Evaluation Board User Guide

TMC9660-3PH-EVKIT

TMC9660 with Highly Integrated Monolithic Motor Controller and Gate Driver IC for Three-Phase BLDC Motors

General Description

The TMC9660-3PH-EVKIT is part of the TRINAMIC evaluation board system. It is a 70V/10A permanent magnet synchronous motors (PMSM)/brushless DC (BLDC) evaluation kit (EV kit) that allows evaluation of the TMC9660, which is a highly integrated monolithic motor controller and gate driver IC for three-phase BLDC motors, two-phase bipolar stepper motors, and DC motors.

The TMC9660-3PH-EVAL, included in this kit, focuses on the usage of three-phase BLDC motors with the possibility to use ABN encoders or digital hall sensors as position feedback mechanism. Additionally, the board allows simultaneous control of a brake chopper and an electromechanical brake through the otherwise unused fourth half-bridge.

The boards included in this kit, in combination with the TMCL-IDE, allow for an uncomplicated first evaluation of the TMC9660, while also providing full control of all its features.

Features

- Three-Phase PMSM/BLDC Motors and DC Motors up to 10A RMS Coil Current (20A Peak)
- 8V to 70V DC Single-Supply Voltage Range
- Field-Oriented Controller (FOC) in Hardware
- Position, Velocity, and Torque Controller in Hardware
- Brake Chopper and Electromechanical Brake Outputs
- SPI and UART Interfaces for Communication with a Main Controller

TMC9660-3PH-EVKIT Contents

ITEM	DESCRIPTION
TMC9660-3PH-EVAL	TMC9660 Evaluation Board
Landungsbruecke	PC Interface Board
Eselsbruecke	Bridge Connection Board

Documents Needed

- TMC9660 Data sheet
- TMC9660-3PH-EVAL design files

Software Needed

TMCL-IDE Evaluation Software

Ordering Information appears at end of data sheet.

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One Analog Way, Wilmington, MA 01887-2356, U.S.A. | Tel: 781.329.4700

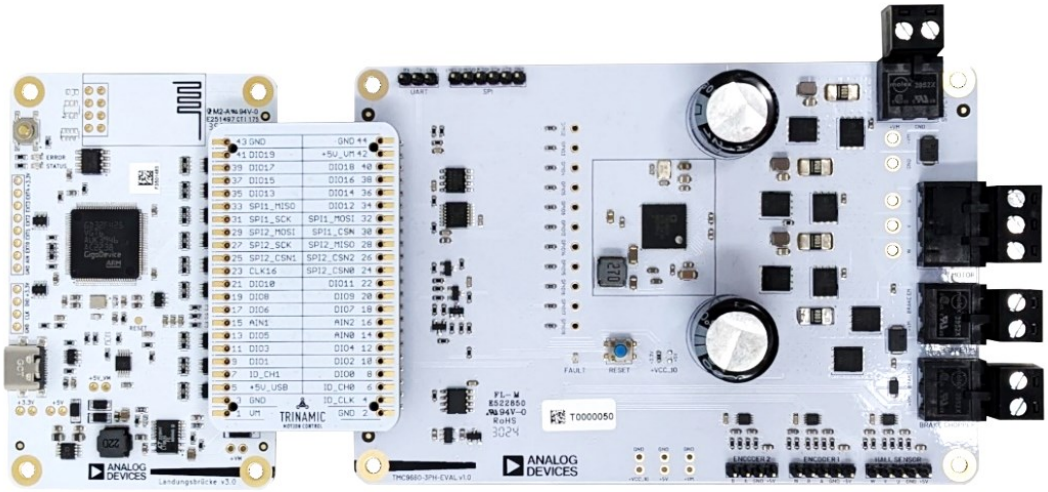

Figure 1. Assembled TMC9660-3PH-EVKIT

Getting Started

Required Items

- TMC9660-3PH-EVAL
- Landungsbruecke board
- Eselsbruecke board
- A compatible motor, for example, a Qmot BLDC motor
- Power supply
- Cables to interface the motor, encoders, and the power supply
- Latest TMCL-IDE

Precautions

- Do not exceed the board's maximum rated supply voltage.
- Do not connect or disconnect the motor while the board is powered.
- Make sure that the used board, cables, and motor are in a good state before using them.
- Mind the used power supply voltage. Voltages greater than 50V are stated as dangerous in some countries.
- Do not touch the power stage section of the board during operation as it might get hot.

