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REF-AIRCON-C302A-IM564 user guide

Air conditioner application reference design kits

About this document

Scope and purpose

This user guide provides an overview of the reference board REF-AIRCON-C302A-IM564 including its main features, key test results and mechanical dimensions.

The REF-AIRCON-C302A-IM564 is a full-featured starter kit, turnkey motor drive designed for high-performance, high-efficiency permanent magnet synchronous motor (PMSM) drive applications, including all of the required elements for air conditioner applications, such as IMC302A iMOTION™ controller, 1ED44175 PFC gate driver and PFC-integrated CIPOS™ Mini IPM IM564-X6D.

The starter kit features and demonstrates Infineon's CIPOS™ Mini IPM and advanced motion control engine (MCE 2.0) technology for PMSM/BLDC motor and PFC driver up to a rating of 600 V and 20 A. It is optimized for major home appliances like air conditioner compressors, fans, pumps and other motor drive applications.

Note: *Please note that this product is not qualified according to the AEC Q100 or AEC Q101 documents of the Automotive Electronics Council.*

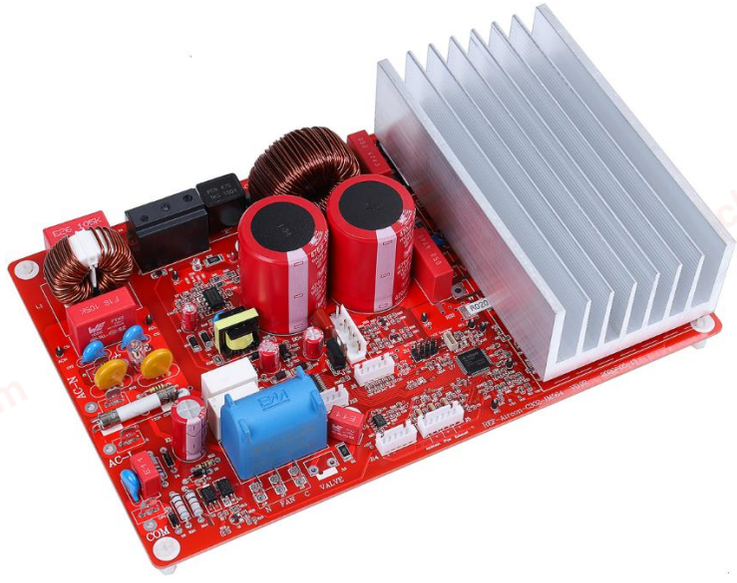
Intended audience

This application note is intended for all technical specialists who are familiar with air conditioner control and electronics converters. The reference design is intended to be used under laboratory conditions only by trained specialists.

Reference board

The Infineon products are embedded on this PCB with functions and form factor close to a commercial design. PCB and auxiliary circuits are optimized for the final design.

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



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Safety precautions

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

Table 1 Safety precautions

	**Warning:** *The DC link potential of this board is up to 400 V_{DC}. When measuring voltage waveforms by oscilloscope, high voltage differential probes must be used. Failure to do so may result in personal injury or death.*
	**Warning***: The 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 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 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 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 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-AIRCON-C302A-IM564 is a part of Infineon's CIPOS™ Mini IPM and iMOTION™ reference design kits. It is designed to provide ready-to-use, air conditioner solutions based on Infineon's PFC-integrated CIPOS™ Mini IPM and advanced motion control engine (MCE 2.0) technology.

The REF-AIRCON-C302A-IM564 is an optimized design for 1400 ~ 2500 W power air conditioner applications. It allows fast prototyping and fast time to market. It is available through regular Infineon distribution partners as well as on Infineon's website. The main features of this board are described in this document, whereas the remaining paragraphs provide information to enable the customers to copy and modify the design for production according to their own specific requirements.

1.1 Delivery content

The board is equipped with all assembly groups for sensorless field-oriented control (FOC), and reserved interface for BLDC/AC fan control, relays and 4-way valve control and 3-channel temperature sensing circuits, so that it can be easily used for air conditioners and similar home applications.

It provides a single-phase AC connector, an EMI filter and soft power-up circuit, input rectifier, DC bus capacitors, on-board PFC inductor emitter shunts for current sensing and overcurrent protection (OCP), thermistor output and a voltage divider for DC-link voltage measurement.

The REF-AIRCON-C302A-IM564 reference design also contains a CoolSET™ based flyback auxiliary power supply to provide 15 V, 12 V & 5 V.

1.2 Block diagram

The block diagram of the REF-AIRCON-C302A-IM564 is depicted in Figure 1.

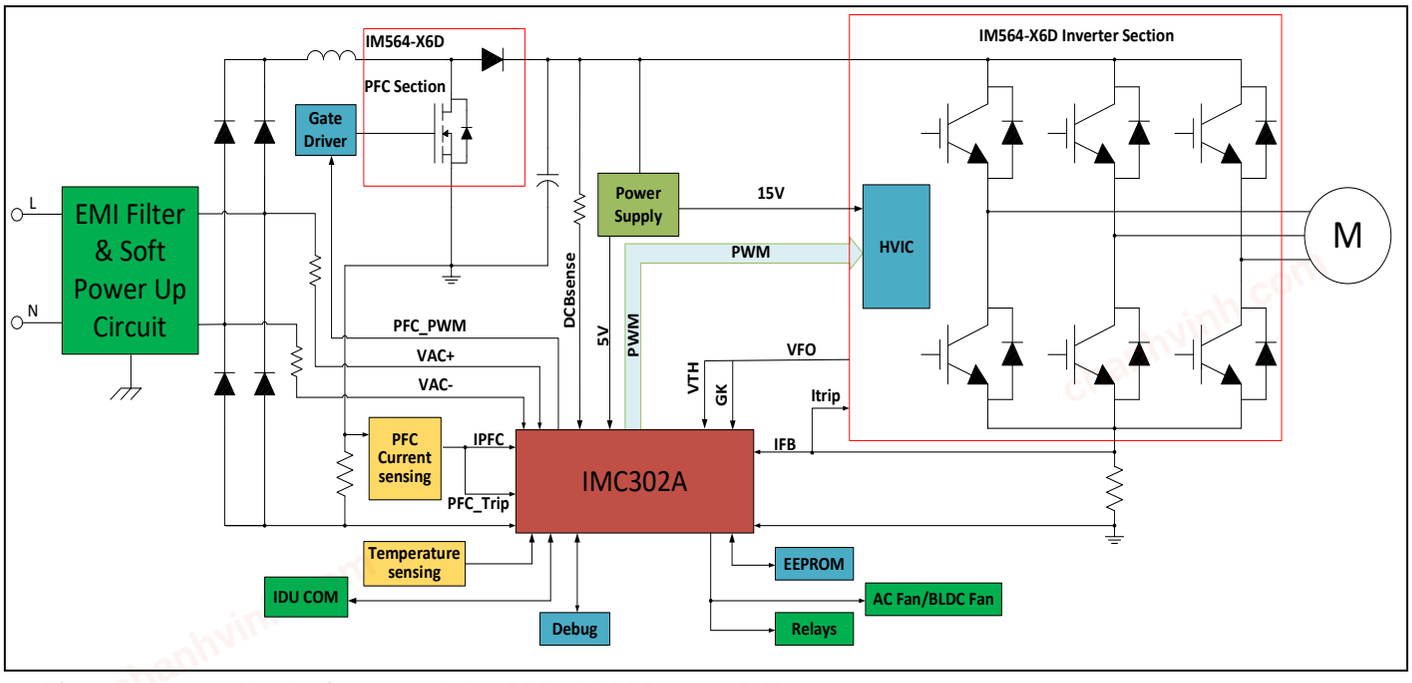
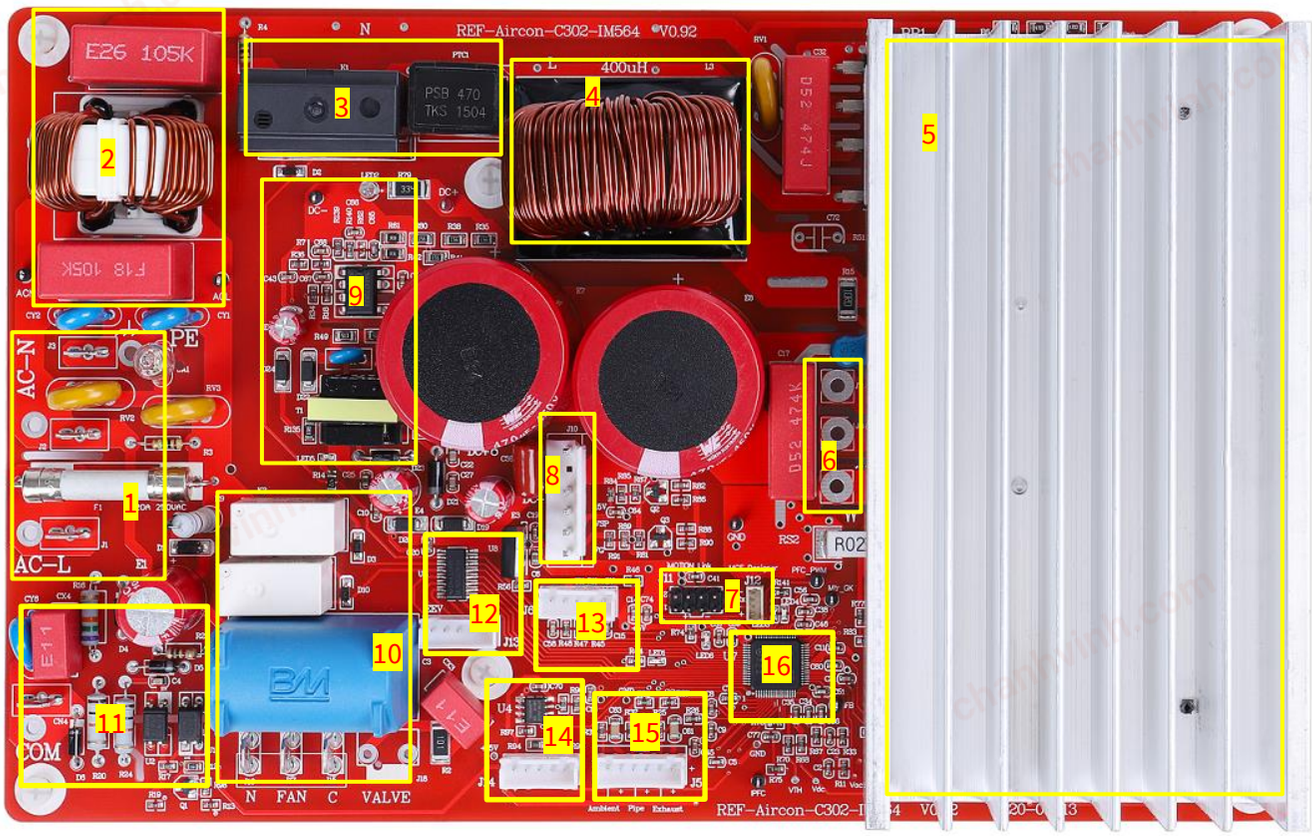


Figure 1 Block diagram of the REF-AIRCON-C302A-IM564

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The board at a glance

Figure 2 points out the functional groups on the top side of the REF-AIRCON-C302A-IM564 reference design:



1. 220 V_{AC} & PE input connector
2. EMI filter
3. In-rush relay control
4. On-board PFC inductor
5. Heat sink (IM564 + 1ED44175 + input rectifier)
6. UVW motor phase connector
7. iMOTION™ link connector, UART 0 & UART1
8. External BLDC fan VSP control
9. Auxiliary power supply
10. AC fan and 4-way valve relay control
11. Single-wire UART interface to IDU
12. EEV connector
13. UART tester connector
14. EEPROM
15. Temperature sensing
16. IMC302A

Figure 2 Functional groups of the REF-AIRCON-C302A-IM564 reference design

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1.3 Main features

The REF-AIRCON-C302A-IM564 board is an optimized reference design for 220 V air conditioner applications, which contains iMOTION™ controller IMC302A, 20 A, 600 V PFC-integrated CIPOS™ Mini IPM and 1ED44175 PFC gate driver.

Major REF-AIRCON-C302A-IM564 characteristics include:

- Input voltage 85~265 V_{AC}
- Maximum 2500 W at 220 V_{AC} power input with forced air cooling
- Maximum 1400 W at 220 V_{AC} power input without forced air cooling
- 20 A, 600 V PFC-integrated CIPOS™ Mini IPM
- On-board 10 A, 400 µH PFC inductor for 40 kHz PFC operation
- VSP host interface for external BLDC fan
- AC fan and 4-way valve control relay
- Single-wire UART communication interface to IDU
- Overcurrent and over temperature protection, fault diagnostic LED output
- Auxiliary power supply with 15 V, 12 V and 5 V
- PCB is 250 mm × 157 mm, 2 layers, 1 oz. copper
- RoHS compliant

1.4 Board parameters and technical data

Table 2 depicts the key specifications of the reference design of REF-AIRCON-C302A-IM564.

Table 2 REF-AIRCON-C302A-IM564 board specifications

Parameter	Symbol	Conditions / comments	Value	Unit
Input voltage	V_{ac}	Optimized design for 220 V_{AC} applications	85 ~ 265	V_{rms}
Maximum input current	$I_{ac(max1)}$	Input 220 V_{AC}, T_a=25°C, natural cooling mode	6	A_{rms}
	$I_{ac(max2)}$	Input 220 V_{AC}, T_a=25°C, with 1 m/s wind cooling	12	A_{rms}
Maximum output power	$P_{in(max1)}$	Input 220 V_{AC}, Motor f_{PWM}= 6 kHz, PFC f_{PWM}=40 kHz, T_a=25°C, IPM T_C = 105 °C, Natural cooling mode	1400	W
	$P_{in(max2)}$	Input 220 V_{AC}, Motor f_{PWM}= 6 kHz, PFC f_{PWM}=40 kHz, T_a=25°C, IPM T_C = 105 °C, 1 m/s force cooling mode	2500	W
Maximum motor current	$I_{mtr(max1)}$	Input 220 V_{AC}, Motor f_{PWM}= 6 kHz, PFC f_{PWM}=40 kHz, T_a=25°C, IPM T_C = 105 °C, Natural cooling mode	6	A_{rms}
	$I_{mtr(max2)}$	Input 220 V_{AC}, Motor f_{PWM}= 6 kHz, PFC f_{PWM}=40 kHz, T_a=25°C, IPM T_C = 105 °C, 1 m/s force cooling mode	10	A_{rms}
DC bus voltage				
Maximum DC bus voltage	$V_{dc(max)}$	DC bus capacitors are 450 V, 470 µF x 2	450	V
Minimum DC bus voltage	$V_{dc(min)}$	Aux power supply brown-in voltage	80	V

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The board at a glance

Parameter	Symbol	Conditions / comments	Value	Unit
Current feedback				
PFC shunt resistance	*RS1*	5 W shunt resistor with external OPA gain 14.7	15	mΩ
Motor shunt resistance	*RS2*	Direct AD sample (without external OPA)	20	mΩ
Protections				
Motor current protection trigger level 1	$MtrI_{trip1}$	Wizard setup for OC trigger level, related to AD range, shunt resistor RS2 and pull-up bias	16 [1]	A_{peak}
Motor current protection trigger level 2	$MtrI_{trip2}$	Hardware comparator overcurrent protection, related to RS2 and IM564's Itrip threshold	26.2	A_{peak}
PFC current protection trigger level 1	$PFCI_{trip1}$	IMC302A's internal comparator for cycle-by-cycle OCP, trip level can be adjusted by R50 & R55	20 [2]	A_{peak}
PFC current protection trigger level 2	$PFCI_{trip2}$	PFC driver local protection for 1ED44175 driver, trip level can be adjusted by RS1, R66 & R71	33.3	A_{peak}
Thermal protection level	$T_{protection}$	Temperature gap between junction and NTC sensor needs to be considered	90	°C
Auxiliary power supply 1 – 15 V				
Output voltage	V_{out1}	Used for IPM driver	15 ± 2%	V
Maximum output current	I_{out1}		150	mA
Auxiliary power supply 2 – 12 V				
Output voltage	V_{out2}	Used for relay control	12 ± 10%	V
Maximum output current	I_{out2}		300	mA
Auxiliary power supply 3 – 5 V				
Output voltage	V_{out2}	Used for IMC controller and protection circuits	5 ± 1%	V
Maximum output current	I_{out2}		200	mA
PCB characteristics				
Dimension		Length × width × height	250×157 ×65	mm
Material		FR4, 1.6 mm thickness, 1 oz. PCB		
System environment				
Ambient temperature	T_a	Non-condensing, maximum RH of 95%	0 ~ 50	°C

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

[2] For iMOTION™ IC IMC302 PFC overcurrent protection, there are two options in MCEWizard setup.

If you select "Enable cycle by cycle" mode, the PWM output immediately goes to logic LOW when the inductor current exceeds the pre-determined OCP threshold, and re-starts at following PWM cycle.

For "Disable" mode, PFC state machine would shift from RUN state to FAULT state when inductor current exceeds the pre-determined OCP threshold for a duration specified by parameter "PFC_GateKillTime", only Fault_clear command can make it back to STOP/RUN mode, which means latch–off OCP.

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2 System and functional description

This chapter provides more function block details on setting up the system, and getting started with the iMOTION™ development platform with the REF-AIRCON-C302A-IM564 reference design.

2.1 Getting started with REF-AIRCON-C302A-IM564

The REF-AIRCON-C302A-IM564 reference designs are shipped with embedded firmware and default parameters.

A 6-pole, GK6063-6AC31 motor is used for the default DEMO functions, whose maximum speed is 2500 RPM and maximum power is 3 KW. Please note that motor parameters need to be double-checked in MCEWizard for a real air conditioner motor.

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

The iMOTION™ software tools, MCEDesigner and MCEWizard, are required to initially set up the system, as well as to control and fine-tune the system performance to match the user's exact needs. These tools are available for download via the Infineon website (https://www.infineon.com/cms/en/product/power/motor-control-ics/digital-motor-controller-imotion/imc302a-f064/#!tools). Please visit this page periodically to check for tool/software updates.

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

Figure 3 shows the basic system connection using REF-AIRCON-C302A-IM564 to run motor with MCEDesigner:

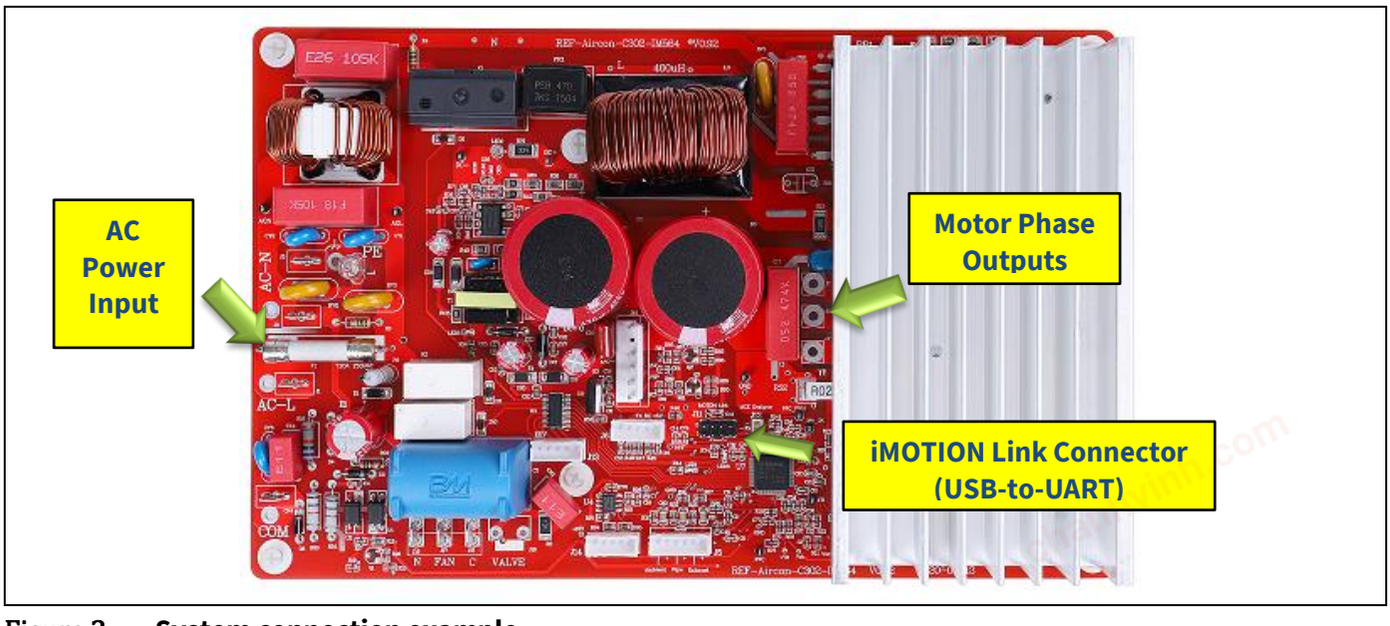


Figure 3 System connection example

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Figure 4 shows the MCEWizard welcome page and interface of MCEDesigner.

