REF-MHA0K2IM2ZPSOC4 user guide

Reference board with PSoC4 for rotary fridge compressor drive

About this document

Scope and purpose

This user manual provides an overview of the REF-MHA0K2IM2ZPSOC4 refererence board including its main features, key data, pin assignments and mechanical dimensions.

The REF-MHA0K2IM2ZPSOC4 is a reference board that supports the design of rotary fridge compressor drives. It includes the PSoC 4100S MCU, which provides the needed flexibility for developing motor control solutions, and the CIPOS™ Micro, a 600 V, 6 A three-phase intelligent power module (IM231-L6S1B), which enables high integration with a space-saving design. Also included is a voltage regulator with TLE4294G V50 LDO for the required auxiliary supply .

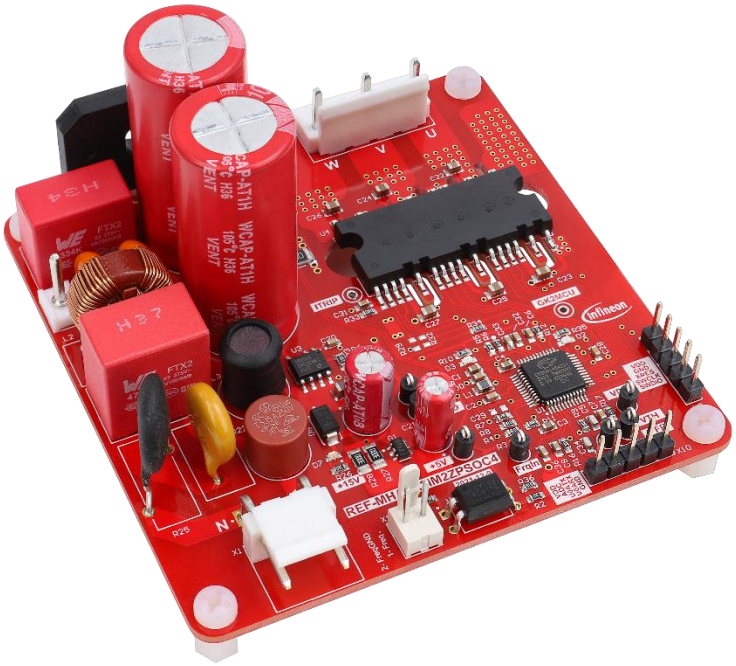
Intended audience

This user manual is intended for all technical specialists who are familiar with motor control and high-power electronics converters, and have experience in developing hardware and motor control software for rotary fridge compressors. This board is intended to be used under laboratory conditions.

Reference board/kit

Product(s) embedded on a PCB with a focus on specific applications and defined use cases that may 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

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

Table 1 Safety precautions

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

Table of contents

1 The board at a glance

The REF-MHA0K2IM2ZPSOC4 is a reference board that supports the design of rotary fridge compressor drives. It includes the PSoC 4100S MCU, which provides the needed flexibility for developing motor control solutions, and the CIPOS™ Micro, a 600 V, 6 A three-phase intelligent power module (IM231-L6S1B), which enables high integration with a space-saving design. Also included is a voltage regulator with TLE4294G V50 LDO for the required auxiliary supply.

1.1 Scope of supply

The scope of supply includes the board, as listed in Table 2. The detailed ordering information is also indicated in Table 2.

Table 2 Delivery content

Base part number	Package	Standard pack		Orderable part number
		Form	Quantity	
REF-MHA0K2IM2ZPSOC4		Boxed	1	REFMHA0K2IM2ZPSOC4TOBO1

1.2 Block diagram

The block diagram of the REF-MHA0K2IM2ZPSOC4 is depicted in Figure 1. The board includes an electromagnetic induction (EMI) filter, auxiliary power supply to provide 15 V and 5 V, the CIPOS™ Micro and the PSoC 4100S MCU.

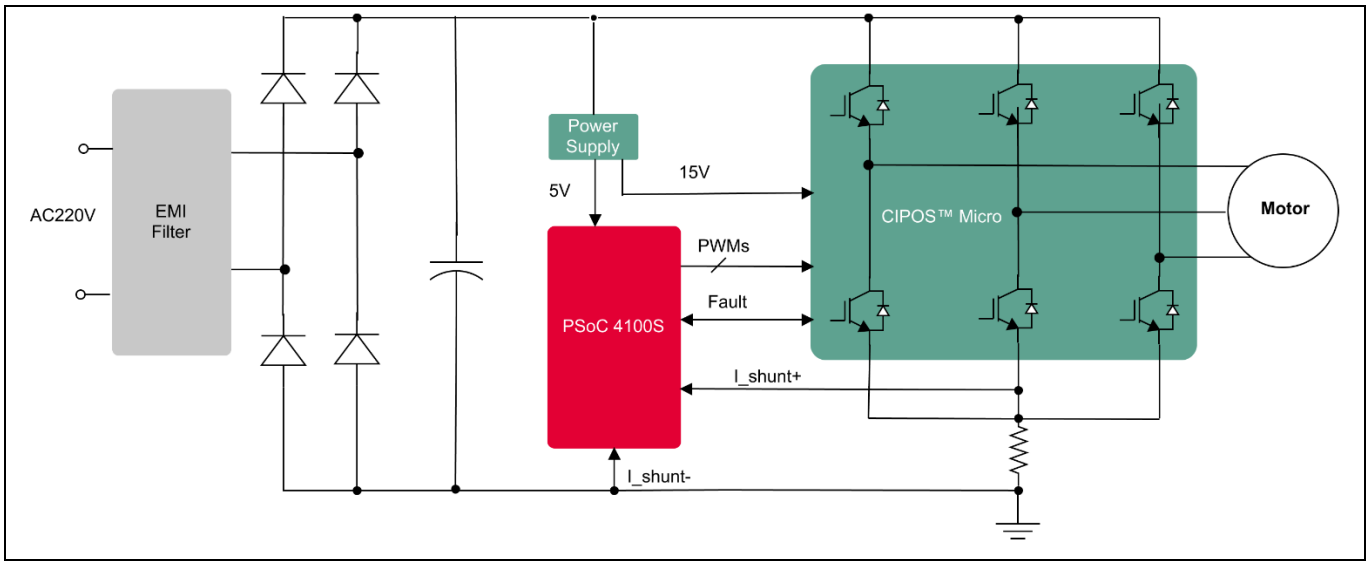

Figure 1 The block diagram of the REF-MHA0K2IM2ZPSOC4

The power supply of this board is 220 VAC, and the MCU is supplied by 5 V. The hardware circuit for overcurrent protection is included on the reference board. The current sampling circuit is based on single-shunt technology and is connected to the internal op-amp of PSoC 4100S.

1.3 Main features

Main features of the reference board are:

- Input voltage 160~265 V_{AC}
- Maximum 200 W motor power output
- Onboard EMI filter
- Single-shunt current sensing
- Auxiliary power supply on-board with 15 V, 5 V
- Overcurrent protection
- Sensing of DC-link voltage
- Fault diagnostic output
- Measurement test points compatible with standard oscilloscope probes

Main features of the PSoC 4100S MCU (CY8C4146AZI-S423) include:

- 32-bit MCU subsystem
  - 48 MHz Arm® Cortex®-M0+
  - 64 KB flash and 8 KB SRAM
- Programmable analog blocks
  - Two op-amps with reconfigurable high drive, external and high-bandwidth internal drive, and comparator modes and ADC input buffering capability. Op-amps can operate in deep-sleep, low-power mode.
  - 12-bit 1-Msps SAR ADC with differential, single-ended modes, and channel sequencer with signal averaging
  - Two current DACs (IDACs) for general-purpose or capacitive sensing applications on any pin
  - Two low-power comparators that operate in deep-sleep, low-power mode
- Programmable digital blocks
  - Programmable logic blocks allowing Boolean operations to be performed on port inputs and outputs
- Low-power 1.71 V to 5.5 V operation
  - Deep-sleep mode with operational analog and 2.5 µA digital system current
- Serial communication
  - Three independent, run-time reconfigurable serial communication blocks (SCBs) with re-configurable I2C, SPI, or UART functionality
- Timing and pulse-width modulation
  - Five 16-bit timer/counter/pulse-width modulator (TCPWM) blocks
  - Center-aligned, edge, and pseudo-random modes
  - Comparator-based triggering of Kill signals for motor drive and other high-reliability digital logic applications
  - Quadrature decoder
- Clock sources
  - PLL to generate 48 MHz frequency
  - ±2% internal main oscillator (IMO)
- Packages
  - 48-pin thin quad flat pack (TQFP)
- I/O subsystem
  - Up to 36 general-purpose input/output (GPIOs)

Main features of the CIPOS™ Micro (IM231L6S1BALMA1) include:

- Based on low $V_{CE(sat)}$ TRENCHSTOP™ IGBT6
- Integrated bootstrap function
- All 6 switches turn off during protection
- Accurate overcurrent protection (±5%)
- Fault reporting and programmable fault clear
- Built-in temperature sensor
- Isolation 2000 V_{RMS}, 1 min
- Motor power rating up to 400 W at 10 kHz
- UL-certified

1.4 Board parameter and technical data

Table 3 shows the board parameters and technical data of REF-MHA0K2IM2ZPSOC4.

