

# REF\_Fridge\_D111T\_RC2\_SL user guide

## Refrigerator compressor driver reference design kit

### About this document

#### Scope and purpose

This user guide provides an overview of the reference design board REF\_Fridge\_D111T\_RC2\_SL including its main features, key data, pin assignments and mechanical dimensions, and the guidance on how to run and design the motor with board.

The REF\_Fridge\_D111T\_RC2\_SL board is a complete reference design board designed for refrigerator compressors. It demonstrates the whole Infineon solution including digital motor control IC iMOTION™ Driver IMD111T-6F040 and the newest 600 V discrete RC-D2 IGBT IKD04N60RC2.

The REF\_Fridge\_D111T\_RC2\_SL board is developed to support customers in designing their refrigerator compressor drive stage with Infineon products.

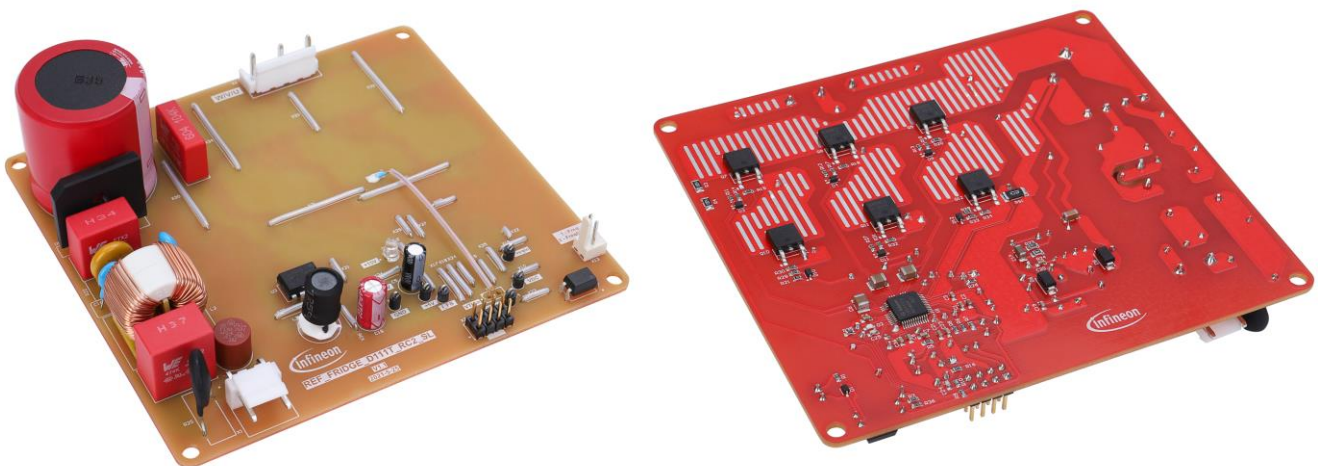
#### Intended audience

This user guide is intended for technical specialists working with the REF\_Fridge\_D111T\_RC2\_SL board and refrigerator compressor driver design.

#### Reference board/kit

Product(s) are embedded on a PCB, with focus on specific applications and defined use cases that can include software. PCB layout and auxiliary circuits are optimized for the requirements of the target application.

*Note: Boards do not necessarily meet safety, EMI, quality standards (for example UL, CE) requirements.*



## 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

	<p><b>Warning:</b> The DC link potential of this board is up to 400 VDC. When measuring voltage waveforms by oscilloscope, high voltage differential probes must be used. Failure to do so may result in personal injury or death.</p>
	<p><b>Warning:</b> 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.</p>
	<p><b>Warning:</b> 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.</p>
	<p><b>Warning:</b> 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.</p>
	<p><b>Caution:</b> 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.</p>
	<p><b>Caution:</b> 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.</p>
	<p><b>Caution:</b> 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.</p>
	<p><b>Caution:</b> 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.</p>
	<p><b>Caution:</b> 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.</p>

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**The reference board at a glance**

## **1 The reference board at a glance**

The REF\_Fridge\_D111T\_RC2\_SL reference design kit is a part of the iMOTION™ reference design kit for motor drives, which is aimed for refrigerator-compressor driver applications. The kit is a ready-to-use solution in combination with full Infineon products such as the newest RC-D2 IGBT, and the motor-control driver iMOTION™ IMD111T-F040. It can be easily translated into a mass production board for refrigerator compressor to speed up the development phase and achieve fast time to market.

The REF\_Fridge\_D111T\_RC2\_SL reference board is available from Infineon. The features of this board are described in Chapter 1.3 of this document (UG-2021-31). The remaining sections provide information to enable customers to re-use, modify and qualify the design for production according to the specific requirements.

Environmental conditions have been considered in the design of the REF\_Fridge\_D111T\_RC2\_SL. The design was tested as described in this document, but not qualified in terms of safety requirements or manufacturing and operation over the whole operating temperature range or lifetime. The boards provided by Infineon are subject to functional testing only.

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

### **1.1 Delivery content**

The scope of delivery contains only the board as shown in Figure 2. The detailed ordering information is indicated in Table 2.

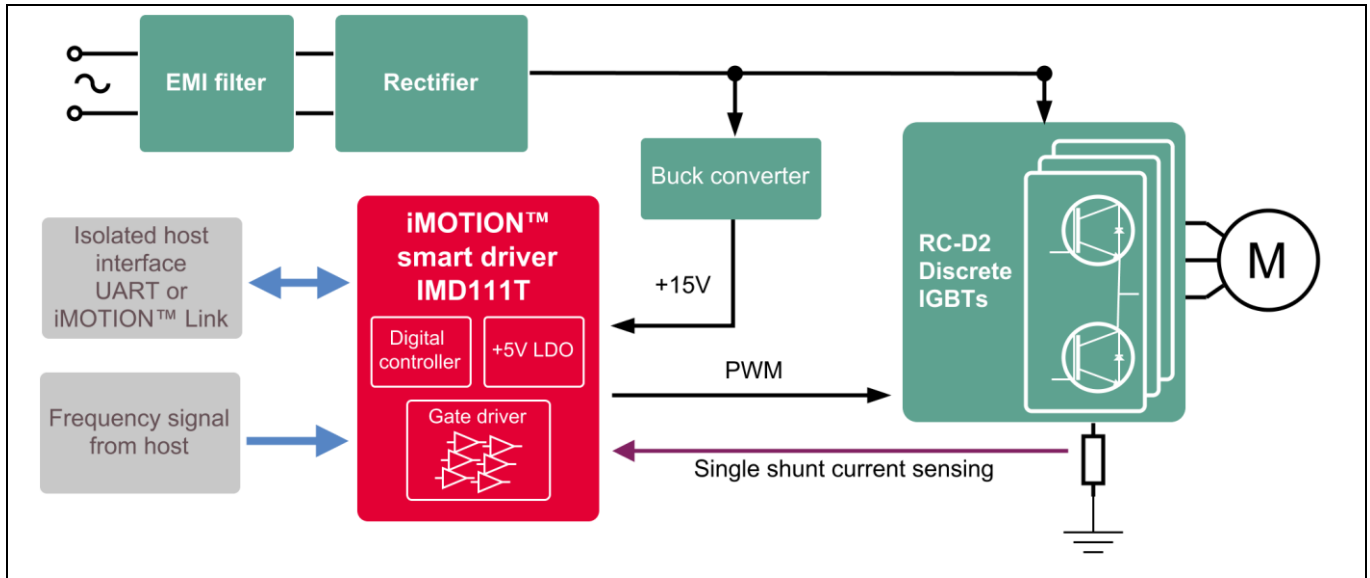
The iMOTION™ Link shown in the Figure 5 is mandatory for tuning the board firmware, and is not included in the delivery content. It can be ordered separately according to the details in Section 5.3.

**Table 2 Delivery content**

<b>Base part number</b>	<b>Package</b>	<b>Standard pack</b>		<b>Orderable part number</b>
		<b>Form</b>	<b>Quantity</b>	
<a href="#">REF_Fridge_D111T_RC2_SL</a>		Boxed	1	REFFRIDGED111TRC2SLTOB01

The reference board at a glance

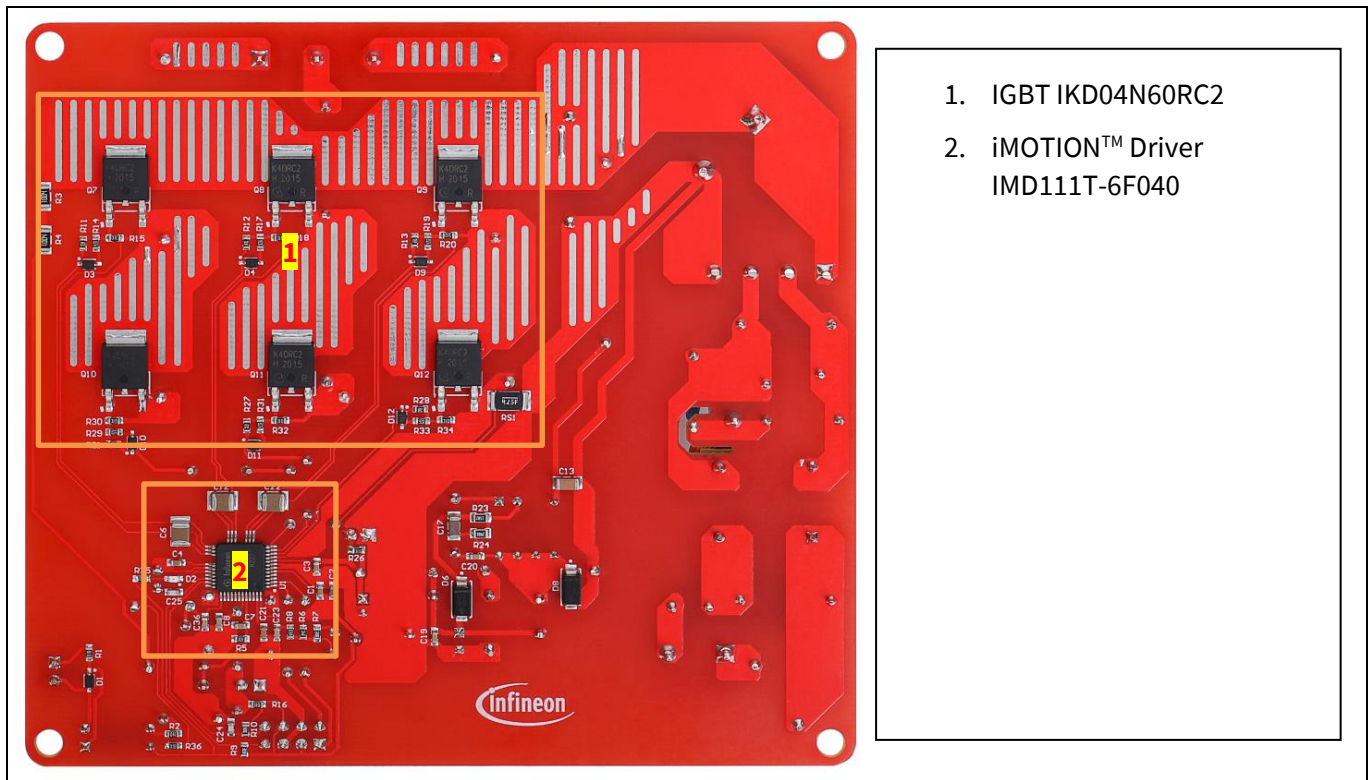
**1.2 Block diagram**



**Figure 1 Block diagram of the REF\_Fridge\_D111T\_RC2\_SL reference board**

Figure 1 shows the block diagram of reference design kit REF\_Fridge\_D111T\_RC2\_SL.

Figure 2 and Figure 3 depict the functional groups of the board. The details of the connectors are described in section 3.4.



**Figure 2 Functional groups on bottom side of board**

The reference board at a glance

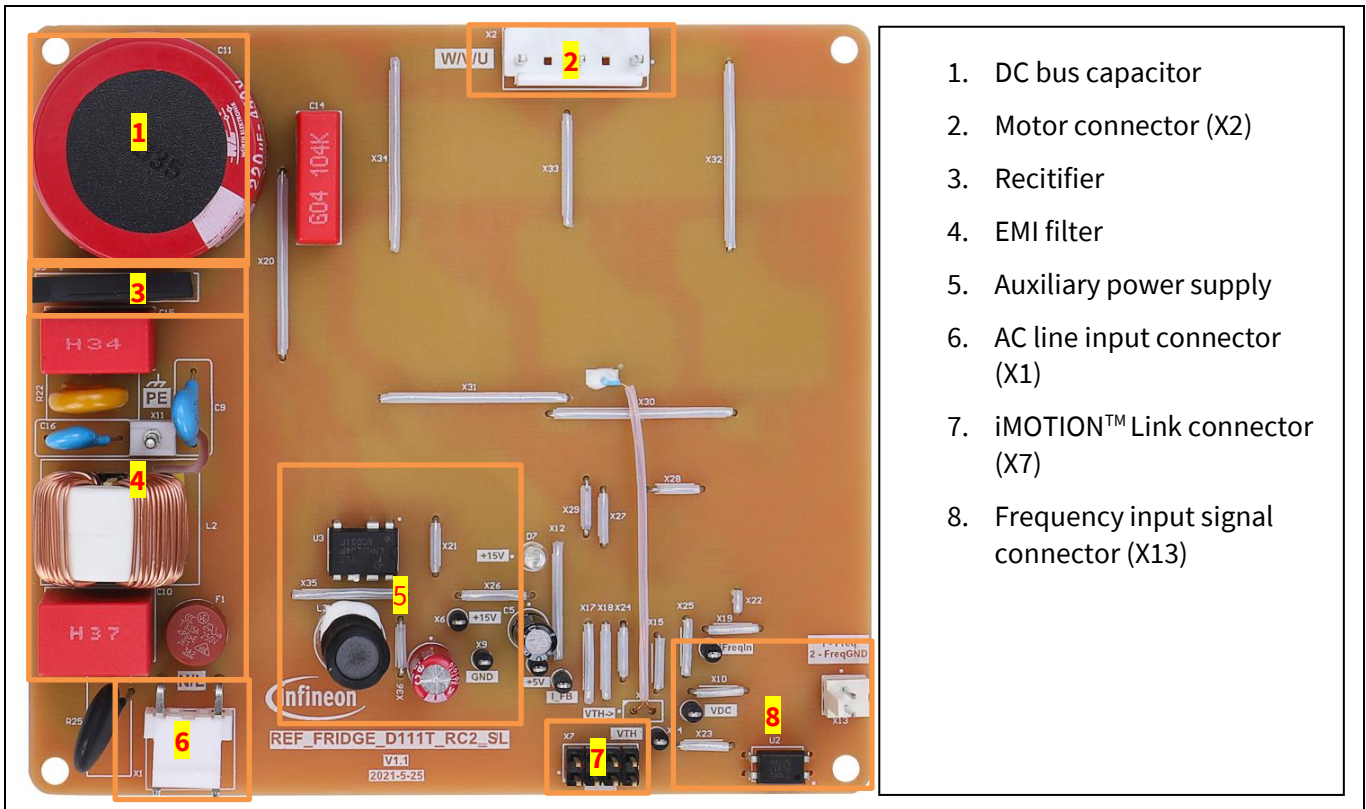


Figure 3 Functional groups on top side of board

### 1.3 Main features

REF\_Fridge\_D111T\_RC2\_SL is a complete reference design board for refrigerator-compressor applications. Main features of the board include:

- iMOTION™ Driver IMD111T-6F040: ready-to-use motion controller with scripting engine and 6-channel silicon on insulator (SOI) driver
- RCD2-600 V IGBT for lowest EMI and losses
- System solution enables highly integrated, flexible design and lowest EMI

600 V RC-D2 is the successor of the RC-DF IGBT. The diode is monolithically integrated, which makes this technology suited for consumer drives. The current rating of the diode was optimized in order to make this product even more competitive in terms of price and performance. The RC-D2 is also the first IGBT family to introduce the SOT-223 package. This package further improves the price due to its smaller size, and is pin-to-pin compatible and replaceable with the DPAK package, fitting the same footprint. Main features of 600 V RC-D2 IGBT compared to RC-DF include <sup>[1]</sup>:

- Adequate performance at competitive price
- Sufficient di/dt controllability in order to reduce electromagnetic noise
- Improved humidity robustness (HV-H3TRB test passed)
- Wide portfolio with current class range from 4 A to 15 A in DPAK

Main features of iMOTION™ Driver IMD111T-6F040 include <sup>[2]</sup>:

- Motion Control Engine (MCE 2.0)
  - Single or leg shunt current measurement

**The reference board at a glance**

- Motor control algorithm (Sensor-less / Hall-based FOC)
- Optional control for boost & totem pole PFC
- Protection features
  - Dead time insertion and shoot-through prevention
  - Overcurrent / overvoltage / undervoltage lockout
- High-voltage, three-phase gate driver with 600 V blocking voltage
- 15 V supply voltage for gate driver
- LQFP-40 package

For more information about the above-mentioned products, refer to the corresponding reference materials.

