Low voltage drives scalable power demonstration board

User manual

About this document

Scope and purpose

This user manual describes the modular platform – low voltage drives scalable power demonstration board. It covers the overview of the platform components, and the assembly procedures for some typical topology set-ups demonstrating several uses of the modular concept. An overview of the software package for an induction motor drive is also included.

Intended audience

The user manual is intended for power electronic engineers and designers who are familiar with power MOSFET-based converters, inverters and gate drivers, and who intend to build a modular set-up for investigating MOSFET suitability, switching optimization or proof-of-concept power electronic system.

Table of contents

1 Introduction

Evaluating implementation of new power MOSFET solutions and comparison of MOSFET capabilities requires a functional hardware set-up offering comparable layout characteristics for different device packages.

Infineon offers an easy-to-use platform intended for first evaluations of power MOSFETs in set-ups ranging from a single half-bridge to a three-phase inverter (motor drive topology).

The platform provides an easy approach to power MOSFET paralleling, without the need for soldering processes on the Insulated Metal Substrate (IMS) boards. All the necessary connections are established through the onboard connectors. This offers a fast method of hardware requirement verification, as the platform can be used instead of various preliminary test designs, thus shortening the initial design phase.
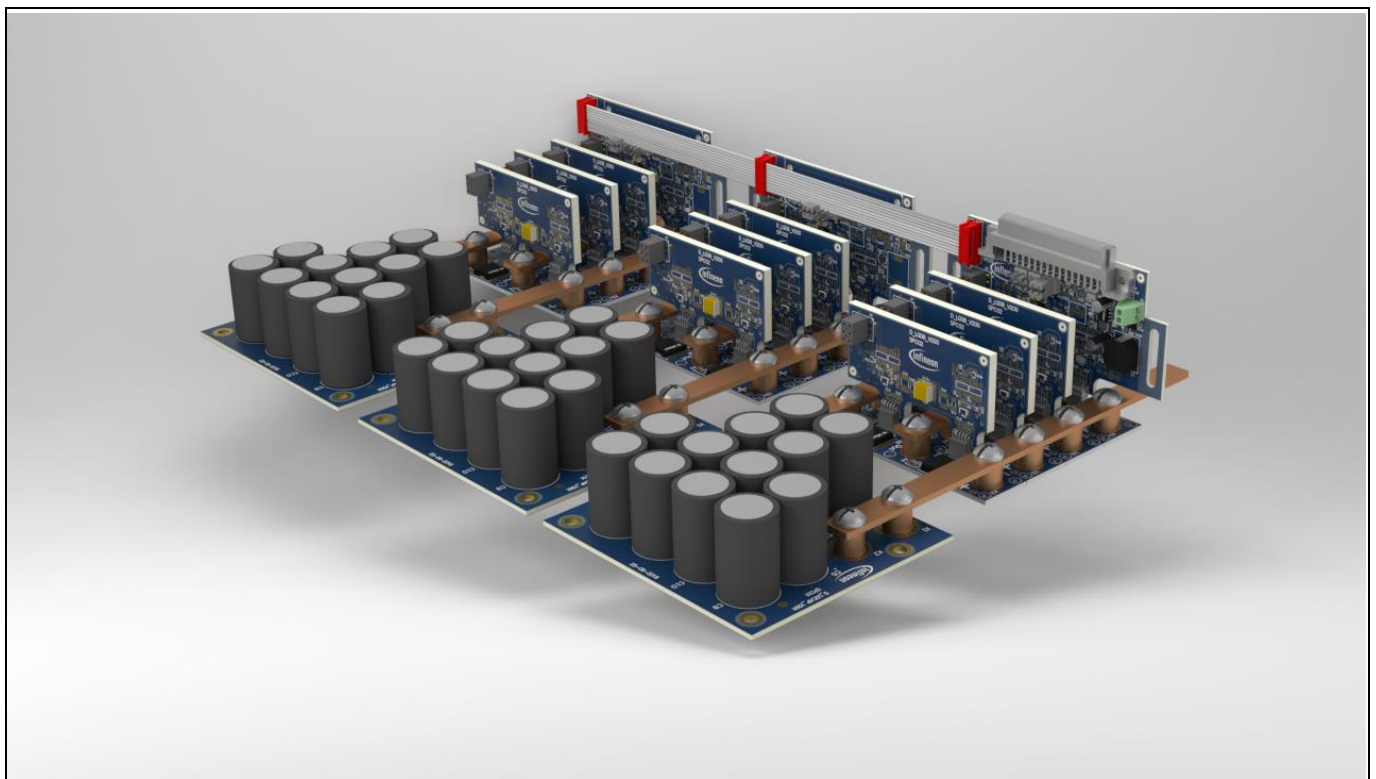

Figure 1 **Three-phase power inverter**

2 Board overview

The modular platform consists of different boards (modules) that can be used to build up a wide variety of functional power assemblies. The modularity offers a range of topology options, at various power handling capabilities. The concept can support applications based on half-bridge, full-bridge or three-phase topologies.

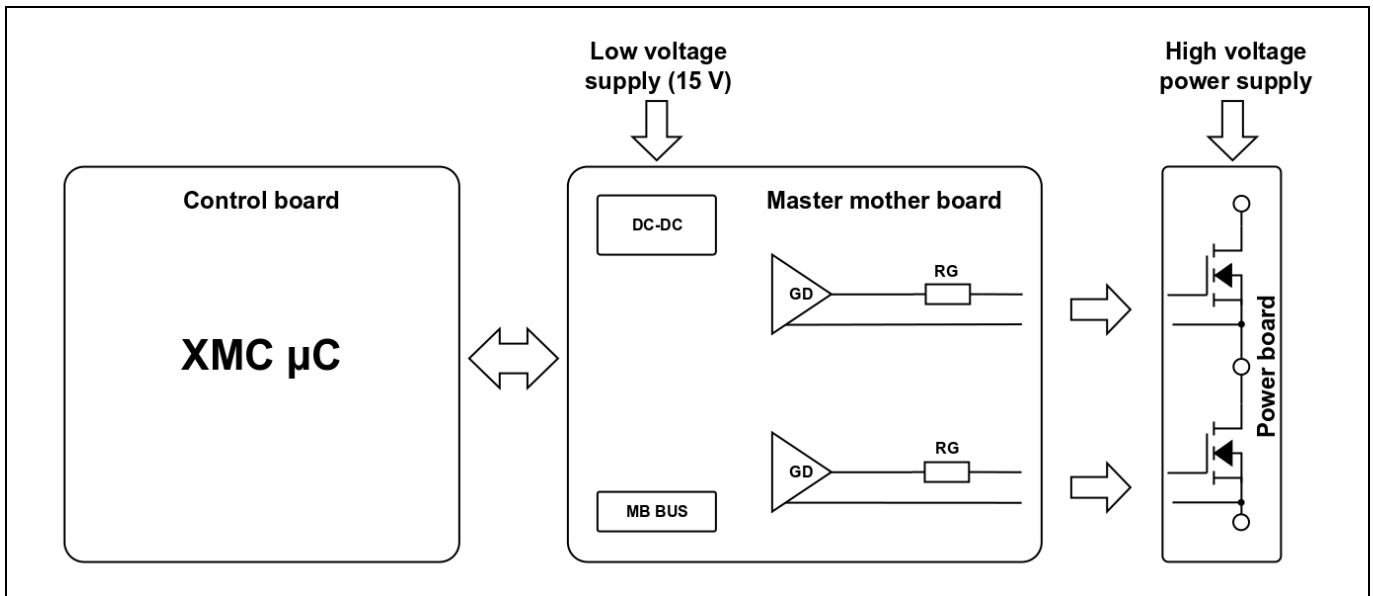The basic principle is illustrated in the block diagram in **Figure 2**.

Figure 2   **Modular design – basic principle**

By role (or functionality) in the set-up, the modules can be arranged into five categories:

- **Power board:** MOSFET half-bridge configuration
- **Mother board and master mother board:** gate driver board – connects to the first paralleled power board
- **Daughter board:** Interconnection between the gate driver and the paralleled power boards
- **Capacitor board:** PCB accommodating up to 12 capacitors connected to the DC bus
- **Control board:** Drive card XMC4400 demonstration board

Figure 2 shows a single-power half-bridge (power board), driven by the gate drivers (master mother board) and controlled by the XMC drive card (control board). Any set-up is controlled by a control board (e.g. XMC™ "Drive card – XMC4400") connected via the X3 connector to the master mother board.

The set-up can be expanded to a multi-phase set-up using additional mother boards connected at the mother board bus (MB BUS) via a ribbon cable.

Each phase can be expanded with several power boards connected in parallel.

Both expansion options are demonstrated in examples covered in chapter **3** – Example set-ups.

2.1   Power boards

The power boards are IMS PCB-based half-bridge sub-assemblies. Comprising a single high-side and a single low-side MOSFET with all the necessary connectors to provide the power and the gate drive connections, the power board is the basic building block of the modular platform.
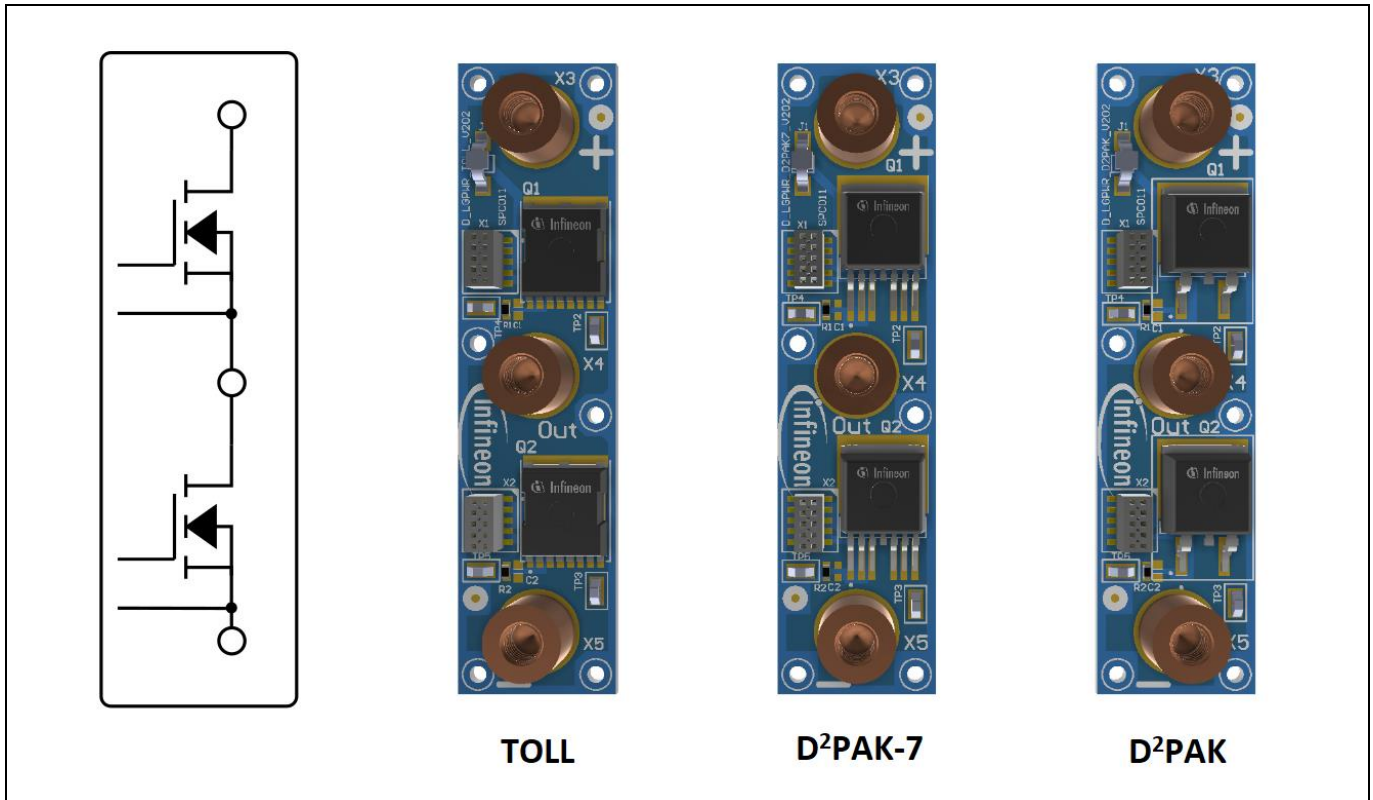

Figure 3   Power board versions: TOLL, D^{2}PAK-7, D^{2}PAK

Figure 3 shows the different versions of the power boards available. Each version implements a different MOSFET package while maintaining the same interconnection layout, so that all the different power board versions are interchangeable.

The package types featured in the power board designs are:

- TO-Leadless (TOLL)
- D^{2}PAK-7
- D^{2}PAK

The modular platform was designed for test purposes. A number of test point connectors are provided on the boards. The jumper provided at the high-side drain (the DC+ node) enables the user to utilize a Rogowski current probe for MOSFET drain current measurements.

The SMD connectors X3, X4 and X5 are provided for interconnection with high current capability. Either cable lugs or copper bars can be used for the power connection to the connector via standard M5 threading screws.

Detailed board dimensions are provided in the assembly drawings with the board schematic document in the documentation packages.

You can find all available versions and variants with regard to MOSFET products provided online.