IO Supply Selection

The TMC9660-3PH-EVAL comes with the possibility to select the input/output (IO) supply voltage to one of 3.3V or 5V, which is accomplished by mounting a 0Ω resistor on either one of R304 and R303. By default, the TMC9660-3PH-EVAL comes with R304.

The selection of an adequate IO supply voltage is especially important when using external peripherals with the UART, SPI, or the GPIO headers. On the contrary, the hall sensor or ABN encoder headers are not affected by the IO supply selection, as they are always referenced to 5V, and their digital signals translated into the selected IO supply level.

Note that using an IO supply voltage of 3.3V is mandatory when the Landungsbruecke board is used as the main controller. However, if an IO supply voltage of 5V is needed, simply unmount R304 and mount it back at R303. For reference, see the schematics detail in *Figure 7*.

Connecting the Peripherals

1. Interface the TMC9660-3PH-EVAL with the Landungsbruecke through the Eselsbruecke bridge board, as shown in *Figure 1*. While connecting the boards together, both the Landungsbruecke and the TMC9660-3PH-EVAL must be unpowered. Make sure that every pin in the connector is connected to its corresponding header. The working area is nonconductive to prevent shorting of pins on the backside of the boards.
2. Plug the selected motor to the Connector J203, labeled as *MOTOR* on the board's silkscreen (see *Figure 5).* Observe the correct order of the U, V, and W motor phases.
3. Plug the selected position feedback mechanism to the pin header J501, J502, or J503, labeled as *HALL SENSOR*, *ENCODER 1*, and *ENCODER 2,* respectively, on the board's silkscreen (see *Figure 5*). At least one position feedback mechanism is required, however, the three of them can be plugged and used simultaneously. However, note that of the ABN Encoders only ABN Encoder 1 can be used for motor commutation, while either of ABN Encoder 1 or Encoder 2 can be used for velocity or position feedback.
4. Connect the Landungsbruecke board to the computer through a USB cable.
5. Plug the power supply cable to the Connector J202, labeled as *SUPPLY* on the board's silkscreen (see *Figure 5*). Make sure the power supply is off before connecting it to the board and that the polarity is correct.
6. Voltages above 50V are stated as dangerous in some countries. Keep the work area clean and do not touch the board while powered on. Keep in mind that the power stage section of the board can get hot during operation.
7. The board is now ready for the next steps, continue with the following section, but do not turn on the power supply yet.

TMCL-IDE Quick Start

Make sure the latest version of the TMCL-IDE is installed on the computer. The latest version can be downloaded from *TMCL-IDE*. Open the IDE, the board should be automatically detected, and it should appear in the *Device tree*, as shown in *Figure 2*. If the board is not automatically detected, manually select it by following the steps shown in *Figure 3*.