**1.4 Board parameters and technical data**

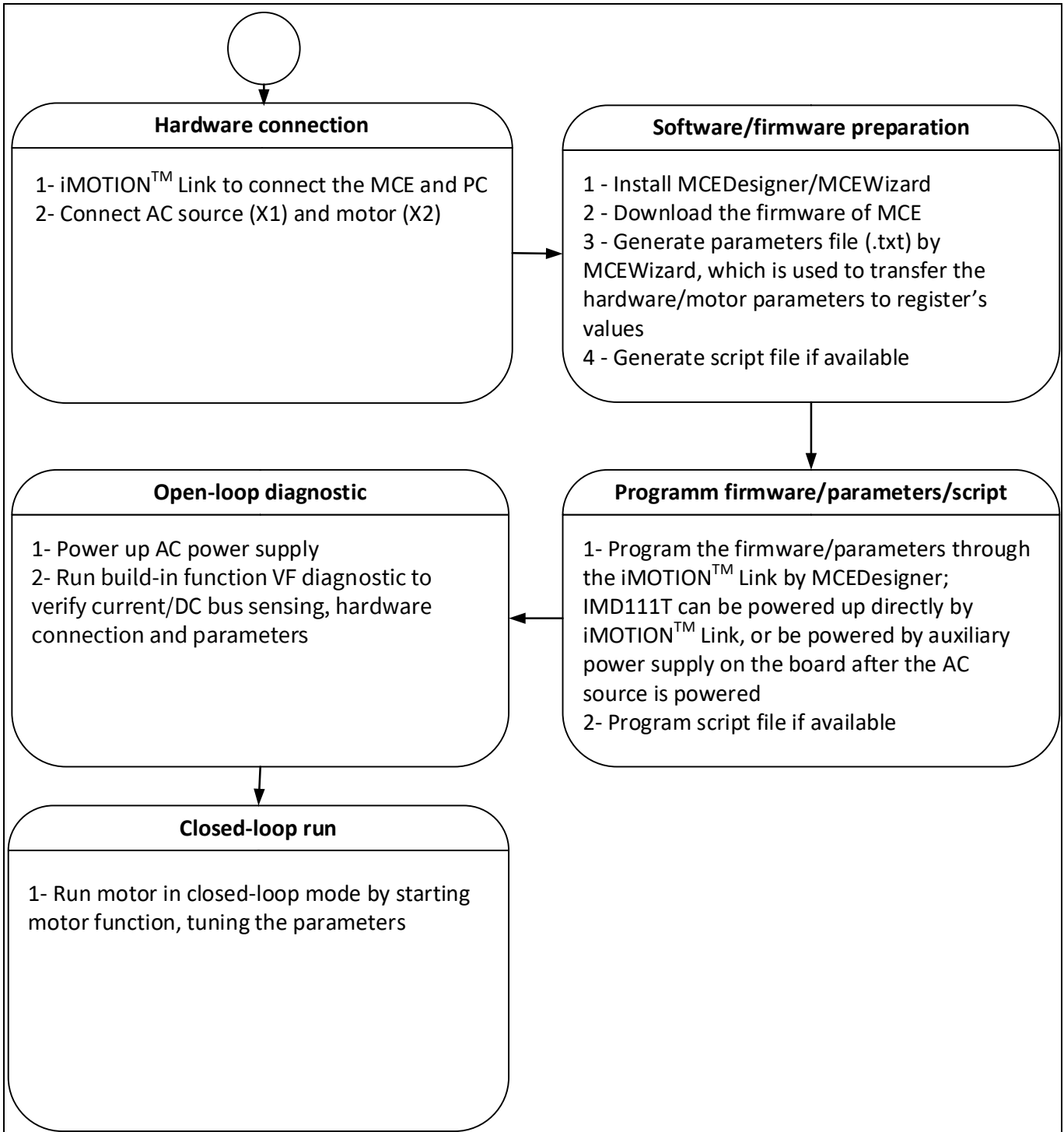
**Table 3 REF\_Fridge\_D111T\_RC2\_SL board specifications**

Parameter	Symbol	Conditions / comments	Value	Unit
Operation input voltage	$V_{ac}$	Lower AC input, less motor power output	165 ~ 270	$V_{rms}$
Maximum input current	$I_{ac(max)}$	Input 220 $V_{AC}$ , $T_a=25^{\circ}C$	1.8	$A_{rms}$
Maximum input power	$P_{in(max)}$	Input 220 $V_{AC}$ , $f_{PWM}=5$ kHz, $T_a=25^{\circ}C$ , $T_{case}=100^{\circ}C$ without heat sink	250	W
Maximum motor current	$I_{mtr(max)}$	Input 220 $V_{AC}$ , $f_{PWM}=5$ kHz, $T_a=25^{\circ}C$ , $T_{case}=100^{\circ}C$ without heat sink	1.2	$A_{rms}$
Maximum DC bus voltage	$V_{dc(max)}$		400	V
Shunt resistance	$R_{sh}$		250	m $\Omega$
<b>Protection</b>				
Current protection trigger level	$I_{trip}$	Set in the MCEWizard	-	$A_{peak}$
Thermal protection level	$T_{protection}$	Recommended is a setting of maximum 105 $^{\circ}C$ for the case temperature of IGBT, considering the gap, set 100 $^{\circ}C$ in the MCEWizard	105	$^{\circ}C$
<b>Auxiliary power supply 1 - 15 V</b>				
Output voltage	$V_{out1}$	Used for IMD111T-6F040, integrate 5 V LDO in the IMD111T-6F040	15 $\pm$ 5%	V
Maximum output current	$I_{out1}$		100	mA
<b>PCB characteristics</b>				
Dimension		Length $\times$ width $\times$ height	115 $\times$ 105 $\times$ 40	mm
Material		1.6 mm thickness, 1 oz. copper	FR4	
<b>System environment</b>				
Ambient temperature	$T_a$	Non-condensing, maximum RH of 95%	0 ~ 50	$^{\circ}C$



## 2 System and functional description

### 2.1 Commissioning



**Figure 4 Basic process for running the motor the first time**

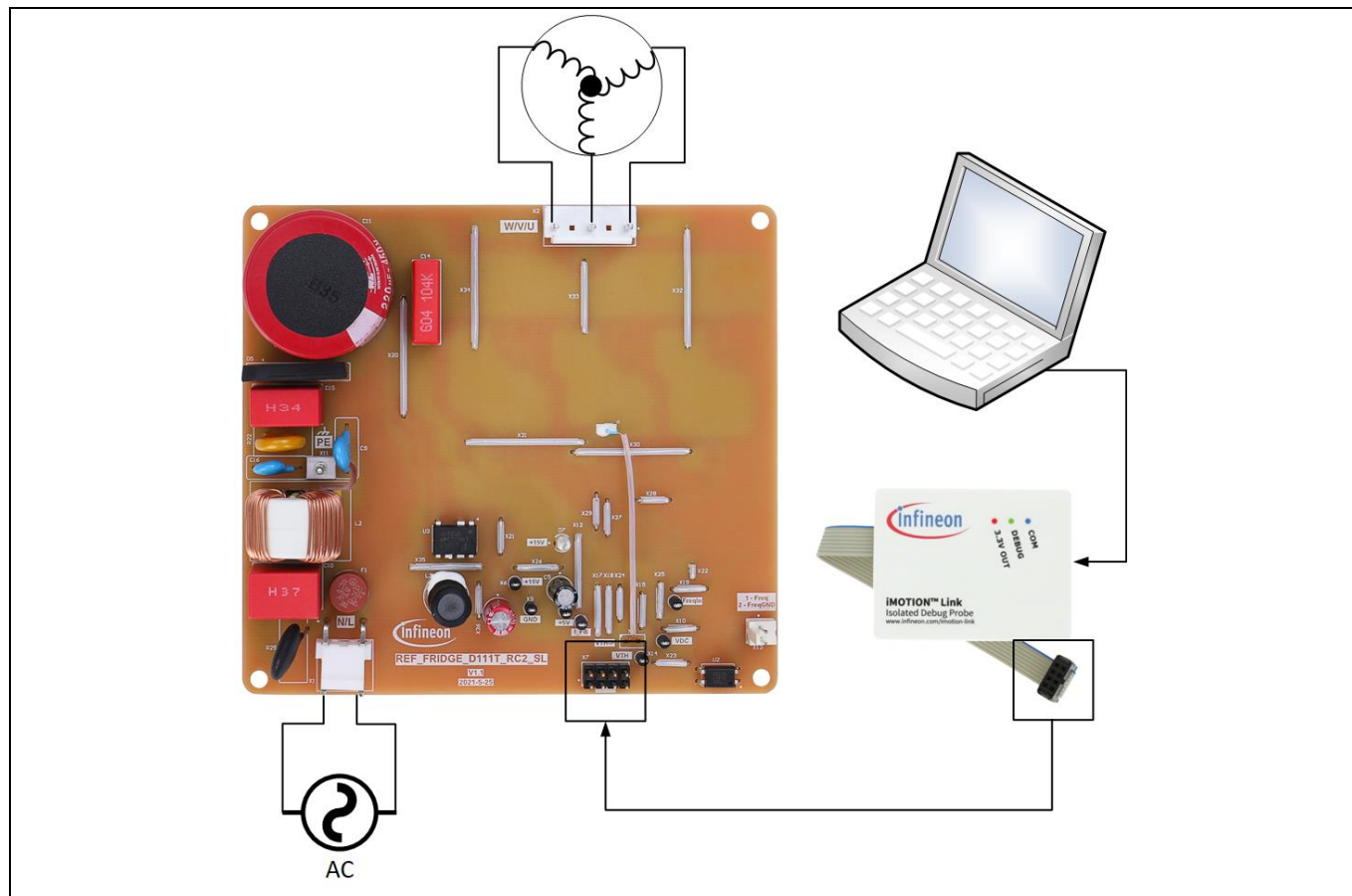
This section describes how to get the system working when the user first installs the board (refer to Figure 4 for general steps). The following items detail these steps. For those who are already familiar with the system, or have already run the board, unnecessary steps can be skipped depending on user's actual situation. For more in-depth commissioning process requirements, please refer to the MCE reference manual or the corresponding reference material <sup>[4][5][6]</sup>.

### 2.1.1 Hardware connection

Figure 5 shows the hardware connection details for the reference design board.

[iMOTION™ Link](#) 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. Users can go to Section 5.3 for more information about iMOTION™ Link.

1. Connect iMOTION™ Link's 8-pin cable to X7 with default pin order, and connect PC and iMOTION™ Link with the USB wire.
2. Then connect AC power supply (X1) and the motor (X2).



**Figure 5** Hardware connection details

### 2.1.2 Software/firmware preparation

1. The iMOTION™ software tools, MCEDesigner and MCEWizard, are required to set up the system, as well as to control and fine-tune the system performance to match users' needs. These tools are available for download via the Infineon website (<http://www.infineon.com/imotion-software>). Please check this page periodically for tool/software updates.
2. The MCE firmware then has to be downloaded on our website; select the proper version of the firmware based on your requirements. Included in the package are the firmware (‘.ldf’), default parameters (‘.txt’), default map file (‘.map’), the file for the MCEDesigner (‘.irc’) and other documents.
3. Generate your parameters’ file.
  - Use MCEWizard to enter the target motor’s system and operating parameters, as well as reference board’s hardware parameters, which will then be used to calculate the controller’s digital parameter set, representing the complete motor drive system.

## System and functional description

- After system and operating parameters are set, go to the “Verify & Save Page” and click on “Calculate” button. If no errors are reported, then save the drive parameter set in your project directory by clicking “Export to Designer file (.txt)” (Figure 8); if some errors are detected, double-click on the error message (highlighted in RED) and adjust the related parameters. Saved Drive System Parameter File will be later used for programmers.

*Note: After you log-in on myInfineon, you could download the default MCEWizard file (.mc2) for this board; you only need to modify the parameters related to your motor to make things easier and save time.*

4. Generate the script if available. For users who are running the board for the first time, it is recommended not to use this function first, but to add the script function after the motor performance commissioning is completed.

### 2.1.3 Program firmware/parameters/script

The REF\_Fridge\_D111T\_RC2\_SL reference design kit is shipped with pre-programmed firmware and default parameters, since the functional tests are performed before the shipment. Users need to program their parameters, as the motor may be different from the one under test.

The following steps have to be performed in order to program the blank IMD111T-6F040:

- Program the firmware of the MCE
- Program parameter sets for system and motor
- Program customer script file (optional)

Or

- Program the combined file, which is generated by MCEWizard and contains all three items above. Customer script file is optional depending on whether it is available. The combined file is usually used for production, since it only needs to be programmed once.

The programming process is as follows:

1. Start the MCEDesigner tool and open MCEDesigner default configuration file (‘.irc’) for IMD111T device (IMD111T\_Vxxx.irc) by clicking “File” > “Open.”

*Note: The IMD111T\_Vxxx.irc file is included in the downloaded firmware package “IMD111T MCE Software Package.”*

2. Power the iMOTION™ control IC with 3.3 V. It is recommended to program the IC with the 3.3 V isolated power supply that comes from the iMOTION™ Link; there is a switch on the iMOTION™ Link to enable the 3.3 V output. The iMOTION™ control IC will also be powered by the on-board auxiliary power supply after the AC source is powered. Caution must be taken in the latter case due to high voltage.

