EVAL-IH-R5IPB-A-V1 Evaluation board

User Guide

About this document

Scope and purpose

This application note is a user guide of the evaluation board for IEWS20R5135IPB. It explains the boards' hardware and provides detailed instructions on how to use it for addressing various measurement tasks. Finally, practical examples demonstrate the benefits of the IEWS20R5135IPB in the real application.

Intended audience

This document is intended for owners and users of the evaluation board. Please read carefully the recommendations provided in this document for safely operating this board.

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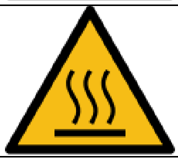
List of Abbreviations

- IH: Induction heating
- SEPR: Single-ended parallel resonant
- E: Emitter pin of the IEWS20R5135IPB
- C: Collector pin of the IEWS20R5135IPB

- VCC: Supply pin of the IEWS20R5135IPB
- CS: Current sense pin of the IEWS20R5135IPB
- INN: Control pin of the IEWS20R5135IPB
- VDET: Voltage detection pin of the IEWS20R5135IPB
- VCE: Collector-to-emitter voltage of the IEWS20R5135IPB
- IC: Current entering in the collector pin of the IEWS20R5135IPB
- VCS: Voltage between pin CS and E
- VVDET: Voltage between pin VDET and E

1 Safety precautions

Table 1 Safety Precautions

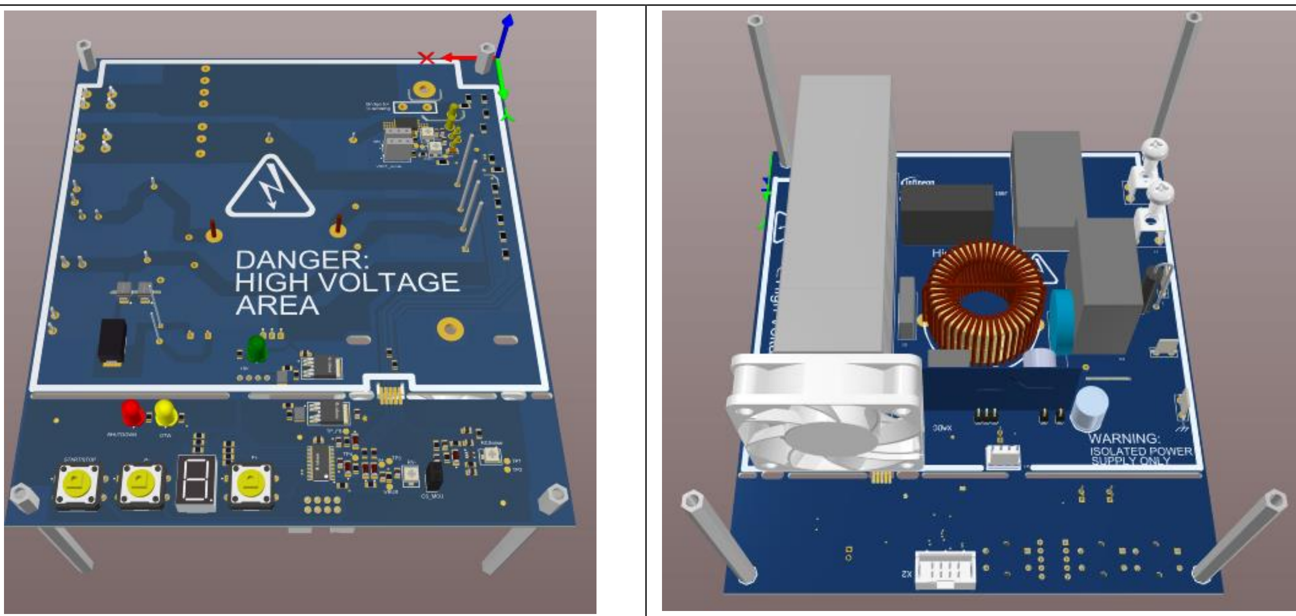
	***Warning: The operating potential of this board are up to 600 V_{RMS}. Peak operating potentials are up to 1350 V. Do NOT touch the board during operation. Even brief accidental contact during operation might result in severe injury or death!***
	***Caution: Only personnel familiar with the high voltage appliances, 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.***
	***Warning: The evaluation or reference board contains DC bus capacitors which may take time to discharge after removal of the main supply. Before working on the system, wait up to five minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.***
	***Warning: The evaluation board DOES NOT offer proper insulation to the user. Do NOT connect the board to the grid in any case. When supplying the AC voltage to the board, USE ISOLATED POWER SUPPLY ONLY, and connect the earth terminal of the board to a proper grounded point.***
	***Caution: The heat sink and IGBT module surfaces of the evaluation or reference board may become hot during testing. Hence, necessary precautions are required while handling the board. Failure to comply may cause injury.***
	***Caution: The evaluation or reference board contains parts and assemblies sensitive to electrostatic discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable ESD protection handbooks and guidelines.***
	***Warning: Remove or disconnect power from the drive before you disconnect or reconnect wires, or perform maintenance work. Wait up to five minutes after removing power to discharge the bus capacitors. Do not attempt to service the board until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.***
	***Caution: Wiring or application errors such as supplying an incorrect or inadequate AC supply, or excessive ambient temperatures may result in system malfunction.***
	***Caution: The evaluation board may be shipped with packing materials that need to be removed prior to installation. Check carefully for all the packing materials that may interfere with the normal operation of the components. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.***

2 Introduction

The evaluation board **EVAL-IH-R5IPB-A-V1** was developed as a test platform for the IEWS20R5135IPB. It replicates a complete, almost stand-alone, solution for induction heating based on SEPR converter. This introductory section provides an overview of the potential of the evaluation board and lists the components included in the delivery.

2.1 Purpose of the board

The purpose of the evaluation board shown in Figure 1 is to have one universal test platform for the IEWS20R5135IPB. It allows users to evaluate the advantages provided by the intelligent protection mechanisms. For detailed information about the device, refer to Application notes [1].



(a) (b)

Figure 1 Evaluation board of the IEWS20R5135IPB: (a) top and (b) bottom

The board implements a SEPR converter for induction heating application in order to demonstrate the functionalities of the IEWS20R5135IPB during the typical operating conditions of an induction heating cooker. This board also represents a design recommendation. Care has been taken to optimize the layout of the PCB in order to guarantee clean signals and reproducible behavior of the device in all operating conditions.

2.2 Scope of delivery

The evaluation board is delivered together with spare parts and complete documentation in an environmentally friendly carton box as illustrated in Figure 2. As depicted, the box contains:

- Evaluation board EVAL-IH-R5IPB-A-V1 with a size of 164 mm x 145 mm x 83 mm (LxWxH).
- 10x IEWS20R5135IPB.

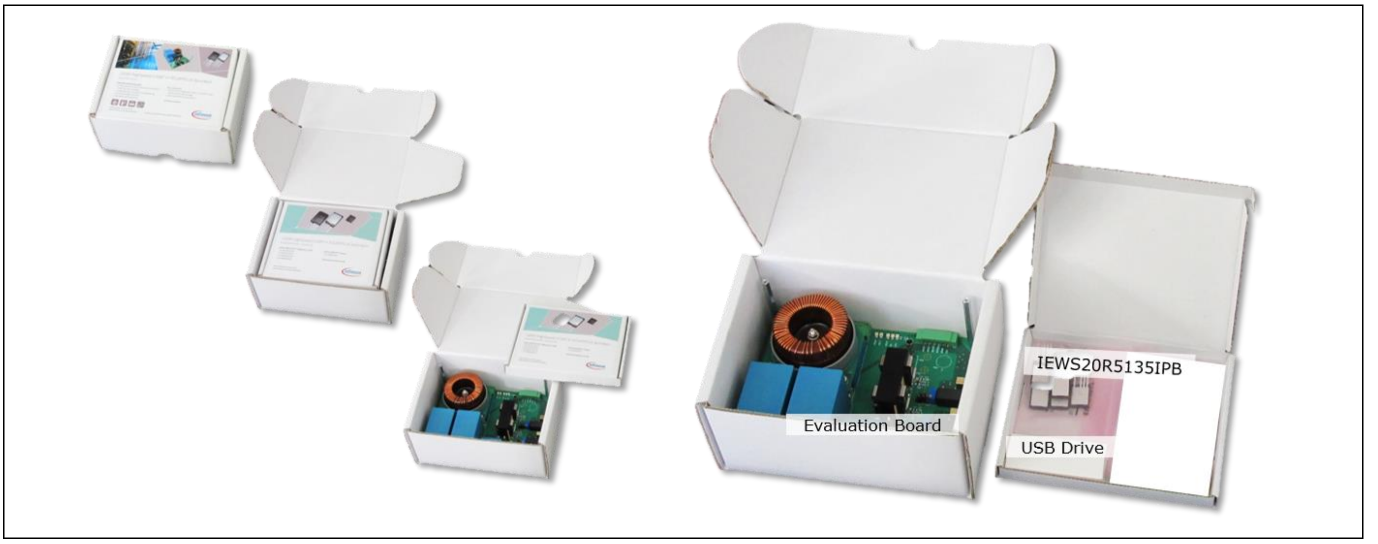


Figure 2 Scope of delivery: evaluation board, spare parts and USB drive with documentation (the picture is only for illustration purpose)

For guaranteeing safe measurement procedures, testing points have been provided on the board for the key signals. The following additional accessories/testing equipment may be useful for performing proper measurements:

- Ground spring PK007-016 [3] or probe tip to PCB adapter PK106-4 [4], both from Teledyne LeCroy, for accurate measurements of low voltage signals.
- PEM CWT1 ultra-mini Rogowski current waveform transducer for measuring the collector current of the IGBT [5].

In order to exploit all the benefits of the IEWS20R5135IPB, specific electromagnetic compatibility (EMC) tests can be performed on the evaluation board (e.g. EFT/bursts, power fail and surge) by means of the following additional equipment:

- Emtest Compact NX5, multifunctional test generator for transients up to 5.5 kV [6].

3 Hardware

This section provides a short description of the board hardware. First, it explains the power circuitry, the auxiliary power stage, the control stage and the connectors. For each of the stages, the main components are presented. Then, the application of the recommended accessories is discussed.

3.1 Scope of delivery

The evaluation board implements an induction heating power inverter, with the IEWS20R5135IPB as the main active device. The pinout of the device is shown in [1].
In addition to the main device, the board also features (from left to right in Figure 4):

- An input filter stage, consisting of a pi-filter with an inductance (L) and two X2 capacitors (C) necessary for attenuation of the high-frequency component of the IGBT pulse current.
- A diode full-bridge rectifier with a maximum rated voltage of 1000 V and a maximum rated current of 15 A.
- An X2 capacitor of 4.7 µF (Cbus) that acts as bus capacitance for the subsequent inverter stage allowing recirculation of the high-frequency current.
- A resonant capacitance of 270 nF (Cres) that implements the resonant chain together with the resonant coil (Lres).
- A resonant coil with a nominal diameter of 200 mm and a nominal inductance of 100 µH[1].

The resonant coil must be connected by means of two screw connectors, which are indicated on the board as L1 and L2. The value of the utilized inductor will be provided as a reference further on in the document.

For the proper implementation of the converter, additional components have been also designed in:

- A metal-oxide varistor among the input AC phases in order to dissipate part of the energy that is injected during a surge test.
- A current sense resistor with a nominal value of 10 mΩ, in series with the IEWS20R5135IPB, which is used for sensing the current of the IGBT for over-current protection and output power control. The sense resistor is placed in series with the emitter pin of IGBT and the bus capacitance.
- An auxiliary power supply stage that provides the supply voltage to the IEWS20R5135IPB, to the fan and to the MCU.
- A resonant capacitance of 270 nF (Cres) that implements the resonant chain together with the resonant coil (Lres).

1	C	Collector
2	E/COM	Emitter/Ground
3	VCC	Supply
4	CS	Current Sense
5	INN	PWM Input
6	VDET	Voltage Sense

Figure 3 Package and pinout of the IEWS20R5135IPB

[1] For more details of the coil, see Section 6.1.