2.2 Mother boards

The master mother board and the mother boards provide the gate drivers to the high-side and low-side MOSFETs, for each of the half-bridges as shown in **Figure 2**.
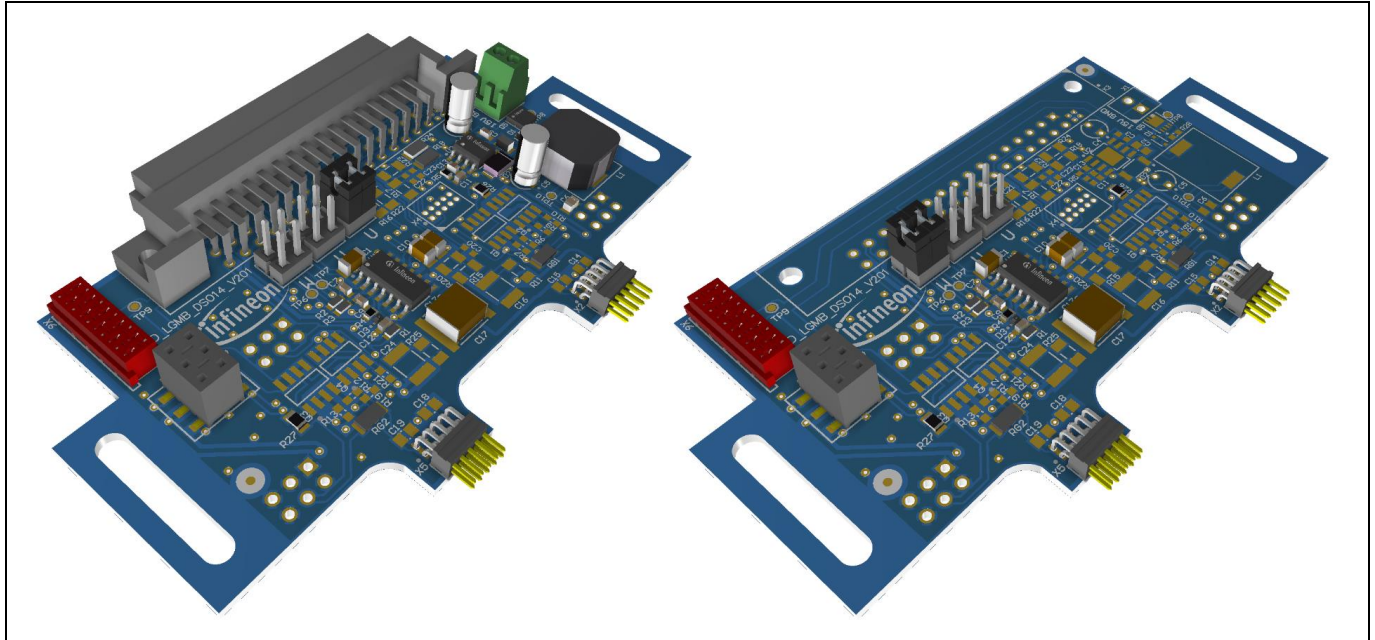

Figure 4 Master mother board (left) and mother board (right)

The difference between the two is the connection to the control board. The connection is only available at the master mother board, along with the onboard power supply sub-circuit that provides the 5 V supply line powering the XMC control board.

Multi-phase set-ups

Mother boards are used alongside a master mother board when a two- or three-phase system is implemented. The mother boards are connected to the master mother board through the mother board bus via a ribbon cable – connector X6. Gate driver supply, gate driver control and enable signals are propagated through the mother board bus.

Selection jumpers "U", "V" and "W" are provided to assign the control signals to each of the gate drivers. Only "V" and "W" control signals are present at the mother board bus (propagated through the ribbon cable). In a three-phase set-up the master mother board shall therefore always be selected as the "U" phase.
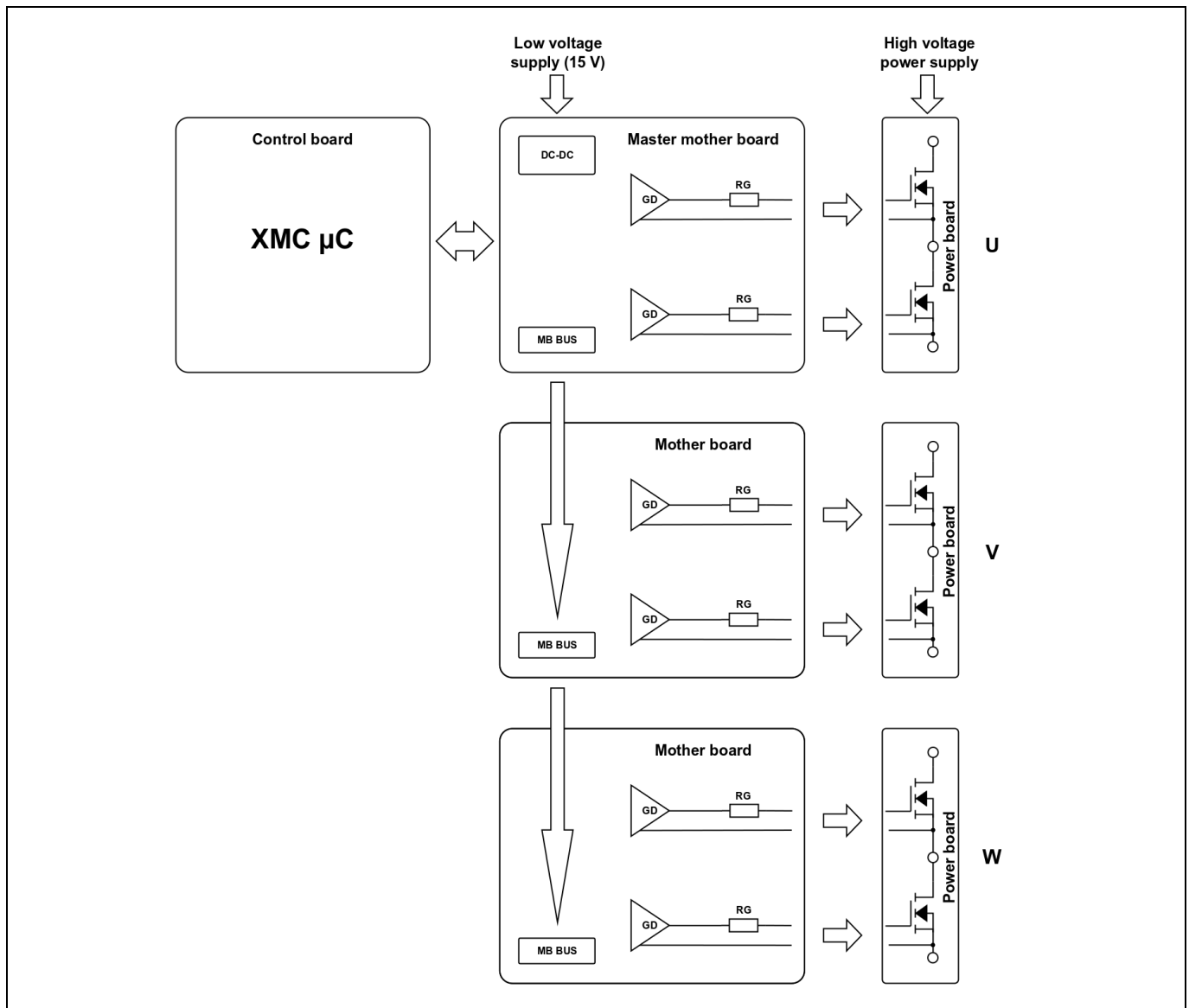
Figure 5   Utilization of master mother boards and mother boards in multi-phase set-ups (e.g. U, V, W)
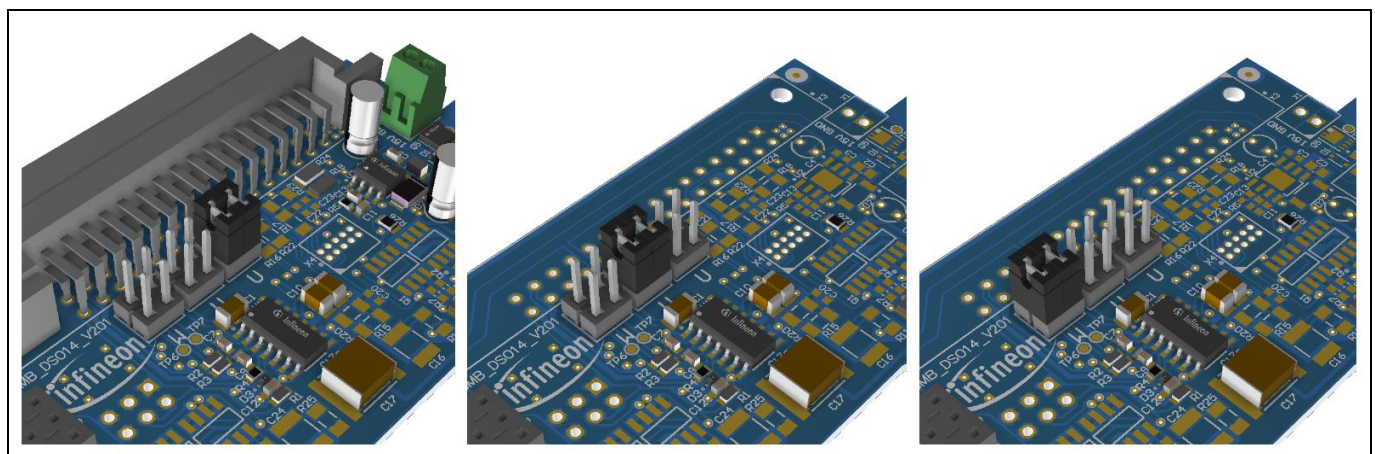

Figure 6   Jumper placement for phase selection – from left to right: U, V, W

System supply

The master mother board is supplied from a single 15 V external source (at the X1 connector teminal) and the onboard IFX91041EJV50 provides all the necessary LV supply to the rest of the system. The 15 V supply is also propagated to the mother boards over the mother board bus and used as the gate driver supply voltage.

Gate drivers

The 2EDL family gate drivers feature integrated high- and low-side gate drivers, with an integrated bootstrap diode. The gate driver output signals are propagated to the power board through header connectors X2 and X5. Mother boards also include the gate resistors (RG) for the two MOSFET gates connected at X2 and X5.

2.3 Daughter boards

Daughter boards are used for the interconnection between the gate driver outputs and power boards (MOSFET gates) via X7 and X11 header connectors, when adding power boards in parallel.

This enables paralleling of the power boards by branching the interconnection of the gate driver signals, and providing each additional MOSFET with the respective gate resistor.

The principle is illustrated in **Figure 8**.
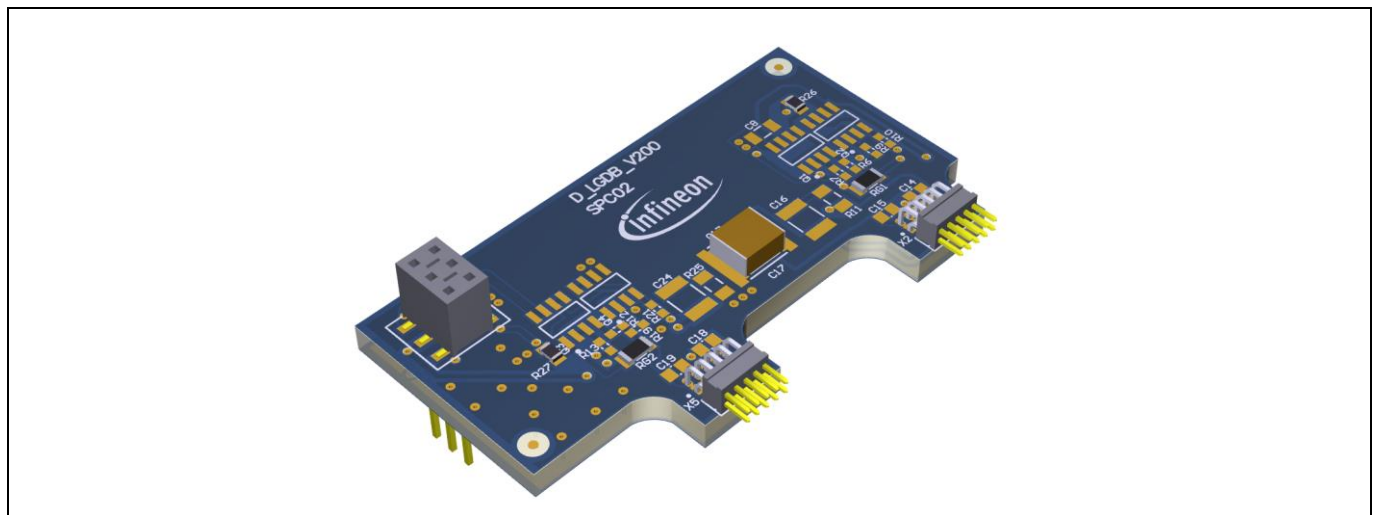

