

EVAL-M1-IM535 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-IM535 including its main features, key data, pin assignments and mechanical dimensions.

The EVAL-M1-IM535 is an evaluation board for motor drive applications, as part of the iMOTION™ modular application design kit. In combination with the control board equipped with the M1 20-pin interface connector such as EVAL-M1-101T, it features and demonstrates Infineon's CIPOS™ Mini IPM technology and advanced motion control engine (MCE 2.0) technology for permanent magnet motors drive.

The IM535-U6D CIPOS™ Mini IPM has 600 V of voltage and 30 A of current rating. It is optimized for major home appliances like air conditioners, pumps, fans and other low & middle power motor drive applications.

This evaluation board EVAL-M1-IM535 is developed to support customers during their first steps designing applications with CIPOS™ Mini IPM IM535-U6D and running any permanent magnet motor via sensorless sinusoidal control.

Intended audience

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

Evaluation Board

This board will be used during design-in, for evaluation and measurement of characteristics, and proof of data sheet specifications.

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



Important notice

Important notice

“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

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 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 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 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 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.

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The board at a glance

1 The board at a glance

The EVAL-M1-IM535 evaluation power board is a part of the iMOTION™ modular application design kit for motor drives (iMOTION™ MADK). The MADK platform is intended for use with various power stages and different control boards. The EVAL-M1-IM535 can easily be interfaced through the 20-pin iMOTION™ MADK M1 connector such as EVAL-M1-101T, and is intended for single-motor control only.

The EVAL-M1-IM535 evaluation board is available through regular Infineon distribution partners as well as on Infineon's website. The features of this board are described in the main features chapter of this document, whereas the remaining paragraphs provide information to enable the customers to copy, modify and qualify the design for production according to their own specific requirements.

Environmental conditions were considered in the design of the EVAL-M1-IM535, but the board is not qualified in terms of safety requirements or manufacturing and operation over the entire operating temperature range or lifetime. The boards provided by Infineon are subject 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 Delivery content

The EVAL-M1-IM535 evaluation board is designed to provide an easy-to-use power stage based on the Infineon's CIPOS™ Mini intelligent power module (IM535-U6D IPM).

The delivery includes the finished board as shown in Figure 1 and Figure 2. It provides a single-phase AC connector, an EMI filter and soft power-up circuit, input rectifier, DC bus capacitors and 3-phase output for connecting the motor.

It also contains CoolSET™ based auxiliary power supply to provide 15 V & 5 V, emitter shunts for current sensing and overcurrent protection, and a voltage divider for DC-link voltage measurement. The board shown here can be operated directly with the required power supply without the need for additional components.

1.2 Block diagram

The block diagram of the EVAL-M1-IM535 is depicted in Figure 1.

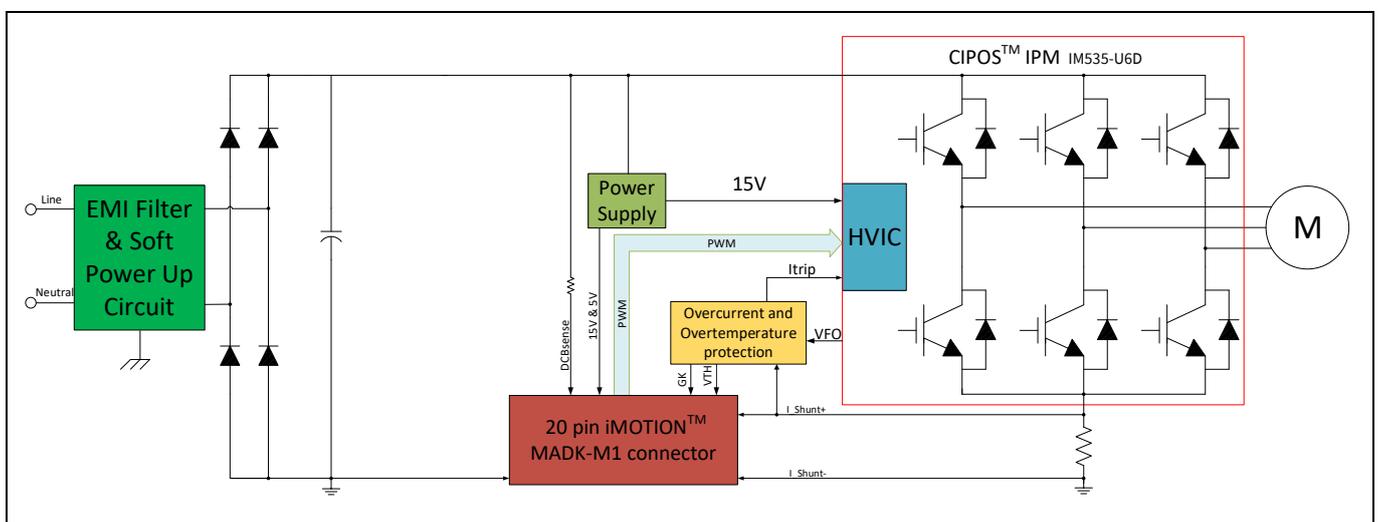


Figure 1 Block diagram of the EVAL-M1-IM535

The board at a glance

Figure 2 points out the functional groups on the top side of the EVAL-M1-IM535 design:

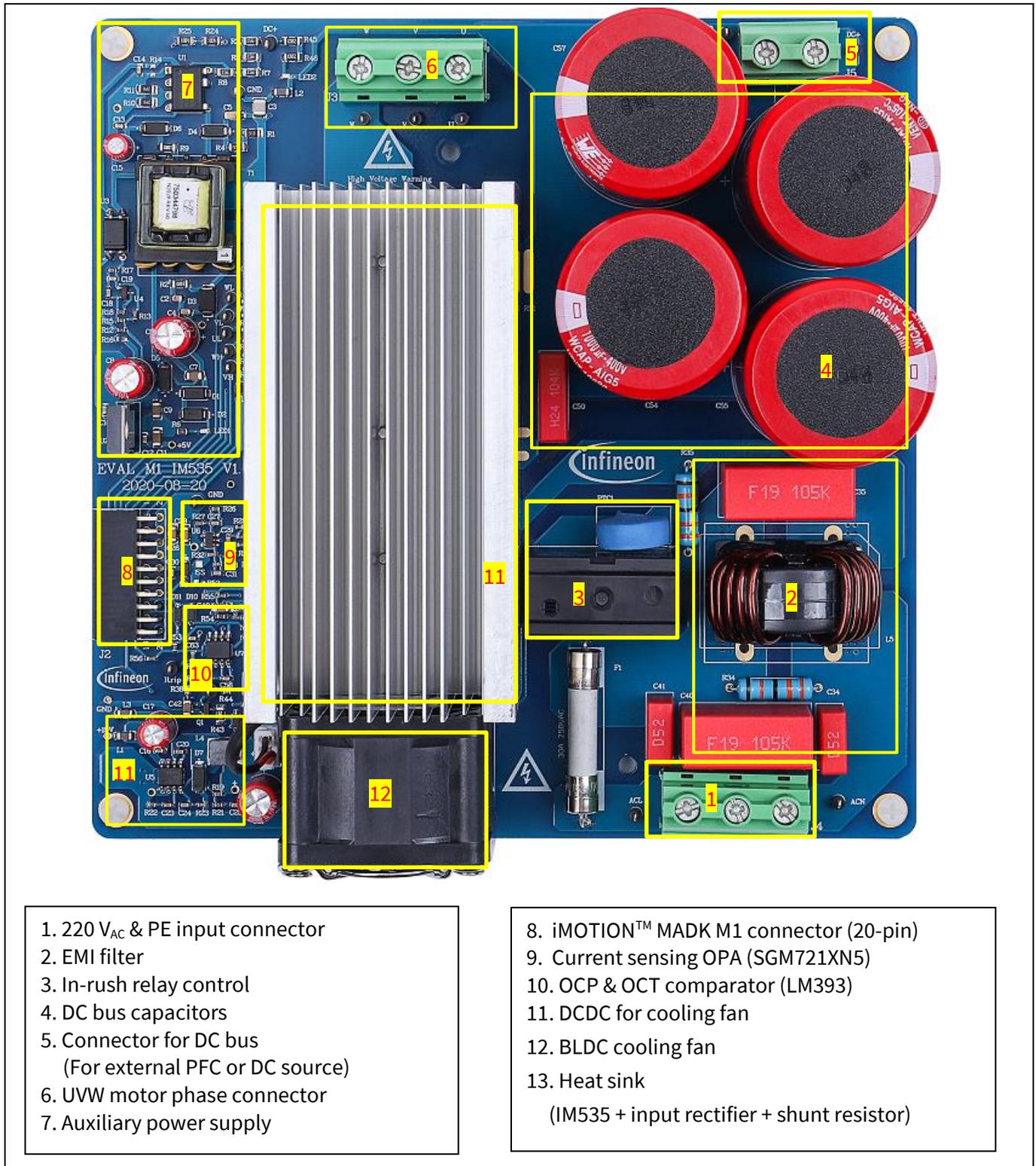


Figure 2 Functional groups of the EVAL-M1-IM535 reference design

The board at a glance

1.3 Main features

The EVAL-M1-IM535 is an evaluation board for motor drive applications. Combined in a kit with one of the available MADK control board options, it demonstrates Infineon’s motion control IC and IPM technology for motor drives.

The evaluation board characteristics include:

- Input voltage 85~265 V_{AC}
- Maximum 20 A input and output current
- Maximum 3000 W motor power output
- On board EMI filter
- Current sensing operational amplifier (OPA) with single shunt
- Auxiliary power supply with 15 V, 5 V
- Overcurrent hardware protection & over temperature protection
- Sensing of DC-link voltage
- Thermistor output
- PCB is 166 mm × 166 mm, two layers with 2 oz. copper
- RoHS compliant

1.4 Board parameters and technical data

Table 2 depicts the important specifications of the evaluation board EVAL-M1-IM535.

Table 2 EVAL-M1-IM535 board specifications

Parameter	Symbol	Conditions / comments	Value	Unit
Input voltage	V_{ac}	Optimized design for 220 V _{AC} application Lower AC input, less motor power output	85 ~ 265	V _{rms}
Maximum input current	$I_{ac(max)}$	Input 220 V _{AC} , T _a =25°C	20	A _{rms}
Maximum input power	$P_{in(max)}$	Input 220 V _{AC} , f _{PWM} = 6 kHz, T _a =25°C, T _{case} = 105°C Force cooling mode	3000	W
Maximum motor current	$I_{mtr(max)}$	Input 220 V _{AC} , f _{PWM} =5 kHz, T _a =25°C, T _{case} = 105°C Force cooling mode	20	A _{rms}
Maximum DC bus voltage	$V_{dc(max)}$	DC bus capacitors are 400 V, 820μFX4 (or 1000μF X4)	400	V
Minimum DC bus voltage	$V_{dc(min)}$	Aux power supply brown-in voltage	80	V
Shunt Resistance	R_{sh}	Two 5 mΩ in parallel, with external OPA gain 10	2.5	mΩ
Protections				
Motor current protection trigger level 1	I_{trip}	Wizard setup for OC trigger level, related to shunt resistor RS1 & RS2 and current sensing bias	30 ¹	A _{peak}

¹ For iMOTION™ IC IMCxxx, there are three types of Gatekill input source options in MCEWizard setup: Gatekill-pin, Comparator and Both. If you select “comparator” mode, the external Gatekill signal will be not used, and the signal I_Shunt will be compared by the internal comparator with the “Device overcurrent trigger level setting” value set in MCEWizard.

The board at a glance

Parameter	Symbol	Conditions / comments	Value	Unit
Motor current protection trigger level 2	I_{trip}	Hardware comparator overcurrent protection, related to shunt resistor and LM393 setup	36	A _{peak}
Thermal protection level	$T_{protection}$	Temperature gap between junction and NTC (negative temperature coefficient) sensor needs to be considered; recommended is a setting of 105°C or less	105	°C

Auxiliary power supply 1 – 15 V

Output voltage	V_{out1}	Used for IPM and cooling fan	15 ± 5%	V
Maximum output current	I_{out1}		450	mA

Auxiliary power supply 2 – 5 V

Output voltage	V_{out2}	Used for IMC controller and protection circuits	5 ± 1%	V
Maximum output current	I_{out2}		150	mA

PCB characteristics

Dimension		Length × width × height	166×166×62	mm
Material		FR4, 1.6 mm thickness, 2oz PCB		

System environment

Ambient temperature	T_a	Non-condensing, maximum RH of 95%	0 ~ 50	°C
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2 System and functional description

2.1 Getting started with EVAL-M1-IM535

In order to run the motor system, a combination of the iMOTION™ MADK power board (EVAL-M1-IM535) and the matching MADK control board (EVAL-M1-101T or other control board) are required. This chapter provides more details on setting up the system and getting started with the iMOTION™ MADK development platform.

Note: If you are using an EVAL-M1-101T control board, please make the following changes to better match EVAL-M1-IM535 for op-amp current sensing, since EVAL-M1-101T's default configuration is directly ADC sample.

1. Remove R6 of EVAL-M1-101T (Since EVAL-M1-IM535 uses external OPA circuit, it has its own bias)
2. Change R7 of EVAL-M1-101T from 2 k Ω change to 0 ohm (To reduce total R & C delay for current sensing path)

The EVAL-M1-IM535 reference designs are tested with EVAL-M1-101T controller boards, which shipped with embedded firmware and default parameters.

The following steps have to be performed in order to achieve a usable motor controller IC from a blank IMC101T:

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

The iMOTION™ software tools, MCEDesigner and MCEWizard, are required to initially set up the system, as well as to control and fine-tune the system performance to match the user's exact needs. These tools are available for download via the Infineon website (<https://www.infineon.com/cms/en/product/power/motor-control-ics/digital-motor-controller-imotion/imc101t-t038/#!tools>). Please visit this page periodically to check for tool/software updates.

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

This chapter provides more details on setting up the system and getting started with the iMOTION™ development platform.

After downloading and installing the iMOTION™ PC tools, MCEWizard and MCEDesigner, the following steps need to be taken to run the motor. Refer to MCEWizard and MCEDesigner documentation for more information.

Figure 3 shows the basic system connection using EVAL-M1-IM535 to run a 3KW GK6081-6AC31 motor with MCE Designer.

