

# EVAL\_2.5KW\_CCM\_4PIN

## 2.5 kW PFC evaluation board with CCM PFC Controller ICE3PCS01G

### About this document

#### Scope and purpose

The 2.5 kW evaluation board is a great example of a full Infineon solution, and includes a PFC Controller, MOSFET Driver and Silicon Carbide (SiC) Diode in order to evaluate the 4pin functionality with its advantages for efficiency and signal quality.

Furthermore, the reader will be presented with additional information on how to use the evaluation board, how the 600 V CoolMOS™ C7 behaves in this PFC application and the benefits that will be achieved by using the TO-247 4pin package.

#### Intended audience

This document is intended for qualified engineers and technicians who are experienced in power electronics technology and want to improve their PFC applications by using 4pin devices.

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## Introduction

## General safety instruction

- Attention:** *The evaluation board contains high voltages that could be deadly for the users. Furthermore no circuits on the board are isolated from the line input. Due to the high power density, the components on the board and/or the heatsink can reach a very high temperature that can cause a burning risk when touched directly. Users should be qualified engineers and technicians who are experienced in power electronics technology and make sure that no danger or risk may occur while operating this board.*
- Note:** *After the operation of the evaluation board, the DC-Link capacitors C21 and C24 may still store a high energy for several minutes, which is indicated by the illumination of LED1. The Capacitors C21 and C24 must be discharged until the LED1 is not lit before touching the board directly.*
- Note:** *The board is designed for a maximum input current of 14 A. To operate it at a mains input of 90 V<sub>AC</sub> the output power must be correspondingly reduced so that the maximum current limit is not exceeded.*
- Note:** *The normal output power of the board is designed for up to 2.5 kW so that the device temperature remains below 80°C. Users can operate the board to a peak output power of 3000 W. However, it is not recommended to operate at this output power level for longer than 2 minutes. In this case, the device temperature of the MOSFET (DUT1) and/or diode (DUT1) can exceed 100°C which presents a risk of burning!*
- Note:** *The EMC filter on the board is designed to cover a wide range of applications according to the standard CISPR 22. Nevertheless, the EMC performance of the board is very dependent on the application settings and load conditions. Users may modify the EMC filter using methods like wire shielding to make their own applications comply with the standard. To fulfill other standards required by different applications, users may need to apply extra or different components.*
- Note:** *The evaluation board is designed to meet any certification requirements. Infineon Technologies will not guarantee any compliance with local certificate requirements or recommendations. The usage of the evaluation board is strictly at your own risk.*

## To get started

- Step 1: Complete connections “V<sub>in</sub>”, “V<sub>out</sub>”, “KL01”, “J11”& “J11a”
  - V<sub>out</sub> : Connect with an output load which is able to operate at 400 V<sub>DC</sub>
  - V<sub>in</sub> : Connect L, N and Earth to the 90 V<sub>AC</sub>...265 V<sub>AC</sub> main power supply
  - KL01 : Optional DC-Power that is used to power-up the cooling fans externally see: Thermal concept
- Step 2: Switch on the main power supply and check V<sub>out</sub> for the presence of 400 V<sub>DC</sub>
- Step 3: For more instructions please refer to the following guidelines.

## 1 Introduction

### 1.1 Evaluation board

This document describes the evaluation board EVAL\_2.5KW\_CCM\_4PIN, which is designed to evaluate the performance of the TO-247 4pin CoolMOS™ C7 family. The board is developed for laboratory use only and does not serve any commercial purpose. Before operating the evaluation board, please read the general safety instruction section.

The aim of this document is to help the customers to get familiar with the evaluation board, and to investigate the different behavior of conventional 3pin devices compared to the high performance TO-247 4pin CoolMOS™ devices within a PFC application.

The following table gives the main technical specifications of the evaluation board:

**Table 1 Technical specifications of the 2.5 kW CCM PFC evaluation board**

|                            |                                                                                             |
|----------------------------|---------------------------------------------------------------------------------------------|
| Input voltage              | 85 V <sub>AC</sub> ~ 265 V <sub>AC</sub>                                                    |
| Input current              | 14 A <sub>eff</sub>                                                                         |
| Input frequency            | 47 ~ 63 Hz                                                                                  |
| Output voltage and current | 400 V <sub>DC</sub> , 6.25 A                                                                |
| Output power               | ~ 2.5 kW (at V <sub>in</sub> = 230 V <sub>AC</sub> )                                        |
| Average efficiency         | >95% at 115 V <sub>AC</sub>                                                                 |
| Switching frequency        | Possible range: 40 kHz ~ 250 kHz;<br>Board frequency is set to 65 kHz;<br>Changeable by R20 |
| Power switch               | 4pin and 3pin MOSFET                                                                        |

### 1.2 CoolMOS™ C7

CoolMOS™ C7 ([IPZ60R040C7](#)) achieves extremely low conduction and switching losses per package. The extremely low switching losses enable the designer to operate with higher switching frequencies in order to shrink the magnetic components and increase the power density.

E<sub>oss</sub> reduction brings efficiency benefits at light load, the low Q<sub>G</sub> correlates to faster switching and also lower E<sub>on</sub> and E<sub>off</sub> which gives efficiency benefits across the whole load range.

The CoolMOS™ C7 balances several parameters to give best-in-class performance improves the implementation and ease of use behavior when compared to other fast switching MOSFET families. Moreover, with its broad product portfolio, C7 can address the specific needs of hard switching applications for server, PC power, telecom rectifiers and solar. C7 offers the best-in-class performance on the market today with the lowest R<sub>DS(on)</sub> per package.

### 1.3 thinQ!™ SiC Diode Generation 5

The thinQ!™ Generation 5 Silicon Carbide Diode ([IDH16G65C5](#)) represents Infineon's leading edge technology for SiC Schottky Barrier Diodes. The Infineon proprietary diffusion soldering process, already introduced with generation 3, is now combined with a new, more compact design and thin wafer technology. The result is a new

## Introduction

family of products showing improved efficiency over all load conditions, resulting from both the improved thermal characteristics and a lower figure of merit ( $Q_c \cdot V_i$ ). It also offers improved dv/dt robustness up to 100 V/ns which enables very fast switching. This is a perfect fit to the fast switching CoolMOS™ C7 family.

### 1.4 CCM-PFC Controller

The evaluation board presented here is a 2.5 kW power factor correction (PFC) circuit with 85~265 V<sub>AC</sub> universal input and an output of 400 V<sub>DC</sub>. The continuous conduction mode (CCM) PFC Controller ([ICE3PCS01G](#)) is employed in this board to achieve a unity power factor.

The ([ICE3PCS01G](#)) is specially designed for applications of power supplies used in PC, server, and telecom, requiring high efficiency and an excellent power factor. The voltage loop compensation is integrated digitally for better dynamic response and lower design effort. Recognized for its highly integrated design, ([ICE3PCS01G](#)) can achieve the full requirements of the PFC application implemented in the 14pin in DSO14 package while minimizing the number of peripheral components. The gate switching frequency is adjustable from 21 kHz to 250 kHz and is able to synchronize with an external switching frequency from 50 kHz to 150 kHz.

