

REF-Vacuum-C101-2ED User Guide

SOI driver & Vacuum Application Reference Design Kits

About this document

Scope and purpose

This user guide provides an overview of the reference board REF-Vacuum-C101-2ED including its main features, key data and mechanical dimensions.

REF-Vacuum-C101-2ED is a full-featured starter kit, turnkey low-voltage motor drive designed for high-performance, high-efficiency PMSM/BLDC motor drive applications, including all of the required elements for vacuum applications, such as IMC101T iMOTION™ controller, 2ED2304S06F SOI half-bridge gate driver and BSC030N04NS OptiMOS™.

The starter kit features and demonstrates Infineon's thin-film SOI technology and advanced motion control engine (MCE 2.0) technology for low-voltage, permanent-magnet motors drive up to 120 kRPM speed, and inverter section up to a rating of 30 V and 25 A. It is optimized for major low-voltage home appliances like vacuums, fans, pumps, compressors and other low-voltage motor drive applications.

Intended audience

This application note is intended for all technical specialists who are familiar with high-speed motor control and low-voltage electronics converters. The reference design is intended to be used under laboratory conditions only by trained specialists.

Ordering information

Base Part Number	Package	Standard Pack		Orderable Part Number
		Form	Quantity	
REF-VACUUM-C101-2ED	EVAL	Boxed	1	REFVACUUMC1012EDTOBO1
IMC101T-T038	PG-TSSOP-38-9	Tape and Reel	3000	IMC101TT038XUMA1
BSC030N04NS G	PG-TDSON-8	Tape and Reel	5000	BSC030N04NSGATMA1
2ED2304S06F	PG-DSO-8	Tape and Reel	2500	2ED2304S06FXUMA1

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1 Safety precautions

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

Table 1 Safety precautions

	<p>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.</p>
	<p>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.</p>
	<p>Caution: REF-Vacuum-C101-2ED reference board contains parts and assemblies sensitive to Electrostatic Discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable ESD protection handbooks and guidelines.</p>
	<p>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 DC supply, or excessive ambient temperatures may result in system malfunction.</p>
	<p>Caution: REF-Vacuum-C101-2ED reference board is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.</p>

2 Introduction

The REF-Vacuum-C101-2ED is part of the iMOTION™ reference design kits. It is designed to provide ready-to-use, low-voltage and high-speed vacuum solutions based on Infineon’s thin-film SOI technology and advanced motion control engine (MCE 2.0) technology. It allows fast prototyping and fast time to market. The board is equipped with all assembly groups for sensorless field-oriented control (FOC), and reserved interface for three digital Hall sensors, so that it can be extended to other low-voltage and high-current motor applications.

The block diagram of the REF-Vacuum-C101-2ED is depicted in Figure 1, which contains iMOTION™ controller IMC101T, 3 mOhm 40 V OptiMOS™, and 2ED2304S06F half-bridge gate driver with integrated bootstrap diode.

This reference design includes:

- Gate driver IC for MOSFET
- Anti-reverse connection protection
- 12 V & 3.3 V auxiliary power supply
- VSP speed command potentiometer
- Over temperature and overcurrent protection
- Turnkey version sensor less & sensor FOC control

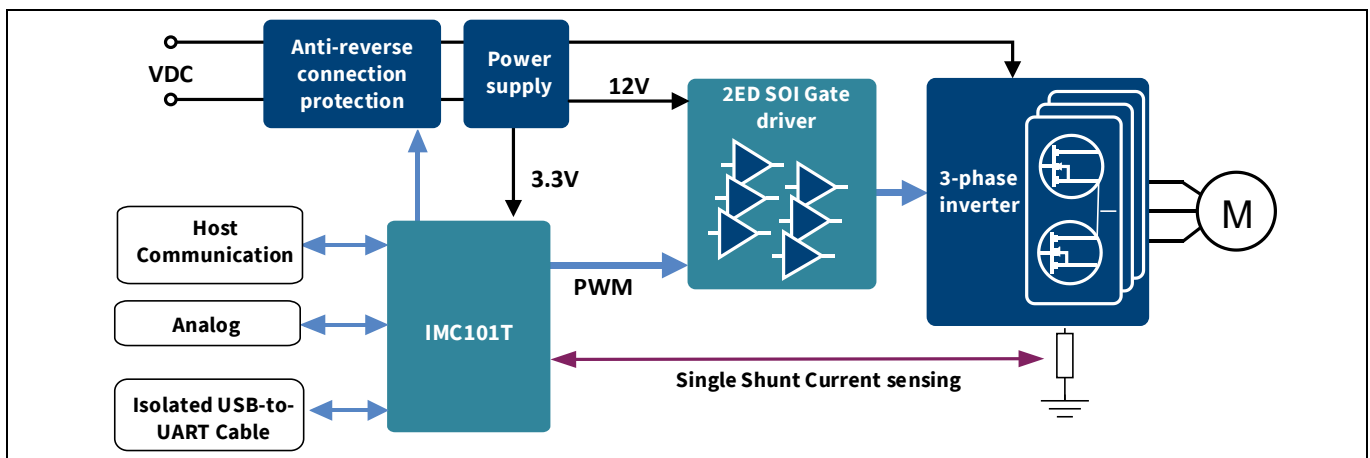


Figure 1 Block diagram of the REF-Vacuum-C101-2ED

The REF-Vacuum-C101-2ED reference design 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, modify and qualify the design for production according to their own specific requirements.

An 18 V, 250 W vacuum motor is used for the default DEMO function, whose maximum speed is 100 kRPM. Please note that motor parameters need to be double-checked in MCEWizard if a different motor is used.

3 REF-Vacuum-C101-2ED main features

REF-Vacuum-C101-2ED is a reference design for 24 V (like 6~7S Li battery) low-voltage motor drive applications.

Main features of SOI half-bridge gate driver 2ED2304S06F include:

- Infineon thin-film SOI technology
- Fully operational to +650 V, floating channel designed for bootstrap operation
- Output source/sink current capability +0.36 A/-0.7 A
- Integrated ultra-fast, low $R_{DS(ON)}$ bootstrap diode
- dV/dt immune ± 50 V
- Tolerant to negative transient voltage up to -100 V
- 10 ns typ., 60 ns max. propagation delay matching
- Integrated minimum dead time 75 ns, shoot-through prevention
- Gate drive supply range from 10 V to 20 V, undervoltage lockout for both channels
- 3.3 V, 5 V and 15 V input logic compatible

Main features of iMOTION™ controller IMC101T include:

- 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

The REF-Vacuum-C101-2ED reference design characteristics include:

- Input voltage 18~30 V DC (6S ~ 7S Li battery)
- Maximum 600 W at 25 A, 24 V DC power input with on-board cooling fan
- Anti-reverse connection protection
- VSP speed command potentiometer
- 3 digital Hall interface
- User UART for script function
- Overcurrent and over temperature protection, fault diagnostic LED output
- Low-noise, single-shunt current sample
- Auxiliary power supply with 12 V, 3.3 V
- PCB is 60 mm × 115 mm (or 60 mm × 63.5 mm if cooling fan is removed), 2 layers, 1 oz. copper
- RoHS compliant

3.1 REF- Vacuum -C101-2ED board specifications

Table 2 depicts the key specifications of the reference design REF-Vacuum-C101-2ED.

Table 2 REF-Vacuum-C101-2ED board specifications

Parameters	Values	Conditions / comments
Input		
Voltage	18 - 30 V_{rms}	6S ~ 7S Li battery or 24VDC input
Input current	25 A_{rms}	Input 24 V_{DC} , $T_a=25^\circ C$, BSC030N04NS with cooling fan
Output		
Power (3 phases)	600 W	Input 24 VDC, $f_{PWM}=22$ kHz, $T_a=25^\circ C$, $T_{mos}= 105^\circ C$
Current per phase	22 A_{rms}	Input 24 VDC, $f_{PWM}=22$ kHz, $T_a=25^\circ C$, $T_{mos}= 105^\circ C$
DC bus voltage		
Maximum DC bus voltage	30 V (max)	MOSFET BSC030N04NS's $V_{(BR)DSS}$ is 40 V
Minimum DC bus voltage	10 V (min)	Need bypass ZD2, ZD3 and U1 2ED2304 undervoltage negative-going threshold 9 V
Switching frequency		
Maximum inverter switching frequency f_{PWM}	80 kHz (max)	IMC101T's firmware max. time usage depends on enabled function blocks and control rate setup
Minimum inverter switching frequency f_{PWM}	6 kHz *	Depends on motor control performance and Wizard calculation (motor poles and R & L) IMC101T's firmware scaling limit is 2 kHz
Current feedback		
Inverter current sensing resistor RS1	2 m Ω	Can adjust to 5~10 m Ω for lower current motor application (with external OPA) Or above 20 m Ω shunt resistor for directly ADC sample (without external OPA)
Protections		
Output current trip level	80 A_{peak}^1	Wizard setup for OC trigger level Related to shunt resistor RS1 and OPA's bias
Temperature trip level	105 $^\circ C$ (typ)	Needs to consider the temperature gap between MOS and NTC sensor
On-board power supply		
12 V	12 V \pm 1 %, max. 100 mA	Used for MOS gate driver and 3.3 V LDO
3.3 V	3.3 V \pm 1 %, max. 100 mA	Used for IMC controller and protection circuits
PCB characteristics		
Material	FR4, 1.6 mm, 1oz PCB	2 layers
Dimension	60 mm \times 115 mm	60 mm \times 63.5 mm if cooling fan is removed
System environment		
Ambient temperature	From 0 to 50 $^\circ C$	Non-condensing, maximum RH of 95 %

¹ For iMOTION™ IC IMC1xx, there are three types of Gatekill Input Source options in MCEWizard setup.

If select "comparator" mode, the external Gatekill signal will be not used, and the signal I_Shunt will be compared by the internal comparator with the "Device Overcurrent trigger level setting" value set in MCEWizard.

Figure 2 points out the functional groups on the top side of the REF-Vacuum-C101-2ED reference design

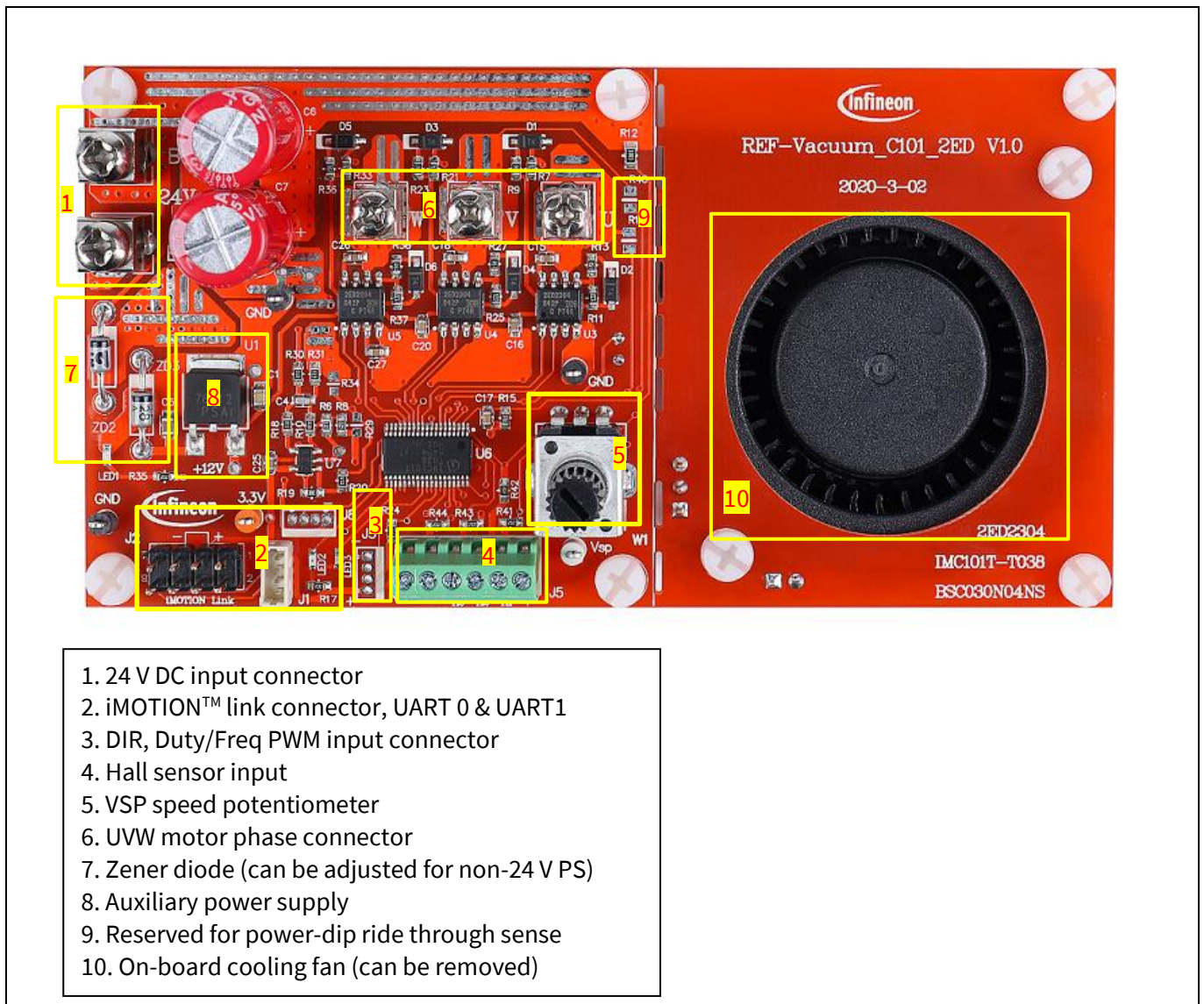


Figure 2 Functional groups of the REF-Vacuum-C101-2ED reference design's top side

Figure 3 points out the functional groups on the bottom side of the REF-Vacuum-C101-2ED reference design

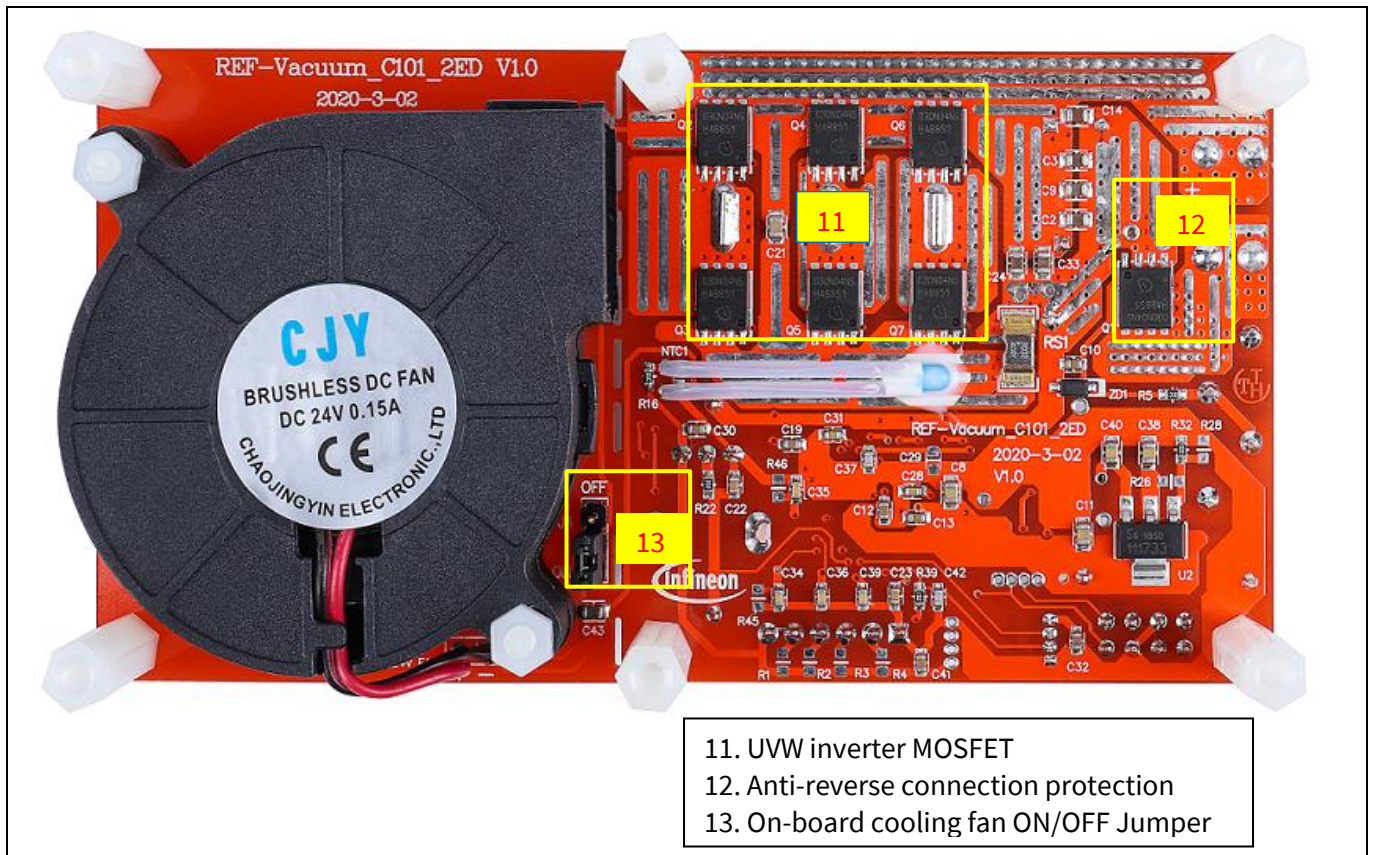


Figure 3 Functional groups of the bottom side of REF-Vacuum-C101-2ED reference design

3.2 Connector pin assignment

General information about the connectors of the REF-Vacuum-C101-2ED reference design is reported in this section. Table 3 includes the details of the DC input connector.