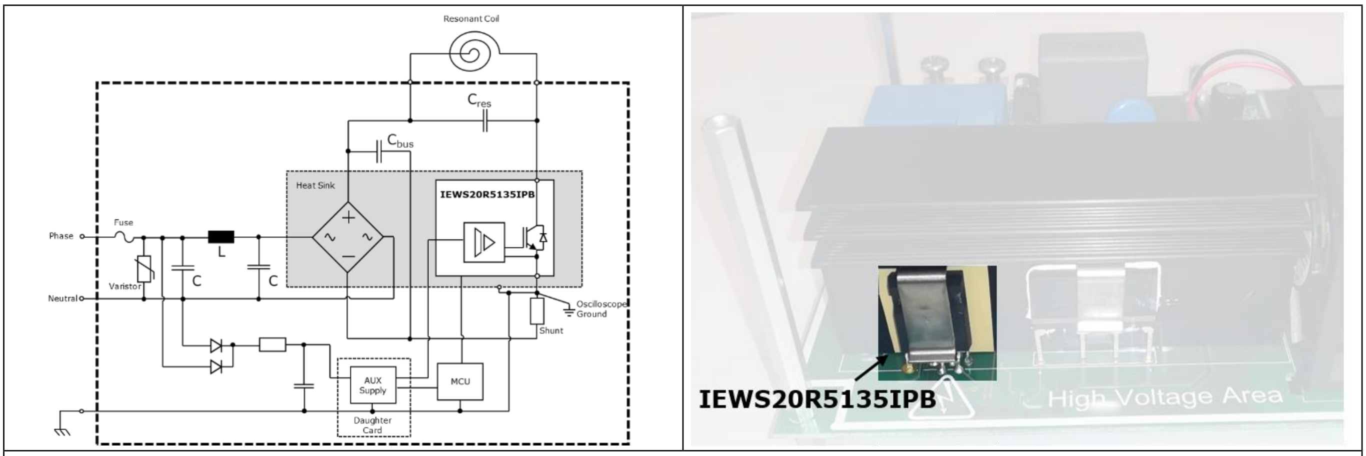


Figure 4 Overview of the board schematics (a) and components (b)

For versatility, the evaluation board has been equipped with a control stage that allows the output power of the converter to be changed, and that offers optical feedback of the status of the IEWS20R5135IPB during operation. An Infineon 32-bit XMC™ 1000 Industrial Microcontroller ARM® Cortex®-M0 has been used as core of the control. The control stage is implemented on a separate area of the evaluation board in order to offer a safe, low-voltage region for controlling the operation of the main converter. The board also comes with a heatsink and fan arrangement, the size and shape of which provides enough cooling performance required for continuous operation. The fan speed is regulated by the MCU according to the feedback of the status provided by the IEWS20R5135IPB.

The experimental analysis of the IEWS20R5135IPB operation requires oscilloscope measurements of the collector-emitter voltage (V_{CE}), the voltage at pin INN, and the collector current. These three measurements allow for a complete understanding of the IEWS20R5135IPB operation and status. A more detailed analysis of the IEWS20R5135IPB behavior could require also the measurement of the voltages at the VDET and CS pins. All the voltages, except the one at the CS pin, can be measured by connecting the oscilloscope probe to the test points that are provided on the board.

- In order to measure the collector-emitter voltage, a high-voltage probe must be used, as the peak value of such a voltage exceeds the value of 1 kV also during normal operation, and may even be higher if surge tests are performed.
- For the measurement of the voltages at the INN and VDET pins, a standard passive probe in combination with a ground spring can be used, as shown in Figure 5a.

(a) (b) (c)

Figure 5 Example of probe connection for the measurement of: VINN and VVDET (a), IC (b) and VCS (c)

- The best solution for measuring the collector current is to use a Rogowski current probe, and connect it to the board as shown in Figure 5b.
- The measurement of the voltage at the CS pin is particularly tricky, as its value is in the range of hundreds of millivolts. Therefore, the measurements can be affected by the noise generated by the IGBT switching. In order to perform reasonable measurements, a low inductive connection between CS pin and emitter pin of the IEWS20R5135IPB has to be made. A possible solution consists of soldering a header connector and use the ground spring ([4]) as shown in Figure 5c.

4 Usage

The main purpose of the evaluation board is to show the features provided by the IEWS20R5135IPB in typical application conditions. While the previous sections explained the basic purpose as well as the hardware of the board, this section provides detailed instructions on how to set up and operate the board. Section 4.1 describes how to replace the active switch and how to modify certain board settings, whilst section 5 deals with the preparation and execution of different experiments.

4.1 Settings

The evaluation board is intended for testing the IEWS20R5135IPB that comes in a TO-247 6 pin package. Due to the high number of leads, the assembly and disassembly of the device may pose particular difficulties. The following section explains the best way to replace the switch in order to avoid damage to the PCB.

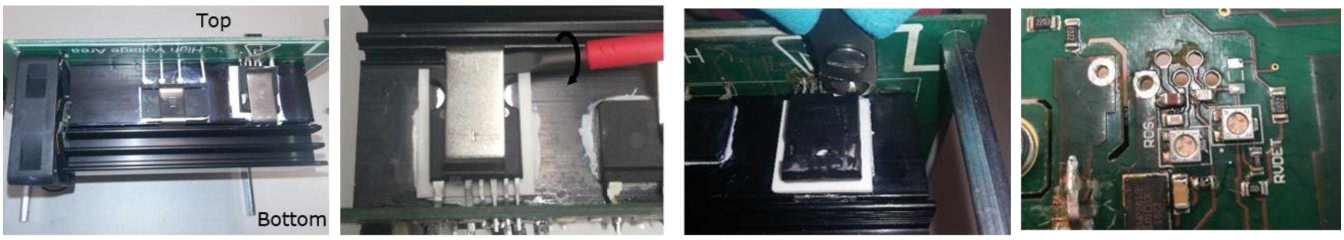
Attention: ***Prevent potential exposure to hazardous voltages by turning off all power supplies and discharging the capacitors before undertaking any of the modifications described in the remainder of this section.***

4.1.1 Replacing the IEWS20R5135IPB

A PCB is subject to severe thermomechanical stress when soldering and unsoldering components. As a consequence, the adhesion between the copper layers and the core material gets weaker and eventually copper pads or traces may lift off and break. Normally, the best way to avoid damage to the PCB is to use press-fit pins for connecting the TO packages and the PCB. However, such a solution cannot be used in the case of the IEWS20R5135IPB, as the additional parasitic inductance caused by the pins would dramatically affect the behavior of the device. As a compromise to ease the assembly and disassembly process of the device, the mounting holes on the PCB have been deliberately designed bigger than what is normally advised by the footprint. There are several ways of removing the TO packages from the heatsink and the board. The simplest approach is to cut the package leads, remove the package body from the heatsink, and unsolder one lead after another from the press-fit pins. This guarantees minimum stress on the PCB. The process is shown in Figure 6:

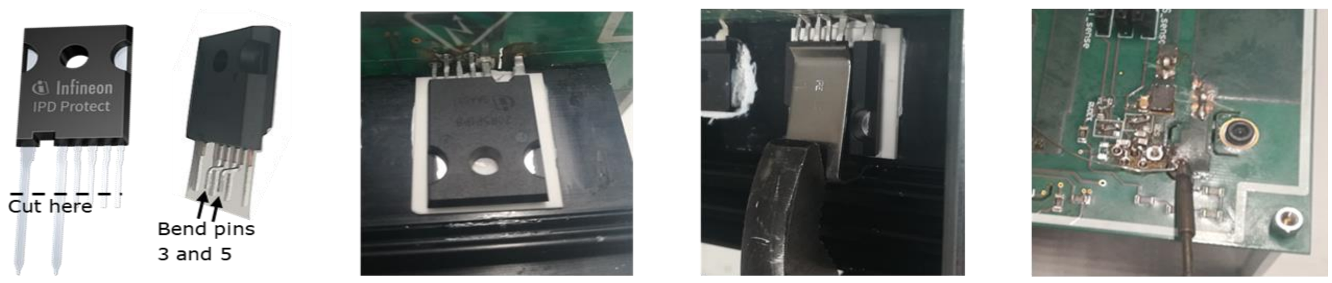
1. Put the board in an upright position so that the device packages face upwards (a).
2. Push a flat screw driver between the clip and the package body and twist it to pull the clip out of the heatsink's groove (b).
3. Cut the 6 leads off the device, starting from the collector and proceed until the VDET pin (c).
4. Remove the leftover part of the pins and clean the pads by using a soldering iron and soldering wick (d).

It is highly recommended to check the spring after mounting, as the disassembly process could modify its shape thus loosening the pressure force. In case this happens, the original shape can be restored by means of pliers.



(a) (b) (c) (d)

Figure 6 Disassembling a device from the heatsink and the PCB



(a)	(b)	(c)	(d)

Figure 7 Assembling a device onto the heatsink and the PCB

Assembling process is easier than disassembling. Figure 7 presents a possible sequence of steps:

1. Prepare the TO package by cutting the leads to a length of around 5 mm (a).
2. Bend the pins 3 and 5 towards the front of the package in order to provide an offset of roughly 3.5 mm with respect the other pins (a).
3. Put a sufficient amount of thermal grease on the insulator material in order to guarantee a good thermal contact.
4. Place the package on the heatsink making sure that it lays perfectly flat on the surface of the heatsink (b).
5. Put the spring clip on the package and heatsink groove, and fasten it using pliers (c).
6. Solder one lead after the other on the top side of the PCB (d).

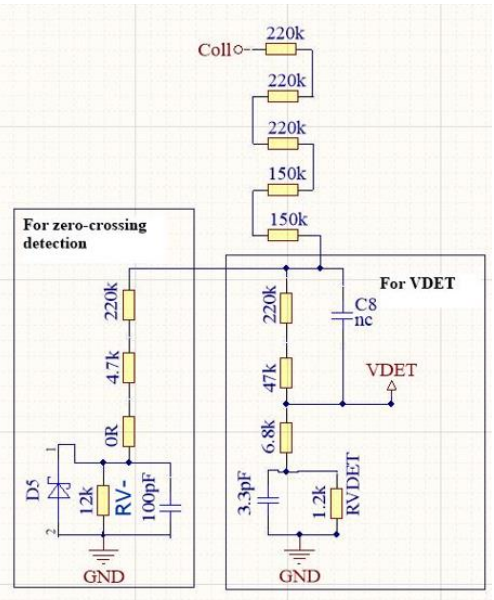
4.1.2 Tuning collector-emitter voltage sense network

The IEWS20R5135IPB features an over-voltage protection functionality that prevents the V_{CE} voltage to exceed defined values. It also prevents the device from turning on if V_{CE} is higher than a determined threshold. The behavior of the over-voltage protection is determined by the voltage at the VDET pin, and can be adjusted by modifying this voltage value. The evaluation boards implement a resistor chain to supply the voltage at VDET pin, as shown in Figure 8a. The resistor RVDET can be replaced in order to change the voltage at VDET. Figure 8b shows the relation of the resistance RVDET and the corresponding value of the limiting voltage. When the V_{CE} exceeds the limiting voltage, the IEWS20R5135IPB switches to over-voltage shutdown (INN voltage is pulled to 0 V). In this mode, the device can actively clamp the voltage in order to prevent it from exceeding the maximum V_{CE} of the IGBT. The over-voltage shutdown mode is deactivated as soon as VVDET falls below a restart threshold[1], with a minimum blanking time of 3 ms. Figure 8a also shows that a second resistor chain is derived from the main resistor dividers. This chain is used to provide the information from the V_{CE} to the MCU, so that it can determine when the IGBT has to be turned on. The usage of a shared chain for sensing VVDET and for triggering the the turn-on of the IGBT is a cheaper and less space-consuming solution compared to a solution with two distinct resistor divider chains.

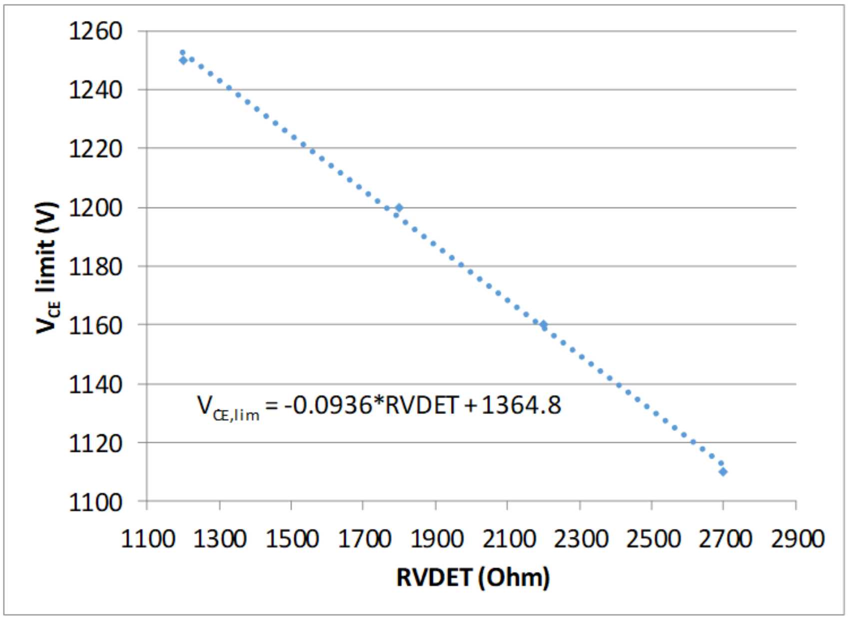
Figure 8c shows a reference of how the VVDET should look in comparison to V_{CE} voltage. As can be seen in the picture, the voltage at VDET and the voltage V_{CE} show the same behavior except for a small shift in time that is caused by the capacitance between VDET and GND. In general, the parasitic capacitance that is present at the package level between the heatsink and VDET pin has to be considered in addition to the external capacitance shown in Figure 8a[2].

