuring that the kit has been properly set up in accordance with the manual, power on the system. The firmware code will start, enabling the control and operation of the BLDC motor using the Hall-effect sensors.

6.3. Code documentation

A *Doxygen* generated code document is provided along with the down-loadable source code. This documentation provides a comprehensive understanding of the code-base, making it an invaluable resource for both new and experienced developers.

Each function, class, macro, and variable is documented including their purpose, usage instructions, parameter explanations, and return value details. These are cross-referenced allowing it to be easy to navigate between related elements, such as functions that call each other, or variables and the functions that use them. Where applicable, the documentation includes diagrams and graphs to visually represent the relationships and interactions within the code. Mathematical formulas and logic are already provided so it’s easy to translate between scaled and register values. The to do section lists all the macros that can be set by the user to quickly modify operating parameters such as switching frequencies and speed control methods. There is also extensive documentation and examples of remote operation using SCPI in the documentation.

The documentation is located alongside the source code in the project repository or down-loadable zip.

6.4. Default firmware configuration

The following are some of the default configurations for the most commonly changed parameters used by in the firmware code provided for version NEVC-MCTRL-100-t01-1.0.0:

- MOSFET switching frequency: 20,000 Hz
- Dead-time: 350 ns
- Number of motor poles: 8
- Speed control method: open loop
- Turn-off mode: braking

Note: This may not be the firmware version uploaded to the micro controller, so it is best to download the latest version and check the configuration used before if running with a new motor.

6.5. Remote operation

The firmware code includes an implementation of the SCPI protocol. This allows remote operation of the motor via any programming language or software compatible with SCPI. The command set is minimal at this stage and it is intended that further development will be carried out in the future.

6.5.1. SCPI implementation

SCPI is a widely-accepted standard for syntax and commands, designed to provide a uniform method of controlling test and measurement devices. For a quick overview of SCPI, please refer to "SCPI Quick Guide" in the code documentation. **Note:** while the SCPI implementation adheres to the core principles of the SCPI standard and relevant IEEE standards, it may not fully comply with the full required specification. The implementation focuses on the essential commands and functionality necessary for evaluation only.

For detailed command information, see the "SCPI Command Set" section in the code documentation.

6.5.2. Firmware SCPI command set

For the complete updated command set supported by the specific firmware code version in use, please refer to the code documentation. Some of the basic commands supported by the firmware are listed in Table 15.

Table 15. Firmware SCPI command set

Command	Description	Parameters	Return value
`CONFigure:MOTOr:ENABle`	Configures the motor enable state	Boolean (ON or 1 to enable	OFF or 0 to disable
`CONFigure:MOTOr:ENABle?`	Queries the motor enable state	None	Boolean state of the motor (1 if enabled or 0 if disabled)
`CONFigure:MOTOr:GATE:FREQuency`	Sets the gate drive frequency for the motor	Frequency value in Hertz (Hz); minimum 7,183 Hz, maximum 100,000 Hz	None or error code and message if the frequency is out of range
`CONFigure:MOTOr:GATE:FREQuency?`	Queries the gate drive frequency	None	Current gate drive frequency in Hertz (Hz)
`CONFigure:MOTOr:GATE:DEADtime`	Sets the gate dead time for the motor.	Dead time value in nanoseconds (ns). Min 350 ns, max 1750 ns.	None or error code and message if the dead time is out of range.
`CONFigure:MOTOr:GATE:DEADtime?`	Queries the gate dead time	None	Current gate dead time in nanoseconds (ns)
`CONFigure:MOTOr:DIREction`	Sets the motor direction	Direction value (FORWard or REVErse)	None or error code and message if incorrect parameter
`CONFigure:MOTOr:DIREction?`	Queries the motor direction	None	The configured motor direction as a string (FORWard or REVErse)
`MEASure:MOTOr:SPEEd?`	Measures the motor speed	None	Motor speed in revolutions per minute (RPM)
`MEASure:MOTOr:CURRent?`	Measures the motor current	None	Motor current in Amperes (A)
`MEASure:MOTOr:DIREction?`	Measures the motor direction	None	The motor direction as a string (FORWard, REVErse or UNKNown)

6.5.3. Using remote mode

To use remote mode, the Leonardo R3 development board must be booted with the remote switch in the ON position. This can be done by toggling the remote switch and pressing the reset button on the Leonardo R3 development board.

Any serial interface can be used, given its configured correctly.

In this example, the serial monitor of the Arduino™ IDE V1 is used.

- Click the button to open the serial monitor or navigate to “Tools > Serial Monitor”.

- At the bottom right corner of the Serial Monitor, you will find a drop-down menu for setting the baud rate and other parameters. Set them as follows to match the board's configuration:
  - Baud rate: 115200
  - Line ending: Newline (LF)
    For more customizable serial terminals, the following configuration can be used:
  - Data bits: 8
  - Parity: None
  - Stop bits: 1
  - DTR (Data Terminal Ready): Checked/Enabled
  - RTS (Request to Send): Checked/Enabled
- To test the communication, you can send a simple SCPI command and check for a response. For example, enter '***IDN?**' in the input field and press `Send`. The board should respond with its identification string.
- For a practical example, let's configure and query the motor state. Enter the command `**CONFigure:MOTOr:ENABle ON**` to enable the motor. The board should acknowledge the command. Next, to query the speed of the motor, enter `**MEASure:MOTOr:SPEEd?**`. The board should respond with the speed in RPM.

Remote operation can provide opportunities to test and evaluate devices quicker and more extensively. However, ensure that incorrect commands or setting parameters outside the range supported by the system (including the motor) are <u>not</u> sent.

7. Customized operation

7.1. Using a different motor

If a different motor is to be used observe the following steps and refer to table Table 16.

1. Review the motor data sheet for voltage and current requirements and compare with 3-phase inverter board specifications (reviewed below)
2. Review the motor data sheet for required Hall-effect sensor voltages if applicable
3. Correlate correct hall effect sensor wire to motor phase and ensure they match when connecting them to the 3-phase inverter motor control board
4. Review the "ToDo"" section in the motor control firmware and change where applicable, (Note: Nexperia cannot support questions regarding changes to the firmware)

The terminal block J4 provides a convenient connection, but screw terminals J1 - J3 can be used for higher current. The terminal block J4 can withstand 32 A, which is suitable for the 42BLS40-24-01 motor. The screw terminals J1 - J3 can withstand up to 70 A.

Table 16. Motor connections

Wire color	Board	Location	Description
Red (RED)	Motor controller board	Pin 5 of J12	5 V need to power hall effect sensors (IO_REF)
Blue (BLU)	Motor controller board	Pin 4 of J12 / Pin 3 of J12	Hall-effect sensor C output correlated with Phase W (HALL_3)
White (WHT)	Motor controller board	Pin 3 of J12 / Pin 4 of J6	Hall-effect sensor B output correlated with Phase V (HALL_2)
Yellow (YEL)	Motor controller board	Pin 2 of J12 / Pin 3 of J6	Hall-effect sensor A output correlated with Phase U (HALL_1)
Black (BLK)	Motor controller board	Pin 1 of J12	GND reference needed for Hall-effect sensors (GND)
Orange (ORG)	3-phase inverter board	Pin 3 of J4	Phase U of the motor terminal block (PHASE_U)
	3-phase inverter board	J9	
Green (GRN)	3-phase inverter board	Pin 2 of J4	Phase V of the motor terminal block (PHASE_V)
	3-phase inverter board	J10	
Brown (BRW)	3-phase inverter board	Pin 1 of J4	Phase W of the motor screw terminal (PHASE_W)
	3-phase inverter board	J15	

7.2. Using a different motor algorithm

The flexibility of the BLDC kit allows the user to use a new development board or controller board:

1. Review the development board or microcontroller board connections section to ensure microcontroller pin compatibility
2. Take note of essential signals, such as gate voltage signals
3. Develop break-out board for new development board

Note: Nexperia cannot support questions regarding changes to the firmware

7.3. Using different MOSFETs

1. Review 5 x 6 footprint compatibility with selected MOSFET
2. Review the gate driver requirements for the MOSFETs and calculate the appropriate gate currents and gate resistors
3. Understand the differences in switching characteristics and power loss requirements

8. Design details

Section 8.1 shows the schematic diagrams of the motor controller board.

Section 8.2 shows the schematic diagrams of the 3-phase inverter board.

Section 8.3 shows the PCB layout of the motor controller board.

Section 8.4 shows the PCB layout of the 3-phase inverter board.

Section 8.5 lists the full Bill of Materials for the BLDC driver kit.