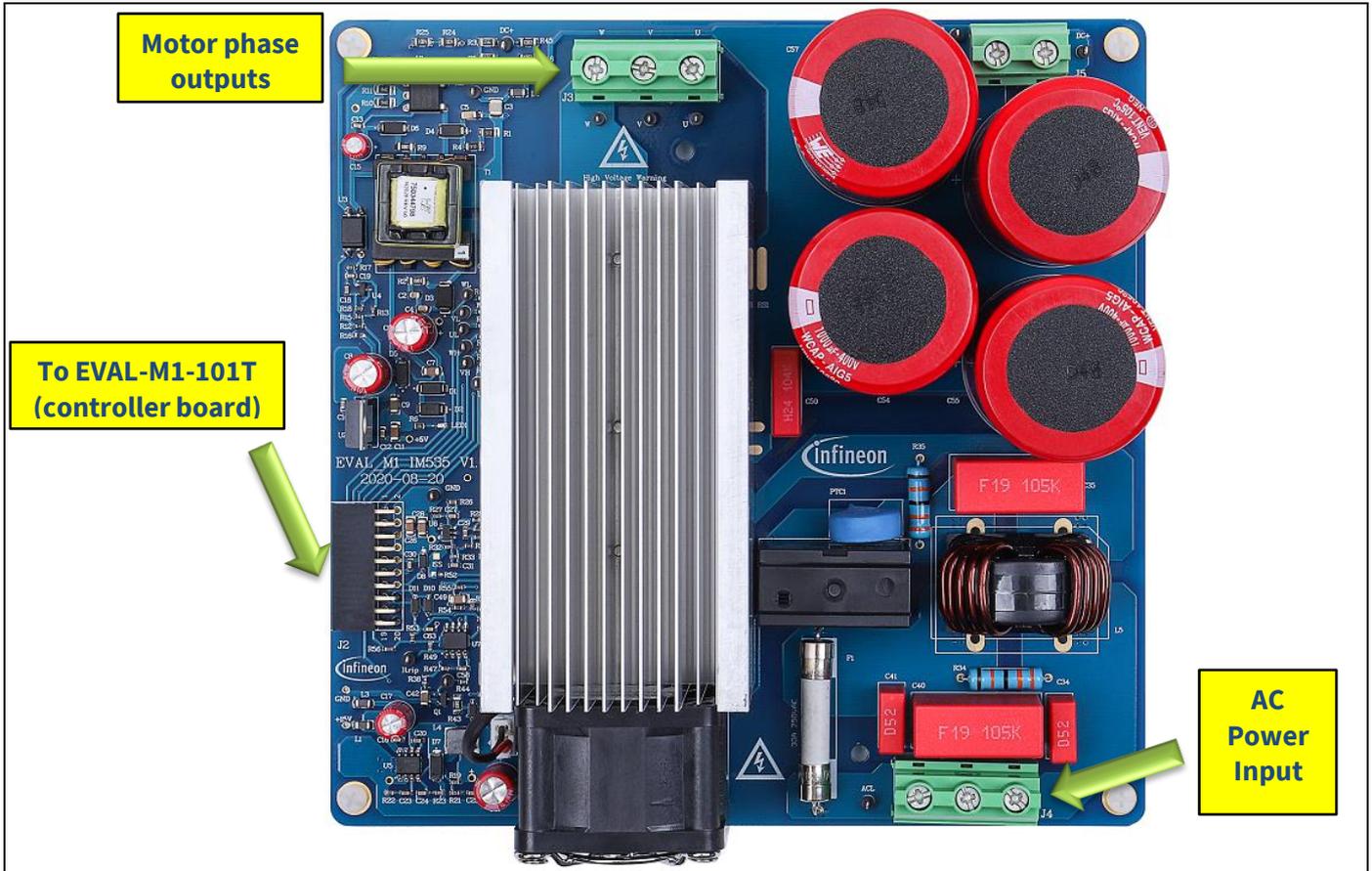


Figure 3 System connection example

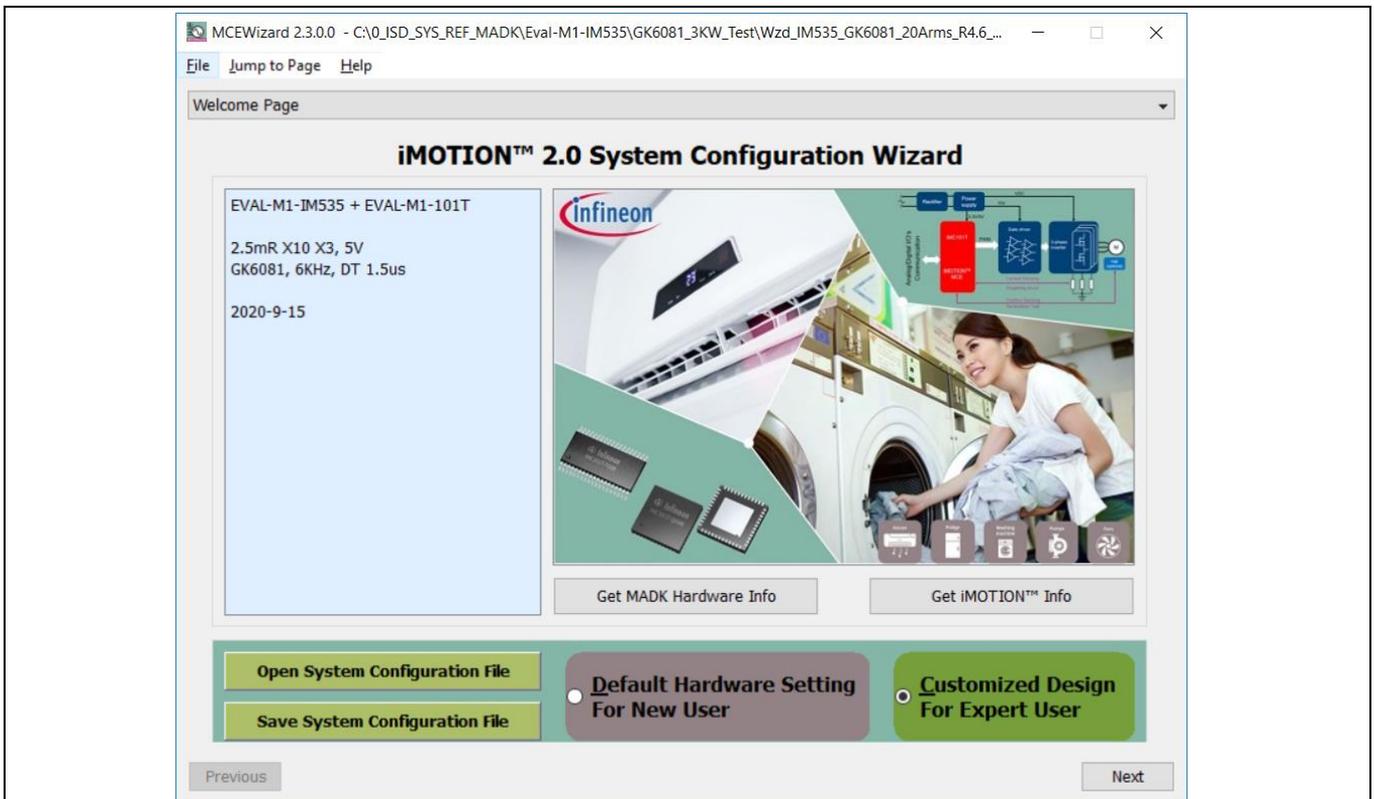


Figure 4 MCEWizard welcome page

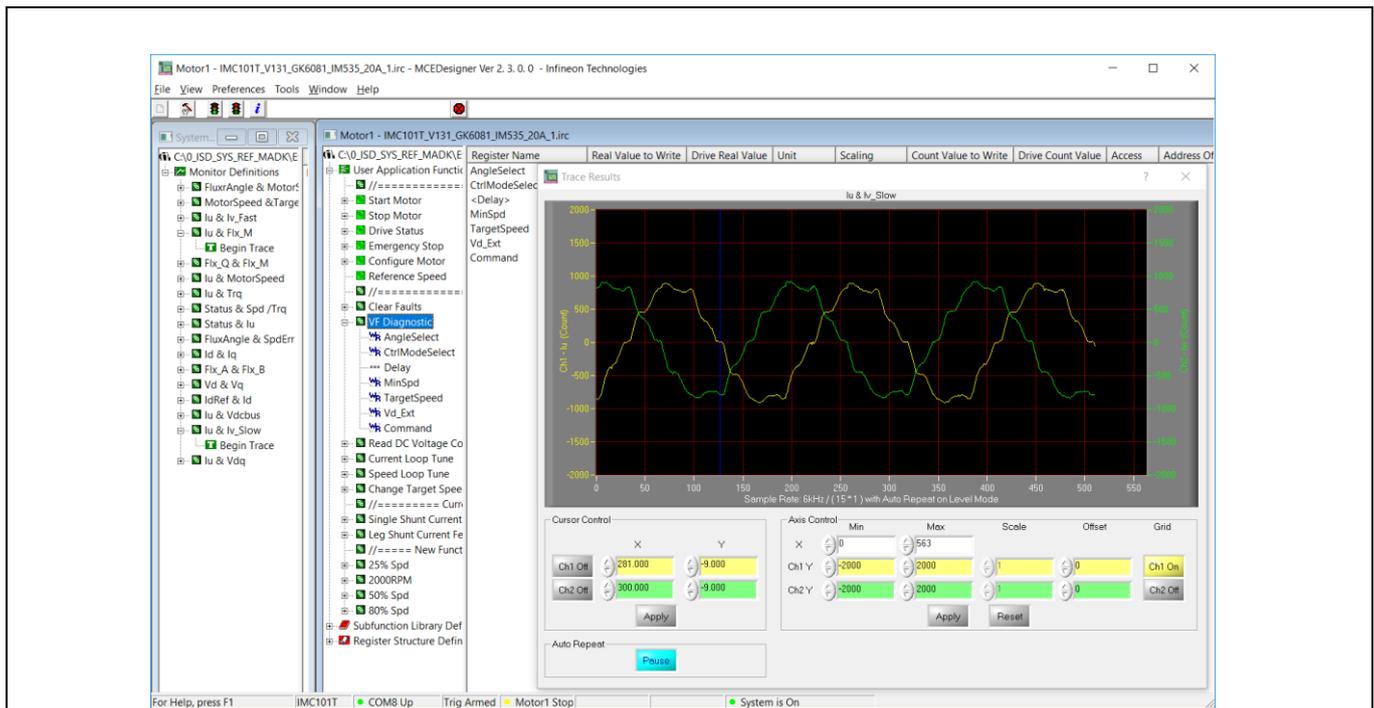


Figure 5 MCEDesigner user interface

Here are the steps needed to run the motor:

1. Connect EVAL-M1-101T control board to EVAL-M1-IM535, and connect PC-USB connector to EVAL-M1-101T.
2. Connect 220 V AC power supply and UVW outputs to the motor.
3. Use MCEWizard to enter the target motor’s system and operating parameters, as well as evaluation board’s hardware parameters, which will then be used to calculate the digital parameter set of the controller representing the complete motor drive system.
4. After system and operating parameters are set, go to the “Verify & Save Page” and click on “Calculate Parameters” button. If no errors are reported, then save the drive parameter set into your project directory by clicking “Export to MCEDesigner file (.txt)” (Figure 6); if an error is detected, double-click on the error message (highlighted in **RED**) and adjust the related parameter. The saved drive system parameter file will be later used by the MCEDesigner in step 9.

*(Please refer to **MCEWizard_V2.3.0.0 User Guide.pdf** for more details, which is in MCE Wizard’s install path)*

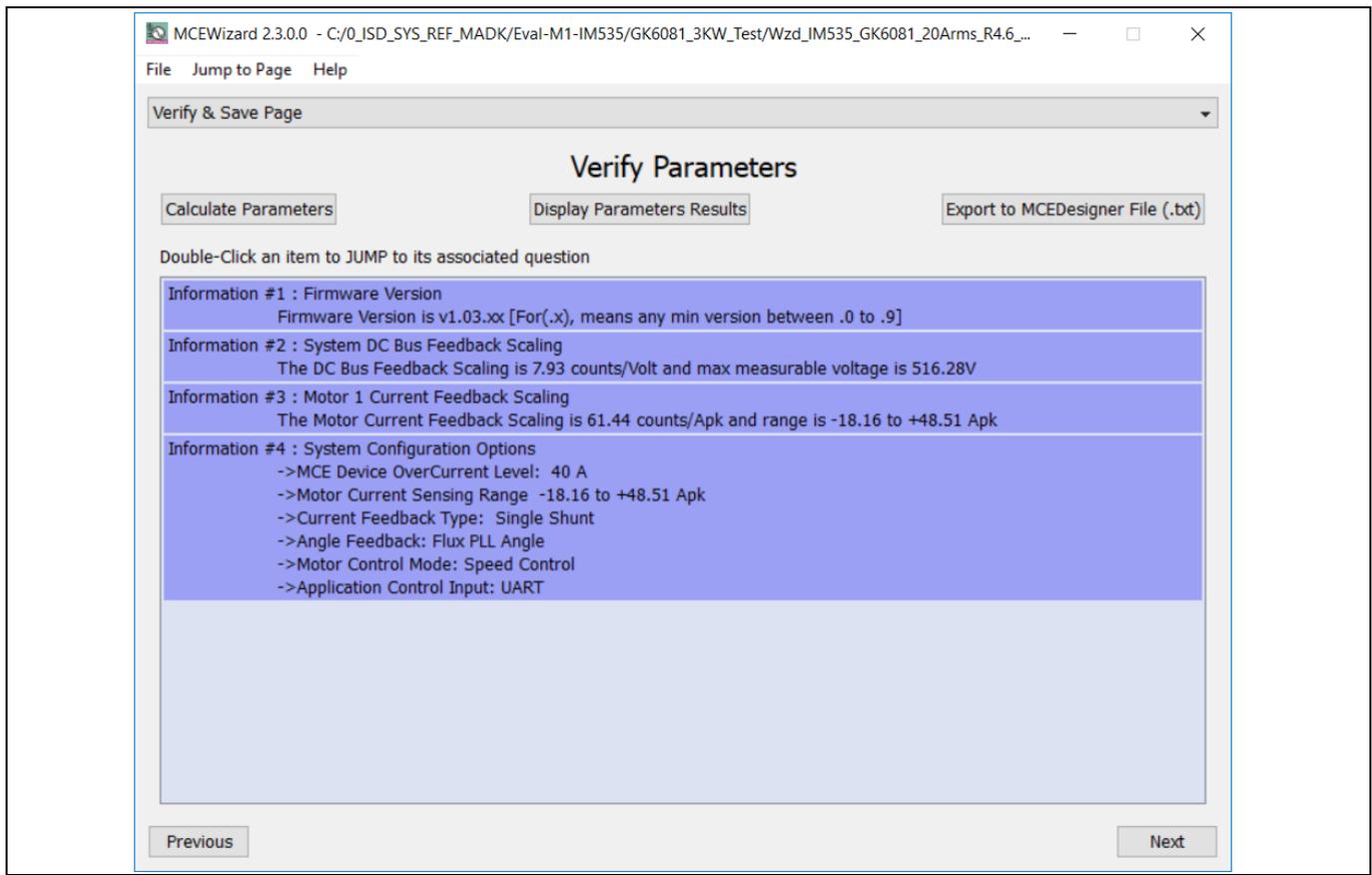


Figure 6 MCEWizard Verify and Save page

5. Turn on 220 V AC power supply, red LED1 & LED2 ON.
6. Start MCEDesigner tool and open MCEDesigner default configuration file (.irc) for IMC101T device (IMC101T_Vxxx.irc) by clicking “File” > “Open”.
(IMC101T_Vxxx.irc file is included in downloaded “IMC101T MCE Software Package”)
7. MCEDesigner should automatically connect to the EVAL-M1-101T board using default COM port (Indicated by green circle next to “COMx Up” status in the bottom frame of the MCEDesigner GUI). If it cannot establish the connection due to incorrect COM port, change COM port by doing the following steps: click on the “System Page” window and then click on “Preferences > Connection > Connect using”, and choose one of the other available COM ports from the drop-down list.
8. In case of blank IC: If the firmware has been erased from the IMC101T, a warning message will pop up saying “Target device firmare and parameters files are not programmed! (Figure 7) Please program firmware and parameters file.” See step 9 on how to obtain/program firmware and parameters.