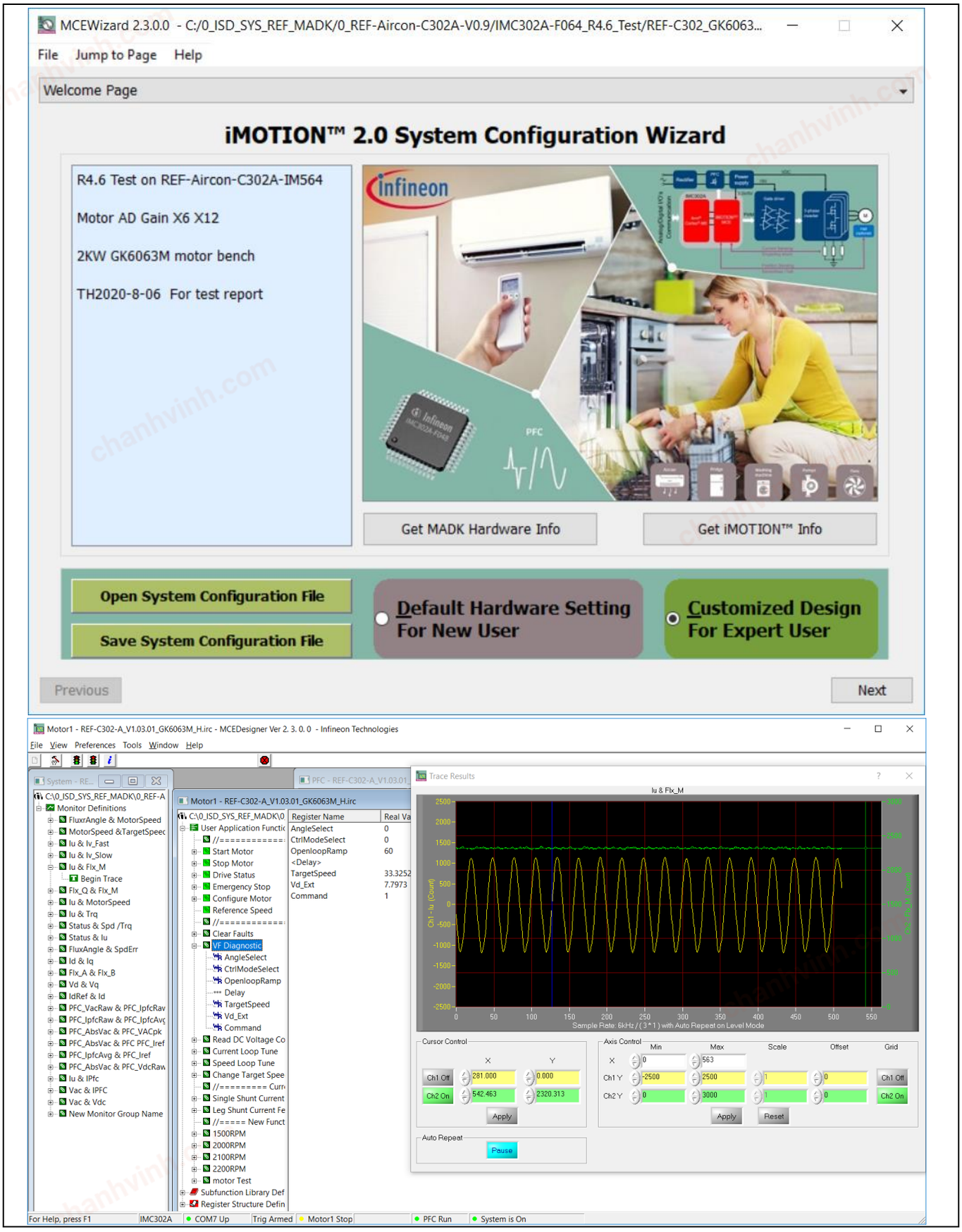


Figure 4 MCEWizard welcome page and MCEDesigner interface

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Here are the steps needed to run the motor:

1. Connect iMOTION™ Link's 8-pin cable to J11 **with default pin order** (align connector orientation markings with PCB silkscreen markings), and connect PC-USB connector to iMOTION™ Link.
2. Use MCEWizard to enter the target motor's system and operating parameters, as well as evaluation board's hardware parameters, which will then be used to calculate the digital parameter set of the controller representing the complete motor drive system.
3. After system and operating parameters are set, go to the "Verify & Save Page" and click on "Calculate Parameters" button. If no errors are reported, then save the drive parameter set into your project directory by clicking "Export to MCEDesigner file (.txt)" (Figure 5); if an error is detected, double-click on the error message (highlighted in **RED**) and adjust the related parameter. The saved drive system parameter file will be later used by the MCEDesigner in step 9.
   *(Please refer to **MCEWizard_V2.3.0.0 User Guide.pdf** for more details, which is in MCEWizard's install path)*

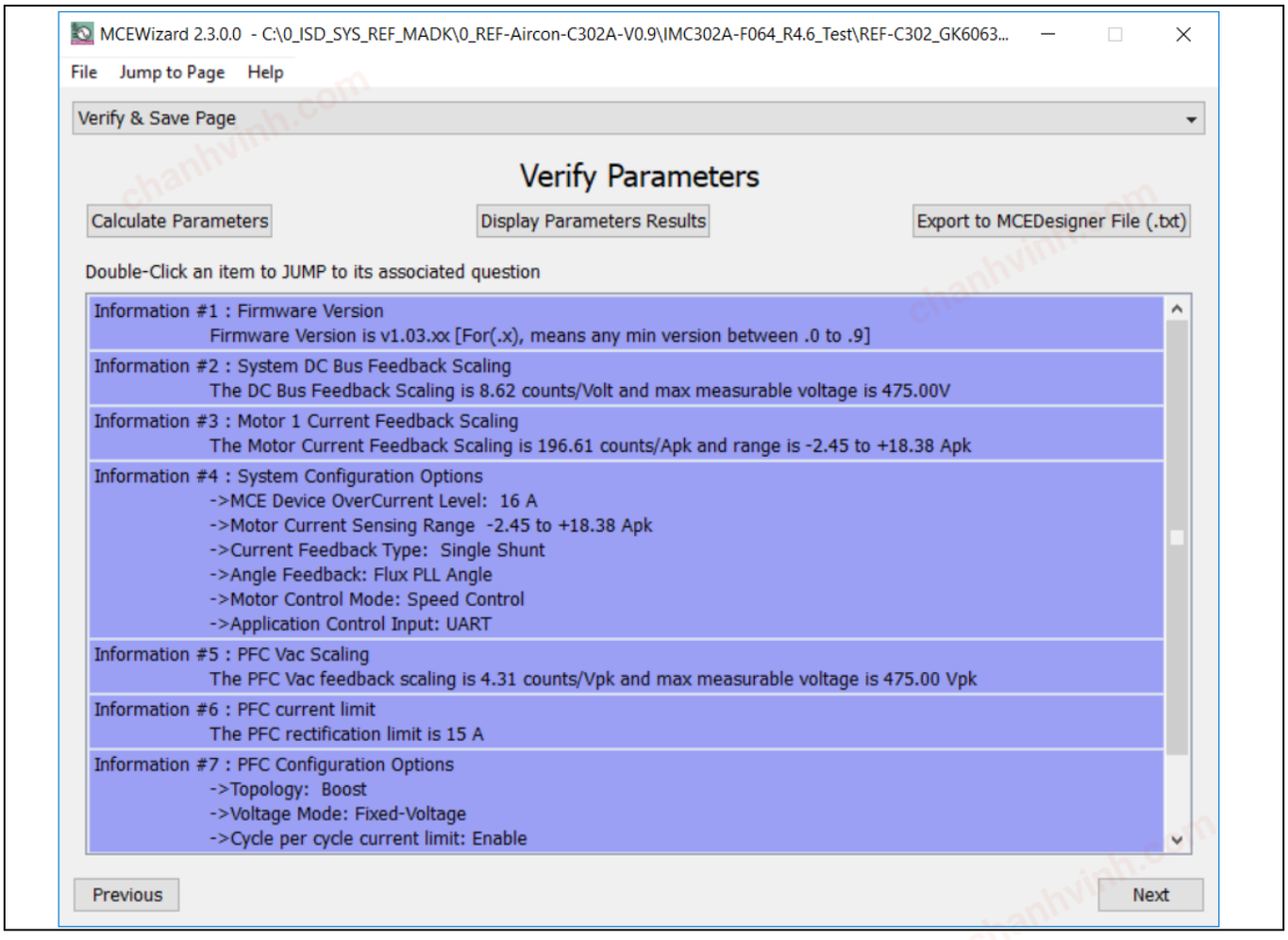


Figure 5 MCEWizard Verify and Save page

4. Connect 220 V AC power supply and UVW outputs to the motor.
5. Turn on 220 V AC power supply, LED2 and LED5 ON.
6. Start MCEDesigner tool and open MCEDesigner default configuration file (.irc) for IMC302A device (IMC302A_Vxxx.irc) by clicking "File" > "Open".
   (IMC302A_Vxxx.irc file is included in downloaded "IMC302A MCE Software Package")
   MCEDesigner should automatically connect to the REF-AIRCON-C302A-IM564 board using default COM port *(Indicated by green circle next to "COMx Up" status in the bottom frame of the MCEDesigner GUI)*.

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If it cannot establish the connection due to 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.

7. *In case of blank IC: If the firmware has been erased from the IMC302A, a warning message will pop up saying "Target device firmware and parameters file are not programmed! Please program firmware and parameters file." (Figure 6) See step 9 on how to obtain/program firmware and parameters.*

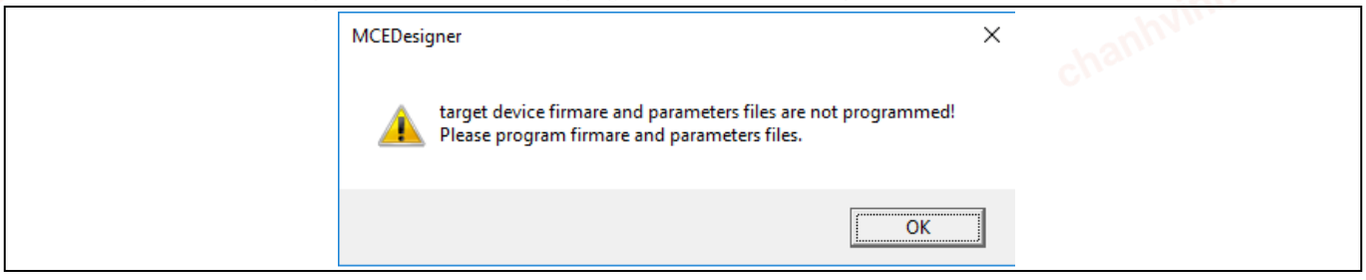


Figure 6 MCEDesigner warning message

8. *In case of blank IC: Do the following to program the firmware and the parameters' file into the internal Flash memory of iMOTION™ Control IC: Click on system page, click "Tools" > "Programmer" and select "Program Firmware and Parameters," shown as Figure 7 below. The encrypted firmware is available in IMC302A MCE Software Package, regarding the parameters file, browse and select the .txt file in step 3.*

*(If blank IMC302A IC, MCEDesigner will pop up information "Target device firmware and parameter files are not programmed!") Program the MCE firmware and system parameters into the internal Flash memory of iMOTION™ IC by clicking "Tools > Programmer "in the pull-down menu, and then clicking on the "Program Firmware and Parameter" check box. Select right Parameter file and firmware file. Finally click "Start" button to program firmware and parameter. Then click YES and then the OK button to update IRC file with parameter file; finally "Save As" the IRC file to your own file name that contains COM config, Parameters & firmware file path information. (Please refer to **MCEDesigner User Guide.pdf** and **MCEDesigner_V2.3.0.0 Application Guide.pdf** for more details, which is in MCEDesigner's install path)*

Red LED4 will flash on after the program is done.

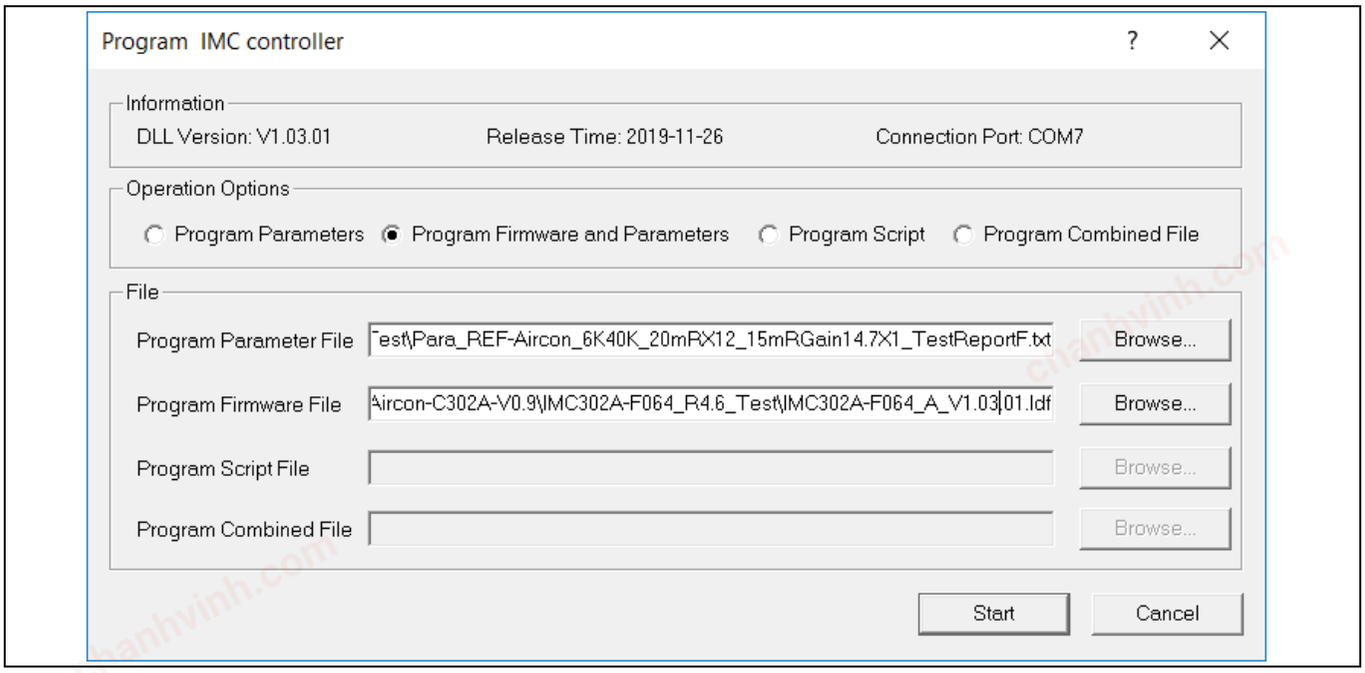


Figure 7 MCEDesigner program page

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9. 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 target speed and Vd_Ext in VF Diagnostic sub-function, then double-click “VF Diagnostic” until 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 MCEWizard. The sampled motor current amplitude should be over 300 cts ~500 cts (corresponding to 30%~50% motor rate current); otherwise, the motor-current sample related hardware and setup need tuning.

   “VF Diagnostic” sub function can verify:

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

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

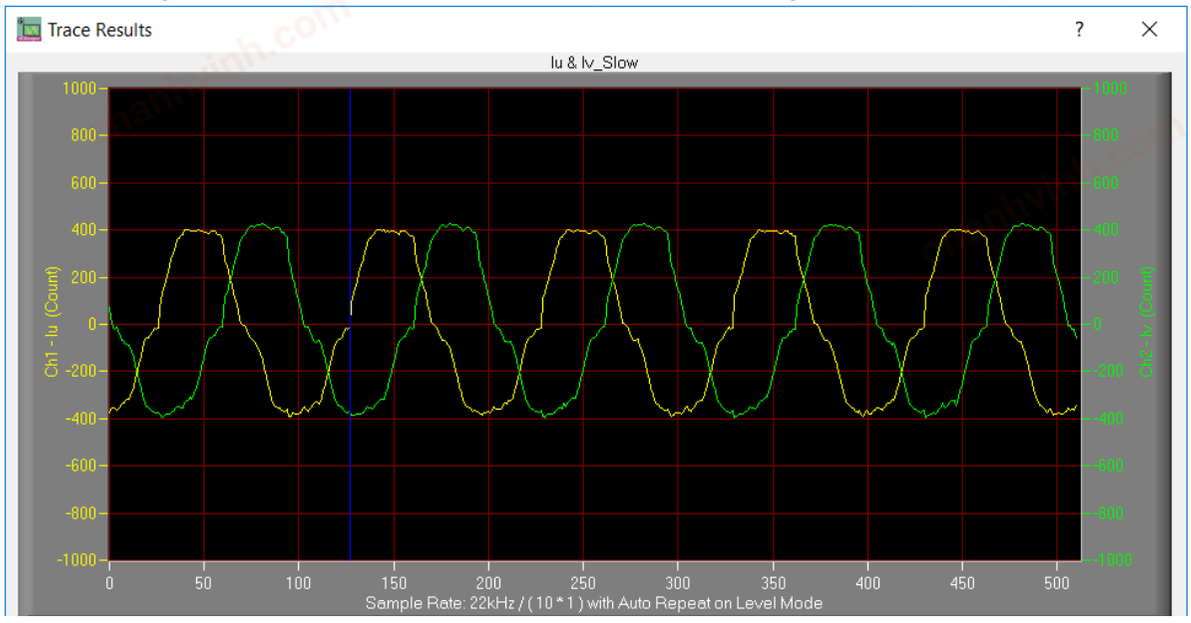


Figure 8 Trace waveform for Iu & Iv open loop diagnostic

10. Start the motor by clicking the green traffic light button in the control bar (or double-click Start Motor sub function in Motor1 page, group of User Application Function Definitions); motor runs if above step goes well.
11. Check motor spin direction, adjust UVW connection order or set negative target speed in MCEDesigner if direction is wrong.
12. Set target speed to about 50% of MAX speed, start “Iu & Flx_M” trace with “Auto Repeat on Level”. As Figure 9. Flx_M is better within the range of 2000~2500 cts (rated value is 2048), and MUST be steady and DC-like.