8.1. Motor controller board schematics

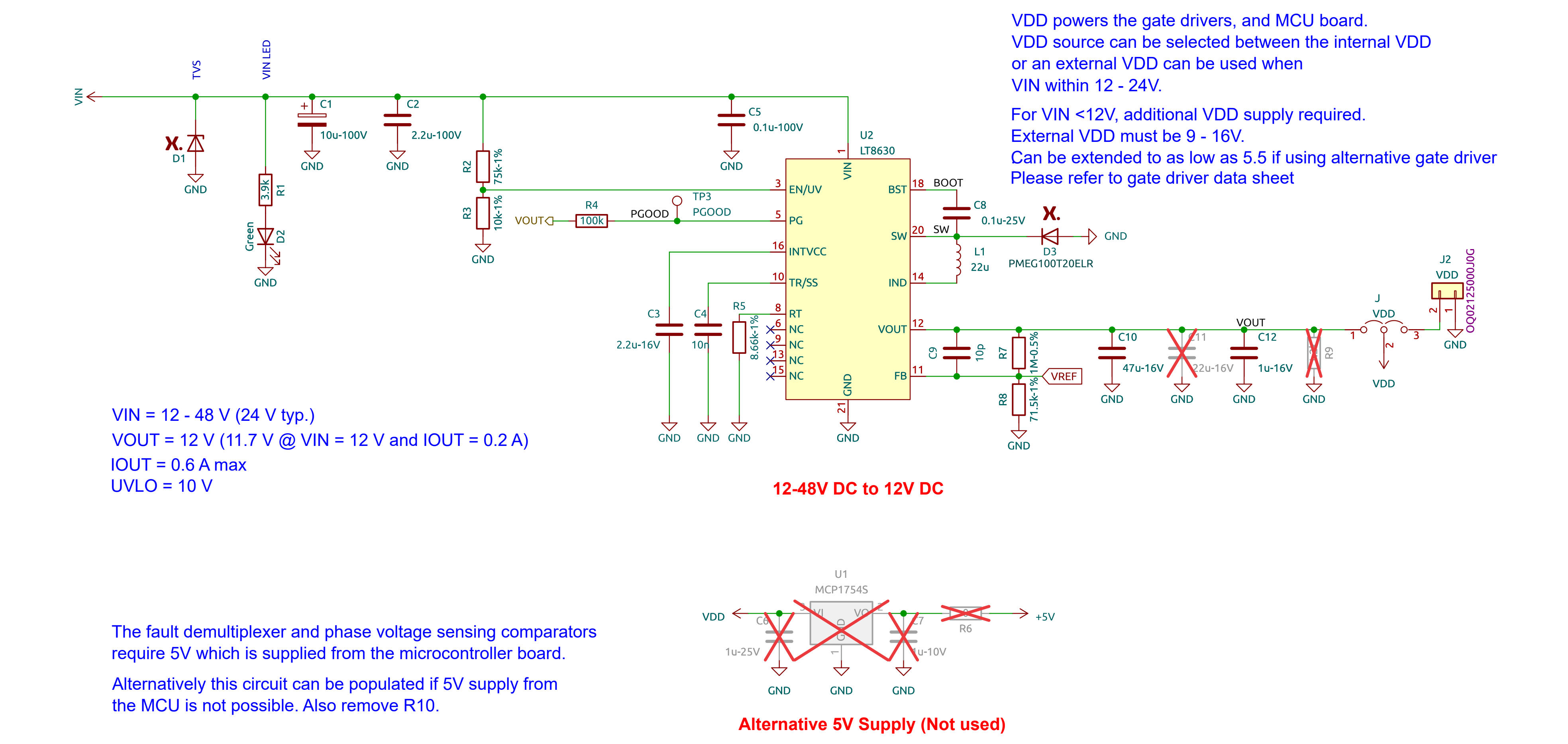


Fig. 25. Motor controller board schematic sheet 1

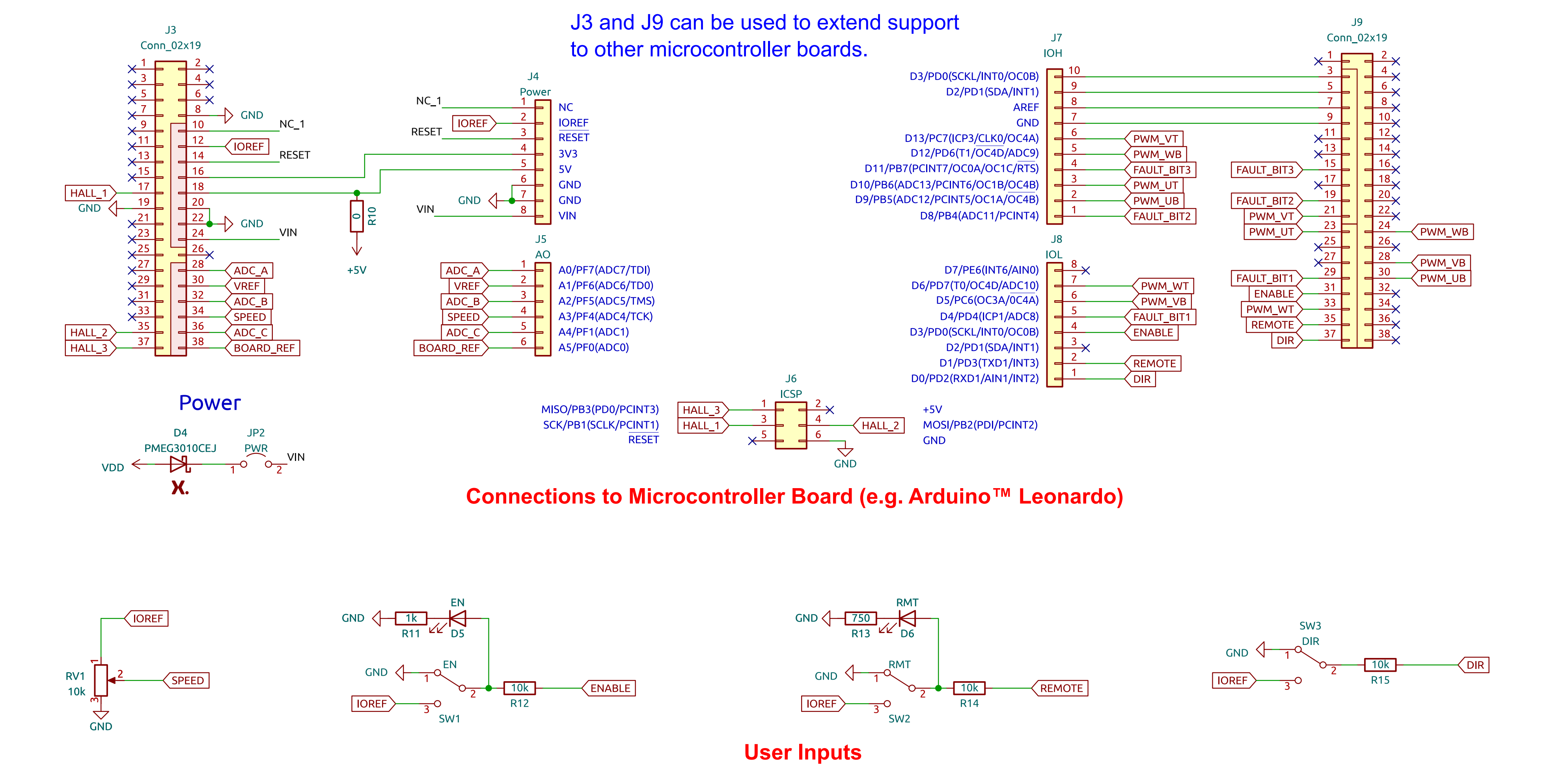


Fig. 26. Motor controller board schematic sheet 2

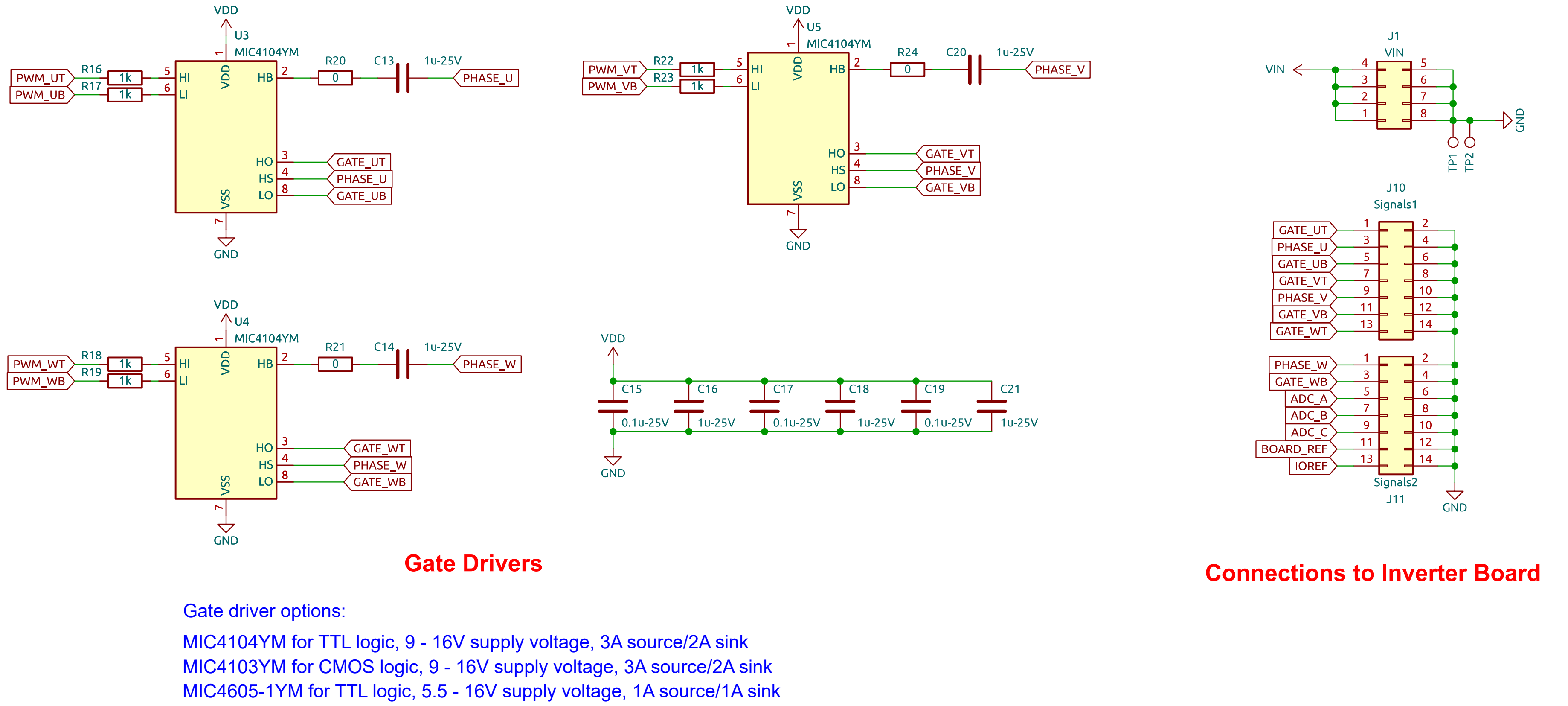


Fig. 27. Motor controller board schematic sheet 3

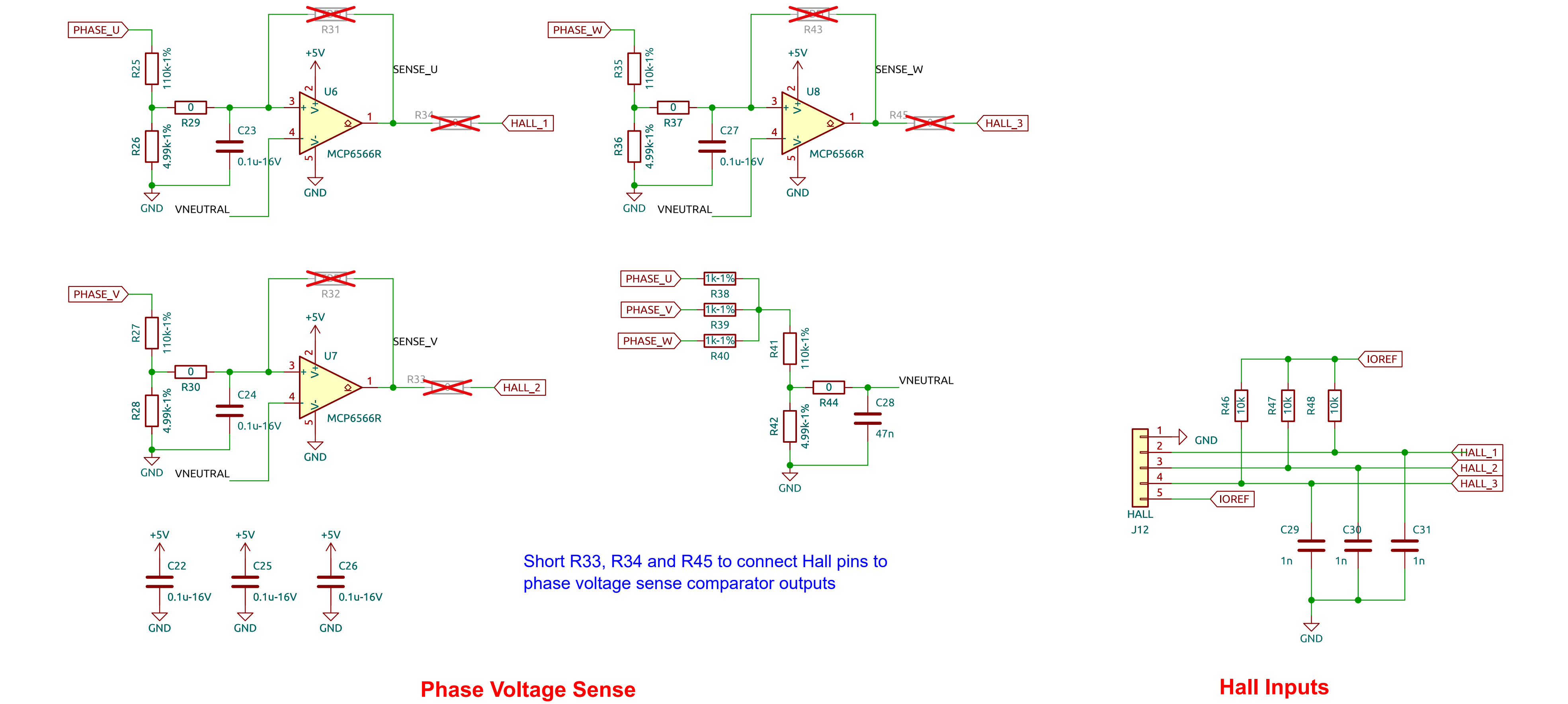


Fig. 28. Motor controller board schematic sheet 4