### 1.5 Gate Driver ICs (EiceDRIVER™ Compact)

The Infineon EiceDRIVER™ family (IEDI60N12AF) offers a wide range of CT (Coreless Transformer) based Gate Drivers that support all topologies using CoolMOS™ in 3 and 4pin packages. CT utilizes on-chip coupled inductors realized in the existing metal layers to transmit the gate drive signals from the input to the output stage with isolation of more than 1200 V provided by a thick inter-metal oxide. This approach offers high speed and very good common-mode transient immunity, which is crucial to drive the MOSFET with fast voltage transients.

With the use of IEDI60N12AF on this evaluation board, the benefits of Infineon's TO-247 4pin package demonstrates very fast switching behavior alongside clean gate waveforms. Based on the CT technique, the Kelvin source can be completely isolated from the power source and higher efficiency and better system stability can be achieved.

The 6 A capability of the driver output is necessary to switch the 19 mΩ CoolMOS™ very quickly. Even if the board is used with higher ohmic devices, it is an advantage to have a very strong drive capability in order to minimize gate oscillation at fast switching.

The output of the driver features separate positive and negative outputs for easy tuning. The turn-on and turn-off behavior of the MOSFET can be changed by using different gate resistors. This is connected to the different outputs without any diode for separating the turn-on and turn-off phases.

In the evaluation board the two output pins are joined together. When creating a parallel design for 3 and 4pin devices two different changeable gate resistors are created. In order to keep the complexity low, the design did not take the opportunity to separate turn-on and turn-off gate resistors as this is not highly relevant for efficiency analysis.

This driver is the only currently known driver that has a CMTI (common mode transient immunity) of dv/dt ≥ 100 V/ns which is required for high transition noise feedback from the drain to the gate signal in a fast switching mode.

## 2 Application

The evaluation board described within this document is based on a CCM PFC (continuous conduction mode power factor correction). The principal schematic is shown below.

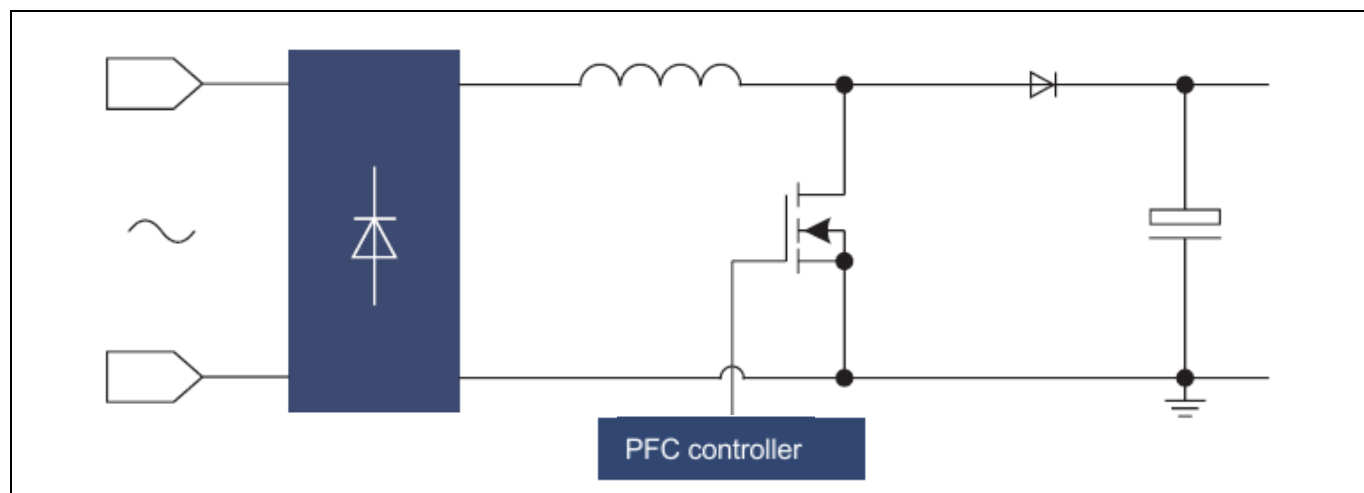


Figure 1 Schematic of the topology



Figure 2 EVAL\_2.5kW\_CCM\_4PIN evaluation board

## 3 Circuit description

### 3.1 Line input

The AC line input side does not include any input fuse. Please ensure proper external over-current protection. The input is fitted with 2 connectors in order to offer proper input voltage measurement for precise power metering. The choke L3, X2-capacitor C4/C5/C23 and Y1-capacitors C17/CY18 are used to suppress common and differential mode noise. R\_NTC2 is placed in series to limit inrush current during each power on. A relay is mounted across the R\_NTC2 to short the resistor when  $V_{OUT}$  is higher than ~60 V.

### 3.2 Power stage – boost type PFC converter

After the bridge rectifier GL1 and GL2, there is a boost type PFC converter consisting of L1, IPZ60R040C7, IDH16S65C5, C30, C8, C21 and C24. The seventh generation CoolMOS™ IPZ60R040C7 and the SiC Diode IDH16S65C5 share the same heat sink so that the system heat can be equally spread. Output capacitor C30, C8, C21 and C24 provides energy buffering to reduce the output voltage ripple (100 Hz at 50 Hz AC input) to an acceptable level and to meet the hold-up time requirement.

#### 3.2.1 Separate source Power MOSFET

Infineon's TO-247 4pin package enables significant efficiency improvements in hard switching topologies for CoolMOS™ high voltage Power MOSFETs. The fourth pin acting as a Kelvin source can be used to reduce the parasitic inductance of the source lead of the Power MOSFET.

The benefit will be seen in various hard switching topologies such as Continuous Conduction Mode Power Factor Correction (CCM PFC), Boost and Two Transistor Forward (TTF). The new package offers improved efficiency by reducing switching losses up to 8% which equates to 3.5 W of saved power in a CCM Mode PFC running at 1.2 kW, which is equal to 0.3% extra full load efficiency compared to the same MOSFET in the standard TO-247 3pin package.

The evaluation board is available to test the physically identical devices in either 3pin or 4pin (with sense source) configuration. The standard setting of the set-up is 4pin configuration. To change the testing device to 3pin configuration, it is necessary to open the connection point J7 and connect the solder point J8 or J6. Please check chapter 9 on page 18 for more detailed information.

### 3.3 PWM control of boost converter

The ICE3PCS01G is a 14pin control IC for power factor correction converters and is suitable for wide range line input applications from 85 to 265 V<sub>AC</sub> with overall efficiency above 97%. The IC supports converters in boost topology and it operates in continuous conduction mode (CCM) with average current control.