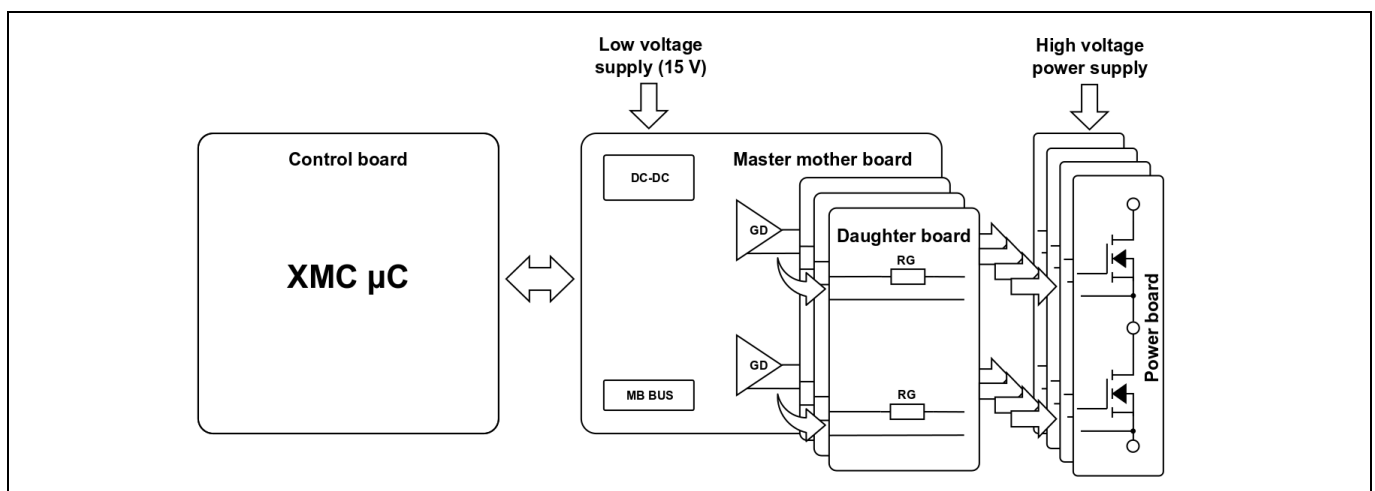Figure 7   Daughter board

Figure 8   Paralleling approach

2.4 Capacitor boards

The capacitor boards provide the system with an interconnection platform to connect leaded capacitors to the DC bus supplying the power half-bridges. Two power connector terminals per node are provided, and the four-layer PCB is designed to handle high currents.
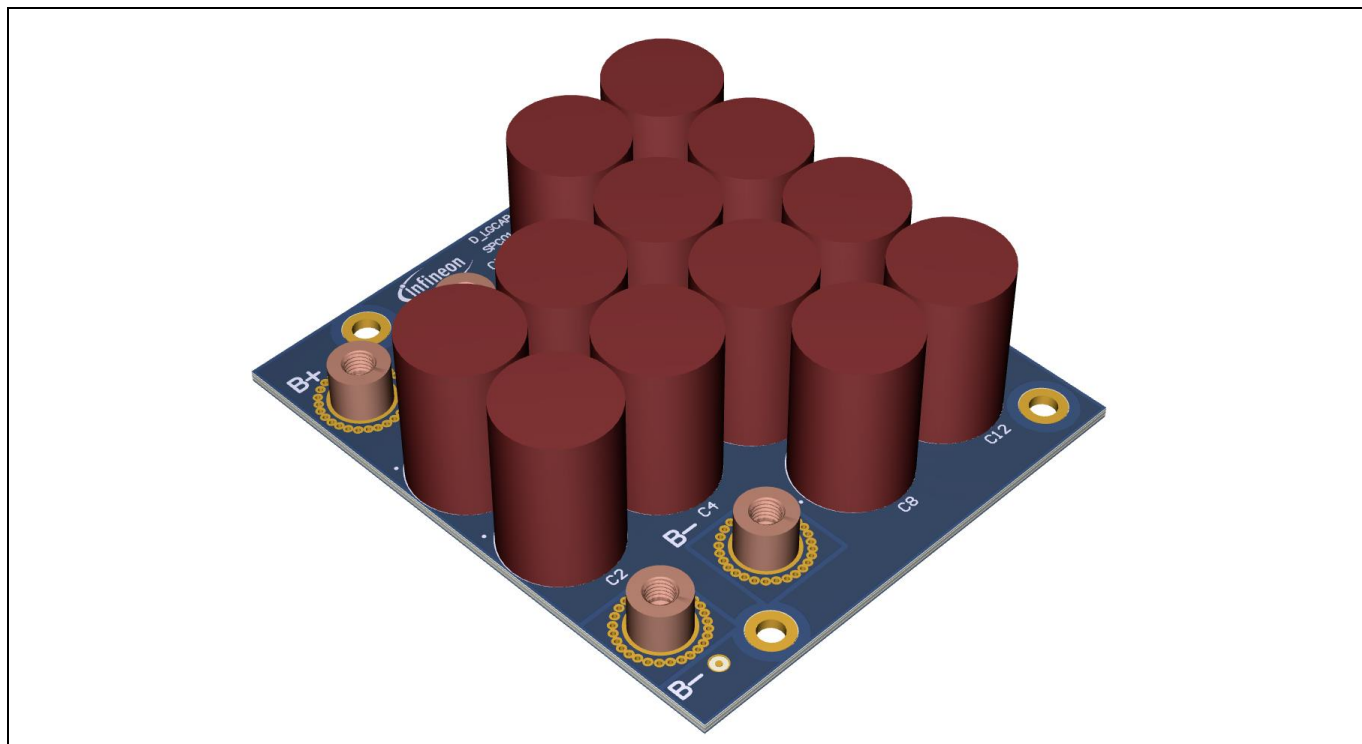

Figure 9   **Capacitor board**

Infineon provides this board, excluding the electrolytic capacitors. This is so that the user can select the capacitors according to project voltage and capacitance requirements. The boards can fit up to 12 capacitors; however, partially populating the boards is optional.

Table 1   **Capacitor selection – size requirements**

Parameter	Values			Unit
	Min.	Typ.	Max.	
Capacitor diameter			18	mm
Lead spacing		7.5		mm

Attention: ***The bus capacitor can store high energy at high voltage. Make sure to discharge the capacitors to a safe level before handling the board.***

2.5 Control board

Various control boards can be used with the demo board. The X3 connector (HIROSE PCN13-32S-2.54DS(71)) provided on the master mother board is adapted for interfacing with Infineon's XMC™ demonstration board: drive card XMC4400, which is used in the examples covered in this document.

The control signals are then propagated to the master mother board gate driver and the mother board bus, as described in chapter **3.2**.
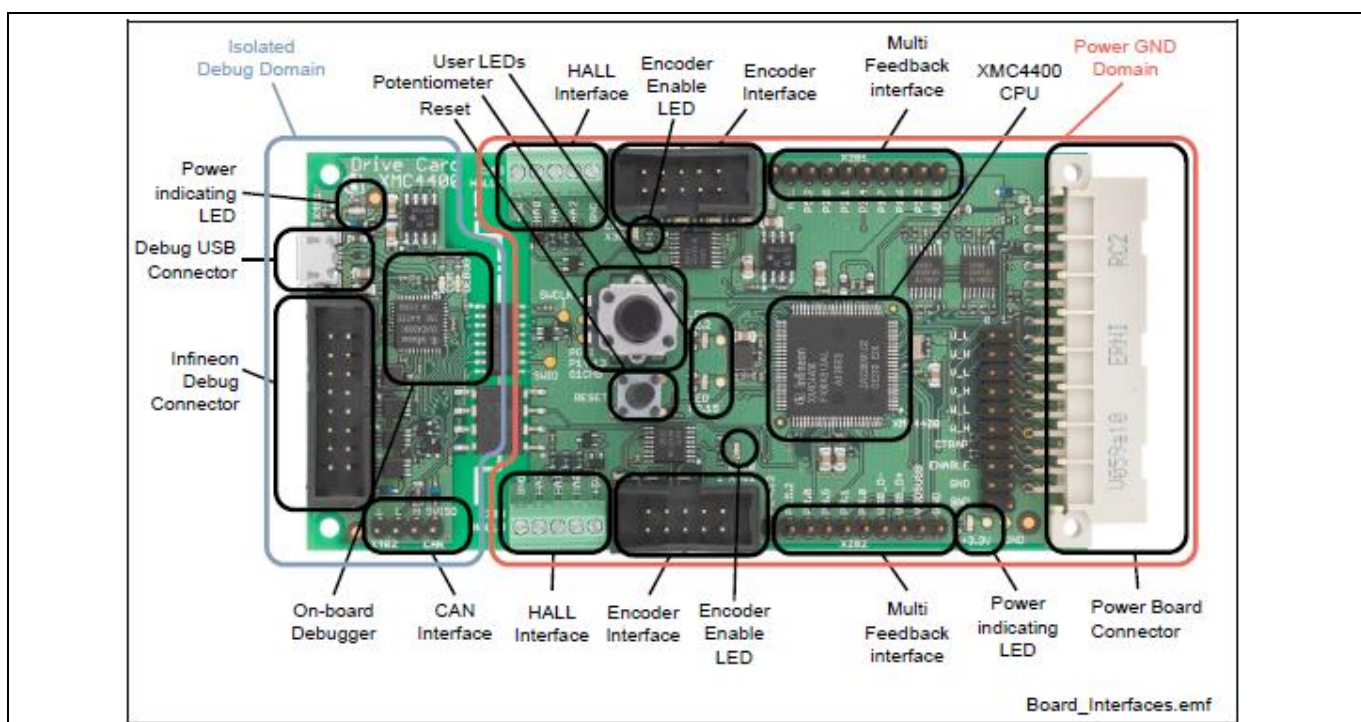
Figure 10   XMC4400 drive card demonstration board

A detailed description of the XMC4400 drive card can be found **online**.

2.6   Mechanical and interconnection accessories

Some additional accessories are required to complete the connections of the set-up. The quantities depend on the actual set-up being assembled. Some recommendations are given in **Table 2**, and are described below.

Table 2

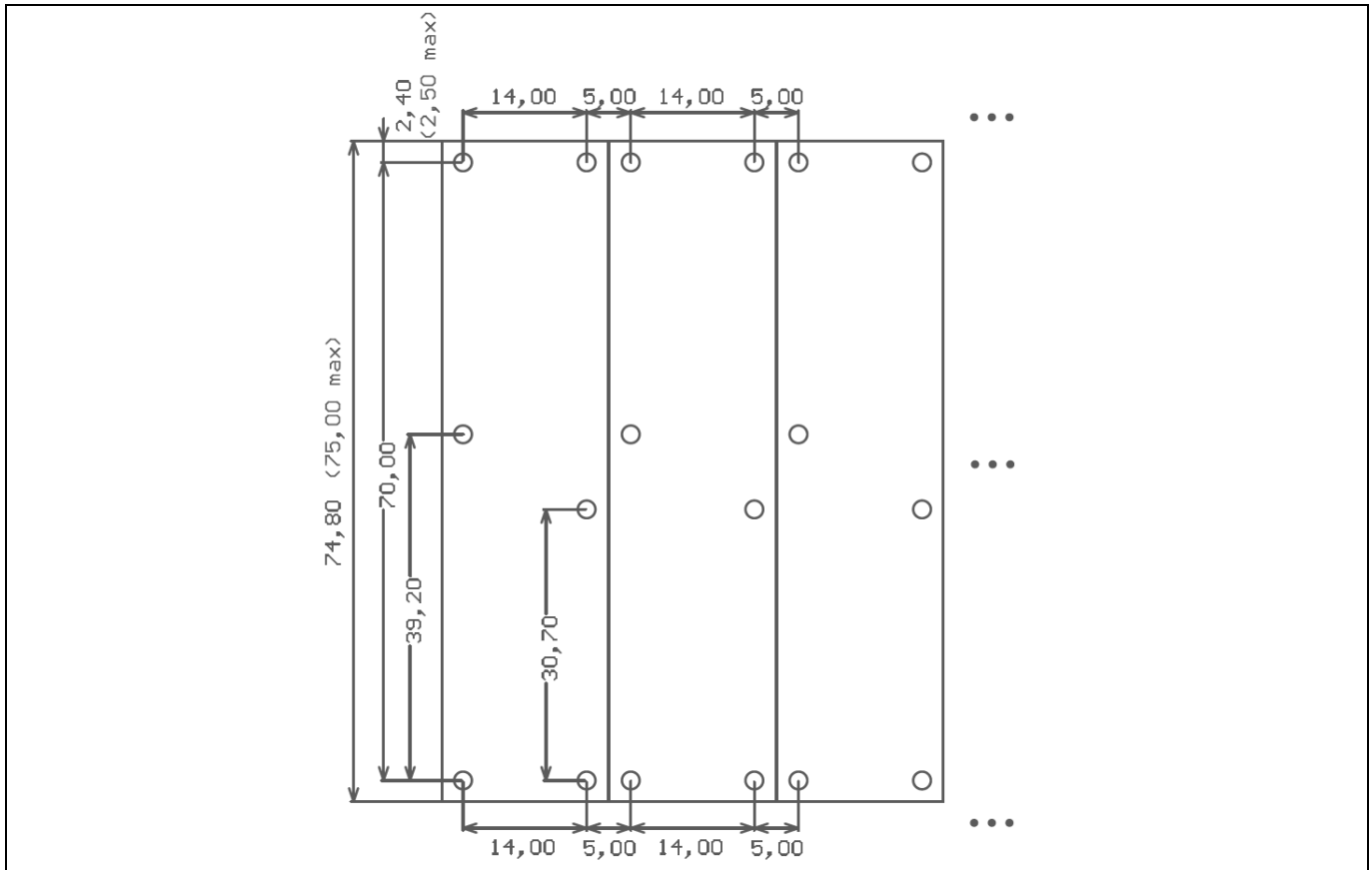| Part	Description	Note
Heatsink	100 mm width, length according to number of power boards	A 100 mm x 100 mm heatsink is recommended for four parallel power board set-ups (e.g. chapters **3.1.2** and **3.2**)
Copper bars with holes	2 mm thickness	See recommended dimensions below
Copper spacer	2 mm (min. thickness), 10 mm x 10 mm, hole dia. = 6.2 mm	Used to attach the multi-phase supply interconnection bars to phase-supply bars
Screw for power terminals	M5, 6 mm (max. threading length)	Recommended for use with 2 mm thick copper bars
Interconnection bolts and nuts	M5 or M6 recommended	Length depends on copper spacer thickness and cable lug thickness
Screw for attaching IMS boards to heatsink	M2, 5 mm (min. threading length)	Threading length needs to be in accordance with heatsink threaded hole depth

Heatsinks

Figure 11   Layout of heatsink threadings for power boards

In order to fully utilize the properties of the IMS boards, use of heatsinks is recommended.

Figure 11 shows the recommended layout for M2 threaded holes according to power board shape. The pattern is continued according to the number of power boards. The screw holes and the power connector layout are the same for all the power board versions of the modular platform.

It is also recommended to use thermal paste to improve the heat conduction from IMS (power boards) to heatsink.

Copper bars

A simple and effective approach for connecting the high-power connections is using copper bars that are attached to the power terminals via M5 screws. There are two different sets of copper bars. The length and number of holes of the phase supply and phase output copper bars depend on the number of paralleled power boards.

