Motor Development Kit (MDK) 4 kW Board with Intelligent Power Module SPM31 650 V

SECO-MDK-4KW-65SPM31-GEVB

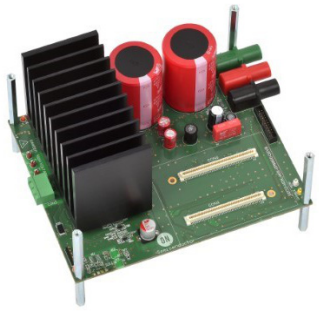

Figure 1. SECO−MDK−4KW−65SPM31−GEVB

Description

The SECO−MDK−4KW−65SPM31−GEVB is a development board for three−phase motor drives, part of the Motor Development Kit (MDK). The board features the *NFAM5065L4B* Intelligent Power Module in a DIP39 package and is rated for 400 Vdc input, delivering continuous power in excess of 1 kW, with the capability of delivering up to 4 kW power for a short period. The board is fully compatible with the *Universal Controller Board (UCB),* based on the Xilinx Zynq−7000 SoC, which embeds FPGA logic and two Arm® Cortex®−A9 processors. As such, the system is fit for high−end control strategies and enables operation of a variety of motor technologies (AC induction motor, PMSM, BLDC, etc.).

Features

- 4 kW Motor Control Solution Supplied with up to 410 Vdc
- Compatible with the Universal Controller Board (UCB) FPGA−controller Based on Xilinx Zynq−7000 SoC
- Out of the Box Use Cases for FOC and V/F Control with Graphical User Interface (GUI)
- Highly Integrated Power Module *NFAM5065L4B* 650 V/50 A High Voltage 3−phase Inverter in a DIP39 Package
- DC/DC Converter Producing Auxiliary Power Supply 15 Vdc – Non−isolated Buck Converter using *NCP1063*, DC/DC Converter Producing Auxiliary Power Supply 5 Vdc – Non−isolated Buck Converter using *FAN8303*, and LDO Producing Auxiliary Power Supply 3.3 Vdc – using *NCP718*
- Three−phase Current Measurement using 3 x *NCS20166* Operational Amplifiers
- Three−phase Inverter Voltage and DC−Link Voltage Measurement – using Resistive Voltage Divider Circuit
- 512 kB EEPROM I^2C – using *CAT24C512*
- Encoder Interface Compatible with either 3−HALL Sensors 1 Channel Quadrature Encoder
- Temperature Sensing via Build in Thermistor
- Over Current Protection using *NCS2250* Comparator

Applications

- White Goods
- Industrial Fans
- Industrial Automation
- Industrial Motor Control

Collateral

- SECO−MDK−4KW−65SPM31−GEVB
- Universal Control Board (UCB) [1]
- NFAM5065L4B (IPM) [2]
- NCP1063 (15 V non−isolated buck) [3]
- FAN8303 (5 V non−isolated buck) [4]
- NCP718 (3.3 V LDO) [5]
- NCS20166 [6]
  (Op−Amp for Current Measurement)
- NCS2250 [7]
  (Comparator for Over−current Protection)
- CAT24C512 (EEPROM) [8]

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Scope and Purpose

This user guide provides practical guidelines for using and implementing a three−phase industrial motor driver with the Intelligent Power Module (IPM). The design was tested as described in this document but not qualified regarding safety requirements or manufacturing and operation over the entire operating temperature range or lifetime. The development board has been layout in a spacious manner so that it facilitates measurements and probing for the evaluation of the system and its components. The hardware is intended for functional testing under laboratory conditions and by trained specialists only.

Hardware Revision – this user manual is compatible with version 1.0 *SECO−MDK−4KW−65SPM31−GEVB*.

Attention: The *SECO−MDK−4KW−65SPM31−GEVB* is exposed to high voltage. Only trained personnel should manipulate and operate on the system. Ensure that all boards are properly connected before powering, and that power is off before disconnecting any boards. *It is mandatory to read the Safety Precautions section before manipulating the board.* Failure to comply with the described safety precautions may result in personal injury or death, or equipment damage.

Prerequisites

All downloadable files are available on the board website.

- Hardware
  - SECO−MDK−4KW−65SPM31−GEVB
  - DC power supply (includes earth connection)
  - Universal Control Board (UCB)
  - USB isolator (5 kV optical isolation, also see Test Procedure)
- Software
  - Strata Developer Studio [17]
  - Downloadable UCB motor control firmware as boot image

DESIGN OVERVIEW

This report aims to provide the user manual for the development board SECO−MDK−4KW−65SPM31−GEVB. This development board (from here on *MDK_SPM31*) is a DC supplied three−phase motor drive inverter intended for industrial motion applications < 4 kW range. In this field, a trade−off between switching frequency and power management is the key to fulfil the requirements while providing a simple and robust solution. The system is compatible with three phase motors (BLDC, Induction, PMSM, Switched Reluctance etc.). The *MDK_SPM31* power board is illustrated in Figures 2 and 3 (top and bottom view, respectively). The block diagram of the whole system is depicted in Figure 4.

The foremost advantages that this development board brings are:

- System solution for industrial motor control applications
- Low component count with integrated IGBT power module
- Design fit for different motor technologies
- Friendly user experience with Graphical User Interface and selectable open loop/FOC closed loop control
- Rapid evaluation close to application condition

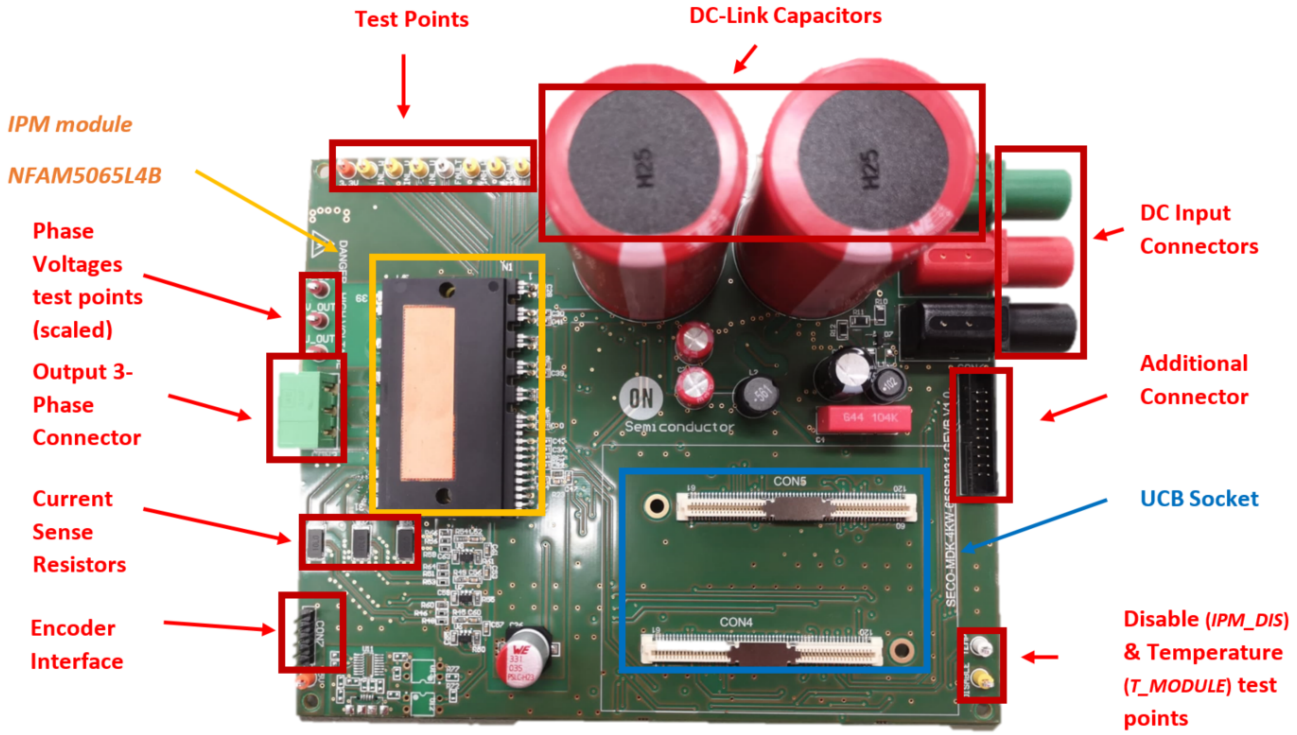

Figure 2. Picture of SECO−MDK−4KW−65SPM31−GEVB Board − Top Side

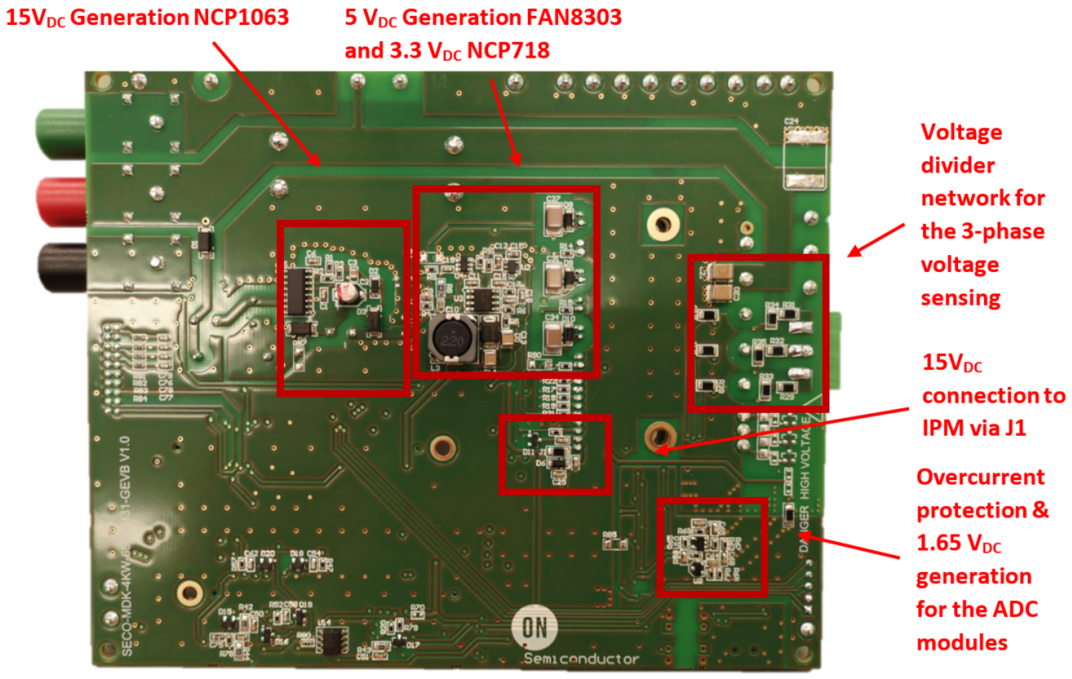

Figure 3. Picture of SECO−MDK−4KW−65SPM31−GEVB − Bottom Side

SPECIFICATION

The specification and main features are elaborated in Table 1.

Table 1. MDK_SPM31 SPECIFICATIONS

Parameters	Values	Conditions/Comments
INPUT		
Voltage DC	200−400 Vdc	Absolute maximum input voltage 410 V
OUTPUT		
Power	1 kW (continues)	Input 200−400 Vdc
	4 kW (short period)	Maximum operation period 15 min @ Ta = 25°C
Current per IPM Leg	±2.5 Arms / 1 kW (140 Vrms Phase voltage and PF 0.98)	Lower output phase voltage will result in higher phase currents for same power
Module Temperature at 25°C Ambient	T_C = 65°C after 25 min @ 400 Vdc / 1 kW	Measured @ F_{PWM} = 16 kHz; lower frequency will result to higher ripple currents which might increase temperature
	T_C = 83°C after 8 min @ 400 Vdc / 4 kW	
CURRENT FEEDBACK		
Current Sensing Resistors	10 mΩ	Three 10 mΩ, one for each phase
Op−Amp Power Supply	3.3 V	Generated by the *NCP718 LDO*
Op−Amp Gain	10	Via resistors
Op−Amp Output Offset	1.65 V	Because of negative current measurement requirement
Current Measurement Resolution	0.016 A / bit	Based on *UCB* integrated 11 bits ADC *NCD98011* [9]
Current Measurement Sampling Frequency	Up to 2 Msamples/sec	Configurable via the *UCB*
Measured Current Range	±16.5 A_{peak}	Configured by the shunt resistors and *NCS20166* output offset and gain
Overcurrent Protection	+21.5 A_{peak} (rise time delay 500 ns)	Configured by the shunt resistors and the − *NCS2250SN2T3G* − comparator threshold
DC−LINK VOLTAGE MEASURING		
DC−Link Voltage Range	0 V − 483.7 V	
DC−Link Voltage Divider Gain	0.0068218	Configured by the voltage divider
DC−Link Voltage Resolution	0.236 V / bit	Based on MDK integrated 11 bits ADC
INVERTER PHASE VOLTAGES MEASURING		
Phase Voltages Range	0 V − 241.7 V	
Phase Voltages Divider Gain	0.0136495	Configured by the voltage divider
Phase Voltages Resolution	0.472 V / bit	Configured by *MDK_SPM31* integrated 11 bits ADC
AUXILIARY POWER SUPPLIES MAXIMUM DEMAND		
15 V	4.4 W	Generated by the *NCP1063*
5 V	2.9 W	Generated by the *FAN8303*
3.3 V	0.05 W	Generated by the *NCP718*
CONTROL (Note 1)		
UCB		Pluggable via two polarized Bergstak® 0.80 mm Pitch connectors
Type of Control (in Flash)		V/f / FOC
Supported Type of Motors		ACIM, PMSM, BLDC
APPLICATION		
White Goods (Washers), Industrial Fans, Industrial Automation		