Table 3 DC input connector

Pin	Details
J6 (B+)	DC+ 24 V input
J9 (B-)	DC- 24 V ground

Table 4 denotes the details of the UART related connector (iMOTION™ Link connector J2, J1 & J8)

Table 4 J2- iMOTION™ link connector

S. No.	Pin	Details
1	TXD1	User UART for Script communication (Same as J8 Pin3)
2	RXD1	User UART for Script communication (Same as J8 Pin2)
3 & 6	+3.3 V	On board 3.3 V supply
4 & 5	GND	Ground
7	RXD0	MCE Designer & firmware download (Same as J1 Pin2)
8	TXD0	MCE Designer & firmware download (Same as J1 Pin3)

Table 5 provides the details of the motor UVW output connector

Table 5 Motor side connector

S. No.	Pin	Details
J10	U	Connected to motor phase U
J11	V	Connected to motor phase V
J12	W	Connected to motor phase W

Table 6 provides the pin assignments of digital Hall interface connector J5

Table 6 J5 - HALL connector to motor

Pin	Name	Pin name connectors
1	GND	Ground
2	-----	Reserved for analog Hall input AHall2-
3	DHAL3	Digital Hall input3
4	DHAL2	Digital Hall input2
5	DHAL1	Digital Hall input1
6	+3.3 V	On board 3.3 V supply

Table 7 provides the pin assignments of external Duty & Freq and direction input connector J3

Table 7 J3 – External PWM command and DIR input

Pin	Name	Pin name connectors
1	GND	Ground
2	DIR	External motor direction input
3	Duty/Freq	External PWM speed command input (duty cycle or frequency mode)
4	+3.3 V	On board 3.3 V supply

4 Product overview of 2ED2304S06F

Traditional motor control is between 4 – 20 kHz PWM frequency, while new motor control applications need up to 30-50 kHz. Hence, gate drivers will be required with lower level-shift switching losses and lower leakage currents to reduce the dissipated power during operation.

Higher PWM frequency allows users to achieve higher motor control dynamics, and reduce motor size and weight, which is especially applicable to hand-held electronic devices. Higher PWM frequency requires lower PWM propagation delay matching time between high-side and low-side MOS drives to reduce the waveform distortion. Moreover, higher time accuracy of the motor current sampling also requires gate drivers to deliver delay matching as low as possible.

International Rectifier was the first innovator of junction isolation technology and Infineon is now continuing the history of innovation with its unique SOI technology for high voltage. Infineon’s SOI-based level-shift technology requires less energy to transfer the control (PWM) signal from the low voltage control side to the high-voltage portion of the gate driver (the high voltage well), and provides additional performance and reliability with reduced leakage currents and increased latch-up immunity. It also enables higher switching frequencies above 100 kHz. Some key parameters of 2ED2304 compared with IRS2304 are shown in Table 8.

Table 8 IRS2304S Vs. 2ED2304

Parameter	IRS2304S	2ED2304S
Operating voltage	600 V	650 V
Input configuration	HIN, LIN	HIN, LIN
Bootstrap diode	External	Integrated
Negative V_s transient [Max]	< -50 V	<= -100 V
I_{o+} / I_{o-} [TYP]	290 mA / 600 mA	360 mA / 700 mA
Prop. delay - $t_{ON/OFF}$ (ns - Typ)	220 / 200	310 / 300
Delay matching – MT (ns – Typ)	46	20
Dead time – DT (ns) (Typ)	100	75
Matching DT (ns - Max)	50	50
$t_{r/f}$ (ns – Typ)	70 / 35	48 / 24
Level shift losses	-	50% lower
Logic operation for V_s of COM	-5V ~ +600V	-8 V ~ +600 V

Infineon’s new SOI drivers with increased performance and integration are now being expanded with the 2ED2304S06F 650 V half-bridge SOI gate driver with integrated bootstrap diode, superior negative V_s robustness, reduced level-shift losses, and more reliable performance.

2ED2304S06F has successfully operated at 120 kRPM with an iMOTION™ controller in a battery-powered vacuum cleaner application. Other new applications utilizing HB-LLC topology that switch above 100 kHz can now be implemented using the 2ED2304S06F.

4.1 Internal block diagram

Figure 4 illustrates the internal block diagram of the 2ED2304S06F.

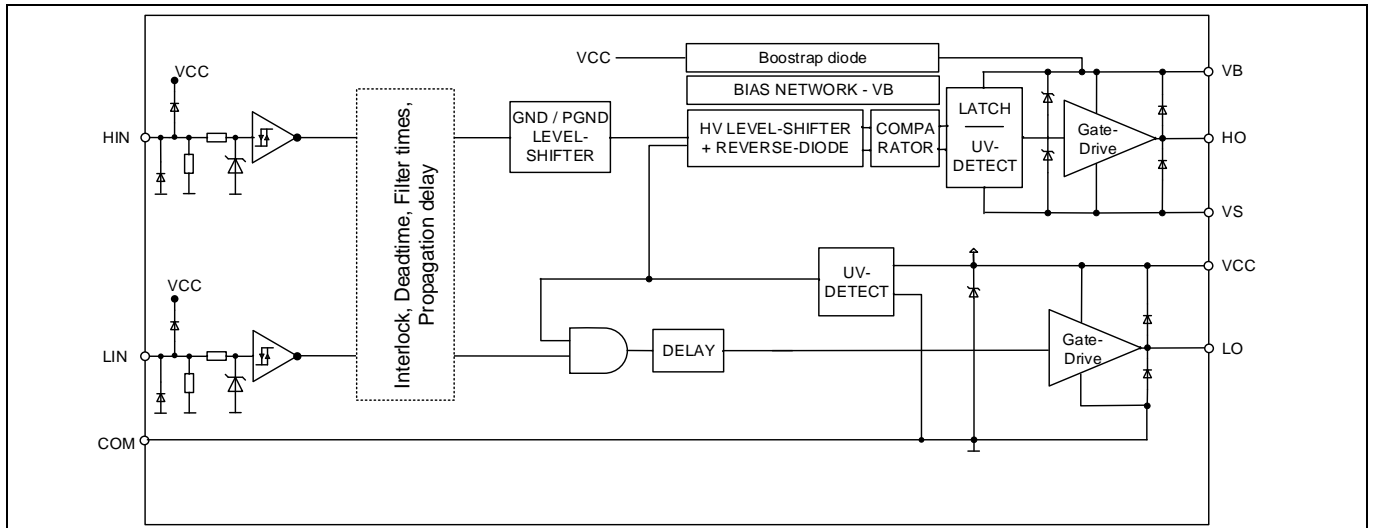


Figure 4 Block diagram of 2ED2304

The Schmitt trigger logic inputs are compatible with standard CMOS or LSTTL logic down to 3.3 V. The output drivers feature a high-pulse current buffer stage designed for minimum driver cross-conduction. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high-side configuration, which operates up to 650 V.

Additionally, the offline clamping function provides an inherent protection of the parasitic turn-on by floating gate conditions when the IC is not power-supplied.

2ED2304S06F is DSO-8 package; the pin definition is the same as IRS2304, as shown in Figure 5.

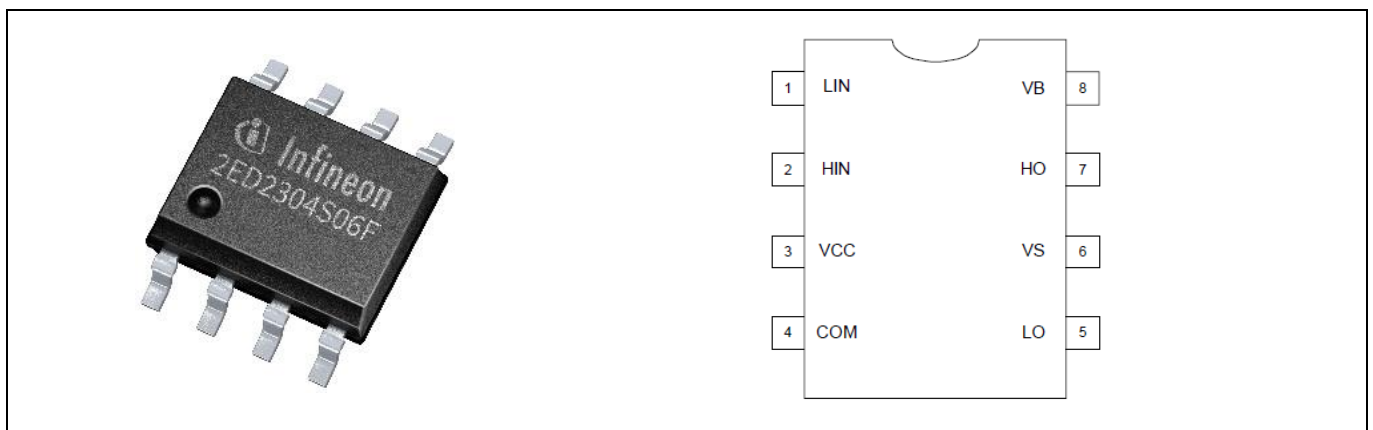


Figure 5 2ED2304S06F lead assignments PG-DSO-8 (top view)

4.2 The detailed features and functions of 2ED2304

- Infineon thin-film-SOI technology, high reliability and lower power loss
- Fully operational to +650 V
- Output source/sink current capability +0.36 A/-0.7 A
- Floating channel designed for bootstrap operation
- Integrated ultra-fast, low $R_{DS(ON)}$ bootstrap diode, reduced PCB and internal logic complexity
- Tolerant to negative transient voltage up to -100 V (pulse width is up 300 ns) provided by SOI technology
- Internal dead time 75 ns (typical) and dead time matching time 10 ns (typical)
- dV/dt immune ± 50 V
- 10 ns (typical), 60 ns max. propagation delay matching
- Gate drive supply range from 10 V to 20 V
- Undervoltage lockout for both channels
- RoHS compliant
- 3.3 V, 5 V and 15 V input logic compatible

4.3 Tolerant to negative transient voltage on V_S pin (- V_S)

A common problem in today's power switching converters is the transient response of the switch node's voltage, as the power switches transition on and off quickly while carrying a large current, as illustrated in Figure 6.

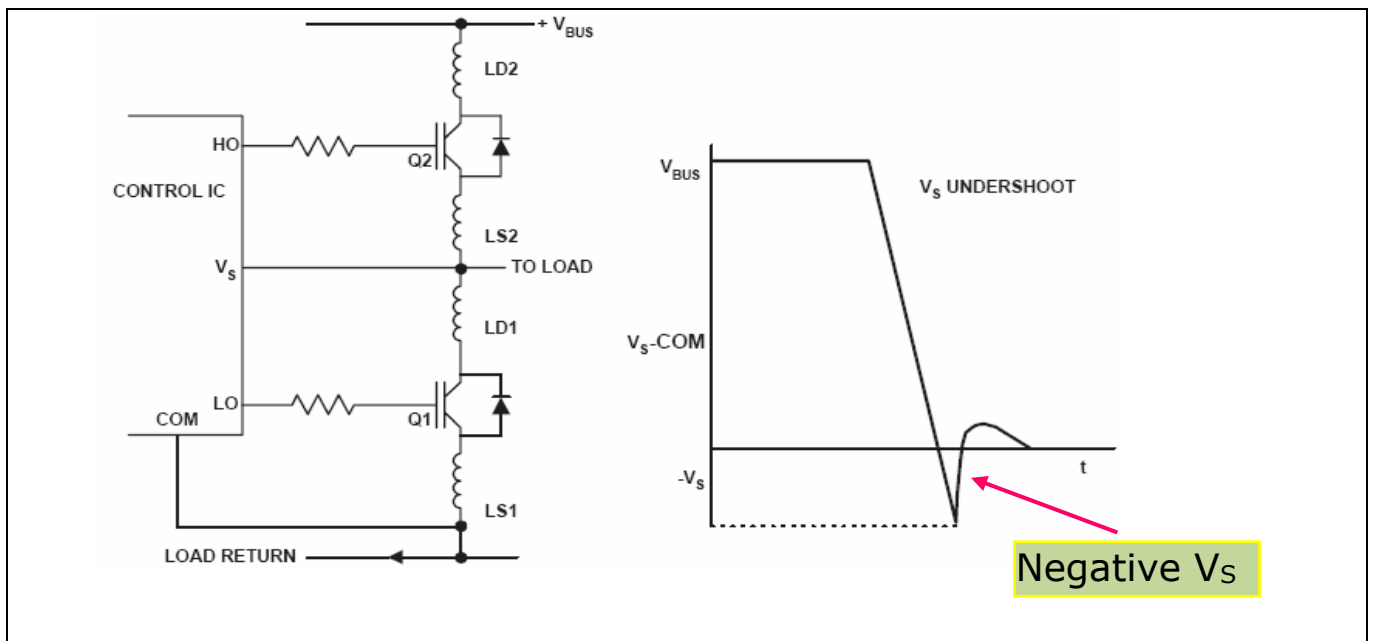


Figure 6 Negative V_S

This negative V_S voltage can cause the high side output to change state, or the device to latch up resulting in large currents or I_{QCC} shifts. A high side output transition from high to low will not damage the IC or the switch,

however, a high side output transition from low to high when the low side is on can cause switch damage or unreliable motor operation.

Negative V_s excursions occur during faster switching events over long PCB traces or wiring harnesses that form a parasitic inductor. The higher the parasitic inductor value and switching frequency, the larger is the potential negative V_s voltage that is developed during a switching event.

Negative V_s immunity is a key determining factor in selecting a robust gate driver IC that will be more immune to negative V_s excursions due to inductive parasitic on the PCB or wiring harness.

In a typical motor drive system, dV/dt is typically designed to be in the range of 3-5 V/ns. The negative transient voltage can exceed this range during some events such as short-circuit and overcurrent shutdown, when di/dt is greater than in normal operation.

2ED2304S06F has been designed for the robustness required in many of today’s demanding applications. An indication of the robustness of 2ED2304S06F can be seen in Figure 7, where the 2ED2304S06F safe operating area (SOA) is shown at $V_{BS}=15$ V based on repetitive negative transient voltage spikes. A negative transient voltage falling in the gray area (outside SOA) may lead to IC permanent damage; and vice versa, unwanted functional anomalies or permanent damage to the IC do not appear if negative V_s transients fall within the SOA.

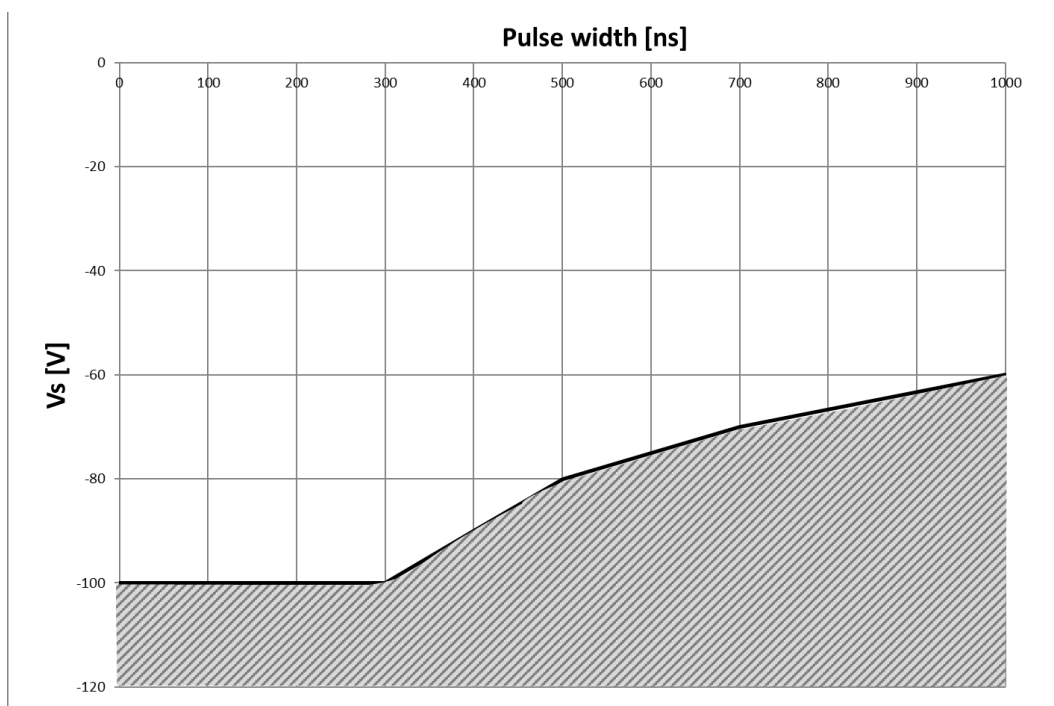


Figure 7 Negative transient voltage SOA on V_s pin for 2ED2304S06F @ $V_{BS}=15$ V

Even though the 2ED2304S06F has been shown to be able to handle these large, negative transient voltage conditions, it is highly recommended that the circuit designer always limit the negative transient voltage on the V_s pin as much as possible by careful PCB layout and component use.

