EVAL-M1-IM523 user guide

iMotion™ modular application design kit

About this document

Scope and purpose

This user guide provides an overview of the evaluation board EVAL-M1-IM523 including its main features, key data, pin assignments, and mechanical dimensions.

This evaluation board has been developed to provide initial support to customers in designing motor drive applications for major home appliances such as air conditioners, pumps, fans, and other variable-speed drives.

The EVAL-M1-IM523 is part of the iMOTION™ modular application design kit (MADK). Together with a control board equipped with the M1 20-pin interface connector, such as the EVAL-M1-101T, it features and demonstrates the Infineon CIPOS™ Mini intelligent power module (IPM) technology and advanced motion control engine (MCE 2.0) technology for permanent magnet motor drives. EVAL-M1-IM523 is based on the IM523-X6A CIPOS™ Mini IPM. The IM523-X6A is designed to control 3-phase AC motors and permanent magnet motors in variable-speed drives. It works with a voltage of 600 V and provides a current rating of 17 A.

Intended audience

This user guide is intended for all technical specialists who know motor control and low-power electronic converters. The evaluation board is intended to be used under laboratory conditions.

Evaluation board

This evaluation board is to be used during the design-in process for evaluating and measuring characteristic curves, and for checking datasheet specifications.

Note: PCB and auxiliary circuits are NOT optimized for final customer design.

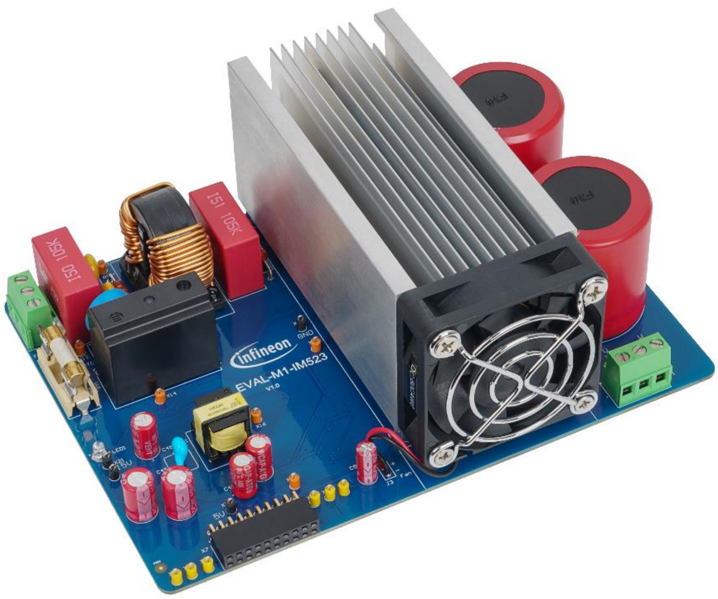

Figure 1 The iMotion™ MADK evaluation board for IM523-X6A CIPOS™ Mini IPM

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"Evaluation Boards and Reference Boards" shall mean products embedded on a printed circuit board (PCB) for demonstration and/or evaluation purposes, which include, without limitation, demonstration, reference and evaluation boards, kits and design (collectively referred to as "Reference Board").

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Safety precautions

Note: *Please note the following warnings regarding the hazards associated with development systems.*

Table 1 **Safety precautions**

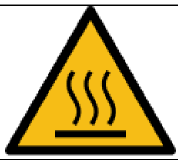
	**Warning:** *The DC link potential of this board is up to 400 V_{DC}. When measuring voltage waveforms by oscilloscope, high voltage differential probes must be used. Failure to do so may result in personal injury or death.*
	**Warning**: *The evaluation or reference board contains DC bus capacitors which take time to discharge after removal of the main supply. Before working on the drive system, wait five minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	**Warning:** *The evaluation or reference board is connected to the grid input during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by oscilloscope. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	**Warning:** *Remove or disconnect power from the drive before you disconnect or reconnect wires, or perform maintenance work. Wait five minutes after removing power to discharge the 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.*
	**Caution:** *The heat sink and device surfaces of the evaluation or reference board may become hot during testing. Hence, necessary precautions are required while handling the board. Failure to comply may cause injury.*
	**Caution:** *Only personnel familiar with the drive, power electronics and associated machinery should plan, install, commission and subsequently service the system. Failure to comply may result in personal injury and/or equipment damage.*
	**Caution:** *The evaluation or reference board contains parts and assemblies sensitive to electrostatic discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable ESD protection handbooks and guidelines.*
	**Caution:** *A drive that is incorrectly applied or installed can lead to component damage or reduction in product lifetime. Wiring or application errors such as undersizing the motor, supplying an incorrect or inadequate AC supply, or excessive ambient temperatures may result in system malfunction.*
	**Caution:** *The evaluation or reference board is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.*

Table of contents

1 The board at a glance

The EVAL-M1-IM523 evaluation power board is part of the iMOTION™ modular application design kit for motor drives (iMOTION™ MADK). The MADK platform is intended to be used with various power stages and different control boards. The EVAL-M1-IM523 can be easily connected to a control board such as the EVAL-M1-101T through the 20-pin iMOTION™ MADK M1 connector. The EVAL-M1-101T control board is designed to control a single motor.

The EVAL-M1-IM523 is available through regular Infineon distribution partners and through Infineon's website. This user guide details the features of the evaluation board (Section 1.3) and provides information on how customers can copy, modify, and qualify the design for production according to their specific requirements.

Environmental conditions were considered in the design of the EVAL-M1-IM523, but the evaluation board is not qualified, in terms of safety requirements, for manufacturing and operation over the entire operating temperature range or lifetime. The boards provided by Infineon are subjected to functional testing only.

The evaluation boards are not subject to the same procedures as regular products regarding returned material analysis (RMA), process change notification (PCN), and product discontinuation (PD). Evaluation boards are intended to be used under laboratory conditions by technical specialists only.

1.1 Scope of supply

The EVAL-M1-IM523 evaluation board is designed to provide an easy-to-use power stage based on Infineon's CIPOS™ Mini intelligent power module (IPM) IM523-X6A.

The delivery includes the finished evaluation board as shown in Figure 1. It provides a single-phase AC-input connector, an EMI filter, an input rectifier, DC bus capacitors, and a 3-phase output to connect the motor. It also contains:

1. A CoolSET™ based auxiliary power supply to provide output of 15 V and 5.0 V
2. Emitter shunts for current sensing and overcurrent protection
3. A voltage divider for DC-link voltage measurement

The evaluation board shown in Figure 1 can be operated directly with the required power supply without additional components.

1.2 Block diagram

The block diagram of the EVAL-M1-IM523 board is shown in Figure 2.

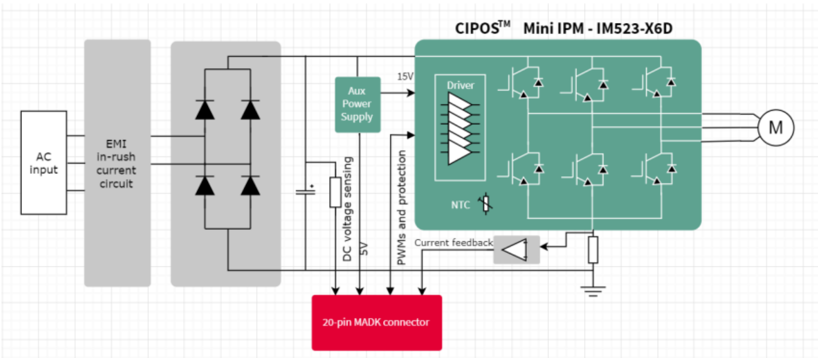


Figure 2 Block diagram of the EVAL-M1-IM523 evaluation board

Figure 3 shows the functional groups of the EVAL-M1-IM523 board.

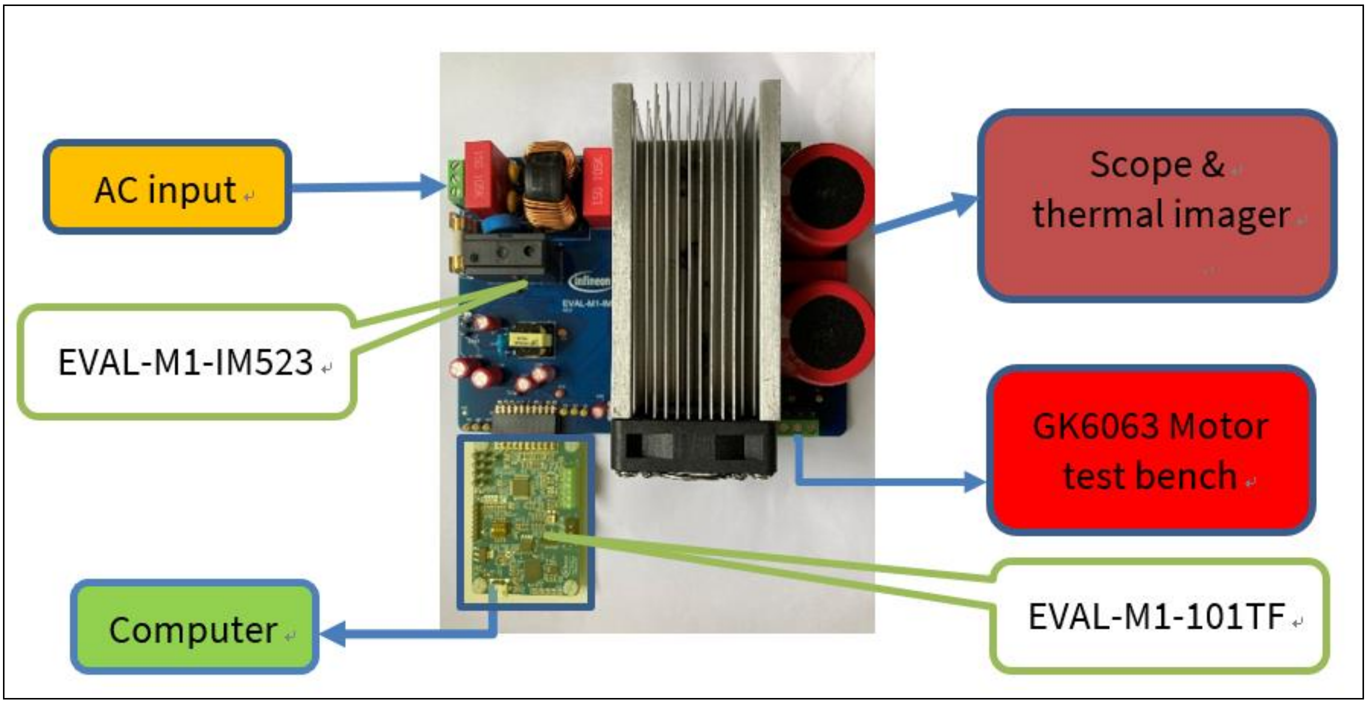


Figure 3 The functional groups of the EVAL-M1-IM523 evaluation design

1.3 Main features

The EVAL-M1-IM523 evaluation board, combined in a kit with one of the available MADK control boards, has the following features:

- Input voltage 85 V_{AC} to 255 V_{AC}
- PWM frequency 15 kHz and 3 A_{rms} input current at 110 V_{AC} (output power around 500 W)
- PWM frequency 15 kHz and 5.5 A_{rms} input current at 220 V_{AC} (output power around 900 W)
- Inrush current limiter for circuit protection
- On-board EMI filter
- Auxiliary power supply with 15 V, 5.0 V
- Overcurrent hardware protection and over-temperature protection
- Sensing of DC-link voltage
- Thermistor output
- Temperature-controlled cooling fan speed adjustment
- PCB size is 160 mm × 115 mm, two layers with 1 oz. copper
- RoHS compliant

1.4 Board parameters and technical data

Table 2 lists the important specifications of the EVAL-M1-IM523.

Table 2 Parameters

Parameter	Symbol	Conditions	Value	Unit
Input				
Input voltage	V_{AC}	Lower AC input, less motor power output	85 - 255	V_{rms}
Input current	$I_{AC(condition\ 1)}$	Input 220 V_{AC} , f_{PWM} = 15 kHz, T_A = 29°C, T_C = 90°C, with heat sink	5.6	A_{rms}
	$I_{AC(condition\ 2)}$	Input 110 V_{AC} , f_{PWM} = 15 kHz, T_A = 29°C, T_C = 90°C, with heat sink	3.1	A_{rms}
Output				
Power (3-phase)	$P_{out(condition\ 1)}$	Input 220 V_{AC} , f_{PWM} = 15 kHz, T_A = 29°C, T_C = 90°C, with heat sink	930	W
	$P_{out(condition\ 2)}$	Input 110 V_{AC} , f_{PWM} = 15 kHz, T_A = 29°C, T_C = 90°C, with heat sink	512	W
DC bus				
Maximum DC-bus voltage	$V_{DC(max)}$	AC input 255 V_{rms}	360	V
Minimum DC-bus voltage	$V_{DC(min)}$	AC input 85 V_{rms}	125	V
Current feedback				
Shunt resistance	RS1	Leg shunt	10	mΩ
Protection				
Overcurrent protection	I_{OCP}	Configured by changing shunt resistors RS1 for current sensing	10.1 [1]	A_{peak}
Auxiliary power supply				
Voltage circuit (VCC) voltage output	V_{CC}	Used for IPM power supply	15 ±5%	V
5.0 V voltage output	$V_{5.0\ V}$	Used for IMC101T controller and protection circuits	5.0 ±5%	V
PCB characteristics				
Dimension		Length × width	160 × 115	Mm
Material		FR4, 1.6 mm thickness, 1 oz. PCB		

[1] For iMOTION™ IC IMCxxx, there are three types of gatekill input source options in the MCEWizard setup: gatekill-pin, comparator, and both. If you select the "comparator" mode, the external gatekill signal will not be used, and the signals I_U+/I_V+/I_W+ will be compared by the internal comparator with the "Device overcurrent trigger level setting" value set in the MCEWizard.

2 System and functional description

2.1 Getting started

To run the motor system, a combination of iMOTION™ MADK power board (EVAL-M1-IM523) and a matching MADK control board (EVAL-M1-101T or other control board) is required. This chapter provides information on setting up the system and getting started with the iMOTION™ MADK development platform.

EVAL-M1-IM523 evaluation boards are tested with EVAL-M1-101T control boards that are shipped with embedded firmware and default parameters.

The following actions must be performed to achieve a usable motor controller IC from a blank IMC101T:

- Programming the motion control engine (MCE)
- Programming the parameter sets for system and motor
- Programming customer scripts (optional)
- Programming the combined file for an integrated system (optional)

The iMOTION™ software tools—MCEDesigner and MCEWizard—are required for initial system setup, and to control and fine-tune the system performance to match the user's exact needs. These tools can be downloaded from the Infineon website. Please check this page periodically for tool and software updates.

An iMOTION™ link or an on-board USB-to-UART cable is needed to bridge the PC/debugger side and the motor drive system (on the target iMOTION™ device, hot side) with a 1 kV DC galvanic isolation.

Figure 4 shows the basic system connection using the EVAL-M1-IM523 board to run a 3000 W GK6036 motor with MCEDesigner. Refer to the MCEWizard and MCEDesigner documentation for more information.

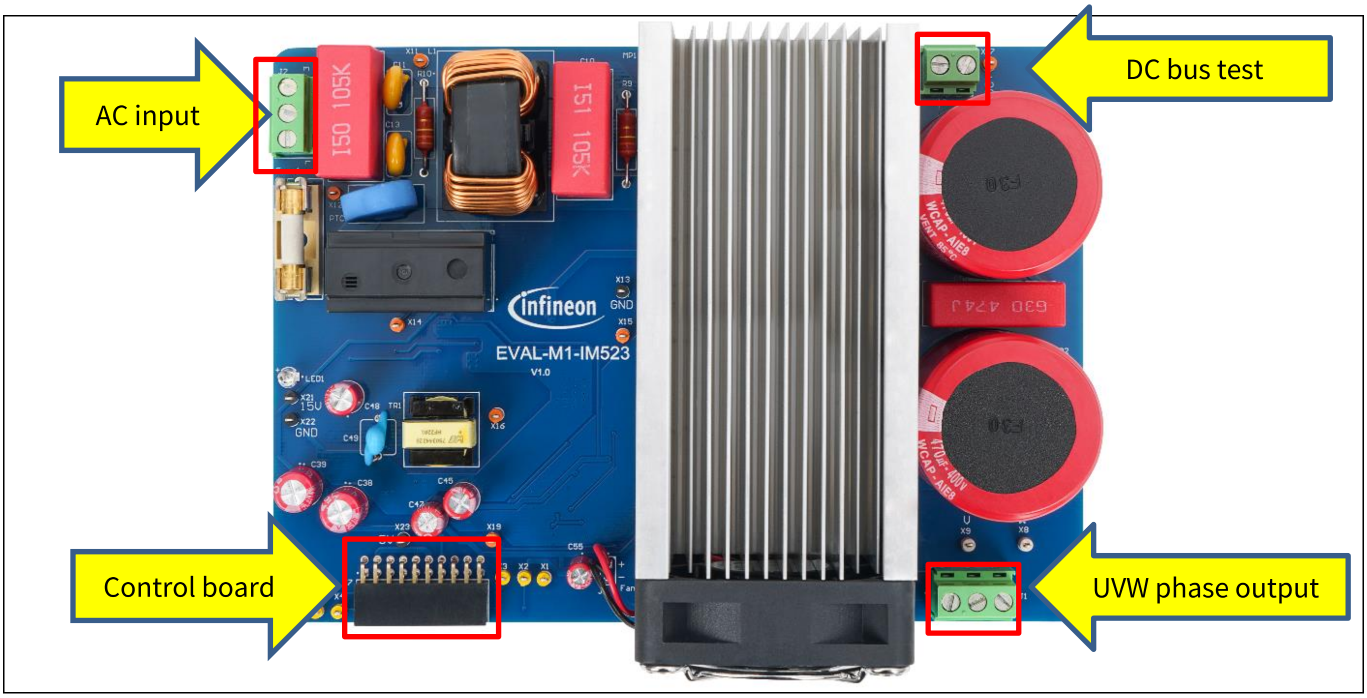


Figure 4 Example of the system connection

Figure 5 MCEWizard's welcome page

After downloading and installing the MCEWizard and MCEDesigner, follow these steps to run the motor:

1. Connect the EVAL-M1-101T control board to the EVAL-M1-IM523 evaluation board. Then, connect the PC-USB connector to the EVAL-M1-101T control board.
2. Connect the 220 V AC power supply and the UVW outputs to the motor.
3. In the MCEWizard, enter the system and operating parameters of the target motor, and the hardware parameters of the evaluation board. This data is used for calculating the digital parameter set of the controller, representing the complete motor drive system.
4. After setting the system and operating parameters, go to the Verify & Save page and click **Calculate Parameters**. If no errors are reported, save the drive parameter set into your project directory by clicking **Export to MCEDesigner file (.txt)** (see Figure 6); if an error message appears, double-click the error message (highlighted in RED) and adjust the erroneous parameters. This drive-system parameter file is later used by the MCEDesigner (step 9.)