[1] For a detailed explanation of the clamping behavior refer to the application note of the IPD [1].

[2] Please note that in this board the heatsink is connected to GND for safety reasons. In industrial designs the heatsink is usually at the same potential as the collector of the IGBT. As a consequence, the effect of the parasitic capacitance between VDET and the heatsink



(a)



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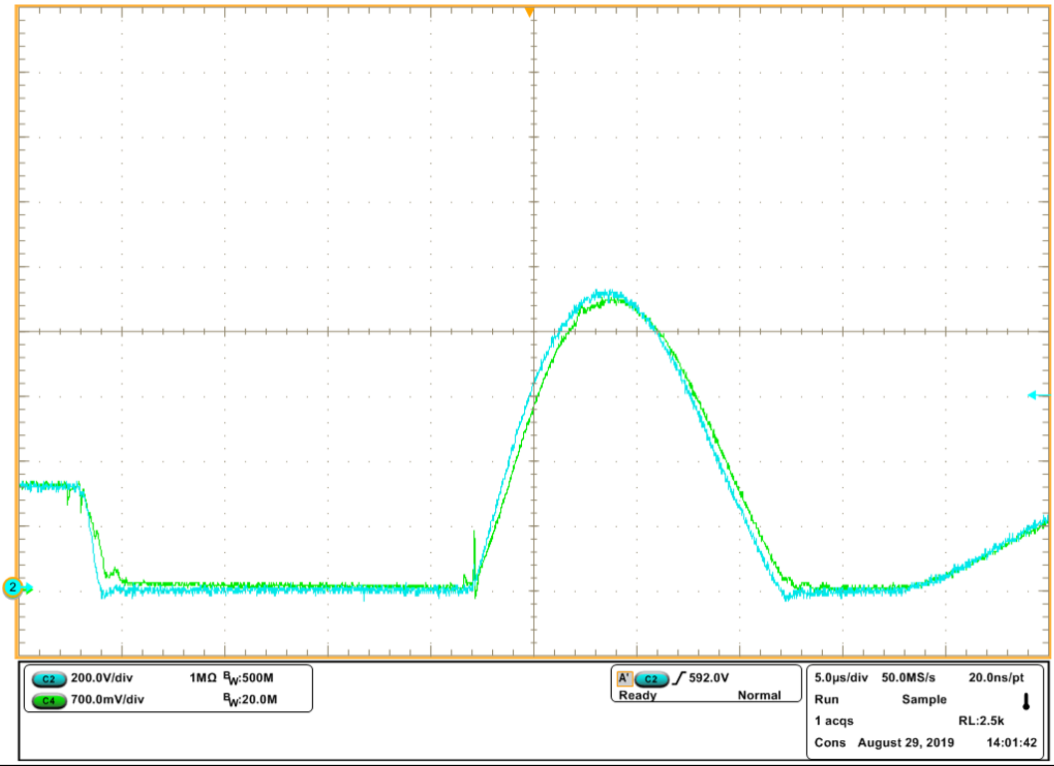
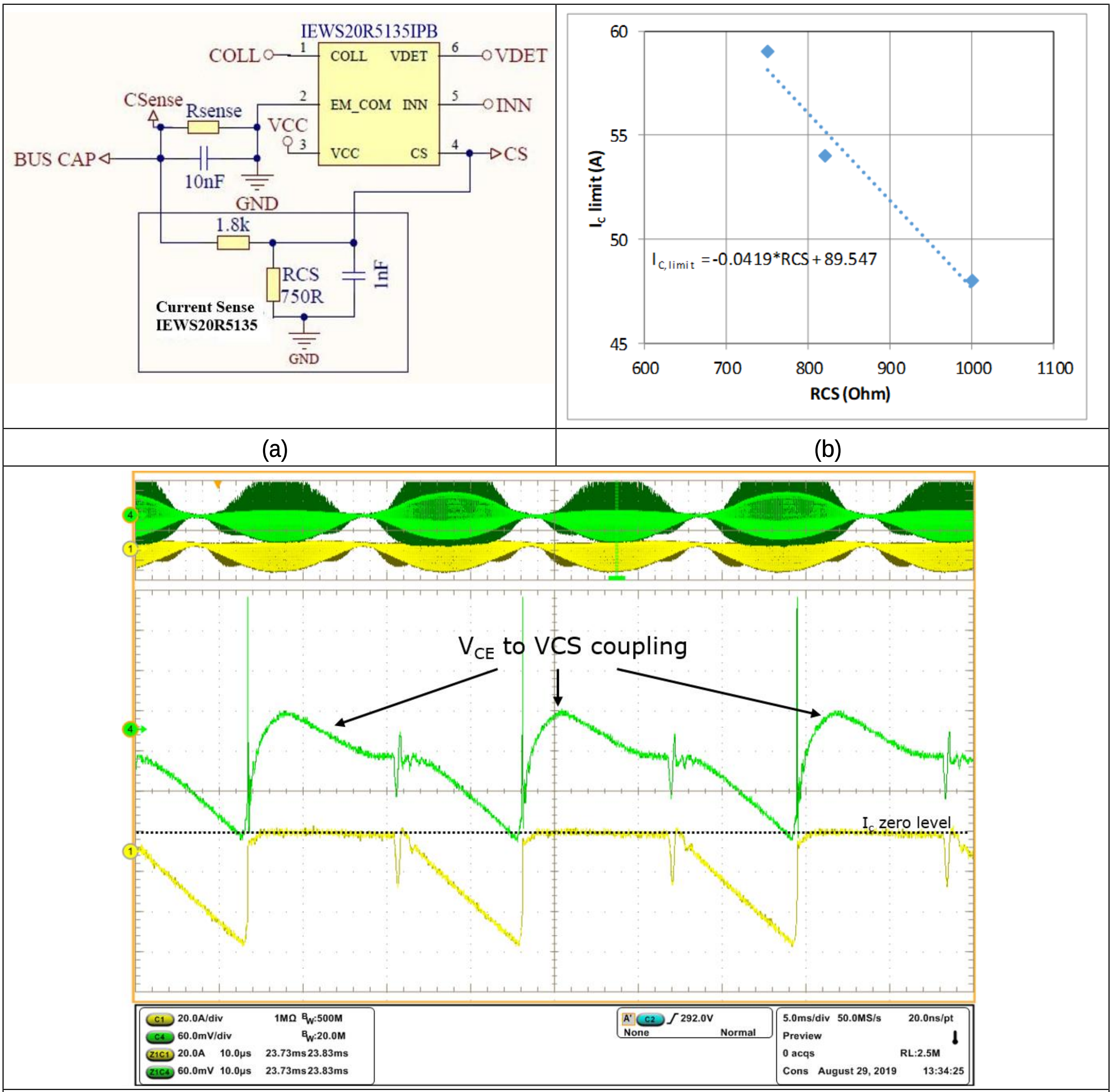


(c)

Figure 8 (a) Schematic of the collector-voltage sensing network; (b) dependence of the over-voltage clamping voltage on the value of RVDET; (c) experimental waveforms of VVDET (green curve, 700 mV/div) and VCE (cyan curve, 200 V/div), time scale: 5 µs/div.

may produce a different shift between VVDET and V_{CE} that should therefore be compensated by a higher external capacitance between VDET and GND.



(a) (b) (c)

Figure 9 **Collector-current sensing: (a) schematic of sense circuit; (b) dependence of the IGBT peak current on the resistance RCS; (c) comparison between IGBT collector current measured by Rogowski coil (yellow curve, 20 A/div) and voltage measured at pin CS (green curve, 60 mV/div), time scale: 10 µs/div.**

4.1.3 Tuning turn-on detection point of the IGBT

One of the critical aspects of the SEPR converter is to determine the optimal turn-on point of the IGBT, which is during the conduction phase of the parallel diode. The evaluation board is already optimized to match the optimal turn-on point of the IGBT. However, in case the resonant capacitance is replaced with a different value, the turn-on detection point has to be changed. In order to do so, the resistance RV- has to be changed to adjust the turn-on point of the IGBT (as shown in Figure 8a). It is recommended to change the value of the resistance only if the value of the resonant capacitance is changed.

4.1.4 Tuning collector-current sense network

The IEWS20R5135IPB for induction heating also features an overcurrent protection functionality that allows the IGBT to be switched off as soon as the collector current reaches a selected threshold. Such a functionality requires a voltage replica of the collector current, available at the CS pin. Such a voltage signal has to be as clean as possible in order to avoid unpredictable behavior of the IGBT[1].

The evaluation board utilized a 10 mΩ SMD metal-film resistor as sensing element of the collector current, followed by a passive low-pass filter, as shown in Figure 9a. The DC gain of the low-pass filter determines the current at which the IGBT is shut down. By means of the R_{CS} resistance, the gain can be changed, thus changing the maximum current that can flow in the IGBT. Figure 9b shows the measured dependence of the maximum collector current on the value of the resistance RCS. The dependence is not perfectly linear, as at higher RCS the effect of the capacitance in parallel becomes more prominent.

In Figure 9c, a comparison is shown between the collector current measured by the Rogowski coil and the voltage measured among CS and emitter pins of the IEWS20R5135IPB. It can be noticed that during the on-time of the IGBT, where the collector current is almost linearly increasing, the voltage at the CS pin (green curve) replicates the current measured with the Rogowski coil (yellow curve). During the off-time, the collector current is almost zero[2], but V_{CS} shows similar behavior like the V_{CE} (see Figure 11). This behavior is caused by the parasitic capacitance of the package that creates a coupling between the collector potential and the CS potential. Such behavior, however, does not affect the IEWS20R5135IPB operation, since the coupling is present only in the off-state of the IGBT.

[1] The threshold of the current sense limitation is set to a typical value of -200 mV. The resistor divider of the low pass filter in Figure 9a is chosen so that for the designed peak current, the voltage at CS is equal to -200 mV.

[2] The offset of the I_C in the off-state is due to the AC nature of the Rogowski probe.

5 Experimental results

5.1 Operation

Once the system has been properly tuned, as explained in the previous sections, the board can be powered up by connecting it to an AC power supply. The nominal value of the AC voltage is 230 V/50 Hz. If not otherwise specified, all the results presented in the following are obtained with such a supply voltage.

Attention: ***Prior to starting measurements, ensure that the board settings are correct. Take special care that no physical short circuits or floating gates are present.***

Attention: ***When supplying the AC voltage to the board, USE ISOLATED POWER SUPPLY ONLY, and connect the earth terminal of the board to a proper grounded point.***

DANGER: the board DOES NOT offer proper insulation to the user. Do NOT connect the board to the grid in any case.

The evaluation board is set up as explained in Section 4.1. Following the recommendations on page 8, current measurements are made using a Rogowski-coil current sensor, and voltage probes were connected via PCB adapters. No probe has been connected on the CS pin, as this can be a significant cause of disturbance for some of the tests explained below. Figure 10 shows the evaluation board and the measurement hardware as the main part of the setup – AC power supplies and the surge test generator are not shown in the figure.

The board is provided with a 7-segment display that indicates whether the converter is operating and, in case it is, what the target output power level is.

In the next section, the typical operation of the board is shown.

5.1.1 Stand-by mode

Once the board is supplied with the main AC voltage, the board turns on in stand-by mode. In this condition, the display shows simply a dot. The board returns to stand-by mode:

- When the ON/OFF button is pressed while the converter is in operation.
- When the system is switched on, but no cooking vessel is detected.