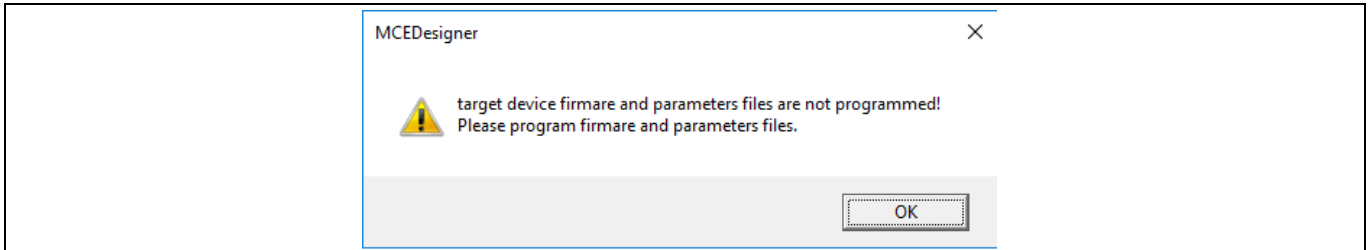
*Note: The output voltage of LDO combined in the IMD111T-6F040 is 5 V, i.e. the controller of IMD111T-6F040 is powered by 5 V. However, it is also possible to use the 3.3 V power supply in the iMOTION™ Link to power the IMD111T-6F040 (for programmers).*

3. MCEDesigner should automatically connect to the board using default COM port (indicated by green circle next to “COMx Up” status in the bottom frame of the MCEDesigner GUI) when iMOTION™ control IC is powered. If it cannot establish the connection due to an incorrect COM port, change the COM port by doing

**System and functional description**

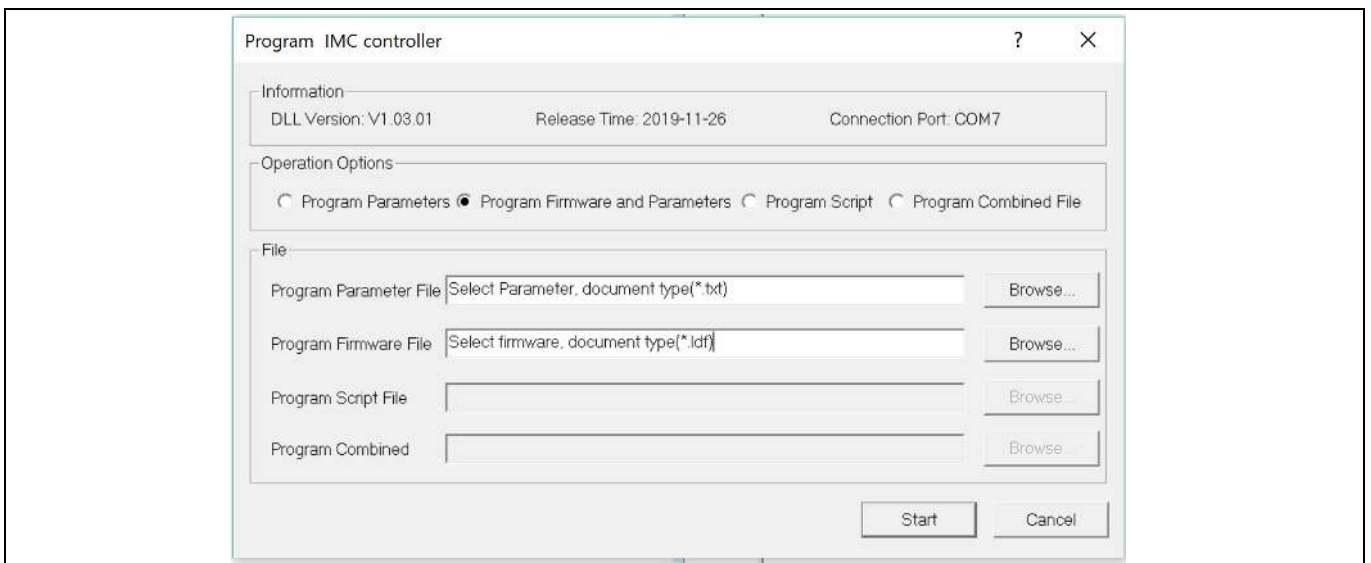
the following: click on the “System Page” window and then click on “Preferences > Connection > Connect using,” and choose one of the other available COM ports from the drop-down list.

- 4. (In case of a blank IC) If the firmware has been erased from the IMD111T-6F040, the following warning message will pop up “Target device firmware and parameters file are not programmed! Please program firmware and parameters file” as Figure 6. Then you can program the firmware and parameters as described in Step 5. If it is not a blank IC, no such message will be indicated.



**Figure 6 MCEDesigner warning message**

- 5. Use 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 in Figure 7 below. The encrypted firmware is available at “IMD111T MCE Software Package;” regarding the parameters file, browse and select the’.txt’ file in the section 2.1.2.



**Figure 7 Program the parameters and firmware**

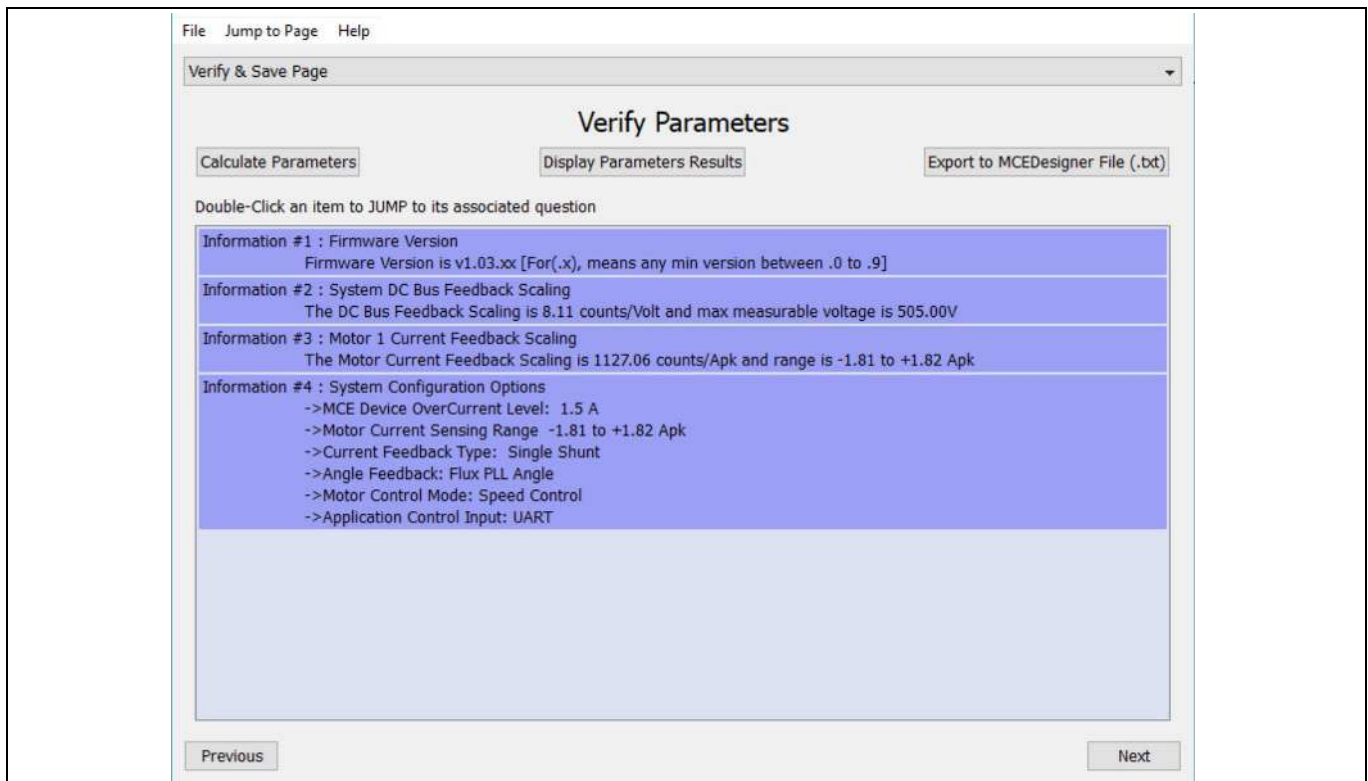


Figure 8 MCEWizard verify and save page

### 2.1.4 Open-loop diagnostic

Double-click the “VF Diagnostic” function in the window of motor1, and monitor motor current with oscilloscope. If the motor current is not sinusoidal, change register TargetSpeed and Vd\_Ext in the VF Diagnostic sub-function, then double-click “VF Diagnostic” until the oscilloscope shows a steady sinusoidal current with an amplitude of 30~50% motor rate current.

Double-click “Iu & Iv\_Slow” in System page > Monitor Definitions. The motor current feedback should be very clean and sinusoidal, as shown in Figure 9; otherwise please tune “Gating Propagation Delay & Phase Shift Window Size” in MCEWizard.

“VF Diagnostic” sub-function can verify whether:

- The motor is connected correctly
  - The power stage works as expected
  - Current-sensing related parameters are correctly configured
  - The PCB layout and DC bus decoupling have been done correctly
- After “VF Diagnostic” is done, click STOP button (the red traffic light button) or run “stop motor” function to stop the motor.

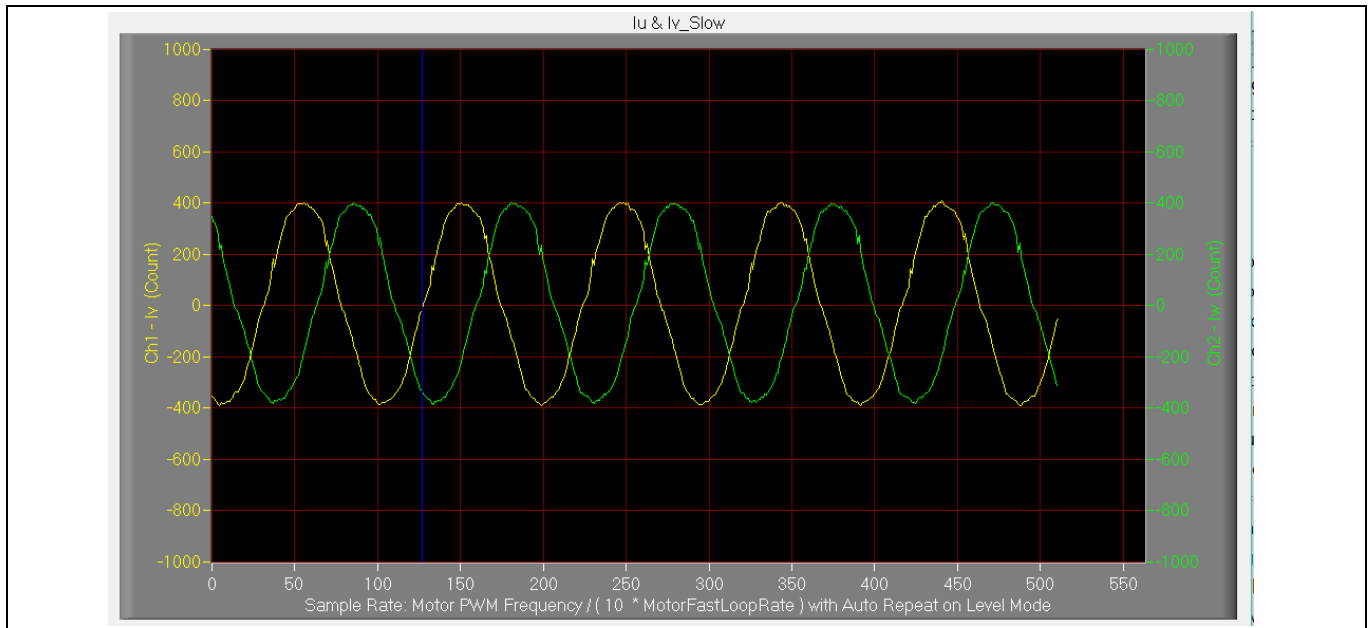


Figure 9 Trace waveform for lu & lv open loop diagnostic

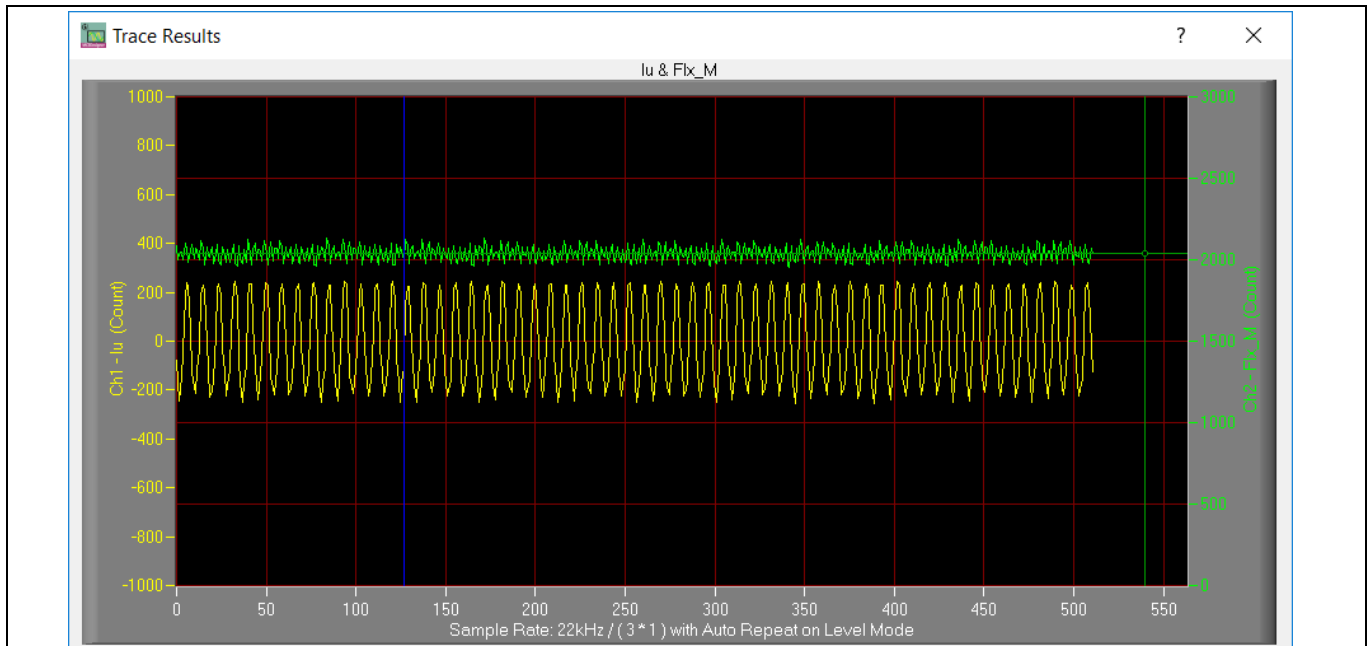
### 2.1.5 Closed-loop run

If the VF Diagnostic works correctly, the hardware circuit and signal sampling will work normally, at which point you can try to run the motor in a closed-loop mode. The steps are listed below.

1. Start the motor by clicking the green traffic light button in the control bar (or double click Start Motor sub-function in the window of motor1, which is in the group of User Application Function Definitions). The motor will run if above step works well.
2. Check the motor spin direction, adjust the connection order of the motor's winding, or set negative TargetSpeed in MCEDesigner if the direction is wrong.
3. Set TargetSpeed to about 50% of maximum speed, start "lu & Flx\_M" trace with "Auto Repeat on Level," see Figure 10. Flx\_M is good within the range of 2000~2500 (rated value is 2048), and must be steady and DC-like.

Here are some key tips for better motor performance tuning:

- If Flx\_M is not steady (swing or oscillation), motor parameters, speed loop PI gain, flux estimator time constant and PLL PI bandwidth (parameters PLLKp and PLLKi) and related setup need to be checked.
- If Flx\_M is very noisy, current feedback and  $V_{dc}$ -related hardware and parameters need to be checked.
- If Flx\_M does not come close to 2048, "Motor Back EMF Constant ( $K_e$ )" needs to be adjusted in MCEWizard.



**Figure 10** Trace waveform for  $I_u$  &  $Flx\_M$  at 50% speed

- Once the firmware has been programmed, and only a new parameter file has to be programmed, follow the same instructions given in Section 2.1.3. In this case, the firmware programming is no longer needed, and you can 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.

## 2.2 Description of the functional blocks

### 2.2.1 Inverter stage

The inverter section is implemented with the newest generation of RC-D2 IGBT in a DPAK package. 600 V RC-D2 is the successor of the RC-D/DF IGBT. The newest version of the RC-D technology has several improvements compared to its older version: better price position, lower power losses, and better controllability over the  $di/dt$  in order to further reduce EMI compared to RC-D/DF. The device is also robust for high-voltage and high-humidity operations.

Figure 11 shows the diagram of the inverter and peripheral circuit.

System and functional description

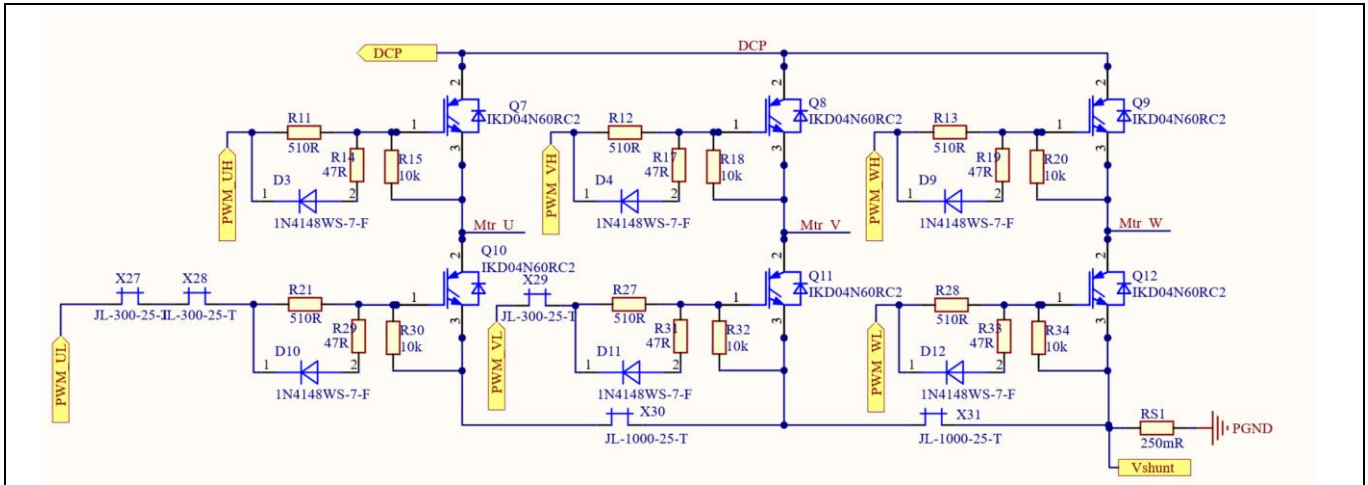


Figure 11 The inverter and peripheral circuit

2.2.2 EMI filter

Figure 12 shows the diagram of the EMI filter. The stages consist of two X-capacitors, of 470 nF and 330 nF respectively, a Y-capacitor of 4.7 nF, and a common-mode inductor whose parameters are shown in Table 4. Detailed specification of the inductor can be downloaded from the board web page after logging in your myInfineon account.

