

# REF\_Fridge\_C101T\_6ED 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\_C101T\_6ED 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\_C101T\_6ED board is a complete reference design board designed for refrigerator compressors. It demonstrates the entire Infineon solution including 600 V three-phase gate driver IC 6EDL04I06PT, 600 V RC-D2 IGBT IKD04N60RC2, digital motor control IC iMOTION™ IMC101T-T038 and linear voltage regulators IXF54211MB V33.

The REF\_Fridge\_C101T\_6ED board is developed to support customers in designing their refrigerator compressor drivers with Infineon products.

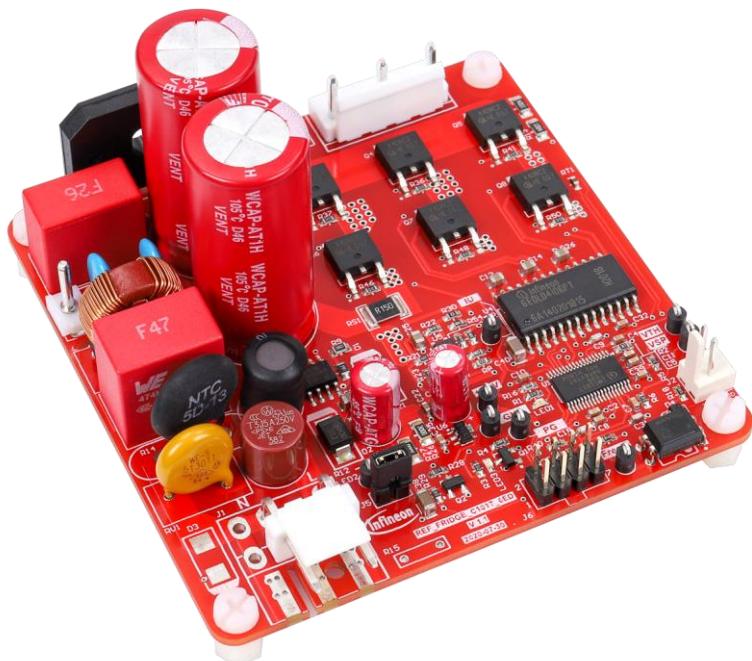
#### Intended audience

This user guide is intended for technical specialists working with the REF\_Fridge\_C101T\_6ED board and refrigerator compressor driver design.

#### Reference board/kit

Product(s) embedded on a PCB, with focus on specific applications and defined use cases that can include software. PCB 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.*



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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**

	<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.
	<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.
	<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.
	<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.
	<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.
	<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.
	<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.
	<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.
	<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.

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## 1 The board at a glance

The REF\_Fridge\_C101T\_6ED reference design kit is a part of the iMOTION™ reference design kit for motor drives, which is aimed at driver applications for refrigerator compressors. The kit is a ready-to-use solution in combination with Infineon products such as 600 V SOI three-phase gate driver IC 6EDL04I06PT, 600 V RC-D2 IGBT IKD04N60RC2, digital motor control IC iMOTION™ IMC101T-T038 and linear voltage regulator IFX54211MB V33. It can easily be switched to a final mass-production application board, and has a fast time to market.

The REF\_Fridge\_C101T\_6ED reference board is available from Infineon. The features of this board are described in Chapter 1.3 of this document (UG-2020-20). The remaining sections provide information to enable customers to copy, modify and qualify the design for production according to their own specific requirements.

Environmental conditions have been considered in the design of the REF\_Fridge\_C101T\_6ED. The design was tested as described in this document but 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 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). Reference boards are intended for use under laboratory conditions by specialists only.

### 1.1 Delivery content

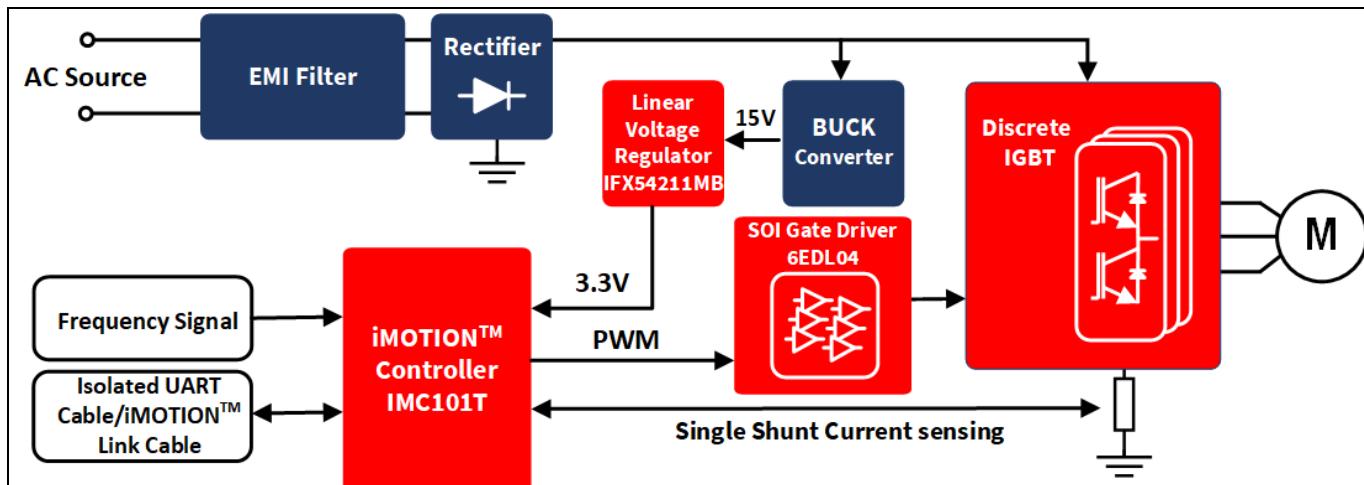
The delivery content only contains the board as shown in Figure 2; detailed ordering information is indicated in Table 2.

The iMOTION™ Link cable shown in Figure 4 is mandatory for tuning, and it is not included in the delivery content. Please order it if you have not already done so; ordering information can be found in section 5.3.

**Table 2 Delivery content**

Base part number	Package	Standard pack		Orderable part number
		Form	Quantity	
<a href="#">REF_Fridge_C101T_6ED</a>		Boxed	1	REFFRIDGECE101T6EDTOB01

### 1.2 Block diagram



**Figure 1 The block diagram of the REF\_Fridge\_C101T\_6ED reference board**

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Figure 1 shows the reference design kit REF\_Fridge\_C101T\_6ED. This document explains the features and details.

Figure 2 depicts the functional groups of the board. Connector definition details are described in section 3.4; please see this section if you need more information.

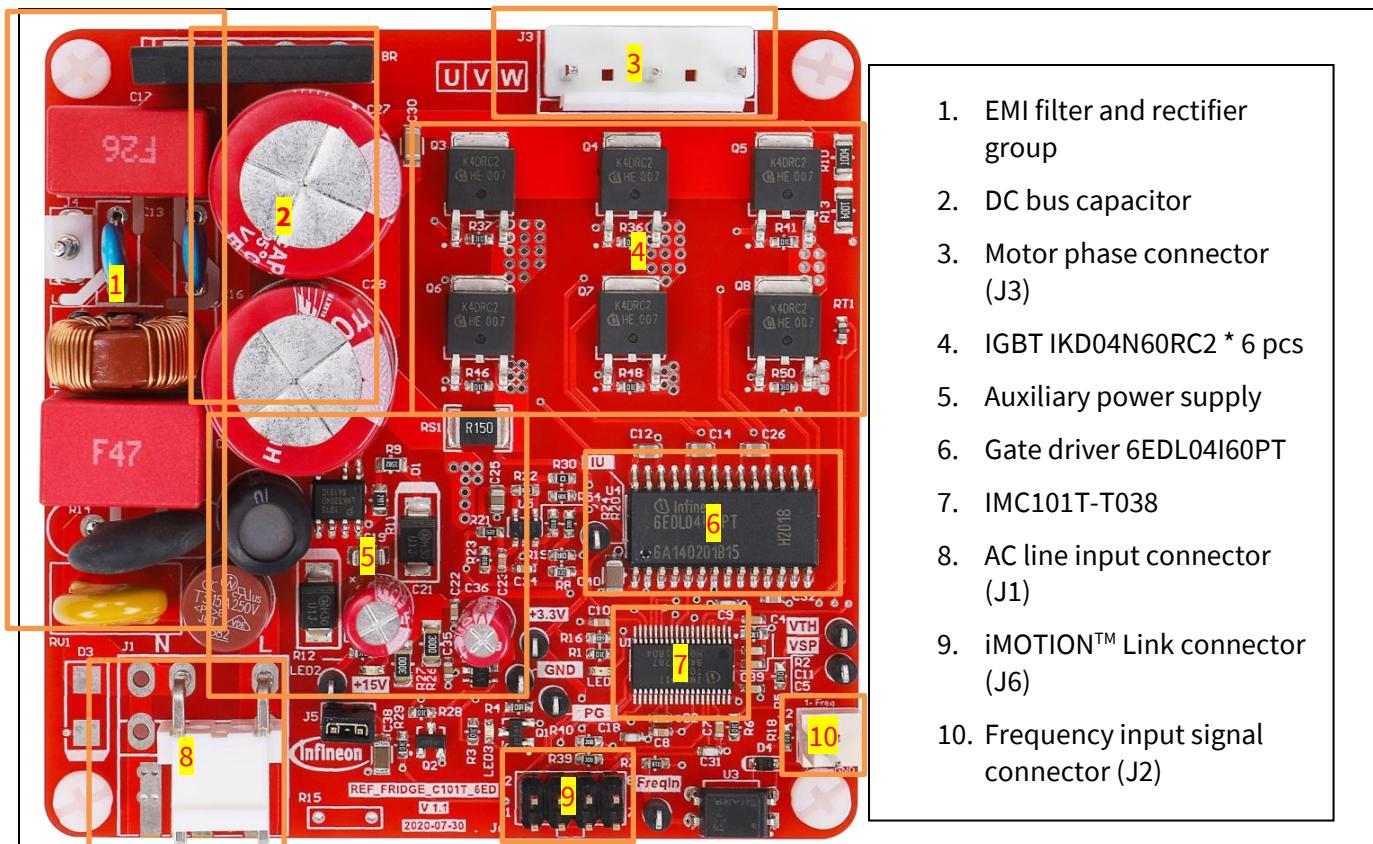


Figure 2 Functional groups on top side of board

### 1.3 Main features

REF\_Fridge\_C101T\_6ED is a complete reference design board for motor drive applications. The kit demonstrates Infineon's products for motor drives.

Main features of 6EDL04I60PT<sup>[1]</sup>:

- Thin-film SOI technology
- Maximum blocking voltage +600 V
- Separate control circuits for all six drivers
- CMOS and LSTTL-compatible input (positive logic)
- Signal interlocking of every phase to prevent cross-conduction
- Detection of overcurrent and undervoltage supply

## Refrigerator compressor driver reference design kit

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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:

- 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 classes range from 4 A to 15 A in DPAK

Main features of iMOTION™ controller IMC101T include [3]:

- Motion control engine as ready-to-use controller solution for sensorless and Hall-sensor motor drives
- Field-oriented control (FOC) for permanent magnet synchronous motor (PMSM/BLDC)
- Optional support for Hall sensors (analog or digital)
- Space vector PWM with sinusoidal commutation and integrated protection features
- Current sensing via single shunt or leg shunt
- Integrated analog comparators for overcurrent protection
- Integrated scripting engine for application flexibility
- 3.3 V or 5.0 V supply voltage options for controller
- Flexible host interface options for speed commands: UART, SPI, PWM or analog signal
- Class B pre-certification (IEC60335) for MCE2.0 firmware

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

## 1.4 Board parameters and technical data

Table 3 depicts the important specifications of the reference design REF\_Fridge\_C101T\_6ED.

**Table 3** REF\_Fridge\_C101T\_6ED board specifications

Parameter	Symbol	Conditions / comments	Value	Unit
Operation input voltage	$V_{ac}$	Lower AC input, less motor power output	165 ~ 265	$V_{rms}$
Maximum input current	$I_{ac(max)}$	Input 220 V <sub>AC</sub> , $T_a=25^\circ C$	1.5	$A_{rms}$
Maximum input power	$P_{in(max)}$	Input 220 V <sub>AC</sub> , $f_{PWM}=5$ kHz, $T_a=25^\circ C$ , $T_{case}=100^\circ C$ without heat sink	240	W
Maximum motor current	$I_{mtr(max)}$	Input 220 V <sub>AC</sub> , $f_{PWM}=5$ kHz, $T_a=25^\circ C$ , $T_{case}=100^\circ C$ without heat sink	0.66	$A_{rms}$
Maximum DC bus voltage	$V_{dc(max)}$		400	V
Shunt Resistance	$R_{sh}$		150	$m\Omega$

### Protection

Current protection trigger level	$I_{trip}$	Level by external comparator circuit	3.05 <sup>1</sup>	$A_{peak}$
Thermal protection level	$T_{protection}$	Temperature gap between IGBT's case and NTC (negative temperature coefficient) sensor needs to be considered; recommended is a setting of 105°C	105	°C

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Parameter	Symbol	Conditions / comments	Value	Unit
		for the case temperature, considering the gap, set about 75°C in the MCEWizard.		