Recommended copper bar dimensions for the set-up described in chapter **3.2** are given in **Figure 12** and **Figure 13**; their use is described in chapter **3** – Example set-ups. The 19 mm hole spacing is defined according to the power board width, as shown in **Figure 11**.
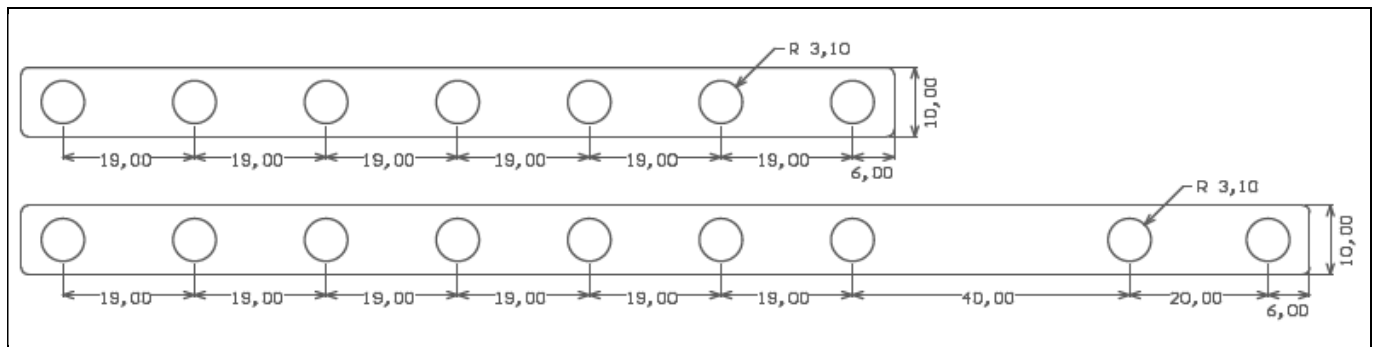
Figure 12 **Copper bar dimensions – phase output and phase supply (DC bus)**

Figure 13 **Copper bar dimensions – multi-phase supply interconnection**

Low voltage drives scalable power demonstration board
User manual
Example set-ups

3 Example set-ups

Attention: *This evaluation board has exposed high-voltage contacts. Use appropriate protective measures to avoid electrical shock. The evaluation board has no over-current shutdown, so it is possible to drive the MOSFETs to currents beyond their rating, which may result in their destruction. Use appropriate protective covers to prevent any possible injury from exploding components. Observe the drain-source breakdown voltage rating ($V_{(BR)DSS}$) of the MOSFETs used, and set the bus voltage accordingly. Always set appropriate current limit values on the external lab power supplies to minimize catastrophic damage to the board in the event of a fault. It is up to the user to set the PWM input signals appropriately to avoid damage.*

Several topologies can be assembled using different combinations of the boards. The following examples will guide the user through the procedures for handling and assembling a few typical set-ups, showcasing the principle of assembling systems of different topologies.

The examples also serve to further explain the roles of individual board categories in a working set-up.

A single half-bridge topology is used to explain the basic use of the master mother board and how to connect it to the power board. Power MOSFET paralleling in a single half-bridge covers the utilization of daughter boards, providing the connection from gate drivers to MOSFET gates of all the additional MOSFETs connected in parallel to the initial pair.

The final example shows the use of the additional mother boards connected to the master mother board via the mother board bus to form a multi-phase system controlled by the single microcontroller, connected at the master mother board.

In short – a master mother board is used in any single-phase set-up. Additional mother boards are added when additional phases are added to the system.

3.1 Single-phase set-up

The basic building blocks comprising a functional power half-bridge include two power transistors (e.g. MOSFETs), gate drivers for high-side and low-side MOSFETs, and a control unit (e.g. XMC microcontroller).

Mother boards of the modular platform provide the gate drivers for the system. A single mother board is used for any individual phase. The distinct feature of the master mother board is that it also provides the supply and direct interconnection to the control board, whereas mother boards connect to the control board indirectly via the ribbon cable through the master mother board, and do not include a supply circuit.

3.1.1 No paralleling

This is the single-phase set-up that can be used as a buck or boost converter topology, with or without synchronous rectification.

The minimal assembly, without any paralleling of the power boards, consists only of:

- **Power board** (one piece)
- **Master mother board** (one piece)
- **Infineon's XMC™ demonstration board drive card XMC4400** (one piece)
- **Capacitor board** (one piece)

The block diagram in **Figure 14** shows the basic elements of the full system.
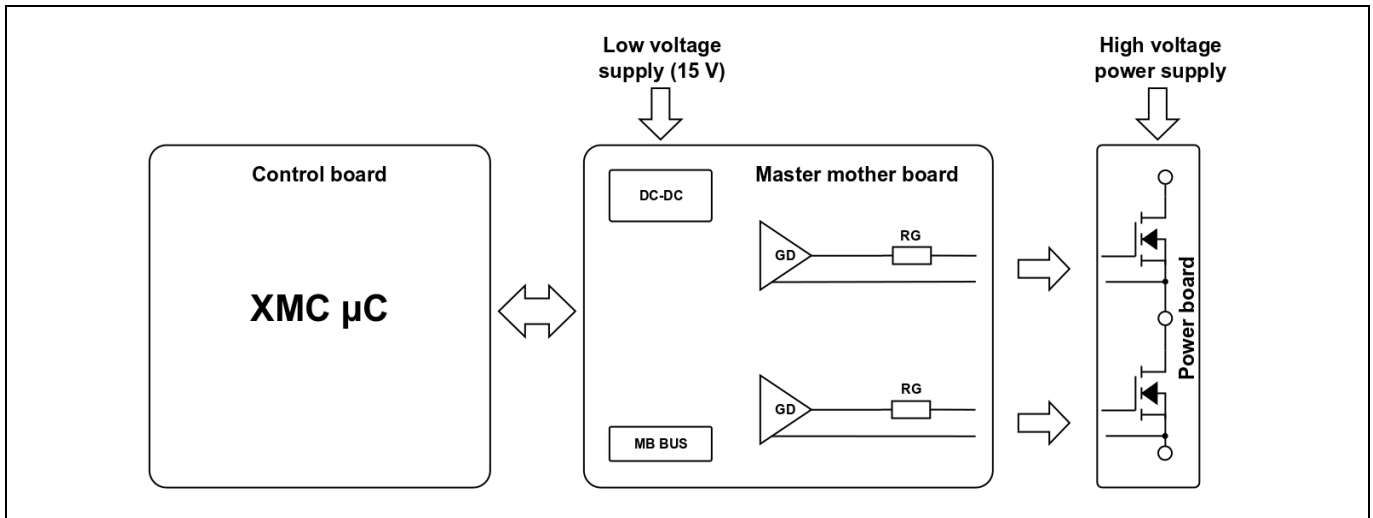
Figure 14   Block diagram

The master mother board and the power board are connected through the header conectors. X2 and X5 on the master mother board connect to X1 and X2 on the power board, as shown in **Figure 15**. The detail on the right shows the setting of the phase selection jumpers. To connect the gate driver control signals from the control board to the gate driver inputs on the master mother board, set the jumpers to position "U", as shown. This will connect the "U_L" and "U_H" signals to the gate driver – thus assigning the phase as the "U" phase.
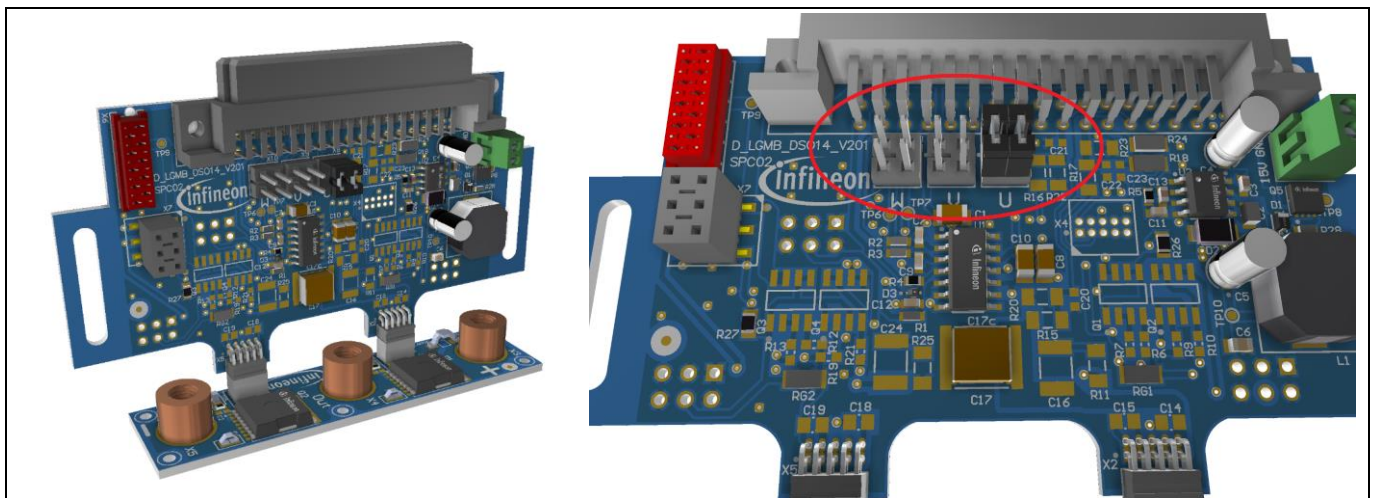

Figure 15   Master mother board connection to the power board, and jumper setting

A typical connection on the power side is either copper bars or cables terminated with cable lugs. The SMD screw terminals on the power boards provide standard M5 threading to attach the power connections.

Connect the capacitor bank (according to system requirements).

See chapter **3.3** for connection of the control board and the LV supply.

3.1.2   Power board paralleling

Additional power boards (half-bridges) can be connected in parallel, to increase the current handling capabilities. To do this, the same number of daughter boards are required to provide connections from the MOSFETs to the gate driver on the master mother board.
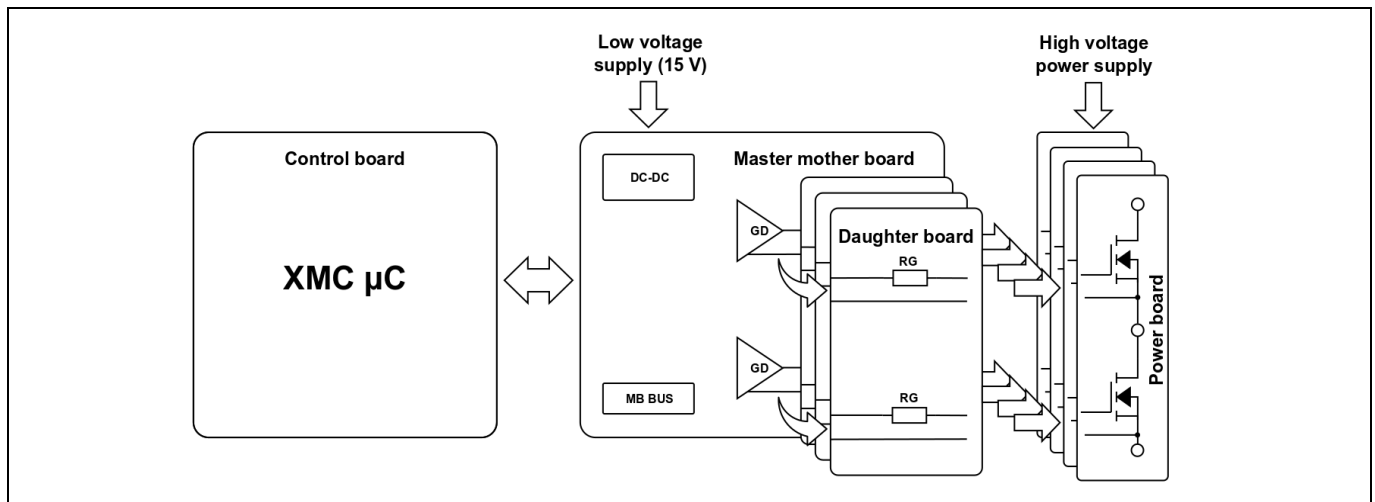
Figure 16   Block diagram – power board paralleling

From the connection point of view, any number of power boards can be added in parallel; however, gate driver current capabilities need to be considered. All power boards connected in parallel are driven by the same gate driver.

As shown in this example, using copper bars for the power connections is recommended (see chapter **2.6**).

The single-phase assembly, utilizing four power boards in parallel, consists of:

- **Power boards** (four pieces)
- **Master mother board** (one piece)
- **Daughter boards** (three pieces)
- **Infineon's XMC™ demonstration board drive card XMC4400** (one piece)
- **Capacitor board** (one piece)

Assembly procedure

Align the power boards next to each other. Holes are provided on the power boards to attach the power boards to a heatsink. Using thermal paste to improve the heat transfer to the heatsink is recommended.
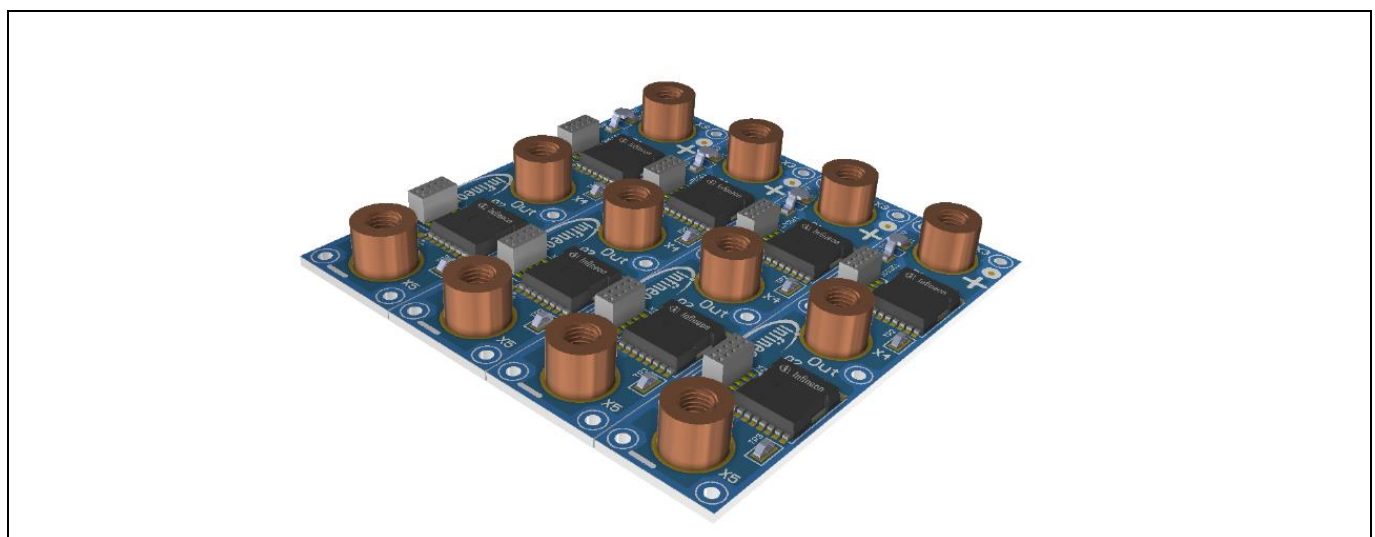

Figure 17   Four power boards – unconnected

Low voltage drives scalable power demonstration board
User manual
Example set-ups

The next step is to attach the copper bars to the threaded power terminals – **Figure 18**. M5 threaded screws should be used, and the screw should not protrude into the terminal more than 4 mm.