Note: Refer to the MCEWizard_V2.3.0.1 User Guide.pdf for details. This guide is available in the MCE Wizard's installation path.

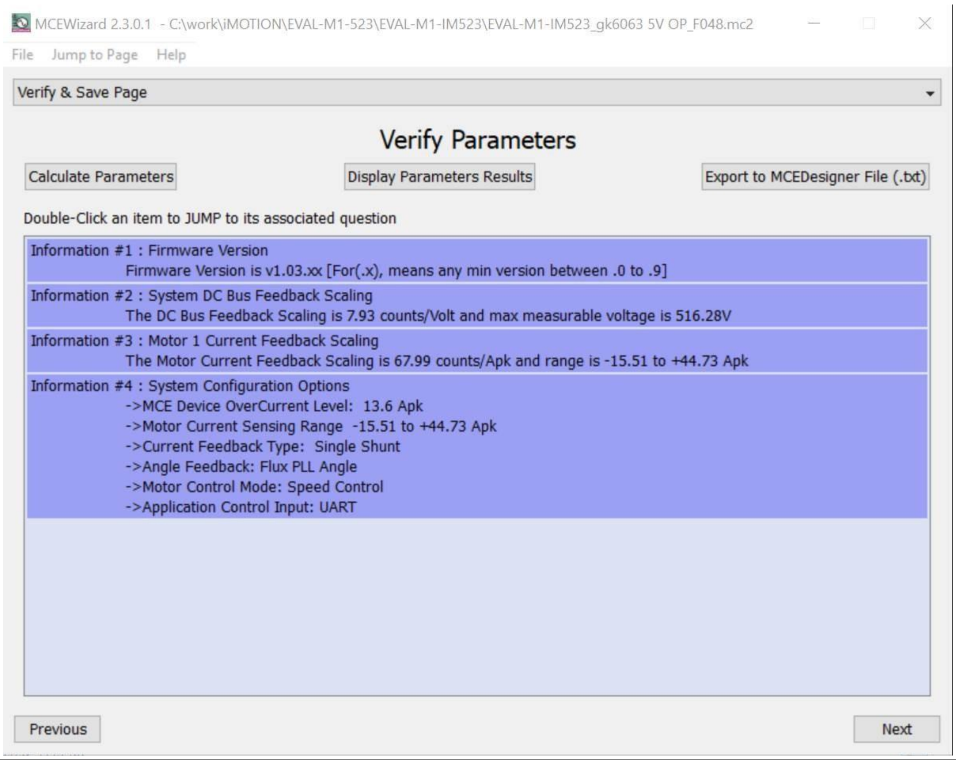


Figure 6 MCEWizard's Verify & Save page

5. Turn on the 220 V AC power supply, LED 1 and 2 turn red.
6. Start the MCEDesigner tool and click **File** > **Open** to open the MCEDesigner default configuration file (.irc) for the IMC101T device (IMC101T_Vxxx.irc.)
   (The IMC101T_Vxxx.irc file is included in the downloaded IMC101T MCE software package).
7. The MCEDesigner should automatically connect to the EVAL-M1-101T board using the default COM port (indicated by a green circle next to the "COMx Up" status in the bottom frame of the MCEDesigner GUI). If the connection cannot be established due to an incorrect COM port, change the COM port by following these steps:
   a) Open the System Page window.
   b) Click **Preferences** > **Connection** > **Connect using**.
   c) Choose one of the other available COM ports from the drop-down list.
8. In case of a blank IC: If the firmware has been erased from the IMC101T, a warning message will pop up (see Figure 7) "Target device firmware and parameters files are not programmed! Please program firmware and parameters file." See step 9 on how to obtain/program firmware and parameters.

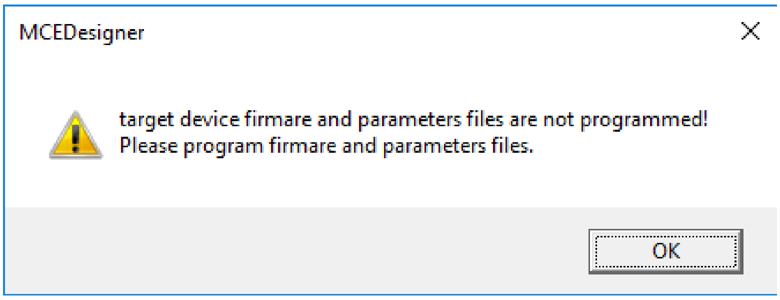


Figure 7 MCEDesigner warning message

9. In case of a blank IC: To program the firmware and the parameters file into the internal Flash memory of the iMOTION™ Control IC, follow these steps:
   a) Open the System Page.
   b) Click **Tools** > **Programmer** and select Program Firmware and Parameters, as shown in Figure 8.
   c) The encrypted firmware is available in the IMC101T MCE Software Package. For the parameters file, browse and select the .txt file generated in step 4.
   d) If the IMC101T IC is blank, the MCEDesigner will generate the pop-up message"Target device firmware and parameter files are not programmed!"
   e) Program the MCE firmware and system parameters into the internal Flash memory of the iMOTION™ IC by selecting **Tools** > **Programmer** from the pull-down menu, and then selecting the Program Firmware and Parameter check box.
   f) Select the right parameter file and firmware file.
   g) Click **Start** to program the firmware and parameter.
   h) Click **YES** and then **OK** to update the IRC file with the parameter file.
   i) Click **Save As** to save the IRC file with a file name that contains the COM config, parameters, and firmware file path information.

Note: *Refer to the MCEDesigner User Guide.pdf and the MCEDesigner_V2.3.0.1 Application Guide.pdf (available in MCEDesigner's install path) for details.*

After the programming is complete, the red LED1 on EVAL-M1-101T will flash on.

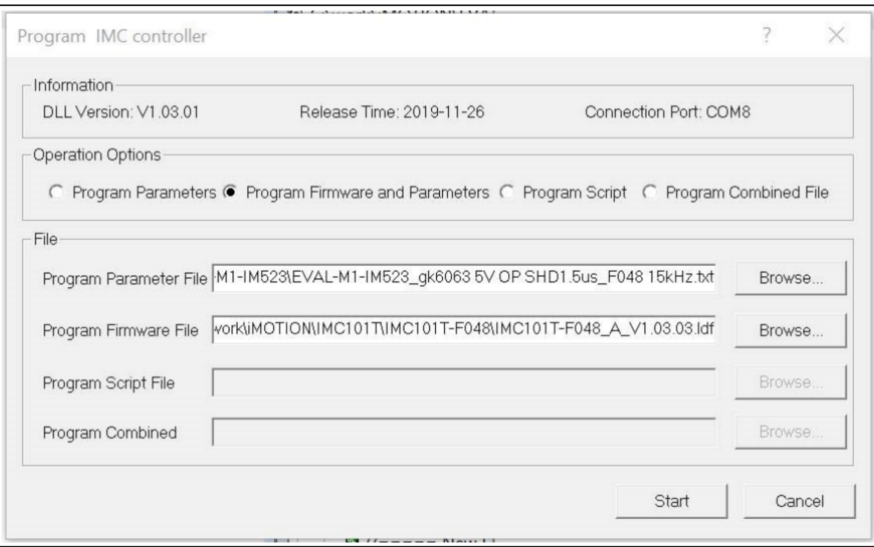


Figure 8 MCEDesigner's program page

10. Double-click the **VF Diagnostic** function in the motor1 page and monitor the motor current with an oscilloscope. If the motor current is not sinusoidal, change the target speed and Vd_Ext in VF Diagnostic sub-function, then double-click **VF Diagnostic** again. Repeat until the oscilloscope shows a steady sinusoidal current with an amplitude that is 30–50% of the motor rate current.
11. Open System Page > Monitor Definitions and double-click **I_u & I_v_Slow**. The motor current feedback should be clean and sinusoidal, as shown in Figure 9. If not, please tune the Gating Propagation Delay & Phase Shift Window Size in the MCEWizard. The sampled motor-current noise amplitude should be less than 50–100 counts (below 5% of the motor current or below 5% of the maximum AD (analog to digital converter) range, which is 2048 counts.) If not, the motor current sample-related hardware and the setup need tuning.

The VF Diagnostic sub-function can verify whether the:

- Motor is correctly connected
- IGBT/MOS and gate driver work as expected
- Parameters related to current-sensing are correctly configured
- PCB layout and DC bus decoupling have been done correctly

12. After the VF Diagnostic is complete, click **STOP** (the red traffic light button) to stop the PWM (Pulse Width Modulation).

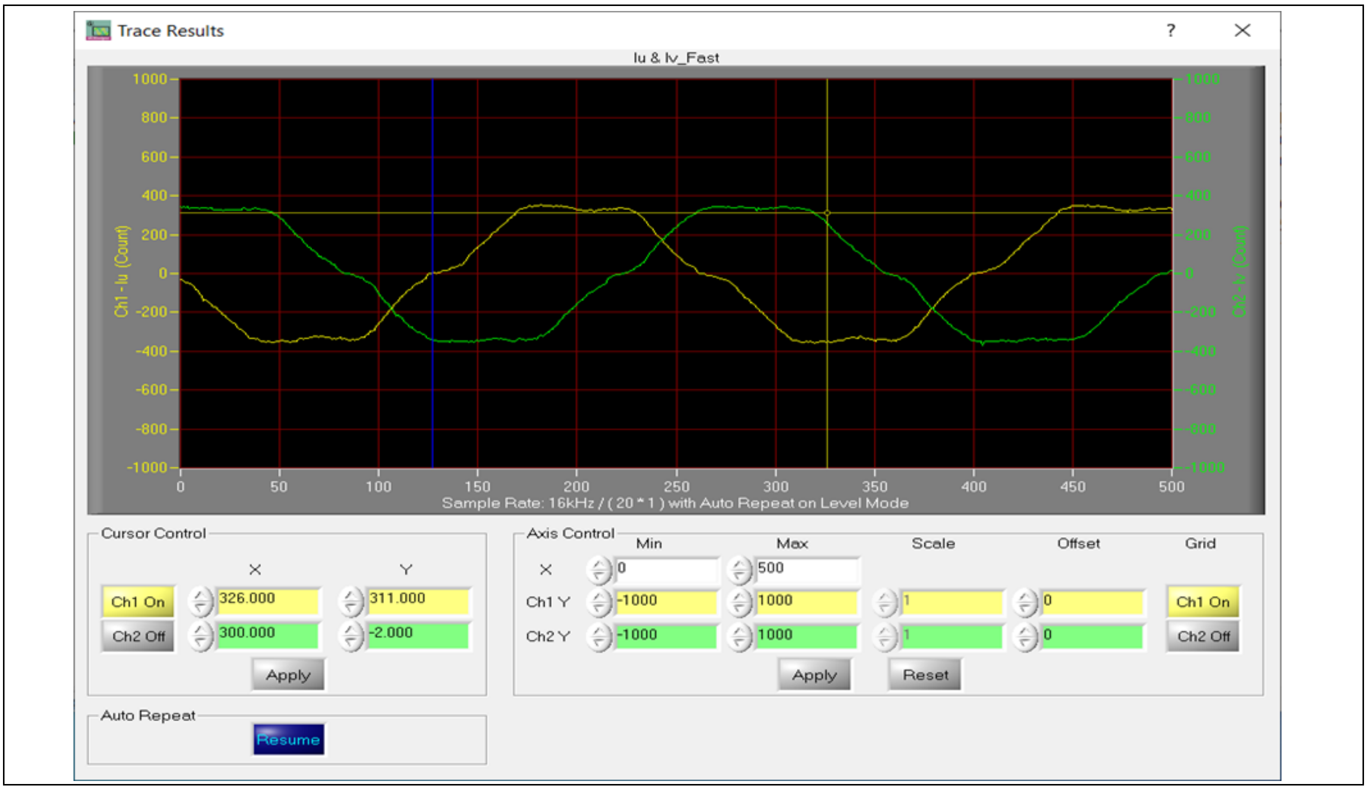


Figure 9 Trace waveform for I_u & I_v open loop diagnostic

13. Click the green traffic light button in the control bar to start the motor or double-click **Start Motor** sub-function in the Motor1 page "group of User Application Function Definitions." The motor runs when this step functions properly.
14. Check the motor-spin direction, adjust the UVW connection order, or set negative target speed in the MCEDesigner if the direction is wrong.
15. Set the target speed to about 50% of the maximum speed and start the I_u & Flx_M trace with Auto Repeat on Level Mode (see Figure 10.) Flx_M is better within the range of 2000 to 2500 (rated value is 2048), and must be steady and DC-like.

    Some key tips for better motor-performance tuning are:

    - If Flx_M is not steady (i.e. swinging or oscillating), double-check the motor parameters, speed loop Propotional-Intergra (PI) gain, flux estimator time constant, and the setup related to the PLL PI bandwidth (parameters PLLKp and PLLKi).
    - If Flx_M is noisy, double-check the current feedback, and the hardware and parameters related to V_{DC}.
    - If Flx_M is far from 2048, adjust the Motor Back EMF Constant (Ke) in the MCEWizard.

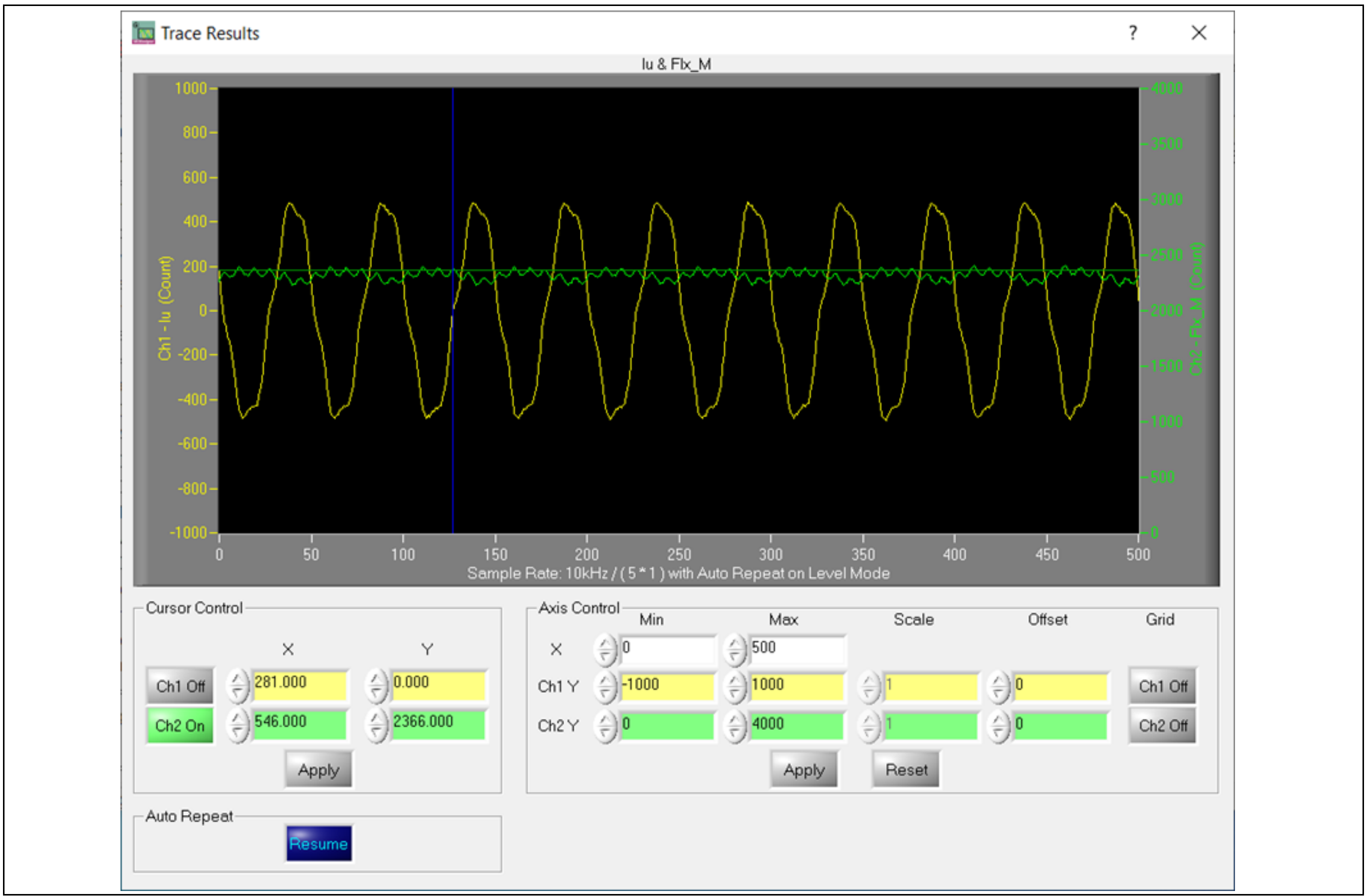


Figure 10 Trace waveform for I_u & Flx-M at 50% speed

16. To program a new parameter file after the firmware has been programmed, follow the instructions given in Step 9. In such cases, firmware programming is not needed.

Note: *For detailed information on controller programming, refer to the Application Note AN2018-33 iMOTION™ 2.0 Device Programming, and the documentation for the MCEDesigner and MCEWizard.*

2.2 Description of functional blocks

The motor inverter in the EVAL-M1-IM523 evaluation design is implemented using the CIPOS™ Mini IPM IM523-X6A, and the auxiliary power supply is based on the fixed-frequency CoolSET™ ICE5GR4780AG.

The CIPOS™ Mini IPM IM523 product group enables the integration of various power and control components to increase reliability, optimize PCB size, and reduce system costs. It is designed to control 3-phase AC motors and permanent-magnet motors in variable speed drives for applications such as air conditioners and refrigerators.

The package concept is especially adapted to power applications that need good thermal conduction, electrical isolation, EMI control, and overload protection. The integrated reverse-conducting IGBTs are combined with an optimized silicon on insulator (SOI) gate driver for excellent electrical performance.

Figure 11 shows the internal block diagram of the CIPOS™ Mini IPM IM523-X6A.