#### Auxiliary power supply 1 - 15V

Output voltage	$V_{out1}$		$15 \pm 5\%$	V
Maximum output current	$I_{out1}$		100	mA

#### Auxiliary power supply 2 - 3.3V

Output voltage	$V_{out2}$		$3.3 \pm 5\%$	V
Maximum output current	$I_{out2}$		150	mA

#### PCB characteristics

Dimension		Length × width × height	78×78×46	mm
Material		1.6 mm thickness, 1 oz. copper	FR4	

#### System environment

Ambient temperature	$T_a$	Non-condensing, maximum RH of 95%	0 ~ 50	°C
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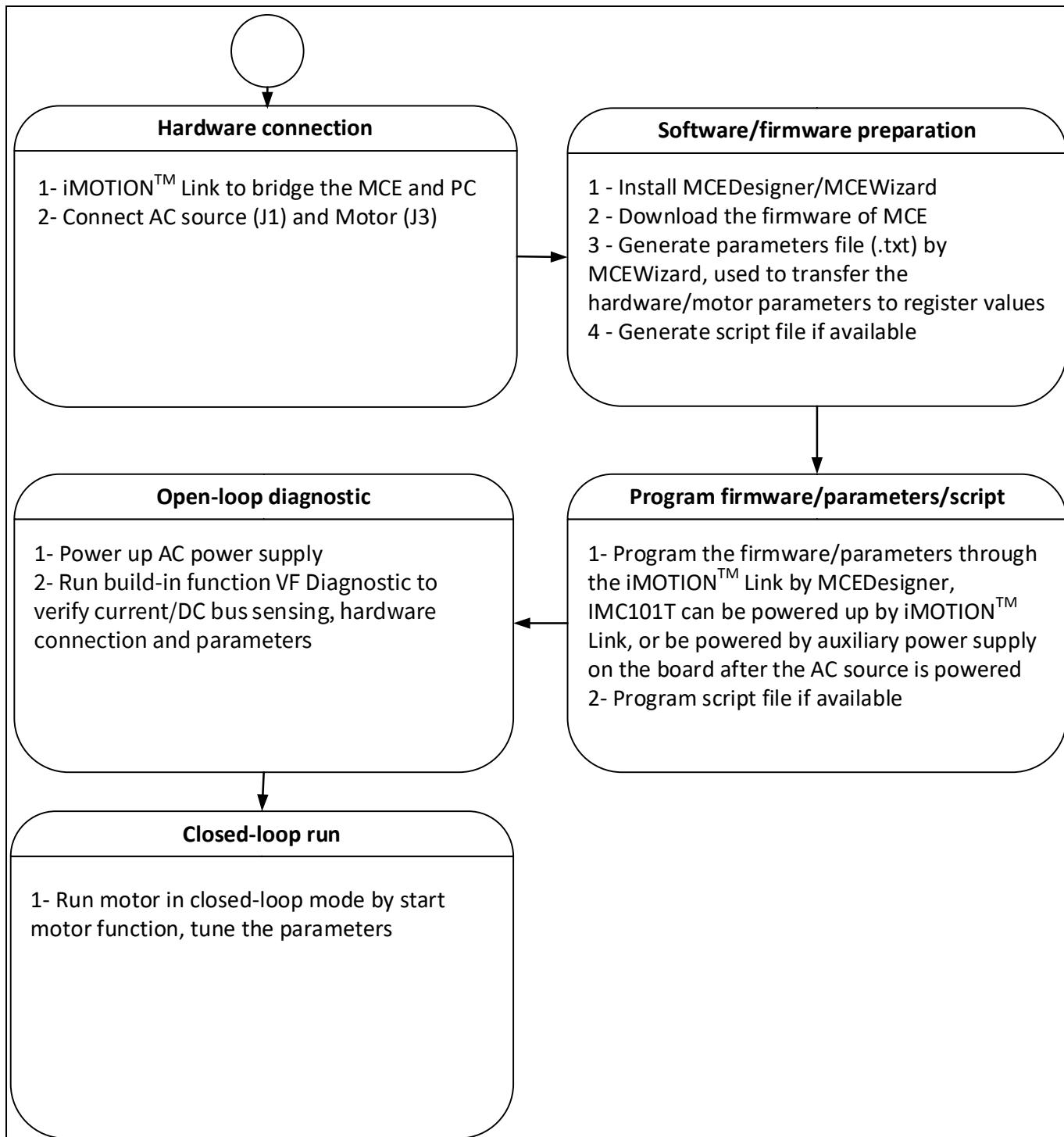
Note:

1. For iMOTION™ IC IMC1xx, there are three types of Gatekill input source options in MCEWizard setup. If "comparator" mode is selected, the external Gatekill signal will not be used, and the signal  $V_{Shunt}$  will be compared by the internal comparator with the "Device overcurrent trigger level setting" value set in MCEWizard.

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## 2 System and functional description

### 2.1 Commissioning



**Figure 3 Basic process for running the motor the first time**

This section describes how to get the system working when user first installs the board (refer to Figure 3 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 requirements, please refer to the MCE reference manual or the corresponding reference material <sup>[6][7][8]</sup>.

# Refrigerator compressor driver reference design kit

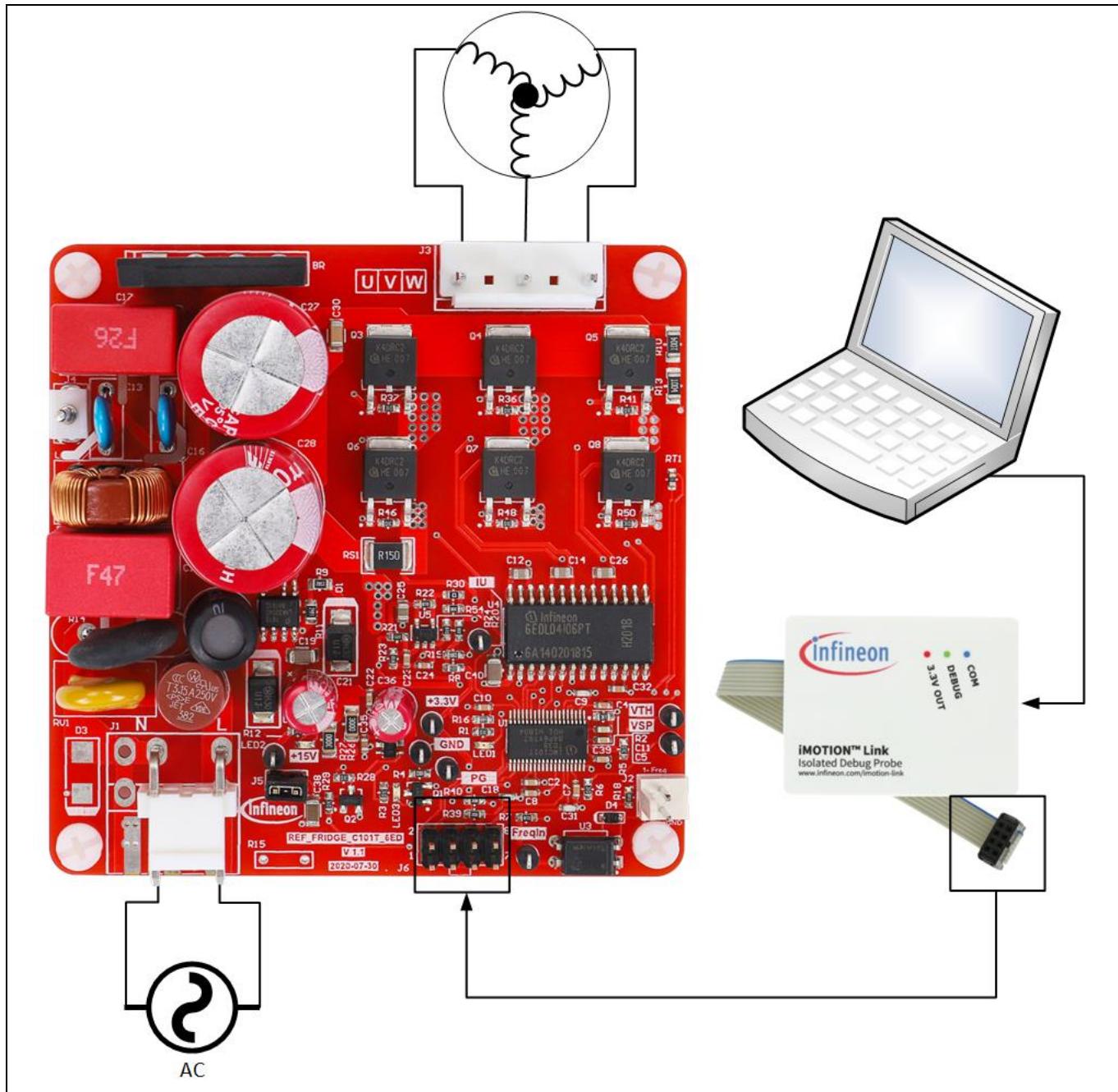
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### 2.1.1 Hardware connection

Figure 4 shows the hardware connection details for the reference design board.

The [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 J6 with default pin order, and connect PC and iMOTION™ Link with the USB wire.
2. Then connect AC power supply (J1) and the motor (J3).



**Figure 4**      **Hardware connection details**

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### 2.1.2 Software/firmware preparation

1. The iMOTION™ software tools MCEDesigner and MCEWizard are required in order 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 (<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'), the 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.
  - 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 7); 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 tuning the board for the first time, it is recommended not to use this function first, but to add the script function after the motor commissioning is completed.

### 2.1.3 Program firmware/parameters/script

The REF\_Fridge\_C101T\_6ED reference design kit is shipped with pre-programmed firmware and default parameters, since the functional tests were done before shipment. Users need to program their parameters, as the motor is different from the one under test.

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

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

Or

- Program the combined file, which is combined by MCEWizard containing 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.

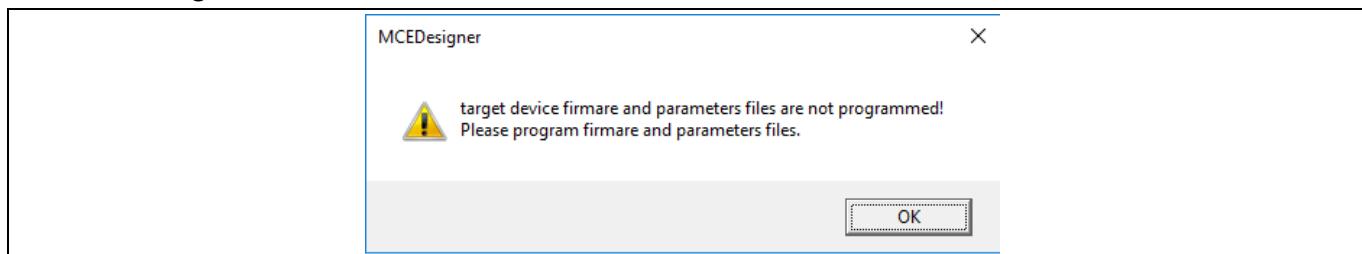
The programming process is as follows:

1. Start the MCEDesigner tool and open MCEDesigner default configuration file (.irc) for IMC101T device (IMC101T\_Vxxx.irc) by clicking "File" > "Open".

**Note:** *The IMC101T\_Vxxx.irc file is included in the downloaded firmware package "IMC101T MCE Software Package."*

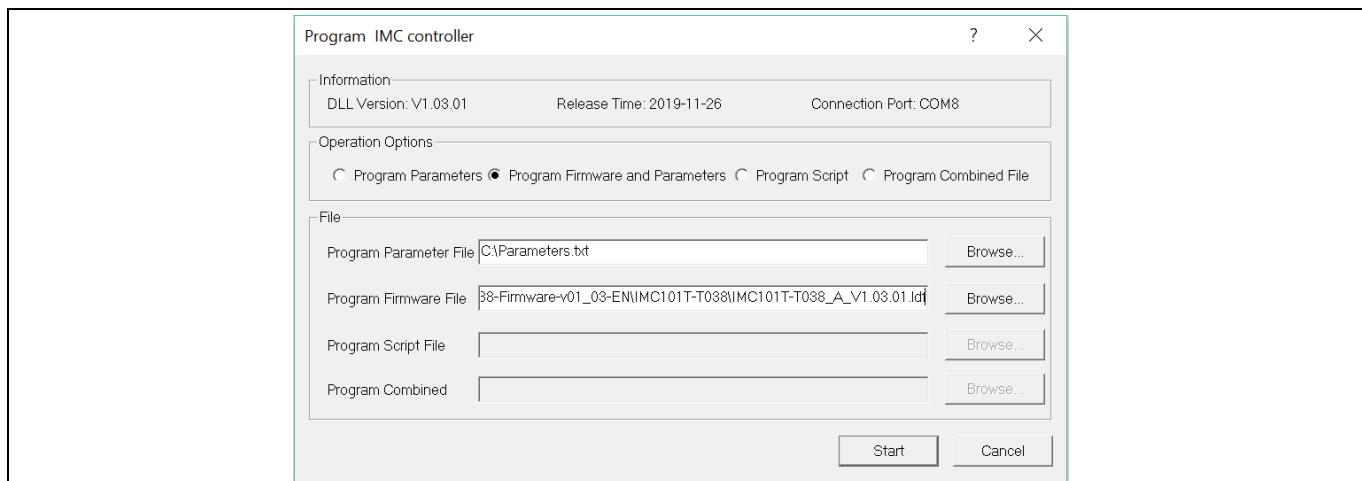
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2. Power the iMOTION™ control IC with 3.3 V. It is recommended to program the IC with the 3.3 V isolated power supply that comes from the iMOTION™ Link. There is a switch on the iMOTION™ Link to enable the 3.3 V output. The iMOTION™ control IC will also be powered by the onboard auxiliary power supply after the AC source is powered, but caution due to high voltage.
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 COM port by doing 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 the case of a blank IC) If the firmware has been erased from the IMC101T, the following warning message will pop up "Target device firmware and parameters file are not programmed! Please program firmware and parameters file" as Figure 5. Then you can program as described in the step 5. If it is not the blank IC, no such message will be indicated.