    Some key tips for better motor-performance tuning:

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

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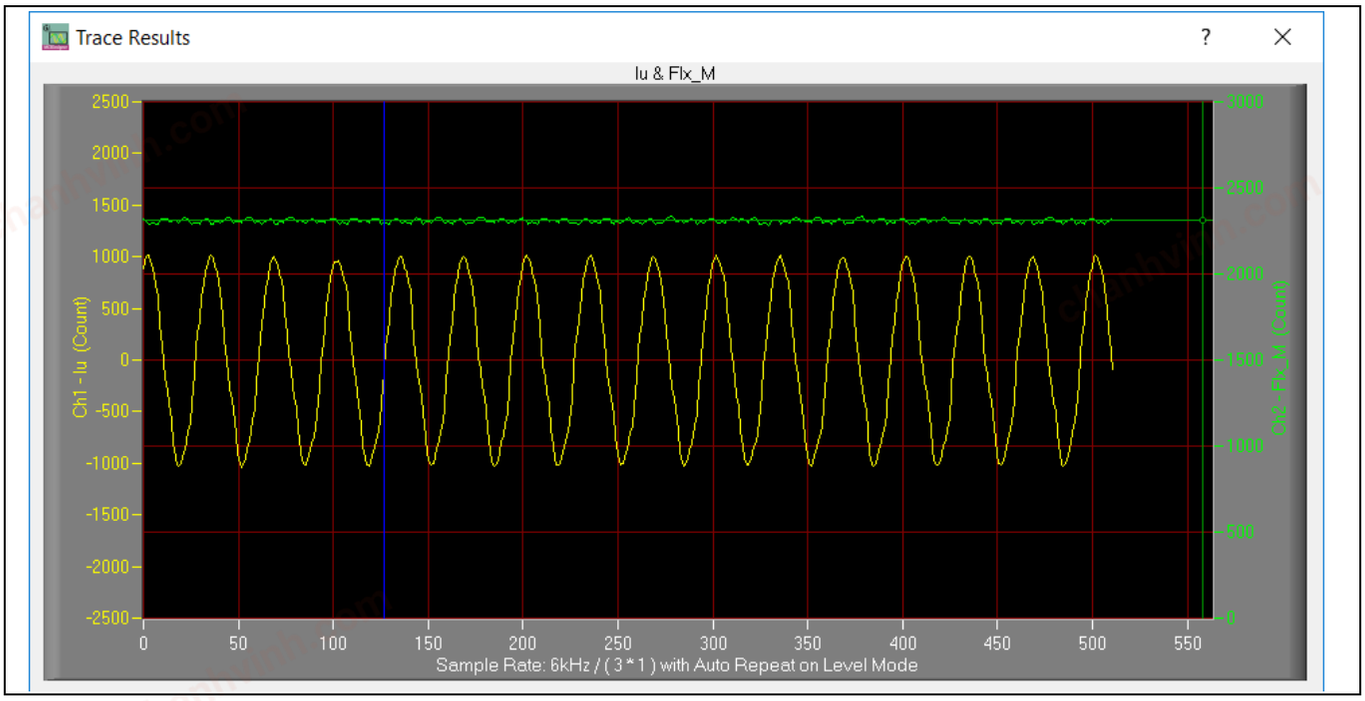


Figure 9 Trace waveform for Iu & Flx-M at 50% speed

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

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

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2.2 Description of the functional blocks

The motor inverter and PFC convertor of the REF-AIRCON-C302A-IM564 reference design are implemented by the IM564-X6D IPM module, and the PFC MOSFET gate driver is 1ED44175.

The control functions of the air conditioning system, motor and PFC are implemented by IMC302A.

Motor current sensing is single shunt mode, with lowest cost configuration of direct AD sample.

An external 14.7 X gain operational amplifiers (OPA) SGM8968-1 is used for PFC current sensing.

The flyback auxiliary power supply is based on fixed-frequency CoolSET™ ICE5AR4770BZS.

2.2.1 Overview of IMC302A

The IMC302A combined dual core computation, Motion Control Engine (MCE) and ARM® Cortex®-M0 based user application controller (MCU). The internal block and application diagram is shown in Figure 10.

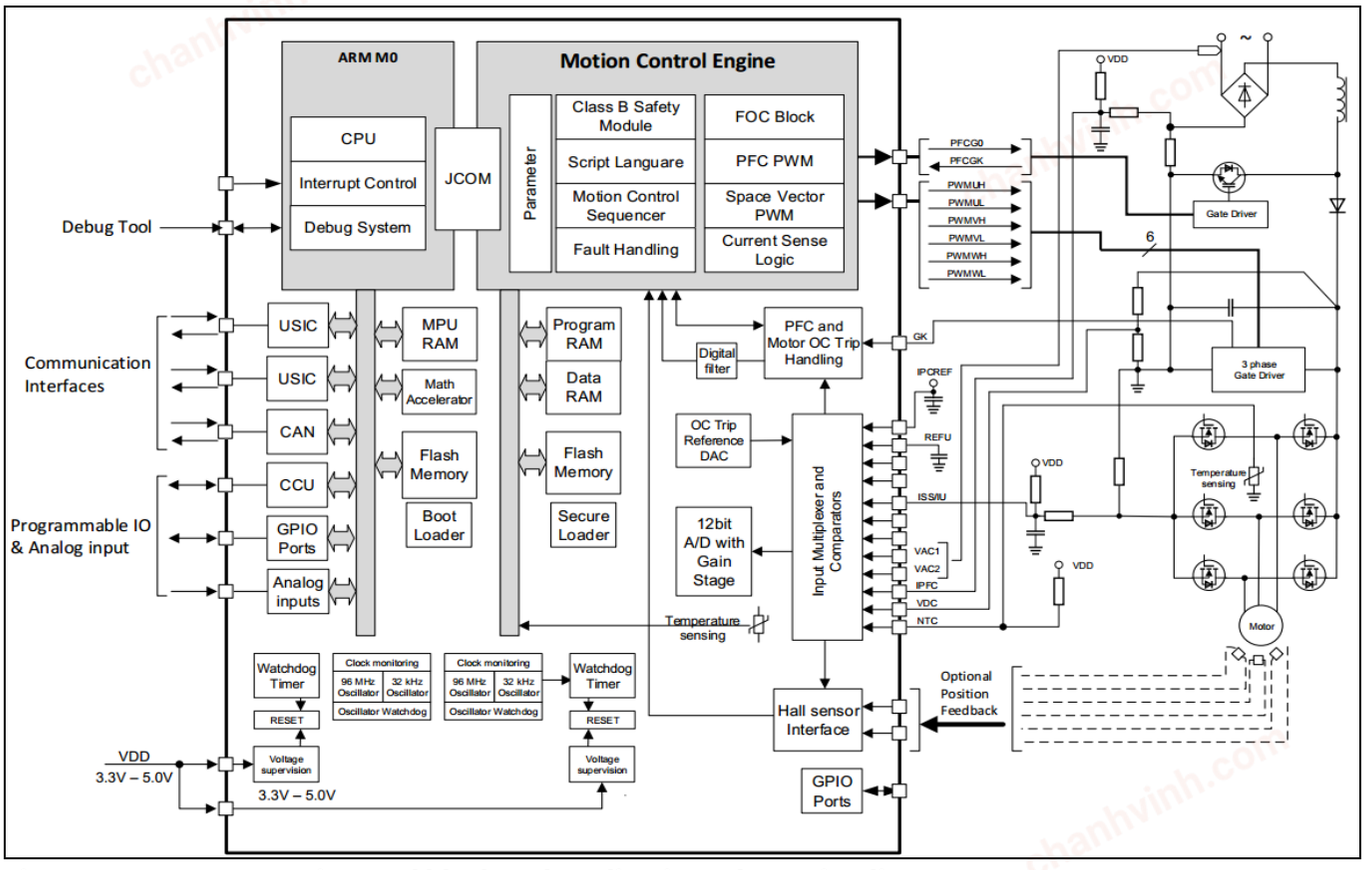


Figure 10 IMC302A internal block and application schematics diagram

Main features of the iMOTION™ controller IMC302A include:

Motion control engine (MCE)

- MCE as ready-to-use controller solution for sensorless motor drives
- Field-oriented control (FOC) for permanent magnet synchronous motor (PMSM)
- Integrated protection features (overvoltage /undervoltage, overcurrent and over-temperature, etc.)
- Current sensing via single shunt or leg shunt

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- Integrated analog comparators for overcurrent protection
- Integrated scripting engine for application flexibility
- Flexible host interface options for speed commands: UART, SPI, PWM or analog signal
- Class B pre-certification (IEC60730) for MCE2.0 firmware

User application controller (MCU)

- Arm® Cortex®-M0 based MCU with flexible peripherals and communication interfaces
- 48 / 96 MHz core / peripherals clock
- 8 Kbyte ROM, 16 Kbyte SRAM and 128 Kbyte FLASH memory (with ECC)
- 3.3 V or 5.0 V supply voltage options for controller
- On-chip clock monitor

2.2.2 Overview of IM564-X6D

The IM564-X6D is a part of the CIPOS™ Mini IPM series, with CoolMOS™ power MOSFET and a rapid switching diode for PFC stage. The IM564-X6D main application-related data are as follows:

- Inverter section continuous output ability is 20 A at Tc = 25℃, and 15 A at Tc = 80℃
- Inverter IGBT short-circuit withstand time is 5 µs
- Recommended minimum input pulse width is 1 µs
- Recommended external dead time of motor PWM is 1.5 µs
  Maximum motor PWM carrier frequency is 20 kHz
- PFC continuous input ability is 20 A at Tc = 25℃, and 15 A at Tc = 80℃,
- Maximum PFC peak current is 40 A at Tc = 25℃.
- Maximum PFC PWM carrier frequency is 150 kHz

Figure 11 illustrates the internal block diagram of IM564-X6D. Its main features include:

- Fully isolated dual in-line molded module
- Very low thermal resistance due to DCB substrate
- Lead-free terminal plating and RoHS compliant
- 3.3 V, 5 V and 15 V input logic compatible
- TRENCHSTOP™ IGBTs for Inverter and CoolMOS™ Power MOSFET for PFC
- Rugged SOI gate driver technology with stability against transient and negative voltage
- Allowable negative VS potential up to -11 V for signal transmission at VBS = 15 V
- Integrated bootstrap diode, cross-conduction prevention and rapid switching emitter-controlled diode
- Built-in NTC thermistor for temperature monitor
- All of 6 switches turn off during OCP and undervoltage lockout
- Sleep function is activated after ITRIP or undervoltage lockout
- Fast-track shutdown allows low-side outputs to be turned off faster than high-side outputs by about 200 ns

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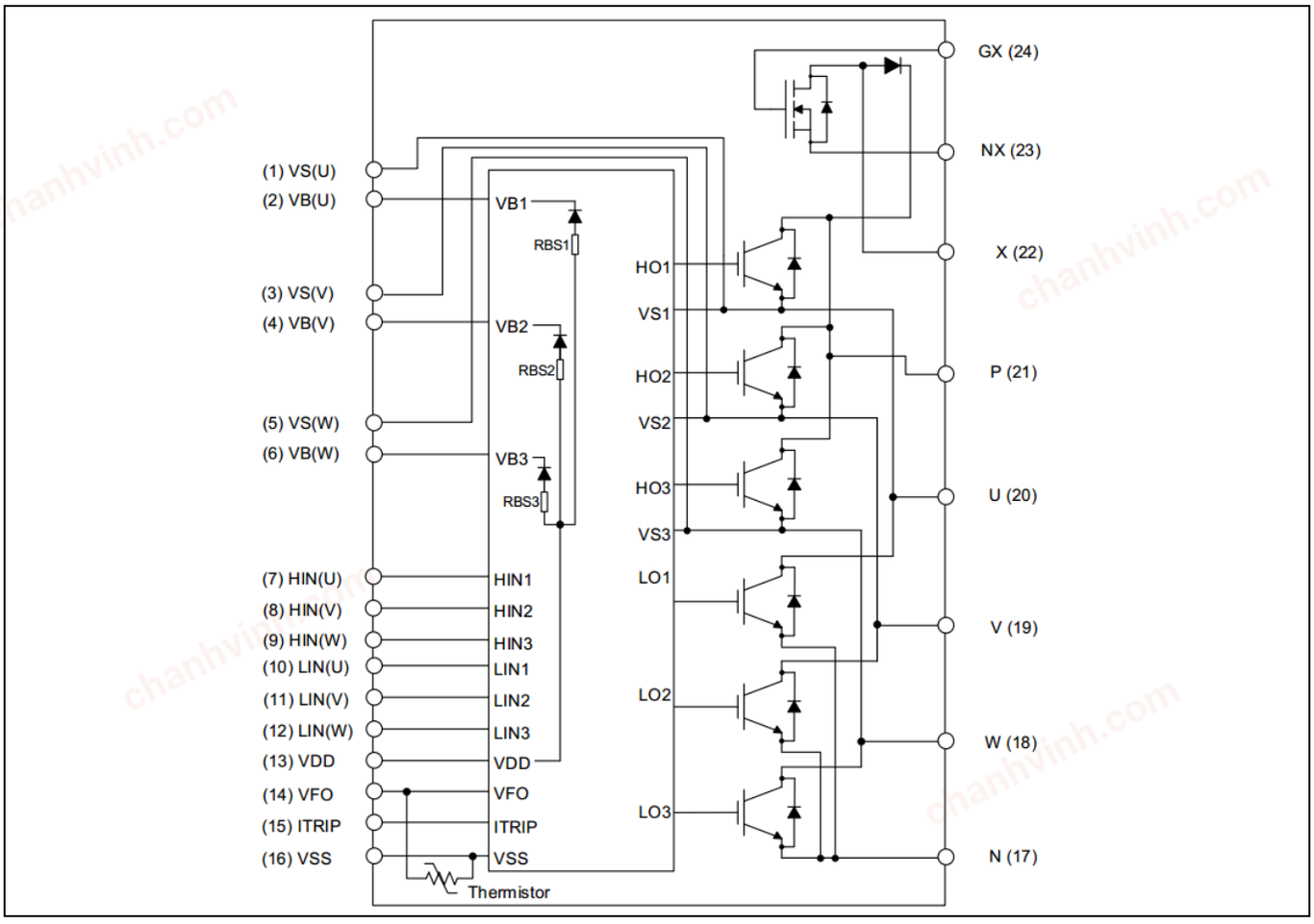


Figure 11 Block diagram of IM564-X6D

The IM564-X6D is in DIP 36x21D package; the pin definition and package outline are shown in Figure 12.

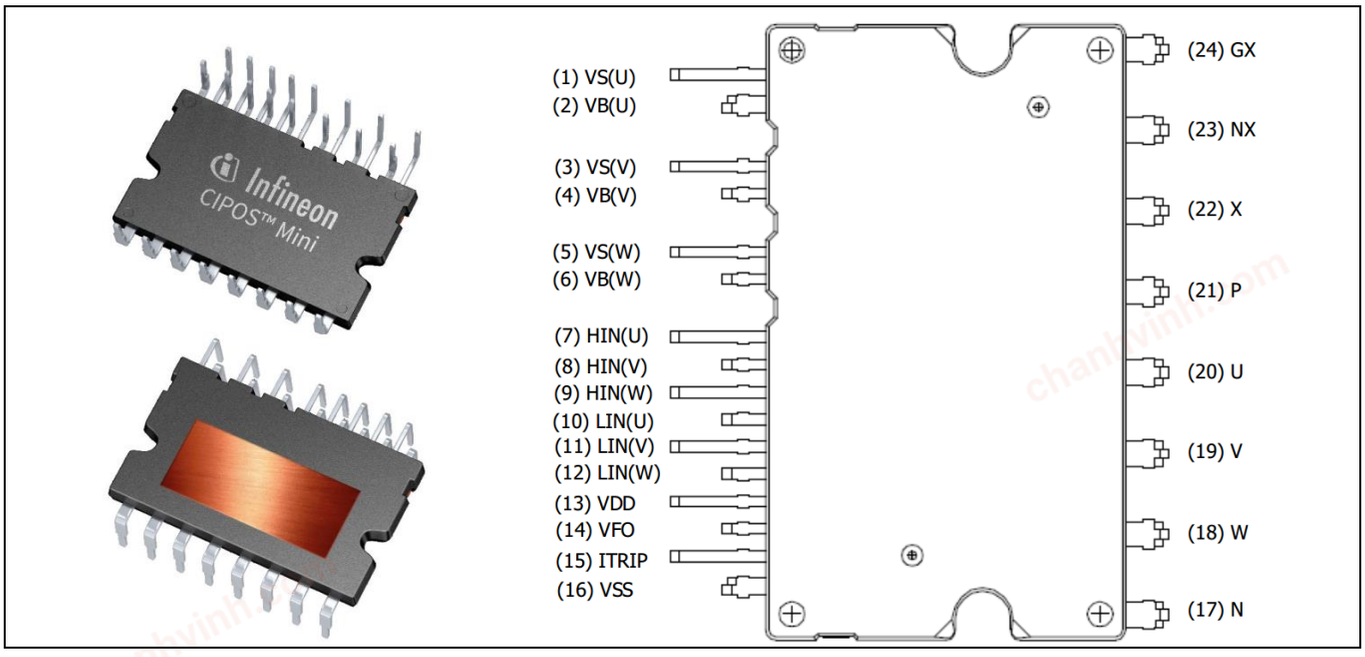


Figure 12 IM564-X6D lead assignments

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2.2.3 Overview of 1ED44175

A 1ED44175 is used for the PFC MOSFET drive and PFC OCP, its main functions and features are as follows:

- 2.6 A low-side driver with overcurrent protection and fault/enable pin
- Overcurrent detection with negative input, -246 mV overcurrent threshold (with accurate ±5% tolerance)
- Enable input and fault output
- Output in phase with input, active-high input logic
- Programmable fault clear time, OUT keeps “Low” during protection time
- Undervoltage lockout
- CMOS Schmitt-triggered inputs, 3.3 V, 5 V and 15 V input logic-compatible
- 3 kV ESD HBM

The 1ED44175 is in a SOT23-6 package; the pin definition and package outline are shown in Figure 13.

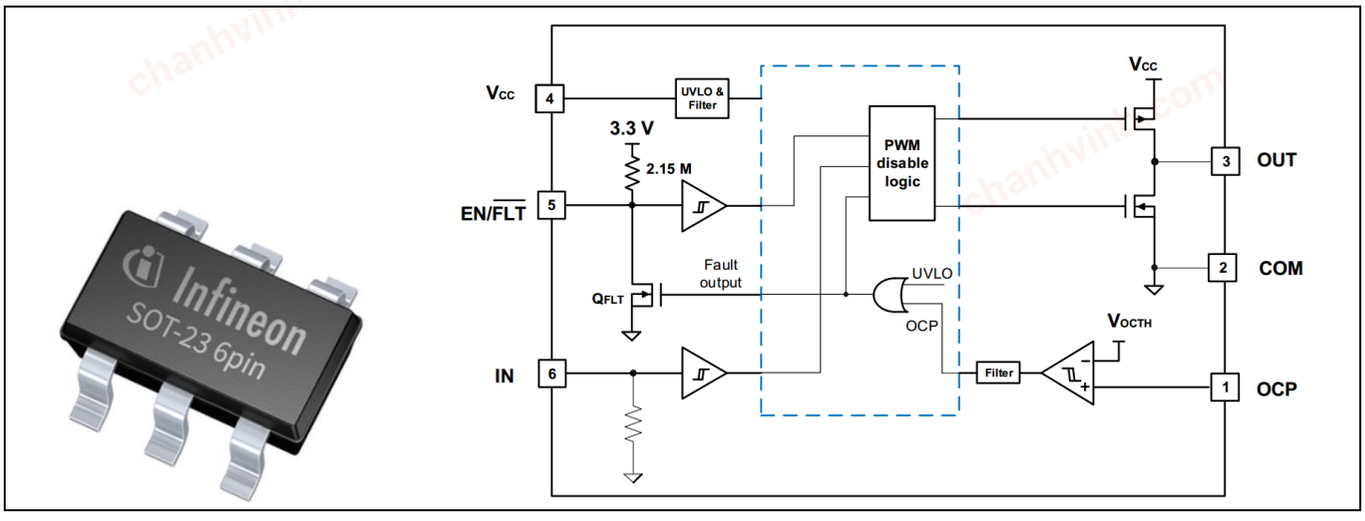


Figure 13 Package and block diagram of 1ED44175

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2.2.4 Overview of ICE5AR4770BZS

The ICE5AR4770BZS is Infineon's latest (5th generation) fixed-frequency CoolSET™ offering high performance and integration of the latest generation of 700 V CoolMOS™ superjunction MOSFETs in DIP-7 packages.