Its main features include:

- A 600 V reverse-conducting RCD2 IGBT

- A rugged SOI gate driver technology with stability against transient and negative voltage
- An allowable negative V_S potential up to -11 V for signal transmission at V_{BS} = 15 V
- An integrated bootstrap functionality
- An overcurrent shutdown mechanism
- A built-in NTC thermistor for temperature monitoring
- Undervoltage lockout at all channels
- Low-side emitter pins accessible for phase-current monitoring (open emitter)
- A sleep function
- Cross-conduction prevention
- All six switches turn off during protection

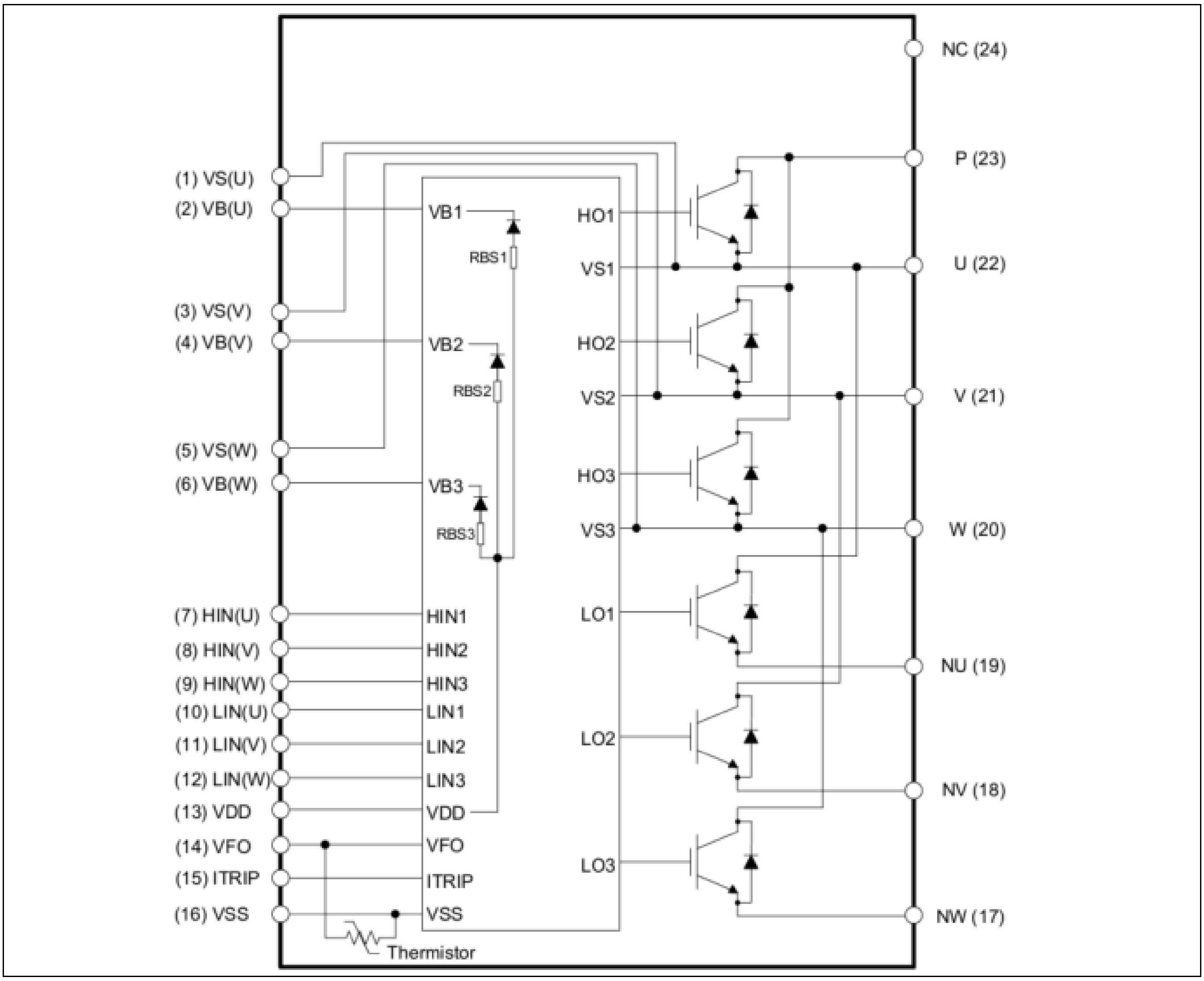


Figure 11 Internal block of the IM523-X6A

3 System design

The EVAL-M1-IM523 board is an optimized design for 220 V small home appliances like air conditioners, pumps, and fan applications. To meet individual customer requirements, and to make the EVAL-M1-IM523 evaluation design a basis for development or modification, all board design data such as schematics, Gerber, and AD files can be found on Infineon's website.

3.1 EMI filter and soft power-up circuit

Figure 12 shows the schematic from the AC input connector X1 to the rectified DC bus voltage. This circuitry includes a passive EMI filter consisting of elements X, Y capacitors and common-mode inductor, a 10 A/600 V rectifier bridge D3 (GBJ1006-BP), an F1 fuse for circuit protection, a PTC resistor, and an RY1 relay for soft power-up and reduction of conduction losses in steady state.

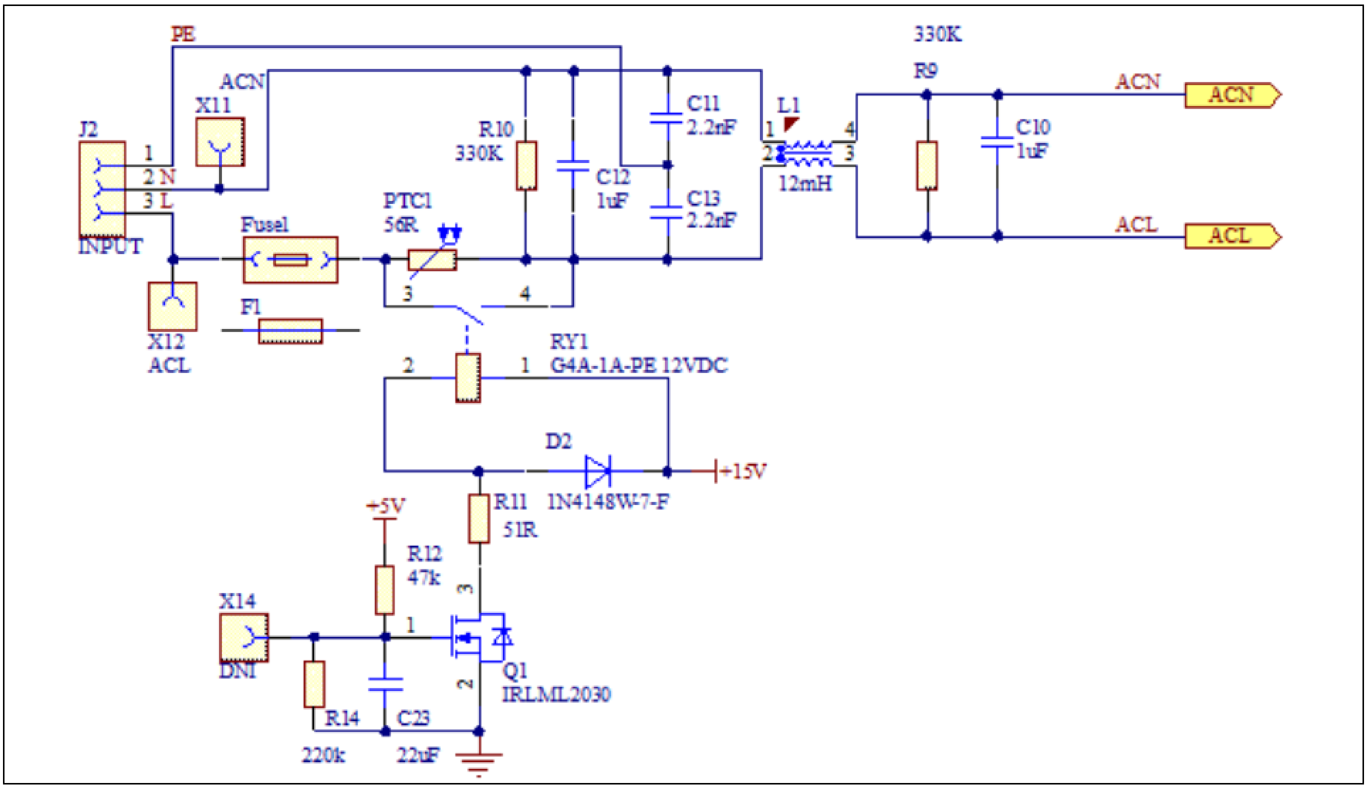


Figure 12 Schematics for EMI filter and a soft power-up circuit

3.2 Inverter section using CIPOS™ Mini IPM

The inverter section is implemented using the CIPOS™ Mini IPM as shown in Figure 13. The module includes a combination of an optimized reverse-conducting IGBT Gen 2 (RCD2), and industry-benchmark, robust half-bridge drivers. The shunt resistor section is also provided in the inverter section, including 10 mΩ RS1 resistors. The overcurrent level can be set up by using an OPAMP. The three capacitors C3, C6, and C8 are used as bootstrap capacitors to provide the necessary floating supply voltages VBS1, VBS2, and VBS3, respectively.

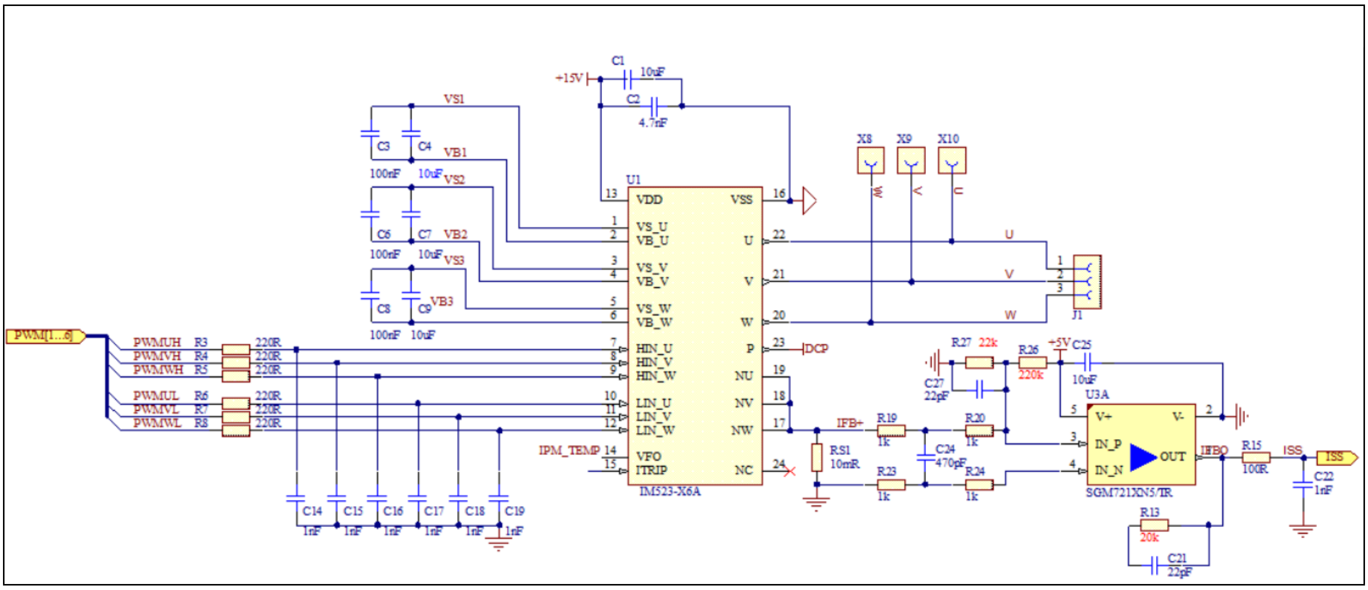


Figure 13 Schematics for the IM523-X6A IPM and peripheral circuit

3.3 Auxiliary power supply

Figure 14 shows the schematic of the auxiliary power supply for the EVAL-M1-IM523 board. The circuit includes the latest CoolSET™ 5 (ICE5GR4780AG) from Infineon and a flyback topology with direct output of 15 V and 6 V. The VCC is connected to the gate drivers inside the CIPOS™ IPM.

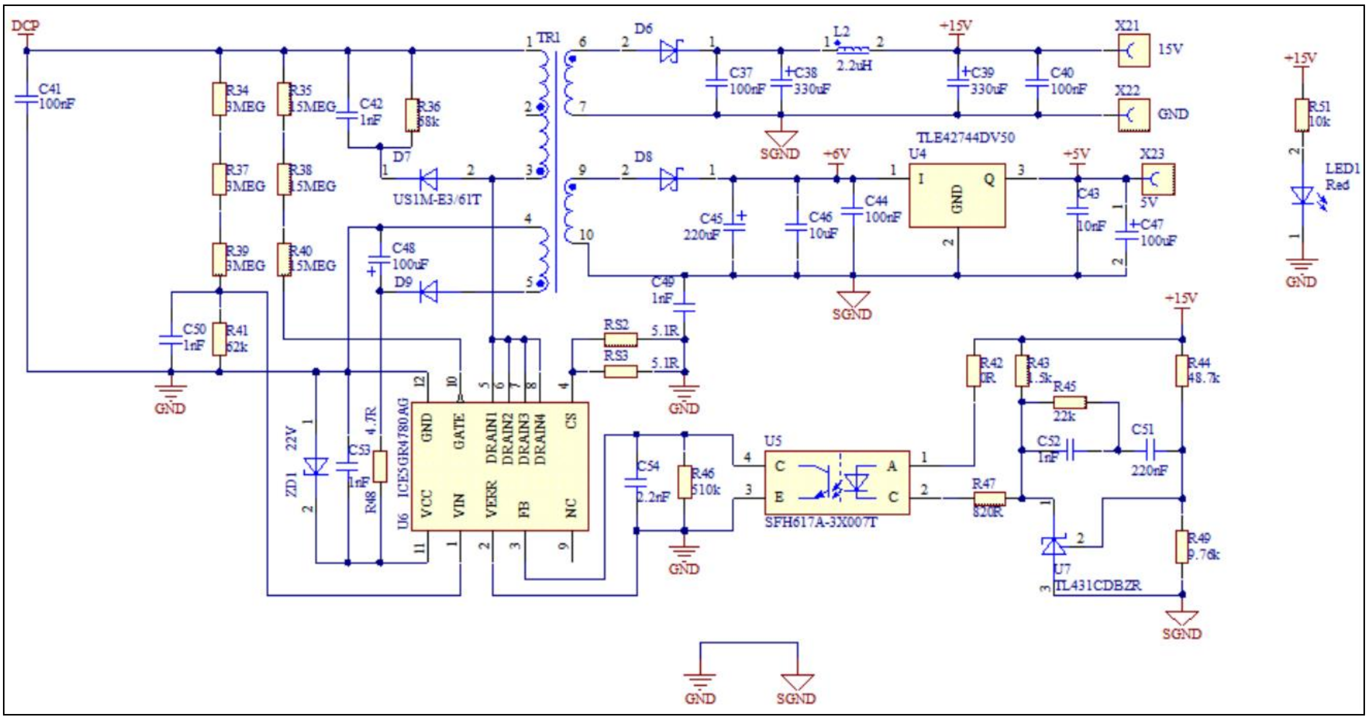


Figure 14 Auxiliary power supply of the EVAL-M1-IM523

The linear voltage regulator TLE42744DV50 generates 5.0 V from a 6 V power supply VCC. The 5.0 V power supply is used in the inverter's external overcurrent comparator circuit. Both VCC and 5.0 V are also present on the 20-pin iMOTION™ MADK-M1 interface connector to power the circuitry on the control board.

3.4 Layout

The EVAL-M1-IM523 board has two electrical layers with 140 µm copper (1 oz.) and a dimension of 160 mm x 115 mm. The thickness of the PCB board is 1.6 mm. Figure 15 and Figure 16 show the PCBA assembly of the EVAL-M1-IM523.

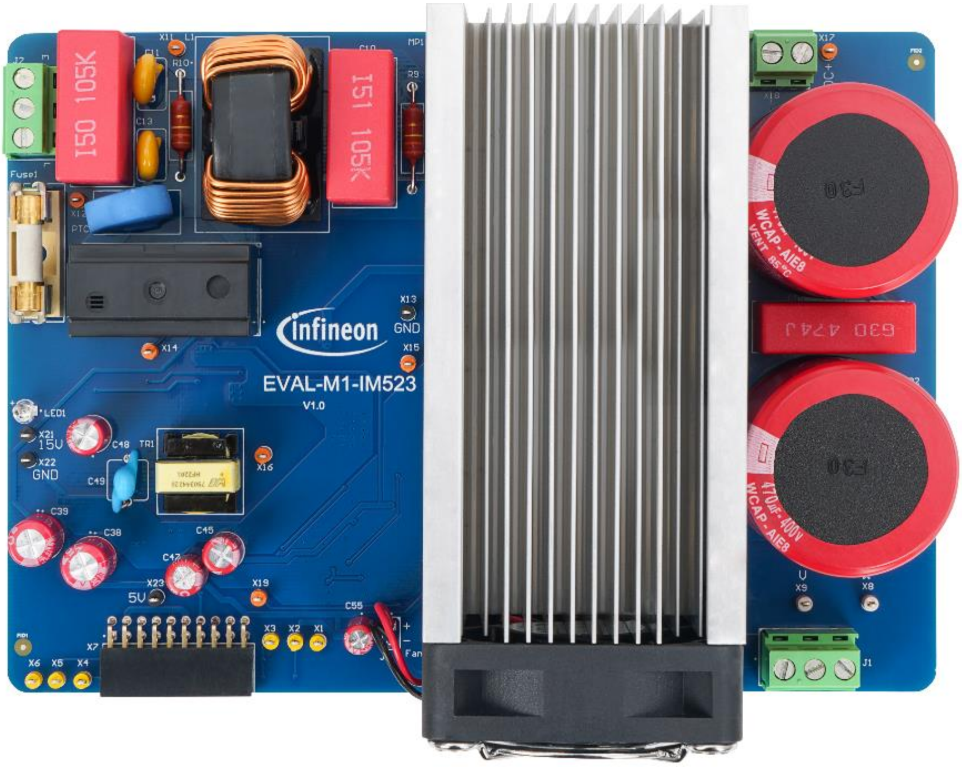


Figure 15 Top-assembly PCBA of the EVAL-M1-IM523

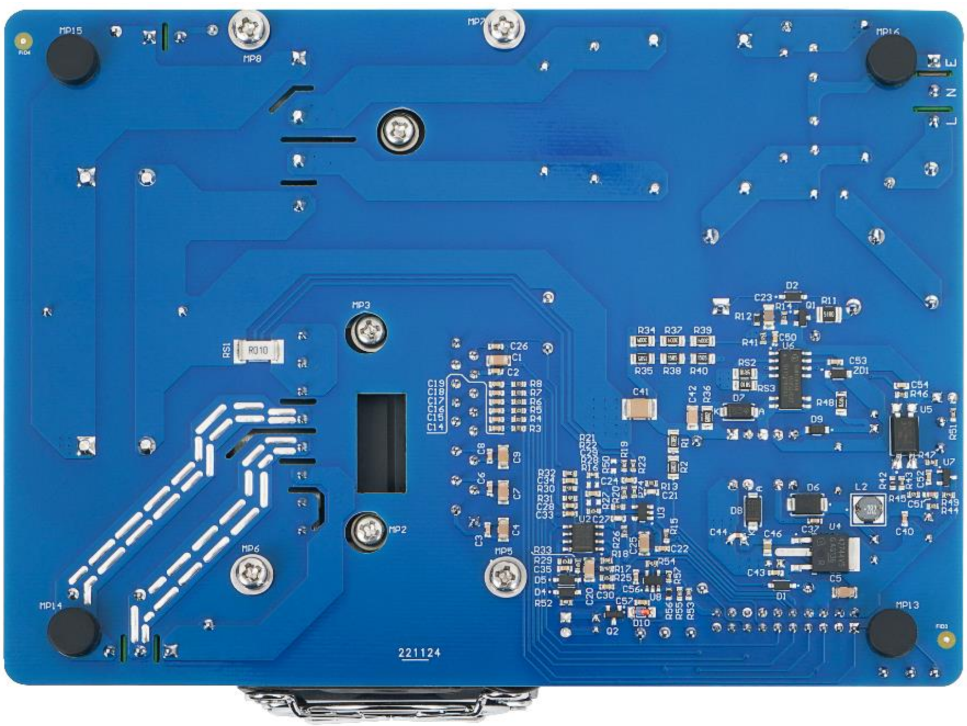


Figure 16 Bottom-assembly PCBA of the EVAL-M1-IM523

3.5 Bill of material

The complete bill of material can be downloaded (a customer login is required) from the Download section on the homepage of Infineon's website.