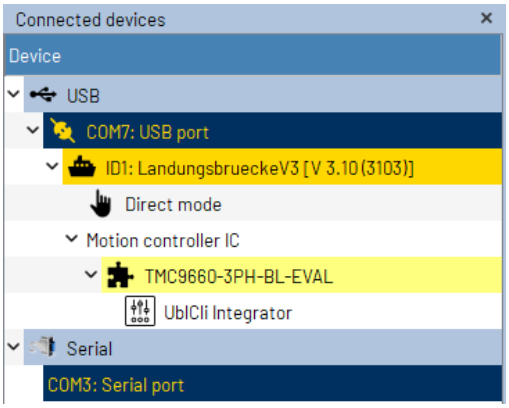

Figure 2. TMCL-IDE Device Tree

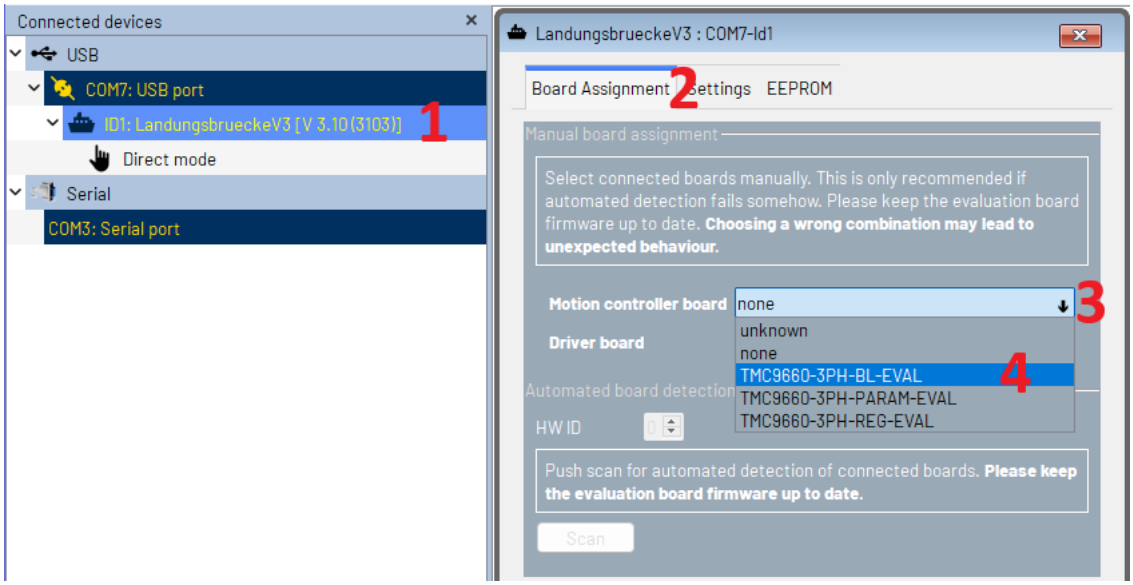

Figure 3. TMCL-IDE, Manual Selection of a Board

Turn on the power supply now.

The TMC9660 includes a bootloader that handles system bootstrapping and helps set low-level configuration of the chip. Such configuration is referred to in this manual as bootloader configuration, and may include GPIO matrix settings, clock-related settings, enabled communication interfaces, etc. The bootloader configuration should be set according to the used hardware and the intended application; for this reason, every TMC9660 must have its bootloader configuration correctly set before launching the full application included in its ROM. A detailed explanation of the bootloader and its configuration is given in the corresponding section of the TMC9660 data sheet.

Unless stored in the so-called one-time programmable (OTP) memory, the bootloader configuration in the TMC9660 is set to its default values on every power cycle or power-on reset. The TMCL-IDE includes a dedicated tool to facilitate the task of setting the bootloader configuration after power-on. Simply, click on the UblCli bootloader configuration tool located in the IDE's *Device tree* and follow the steps presented there.

After configuring the bootloader settings, the TMC9660 should be ready for operation. Click the **Wizard Pool** button, as shown in *Figure 4* , which is located on the right side of the *Button bar* at the top of the window. Alternatively, if the *Button bar* is not visible, click the **Tools** menu on the menu bar, and select **Wizard Pool**.

Figure 4. TMCL-IDE Wizard Pool Selection

Once the wizard launches, simply follow the steps presented in it. The wizard provides an uncomplicated guide to set up the TMC9660 with the connected motor and additional peripherals, as well as the needed tuning of the PI controllers.

For further instructions and clarifications on how to use the IDE, see the *TMCL-IDE User Manual*, which can be accessed by clicking the **Help** menu on the menu bar.

Hardware Description

Download the TMC9660-3PH-EVAL design files linked *above* and use them as a reference alongside this section of the user guide. These files include a BOM, component placement drawings, schematics, and fabrication files.