Figure 14 illustrates the internal block diagram and typical isolated flyback application.

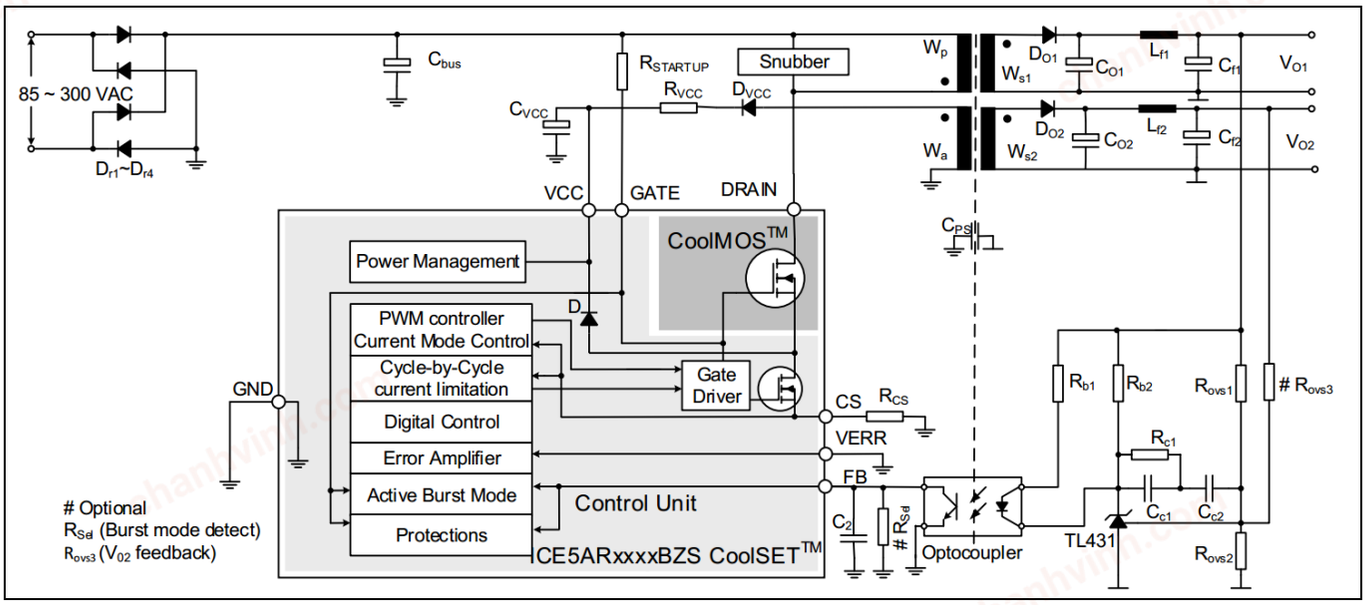


Figure 14 ICE5AR4770BZS internal block and typical application in isolated flyback mode

Main features of ICE5AR4770BZS include:

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

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2.2.5 Design tips for direct motor current sensing

From the point view of the AD converter, the current input scaling value is the product of the voltage over shunt resistor and the gain of the external current-sense amplifier, as shown in Figure 15.

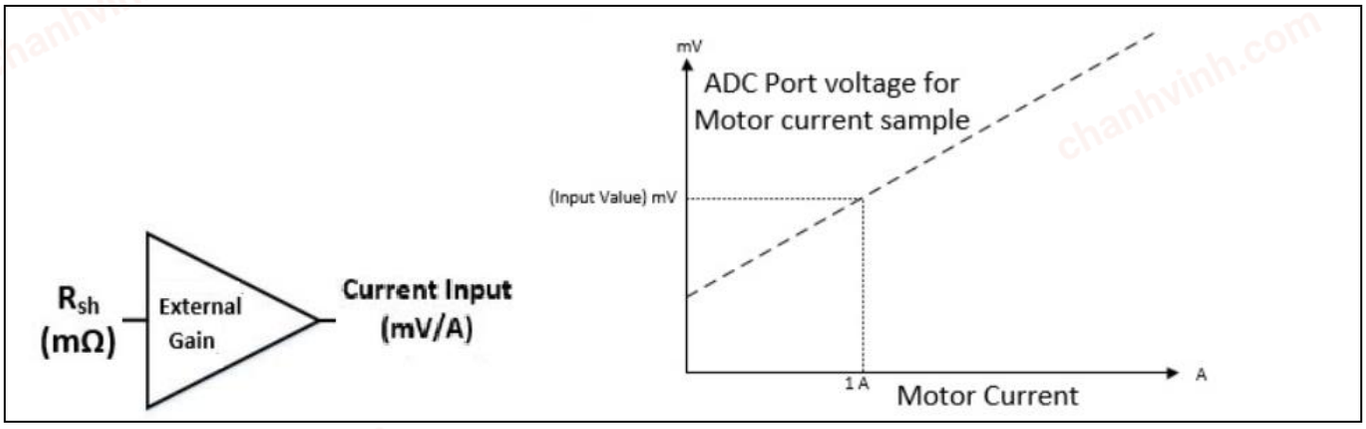


Figure 15 Current feedback scaling outside IMC302A

Direct AD sample is used in the motor section of REF-AIRCON-C302A-IM564 reference design, i.e., motor current sensing is done without an external OPA (Only C51, R83 & R77 used for operational gain, bias and low pass filter), as shown in Figure 16.

The real AD input voltage is decided by the divider of R83 & R77, with bias of 49 mV and gain of 0.99:

$$AD\ input = \frac{R_{83}}{R_{77}+R_{83}} RS_1 * I_{bus} = \frac{1K}{0.01K+1K} RS_1 * I_{bus} = 0.99 * RS_1 * I_{bus}$$

R77 & C51 is a low pass filter (LPF) for switching noise suppression, whose time constant is about 0.1~0.5 µs normally.

A 20 mOhm, 5 W single shunt resistor (50110 package), and 1 k & 10 Ohm pull-up net are the default configuration for the motor section of the REF-AIRCON-C302A-IM564 reference design. In other words, a 1 A motor current produces 19.8 mV voltage to the ADC input, so the MCEWizard's "Motor1 Current Input Scaling" needs input at 19.8 mV/A (20*0.99=19.8).

Please note that "Internal Current Feedback Amplifier Gain" (Question 84 for MCEWizard V2.3.0.0) is ADC's internal gain, which defines the MAX ADC input range at V_{CC}/Gain. For a 5 V power supply, the ADC sensing range is 0 ~ 833 mV if 6 times the internal gain is selected, and 0 ~ 416.6 mV if 12 times the internal gain is selected.

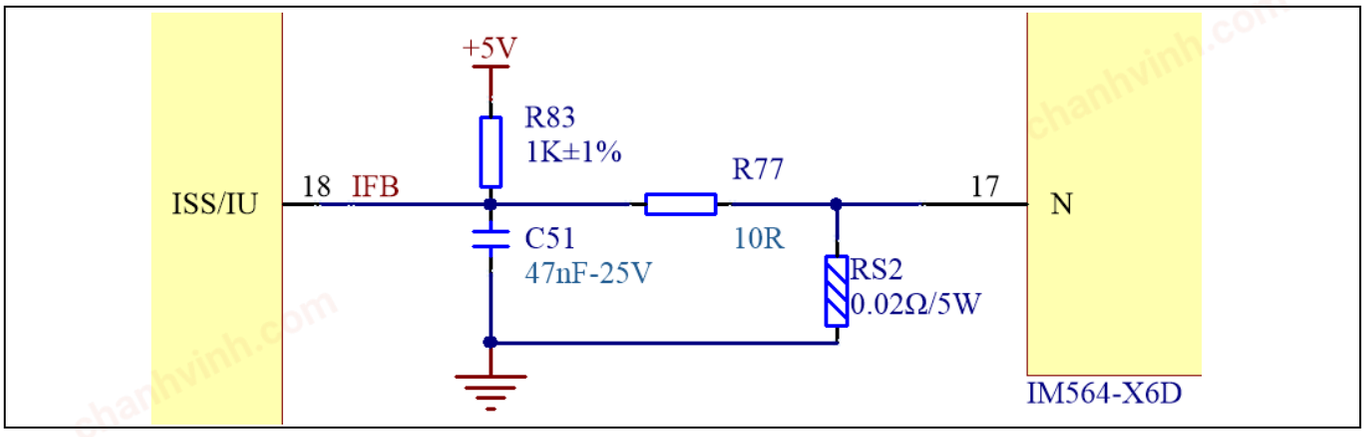


Figure 16 Direct AD sample (current feedback without external op-amp)

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R77 & R83 also determine the 49 mV ADC operational bias for current sensing, which corresponds to the motor regeneration operation range.

For air conditioner applications and other applications that only work in motoring mode, the bias can be as low as possible to reserve enough ADC range for the motoring mode, since negative current sensing would not occur.

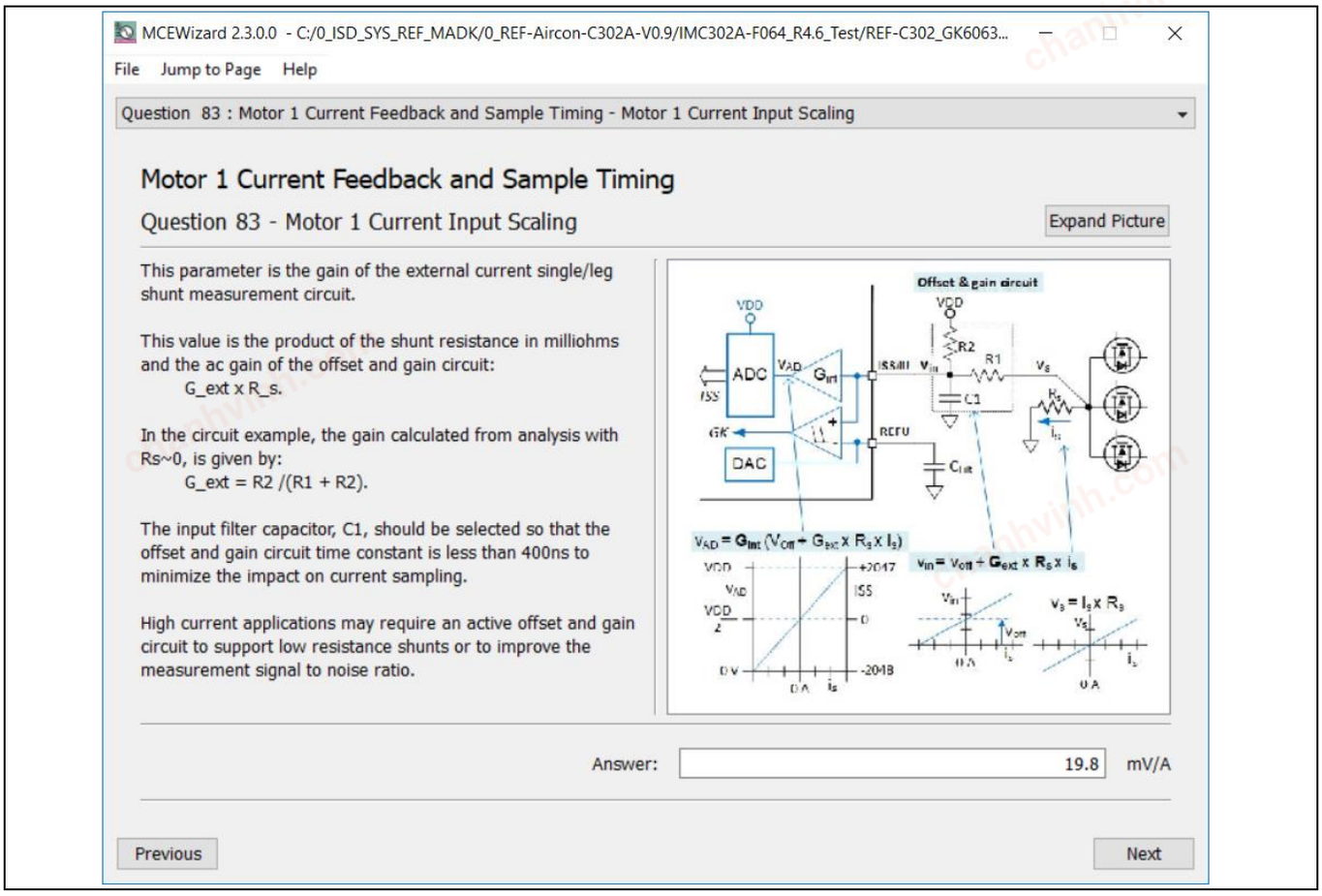


Figure 17 Current feedback configuration in MCEWizard

Please note the following two design guidelines for direct AD sample:

- The external RC network's input gain is less than 1. Normally ADC internal gain needs to be configured to X3, X6 or X12 to lower the required input signal range, and reduce shunt resistor power dissipation. RS2 must be much higher than 10 mOhm to achieve enough current sensing signal-to-noise ratio (SNR), and improve control performance: For example, to achieve sufficiently high SNR, motor current sensing counts need be **over** 30~50% of the AD range (traced Iu peak **over** 600 cts~1000 cts) at the rate motor current, and PCB ground noise lower than 5% of total sampled signal (check in MCEDesigner trace result). Very low current sensing SNR might cause motor start to fail, or not running smoothly at low power.
- There is NO common-mode noise-rejection ability, compared to external op-amp sample mode. Direct AD current-sensing mode needs to deal with the PCB GND network very carefully to reduce grounding noise as much as possible, to make shunt resisters **as close as possible** to IMC302A IC and DC bus capacitor. Please note that any voltage difference between IMC302A's ADC ground and shunt resistor ground will be considered as an "input signal" and will deteriorate control performance or increase motor audible noise.

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2.2.6 Design tips for PFC current sensing

As mentioned in the motor current sensing section, common mode noise rejection (CMR) is vitally important for direct current AD sample. The PFC current sensing shunt resistor is located at a long distance from the IMC302A IC in the REF-AIRCON-C302A-IM564 board, i.e. PFC current sensing cannot use the direct AD sample mode any more.

An 11 MHz rail-to rail I/O CMOS OPA SGM8968-1 is used for PFC current sensing to achieve enough common mode noise rejection ability.

A 15 mOhm 5 W shunt resistor (50110 package) and 14.7X external-gain OPA is the default configuration for the REF-AIRCON-C302A-IM564 reference design, i.e., 1 A PFC current produces 220.5 mV voltage to ADC input. So MCEWizard's "PFC Current Measurement Input Scaling" needs an input of 220.5 mV/A, as shown in Figure 18.

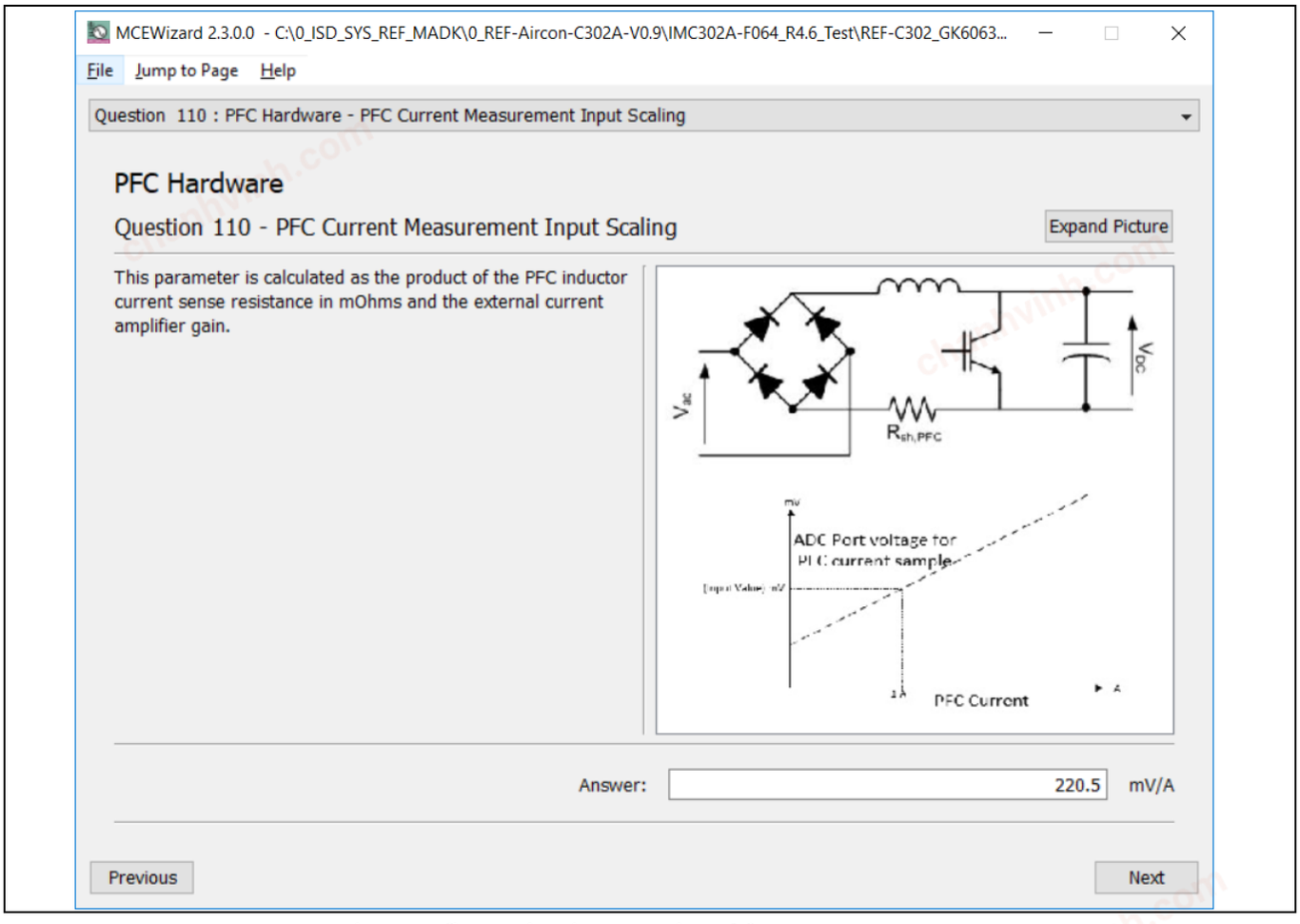


Figure 18 PFC current sensing configuration in MCEWizard for REF-AIRCON-C302A-IM564

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Figure 19 shows the external amplifier gain circuit in the REF-AIRCON-C302A-IM564 reference design, which is a typical differential amplifier, with input LPF and operational bias. C24, R43, R52, R58, R59 build the input differential mode LPF, which can damp part of the PWM switching noise. The default low-pass filter time constant is 2*RC = 2*(R43//R58)*C24 = 239 ns, which corresponds to DC bus current ring time.

The typical setup time is 0.1 ~ 0.5 µs, depending on the PCB layout, DC bus decouple capacitors and the PFC MOS gate driver configuration.