The IC operates with a cascaded control; the inner current loop and the outer voltage loop. The inner current loop of the IC controls the sinusoidal profile for the average input current. It uses the dependency of the PWM duty cycle on the line input voltage to determine the corresponding input current. This means the average input current follows the input voltage as long as the device operates in CCM. Under light load condition, depending on the choke inductance, the system may enter into discontinuous conduction mode (DCM) by enlarging the harmonics, but still meeting the Class D requirement of IEC 1000-3-2.

The outer voltage loop controls the output bulk voltage, integrated digitally within the IC. Depending on the load condition, internal PI compensation output is converted to an appropriate DC voltage that controls the amplitude of the average input current.



## Circuit description

The IC is equipped with various protection features to ensure safe operating condition for both the system and the device.

### 3.4 Thermal concept

The evaluation board is fitted with different thermal management for the two different heat sinks mounted on the board. The thermal concept for the input bridge rectifier is managed by an adjustable-speed cooling fan. The fan speed is adjustable to optimize between noise generation and cooling by changing resistor R28 near the fan for the bridge rectifier.

The main heat sink for the DUT offers cooling and heating functionality in parallel. To heat up the heat sink to target temperature (standard setting = 50°C), it is necessary to:

- Set Jumper “J11a” to “Extern”
- Set Jumper “J11” to “Extern”
- Supply a galvanically isolated 12 V to connector KL01 between GND and +12 V with current limit of 1 A
- Supply 17 V to connector KL01 between GND and heating with current limit of 3.5 A
- Set R4 according to the temperature, which is intended for the devices

The control circuit will then heat up the heat sink to the adjusted temperature that is set by the variable resistor R4. Once the temperature is reached it will start the fan to cool the system. Thus, it is possible to operate the application with regulated heat sink temperature for the MOSFET and the diode.

#### 3.4.1 Operate without thermal control feature

If one wants to operate the evaluation board without any external heating it is recommended to use the internal cooling option through the following setting:

Change the wire connected to “J11a” to the bottom layer and insert 3pin connector for jumper into the PCB.

- Set Jumper “J11a” to “Intern”
- Set Jumper “J11” to “Intern”



Figure 3 Wire change from top layer to bottom layer



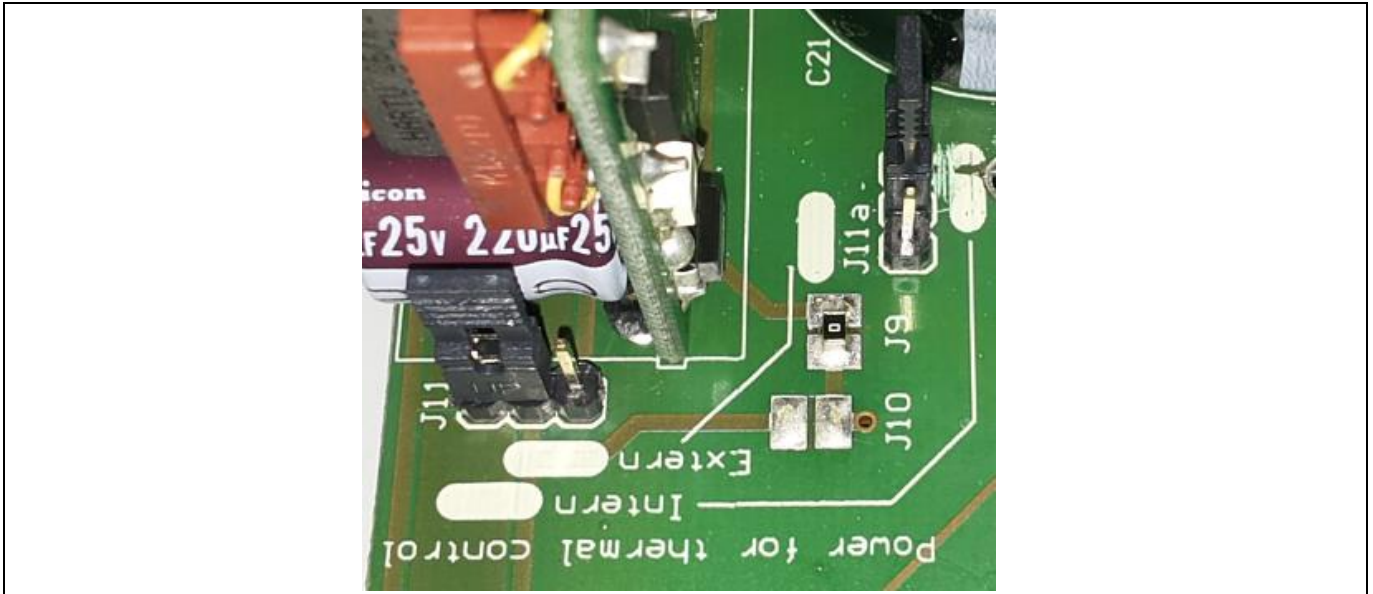


Figure 4 Setting for internal cooling powering

With this setting the board will permanently cool the input bridge rectifier and keep the temperature of the diode and the MOSFET below the temperature setting by the changeable resistor R4.

If the board has been modified as described above and one wants to investigate the efficiency without the thermal power losses, please set the Jumper "J11" and "J11a" to the "Extern" position.

## 4 Circuit operation

### 4.1 Soft startup

During power up when the  $V_{OUT}$  is less than 96% of the rated voltage, the internal voltage loop output of the IC increases from initial voltage under soft-start control. This results in a controlled linear increase of the input current from 0 A, thus reducing the current stress in the power components.

Once  $V_{OUT}$  has reached 96% of the rated level, the soft-start control is released to achieve good regulation and dynamic response and the VB\_OK pin delivers 5 V indicating the PFC output voltage is in the normal range.

### 4.2 Gate switching frequency

The switching frequency of the PFC converter can be set with an external resistor  $R_{FREQ}$  at pin FREQ with reference to pin SGND. The voltage at pin FREQ is typically 1 V. The corresponding capacitor for the oscillator is integrated into the device and the  $R_{FREQ}/\text{frequency}$  is given in Figure 3. The recommended operating frequency range is from 21 kHz to 250 kHz. As an example, a  $R_{FREQ}$  of 43 k $\Omega$  at pin FREQ will typically set a switching frequency  $f_{SW}$  of 100 kHz.