Table 4 Inductance of common-mode inductor

Item	Value	Test condition	Test equipment
Inductance	50 mH	1 kHz, 0.25 V, 25 °C	TH2826 or equivalent
	45 mH	10 kHz, 0.25 V, 25 °C	
	30 mH	100 kHz, 0.25 V, 25 °C	

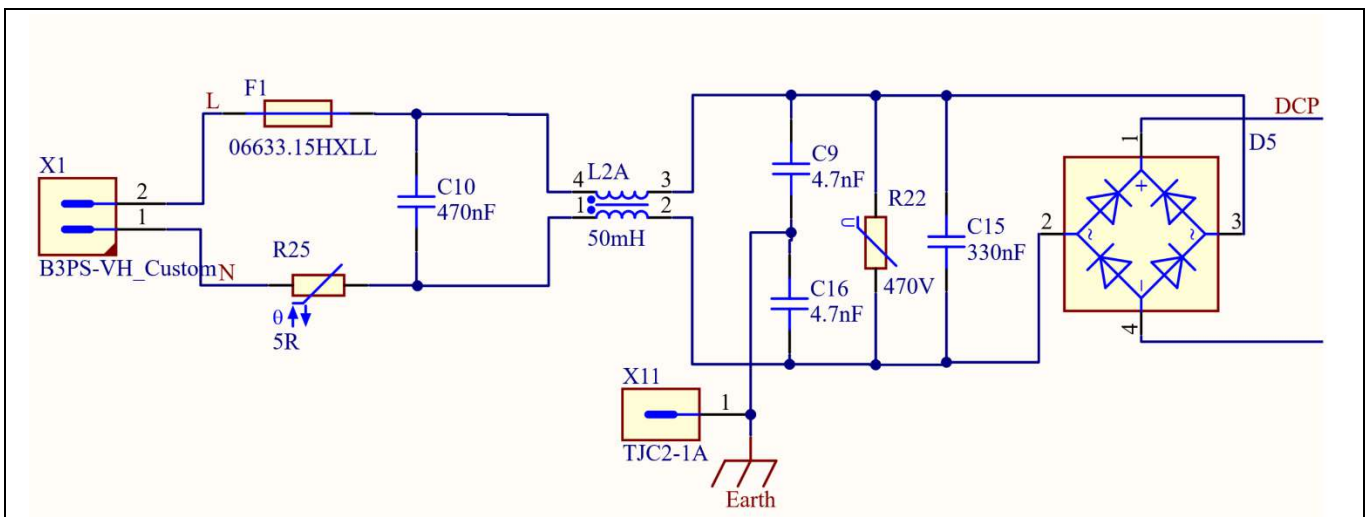


Figure 12 EMI filter

The conducted electromagnetic interference of this board is shown in Section 4.2. Here is a design tip to note for your reference.



## REF\_Fridge\_D111T\_RC2\_SL user guide

### Refrigerator compressor driver reference design kit

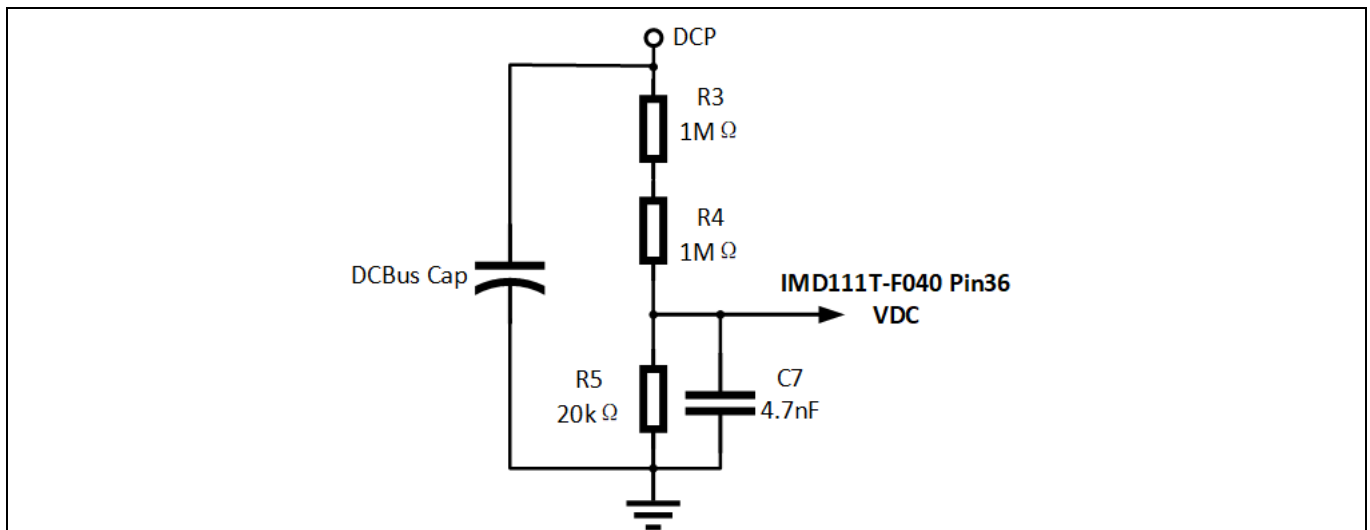
#### System and functional description

**Note:** No surge tests have been conducted on the REF\_Fridge\_D111T\_RC2\_SL board. X-capacitors (C10 and C15) on the board are X2 grade, therefore the surge test capability of these components is 2.5 kV according to the IEC60384-14. If higher surge level rating is needed, the X capacitors must be replaced with X1 grade components. Alternatively, additional surge-protection devices at the input side of the board must be added.

### 2.2.3 DC bus sensing and MCEWizard configuration

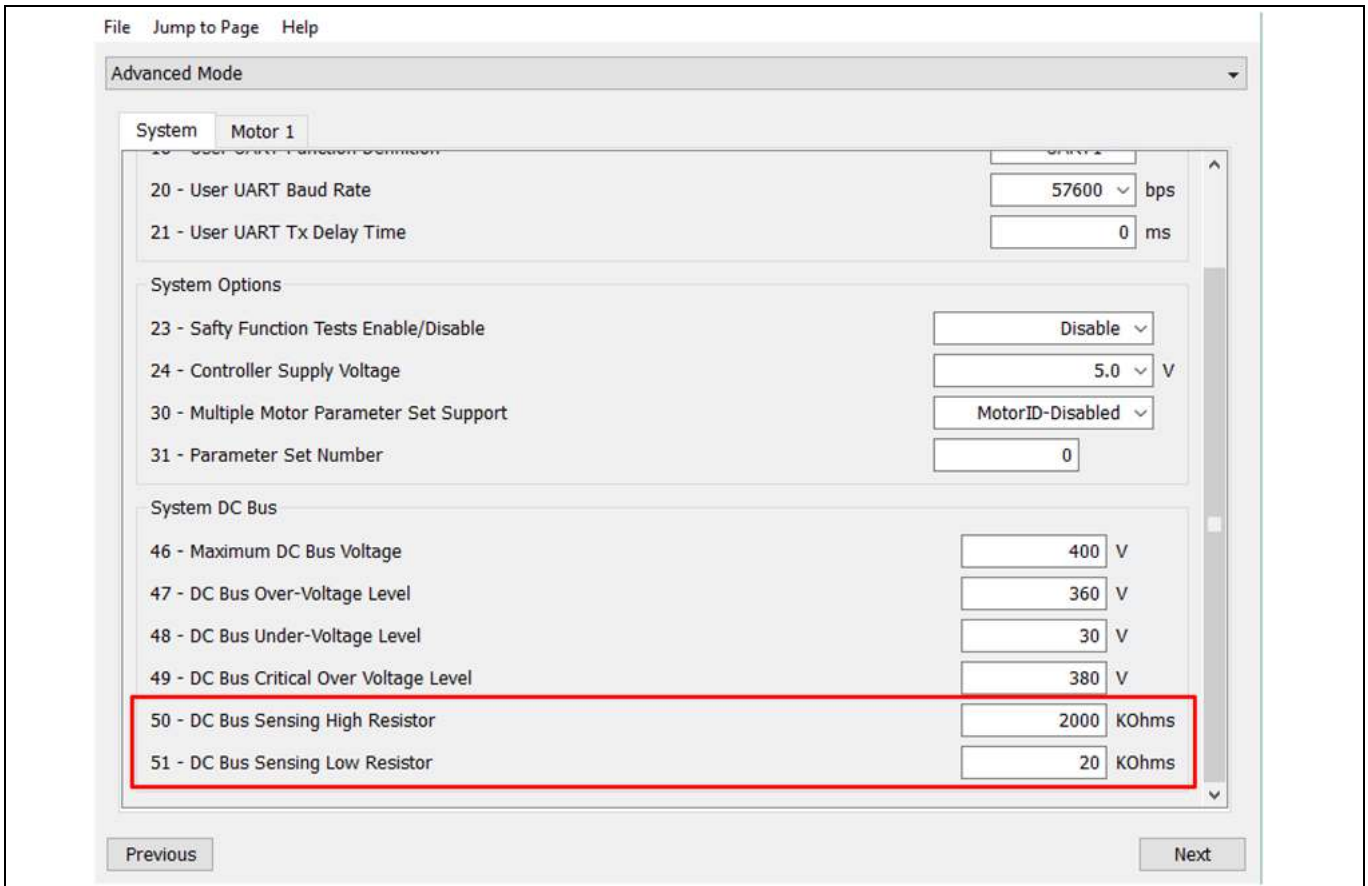
Figure 13 shows the detail of the DC bus sensing resistor divider stage.

With the values shown in the figure, the default DC bus-sense voltage results in a range of 0 V to 5 V on the ADC input of the microcontroller (MCU), reflecting an input voltage range from 0 V to 505 V.



**Figure 13** DC bus sensing

The hardware parameters need to be configured in MCEWizard as shown in Figure 14.



**Figure 14 DC bus sensing configuration in MCEWizard**

The  $V_{dc}$ -sensing stage features a low-pass-filter time constant that can be calculated as:

$$\text{Time constant} = ((R10 + R13))/(R15) * C4 = (2 \text{ M}\Omega // 20 \text{ k}\Omega) * 4.7 \text{ nF} = 93.1 \mu\text{s} \quad \text{Eq. 1}$$

The value of capacitor C17 can be adjusted to improve the  $V_{dc}$  noise rejection ratio.

## 2.2.4 Current sensing and overcurrent protection

### 2.2.4.1 Current sensing

The current sensing on this board uses only a RC network for operational bias and low-pass filter to minimize the cost. No additional operational amplifier is needed.

Referring to Figure 15, by applying the principle of Kirchhoff's voltage law, and assuming that the the MCU analog-to-digital converter (ADC) input port has an infinite impedance, one can derive the equation below.

$$V_{ADC} = \frac{(V_{cc} - V_{shunt})}{R_1 + R_2} * R_1 + V_{shunt} \quad \text{Eq. 2}$$

The equation can thus be adjusted as shown:

$$V_{ADC} = \frac{R_2 * V_{shunt}}{R_1 + R_2} + \frac{R_1 * V_{cc}}{R_1 + R_2} \quad \text{Eq. 3}$$

Since the impedance of the RC network is much larger than the  $R_{shunt}$ , it follows that:

System and functional description

$$V_{shunt} = I_{shunt} * R_{shunt} \tag{Eq. 4}$$

As a consequence,  $V_{ADC}$  can then be written as:

$$V_{ADC} = \frac{R_2}{R_1 + R_2} * R_{shunt} * I_{shunt} + \frac{R_1 * V_{CC}}{R_1 + R_2} \tag{Eq. 5}$$

Where  $\frac{R_1 * V_{CC}}{R_1 + R_2}$  is the offset, and  $\frac{R_2}{R_1 + R_2} * R_{shunt}$  is the gain of the shunt current.

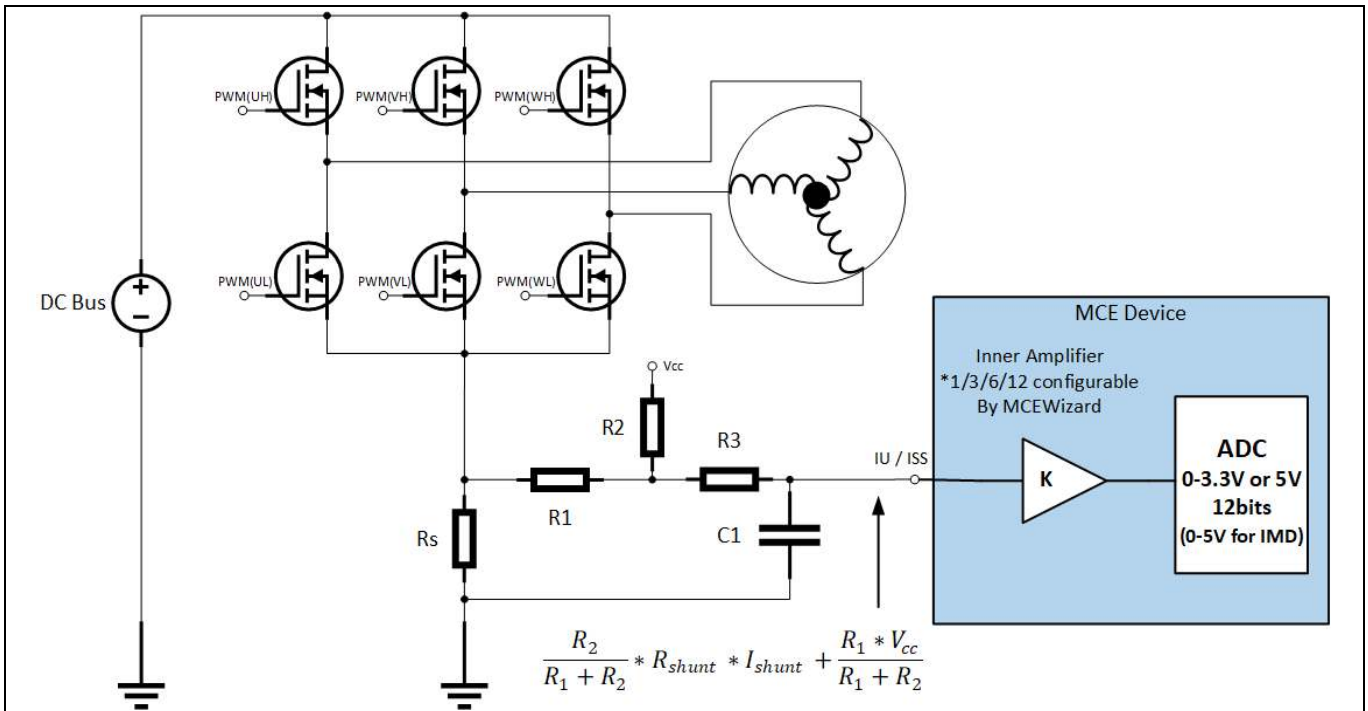


Figure 15 Current-sensing topology

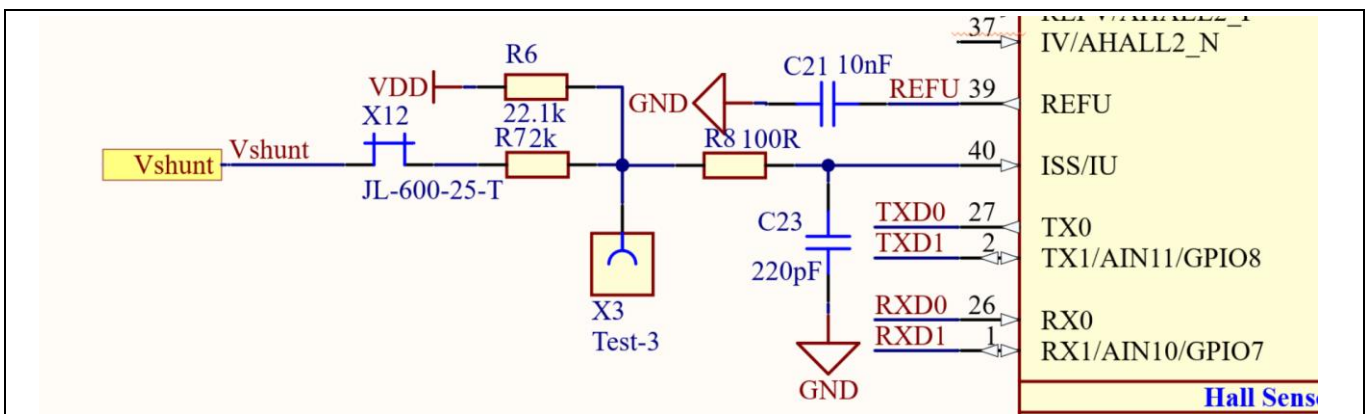


Figure 16 Current-sensing circuit on the board

As an example in Figure 16, this board has the following values:  $R_1 = R_7 = 2 \text{ k}\Omega$ ,  $R_2 = R_6 = 22.1 \text{ k}\Omega$ ,  $V_{CC} = 5 \text{ V}$ . By using the formula Eq. 5, the offset is 0.415 V, and the gain is  $\frac{R_2}{R_1 + R_2} * R_{shunt} = 229.3 \text{ mV/A}$ .