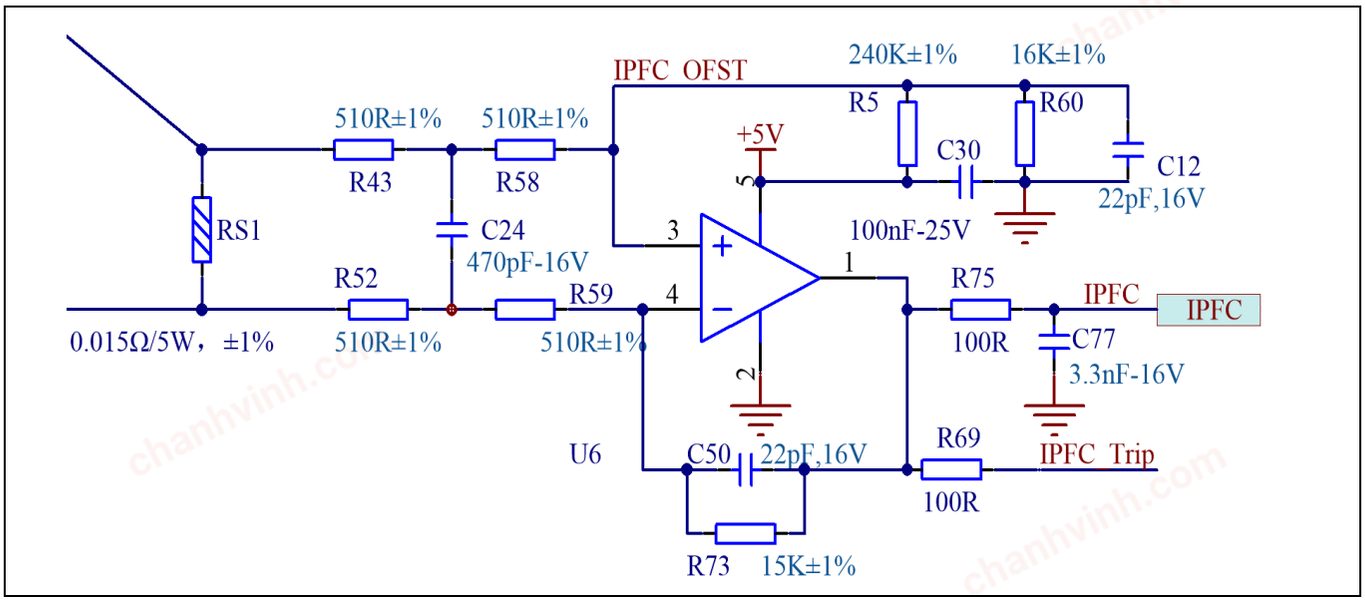


Figure 19 PFC current feedback with external op-amp

For better CMR ability, a balanced differential amplifier is highly recommended, which means R73 is equal to the value of R5 & R60 in parallel.

The divider of R5 & R60 provides operational bias for the amplifier, which affects the maximum motoring current and regeneration current range. With the default configuration of REF-AIRCON-C302A-IM564, R60=16 k & R5=240 k, the op-amp operational bias is 5000 mV * 16 / (16+240) = 312 mV, which means:

- Op-amp outputs 312 mV at zero PFC current (PFC stopped)
- If 1X ADC internal gain is selected, 5000 mV range for PFC current sensing (5000 mV – 312 mV = 4688 mV). And 4688 mV/op-amp gain/RS1 is the maximum allowable PFC current. “PFC Average Inductor Current Limit Amps * 1.414” should be below this maximum allowable range with at least 10% margin, which is related to input parameters in MCEWizard.

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3 System design

The REF-AIRCON-C302A-IM564 board is an optimized design for 220 V major home appliances like air conditioner applications. To meet individual customer requirements and to make the REF-AIRCON-C302A-IM564 reference design a basis for development or modification, all board design data such as schematics, Gerber and Altium design data can be found on the Infineon homepage.

3.1 Inverter section of REF-AIRCON-C302A-IM564

The inverter section is implemented by IM564-X6D as sketched in Figure 20.

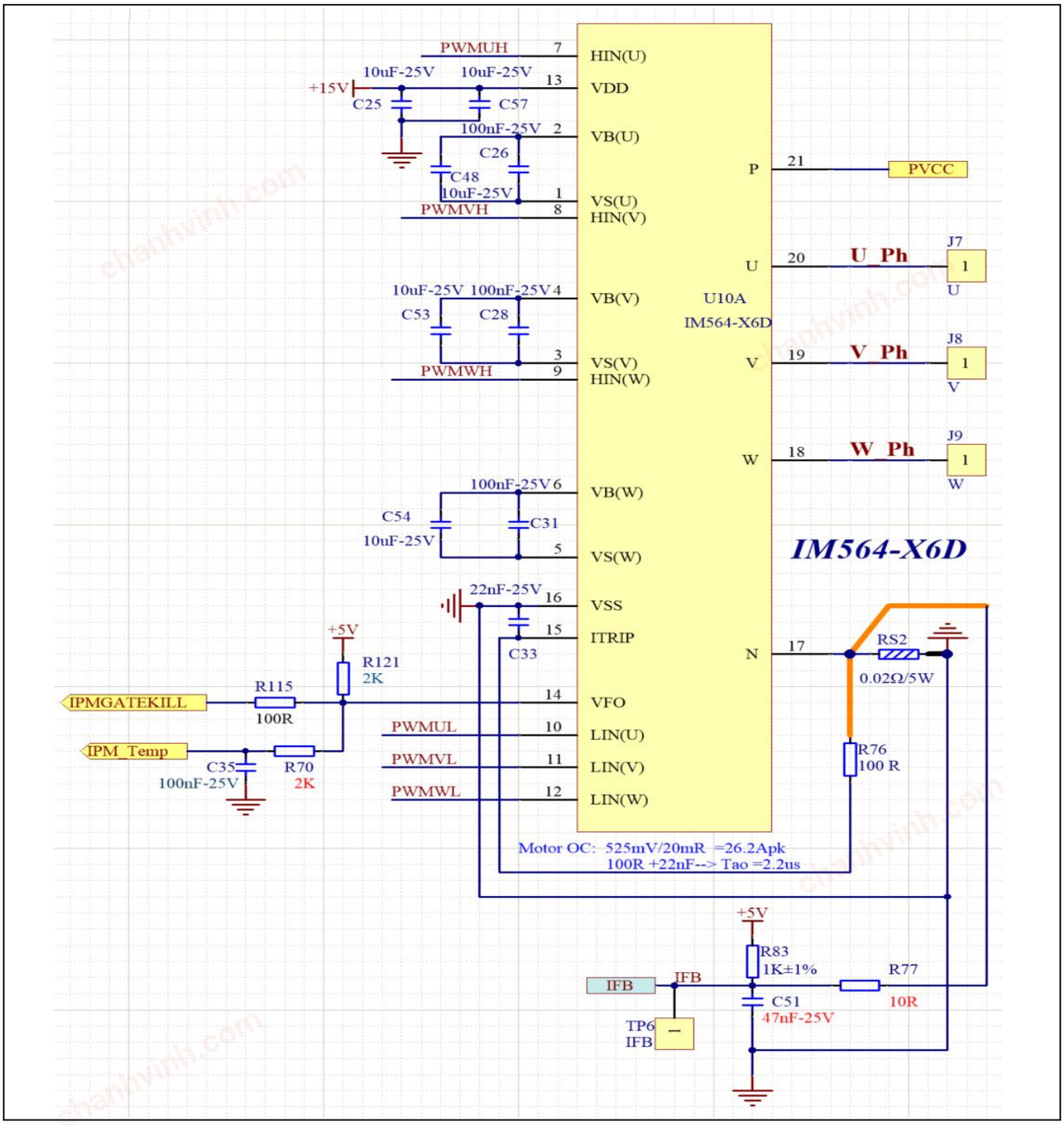


Figure 20 Inverter section of REF-AIRCON-C302A-IM564

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- The REF-AIRCON-C302A-IM564 reference design's motor current sensing is a direct AD sample, which means the output of RS2 shunt resister is send to AD directly, with R83, R77 and C51 to provide sensing bias and LPF.
- R76 and C33 is a low pass filter for IM564's local hardware OCP, 1 ~ 3 µs time constant is recommended.
- VFO of IM564 (pin 14) is a multi-function pin, which means it is:
  - an analog output pin for IPM temperature sensing to IMC302A's AD pin (net of IPM_Temp, with LPF of R70 and C35)
  - a digital output pin for motor gatekill to IMC302A's GK pin (net of IPMGATEKILL, with LPF of R115 and C56)

3.2 PFC section of REF-AIRCON-C302A-IM564

Figure 21 provides the PFC MOSFET driver and current sensing details.

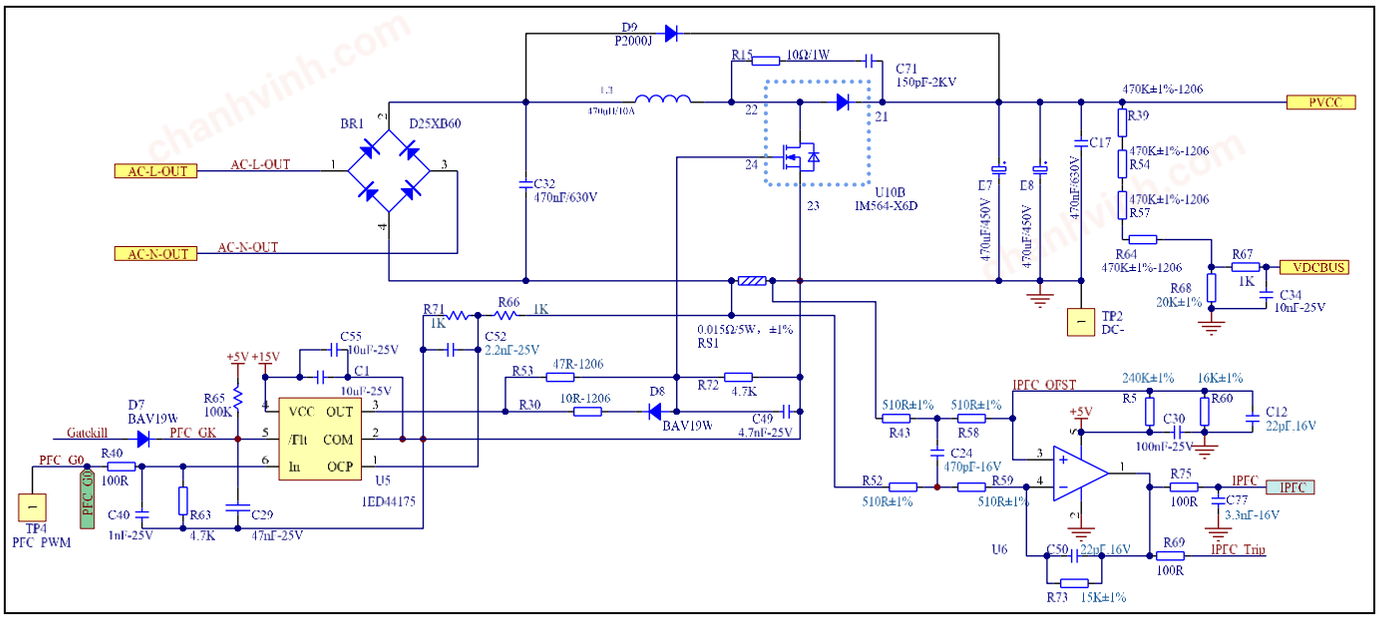


Figure 21 Schematics for PFC driver and current sensing

- A 1ED44175 used for PFC MOS drive and PFC overcurrent protection.
  - R66 & R71 select the threshold of 1ED44175's OCP; default setup is 33.3 A_{PEAK} which is 150% ~ 200% of IMC302A's internal OCP threshold
  - C52, R66 & R71 is the low-pass filter of hardware OCP, 1 ~ 2 µs time constant is recommended
  - C49, R30 & R53 select the PFC MOSFET switching du/dt; trade-off between switching noise and power loss is required
  - D7 sends the fault output of 1ED44175 to IMC302A's GK pin, so that the motor can stop immediately at the PFC overcurrent condition. Please remove D7 if IMC302A's system control software already handles the PFC OCP and restart related sequence.
- The bypass diode D9 is designed to withstand in-rush current during an abnormal power-up, and to withstand repetitive pulse-charge current when the motor is running and the PFC is off. In the absence of this diode, the excessive in-rush current or pulse-charge current that exceeds the specification of maximum input current is likely to damage the IPM diode.

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- An 11 MHz rail-to rail I/O CMOS operational amplifiers SGM8968-1 used for PFC current sensing.
  - R5 and R60 select the OPA's bias; a very low bias is recommended (less than 10% of VCC)
  - R73 must be equal to parallel value of R5 and R60 to achieve better CMR
  - R43, R58, R52, R59 and C24 build a difference mode LPF; time constant 0.1 ~ 0.5 µs is recommended

3.3 Auxiliary power supply

Infineon's latest (5th generation) fixed-frequency CoolSET™ ICE5AR4770BZS is used for the flyback auxiliary power controller to output +15 V and +7 V. Figure 22 depicts the schematic of the auxiliary power supply for the REF-AIRCON-C302A-IM564 board. The 15 V and 12 V power supply output ability is 450 mA; for 5 V power supply, the output ability is 200 mA.

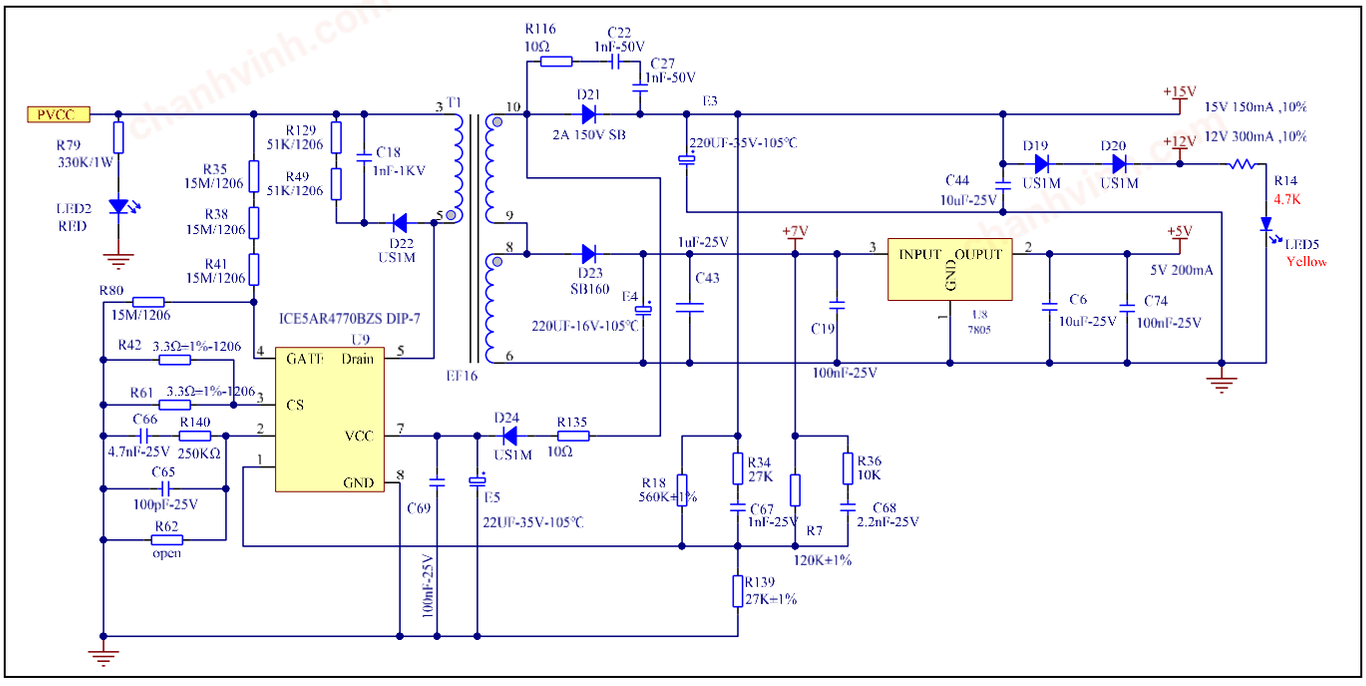


Figure 22 Power supply section of the REF-AIRCON-C302A-IM564 reference design

Please note that IMC302A's AD sensing reference is VDD, which means VDD's accurateness can affect the ADC result. A linear regulator LM7805 (U8) is used for 5 V VDD (from +7 V of flyback output) to make sure IMC302A's power is steady and clean. The LM7805's GND pin should be as close to IMC302A's GND as possible to reduce ground noise.

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3.4 PCB Layout for REF-AIRCON-C302A-IM564

This board has two electrical layers with 35 µm copper (1 oz. copper) and dimensions of 250 mm × 157 mm. The thickness of the PCB board is 1.6 mm. Contact our technical support team for more detailed information and the latest Gerber files.

Figure 23 illustrates the top assembly print of the reference design.

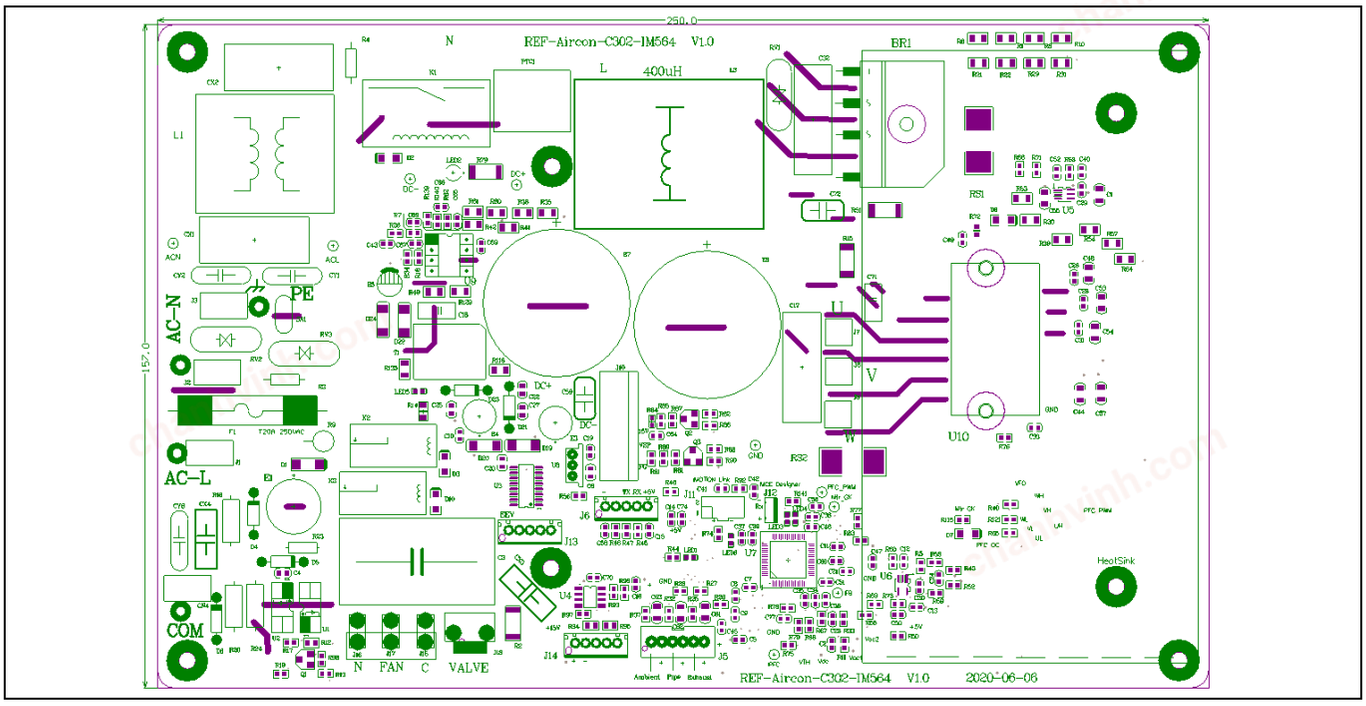


Figure 23 Top assembly print of the REF-AIRCON-C302A-IM564 reference design

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The top layer and bottom layer routing of the PCB is provided in Figure 24 and Figure 25.