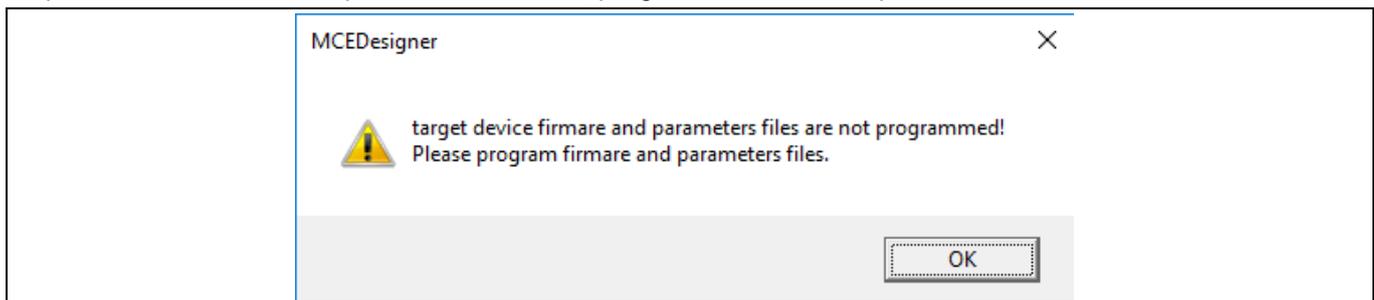


Figure 7 MCEDesigner warning message

System and functional description

9. In case of blank IC: Take the following steps to program the firmware and the parameters file into the internal Flash memory of iMOTION™ Control IC: Click on system page, click “Tools” > “Programmer” and select “Program Firmware and Parameters,” shown as Figure 8 below. The encrypted firmware is available in “IMC101T MCE Software Package,” regarding the parameters file, browse and select the .txt file in step 3.

(If blank IMC101T IC, MCE Designer will pop up information “Target device firmware and parameter files are not programmed!”) Program the MCE firmware and system parameters into the internal Flash memory of iMOTION™ IC by clicking “Tools > Programmer” in the pull-down menu, and then clicking on the “Program Firmware and Parameter” check box. Select right parameter file and firmware file. Finally click “Start” button to program firmware and parameter. Then click YES and then the OK button to update IRC file with parameter file; finally “Save As” the IRC file to your own file name that contains COM config, Parameters & firmware file path information.

(Please refer to **MCEDesigner User Guide.pdf** and **MCEDesigner_V2.3.0.0 Application Guide.pdf** for more details, which is in MCE Designer’s install path)

Red LED1 on EVAL-M1-101T will flash on after the program is done.

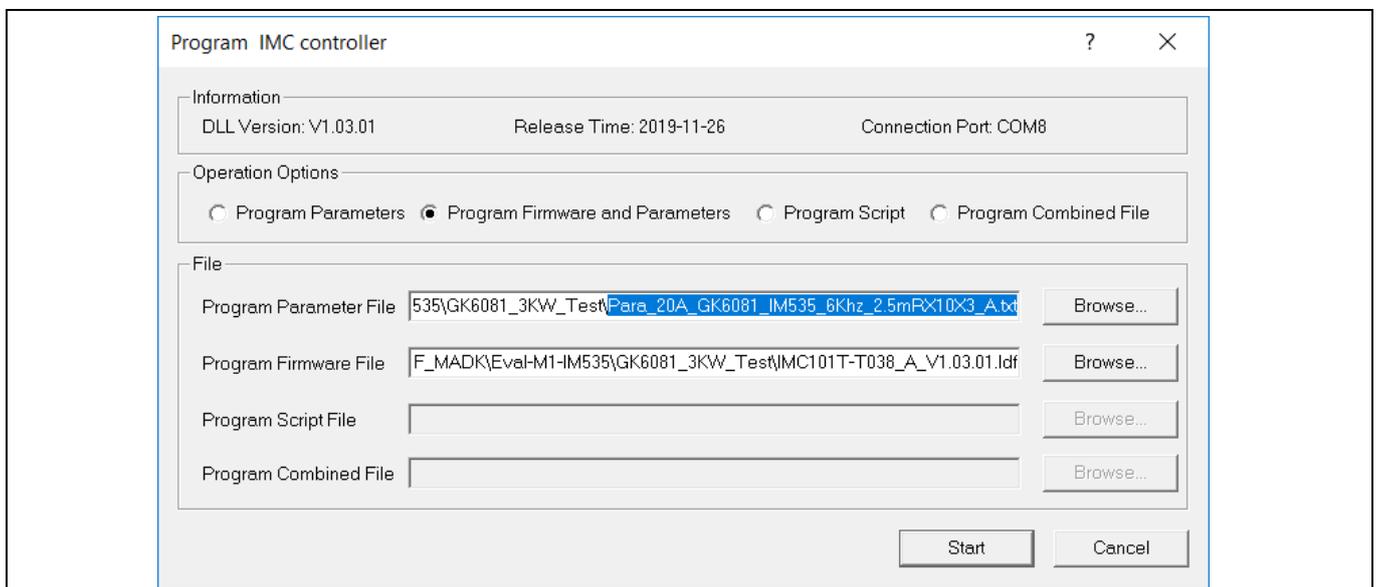


Figure 8 MCEDesigner program page

10. Double click “VF Diagnostic” function in motor1 page, monitor motor current with oscilloscope. If motor current is not sinusoidal, change target speed and Vd_Ext in VF Diagnostic sub-function, then double-click “VF Diagnostic” until oscilloscope shows a steady sinusoidal current, with amplitude of 30~50% motor rate current.

Double-click “Iu & Iv_Slow” in System page > Monitor Definitions, the motor current feedback would be very clean and sinusoidal, as shown in Figure 9, otherwise please tune “Gating Propagation Delay & Phase Shift Window Size” in MCE Wizard. The sampled motor current noise amplitude should be less than 50 cts ~100 cts (below 5% of motor current, or below 5% of max AD range 2048 cts); otherwise, motor current sample related hardware and setup need tuning.

“VF Diagnostic” sub function can verify:

- If motor is correctly connected
- If IGBT / MOS & gate driver work as expected
- If current sensing related parameters are correctly configured
- If PCB layout and DC bus decouple have been done correctly

After “VF Diagnostic” is done, click STOP button (the red traffic light button) to stop PWM.

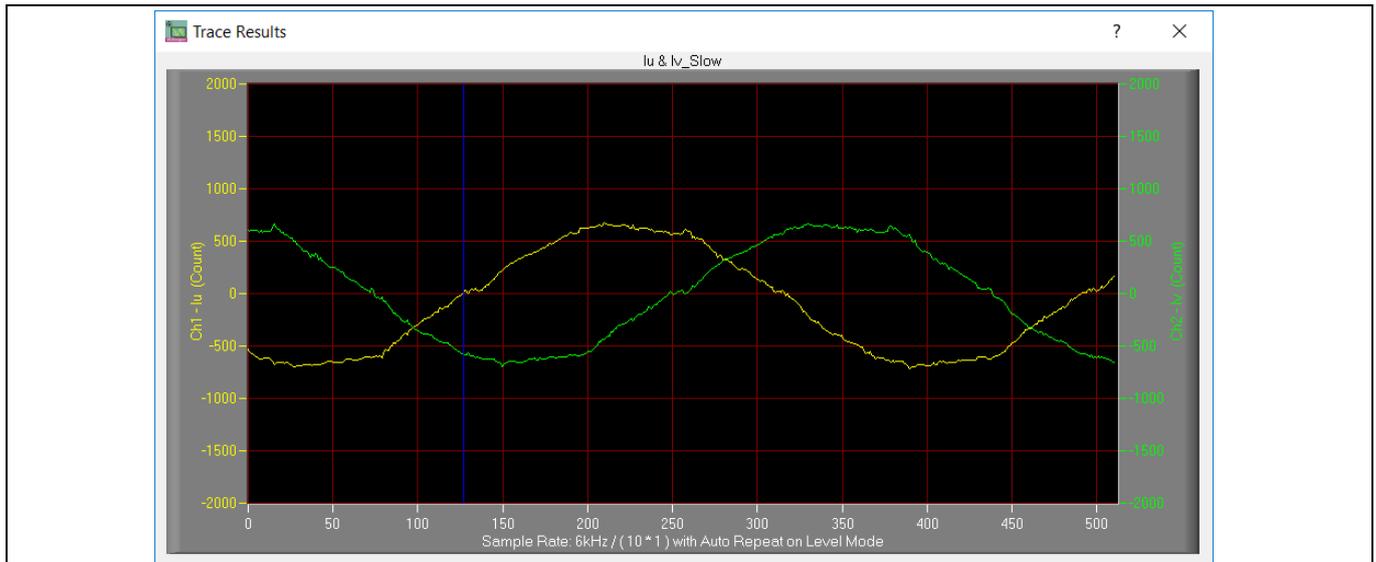


Figure 9 Trace waveform for lu & lv open loop diagnostic

11. Start the motor by clicking the green traffic light button in the control bar (or double-click Start Motor sub function in Motor1 page, group of User Application Function Definitions); motor runs if above step goes well.
12. Check motor spin direction, adjust UVW connection order or set negative target speed in MCE Designer if direction is wrong.
13. Set target speed to about 50% of MAX speed, start “lu & Flx_M” trace with “Auto Repeat On Level,” see Figure 10. Flx_M is better within the range of 2000~2500 (rated value is 2048), and MUST be steady and DC-like.

Some key tips for better motor-performance tuning:

- If Flx_M is not steady (swinging or oscillating), double-check motor parameters, speed loop PI gain, flux Estimator time constant and PLL PI bandwidth (parameters PLLKp & PLLKi) related setup.
- If Flx_M is very noisy, double-check current feedback and Vdc-related hardware and parameters.
- If Flx_M is far from 2048, “Motor Back EMF Constant (Ke)” needs to be adjusted in MCE Wizard.

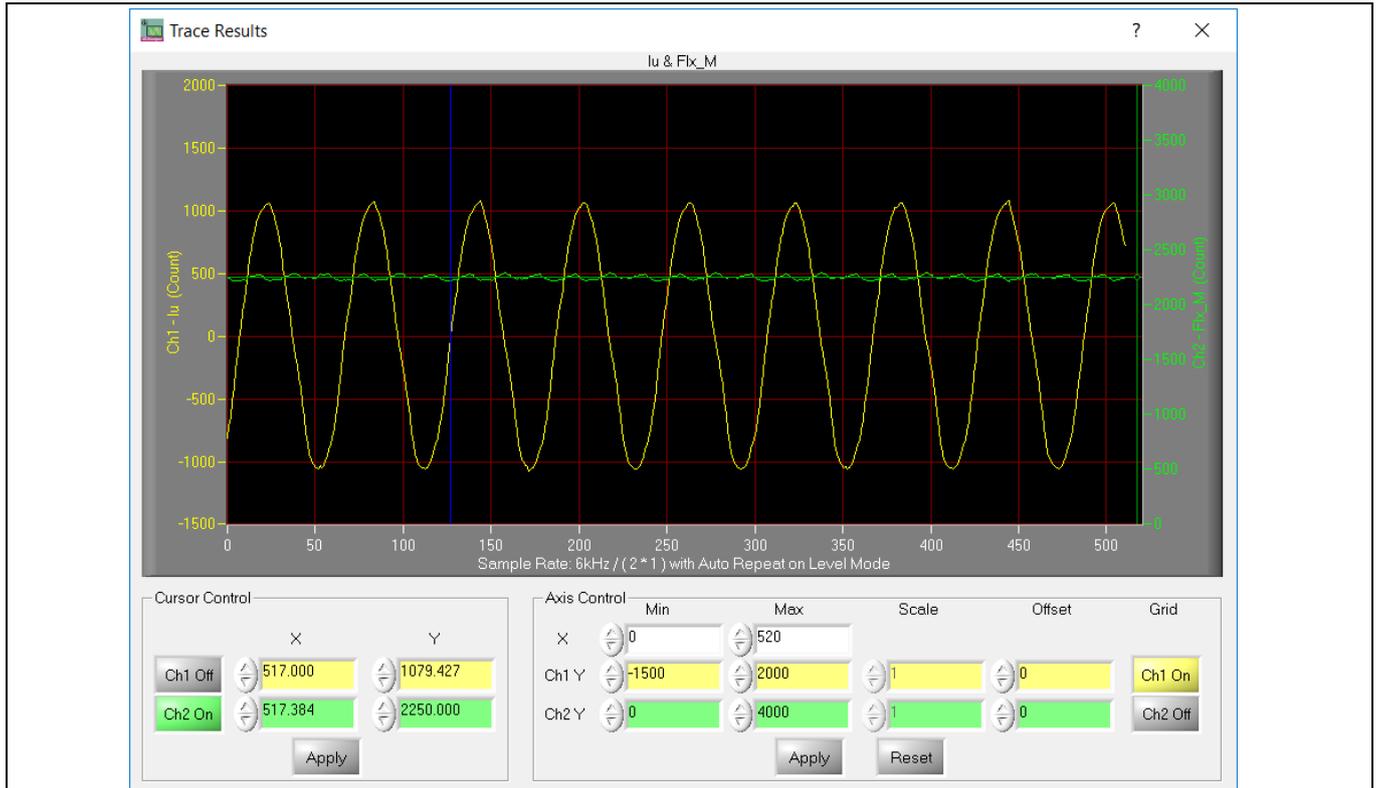


Figure 10 Trace waveform for Iu & Flx-M at 50% speed

14. Once the firmware has been programmed, in case a new parameter file has to be programmed, follow the same instructions given in step 9. In this case, firmware programming is no longer needed and it is possible to select the first option “Program Parameters.”

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

System and functional description

2.2 Description of the functional blocks

The motor inverter of EVAL-M1-IM535 reference design is implemented by the IM535 module, and the auxiliary power supply is based on fixed frequency CoolSET™ ICE5AR4770BZS.

Motor current sensing is single shunt mode, with an external OPA SGM721XN5 for 10 X gain.

2.2.1 Overview of IM535-U6D

Figure 11 illustrates the internal block diagram of the CIPOS™ Mini IPM IM535-U6D.