Table 3 REF-MHA0K2IM2ZPSOC4 board specifications

Parameters	Values	Conditions / comments
Input		
Voltage	160 ~265 V_{rms}	Lower AC input, less motor power output
Input current	1.5 A	Input 220 V_{AC}, T_a=25°C
Output		
Power (3 phases)	200 W	Input 220 V_{AC}, f_{PWM}=5 KHz, T_a=25°C, T_h=70°C
Current per leg	0.6 A_{rms}	Input 220 V_{AC} , f_{PWM}=5 KHz, T_a=25°C, T_h=70°C
DC bus voltage		
Maximum DC bus voltage	400 V	
Minimum DC bus voltage	120 V	
Switching frequency		
Inverter switching frequency	5 KHz	
Current feedback		
Inverter current sensing resistor	150 mΩ	
Protections		
Output current trip level	3.05 A	Configur by resistor R5,R6
Temperature trip level	105 °C	VTH is pulled up to a rail voltage such as VDD (5 V) by a 10 K resistor on REF-MHA0K2IM2ZPSOC4
Onboard power supply		
15 V	15 V ± 2 %, max. 500 mA	Used for CIPOS™ IPM gate driver and LDO
5 V	5 V ± 1 %, max. 300 mA	Supplying the 5 V to the MCU and protection circuits
PCB characteristics		

Parameters	Values	Conditions / comments
Material	FR4, 1.6 mm thickness, 2 layers. 35 µm copper thickness	
Dimensions	78 mm x 78 mm	
System environment		
Ambient temperature	From 0 to 50 °C	Non-condensing, maximum RH of 95 %

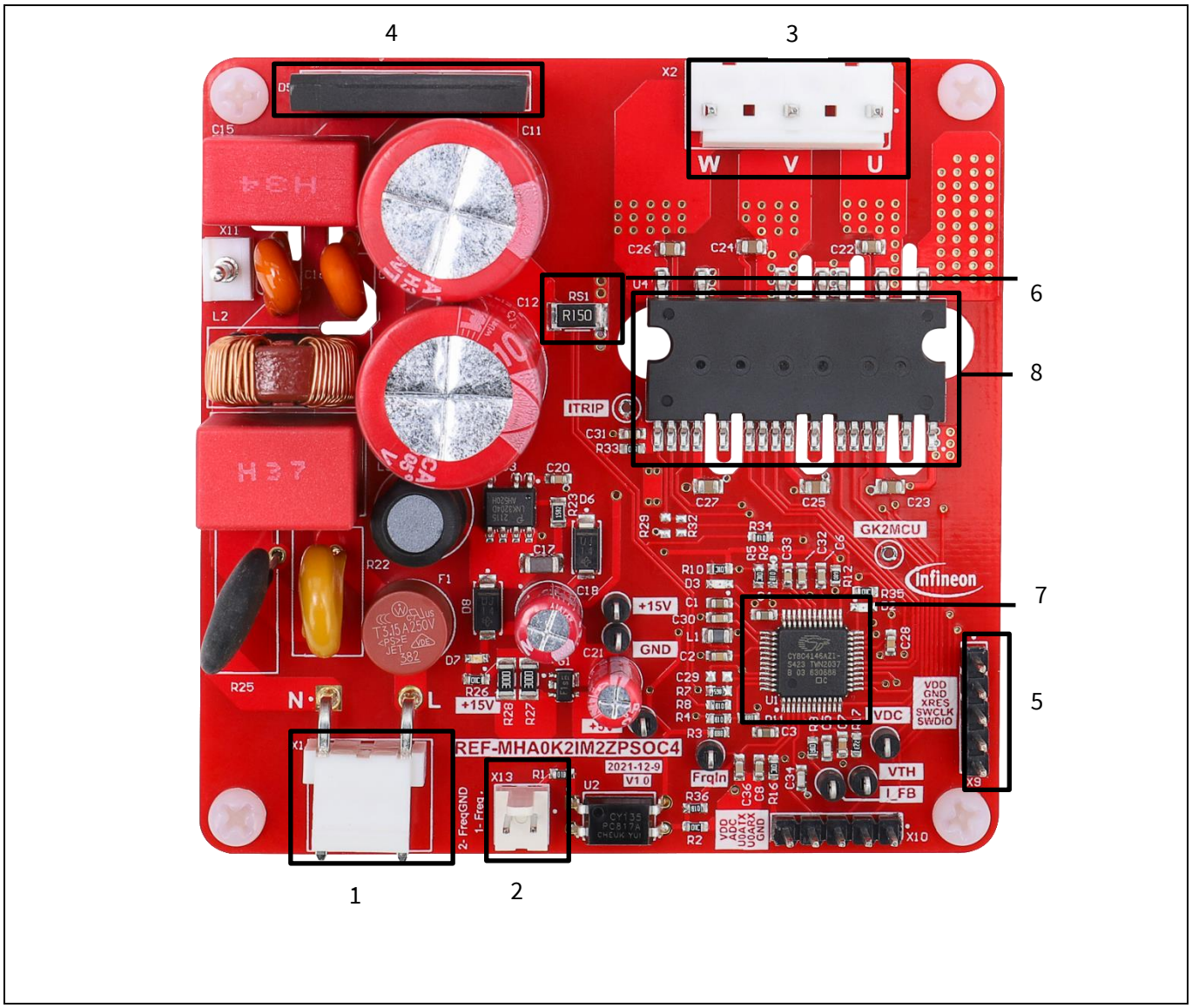

Figure 2 Functional groups of the REF-MHA0K2IM2ZPSOC4 reference board

1. AC input connector
2. Speed control port by PWM frequency
3. Motor phase connector
4. Rectifier bridge
5. J-LINK debugger connector
6. Current-sensing resistors
7. PSoC 4100S
8. IM231L6S1BALMA1

2 System and functional desciption

This chapter describes the development environment. Please note that the firmware for getting started is available on request through an Infineon sales representative.

Table 4 Hardware environment

System	Description
MCU	CY8C4146AZI-S423
Hardware	REF-MHA0K2IM2ZPSOC4
Emulator	J-Link debugger with isolator

Table 5 Software environment

System	Description
PC System	Windows 7 (64-bit) or later
Software developing IDE	PSoC creator
	IAR workbench

2.1 Getting started

Figure 3 shows the system connection of REF-MHA0K2IM2ZPSOC4.

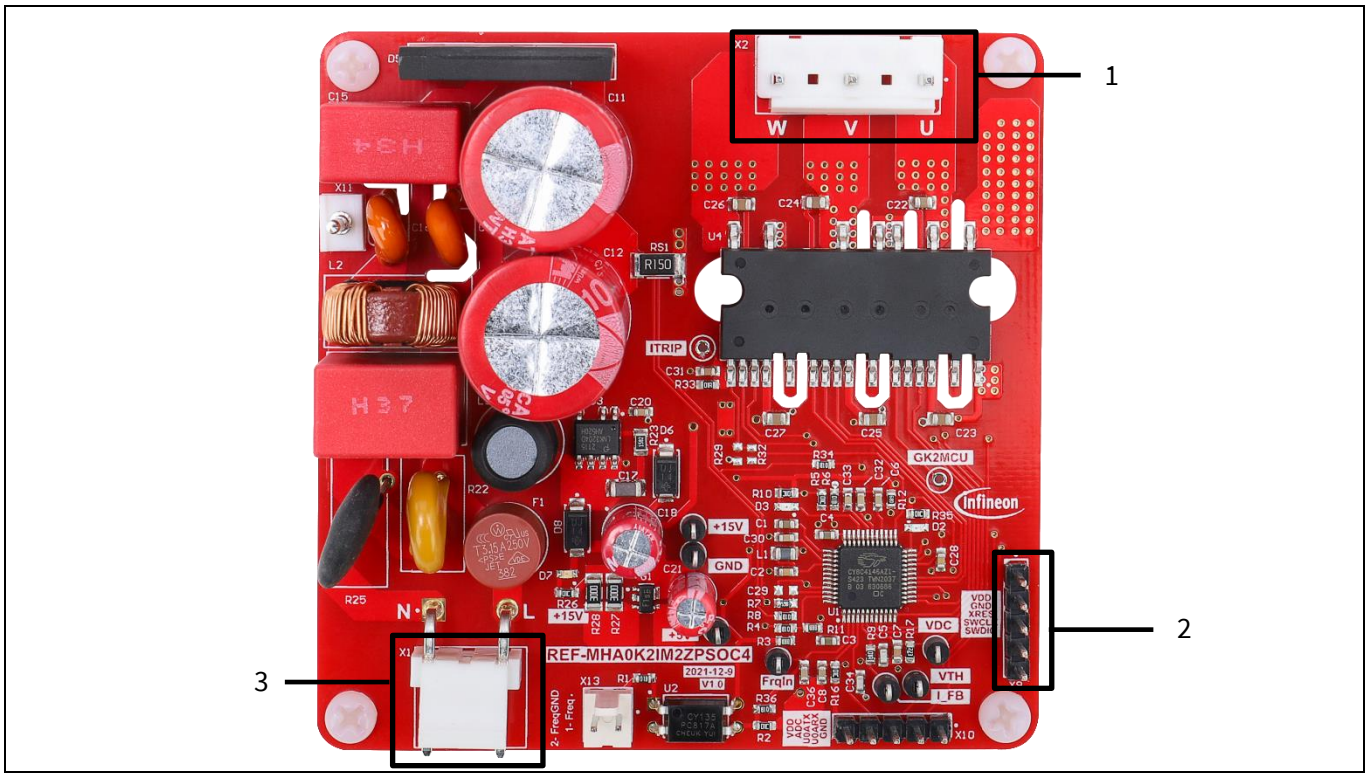

Figure 3 Connectors of the REF-MHA0K2IM2ZPSOC4 reference board

In order to get started with the board, the following steps are required:

1. Connect the motor phase outputs to the motor
2. Connect the debug connector on the board
3. Connect the AC power-to-power input connector and power-on the system

2.2 FOC introduction

Figure 4 shows the basic field-oriented control (FOC) control block diagram. The FOC control system includes:

1. Coordination of transformation, which includes Clarke/Park transforms and inverse Clarke/Park transforms
2. Sensorless rotor estimate for position and speed
3. Proportional-integral (PI) control for two currents (d/q axis current) with PI loop and one-speed PI loop
4. Space vector pulse width modulation(SVPWM) block
5. Single-shunt module reconstructs the phase current of motor

The algorithm controls the motor speed using a proportional-integral (PI) controller based on a mathematical model of the PMSM. The control result is sent to a space-vector pulse-width modulation (SVPWM) block. The SVPWM block generates three-phase voltages that change the stator currents.