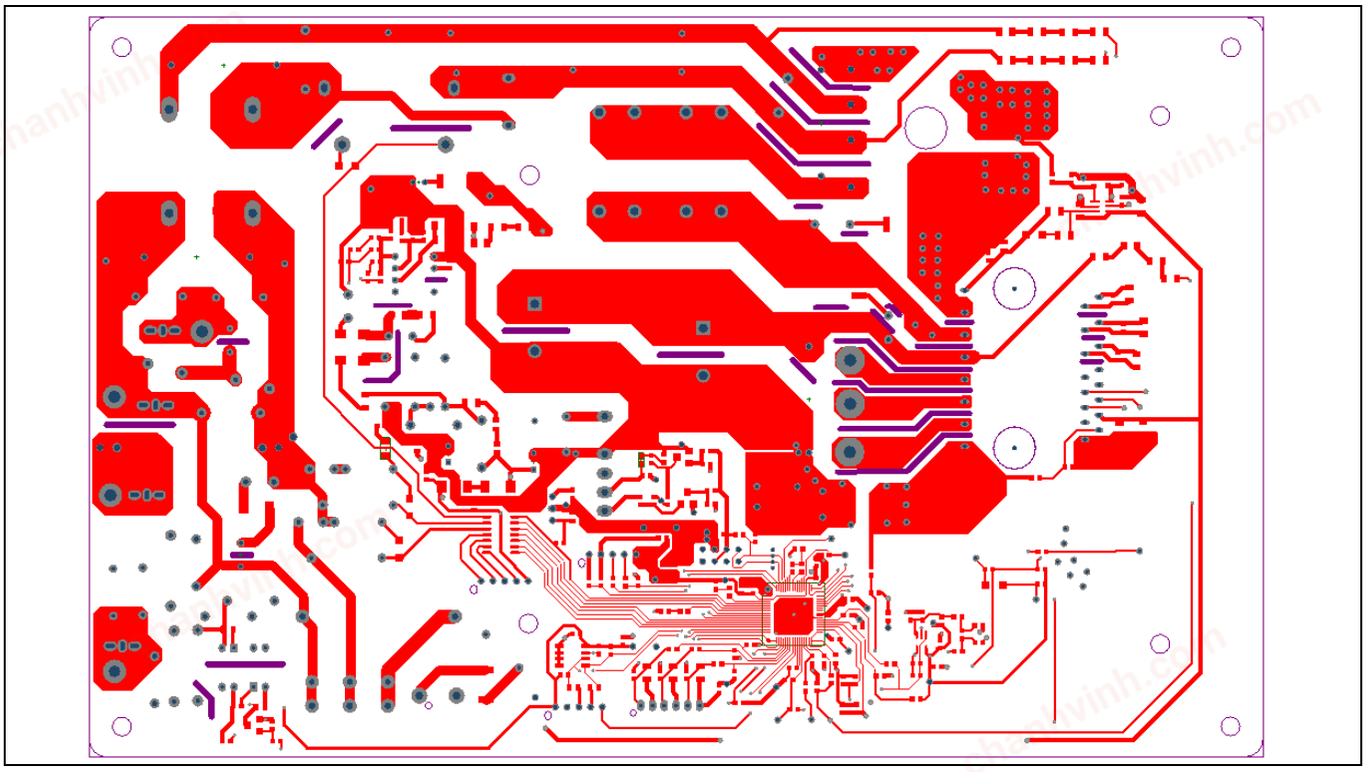


Figure 24 Top layer routing of the REF-AIRCON-C302A-IM564

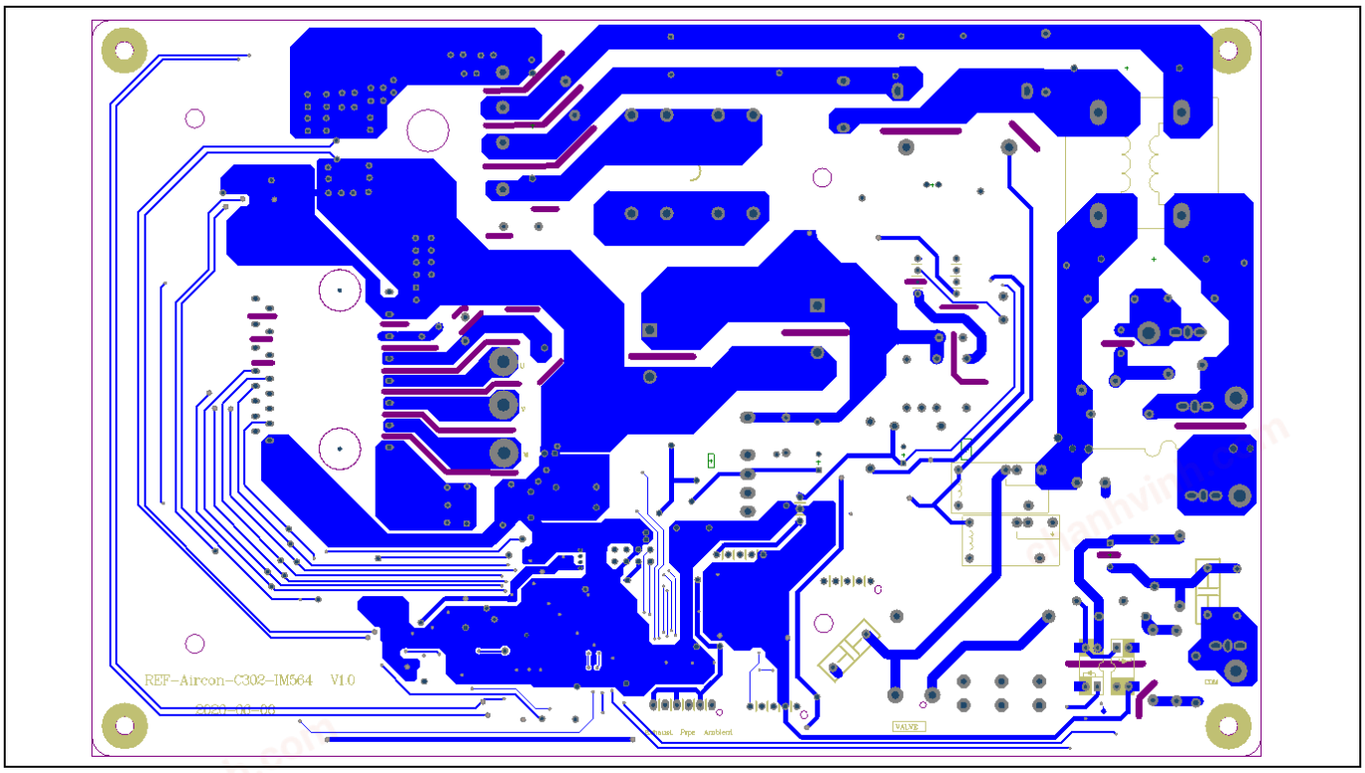


Figure 25 Bottom layer routing of the REF-AIRCON-C302A-IM564

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3.5 Bill of material

Table 3 provides the major parts for the REF-AIRCON-C302A-IM564 design.

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

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

S. No.	Ref Designator	Description	Manufacturer	Manufacturer P/N
1	U5	2.6A low side driver with OCP	Infineon	1ED44175
2	U7	iMOTION™ Motor control IC with additional microcontroller	Infineon	IMC302A-F064
3	U9	Fixed frequency 700 V CoolSET™	Infineon	ICE5AR4770BZS DIP-7
4	U10	CIPOS™ Mini PFC integrated IPM	Infineon	IM564-X6D
5	RS1	0.015 Ω / 5 W，±1%		KRL50110-CR015-FT
6	RS2	0.02 Ω / 5 W，±1%		KRL50110-CR020-FT
7	U6	11 MHz, 8.5 V/µS, Rail-to-Rail I/O OPA	SG Micro	SGM8968-1/XN5G
8	L1	36 mH-12 A common mode choke	Qindao Yunlu	CMF-012C36HR
9	L3	470 µH / 10 A inductor	Qindao Yunlu	S-L/10A/400u
11	BR1	25 A 600 V diode bridge		D25XB60
12	RL1	20 A relay		G4A-1A-PE
10	E7,E8	470 µF, 450 V	Wurth Elektronik	861221486023
12	CX1, CX2	WCAP-FTX2 Film Capacitor, THT, L26W11H20, 1 µF, 275 V	Wurth Elektronik	890324026027CS

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3.6 Connector details

General information about the connectors of the REF-AIRCON-C302A-IM564 reference design is described in this section.

Table 4 includes the details of the DC input connector.

Table 4 AC input connector (To IDU)

	Function
J1 (ACL)	AC line input
J2 (ACN)	AC line input
J3 (PE)	Protective earth
J4 (COM)	Communicate wire to indoor unit

Table 5 denotes the details of the UART related connector (iMOTION™ Link connector J11 & J12)

Table 5 J11- iMOTION™ Link connector

Pin	Label	Function
1	SWDCLK	A core debug CLK
2	SWDDIO	A core debug IO
3 & 6	+5 V	On-board 5 V supply
4 & 5	GND	Ground
7	RXD0	MCEDesigner & firmware download (Same as J12 Pin2)
8	TXD0	MCEDesigner & firmware download (Same as J12 Pin3)

Table 6 provides the details of the motor UVW output connector

Table 6 Motor side connector

	Label	Function
J7	U	Connected to motor phase U
J8	V	Connected to motor phase V
J9	W	Connected to motor phase W

Table 7 provides the pin assignments of air conditioner's temperature-sensing interface connector J5

Table 7 J5 – Temperature-sensing connector to external NTC

Pin	Label	Function
1	Ambient	To ambient temperature sensing NTC
2, 4, 6	+5 V	On-board 5 V supply
3	Defrost	To defrost temperature sensing NTC

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Pin	Label	Function
5	Exhaust	To exhaust temperature sensing NTC

Table 8 provides the pin assignments of EEPROM program interface:

Table 8 J14 – External EEPROM program port

PIN	Label	Function
1	+5 V	On-board 5 V supply
2	GND	Ground
3	SCL	Clock wire for I2C bus
4	SDA	Data wire for I2C bus
5	WC	Write protection for EEPROM

3.7 Test points

Table 9 provides the assignments of the on-board test points.

Table 9 Test points on REF-AIRCON-C302A-IM564

Pin	Name	Functions & net label describe
TP1	DC+	DC+ test point
TP 2	DC-	Power GND test point (DC-)
TP 3	IPFC	PFC current sensing (output for U6 OPA pin1)
TP 4	PFC_PWM	PFC PWM (to pin 6 of U5)
TP 5	Mtr_GK	Output of OCP circuit (output from IM564, pin 14 VFO)
TP 6	IFB	Motor current sensing (to IMC302A's pin 18)
TP 7	GND	Ground test point for signals ground
TP 8	ACL	AC voltage measure point (L)
TP 9	ACN	AC voltage measure point (N)

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4 System performance

4.1 Thermal characterization

The thermal characterization test was performed under the following conditions: T_a= 25°C, V_{AC}= 220 V, 6 kHz motor PWM and 40 KHz PFC PWM frequency, and under different phase-current values until the surface temperature of the main components reached 105°C .

Figure 26 shows the thermal characterization of REF-AIRCON-C302A-IM564, which depict the maximum motor power at different cooling modes:

- 1400 W at natural cooling mode, IPM T_C reaches 105°C
- 2500 W at 1 m/s air cooling mode, input common-mode choke reaches 105°C

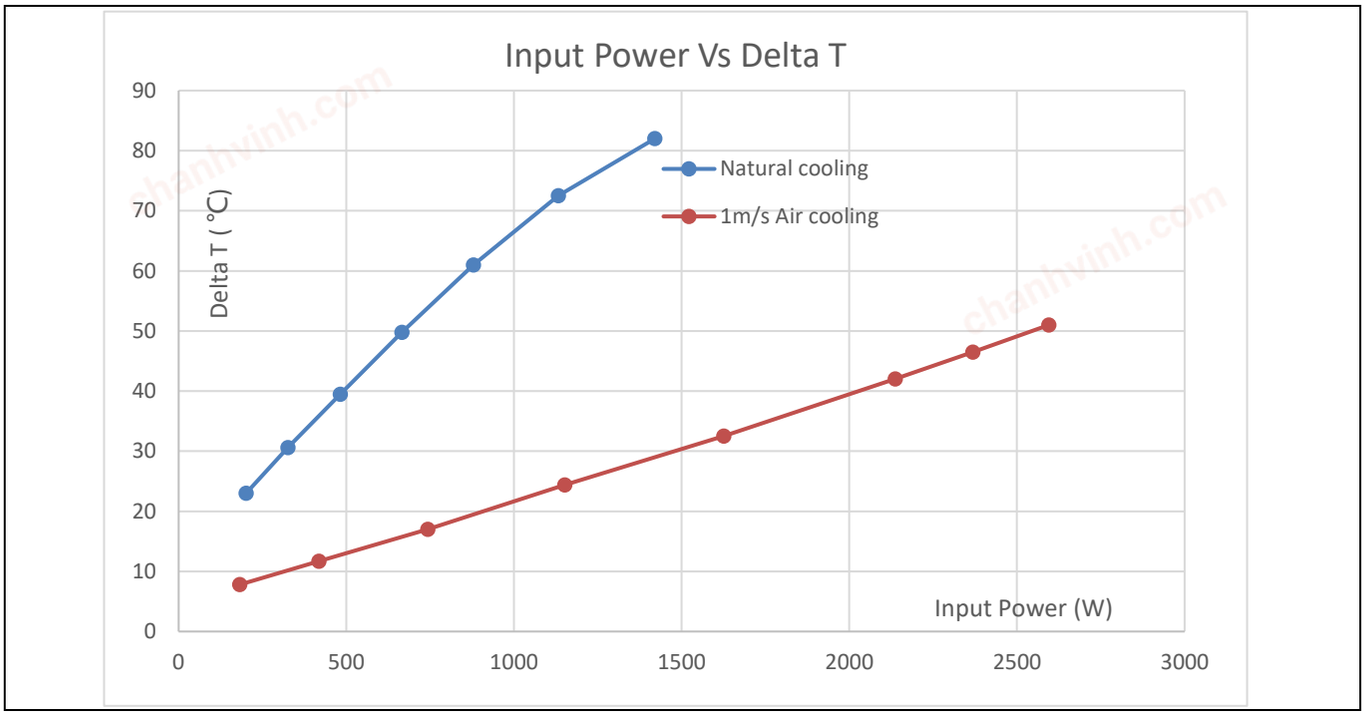


Figure 26 REF-AIRCON-C302A-IM564 thermal characterization (Input power vs IPM temperature rise)

4.2 NTC thermistor characteristics and overheat protection

IMC302A's MCE firmware has overheat protection; pin 13 (NTC/AIN4) is the dedicated input of NTC temperature sensing. IM564 IPM has an internal NTC resistor, which connects to VFO multifunction pin, as shown in Figure 27.

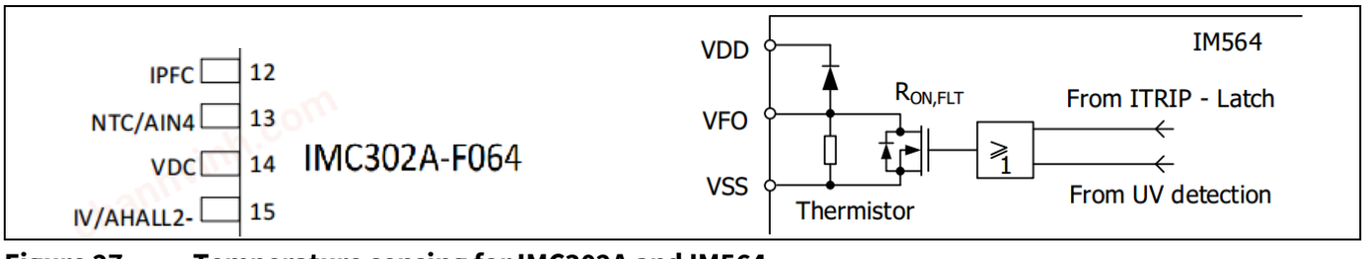


Figure 27 Temperature sensing for IMC302A and IM564

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To activate over-temperature protection (OTP), 2 setups are needed in MCEWizard as shown in Figure 28:

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

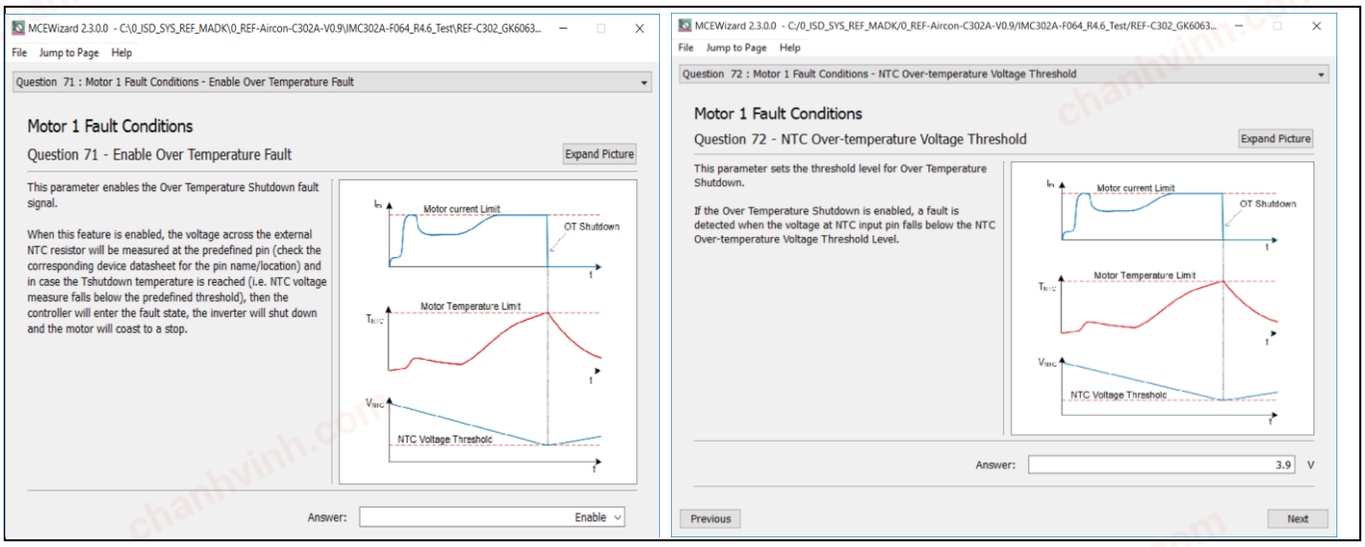


Figure 28 Over-temperature protection enabled in MCEWizard

The IM564 IPM built-in NTC thermistor is 85 kOhm at 25℃, and its B-constant is 4092; typical resistance and output of the temperature-sensing voltage is listed in Table 10.

Table 10 NTC – Thermistor characteristics

Temperature (℃)	Resistance (kOhm)	Vout (mV)
50	29.972	4687
60	20.515	4556
70	14.315	4387
80	10.169	4178
90	7.345	3930
100	5.388	3646
110	4.009	3336
120	3.024	3010
125	2.639	2844

Given that the VFO pin is fault-output compatible (LOW true at IPM fault status), the temperature-sensing pull-up resistor needs to keep the temperature detection output as far away from the low level threshold of the digital IO as possible.

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The pull-up resistor R121 is 2 k, and IMC302A's temperature-related AD input voltage is shown in Figure 29.