Main features include:

- 3 half bridges with TRENCHSTOP™ 30 A / 600 V and antiparallel diodes for inverter section
- Very low thermal resistance due to DCB
- Rugged SOI gate driver technology with stability against transient and negative voltage
- Negative potential allowed up to $V_S = -11\text{ V}$ for single transmission at $V_{BS} = 15\text{ V}$
- Integrated bootstrap functionality
- Overcurrent shutdown, and build-in temperature monitor
- Undervoltage lockout and all six switches turn off during protection
- Low-side emitter pins accessible for phase current monitoring (open emitter)
- Cross conduction prevention and sleep function

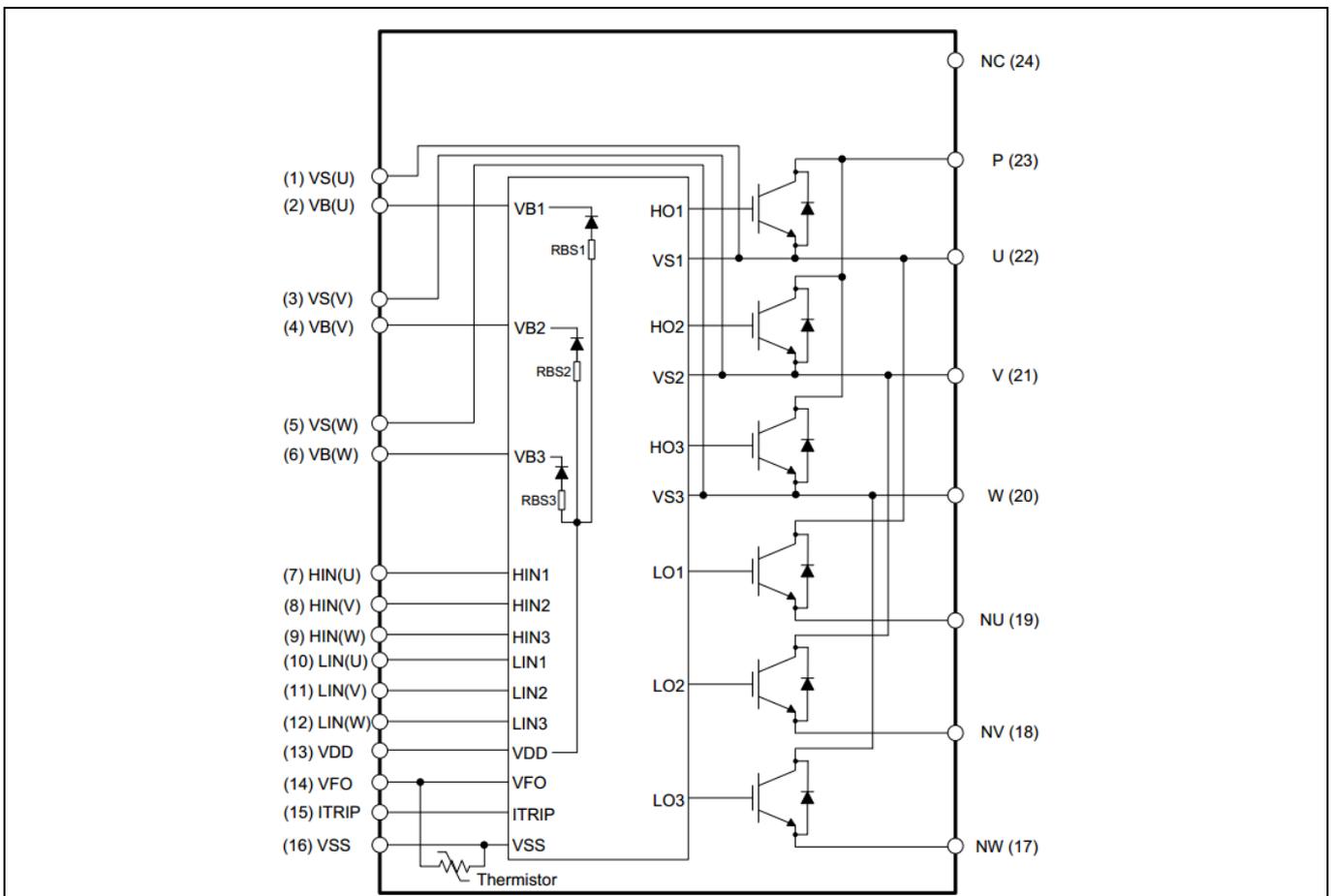


Figure 11 IM535 internal block

System and functional description

2.2.2 Overview of ICE5AR4770BZS

The ICE5AR4770BZS is Infineon’s latest 5th generation fixed frequency CoolSET™, offers high performance and integration of latest generation of 700 V CoolMOS™ superjunction MOSFETs in DIP-7 package.

Figure 12 illustrates the internal block diagram and typical isolated flyback application.

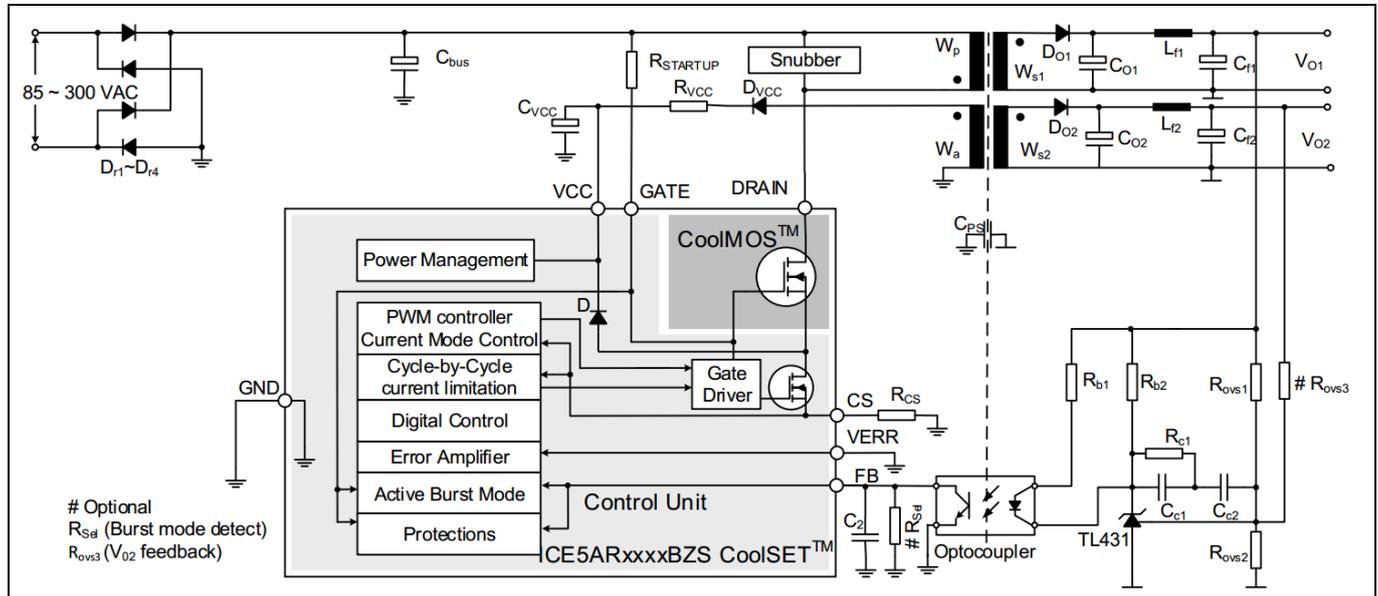


Figure 12 ICE5AR4770BZS internal block and typical application in isolated flyback mode

Main features of ICE5AR4770BZS include:

- 100 kHz maximum switching frequency with 700 V integrated MOSFET
- Power delivery of up to 15 W with universal wide input range (85~300 V_{AC}) DCM design
- Brown-in protection, fast and robust start-up operation with cascode configuration
- 3-level selectable entry/exit active-burst mode profile (optional)
- Built-in digital soft-start
- Cycle by cycle peak current limitation
- Support both DCM and CCM operation with slope compensation
- Integrated error amplifier to support direct feedback typical with non-isolated flyback topology
- Digital frequency reduction with decreasing load for higher efficiency
- Frequency jitter and soft gate driving for low EMI
- Limited charging current for V_{CC} pin short to ground
- Comprehensive protection with V_{CC} over voltage, V_{CC} undervoltage, overload/open loop, over-temperature protection
- Auto-restart for all protection features

2.2.3 Motor current sensing op-amp configuration and calculation

In order to suppress common mode noise between this power board and the MADK control board, an 11 MHz rail-to-rail I/O CMOS OPA SGM721XN5 is used for motor current sensing.

Two 5 mΩ 2.5 W (2512 package) shunt resistor and 10X external-gain OPA is the default configuration for the EVAL-M1-IM535 evaluation design, which means 1 A motor current produces 25 mV voltage to ADC input, MCEWizard’s “Motor1 Current Input Scaling” needs input of 25 mV/A.

Motor 1 Current Feedback and Sample Timing
Question 83 - Motor 1 Current Input Scaling

This parameter is the gain of the external current single/leg shunt measurement circuit.

This value is the product of the shunt resistance in milliohms and the ac gain of the offset and gain circuit:
 $G_{ext} \times R_s$.

In the circuit example, the gain calculated from analysis with $R_s \sim 0$, is given by:
 $G_{ext} = R_2 / (R_1 + R_2)$.

The input filter capacitor, C1, should be selected so that the offset and gain circuit time constant is less than 400ns to minimize the impact on current sampling.

High current applications may require an active offset and gain circuit to support low resistance shunts or to improve the measurement signal to noise ratio.

Answer: mV/A

Equations shown in the diagram:
 $V_{AD} = G_{int} (V_{off} + G_{ext} \times R_s \times I_s)$
 $V_{in} = V_{off} + G_{ext} \times R_s \times I_s$
 $V_s = I_s \times R_s$

Figure 13 Current feedback configuration in MCEWizard for EVAL-M1-IM535

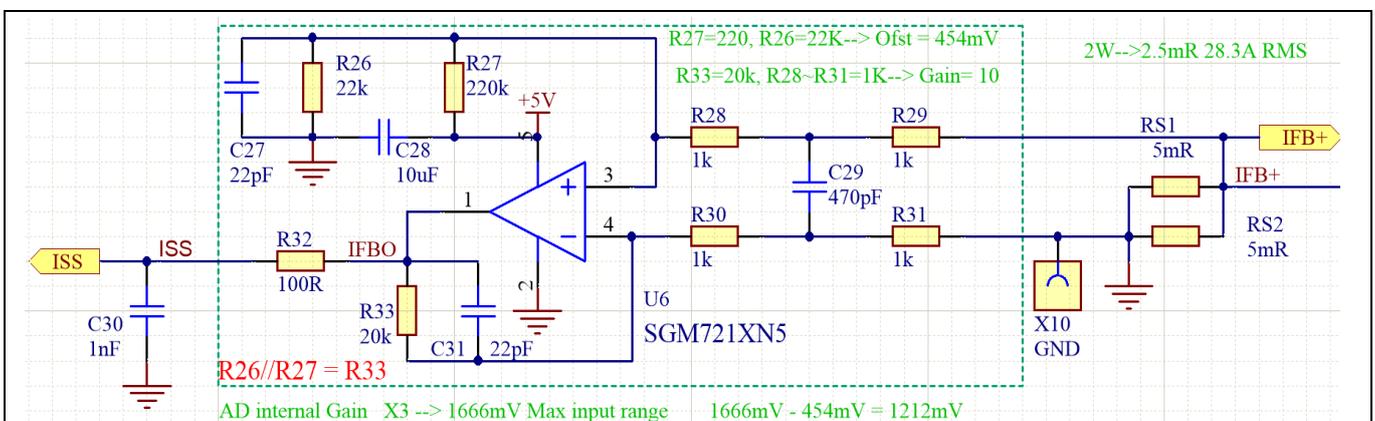


Figure 14 Current feedback with external 10X op-amp

Figure 14 shows the external amplifier gain circuit in EVAL-M1-IM535 evaluation design, which is a typical differential amplifier based on SGM721XN5, with input low-pass filter (LPF) and operational bias. C29, R28, R29,

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R30 and R31 build the input differential mode LPF, which can damp parts of PWM switching noise. The default LPF time constants is $2*RC = 2*(R28//R29)*C29 = 470$ ns. The typical setup time is 0.1~0.5 μ s, which depends on PCB layout, DC bus decouple capacitor and IGBT / MOS gate driver configuration.

For better common-mode noise-rejection ability, a balanced differential amplifier is highly recommended, which means R33 is equal to the value of R26 & R27 in parallel.

The divider of R26 & R27 provide operational bias for the amplifier, which affects the maximum motoring current and regeneration current range. With the default configuration of EVAL-M1-IM535, R26=22 k & R27=220 k, the op-amp operational bias is $5000 \text{ mV} * 22 / (22+220) = 454$ mV, which means:

- Op-amp outputs 454 mV at zero motor current (motor stopped), $454 \text{ mV}/\text{op-amp gain}/R_{S1}$ is the maximum allowable regeneration current.
- If 1X ADC internal gain is selected, 4546 mV range for motor current sensing ($5000 \text{ mV} - 454 \text{ mV} = 4546 \text{ mV}$). And $4546 \text{ mV}/\text{op-amp gain}/R_{S1}$ is the maximum allowable motor current. “Motor Rated Amps * Motoring Current Limit” should be below this maximum allowable range.
- If 3X ADC internal gain is selected, 1212 mV range for motor current sensing ($5000/3 - 454 \text{ mV} = 1666 - 454 \text{ mV} = 1212 \text{ mV}$). And “1212 mV/op-amp gain/ R_{S1} ” is the maximum allowable motor current. “Motor Rated Amps * Motoring Current Limit” should be below this maximum allowable range.
- For applications that never work at regeneration mode (e.g. air conditioner), the OPA output bias wastes the available range of ADC, and reduces the available ADC range.
- For applications that need more current range for regeneration (e.g. fan application), the amplifier bias needs an increase based on the regeneration requirement. For example, $R26 = R27 = 2 * R33$ for a bias of 2.5 V (50% of AD range) so that they have the same range for motoring current and regeneration current.

Please note that EVAL-M1-101T default configuration is in direct current sensing mode, R6 & R7 on EVAL-M1-101T are not needed for EVAL-M1-IM535’s motor current sensing. We **need to remove R6, and short R7 on EVAL-M1-101T control board**, as shown in Figure 15.

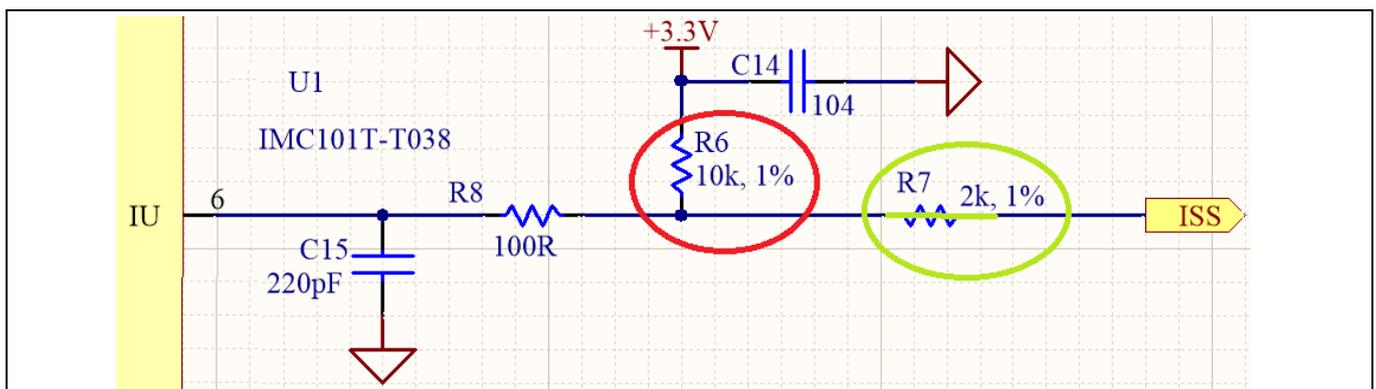


Figure 15 Modification on EVAL-M1-101T (remove R6 and short R7)

System design

3 System design

The EVAL-M1-IM535 board is an optimized design for 220 V major home appliances like air conditioners applications. To meet individual customer requirements and to make the EVAL-M1-IM535 reference design a basis for development or modification, all board design data such as schematics, Gerber and Altium design data can be found on the Infineon homepage.

3.1 Schematics

The overall schematic diagram for EVAL-M1-IM535 are provided in Figure 16 and Figure 17.