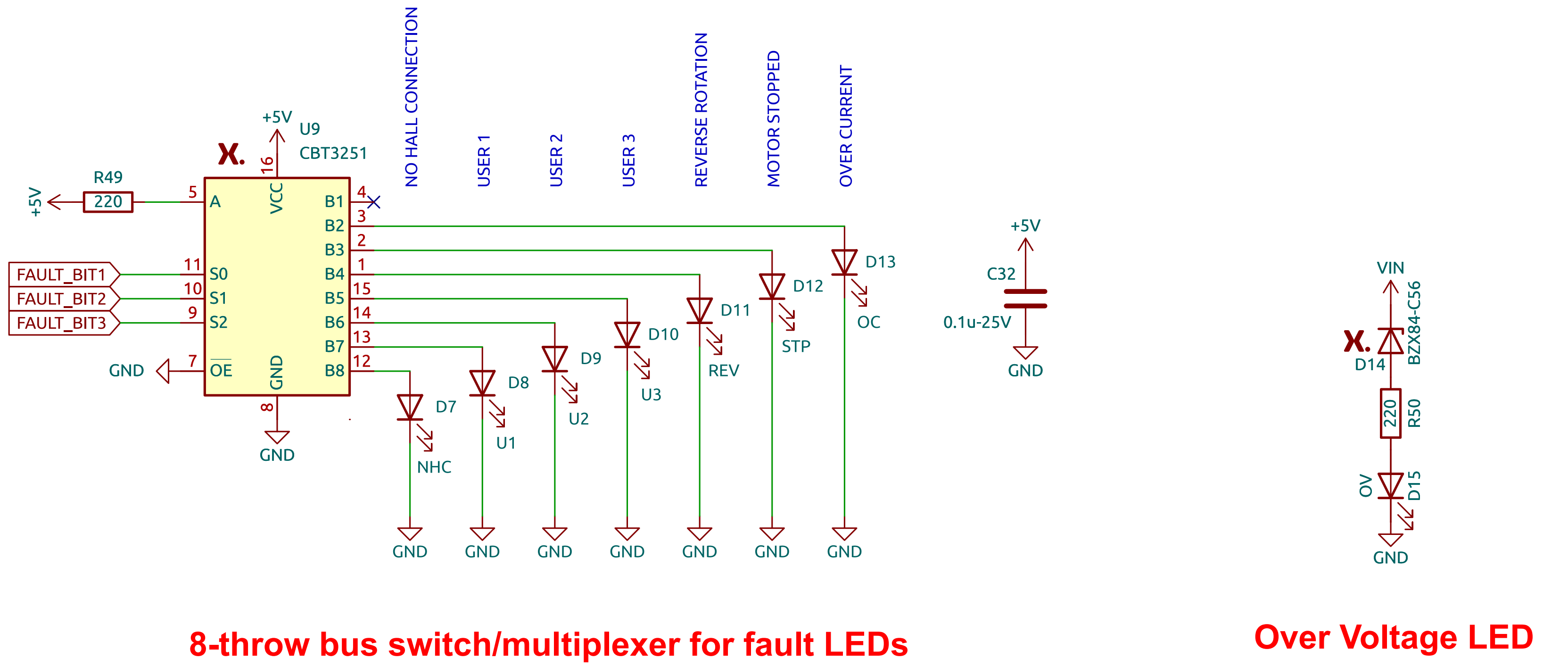


Fig. 29. Motor controller board schematic sheet 5

8.2. 3-phase inverter board schematics

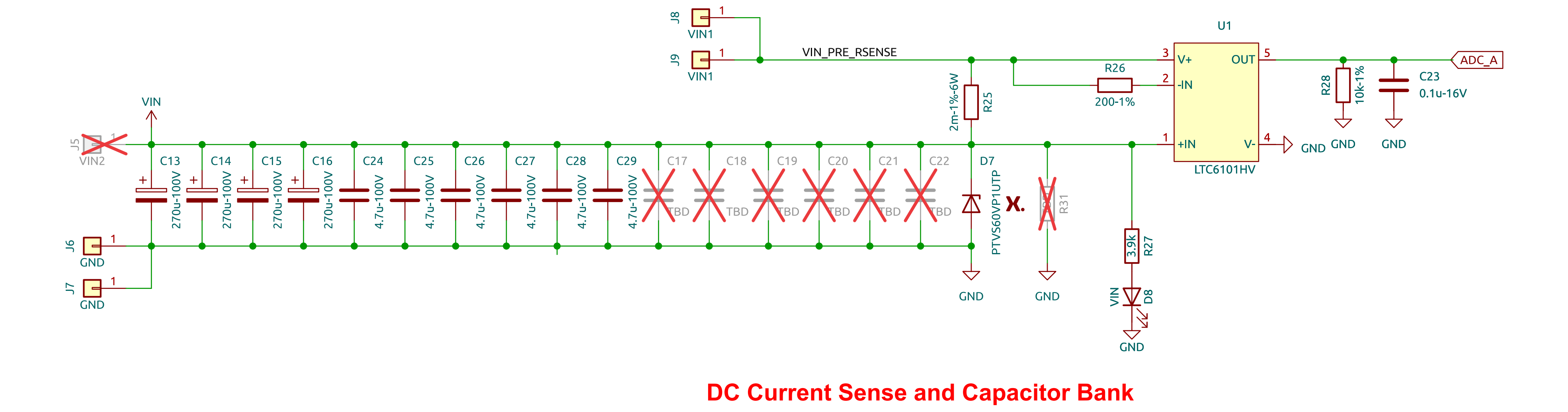


Fig. 30. 3-phase inverter board schematic sheet 1

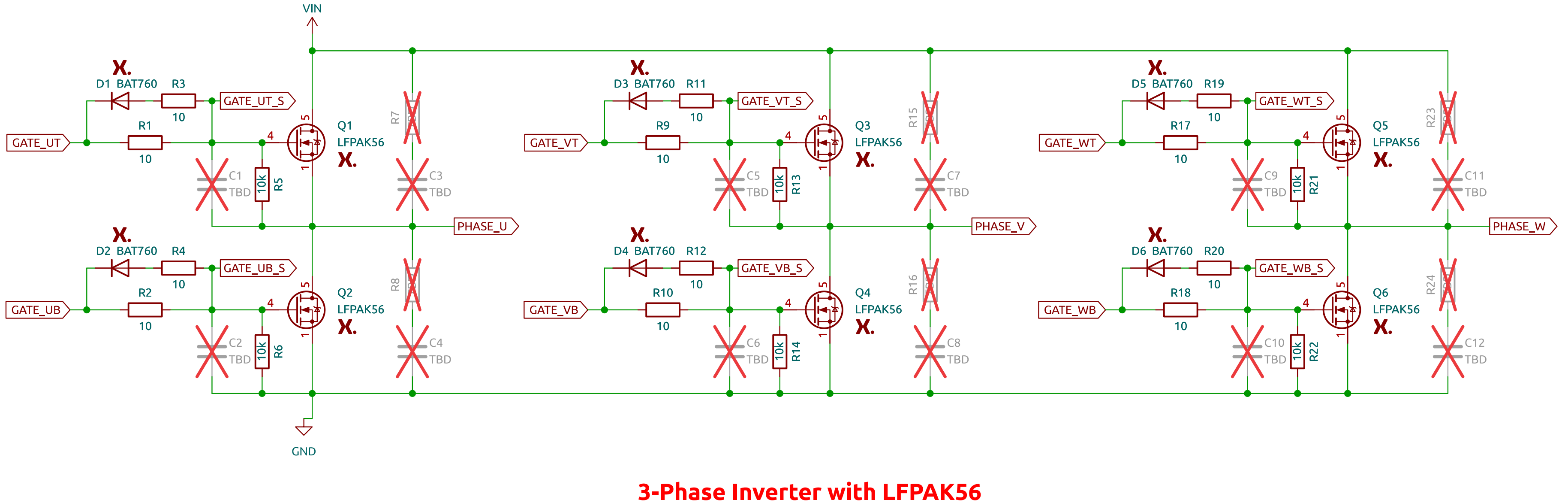


Fig. 31. 3-phase inverter board schematic sheet 2

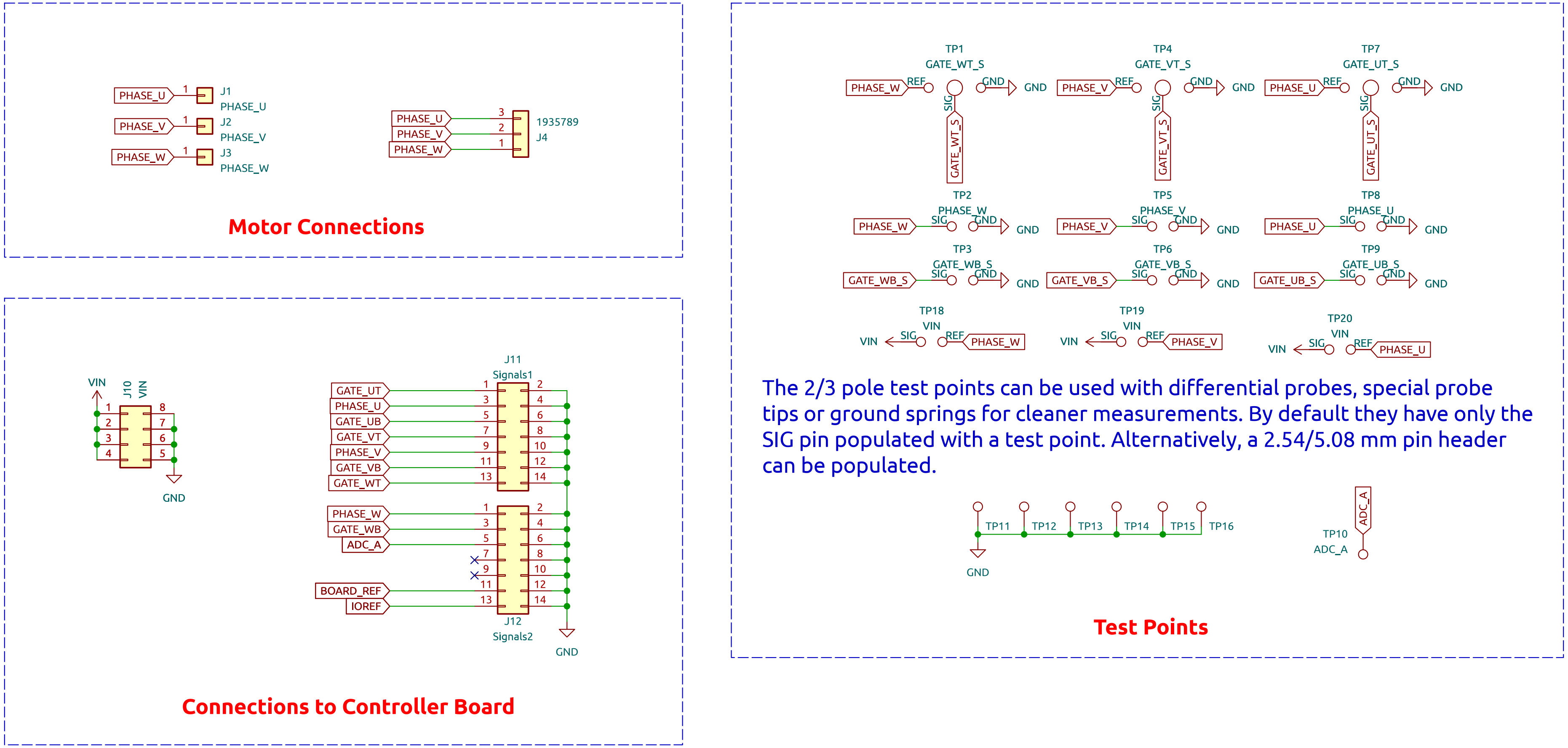


Fig. 32. 3-phase inverter board schematic sheet 3

8.3. Motor controller board PCB layout

Motor controller board PCB characteristics:

- Copper layer count: 4
- Board thickness: 1.58 mm
- Overall dimensions: 83.7 mm x 88.4 mm
- Min track / spacing: 0.20 mm / 0.20 mm
- Copper thickness (outer layers): 1 oz per sq. feet / 0.035 mm
- Copper thickness (inner layers): 1 oz per sq. feet / 0.035 mm
- Copper finish: ENIG