Table 3 BOM of the most important/critical parts of the evaluation board

Quantity	Ref Designator	Description	Manufacturer	Manufacturer P/N
7	C1, C4, C5, C7, C9, C20, C25	Chip Monolithic Ceramic Capacitor	MuRata	GRM31CR71E106MA12
1	C2	Chip Monolithic Ceramic Capacitor	MuRata	GCM188R71E472JA37
7	C3, C6, C8, C28, C37, C40, C56	Chip Monolithic Ceramic Capacitor, CAP / CERA / 100nF/ 50V/ 10%/ X7R (EIA)/ -55℃ to 125℃/ 603(1608)/ SMD	MuRata, AVX	GRM188R61E104KA01, 06035C104K4Z2A
2	C10, C12	CAP / FILM / 1uF / 630V / 10% / MKT (Metallized Polyester) / -40℃ to 105℃ / 22.50mm C X 0.80mm W 26.00mm L X 11.00mm T X 20.50mm H / THT / -	Wurth Elektronik	890324026027CS
2	C11, C13	CAP / CERA / 2.2nF / 1kV / 20% / Y5U (EIA) / -40℃ to 125℃ / 5.00mm C X 0.60mm W 9.00mm L X 5.00mm T X 13.00mm H / THT / -	Vishay	VY2222M35Y5US6TV5
12	C14, C15, C16, C17, C18, C19, C22, C26, C29, C30, C52, C53	Chip Monolithic Ceramic Capacitor, CAP / CERA / 1nF / 25V / 5% / C0G (EIA) / NP0 / -55℃ to 125℃ / 0603(1608) / SMD	MuRata	GRM188R71E102JA01, GRM1885C1E102JA01
2	C21, C27	Chip Monolithic Ceramic Capacitor	MuRata	GRM1885C1H220JA01
1	C23	MLCC Chip Capacitor, SMD	TDK Corporation	C3216X5R1E226M160AB
1	C24	Chip Monolithic Ceramic Capacitor	MuRata	GRM188R71H471KA01
2	C31, C32	CAP / ELCO / 470uF / 400V / 20% / Aluminiumelectrolytic / -25℃ to 85℃/ 10.00mm C X 1.50mm W 35.00mm Dia X 37.00mm H / - / -	Wurth Elektronik	861221386021'
4	C33, C34, C35, C43	Chip Monolithic Ceramic Capacitor, CAP / CERA / 10nF / 50V / 10% / X7R (EIA) / -55℃ to 125℃ / 0603 / SMD / -	MuRata, AVX	GRM188R71C103KA01, 06035C103K4Z2A
1	C36	CAP / FILM / 470nF / 630V / 5% / MKP (Metallized Polypropylene) / -40℃ to 105℃ / 22.50mm C X 0.80mm W 26.00mm L X 9.00mm T X 19.00mm H / THT / -	Wurth Elektronik	890303326009CS
2	C38, C39	CAP / ELCO / 330uF / 25V / 20% / Aluminiumelectrolytic / -40℃ to 85℃ / 3.50mm C X 0.60mm W 8.00mm Dia X 13.00mm H / THT / -	Wurth Elektronik	860010474012'
1	C41	CAP / CERA / 100nF / 630V / 10% / X7R (EIA) / -55℃ to 125℃ / 1812 / SMD / -	Wurth Elektronik	8.85342E+11
1	C42	CAP / CERA / 1nF / 630V / 10% / X7R (EIA) / -55℃ to 125℃ / 1206(3216) / SMD	MuRata	GRM31BR72J102KW01
1	C44	CAP / CERA / 100nF / 50V / 10% / X7R (EIA) / -55℃ to 125℃ / 0603 / SMD / -	AVX	06035C104KAT2A
1	C45	CAP / ELCO / 220uF / 16V / 20% / Aluminiumelectrolytic / -40℃ to 85℃ / 2.50mm C X 0.50mm W 6.30mm Dia X 12.50mm H / THT / -	Wurth Elektronik	860010373010'
1	C46	CAP / CERA / 10uF / 16V / 10% / X5R (EIA) / -55℃ to 85℃ / 0805(2012) / SMD	MuRata	GRM219R61C106KA73
1	C47	CAP / ELCO / 100uF / 16V / 20% / Aluminiumelectrolytic / -40℃ to 85℃ / 2.00mm C X 0.50mm W 5.00mm Dia X 12.50mm H / THT / -	Wurth Elektronik	860010473007'

Quantity	Ref Designator	Description	Manufacturer	Manufacturer P/N
1	C48	CAP / ELCO / 100uF / 35V / 20% / Aluminiumelectrolytic / -40℃ to 85℃ / 2.50mm C X 0.50mm W 6.30mm Dia X 12.50mm H / - / -	Wurth Elektronik	860010573007'
1	C49	CAP / CERA / 1nF / / 20% / E (JIS) / -40℃ to 125℃ / 7.50mm C X 0.60mm W 7.00mm L X 7.00mm T X 10.00mm H / THT / -	MuRata	DE6E3KJ102MN3A
2	C50, C57	CAP / CERA / 1nF / 16V / 10% / X7R (EIA) / -55℃ to 125℃ / 0603(1608) / SMD	Kemet	C0603C102K4RACTU, C0603C102F5GAC
1	C51	CAP / CERA / 220nF / 25V / 10% / X5R (EIA) / -55℃ to 85℃ / 0603(1608) / SMD	MuRata	GRM188R61E224KA88
1	C54	CAP / CERA / 2.2nF / 50V / 10% / X5R (EIA) / -55℃ to 85℃ / 0603(1608) / SMD	MuRata	GRM188R61H222KA01
1	C55	CAP / ELCO / 47uF / 25V / 20% / Aluminiumelectrolytic / -40℃ to 105℃ / 2.00mm C X 0.50mm W 5.00mm Dia X 12.50mm H / THT / -	Wurth Elektronik	860020472006'
4	D1, D2, D4, D5	Surface Mount Fast Switching Diode	Diodes Incorporated	1N4148W-7-F
1	D3	Glass Passivated Bridge Rectifier 600V	Micro Commercial Components	GBJ1006-BP
1	D6	High Voltage Surface-Mount Schottky Rectifier, VRRM 100V	Vishay	SS2H10-E3/52T
1	D7	Surface Mount Ultrafast Rectifier 1.0A/1000V	Vishay	US1M-E3/61T
1	D8	Surface-Mount Schottky Barrier Rectifier, VRRM 45V	Vishay	BYS10-45-E3/TR3
1	D9	Super Fast Recovery Diode, VR 200 V, IF 1 A	ROHM Semiconductors	RF071MM2STR
1	D10	Zener Diode, 5% 13V	Solid State Devices Inc.	SZ25B13SM
1	F1	FUSE CERAMIC 12.5A 250VAC 125VDC,5x20mm	Schurter	0001.2715.11
1	Fan	DC Axial Fan for omniCOOL bearing system,50 x 50 mm frame. Mulitple Speed options	CUI	CFM-5015V-138-201
1	Fuse1	Fuse Holder Block, PCB Clip Cover, 18A, 250VAC	Wurth Elektronik	696101000002'
2	J1, J2	Horizontal Cable Entry with Rising Cage Clamp - WR-TBL, 3Pins	Wurth Elektronik	691216510003S
1	J3	Header, 2.54mm Pitch, 2 pin, Vertical, Single Row	Wurth Elektronik	61300211121
1	L1	IND / STD / 12mH / 10A / 50% / -40℃ to 125℃ / 15mR / THT / Inductor, THT, 4 pin, 23.00 mm L X 34.00 mm W X 33.00 mm H body / THT / -	Wurth Elektronik	7448051012
1	L2	IND / STD / 2.2uH / 2.5A / 20% / -40℃ to 125℃ / 71mR / SMD / Inductor, SMD; 2-Leads, 4.50 mm L X 4 mm W X 3.50 mm H body / SMD / -	Wurth Elektronik	744773022
1	LED1	LED 3mm Red Through Hole Lamp	LiteOn Optoelectronics	LTL-1CHEE
1	MP1	Standard Heatsink	Infineon Technologies	HS-5050-100
3	MP2, MP3, MP4	M3 Metric Countersunk Head Screw, Length 10mm	Duratool	M310 KRSTMCZ100-
4	MP5, MP6, MP7, MP8	Pan Head Screw, M3X0.5	Keystone Electronics Corp.	9191-4
4	MP9, MP10, MP11, MP12	WA-SSTIE Steel Spacer Stud, M3	Wurth Elektronik	971060321

Quantity	Ref Designator	Description	Manufacturer	Manufacturer P/N
4	MP13, MP14, MP15, MP16	3M Bumpon Protective Product SJ61A1 is a self-adhesive rubber bumper	3M	SJ61A1
1	PTC1	PTC thermistor for overcurrent protection and as inrush current limiters	TDK Corporation	B59451C1130B070
1	Q1	30V 154mOhm@4.5V MOSFET	Infineon Technologies	IRLML2030TRPbF
1	Q2	NPN Silicon Switching Transistor	Infineon Technologies	SMBT3904
2	R1, R2	Standard Thick Film Chip Resistor	Vishay	CRCW1206680KFK
6	R3, R4, R5, R6, R7, R8	General Purpose Chip Resistor	Yageo	RC0603FR-07220RL
2	R9, R10	330k/500V/5%	Vishay	PR02000203303JR500
1	R11	RES / STD / 51R / 500mW / 1% / 100ppm/K / -55℃ to 155℃ / 1210 / SMD	Vishay	CRCW121051R0FK
2	R12, R56	Standard Thick Film Chip Resistor, RES / STD / 47k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603(1608) / SMD / -	Vishay	CRCW060347K0FK
1	R13	Standard Thick Film Chip Resistor	Vishay	CRCW060320K0FK
2	R14, R26	Standard Thick Film Chip Resistor	Vishay	CRCW0603220KFK
1	R15	General Purpose Chip Resistor	Yageo	RC0603FR-07100RL
1	R28	General Purpose Chip Resistor	Yageo	RC0603FR-07100RL
5	R16, R17, R25, R29, R30	General Purpose Chip Resistor	Yageo	RC0603FR-074K7L
5	R18, R19, R20, R23, R24	Standard Thick Film Chip Resistor	Vishay	CRCW06031K00FK
1	R21	Standard Thick Film Chip Resistor	Vishay	CRCW06034K53FK
1	R22	Standard Thick Film Chip Resistor	Vishay	CRCW06034K53FK
1	R27	General Purpose Chip Resistor	Yageo	RC0603FR-0722KL
2	R31, R33	16k/50V/1%	ROHM Semiconductors	MCR03EZPFX1602
2	R32, R51	General Purpose Chip Resistor, RES / STD / 10k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603 / SMD / -	Yageo	RC0603FR-0710KL
3	R34, R37, R39	RES / STD / 3MEG / 250mW / 1% / 100ppm/K / -55℃ to 155℃ / 1206 / SMD	Vishay	CRCW12063M00FK
3	R35, R38, R40	RES / STD / 15MEG / 250mW / 5% / 200ppm/K / -55℃ to 155℃ / 1206 / SMD	Yageo	RC1206JR-0715ML
1	R36	RES / STD / 68k / 250mW / 1% / 100ppm/K / -55℃ to 155℃ / 1206 / SMD	Vishay	CRCW120668K0FK
1	R41	RES / STD / 62k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603 / SMD	Vishay	CRCW060362K0FK
1	R42	RES / STD / 0R / 100mW / 0R / 0ppm/K / -55℃ to 155℃ / 0603 / SMD	Yageo	RC0603JR-070RL
1	R50	RES / STD / 0R / 100mW / 0R / 0ppm/K / -55℃ to 155℃ / 0603 / SMD	Yageo	RC0603JR-070RL
1	R43	RES / STD / 1.5k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603 / SMD	Yageo	RC0603FR-071K5L
1	R44	RES / STD / 48.7k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603 / SMD	Vishay	CRCW060348K7FK
1	R45	RES / STD / 22k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603 / SMD	Vishay	CRCW060322K0FK
1	R46	RES / STD / 510k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603 / SMD	Vishay	CRCW0603510KFK
1	R47	RES / STD / 820R / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603 / SMD	Vishay	CRCW0603820RFK
1	R48	RES / STD / 4.7R / 250mW / 1% / 100ppm/K / -55℃ to 155℃ / 1206 / SMD	Vishay	CRCW12064R70FK

Quantity	Ref Designator	Description	Manufacturer	Manufacturer P/N
1	R49	RES / STD / 9.76k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603 / SMD	Vishay	CRCW06039K76FK
2	R52, R53	RES / STD / 2k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603(1608) / SMD	Vishay	CRCW06032K00FK
1	R54	RES / STD / 9.1k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603(1608) / SMD	Vishay	CRCW06039K10FK
1	R55	RES / STD / 1k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603(1608) / SMD	Yageo	RC0603FR-071KL
1	R57	RES / STD / 390k / 100mW / 1% / 100ppm/K / -55℃ to 155℃ / 0603(1608) / SMD / -	Vishay	CRCW0603390KFK
1	RS1	RES / STD / 10mR / 3W / 1% / 50ppm/K / -55℃ to 170℃ / 2512(6332) / SMD / -	Bourns	CRA2512-FZ-R010ELF
2	RS2, RS3	RES / STD / 5.1R / 250mW / 1% / 100ppm/K / -55℃ to 155℃ / 1206 / SMD / -	Vishay	CRCW12065R10FK
1	RY1	RELAY GENRAL PURPOSE SPST 20A 12V	Omron	G4A-1A-PE 12VDC
1	TR1	Flyback Transformer, Offline aux SMPS for server, PC power applications	Wurth Elektronik	750344226
1	U1	CIPOS Mini IM523	Infineon Technologies	IM523-X6A
1	U2	Dual Comparators	Texas Instruments	LM393ADR
1	U3	11MHz, Rail-to-Rail I/O CMOS Operational Amplifiers	-	SGM721XN5/TR
1	U4	Low Dropout Linear Voltage Regulator, 5.0 V Output	Infineon Technologies	TLE42744DV50
1	U5	Optocoupler, Phototransistor Output, High Reliability, 5300 VRMS, 110℃ Rated	Vishay	SFH617A-3X007T
1	U6	Fixed Frequency 700 V/800 V CoolSET, lowest standby power <100 mW	Infineon Technologies	ICE5GR4780AG
1	U7	Precision Programmable Reference	Texas Instruments	TL431CDBZR
1	U8	Low-Power Single Voltage Comparator	STMicroelectronics	TS391RIYLT
6	X1, X2, X3, X4, X5, X6	Test Point THT, Yellow	Keystone Electronics Corp.	5004
1	X7	WR-PHD 2.54 mm Angled Dual Socket Header	Wurth Elektronik	613020243121'
3	X8, X9, X10	Test Point THT, White	Keystone Electronics Corp.	5002
7	X11, X12, X14, X15, X16, X17, X19	Test Point THT, Orange	Keystone Electronics Corp.	5003
5	X13, X20, X21, X22, X23	Test Point THT, Black	Keystone Electronics Corp.	5001
1	X18	Horizontal Cable Entry with Rising Cage Clamp - WR-TBL, 2 Pins	Wurth Elektronik	691216510002S
1	ZD1	Zener Diode with Surge Current Specification	Vishay	BZD27C22P-HE3-08

4 System performance

4.1 Auxiliary power supply & inrush current test

Table 4 Table 1 Auxiliary power supply voltage and inrush current test

Specification	15 V: 15±0.5 V; 5 V: 5 V±5%; inrush current <10 A_{peak};						
Condition	Inrush tested at the 25℃ ambient temperature.						
Conclusion	● 15 V & 5 V power supply are within 85~255 V_{AC} input range. ● The maximum inrush current is 6.8 A_{peak} at 255 V_{AC} input. ● The 5 V build-up is 5.4 ms after 15 V build-up. ● The auxiliary power supply browns in at minimal 50 V_{AC} input ● The auxiliary power supply browns out at 31 V, V_{DC}_BUS voltage. (Figure 18)						
Test Data							
Input voltage (V_{rms})	**Inrush line current Max.** ($A_{peak-peak}$)	**Bus caps charge time** (ms) **(power-on to relay close)**	**15 V build-up time** (ms) **(power-on to 15 V build-up)**	**Vdc_BUS** (V)	**+15 V** (V)	**+5 V** (V)	**Test waveform**
85	3.653	1233	421	125	14.861	4.987	Figure 19
220	10.966	1170	373	314	14.865	4.987	Figure 20
255	13.602	1162	362	360	14.860	4.986	Figure 21
Legend	CH1: 15 V, CH2: 5 V, CH3: Vdc_BUS, CH4: Line current						