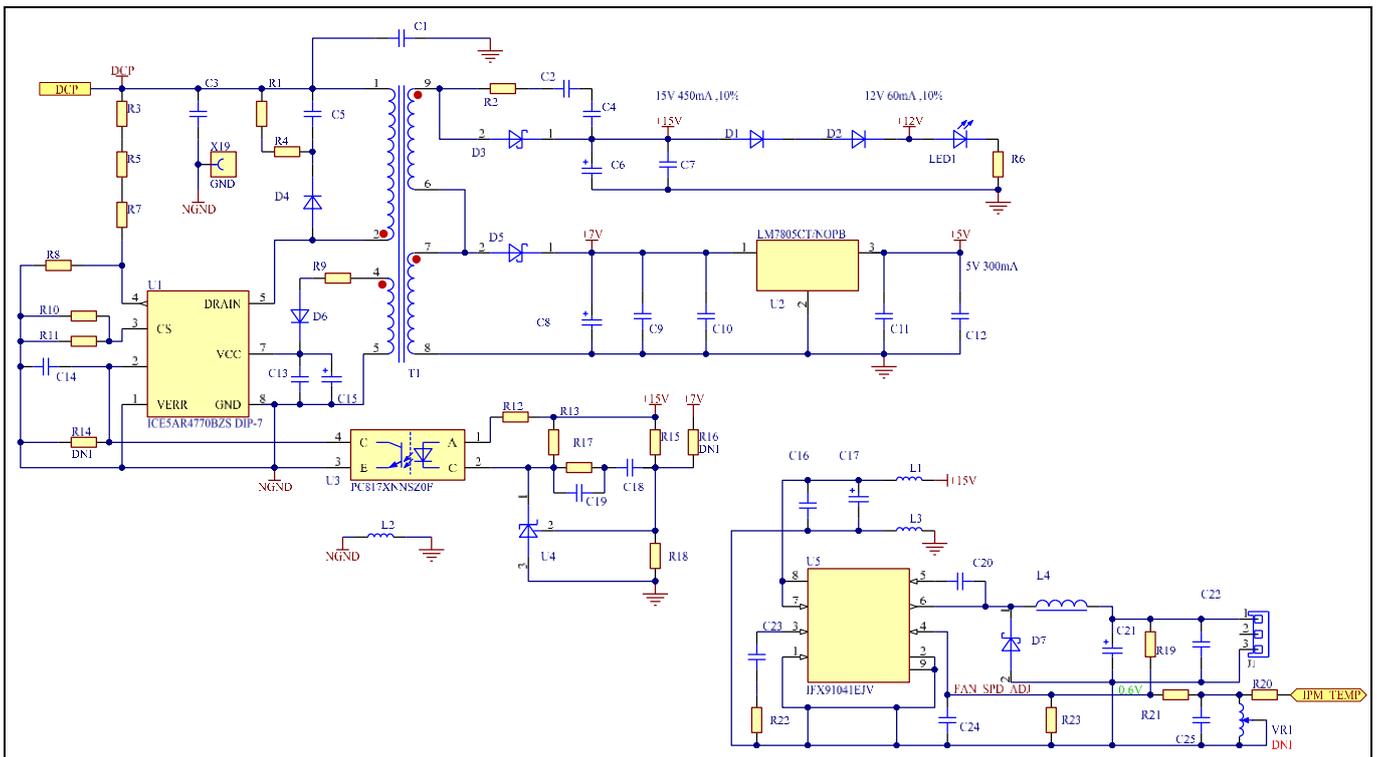


Figure 16 Aux power supply for EVAL-M1-IM535

Figure 16 shows the 8 W isolated flyback power supply based on ICE5AR4770BZS, +15 V and +5 V output for IPM and controller, the major function information are listed as below:

- Transformer T1 is based on EE16 core, and the rated power is 8 W, which is suitable for most air conditioner applications
- R3, R5, R7 and R8 decide the brown-in and brown-out voltage for power-on and power-off, which means ICE5AR4770BZS start work when DC bus voltage is over 82 V and stop work when DC bus below 40 V.
- R10 and R11 sensing the maximal peak current, related to cycle-by cycle current limitation.
- R15, R16 and R18 decide the output voltage for +15 V and +7 V.
- U5 is the DC-DC controller for cooling fan speed, R19, R23 and R21 can be adjusted to tune initial fan speed and adjustment based on IPM temperature. VR1 is reserved for manual fan speed adjustment (by removing R20).
- 12 V power supply for relay control is from +15 V via D1 and D2, which is not very accurate

System design

- PC817 used for primary isolation of flyback power supply, is not for real isolation, but for easier PCB layout for signal ground and power ground connections. This can reduce common-mode noise for controller board, and achieve higher SNR for motor current sensing.

Figure 17 shows the inverter section of EVAL-M1-IM535, which contains IM535-U6D and its peripheral circuits, the major function information is listed below:

- U6 (SGM721) is a typical balanced difference amplifier for 10 X gain, the OPA bias decided by divider of R26 & R27; C29, C27 and C31 effect the total LPF bandwidth.
- U7A (LM393) for overcurrent protection; R50 is the major resistor for overcurrent threshold adjustment.
- U7B (LM393) for over-temperature protection; the pull-up resistor for IPM internal NTC is not a unique device, which is a combination of R55, R56, D10 and circuit in “Gatekill” and “IPM_TEMP” networks on control board, it is not recommended to change the hardware setup of U7B. Please adjust MCEWizard setup for over-temperature protection as shown in Figure 17, which is easier and safer.
- J5 is reserved for Vdc bus voltage test or applications that use external DC source or PFC circuits.
- C54 ~ C57 are DC bus capacitors; default value is 400 V, 820 μ F or 1000 μ F. Please replace them by 450 V capacitors if there are external 380 V PFC or over 265 V_{AC} inputs.
- L5 is common-mode choker, which is the key component for EMI performance. Two packages placed on the PCB for convenient EMI performance testing and evaluation, suitable for 3 ~ 9 mH and 18~23 A common mode inductor.
- J2 is 20-pin interface for MADK control boards; only pin 10 & pin 12 (IU+ & IU-) are used for single-shunt current sensing (ISS from OPA output).

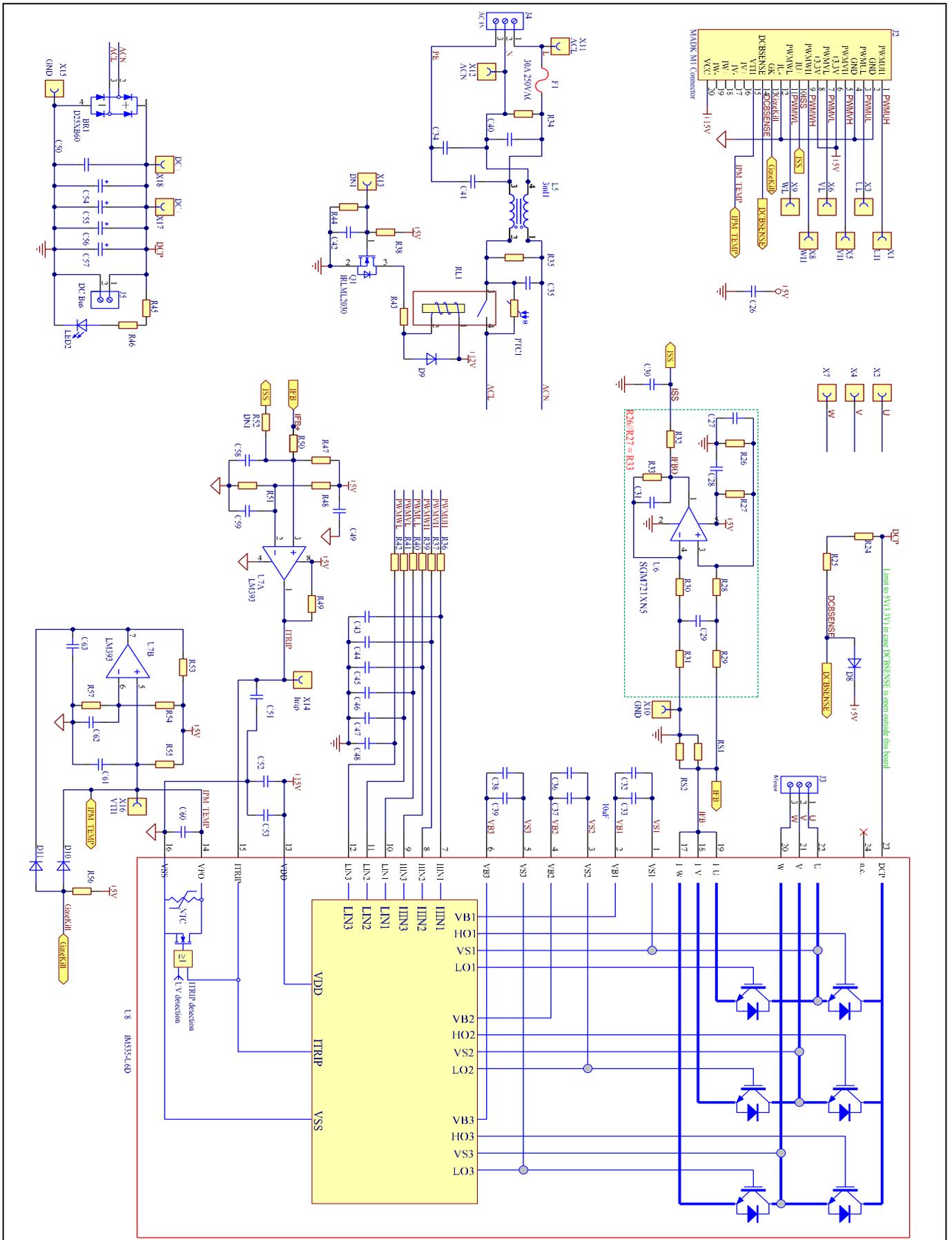


Figure 17 Schematics for IM535 IPM and peripheral circuit

System design

3.2 Layout

This board has two electrical layers with 70 μm copper (2 oz. copper) and dimensions of 166 mm × 166 mm. The thickness of the PCB board is 1.6 mm. Figure 18 illustrates the top assembly print of the reference design.

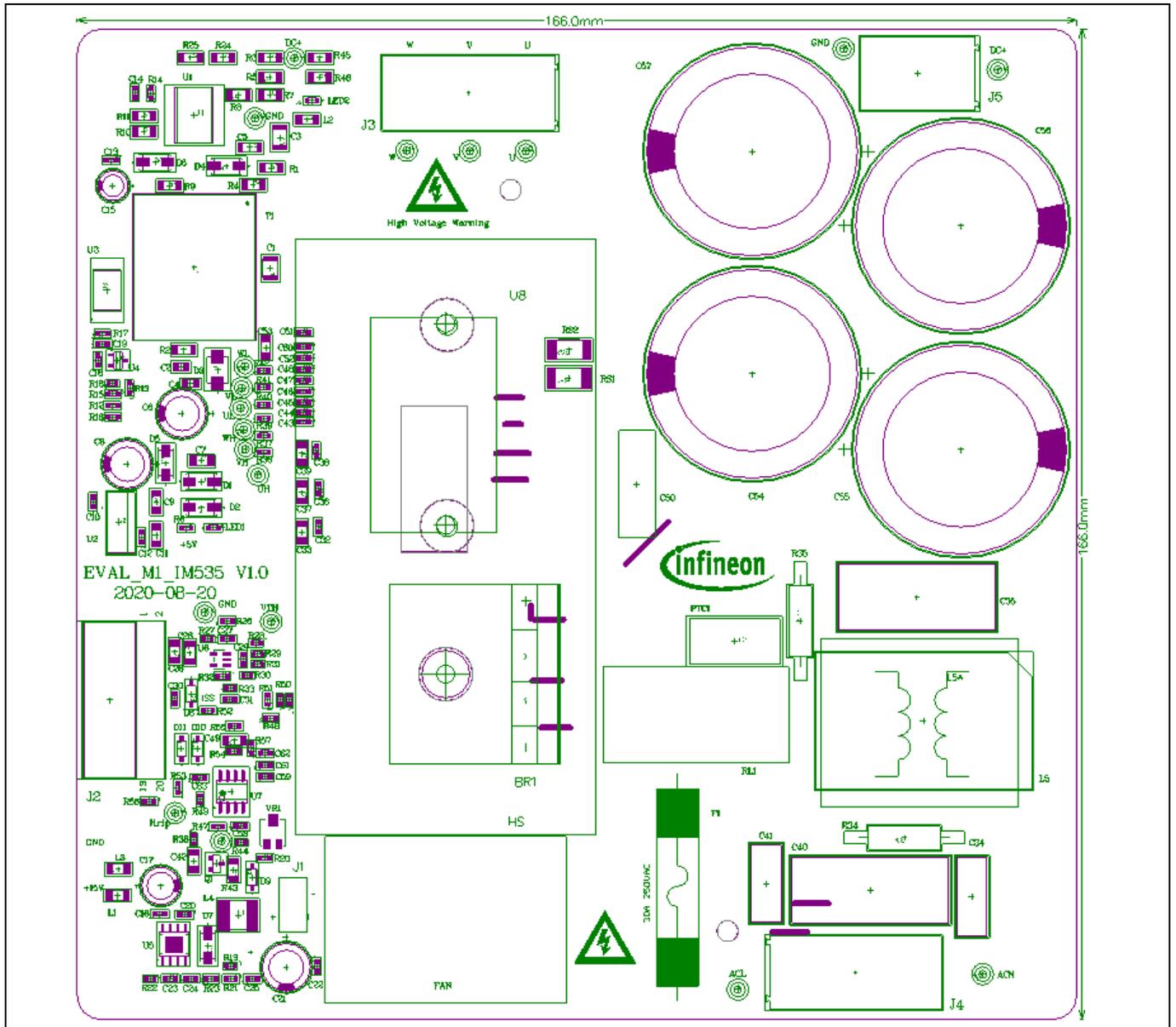


Figure 18 Top assembly print of the EVAL-M1-IM535 reference design

System design

The top layer and bottom layer routing of the PCB are provided in Figure 19 and Figure 20.