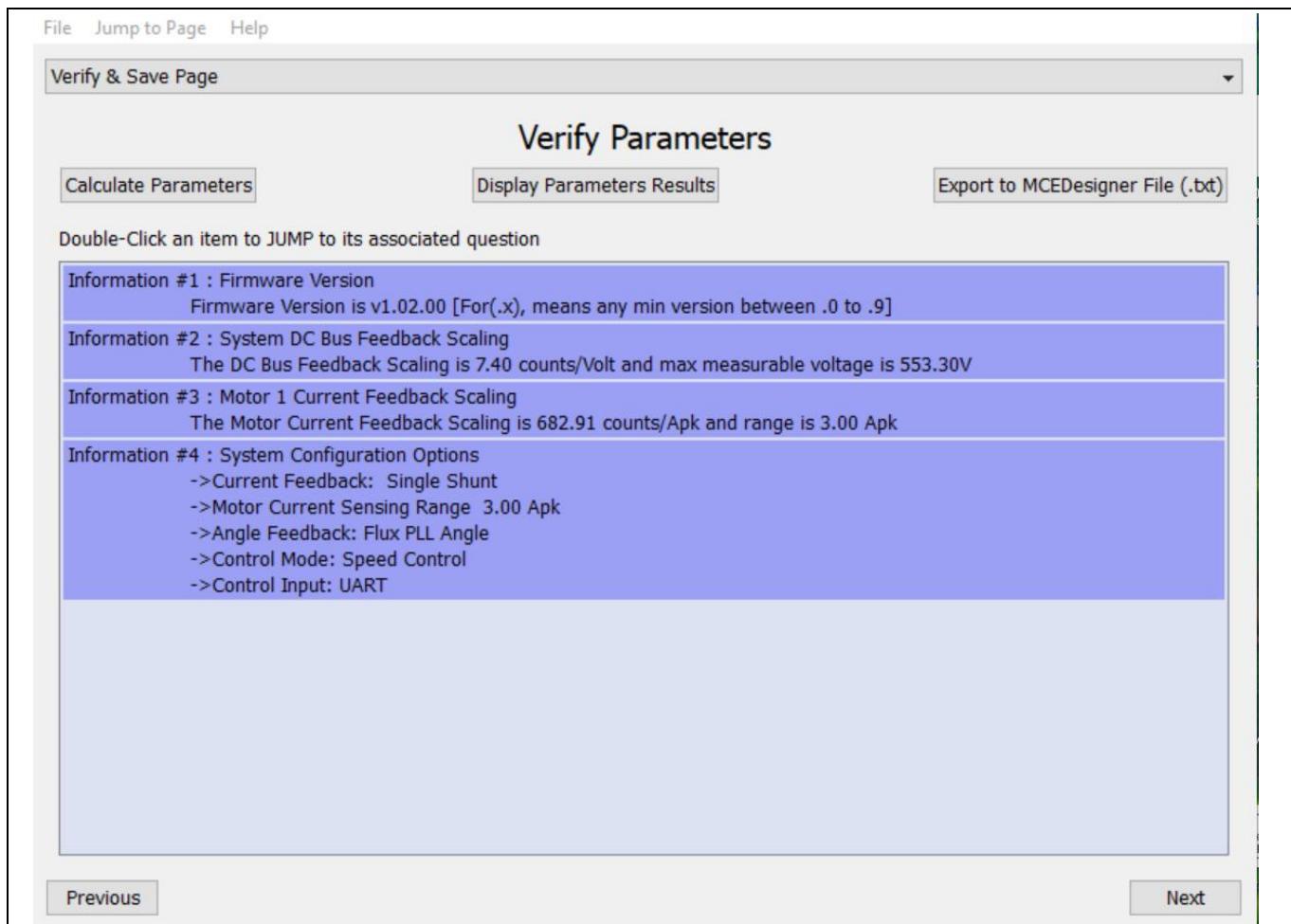
**Figure 5 MCEDesigner warning message**

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 6 below. The encrypted firmware is available at "IMC101T MCE Software Package;" regarding the parameters' file, browse and select the '.txt' file in Section 2.1.2.



**Figure 6 Program the parameters and firmware**

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**Figure 7 MCEWizard verify and save page**

### 2.1.4 Open-loop diagnostic

Double click the “VF Diagnostic” function in motor1 page, and monitor the motor current with oscilloscope. If the motor current is not sinusoidal, change the TargetSpeed and Vd\_Ext in 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.

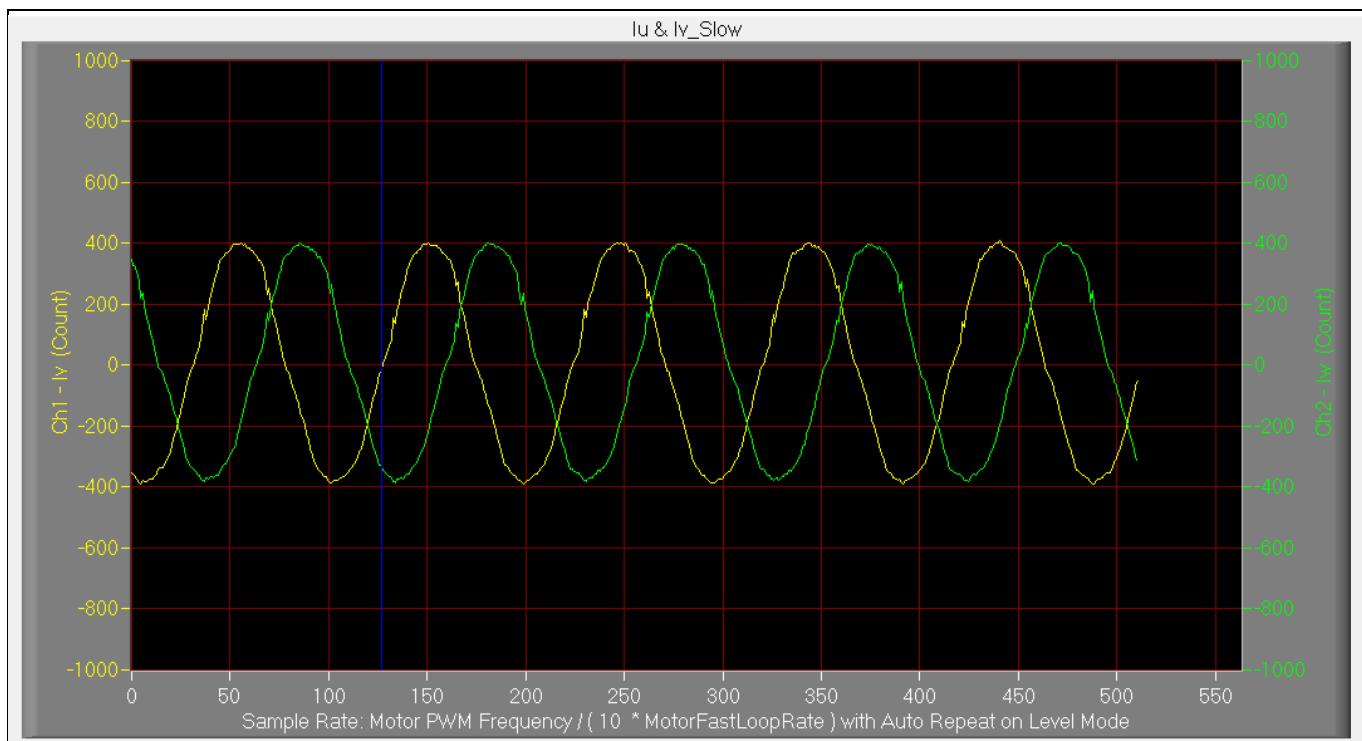
Double click “Iu & Iv\_Slow” in System page - Monitor Definitions. The motor current feedback should be very clean and sinusoidal, as shown in Figure 8; otherwise please tune “Gating Propagation Delay & Phase Shift Window Size” in MCE Wizard.

“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 has been done correctly

After the “VF Diagnostic” is done, click STOP button (the red traffic light button) or run “Stop Motor” function to stop the motor.

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**Figure 8** Trace waveform for Iu & Iv open loop diagnostic

### 2.1.5 Closed-loop run

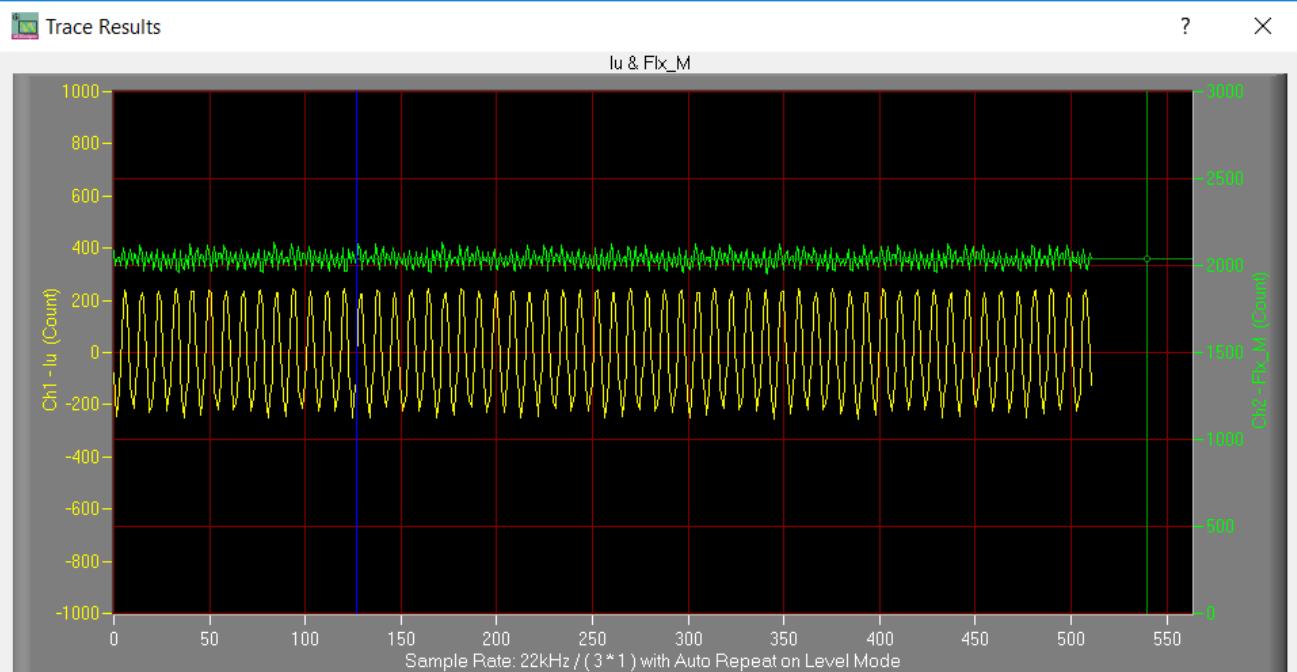
If the VF Diagnostic works correctly, the hardware circuit and signal sampling will work normally, at which point you can try to run the motor in a closed-loop mode. The steps are listed below.

1. Start the motor by clicking the green traffic light button in the control bar (or double-click "Start Motor" function on Motor1 page, which is in the group of user application function definitions). The motor will run if the above step works well.
2. Check the motor spin direction, adjust the motor winding's connection order, or set negative TargetSpeed in MCE Designer if the direction is wrong.
3. Set TargetSpeed to about 50% of maximum speed, start "Iu & Flx\_M" trace with "Auto Repeat On Level," see Figure 9. 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), the motor parameters, speed loop PI gain, flux Estimator time constant and PLL PI bandwidth (parameters PLLKp & PLLKi) and related setup need to be checked.
- If Flx\_M is very noisy, the current feedback and V<sub>dc</sub>-related hardware and parameters need to be checked.
- If Flx\_M does not come close to 2048, the "Motor Back EMF Constant (Ke)" needs to be adjusted in MCE Wizard.

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**Figure 9 Trace waveform for Iu & Flx-M at 50% Speed**

- Once the firmware has been programmed, and a new parameter file has to be programmed, follow the same instructions given in 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 section

The inverter section is implemented using the new generation IGBT RC-D2; its part number is IKD04N60RC2<sup>[1]</sup>. 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.

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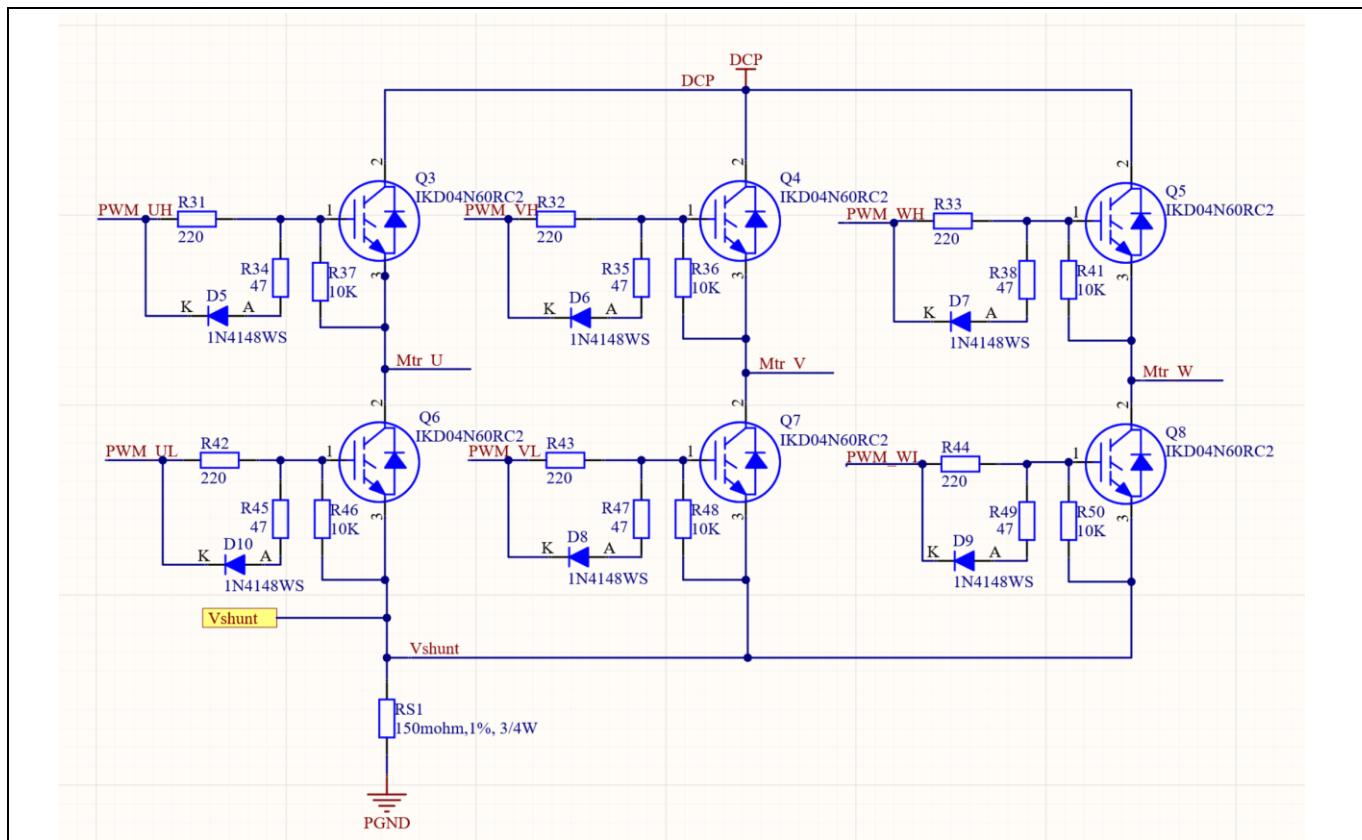


Figure 10 Inverter section circuit

## 2.2.2 Gate driver

6EDL04N60PT is a three-phase gate driver with overcurrent (OCP), enable (EN), fault and integrated bootstrap diode (BSD). It is based on the SOI technology, which means there is an excellent robustness in terms of transient voltages.