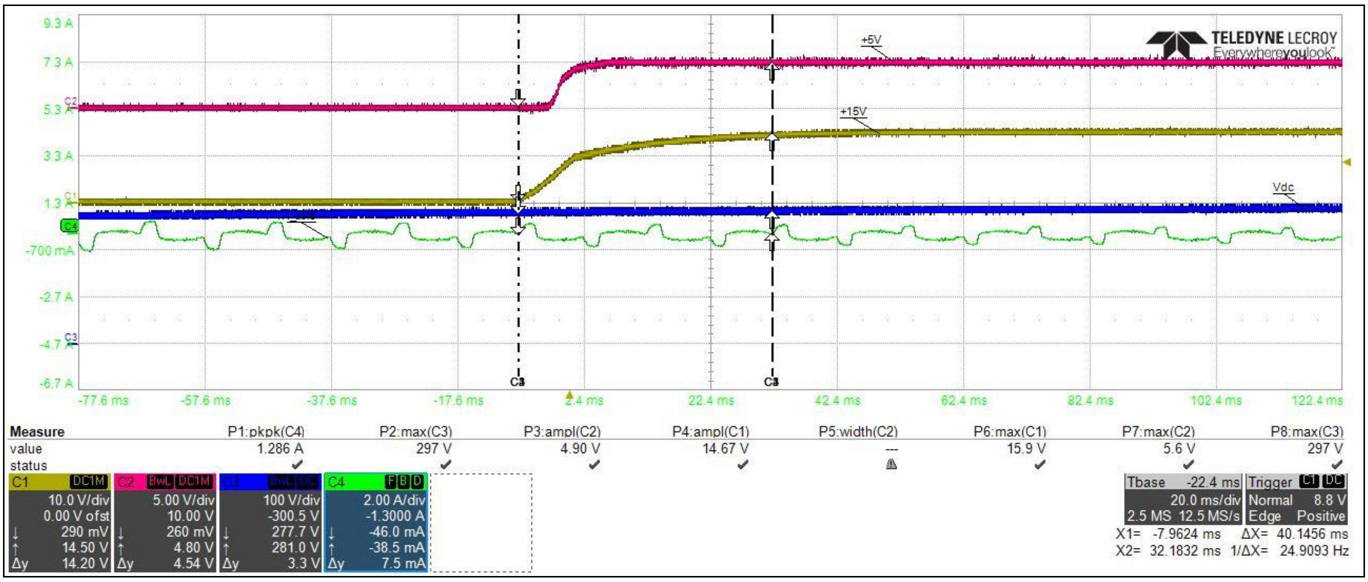


Figure 17 Power supply voltage (15 V & 5 V)

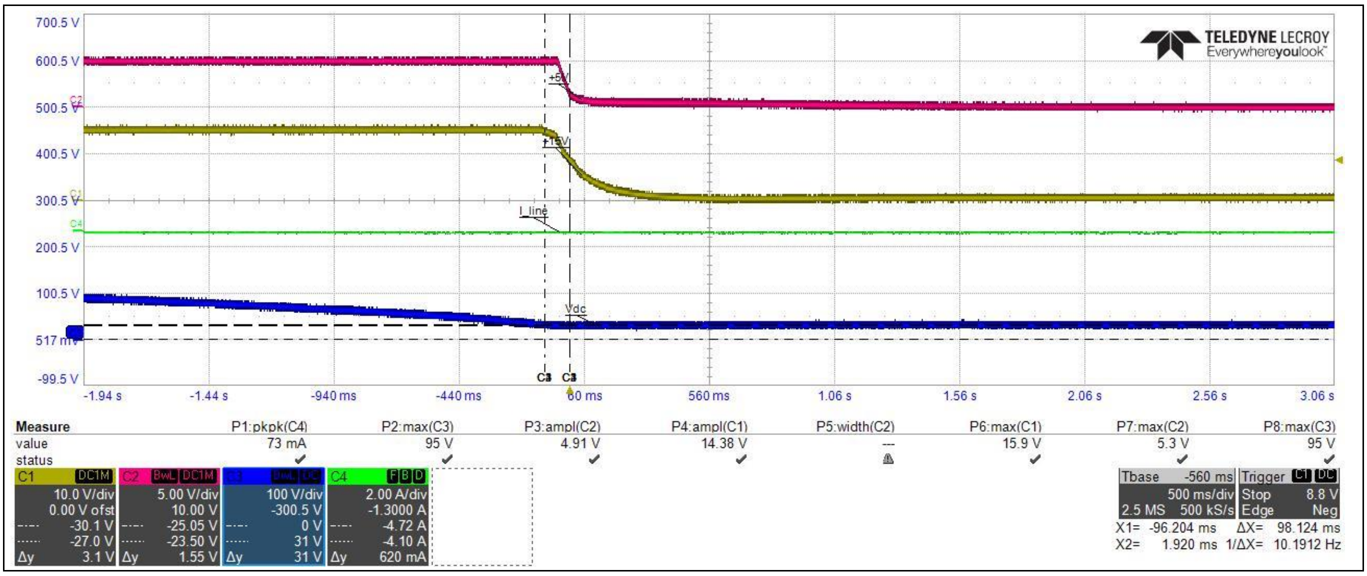


Figure 18 Auxiliary power supply browns out

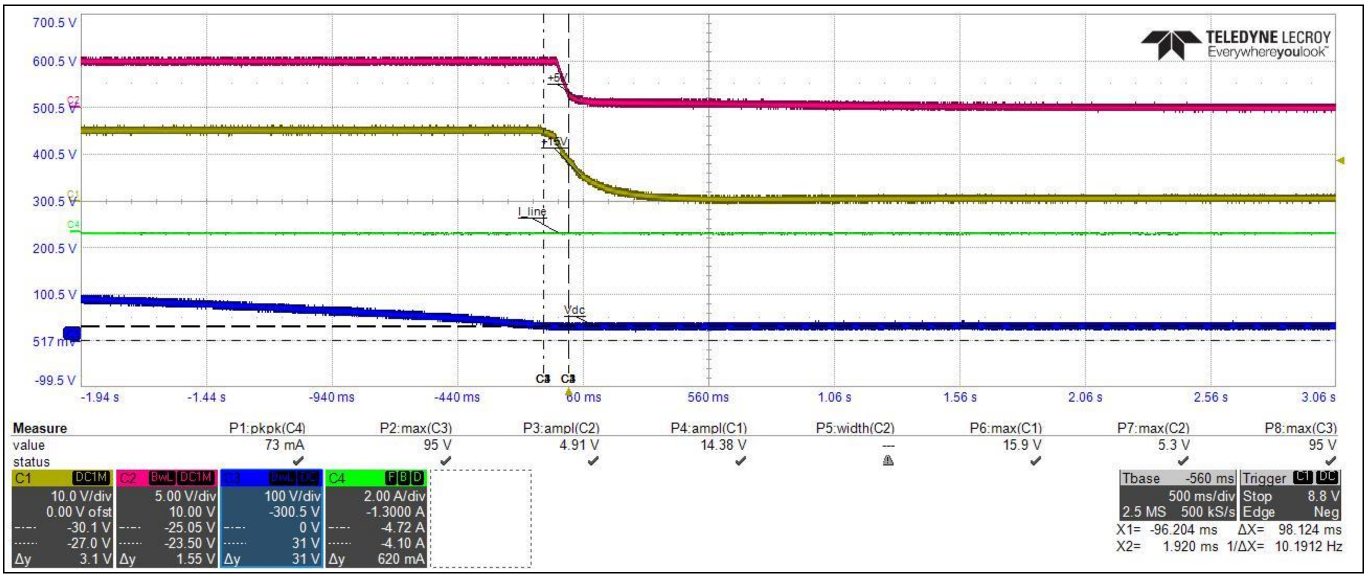


Figure 19 Input 85 V_{AC}

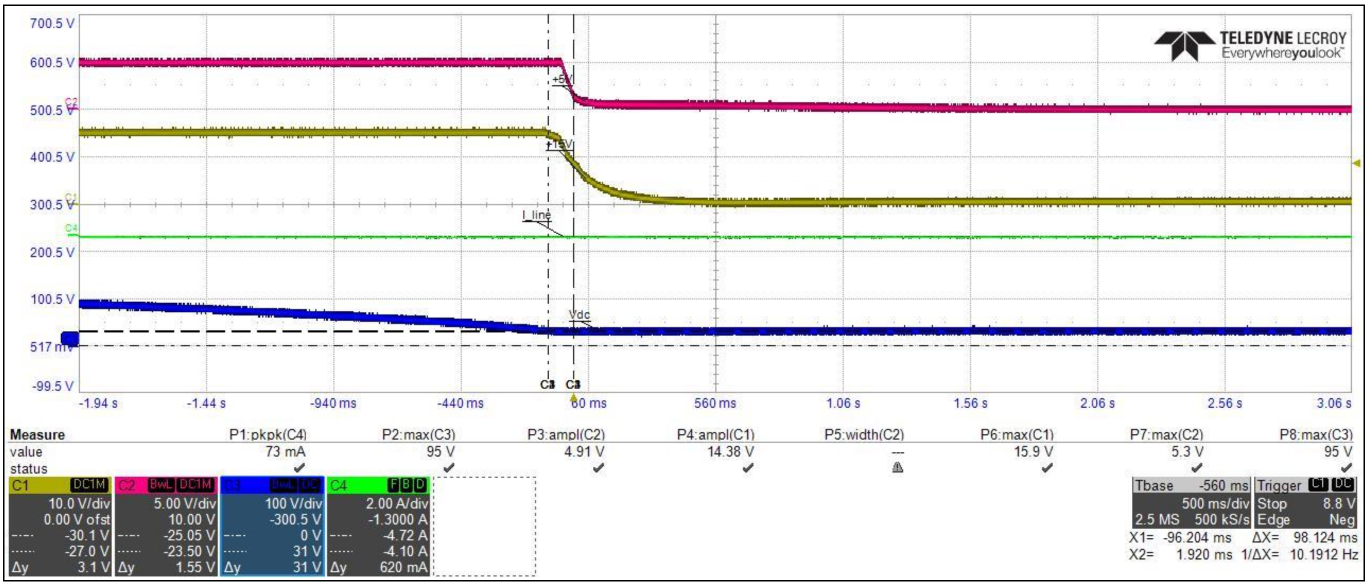


Figure 20 Input 220 V_{AC}

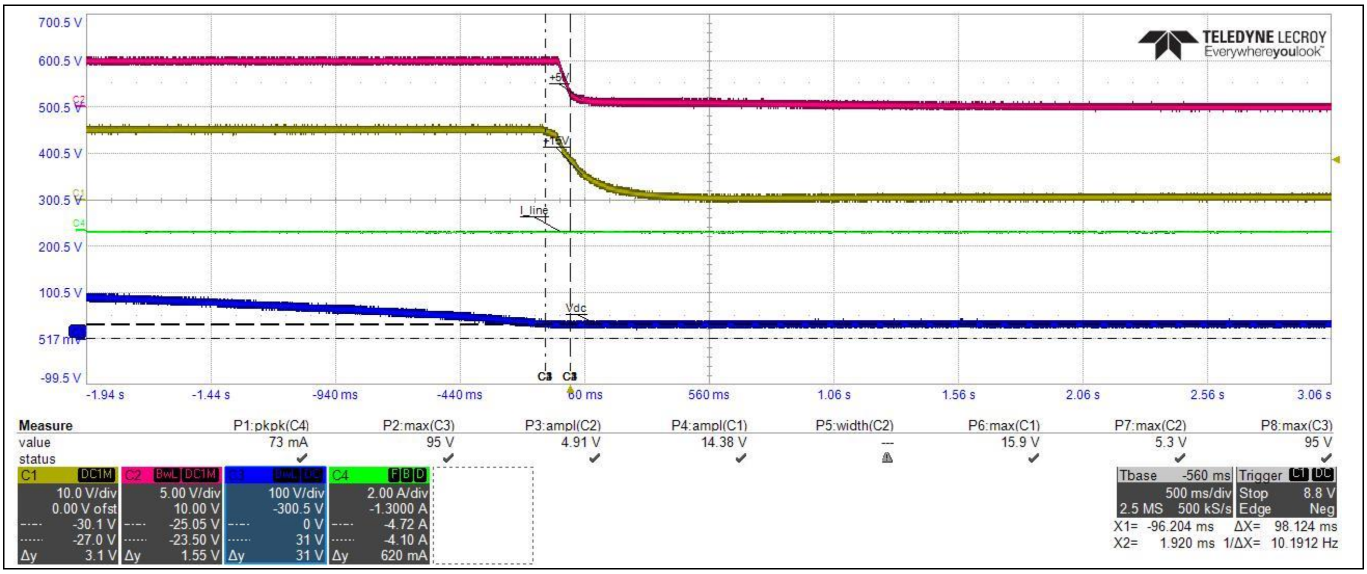


Figure 21 Input 255 V_{AC}

4.2 V_{DC} bus capacitors and V_{DC} ripple

Table 5 V_{DC} bus capacitors and V_{DC} ripple

Specification	V_{DC}_Bus voltage ripple ratio is less than 10%.
Condition	Tested the V_{DC} bus voltage ripple at the 220 V_{AC} input and 5.5 A_{rms} phase current. fpwm=15 kHz; 110 V_{AC} input tested at the conditions 500 W output power, 15 kHz PWM and 3 A_{rms} phase current.
Conclusion	● The V_{DC} bus voltage ripple ratio is 4.93% ((28.5/2)/289=0.0493=4.93%) at 220 V_{AC} input and 5.5 A_{rms} phase current output. ● 110 V_{AC} input, V_{DC} bus voltage ripple ratio is 9.17% ((25.5/2)/139=0.0917=9.17%).

Test Data

Input voltage (V)	**Input power (W)**	**Phase current (A_{rms})**	**V_{DC}_bus (V)**	**V_{DC}_bus ripple (Vpeak-peak)**	**Ripple ratio (%)**	**Picture**
220 V_{AC}	930	5.597	289	28.5	4.93	Figure 22
110 V_{AC}	512	3.125	139	25.5	9.17	Figure 23
Legend	CH1: I_{AC}, CH2: V_{DCBUS}, CH3: I_U, CH4: V_{AC}					

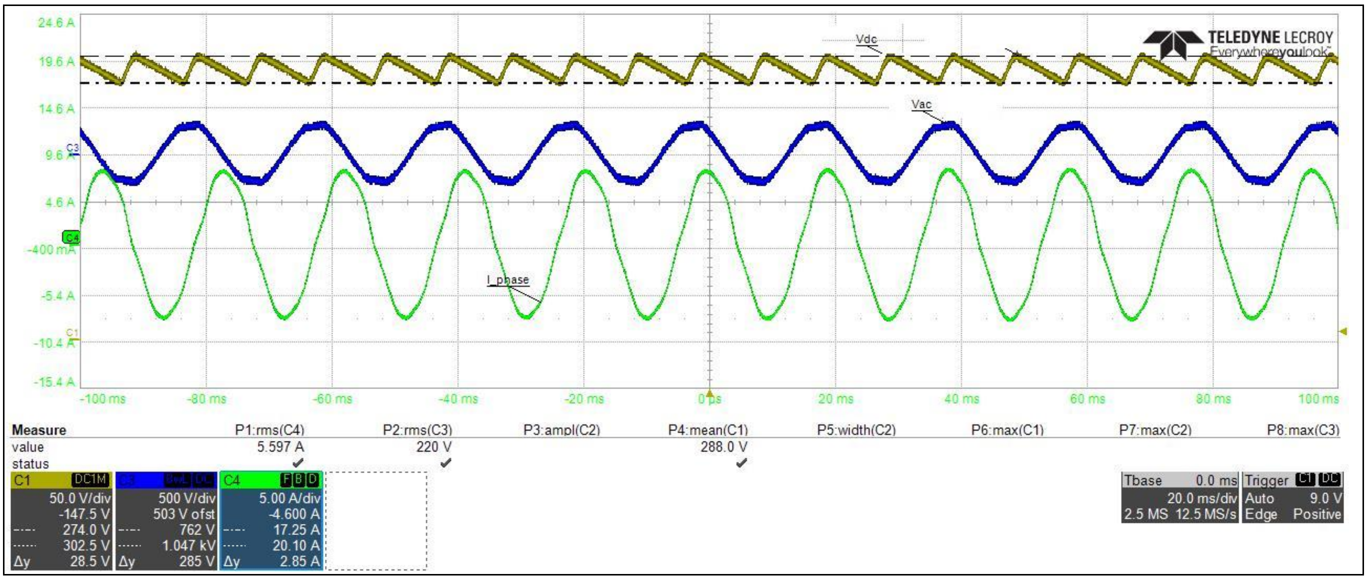


Figure 22 220 V_{AC} input, V_{DC} bus voltage ripple

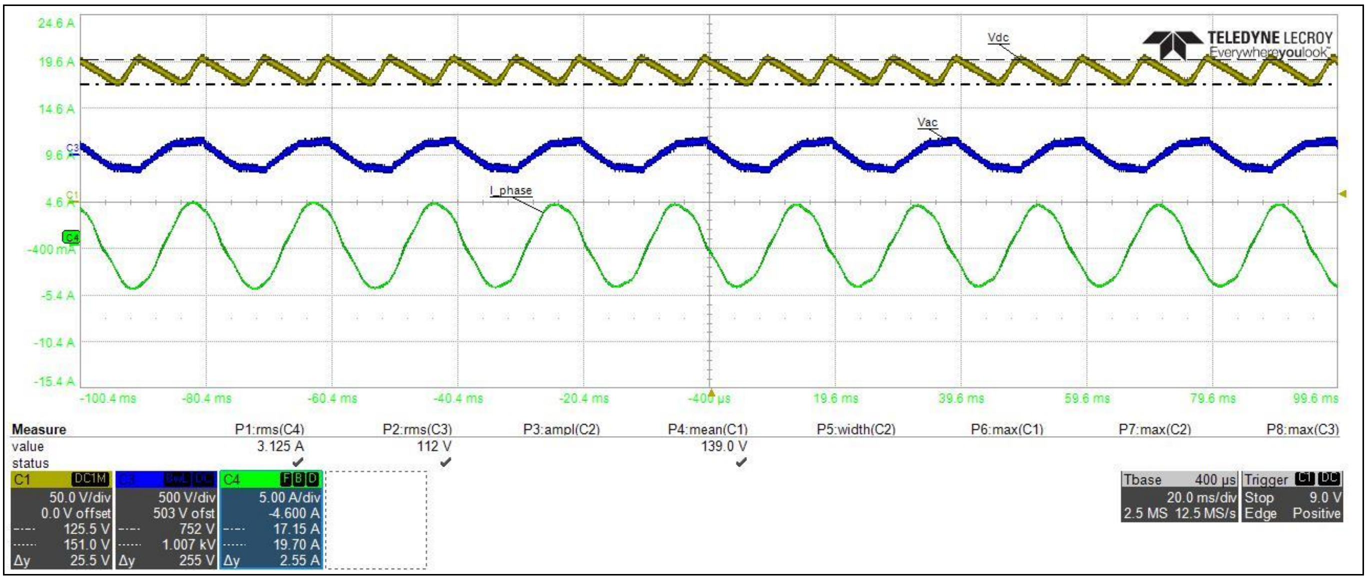


Figure 23 110 V_{AC} input, V_{DC} bus voltage ripple

4.3 Current output capability and thermal test

Table 6 Phase current and IPM case temperature at different PWM and load

Specification		PWM:4-20 kHz; IPM max. case temperature: about 100℃ ; input voltage range: 110~230 V_{AC}; Ta: room temperature; The output power is 900 W (5.5 A_{rms}) at 220 V_{AC} input and 15 kHz PWM. The output power is up to 500 W when the input voltage is 110 V_{AC}.