Component Placement Drawing

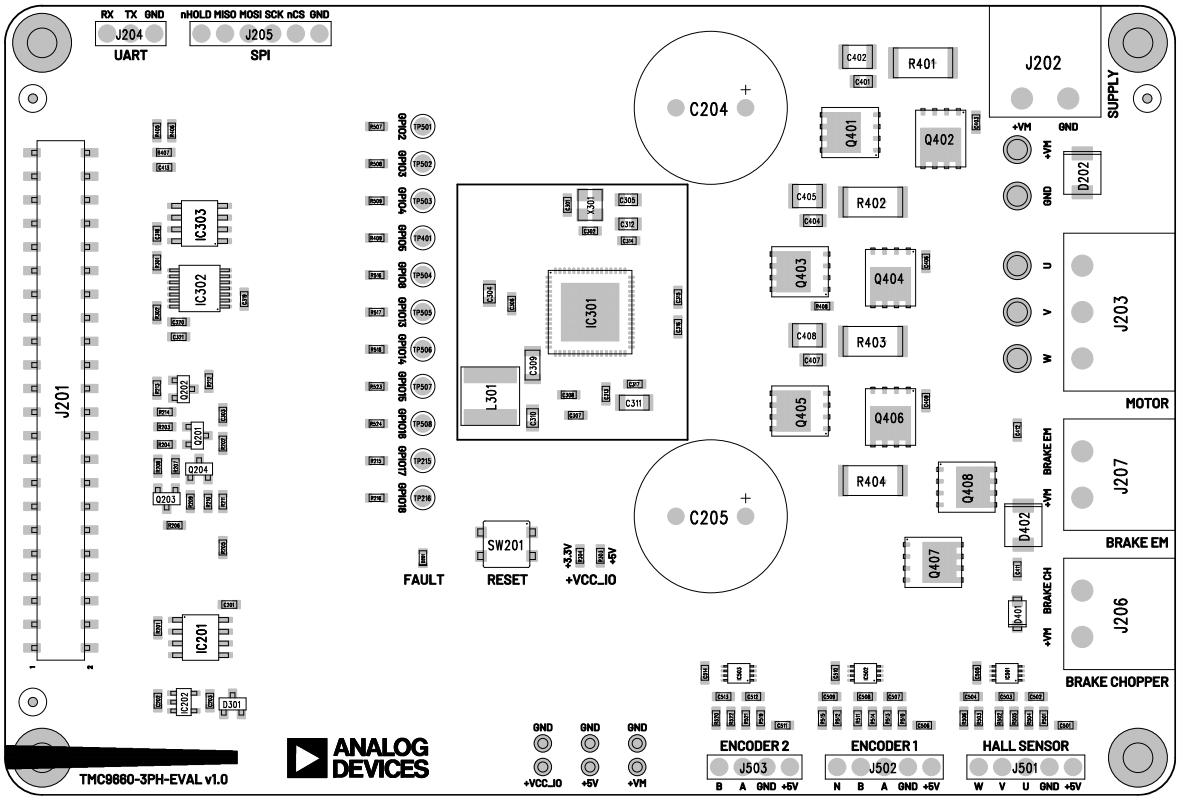

Figure 5. TMC9660-3PH-EVAL Component Placement and Silkscreen

Onboard Connectors and Pin Headers

The TMC9660-3PH-EVAL has four power connectors and five pin headers. These can be found in the component placement drawing in *Figure 5* and are described in detail in the following table.