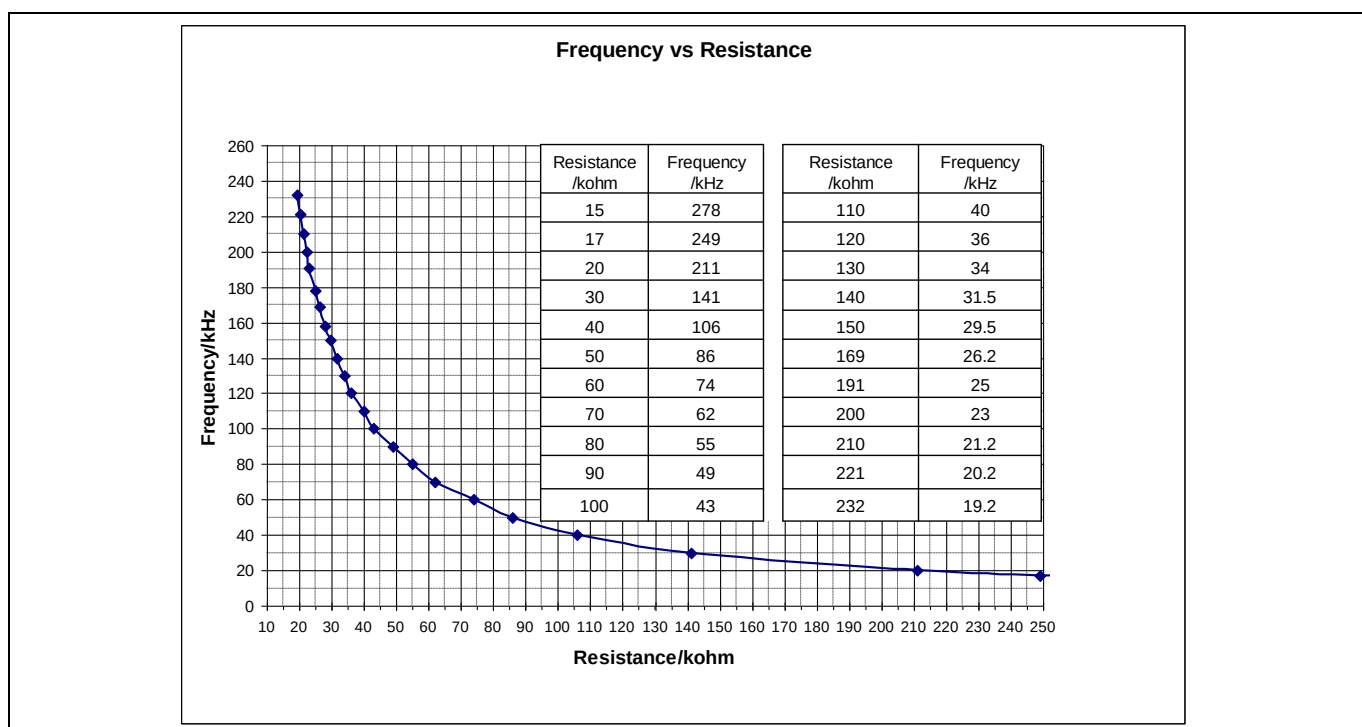


Figure 5 Frequency setting

The switching frequency can be changed by the variable resistor R31. For easy adjustment please use the X8 connection pins to measure the value. Please make sure to connect the positive cable of the measurement tool to the left (towards the side of the fan) pin of X8. To use the table and plot in Figure 5 you have to subtract 10 k $\Omega$  from the serial resistance R15. If the polarity of the measurement tool is flipped compared to the way described above, please subtract 23 k $\Omega$  due to additional internal resistance from the controller itself. Please make sure the board is not connected to the main supply when connecting the measuring instrument to X8!

## Circuit operation

Therefore, the measureable resistance on X8 for the standard setting of 65 kHz will be 56 k $\Omega$  with positive polarity on the left pin and 43 k $\Omega$  with positive polarity on right pin.

### 4.3 Protection features

#### 4.3.1 Open loop protection (OLP)

Open-loop protection is available for this IC to safeguard the output. Whenever voltage  $V_{SENSE}$  falls below 0.5 V, or  $V_{OUT}$  falls below 20% of its rated value, it indicates an open loop condition (i.e.  $V_{SENSE}$  pin not connected). In this case, most of the blocks within the IC will be shutdown. It is implemented using a comparator with a threshold of 0.5 V.

#### 4.3.2 First over-voltage protection (OVP1)

Whenever  $V_{OUT}$  exceeds the rated value by 8%, the first over-voltage protection OVP1 is active. This is implemented by sensing the voltage at pin  $V_{SENSE}$  with respect to a reference voltage of 2.7 V. A  $V_{SENSE}$  voltage higher than 2.7 V will immediately block the gate signal. After the bulk voltage falls below the rated value, the gate drive resumes switching again.

#### 4.3.3 Peak current limit

The IC provides a cycle-by-cycle peak current limitation (PCL) that is active when the voltage at pin  $I_{SENSE}$  reaches -0.2 V. This voltage is amplified by a factor of -5 and connected to the comparator with a reference voltage of 1.0 V. A 200 ns deglitcher after the comparator improves noise immunity to the activation of this protection. In other words, the current sense resistor should be designed for lower than -0.2 V PCL in normal operation.

#### 4.3.4 IC supply under voltage lockout

When the voltage  $V_{CC}$  is below the under voltage lockout threshold  $V_{CCUVLO}$  (typically 11 V) the IC will turn off the gate for safety reasons. The current consumption reduces to 1.4 mA.

#### 4.3.5 Bulk voltage monitor and enable function (VBTHL\_EN)

The IC monitors the bulk voltage status through the  $V_{SENSE}$  pin and outputs a TTL signal to enable the PWM IC or control the inrush relay. During soft-start, once the bulk voltage is higher than 95% rated value, pin  $VB\_OK$  outputs a high level. The threshold to trigger the low level is determined by the pin  $VBTHL$  where the voltage is adjustable externally.

When pin  $VBTHL$  is pulled down externally to lower than 0.5 V, most function blocks are turned off and the IC enters into a standby mode for low power consumption. When the disable signal is released the IC recovers by soft-start.