5 Getting started with REF- Vacuum -C101-2ED

The REF-VACUUM-C101-2ED reference designs are shipped with embedded firmware and default parameters.

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

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

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

iMOTION™ Link or 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.

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

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

Figure 8 shows the basic system connection using REF-Vacuum-C101-2ED to run a vacuum motor with sensorless mode:

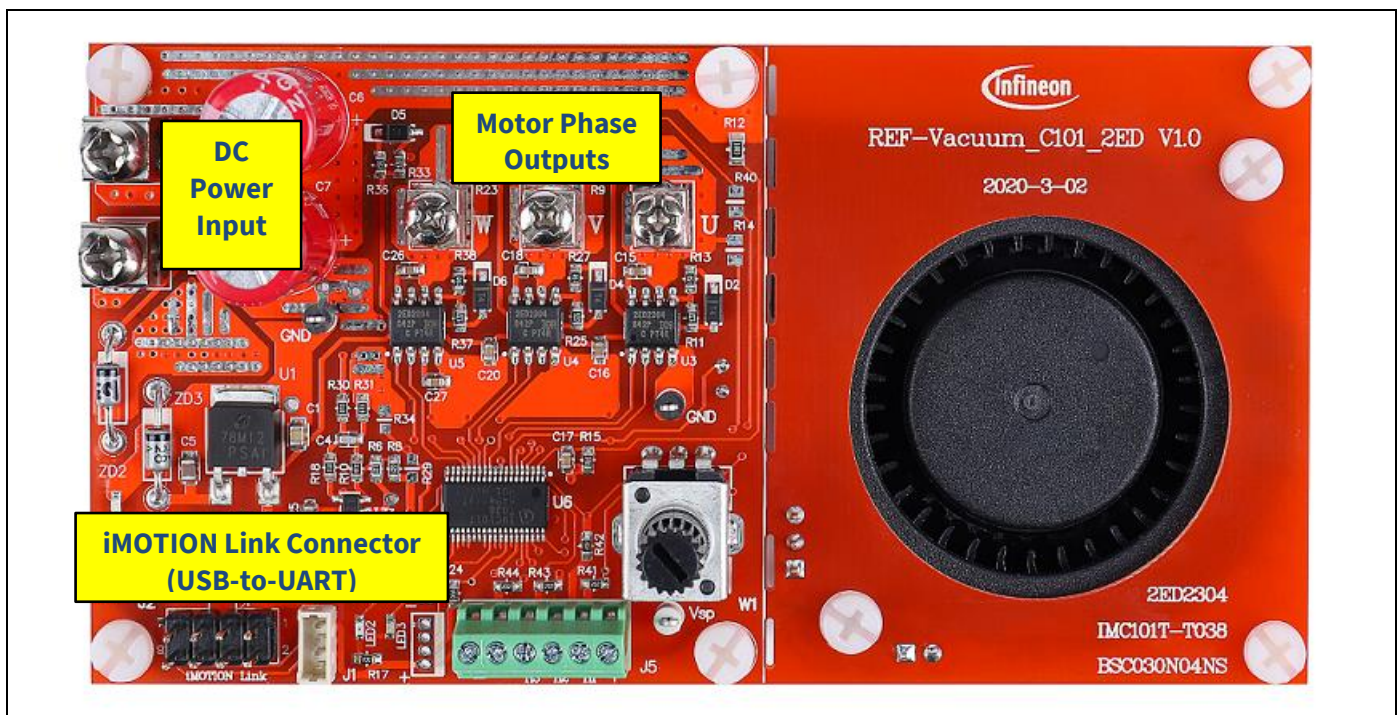


Figure 8 System connection example

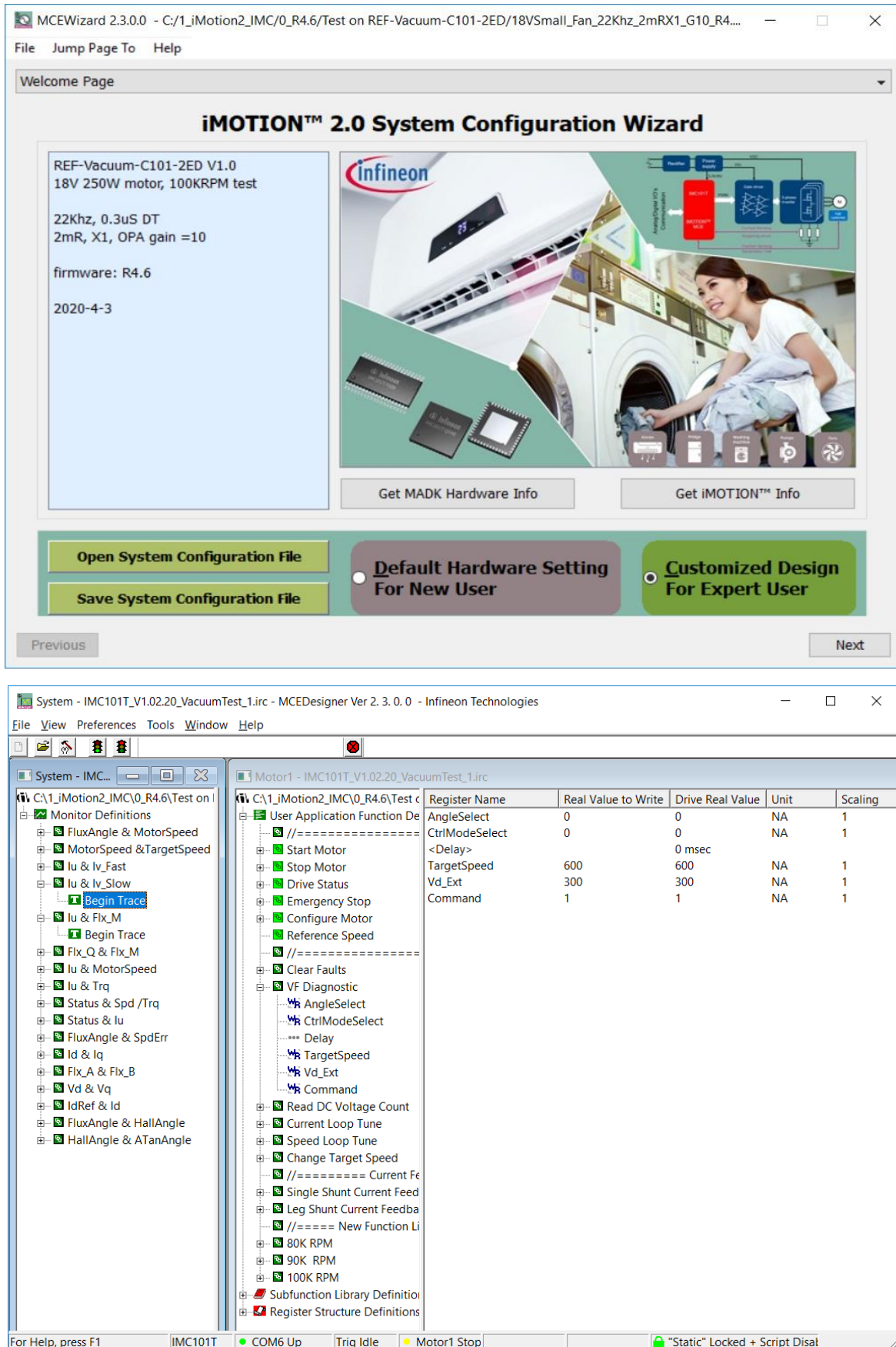


Figure 9 MCEWizard welcome page and MCEDesigner

Here are the steps needed to run the motor:

1. Connect iMOTION™ Link's 8-pin cable to J2 **with default pin order**, and connect PC-USB connector iMOTION™ Link. (Or connect third party isolated USB-to-UART cable to J1).
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" button. If no errors are reported, then save the drive parameter set into your project directory by clicking "Export to Designer file (.txt)" (Figure 10); if an error is detected, double-click on the error message (highlighted in **RED**) and adjust the related parameter. Saved drive system parameter file will be later used by the MCEDesigner in step 9.

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

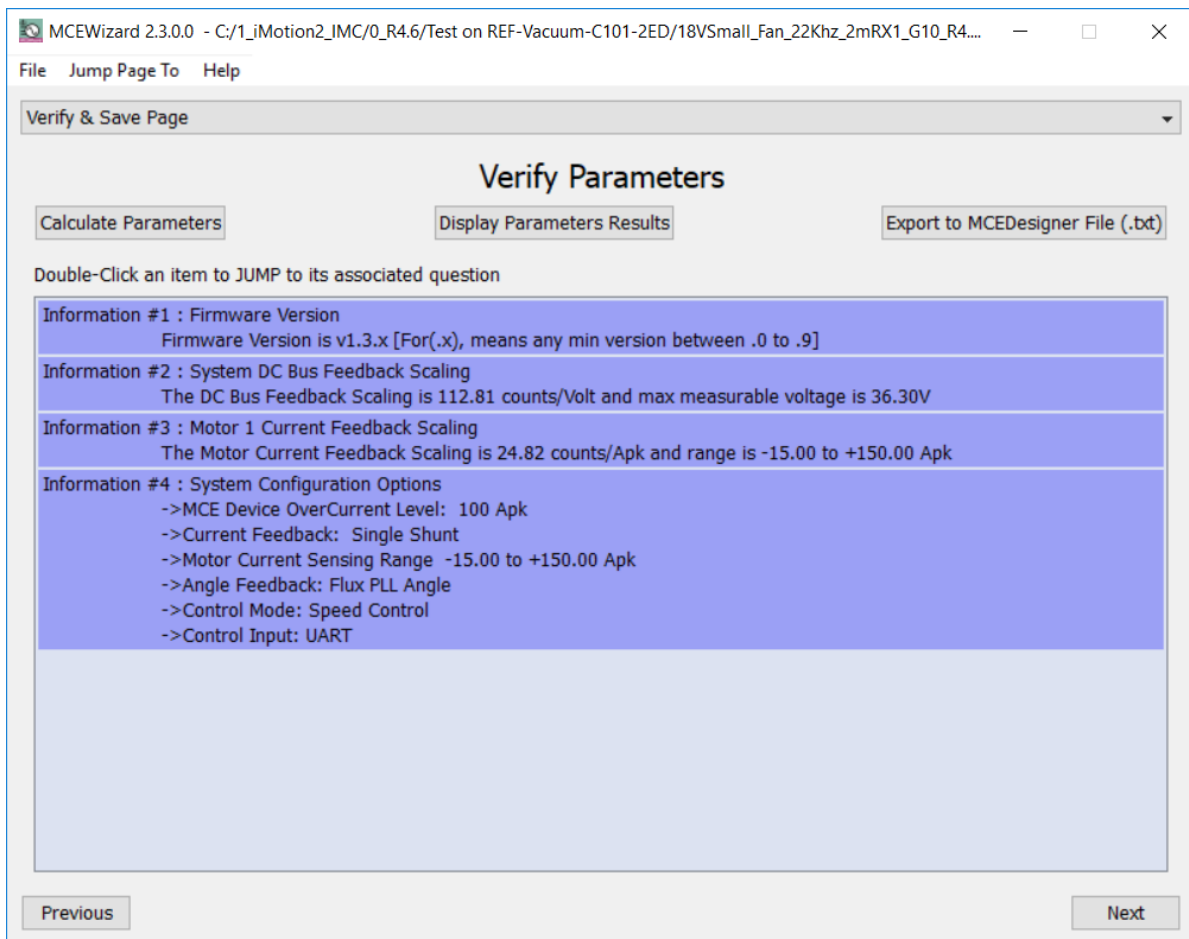


Figure 10 MCEWizard Verify and Save page

4. Connect 24 V power supply and UVW outputs to the motor.
5. Turn on 24 V power supply or connect 6S ~ 7S Li battery, green LED1 ON.
6. Start MCEDesigner tool and open MCEDesigner default configuration file (.irc) for IMC101T device (IMC101T_Vxxx.irc) by clicking "File" > "Open".
(IMC101T_Vxxx.irc file is included in downloaded "IMC101T MCE Software Package")
7. MCEDesigner should automatically connect to the REF-VACUUM-C101-2ED board using default COM port (Indicated by green circle next to "COMx Up" status in the bottom frame of the MCEDesigner GUI). If it cannot

establish the connection due to incorrect COM port, change COM port by doing the following steps: click on the “System Page” window and then click on “Preferences > Connection > Connect using”, and choose one of the other available COM ports from the drop-down list.

- In case of blank IC: If the firmware has been erased from the IMC101T, a warning message will pop up saying “Target device firmware and parameters file are not programmed! Please program firmware and parameters file” (Figure 11). See step 9 on how to obtain/program firmware and parameters.

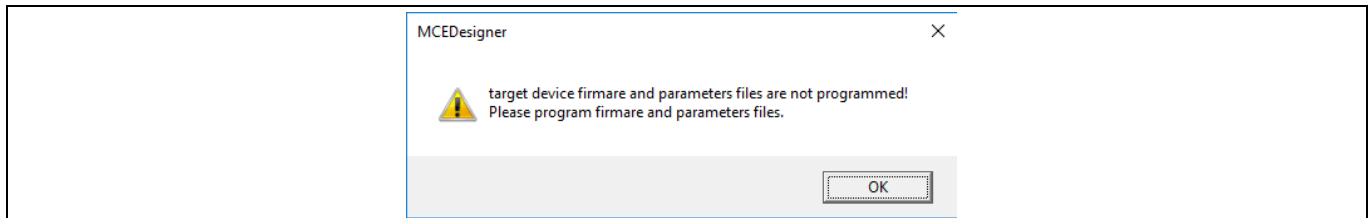


Figure 11 MCEDesigner warning message

- In case of blank IC: 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 Figure 12 below. The encrypted firmware is available in “IMC101T MCE Software Package,” regarding the parameters file, browse and select the .txt file in step 3.

(If blank IMC101T IC, MCE Designer will pop up information “Target device firmware and parameter files are not programmed!”) Program the MCE firmware and system parameters into the internal Flash memory of iMOTION™ IC by clicking “Tools > Programmer” in the pull-down menu, and then clicking on the “Program Firmware and Parameter” check box. Select right Parameter file and firmware file. Finally click “Start” button to program firmware and parameter. Then click YES and then OK button about 20 seconds later; finally “Save As” the IRC file to your own file name that contains COM config, Parameters & firmware file path information. (Please refer to **MCEDesigner User Guide.pdf** and **MCEDesigner_V2.3.0.0 Application Guide.pdf** for more details, which is in MCE Designer’s install path)

Red LED2 will flash on after the program is done.