Note the following points concerning current sensing:

- R8 and R20 in Figure 16 also determine ADC operational bias for current sensing, which corresponds to the motor regeneration operation range. For the applications that do not work with regenerative braking mode,

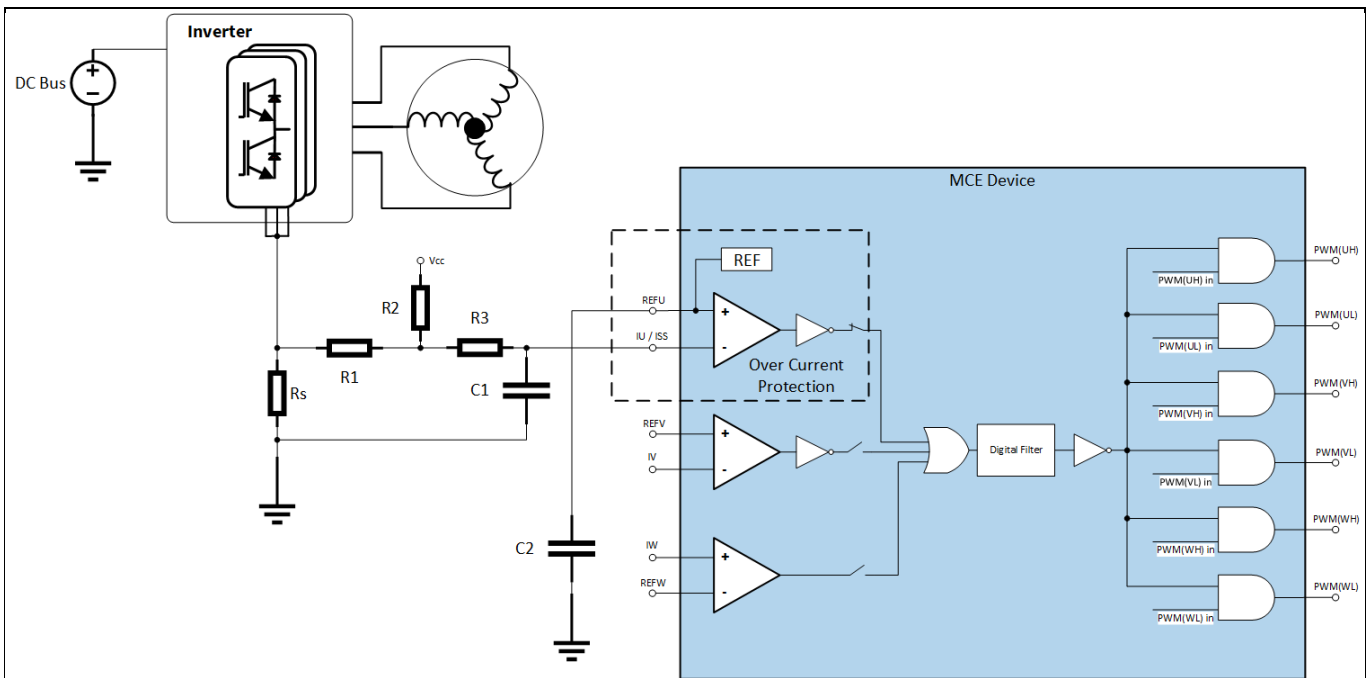
**System and functional description**

the bias can be as low as possible to reserve enough ADC range for the drive mode, since the current in the sense resistance always flows in one direction only.

- Since the gain of the external RC circuit is less than 1, internal signal amplification is required to increase the current signal acquired with low shunt resistance values. MCE provides an inner current sampling amplifier with \*1, \*3, \*6 and \*12 gain selections, which can be configured in the MCEWizard.
- There is no common mode noise-rejection capability without an outer operational amplifier, so the GND network of the PCB needs to be designed very carefully, since any voltage difference between IMD111T’s ADC ground and shunt resistor ground will be considered as an “input signal,” and will deteriorate the control performance or increase audible noise.

**2.2.4.2 Overcurrent protection**

The overcurrent condition can be detected by IMD111T-6F040 by the internal comparator as shown in Figure 17.



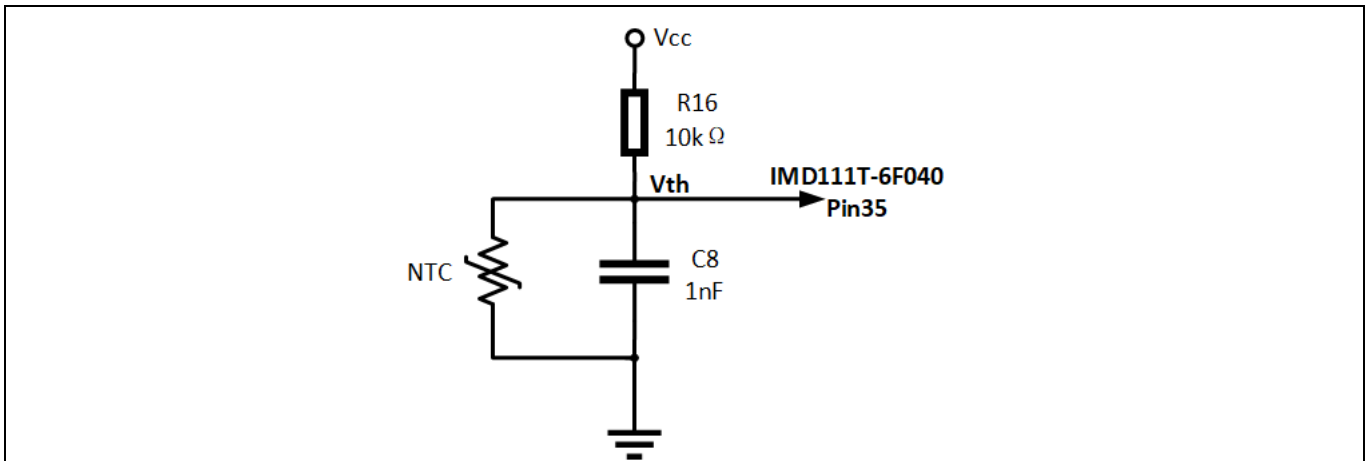
**Figure 17 Overcurrent protection on the board**

For more details about the overcurrent protection (OCP) in the IMD111T, refer to the chapter about motor overcurrent protection in the reference material [6].

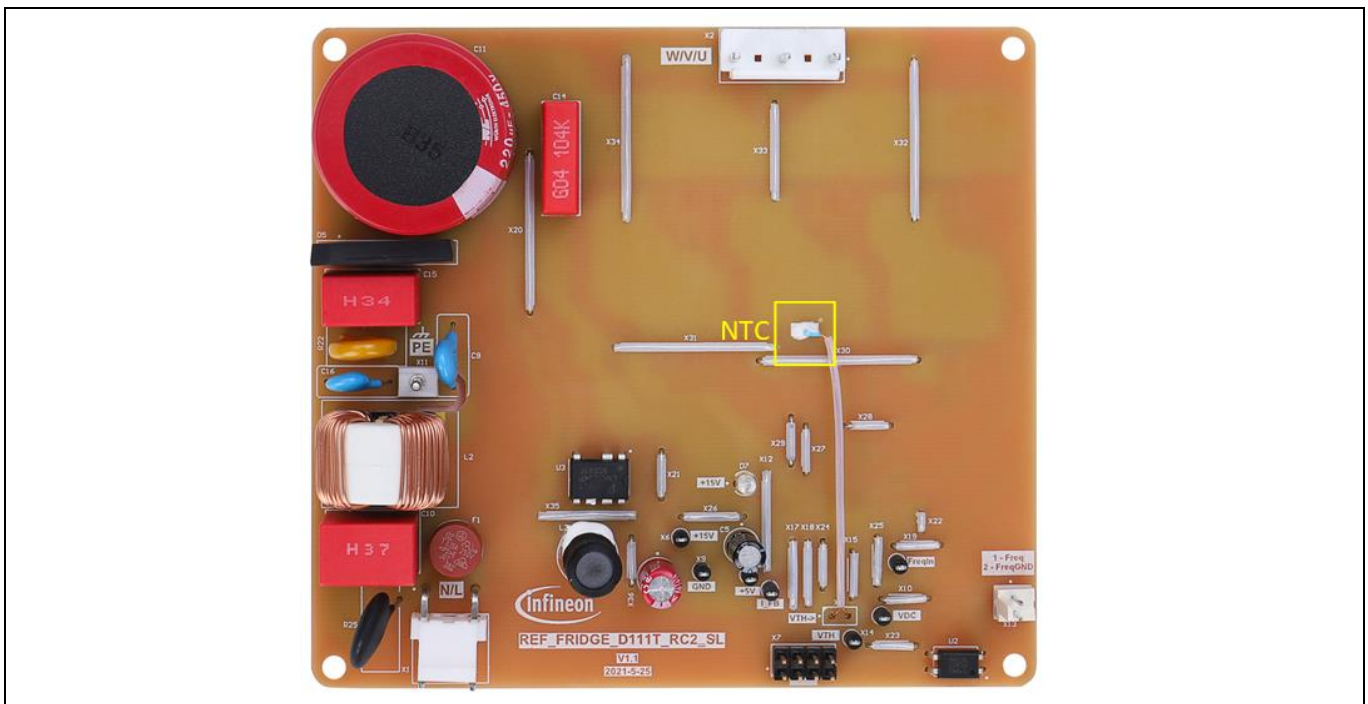
The internal comparator’s reference level is set by the internal digital-to-analog converter (DAC) so the level can be set in the MCEWizard by “Device overcurrent trigger level setting for comparator” and “Motor1 current input to ADC offset voltage.” The DAC output pin REFU needs to be connected to a capacitor to improve noise rejection (e.g. a 10 nF/16 V capacitor is used on the board).

**2.2.5 NTC sensing and thermal protection**

Pin 35 of the IMD111T-6F040 is connected to the ADC port dedicated to the temperature sensing. On the board, a negative temperature coefficient resistance (NTC) must be connected to the ADC port by means of the circuit shown in Figure 18. The position of the NTC resistance on the board is shown in Figure 19. The NTC is mounted at the bottom of the low-side IGBT of the motor phase ‘V’, which is close to the hottest IGBT on the board.



**Figure 18** NTC sensing circuit



**Figure 19** NTC position on the board

The parameters of the NTC resistance are: B-constant =  $4050\text{ K} \pm 1\%$ ,  $R_{25} = 47\text{ k}\Omega \pm 1\%$ . Based on the typical value of the thermistor resistance, the voltage of the  $V_{th}$  can be obtained in Table 5.

The firmware inside the IMD111T-6F040 integrates the over-temperature protection device, which will be triggered by the voltage  $V_{th}$ . The user must simply set the proper trigger level in the MCEWizard. More information can be found in the over-temperature protection section of the reference material<sup>[6]</sup>.

System and functional description

Table 5 Thermistor characteristics with V = 5 V, R16=10 kΩ

Temperature (°C)	Resistance typ. (kΩ)	V <sub>th</sub> (V)	V <sub>th</sub> register value
15.00	75.31	4.41	3615
20.00	59.25	4.28	3504
25.00	47.00	4.12	3377
30.00	37.57	3.95	3234
35.00	30.25	3.76	3077
40.00	24.52	3.55	2909
45.00	20.01	3.33	2730
50.00	16.43	3.11	2546
55.00	13.58	2.88	2358
60.00	11.28	2.65	2171
65.00	9.42	2.43	1987
70.00	7.92	2.21	1809
75.00	6.68	2.00	1640
80.00	5.67	1.81	1481
85.00	4.83	1.63	1333
90.00	4.13	1.46	1197
95.00	3.55	1.31	1073
100.00	3.06	1.17	961
105.00	2.65	1.05	859
110.00	2.31	0.94	768
115.00	2.01	0.84	687

### 2.3 Frequency-signal interface

Since current refrigerator applications mainly use frequency signals to control the compressor speed, the board is designed with a frequency-signal interface. Figure 20 shows the interface circuit. The input signal is isolated from the control and power parts on the board.

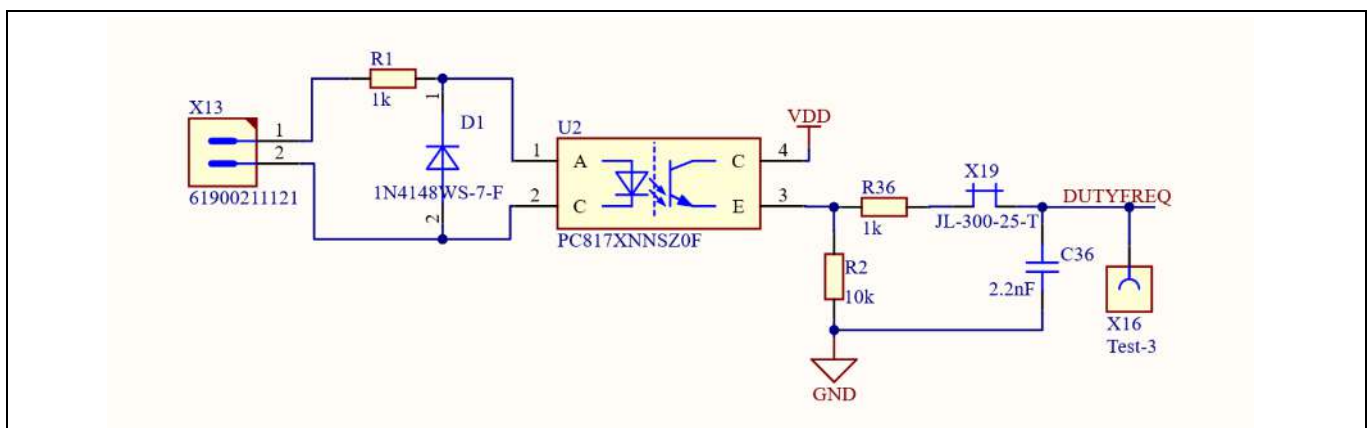


Figure 20 Frequency-interface circuit

A typical square-wave, input-control signal for refrigerator applications is shown in Table 6 for reference.