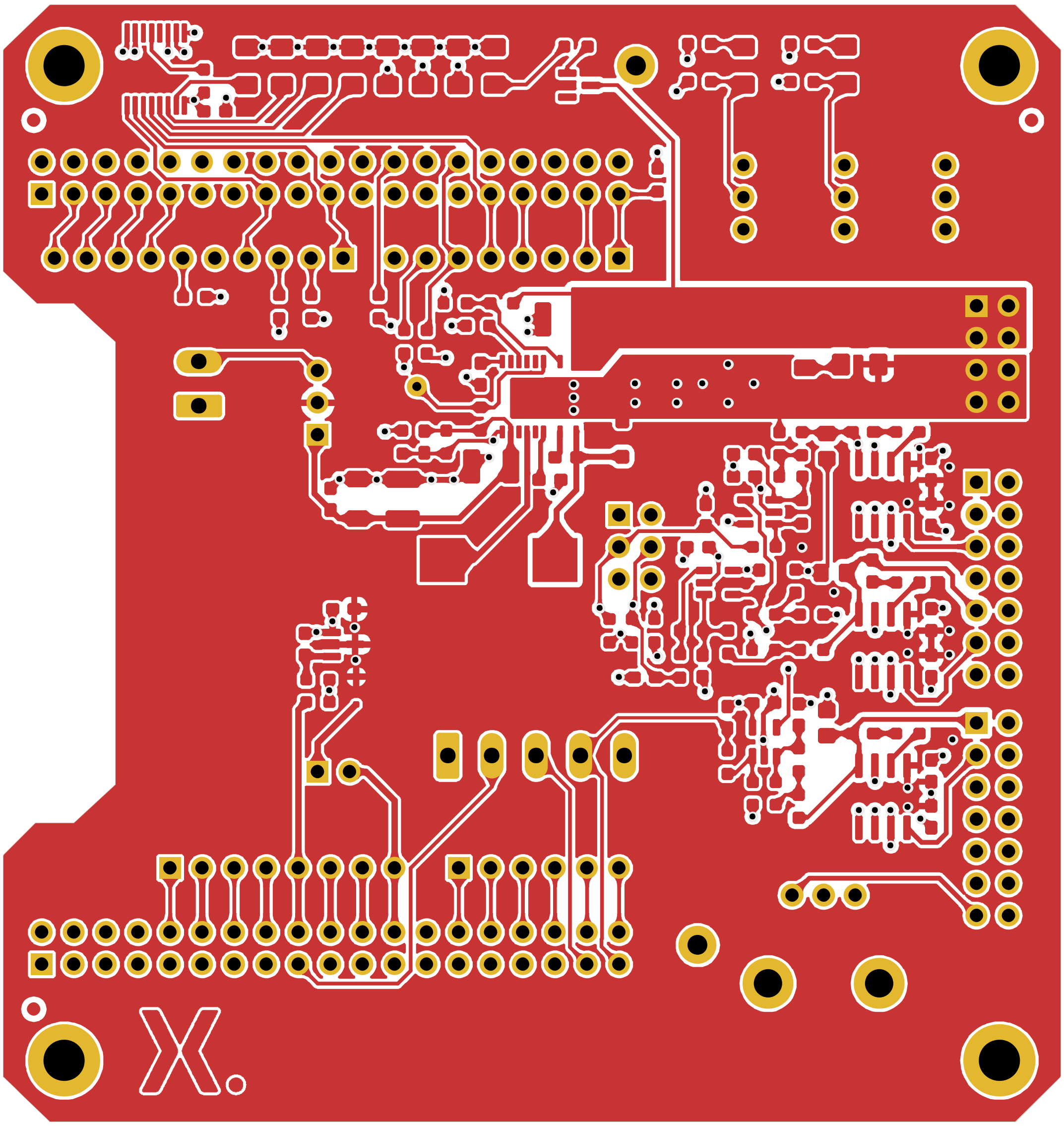


Fig. 33. Motor controller board PCB - top layer

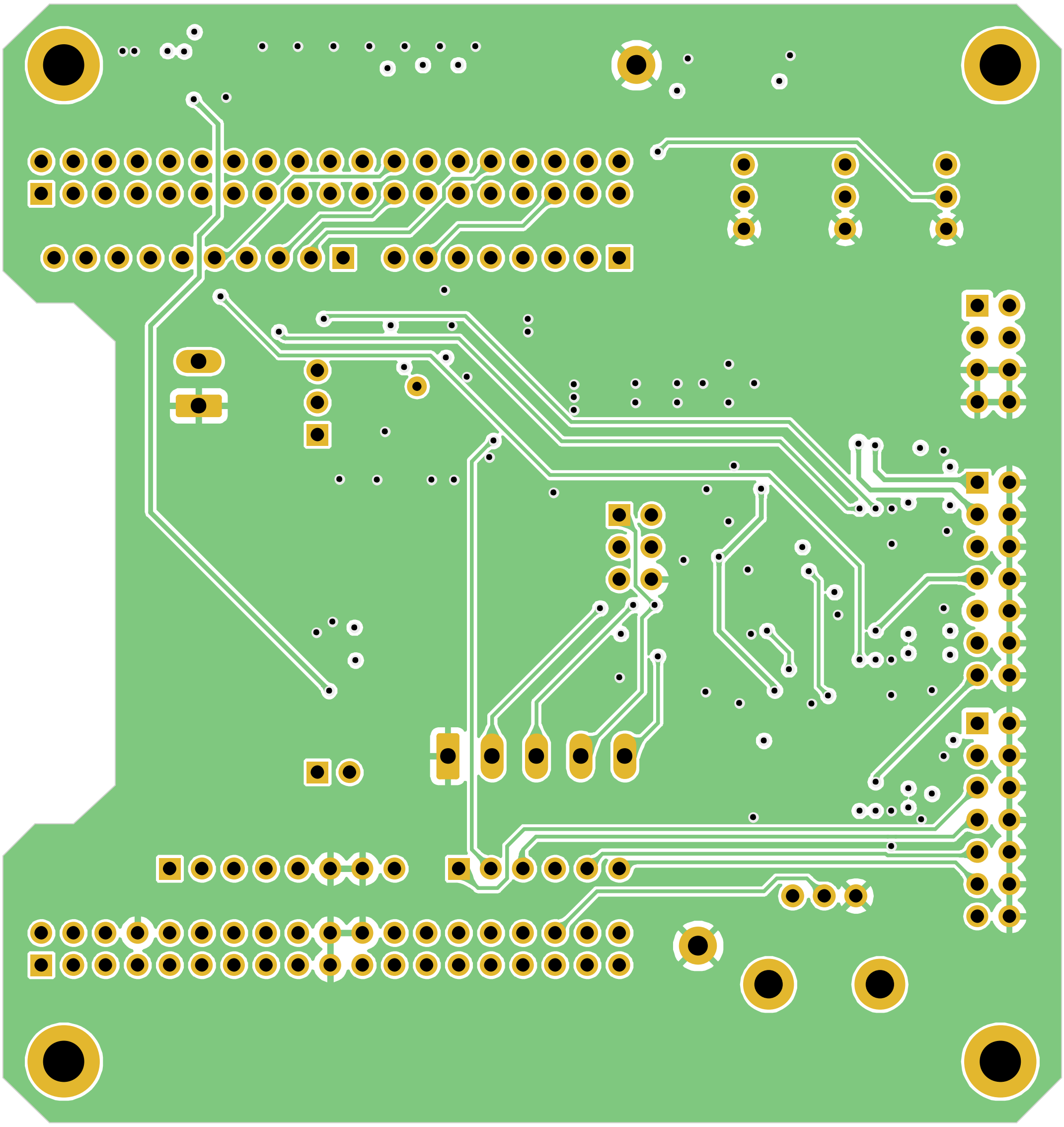


Fig. 34. Motor controller board PCB - inner layer 1

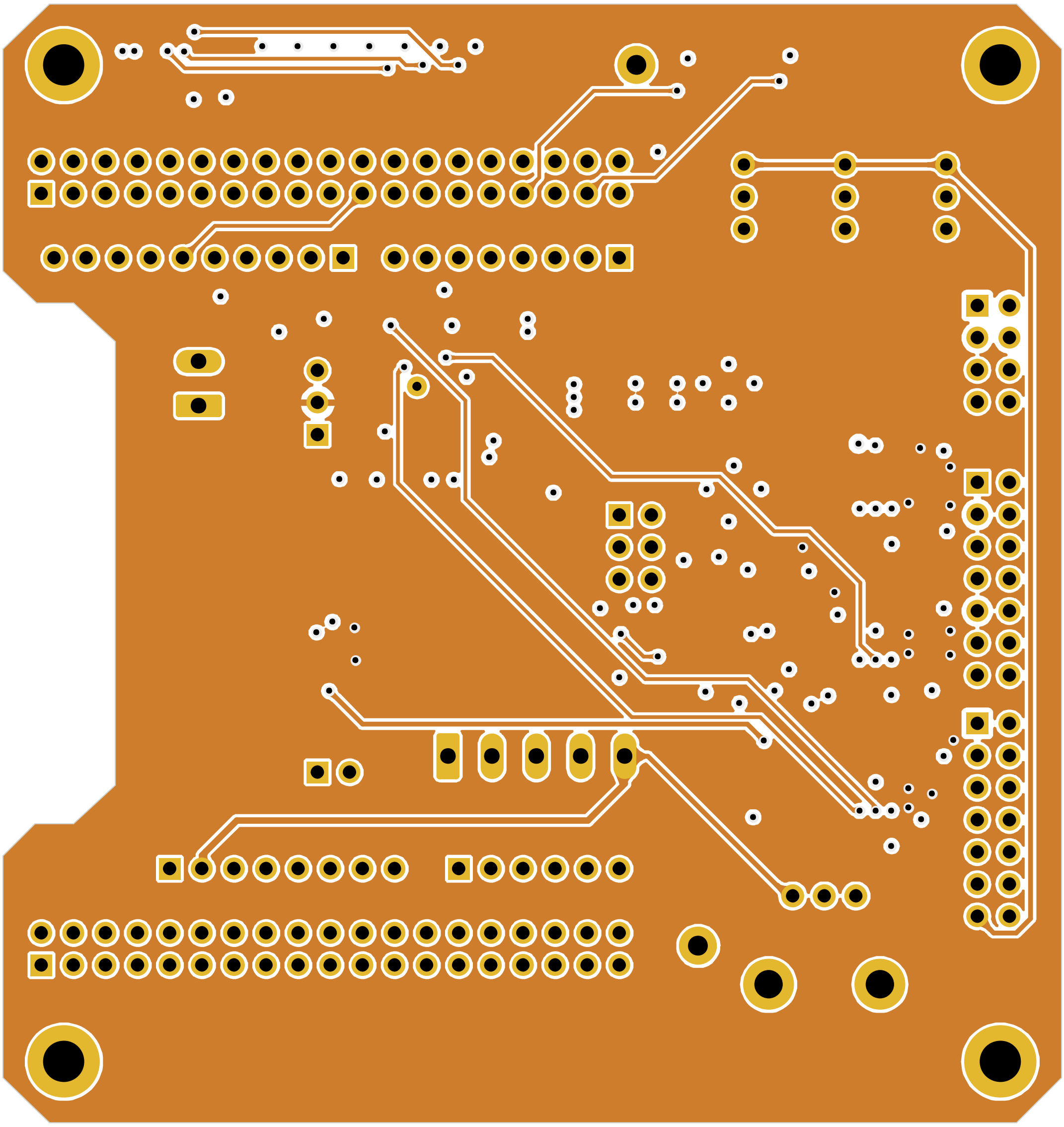


Fig. 35. Motor controller board PCB - inner layer 2

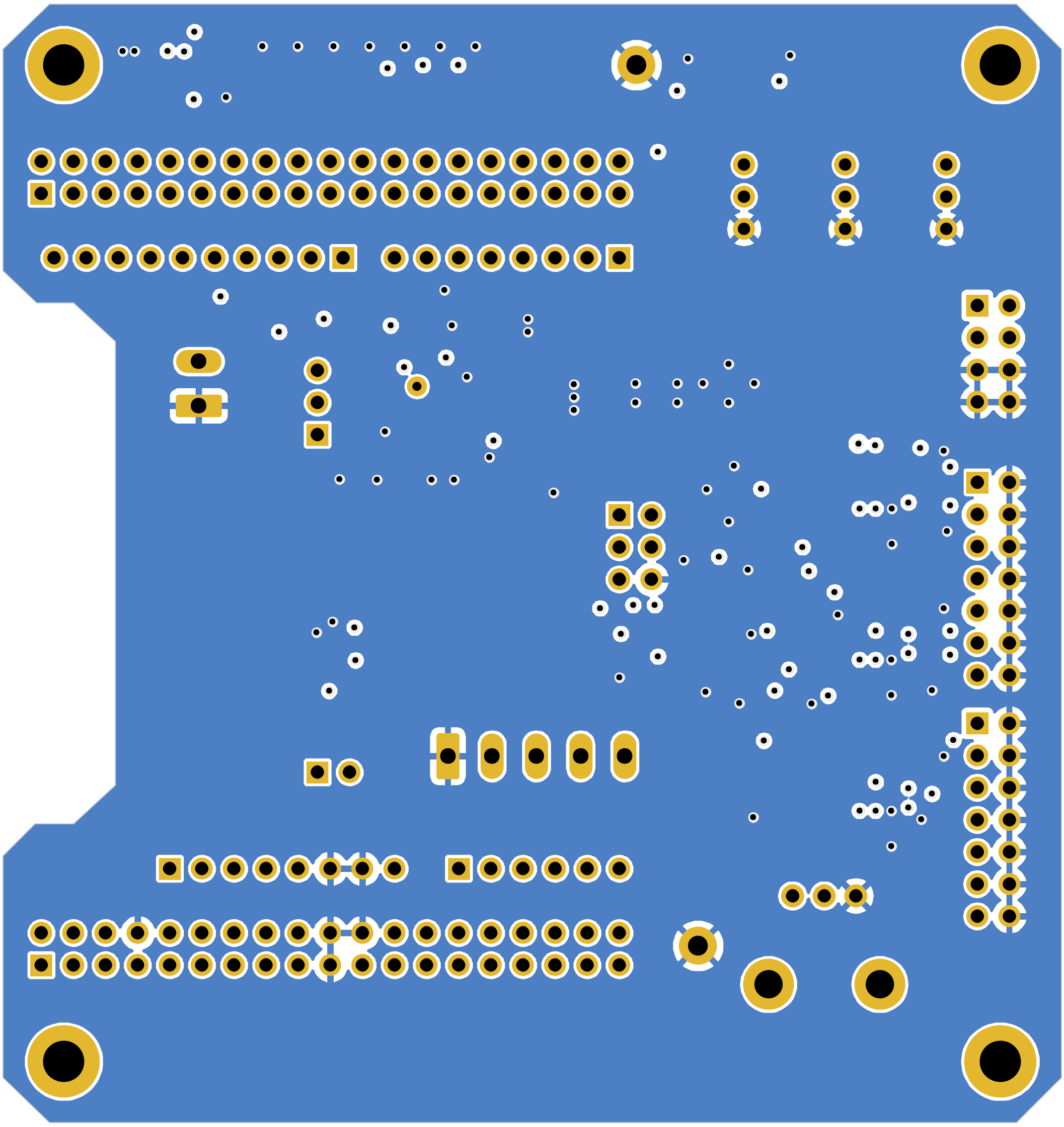


Fig. 36. Motor controller board PCB - bottom layer

8.4. 3-phase inverter board PCB layout

3-phase inverter board PCB characteristics.

- Copper layer count: 4
- Board thickness: 1.62 mm
- Overall dimensions: 96.12 mm x 125.6 mm
- Min track / spacing: 0.20 mm / 0.20 mm
- Copper thickness (outer layers): 2 oz per sq. feet / 0.070 mm
- Copper thickness (inner layers): 1 oz per sq. feet / 0.035 mm
- Copper finish: ENIG