1. It comes with a with a graphical user interface that is available through the link in [12]

BLOCK DIAGRAM

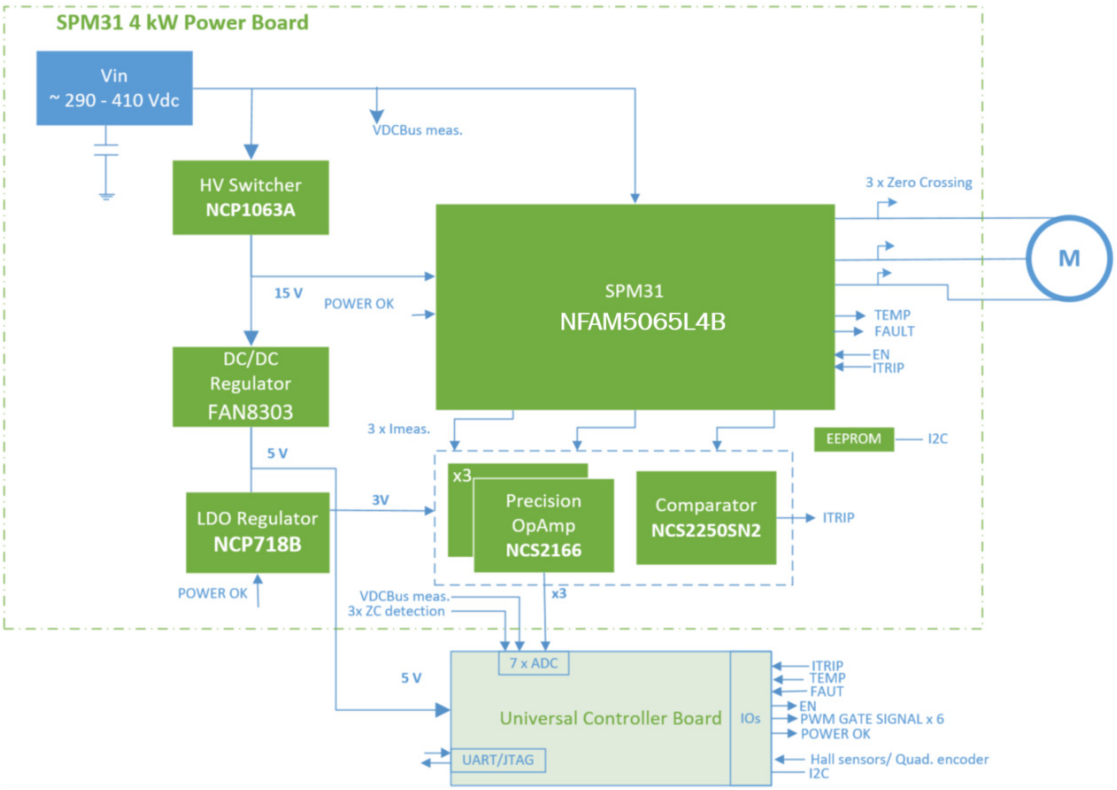

Figure 4. Block Diagram of the MDK_SPM31 Board

Out of a variable Vdc input (200–400 Vdc), the board can deliver continuous power in excess of 1 kW or up to 4 kW for a short period to a three−phase motor. The foremost circuitries conforming the system are, the auxiliary power supplies, the current and voltage sensing, the overcurrent protection, and of course the three−phase inverter, build with the *NFAM5065L4B* IPM. Figure 4 illustrates the overall view of the above circuitries.

Inverter Stage with Intelligent Power Module (IPM) Technology

The inverter power stage is the backbone of this development board and it performs the DC/AC conversion. It utilizes the *NFAM5065L4B* IPM module, a fully integrated power stage for three−phase motor drives consisting of six IGBTs with reverse diodes, an independent high side gate driver, LVIC, and a temperature sensor (VTS). The IGBT's are configured in a three−phase bridge with separate emitter connections for the lower legs to allow the designer flexibility in choosing the current feedback topology and resolution. This module leverages the Insulated Metal Substrate (IMS) technology from **onsemi**. Packaged in the DIP39 format, the *NFAM5065L4B* (from here on *IPM*) not only provides a highly integrated, compact and rugged solution, but also best−in−class thermal management capabilities. In short, the module enables lower component count designs for industrial motor drives and simplifies the development, reducing the time−to−market of new solutions.

Protection function in the system include under−voltage lockout, and external hardware shutdown for over−current protection via a comparator−based trigger event, which is currently configured at +21 A via the current sense and voltage−divider selection. By changing the voltage divider resistors, the designer can change the over−current protection threshold. Finally, external shutdown via software is also possible (via *CIN* pin), allowing the user to define a multilayer current protection function.

In this development board the DC−Link, which is provided by an external power supply, serves as the power input to the inverter module. The module needs to be supplied as well with 15 Vdc, necessary for the IGBT gate drivers, 5 Vdc necessary for the *MDK_SPM31,* as well as with 3.3 Vdc voltage necessary for the current measurement Op−Amps and over−current protection comparators. The auxiliary power supplies that have been referred earlier (*NCP1063, FAN8303,* and *NCP718*) in the document provide these voltage rails.

IPM_FAULT and *T_MODULE* (temperature) are the output signals from the IPM module, which are routed to the *UCB* controller and can be used by the end−user for control and protection purposes. All operational input and output signals and the corresponding voltage references are

described in more detail in the UCB Controller section and in Low−power Connectors, High−power Connectors, and in Appendix. The applied design has been influenced by the AND9390/D [10] and the NFAM5065L4B [2] data sheet.

Current Measurement

The development system is round out by the *NCS2250* High Speed Comparator, the *NCS20166* precision low−offset Op−Amp, and the *NCD98011 UCB* integrated ADC module. Currently, ADC resolution is 11−bit resulting in an overall resolution of 0.016 A/bit, while the range of phase−current measurement is set to ±16.5 A. The *NCS20166* gain selection, the current sense resistor selection, and the *NCD98011* ADC module that is integrated in *UCB* define the overall current resolution. The overall resolution and maximum current range can be found in Table 1. More details around the SAR concept and *NCD98011* can be found in [9].

DC−Link and Inverter Phase−voltages Measurement

The DC−Link and inverter phase−voltage are both sensed via resistive voltage divider circuits, where the scaled−down voltage signals are used as inputs for the integrated *UCB* ADC – *NCD98011* – modules. As mentioned above, overall resolution and maximum voltage range can be found in Table 1.

Over−current Protection and Under Voltage Protection Fault

The hardware over−current protection leverages the disable−option on the *IPM*. This function exploits the disable pin (*CIN* pin) of *IPM*, via the ITRIP signal that is provided to the power module by the *NCS2250* comparator. The disable−pin (*CIN* pin) is also controlled by *UCB* controller, allowing the end−user to configure a multilayer overcurrent protection. Finally, the end−user may also leverage the output fault signal of *IPM (VFO),* using the *UCB* controller. Note that VFO output is routed to *UCB*. As such, when a fault arises the software can use VFO output accordingly to shut down system operation or take other actions. Note that the above protection mechanism is implemented in software level, and as such it might be subjected to delays or spurious tripping if not properly handled.

UCB Controller

The *UCB* is a powerful universal motor controller that is based on SOC Zynq 7000 series [11]. It includes a dual 667 MHz CPU Cortex A9 core, with freely configurable digital peripheral, bootloader capability via micro SD card, USB/UART/JTAG interface, 32 Mbyte Flash memory, 32−Bit−wide 256 MByte DDR3 SDRAM, on−board Ethernet phy, 10 ADC channel – using **onsemi** *NCD98011*), and 12 complementary PWM channels. The *UCB* is an industrial−grade System on Module (SoM) that can be used for advanced networked motor and motion control systems, capable of delivering advanced control strategies for different types of motors (AC induction motor, PMSM, BLDC).

The *UCB* controller interacts with the power board via specific pins, which are routed to two – 120 pins each – connectors. More details around the connectors can be found in Board Connectors. Auxiliary 5 Vdc and 3.3 Vdc power supplies can be used for powering−up the *UCB* board. They are located at the main power board. Alternatively, the *UCB* can be powered−up from the 5 Vdc USB cable, which is connected to the controller. Then, the *UCB* generates all the voltage rails (3.3 Vdc included) that are required for its proper operation. In addition, it also delivers (independently of the main auxiliary supplies) the necessary 5 Vdc and 3.3 Vdc reference voltages for the Op−Amps and comparators on the power board. Therefore, functionality of the controller, as well as the functionality of the Op−Amps and comparators can be evaluated even when the main power board auxiliary supplies are off.

Finally, the *UCB* provides the control capabilities of the system, and supports the user interface communication. End user can develop its own applications to exploit the *UCB* features and capabilities. As mentioned earlier the *MDK_SPM31* power board provides all the required feedback to the *UCB* for the generation of PWM driving signals to control the IGBT module gate drivers as well as to enable/disable the module in the event of faults arising. This allows end−user to develop many different control strategies from simple V/F and Field Oriented Control (FOC) up to predictive control algorithms. Moreover, the UCB enables bidirectional serial communication to transfer measurements data for visualization purposes. A Graphical User Interface is provided, along with an appropriate code in flash that can run a simple V/F control or an FOC and allow visualization of key electrical quantities. More details around the software can be found in Software section. The interface header pinout of *MDK_SPM31* is described in detail in Board Connectors. A detailed description of the UCB connector can be found in Appendix. Finally, the documentation around *UCB* can be found in [1].

Auxiliary Power Supplies

There are three auxiliary supplies on the power board to provide the necessary 15 Vdc, 5 Vdc, and 3.3 Vdc rails. The first one is a non−isolated buck converter using NCP1063. This auxiliary supply provides the 15 Vdc, which are necessary for the *IPM* drivers. The *NCP1063* high−voltage switcher serves well this purpose, featuring a built−in 700 V MOSFET with $R_{DS(on)}$ of 11.4 Ω and 100 kHz switching frequency. *NCP1063* is fed directly from the high−voltage DC−Link. A minimum 90 V DC−Link voltage is required for operation. Next, the *FAN8303* non−isolated buck is used to convert the 15 Vdc to the 5 Vdc that is necessary for the *UCB* controller circuitry. Last but not least, the LDO *NCP718* converts the 5 Vdc to 3.3 Vdc, necessary for the current measuring and protection circuitry, and for the integrated *UCB NCD98011* ADC modules. The non−isolated power supplies provides a simple and effective solution for industrial and commercial motor control applications. More details about the auxiliary power supplies can be found in the corresponding ICs data sheets, [3], [4], and [5], respectively. Last but not least, the power rating of the auxiliary power supplies can be found in Table 1.

EEPROM

The main power board is equipped with the *CAT24C512* EEPROM unit. The *CAT24C512* is an EERPOM Serial 512−Kb I^2C, which is internally organized as 65,536 words of 8−bits each. It features a 128−byte page write buffer and supports the Standard (100 kHz), Fast (400 kHz) and Fast−Plus (1 MHz) I^2C protocol. External address pins make it possible to address up to eight *CAT24C512* devices on the same bus. The device Serial Click and Serial Data pins of the *CAT24C512* (pins *DIO_1_1, DIO_1_2*) are routed to the *UCB* controller B35 buss (*B35_L16_N* and *B35_L16_P*, respectively), via CON4 (*pin 13* and *pin 14*). The data sheet of *CAT24C512* EEPROM device can be found in [8].

SCHEMATIC AND DESIGN

To meet customer requirements and make the evaluation board a basis for development, all necessary technical data like schematics, layout and components are included in this chapter. This section will also discuss the design remarks, trade−offs and recommendations for the design.

NCP1063 15 V Auxiliary Power Supply

As mentioned earlier, there are three Auxiliary power supplies that generate the necessary voltage rails for the proper function of the *MDK_SPM31* and *UCB* controller boards. The *NCP1063* is a non−isolated buck that is used as converter from DC−Link to 15 Vdc output, to supply the IPM board, as well as the *UCB* board and Op−Amp circuitry through the *FAN8303* and *NCP718*. The maximum power demand is up to 4.6 W. Figure 5 depicts the schematic of the 15 Vdc auxiliary power supply. The design and sizing of the passive components has been inspired by the applications notes in [3]. The desired output voltage value can be set by tuning the values of the voltage divider (*R1* and *R3*) connected to the *FB* pin. Additionally, the value of *C6* on the *COMP* pin is tuned empirically to reflect the desired voltage at the converter output. It is noted that the frequency Jittering function helps spreading out energy in conducted noise analysis. To improve the EMI signature at low power levels, the jittering remains active in frequency foldback mode. Finally, the switching frequency is 100 kHz, which allows designs with small inductor (for this design we used 560 μH, see *L2*) and output capacitance requirements (for this design we used two 220 μF, see *C8* and *C9*) and low current ripple output.