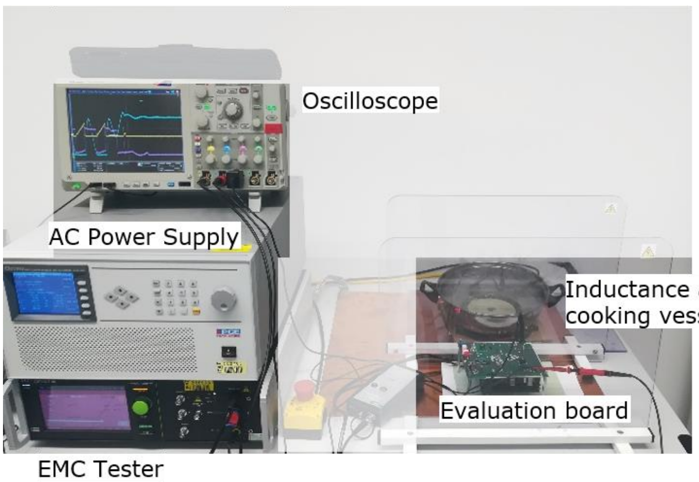


Figure 10 **Main parts of the test setup**

5.1.2 Normal operation and change of output power

Table 2 Target output power according to the power setting

Power level setting	Target input power level (W)
1	1000
2	1200
3	1400
4	1600
5	1700
6	1900
7	2100

Starting from stand-by mode, by pressing the ON/OFF button once, the system turns on and performs a check to verify the presence of a vessel on the resonant inductor. The detection process is repeated five times, once per second. In case a vessel is detected, the output power level is automatically set to '5', as also indicated by the display, and the system starts the operation. In this condition, the target output power is 1700 W. In case there is no vessel, the system returns to stand-by mode. While in operation, the output power of the system can be increased and reduced by means of buttons P+ and P-. Table 2 shows the power levels and the corresponding target output power.

During normal operation conditions the IEWS20R5135IPB is driven by the INN signal, as shown in Figure 11. When the INN voltage changes from high to low, the IGBT is turned on, with a typical propagation delay of 700 ns; on

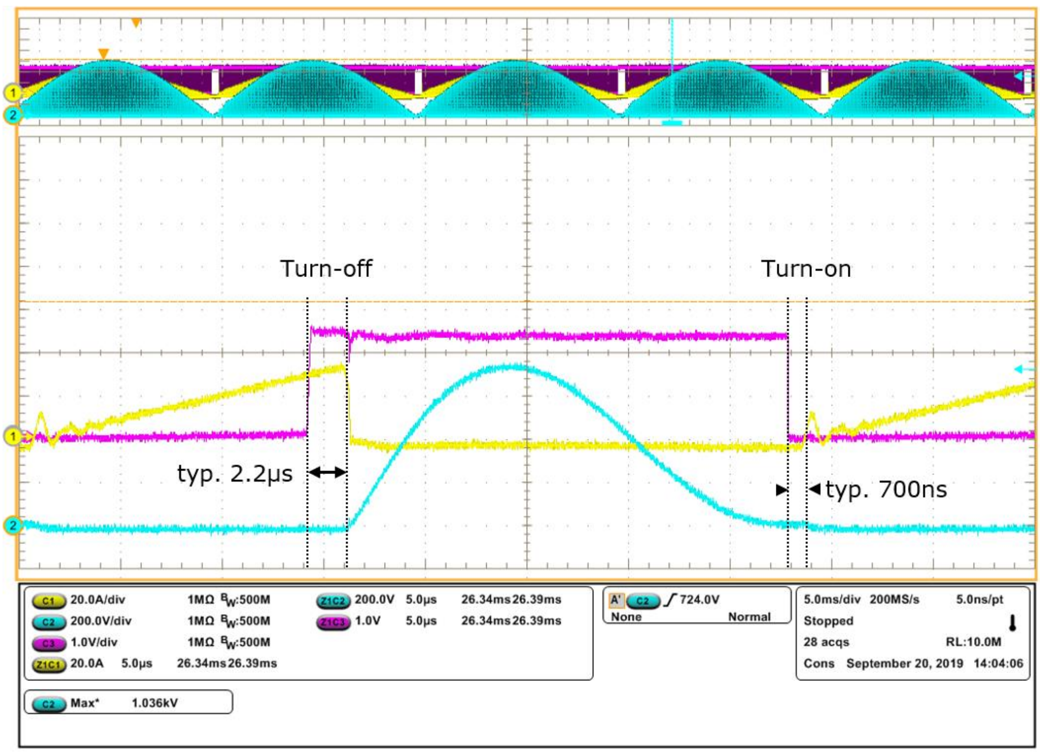


Figure 11 Normal operation of IEWS20R5135IPB: turn-off and turn-on INN-to-IC propagation delay. IC (yellow curve, 20 A/div), VCE (cyan curve, 200 V/div) and INN (magenta curve, 1V/div), time scale: 5 µs/div

the other hand, when the INN voltage changes from low to high, the IGBT is turned off, with a typical propagation delay of 2.2 µs. The larger propagation delay at turn-off is due to an increased filtering time to avoid spurious turn-off events. As a consequence, the turn-off of the current in normal operation occurs with a delay, with respect to the INN transition, from low to high. During normal operation, the high value of the voltage at pin INN is typically equal to 2.5 V. Such a value corresponds to 'normal' condition of the IEWS20R5135IPB.

5.1.3 Operation in current limitation

Depending on the chosen setting of the maximum current, a current limitation can already be reached during normal operation mode, especially at high power levels. When this happens, the 100 Hz envelope of the collector current changes as shown in Figure 12a. In the single switching event, a strong current limitation can be identified if the IGBT current switches off before the INN voltage changes from low to high, as shown in Figure 12b.The operation in current limitation is still considered a 'normal' condition for the IEWS20R5135IPB and therefore no change in the value of the off-state INN voltage is produced in this case. Nevertheless, it is important to mention that when current limitation occurs during the operation, the input current of the overall system changes its shape according to the envelope shown in Figure 12a. As a consequence, the total harmonic distortion (THD) of the input current increases. For this reason, the current limitation features should be mainly used for protection, and the limitation threshold should be set in a way that the current is not limited during the normal operation of the system.

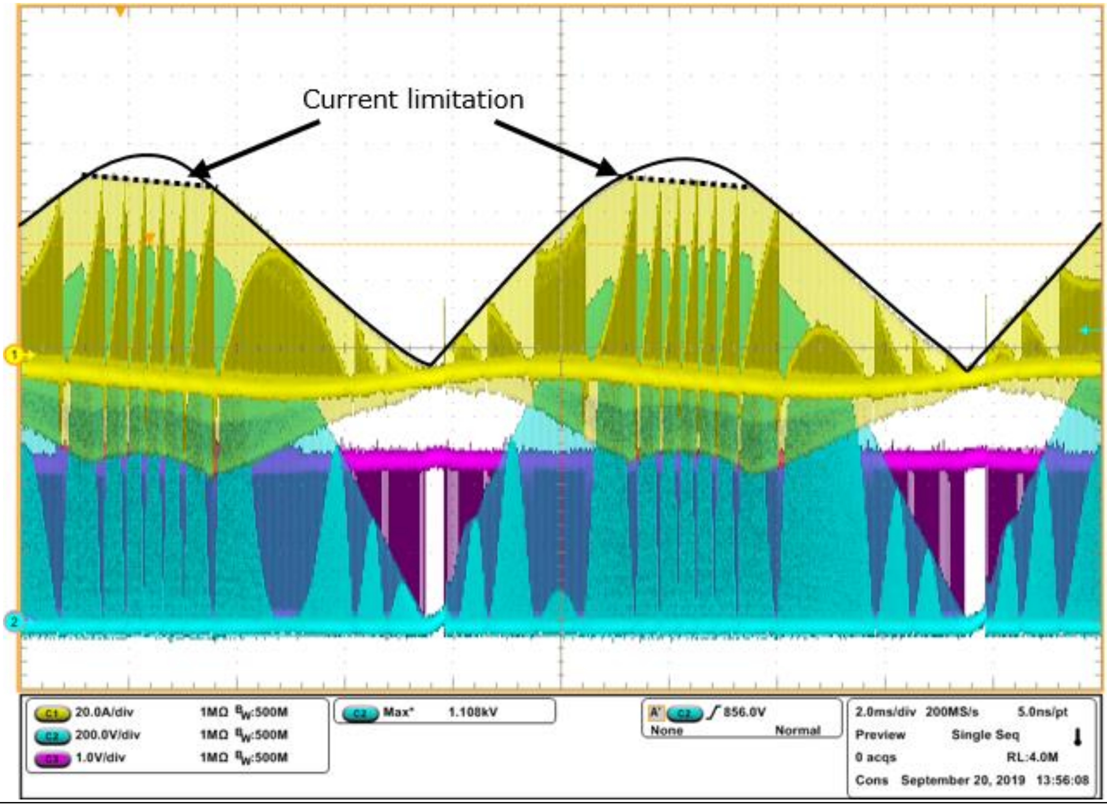
5.1.4 Operation in case of overtemperature warning and overtemperature shutdown conditions

In case the temperature of the device exceeds 75°C, the status of the IEWS20R5135IPB changes to 'overtemperature warning' mode. In this condition, the high value of the INN voltage changes from 2.5 V to a typical value of 4 V, as shown in Figure 13a. The MCU continuosly monitors the average value of the INN pin and can therefore detect the status and react consequently. In particular, in 'overtemperature warning' mode:

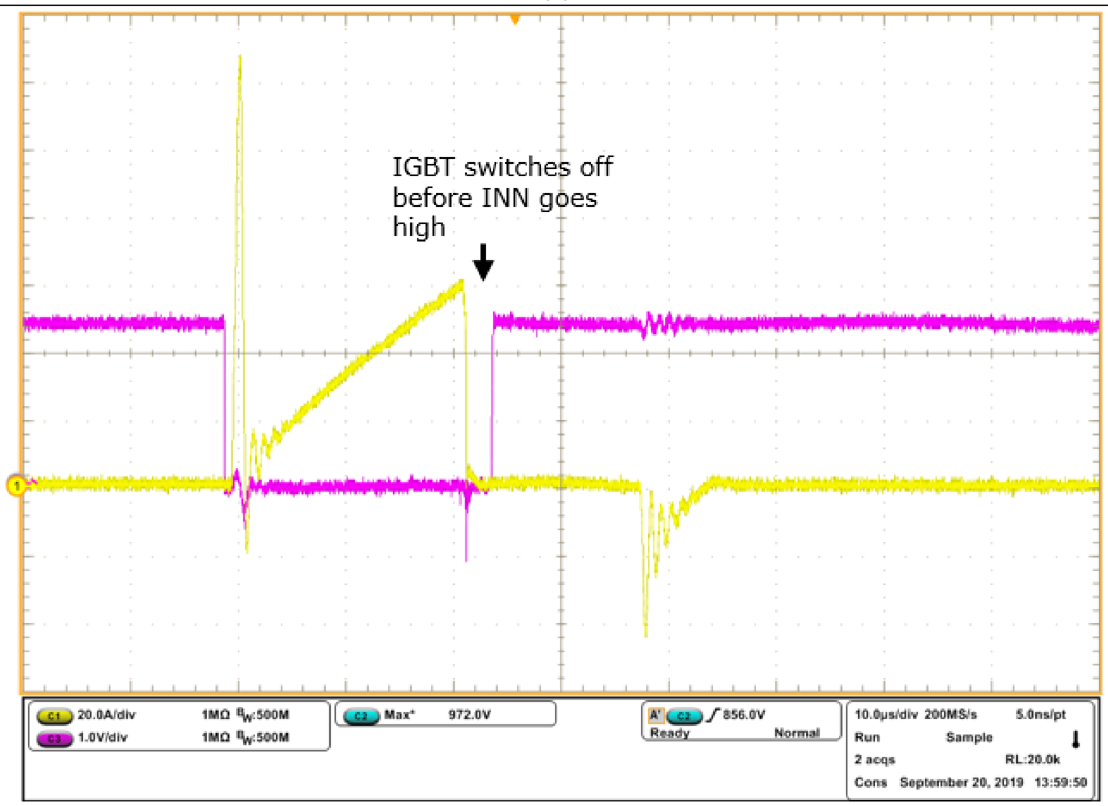
- The LED OTW on the board turns on.
- The speed of the fan is increased.

As soon as the temperature of the device drops again below 75°C, the OTW LED switches off, and the speed of the fan is again reduced. In case of significant power dissipation (e.g. strong hard switching turn-on at lower power), the temperature of the IGBT can increase even more, and eventually reach the value of 150°C. When this happens, the IEWS20R5135IPB enters 'overtemperature shutdown' mode. In this condition, the device stops operating and keeps the INN voltage constantly at a value that is <0.5 V, as shown in Figure 13b. In this condition, the led OTS (red) is turned on. The 'overtemperature shutdown' mode ceases as soon as the temperature of the IGBT drops below 75°C; the OTS LED switches off, and the system restarts automatically, performing the vessel detection. The fan speed is also reduced when the device restarts in 'normal' status. The circuit for detecting the INN status is shown in Figure 13c whilst its operation is explained as follows:

- The INN signal is split and fed into a peak-detector circuit consisted of the Schottky diode D3 and the capacitor C10. The voltage across the capacitance is sensed by an A/D converter of the MCU. By means of this circuit, the IEWS20R5135IPB status read can be performed in a relaxed time without the need to be synchronized with PWM driving signal.
- When the IEWS20R5135IPB enters overtemperature warning mode, the INN voltage increases to 4 V during the off-state; the capacitance is therefore charged up to 3.8 V (considering the voltage drop across D3) during roughly 100 ns because the charging current is mainly limited by the maximum output current of the INN pin. Resistor R22 is instead used for allowing the discharge of the capacitance C10 when the IEWS20R5135IPB is in shutdown mode, since it can't be discharged by the INN current because of the diode D3.