Data

Input voltage (V)	PWM (kHz)	V_{DC}_bus (V)	Input power (A)	Phase current (A_{rms})	Ta (℃)	IPM case temperature (℃)	ΔT(℃)	Picture
220	4	299.3	369	2.136	22.6	55.6	33	
220	4	297.4	517	3.257	23.4	71.5	48.1	
220	4	294.3	666	4.061	23.8	78.1	54.3	
220	4	290.8	917	5.552	24	85.8	61.8	
220	6	294.7	343	2.2	22.6	57.9	35.3	
220	6	293.4	498	3.095	21.4	72.8	51.4	
220	6	289.8	680	4.137	22.2	79.2	57	
220	6	286.6	921	5.504	22.7	86	63.3	
220	10	298.2	356	2.198	21.2	59.1	37.9	
220	10	295.5	500	3.073	21.9	74.4	52.5	
220	10	293.5	670	4.053	22.6	80.2	57.6	
220	10	288.2	934	5.56	22.7	88.4	65.7	
220	15	298.9	365	2.23	21.6	63.9	42.3	
220	15	297.1	488	2.987	21.7	75.1	53.4	
220	15	292.4	663	4.017	22.7	82.4	59.7	
220	15	289.3	937	5.57	23.4	91.9	68.5	Figure 27, Figure 28
220	20	295	338	2.065	22.5	66	43.5	
220	20	291.7	493	3.009	22.8	77.6	54.8	
220	20	293.2	669	4.037	23.4	86.3	62.9	
220	20	290.3	931	5.512	23.8	97.1	73.3	
110	15	141.8	330	2.058	22.6	63	40.4	
110	15	139.6	455	2.818	23	72.2	49.2	
110	15	139	512	3.125	23	74.5	51.5	Figure 29

Legend	CH1: V_{DC}; Ch3: V_{AC}; CH4: phase current
Condition	● With external amplifier for iMOTION controller current sensing input
Results	● The board works well: – with 937 W input power at 220 V_{AC} input and 15 kHz PWM – for the 4 to 20 kHz PWM range – up to 500 W (3 A_{rms}) output power at the 110 V_{AC} input due to higher bus voltage ripple and higher input line current

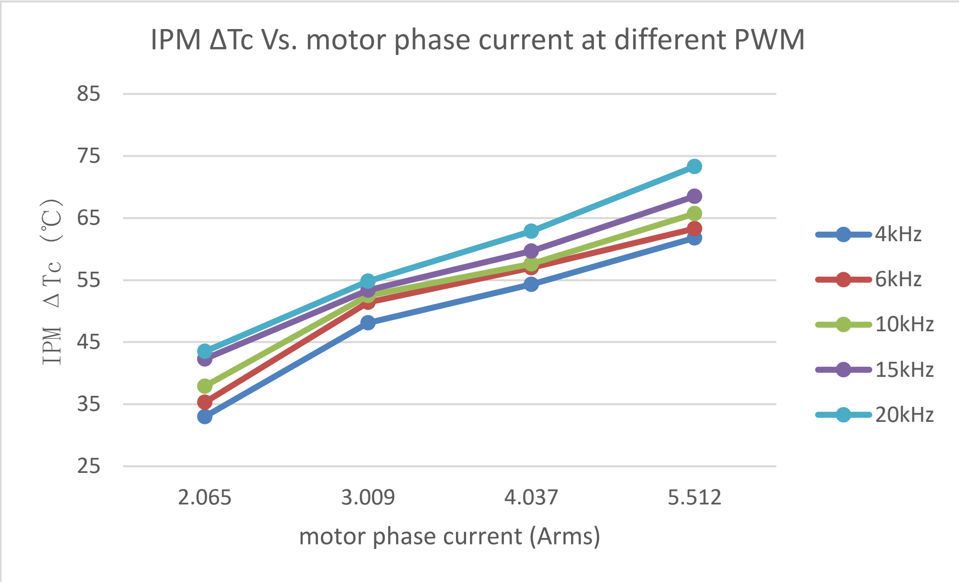


Figure 24 IPM ΔTc Vs. motor phase current at different PWM

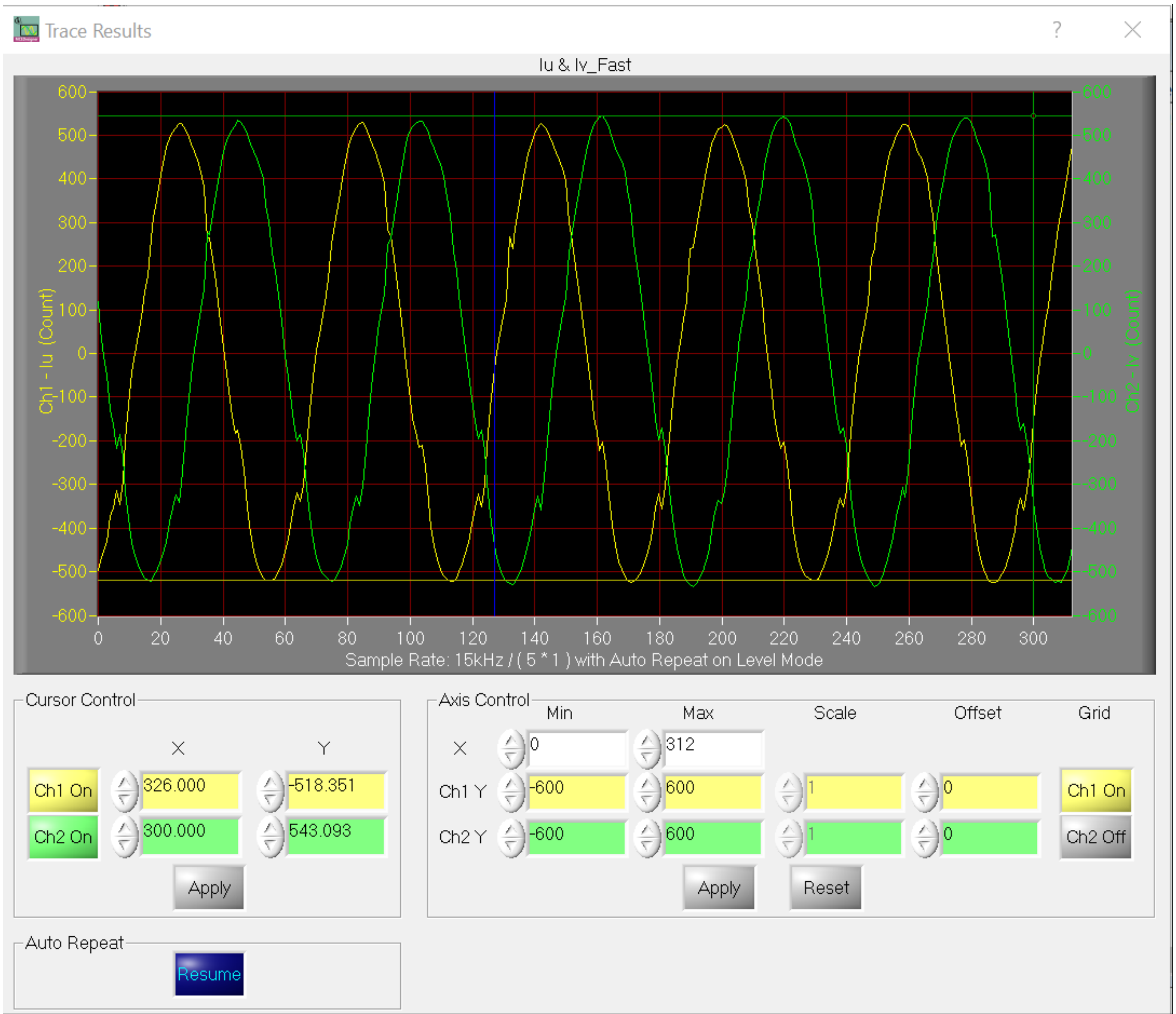


Figure 25 Iu & Flx_M at 15 kHz PWM, 220 V_{AC} input, 900 W output (5.5 A_{rms} phase current)

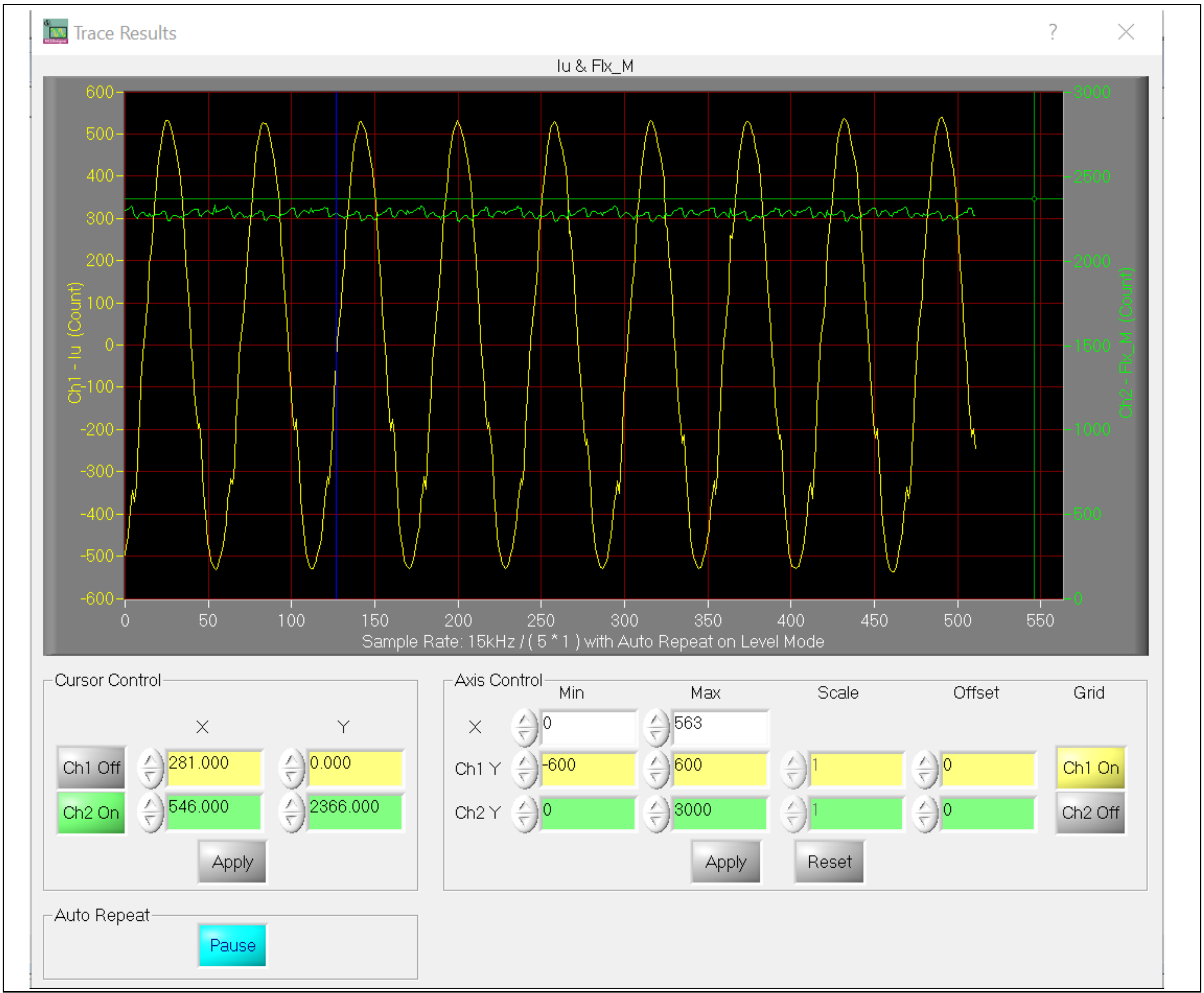


Figure 26 Iu & Flx_M at 15 kHz PWM, 220 V_{AC} input, 900 W output (5.5 A_{rms} phase current)

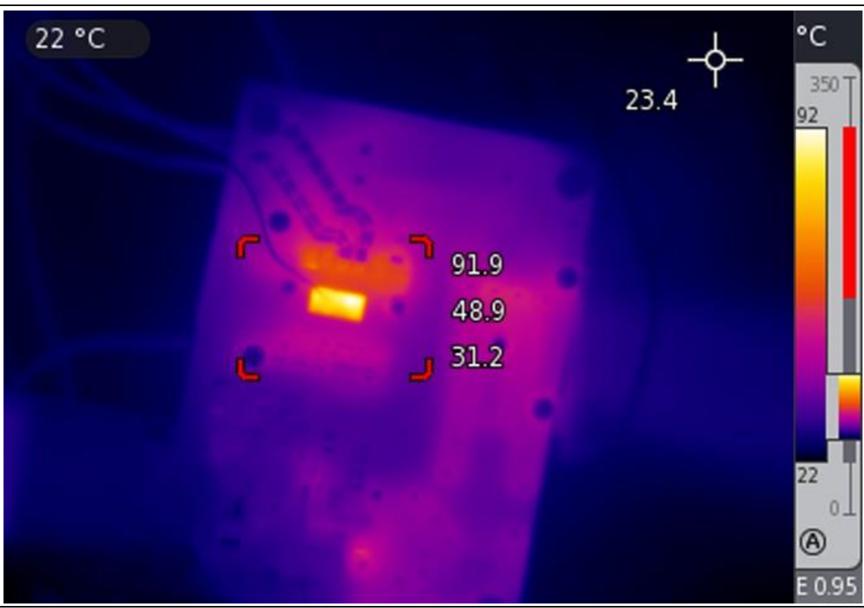


Figure 27 Thermal test at 220 V_{AC} input, 15 kHz PWM and 900 W output

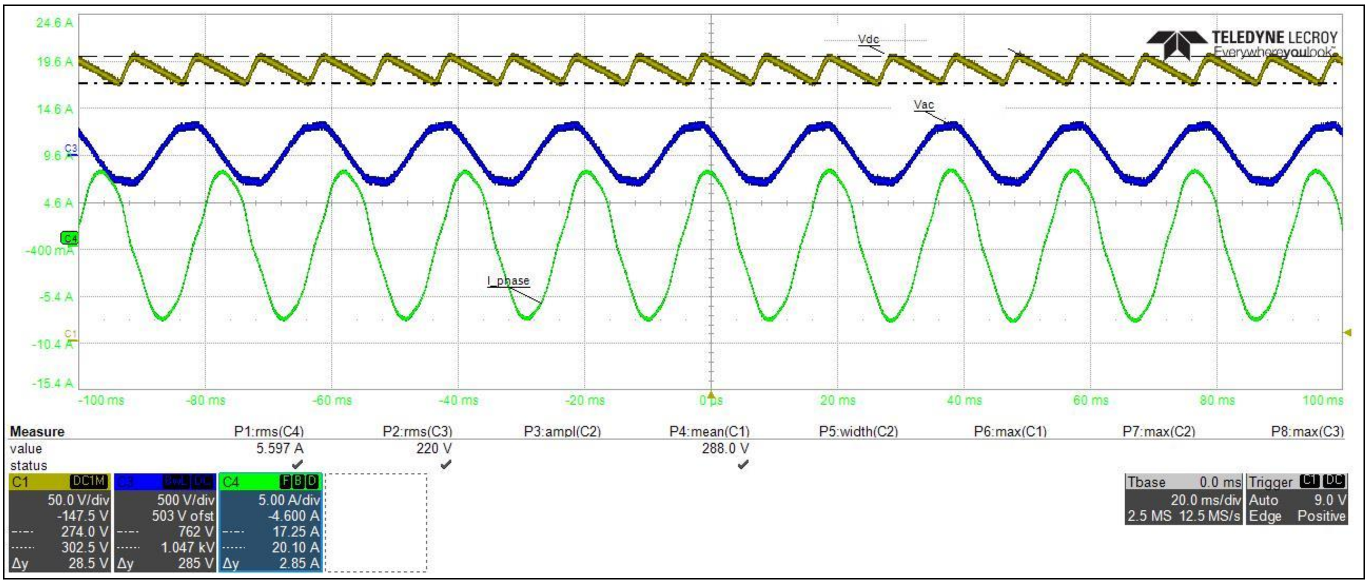


Figure 28 Scope waveform at 220 V_{AC} input, 15 kHz PWM and 900 W output

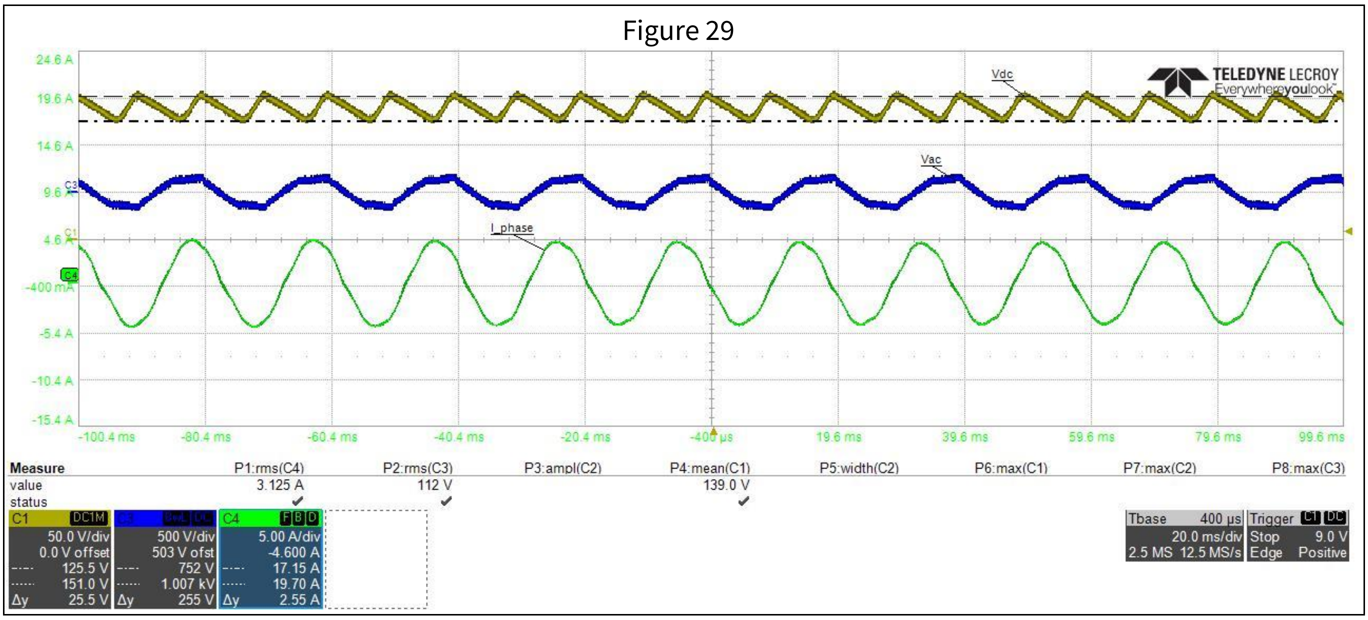


Figure 29 Scope waveform at 110 V_{AC} input, 500 W output power, and 15 kHz PWM

4.4 Overvoltage & undervoltage protection

Table 7 Overvoltage & undervoltage protection

Specification	The overvoltage & undervoltage (OV/UV) protection threshold are set at OV=340 V(2697 counts); UV=100 V(793 counts). The system can be shut down when the DC bus voltage is over/under the threshold (±3 V); voltage scaling is 7.93 cnts/V.		
Data			
Operation	**Threshold**	**Test results**	**Figures**
OV protection	340 V (2697 counts)	2699.4 counts	Figure 30
UV protection	100 V (793 counts)	793.6 counts	Figure 31
Legend	CH1: Iu; Ch2: Vdc		
Condition	The fault flag was 1 and reported OV/UV faults on the MCEDesigner when the V_{DC} bus voltage reached the OV/UV threshold.		
Result	OV/UV protection is in working order. The system is stopped when OV/UV fault appears.		