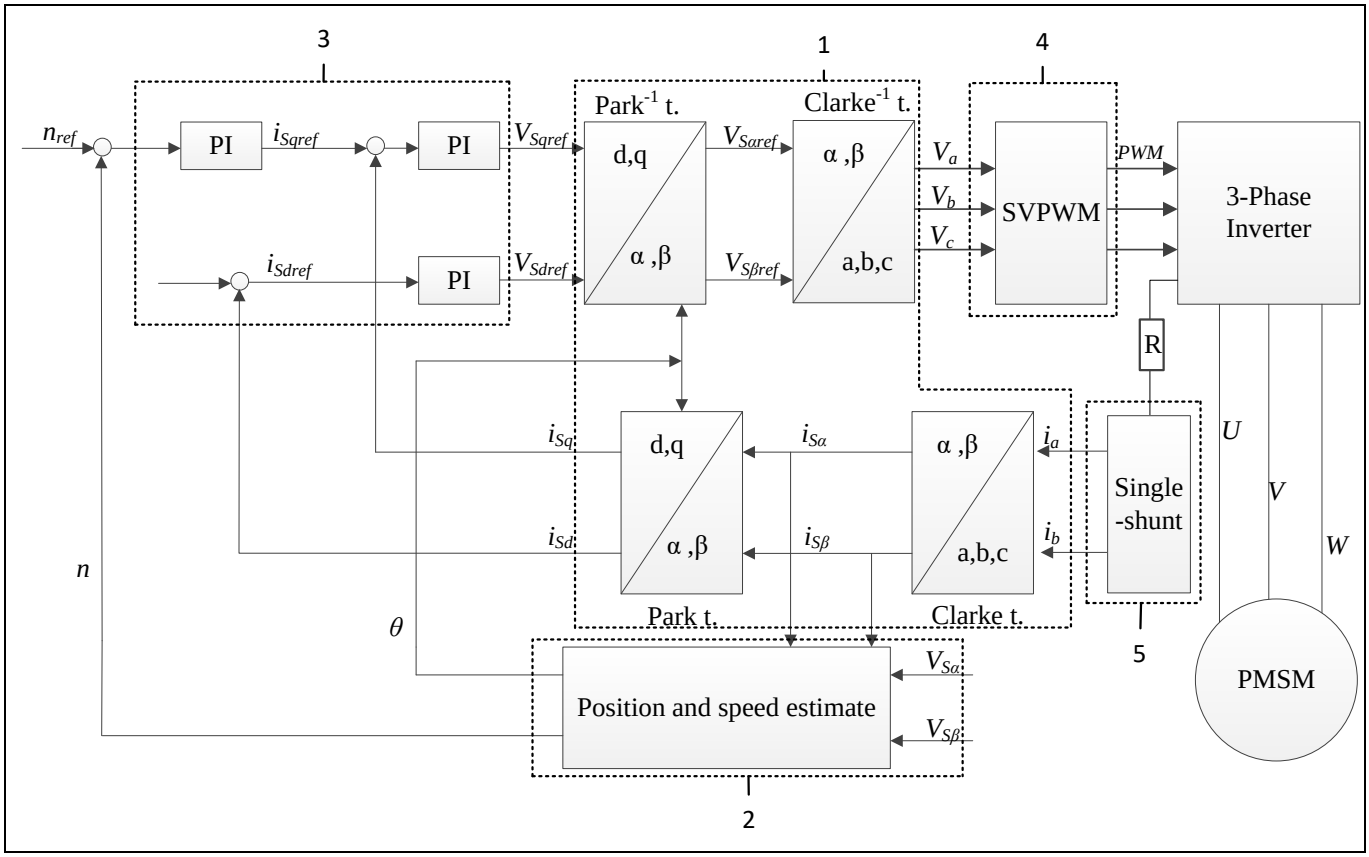

Figure 4 FOC control block diagram

2.3 Main features

- Carrier frequency is 5 KHz
- Single shunt current sample
- High-performance of PSoC4 MCU: integrated 2 unit op-amps and 2 unit comparators
- Phase lock loop(PLL) estimation of rotor position; precision can reach 1%
- Direct closed-loop start-up function to decrease start-up power cost
- Supports high-speed, field-weakening control
- Motor resistor self-check at start-up
- Motor lock recovery function
- Wide range speed adjustment: 20 Hz to 75 Hz
- Full protection

3 System design

3.1 Schematics

3.1.1 MCU section using PSoC 4100S

Figure 5 shows the schematic diagram of this chip.

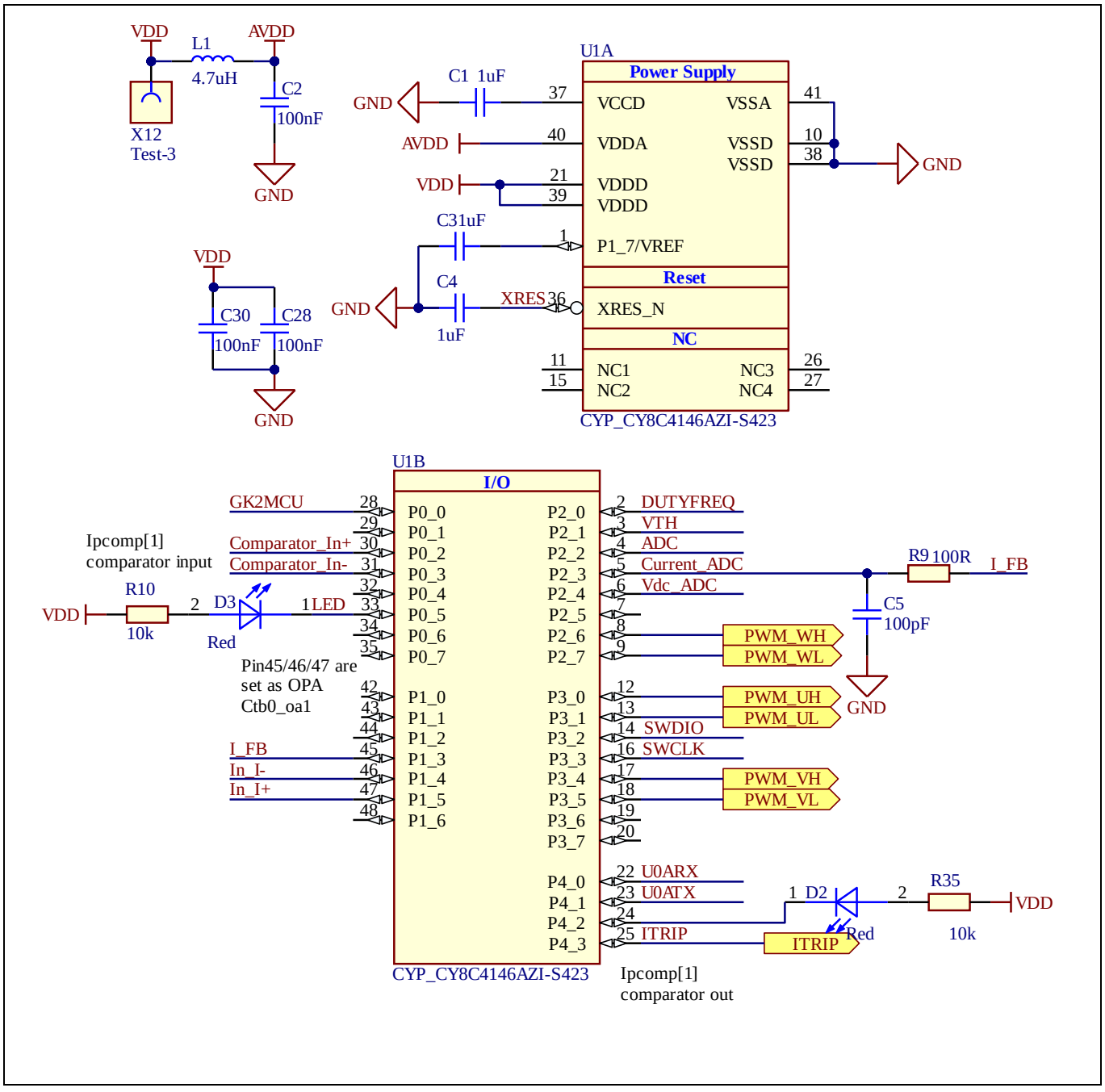

Figure 5 Schematic diagram of PSoC4 MCU

Several points must be considered:

1. Pin 1 (P1.7) is the ADC bypass pin for ADC sampling, and is connected with a 1 uF capacitor to avoid noise.

2. Pin 37 (VCCD) should be connected with a 1 uF capacitor.
3. For the minimum application system, please refer to the schematic diagram in Figure 5.
4. Only IMO should be used as the main oscillator for clock system.
5. It is recommended to keep the PWM signal pins as shown in the diagram. High-side and low-side signals must not be exchanged.
6. Internal op-amp and comparator pins are fixed.
7. P2.0~P2.5 can be used as ADC sampling pins.

3.1.2 Inverter section using CIPOS™ Micro (IM231L6S1BALMA1)

Figure 6 shows the schematic diagram of the inverter circuit using CIPOS™ Micro IPM IM231-L6S1B, which is a 600 V, 6 A, three-phase intelligent power module (IGBT-based) with an open emitter in SOP 29x12 packaging. It provides a fully-featured compact inverter solution for low-power motor drive applications, such as refrigerators. The module includes a combination of low $V_{CE\,(sat)}$ trench IGBT technology and robust half-bridge drivers, the industry benchmark.