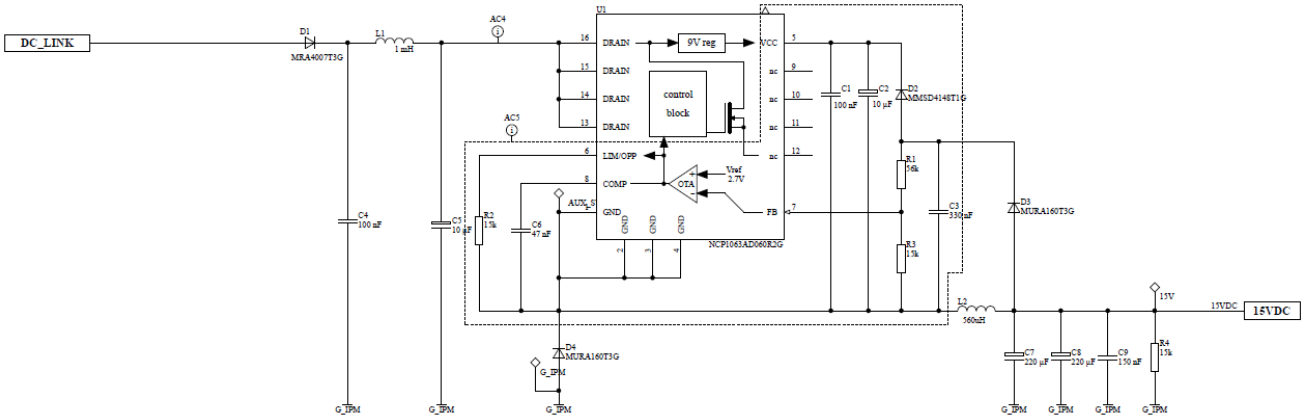

Figure 5. Schematic of Auxiliary 15 Vdc Power Supply

FAN8303 and NCP718 Auxiliary Power Supplies

The *FAN8303* is a non−isolated buck that is used as converter from 15 Vdc to 5 Vdc output. The maximum power demand is 2.9 W. Figure 6 depicts the schematic of the 5 Vdc auxiliary power supply. Similarly to the *NCP1063*, the design and sizing of the passive components has been inspired by the applications notes in [4]. The desired output voltage value can be set by tuning the values of the voltage divider (*R5* and *R6*) connected to the FB pin. Additionally, the value of *C17* on the *COMP* pin is tuned empirically to reflect the desired voltage at the converter output. The controller operates at fixed 370 kHz with an efficiency up to 90%. This allows a design with only 22 µH magnetizing inductance (see L3) and two 22 µF capacitors (see *C13* and *C14*). Finally, Figure 6 depicts the *NCP718* LDO, which is responsible for the 3.3 Vdc rail generation.

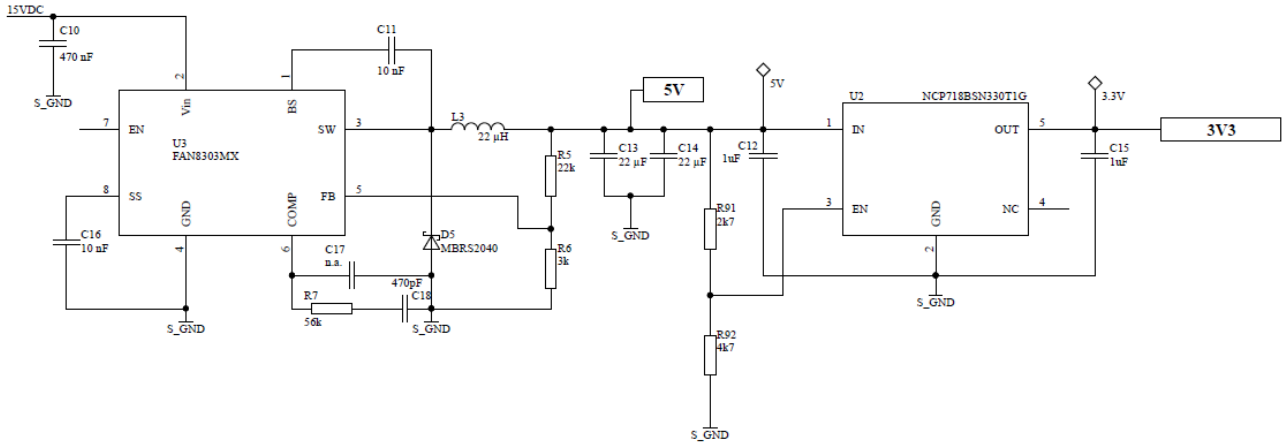

Figure 6. Schematic of Auxiliary 5 Vdc and 3.3 Vdc Power Supply

Inverter Stage: Compact Intelligent Power Module (IPM) Technology

This subsection shows how the necessary circuitry for operation, measurement and protection is setup around the *NFAM5065L4B IPM*. In addition, it illustrates the necessary circuitry to provide and capture the signals around the module (i.e. the output signals: *T_MODULE, IPM_FAULT;* and the input signals: *ITRIP, IPM_DIS,* and gate driver signals *INH_U, INH_V, INH_W, INL_U, INL_V, INL_W*). Finally, it illustrates the provision of the voltage rails for the *IPM* (15 Vdc rail reference), as well as the measurement of the DC−Link and inverter−phase voltages. Activation of IPM stage (connection to 15 Vdc power supply) is via J1 (soldered pads). Figure 7 shows the *J1* pads at the bottom side of the board; mind that pads should be soldered together to enable the 15 Vdc to the *IPM*. Following, Figure 8 shows the schematic of the inverter stage and the necessary circuitry around it. Finally, Figure 8 depicts the DC−Link voltage (voltage divider containing *R46, R52, R53* and *R55*) and the inverter output phase−voltage measurement circuitry (voltage divider for phase−U containing *R31, R34, R40* and *R42*; voltage divider for phase−V containing *R32, R35, R41* and *R43*; and voltage divider for phase−W containing *R29, R33, R39* and *R44*). The inverter output voltage phases can be used by the software for zero crossing detection or other control purposes. The signals from the 10 mΩ shunt resistors are going to current measurement and over−current protection circuits. Details regarding the ADC resolution of the above sensed electrical quantities can be found in Table 1. Next paragraphs are dedicated to the elaboration of the above mentioned circuitries.

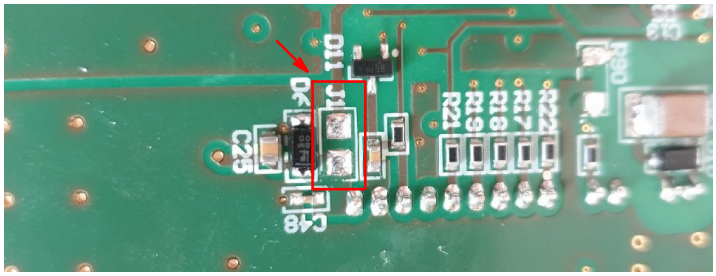

Figure 7. J1 Pads at the Bottom of the Board (the Pads should be Soldered to Enable the 15 Vdc in the IPM)

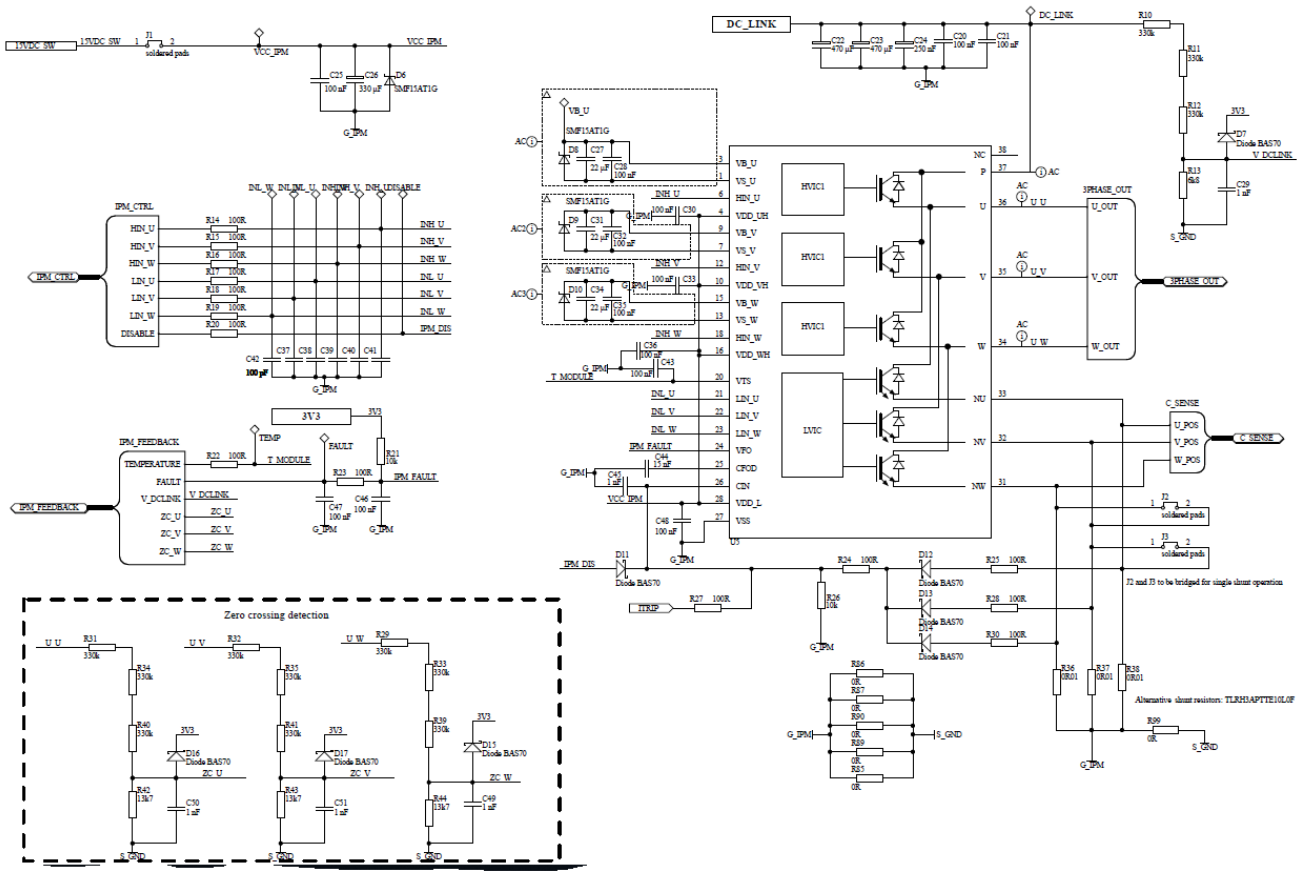

Figure 8. Schematic of − IPM − Inverter Stage

Considering that the reference voltage for the ADC *NCD98011* modules is 3.3 Vdc, the resistors of the DC−Link voltage measurement were designed according to the following voltage divider formula, where V_{ADC} is the voltage arriving at *NCD98011:*

$$V_{ADC} = V_{DC-Link} \cdot R_{13} \cdot (R_{10} + R_{11} + R_{12} + R_{13)} \leq 3.3\ V$$

To minimize the current flowing through the voltage divider and also power losses, the values of resistors should be chosen in hundreds kΩ. With the chosen values of resistors, the maximal possible measured $V_{DC-Link}$ can be:

$$V_{DC-Link,max} = 3.3 \cdot \frac{(R_{10} + R_{11} + R_{12} + R_{13})}{R_{13}} = 483.7\ V$$

As the DC−Link maximum allowed value is 410 V, we have around 15% margin.

As discussed earlier, the effective resolution of the ADC *NCD98011* is 11−bit, which results in a total resolution of:

$$V_{DC-Link,res} = \frac{483.7}{2^{11}} = 0.236\ V$$

On the other hand, the maximum possible measured voltage for the inverter output phases can be:

$$V_{U,V,W,max} = 3.3 \cdot \frac{(R_{31,32,29} + R_{34,35,33} + R_{40,41,39} + R_{42,43,44})}{R_{42,43,44}}$$

$$= 241.7\ V,$$

which results to a resolution of:

$$V_{U,V,W-Link,res} = \frac{241.7}{2^{11}} = 0.472\ V$$

Please note that the inverter phase voltage measurement with the currently used resistors will be saturated for DC−Links higher than 241.7 V, as demonstrated in the figures below. However, this configuration allows detection of the zero crossing BEMF with increased accuracy, as you can compare the inverter output phase with the half of the DC−Link voltage. It should be noted that with the currently used resistor network, the inverter output phase−voltage could be used only to detect the BEMF zero crossing for trapezoidal−type controls with respect to the half of the DC−Link voltage. For different zero−crossing detection methods, such as the reconstruction of inverter neutral voltage in software, or for different control algorithms where the full range of inverter phase voltages is required, you should replace the three bottom 13.7 kΩ resistors *R42, R43, R44* with 6.8 kΩ ones. The main reason of using this limited voltage range for the inverter output phase is to increase the voltage resolution around the BEMF zero crossing, where only two out of three inverter phases are energized.

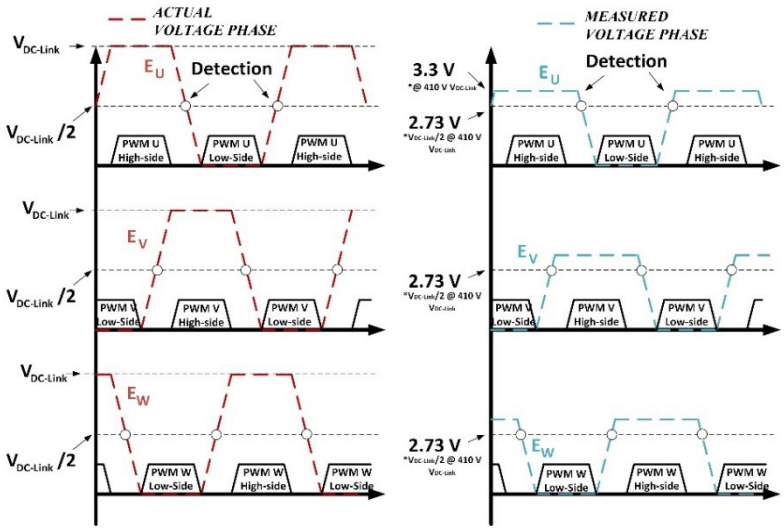

Figure 9. Actual and Measured Voltage Phase with Currently used Voltage Divider

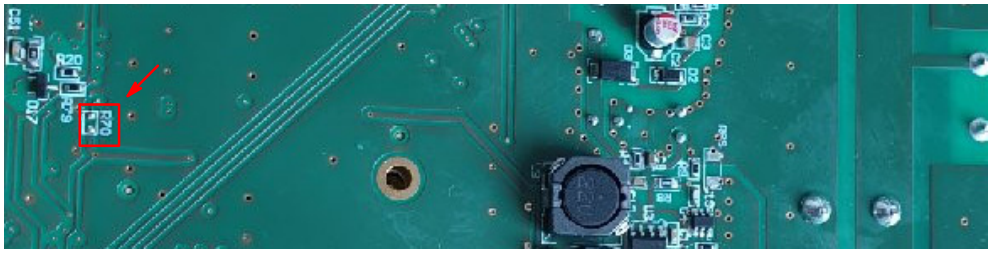

Figure 10. UCB UART Disable via Soldering R70 at MDK Board

On Board (UCB) UART

The UART module that is integrated at *UCB* can be disabled by soldering R70. To allow UART communication at *UCB* you should keep R70 empty, as in Figure 10.