Assemble the gate drive sub-assembly of the master mother board and the three daughter boards, as shown in **Figure 19**. The X7 headers should not be inserted all the way.
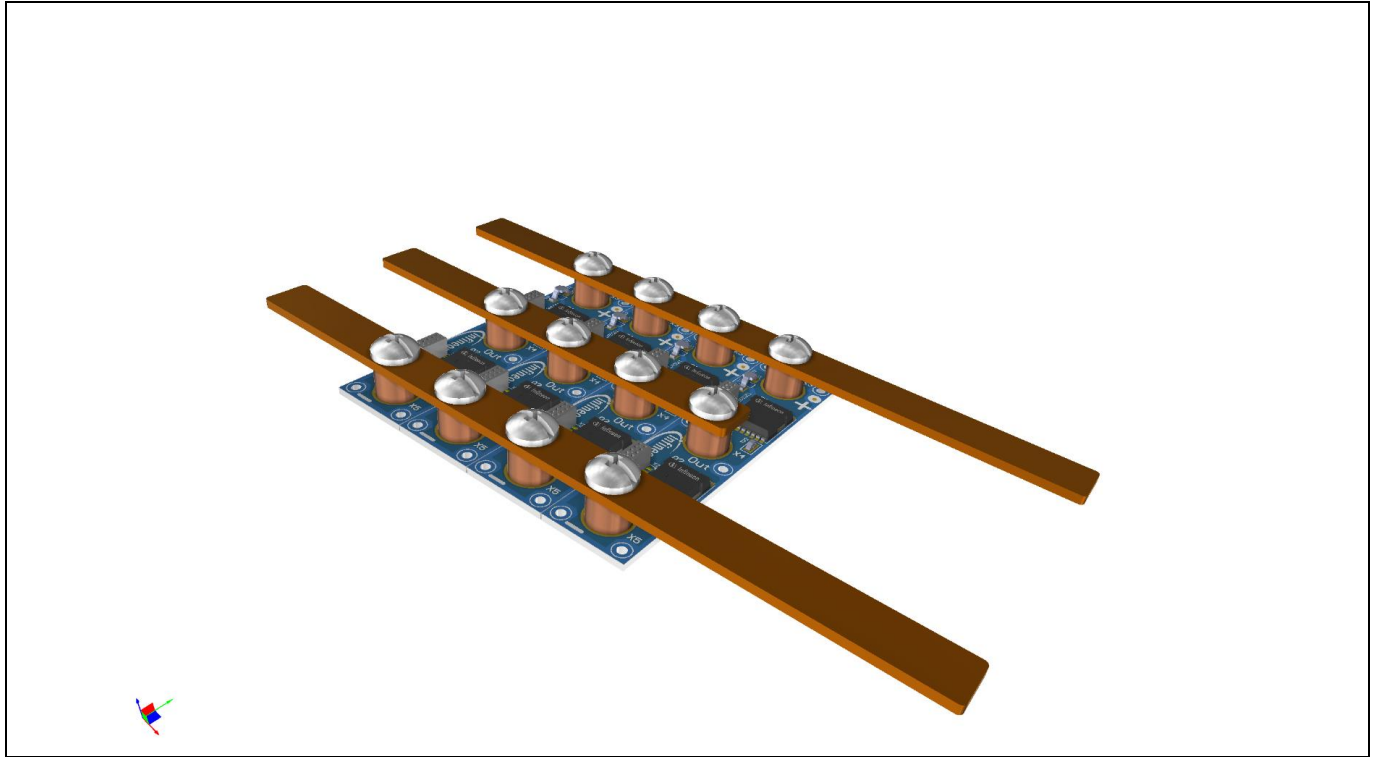

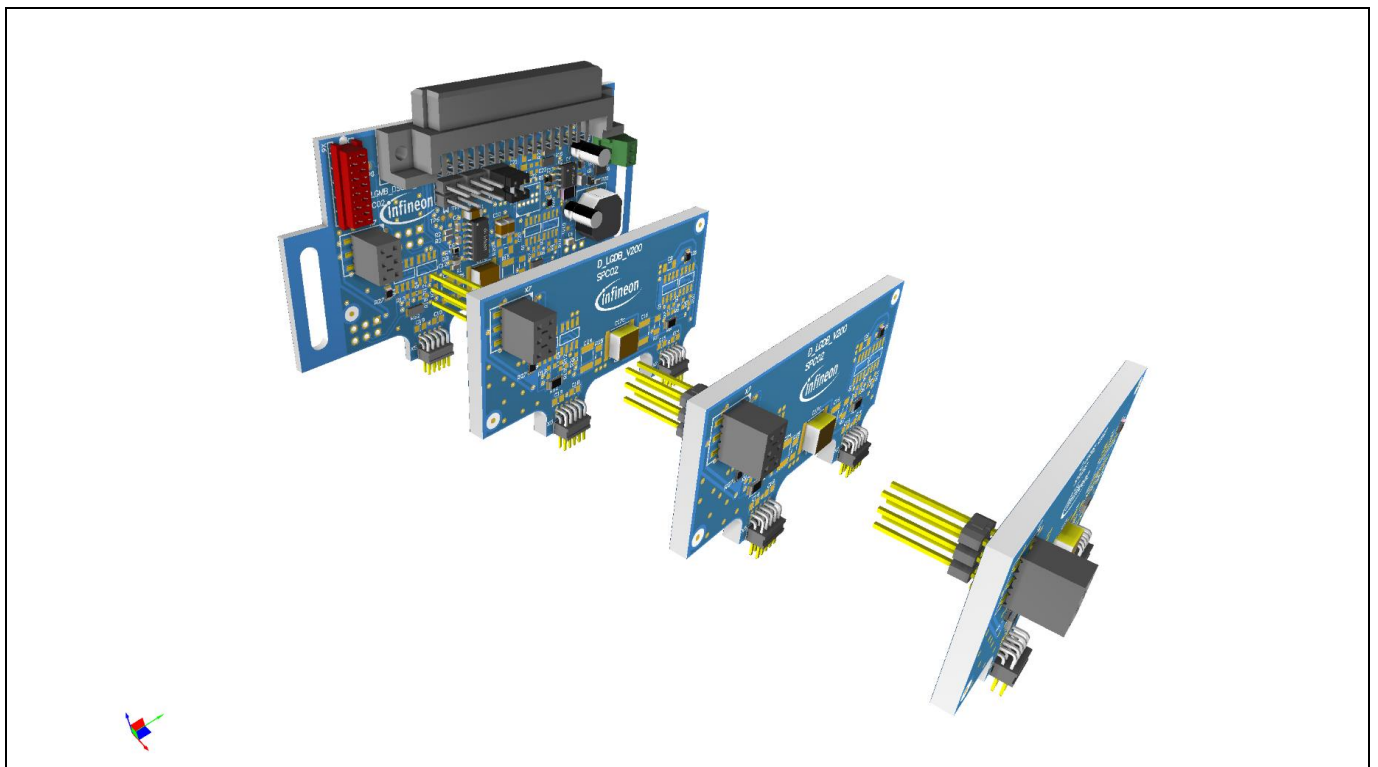**Figure 18**   **Four power boards connected in parallel via copper bars**

Figure 19   **Master mother board and daughter boards**

Low voltage drives scalable power demonstration board
User manual
Example set-ups

Connect the gate drive sub-assembly from **Figure 19** with the power boards. Make sure all eight mother board and daughter board headers are aligned with respect to the power board headers before pushing the connectors all the way in. See **Figure 20**, **Figure 21** and **Figure 22** for details.
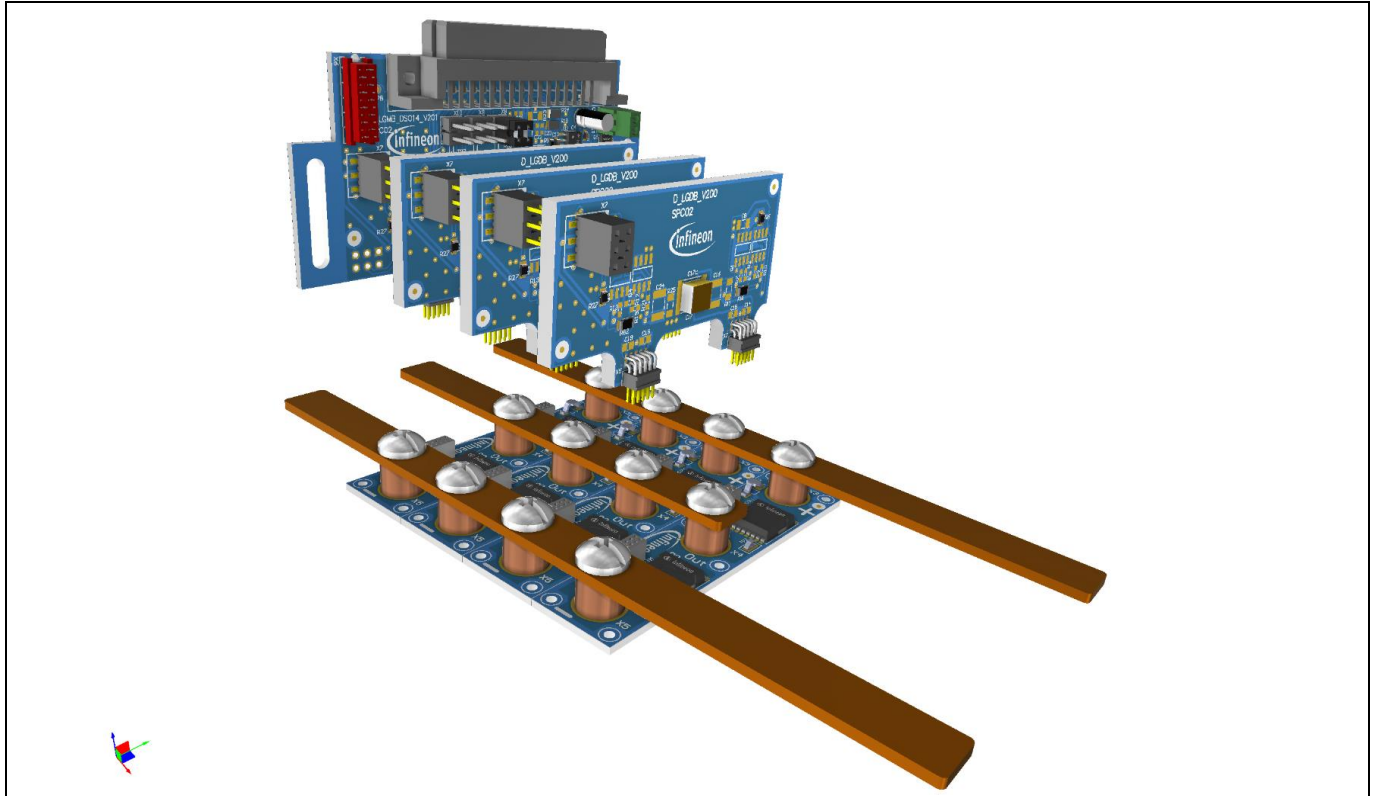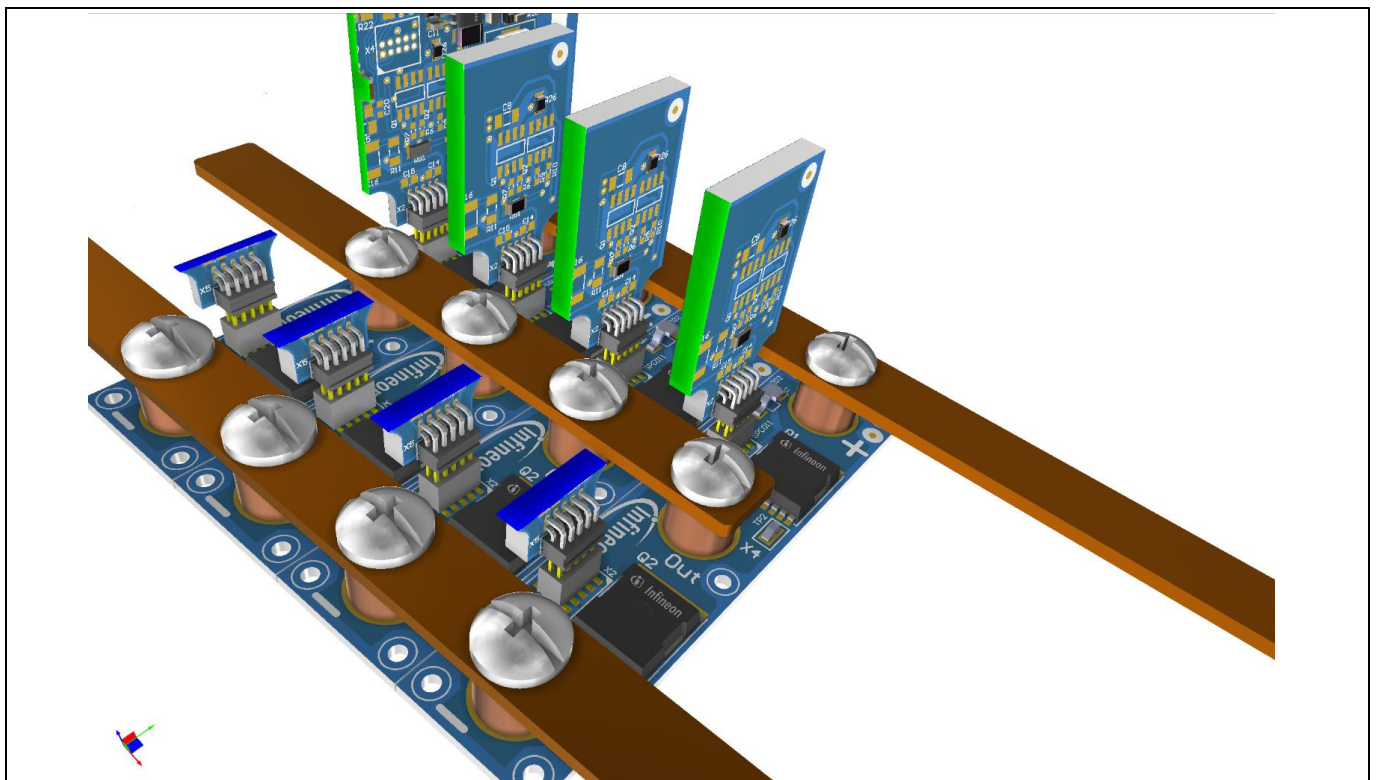

Figure 20   Gate drive and power sub-assemblies

Figure 21   Detail – align all eight header connectors

Once all the header conectors are aligned, make sure that they are pressed all the way into their respective receptacles.