The current sampling on this board is implemented by a single-shunt topology with 150 mΩ resistor. The three capacitors C22, C24 and C26 are used as bootstrap capacitors to provide the necessary floating supply voltages VBS1, VBS2 and VBS3, respectively.

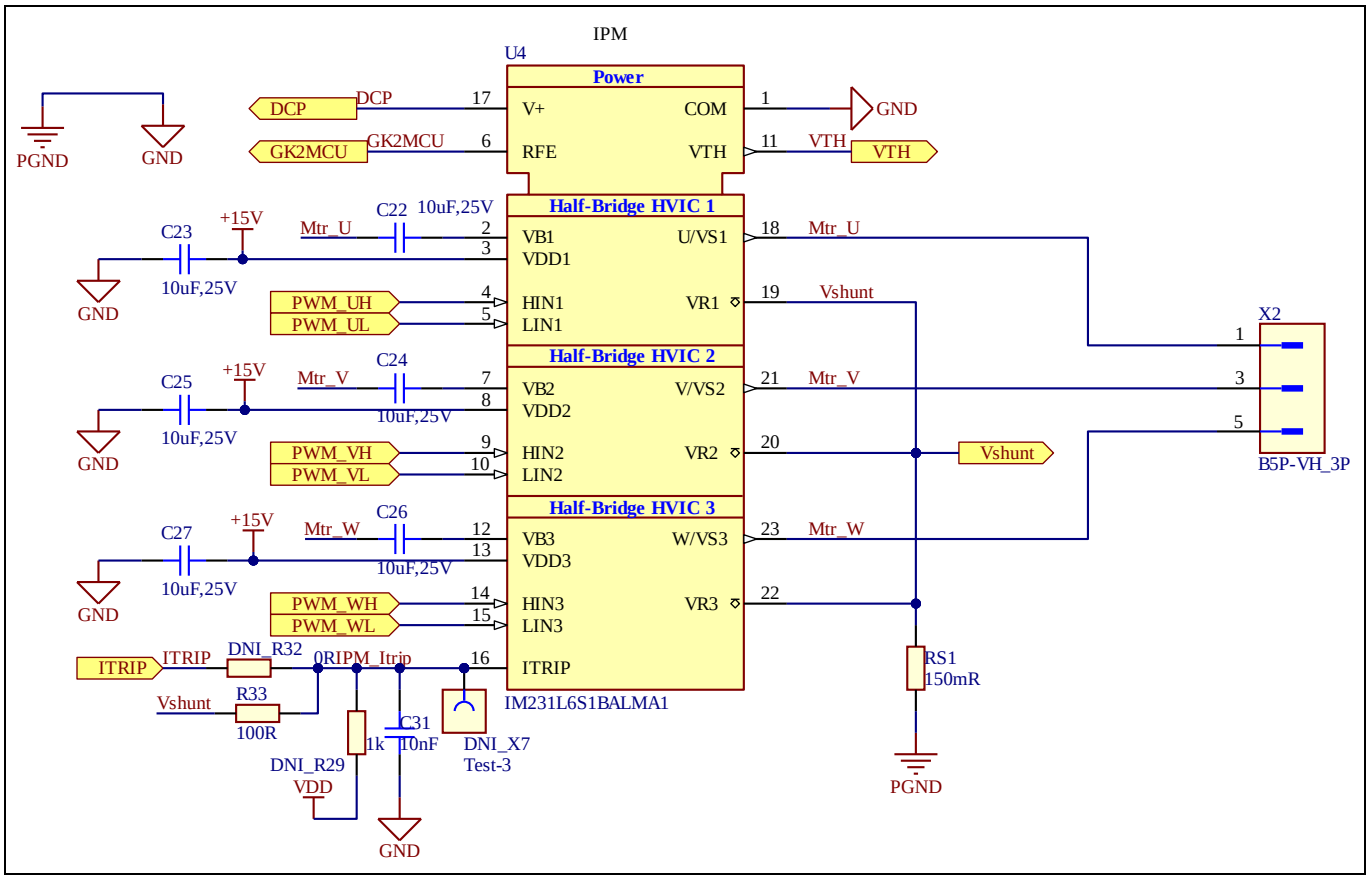

Figure 6 Schematic of inverter section using CIPOS™ Micro (IM231L6S1BALMA1)

3.1.3 DC bus voltage sampling section

Figure 7 shows the detailed schematic diagram of the DC bus sense circuit. **DCP** is the net label of DC bus voltage, and **Vdc_ADC** is the net label that is connected with the MCU. The DC bus sense voltage is in the range of 0 to 5 V on the pin, reflecting a DC bus voltage range of 0 to 463 V.

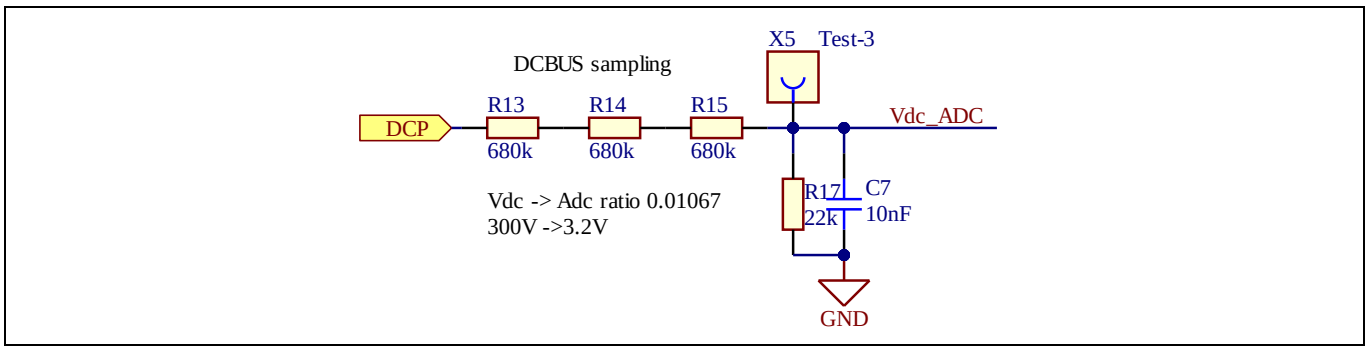

Figure 7 Schematic diagram of DC bus voltage sampling

The value of DC bus (V_{DC_bus}) and voltage sense coefficient ($_{VDC\_factor}$) can be calculated using the following equations

$$V_{DC\_BUS} = V_{DC\_Factor} * V_{DC\_Sample}$$

$$V_{DC\_Factor} = \frac{R13+R14+R15+R17}{R17}$$

3.1.4 Motor-phase current sampling with internal op-amps

Figure 8 shows the schematic diagram of the motor-phase current sampling circuit, which consists of two internal op-amps of PSoC 4100S and resistor circuit. This circuit is magnified by 4 and the offset voltage of this circuit is 2.5 V (when input voltage is 0 V).

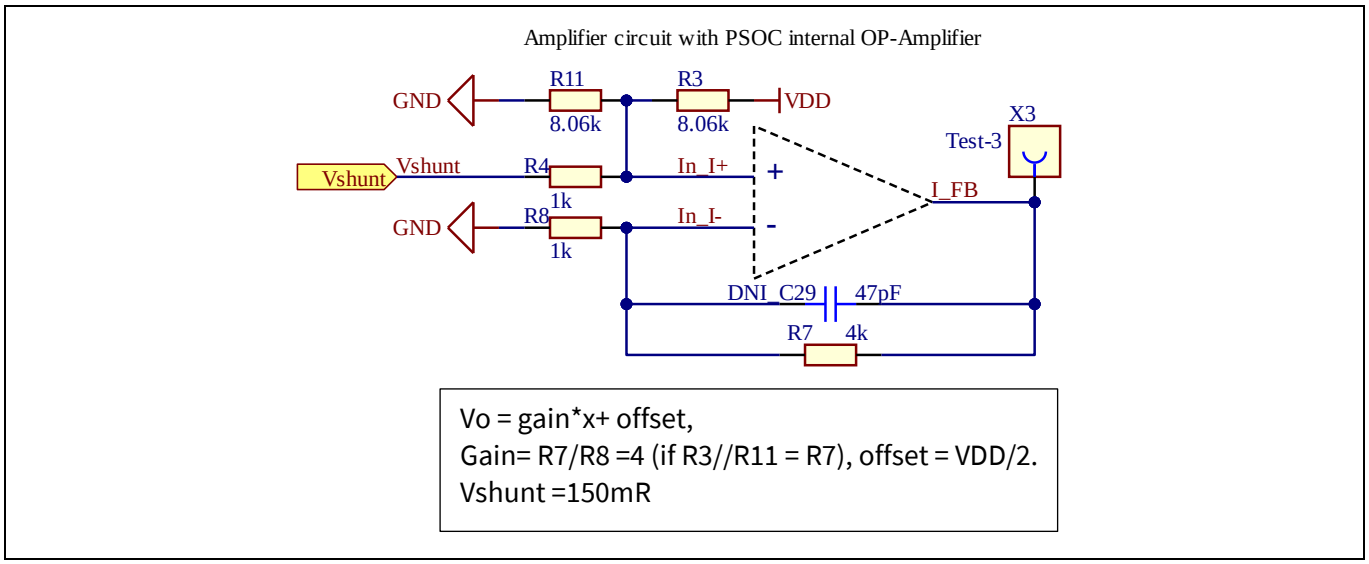

Figure 8 Current sampling circuit with internal op-amps

3.1.5 Inverter overcurrent protection section with internal comparator

Figure 9 depicts the schematic diagram of the inverter overcurrent protection circuit using an internal comparator.