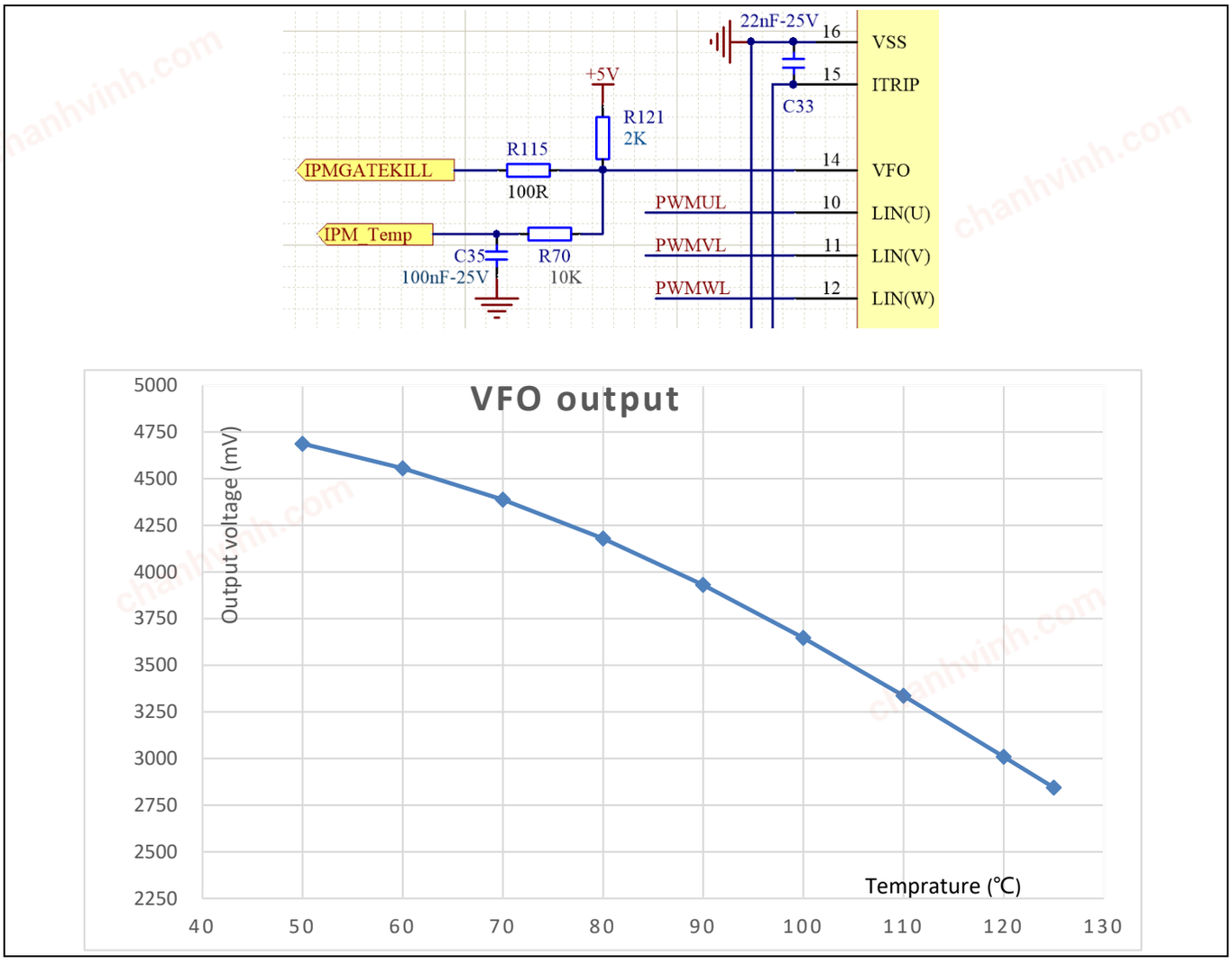


Figure 29 NTC circuit and output voltage curve

The temperature value of overheat shutdown can be calculated as shown below and configured in MCEWizard as shown in Figure 28.

The MCEWizard default setup is at 3.9 V, which sets the shutdown NTC temperature ($T_{protection}$) to about 90°C when the whole IPM is in a heat balance state. Please note that there might be a 3 ~ 15°C temperature difference between IPM NTC and the hottest point during motor power increase fast (non-thermal equilibrium state).

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4.3 Motor overcurrent protection (OCP) test

Figure 30 displays the OCP circuit for the IMC302A applications.

The output voltage of R83 & R77 divider is sensed by IMC302A's internal comparators to achieve the overcurrent protection function. The reference of the internal comparators is set by IMC302A's internal DAC, and external C36 is the LPF capacitor for DAC. MCEWizard calculates the DAC reference voltage based on the question input of "Device Overcurrent trigger level setting for Comparator" and "Motor1 Current Input to ADC Offset Voltage."

MCEWizard output parameter CompRef defines the DAC output voltage, which depends on the three items listed below:

A: Expected overcurrent threshold

B: Gain of external current sensing network

C: Offset of the external op-amp or RC divider

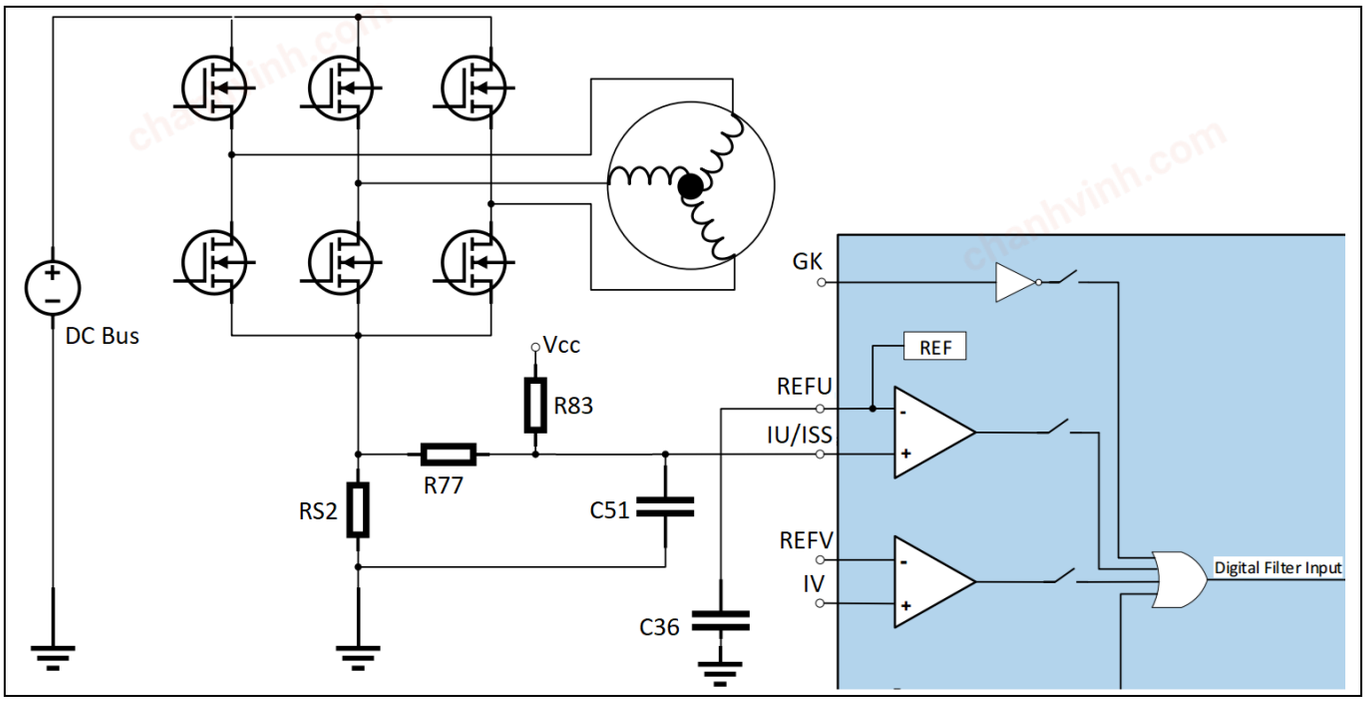


Figure 30 Overcurrent protection circuit on the REF-AIRCON-C302A-IM564 reference design

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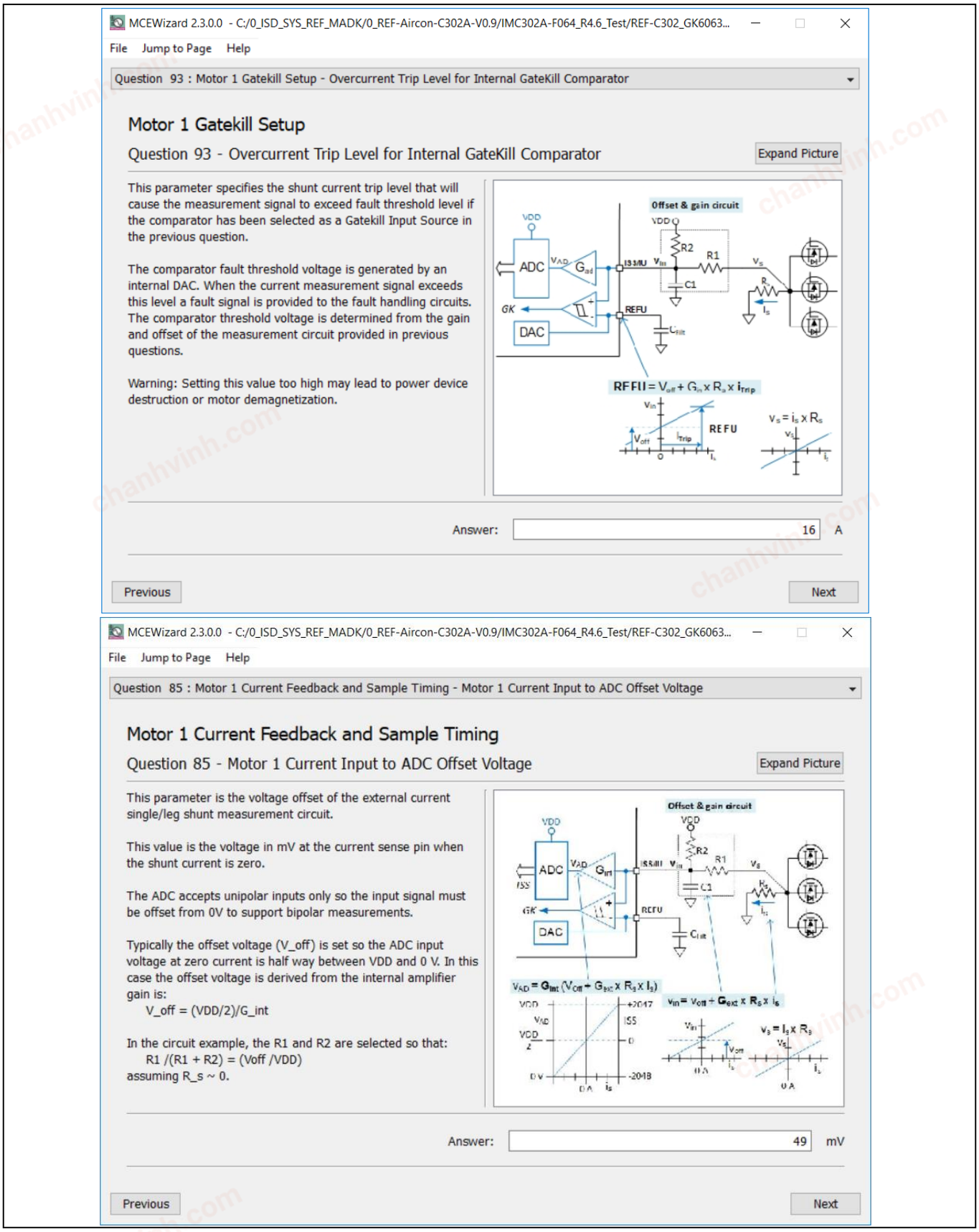


Figure 31 Motor overcurrent protection setup in MCEWizard

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Normally it is recommended to set a value higher than motor maximum peak current (maximum RMS current * 1.414) in “Overcurrent Trip Level for Internal GateKill Comparator,” with a reserve of at least a 20% margin. Or set 70~90% of the motor demagnetization current for the OCP threshold.

Figure 32 shows the OCP test result of REF-AIRCON-C302A-IM564:

- Set OCP threshold ($MtrI_{trip1}$) to 10 A in MCEWizard, program parameters to MCE
- Run motor to high speed and high load
- Overcurrent protection occurs at about 11 A peak motor current; GK fault reports and motor stops.

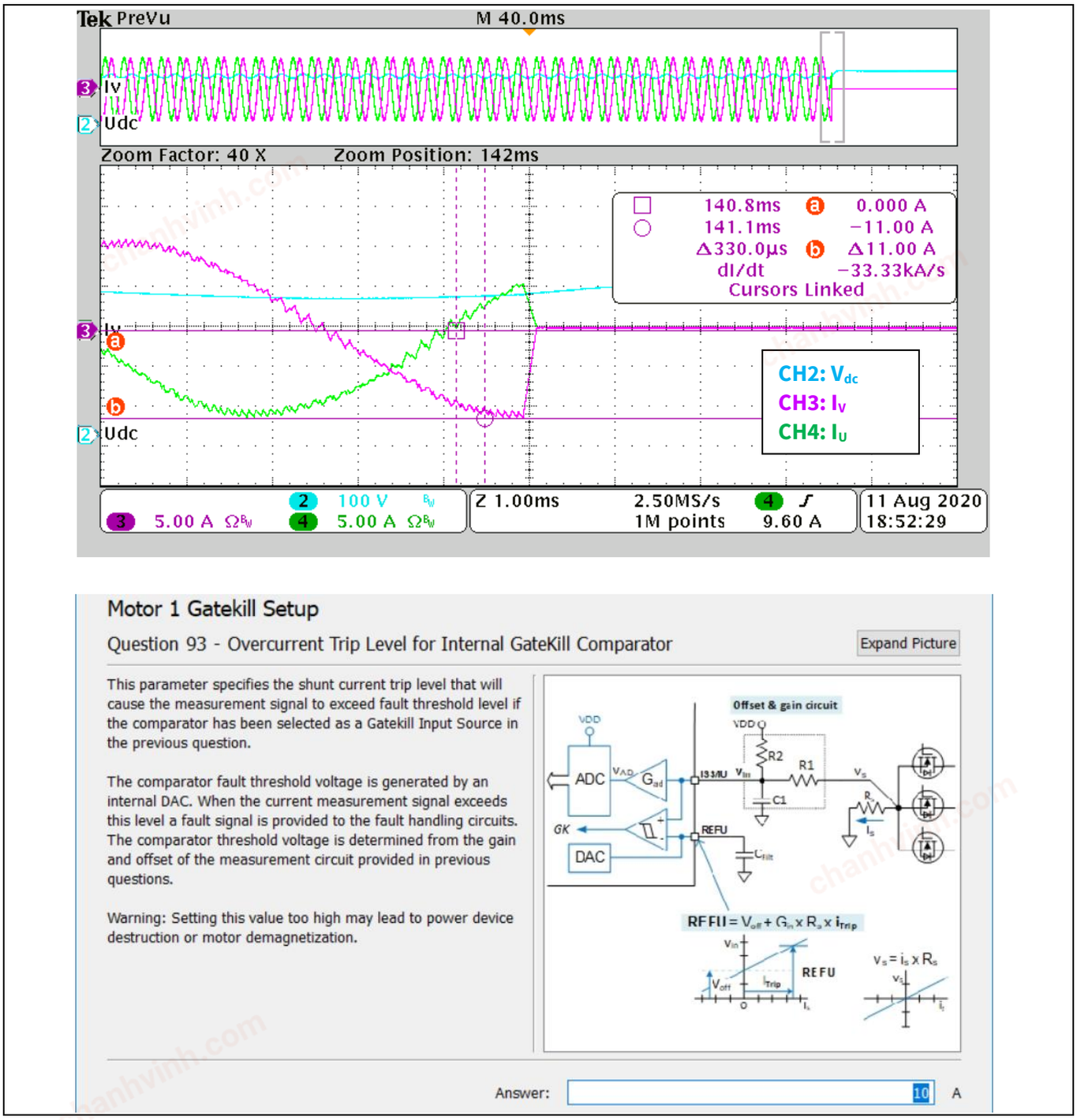


Figure 32 Motor OCP by internal Gatekill comparator

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4.4 PFC overcurrent protection test

The IMC302A's MCE firmware has two options for PFC overcurrent protection: cycle-by-cycle and latch-up OCP.

Figure 33 shows the OCP behavior of cycle-by-cycle current protection. When input current I_{ac} reaches 18 A_{PEAK} (13.6 A_{RMS}), it becomes flat-topped, which means input peak current is limited by cycle-by-cycle function.

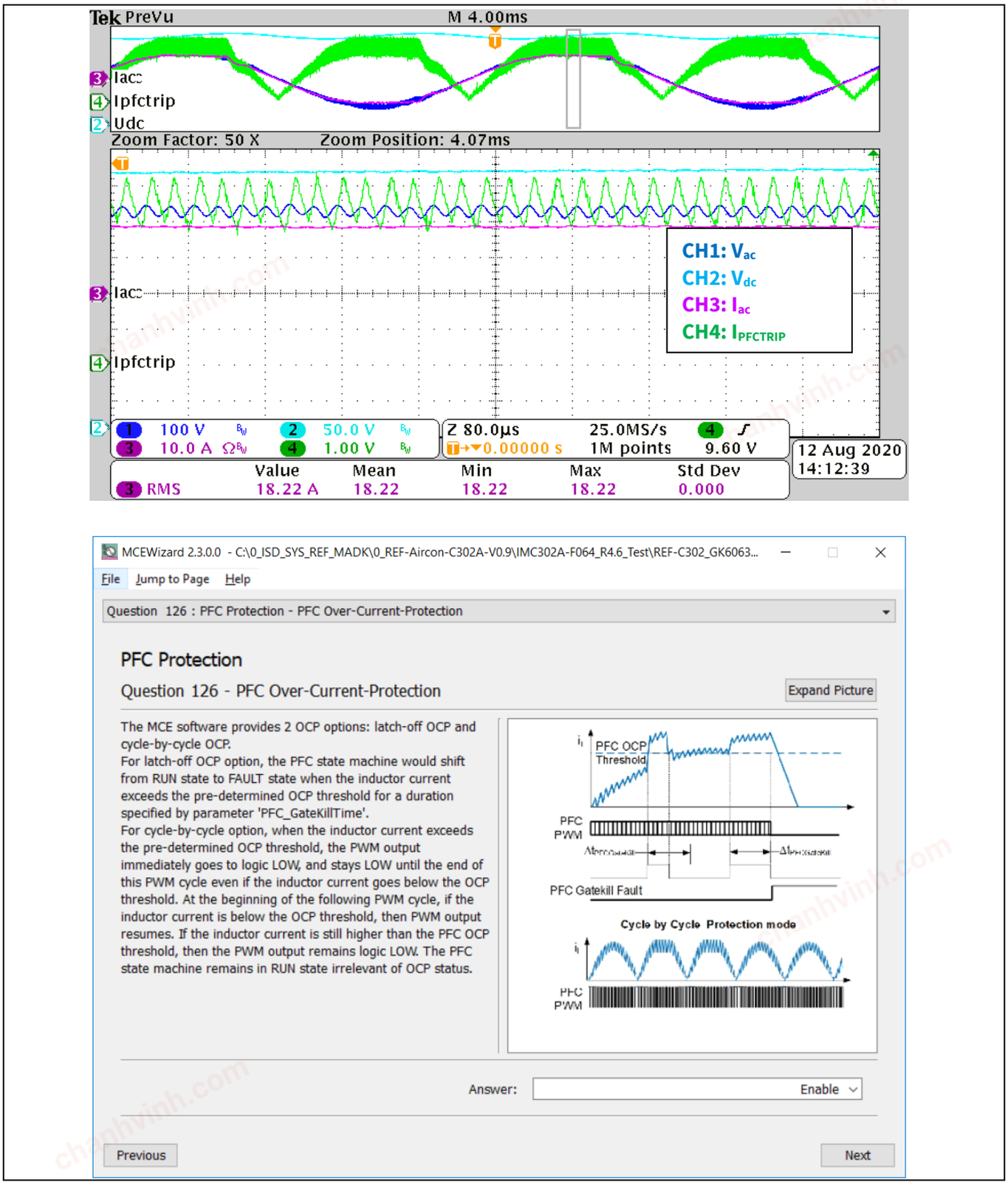


Figure 33 PFC Cycle-by cycle OCP test

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Figure 34 shows the behavior of latch-up OCP. When input current I_{ac} reaches 18 A_{PEAK}, and $I_{PFCTRIP}$ reaches 4.86 V OCP threshold, PFC Gatekill fault occurs, and PFC turns off.