## 5 Circuit diagram

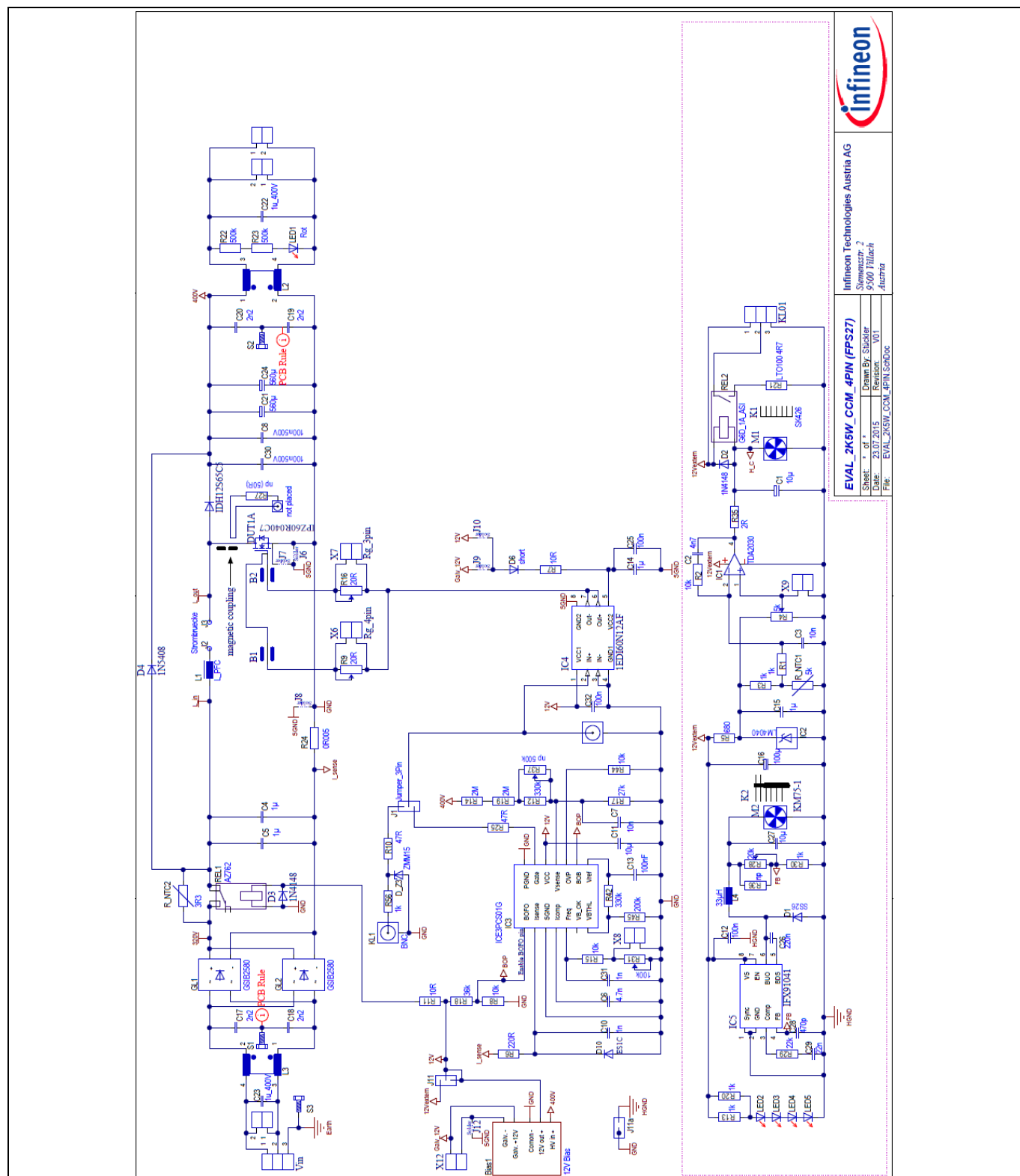
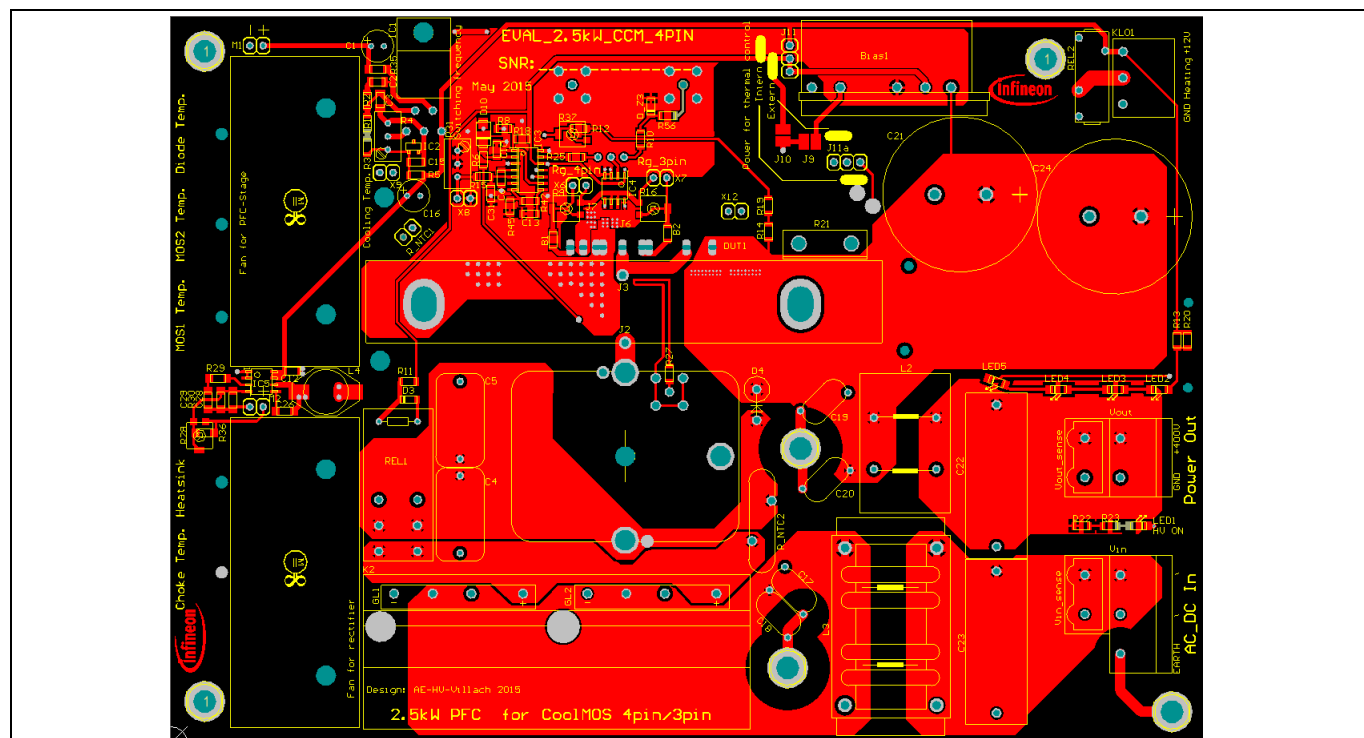