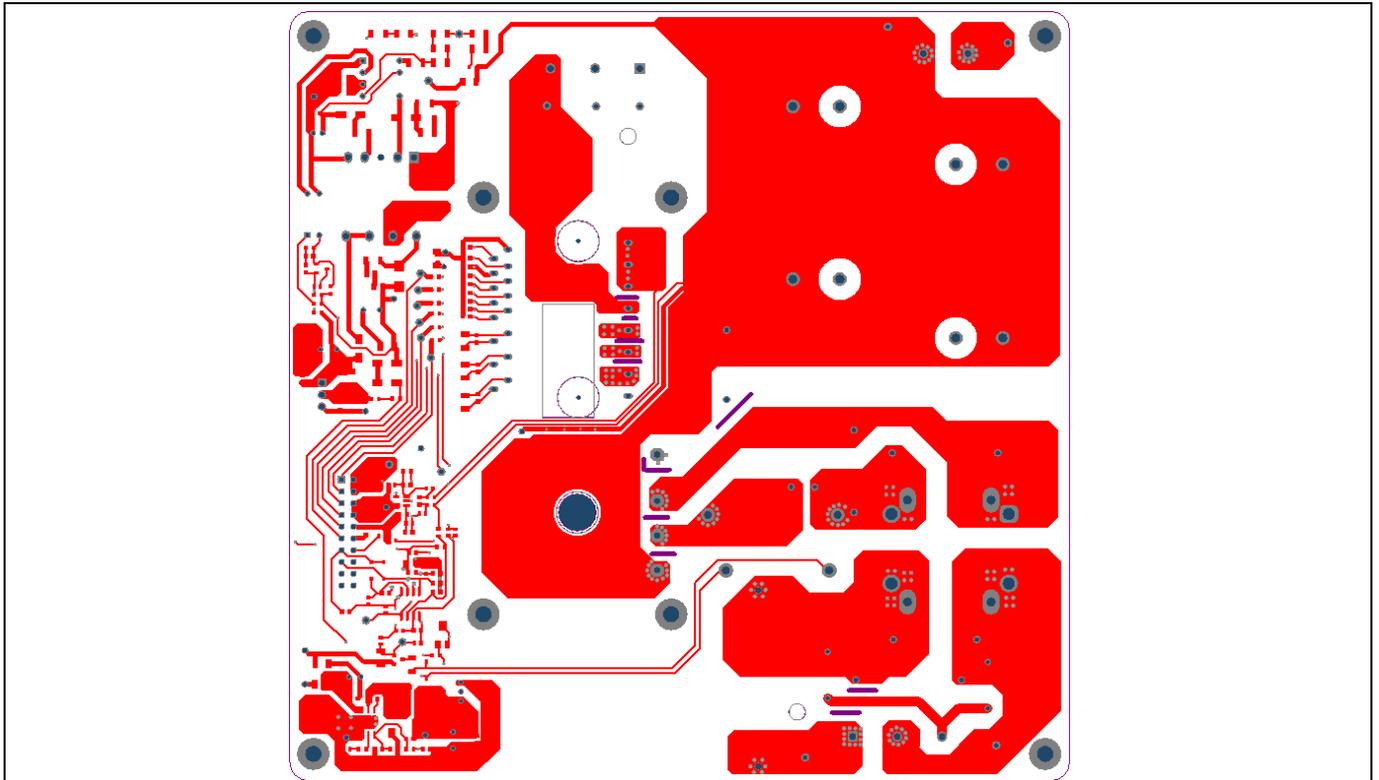


Figure 19 Top layer routing of the EVAL-M1-IM535

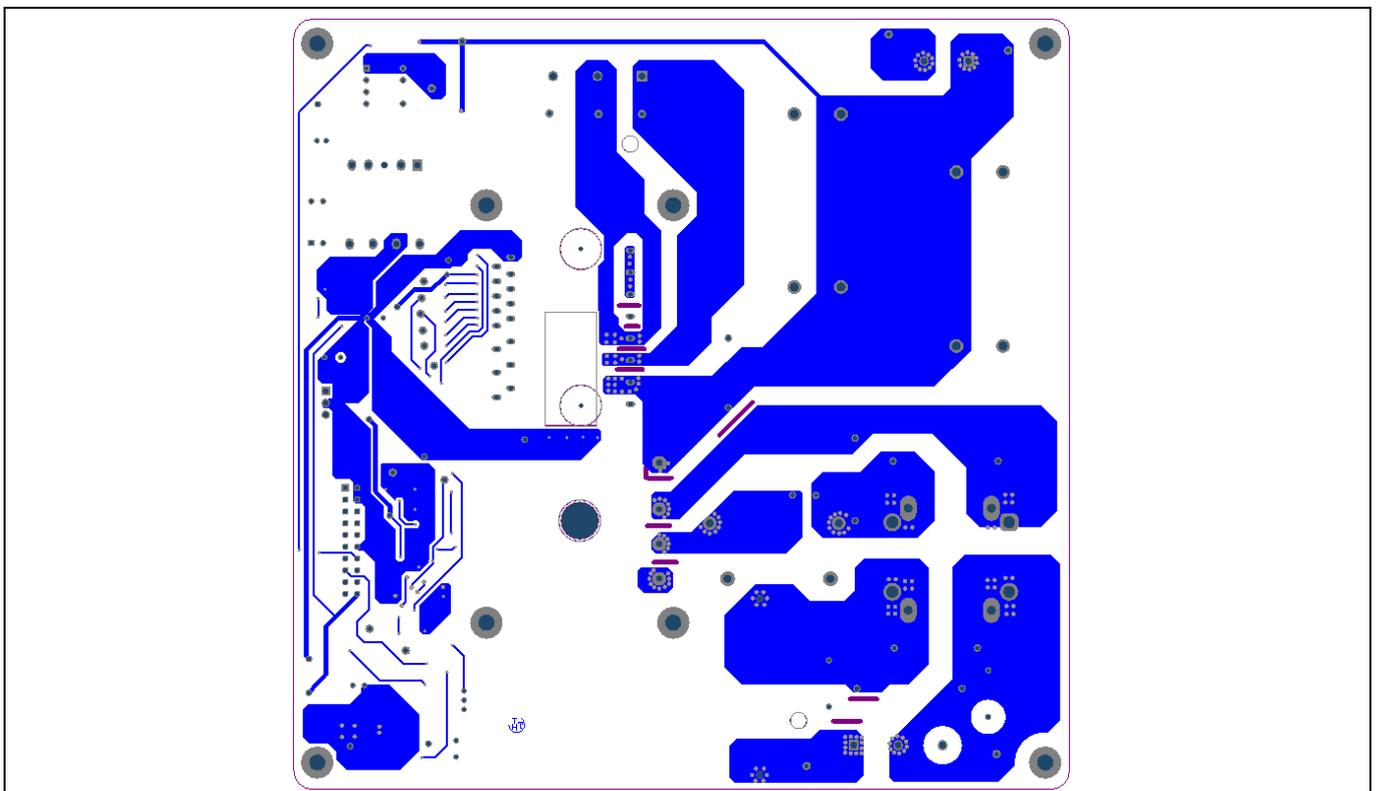


Figure 20 Bottom layer routing of the EVAL-M1-IM535

System design

3.3 Bill of material

Table 3 shows the major parts of EVAL-M1-IM535 design.

The complete bill of material is available on the download section of the Infineon homepage. A log-in is required to download this material.

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

S. No.	Ref Designator	Description	Manufacturer	Manufacturer P/N
U6	SGM721XN5	11MHz, 8.5V/μS, Rail-to-Rail OPA	SG Micro	SGM721XN5/TR
U7	LM393	Dual comparator		
Q1	IRLML2030	30V 154mOhm@4.5V MOSFET	Infineon Technologies	IRLML2030
U8	IM535-U6D	CIPOST™ MINI	Infineon Technologies	IM535-U6D
U5	IFX91041EJV	1.8A DC/DC Step-Down Voltage Regulator, Adjustable	Infineon Technologies	IFX91041EJV
U1	ICE5AR4770	Fixed Frequency 700 V CoolSET™	Infineon Technologies	ICE5AR4770BZS DIP-7
RL1	G4A-1A-PE	20A Relay		
FAN	FAN4028	FAN4028 12V 3.36W, 14500rpm, 19.1CFM;	SANYO	9GA0412P3H01
BR1	D25XB60	25A 600V Diode Bridge		
C54~C57	820uF, 400V	Diameter 35mm, Height 45mm~60mm, 820uF~1000uF, 400V	Würth Elektronik	861021386035
T1	710uH/EE16	Würth Electronics Midcom (750343739), Core: 150-2182 (EE16/8/5), bobbin: 070-5280 (9-pin EXT, THT, horizontal version)	Würth Electronics	750343739
R24, R25	680k	1206 Thick Film Chip Resistor		
L1, L2, L3	650R	WE-CBF SMD EMI Suppression Ferrite Bead	Würth Elektronik	INDC3216X130N
C50	470nF / 630V	CBB22 Film Capacitors		
F1	30A 250VAC	30A 250VAC fuse		
C34, C41	5.6nF, 275V	Film Capacitor, THT, L13W5H10, 5.6nF, 275V	Würth Elektronik	890324023002CS
RS1, RS2	5mR	Current Sense Precision Resistor	Isabellenhuetten	BVT-I-R005
L5	3mH	WE-CMBNC Common Mode Power Line Choke, Type XL, 3mH, 23A, 250V	Würth Elektronik	7448052303
C35, C40	1uF, 275V	WCAP-FTX2 Film Capacitor, THT, L26W11H20, 1uF, 275V	Würth Elektronik	890324026027CS

System design

3.4 Connector details

General information about the connectors of the EVAL-M1-IM535 reference design is provided in this section. Table 4 includes the details of the AC input connector.

Table 4 AC input connector (J4)

PIN	Label	Function
1	L	AC line
2	N	AC neutral
3	PE	Protection earth

Table 5 provides the details of the motor UVW output connector J3.

Table 5 Motor side connector (J3)

PIN	Label	Function
1	U	Connected to motor phase U
2	V	Connected to motor phase V
3	W	Connected to motor phase W

Table 6 provides the details of the DC bus output connector J5, for external PFC or DC source connection.

Table 6 DC bus connector (J5)

PIN	Label	Function
1	DCP	Connected to DC+
2	GND	Connected to DC-

Table 7 provides the pin assignments of the 20-pin iMOTION™ MADK-M1 interface connector J2. This connector is the interface to the controller board.

Table 7 J2 - iMOTION™ MADK-M1 20-pin interface connector for controller board

Pin	Name	Pin name connectors
1	PWМУH	5 V compatible logic input for high side gate driver-Phase U
2	GND	Ground
3	PWМУL	5 V compatible logic input for low side gate driver-Phase U
4	GND	4 GND ground
5	PWМVH	5 V compatible logic input for high side gate driver-Phase V
6	+5 V	On board 5 V supply
7	PWМVL	5 V compatible logic input for low side gate driver-Phase V
8	+5 V	On board 5 V supply
9	PWМWH	5 V compatible logic input for high side gate driver-Phase W

System design

Pin	Name	Pin name connectors
10	I_U	Positive current sense output
11	PWMWL	5 V compatible logic input for low side gate driver-Phase W
12	I_U-	Negative current sense output or ground
13	GK	Gatekill signal – active low when overcurrent is detected
14	DCBSense	DC bus positive voltage, scaled in 0-5 V range by a voltage divider
15	VTH	Thermistor output
16	I_V	Not used
17	I_V-	Not used
18	I_W	Not used
19	I_W-	Not used
20	VCC	15 V power supply

3.5 Test points

Table 8 provides the assignments of the on-board test points.

Table 8

Pin	Name	Functions & net label describe
X1	UH	High side gate driver PWM-Phase U
X2	U	Invertor output, motor phase U
X3	UL	Low side gate driver PWM-Phase U
X4	V	Invertor output, motor phase V
X5	VH	High side gate driver PWM-Phase V
X6	VL	Low side gate driver PWM-Phase V
X7	W	Inverter output, motor phase W
X8	WH	High side gate driver PWM-Phase W
X9	WL	Low side gate driver PWM-Phase W
X10	GND	Ground test point for controller board (signals ground)
X11	ACL	AC voltage measure point (L)
X12	ACN	AC voltage measure point (N)
X13	<i>DN/</i>	
X14	Ittrip	Output of over current protection circuit (Pin 1 for LM393)
X15	GND	Power GND test point (DC-)
X16	VTH	Test point for temperature sensing (Pin 15 of IM535)
X17, X18	DC+	DC+ test point
X19	GND	Ground test point for primary side of fly-back power supply

System performance

4 System performance

4.1 Heatsink thermal resistance test result

In order to test the thermal impedance of heatsink to ambient R_{thCA} , the DC source is used to conduct the IPM internal diodes, as shown in Figure 21. With the DC source voltage increasing, current through IPM I_{IPM} and voltage on IPM V_{IPM} are monitored by current and voltage meter, the IPM case-temperature test point is between IPM and heatsink, the same as T_c point of inverter IGBT of the IPM datasheet.

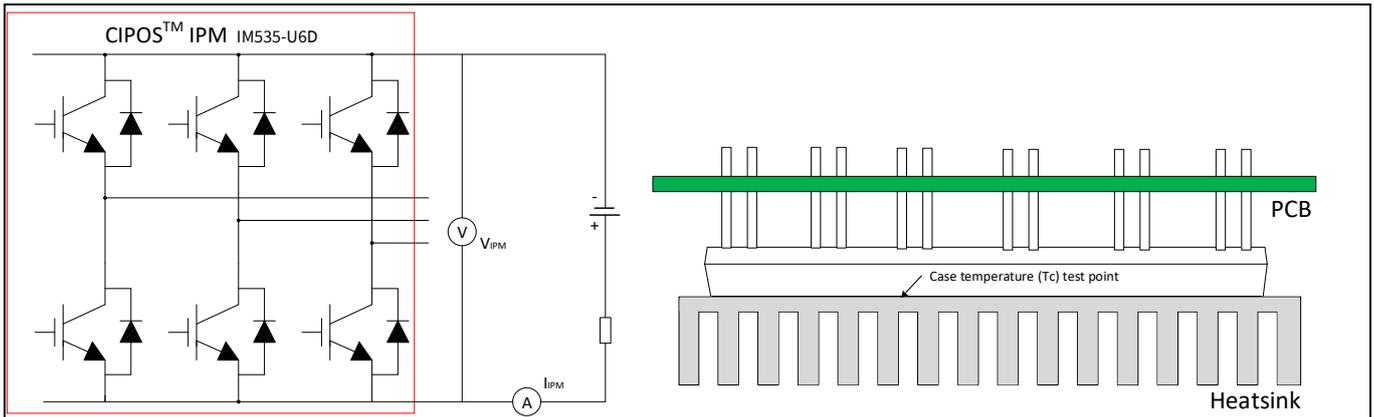


Figure 21 Heatsink thermal testing set-up

Thermal resistance between junction to ambient R_{thJA} is divided into 2 parts as in the following formula: thermal resistance between junction to case R_{thJC} and thermal resistance between case to ambient R_{thCA} .

$$R_{thJA} = R_{thJC} + R_{thCA}$$

Thus, we get the following formula:

$$R_{thCA} = \frac{\Delta T_{CA}}{P_{D.tot}} = \frac{T_C - T_A}{V_{IPM} \times I_{IPM}}$$

According to the test set-up, the test results are shown in Figure 22 below. The IPM case temperature is detected for about one hour until the temperature is stable.

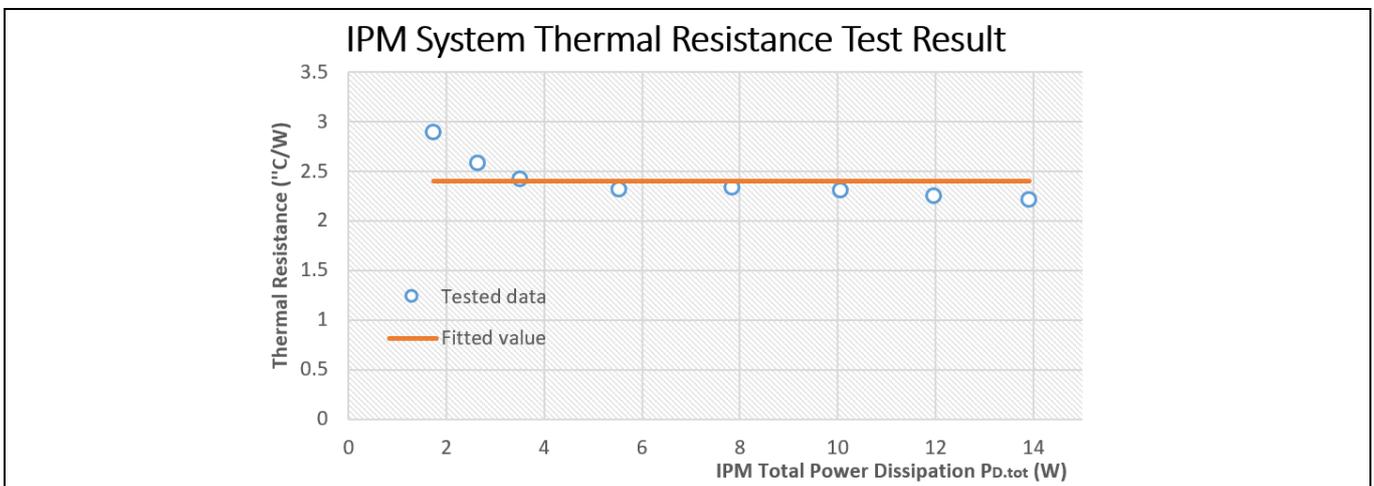


Figure 22 Heatsink thermal testing result

System performance

Therefore, the final case-to-ambient resistance value is roughly:

$$R_{thCA} = 2.4 \text{ }^{\circ}\text{C}/\text{W}$$

Please note that:

- 2.4 $^{\circ}\text{C}/\text{W}$ thermal resistance is calculated with a fan voltage of 10 V.
- DC-DC output voltage for EVAL-M1-IM535's cooling fan is 7~14.3 V in default hardware configuration, which is adjusted by IPM temperature from 25 ~ 125 $^{\circ}\text{C}$
- Cooling fan's rate voltage is 12 V corresponding to 110 $^{\circ}\text{C}$ IPM surface temperature.
- Tuning R19, R23 and R21 can change the relationship between fan speed (voltage) and IPM temperature

4.2 Test results for output ability

In order to test the total output power capability of EVAL-M1-IM535 design, the IPM case temperature is tested with different MADK input power and motor output current.