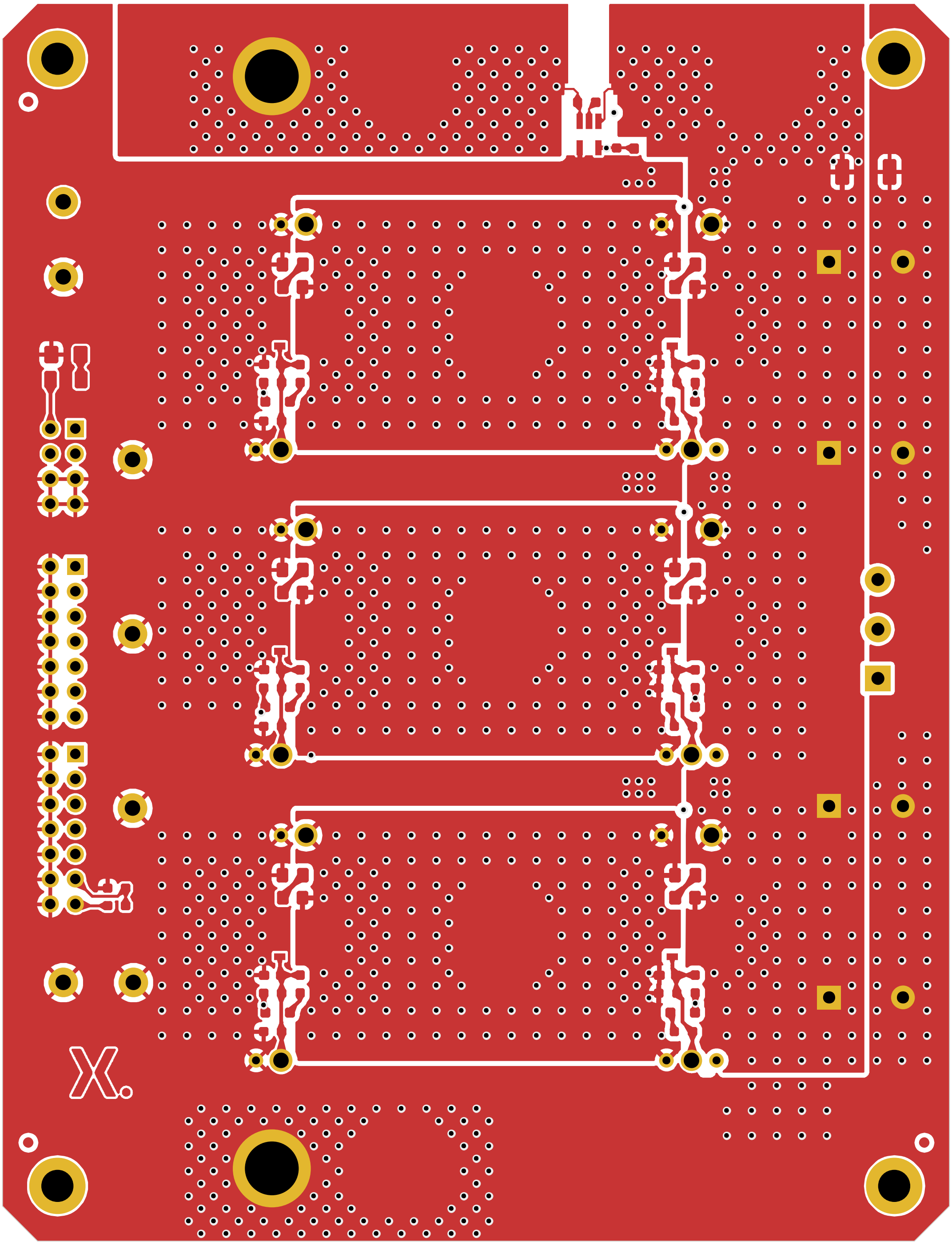


Fig. 37. 3-phase inverter board PCB - top layer

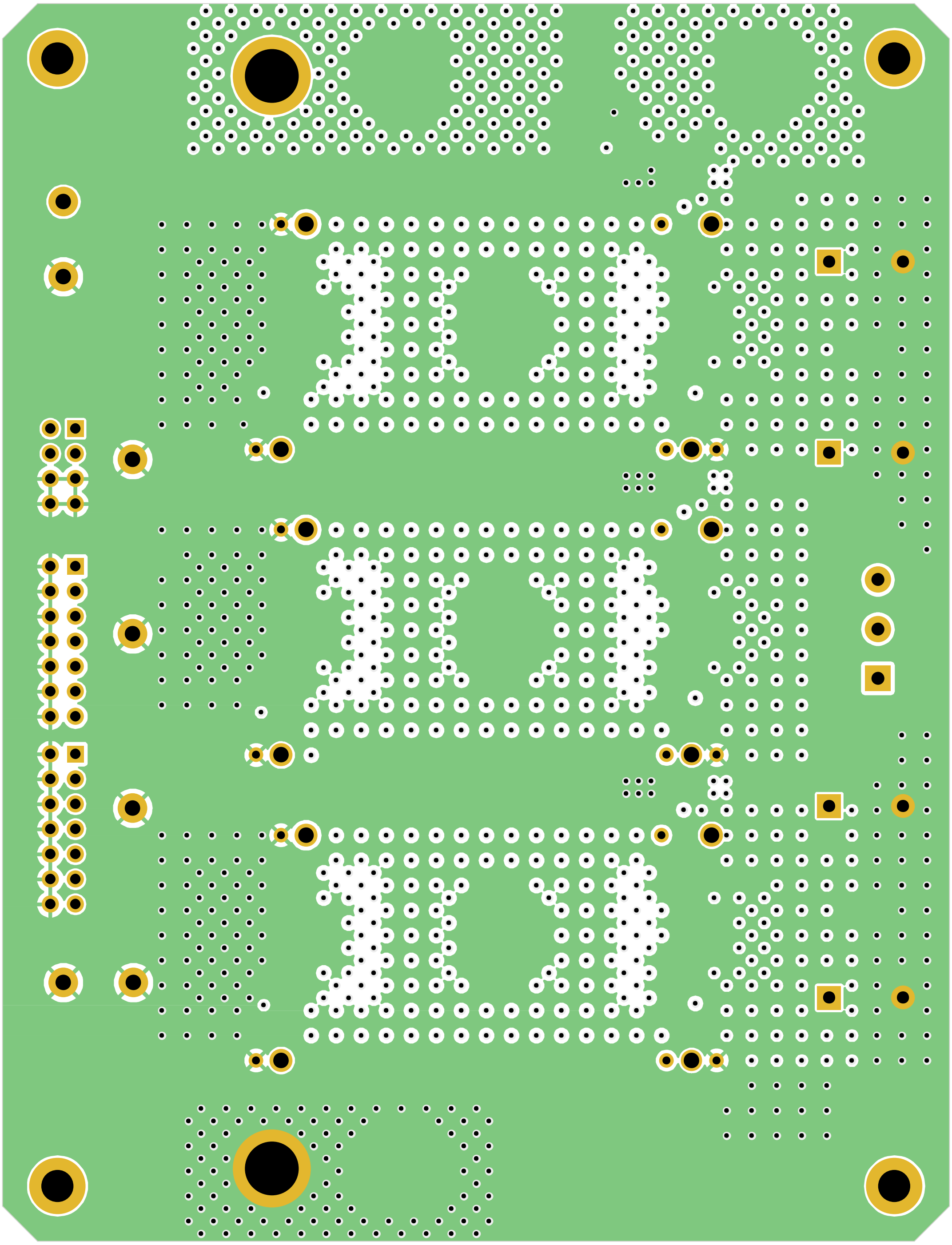


Fig. 38. 3-phase inverter board PCB - inner layer 1

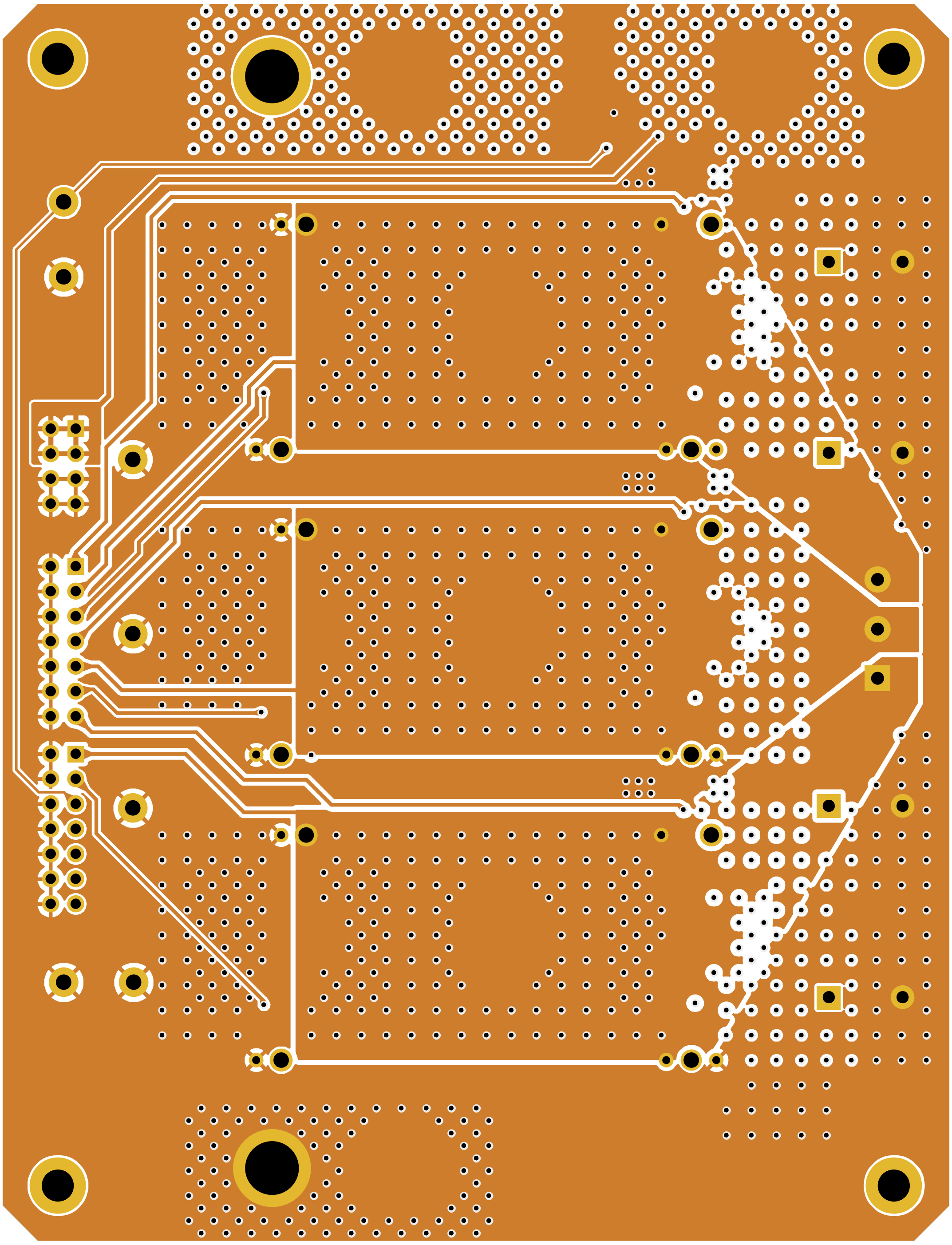


Fig. 39. 3-phase inverter board PCB - inner layer 2

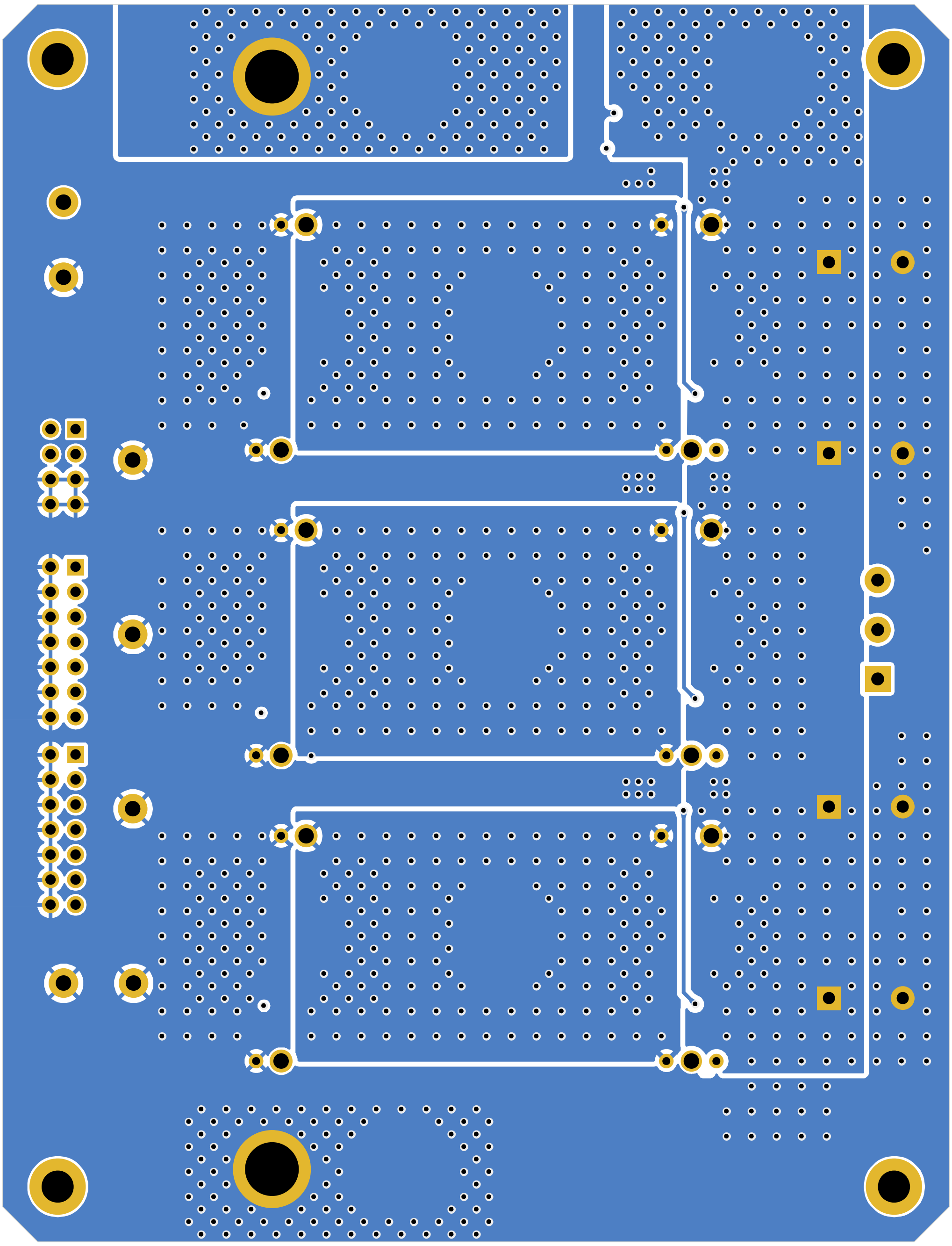


Fig. 40. 3-phase inverter board PCB - bottom layer

8.5. Bill of Materials

Table 17. Motor control board (NEVB-MCTRL-100-01) Bill of Materials

Reference	Qty	Value	Footprint	Manufacturer	Mfg Part No	
C1	1	10u-100V	Capacitor_SMD:CP_Elec_6.3x9.9	WURTH ELEKTRONIK	865060845002	
C2	1	2.2u-100V	Capacitor_SMD:C_1210_3225Metric_Pad1.33x2.70mm_HandSolder	SAMSUNG	CL32B225KCJSNNE	
C3	1	2.2u-16V	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	YAGEO	CC0603KRX7R7BB225	
C4	1	10n	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	MURATA	GRM188R72A103KA01J	
C5	1	0.1u-100V	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	SAMSUNG	CL10B104KC8NNNC	
C6	1	1u-25V	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	SAMSUNG	CL10B105KA8NNNC	**DNP**
C7	1	1u-10V	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	SAMSUNG	CL10B105KA8NNNC	**DNP**
C8, C15, C17, C19, C32	5	0.1u-25V	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	SAMSUNG	CL10B104KC8NNNC	
C9	1	10p	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	YAGEO	CC0603JRNPO0BN100	
C10	1	47u-16V	Capacitor_SMD:C_1210_3225Metric_Pad1.33x2.70mm_HandSolder	MURATA	GRM32EC81C476KE15L	
C11	1	22u-16V	Capacitor_SMD:C_1210_3225Metric_Pad1.33x2.70mm_HandSolder	SAMSUNG	CL32A226MOJNNNE	**DNP**
C12	1	1u-16V	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	SAMSUNG	CL10B105KA8NNNC	
C13, C14, C16, C18, C20, C21	6	1u-25V	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	SAMSUNG	CL10B105KA8NNNC	
C22, C23, C24, C25, C26, C27	6	0.1u-16V	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	SAMSUNG	CL10B104KC8NNNC	
C28	1	47n	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	YAGEO	CC0603KRX7R9BB473	
C29, C30, C31	3	1n	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	MULTICOMP PRO	MC0603B102K500CT	
D1	1	PTVS60VP1UTP	Diode_SMD:D_SOD-128	NEXPERIA	PTVS60VP1UTP,115	
D2	1	Green	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008280	
D3	1	PMEG100T20ELR	Diode_SMD:D_SOD-123F	NEXPERIA	PMEG100T20ELR-QX	
D4	1	PMEG3010CEJ	Diode_SMD:D_SOD-323F	NEXPERIA	PMEG3010CEJ,115	
D5	1	EN	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	DIALIGHT	599-0230-007F	
D6	1	RMT	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008280	

Reference	Qty	Value	Footprint	Manufacturer	Mfg Part No	
D7	1	NHC	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008281	
D8	1	U1	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008281	
D9	1	U2	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008281	
D10	1	U3	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008281	
D11	1	REV	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008281	
D12	1	STP	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008281	
D13	1	OC	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008281	
D14	1	BZX84-C56	Package_TO_SOT_SMD_Custom:SOT-23-Nexperia-Diode	NEXPERIA	BZX84-C56,215	
D15	1	OV	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008281	
G1, G3	2	2.54mm Jumper		HARWIN	M7685-05	
G2, G6, G8, G12	4	M3x8mm Screw		RS PRO	264-6436	
G4, G5, G9, G10	4	M3x30mm F/F Standoff		RS PRO	806-6610	
G7	1	For J2		TE CONNECTIVITY	2350398-2	
G11	1	For J12		IMO PRECISION CONTROLS	20.1551M/5-E	
J1	1	VIN	Connector_PinHeader_2.54mm:PinHeader_2x04_P2.54mm_Horizontal	WURTH ELEKTRONIK	61300821021	
J2	1	VDD	Connector_Phoenix_MC:PhoenixContact_MCV_1,5_2-G-3.5_1x02_P3.50mm_Vertical	AMPHENOL ANYTEK	OQ02125000J0G	