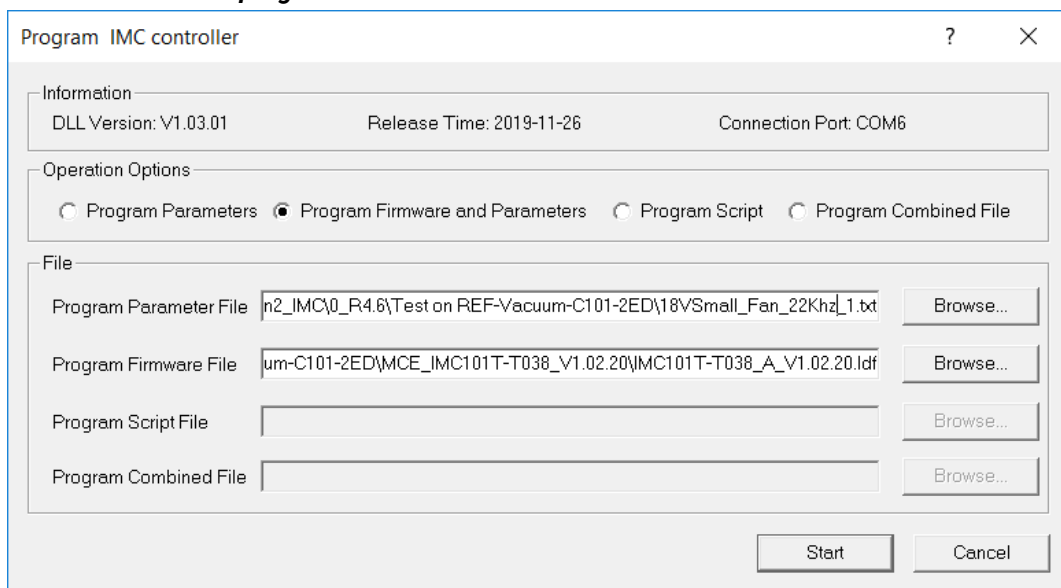


Figure 12 MCEDesigner warning message

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

Double-click “Iu & Iv_Slow” in System page > Monitor Definitions, the motor current feedback would be very clean and sinusoidal, as shown in Figure 13, otherwise please tune “Gating Propagation Delay & Phase Shift Window Size” in MCE Wizard. The sampled motor current amplitude should be over 300 cts ~500 cts (corresponding to 30%~50% motor rate current); otherwise, 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 decouple have been done correctly

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

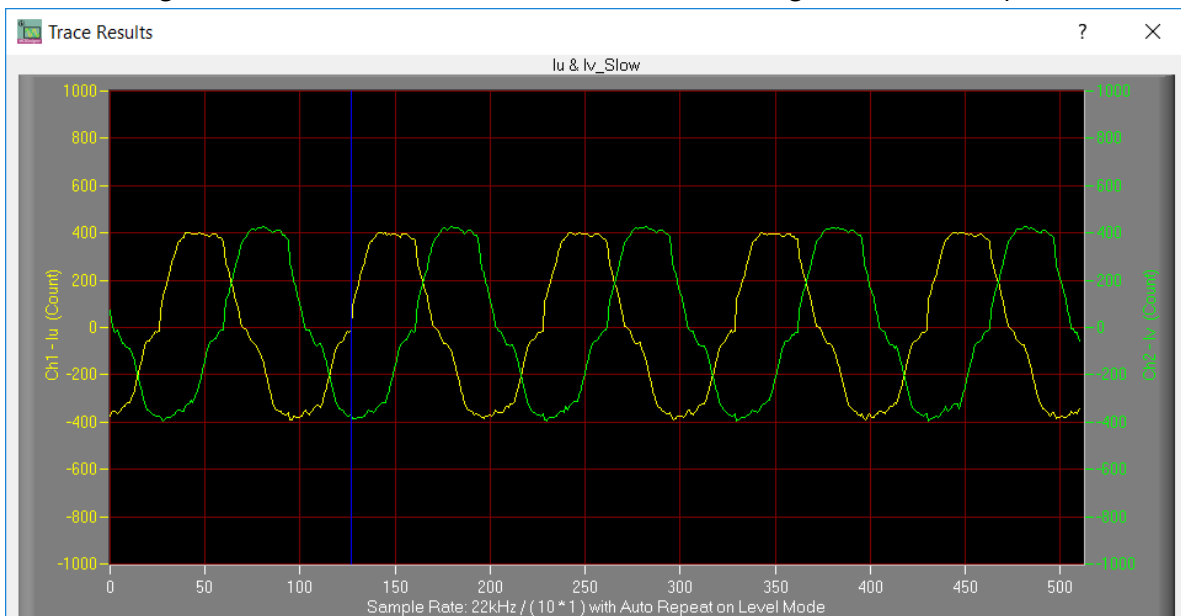


Figure 13 Trace waveform for Iu & Iv open loop diagnostic

11. Start the motor by clicking the green traffic light button in the control bar (or double-click Start Motor sub function in Motor1 page, group of User Application Function Definitions); motor runs if above step goes well.
12. Check motor spin direction, adjust UVW connection order or set negative target speed in MCE Designer if direction is wrong.
13. Set target speed to about 50% of MAX speed, start “Iu & Flx_M” trace with “Auto Repeat On Level,” see Figure 14. Flx_M is better within the range of 2000~2500 (rated value is 2048), and MUST be steady and DC-like.

Some key tips for better motor-performance tuning:

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

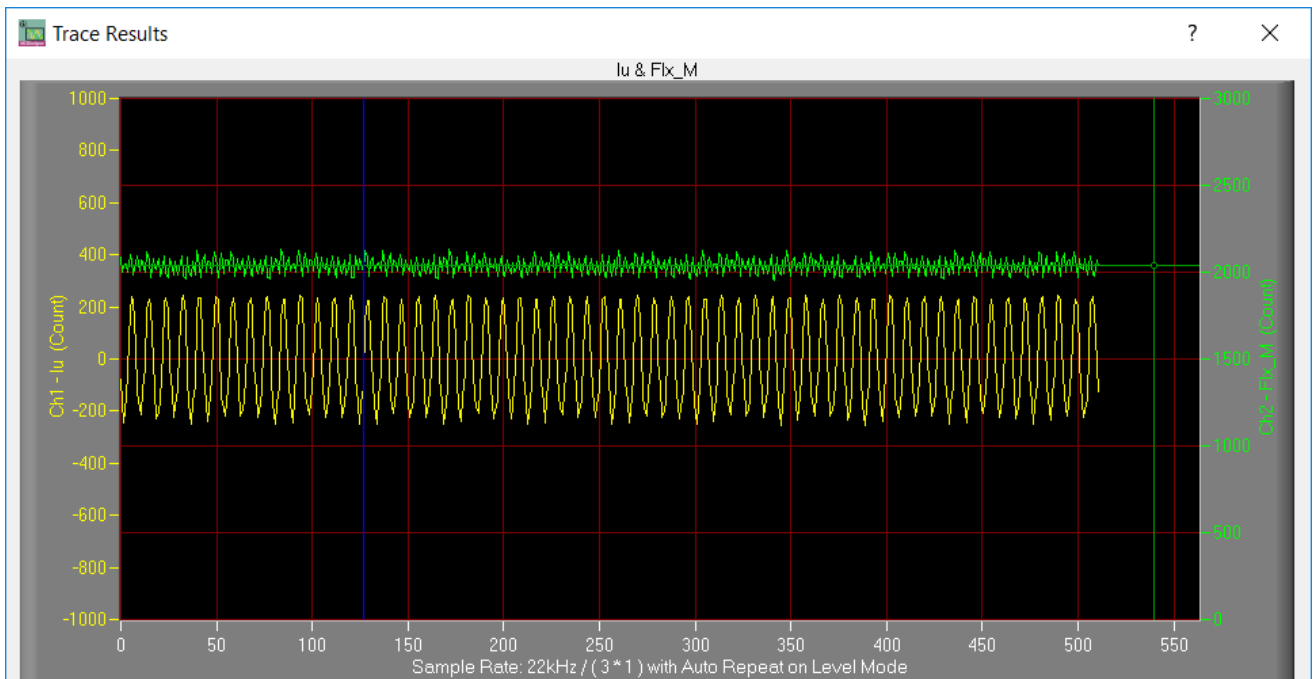


Figure 14 Trace waveform for lu & Flx-M at 50% speed

14. 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.

6 Hardware description of REF-Vacuum-C101-2ED

The REF-Vacuum-C101-2ED board is an optimized design for 6S ~ 7S Li battery power vacuum applications, which can be used for different voltages (outside the range of 18 V~30 V) or different power classes (well below 600 W), by replacing different MOS, current-sensing resistors and by modifying auxiliary power supply. To meet individual customer requirements and to make the REF-Vacuum-C101-2ED reference design a basis for development or modification, all necessary technical data like schematics, layout and components are included in this chapter.

6.1 Inverter section

The inverter section is implemented using 2ED2304S06F plus BSC030N04NS as sketched in Figure 15.

2ED2304S06F driver ability is source current +0.36 A and sink current -0.7 A; R7 & R11 is the gate resistor to control the U-phase MOSFET’s ON time, and R9 & R13 together with R7 & R11 to set the OFF time.

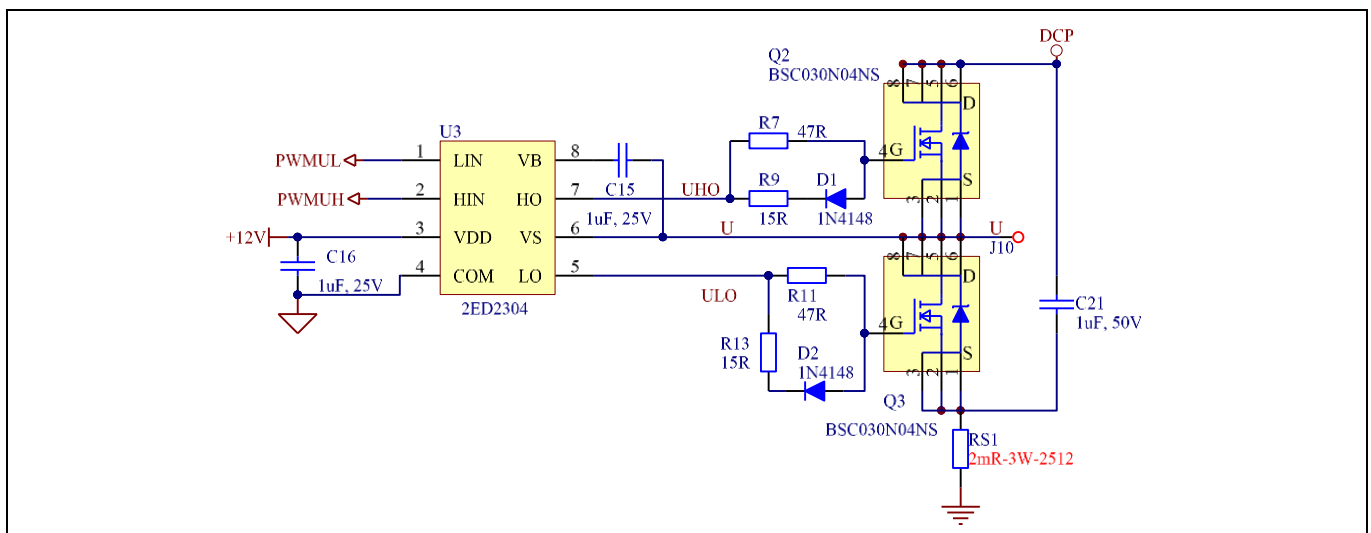


Figure 15 Inverter section on REF-Vacuum-C101-2ED

The recommended dead time is 200~400 ns for MCEWizard setup, which represents a real ON/OFF time of 150~200 ns, as shown in Figure 16 and Figure 17.

Note: The gate resistors and dead time setup need adjusting if new MOSFETs are used, since different MOS have different Qg.

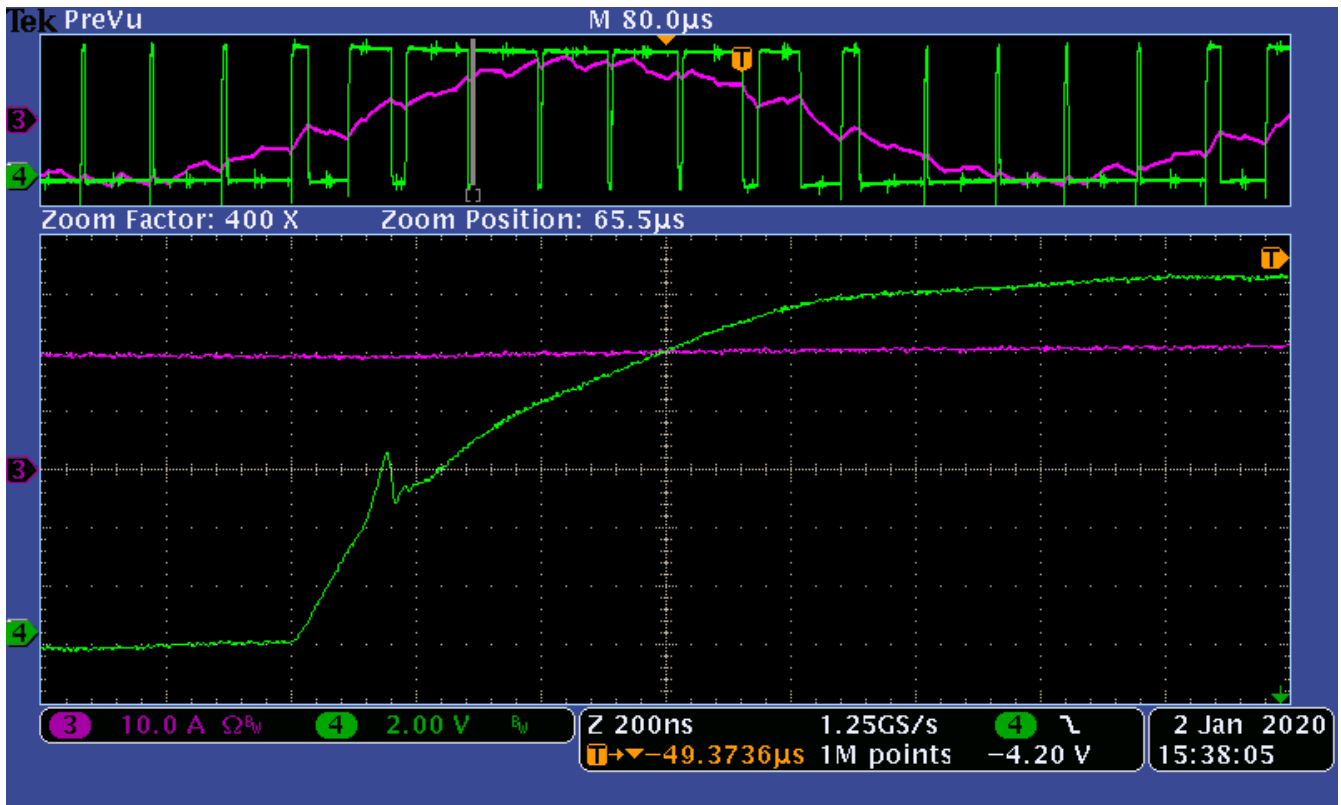


Figure 16 ON-time test waveform

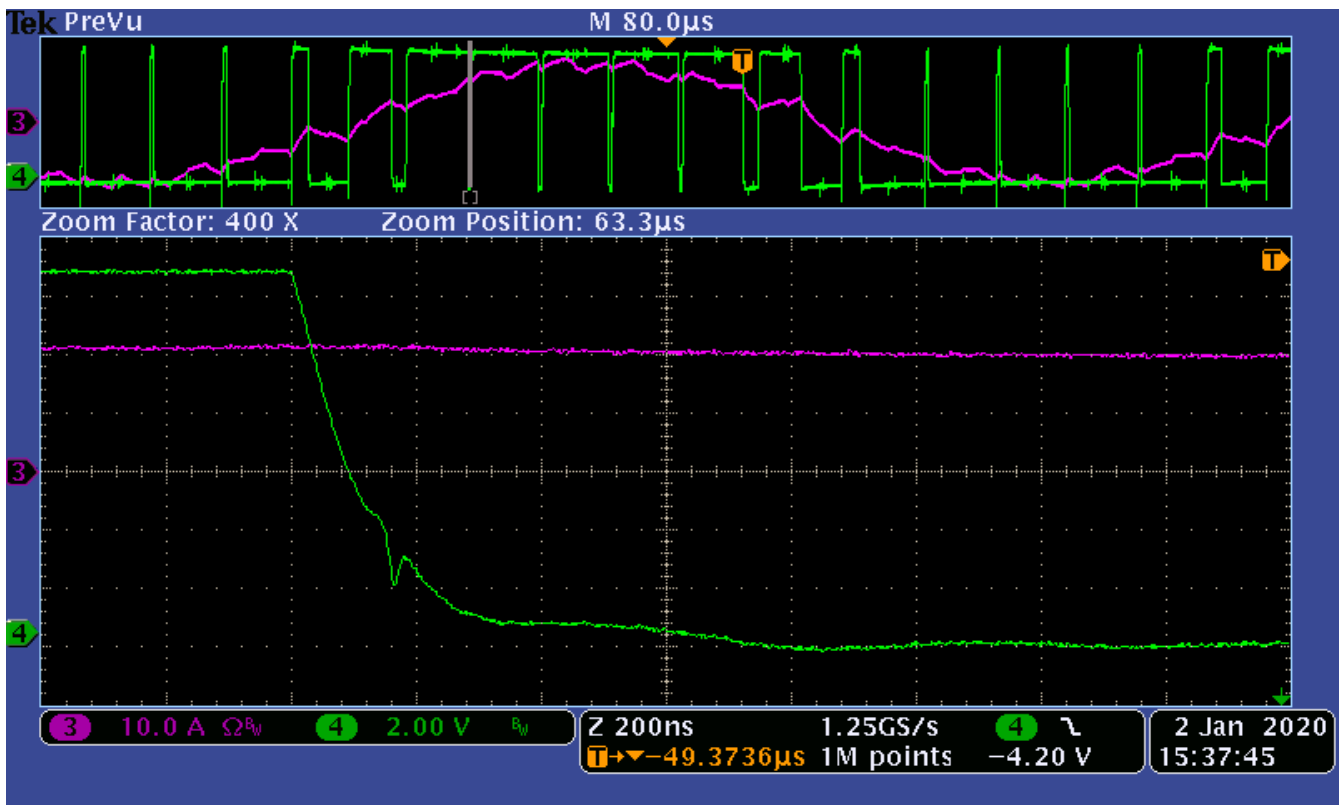


Figure 17 OFF-time test waveform

6.1.1 DC bus sensing and MCEWizard configuration

Figure 18 provides the DC bus sense resistor details on the REF-Vacuum-C101-2ED reference design.