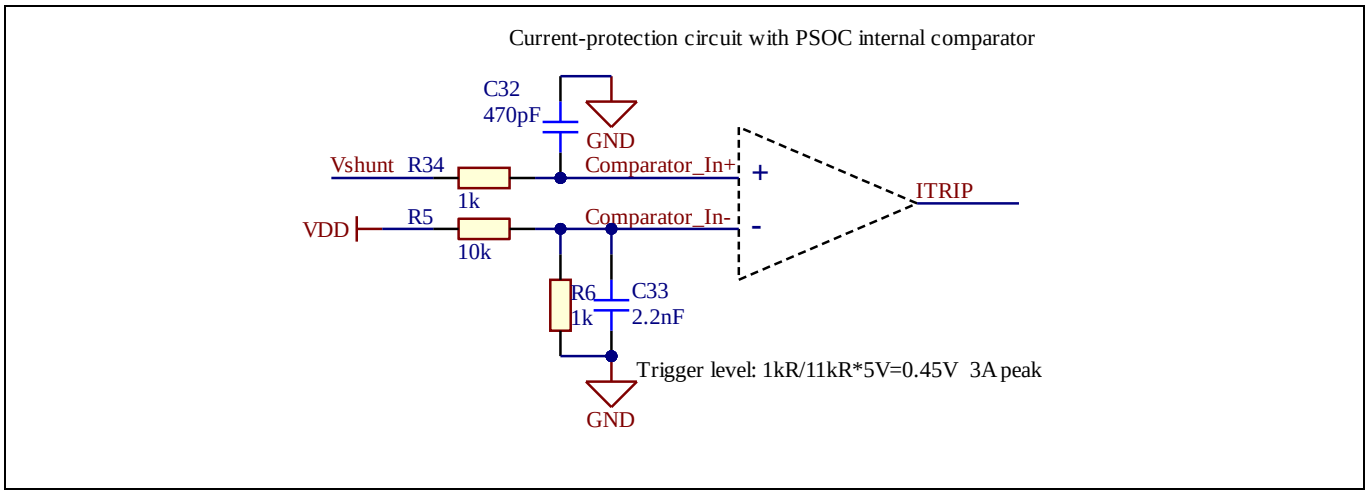

Figure 9 Hardware overcurrent protection circuit with internal comparator

The following equation calculates the peak current of the inverter output by internal comparator.

$$Itrip = ((5 * R6)/(R5 + R6))/RS1 \ = \ 3(A)$$

3.1.6 Over-temperature and VFO circuit

Pin 3 of MCU is the ADC port dedicated to NTC temperature sampling. On the board, Pin 11 of the IPM IM231-L6S1B is connected to the ADC channel by the circuit shown in Figure 10.

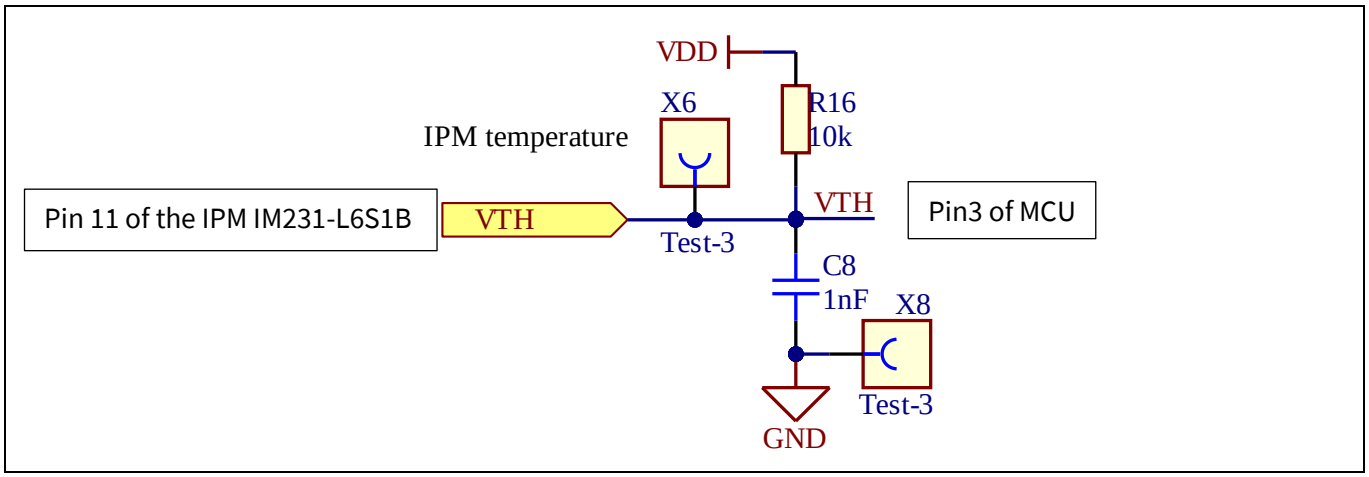

Figure 10 NTC sensing circuit

The firmware integrates the over-temperature protection function, which is triggered by the voltage V_{th}. The protect value is set to 105℃.

VFO circuit introduction

The VFO pin indicates a module failure in case of undervoltage at pin VDD, or in case of triggered overcurrent detection at ITRIP. Figure 11 also depicts the VFO circuit of the CIPOS™ Micro (IM231L6S1BALMA1).

There are two-branch current protection circuits, which can be selected by R32/R33. The default setting directly connects to the shunt resistor; the other branch is protected by the comparator located inside the PSoC IC.

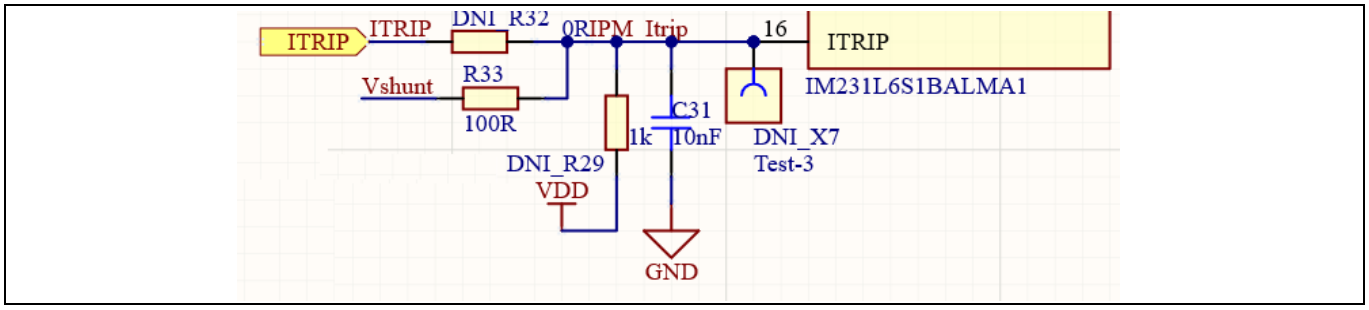

Figure 11 Hardware overcurrent circuit at pin VFO

3.1.7 Frequency signal interface

Since current refrigerator applications mainly use the frequency signals of square waves to control the compressor speed, the board is designed with a frequency signal interface. Figure 12 shows the interface circuit. The input signal is isolated by U2 from the control and power parts on the board.

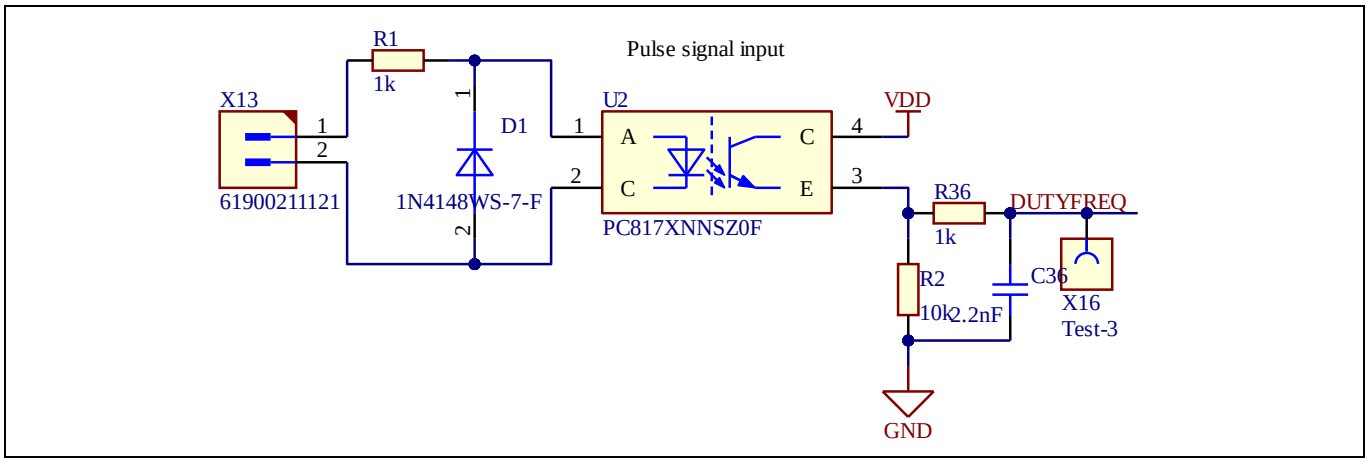

Figure 12 Frequency interface circuit

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

Table 6 Typical frequency/speed characteristic

Signal frequency f_n (Hz)	Motor speed n (RPM)
$f_n < 35$	Stop
$35 \le f_n < 40$	Minimum speed
$40 \le f_n < 150$	$30 * f_n$
$150 \le f_n < 160$	Maximum speed
$f_n \ge 160$	Stop

3.1.8 EMI filter and AC-DC conversion

Figure 13 depicts the schematic diagram of the AC input connector to the rectified DC bus voltage. This circuit includes a rectifier bridge D5, a negative temperature coefficient (NTC) resistor R25, a passive EMI filter consisting of elements C9,C16,L2, etc.