System and functional description

**Table 6** Typical frequency/speed characteristics

Signal frequency $f_n$ (Hz)	Motor speed $n$ (RPM)
$f_n < 30$	Stop
$30 \leq f_n < 40$	Minimum speed
$40 \leq f_n < 150$	$30 * f_n$
$150 \leq f_n < 200$	Maximum speed
$f_n \geq 200$	Stop

System design

### 3 System design

This section provides the complete details of the schematics, layout and connectors. Please note that the schematics, routing and Gerber files are done in Altium® Designer. Users who are interested in the original project files or pdf files can visit the website [www.infineon.com](http://www.infineon.com).

#### 3.1 Schematics

The major function blocks are introduced in Section 2.2. Users who are interested in further details can download the design files after logging in to the myInfineon account on the board's web page.

#### 3.2 Layout

The board is designed in a single layer, with dimensions of 115 mm × 105 mm. The board is manufactured with a copper thickness of 1 oz. (35 µm).

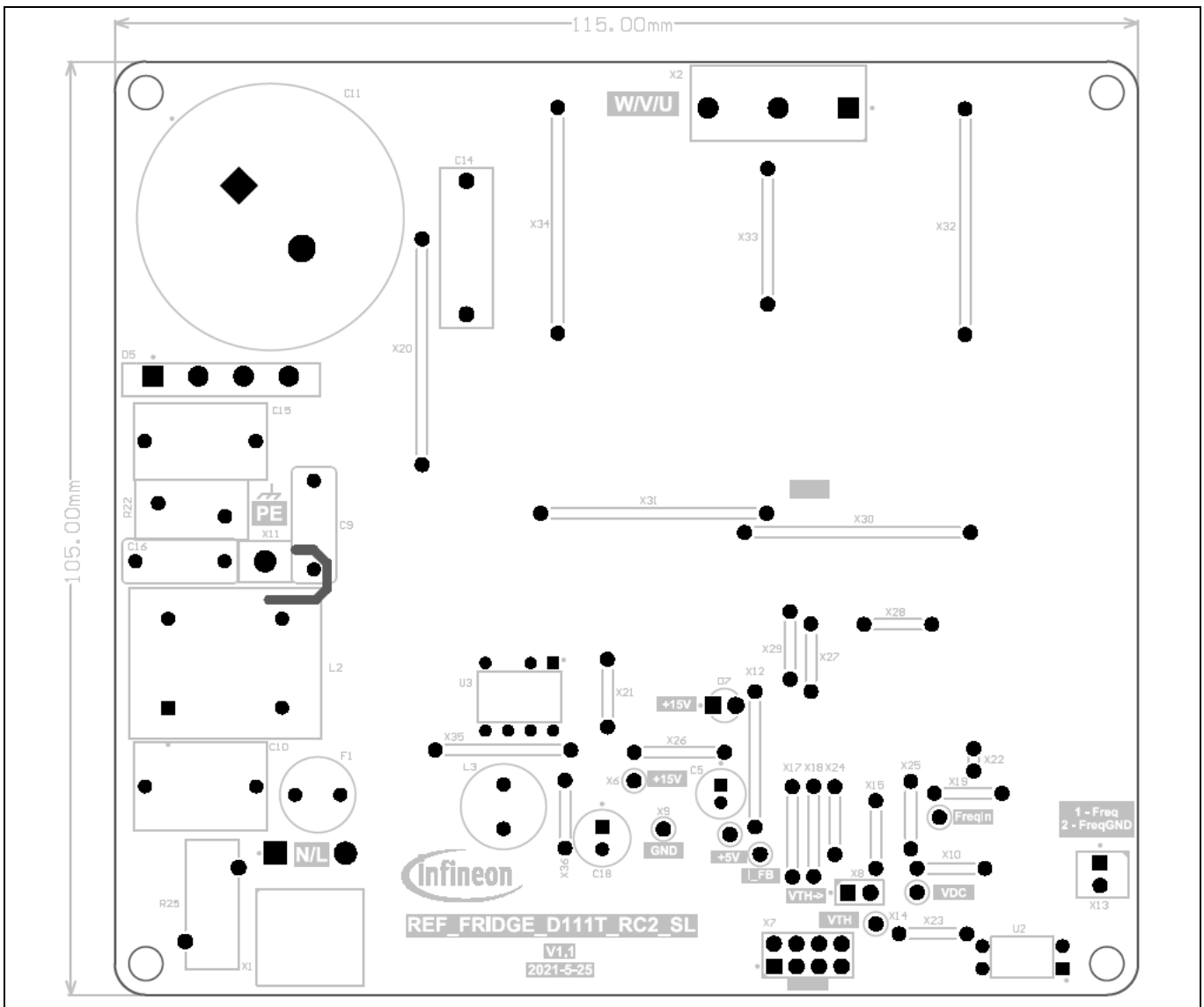
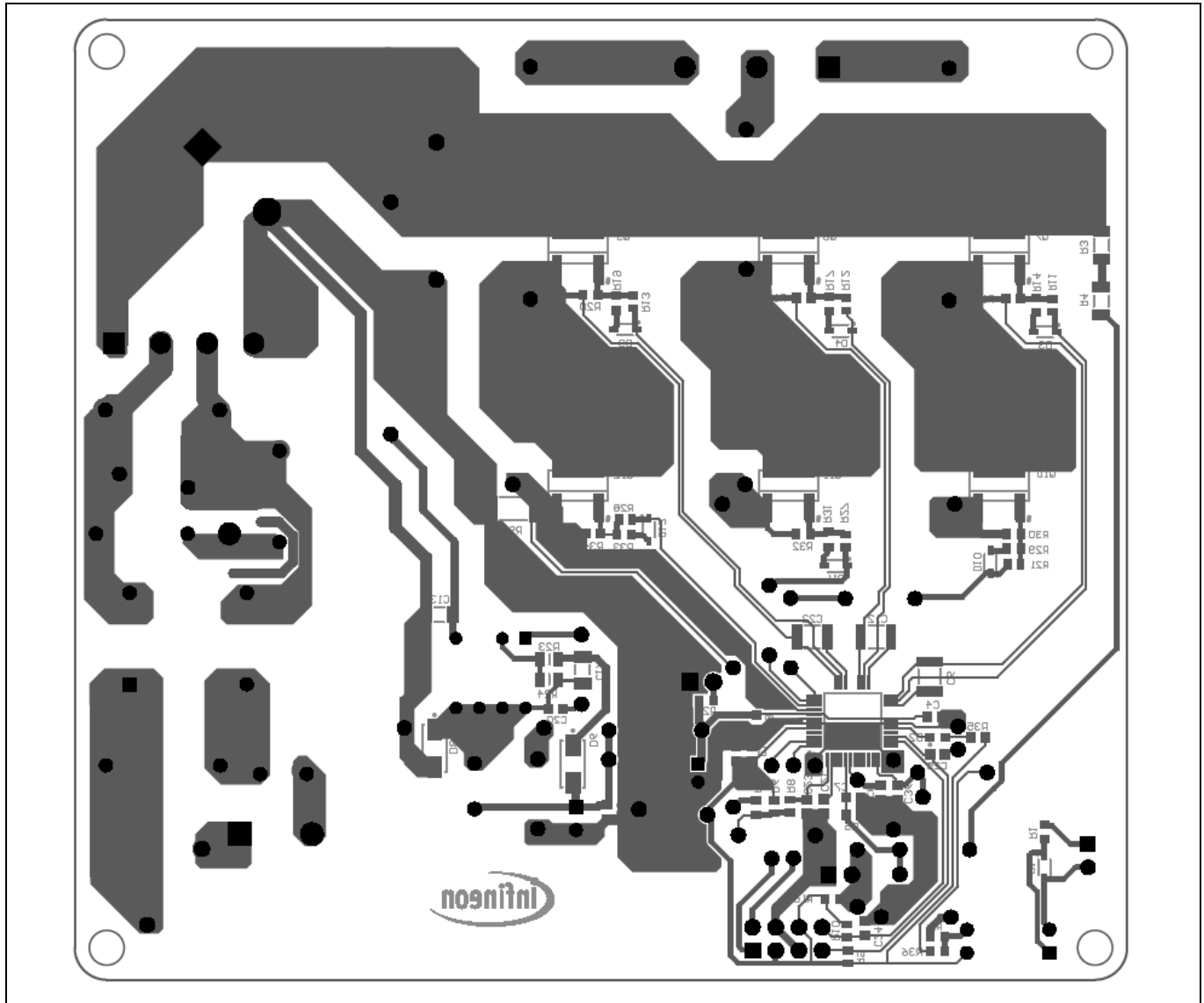


Figure 21 Top view of the board





**Figure 22** Bottom view of the board

Here are a few design tips to note for user reference:

- Thermal performance

Collector terminal of the IGBT is directly connected to the IGBT lead frame. Maximizing the copper area connected to the IGBT connector's pin can effectively reduce the IGBT junction temperature, so the board can deliver more power.

- Ground layout

Since current sampling is non-differential and is performed without additional operational amplifier, the ground area should be carefully designed; the digital ground should have a low-impedance connection to the shunt ground to ensure a proper sampling of the current.

### 3.3 Bill of material

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

System design

**Table 7 BOM of the most important/critical parts of the reference board**

S. No.	Ref Designator	Description	Manufacturer	Manufacturer P/N
1	U1	Motor controller with integrated high-voltage gate driver	Infineon Technologies	IMD111T-6F040
2	Q7, Q8, Q9, Q10, Q11, Q12	TRENCHSTOP RC-Series for hard switching applications, VCE 600 V, IC 4 A	Infineon Technologies	IKD04N60RC2
3	C10	CAP / FILM / 470 nF / 275 V / 10% / MKP (Metallized Polypropylene) / -40°C to 105°C / 12.50 mm C X 0.60 mm W 15.00 mm L X 10.00 mm T X 16.50 mm H / - / -	Würth Elektronik	890324024005
4	C11	CAP / ELCO / 220 µF / 450 V / 20% / Aluminium electrolytic / -25°C to 105°C / 10.00 mm Pitch X 30.00 mm Dia X 38.00 mm H / THT / -	Würth Elektronik	861141485017
5	C15	CAP / FILM / 330 nF / 275 V / 10% / MKP (Metallized Polypropylene) / -40°C to 105°C / 12.50 mm C X 0.60 mm W 15.00 mm L X 8.50 mm T X 14.50 mm H / - / -	Würth Elektronik	890324025017CS
6	C27, C28	WCAP-AT1H THT Aluminum Electrolytic Capacitors, D 16 mm x L 35.5 mm, 100 µF, +/-20%, 450 VDC	Würth Elektronik	860241480001
7	R22	RES / VDR / 470 V / 400 mW / 10% / - / -40°C to 85°C / 7.50 mm C X 0.80 mm W 12.50 mm L X 6.80 mm T X 16.00 mm H / - / -	Würth Elektronik	820513011

### 3.4 Connector details

**Table 8 X1- AC line connector**

PIN	Label	Function
1	L	AC line input
2	N	AC neutral input

System design

**Table 9 X2- Motor-side connector**

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 10 X7- iMOTION™ Link connector**

PIN	Label	Function
1	TXD1	User UART for script communication
2	RXD1	User UART for script communication
3 & 6	+3.3V	On board 3.3 V supply
4 & 5	GND	Ground
7	RXD0	MCEDesigner & firmware download
8	TXD0	MCEDesigner & firmware download

**Table 11 X11- Earth connector**

PIN	Label	Function
1	Earth	

**Table 12 X13- Frequency input signal connector**

PIN	Label	Function
1	Frequency input	Frequency input signal, isolated by optocoupler
2	Frequency ground	Frequency input signal ground, isolated by optocoupler

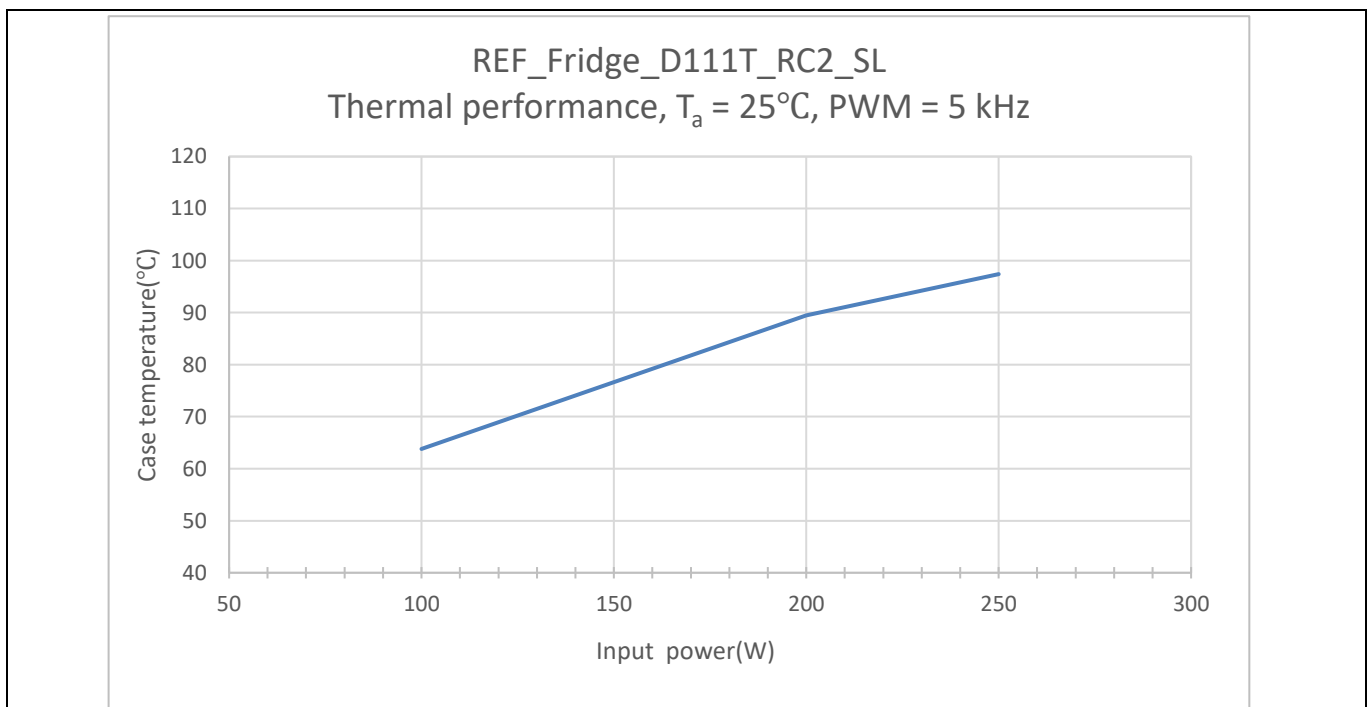
System performance

## 4 System performance

### 4.1 Thermal characterization

Figure 23 and Figure 24 show the thermal characterizations of REF\_Fridge\_D111T\_RC2\_SL, based on single layer FR4 PCB with 1 oz. copper.

The tests reported were performed under the following conditions:  $T_{amb} = 25^{\circ}\text{C}$ ,  $V_{ac} = 220\text{ V}$  and with different input power until the IGBT’s case temperature reaches  $100^{\circ}\text{C}$ . A 3-phase, pulse-width modulation strategy has been used with a carrier frequency of 5 kHz.