J3, J9	2	Conn_02x19	Connector_PinSocket_2.54mm:PinSocket_2x19_P2.54mm_Vertical	SAMTEC	SSQ-119-03-T-D	
J4	1	Power	Connector_PinSocket_2.54mm:PinSocket_1x08_P2.54mm_Vertical	SAMTEC	SSQ-108-03-T-S	
J5	1	AO	Connector_PinSocket_2.54mm:PinSocket_1x06_P2.54mm_Vertical	SAMTEC	SSQ-106-03-T-S	
J6	1	ICSP	Connector_PinSocket_2.54mm:PinSocket_2x03_P2.54mm_Vertical	SAMTEC	SSQ-103-03-T-D	
J7	1	IOH	Connector_PinSocket_2.54mm:PinSocket_1x10_P2.54mm_Vertical	SAMTEC	SSQ-110-03-T-S	
J8	1	IOL	Connector_PinSocket_2.54mm:PinSocket_1x08_P2.54mm_Vertical	SAMTEC	SSQ-108-03-T-S	
J10	1	Signals1	Connector_PinHeader_2.54mm:PinHeader_2x07_P2.54mm_Horizontal	WURTH ELEKTRONIK	61301421021	

Reference	Qty	Value	Footprint	Manufacturer	Mfg Part No	
J11	1	Signals2	Connector_PinHeader_2.54mm:PinHeader_2x07_P2.54mm_Horizontal	WURTH ELEKTRONIK	61301421021	
J12	1	HALL	Connector_Phoenix_MC:PhoenixContact_MCV_1,5_5-G-3.5_1x05_P3.50mm_Vertical	CAMDENBOSS	CTBP93VD/5	
JP1	1	VDD	Connector_PinHeader_2.54mm:PinHeader_1x03_P2.54mm_Vertical	MULTICOMP PRO	2211S-03G	
JP2	1	PWR	Connector_PinHeader_2.54mm:PinHeader_2x01_P2.54mm_Vertical	MULTICOMP PRO	2211S-02G	
L1	1	22u	Inductor_SMD:L_Bourns_SRP1038C_10.0x10.0mm	BOURNS	SRP1038A-220M	
R1	1	3.9k	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder	BOURNS	CR1206-FX-3901ELF	
R2	1	75k-1%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	AC0603FR-0775KL	
R3	1	10k-1%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	KAMAYA	RMC1/16103JTP	
R4	1	100k	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	RT0603FRE07100KL	
R5	1	8.66k-1%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	RC0603FR-078K66L	
R6, R33, R34, R45	4	0	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	RC0603FR-070RL	
R7	1	1M-0.5%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	RC0603DR-071ML	
R8	1	71.5k-1%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	RE0603FRE0771K5L	
R9	1	1.2k	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder	YAGEO	RC1206JR-071K2L	**DNP**
R10, R20, R21, R24, R29, R30, R37, R44	8	0	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	RC0603FR-070RL	
R11, R16, R17, R18, R19, R22, R23	7	1k	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	KAMAYA	RMC1/16-102JTP	
R12, R14, R15, R46, R47, R48	6	10k	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	KAMAYA	RMC1/16103JTP	
R13	1	750	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	BOURNS	CR0603-JW-751ELF	
R25, R27, R35, R41	4	110k-1%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	AC0603FR-07110KL	
R26, R28, R36, R42	4	4.99k-1%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	PANASONIC	ERJ-3EKF4991V	

Reference	Qty	Value	Footprint	Manufacturer	Mfg Part No	
R31, R32, R43	3	TBD	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder			**DNP**
R38, R39, R40	3	1k-1%	Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder	YAGEO	RC0805FR-101KL	
R49, R50	2	220	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	RC0603JR-07220RL	
RV1	1	10k	Potentiometer_THT:Potentiometer_Bourns_PTV09A-1_Single_Vertical	BOURNS	PTV09A-4225U-B103	
SW1	1	EN	Switches:EG1218	E-SWITCH	EG1218	
SW2	1	RMT	Switches:EG1218	E-SWITCH	EG1218	
SW3	1	DIR	Switches:EG1218	E-SWITCH	EG1218	
TP1, TP2	2	GND	TestPoint:TestPoint_THTPad_D3.0mm_Drill1.5mm	KEYSTONE	5288	
TP3	1	PGOOD	TestPoint:TestPoint_THTPad_D1.5mm_Drill0.7mm			**DNP**
U1	1	MCP1754S	Package_TO_SOT_SMD:SOT-23	MICROCHIP TECHNOLOGY	MCP1754ST-5002E/CB	**DNP**
U2	1	LT8630	ICs:TSSOP-20-16-1EP_4.4x6.5mm_P0.65mm_EP2.15x3.35mm	ANALOG DEVICES	LT8630EFE#PBF	
U3, U4, U5	3	MIC4104YM	Package_SO:SOIC-8_3.9x4.9mm_P1.27mm	MICROCHIP TECHNOLOGY	MIC4104YM	
U6, U7, U8	3	MCP6566R	Package_TO_SOT_SMD:SOT-23-5	MICROCHIP TECHNOLOGY	MCP6566RT-E/OT	
U9	1	CBT3251	Package_SO:TSSOP-16_4.4x5mm_P0.65mm	NEXPERIA	CBT3251PW,118	
DNP = DO NOT POPULATE						