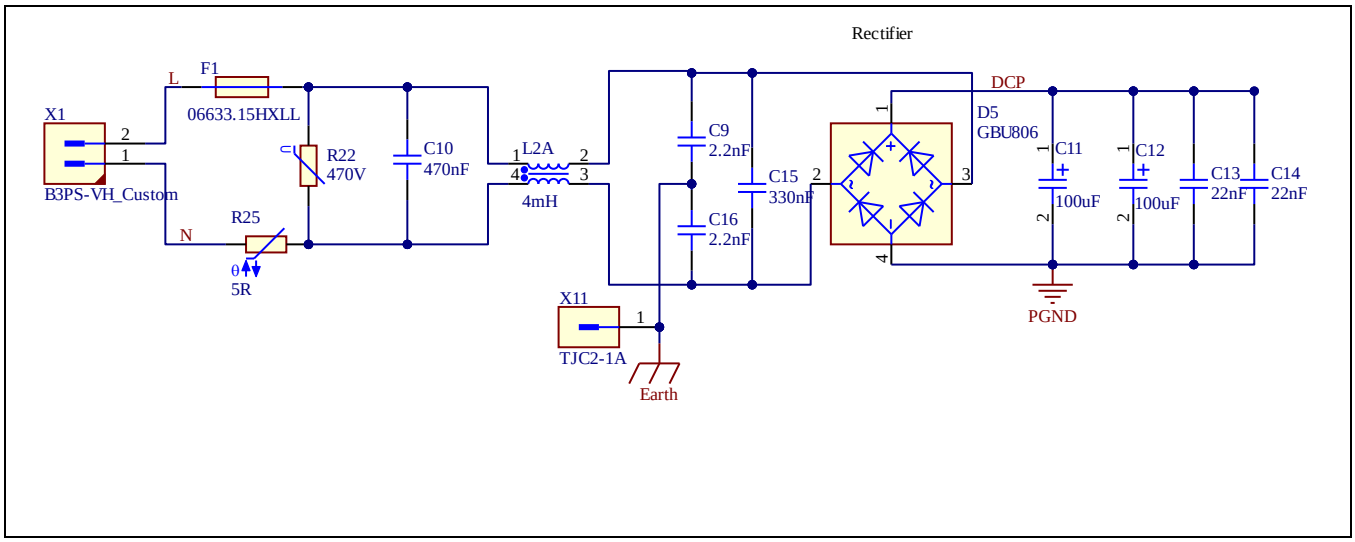

Figure 13 Schematic from the AC input connector to the rectified DC bus voltage

3.1.9 Auxiliary power supply

Figure 14 depicts the schematic diagram of the auxiliary power supply available on the REF-MHA0K2IM2ZPSOC4 reference board. The circuit includes LNK3204D, which is used to generate 15 V directly from the DC bus voltage that is connected to the gate driver inside the IPM.

The LDO voltage regulator TLE4294G V50 generates 5 V from 15 V power supply. The 5 V power supply is used in the MCU system.

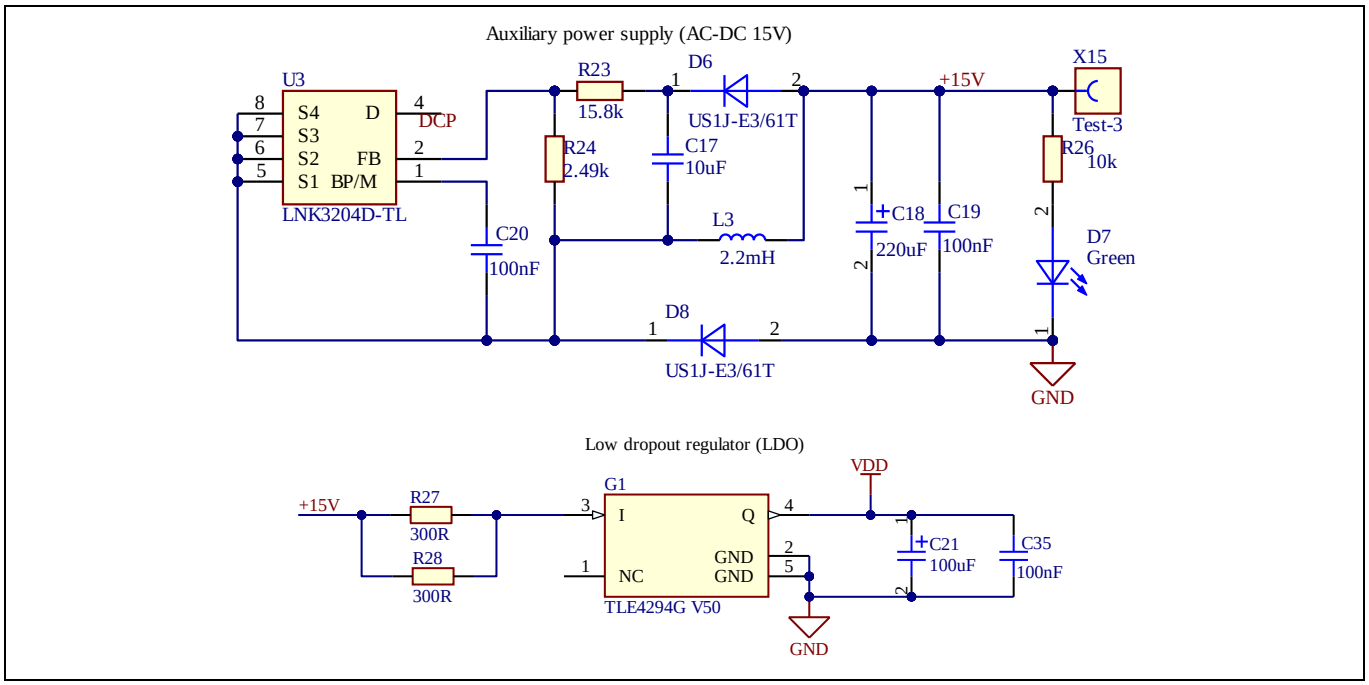

Figure 14 Schematic of the auxiliary power supply available on the REF-MHA0K2IM2ZPSOC4

3.2 PCB layout

The board is designed in two layers, and its dimensions are 78 mm × 78 mm, manufactured with 1 oz. (35 µm) copper thickness. The project is designed with Altium Designer, and all design files can be downloaded after logging into your account on the Infineon website.

Figure 15 illustrates the top assembly print of the board.

Figure 16 illustrates the bottom assembly print of the board.