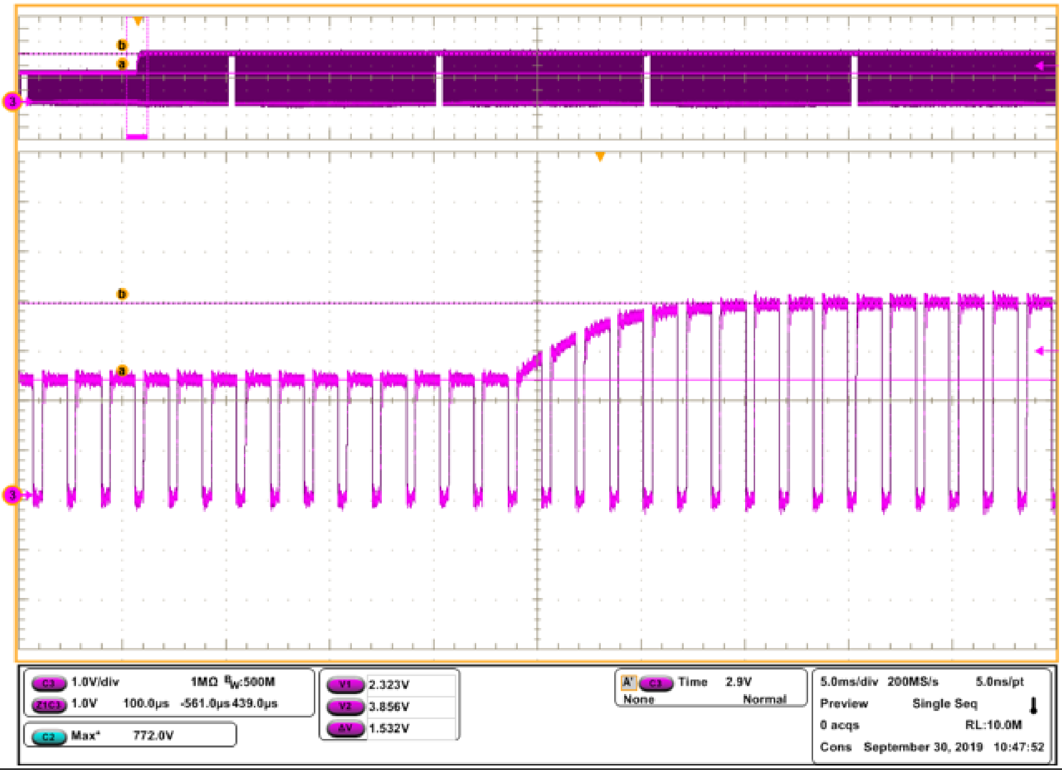


(a)

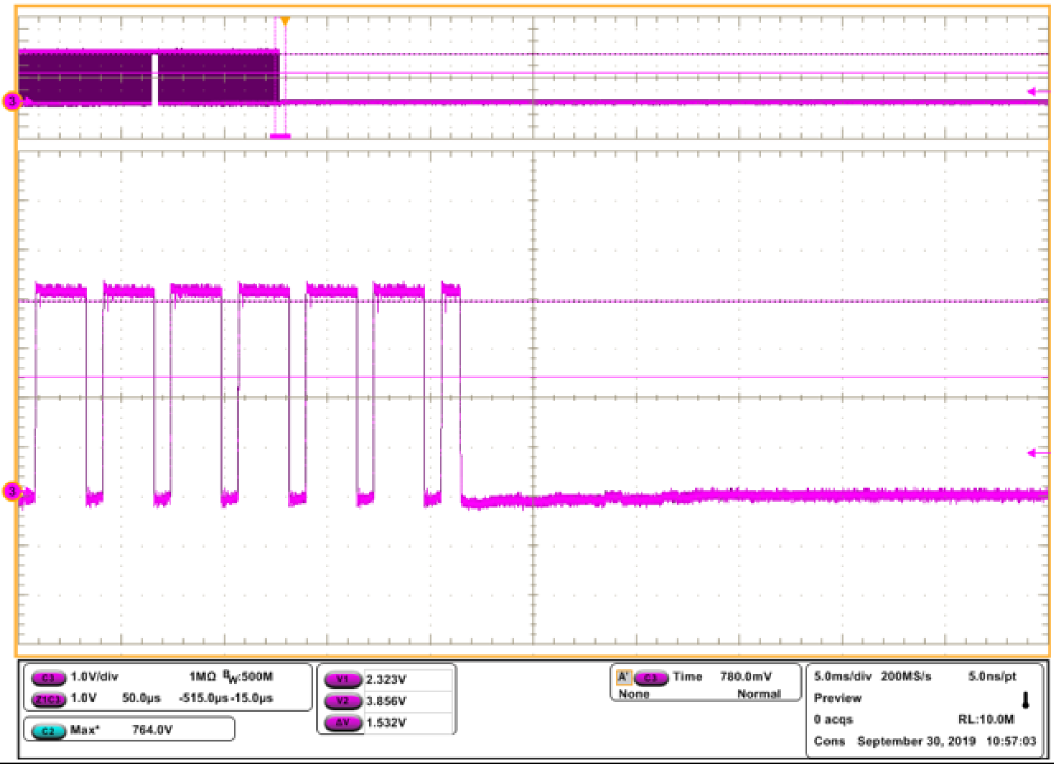


(b)

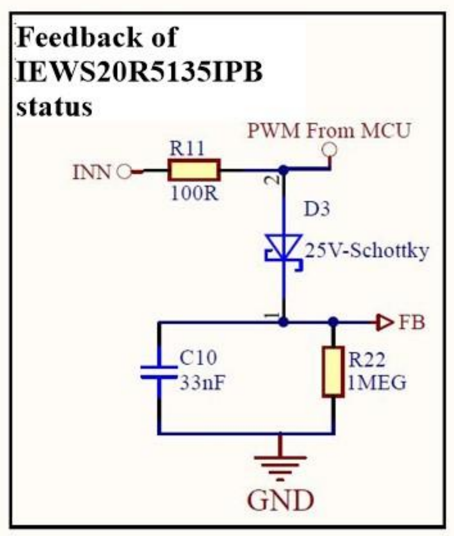
Figure 12 **Current limitation operation of IEWS20R5135IPB: (a) 100 Hz envelop, 2 ms/div; (b) single-switching event, 10 µs/div. IC (yellow curve, 20 A/div), VCE (cyan curve, 200 V/div) and INN (magenta curve, 1V/div)**


C3 1.0V/div 1MΩ BW:500M
Z1C3 1.0V 100.0µs -561.0µs 439.0µs
C2 Max* 772.0V
V1 2.323V
V2 3.856V
ΔV 1.532V
A' C3 Time 2.9V
None Normal
5.0ms/div 200MS/s 5.0ns/pt
Preview Single Seq
0 acqs RL:10.0M
Cons September 30, 2019 10:47:52

(a)


C3 1.0V/div 1MΩ BW:500M
Z1C3 1.0V 50.0µs -515.0µs -15.0µs
C2 Max* 764.0V
V1 2.323V
V2 3.856V
ΔV 1.532V
A' C3 Time 780.0mV
None Normal
5.0ms/div 200MS/s 5.0ns/pt
Preview
0 acqs RL:10.0M
Cons September 30, 2019 10:57:03

(b)



(c)

Figure 13 INN voltage change: (a) in overtemperature warning (OTW) operation and (b) in overtemperature shutdown (OTS) (1 V/div – 100 µs/div); (c) schematic of the INN voltage sense

5.2 Performing EMC tests on the board

The most stressful situations for the SEPR-based induction cooking systems occur when the grid voltage experiences sudden changes. In fact, this leads to an increase in the bus voltage and finally, due to the voltage resonant operation, to a significant increase of the peak-collector current and the peak collector-emitter voltage of the IGBT. In order for an induction cooking system to be reliable and usable in the market, it has to fulfill the electromagnetic compatibility (EMC) requirements, which comprises, among other things, system testing under sudden variations of the grid voltage. The IEC 61000-4 norm [8] provides guidelines on how to test the reliability of a system against grid transients. Among the different tests considered, two are of major interest to show how the IEWS20R5135IPB could improve system reliability: test of instantaneous AC power supply interruption and surge tests. These tests have been performed by using the test generators presented in section 2.2, and the results are addressed in the next sections. Before addressing the details of each test, it is important to mention that the system is only properly protected by means of the IEWS20R5135IPB, which is only guaranteed if the device can sense accurately the collector-emitter voltage and the collector current. The general recommendation provided in section 4.1 should guarantee the best and most reproducible behavior of the device.

5.2.1 Test during an AC instantaneous supply interruption

Instantaneous interruption of the AC supply (i.e., loss of supply voltage during a time shorter than 30 cycles) can occur because of damages to the electrical grid that cannot be immediately compensated by the utility infrastructure. In the case of an induction cooker that is based on the SEPR topology, the effect of an instantaneous AC loss can be catastrophic, as it may ultimately lead to the failure of the IGBT. This is because during a short interruption of the main supply, the bus capacitor, which feeds the energy to the resonant inverter, is rapidly discharged and then charged again. By the effect of the resonance between the bus capacitance and the input filter inductance, the voltage on the bus capacitor can exceed the input voltage, as shown in Figure 14.