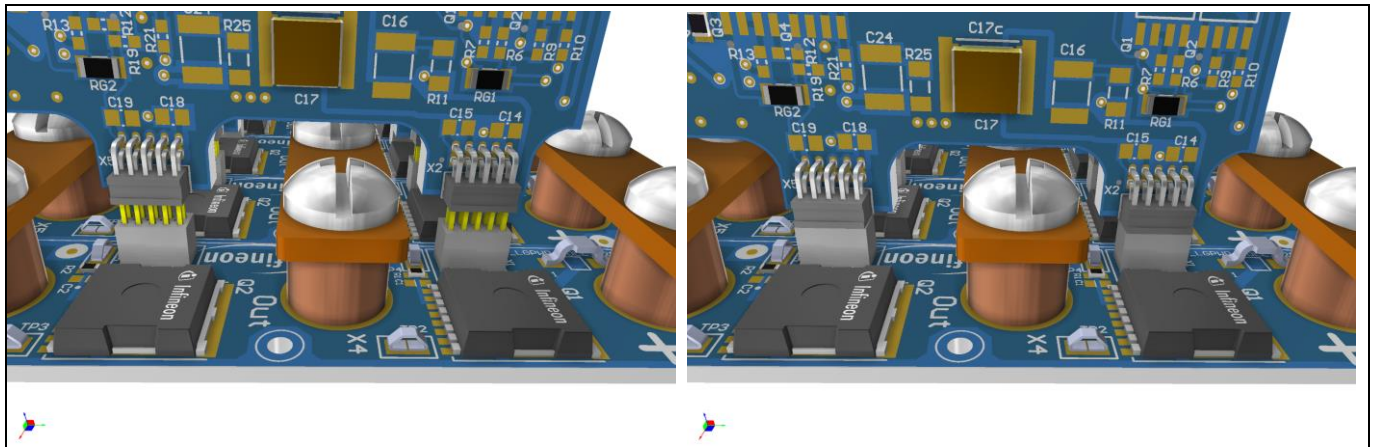**Figure 22**   **After alignment, push all the headers all the way into the receptacles**

Finally, attach the capacitor board to the copper bars, forming the DC bus (**Figure 23**). The other end of the copper bars is used for the connection of the motor cables (use cable lugs to connect them to the copper bars via M5 bolts and nuts).
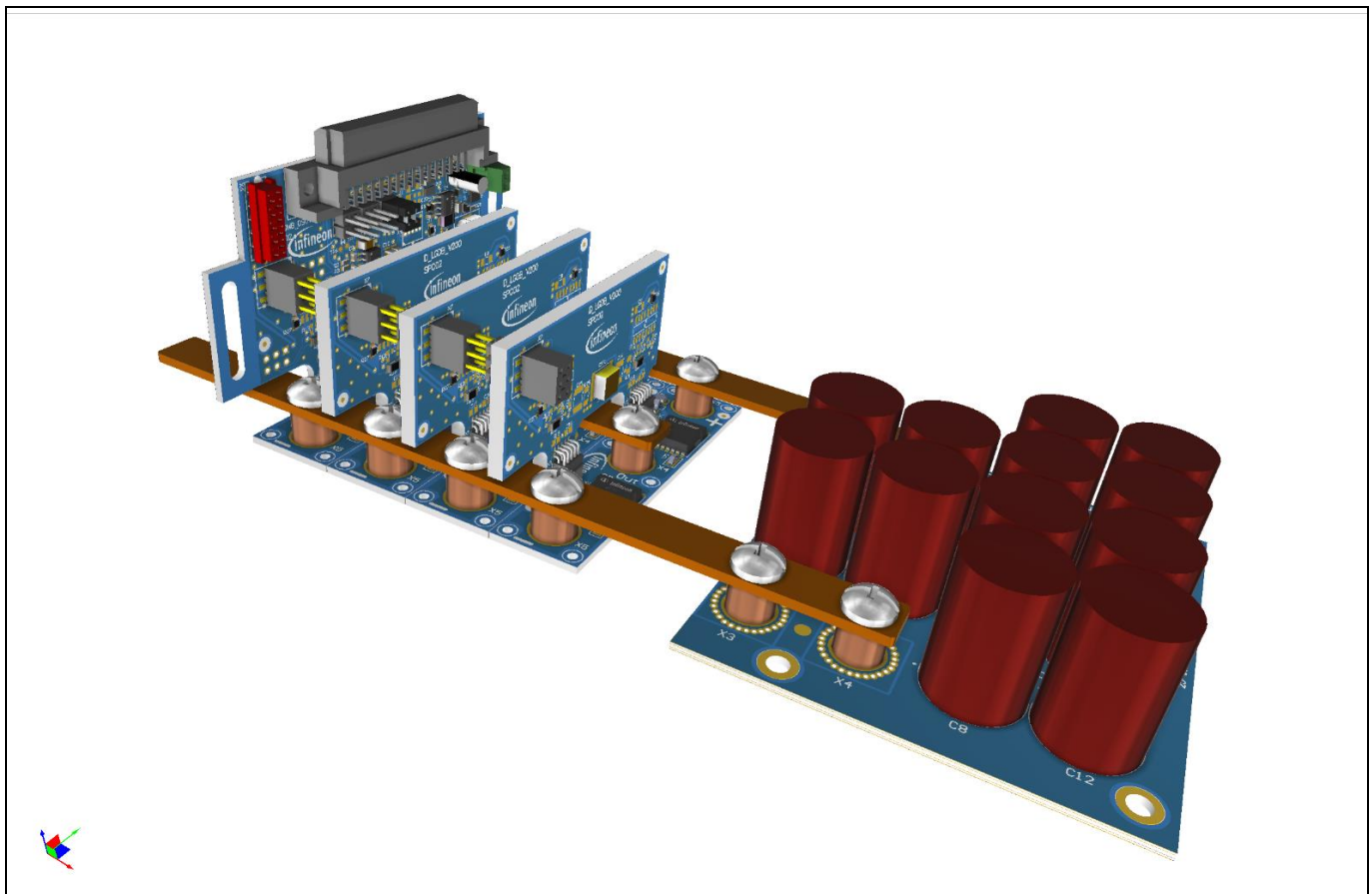

Figure 23   **"U" phase assembly with four power boards in parallel**

Low voltage drives scalable power demonstration board
User manual
Example set-ups

3.2 Three-phase set-up

Also known as the B6 inverter, this is a three-phase system used for electric motor control.

The gate drivers for the additional two phases ("W" and "V") are provided using two mother boards. The mother boards are connected via a ribbon cable to the master mother board. The master mother board provides the gate driver for phase "U", and extends the connections between the ribbon cable, which connects to the mother boards, and the control board outputs.
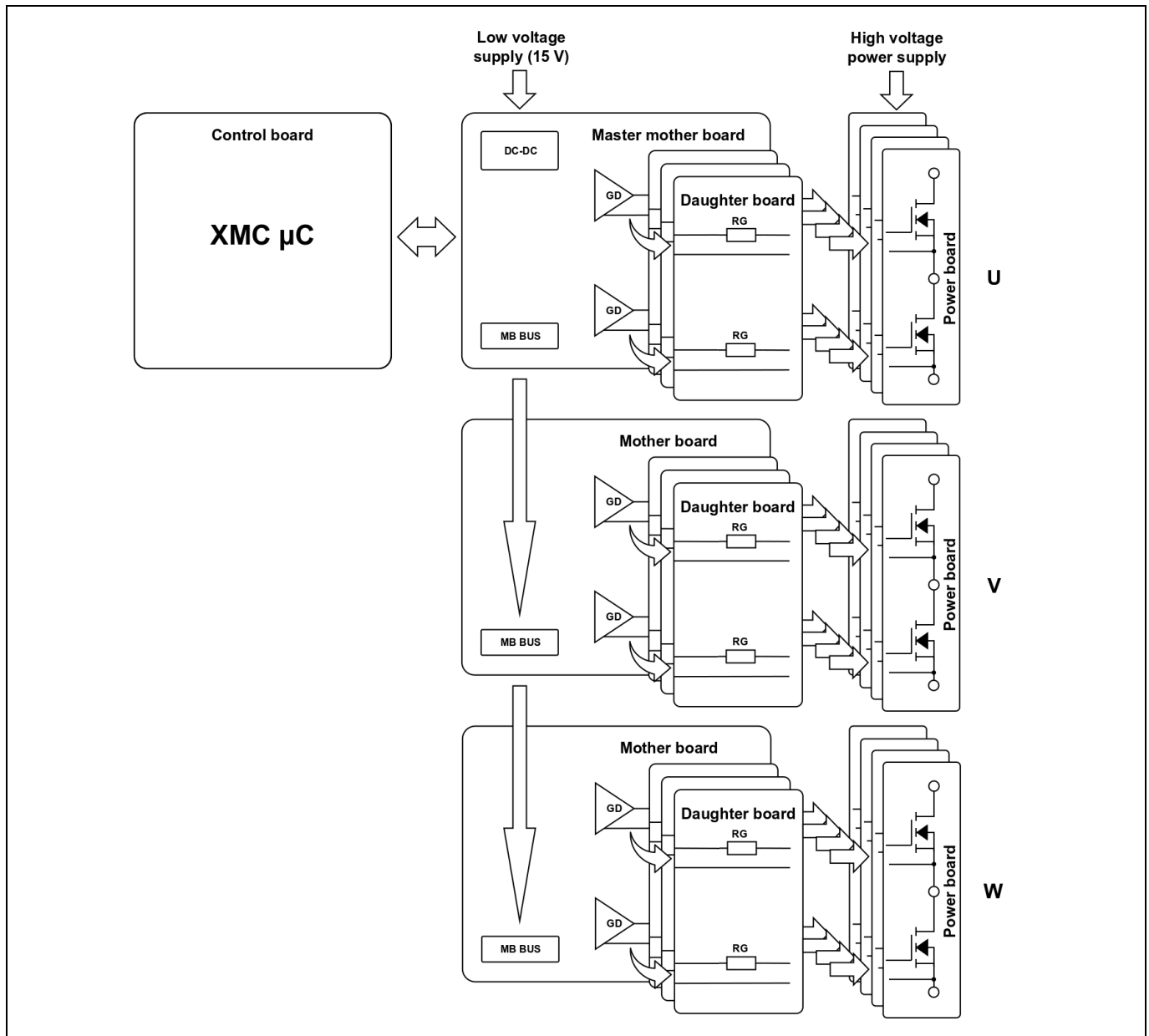

Figure 24   **Block diagram – B6 inverter topology with four parallel power boards per phase**

As in the previous example the master mother board provides the 5 V supply for the control board, while drawing from the 15 V supply that is also distributed to the mother boards via a ribbon cable.

Again, the number of paralleled power boards per phase is optional.

Example set-ups

The assembly, utilizing four power boards in parallel for each of the three phases, will consist of:

- **Power boards** (12 pieces)
- **Master mother board** (one piece)
- **Mother board** (two pieces)
- **Daughter boards** (nine pieces)
- **Infineon's XMC™ demonstration board drive card XMC4400** (one piece)
- **Capacitor board** (three pieces)

Assembly procedure

Set the phase selection jumpers on the master mother board to phase "U", and the jumpers on the mother boards to "W" and "V". In a three-phase system the master mother board should always have the phase selection jumpers set to "U", because only control signals for phases "W" and "V" are propagated through the mother board bus to the mother boards.
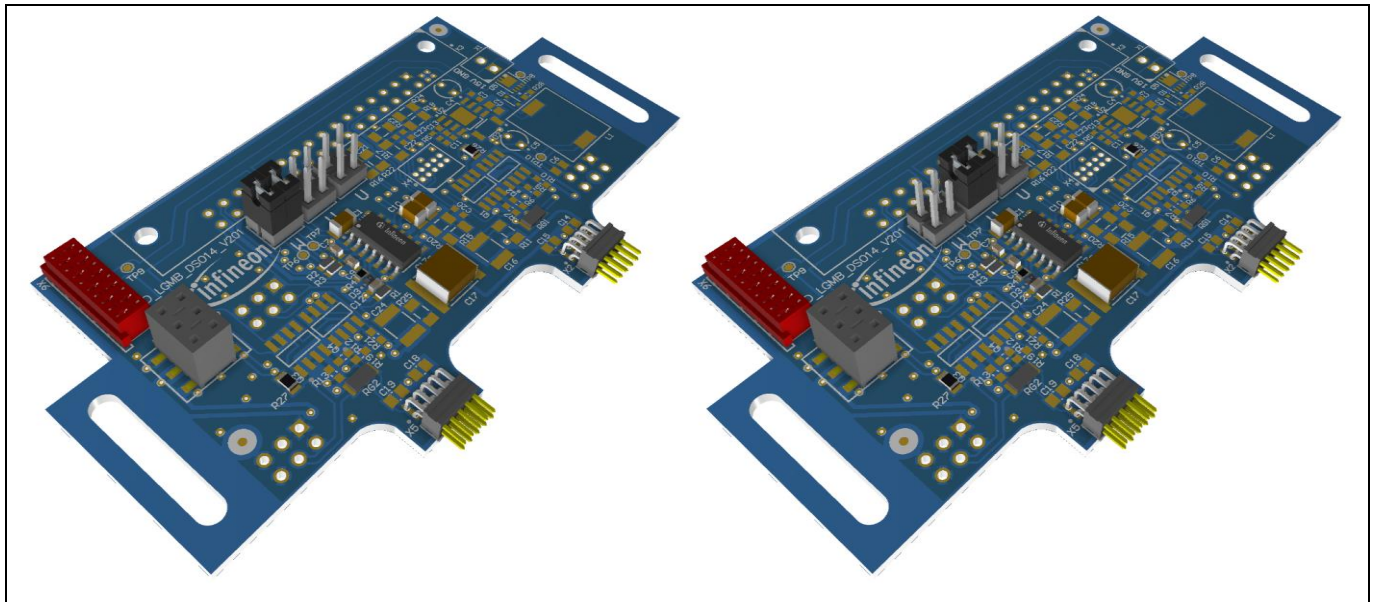

Figure 25   Mother boards – "W" and "V" jumper positions

Construct the first phase following the procedure in paragraph 3.1.2. Make sure to use the master mother board with the phase set jumpers set to the "U" position (**Figure 23**).