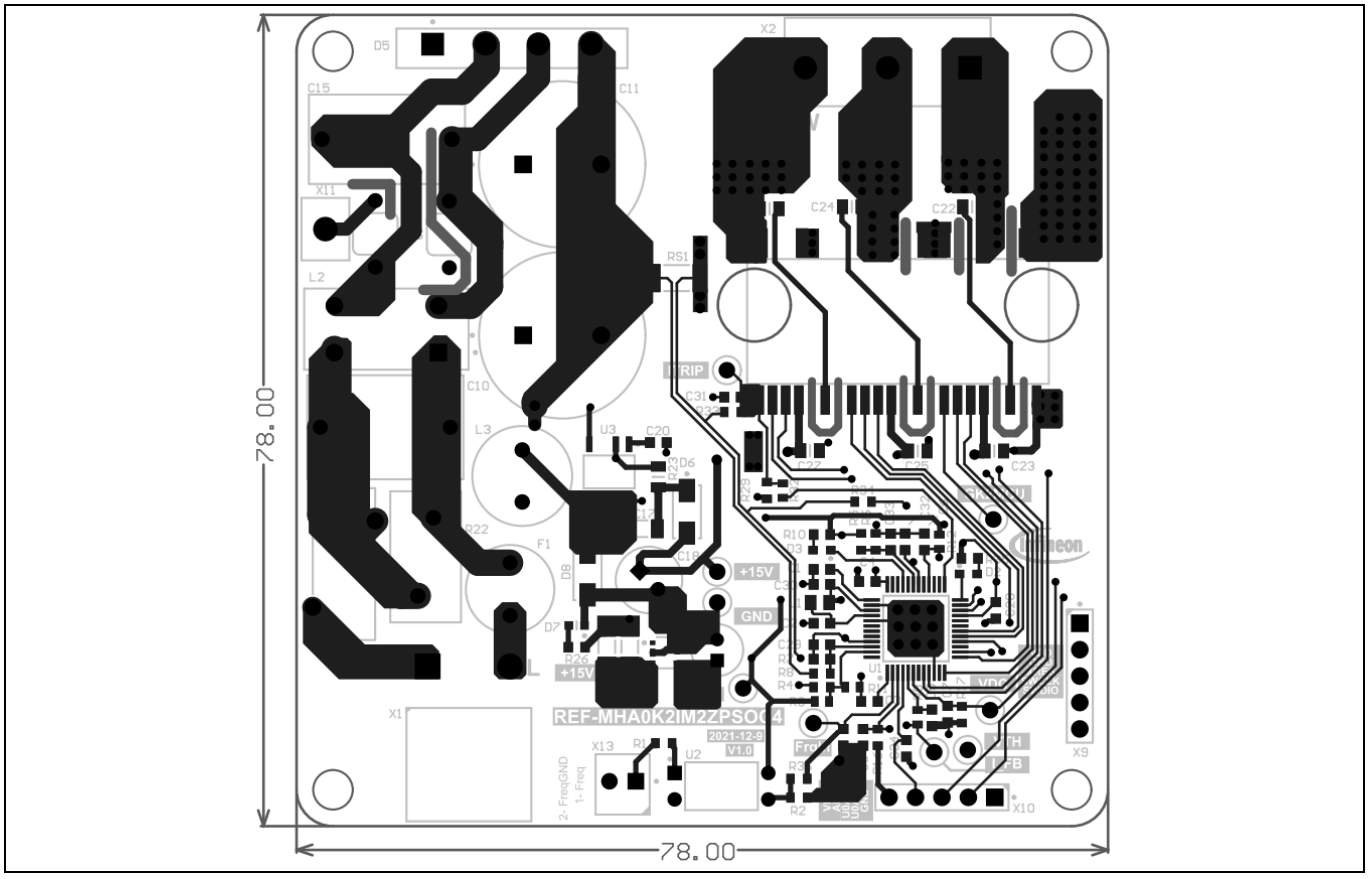

Figure 15 Top view of the board

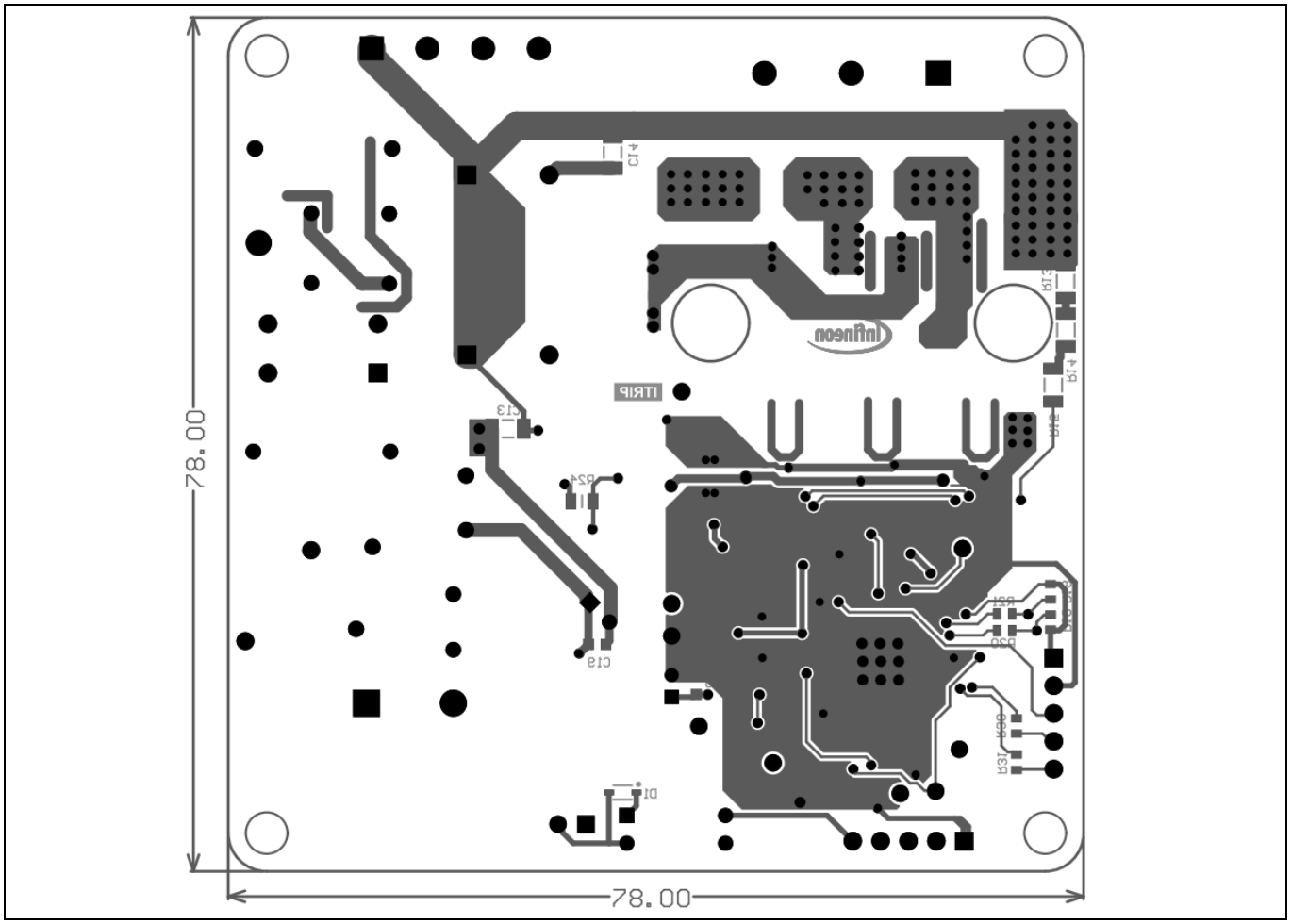

Figure 16 Bottom view of the board

3.3 Bill of material (BOM)

Table 7 provides the key components for the REF-MHA0K2IM2ZPSOC4. The complete bill of material is available on the download section of the Infineon homepage. A log-in is required to download this material.

Table 7 Key components of REF-MHA0K2IM2ZPSOC4

No.	Ref designator	Description	Manufacturer	Manufacturer P/N
1	U1	Programmable system-on-chip (PSoC)	Infineon Technologies	CY8C4146AZI-S423
2	U4	Control-integrated power system (CIPOS)	Infineon Technologies	IM231-L6S1B
3	G1	Monolithic-integrated low drop out voltage regulator	Infineon Technologies	TLE4294G V50
4	C10	CAP / FILM / 470nF / 275V / 10% / MKP (Metallized Polypropylene) / -40°C to 105°C /	Wurth Elektronik	890324024005

No.	Ref designator	Description	Manufacturer	Manufacturer P/N
		12.50mm C X 0.60mm W 15.00mm L X 10.00mm T X 16.50mm H / - / -		
5	C17	CAP / CERA / 10uF / 25V / 20% / X7R (EIA) / -55°C to 125°C / 1206(3216) / SMD / -	Wurth Elektronik	890324024003
6	C18	CAP / ELCO / 220uF / 25V / 20% / Aluminiumelectrolytic / -40°C to 85°C / 2.50mm C X 0.50mm W 6.30mm Dia X 12.50mm H / - / -	Wurth Elektronik	860010473011
7	C21	CAP / ELCO / 100uF / 16V / 20% / Aluminiumelectrolytic / -40°C to 85°C / 2.00mm C X 0.50mm W 5.00mm Dia X 12.50mm H / THT / -	Wurth Elektronik	860010372006
8	X13	Vertical Locking Header, 2.54mm Pitch, 2 pin, Single Row	Wurth Elektronik	61900211121
9	L2	IND / STD / 4mH / 1.5A / 30% / -40°C to 125°C / 140R / THT / Inductor,THT, 4 Pin, 15.80 mm L X 7.80 mm W X 18.00 mm H body / THT / -	Wurth Elektronik	744821240

4 System performance

Figure 17 shows the start-up waveforms of a compressor in a refrigerator system, illustrating the start-up characteristics of the solution:

- Direct closed-loop start-up. There is no open-loop positioning and driving process.
- Good closed-loop performance, smooth current in closed loop, and lower speed overshoot at start-up speed.
- Compressor is stable at minmum speed of 1200 r and maximum speed of 4500 r.