The high-side resistor is 100 kOhm and the low-side resistor is 10 kΩ; 0 ~ 36.3 V DCBUS reflecting 0 ~ 3.3 V at the ADC input pin with 3.3 V power supply, and 0~55 V for 5 V power supply (by replacing U2 to 5V LDO).

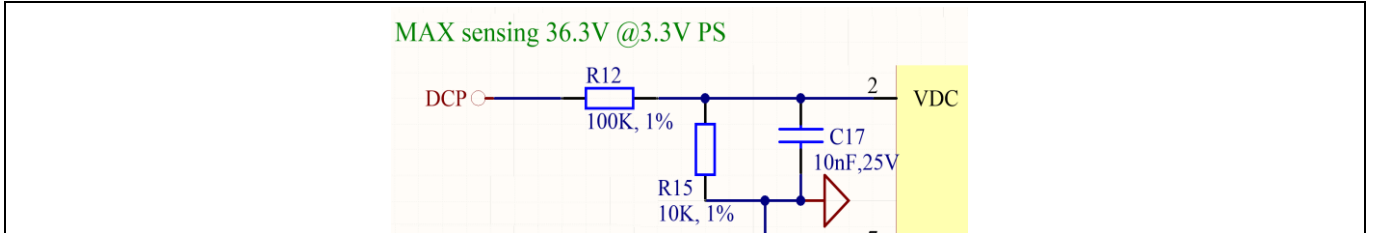


Figure 18 DC bus sense resistor on REF-Vacuum-C101-2ED reference design

For a wider DC sensing range, R12 can be adjusted to a higher value; the hardware changes should be configured in MCEWizard, as shown in Figure 19.

Figure 19 DC bus sensing configuration in MCEWizard

The Vdc sensing low-pass filter time constant is $(R12//R15) * C17 = (100\text{ k} // 10\text{ k}) * 10\text{ nF} = 91\text{ us}$, which is at least two times the 22 kHz PWM periods (45 us); C17 can be adjusted to higher capacitance for clean Vdc sensing, if new motor and new MOSFET cause Vdc bus sensing noise at MCEDesigner trace.

6.1.2 External op-amp configuration and calculation for current feedback

The current input scaling value is the product of the shunt resistance in milliohms and gain of external current sense amplifier for the REF-Vacuum-C101-2ED reference design, as shown in Figure 20.

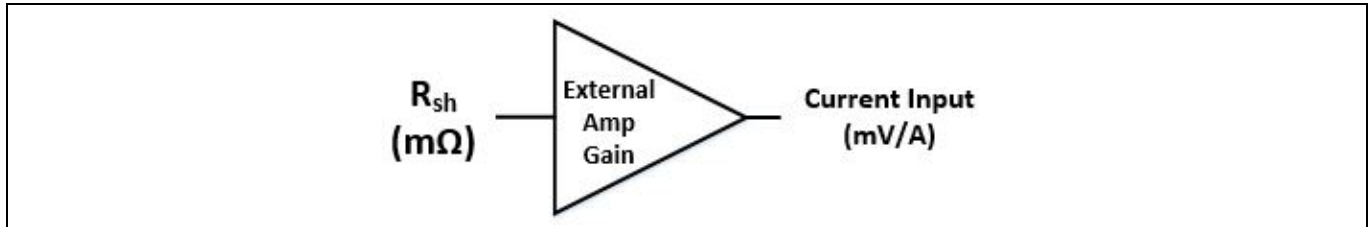


Figure 20 Current feedback scaling outside IMC101T

A 2 mOhm 3 W 2512 package shunt resistor and 10X external-gain operational amplifier (op-amp) is the default configuration for the REF-Vacuum-C101-2ED reference design, which means 1 A DC bus current produces 20 mV voltage to ADC input, MCEWizard’s “Motor1 Current Input Scaling” needs input of 20 mV/A.

Please note that the Internal Current Feedback Amplifier Gain (Question 84 for MCEWizard V2.3.0.0) is ADC’s internal gain, which defines the maximum ADC input range to $V_{CC}/Gain$. For 3.3 V power supply, the ADC sensing range is 0~1.1 V if 3X internal gain is selected, and 0~550 mV if 6X internal gain is selected, 0~275 mV if 12X internal gain is selected.

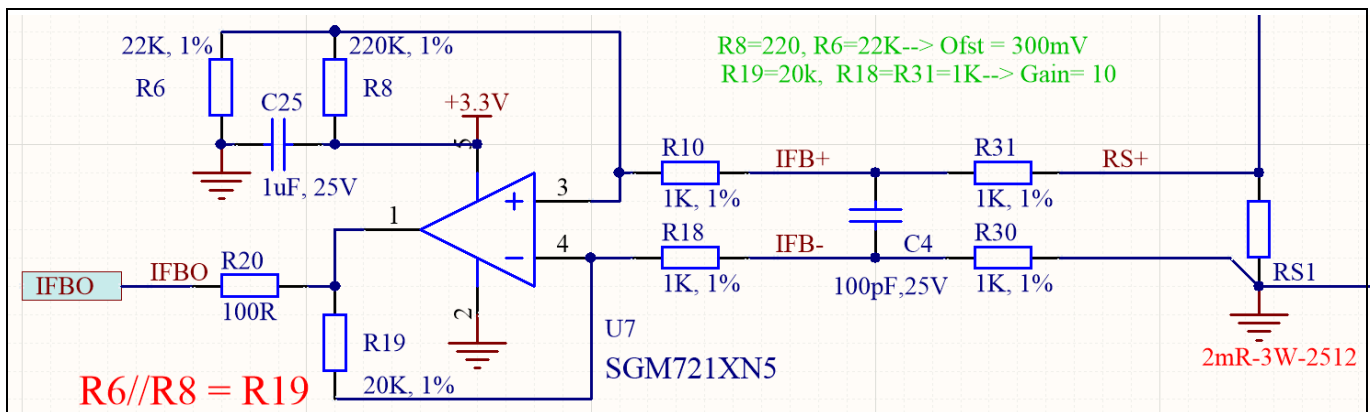


Figure 21 Current feedback with external op-amp

Figure 21 shows the external amplifier gain circuit in REF-Vacuum-C101-2ED reference design, which is a typical differential amplifier, with input low pass filter and operational bias. C4, R30, R31 R10, R18 build the input differential mode LPF, which can damping parts of PWM switching noise. The default LPF time constants is $2 \cdot RC = 2 \cdot (R31 // R10) \cdot C4 = 100 \text{ ns}$, which corresponds to DC bus current ring time. The typical setup time is 0.1~0.5 us, which depends on PCB layout, DC bus decouple capacitor and MOS gate driver configuration.

For better common-mode, noise-rejection ability, a balanced differential amplifier is highly recommended, which means R19 is equal to the value of R6 & R8 in parallel.

The divider of R6 & R8 provide operational bias for the amplifier, which affects the maximum motoring current and regeneration current range. With the default configuration of REF-Vacuum-C101-2ED, R6=22 k & R8=220 k, the op-amp operational bias is $3300 \text{ mV} \cdot 22 / (22+220) = 300 \text{ mV}$, which means:

- Op-amp outputs 300 mV at zero motor current (motor stopped)

- Negative current range sensing range is $300 \text{ mV}/\text{op-amp gain}/R_{S1}$, corresponding to regeneration current limit in MCEWizard (parameters of RegenLim)
- If 3X ADC internal gain is selected, there is 800 mV range for motoring condition current sensing ($3300 \text{ mV}/3 - 300 \text{ mV} = 800 \text{ mV}$, and $800 \text{ mV}/\text{op-amp gain}/R_{S1}$ is the maximum allowable motor current. "Motoring current limit * Motor Rated Amps * 1.414" should be below this maximum allowable range, which is related to input parameters in MCEWizard.
- If 1X ADC internal gain is selected, 3000 mV range for motoring mode current sensing ($3300 \text{ mV} - 300 \text{ mV} = 3000 \text{ mV}$).

For a better system signal-to-noise ratio (SNR), 6X and 12X internal AD gain is not recommended when there is an external amplifier. And even for direct AD sensing mode (without external op-amp), whether 12X/6X internal gain is acceptable or not depends on the ground noise level, or the final motor control performance.

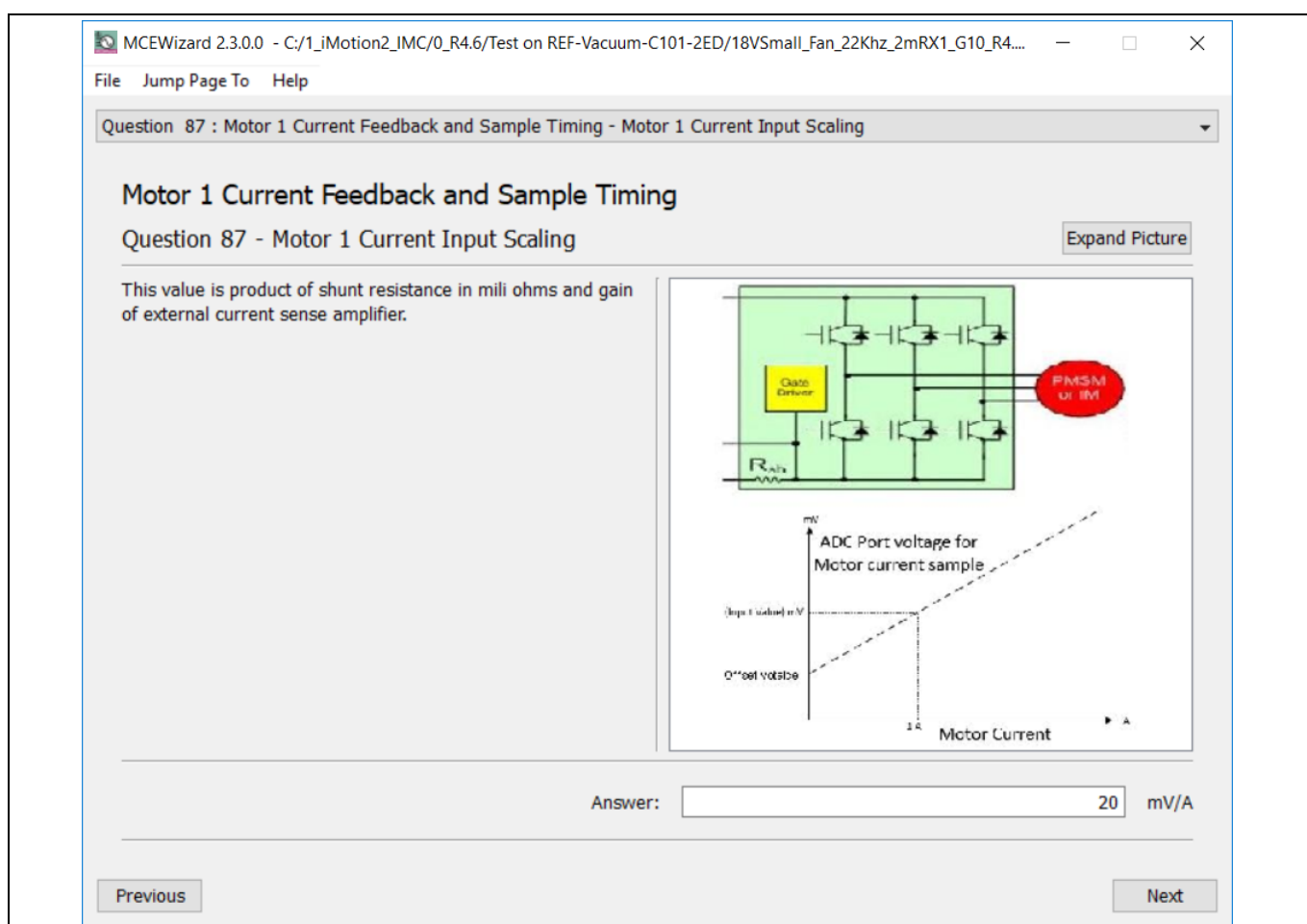


Figure 22 Current feedback configuration in MCEWizard for REF- Vacuum -C101-2ED

6.1.3 Configuration and calculation for direct current sensing

For applications that require minimal hardware costs, direct AD samples can be used, which means, without external op-amp, and only RC for operational bias and low pass filter, as shown in Figure 23.

Based on the principle of Kirchhoff's voltage law, the real AD input voltage is decided by the divider of R29 & R34:

$$AD\ input = \frac{R_{29}}{R_{29} + R_{34}} RS_1 * I_{bus} = \frac{5.1K}{5.1K + 0.1K} RS_1 * I_{bus} = 0.98 * RS_1 * I_{bus}$$

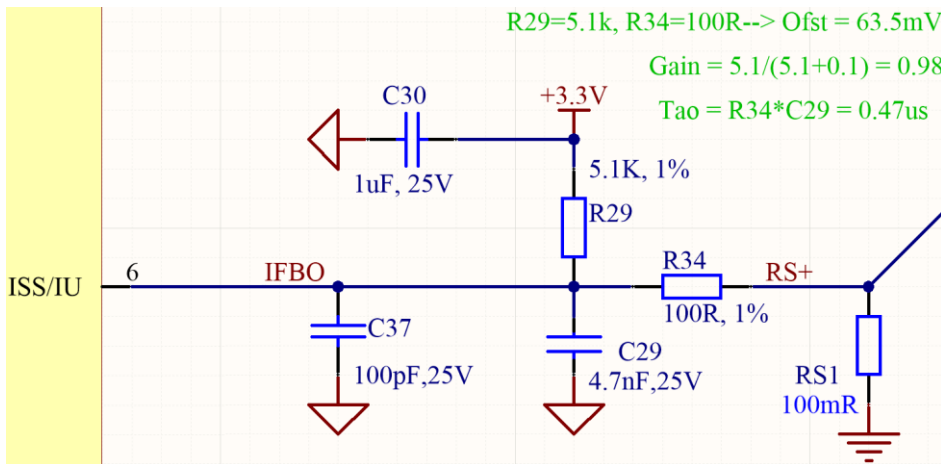


Figure 23 Current feedback without external op-amp

R29 & R34 also determine the ADC operational bias for current sensing, which corresponds to the motor regeneration operation range. For those applications that only work in motoring mode, the bias can be as low as possible to reserve enough ADC range for motoring mode, since negative input would not occur.

Please note that in direct AD sample mode (without external op-amp):

- 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. RS1 must be much higher than 2 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 AD range (traced 1u peak over 600 cts~1000 cts) at rate motor current, and PCB ground noise lower than 5% of total sampled signal in MCEdesigner trace result.
- There is NO common mode noise rejection ability, compared to external op-amp sample mode. Directly AD current sensing mode needs to deal with PCB GND network very carefully to reduce grounding noise as low as possible. Please note that any voltage difference between IMC101T's ADC ground and shunt resistor ground will be considered as an "input signal" and deteriorate control performance or increase motor audible noise.

For the power rating of the shunt resistor, the following list should be considered:

- Maximum input current of inverter (I_{busRMS})
- Maximum motor current output ($I_{motorRMS}$)
- Shunt resistor value at $T_c = 25^\circ C$ (R_{SH})
- Power derating ratio of shunt resistor at $T_{SH}=100^\circ C$ according to the manufacturer's datasheet
- Safety margin and measure margin (total 50%~60% derating)
- Power supply for IMC101T (3.3 V or 5 V)

An example for shunt resistor and ADC internal gain selection:

- Maximum DCBUS input current of inverter (I_{rms}) is 3 A, and already includes 20~30% overload margin
- Shunt resistor rate power is 1 W (low cost of thin film 2512 package), 60% derating (allow maximum 0.6 W)

The shunt resistor power rating is calculated by the following equation.

$$P_{SH} = \frac{I_{rms}^2 \times R_{SH}}{\text{derating ratio}} = 0.6 \text{ W} = I_{rms}^2 \times R_{SH} \implies R_{SH} = 0.066 \text{ Ohm} = 66 \text{ mOhm}$$

75 mΩ or 50 mΩ can be considered, supposing maximum input current occurs at maximum PWM modulation rate, according to the conservation of power:

$$\text{Power input} = V_{dc} * I_{busRMS} = 3 * \frac{V_{dc}}{1.414} * I_{motorRMS}$$

$$I_{motorRMS} = 0.47 * I_{busRMS}$$

Maximum voltage to ADC pin: $3A * 0.47 * 1.414 * 50 \text{ Ohm} = 99.7 \text{ mV}$, which is about 1/33 of 3300 mV.