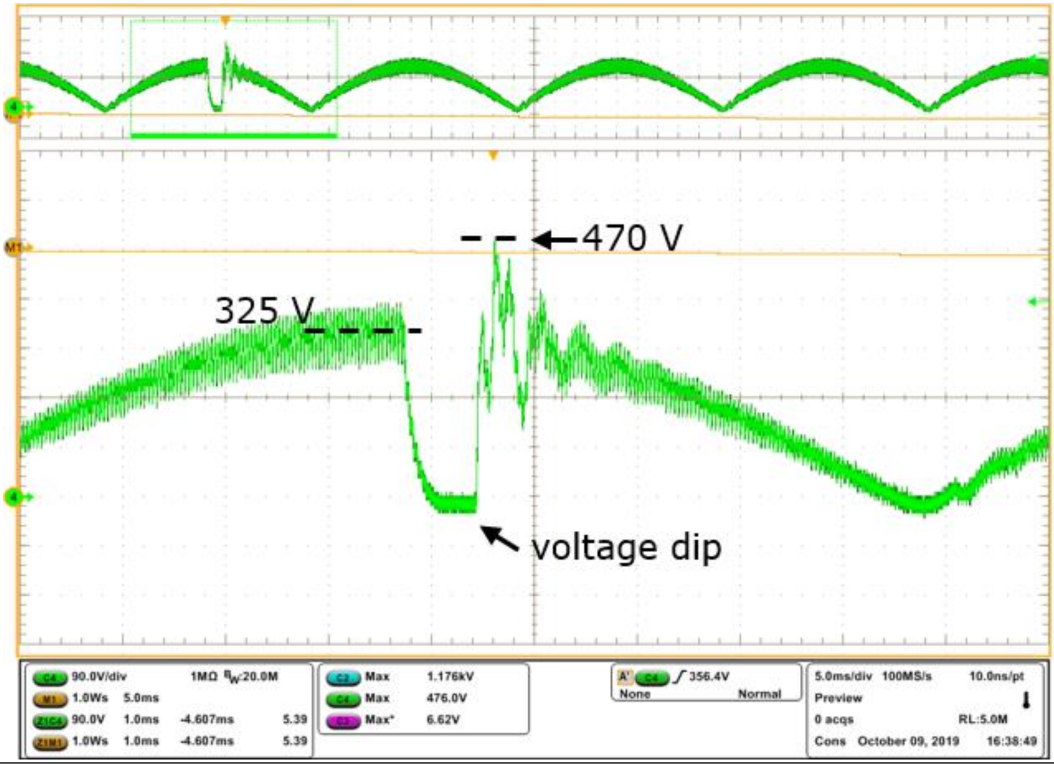
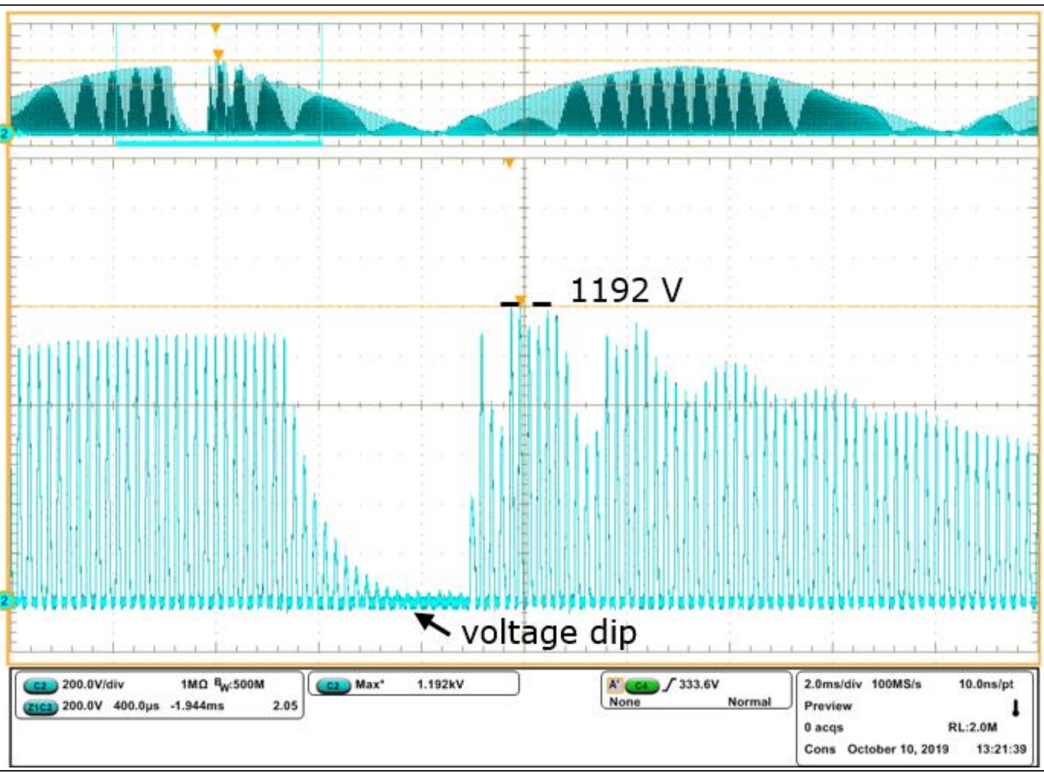
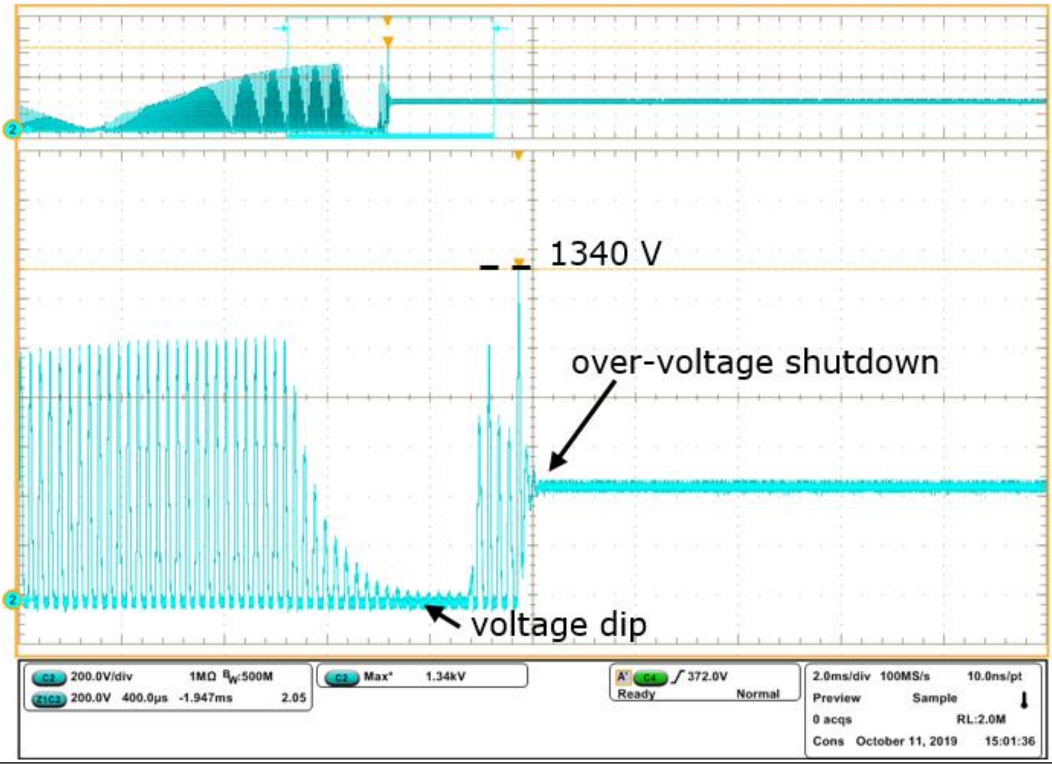


Figure 14 **Voltage of the bus capacitor of the SEPR during an instantaneous supply voltage interruption (90 V/div – 5 ms/div): duration of the interruption: 4 ms; amplitude of the interruption: 40% of the peak nominal value**



(a)



(b)

Figure 15 Collector-emitter voltage during the instantaneous supply voltage interruption (200 V/div – 400 µs/div): (a) when current limitation of the IEWS20R5135IPB is active (RCS= 750 Ω); (b) when the current limitation is deactivated (RCS= 0 Ω)

As explained previously, a sudden increase of the bus voltage is dangerous for the IGBT as, due to the additional energy that it is stored in the inductance, the VCE peak voltage at turn-off can become extremely high. In these conditions, the current limitation feature of the IEWS20R5135IPB limits the maximum current that can flow in the inductor thus limiting the maximum energy stored, and finally the maximum VCE. In order to show the benefit of the current limitation, the same voltage dip test has been conducted a first time by limiting the IGBT collector current at 59 A, and a second time without limiting the IGBT current. The experimental results show that the same voltage dip event leads to two different VCE_{max} when the IEWS20R5135IPB current limitation is activated (Figure 15a) or not (Figure 15b). In the latter case, the peak VCE becomes high enough that it even triggers the over-voltage mode of the IEWS20R5135IPB with the consequent shutdown of the device.

5.2.2 Surge test

Surges may be caused by nearby heavy equipment shutting down or going offline, or by lightning strikes to buildings or close to outdoor cables. The reference standard for the surge test is the IEC 61000-4-5, which defines the transient shape of the surge. The standard also defines classes of installation that are directly related to the amplitude of the surge. For home appliances, the minimum voltage is 1 kV, line-to-neutral (or line-to-line), even if many applications are nowadays tested with 1.5 kV or even 2 kV. For line-to-earth surge events, the minimum allowed voltage that the system must withstand is 2 kV. The effect of a line-to-neutral voltage on a SEPR-based inverter is a consequent increase of the voltage of the bus capacitance. The final voltage across the capacitance can depend on many factors like the input voltage at the moment that the surge occurs, the type of MOV that is used for limiting the voltage at the input, and the type of input filter inductor that is used[1].

[1] An air core inductor could limit the current rise much better than an iron core inductor, which would probably saturate much earlier.

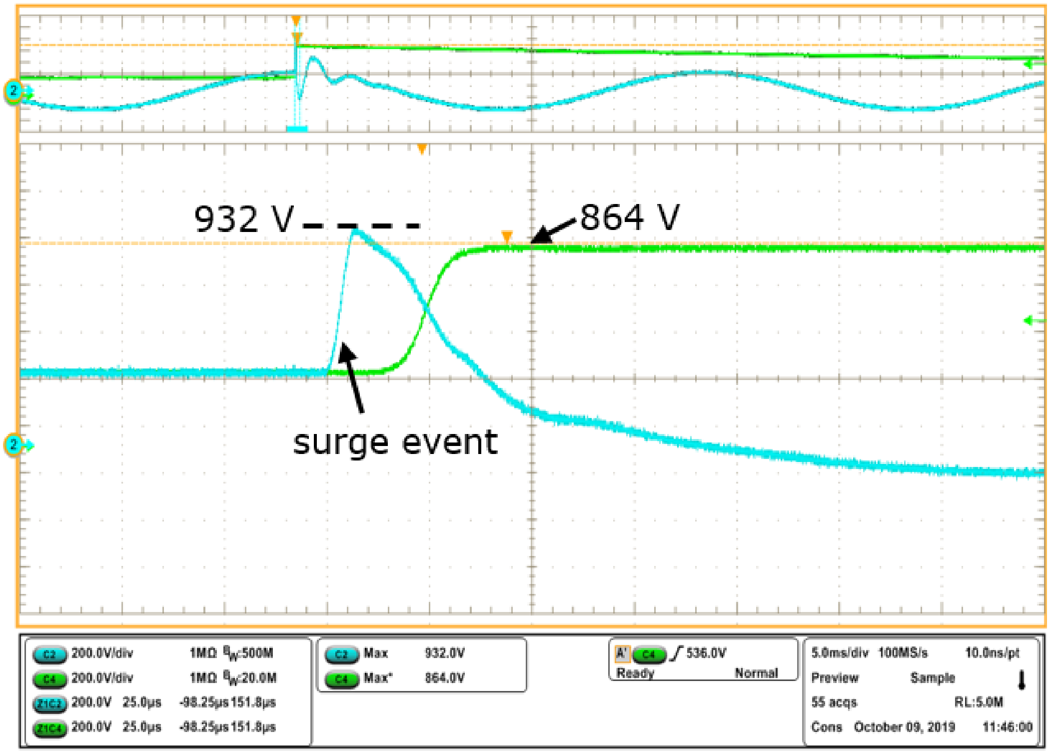


Figure 16 Experimental AC input voltage (blue waveform, 200 V/div) and bus capacitor voltage (green waveform, 200 V/div) of the SEPR during a 2 kV surge, time scale: 25 µs/div

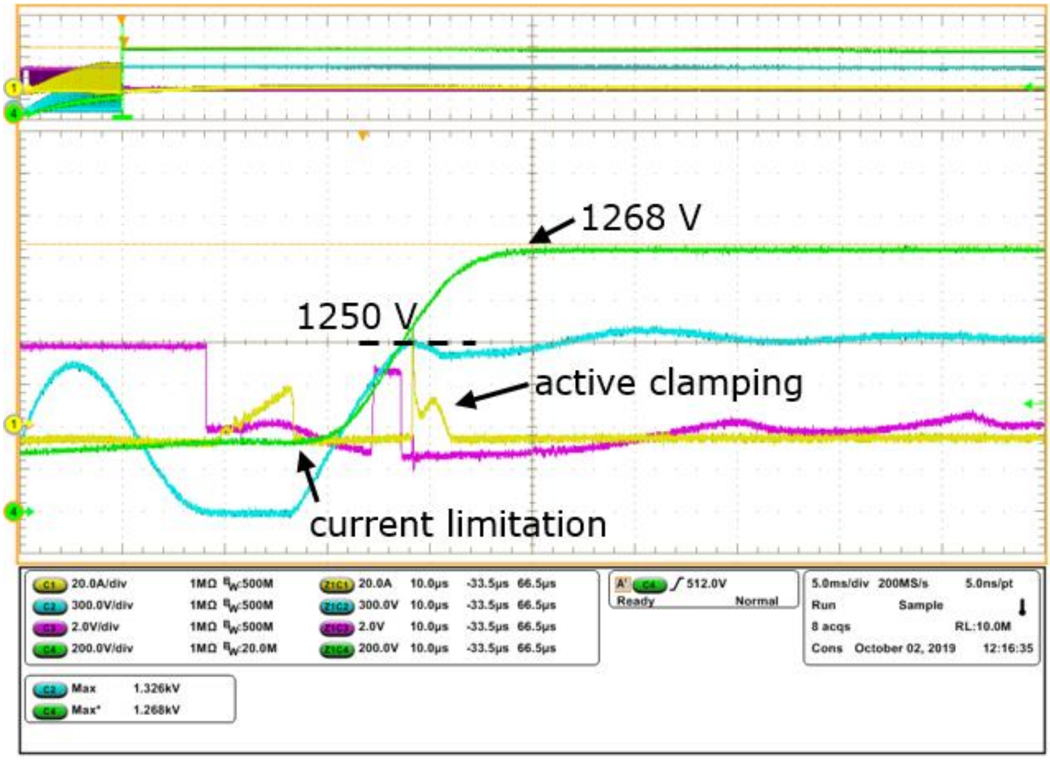


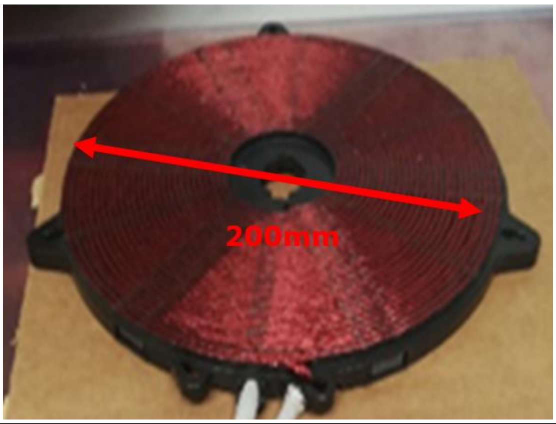
Figure 17 Experimental waveforms of the IEWS20R5135IPB during a 2 kV surge voltage: IC (yellow waveform, 20 A/div), VCE (cyan waveform, 200 V/div), VINN (magenta waveform, 2 V/div) and bus voltage (green waveform, 200 V/div), time scale: 10 µs/div