Current Measurement and Over−Current Protection

The maximum current that can be measured with the existing circuitry can be calculated as:

$$I_{max+} = \frac{V_{ADC,max} - V_{offset}}{G \cdot R_{shunt}} = 16.5\ A$$

$$I_{max-} = \frac{-(V_{offset})}{G \cdot R_{shunt}} = -16.5\ A,$$

where $V_{ADC,max}$ is the maximum voltage at *NCD98011* ADC modules (i.e. 3.3 V as mentioned earlier), V_{offset} is the external offset for the Op−Amps (i.e 1.65 V), G is the Op−Amps gain (i.e is 10), and R_{shunt} is the value of the shunt resistors (i.e 0.01 Ω). The total resolution considering also the *NCD98011* ADC modules is:

$$I_{res} = \frac{16.5 \cdot 2}{2^{11}} = 0.016\ A$$

Considering the layout design, a good practice consists of using kelvin sensing and place the op amp as close as possible to the shunt resistors as illustrated in Figure 11.

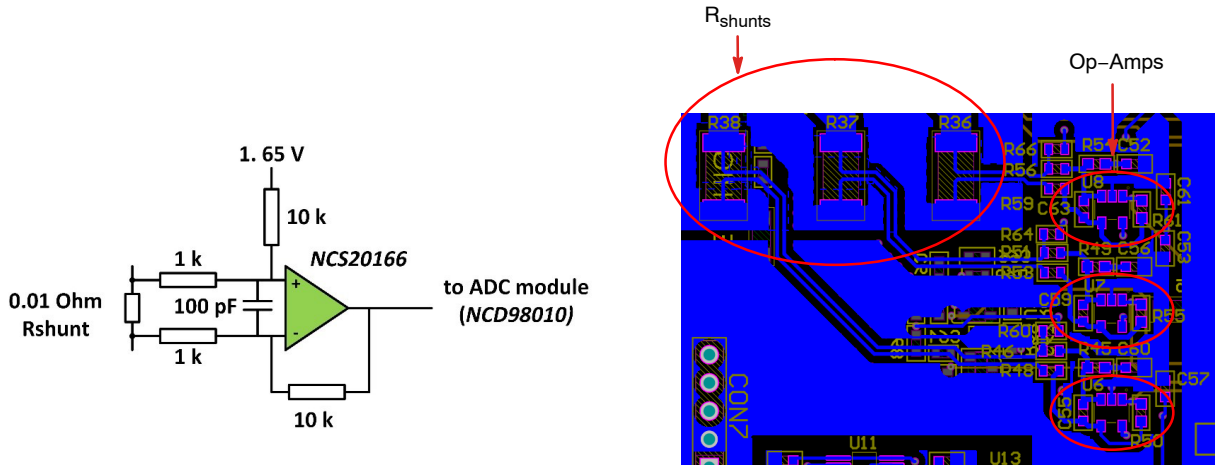

Figure 11. Block Diagram of One Phase Current Measurement and Layout of the Current Measurement Parts

The schematic of current measurement and over−current protection can be seen in Figure 12. As mentioned above the information of currents is provided via the 10 mΩ shunt resistors. The voltage across the shunt resistor is used as input to the *NCS20166* Op−Amps, the gain of which is set to 10 via the 1 kΩ and 10 kΩ resistor, according to Figure 11. U9 (*TLV431*) is generating the 1.65 Vdc voltage reference, which is connected to the non−inverting input of Op−Amps through a 10 kΩ resistor − as in Figure 11. This connection provides voltage offset at the output of the Op−Amps, which is needed for negative current measurement.

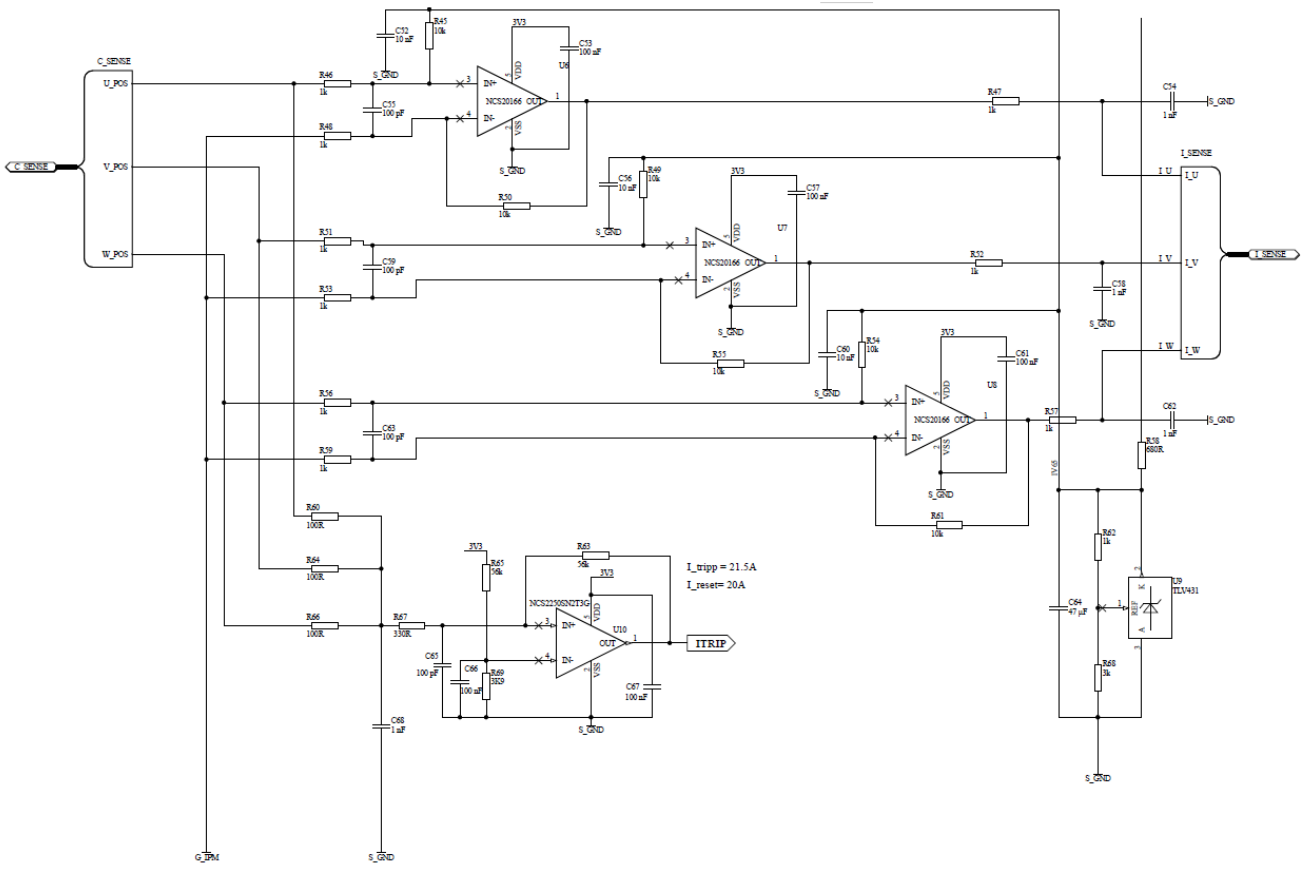

Figure 12. Schematic of Current Measurement Circuitry

IPM can be shut−down by setting the voltage level of the *CIN* pin to 0.5 V or higher. The NCS2250 comparator is responsible for asserting the *CIN* pin high, protecting the board against an overcurrent incident (the output of the overcurrent comparator drives *ITRIP* signal, which is routed to *CIN*, Figure 8). *CIN* pin is also controlled by the *UCB* controller, which allows the end−user to design multilayer protection. Comparator threshold is set by a voltage divider, which consists of the *R65* and *R69* resistors. That threshold is compared against the non−inverting pin voltage, which comes from the voltage across the shunt resistors *R60, R64* and *R66*. The comparator also incorporates a hysteresis loop by providing a feedback to the non−inverting pin via the *R63* resistor. Based on the above selected resistors the tripping threshold corresponds to +21 A. To prevent spurious operation of comparator, a low pass filter is implemented, formed by the capacitor *C68* along with resistors *R60, R64,* and *R65*. The cut−off frequency of the formed low−pass filter results in a delay of around 500 ns, which is sufficient for the fast reaction of the current protection.

On top of that, IPM asserts fault pin (*VFO*), which can be used by the *UCB* to shut down the inverter. The voltage level of that pin is low during normal state. After a fault occurrence at the driver, the output of fault pin is switched high. The output of fault pin is held on for a time determined by the *C44* capacitor (15 nF) that is connected to the *CFOD* pin (*IPM* pin 25), which can be used by the software for further actions. The equation that gives the on time of the pulse (ton_{fault}) is:

$$ton_{fault} = 0.1 \cdot 10^6 \cdot C44 = 1500\ \mu s$$

Board Connectors

MDK_SPM31 comes with several connectors that allow the board to interact with external systems, such as encoders and different control platforms (i.e. *UCB*). *MDK_SPM31* also carries the appropriate connectors to host the *UCB* controller. The interconnections/routing of the signals that are associated with the connectors of the *MDK_SPM31,* as well as the power−connectors of the board are described later in this subsection.

Low−power Connectors

The *MDK_SPM31* board has seven connectors in total. Five of those connectors (CON7, CON6, J4, and CON4 and CON5,) interfere with the various low−power signal and voltage rails, while the rest two connectors handle the high dc−input and the three−phase ac−output high power voltages.

Figures 13−15 depict the low power connectors schematics of the board along with their physical visualization.

CON7 (Figure 13) can be used as an interface between the encoder and the UCB controller, enabling sensored−FOC control algorithms.

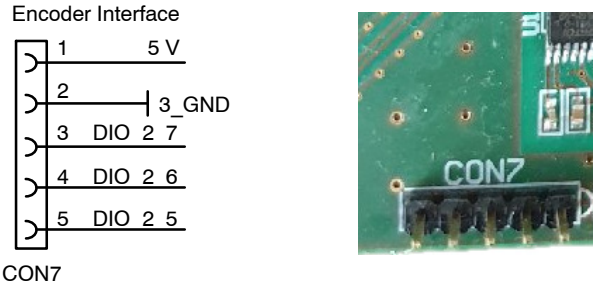

Figure 13. Schematic and Physical Visualization of Encoder Interface

The connector CON6 gives access to additional digital I/O, PWM, and ADC pins of the *UCB* controller. Low pass filters for current and/or voltage measurement signals are placed closed to the headers (see Figure 14).

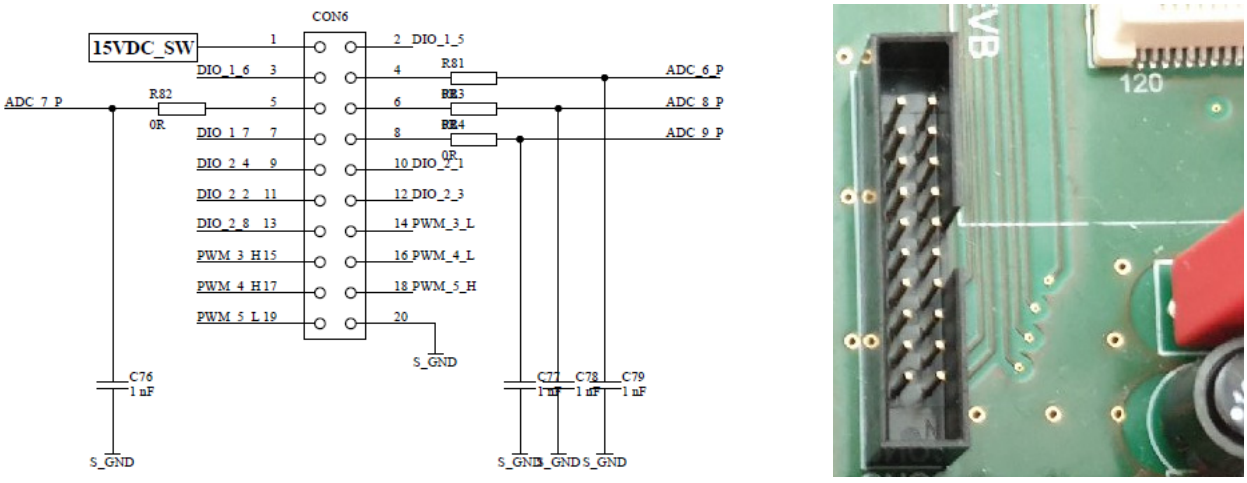

Figure 14. Schematic and Physical Visualization of CON6

CON4 and CON5 are hosting the *UCB* controller (Figure 15). Most of the signals that are associated with the low−power connectors are routed to the *UCB* controller via CON4 and CON5. On the contrary, signals like the IPM_DIS, and the PWM pulses are directed from CON4 and CON5 to the *NFAM5065L4B* inverter for control purposes.