Table 1. TMC9660-3PH-EVAL Available Connectors

REFERENCE DESIGNATOR	CONNECTOR TYPE	DESCRIPTION
J202	Terminal block 2 pos. (Molex 395221002)	Connector for the main power supply input. This connector is rated for up to 10A, and if more current is needed, fitting wires should be soldered to the two plated through-holes located in front of the connector.
J203	Terminal block 3 pos. (Molex 395221003)	Connector for the U, V, and W phases of the motor. This connector is rated for up to 10A, and if more current is needed, fitting wires should be soldered to the three plated through-holes located in front of the connector.
J206	Terminal block 2 pos. (Molex 395221002)	Connector for the brake chopper output. Even though the connector itself is rated for up to 10A, the current rating of 1A of the fly-back diode D401 attached to this connector must be considered when choosing a load resistor.
J207	Terminal block 2 pos. (Molex 395221002)	Connector for the electromechanical brake output. This connector is rated for up to 10A.
J201	2.54mm female pin header 22x2 (W+P 46-3492-44-3-00-10-PPTR)	Main IO connector to interface with the Landungsbruecke through the Eselsbruecke bridge board. A detailed view of this connector is given in *Figure 6*.
J501	2.54mm pin header 5x1	Connector for the digital hall sensor. This connector is always referenced to 5V and includes 4.7kΩ pull-up resistors on all its inputs. The input signals get translated into the appropriate IO level internally.
J502	2.54mm pin header 5x1	Connector for the ABN encoder. This connector is always referenced to 5V and includes 4.7 kΩ pull-up resistors on all its inputs. The input signals get translated into the appropriate IO level internally.
J503	2.54mm pin header 4x1	Connector for the second ABN encoder. Note that only A and B inputs are available. This connector is always referenced to 5V and includes 4.7kΩ pull-up resistors on all its inputs. The input signals get translated into the appropriate IO level internally.
J204	2.54mm pin header 3x1	Connector for the UART communication with the board. This connector is referenced to the selected IO supply level.
J205	2.54mm pin header 6x1	Connector for the SPI communication with the board. This connector is referenced to the selected IO supply level.

Additional Connectors

In addition to the connectors shown in *Table 1*, some unpopulated THM test points are available in the TMC9660-3PH-EVAL. See the component placement drawing in *Figure 5*.The additional connectors are described in the following table.

Table 2. TMC9660-3PH-EVAL Additional Connectors and Test Points

REFERENCE DESIGNATOR	CONNECTOR TYPE	DESCRIPTION
PTH205 and PTH206	Unpopulated THM test point. These are placed 2.54mm apart from each other, so a standard pin header could also be mounted.	Test points for the main supply voltage and ground. They are labeled as *+VM* on the board's silkscreen.
PTH207 and PTH208	Unpopulated THM test point. These are placed 2.54mm apart from each other, so a standard pin header could also be mounted.	Test points for the 5V line and ground. They are labeled as *+5V* on the board's silkscreen.
PTH209 and PTH210	Unpopulated THM test point. These are placed 2.54mm apart from each other, so a standard pin header could also be mounted.	Test points for the selected IO supply voltage and ground. They are labeled as *+VCC_IO* on the board's silkscreen.
TP501, TP502 TP503, TP401, TP504, TP505, TP506, TP507, TP508, TP215, TP216	Unpopulated THM test point	Test point for GPIO2 through GPIO5, GPIO8 and GPIO13 through GPIO18. These are all referenced to the selected IO supply level. Each one of them is labeled accordingly on the board's silkscreen.

Pay close attention when using any of the 5V or 3.3V lines to supply external loads. These two voltage lines are directly pulled from the TMC9660 integrated configurable LDOs. For this reason, the load current of each of the LDOs must not exceed 150mA, including the components already present in the TMC9660-3PH-EVAL.

Note that most of the GPIO pins available in the TMC9660 are used in the TMC9660-3PH-EVAL with one of their alternative functionalities, for example, encoder inputs, UART, SPI. If any of the alternative functionalities is not needed in the application, the GPIOs can be freely used. To make use of them, it is necessary to remove the 0Ω resistor that is right in front of the selected GPIO's test point. See the board's schematics for more details.

User Input and Feedback

The TMC9660-3PH-EVAL includes a push button (SW201) labeled as *RESET* on the board's silkscreen, as seen in the component placement drawing in *Figure 5*. This button is tied to the RESETN pin of the TMC9660 and includes a 12kΩ pull-up resistor referenced to the 5.8V line, that is, the output of the TMC9660 internal buck regulator.