Table 18. 3-phase inverter board (NEVB-3INV-001-01) Bill of Materials

Reference	Qty	Value	Footprint	Manufacturer	Mfg Part No	
C1, C2, C5, C6, C9, C10	6	TBD	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder			**DNP**
C3, C4, C7, C8, C11, C12	6	TBD	Capacitor_SMD:C_0805_2012Metric_Pad1.18x1.45mm_HandSolder			**DNP**
C13, C14, C15, C16	4	270u-100V	Capacitor_THT:CP_Radial_D12.5mm_P7.50mm	CHEMI-CON	EKYB101E271MK30S	
C17, C18, C19, C20, C21, C22	6	TBD	Capacitor_SMD:C_2220_5650Metric_Pad1.97x5.40mm_HandSolder			**DNP**
C23	1	0.1u-16V	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	SAMSUNG	CL10B104KC8NNNC	
C24, C25, C26, C27, C28, C29	6	4.7u-100V	Capacitor_SMD:C_1206_3216Metric_Pad1.33x1.80mm_HandSolder	MURATA	GRM31CZ72A475KE11L	
D1, D2, D3, D4, D5, D6	6	BAT760	Diode_SMD:D_SOD-323_HandSoldering	NEXPERIA	BAT760,115	
D7	1	PTVS60VP1UTP	Diode_SMD:D_SOD-128	NEXPERIA	PTVS60VP1UTP,115	
D8	1	VIN	LED_SMD:LED_1206_3216Metric_Pad1.42x1.75mm_HandSolder	MULTICOMP PRO	MP008280	
G1, G3, G7, G11, G13	5	M5x6mm Screw		RS PRO	908-7693	
G2, G6, G8, G12	4	M3x8mm Screw		RS PRO	264-6436	
G4, G5, G9, G10	4	M3x30mm F/F Standoff		RS PRO	806-6610	
J1	1	PHASE_U	Connectors:Wurth_7466205R_M5_70A_Top_Mod	WURTH ELEKTRONIK	7466205R	
J2	1	PHASE_V	Connectors:Wurth_7466205R_M5_70A_Top_Mod	WURTH ELEKTRONIK	7466205R	
J3	1	PHASE_W	Connectors:Wurth_7466205R_M5_70A_Top_Mod	WURTH ELEKTRONIK	7466205R	
J4	1	1935789	TerminalBlock_Phoenix:TerminalBlock_Phoenix_PT-1,5-3-5.0-H_1x03_P5.00mm_Horizontal	PHEONIX CONTACT	PT 2,5/ 3-5,0-H	

Reference	Qty	Value	Footprint	Manufacturer	Mfg Part No	
J5	1	VIN2	Connectors:Wurth_7466205R_M5_70A_Top_Mod	WURTH ELEKTRONIK	7466205R	**DNP**
J6	1	GND	Connectors:Wurth_7466205R_M5_70A_Top_Mod	WURTH ELEKTRONIK	7466205R	
J7	1	GND	Connector_Custom:KEYSTONE_575-4	KEYSTONE	575-4	
J8	1	VIN1	Connector_Custom:KEYSTONE_575-4	KEYSTONE	575-4	
J9	1	VIN1	Connectors:Wurth_7466205R_M5_70A_Top_Mod	WURTH ELEKTRONIK	7466205R	
J10	1	VIN	Connector_Custom:PinSocket_2x04_P2.54mm _Horizontal_Clipped_SilkScreen	WURTH ELEKTRONIK	613008243121	
J11	1	Signals1	Connector_Custom:PinSocket_2x07_P2.54mm _Horizontal_Clipped_SilkScreen	WURTH ELEKTRONIK	613014243121	
J12	1	Signals2	Connector_Custom:PinSocket_2x07_P2.54mm _Horizontal_Clipped_SilkScreen	WURTH ELEKTRONIK	613014243121	
Q1, Q2, Q3, Q4, Q5, Q6	6	PSMN3R9-100YSF	Package_TO_SOT_SMD:LFPAK56	NEXPERIA	PSMN3R9-100YSFX	
R1, R2, R3, R4, R9, R10, R11, R12, R17, R18, R19, R20	12	10	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	KAMAYA	RMC1/16K10R0FTP	
R5, R6, R13, R14, R21, R22	6	10k	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	KAMAYA	RMC1/16103JTP	
R7, R8, R15, R16, R23, R24	6	TBD	Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder			**DNP**
R25	1	2m-1%-6W	Resistor_SMD:R_2512_6332Metric_Pad1.40x3.35mm_HandSolder	VISHAY / DALE	WSLF25122L000FEA	
R26	1	200-1%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	RT0603FRE10200RL	
R27	1	3.9k	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder	BOURNS	CR1206-FX-3901ELF	
R28	1	10k-1%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	KAMAYA	RMC1/16103JTP	
R29	1	12k-1%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	AC0603FR-1012KL	

Reference	Qty	Value	Footprint	Manufacturer	Mfg Part No	
R30	1	3k-1%	Resistor_SMD:R_0603_1608Metric_Pad0.98x0.95mm_HandSolder	YAGEO	RC0603FR-133KL	
R31	1	TBD	Resistor_SMD:R_2010_5025Metric_Pad1.40x2.65mm_HandSolder			**DNP**
TP1	1	GATE_WT_S	Connectors:TestPoint_3Pads_Pitch2.54mm_Drill1.5mm	KEYSTONE	5013	
TP2	1	PHASE_W	Connectors:TestPoint_2Pads_Pitch2.54mm_Drill1.5mm	KEYSTONE	5013	
TP3	1	GATE_WB_S	Connectors:TestPoint_2Pads_Pitch2.54mm_Drill1.5mm	KEYSTONE	5013	
TP4	1	GATE_VT_S	Connectors:TestPoint_3Pads_Pitch2.54mm_Drill1.5mm	KEYSTONE	5013	
TP5	1	PHASE_V	Connectors:TestPoint_2Pads_Pitch2.54mm_Drill1.5mm	KEYSTONE	5013	
TP6	1	GATE_VB_S	Connectors:TestPoint_2Pads_Pitch2.54mm_Drill1.5mm	KEYSTONE	5013	
TP7	1	GATE_UT_S	Connectors:TestPoint_3Pads_Pitch2.54mm_Drill1.5mm	KEYSTONE	5013	
TP8	1	PHASE_U	Connectors:TestPoint_2Pads_Pitch2.54mm_Drill1.5mm	KEYSTONE	5013	
TP9	1	GATE_UB_S	Connectors:TestPoint_2Pads_Pitch2.54mm_Drill1.5mm	KEYSTONE	5013	
TP10	1	ADC_A	TestPoint:TestPoint_THTPad_D3.0mm_Drill1.5mm	KEYSTONE	5013	
TP11, TP12, TP13, TP14, TP15, TP16	6	GND	TestPoint:TestPoint_THTPad_D3.0mm_Drill1.5mm	KEYSTONE	5288	
TP18, TP19, TP20	3	VIN	Connectors:TestPoint_2Pads_Pitch5.08mm_Drill1.5mm	KEYSTONE	5013	
U1	1	LTC6101HV	Package_TO_SOT_SMD:SOT-23-5_HandSoldering	ANALOG DEVICES	LTC6101VHVCHS5#TRMPBF	
						DNP = DO NOT POPULATE

9. Revision history

Table 19. Revision history

Revision number	Date	Description
1.0	2024-04-15	Initial version.

10. Terms and conditions

EVALUATION BOARD TERMS OF USE

By using this evaluation board or kit (together with all related software, firmware, components, and documentation provided by Nexperia, “Evaluation Board”), You (“You”) are agreeing to be bound by the terms and conditions of this Evaluation Board Terms of Use (“Agreement”). Do not use the Evaluation Board until You have read and agreed to these terms of use. Your use of the Evaluation Board constitutes Your acceptance of these terms of use.

Purpose and Use

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Operation of Board

It is important to operate the board within Nexperia’s recommended specifications and environmental considerations as described in the Documentation. Exceeding specified ratings (such as input and output voltage, current, power, or environmental ranges) may cause property damage. If you have questions about these ratings, please contact Nexperia at……. prior to connecting interface electronics (including input power and intended loads). Any loads applied outside of a specified output range may result in adverse consequences, including unintended or inaccurate evaluations or possible permanent damage to the board or its interfaced electronics. Please consult the Documentation prior to connecting any load to the board. If you have any questions about load specifications for the board, please contact Nexperia at https://www.nexperia.com/about/contact-us. for assistance. Users should ensure that appropriate safety procedures are followed when working with the board as serious injury, including death by electrocution or serious injury by electrical shock or electrical burns can occur if you do not follow proper safety precautions. It is not necessary in proper operation for the user to touch the board while it is energized. When devices are being attached to the board for testing, the board must be disconnected from the electrical source and any bulk capacitors must be fully discharged. When the board is connected to an electrical source and for a short time thereafter until board components are fully discharged, some board components will be electrically charged and/or have temperatures greater than 50˚ Celsius. These components may include bulk capacitors, connectors, linear regulators, switching transistors, heatsinks, resistors and SiC diodes that can be identified using board schematic. Users should contact Nexperia at https://www.nexperia.com/about/contact-us. for assistance if a board schematic is not included in the Documentation or if users have questions about a board's components. When operating the board, users should be aware that these components will be hot and could electrocute or electrically shock the user. As with all electronic evaluation tools, only qualified personnel knowledgeable in handling electronic performance evaluation, measurement, and diagnostic tools should use the board.

Safe Handling and Compliance with Laws

Users should read the Documentation and, specifically, the various hazard descriptions and warnings contained in the Documentation, prior to handling the board. The Documentation contains important safety information about voltages and temperatures. Users assume all responsibility and liability for the proper and safe handling of the board. Users are responsible for complying with all safety laws, rules, and regulations related to the use of the board. Users are responsible for (1) establishing protections and safeguards to ensure that a user's use of the board will not result in any property damage, injury, or death, even if the board should fail to perform as described, intended, or expected, and (2) ensuring the safety of any activities to be conducted by the user or the user's employees, affiliates, contractors, representatives, agents, or designees in the use of the board. User questions regarding the safe usage of the board should be directed to Nexperia at https://www.nexperia.com/about/contact-us..

In addition, users are responsible for:

- compliance with all international, national, state, and local laws, rules, and regulations that apply to the handling or use of the board by a user or the user's employees, affiliates, contractors, representatives, agents, or designees.
- taking necessary measures, at the user's expense, to correct radio interference if operation of the board causes interference with radio communications. The board may generate, use, and/or radiate radio frequency energy, but it has not been tested for compliance within the limits of computing devices pursuant to applicable laws
- compliance with applicable regulatory or safety compliance or certification standards such as those established by EU Directive 2011/65/EU of the European Parliament and of the Council on 8 June 2011 about the Restriction of Use of Hazardous Substances (or the RoHS 2 Directive) and EU Directive 2002/96/EC on Waste Electrical and Electronic Equipment (or WEEE). The board is not a finished end product and therefore may not meet such standards. Users are also responsible for properly disposing of a board's components and materials.

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