The configuration of the 6EDL04N60PT is depicted in Figure 11. For more details, please refer to the reference material<sup>[2]</sup>.

VCC (pin 1) is the power supply of the 6EDL04N60PT, which provides power to both logic input and to low-side output power stage. It is recommended to place C40 near pin1, and its value should exceed C12/C14/C26.

EN (pin 10) is directly pulled up by a resistor, so the IC is always enabled on the board.

FAULT pin (pin 8) is connected to the GK pin of the controller IMC101T-T038. When the overcurrent protection (Itrip, pin 9) is triggered, the FAULT pin will be pulled down so that the IMC101T-T038 will receive the fault signal. Please refer to section 2.2.4 for more information about the overcurrent protection.

RCIN (Pin 11) input/output pin is used to determine the reset time of the fault condition<sup>[2]</sup>.

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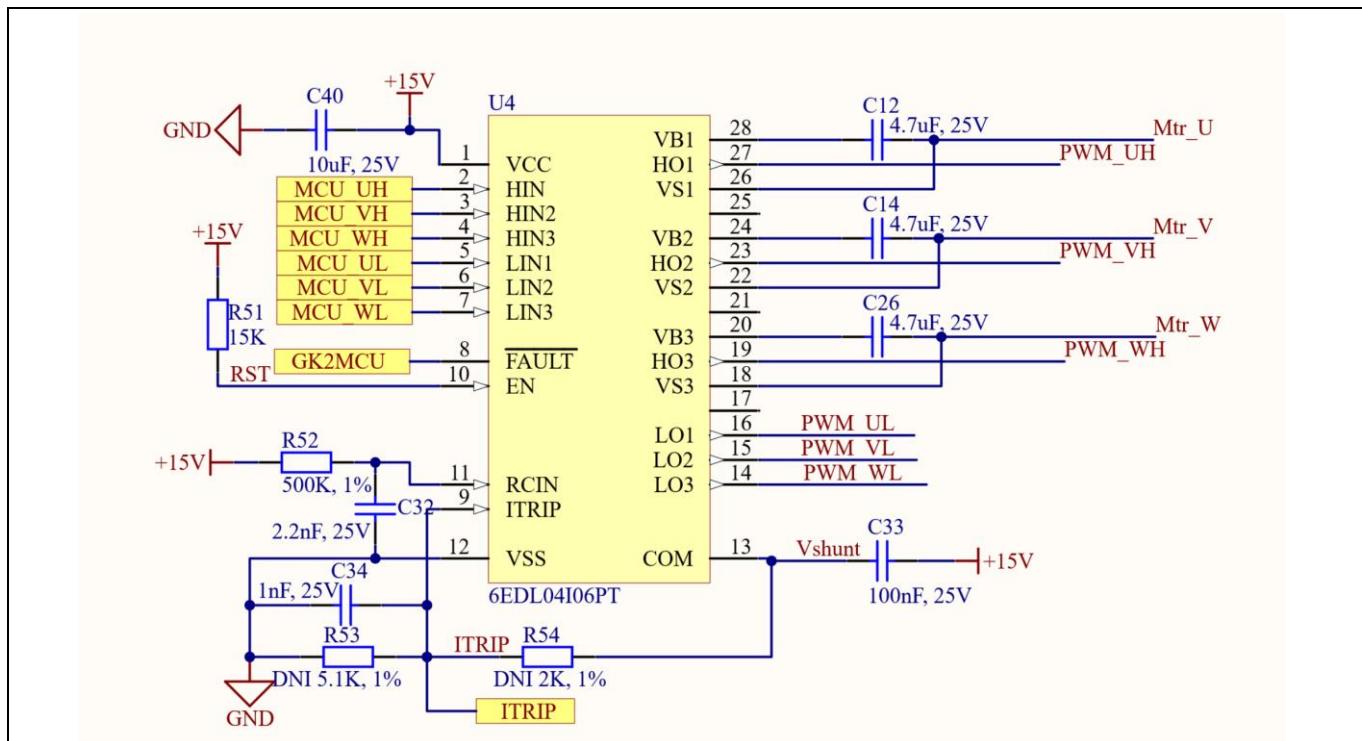


Figure 11 Gate driver part

## 2.2.3 DC bus sensing and MCEWizard configuration

Figure 12 provides the DC bus sensing resistor details on the reference design.

The high-side resistors are  $2\text{ M}\Omega$  and the low-side resistor is  $13.3\text{ k}\Omega$ . The default DC bus-sense voltage results in a range of 0 to 3.3 V on the ADC input reflecting a range of 0 to 500 V.

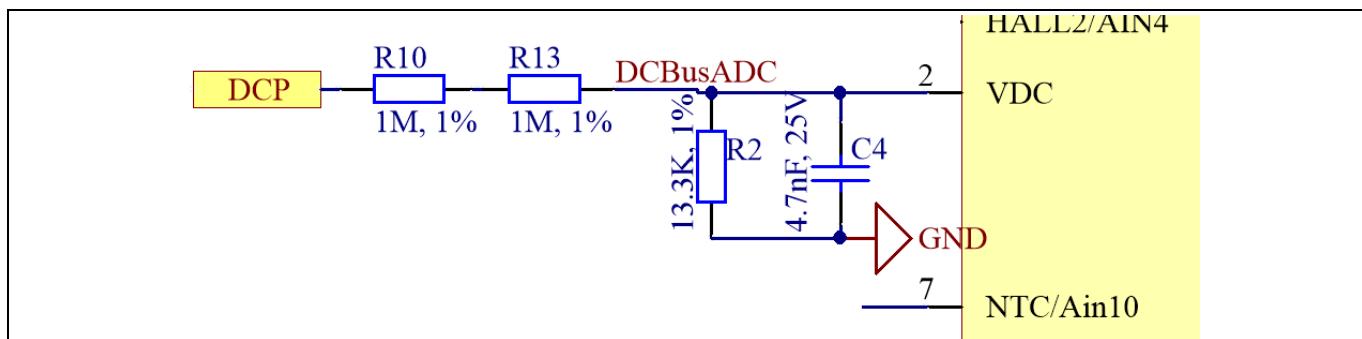
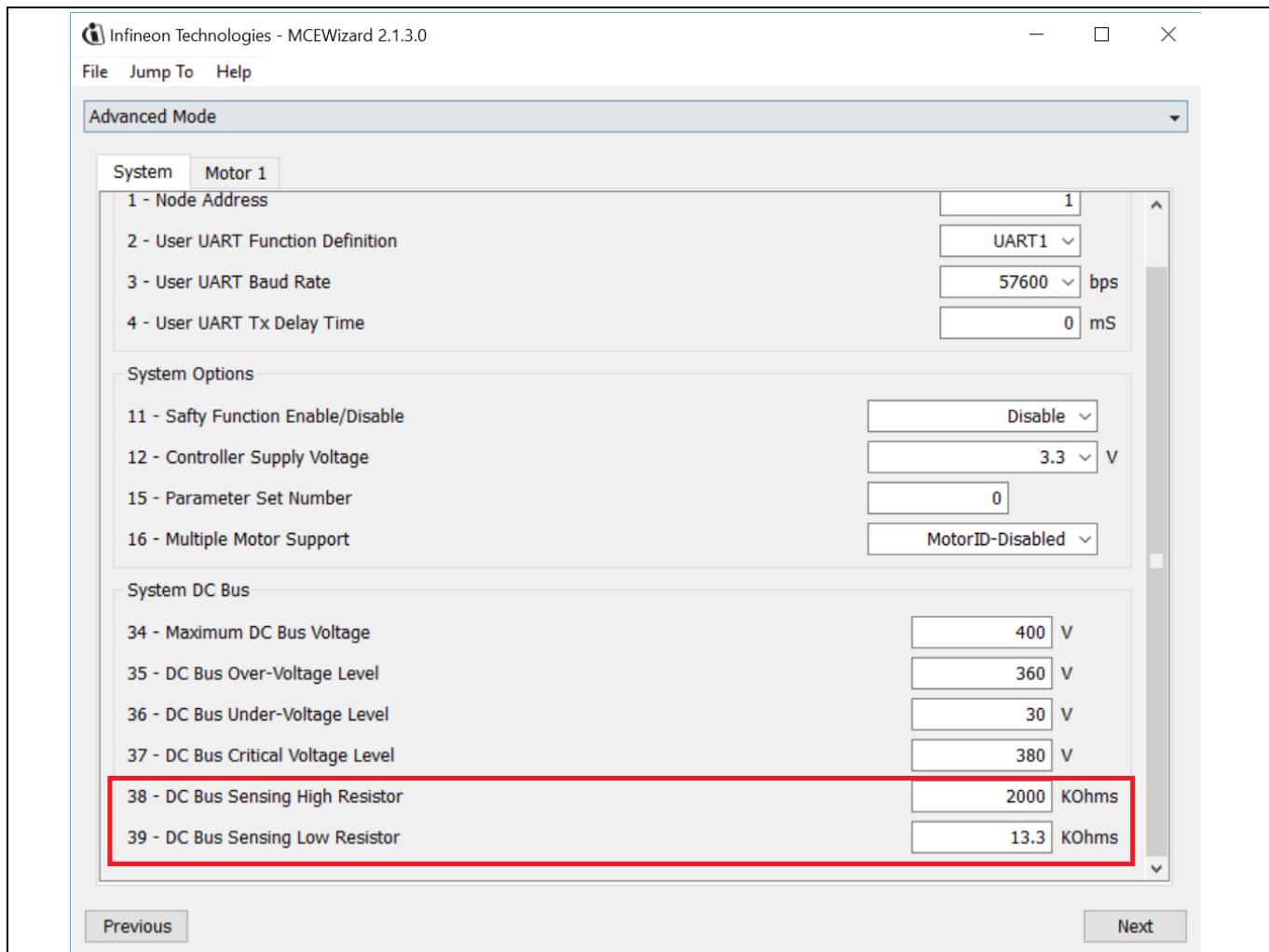


Figure 12 DC bus sensing part

The hardware parameters need to be configured in MCEWizard as show in Figure 13.

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**Figure 13 DC bus sensing configuration in MCEWizard**

The time constant of the  $V_{dc}$  sensing low pass filter is  $((R10 + R13) // R15) * C4 = (2 M\Omega // 13.3 k\Omega) * 4.7 nF = 62.1 \mu s$ . C17 can be adjusted to higher capacitance for clean  $V_{dc}$  sensing.