A red LED (D201) is also included for user feedback, and this is labeled as *FAULT* on the board's silkscreen. The LED is connected to the 5.8V line in such a way that it lights up when the FAULTN pin is active. Note that the behavior of the FAULTN pin is dependent on the bootloader configuration of the TMC9660, and it does not necessarily imply a fault condition in all cases. This behavior is described in detail in the bootloader section of the TMC9660 data sheet.

Landungsbruecke Connector

The Landungsbruecke connector section of the TMC9660-3PH-EVAL schematics is shown in *Figure 6*. Important control signals are interfaced through the Landungsbruecke, for example, the TMC9660 WAKE, DRV_ENABLE, and RESETN input pins, as well as the FAULTN output pin. The UART and SPI communication signals are also interfaced through this connector.

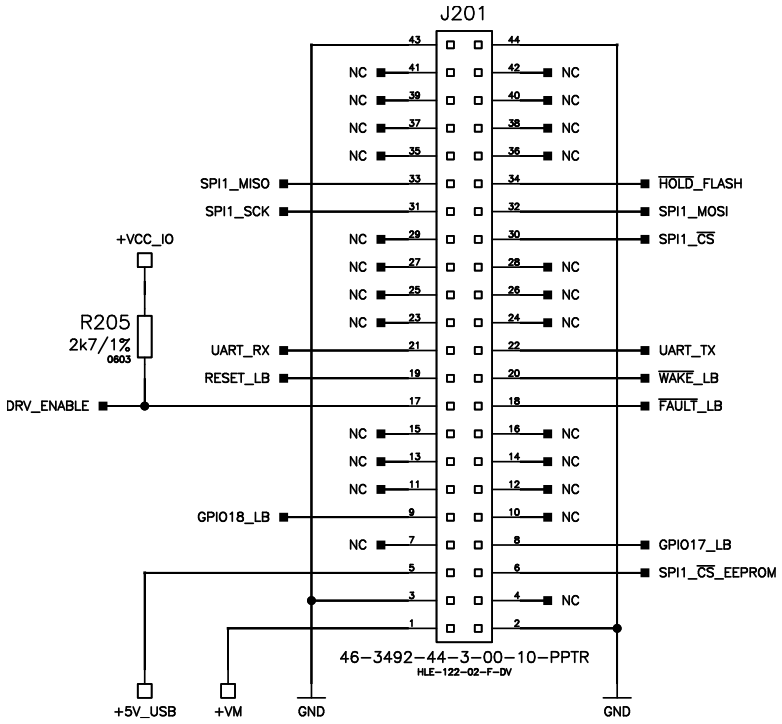

Figure 6. TMC9660-3PH-EVAL Schematics Detail of the Landungsbruecke Connector

An extra supply line (+5V_USB) coming from the Landungsbruecke, provides a temporary power source for the TMC9660's V_{CC_IO} pin, that is, its IO supply input. This external supply is required on a TMC9660-3PH-EVAL as long as the IC's integrated LDOs (from which VCCIO is normally pulled) are not configured and enabled. This can be better understood by looking at the board's schematics details in *Figure 7*, where pins V_{EXT1} and V_{EXT2} of IC301 correspond to the output of the TMC9660's integrated LDOs.