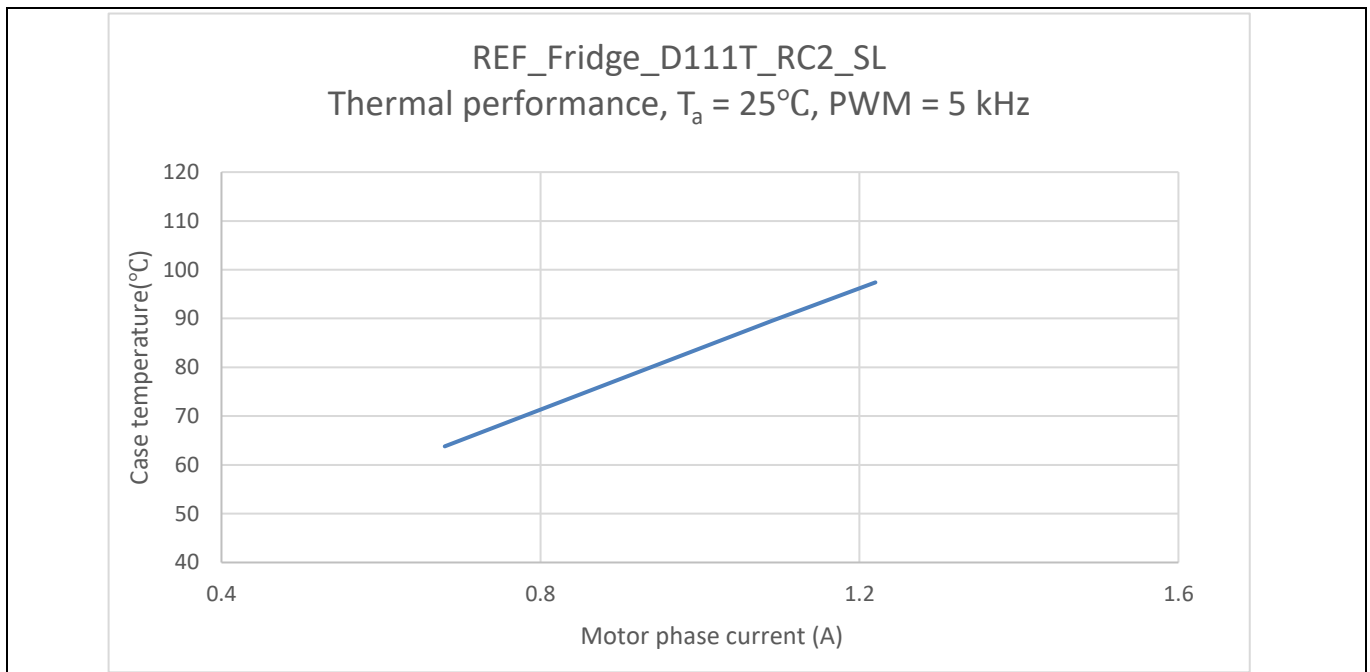


**Figure 23** REF\_Fridge\_D111T\_RC2\_SL thermal characterization case temperature - input power,  $t_a = 25^{\circ}\text{C}$ , PWM = 5 kHz

**Table 13** Input power and current characterization (PF = 0.56)

Input power (W)	100	200	250
Input current (A)	0.8	1.6	1.99

System performance



**Figure 24** REF\_Fridge\_D111T\_RC2\_SL thermal characterization, case temperature - motor phase current,  $t_a = 25^\circ\text{C}$ , PWM = 5 kHz

## 4.2 Electromagnetic interference (EMI) conducted

This section shows the conducted EMI of REF\_Fridge\_D111T\_RC2\_SL. Test limits follow the EN 55032 – conducted disturbance at the mains ports of class B ITE (information technology equipment).

**Table 14** Limits for conducted disturbance at the mains ports of class B ITE

Frequency range (MHz)	Limits (dB(μV))	
	Quasi-peak	Average
0.15 to 0.5	66 to 56	56 to 46
0.5 to 5	56	46
5 to 30	60	50

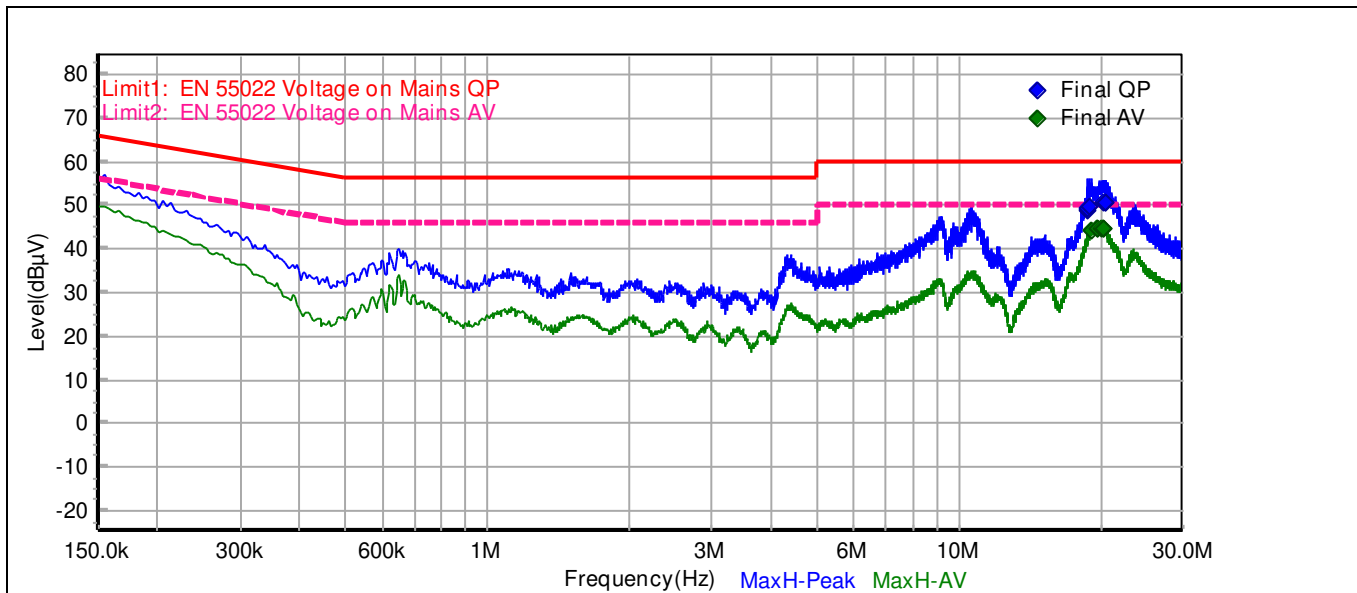
- Note:
1. The lower limit shall apply at the transition frequencies
  2. The limit decreases linearly with the logarithm of the frequency in the range 0.15 MHz to 0.50 MHz

A fan with 180 W rated power has been used as load motor for this test. The conducted EMI test was conducted under the four different combinations below.

1. AC L line, 100 W (light load)
2. AC L line, 180 W (heavy load)
3. AC N line, 100 W (light load)
4. AC N line, 180 W (heavy load)

**System performance**

The test results are listed in Figure 25 to Figure 28, and the final mark tables in Table 15 to Table 22, respectively. The user may notice that all the final measured values have a margin of more than 5 dB to the limits provided by the EN 55032 standard.



**Figure 25 AC L line, 100 W result chart**

**Table 15 Final mark table of quasi-peak value in Figure 25**

No.	Frequency (MHz)	Read Value (dBµV)	Factor (dBµV)	Measured Value (dBµV)	Limit (dBµV)	OverLimit (dB)	Detector	Measure Time (ms)
1	18.813900	38.70	10.30	49.00	60.00	-11.00	QP	1000
2	18.845550	39.08	10.30	49.38	60.00	-10.62	QP	1000
3	19.032170	39.50	10.25	49.75	60.00	-10.25	QP	1000
4	20.292600	40.42	10.23	50.66	60.00	-9.34	QP	1000
5	20.422830	40.47	10.24	50.71	60.00	-9.29	QP	1000
6	20.482200	40.20	10.25	50.45	60.00	-9.55	QP	1000

**Table 16 Final mark table of average value in Figure 25**

No.	Frequency (MHz)	Read Value (dBµV)	Factor (dBµV)	Measured Value (dBµV)	Limit (dBµV)	OverLimit (dB)	Detector	Measure Time (ms)
1	19.138100	33.90	10.23	44.13	50.00	-5.87	AV	1000
2	19.690630	34.28	10.23	44.51	50.00	-5.49	AV	1000
3	19.794400	34.43	10.23	44.66	50.00	-5.34	AV	1000
4	20.127760	34.65	10.23	44.88	50.00	-5.12	AV	1000
5	20.327130	34.59	10.23	44.83	50.00	-5.17	AV	1000
6	20.351350	34.59	10.23	44.83	50.00	-5.17	AV	1000

System performance

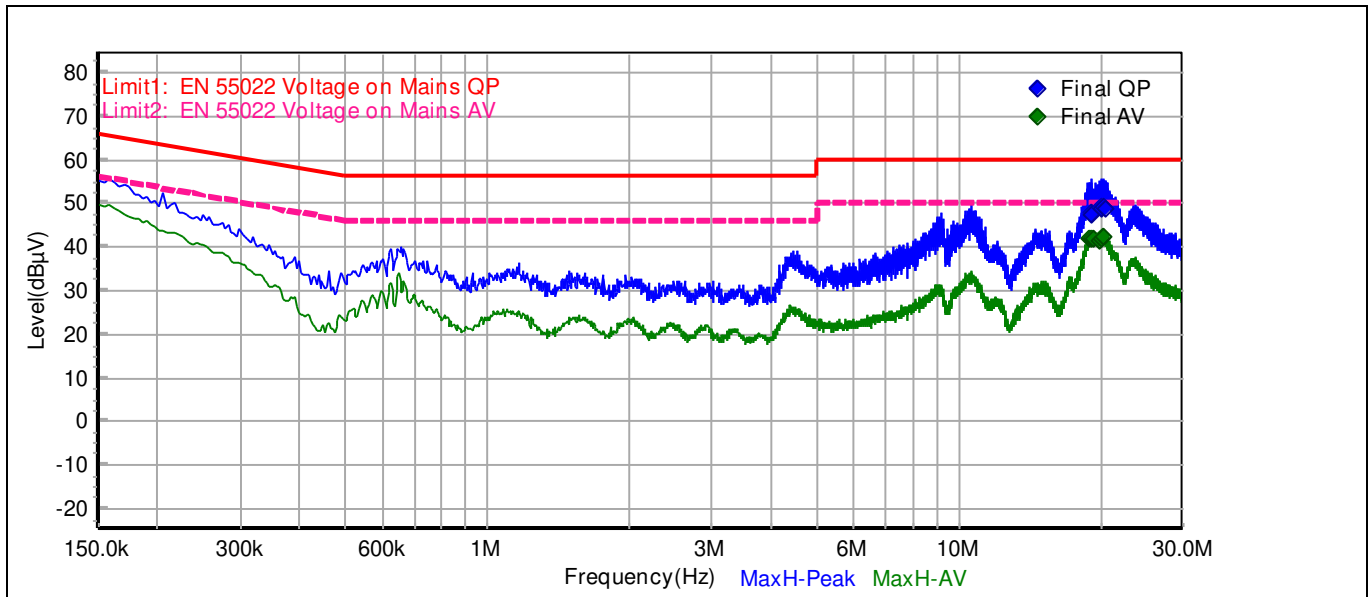


Figure 26 AC L line, 180 W result chart

Table 17 Final mark table of quasi-peak value in Figure 26

No.	Frequency (MHz)	Read Value (dBµV)	Factor (dBµV)	Measured Value (dBµV)	Limit (dBµV)	OverLimit (dB)	Detector	Measure Time (ms)
1	19.043860	37.78	10.24	48.03	60.00	-11.97	QP	1000
2	19.225150	37.34	10.22	47.56	60.00	-12.44	QP	1000
3	20.090370	38.83	10.23	49.06	60.00	-10.94	QP	1000
4	20.141420	38.72	10.23	48.95	60.00	-11.05	QP	1000
5	20.294830	38.92	10.23	49.15	60.00	-10.85	QP	1000
6	20.449000	38.67	10.24	48.91	60.00	-11.09	QP	1000

Table 18 Final mark table of average value in Figure 26

No.	Frequency (MHz)	Read Value (dBµV)	Factor (dBµV)	Measured Value (dBµV)	Limit (dBµV)	OverLimit (dB)	Detector	Measure Time (ms)
1	19.000500	31.59	10.26	41.85	50.00	-8.15	AV	1000
2	19.118290	31.73	10.23	41.96	50.00	-8.04	AV	1000
3	19.239310	31.67	10.22	41.90	50.00	-8.10	AV	1000
4	19.872120	31.28	10.23	41.51	50.00	-8.49	AV	1000
5	20.054190	31.71	10.23	41.94	50.00	-8.06	AV	1000
6	20.283510	31.97	10.23	42.20	50.00	-7.80	AV	1000

System performance

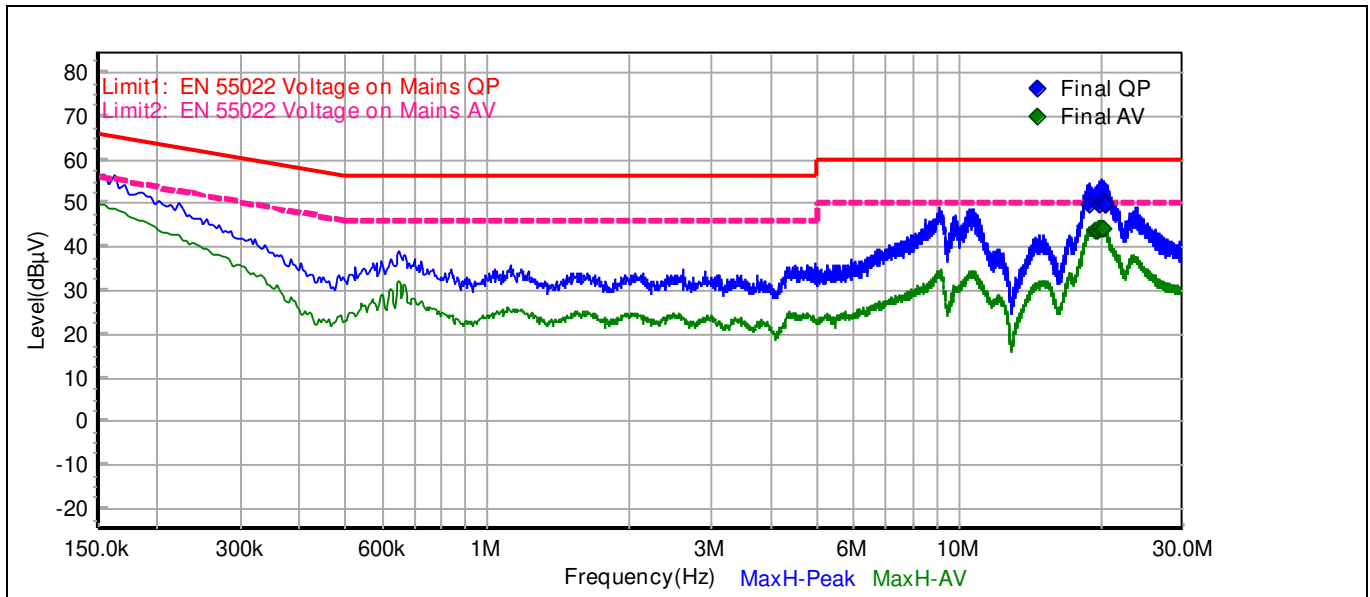


Figure 27 AC N line, 100 W result chart

Table 19 Final mark table of quasi-peak value in Figure 27

No.	Frequency (MHz)	Read Value (dBµV)	Factor (dBµV)	Measured Value (dBµV)	Limit (dBµV)	OverLimit (dB)	Detector	Measure Time (ms)
1	18.975650	39.28	10.27	49.55	60.00	-10.45	QP	1000
2	19.969040	39.37	10.23	49.60	60.00	-10.40	QP	1000
3	20.200190	39.93	10.23	50.16	60.00	-9.84	QP	1000
4	20.395600	39.83	10.24	50.07	60.00	-9.93	QP	1000
5	20.418530	39.67	10.24	49.91	60.00	-10.09	QP	1000
6	20.444660	39.71	10.24	49.95	60.00	-10.05	QP	1000

Table 20 Final mark table of average value in Figure 27

No.	Frequency (MHz)	Read Value (dBµV)	Factor (dBµV)	Measured Value (dBµV)	Limit (dBµV)	OverLimit (dB)	Detector	Measure Time (ms)
1	19.513210	33.58	10.23	43.81	50.00	-6.19	AV	1000
2	19.631230	33.62	10.23	43.85	50.00	-6.15	AV	1000
3	19.655210	33.73	10.23	43.95	50.00	-6.05	AV	1000
4	19.889460	33.96	10.23	44.19	50.00	-5.81	AV	1000
5	20.091340	34.15	10.23	44.38	50.00	-5.62	AV	1000
6	20.238820	34.06	10.23	44.29	50.00	-5.71	AV	1000