Repeat the procedure from chapter **3.1.2** with the "W" and "V" mother boards (**Figure 26**).

Figure 26 Phase "W" and "V" assemblies – mother board

Figure 27 Full three-phase assembly with four parallel power boards per phase

Arrange the three-phase assemblies side by side and connect them with the ribbon cable provided (X6 connector) as shown in **Figure 27**.

Attach the power connections as illustrated in **Figure 28**. When connecting the HV supply to all three-phase assemblies, make sure that the parasitic inductance and resistance of the interconnections between phases are kept at minimum. Using copper bars is recommended – see chapter **2.6** for the recommended dimensions. The

copper bar connecting the negative power supplies should be as close as possible to the mother boards, as indicated in **Figure 28**.

Figure 28   Power connections

The horizontal copper bars in **Figure 28** represent phase output and phase supply connections, and the vertical bars are the multi-phase supply interconnection copper bars, as described in chapter **2.6**.
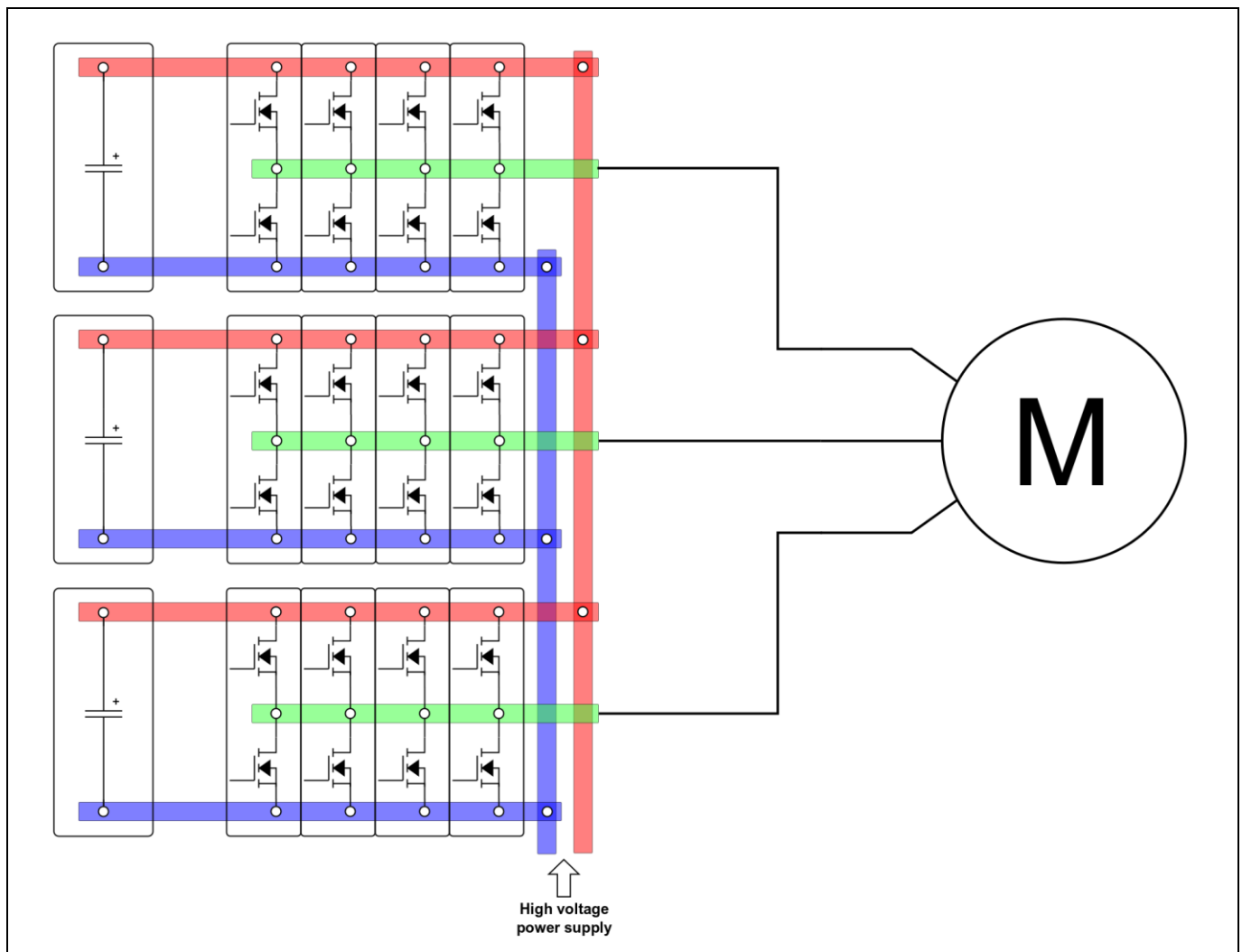
Low voltage drives scalable power demonstration board
User manual
Example set-ups

3.3 Control board and supply connection

Figure 29 Control board and LV supply connection

The control board connects to the master mother board via X3, and the 15 V supply for the system is connected at the X1 screw terminal, both shown in **Figure 29**. The USB interface to the PC is located at the top of the control board. Drive card XMC4400 provides galvanic isolation to the connected PC.

LV supply

The 15 V supply for the system connected at the X1 terminal is limited by the gate driver.

Table 3 LV system supply

Parameter	Values			Unit	Note
	Min.	Typ.	Max.		
LV system supply	12	15	20	V	Max. according to 2EDL23N06PJ

High-voltage/high-power supply

Attention: **In addition to supply voltage, the voltage spikes caused by switching need to be considered. The V_{DSS} should not exceed the $V_{(BR)DSS}$ rating of the MOSFET at any point. The supply voltage needs to be adapted accordingly.**

Supply voltage used on the power side of the set-up will be limited by the MOSFET drain-source breakdown voltage ($V_{(BR)DSS}$). Recommended nominal supply voltages are given below, with regard to the breakdown voltage rating of the MOSFET being used.

Table 4   Nominal power supply voltage recommendations

$V_{(BR)DSS}$ rating (V)	Supply voltage		Unit
	Typ.	Max.	
60	24	32	V
80	48		V
100	48		V
150	72	96	V
200	144		V
250	157		V

4 Software package overview and driving an induction motor

Infineon provides a software package supporting the demonstration board. The software package is intended for using the B6 set-up to drive an induction motor. Provided in the software package are the firmware for Infineon's XMC™ demonstration board drive card XMC4400, and a basic GUI for controlling the set-up.

The implemented induction motor drive firmware is based on the open-loop V/f control method. The method adapts the output voltage (PWM duty cycle) according to the field rotation speed (frequency), as shown in **Figure 30**.

The V/f ratio is set by the user according to motor characteristics and the applied load. The principle of the V/f control is to maintain a constant torque across the available rotating speed range by increasing output voltage amplitude in linear relation to field rotation speed. For a given motor at stable supply voltage, the load will determine the maximum achievable turning speed according to torque vs. phase voltage characteristics of the motor.

The V/f control includes a settable V/f offset. The V/f offset is used to compensate for the resistive component of the rotor winding (see **Figure 30**).
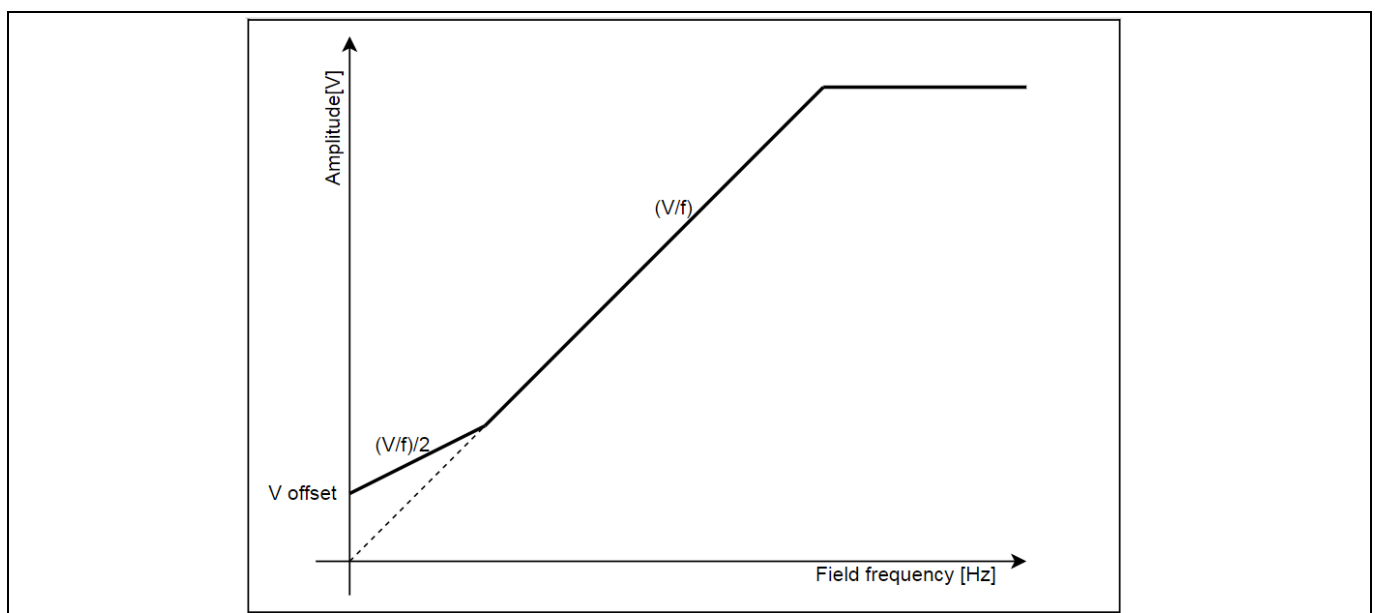

Figure 30 **V/f control characteristics with implementation of the V/f offset**

4.1 Uploading the firmware and installing the GUI

Prerequisites (follow the instructions from provider to install):

- Infineon – LVD scalable power demonstation board – software package (unzip to preferred location)
- User interface for programming target Flash memory, like the "J-Flash Lite" that is a part of the J-Link software pack, available here:
  https://www.segger.com/downloads/jlink/#J-LinkSoftwareAndDocumentationPack
- XMC™ Flasher tool for XMC™ MCU Flash programming:
  https://www.infineon.com/cms/en/product/microcontroller/32-bit-industrial-microcontroller-based-on-arm-cortex-m/#!tools
- It is also recommended to install the latest version of Microsoft .NET Framework

Table 5   Programming the .hex file to Flash

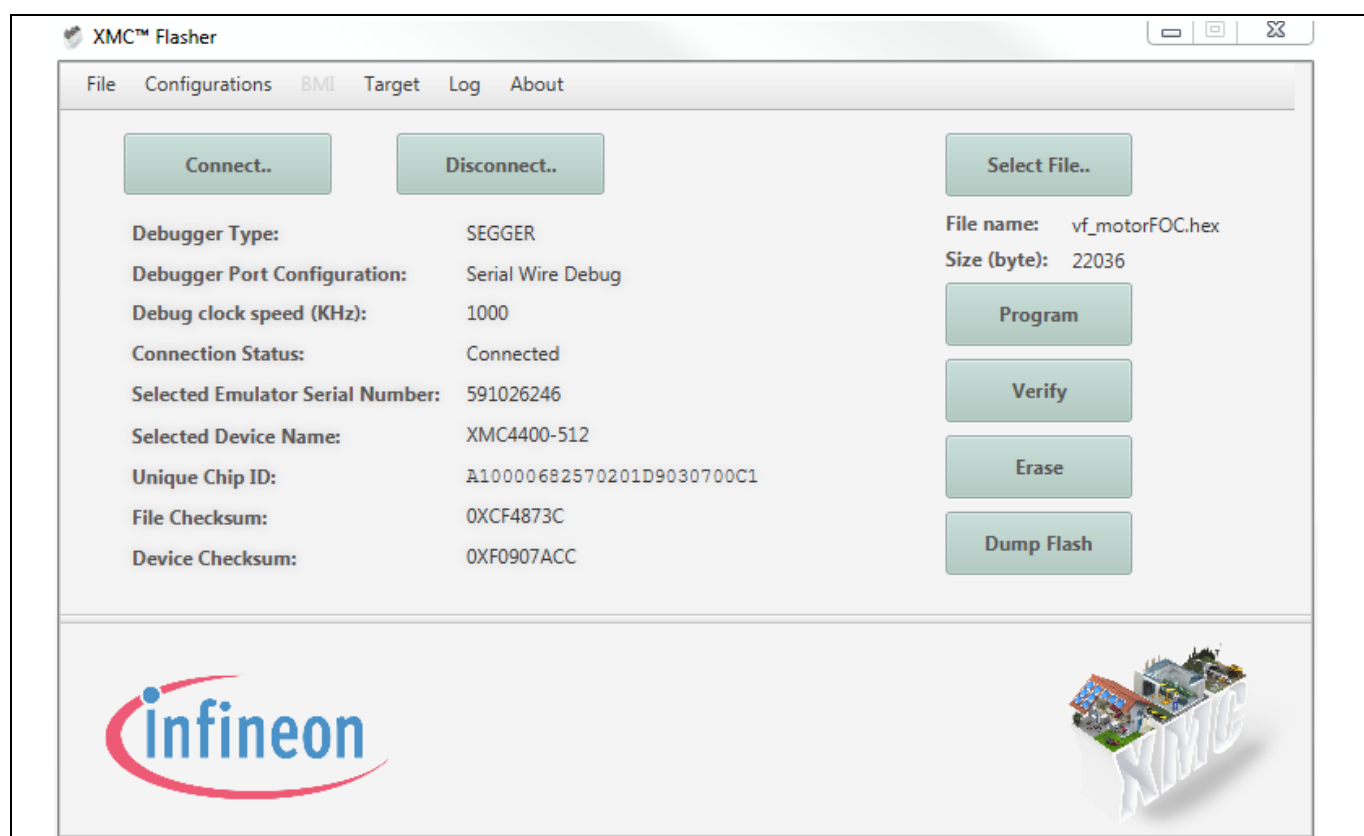| Step	Instruction
1	Connect the XMC drive card via USB cable.
2	Provide the 15 V supply to the master mother board, thus providing the supply to the drive card.
3	Open XMC™ Flasher and click: Configurations >> Change >> Select device name
4	Select the target device according to the microcontroller being used (e.g. XMC4400-512).
5	Click "Select file", and navigate to the .hex file to be programmed (…\vf_motorFOC.hex).
6	Click "Program".