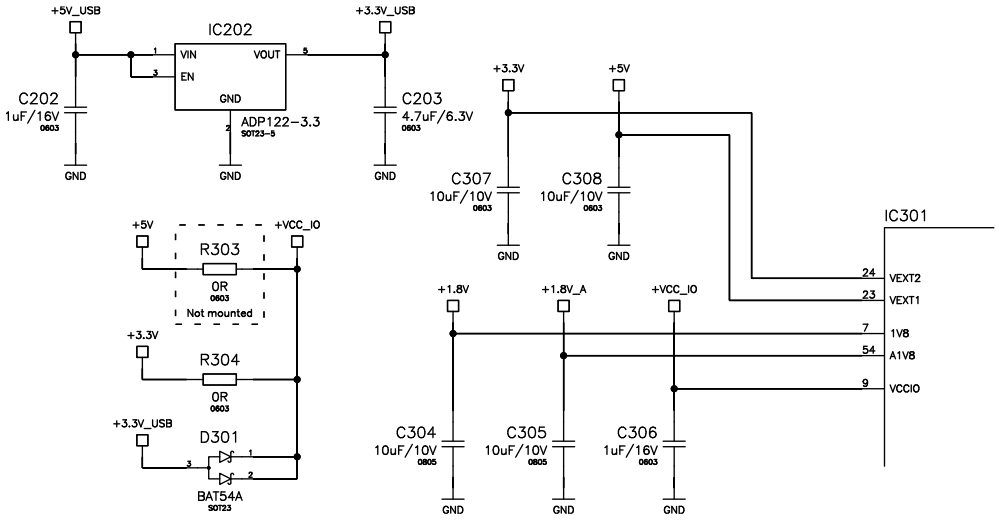

Figure 7. TMC9660-3PH-EVAL Schematics Detail of the IO Supply Circuit

Standalone Operation

Standalone operation refers to the option of using the TMC9660-3PH-EVAL outside of the TRINAMIC evaluation board system, that is, without the Landungsbruecke board as a controller. To achieve this, two separate categories should be considered: the hardware connections and the bootloader configuration.

Hardware Requirements

As mentioned, the 5V and 3.3V supply voltage lines in the TMC9660-3PH-EVAL are directly pulled from the integrated LDOs of the TMC9660. Such LDOs are not enabled by default in an unconfigured IC; for this reason, an external IO supply source is needed for bootstrapping of the standalone setup.

Make sure to populate PTH209 and PTH210 with, for example, a standard 2.54mm 2 x 1 pin header. These connectors are tied to the TMC9660's IO supply line, as described in *Table 2*. Connect a power supply to the chosen connectors, paying attention to the correct polarity. For a standard configuration, it is recommended to use a 3.3V supply voltage and, ideally, passing through diode with a low forward voltage. This is to prevent having a reverse voltage on the internal LDOs once they are configured and enabled. See diode D301 in *Figure 7* and in the board schematics as a reference.

Next, an appropriate communication channel to a main controller is required; this can be either UART or SPI. For a standard configuration, it is recommended to use UART as communication channel with a main controller. This allows the SPI Flash memory included in the TMC9660-3PH-EVAL to be used by the TMC9660. Regardless of the chosen option, make sure the chosen interface device uses the same reference voltage as the chosen IO supply on the board.

For UART operation, plug the selected interface to the Connector J204, whose pins are readily labeled as *RX*, *TX,* and *GND* in the board's silkscreen. The selected UART interface could be for example, an *FTDI USB to UART cable*.

Plug the selected motor to the Connector J203, the chosen position feedback mechanism to the corresponding pin header, and the power supply cable to the Connector J202 as described in the *Connecting the Peripherals* section.

The WAKE, DRV_ENABLE, and RESETN pins of the TMC9660 have a pull-up resistor in the TMC9660-3PH-EVAL so, unless special control over these inputs is required, no special consideration is needed for standalone operation.

The board is ready for the next steps. Power-on the external IO power supply and the main power supply, and continue with the following section.

Bootloader Configuration

As mentioned in the user guide , every TMC9660 must have its bootloader configuration correctly set before launching the full application included in its ROM. Therefore, the next step, once the hardware requirements are fulfilled, is to set the right bootloader configuration. For the standalone operation case, this task is accomplished through the so-called UblCli-executable Python script, which can be downloaded from *Motor and Motion Control Software*.

In brief, the UblCli is a command line tool meant for interaction and configuration of the TMC9660's bootloader. The command line tool can be used on a Windows PC through a terminal application such as *Git for Windows* or the *Windows Terminal*. This tool is described in detail in its own manual, which can be downloaded from the links provided *above*.