ADC internal gain can be 12X, whose maximum input range is $3300 \text{ mV}/12 = 275 \text{ mV}$, consider equaled MotorLim and RegenLim, the maximum motoring and regenerating sensing range is $275/2 = 137.5 \text{ mV} > 99.7 \text{ mV}$.

Measure margin check: 50 mΩ shunt resistor has a margin of $(137.5-99.7)/99.7 = 37.9\%$

Next, checking the real derating of 50 mΩ and 75 mΩ shunt resistors:

$$\text{Derating for } 50\text{m}\Omega = \frac{I_{rms}^2 \times R_{SH}}{\text{Rate power}} = \frac{3A * 3A * 50\text{m}\Omega}{1W} = 0.45$$

$$\text{Derating for } 75\text{m}\Omega = \frac{I_{rms}^2 \times R_{SH}}{\text{Rate power}} = \frac{3A * 3A * 75\text{m}\Omega}{1W} = 0.675$$

The 50 mΩ shunt resistor has a higher power margin, and 75 mΩ has better SNR. Since the power derating is highly related to the real thermal resistance of the PCB, we can test both 50 mΩ and 75 mΩ shunt resistors and decide which one is better on the tradeoff of SNR and real temperature rising.

6.1.4 Inverter overcurrent protection and motor gatekill configuration

Figure 24 displays the overcurrent protection circuit for the IMC101T application. R29 & R34 sensed voltage (or external op-amp) is connected to ADC and internal comparators to achieve the overcurrent protection function. Only internal comparators are used for overcurrent protection.

The reference of the internal comparators is set by IMC101T's internal DAC, and external C31 is the low pass filter capacitor. MCEWizard calculate 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 define the DAC output voltage, which depends on the 3 items listed below and shown in Figure 24 & 25

A: Expected OC threshold

B: Gain of external current sensing network

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

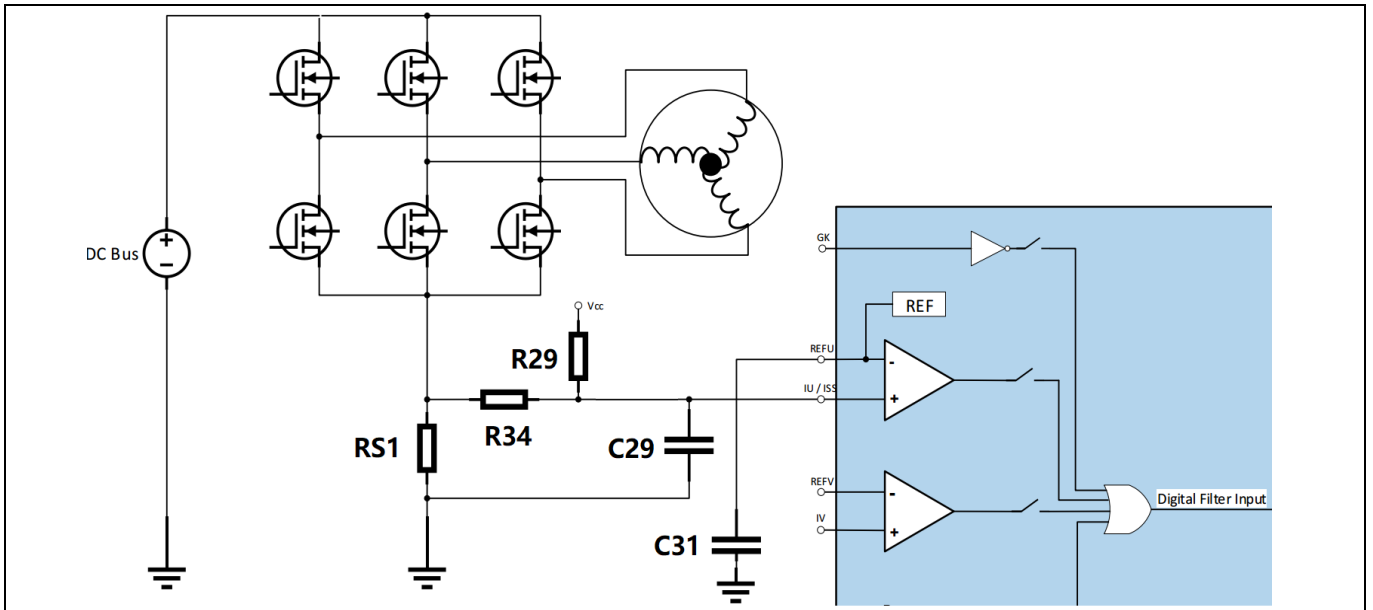


Figure 24 Overcurrent protection circuit on the REF-Vacuum-C101-2ED reference design

MCEWizard 2.3.0.0 - C:/1_iMotion2_JMC/0_R4.6/Test on REF-Vacuum-C101-2ED/18VSmall_Fan_22Khz_2mRX1_G10_R4...

File Jump Page To Help

Question 97 : Motor 1 Gatekill Setup - Device Overcurrent trigger level setting for Comparator

Motor 1 Gatekill Setup

Question 97 - Device Overcurrent trigger level setting for Comparator Expand Picture

This parameter specifies the comparator level for Gatekill signal if comparator has been selected for Gatekill in previous question. The Gatekill signal must be more than comparator reference to generate fault (pwm shut down). This Protection current value setting is used for device internal comparator trigger level. the setting will go to comparator voltage level = Motor 1 Current Input to ADC Offset Voltage + Protection current value * scaling for Current input feedback

For Example: if shunt voltage offset is 0.55V to ADC, Motor is in 2A maximum protection, Motor current scaling is 208.3mV/A, So the Comparator voltage : $0.55V + (2A * 208.3mV/A)/1000mV/V = 0.9666V$, user can check the ADC level at 0.9666V when gatekill happened.

Warning: Too high value may lead to overcurrent in motor or power devices

Answer: A

Previous Next

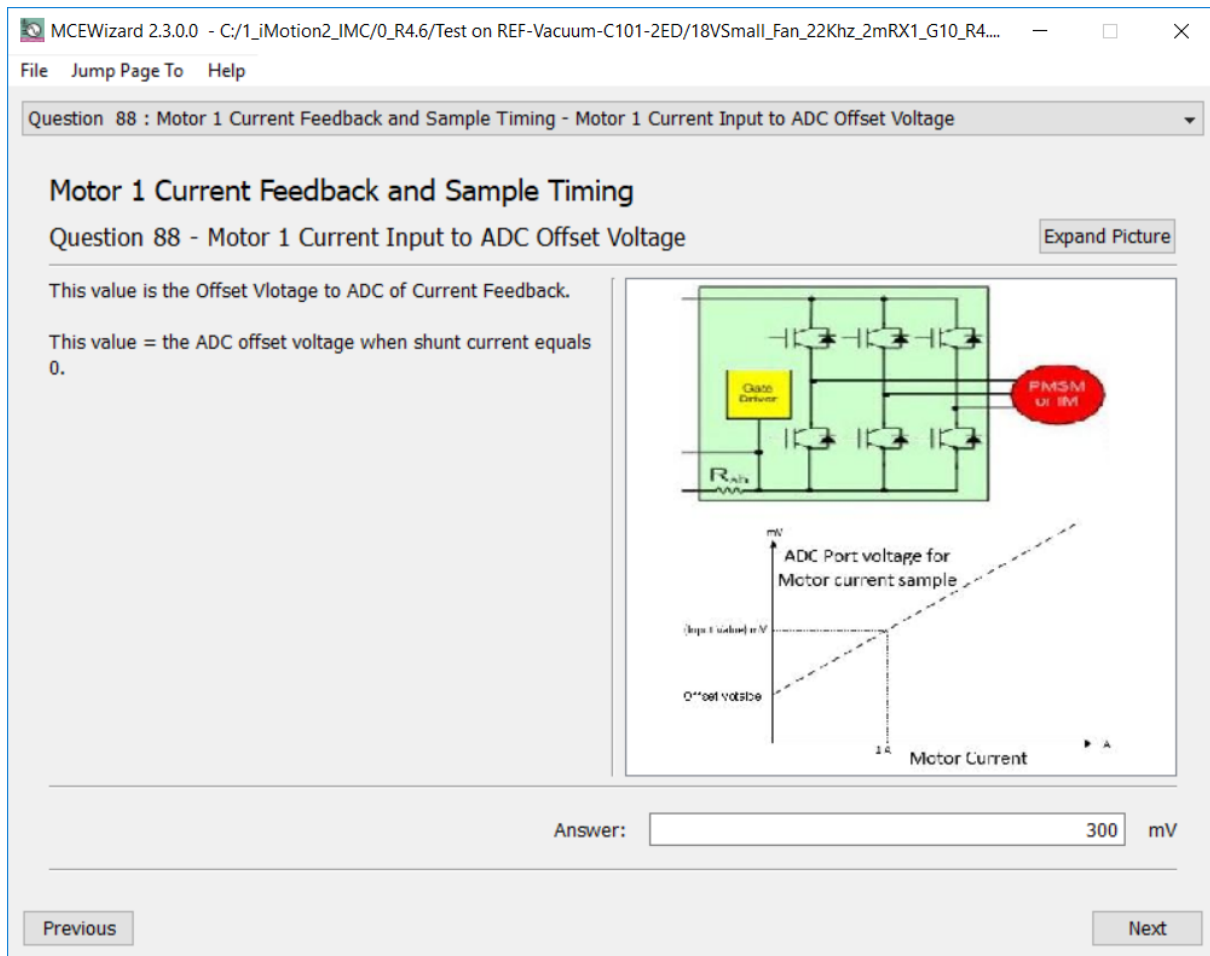


Figure 25 Overcurrent protection setup in MCEWizard

Normally it is recommended to set a value higher than motor maximum peak current (maximum RMS current * 1.414) in “Device Overcurrent trigger level setting for Comparator”, with a reserve of at least 30% margin, especially for ultra-low impedance motors, of which peak saw tooth current would trigger unwanted overcurrent fault.

6.2 NTC thermistor characteristics and overheat protection calculation

IMC101T’s firmware has overheat protection, Pin7 is the dedicated input of NTC temperature sensing. An external NTC thermistor is attached on the copper near Q7 & RS1, where is the hottest point on the board.

To activate over-temperature protection, 2 setups in MCEWizard as shown in Figure 26 & Figure 28 are needed:

- Enable over-temperature shutdown function
- Set voltage for shutdown, consider the temperature difference between MOS and NTC

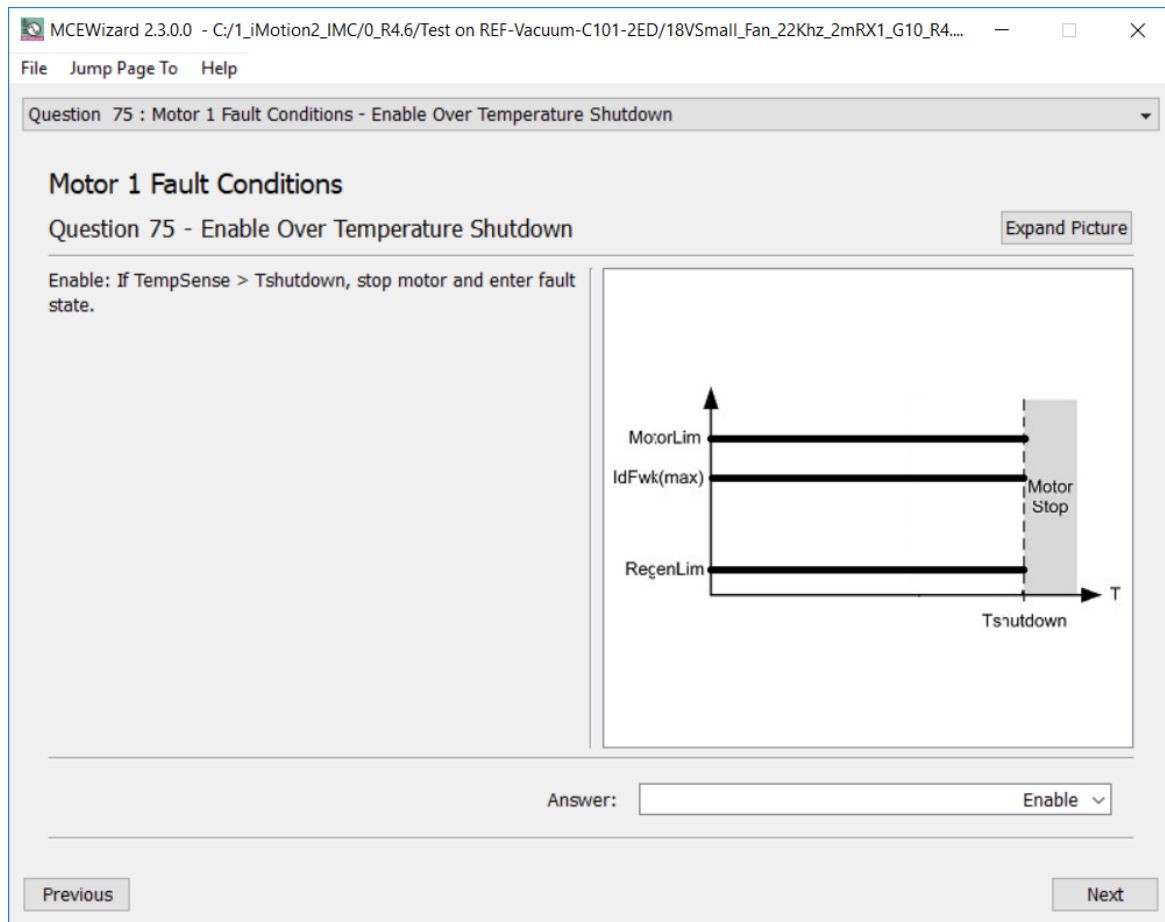


Figure 26 Over-temperature protection enabled in MCEWizard

6.2.1 External NTC thermistor characteristics

The NXFT5WF104 thermistor’s B-constant is 4250, typical resistance and output of temperature-sensing voltage listed in Table 9.

Table 9 NTC – Thermistor Characteristics

Temperature (°C)	Resistance (kOhm)	Vout (mV)
25	100	3000
50	33.195	2536
60	22.224	2276
70	15.184	1990
80	10.566	1695
90	7.481	1412
100	5.384	1155
110	3.934	932
120	2.916	745
	B(25/100)	4250

The pull-up resistor is 10 k, and IMC101T's temperature-related AD input voltage is shown in Figure 27.

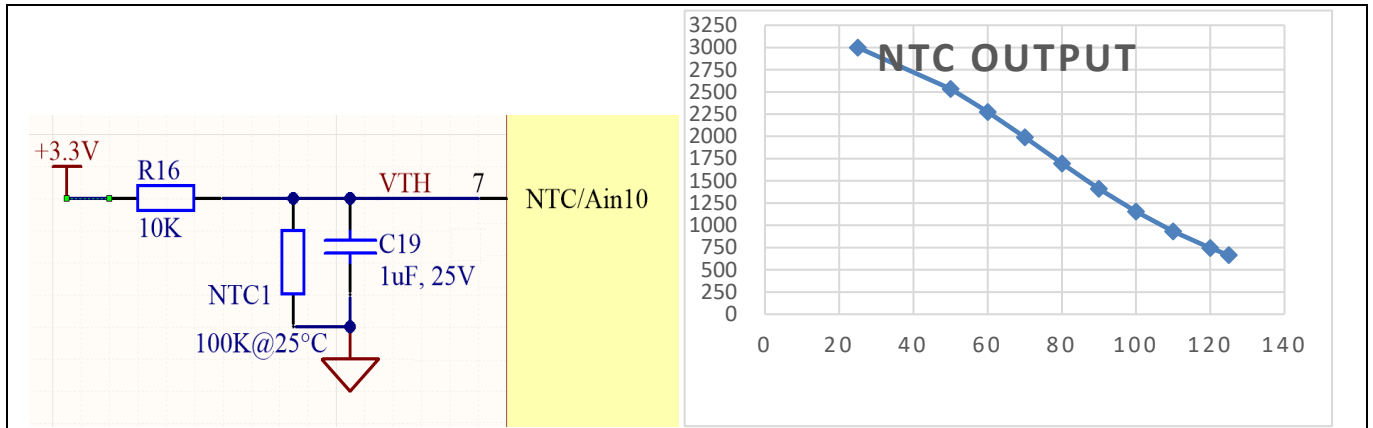


Figure 27 NTC circuit and output voltage curve

External NTC temperature shutdown value can be calculated as shown below and configured in MCEWizard as shown in Figure 28. MCEWizard default setup is 1.1 V, which sets the shutdown temperature to about 100°C.