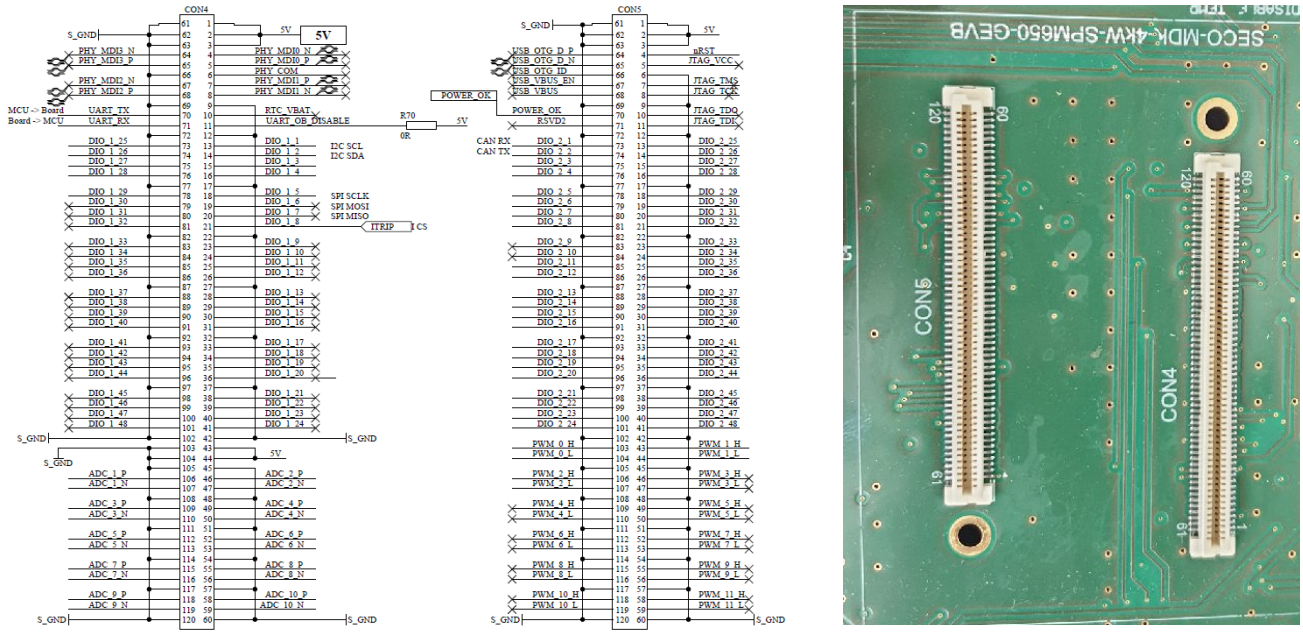

Figure 15. Schematic of Current Measurement Circuitry

High−power Connectors

The high−power connectors that are associated with the input and output system voltages are illustrated in Figures 16 and 17. Figure 16 illustrates the DC−Link input voltage, where the green connector should be connected to earth, the red connector should be connected to the high potential (+), and the black to the ground (−). The inverter output voltages, on the other hand, are available through the connector CON3 (see Figure 17). The output voltage U, V and W sequence is shown in Figure 17.

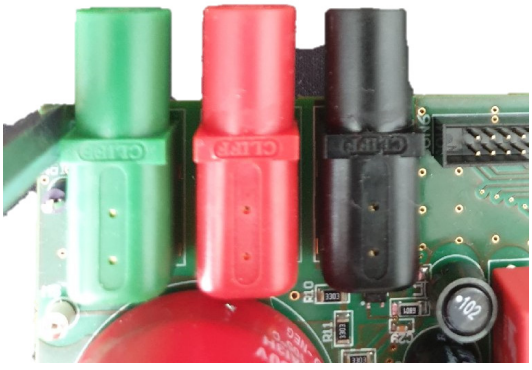

Figure 16. DC−Link Input Voltage Connector

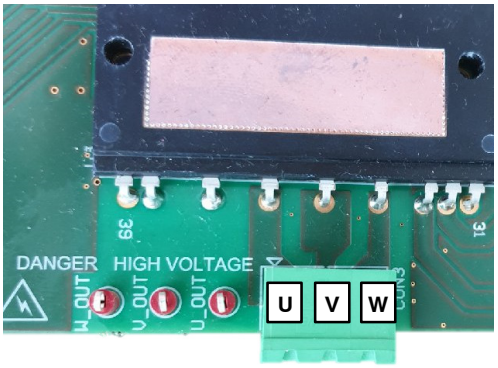

Figure 17. Inverter Output Voltage Phase Connector

Additional Connections to the UCB Controller

Finally, Figure 18 depicts some additional connections from *MDK_SPM31* to the *UCB* controller.

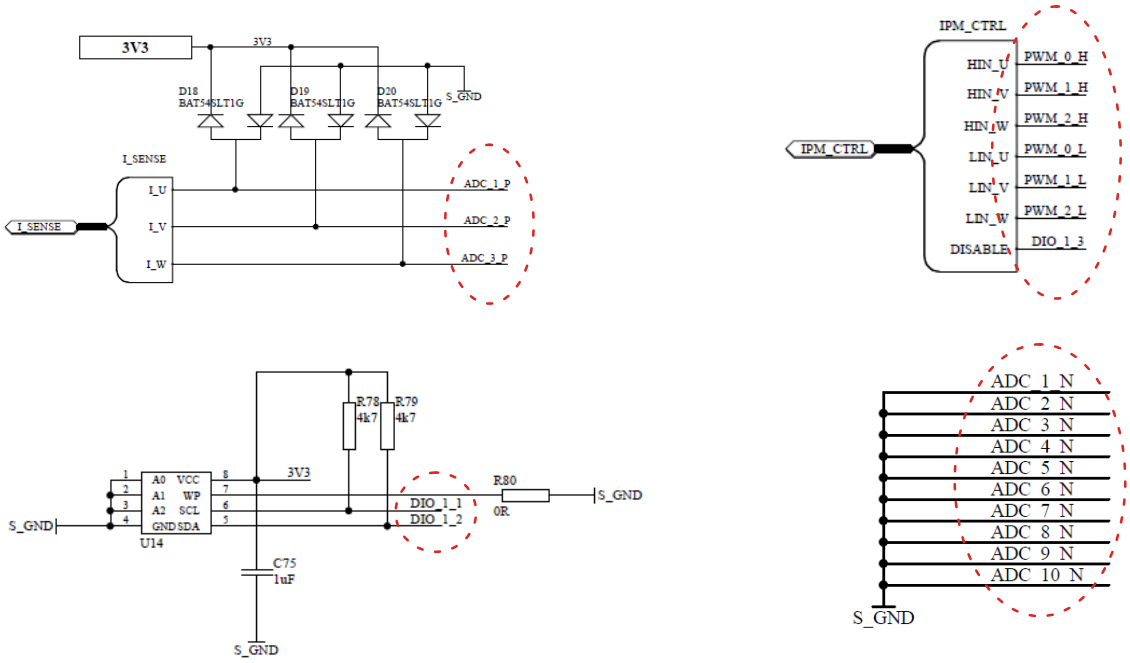

Figure 18. Connections to the UCB

SOFTWARE

FOC has been widely used during the last decade as an efficient way to control various types of motors over wide speed ranges. The controller optimizes the efficiency of the system as it produces the required motor torque with the lowest possible phase−currents, by maintaining a 90o angle between the rotor flux and current. Moreover, it provides fast dynamic response and a low current harmonic content. Numerous scientific and technical papers in literature describe thoroughly the FOC operation. We would like to note that the analysis of FOC falls beyond the scope of this document. For a more comprehensive description of FOC operation, the reader may refer to the corresponding references. [13−15].

UCB with Pre−flashed Firmware

(UCB acquired as part of SECO−MDK−4KW−65SPM31−GEVK)

If you acquired the UCB as part of the **onsemi** kit, the controller is already flashed with V/F control and FOC control. The user does not have to perform any further actions for booting. It is noted however, that booting from the flash, the SD−socket at UCB should be empty. With the flashed controller, the user can control the motor via the graphical user interface (GUI) of Figure 19; to download the GUI, click the link in [12], download the latest version of software, open the *MDK_GUI* zip file, and run the executable *Serial_Gui* file. With the GUI, the user can select between the V/F and FOC strategy. The GUI also assists the end−user to configure and tune the foremost V/F and FOC parameters, while it also provides visual representation of key electrical variables, such as the DC−Link voltage and temperature of IPM, the RMS value of the inverter output current and voltage, and the motor speed.

Rewriting Flash Memory or SD−card Image

(Important when UCB not acquired as part of the SECO−MDK−4KW−65SPM31−GEVK)

In case the user wants to rewrite the flash memory with the default V/F−FOC control, he can use the *boot−image* and *fsbl.elf* files that are accessible via the link in [12]. To download the *boot−image* and *fsbl.elf,* click the link in [12] and download the latest version of software; *boot−image* and *fsbl.elf* files are included in the *UCB_firmware* of the downloaded software file.

The following guide contains material on how to load the boot image:

- Flashing QSPI memory [16] (link).

To boot from SD card, copy the boot image that is found in [12] into the root directory of the SD card. Then place the SD card into the SD socket of UCB. Upon power−up the UCB will automatically boot from the SD card.

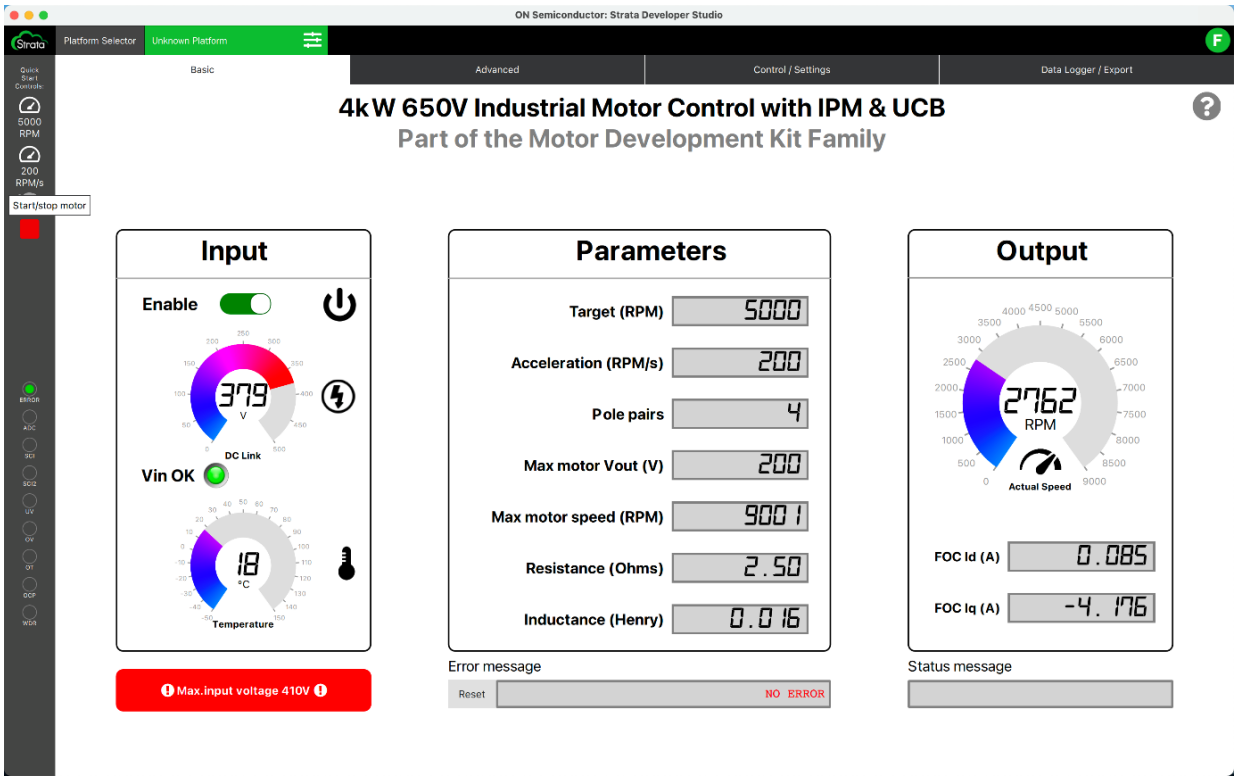

Figure 19. Graphical User Interface (GUI) in Strata Developer Studio

TESTING AND OPERATION

This section describes how to test and operate the development board and present the test results. At the beginning the *Safety and Precautions are described, which are a mandatory read before manipulating the board.*

Safety Precautions

This section describes the Safety Precautions which are a mandatory read before manipulating the board.

Attention:
The SECO−MDK−4KW−65SPM31−GEVB is powered by external DC power supply, and is exposed to high voltage. Only trained personnel should manipulate and operate on the system. Ensure that all boards are properly connected before powering, and that power is off before disconnecting any boards. It is mandatory to read the Safety Precautions Table before manipulating the board. Failure to comply with the described safety precautions may result in personal injury or death, or equipment damage.

Table 2. SAFETY PRECAUTIONS

1	**Ground Potential**	The ground potential of the system is biased to a negative DC bus voltage potential. *When measuring voltage waveform by oscilloscope, the scope's ground needs to be isolated.* Failure to do so may result in personal injury or death.
2	**USB Isolation**	The ground potential of the system is NOT biased to an earth (PE) potential. When connecting the MCU board via USB to the computer, *the appropriate galvanic isolated USB isolator have to be used. The recommended isolation voltage of USB isolator is 5 kV.*
3	**DC BUS Capacitors**	*SECO−MDK−4KW−65SPM31−GEVB* system contains DC bus capacitors which take time to discharge after removal of the main supply. *Before working on the drive system, wait ten minutes for DC BUS capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death.*
4	**Trained Personnel**	*Only personnel familiar with the drive and associated machinery should plan or implement the installation, start−up and subsequent maintenance of the system.* Failure to comply may result in personal injury and/or equipment damage.
5	**Hot Temperature**	*The surfaces of the NFAM5065L4B and development board drive may become hot, which may cause injury.*
6	**ESD**	*SECO−MDK−4KW−65SPM31−GEVB* system contains parts and assemblies sensitive to Electrostatic Discharge (ESD). *Electrostatic control precautions are required when installing, testing, servicing or repairing this assembly.* Component damage may result if ESD control procedures are not followed. *If you are not familiar with electrostatic control procedures, refer to applicable ESD protection handbooks and guidelines.*
7	**Installation and Use**	*A drive, incorrectly applied or installed, can result in component damage or reduction in product lifetime.* Wiring or application errors such as under sizing the motor, supplying an incorrect or inadequate AC supply or excessive ambient temperatures may result in system malfunction.
8	**Powering Down the System**	*Remove and lock out power from the drive before you disconnect or reconnect wires or perform service. Wait ten minutes after removing power to discharge the DC bus capacitors.* Do not attempt to service the drive until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.