Figure 6 Whole evaluation board schematic

## 6 PCB layout



**Figure 7**      **PCB top layer view**

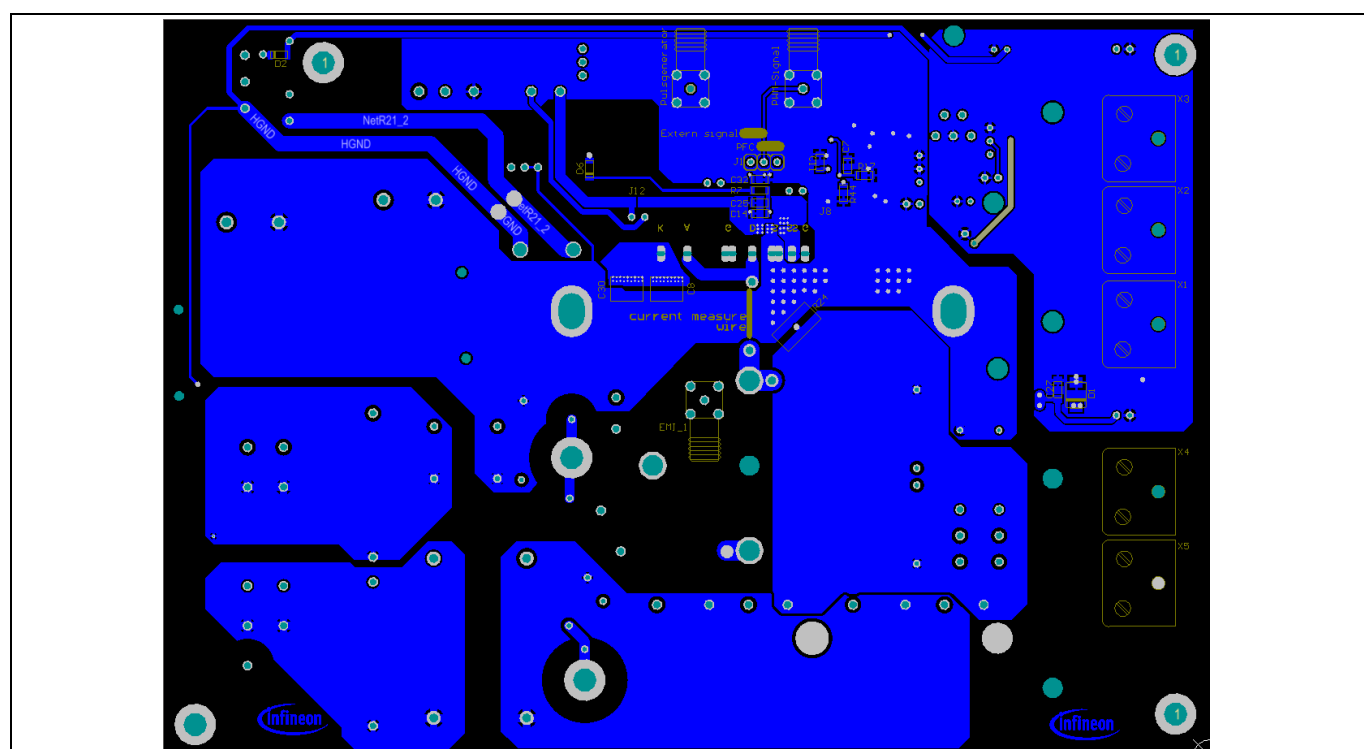


Figure 8 PCB bottom layer view

## Component list

## 7 Component list

Table 2 Component list

| Designator         | Value                  | Description                                       |
|--------------------|------------------------|---------------------------------------------------|
| B1, B2             | closed with 0 $\Omega$ | Placeholder for ferrite bead, 0 $\Omega$ resistor |
| Bias1              | 12 V Bias              | Bias adapter                                      |
| C1                 | 10 $\mu$ F             | 25 V                                              |
| C2                 | 4n7 F                  | 25 V                                              |
| C3                 | 10 nF                  | 25 V                                              |
| C4, C5             | 1 $\mu$ F              | x-capacitor                                       |
| C6                 | 4.7 nF                 | 25 V                                              |
| C7                 | 10 nF                  | 25 V                                              |
| C8, C30            | 100 nF / 500 V         | VJ1825Y104KXEAT                                   |
| C10, C31           | 1 nF                   | 25 V                                              |
| C11                | 10 $\mu$ F             | 25 V                                              |
| C12, C25, C32      | 100 nF                 | 25 V                                              |
| C13                | 100 nF                 | 25 V                                              |
| C14, C15           | 1 $\mu$ F              | 25 V                                              |
| C16                | 100 $\mu$ F            | 25 V                                              |
| C17, C18, C19, C20 | 2.2 nF                 | Y-capacitor                                       |
| C21, C24           | 560 $\mu$ F            | EETHC2G561KA or<br>EKMR421VSN561MR50S             |
| C22, C23           | 1 $\mu$ F / 400 V      | BFC237351105; Farnell 1215540                     |
| C26                | 220 nF                 | 25 V                                              |
| C27                | 10 $\mu$ F             | 25 V                                              |
| C28                | 470 pF                 | 25 V                                              |
| C29                | 22 nF                  | 25 V                                              |
| D1                 | SS26                   |                                                   |
| D2, D3             | 1N4148                 |                                                   |
| D4                 | 1N5408                 |                                                   |
| D6                 | Short                  | 0 $\Omega$                                        |
| D10                | ES1C                   | 1 A 150 V fast diode                              |
| DUT1               | IPZ60R040C7            |                                                   |
| D_Z3               | ZMM15                  | 1N4734A                                           |
| EMI_1              | Not placed             | EMI adapter                                       |
| GL1, GL2           | GSIB2580               | GSIB2580                                          |
| IC1                | TDA2030                | Mount with M2.5x6                                 |
| IC2                | LM4040                 | LM4040D20IDBZRG4                                  |
| IC3                | ICE3PCS01G             | PFC CCM controller                                |
| IC4                | 1EDI60N12AF            | 6 A isolated MOS driver                           |



## Component list

| Designator             | Value                                      | Description                                                              |
|------------------------|--------------------------------------------|--------------------------------------------------------------------------|
| IC5                    | IFX91041                                   | 1.8 A step down switching regulator                                      |
| J1, J11                | Jumper_3pin                                | SPC20486                                                                 |
| J2                     | Current measurement bridge                 | 1.25 mm isolated copper wire                                             |
| J3                     | Drilling                                   | U-shape-Cu-wire 1.25 mm 2 cm distance                                    |
| J6                     | Open                                       | Solder jumper; 4pin as 3pin                                              |
| J7, J12                | Close with solder or 0 $\Omega$ resistance | Solder jumper; driver ground to SS, Solder jumper; isolated driver power |
| J8, J10                | Open                                       | Solder jumper; 3pin ground, Solder jumper; driver power none isolated    |
| J9                     | Close with solder or 0 $\Omega$ resistance | Solder jumper; isolated driver power                                     |
| K1                     | SK426                                      | 100 mm long; mound with 2xM4x15                                          |
| K2                     | KM75-1                                     | KM75-1 +4clip 4597; Fischer                                              |
| KL1                    | BNC                                        | Oscilloscope_function_generator                                          |
| KL01                   | Heating                                    | MSTBA 2,5/ 3-G                                                           |
| KL01-S                 | Complement                                 | MSTB 2,5/3-ST                                                            |
| L1                     | L_PFC                                      | 2times 77083A7 64wind_1.15mm                                             |
| L2                     | 10 A 100 $\mu$ H                           | Würth 744824101                                                          |
| L3                     | 8120-RC                                    | BOURNS_8120-RC_2m4H_17A                                                  |
| L4                     | 33 $\mu$ H                                 | 74454133                                                                 |
| LED1                   | Red                                        | Power on LED                                                             |
| LED2, LED3, LED4, LED5 | Blue                                       | Power on LED                                                             |
| M1, M2                 | Fan 60 mm                                  | PMD1206PTB1-A                                                            |
| M1, M2                 | Finger guard for Fan 60 mm                 | LZ28CP                                                                   |
| PWM-Signal             | SMA                                        | Oscilloscope_Function_generator                                          |
| R1, R3, R13, R20, R56  | 1 k $\Omega$                               | 5%                                                                       |
| R2, R8, R15, R44       | 10 k $\Omega$                              | 5%                                                                       |
| R4                     | 5 k $\Omega$                               | 67WR20KLF                                                                |
| R5                     | 680 $\Omega$                               | 5%                                                                       |
| R6                     | 220 $\Omega$                               | 5%                                                                       |
| R7, R11                | 10 $\Omega$                                | 5%                                                                       |
| R9, R16                | 20 $\Omega$                                | 3314G-1-200E                                                             |
| R10, R25               | 47 $\Omega$                                | 5%                                                                       |
| R12, R42               | 330 k $\Omega$                             | 5%                                                                       |
| R14, R19               | 2 M $\Omega$                               | 5%                                                                       |
| R17                    | 27 k $\Omega$                              | 5%                                                                       |