Before using the UblCli, note the port number of the chosen interface device. This can be found under the *Ports* section of the *Device Manager* on a Windows PC, as shown in *Figure 8*, in which case the port number is COM12.

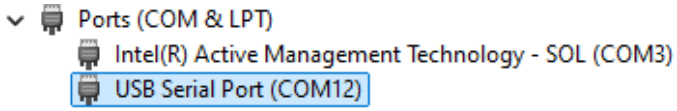

Figure 8. Interface Device Port Number

It is a good idea to first run the command "./ublcli.exe --port COM12 inspect chip" to check for a successful connection to the TMC9660. The output should look similar as shown in *Figure 9* for a successful connection.

```
$ ./ublcli.exe --port COM12 inspect chip
Chip Type:            TM01
Chip Variant:         0x2
Bootloader Version:   v1.0
Features:             RAM, ROM, OTP, SPI, I2C
Bootloader Git info:  d00ba81
Silicon version:      P2
```

Figure 9. Output of UblCli Inspect Chip Command

Then, run the command "./ublcli.exe --port COM12 write config ioconfig_tmc9660-3ph-eval.toml". In this case, the configuration is selected through the toml file called 'ioconfig_tmc9660-3ph-eval', which is in the same directory as the executable Python script. The output should look similar as shown in *Figure 10* for a successful programming of the configuration.

```
$ ./ublcli.exe --port COM12 write config ioconfig_tmc9660-3ph-eval.toml
Writing config values to TM01
Configuration write completed
```

Figure 10. Output of UblCli Write Config Command

Finally, the full application can be launched through the command "./ublcli.exe --port COM12 start ROM". If this step is successful, the TMC9660 should not respond to any further UblCli commands, as the IC is not in bootloader mode anymore, but rather inside of the full application. The standalone setup may now be configured and used through the TMCL-IDE or through the *PyTinamic* Python package.

As mentioned in this user guide, the UblCli tool uses a toml file to write the bootloader configuration of a TMC9660. *Table 3* contains a representation of such configuration file with all the needed settings for a TMC9660-3PH-EVAL. In the table, the rows highlighted in gray represent the toml file tables, whereas the values beneath them represent the key/value pairs for each table.

Table 3. TMC9660-3PH-EVAL Bootloader Configuration toml File Contents

CONFIGURATION KEY	CONFIGURATION VALUE
app_settings	
app_type	"tmcl"
uart	
enabled	true
pin_ic_tx	6
pin_ic_rx	7
baud_rate	"auto16"
chip_address	1
host_address	255
hall	
enabled	true
pin_ux	2
pin_v	3
pin_wy	4
spi_slave	
enabled	false
abn1	
enabled	true
pin_a	8
pin_b	13
pin_n	14
abn2	
enabled	true

pin_a	15
pin_b	16
spi_flash	
enabled	true
spi_block	“SPI0”
pin_cs	12
frequency	10000000
pin_spi0_sck	11
ext_mem	
tmcl_script	“spi_flash”
parameter_storage	“spi_flash”
stimulus_data	“spi_flash”
ldo	
vext1_voltage	5.0
vext1_slope_speed	23.53
vext2_voltage	3.3
vext2_slope_speed	25.53
fault_on_short	false
pll	
enabled	true
source	“ExtOsc”
sys_frequency	40000000
ext_frequency	16000000
xtal_boost	false
watchdog	
enabled	true
timeout	2000
breakchopper	
enabled	true
pin_brakechopper	“Y2”
mechanical_brake	
enabled	true
pin_mech_brake	“Y2”
gpio5	
type	“analog”
gpio17	
type	“input”
pull_resistor	“pulldown”
gpio18	
type	“input”
pull_resistor	“pulldown”

Ordering Information

PART	TYPE
TMC9660-3PH-EVKIT	Evaluation Kit

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	10/24	Initial release	—

Notes