Test Procedure

This section presents the test procedure and results for the evaluation of the platform. The aim of these tests is to show the system level performance of the *IPM* as well as the performance of some of the key subsystems. The described and presented test and results include:

- Load tests
  - 1 kW
  - 4 kW
- Auxiliary power supply
  - Load transient

Setup and Start−up Procedure

Figure 20 shows an overview of the test setup. The test−bench consists of five main parts:

1. DC−power supply
2. *MDK_SPM31* power−board
3. R−L load/or MOTOR
4. PC/Laptop with a USB−C cable connection to a serial com port for the graphical user interface
5. Oscilloscope to monitor the inverter output currents and voltage.

Ensure to follow and implement the Safety precautions descried in Safety Precautions while testing and manipulating the board.

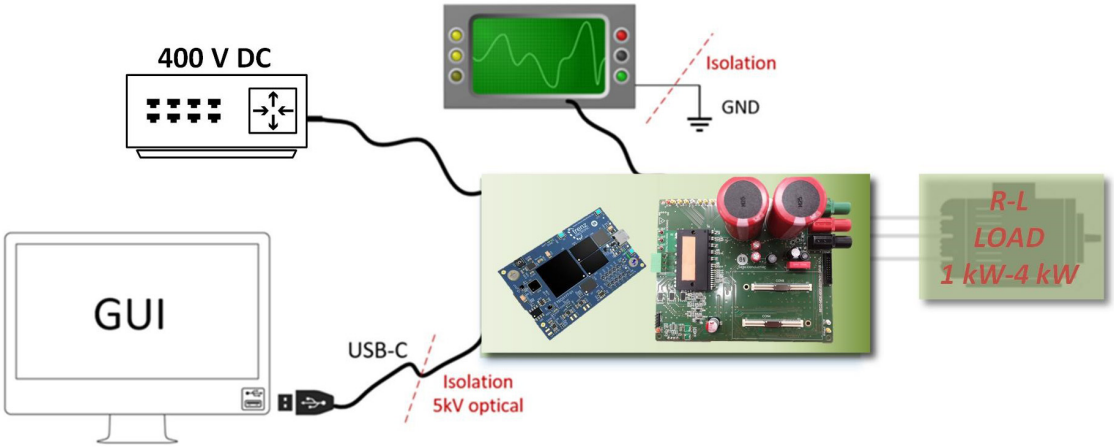

Figure 20. Overview of Schematic Set−up

The procedure to start−up and power down the development board is described below. Please read the mandatory Safety precautions detailed in Safety Precautions before manipulating the board.

1. Connect the DC−power supply cables to the *MDK_SPM31* board. Connect the positive voltage to the red connector of *MDK_SPM31*, while the negative to the black. Connect the green connector to the earth.
2. Set a maximum voltage and current limit at the power supply. Use 410 V and 13 A
3. Connect your laptop to the UCB via the USB−C cable
4. Run the executable file of the GUI that is found in [12]
5. On the pop−window press the “Connect” to connect to the UCB board
6. If the connection is successful, an indication “Connected” will appear at the bottom right of GUI. If connection fail several times, reconnect the USB−C cable and try again
7. After being connected, you can change the following configuration in the GUI: You can select one of the two available control strategies (i.e. FOC or V/F); the maximum motor phase voltage and speed; the pole−pairs of the motor; and finally you can select the gains of the PI controllers (used only in FOC). If one or more of above the parameters is not configured, the software will use the default value. Default values are: control strategy is V/F, maximum voltage 200 Vrms, maximum speed 9000 RPM, 4 pole−pairs, gains of current regulator 30 and 2500, gains of speed regulator 0.08 and 0.05.
8. After having configured the control and motor parameters, push the “RUN” button (the motor will not start yet)
9. Switch on the power supply at 400 V, and observe the voltage at the GUI
10. Set a target speed and a target acceleration and press the “SEND REF VALUE” button
11. The motor should start running
12. To stop the motor press the “STOP MOTOR” button
13. When the test stops and the DC source is disconnected from the *MDK_SPM31* board, there might be still voltage on the DC link capacitor, so *please be careful.*

Test Results

This section presents the results of the experimental test performed on the board. For the experimental test we have used an R−L load which is rated up to 4 kW, instead of a motor. The IPM switching frequency is set to 16 kHz, while the dead−time of the *IPM* is set 1500 ns. Finally, the DC−Link is set to 400 V, via a DC−power supply. The equivalent R−L emulates the motor and consists of three inductors (5 mH per phase) connected in series with a resistive bank that comprises variable resistors from 7.55 Ω up to 30 Ω per each phase. The above configuration forms an equivalent three−phase R−L load in Y connection, which emulates a tree phase motor. Figure 21 illustrates the electrical equivalent of the R−L load along with the electrical quantities under measured. The experimental results and captured waveform are depicted in Figures 22−27, showing the captured current and voltage waveforms, along with the reading from the DC−power supply. Thermal analysis results from FLIR A645SC camera conclude the section.

Table 3 summarizes the electrical parameters that have been used for the test, as well as the values of the electrical quantities that we have measured. The recorded efficiency was 95% and 96% respectively.

Table 3. SYSTEM PARAMETERS − RECAP TABLE

Test	Vdc (V)	Switching Frequency (kHz)	Resistance per phase (Ω)	Inductance per phase (mH)	PF	RMS Current (A)	Phase Volt Target (V_{RMS})	Phase Volt Meas. (V_{RMS})	DC Supply (W)	Temp (°C)	n %
1 kW	400	16	10.5	5	0.99	5.694	67.17	60.46	1091	65.8 (25 min)	95%
4 kW	400	16	10.5	5	0.99	11.1	127.3	120.35	4168	83.1 (8 min)	96.2%

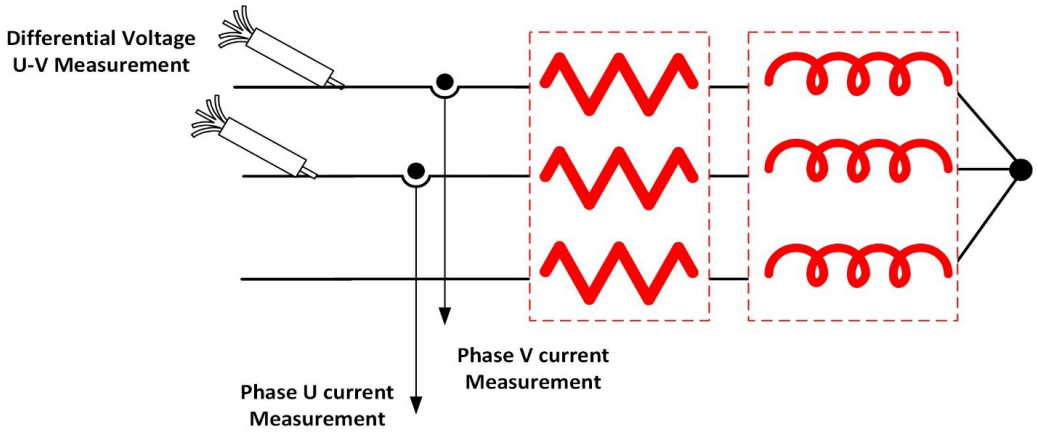

Figure 21. Electrical Schematic of R−L Load/Representation of the Measurement Points

1 kW Test

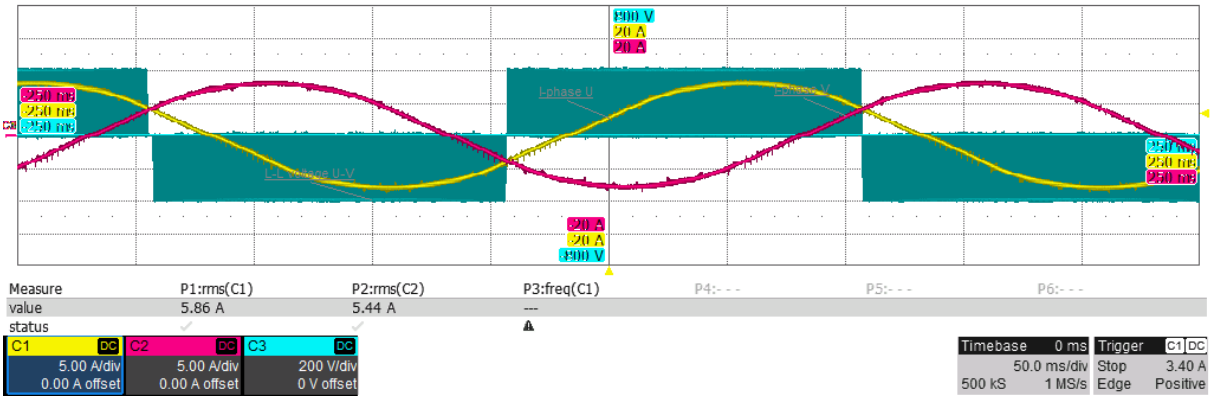

Figure 22. Phase Current U, Phase Current V, Inverter Output L−L voltage (UV) @ 1 kW

Figure 23. DC Power Supply Reading @ 1 kW.

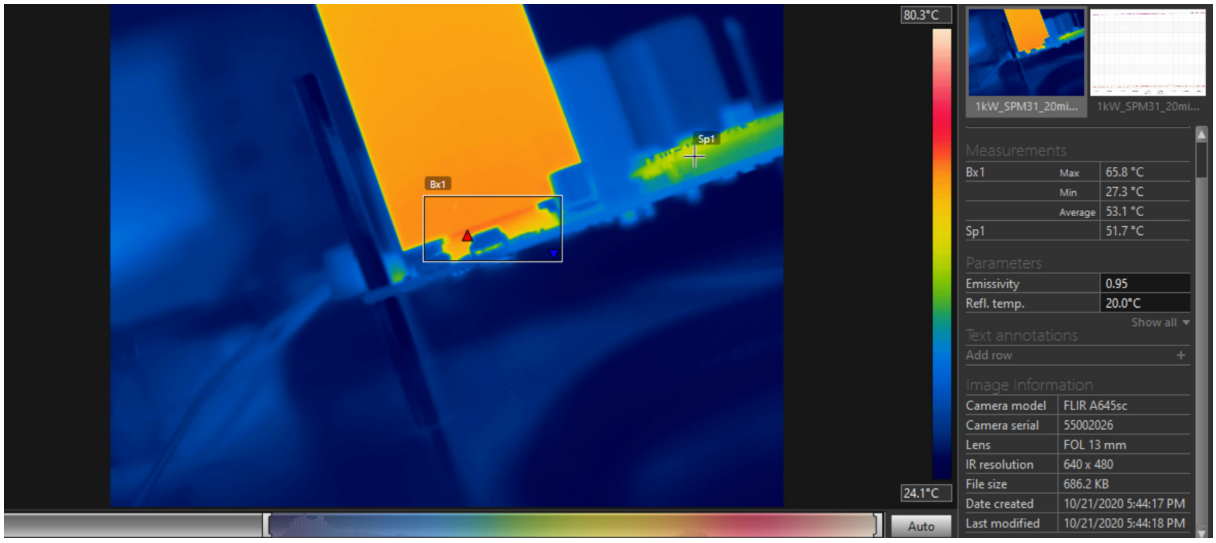

Figure 24. Thermal Camera Capture@ 1 kW after 25 Minutes of Operation

4 kW Test

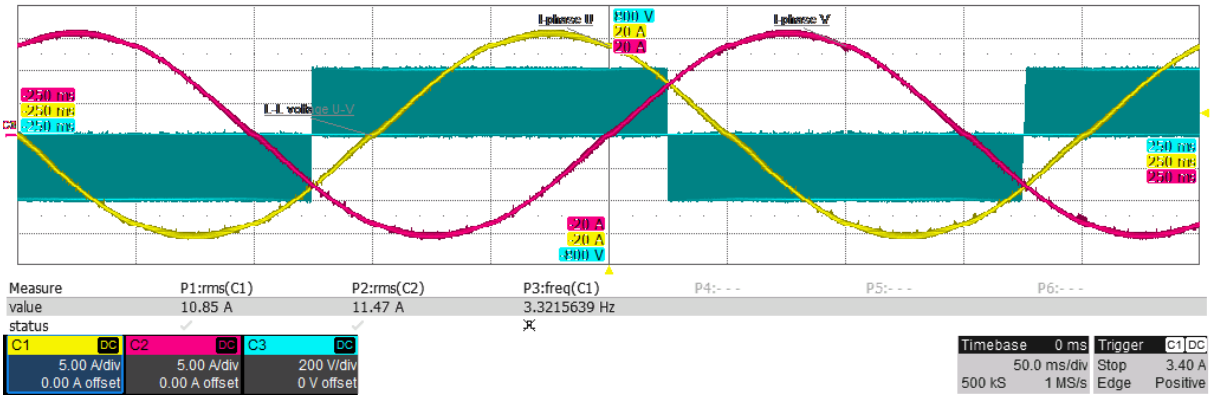

Figure 25. Phase Current U, Phase Current V, Inverter Output L−L Voltage (UV) @ 4 kW