System performance

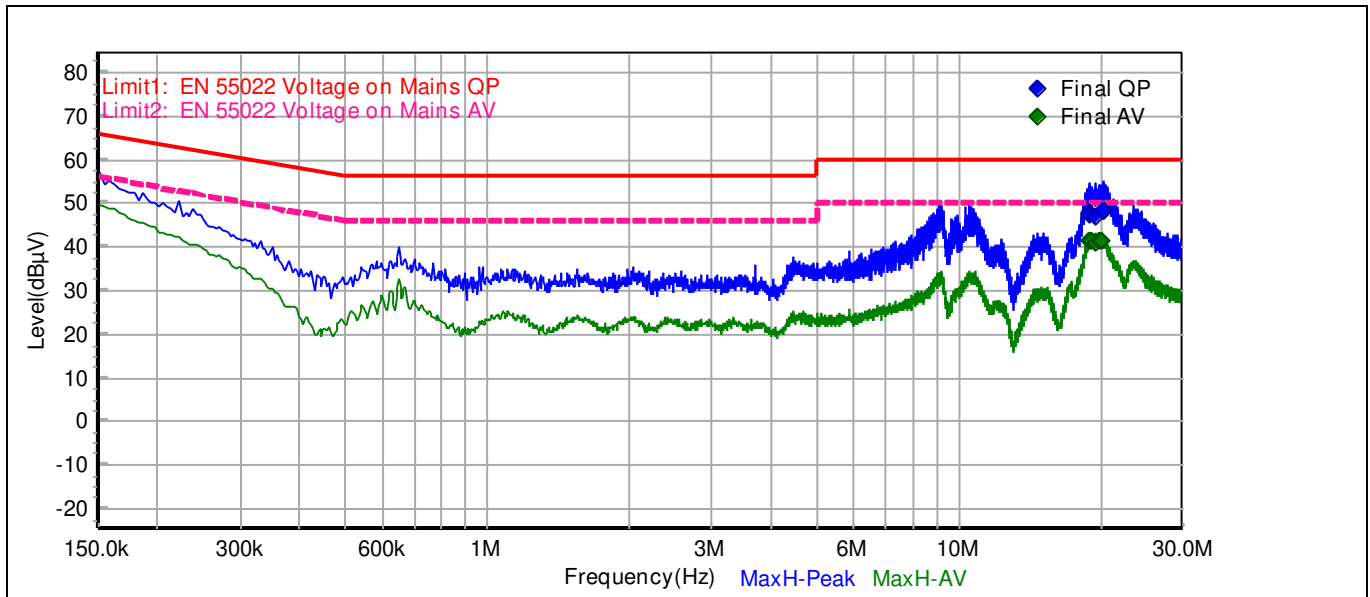


Figure 28 AC N line, 180 W result chart

Table 21 Final mark table of quasi-peak value in Figure 28

No.	Frequency (MHz)	Read Value (dBµV)	Factor (dBµV)	Measured Value (dBµV)	Limit (dBµV)	OverLimit (dB)	Detector	Measure Time (ms)
1	18.957720	37.63	10.28	47.90	60.00	-12.10	QP	1000
2	19.008700	37.38	10.26	47.64	60.00	-12.36	QP	1000
3	19.531730	36.77	10.23	46.99	60.00	-13.01	QP	1000
4	20.234720	38.21	10.23	48.45	60.00	-11.55	QP	1000
5	20.235070	38.30	10.23	48.53	60.00	-11.47	QP	1000
6	20.264600	38.29	10.23	48.52	60.00	-11.48	QP	1000

Table 22 Final mark table of average value in Figure 28

No.	Frequency (MHz)	Read Value (dBµV)	Factor (dBµV)	Measured Value (dBµV)	Limit (dBµV)	OverLimit (dB)	Detector	Measure Time (ms)
1	18.966560	31.32	10.27	41.60	50.00	-8.40	AV	1000
2	19.000130	31.33	10.26	41.59	50.00	-8.41	AV	1000
3	19.060220	31.27	10.24	41.51	50.00	-8.49	AV	1000
4	19.520510	30.98	10.23	41.20	50.00	-8.80	AV	1000
5	19.968470	31.05	10.23	41.28	50.00	-8.72	AV	1000
6	20.105740	31.32	10.23	41.55	50.00	-8.45	AV	1000

System performance

### 4.3 Electrical fast transient (EFT) test

EFT performance of REF\_Fridge\_D111T\_RC2\_SL has been verified based on test conditions below:

- Voltage peak: 4 kV
- Burst frequency: 5 kHz and 100 kHz
- Coupling path: L, N, PE, L+N, L+PE, N+PE, L+N+PE
- Duration: 120 s each

The board drives the motor normally during the test period, without any system crash/reset/damage.

### 4.4 IGBT dV/dt test

This section shows the waveforms of IGBT collector-emitter voltage ( $V_{CE}$ ) during turn-on and turn-off switching. The oscilloscope probe is connected as shown in Figure 29. The turn-on and turn-off gate resistances are  $R_{g(on)} = 510 \Omega$  and  $R_{g(off)} = 47 \Omega$ , respectively. The dV/dt is calculated considering the VCE variation from 10% to 90% of the bus voltage.

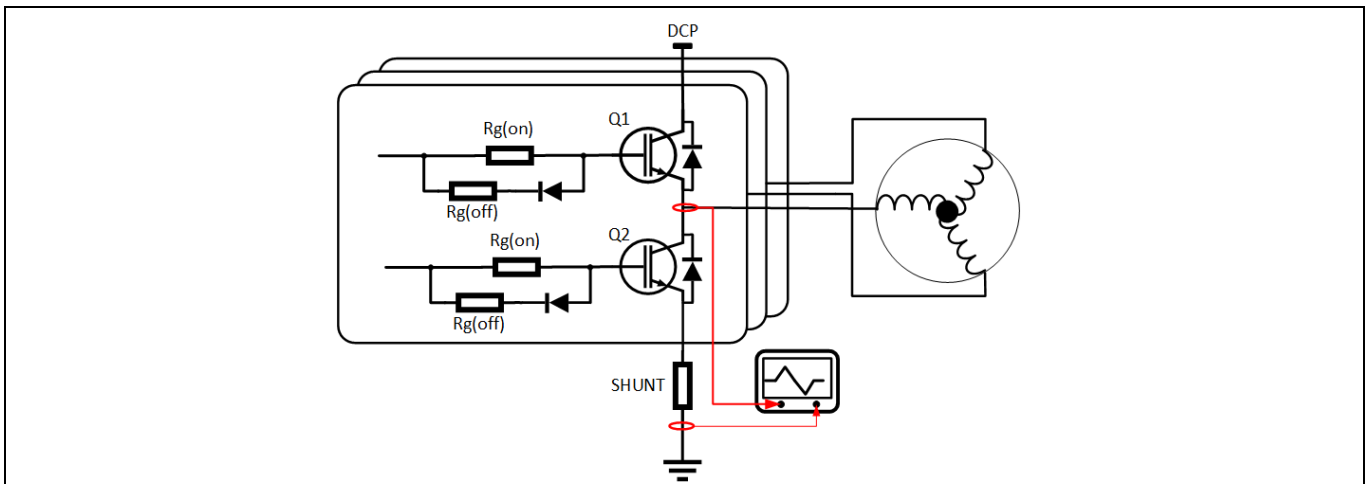


Figure 29 Drain-to-source voltage test - dV/dt control

As shown in Figure 30 and Figure 31, when the low-side IGBT turns on, the  $V_{CE}$  dV/dt is equal to 5.24 V/ns. When the low-side IGBT turns off, the dV/dt is 2.8 V/ns. Users may further adapt the  $R_g$  value to control IGBT's dV/dt if needed.

System performance

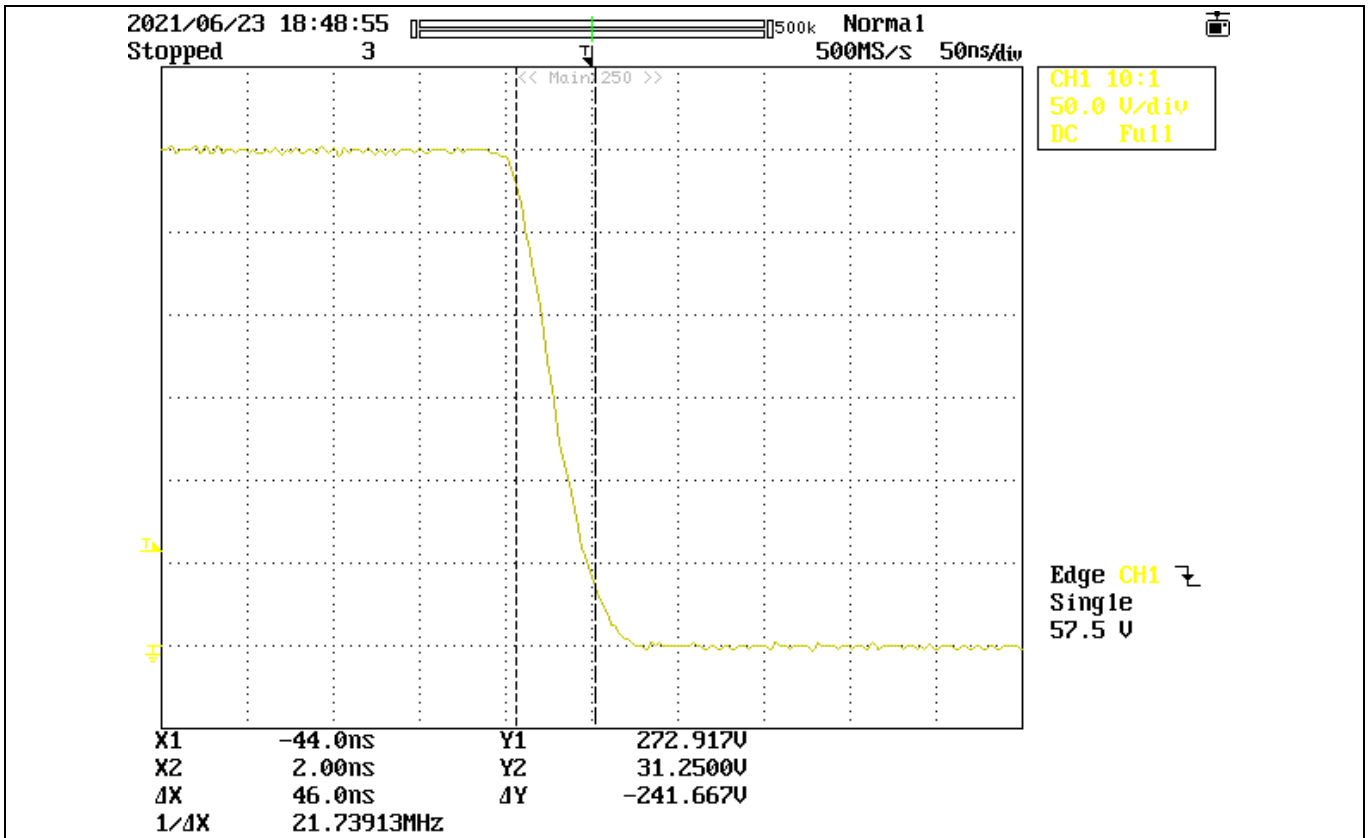


Figure 30 IGBT turn-on waveform

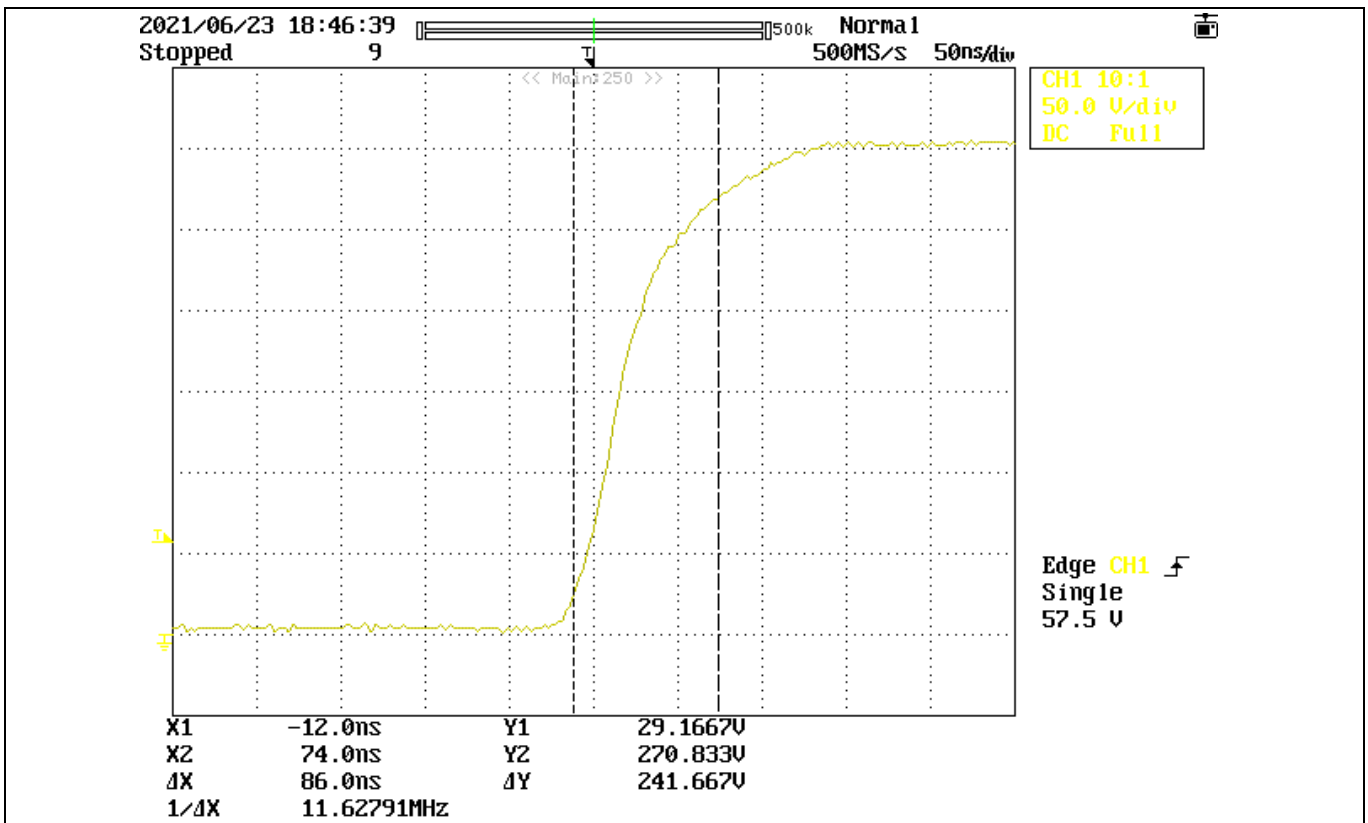


Figure 31 IGBT turn-off waveform

## 5 Reference and appendices

### 5.1 Abbreviations and definitions

**Table 23** Abbreviations

Abbreviation	Meaning
RC-D2	Reverse-conducting drive 2
CE	Conformité Européenne
EMI	Electromagnetic interference
UL	Underwriters Laboratories

### 5.2 References

- [1] Infineon Technologies AG. Datasheet of IKD04N60RC2 (2021) V1.0 [www.infineon.com](http://www.infineon.com)
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### 5.3 Additional information

In order to initiate testing, customers are advised to order the iMOTION™ Link; detailed information is listed in Table 24.

The Infineon components on the board are listed in Table 24 as well. The customers can visit the corresponding webpage for more information.

**Table 24** Additional information on tools and Infineon components

Base part number	Package	Standard pack		Orderable part number
		Form	Quantity	
<a href="#">iMOTION™ Link</a>		Container	1	IMOTIONLINK
<a href="#">IMD111T-6F040</a>	PG-LQFP-40	Tape and reel	1500	IMD111T6F040XUMA1
<a href="#">IKD04N60RC2</a>	PG-TO252-3	Tape and reel	2500	IKD04N60RC2ATMA1

Revision history

Revision history

Document version	Date of release	Description of changes
1.0	2021/07/29	Initial version
1.1	2022/02/10	Updated iMOTION™ Driver

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**Document reference**

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