## 2.2.4 Current sensing and overcurrent protection

### 2.2.4.1 Current sensing

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

Based on the principle of Kirchhoff's voltage law, and assuming the AD port input impedance is infinite, you obtain the equation below:

$$V_{ADC} = \frac{(V_{cc} - V_{shunt})}{R_1 + R_2} * R_1 + V_{shunt}$$

The equation can be transformed to two parts as shown here:

$$V_{ADC} = \frac{R_2 * V_{shunt}}{R_1 + R_2} + \frac{R_1 * V_{cc}}{R_1 + R_2}$$

The impedance of the RC network is much larger than the  $R_{shunt}$ , so it can be assumed that:

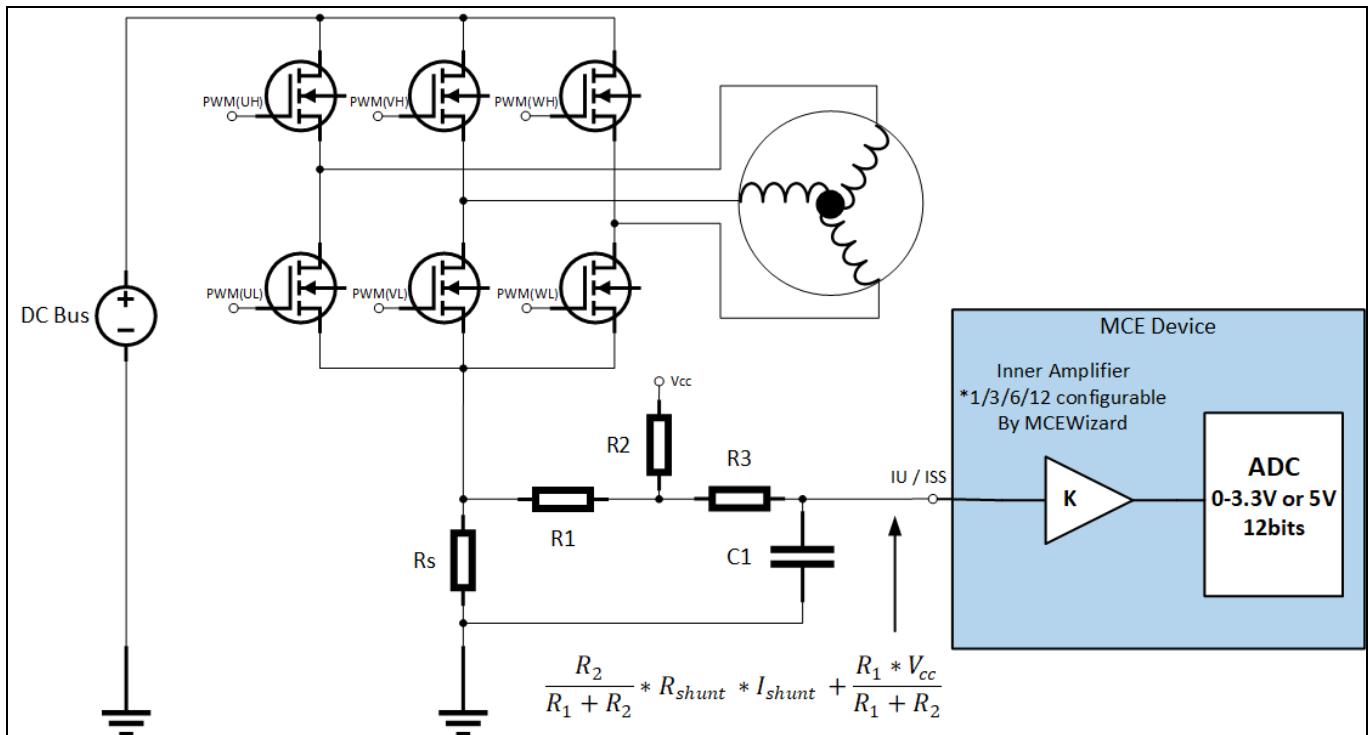
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$$V_{shunt} = I_{shunt} * R_{shunt}$$

$V_{ADC}$  can then be written as:

$$V_{ADC} = \frac{R_2}{R_1 + R_2} * R_{shunt} * I_{shunt} + \frac{R_1 * V_{cc}}{R_1 + R_2}$$

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 14 Current-sensing topology**

As an example, this board has the following values:

$$R1 = R20 = 2 \text{ k}\Omega, R8 = R2 = 22.1 \text{ k}\Omega, V_{cc} = 3.3 \text{ V}, \text{offset} = 0.274 \text{ V}, \text{gain} = \frac{R_2}{R_1+R_2} * R_{shunt} = 137.6 \text{ mV/A.}$$

Note the following points concerning current sampling:

- R8 & R20 also determine the ADC operational bias for current sensing, which corresponds to the motor regeneration operation range. For those applications that do not work at regenerative brake mode, the bias can be as low as possible to reserve enough ADC range for the drive mode, since negative current to DC bus does not occur.
- Since the gain of the external RC circuit is less than 1, internal signal amplification is required to increase the ADC input voltage range with the lower shunt value. If a larger shunt is chosen, the power loss and size are both larger. 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 ability without an outer operational amplifier, so the GND network of the PCB needs to be dealt with very carefully, since any voltage difference between IMC101T's ADC ground and shunt resistor ground will be considered as an "input signal," and will deteriorate control performance or increase audible noise.

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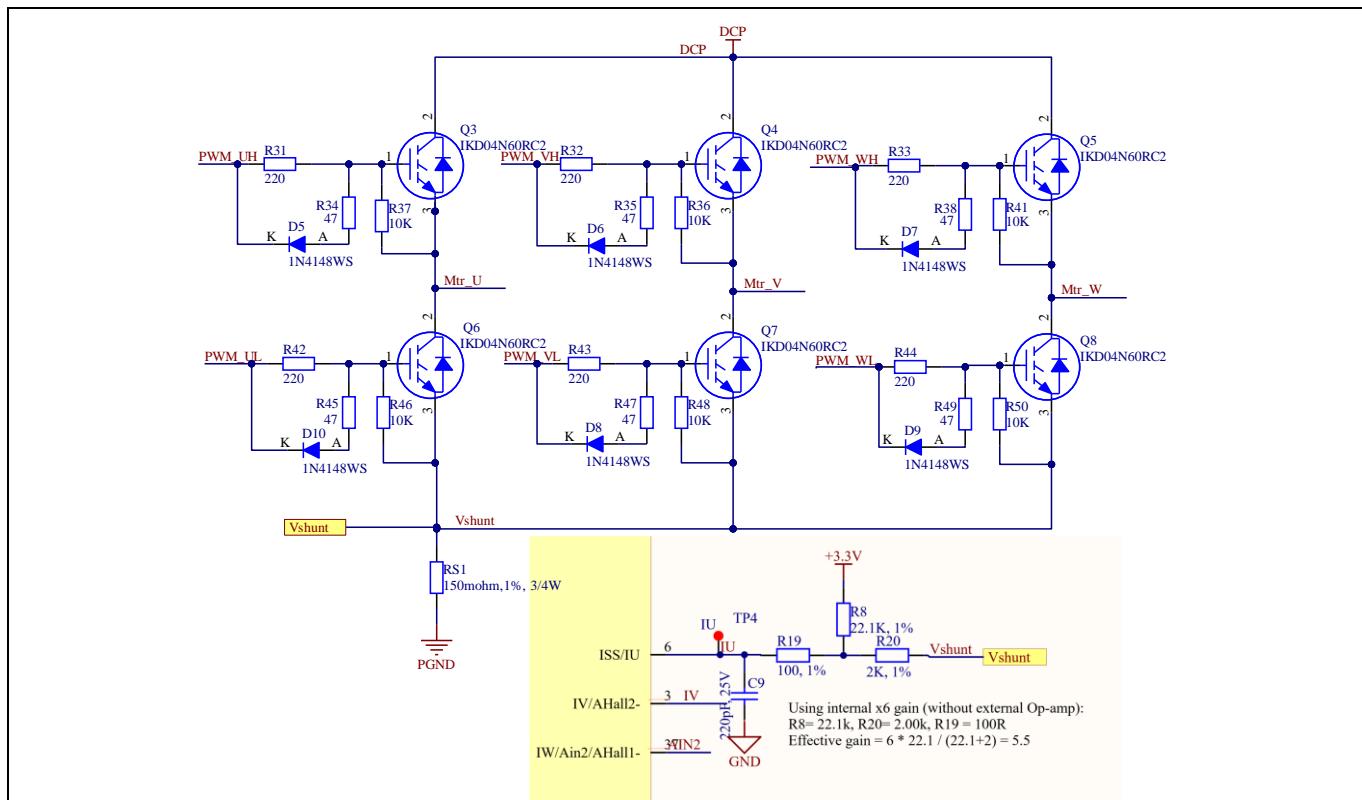


Figure 15 Current-sensing circuit on the board

## 2.2.4.2 Overcurrent protection

The overcurrent condition can be detected by IMC101T by the two input sources, as shown in Figure 16.

- Internal comparator in the IMC101T
- Trigger ITRIP pin on the 6EDL04I06PT to shut down the inverter; the fault signal will transfer to the IMC101T by GK pin, active low

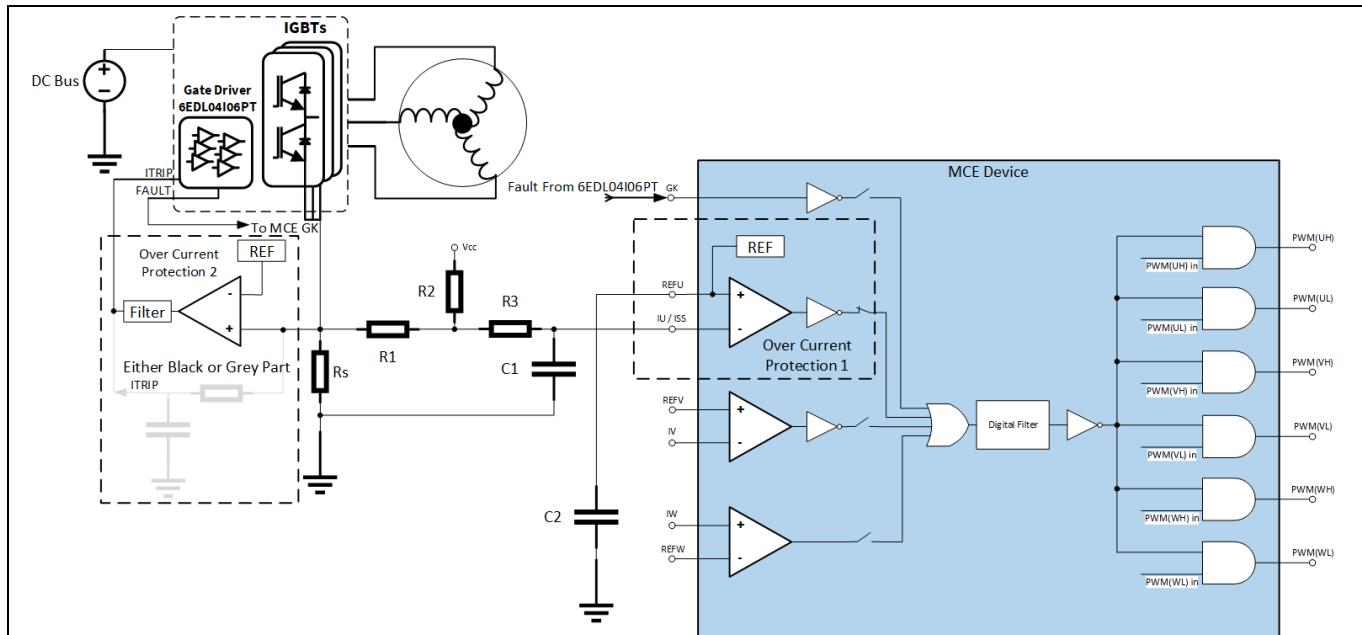


Figure 16 Overcurrent protection on the board

## Refrigerator compressor driver reference design kit

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For more details on overcurrent protection (OCP) in the IMC101T, refer to the chapter on motor overcurrent protection in the reference material<sup>[8]</sup>.

## 1. Internal comparator in the IMC101T

The internal comparator's reference level is set by the internal DAC. 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; 10 nF/16 V is used on the board.

## 2. Trigger ITRIP pin on the 6EDL04I06PT; the fault signal will transfer to the IMC101T by GK pin

The board has designed two ways to trigger the ITRIP pin of the gate driver, and users can select either one to achieve overcurrent protection.

- Trigger by the comparator U5
- Directly trigger from shunt

Figure 17 shows the ITRIP trigger level, which is typically 0.445 V, positive logic. Figure 18 indicates that the inner filter time of the ITRIP signal is 500 ns.

ITRIP positive going threshold	$V_{IT,TH+}$	380	445	510	mV	
ITRIP input hysteresis	$V_{IT,HYS}$	45	70			

Figure 17 6EDL04I06PT ITRIP threshold specification

Shutdown propagation delay ITRIP	$t_{ITRIP}$	400	670	1000	$V_{ITRIP}=1\text{ V}$
Input filter time ITRIP	$t_{ITRIPMIN}$	155	230	380	
Propagation delay ITRIP to FAULT	$t_{FLT}$	-	420	700	

Figure 18 6EDL04I06PT ITRIP dynamic parameters' specification

Short circuit withstand time $V_{GE} = 15.0\text{V}$ , $V_{CC} \leq 400\text{V}$ Allowed number of short circuits < 1000 Time between short circuits: $\geq 1.0\text{s}$ $T_{vj} = 150^\circ\text{C}$	$t_{sc}$			$\mu\text{s}$
		3		

Figure 19 IKD04N60RC2 short-circuit withstand time

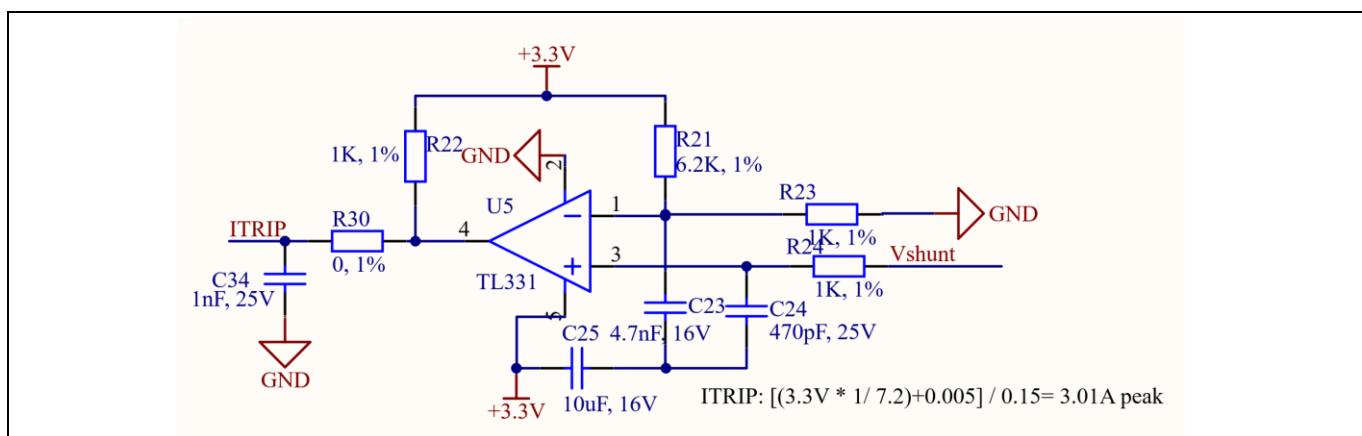


Figure 20 Default current-protection circuit to ITRIP of gate driver

## Refrigerator compressor driver reference design kit

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The default protection circuit on the board is the one triggered by the comparator; it is a more flexible way to set the reference voltage. On this board, we set the voltage as  $3.3 V * \frac{1 k\Omega}{6.2 k\Omega + 1 k\Omega} = 0.458 V$ ; the shunt resistor on the board is 150 mΩ, i.e., the theoretical protection value is 3.05 A peak. The reference voltage can be easily adjusted by the divider resistor.