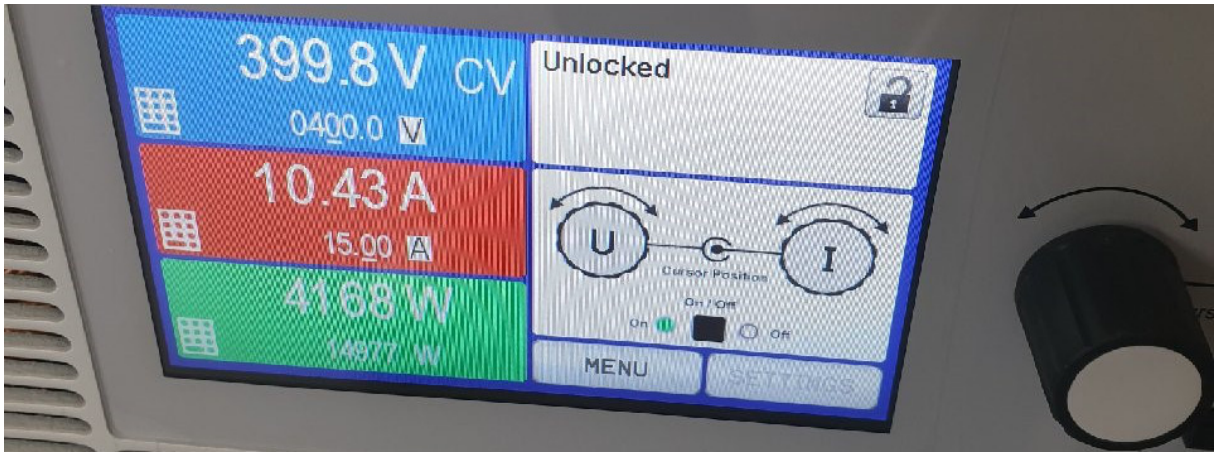

Figure 26. DC Power Supply Reading @ 4 kW

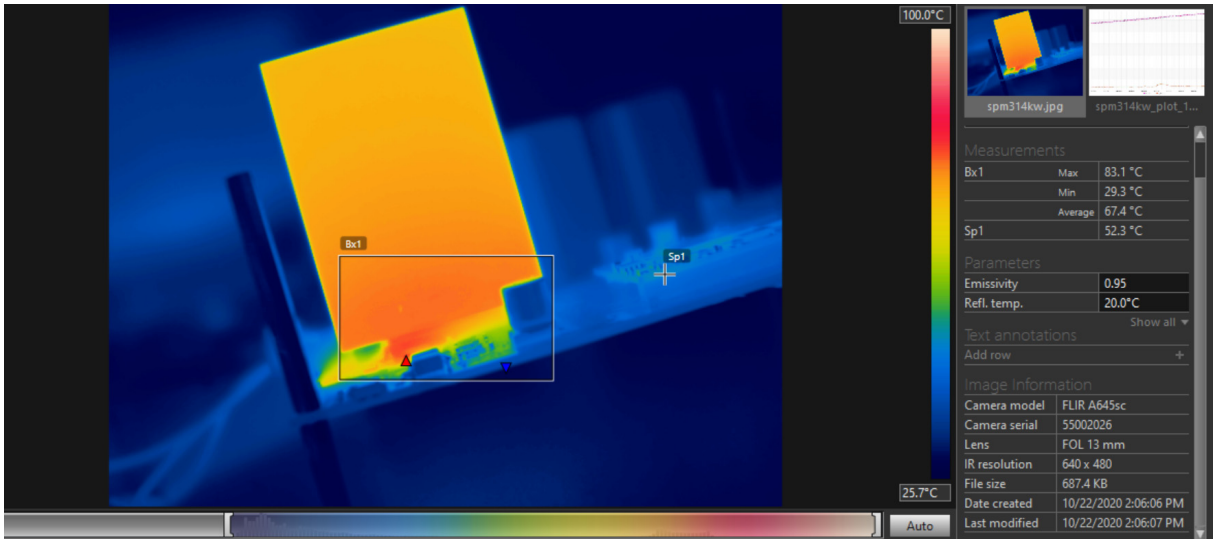

Figure 27. Thermal Camera Capture@ 4 kW after 8 Minutes of Operation

Auxiliary Power Supply

FIgure 28 shows the response dynamics of the output voltage at a constant input of 390 Vdc and for different loads. The output of the power supply is set at 15 Vdc and its max deliverable power is 4.6 W.

Measure 1: 50 mA, Measure 2: Open Circuit, Measure 3: 300 mA

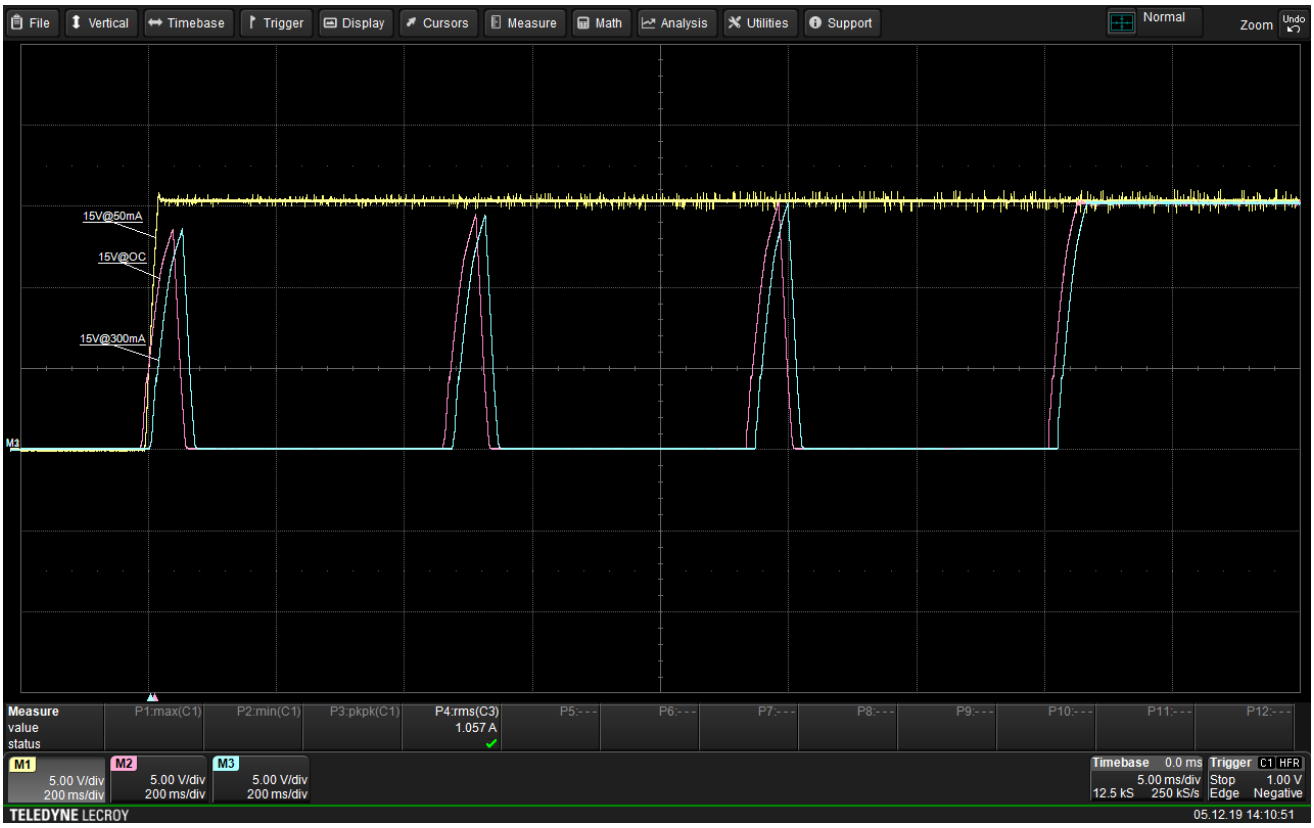

Figure 28. Start Up to Open Circuit, to 50 mA and to 300 mA at 390 V DC Input

DEVELOPMENT RESOURCES AND TOOLS

Collateral, development files and other development resources listed below are available at *SECO−MDK−4KW−MCTRL−GEVB*. Table 4 presents bill of materials (BOM) of the board. Figures 29–32 illustrate the corresponding Altium output layers of the board.

- Schematics
- BOM (below as well)
- Manufacturing files
- PCB layout recommendations and files (below as well)
  Evaluation board consist of 4.0 layers. Following figures are showing all the layers. Board size is 160 x 130 mm. Layout recommendations in AND9390/D have been applied as well. Specifics about the current measurement layout are detailed in Current Measurement and Over−Current Protection
- Executable GUI
- Boot−image for booting from flash or SD card (on delivery UCB is already flashed)

Bill of Materials

Table 4. BILL OF MATERIALS

Designator	Quantity	Value/Description	Manufacturer	Supplier Part Number
3.3 V, 5 V, 15 V	3	15 Vdc	Keystone Electronics	36−5008−ND
AUX_SW, DC_LINK, FAULT, TEMP, VCC_IPM	5	PTH testpoint eyelet	Keystone Electronics	36−5007−ND
C1	1	100 nF	Würth Electronik	732−7989−2−ND
C2	1	10 μF	Würth Electronik	732−8503−1−ND
C3	1	330 nF	Würth Electronik	732−7676−1−ND
C4	1	100 nF	Würth Electronik	732−5748−ND
C5	1	10 μF	Rubycon	1831326
C6	1	47 nF	Würth Electronik	732−8011−1−ND
C7, C8	2	220 μF	Würth Electronik	732−9171−1−ND
C9	1	150 nF	Murata	81−GRM188R71H154KA4D
C10	1	470 nF	Murata	490−11994−1−ND
C11, C16, C52, C56, C60	5	10 nF	Würth Electronik	732−8007−1−ND
C12, C15, C75	3	1 F	AVX	1658870
C13, C14	2	22 μF	Würth Electronik	732−7709−1−ND
C17, C18	2	n.a., 470 pF	Würth Electronik	2495139
C19	1	1 nF	Murata	490−11503−1−ND
C20, C21	2	100 nF	Würth Electronik	732−7411−1−ND
C22, C23	2	470 μF	Würth Electronik	732−6678−ND
C25	1	100 nF	Würth Electronik	732−8061−1−ND
C26	1	330 μF	Würth Electronik	875075661010
C27, C31, C34	3	22 μF	TDK	1843167
C28, C30, C32, C33, C35, C36, C43, C46, C47, C48, C66, C67	12	100 nF	Würth Electronik	732−7495−1−ND
C29, C45, C49, C50, C51, C68	6	1 nF	Würth Electronik	732−8001−1−ND
C37, C38, C39, C40, C41, C42, C55, C59, C63, C65	10	100 pF	Würth Electronik	732−7799−1−ND
C44	1	15 nF	Würth Electronik	2534047

Table 4. BILL OF MATERIALS (continued)

Designator	Quantity	Value/Description	Manufacturer	Supplier Part Number
C53, C57, C61	3	100 nF	Wurth Electronics	732−7965−1−ND
C54, C58, C62, C76, C77, C78, C79	7	1 nF	Würth Electronik	732−7786−1−ND
C64	1	47 μF	Murata	490−13247−1−ND
CON1	1	Banana Connector (positive output)	CLIFF Electronic Components	1854508
CON2	1	Banana Connector (negative output)	CLIFF Electronic Components	1854507
CON3	1	Pluggable Terminal Blocks (inverter output)	Würth Elektronik	691313710003
CON5	1	UCB Controller		
CON6	1	MALE BOX HEADER	Würth Elektronik	62502021621
CON7	1	PTH vertical male header	Würth Elektronik	732−5318−ND
CON8	1	Banana Connector (earth output)	CLIFF Electronic Components	419668
D1	1	MRA4007T3G	**onsemi**	1459137
D2	1	MMSD4148T1G	**onsemi**	MMSD4148T1GOSCT−ND
D3, D4	2	MURA160T3G	**onsemi**	1459149
D5	1	MBRS2040	**onsemi**	MBRS2040
D6, D8, D9, D10	4	SMF15AT1G	**onsemi**	2630276
D7, D11, D15, D16, D17	5	Diode BAS70		
D18, D19, D20	3	BAT54SLT1G	**onsemi**	BAT54SLT1GOSCT−ND
DISABLE, INH_U, INH_V, INH_W, INL_U, INL_V, INL_W	7	PTH testpoint eyelet	Keystone Electronics	36−5009−ND
G_IPM	1	PTH testpoint eyelet	Keystone Electronics	36−5124−ND
HSC1	1	Heatsink SK64550SA	Fischer Elektronik	SK645/50/SA
L1	1	1 mH	Würth Elektronik	2211747
L2	1	560 H	Würth Elektronik	7447452561
L3	1	22 μH	Würth Elektronik	710−7447714220
R1, R7, R63, R65	4	56 kΩ	Panasonic	P56.0KHCT−ND
R2, R3, R4	3	15 kΩ	Panasonic	P15.0KHCT−ND
R5	1	22 kΩ	Panasonic	P22.0KHCT−ND
R6, R68	2	3 kΩ	Panasonic	2059357
R8	1	56.2 kΩ	Panasonic	2326904
R9	1	1 kΩ	Panasonic	2303145
R10, R11, R12, R29, R31, R32, R33, R34, R35, R39, R40, R41	12	330 kΩ	Vishay	1470007
R13	1	6.8 kΩ	Panasonic	667−ERJ−P08F6801V
R14, R15, R16, R17, R18, R19, R20, R22, R23, R27, R60, R64, R66	13	100 Ω	Panasonic	2303059
R21	1	10 kΩ	Panasonic	P10.0KHCT−ND

Table 4. BILL OF MATERIALS (continued)