## Component list

| Designator             | Value                  | Description                                    |
|------------------------|------------------------|------------------------------------------------|
| R18                    | 36 k $\Omega$          | 5%                                             |
| R21                    | LTO100 4R7             | Include two 20F2617 Bürklin connector          |
| R22, R23               | 500 k $\Omega$         | 10%                                            |
| R24                    | 0R005                  | FCSL90R005FE                                   |
| R27                    | Np                     |                                                |
| R28                    | 20 k $\Omega$          | 23AR20KLFTR                                    |
| R29                    | 22 k $\Omega$          | 5%                                             |
| R30                    | 1 k $\Omega$           | 10 V                                           |
| R31                    | 100 k $\Omega$         | 67WR100KLF                                     |
| R35                    | 2 R $\Omega$           | 5%                                             |
| R36                    | Np                     |                                                |
| R37                    | Np 500 k $\Omega$      | 5%                                             |
| R45                    | 200 k $\Omega$         | 5%                                             |
| REL1                   | AZ762                  | 12 V                                           |
| REL2                   | G6D_1A_ASI             | 12 V                                           |
| R_NTC1                 | 5 k $\Omega$           | B57560G502F mound in K1 under MOS              |
| R_NTC2                 | 3R3 $\Omega$           | R_SL22                                         |
| S1, S2, S3, S4, S5, S6 | SCREW_M4               | 3 cm distance holder                           |
| S1, S2, S3, S4, S5, S6 | Mother M4              | M4 screw nut                                   |
| S1, S2, S3, S4, S5, S6 | Washer M4              | washer M4                                      |
| V <sub>in</sub>        | HV <sub>in</sub>       | GMSTBA 2,5/ 3-G-7,62 and GMSTB 2,5/ 3-ST-7,62  |
| V <sub>out</sub>       | V <sub>out</sub>       | GMSTBA 2,5/ 2-G-7,62 and GMSTB 2,5/ 2-ST-7,62  |
| V <sub>out_sense</sub> | V <sub>out_sense</sub> | GMSTBVA 2,5/ 2-G-7,62 and GMSTB 2,5/ 2-ST-7,62 |
| X1                     | Np (Heat sink)         | Thermal couple connector                       |
| X2                     | Np (MOS1)              | Thermal couple connector                       |
| X3                     | Np (Diode)             | Thermal couple connector                       |
| X4                     | Np (Choke)             | Thermal couple connector                       |
| X5                     | Np (MOS2)              | Thermal couple connector                       |
| X6                     | R <sub>g</sub> _4pin   | SPC20485                                       |
| X7                     | R <sub>g</sub> _3pin   | SPC20485                                       |
| X8, X9                 | KL_STANDARD_2          | SPC20485                                       |
| X12                    | Np                     | For adapter power supply                       |

## 8 Boost choke layout

The boost choke on this evaluation board is hand-wound as this is not volume production. It consists of 2 stacked “Kool M $\mu$ ” toroid cores with the part number 77083A7. As a result of the 64 windings with 1.15 mm copper wire the inductance at 100 kHz is about 600  $\mu$ H. As the optimum value of the inductance and magnetic flux depend on the switching frequency and the output power, a change might be needed if the evaluation board is used for different values of power and frequency.



Figure 9 Main inductor

## 9 Source connection options

The source connection for the MOSFET Gate Driver can be set to different options. It is important to make sure that only one of the jumpers J6, J7 or J8 is closed at any time. In Figure 10 the possibilities on the top side of the PCB are shown. For standard through hole packages one can put a  $0\ \Omega$  resistor or a solder bridge on the two surface areas of J6 so that there is an electrical connection if a low inductance gate drive is desired. For standard gate drive inductance it is possible to close J8 (see Figure 11) on the bottom side of the PCB instead J6.

To investigate the performance advantages of the 4pin solution please activate J7 on the top side of the PCB. This will completely separate the gate drive circuit from the power path and therefore result in the cleanest gate drive waveforms.

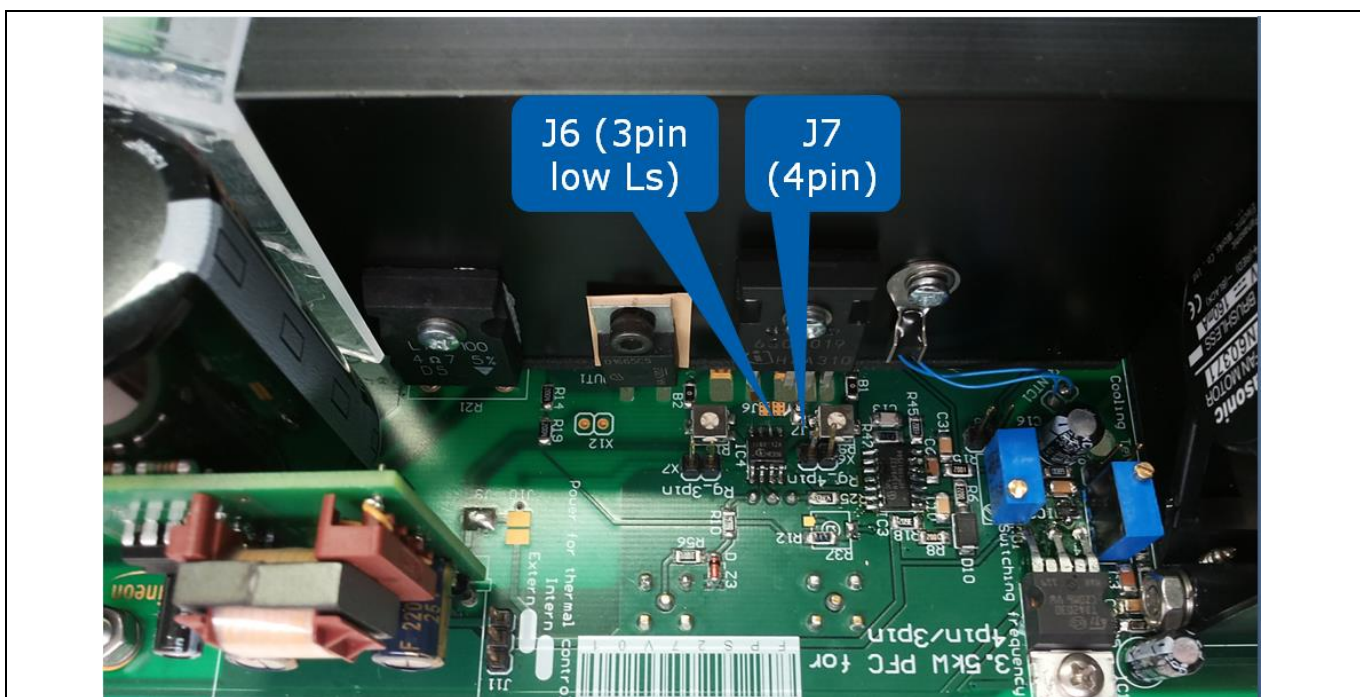


Figure 10 Source connection setting on top side for source sense and low inductance 3pin option