Figure 16 shows the experimental waveforms of the AC input voltage and the bus voltage, during a 2 kV surge event, when the system is in stand-by mode, which means the current in the filter inductor is almost zero. As one can notice, the input AC voltage reaches a peak value of 932 V, limited by the MOV, whilst the bus voltage (green waveform) increases up to 824 V. For the given system, the worst case scenario is when the system is in operation and a positive line-to-neutral surge occurs at a 90° angle of the input sinusoid, as the input AC voltage is at its maximum, and the current into the filter inductor is also maximum (assuming a power factor close to 1). In the latter case, the bus voltage can be even higher than the AC input voltage peak. Since the bus voltage increase is much more significant than in the case presented in section 5.2.1, the effect on the collector-to-emitter voltage of the IGBT is also much more significant. In this case, the single-level protection offered by current limitation of the IEWS20R5135IPB may not be enough to avoid an excess increase of the VCE above the maximum permitted limit of the device. Therefore, the additional protection offered by the over-voltage clamping feature IEWS20R5135IPB reveals to be fundamental to properly protect the IGBT. Figure 17 shows the behavior of the IEWS20R5135IPB during a 2 kV surge event. As soon as the surge occurs, the current of the IGBT (yellow curve) increases faster and is eventually switched off by the over-current protection of the IEWS20R5135IPB. At IGBT turn-off, the VCE increases (blue curve) and, due to the excessive energy injected by the surge, crosses the limiting voltage threshold (which is set to roughly 1250 V), ultimately triggering the over-voltage mode of the IEWS20R5135IPB. As a consequence, the IGBT is turned on shortly afterwards, and the collector current is controlled in order to maintain the VCE to the selected threshold and prevent it from rising even further.

6 Appendix

6.1 Resonant inductor specification

The experiment results presented in this document were conducted with a connecting and external coil, suitable for induction cooking systems. As known, the behavior of the SEPR converter is largely dependent on the particular coil and cooking vessel that is used. In particular, the coil inductance, diameter, and distance to the vessel are important factors to consider when an induction cooking system is designed. The design of the resonant coil is outside the scope of this document. However, in order to provide a reference for the results which have been presented, the details of the resonant coil are shown below. Figure 18 depicts a picture of the coil with the dimensions and the distance to the vessel that should be maintained when the latter is placed on the coil. Finally, Figure 19 depicts the frequency dependence of the series resistance and inductance values of the coil, without the vessel, and with the vessel positioned on top.



(a)

(b)

Figure 18 Picture of the resonant coil (a) and positioning of the cooking vessel (b)

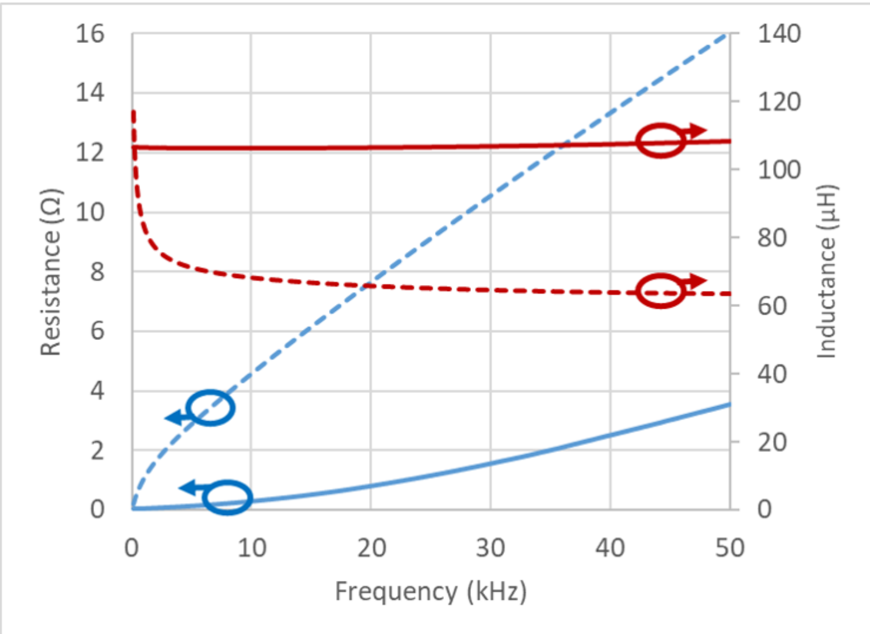


Figure 19 Values of the equivalent series resistance (blue curve) and inductance (red curve) of the resonant coil without the vessel (solid) and with the vessel (dashed)

6.2 Schematic drawing

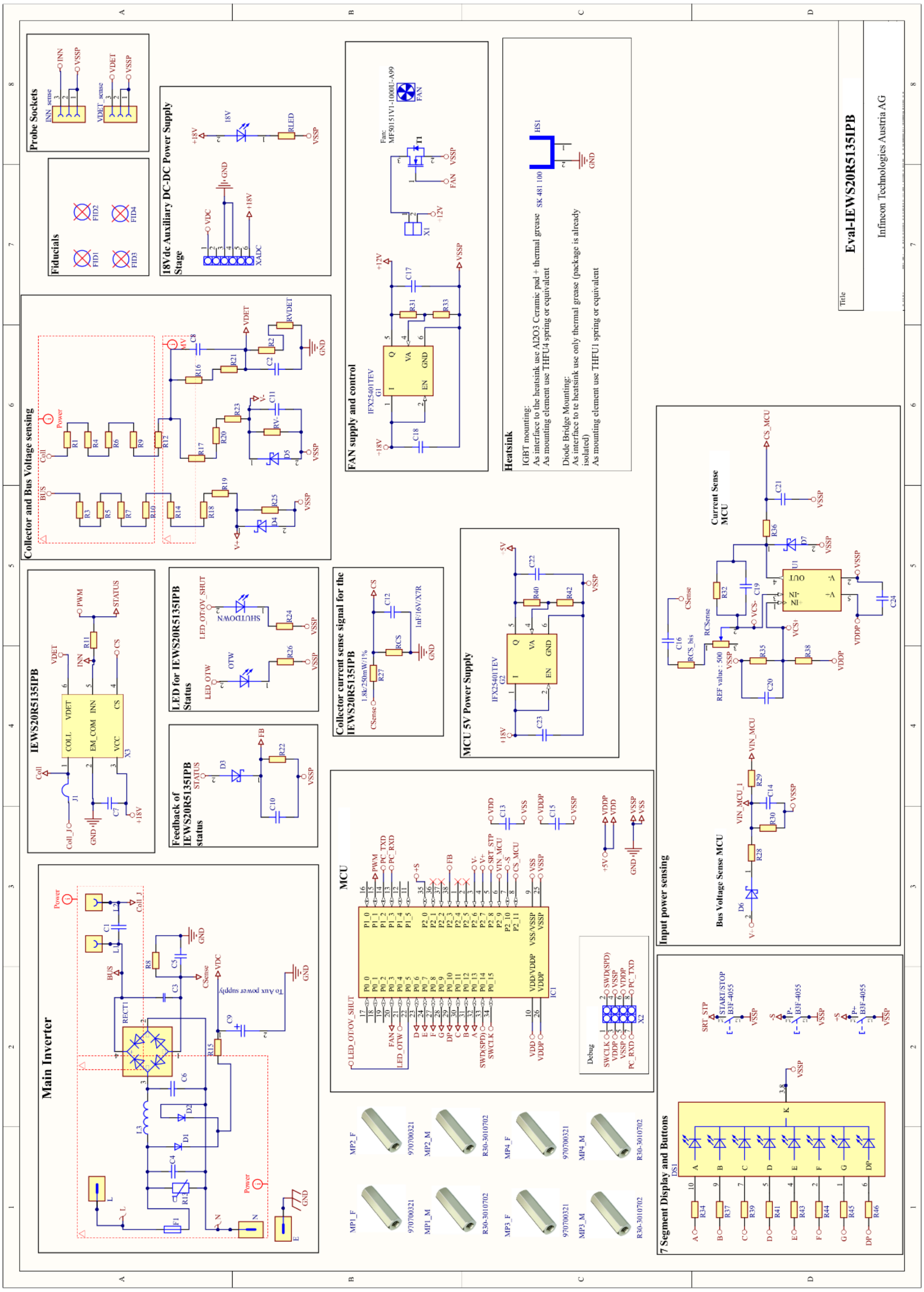


Figure 20 Schematic of the board

6.3 Board layout

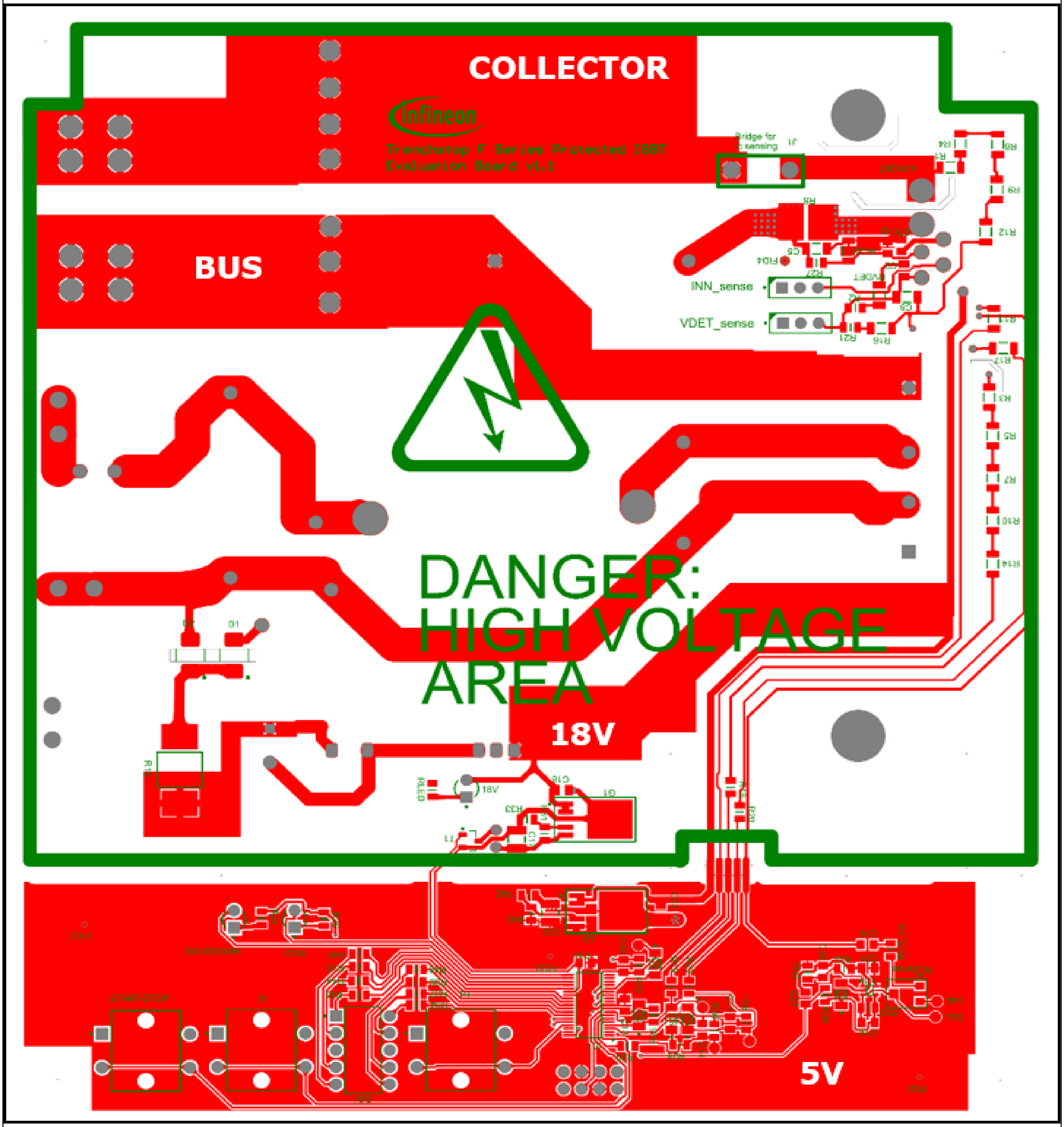


Figure 21 Layer 1 (top layer)