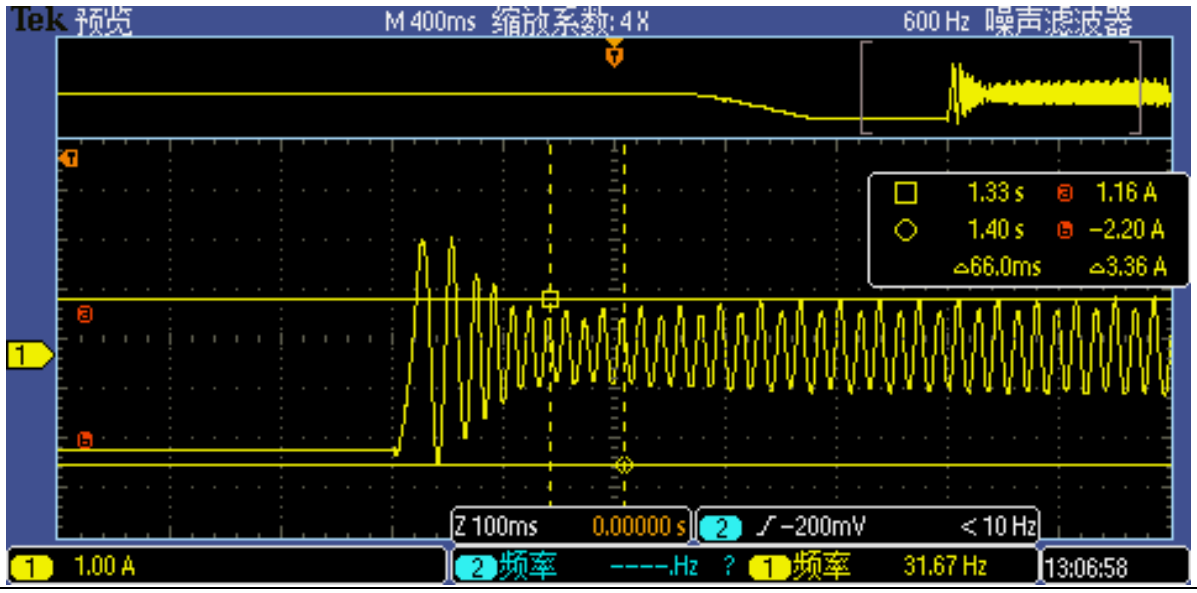

Figure 17 Start-up waveform of fridge at heavy load

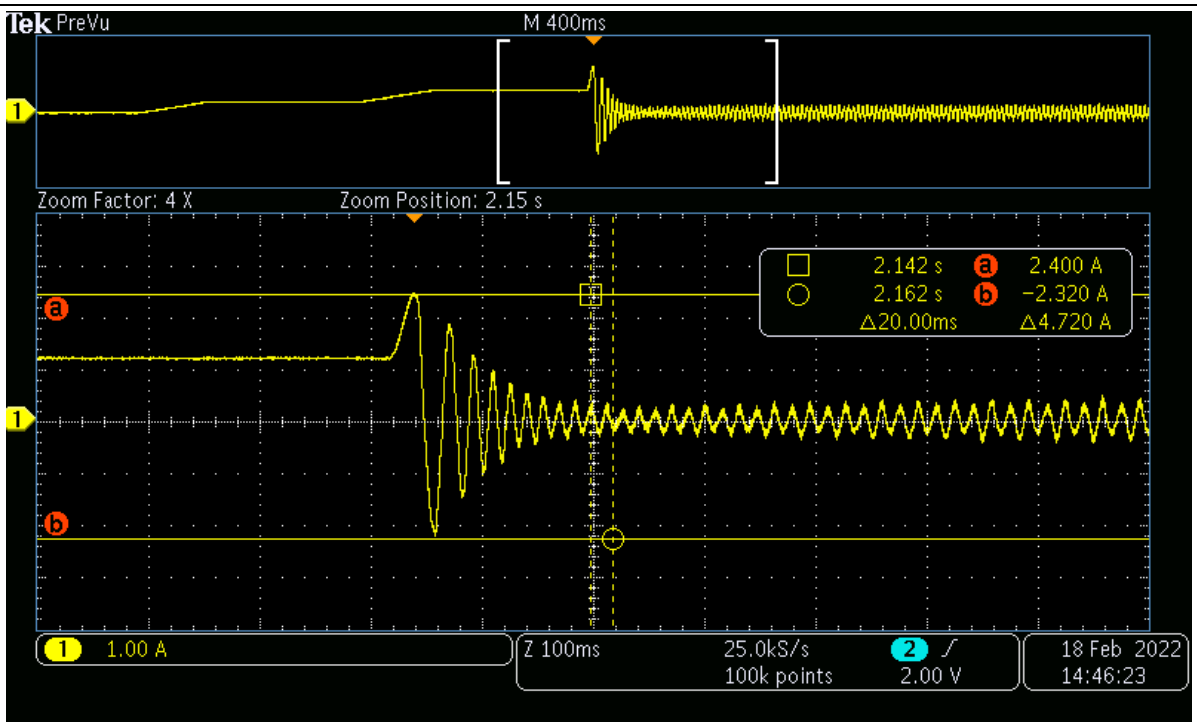

Figure 18 Start-up waveform of fridge at empty load

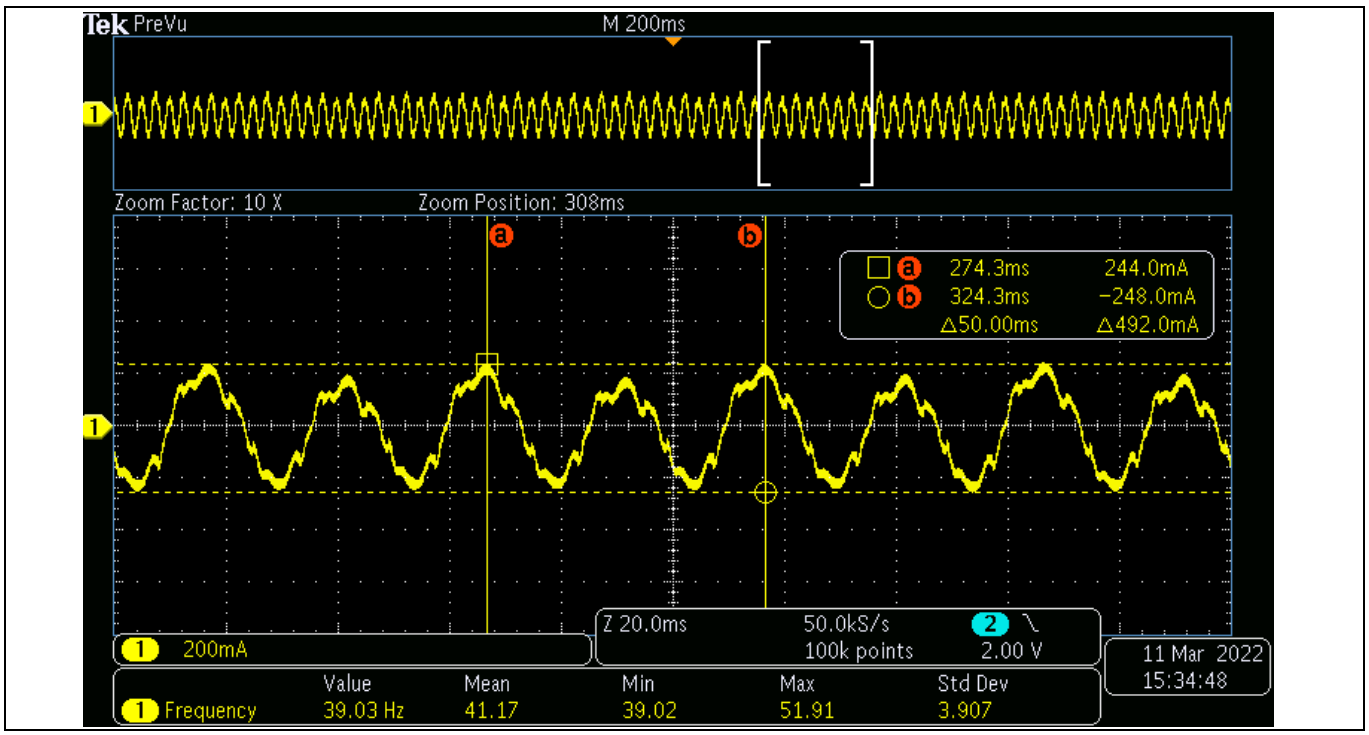

Figure 19 Waveform of fridge at minimun speed 1200 r

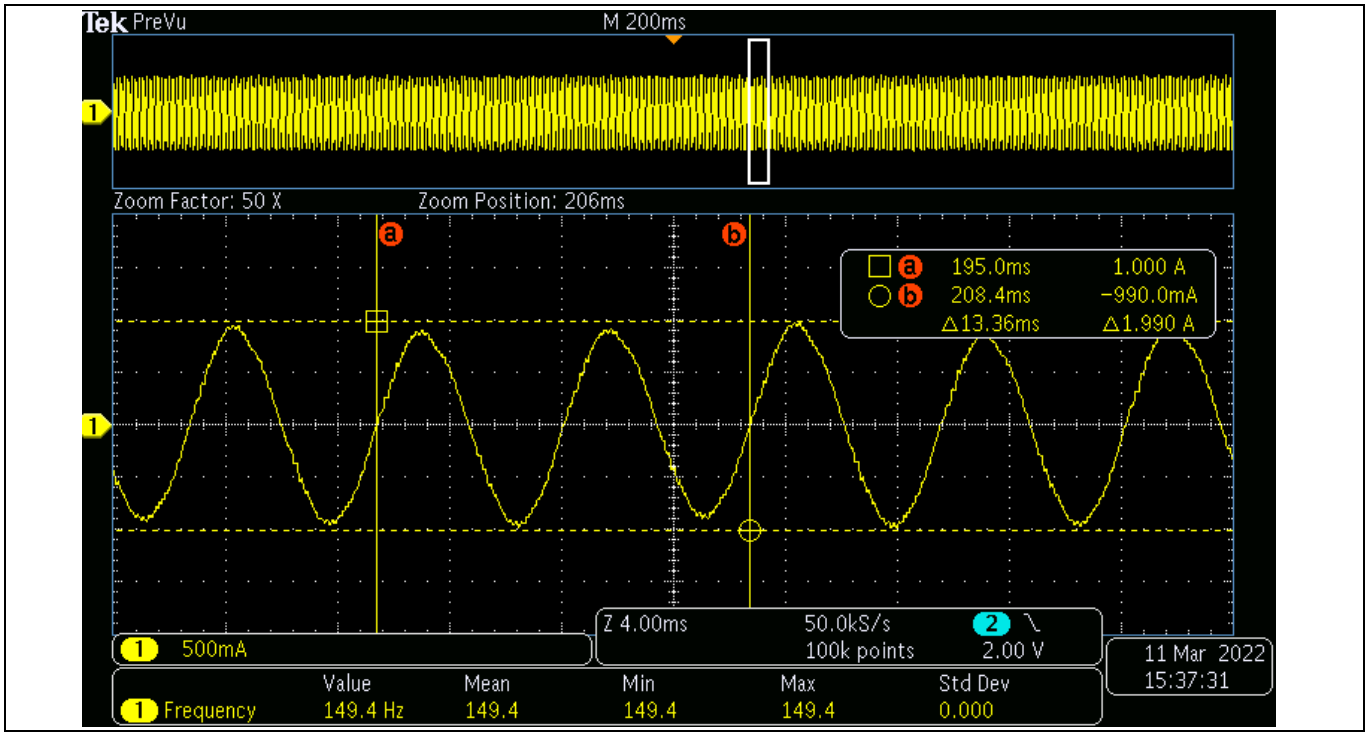

Figure 20 Waveform of fridge at maximum speed 4500 r

5 Appendices

5.1 Abbreviations and definitions

Table 8 Abbreviations

Abbreviation	Meaning
BLDC	Brushless direct current motor
CIPOS	Control-integrated power system
FOC	Field-oriented control
IPM	Intelligent power module
UL	Underwriters' Laboratories
PMSM	Permanent magnet synchronous motor
PLL	Phase lock loop
NTC	Negative temperature coefficient
PI	Proportional integral
SVPWM	Space vector pulse width modulation

Revision history

Document version	Date of release	Description of changes
Revision 1.0	2022-2-14	Initial version

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