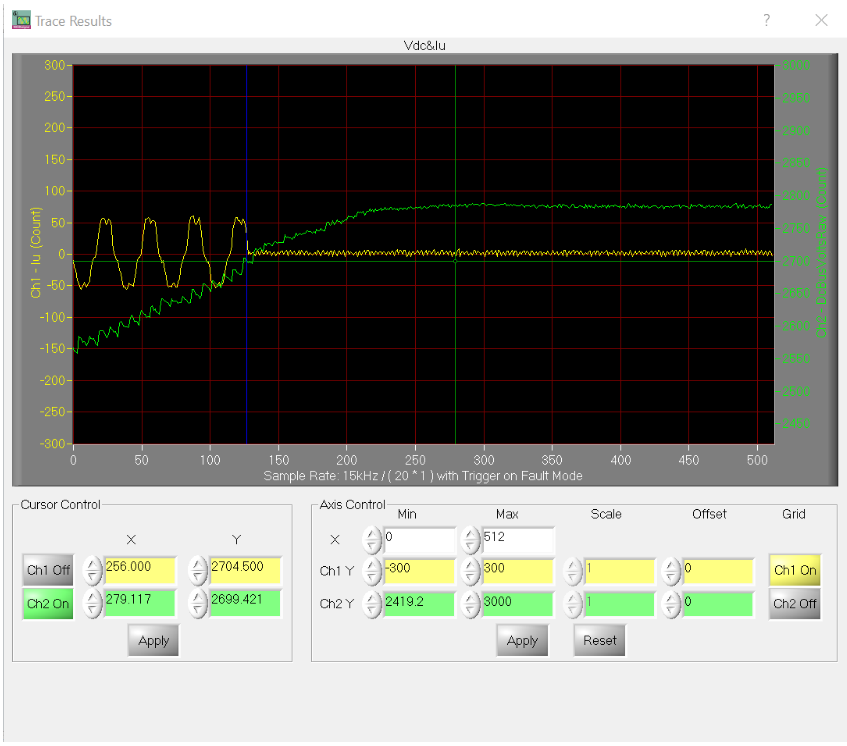


Figure 30 OV protection

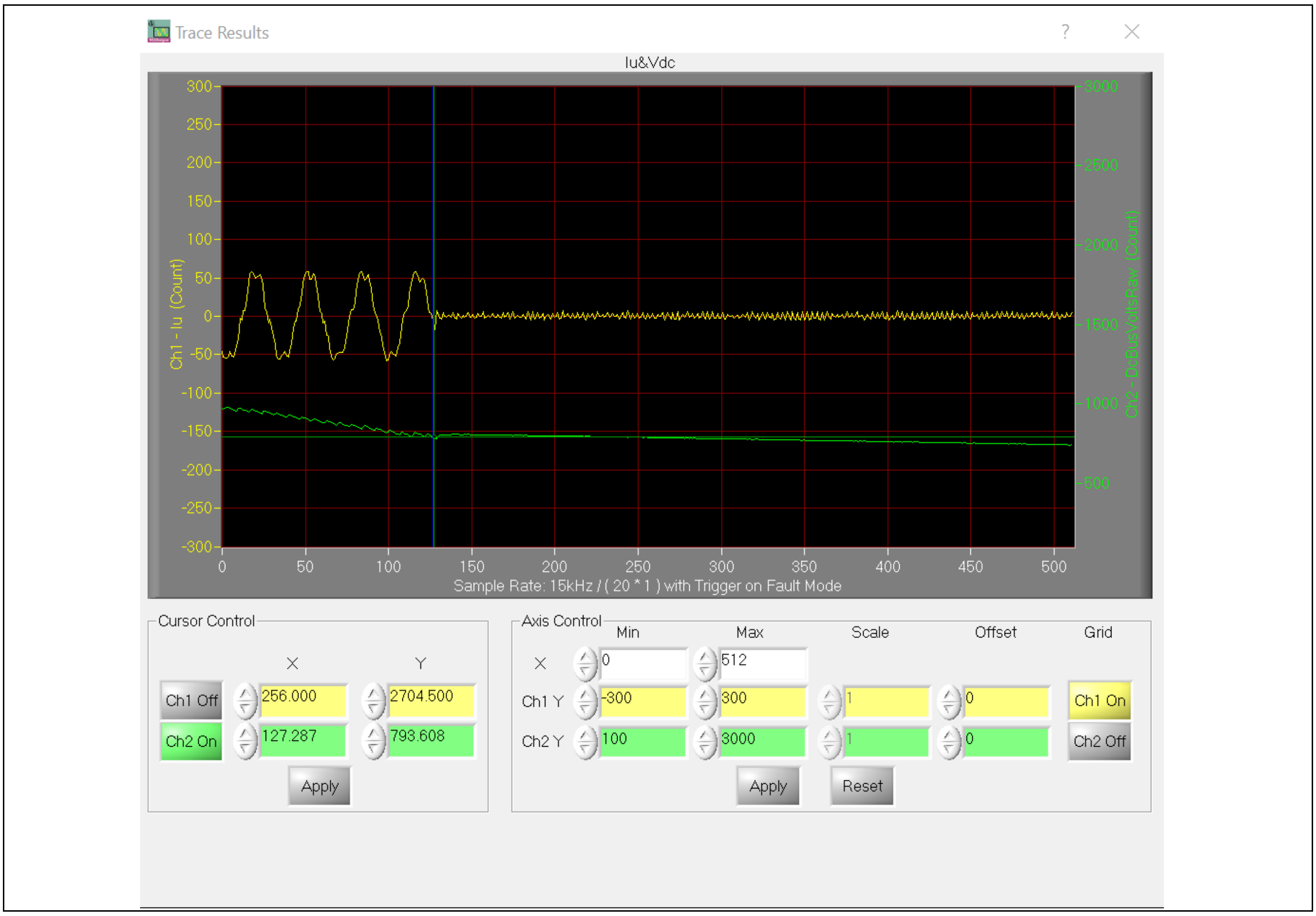


Figure 31 **UV protection**

4.5 Over-temperature protection (OTP) test

Table 8 Over-temperature

Specification	Over-temperaute threshold voltage is set at 3.4 V in MCEWizard and in the comparator on the board. The 3.4 V threshold value corresponds to 105±3℃ IPM case temperature.	
Data		
Operation	**Phenomenon**	**Picture**
iMOTION solftware OTP	The motor stopped and over-temperatue fault reported in MCEDesigner bottom window.	Figure 32
On board hardware OTP	The motor stopped and the Gatekill was activated and the signal goes down.	Figure 33
Legend	CH1: VFO pin voltage; CH2: Gatekill; CH4: phase current.	
Condition	● OTP threshold was set at 3.4 V, the board ran for 20~30 mintues at 220 V_{AC} input, 650 W power and 15 kHz PWM. The forced air-cooled fan was stopped during the test.	
Result	● Both OTP software and hardware worked well. The system stopped as expected.	

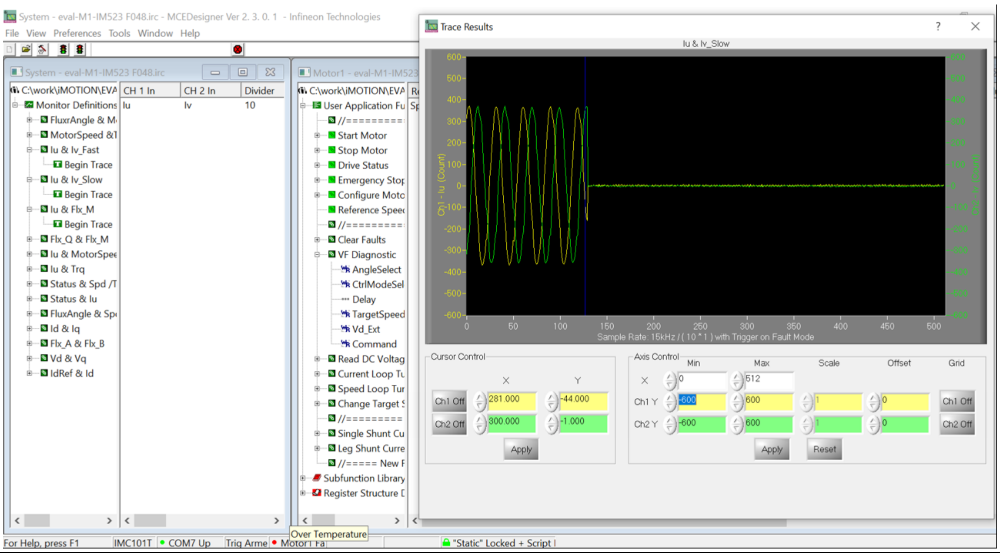


Figure 32 Solftware over-temperature protection

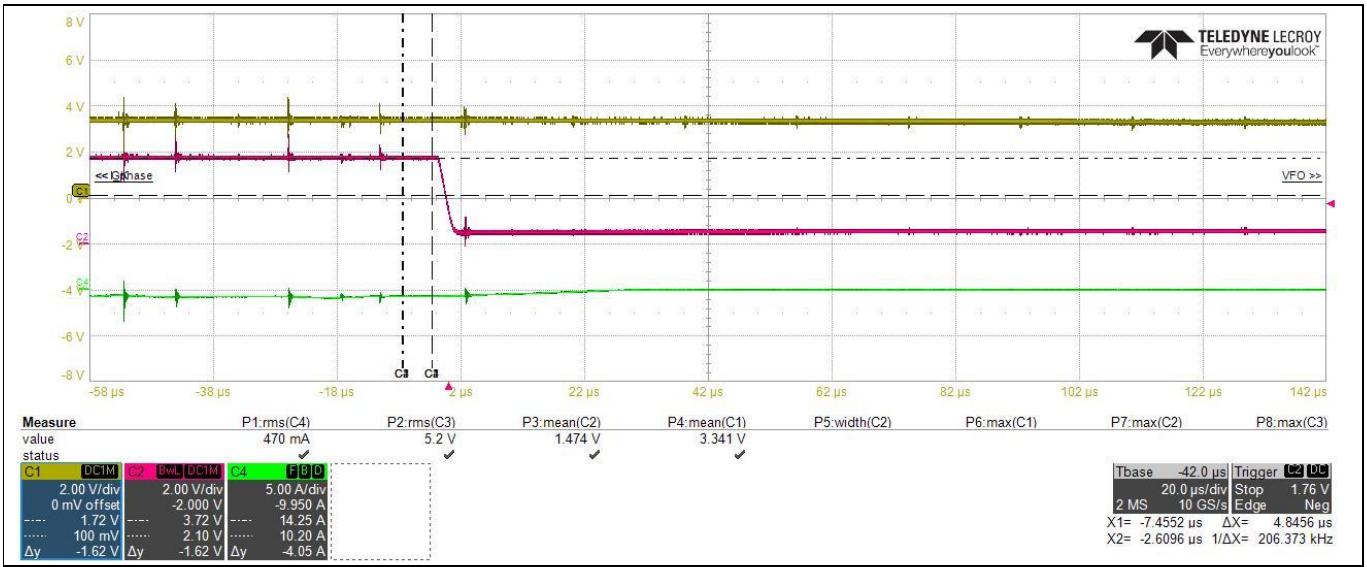


Figure 33 Hardware over-temperature protection

4.6 Overcurrent test

Table 9 Overcurrent

Specification	Verify the software and hardware overcurrent protection (OCP) function.	
	Data	
Operation	**Phenomenon**	**Picture**
Software OCP	The motor stopped at 4.21 A_{peak} phase current and reported overcurrent fault in MCEDesigner fault flag.	Figure 34
Hardware OCP	The OCP threshold was set at 9 A, the comparator triggered at 10.1 A	Figure 35
Legend	Figure 34: (CH1: Vdc; CH3: V_{AC}; CH4: phase current) Figure 35: (CH1: Gatekill; CH2: Vge(on); CH3: Itrip; CH4: phase current)	
Condition	● Software OCP: set at 4 A OCP threshold in MCEWizard. ● Hardware OCP: used a double-pulse tester to create a high-current cross on the shunt resistor.	
Result	● OCP functions well. The system stopped as expected.	

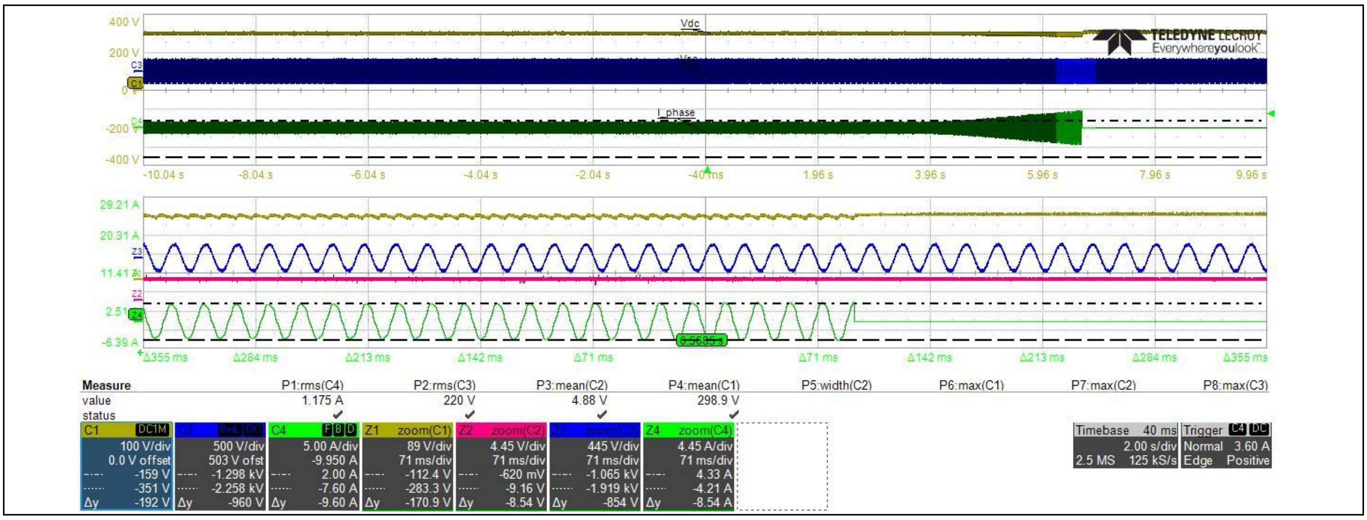


Figure 34 Software OCP

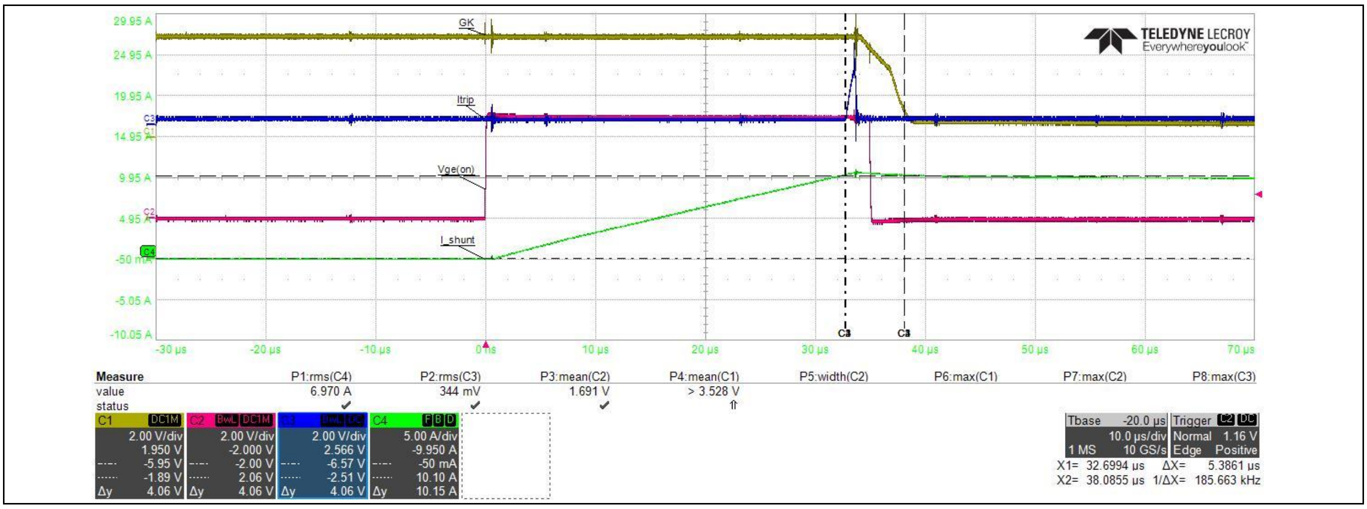


Figure 35 Hardware OCP

4.7 Direct current feedback test

Table 10 Direct current feedback test

Specification	Do not use the external amplifier on the board. The current feedback signal sends messages to the MCU AD input pin directly.			
		Data		
Power source	**PWM (kHz)**	**Input power (W)**	**Phase current (A_{rms})**	**Pictures**
220 V_{AC}	15	320	2	Figure 36
		500	3	Figure 37
		930	5.5	Figure 38; Figure 39
Legend	CH1: Vdc; CH3: V_{AC}; CH4: phase current			
Condition	• R15 and R19 on the EVAL-M1-IM523 were removed from the board; then R50 was soldered to 0 Ohm resistor. The parameters in MCEWizard were calculated with 3 times the internal gain. The current scaling was changed to 8.3 mV/A, ADC offset voltage to 833 mV and gate driver delay time to 0.5 s.			
Results	• We ran the board for the 2 A, 3 A, and 5.5 A current load. We checked the Iu & Iv current waveforms, which are uniformly sinusoidal. • The system is stable. The motor Flx_M is steady (see Figure 40).			