The test conditions are:

- Ambient temperature $T_a=25^{\circ}\text{C}$
- Cooling fan voltage is 14.3 V , 8m/s air flow after heatsink (5 mm distance center of heatsink fins)
- AC input is $V_{AC}=220 \text{ V}/50 \text{ Hz}$ (V_{DC} bus is 290 V~310 V)
- PWM frequency 6 kHz, three-phase modulation, about 40% V_{DQ} modulation (1000 RPM)

Figure 23 shows how to monitor IPM case temperature by infrared camera from the window on PCB bottom. Run motor at 1000 RPM and adjust motor load until the hottest point in the center of IM535-U6D reaches 105 $^{\circ}\text{C}$ (temperature rise reaches 80 $^{\circ}\text{C}$), get the curve for temperature rise and input power as shown in Figure 24.

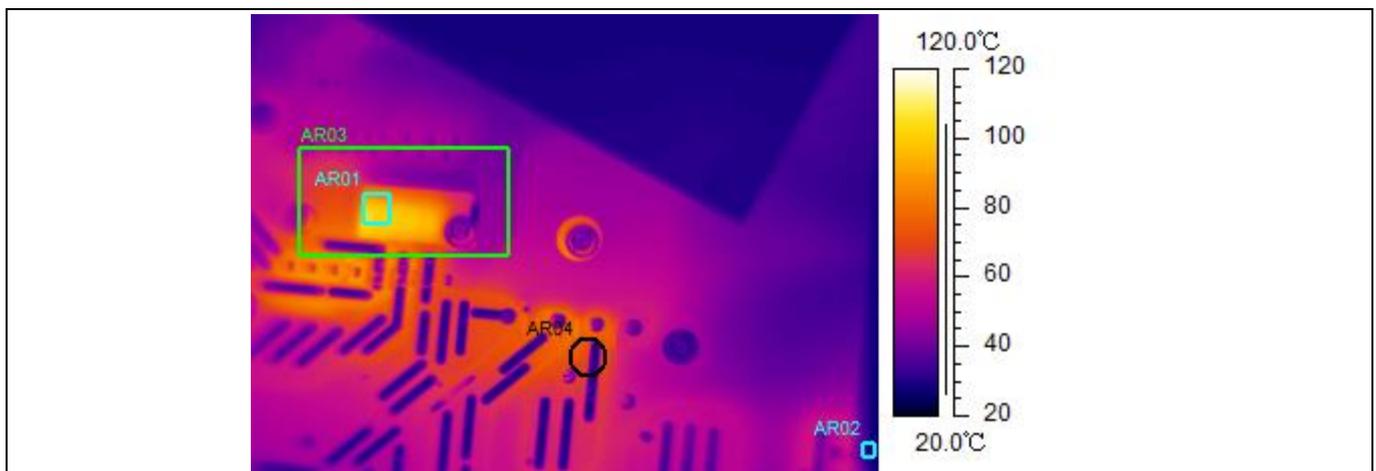


Figure 23 Infrared camera image for IPM temperature test

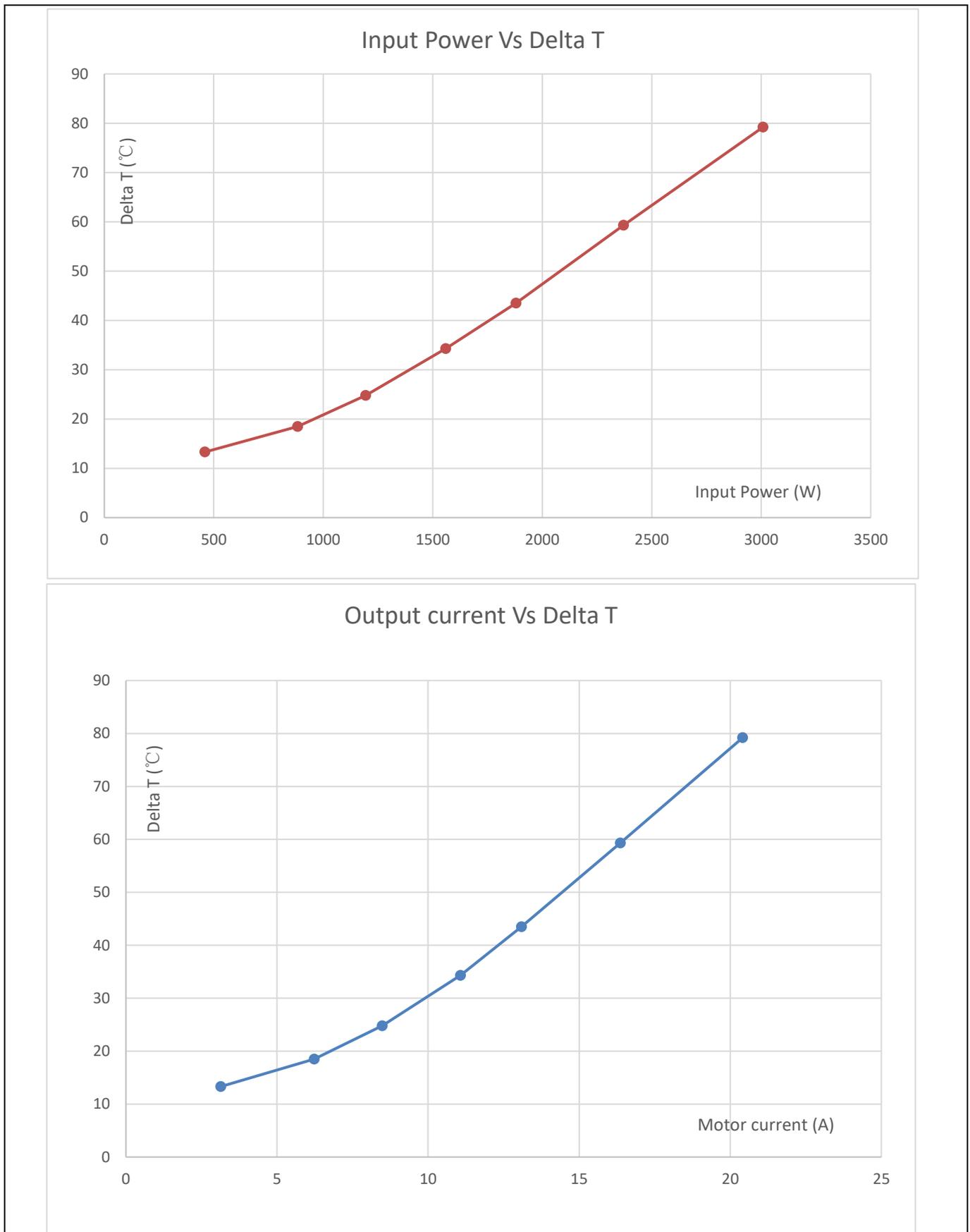


Figure 24 EVAL-M1-IM535 output power capability test result

System performance

4.3 Test results for PWM range

Figure 25 shows the output ability at different PWM frequencies, which are performed under the following conditions:

- 4~20 kHz PWM, three-phase modulation
- Run GK6081 motor at 1000RPM (about 40% V_{DQ} modulation) and increase motor load at given PWM frequency, till the hottest case temperature of IM535-U6D reaches 105°C
- Ambient temperature $T_a=25^\circ\text{C}$
- Cooling fan voltage is 14.3 V , 8m/s air flow after heatsink (5 mm distance, center of heatsink fins)
- AC input is $V_{AC}=220\text{ V}/50\text{ Hz}$ (V_{DC} bus is 290 V~310 V)

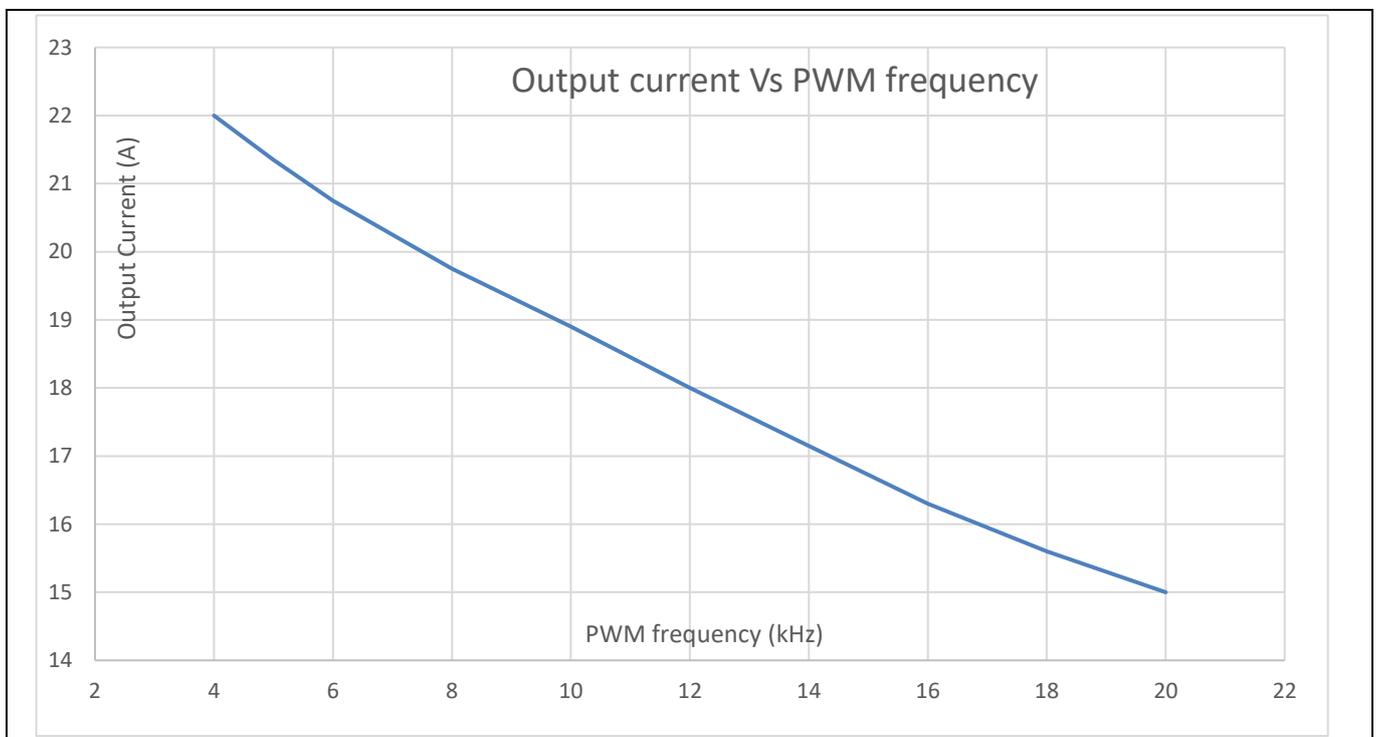


Figure 25 Output ability at different PWM frequency

System performance

4.4 Test results for overcurrent protection

The IM535 product family provides an overcurrent detection function by connecting the ITRIP input with the IGBT current feedback, and IGBT short-circuit withstand time is 5 μs. Overcurrent detection generates a shutdown of outputs of the gate driver if ITRIP pin input is over 525 mV and lasts longer than 300ns.

An external LM393 comparator is used for overcurrent protection in EVAL-M1-IM535 design to lower the request of shunt resistors voltage to 90 mV, since 525 mV means too much current for 2.5 mOhm shunt resistors.

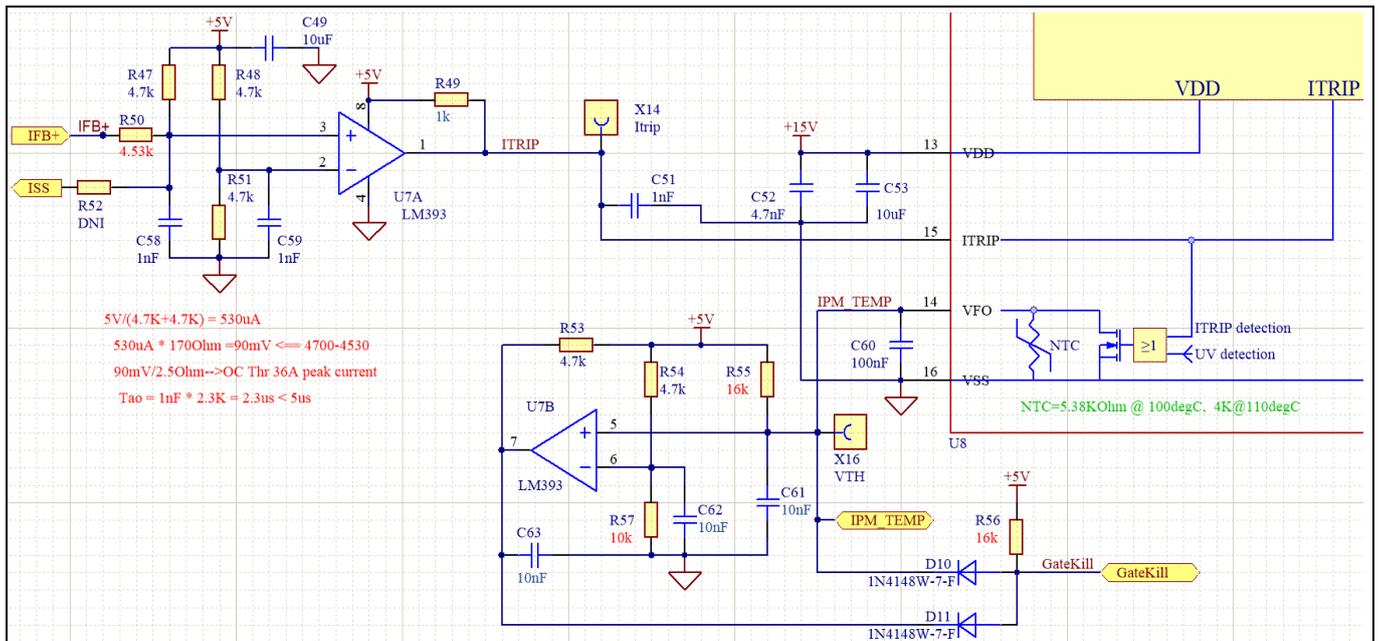


Figure 26 IPM overcurrent protection and over-temperature protection circuit

The small signal and big signal response of this overcurrent protection circuit is shown in Figure 27:

- 2.3 μs for 300 ~ 400 mV shunt resistor voltage, which means 120 ~ 160 A short-circuit condition
- 5.9 μs for 100~150 mV shunt resistor voltage, which means 40 ~ 60 A overcurrent circuit condition