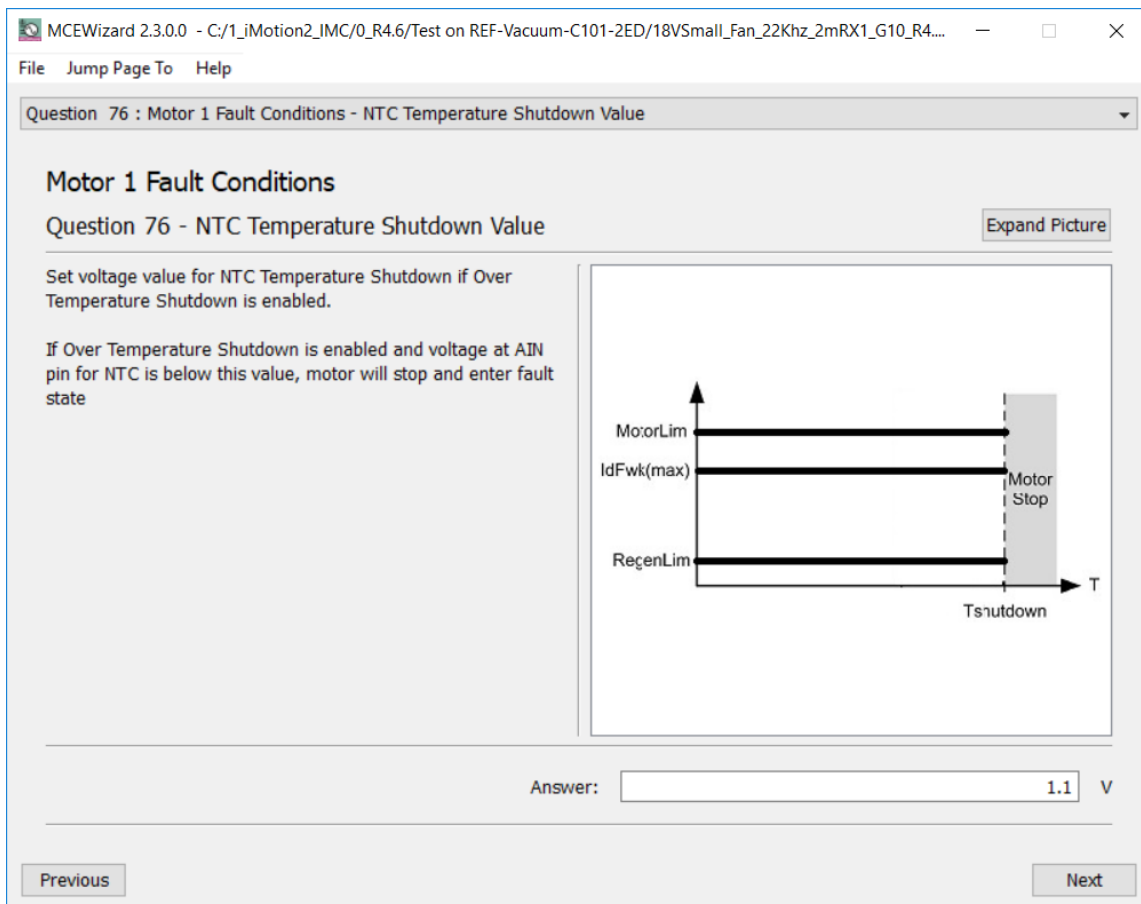


Figure 28 NTC shutdown temperature setup in MCEWizard

6.3 Auxiliary power supply

Figure 29 depicts the schematic of the auxiliary power supply for the REF-Vacuum-C101-2ED board. Two linear LDO used for 12 V and 3.3 V power supply. U2 can be replaced by 5 V LDO or adjustable IFX1117ME V to achieve higher power supply, for the application that needs higher SNR of motor current sample with external OPA.

Please note that the undervoltage level of 2ED2304S06F is 8.3~9.1 V, if the DC input is out of the 18 V~30 V range; the output voltage of 78M12 needs to be double-checked to make sure 2ED2304S06F can respond to PWM command correctly.

ZD2 & ZD3 are used to reduce power consumption on 78M12. For higher DC voltage input, higher-voltage Zener diodes might be needed to make sure 78M12 will not over-heat. And for 12 V or 3S~4S Li battery applications, please short ZD2 & ZD3, or bypass U1 directly.

Both 12 V and 3.3 V power supplies can output 100 mA to external circuit, with on-board cooling fan ON (default configuration). If cooling fan is OFF or removed, the maximum output ability is in sum 100 mA, depending on the temperature of ZD2 & ZD3 & U1.

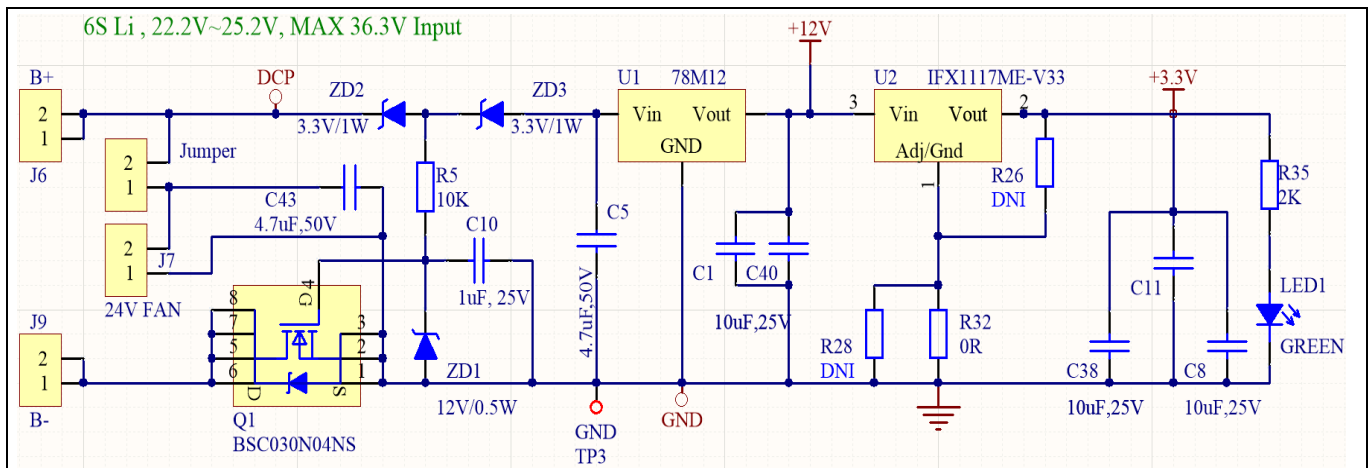


Figure 29 Power supply section of the REF-Vacuum-C101-2ED reference design

6.4 Schematics for REF-Vacuum-C101-2ED

The overall schematic diagram for REF-Vacuum-C101-2ED is provided in Figure 30.

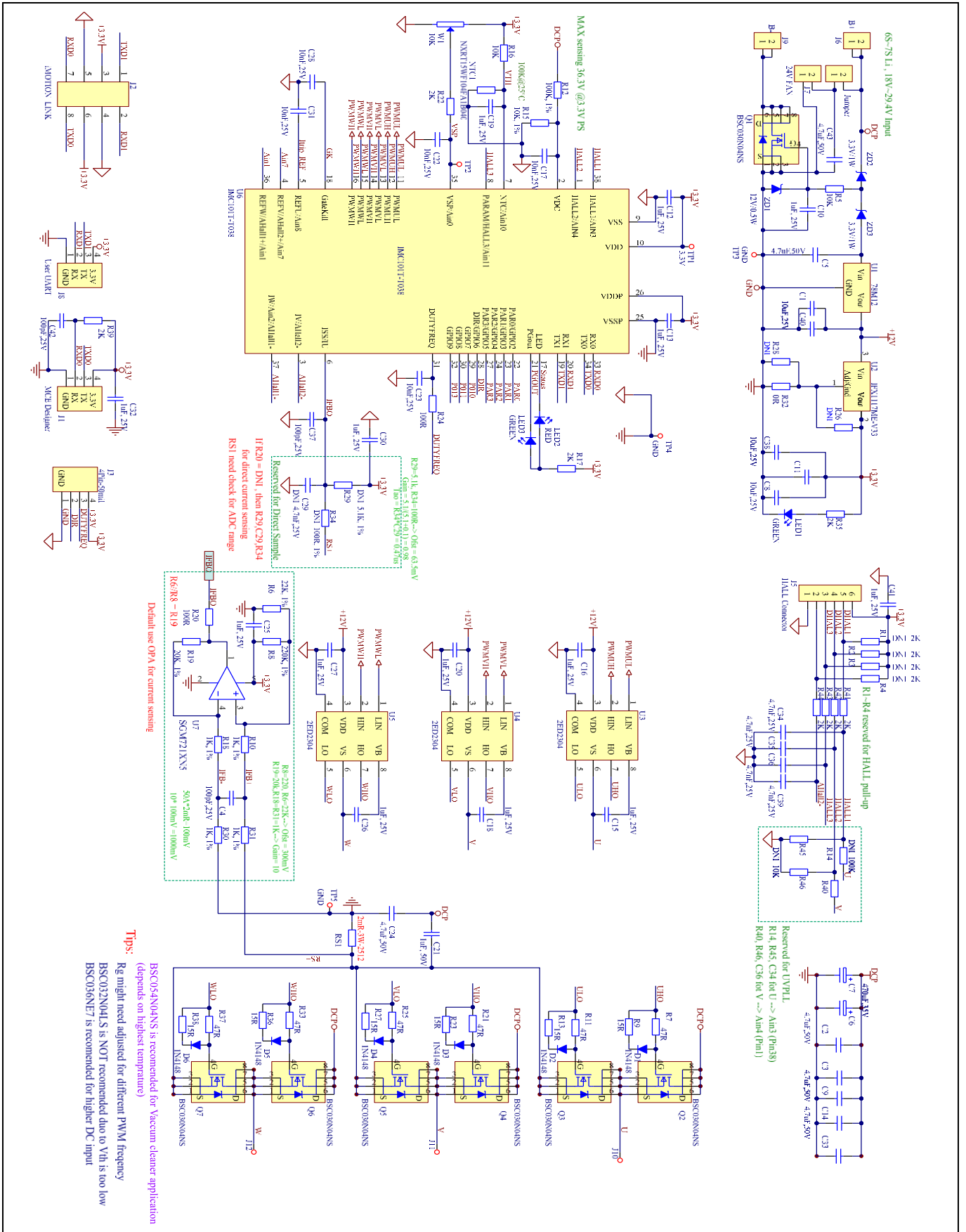


Figure 30 Schematics for REF-Vacuum-C101-2ED

6.5 PCB Layout for REF-Vacuum-C101-2ED

This board has two electrical layers with 35 µm copper (standard) and dimensions of 115 mm × 60 mm. For applications that do not require cooling fans, the size can be 63.5mm x 60mm if the right-hand section of the PCB is removed. 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 31 illustrates the top assembly print of the reference design.

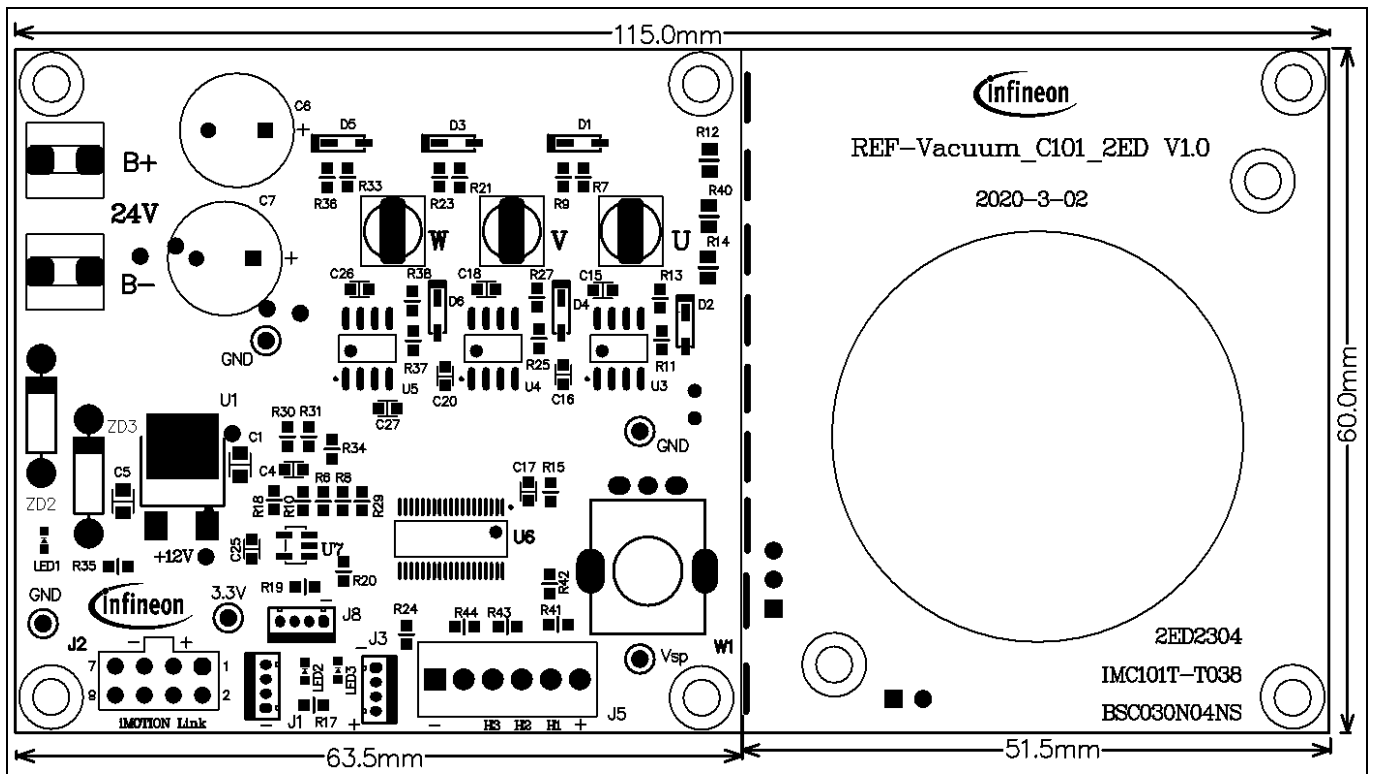


Figure 31 Top assembly print of the REF-Vacuum-C101-2ED reference design

Figure 32 depicts the bottom assembly print of the reference design.

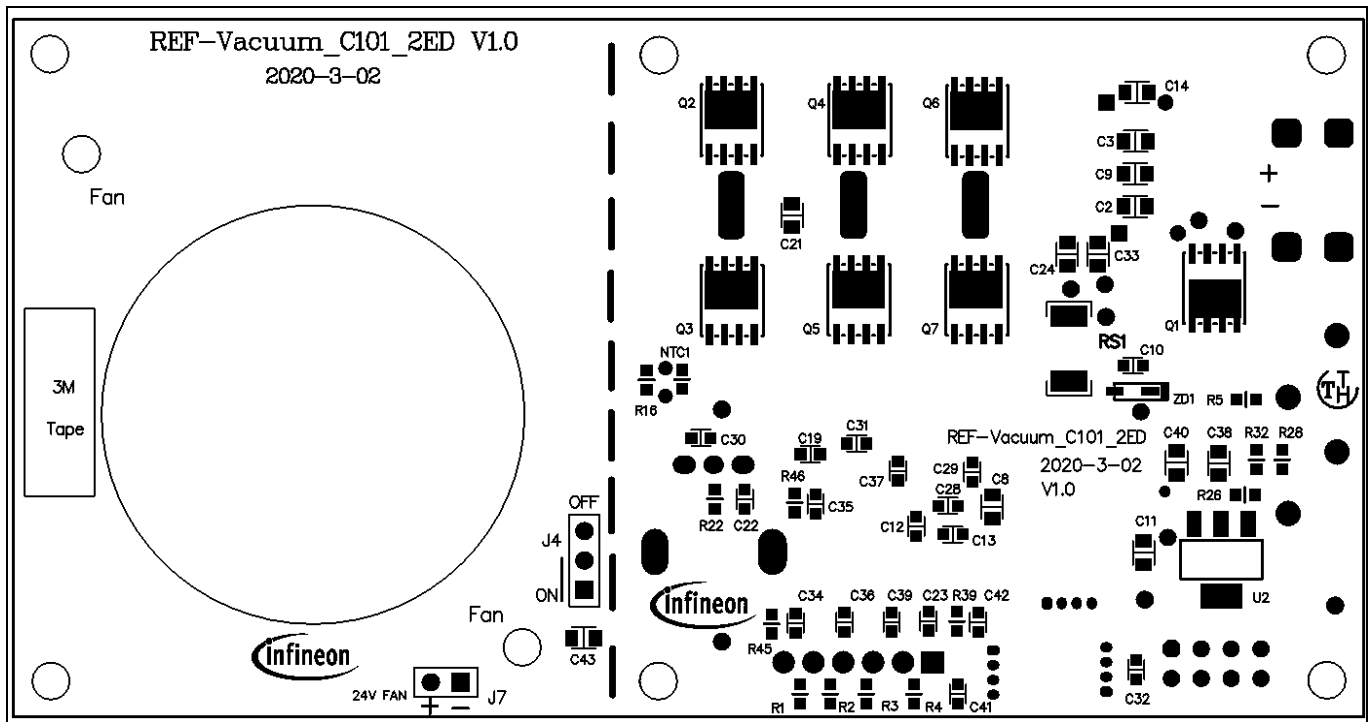


Figure 32 Bottom assembly print of the REF-Vacuum-C101-2ED reference design

The top layer routing of the PCB is provided in Figure 33.