On the board,  $R24 = 1 k\Omega$ ,  $C24 = 470 \text{ pF}$ ; the filter time constant is  $RC = 1 k\Omega * 470 \text{ pF} = 470 \text{ ns}$ ; output part  $R22 = 1 k\Omega$ ,  $C34 = 1 \text{ nF}$ ; the filter time constant is  $RC = 1 k\Omega * 1 \text{ nF} = 1 \mu\text{s}$ . The total delay time is about 1.5 μs.

Figure 21 shows the waveform of the comparator. CH1 is the shunt voltage and CH2 probe the ITRIP pin of the gate driver. The ITRIP signal's rising time (from 0 to 63.2%, 0 - 2.08 V) is approximately 0.95 μs, which is close to the theoretical value of 1 μs, and the ITRIP trigger level is only 0.445 V. Therefore, the total response time of the comparator is about 1 μs, plus the added propagation delay time of 1.38 μs seen in Figure 18, which equals a total time of about 2.4 μs. That is only 80% of the short-circuit withstand time of 3 μs as shown in Figure 19.

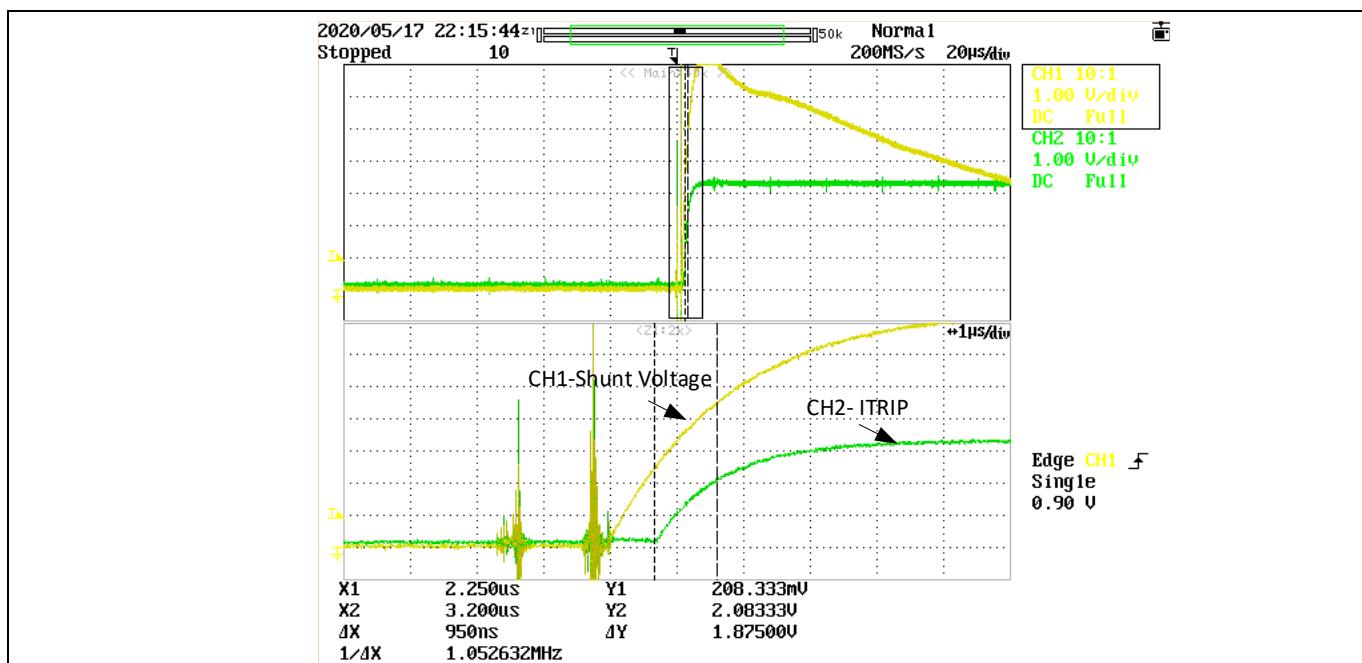


Figure 21 Dynamic response of the protection circuit with comparator

Another way to trigger the ITRIP is to directly connect the shunt to the ITRIP as indicated in Figure 22. The output of the comparator needs to be disconnected by removing R30; and R54 needs to be soldered. If  $R54 = 1 k\Omega$ , the RC filter time constant will equal the RC, which is 1 μs. Figure 22 shows the test waveform.

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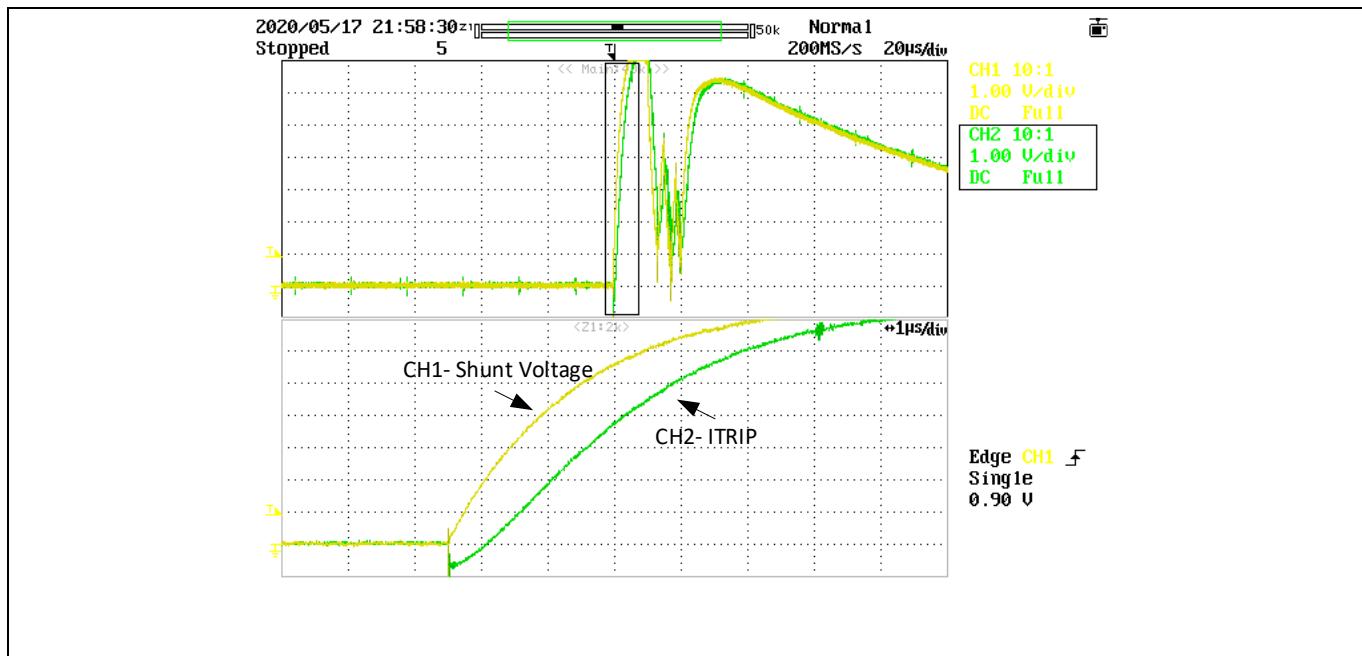


Figure 22 Dynamic response of the protection circuit when directly connecting to shunt

## 2.2.5 NTC sensing and thermal protection

Pin 7 of IMC101T-T038 is the ADC port dedicated to NTC temperature sampling. On the board, an NTC is connected to the ADC channel by the circuit shown in Figure 23. The position of the NTC on the board is shown in Figure 24.

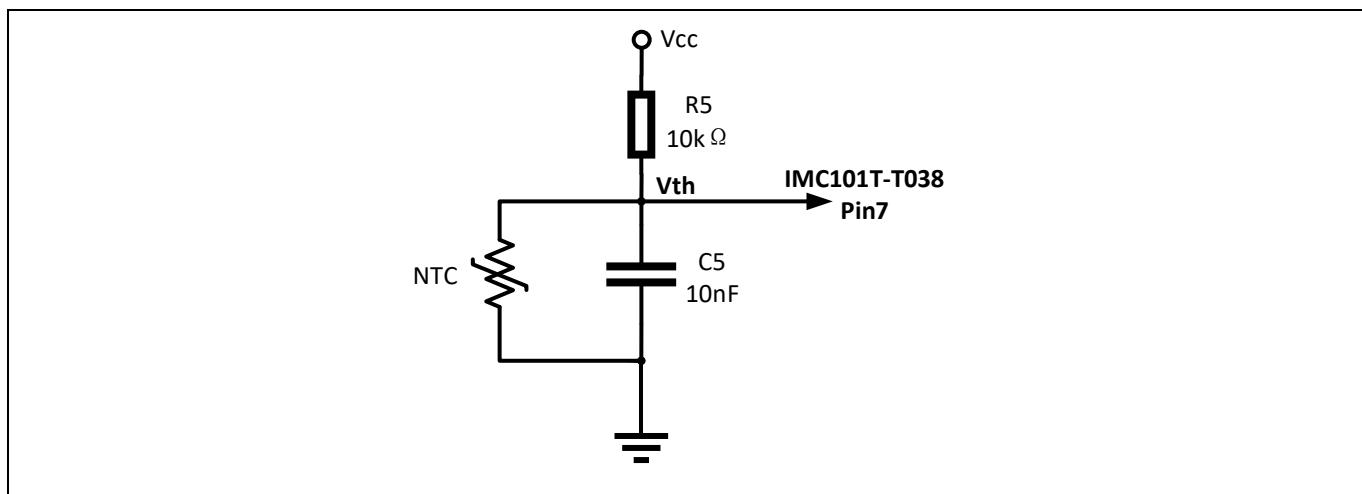


Figure 23 NTC sensing circuit

The parameters of the NTC 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 4.

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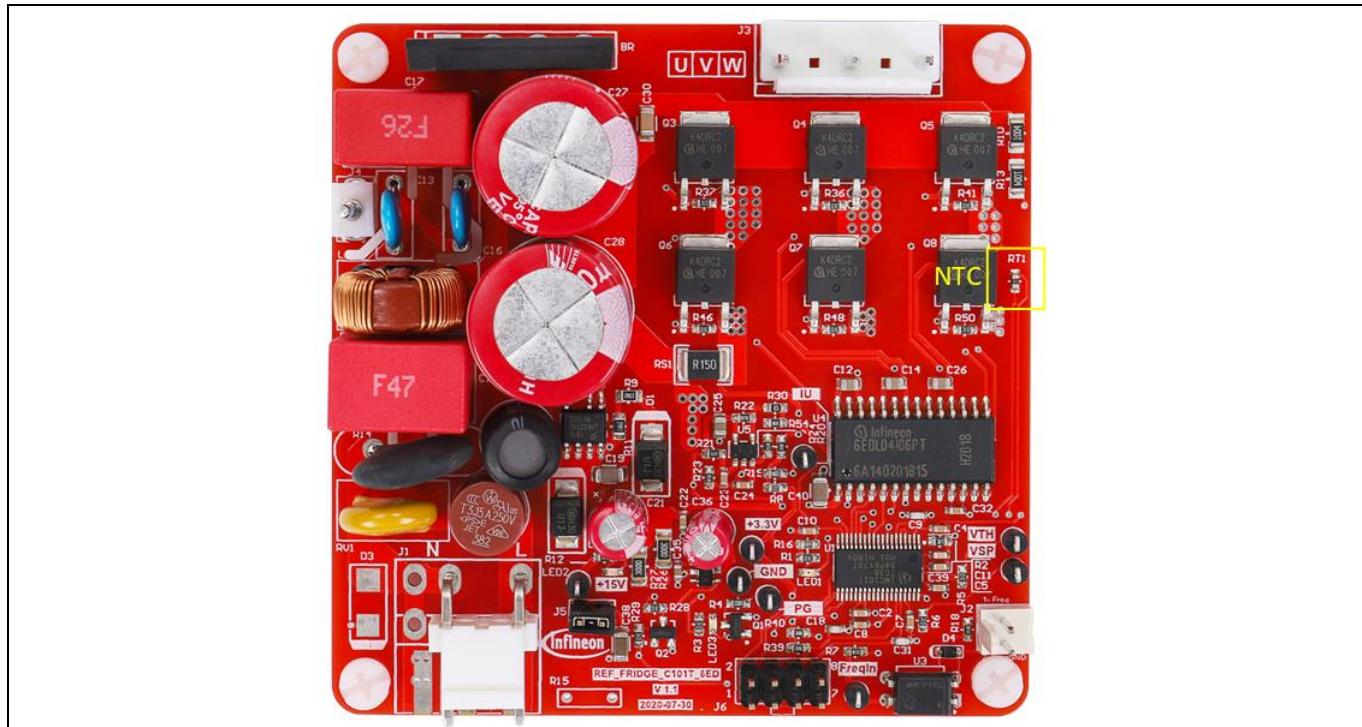


Figure 24 NTC position on the board

Table 4 Thermistor characteristics with  $V_{cc} = 3.3$  V

Temperature (°C)	Resistance, typical (kΩ)	$V_{th}$ (V)	$V_{th}$ 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

## Refrigerator compressor driver reference design kit

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The firmware inside the IMC101T integrates the over-temperature protection device, which will be triggered by the voltage  $V_{th}$ . Simply set the proper trigger level in the MCEWizard. More information can be found in the over-temperature protection section of the reference material [8].