Figure 31   XMC™ Flasher interface

Table 6   Installing and running the GUI

Step	Instruction
1	In the software package folder navigate to: Motor Control GUI\V(f) motor control GUI V2.0
2	Run "Motor_GUI.exe".

4.2 Using the V/f induction motor control GUI

Attention: **Make sure that you understand the limitations of the motor as well as the limitations of the electronic set-up before running the motor.**

Attention: **Always make sure that the motor is securely attached in its place on the test bench, and that the test bench is designed to withstand any forces generated by the motor under test.**
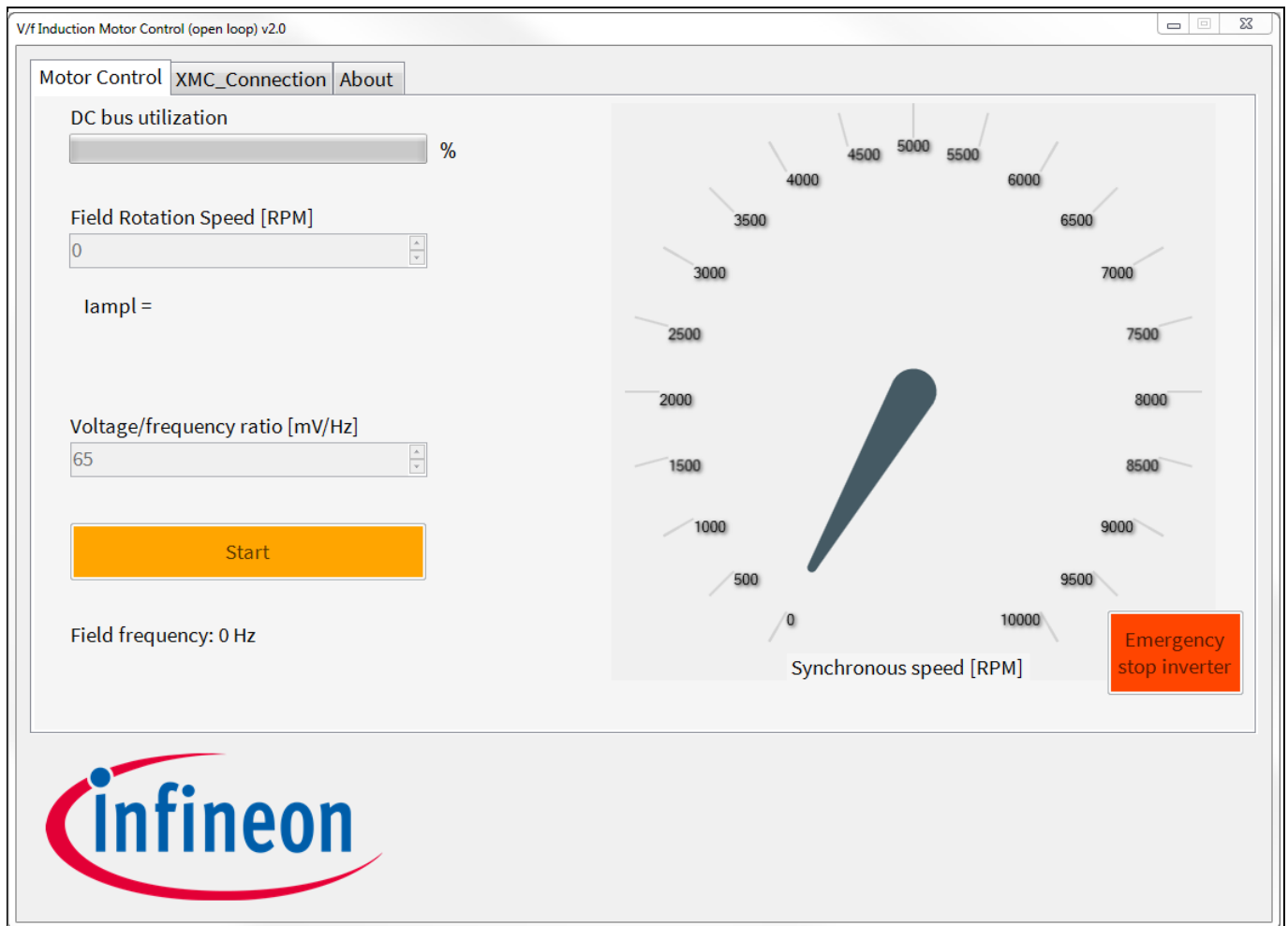

Figure 32 **GUI – motor control tab**

The DC bus utilization bar indicates the maximum duty cycle of the PWM. It is calculated from:

- Voltage/frequency ratio (mV/Hz)
- V/f offset
- Field rotation speed (RPM)
- Input voltage (V)

In effect the bar indicates the limit of the motor control settings (the limit is set to 90 percent).
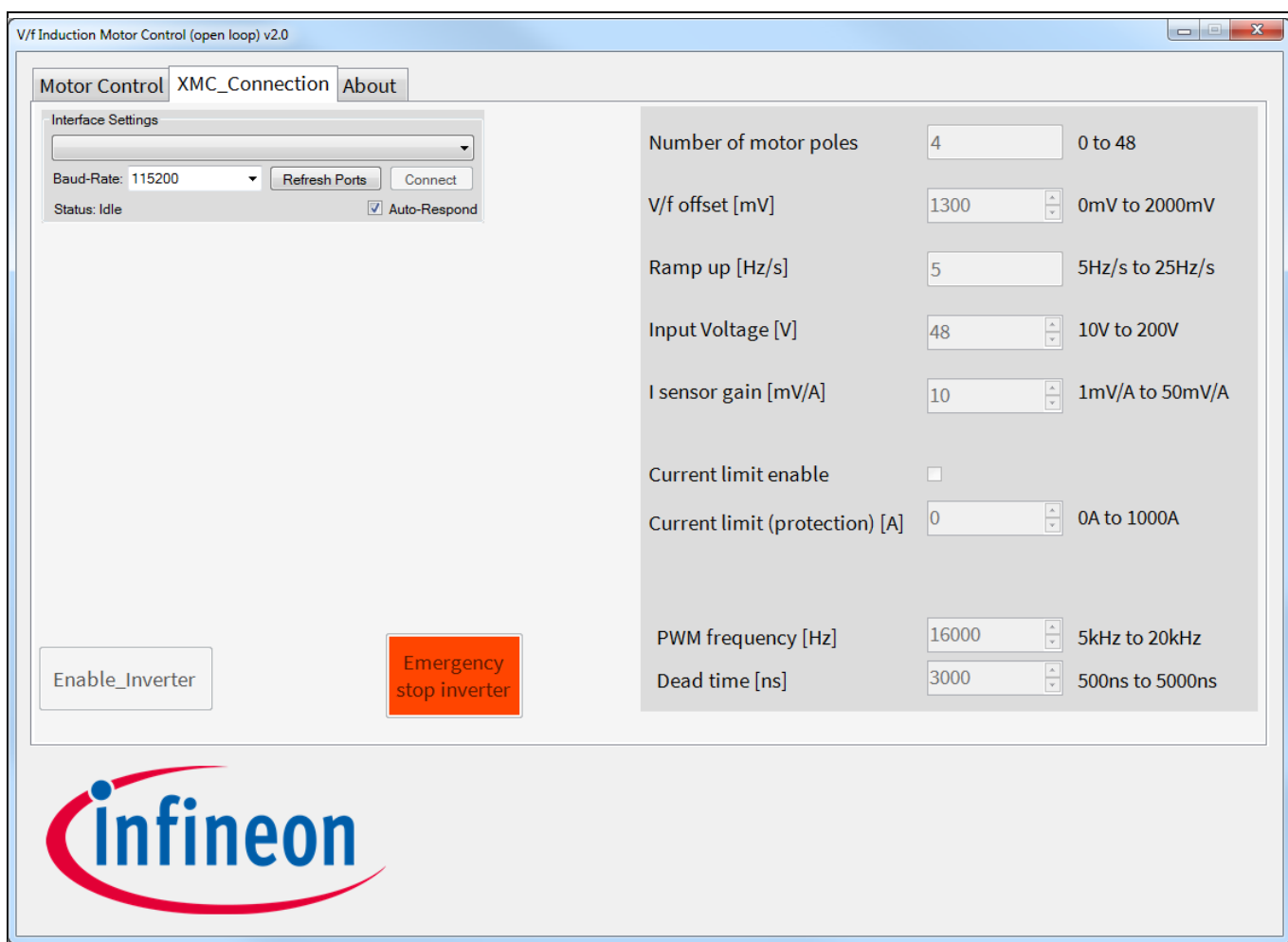
Figure 33   GUI – settings tab

Table 7   Establishing comunication with the drive card

Step	Instruction
1	Connect the drive card to the PC via USB cable.
2	Provide the 15 V supply to the master mother board, thus providing the supply to the drive card.
3	In the XMC_connection tab of the GUI go to Interface Settings, and set baud rate to 115200 (**Figure 33**).
4	Select the demo board in the drop-down menu (refresh ports if needed).
5	Click the "Connect" button.
6	Settings to the right will become available if the connection has been successful.

Table 8   GUI settings description

Setting	Description
Field rotation speed (RPM)	Setting of the stator field rotation speed. Type the value and confirm with return key, or use the mouse scroll button while hovering above the value.
Voltage/frequency ratio (mV/Hz)	The ratio of effective output voltage amplitude vs. field rotation speed
Number of motor poles	Counted in stator pole pairs
V/f offset (mV)	Effective output voltage at standstill – see **Figure 30** for characteristic curve. Set to zero for linear V/f charateristics.
Ramp up (Hz/s)	Rate of change of the field rotation speed (when changing field rotation speed setting)
Input voltage (V)	DC power supply voltage used
I sensor gain (mV/A)	Gain of the current sensor used in mV/A (It is recommended to use sensors with galvanic isolation like the ASC758 (±200 V range, 10 mV/A output gain)
Current limit (A)	Current limit – disable if not using a sensor
PWM frequency (Hz)	PWM frequency setting
Dead-time (ns)	Dead-time setting (off-time of the complementary control signals)

Hints for using the induction motor with the GUI

1) V/f coefficient defines the phase voltage amplitude (peak) vs. frequency. It should be set according to the maximum speed of the induction motor at a target torque.

If the coefficient is set too low, the motor is likely to stall when mechanical load is applied. The motor will slow down and stop.

If V/f coefficient is too high, reactive current is increased, resulting in higher losses, and in extreme cases saturation of the stator. Make sure that motor limits are not exceeded, or permanent damage can occur.

2) V/f offset needs to be tuned to compensate for the resistive component of the rotor winding. Be careful not to set it too high, as the offset current will heat the stator at standstill.

Tuning procedure (approximate):

- Set rotation speed to 0 RPM.
- Set V/f offset to 0 mV.
- Apply supply voltage to the inverter half-bridges.
- Increase "V/f offset" coefficient until a minimum current starts to flow through the stator windings. At some point a small increase of braking torque will become noticeable if the rotor is turned externally. At this point the V/f offset setting should be sufficient for a smoother start-up of the motor. Take care when increasing the setting beyond this point, as a small DC current will be present at motor windings during standstill.

Revision history

V 1.0

Document version	Date of release	Description of changes
V 1.0	2018-10-10	Initial release

Trademarks
All referenced product or service names and trademarks are the property of their respective owners.

IMPORTANT NOTICE

The information contained in this application note is given as a hint for the implementation of the product only and shall in no event be regarded as a description or warranty of a certain functionality, condition or quality of the product. Before implementation of the product, the recipient of this application note must verify any function and other technical information given herein in the real application. Infineon Technologies hereby disclaims any and all warranties and liabilities of any kind (including without limitation warranties of non-infringement of intellectual property rights of any third party) with respect to any and all information given in this application note.

The data contained in this document is exclusively intended for technically trained staff. It is the responsibility of customer's technical departments to evaluate the suitability of the product for the intended application and the completeness of the product information given in this document with respect to such application.

For further information on the product, technology, delivery terms and conditions and prices please contact your nearest Infineon Technologies office (**www.infineon.com**).

WARNINGS

Due to technical requirements products may contain dangerous substances. For information on the types in question please contact your nearest Infineon Technologies office.

Except as otherwise explicitly approved by Infineon Technologies in a written document signed by authorized representatives of Infineon Technologies, Infineon Technologies' products may not be used in any applications where a failure of the product or any consequences of the use thereof can reasonably be expected to result in personal injury.