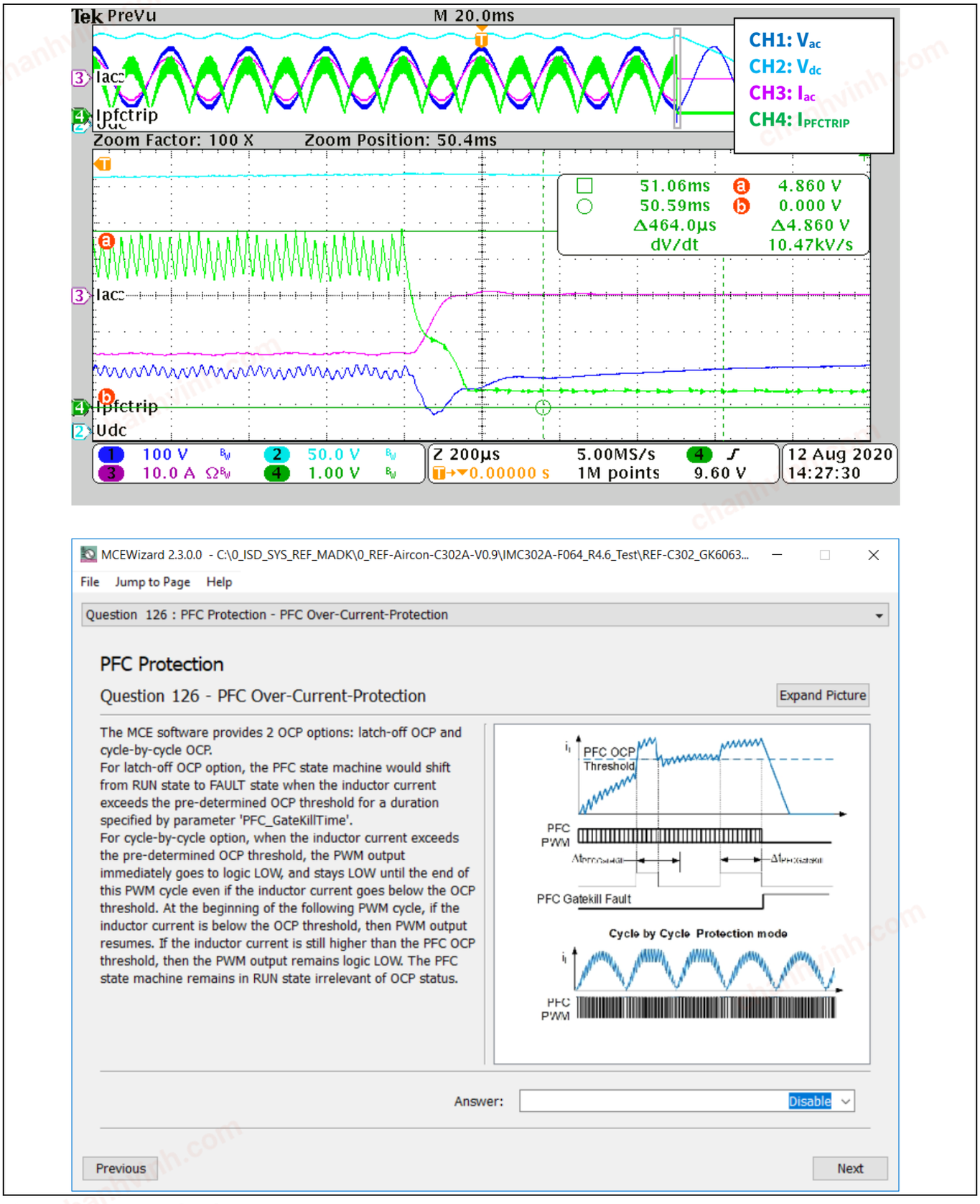


Figure 34 PFC latch-up OCP test

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4.5 DC bus sensing and overvoltage protection

Figure 35 provides the DC bus sense resistor details on the REF-AIRCON-C302A-IM564 reference design.

The high-side resistor is 1880 kOhm and the low-side resistor is 20 kΩ; 0 ~ 475 V DCBUS reflecting 0 ~ 5 V at the ADC input pin.

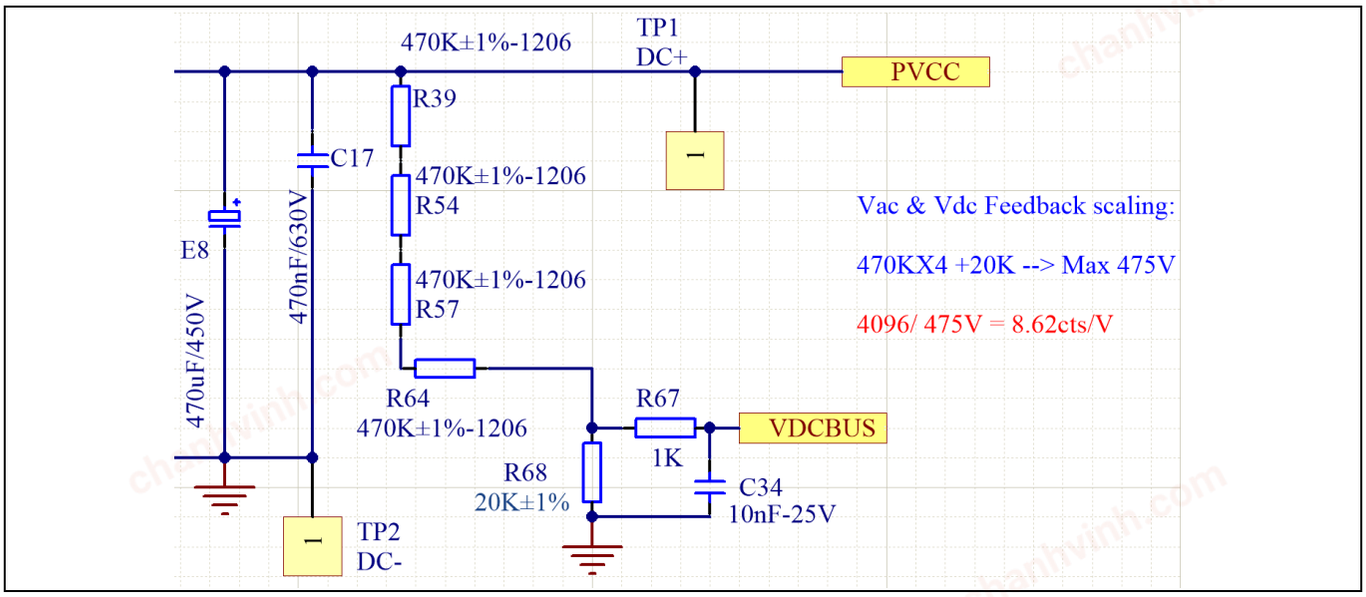


Figure 35 DC bus sense resistor on REF-AIRCON-C302A-IM564 reference design

For a different DC sensing range such as 110 V applications, R68 can be adjusted to a higher value; the hardware changes should be configured in MCEWizard, as shown in Figure 36.

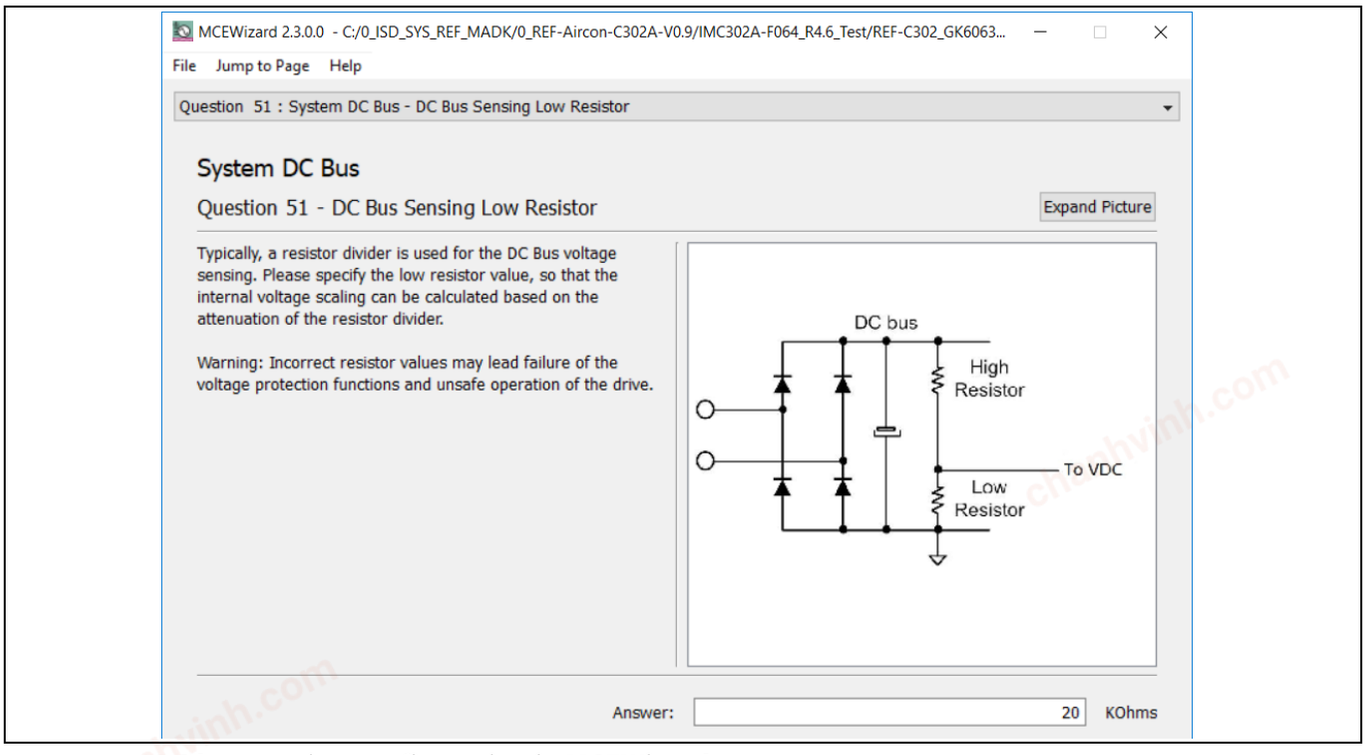


Figure 36 DC bus sensing configuration in MCEWizard

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The V_{DC} sensing low-pass filter time constant is (R67+R68)*C34 = 21 k*10 nF = 210 µs, which is at least two times the 40 kHz PFC PWM periods (25 µs for 40 kHz PFC) and higher than motor PWM periods (166 µs for 6 kHz motor PWM); C34 can be adjusted to fit PFC voltage loop response.

Figure 37 shows the MCE firmware behavior of overvoltage protection (OVP):

- Set OVP threshold to 2900 cts (set write register VdcOvLevel to 2900)
- Start a Vac & Vdc trace with “Trigger on Fault” mode
- Increase input AC voltage rapidly, the OV fault occurs when Vdc is over 2900 cts

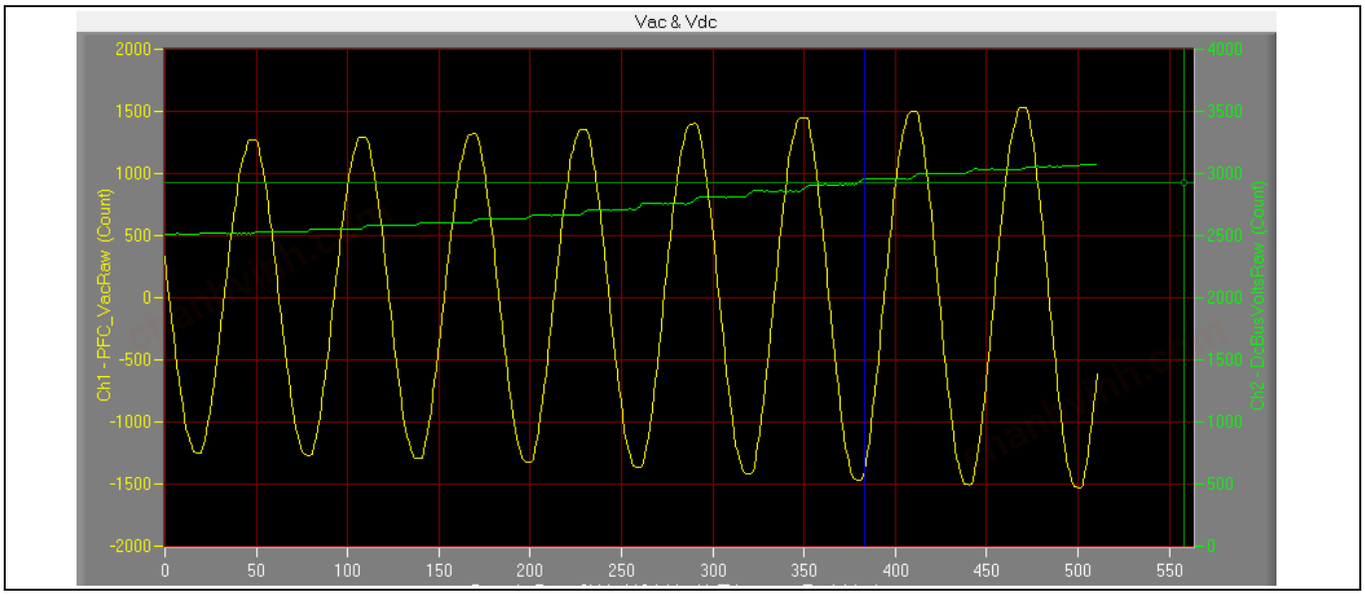


Figure 37 OVP test by MCEDesigner trace function

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4.6 PFC performance test

Figure 38 shows the test result of PFC performance test at the conditions below:

- Set V_{DC}=340 V, input V_{AC} =200 V
- Increase motor load, input power about 1430 W, I_{AC}=7.15 A
- PF=0.999, THD=3.44%

Please notice that channel 1 shows the input AC voltage (V_{ac}) in yellow, and channel 2 shows input AC current (I_{ac}) in blue.

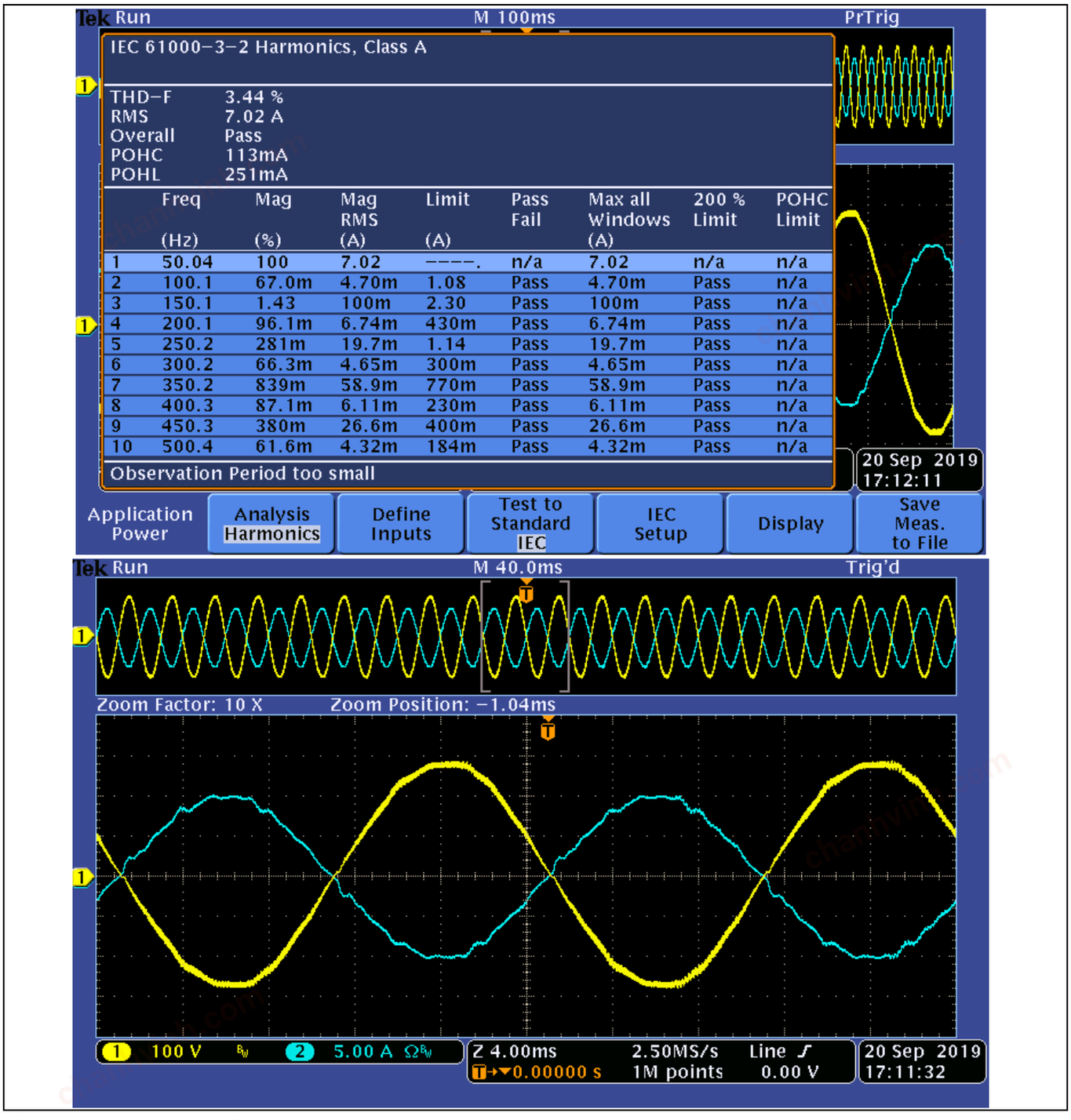


Figure 38 PFC performance test

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5 References and appendices

5.1 Abbreviations and definitions

Table 11 Abbreviations

Abbreviation	Meaning
CE	Conformité Européenne
EMI	Electromagnetic interference
UL	Underwriters Laboratories
NTC	Negative temperature coefficient
PMSM	Permanent magnet synchronous motor
OPA	Operational amplifiers
MCE	Motion control engine
OCP	Overcurrent protection
OTP	over-temperature protection
IDU	Indoor unit
FOC	Field-oriented control
CMR	Common mode noise rejection
LPF	Low pass filter

5.2 References

[1] Datasheet of Infineon IM564-X6D

[2] Datasheet of Infineon IMC302A

[3] MCEWizard User Guide

[4] MCEDesigner User Guide

[5] Infineon-MCESW-RM-User Manual

5.3 Ordering details and other information

Base Part Number	Package	Standard Pack		Orderable Part Number
		Form	Quantity	
REF-AIRCON-C302A-IM564	EVAL	Boxed	1	
IMC302A-F064	PG-LQFP-64	Tape and Reel	1900	IMC302AF064XUMA1
1ED44175N01B	PG-SOT23-6	Tape and Reel	3000	1ED44175N01BXTSA1
ICE5AR4770BZS DIP-7	PG-DIP-7	TUBE	2000	ICE5AR4770BZSXKLA1
IM564-X6D	DIP 36x21D	Tape and Reel	280	IM564X6DXKMA1

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Revision history

Document version	Date of release	Description of changes
1.0	2020-11-25	First release
1.0.1	2021-01-27	Correct some textual details

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