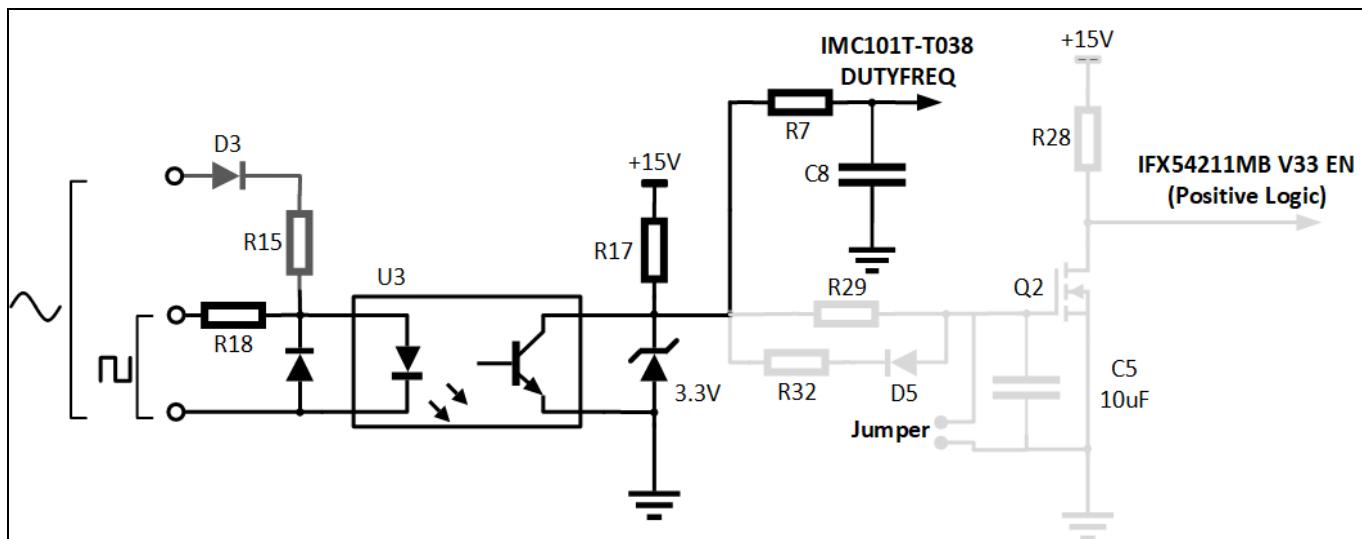
### 2.3 Frequency signal interface

Since current refrigerator applications mainly use frequency signals to control the compressor speed, the board is designed with a frequency signal interface. Figure 25 shows the interface circuit. The input signal is isolated from the control and power parts on the board.

The board has two types of input interface:

- Square wave interface (default, remove the D3, R15 )
- AC 220 V as the control input (you need to remove R18, and install D3, R15)

The first type is a more common signal type, while the second is used less often.



**Figure 25 Frequency interface circuit**

The optocoupler output is pulled up to 15 V, because the board uses the output signal to control the linear voltage regulator IFX54211MB V33. If this function is not needed, the user can use the 3.3 V/5 V to pull up. The grey part of the circuit is used to control the enable/disable of the linear voltage regulator, which can be disabled when there is no control signal input. Details are provided in Section 2.4.

A typical square wave input signal for refrigerator applications is shown in Table 5 for reference.

**Table 5 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

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## 2.4 Linear voltage regulator and control

Considering the requirements for standby power consumption in refrigerator applications, the board selects a linear power supply with an enable function. The part number of this linear voltage regulator is IFX54211MB V33, which is also an Infineon product. On the board, we have designed the circuit to transfer the frequency signal to the enable (EN) signal, as shown in Figure 26. If you do not need this function, jump the jumper J5 on the board so that the linear voltage regulator is always on Enable.

Here is a brief explanation of the principle of the circuit: the enable signal of IFX54211MB V33 is positive logic, which means high-level input enables the 3.3 V output. If there is no frequency signal input, the gate drive voltage of Q2 is high, which means the Q2 is on, the enable signal is low so that the LDO of 3.3 V is disabled. If there is a frequency signal input, the charge in the capacitor C5 will discharge through the D5-R32-U3 during the high level input, and charge through R27, R29. When the voltage of capacitor C5 drops down to the gate threshold voltage of Q2, the Q2 will shut down, and the enable signal will be high, so the LDO of 3.3 V will be enabled.

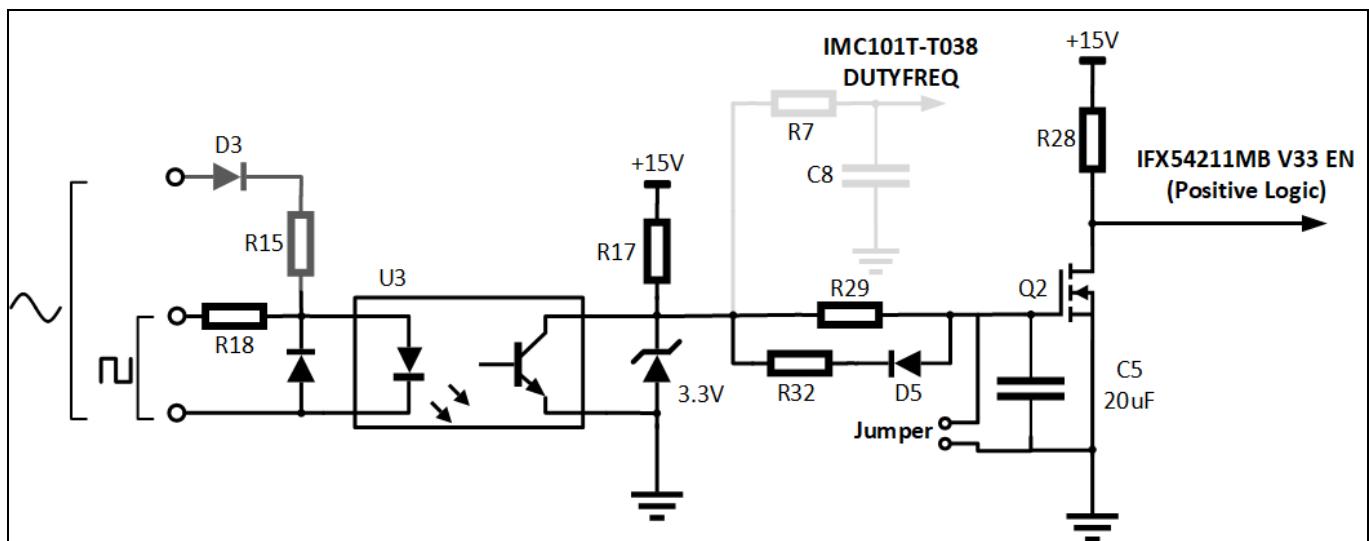


Figure 26 IFX54211MB V33 Enable function control circuit

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### 3 Details of the schematics, layout, BOM and connectors

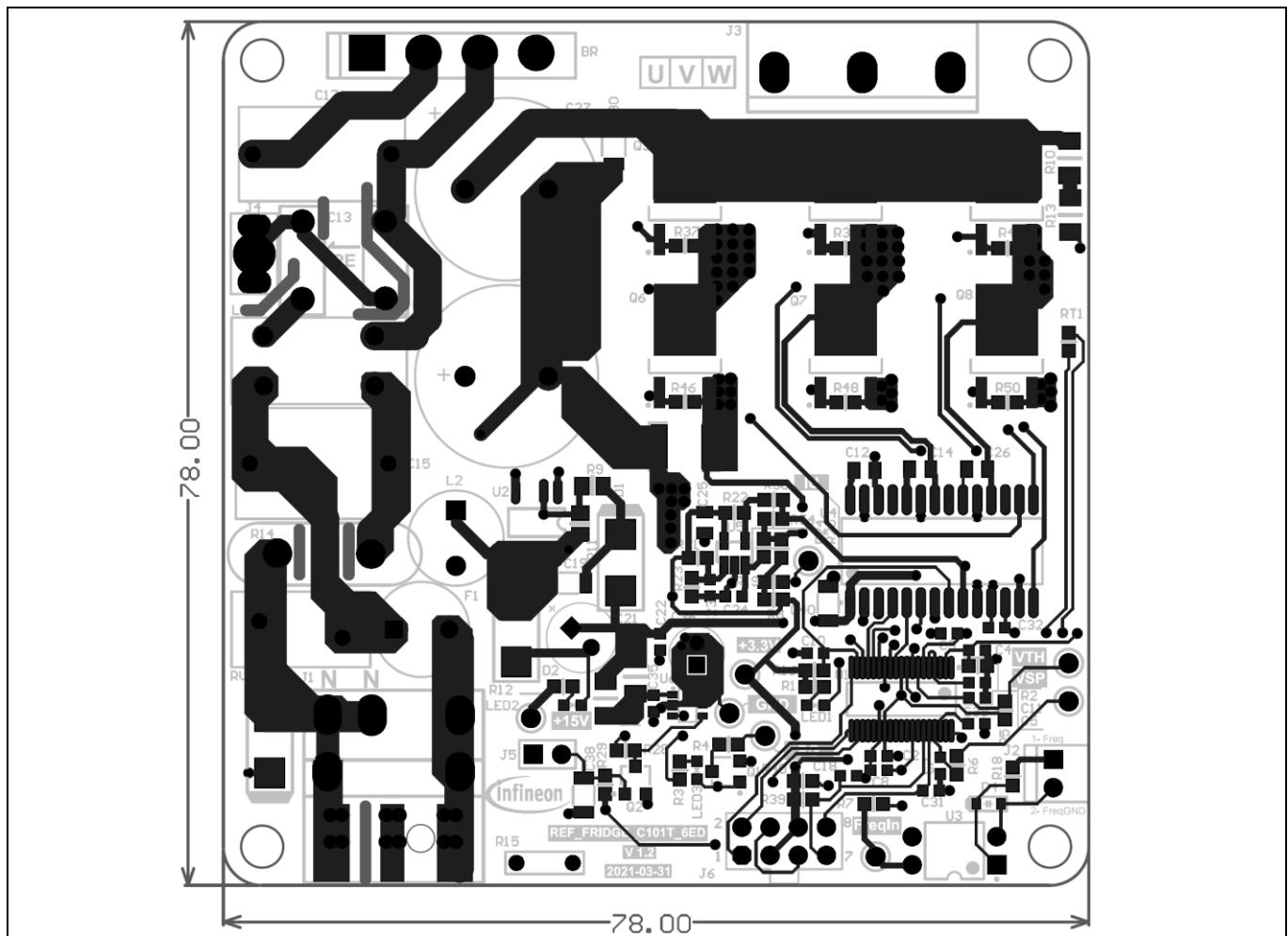
This section provides the complete details of the schematics, layout and connectors. Please note that the schematics, layout and gerber files are done in Altium designer. Customers who are interested in the original Altium format files or pdf files for better clarity can visit [www.infineon.com](http://www.infineon.com).

## 3.1 Schematics

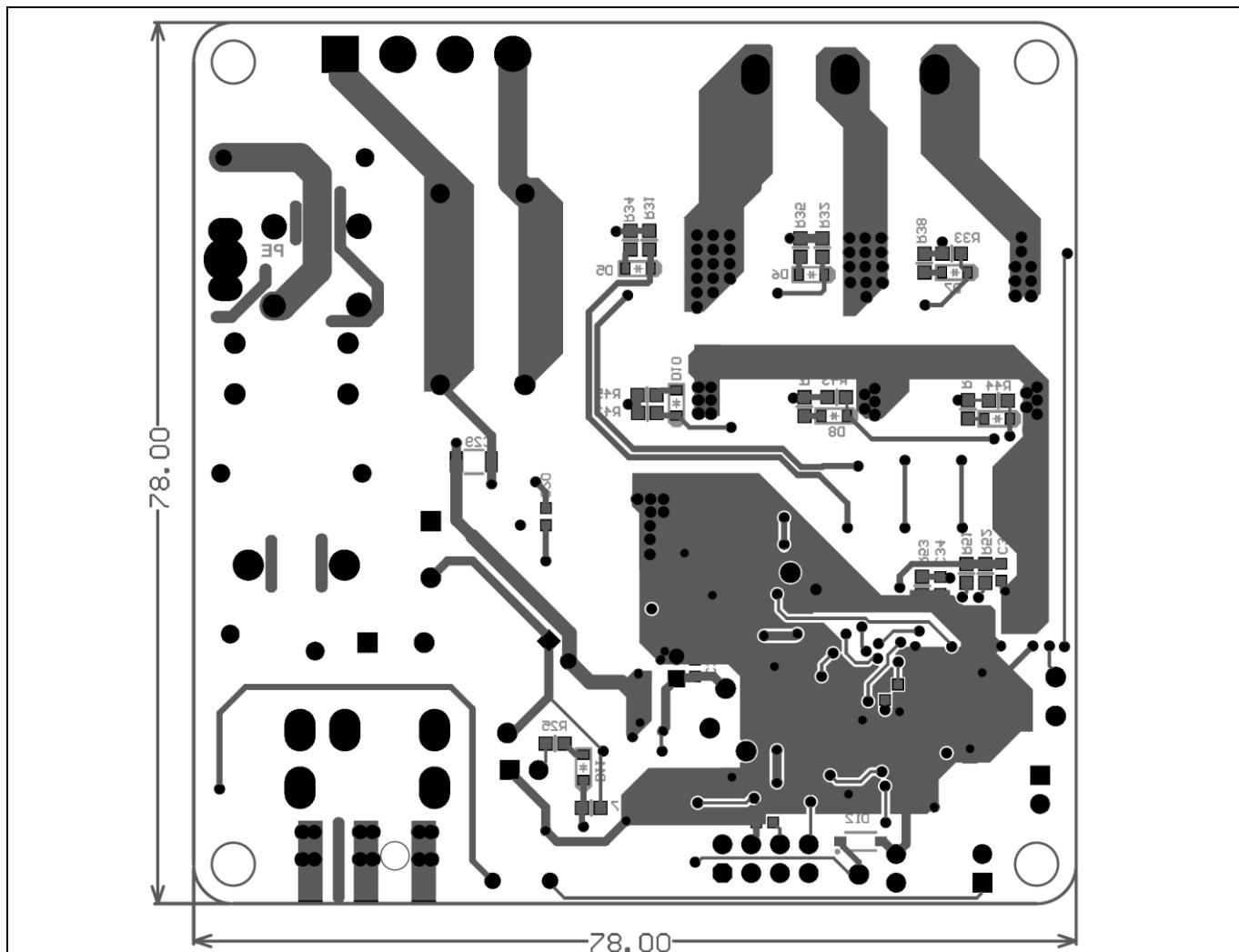
The major function blocks are introduced in Section 2.2. Customers who are interested in further details can download the design files after logging in their account on the Infineon webpage.