System performance

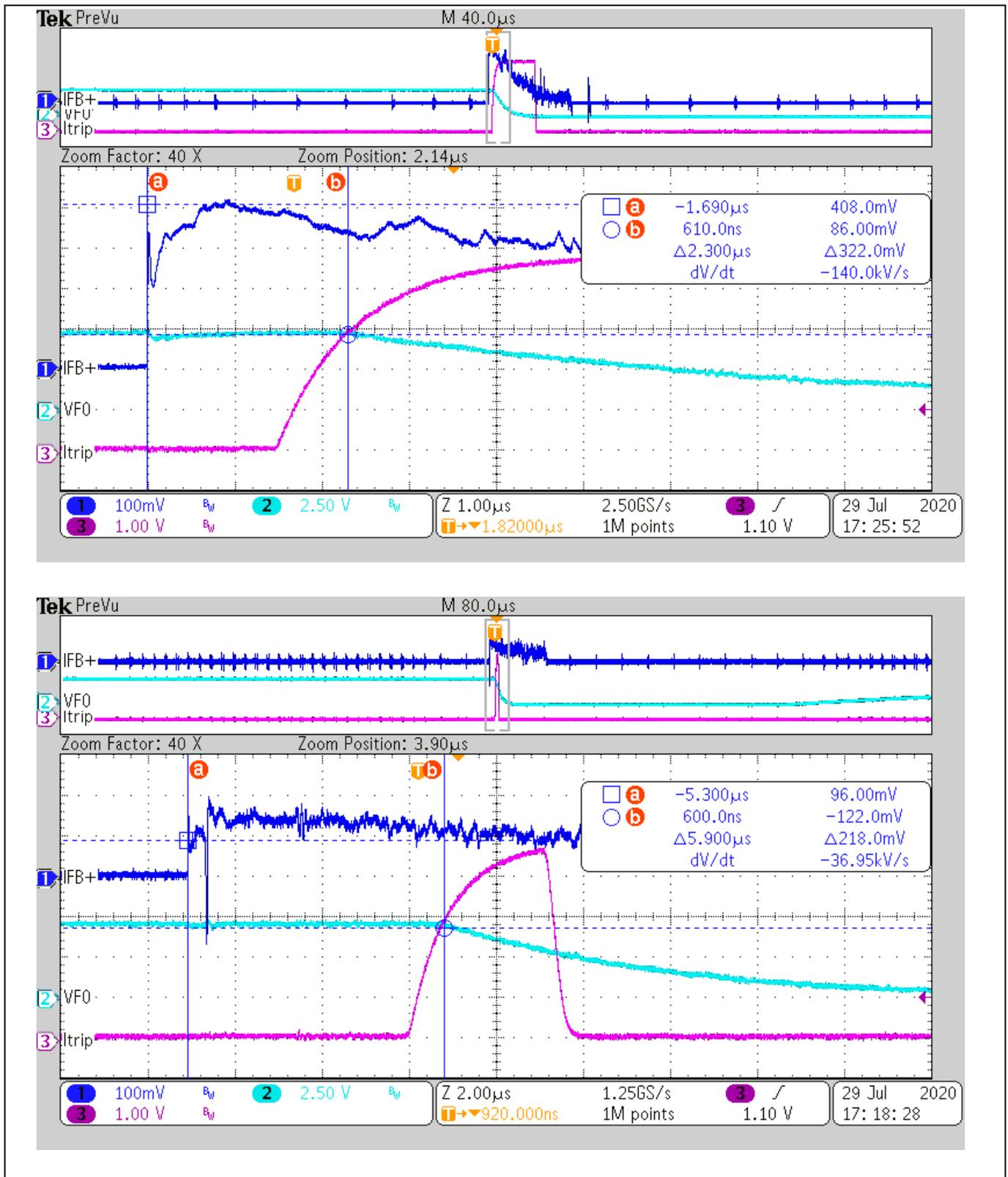


Figure 27 Overcurrent protection response waveform (CH1: IFB+, CH2: VFO, CH3: Itrip)

System performance

4.5 Test results for over-temperature protection

The IM535 IPM has an internal NTC resistor, which connects to VFO multifunction pin, as shown in Figure 28:

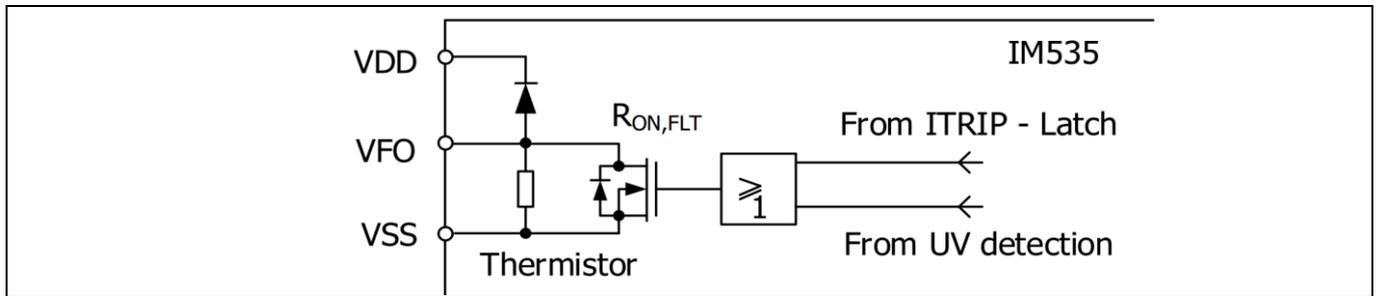


Figure 28 Temperature sensing for IM535-U6D

The IM535-U6D IPM built-in NTC thermistor is 85 kOhm at 25°C and its B-constant is 4092, typical resistance and output of temperature-sensing voltage are listed in Table 9.

Table 9 NTC – Thermistor Characteristics

Temperature (°C)	Resistance (kOhm)	V _{out} (mV)
50	29.972	4220
60	20.515	4160
70	14.315	4080
80	10.169	4000
90	7.345	3920
100	5.388	3830
110	4.009	3720
120	3.024	3600
125	2.639	3520

Given that the VFO pin is fault-output compatible pin (LOW true at IPM fault status), the temperature sensing pull-up resistor needs to keep the temperature detection output as far away from the digital IO’s low level threshold as possible, which means the available range should be beyond 3.5 V (0.7 x V_{DD}) to make sure IMC101T in EVAL-M1-101T considers this input as HIGH.

The pull-up resistor NTC is a complex network (R55, R56, D10 and circuit in EVAL-M1-101T), the final temperature protection (OTP) circuit output voltage to IMC101T’s temperature-related AD input is shown in Figure 29.

System performance

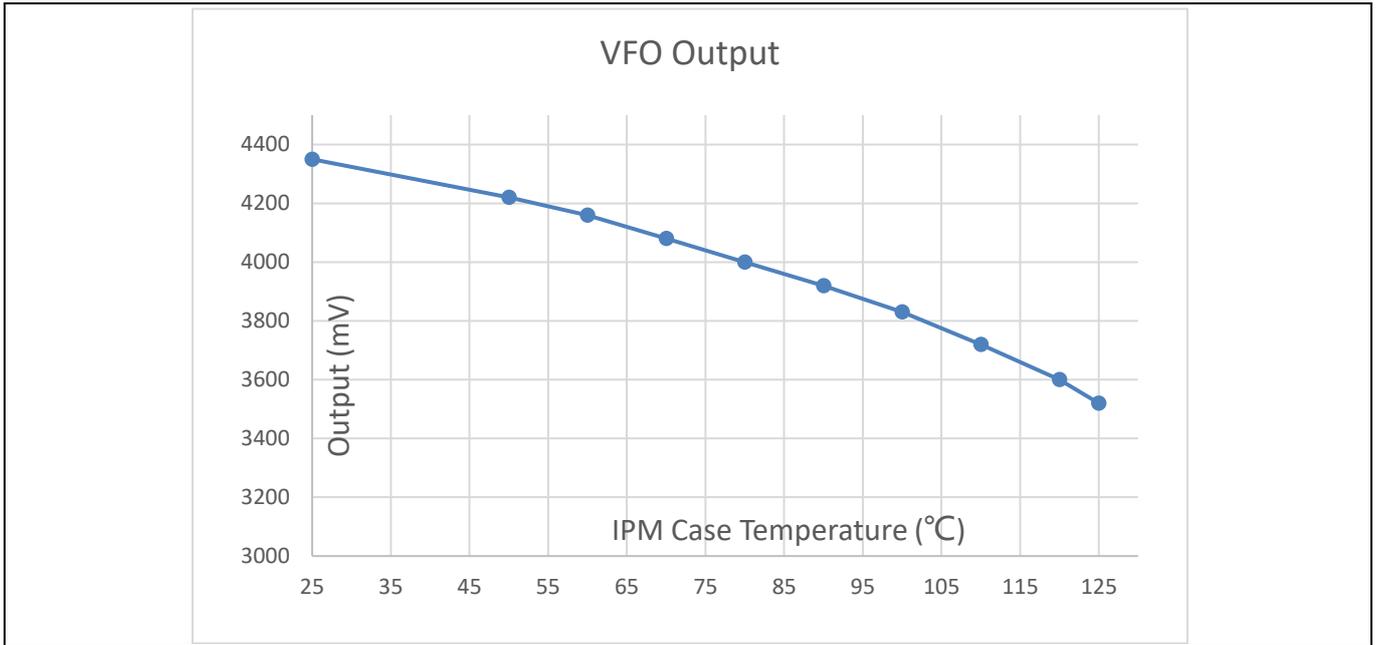


Figure 29 OTP (NTC circuit) and output voltage curve

Please note that output of VFO pin is very noisy; EVAL-M1-101T’s OTP function might be triggered by noise. Normally the MCEWizard setup needs to consider a margin for the input noise, for example, setup 3.3 ~ 3.4 V in MCEWizard corresponding to the real shutdown temperature of 110 ~ 120°C.

To activate over-temperature protection, 2 setups in MCEWizard are needed, as shown in Figure 30 :

- Enable over-temperature shutdown function
- Set voltage for shutdown

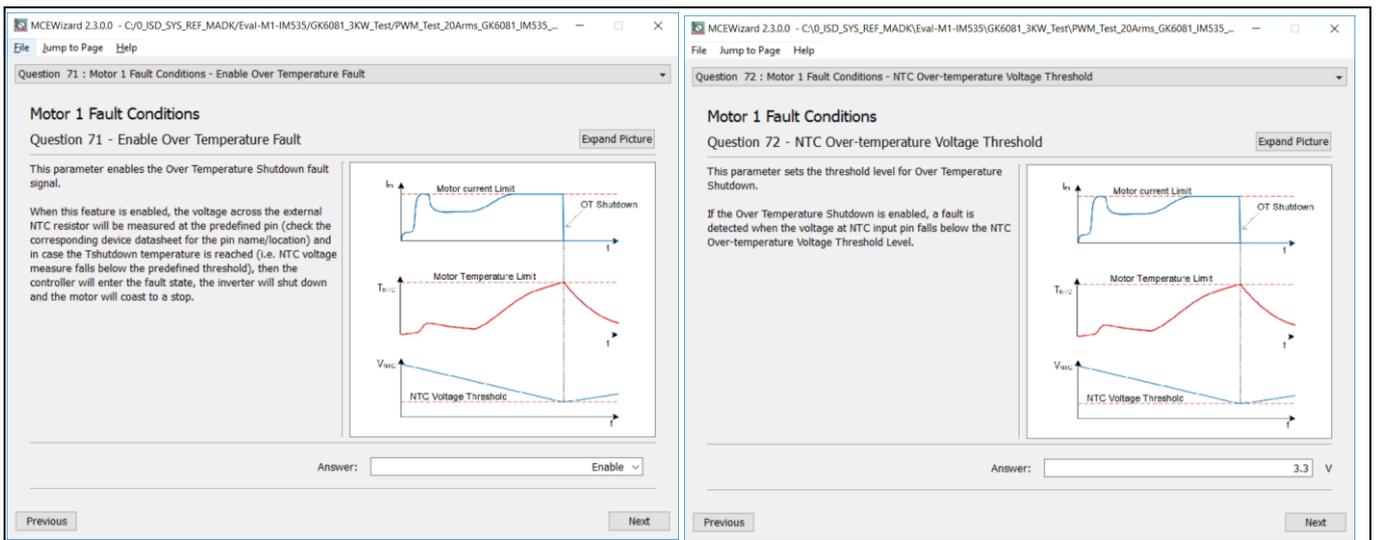


Figure 30 Over-temperature protection setup in MCEWizard

System performance

4.6 Test result for DC bus voltage ripple

The EVAL-M1-IM535 design does not equip PFC function, which means the DC bus voltage is determined by the AC input voltage and the load of motor; the DC bus voltage ripple is the function of IPM inverter load and grid input.

Figure 31 shows the DC bus ripple waveform with 4 x 1000µF capacitors, 220 V_{AC}, 3000 W input power, which is 7.5% (23.6 V / 311 V = 7.5%).

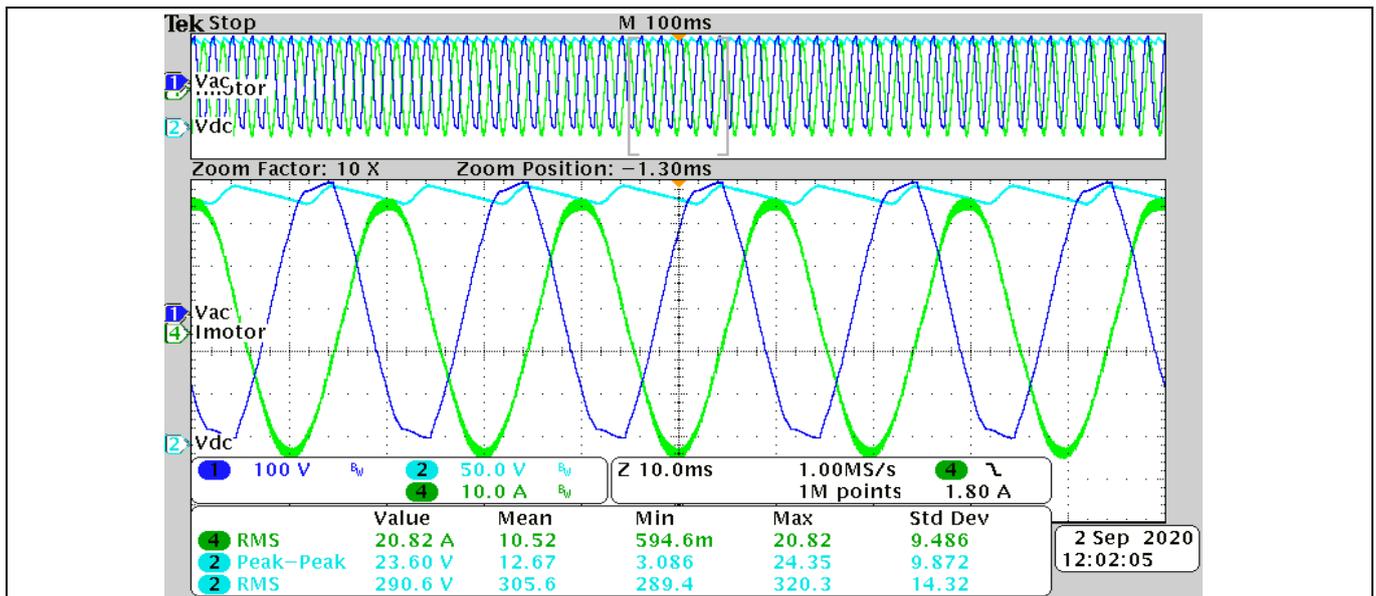


Figure 31 V_{dc} ripple test at 3 kW input power

5 References and appendices

5.1 Abbreviations and definitions

Table 10 Abbreviations

Abbreviation	Meaning
CE	Conformité Européenne
EMI	Electromagnetic interference
UL	Underwriters Laboratories
OPA	Operational amplifier
LPF	Low-pass filter

5.2 References

- [1] Datasheet of Infineon IM535-U6D
- [2] Datasheet of Infineon IMC101T
- [3] MCEWizard User Guide
- [4] MCEDesigner User Guide
- [5] Infineon-MCESW-RM-User Manual

5.3 Ordering details and other information

The power board is now available for customers in small order quantities. In order to initiate the testing, customers are advised to order the following items:

Base Part Number	Package	Standard Pack		Orderable Part Number
		Form	Quantity	
EVAL-M1-IM535	EVAL	Boxed	1	EVALM1IM535TOB01
ICE5AR4770BZS DIP-7	PG-DIP-7	TUBE	2000	ICE5AR4770BZSXXLA1
IM535-U6D	DIP 36x21D	TUBE	280	IM535U6DXKMA1

Revision history

Revision history

Document version	Date of release	Description of changes
V1.0	2020-9-30	First release

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