Designator	Quantity	Value/Description	Manufacturer	Supplier Part Number
R36, R37, R38	3	0.01 Ω	KOA SPEER ELECTRONICS	660−TLRH3APTTE10L0F
R42, R43, R44	3	13.7 kΩ	Panasonic	P13.7KCCT−ND
R45, R49, R50, R54, R55, R61	6	10 kΩ	YAGEO	9238603
R46, R48, R51, R53, R56, R59	6	1 kΩ	Panasonic	2379938
R47, R52, R57	3	1 kΩ	Panasonic	2303145
R58	1	680 Ω	Panasonic	2303131
R62	1	1 kΩ	Panasonic	2303145
R67	1	330 Ω	Panasonic	2303104
R69	1	3.9 kΩ	Panasonic	2397722
R70, R80, R81, R82, R83, R84	6	0 Ω	Panasonic	P0.0GCT−ND
R78, R79	2	4.7 kΩ	Panasonic	P4.70KHCT−ND
R91	1	2.7 kΩ	Panasonic	2303171
R92	1	4.7 kΩ	Panasonic	P4.70KHCT−ND
R99	1	0 Ω	Vishay	71−RCS12060000Z0EA
SB1, SB2, SB3, SB4, SB5, SB6	6	Spacer M3 F/F 50 HEX7		732−10660−ND
SHC1, SHC2, SHC3, SHC4, SHC5, SHC6	6	M3x16 DIN7985		
ST1, ST2, ST3, ST4, ST5, ST6	6	Spacer M3 M/F 6/30 HEX7		732−10465−ND
U1	1	NCP1063AD060R2G	**onsemi**	NCP1063AD060R2GOSCT−ND
U2	1	NCP718BSN330T1G	**onsemi**	NCP718BSN330T1GOSCT−ND
U3	1	FAN8303MX	**onsemi**	FAN8303MXCT−ND
U4	1	FDC6326L	**onsemi**	512−FDC6326L
U5	1	IPM	**onsemi**	NFAM5065L4B−ND
U6, U7, U8	3	NCS20166	**onsemi**	NCS20166SN2T1G
U9	1	TLV431	**onsemi**	863−TLV431CSN1T1G
U10	1	NCS2250SN2T3G	**onsemi**	
U14	1	CAT24C512	**onsemi**	CAT24C512WI−GT3OSCT−ND
U_OUT, V_OUT, VB_U, W_OUT	4	PTH testpoint eyelet	Keystone Electronics	36−5005−ND

Layouts

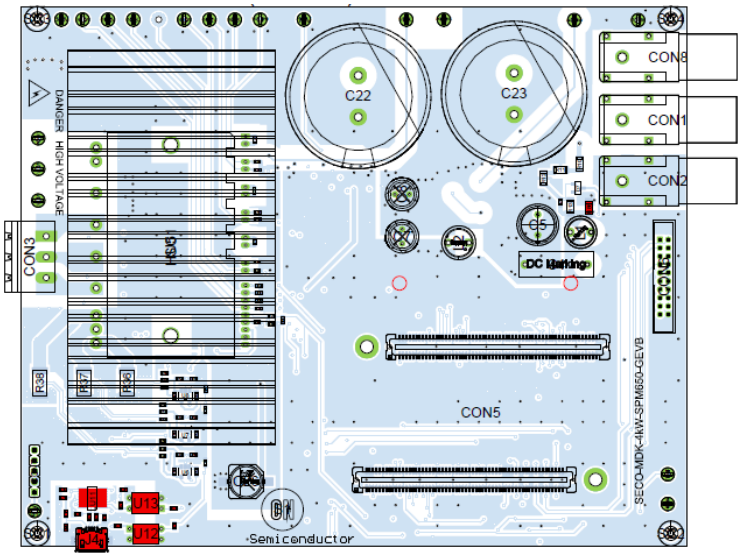

Figure 29. Top Layer Routing and Top Assembly

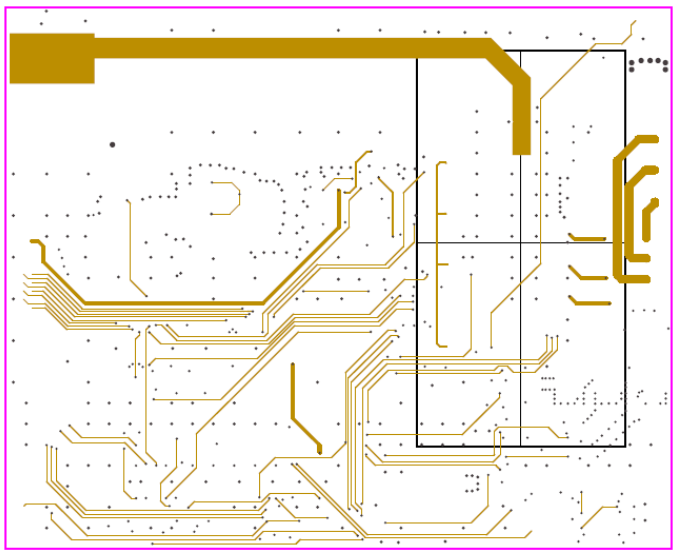

Figure 30. Internal Layer 1

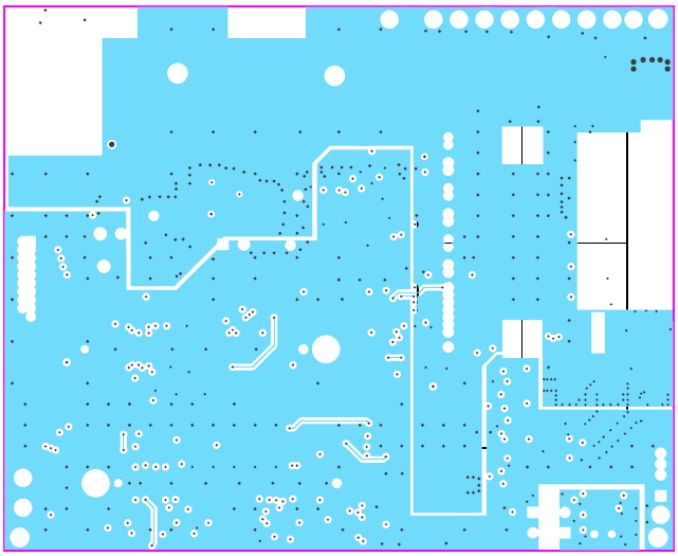

Figure 31. Internal Layer 2

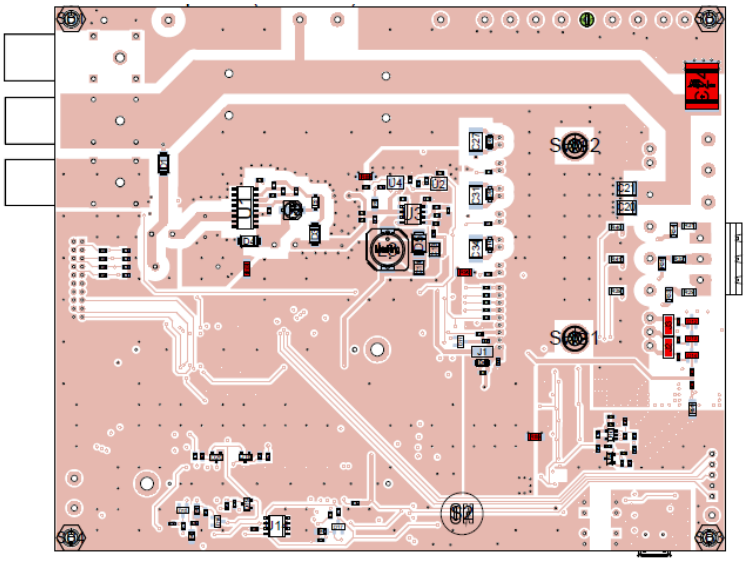

Figure 32. Bottom Layer Routing and Bottom Assembly

APPENDIX

Table 5 recaps all the signals and low−voltage rails that are routed throughout abovementioned connectors. It is noted that CON4 and CON5 host the majority of those signals, which are mainly used for the interaction between the *UCB* controller and *NFAM5065L4B* inverter stage. However, as CON4 and CON5 host 240 pins, we will only partially address those.

Table 5. MDK_SPM31 INTERFACE

MDK INTERFACE	CONNECTOR Pin	MDK	IPM	NET LABEL	Connection Description
CON4	70	U11		UART_TX	Transmitting Data to **UCB** from **U11** (USB to BASICUART IC)
	71	U11		UART_RX	Receiving Data to **U11** from **UCB** (USB to BASICUART IC)
	106			ADC_1_P	I_U current sense
	109			ADC_3_P	I_W current sense
	112			ADC_5_P	IPM Input DC−Link V_DCLINK
	115	CON6 p5		ADC_7_P	Pin 5 of **CON6** via R82
	118			ADC_9_P	**IPM** Output Voltage ZC_V
	46			ADC_2_P	I_V current sense
	49		IPM p20	ADC_4_P	TEMPERATURE from **IPM** p20
	52	CON6 p4		ADC_6_P	Pin 4 of **CON6** via R81
	55			ADC_8_P	**IPM** Output Voltage ZC_U
	58			ADC_10_P	**IPM** Output Voltage ZC_W
	1, 2, 3, 43, 44	CON7 p1		5V	**From the Auxiliary power Supply or UCB**
	9, 12, 17, 22, 27, 32, 37, 42, 45, 47, 48, 50, 51, 53, 54, 56, 57, 59, 60, 61, 62, 63, 66, 69, 72, 77, 82, 87, 92, 97, 102, 103, 104, 105, 107, 108, 110, 111, 113, 114, 116, 117, 119, 120	CON7 p2	IPM p27 via R99	S_GND	**UCB** Ground Connects to IPm p27 (G_IPM) via R99
	11	To 5V via R70		UART_OB_ DISABLE	If R70 is soldered the UART of **UCB** is disabled
	13	U14 p6		DIO_1_1	I^2C SCL to U14 (EEPROM)
	14	U14 p5		DIO_1_2	I^2C SDA to U14 (EEPROM)
	15		IPM p26	DIO_1_3	**IPM** Disable Pin p26 via D11 & R20
	16		IPM p24	DIO_1_4	**IPM** Fault Pin p24
	18	CON6 p2		DIO_1_5	**SPI** via CON 6 (SCLK)
	19	CON6 p3		DIO_1_6	**SPI** via CON 6 (MOSI)
	20	CON6 p7		DIO_1_7	**SPI** via CON 6 (MISO)
	21	ITRIP from U10		DIO_1_8	ITRIP signal from **U10** (NCS2250SN2T3G comparator)
CON5	70	POWER_OK from U4		POWER_OK	From p4 U4 (Power Switch ICs FDC6326L)
	73	CON6 p10		DIO_2_1	For CAN (Rx)
	74	CON6 p11		DIO_2_2	For CAN (Tx)
	75	CON6 p12		DIO_2_3	Debug pin avail. at p12 CON6

Table 5. MDK_SPM31 INTERFACE (continued)

MDK INTERFACE	CONNECTOR Pin	MDK	IPM	NET LABEL	Connection Description
	76	CON6 p9		DIO_2_4	Debug pin avail. at p9 CON6
	78	CON7 p5		DIO_2_5 (Note 2)	Debug pin avail. at p5 CON7
	79	CON7 p4		DIO_2_6 (Note 2)	Debug pin avail. at p4 CON7
	80	CON7 p3		DIO_2_7 (Note 2)	Debug pin avail. at p3 CON7
	81	CON6 p13		DIO_2_8	Debug pin avail. at p13 CON6
	103, 104		IPM p6, IPM p21	PWM_0_H, PWM_0_L	PWM0 H/L output to IPM via R14 and R17, respectively
	106, 107		IPMp18, IPM p23	PWM_2_H, PWM_2_L	PWM2 H/L output to IPM via R16 and R19, respectively
	109, 110	CON6 p17, CON6 p16		PWM_4_H, PWM_4_L	PWM4 output
	43, 44		IPMp12, IPM p22	PWM_1_H, PWM_1_L	PWM1 H/L output to IPM via R15 and R18, respectively
	46, 47	CON6 p15, CON6 p14		PWM_3_H, PWM_3_L	PWM3 output
	49, 50	CON6 p18, CON6 p19		PWM_5_H, PWM_5_L	PWM5 output
	9, 12, 17, 22, 27, 32, 37, 42, 45, 48, 51, 54, 6, 57, 60, 61, 62, 63, 69, 72, 77, 82, 87, 92, 97, 102, 105, 108, 111, 114, 117, 120	CON7 p2	IPM p27 via R99	S_GND	**UCB** Ground Connect to IPM p27 (G_IPM) via R99
	1, 2, 3	CON7 p1		5V	**From the Auxiliary power Supply or UCB**
CON6	1	U4 p4		15VDC_SW	Connected to U4 (Power Switch ICs)
	2			DIO_1_5	**SPI** via CON 6 (SCLK)
	3			DIO_1_6	**SPI** via CON 6 (MOSI)
	7			DIO_1_7	**SPI** via CON 6 (MISO)
	4, 5, 6, 8			ADC_6_P via R81 ADC_7_P via R82 ADC_8_P via R83 ADC_9_P via R84	**Connect to ADC port of UCB via CON4**
	9, 10, 11, 12, 13			DIO_2_4 DIO_2_1 DIO_2_2 DIO_2_3 DIO_2_8	**Debug Pins Connect to UCB via CON5**
	14, 15, 16, 17, 18, 19			PWM_3_L PWM_3_H PWM_4_L PWM_4_H PWM_5_H PWM_5_L	**Connect to PWM port of UCB via CON5**
	20		IPM p27 via R99	S_GND	**S_GND (UCB Ground)**
CON7	1	CON7 p1		5V	**From the Auxiliary power Supply or UCB**
	2		IPM p27 via R99	S_GND	**S_GND (UCB Ground)**
	3			DIO_2_7 (Note 2)	**Pin to UCB via CON5**
	4			DIO_2_6 (Note 2)	**Pin to UCB via CON5**
	5			DIO_2_5 (Note 2)	**Pin to UCB via CON5**

2. Can be used as input from encoder.

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