## 3.2 Layout

The board is designed in two layers, and its dimensions are 78 mm × 78 mm, manufactured with 1 oz. (35  $\mu$ m) copper thickness. The project is designed with Altium Designer, and all design files can be downloaded after users log in their account on the Infineon webpage.



**Figure 27** Top view of the board



**Figure 28 Bottom view of the board**

Here are a few design tips to note for your reference.

- Thermal performance

Collectors of the IGBT are the terminals for directly connecting the lead frame. Maximizing the copper area of these pins could effectively reduce the IGBT junction temperature. Usually the IGBTs (Q4/Q7) have the highest case temperature at the center, so sufficient space for the copper should be left to ensure performance.

- Ground layout

Since current sampling is non-differential and without op-amp, the area should be carefully laid out; the digital ground should refer to the shunt ground to ensure that the sampling noise is correct.

### 3.3 Bill of material

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

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**Table 6 The most critical parts of the reference board**

S. No.	Ref designator	Description	Manufacturer	Manufacturer P/N
1	Q1, Q2	MOSFET N-CH 30 V 2.7 A SOT-23-3	Infineon Technologies	IRLML2030TRPBF
2	Q3, Q4, Q5, Q6, Q7, Q8	IGBT 600 V 8 A TO252-3	Infineon Technologies	IKD04N60RC2
3	U1	IC MOTOR DRIVER 3V-5.5 V TSSOP-38	Infineon Technologies	IMC101TT038XUMA1
4	U4	IC GATE DRVR HALF-BRIDGE DSO28	Infineon Technologies	6EDL04I06PTXUMA1
5	U6	IC REG LINEAR 3.3 V 150 mA SCT595	Infineon Technologies	IFX54211MBV33
6	C15	WCAP-FTX2 Film Capacitors, 15x10x16 mm, 275 V AC, 470 nF	Wurth Elektronik	890324024005
7	C17	WCAP-FTX2 Film Capacitors, 15x8.5x14 mm, 275 V AC, 330 nF	Wurth Elektronik	890324024003
8	C27, C28	WCAP-AT1H THT Aluminum Electrolytic Capacitors, D16 mm x L35.5 mm, 100 $\mu$ F, +/- 20%, 450 VDC	Wurth Elektronik	860241480001
9	L1	WE-CMB Common Mode Power Line Choke, Type XS, 4 mH, 1.5 A, 250 V	Wurth Elektronik	744821240
10	RV1	WE-VD Disk Varistor, size 10 mm, 300 V <sub>rms</sub> , 385 Vdc	Wurth Elektronik	820513011

### 3.4 Connector details

**Table 7 J1- AC Line connector**

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

**Table 8 J2- 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

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**Table 9 J3- Motor-side connector**

<b>PIN</b>	<b>Label</b>	<b>Function</b>
1	U	Connected to motor phase U
2	V	Connected to motor phase V
3	W	Connected to motor phase W

**Table 10 J4- Earth connector**

<b>PIN</b>	<b>Label</b>	<b>Function</b>
1	Earth	

**Table 11 J5- Jumper**

<b>PIN</b>	<b>Label</b>	<b>Function</b>
1	MOSFET's gate	Shorting pin 1 and 2 will enable 3.3 V directly, otherwise 3.3 V is controlled by frequency signal.
2	Ground	

**Table 12 J6- iMOTION™ Link connector**

<b>PIN</b>	<b>Label</b>	<b>Function</b>
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

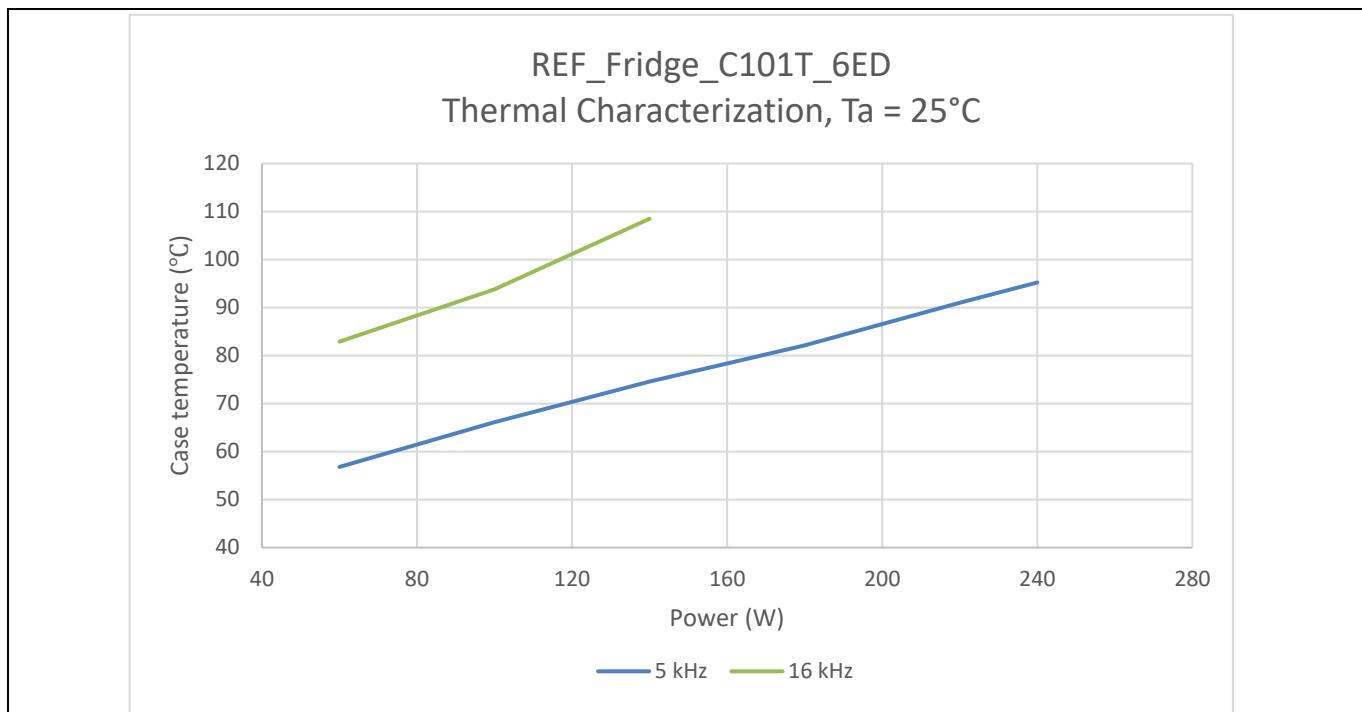
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## 4 System performance

### 4.1 Thermal characterization test

Figure 29 and Figure 30 show the thermal characterizations of REF\_Fridge\_C101T\_6ED, based on 2 layers of FR4 PCB with 1 oz. copper.

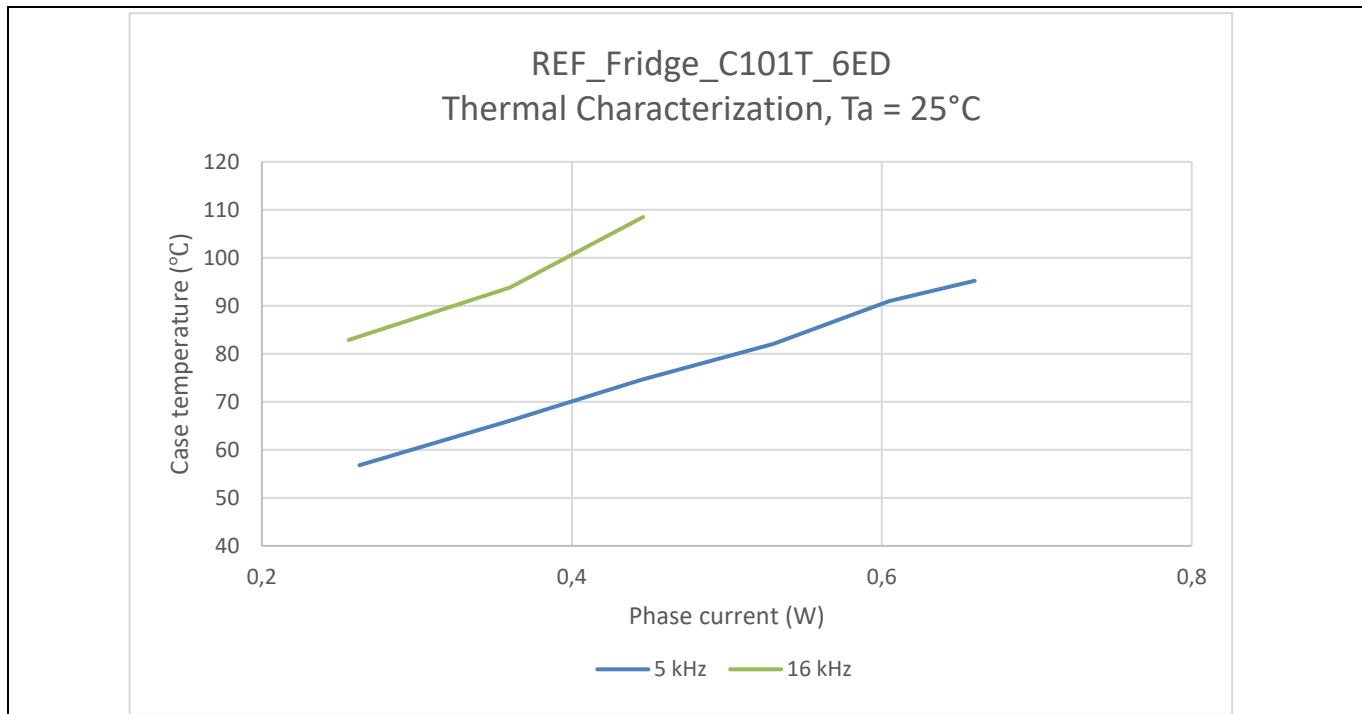
The tests reported on were performed under the following conditions:  $t_{amb}=25^{\circ}\text{C}$ ,  $V_{ac}=220\text{ V}$ , with different input power until the IGBT case reaches about  $100^{\circ}\text{C}$ , at two PWM frequencies (5 and 16 kHz), and 3-phase modulation mode only.



**Figure 29** REF\_Fridge\_C101T\_6ED thermal characterization case temperature – input power,  $t_{amb}=25^{\circ}\text{C}$

**Table 13** Input power and current characterization

Input power (W)	60	100	140	180	220	240
Input current (A)	0.45	0.72	1.03	1.32	1.6	1.82



**Figure 30** **REF\_Fridge\_C101T\_6ED thermal characterization, case temperature - motor phase current,  $t_{\text{amb}} = 25^\circ\text{C}$**

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## 5 Reference and appendices

### 5.1 Abbreviations and definitions

**Table 14 Abbreviations**

Abbreviation	Meaning
BLDC	Brushless direct current motor
FOC	Field-oriented control
PMSM	Permanent magnet synchronous motor
RC-DF	Reverse conducting - drive fast
RC-D2	Reverse conducting - drive 2

### 5.2 Reference

- [1] Infineon Technologies AG. Datasheet of Infineon IKD04N60RC2 (2020). V2.1 [www.infineon.com](http://www.infineon.com)
- [2] Infineon Technologies AG. Datasheet of Infineon 6EDL04I06PT (2019). V2.7 [www.infineon.com](http://www.infineon.com)
- [3] Infineon Technologies AG. Datasheet of Infineon IMC101T-T038 (2019). V1.4 [www.infineon.com](http://www.infineon.com)
- [4] Infineon Technologies AG. Datasheet of Infineon IFX54211MB V33 (2015). V1.0 [www.infineon.com](http://www.infineon.com)
- [5] Infineon Technologies AG. Datasheet of IRLM2030TRPbF (2009) [www.infineon.com](http://www.infineon.com)
- [6] Infineon Technologies AG. MCEWizard\_V2.3.0.0 User Guide (2019) [www.infineon.com](http://www.infineon.com)
- [7] Infineon Technologies AG. MCEDesigner\_V2.3.0.0 Application Guide (2019) [www.infineon.com](http://www.infineon.com)
- [8] Infineon Technologies AG. iMOTION™ Motion Control Engine Software Reference Manual (2020) V1.3 [www.infineon.com](http://www.infineon.com)

### 5.3 Additional information

In order to initiate testing, customers are advised to order the iMOTION™ Link; the information is listed in Table 15.

The components from Infineon that are on the board are listed in Table 15 as well. Customers can visit the corresponding webpage for more information.

**Table 15 Additional information of tools and Infineon's components**

Base part number	Package	Standard pack		Orderable part number
		Form	Quantity	
<a href="#">iMOTION™ Link</a>		Container	1	IMOTIONLINK
<a href="#">IMC101T-T038</a>	PG-TSSOP-38-9	Tape and reel	3000	IMC101TT038XUMA1
<a href="#">6EDL04I06PT</a>	PG-DSO-28	Tape and reel	1000	6EDL04I06PTXUMA1
<a href="#">IKD04N60RC2</a>	PG-TO252-3	Tape and reel	2500	IKD04N60RC2ATMA1
<a href="#">IFX54211MB V33</a>	PGSCT595	Tape and reel	3000	IFX54211MBV33HTSA1
<a href="#">IRLML2030TRPBF</a>	SOT-23	Tape and reel	3000	IRLML2030TRPBF

## Revision history

<b>Document version</b>	<b>Date of release</b>	<b>Description of changes</b>
1.0	2021-04-16	First release

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