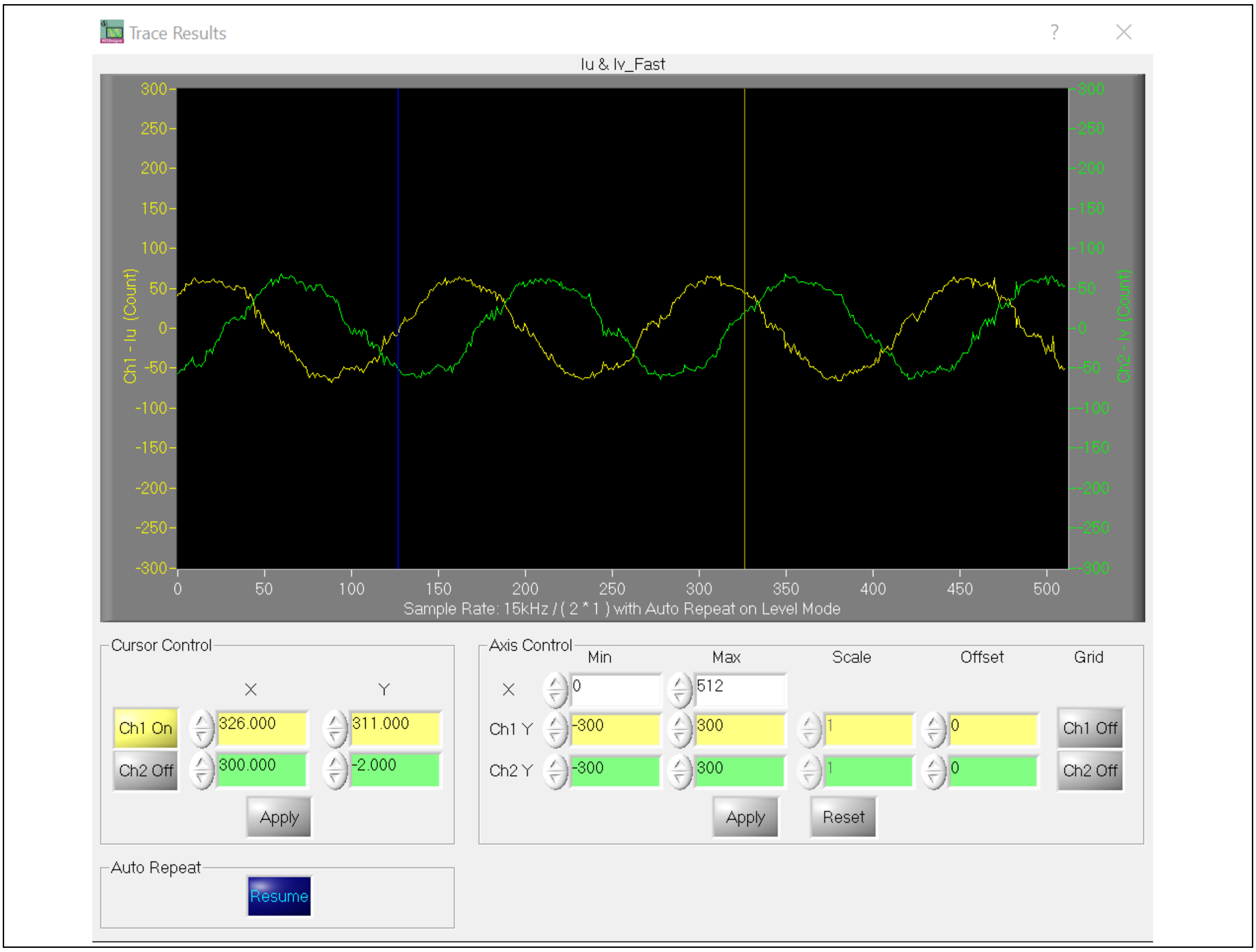


Figure 36 320 W load current feedback, 2 A_{rms} phase current, 15 kHz PWM, 220 V_{AC} input

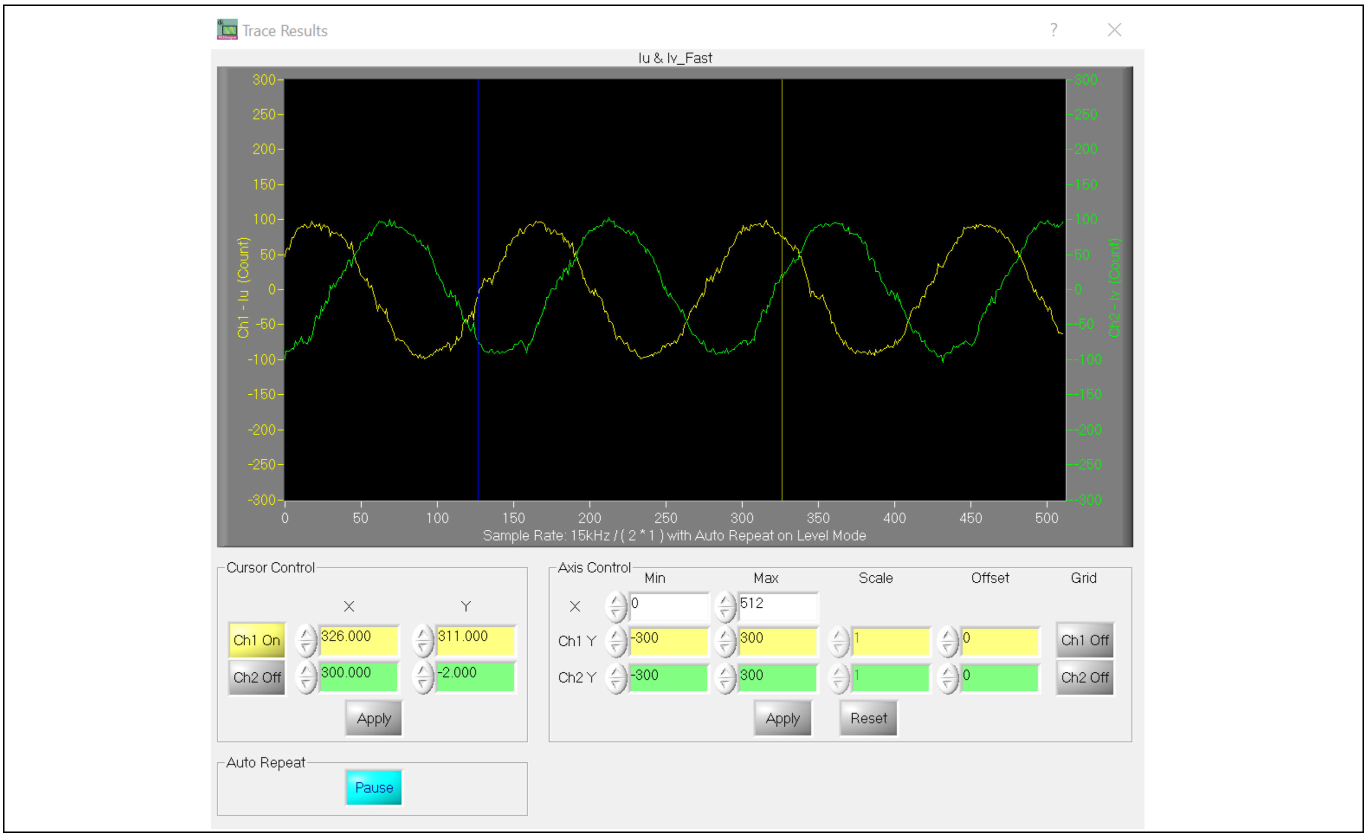


Figure 37 500 W load current feedback, 3 A_{rms} phase current, 15 kHz PWM, 220 V_{AC} input

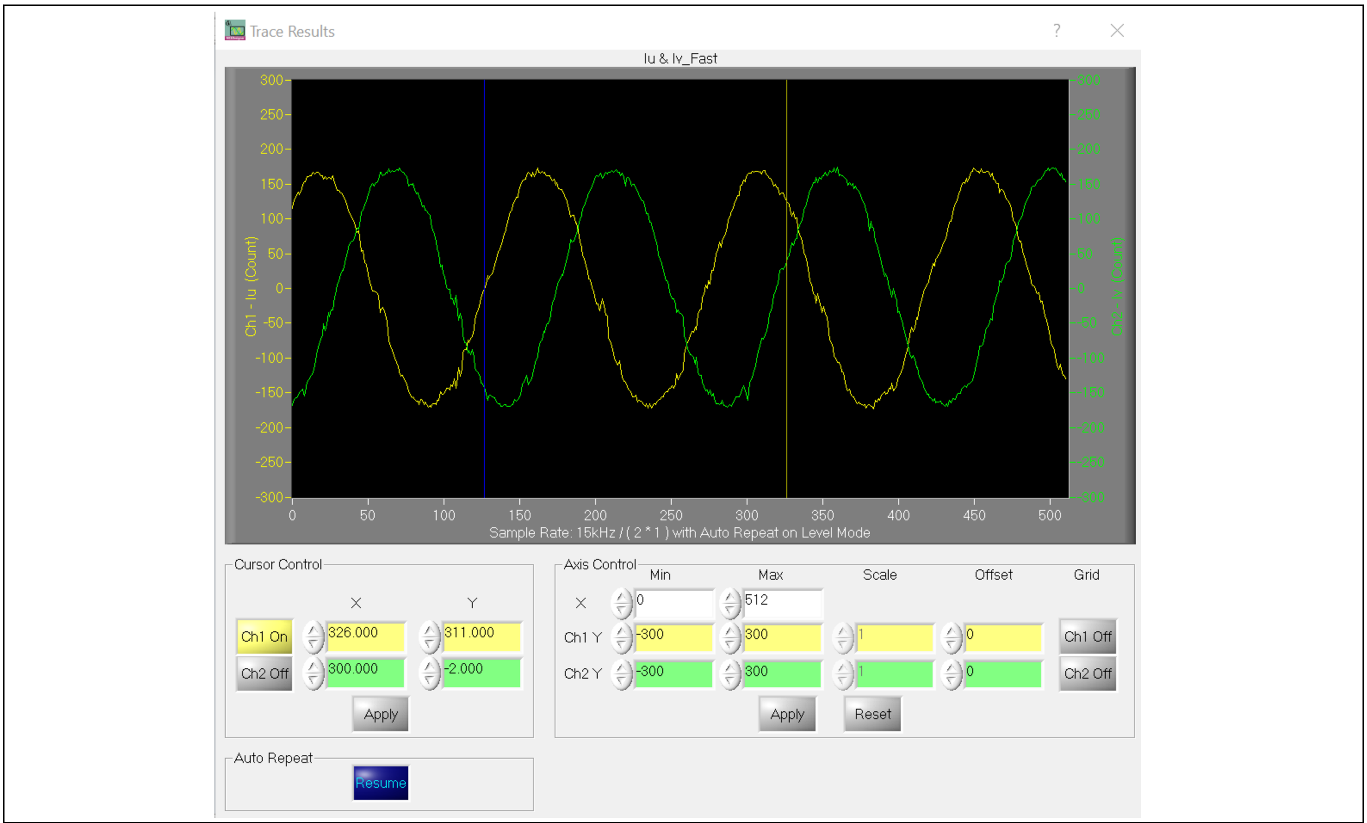


Figure 38 930 W load, 5.5 A_{rms} phase current, 15 kHz PWM, 220 V_{AC} input

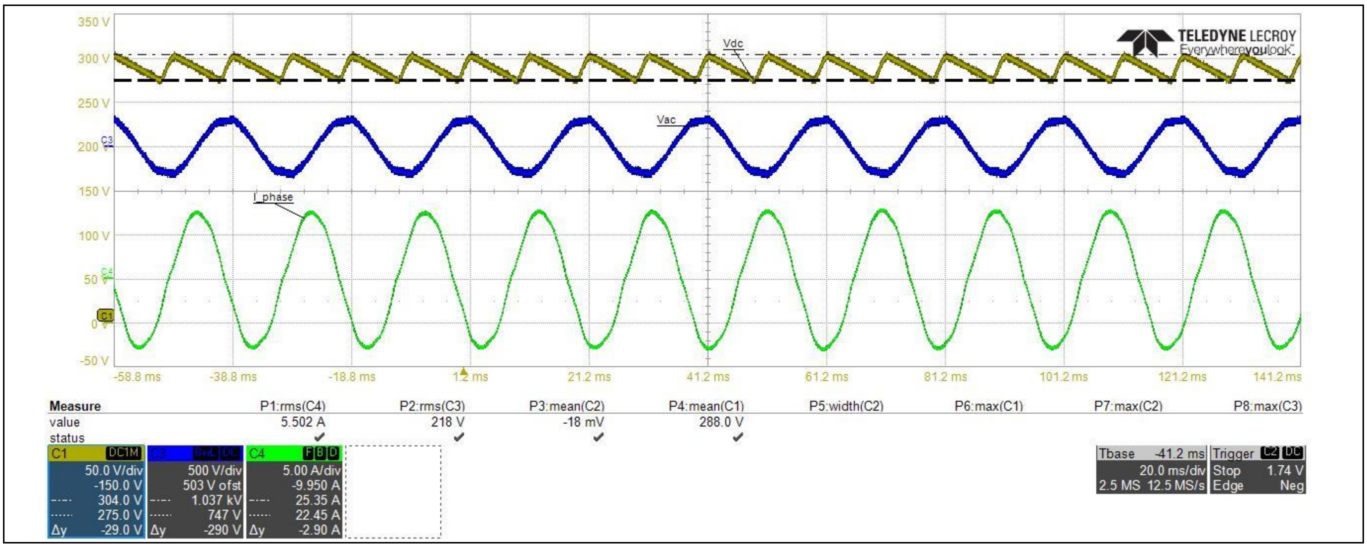


Figure 39 Scope waveforms at 930 W load, 5.5 A_{rms} phase current, 15 kHz PWM, 220 V_{AC} input

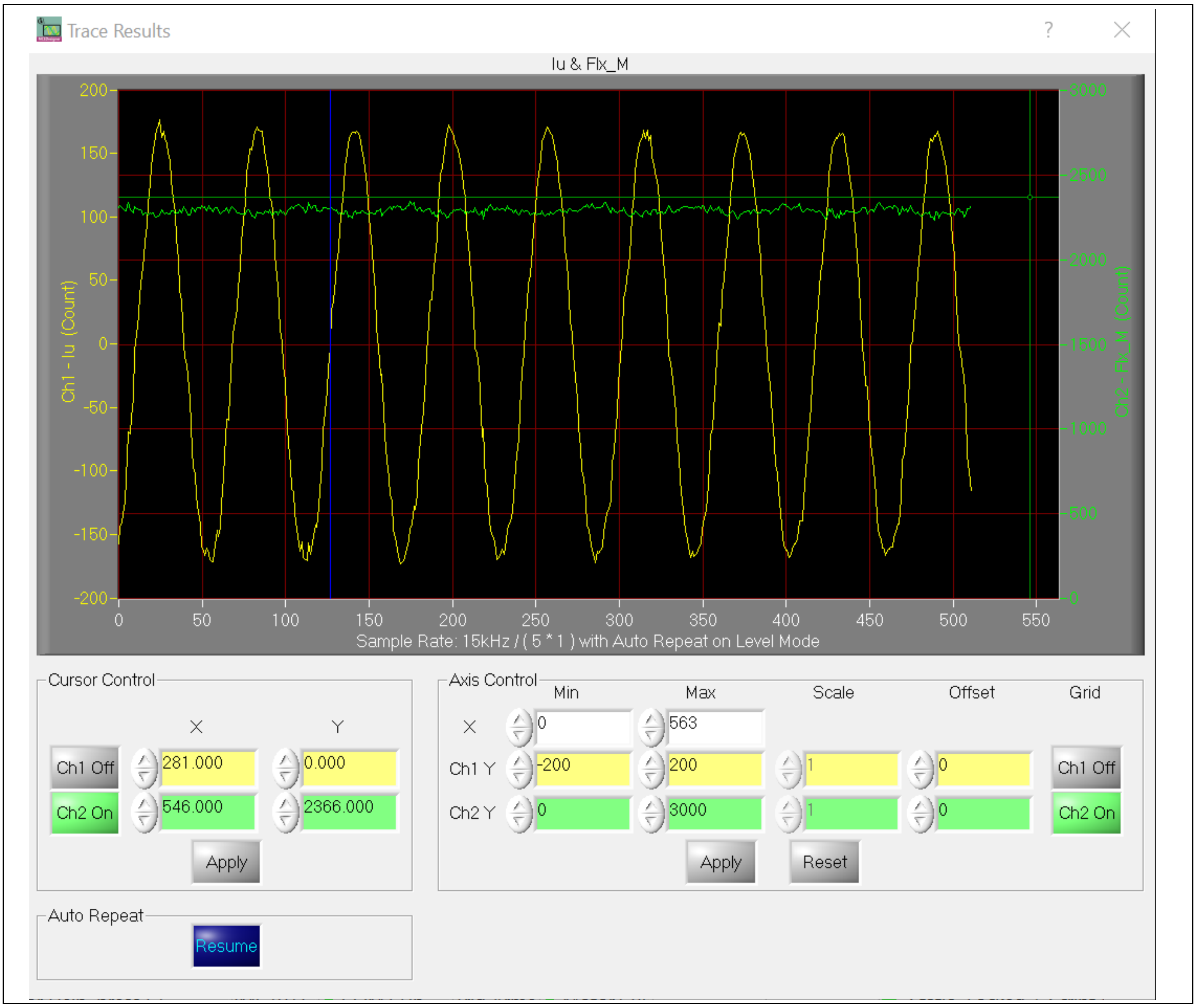


Figure 40 Flx_M & Iu waveform in MCEDesigner

5 Acronyms

Table 11 Abbreviations

Abbreviation	Meaning
AC	Alternating current
AD	Altium designer
CAP	Capacitance
CCM	Continuous conduction mode
CE	Conformité Européenne
CERA	Ceramic
EMI	Electromagnetic interference
EMC	Electromagnetic compatibility
ESD	Electrostatic discharge
EFT	Electrical fast transient
DC	Direct current
DCBUS	Direct current bus voltage
DCM	Discontinuous conduction mode
DCP	Direct current bus voltage positive
ELCO	Electrolytic capacitor
FILM	Film capacitor
GUI	Graphical user interface
GDT	Gas discharge tube
IC	Integrated circuit
IGBT	Insulated gate bipolar translator
IPM	Intelligent power module
LED	Light emitting diode
MADK	Modular application design kit
MCE	Motion control engine
NTC	Negative temperature coefficient
OCP	Overcurrent protection
PC	Personal computer
PCB	Printed circuit board
PCN	Process change notification
PD	Product discontinuation
PE	Protect earth
PGND	Protect ground
PLL	Phase locking loop
PTC	Positive temperature coefficient
PWM	Pulse-width modulation
RES, R	Resistor

Abbreviation	Meaning
RMA	Returned material analysis
RoHS	Restriction of hazardous substances in electrical and electronic equipment
SGND	Secondary ground
SOI	Silicon-on-insulator
UART	Universal asynchronous receiver/transmitter
USB	Universal serial bus
UVW	U phase/V phase/W phase
VCC	Voltage circuit

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Document version	Date	Description of changes
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