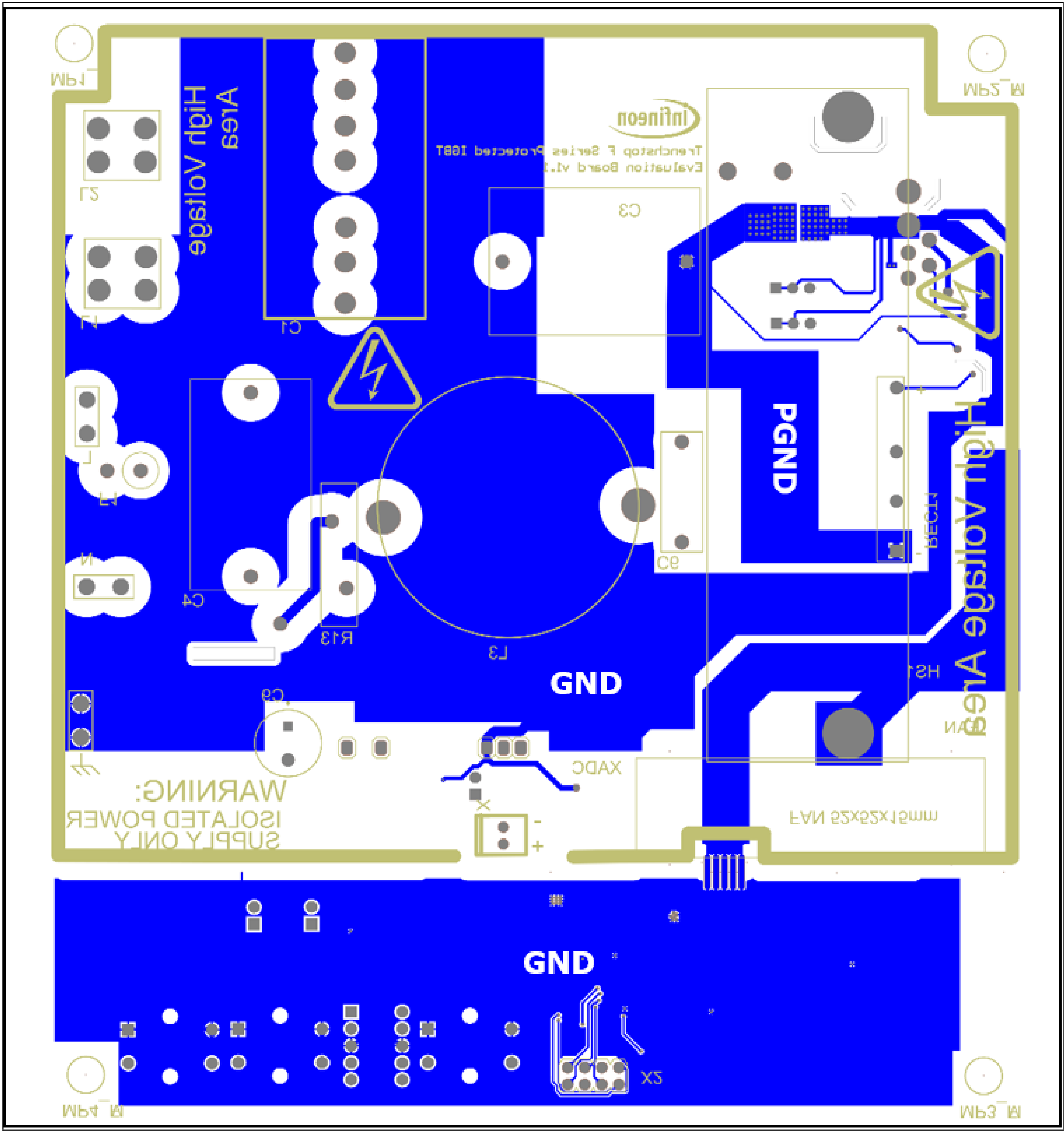


Figure 22 Layer 2 (bottom layer)

6.4 Bill of materials

Designator	Description	Value	Package Reference
Power semiconductor			
X3	IEWS20R5135IPB	Infineon Technologies IEWS20R5135IPB	TO-247 6 pin
Microcontroller			
IC1	XMC1302 ARM Cortex-M0 32-bit MCU	Infineon Technologies XMC1302-T038X0200	PG-TSSOP-38-9
Ceramic Capacitors			
C2		47pF/16V/X7R	C 0805
C5		10nF/16V/X7R	C 1206
C7		10uF/25V/X7R	C 0805
C10, C19		33nF/16V/X7R	C 0805
C11		100pF/16V/X7R	C 0805
C12		1nF/16V/X7R	C 0805
C13, C15		220nF/16V/X7R	C 0805
C14		3.3nF/16V/X7R	C 0805
C16		10uF/16V/X7R	C 0805
C17, C22		22uF/25V/X7R	C 1210
C18, C23		470nF/25V/X7R	C 0805
C20, C21, C24		100nF/16V/X7R	C 0805
Film Capacitors			
C1		EPCOS/TDK B32656T7274K	
C3		KEMET R46KR447050M2K	
C4		KEMET R463R447000M2M	
C6		EPCOS/TDK B32932A3104K000	
Electrolytic Capacitors			
C18V	Aluminum Electrolytic Capacitors	Panasonic EEU-FR1E221	
C9	Miniature Aluminium Electrolytic Capacitor	Panasonic ECA-2WHG4R7	
Light Emitting Diodes			
18V	Backlighting LED Green	Vishay TLHG5205	
DS1	Seven-Segment LED Display	Lite-on LTS-4301JR	
OTW	Backlighting LED Yellow	Vishay TLCY5800	
SHUTDOWN	Backlighting LED Red	Vishay TLCR5800	
Schottky, Zener and Rectifier Diodes			
D1, D2	Rectifier diodes VRRM=1200V; IF=1A	STMicroelectronics STTH112U	SMB

D3, D6	Diode Schottky - VRRM=40V; IF=400mA	Vishay Semiconductors LS103A-GS08	SOD-80
D4, D5, D7		Zener Diode VZ=4.7V	SOD-80
RECT1	15A Single-Phase Bridge Rectifier, 1000V	MCC GBJ1510-BP	
Thick Film Resistors			
R8	Current sense resistor 0.010R/10W/1%	Vishay/Dale WSHP2818R0100FEA	C 2818
R1, R3, R4, R5, R6, R16, R17	Standard Thick Film Chip Resistor	220k/250mW/1%/200V	C 1206
R2, R25	Standard Thick Film Chip Resistor	6.8k/250mW/1%	C 0805
R7, R9, R10, R12, R14	Standard Thick Film Chip Resistor	150k/250mW/1%/200V	C 1206
R11	Standard Thick Film Chip Resistor	100R/250mW/1%	C 1206
R18	Standard Thick Film Chip Resistor	100k/250mW/1%	C 0805
R19	Standard Thick Film Chip Resistor	30k/250mW/1%	C 0805
R20	Standard Thick Film Chip Resistor	4.7k/250mW/1%	C 0805
R21	Standard Thick Film Chip Resistor	47k/250mW/1%	C 0805
R22, R30	Standard Thick Film Chip Resistor	1MEG/250mW/1%	C 0805
R23, R29	Standard Thick Film Chip Resistor	0R/250mW/1%	C 0805
R24, R26	Standard Thick Film Chip Resistor	150R/250mW/1%	C 0805
R27	Standard Thick Film Chip Resistor	1.8k/250mW/1%	C 0805
R28, R32	Standard Thick Film Chip Resistor	33k/250mW/1%	C 0805
R31	Standard Thick Film Chip Resistor	38k/250mW/1%	C 0805
R33, R40, R42	Standard Thick Film Chip Resistor	10k/250mW/1%	C 0805
R34, R37, R39, R41, R43, R44, R45, R46	Standard Thick Film Chip Resistor	294R/250mW/1%	C 0805
R35	Standard Thick Film Chip Resistor	27k/250mW/1%	C 0805
R36, RCS_bis	Standard Thick Film Chip Resistor	1k/250mW/1%	C 0805
R38	Standard Thick Film Chip Resistor	42.2k/250mW/1%	C 0805
RCS	Standard Thick Film Chip Resistor	750R/250mW/1%	C 1206
RLED	Standard Thick Film Chip Resistor	820R/500mW/1%	C 0805
RV-	Standard Thick Film Chip Resistor	12k/250mW/1%	C 0805
RVDET	Standard Thick Film Chip Resistor	1.2k/250mW/1%	C 1206
Wirewound Resistors			
R15	Standard Power resistor 10R/2W/1%	Bourns PWR4525W10R0F	
Connectors			
INN_sense, VDET_sense	3 position Female Header Connector	2.54mm pitch	
L1, L2	M4 Screw Terminal	Keystone Electronics 7796	
X1	2.54mm Male Vertical Locking Header	Wurth Elektronik 61900411121	
X2	8 Position Shrouded Header	Amphenol FCI 75869-132LF	

XADC	Connector for Auxiliary Supply Daughter Board		
Mechanical			
-	Spring Clip for IEWS20R5135IPB	Fischerelektronik THFU 4	
-	Spring Clip for Rectifier	Fischerelektronik THFU 1	
-	Isolation pad for IEWS20R5135IPB	Al2O3 Ceramic pad for TO-247	
E, L, N	Terminals	TE Connectivity / AMP TAB 187 FASTON 032 TPBR	
HS1	Heatsink	Fischerelektronik SK 481 100	
J1	Jumper Wire		
MP1_F, MP2_F, MP3_F, MP4_F	Hexagonal Spacer Female	M3x10mm	
MP1_M, MP2_M, MP3_M, MP4_M	Hexagonal Spacer Male	M3x70mm	
Others			
-	BRUSHLESS DC FAN	Xinruilian XIFAN YD5015MS 18V 0.10A	
-	Resonant coil	100µH	
F1	Fuse 15A	Littlefuse 0218015.MRET1P	
G2	Low Dropout Linear Voltage Regulator	Infineon Technologies IFX25401TEV	PG-TO252-5
L3	Input filter inductor - Toroidal	340µH - 15Arms	
P-, P+, START/STOP	Through Hole Tactile Switch	Omron Electronics B3F-4055	
R13	MOV Resistor	Standard MOV 471/2500A	
RCSense	Top Adjustment Potentiometer	Bourns PVG3G102C01R00	
T1	MOSFET N-Ch 60V 230mA	Infineon Technologies BSS138	SOT-23
U1	Operational Amplifier 10-MHz, Low-Power, Low Noise	Texas Instrument TLV6741	SC70-5

Appendix

[1] Infineon Technologies AG: AN2018-34, IPD Protect - features, description and design tips, Revision 1.3.

[2] Infineon Flash Programmer Memtool for XMC1000 family, https://www.infineon.com/dgdl/Infineon-TOOL_Tutorial_Memtool_XMC1-TR-v01_00-EN.pdf?fileId=5546d462525dbac401530e93cdc9061f, July 2016

[3] Teledyne LeCroy: Probes – Probe Parts and Kits – Ground Spring – PK007-016, https://teledynelecroy.com/probes/probe-parts-and-kits/pk007-016, September 2017

[4] Teledyne LeCroy: Probes – Probe Parts and Kits – Probe Tip to PCB Adapter – PK106-4, http://teledynelecroy.com/probes/probemodel.aspx?modelid=96&categoryid=3&mseries=434, September 2017

[5] PEM CWT1 Ultra-Mini Rogowski Current Waveform Transducer, http://www.pemuk.com/products/cwt-current-probe/cwt-ultra-mini.aspx

[6] Emtest Compact NX5 - Multifunctional test generator for transients (EFT/Burst, Surge & Power Fail) up to 5.5 kV, https://www.emtest.com/products/product/135120100000013883.php

[7] Infineon Technologies AG: IEWS20R5135IPB, TRENCHSTOP™ F Series Protected IGBT datahseet, Revision 2.0, https://www.infineon.com/dgdl/Infineon-IEWS20R5135IPB-DS-v02_00-EN.pdf?fileId=5546d46265e7dffd0165eccd826043e0, June 2018

[8] Electromagnetic compatibility (EMC) - Part 4-1: Testing and measurement techniques - Overview of IEC 61000-4 series https://webstore.iec.ch/publication/24660, April 2016

Revision history

Document version	Date of release	Description of changes
v1.0		First release – Giuseppe De Falco
V1.1	15-01-2020	BOM update; additional minor changes.

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