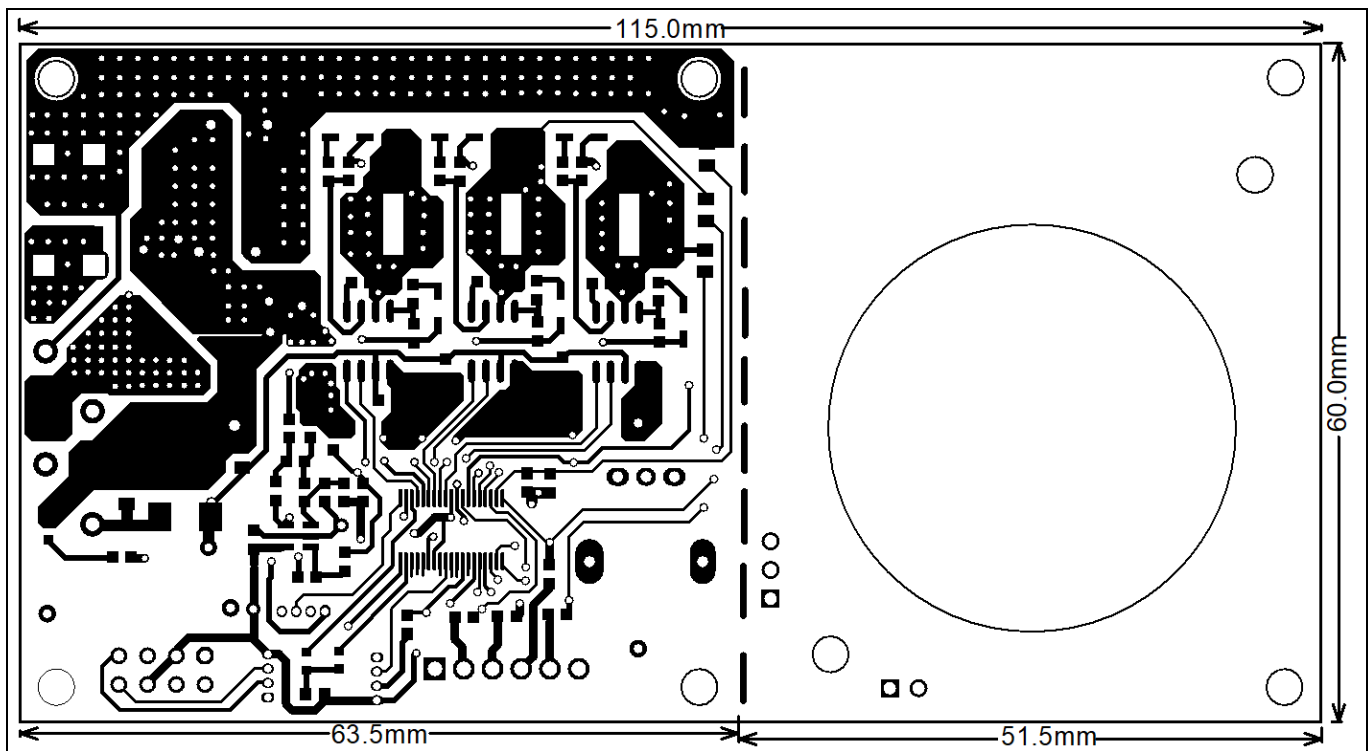


Figure 33 Top layer routing of the REF-Vacuum-C101-2ED

Figure 34 illustrates the bottom layer routing of the PCB.

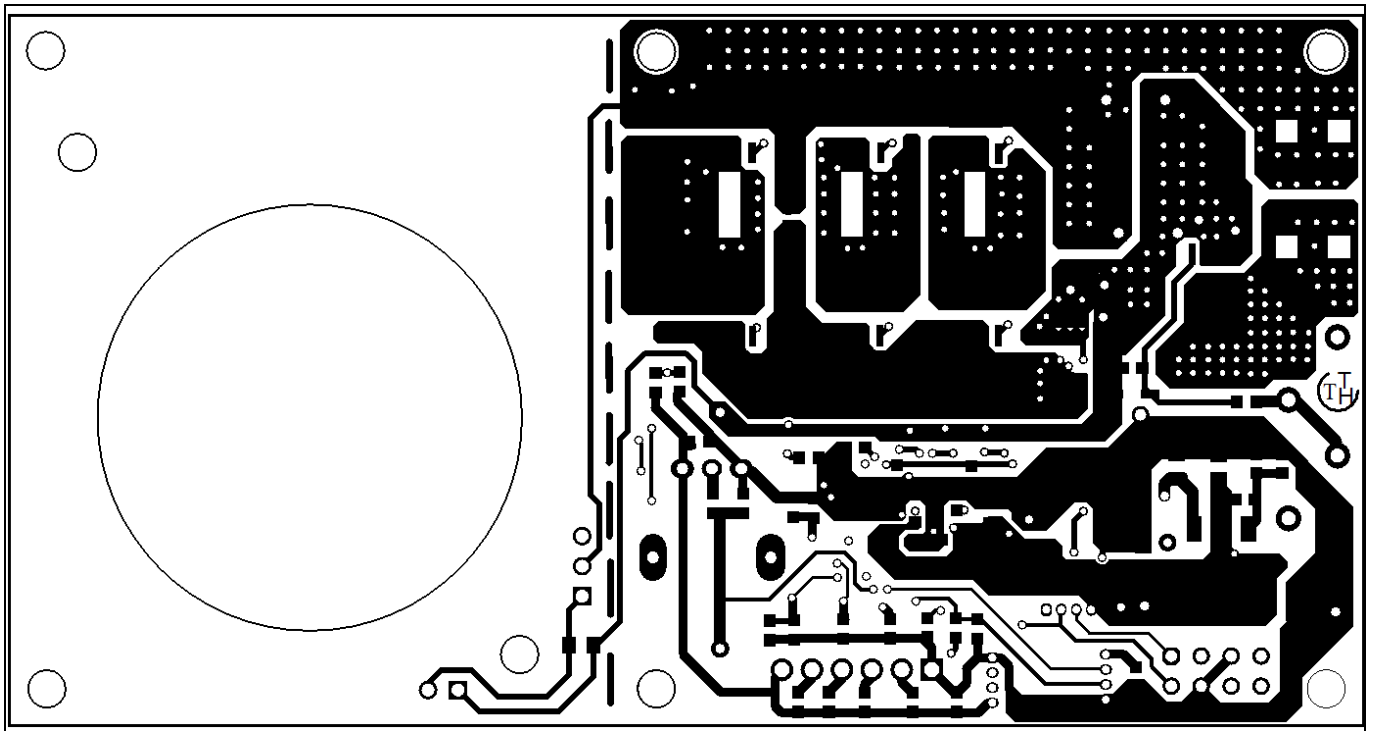


Figure 34 Bottom layer routing of the REF-Vacuum-C101-2ED

7 Thermal characterization

Figure 35 shows the thermal characterizations of REF-Vacuum-C101-2ED, based on 2 layers of FR4 PCB, as shown in Figures 31~34.

The tests reported were performed under the following conditions: $t_{amb}=25^{\circ}\text{C}$, $V_{dc} = 24\text{ V}$, different phase current values until the MOS case reaches 105°C , four PWM frequencies (22, 45, 65 and 80 kHz) tested, 3-phase modulation mode only, since switching loss is no longer a major issue for low voltage motor drive application and 2-phase modulation is normally not needed.

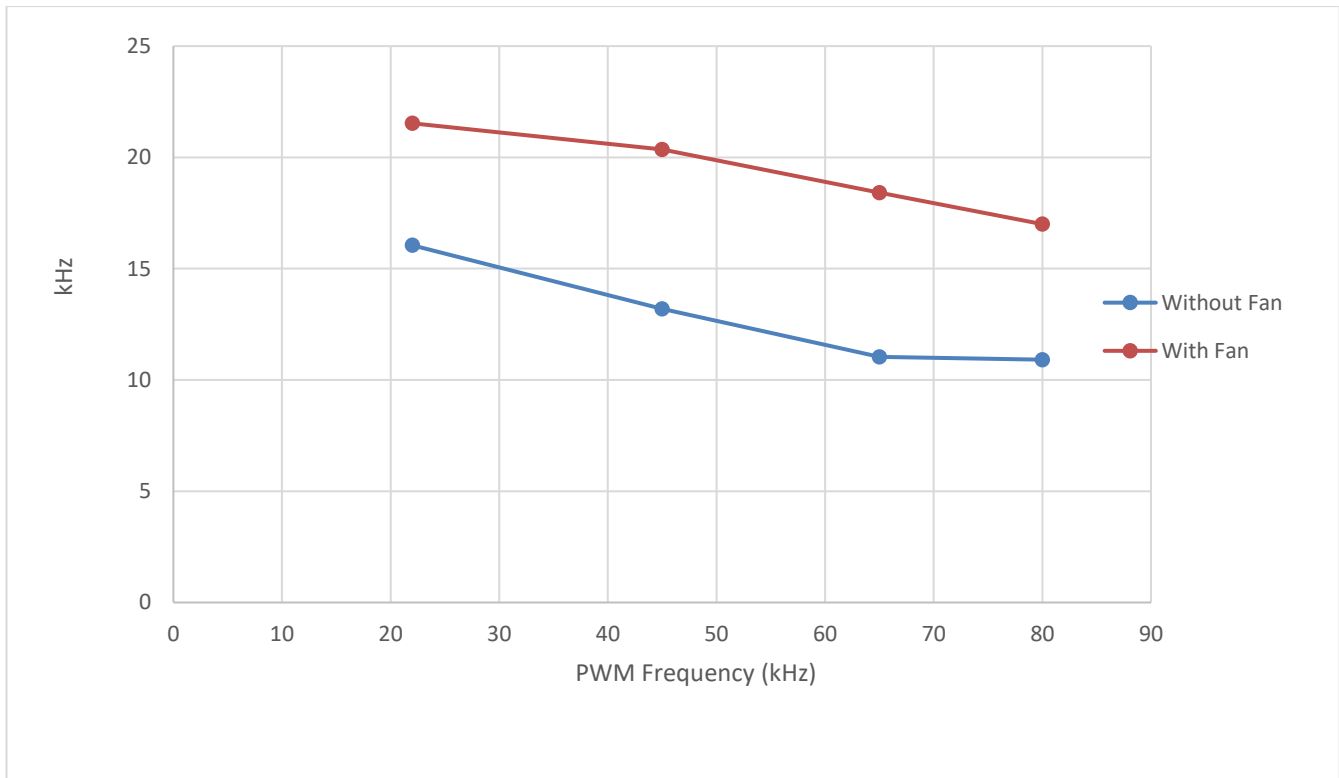


Figure 35 REF-Vacuum-C101-2ED thermal characterization, $t_{amb}=25^{\circ}\text{C}$, different phase current values until the case reaches 105°C

8 Bill of material

Table 10 provides the complete bill of materials for the REF-Vacuum-C101-2ED.

Table 10 Bill of materials

No.	Qty	Part description	Designator	Part number	Manufacturer
1	5	CAP CER 10µF 25V X5R 0805	C1, C8, C11, C38, C40	CC0805KKX5R8BB106	
2	8	CAP CER 4.7µF 50V X5R 0805	C2, C3, C5, C9, C14, C24, C33, C43	CC0805KKX5R9BB475	
3	3	CAP CER 100pF 25V X5R 0603	C4, C37, C42	CC0201KRX5R8BB101	
4	2	CAP ALUM 470uF 35V, Low impedance	C6, C7	860080575017	Würth Elektronik
5	14	CAP CER 1µF 25V X5R 0603	C10, C12, C13, C15, C16, C18, C19, C20, C25, C26, C27, C30, C32, C41	CC0603KRX5R8BB105	
6	5	CAP CER 10nF 25V X5R 0603	C17, C22, C23, C28, C31	CC0201KRX5R8BB103	
7	1	CAP CER 1µF 10% 50V X5R 0805	C21	CC0805KKX5R9BB105	
8	4	CAP CER 4.7nF 25V X5R 0603	C34, C35, C36, C39	CC0201KRX5R8BB472	
9	6	1N4148 Diode	D1, D2, D3, D4, D5, D6	1N4148	
10	3	4Pin 1.25mm Male Vertical Shrouded Header	J1, J3, J8	653004114822	Würth Elektronik
11	1	iMOTION™_LINK Connector, CON4*2	J2		Würth Elektronik
12	1	3-Pin, 2.54mm for jumper	J4	Jumper	Würth Elektronik
13	1	HALL Connector, 6-Pin 2.54mm Header	J5	691210910006	Würth Elektronik
14	2	DC input Connector, M4, 6x6x7.5mm,	J6, J9	M4-6x6x7.5mm Connector	
15	3	Motor Connector, M3, 5x5x6mm	J10, J11, J12	M3-5x5x6mm Connector	
16	2	GREEN LED 0603	LED1, LED3		Würth Elektronik
17	1	REDLED 0603	LED2		Würth Elektronik
18	1	NTC, 100 kOhm, thermal resistor	NTC1	B57371V2104+06	
19	7	3mOhm 40V NMOS	Q1, Q2, Q3, Q4, Q5, Q6, Q7	BSC030N04NS G	Infineon
20	2	RES SMD 10 kOhm 5% 1/10W 0603	R5, R16	AR0603JR-0710KL	
21	1	RES SMD 22 kOhm 1% 1/10W 0603	R6	AR0603FR-0722KL	
22	6	RES SMD 47 Ohm 5% 1/10W 0603	R7, R11, R21, R25, R33, R37	AR0603JR-0747RL	

No.	Qty	Part description	Designator	Part number	Manufacturer
23	1	RES SMD 220 kOhm 1% 1/10W 0603	R8	AR0603FR-07220KL	
24	6	RES SMD 15 Ohm 5% 1/10W 0603	R9, R13, R23, R27, R36, R38	AR0603JR-0715RL	
25	4	RES SMD 1 kOhm 1% 1/10W 0603	R10, R18, R30, R31	AR0603FR-071 L	
26	1	RES SMD 100 kOhm 1% 1/8W 0805	R12	AR0805FR-07100KL	
27	1	RES SMD 10 kOhm 1% 1/10W 0603	R15	AR0603FR-0710KL	
28	8	RES SMD 2 kOhm 5% 1/10W 0603	R17, R22, R35, R39, R41, R42, R43, R44	AR0603JR-072KL	
29	1	RES SMD 20 kOhm 1% 1/10W 0603	R19	AR0603FR-0720KL	
30	2	RES SMD 100 Ohm 5% 1/10W 0603	R20, R24	AR0603JR-07100RL	
31	1	RES SMD 0 Ohm 5% 1/10W 0603	R32	AR0603JR-070RL	
32	1	2 mOhm, 3W 2512 Shunt Resistor	RS1	BVT-I-R002	Isabellen
33	1	78M12, 12V Voltage Regulator	U1	L78M12CDT-TR	
34	1	3.3V 1A Voltage Regulator	U2	IFX1117ME V33	Infineon
35	3	2ED2304, 0.36A/0.7A/650V Gate Driver	U3, U4, U5	2ED2304S06F	Infineon
36	1	IMC101T-T038, iMOTION™2 controller	U6	IMC101T-T038	Infineon
37	1	SGM721XN5, 11 MHz, 8.5V/us, CMOS OPA	U7	SGM721XN5/TR	SG Micro
38	1	10 kOhm 15mm linear Potentiometer	W1	RK09K113	
39	1	12V/0.5W, Surface mount Zener diode	ZD1	BZT52C12	
40	2	1N4730A, 3.9V/1W Zener diode	ZD2, ZD3	1N4730A	
41	1	24V 0.15A cooling Fan		CJY5015	

9 Reference

- [1] Datasheet of Infineon 2ED2304S06F
- [2] Datasheet of Infineon IMC101T
- [3] MCEWizard User Guide
- [4] MCEDesigner User Guide
- [5] Infineon-MCESW-RM-User Manual

Note: All listed reference materials are available for download on Infineon’s website www.infineon.com/.

Note: All iMOTION™ MADK reference design’s user manuals are available at www.infineon.com/MADK

Note: All the datasheets and documents for OptiMOS™ are available at www.infineon.com/OptiMos.

All the iMOTION™ IC’s Datasheets and documents are available at www.infineon.com/iMotion
 All the Datasheets and documents for SOI gate drivers are available at www.infineon.com/SOI

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Revision history

Document version	Date of release	Description of changes
1.0	2020-5-22	First release

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