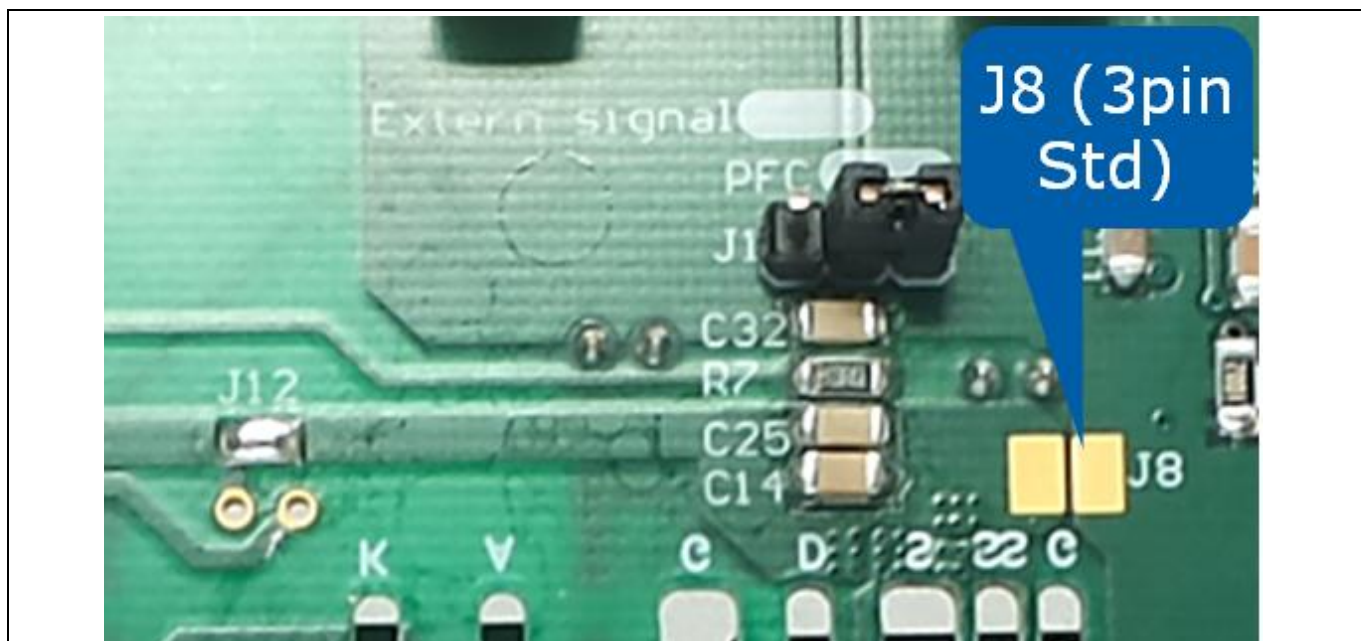


Figure 11 Source connection setting on bottom side for standard 3pin

## 10 Test report

All test conditions are based on a 60°C heat sink temperature.

For the efficiency test it is important to monitor the voltage sensing directly on the input and output power with the  $V_{in\_sense}$  and  $V_{out\_sense}$  right beside the power connections.

**Table 3 Efficiency results of IPZ60R040C7 (4pins) under different line input and loading condition at 100 kHz switching frequency**

| Input               | $V_{IN}$ | $I_{IN}$ | $P_{IN}$ | $V_{OUT}$ | $I_{OUT}$ | $P_{OUT}$ | Eff.      |
|---------------------|----------|----------|----------|-----------|-----------|-----------|-----------|
| 85 V <sub>AC</sub>  | 84.94 V  | 1.4644 A | 123.08 W | 401.49 V  | 0.2877 A  | 115.5 W   | 93.8414%  |
|                     | 84.89 V  | 2.9198 A | 247.12 W | 401.46 V  | 0.5867 A  | 235.53 W  | 95.30997% |
|                     | 84.82 V  | 4.4044 A | 372.57 W | 401.45 V  | 0.8872 A  | 356.17 W  | 95.59814% |
|                     | 84.75 V  | 5.895 A  | 498.4 W  | 401.45 V  | 1.1866 A  | 476.3 W   | 95.56581% |
|                     | 84.68 V  | 7.398 A  | 625.3 W  | 401.42 V  | 1.4857 A  | 596.4 W   | 95.37822% |
|                     | 84.61 V  | 8.924 A  | 753.7 W  | 401.45 V  | 1.7855 A  | 716.8 W   | 95.10415% |
|                     | 84.54 V  | 10.475 A | 884 W    | 401.4 V   | 2.0852 A  | 837 W     | 94.68326% |
|                     | 84.47 V  | 12.034 A | 1014.6 W | 401.36 V  | 2.3852 A  | 957.3 W   | 94.35245% |
|                     | 84.39 V  | 13.616 A | 1146.8 W | 401.38 V  | 2.6852 A  | 1077.7 W  | 93.97454% |
|                     | 84.31 V  | 15.215 A | 1280.2 W | 401.34 V  | 2.9842 A  | 1197.6 W  | 93.54788% |
| 230 V <sub>AC</sub> | 229.84 V | 1.1775 A | 254.23 W | 401.42 V  | 0.6178 A  | 247.99 W  | 97.54553% |
|                     | 229.96 V | 2.2443 A | 507 W    | 401.42 V  | 1.2376 A  | 496.8 W   | 97.98817% |
|                     | 229.88 V | 3.3473 A | 763.2 W  | 401.34 V  | 1.8663 A  | 749 W     | 98.13941% |
|                     | 229.82 V | 4.4451 A | 1016.3 W | 401.32 V  | 2.4872 A  | 998.2 W   | 98.21903% |
|                     | 229.83 V | 5.567 A  | 1274.6 W | 401.29 V  | 3.1173 A  | 1250.9 W  | 98.14059% |
|                     | 229.77 V | 6.677 A  | 1529.3 W | 401.22 V  | 3.7388 A  | 1500 W    | 98.08409% |
|                     | 229.72 V | 7.807 A  | 1789 W   | 401.24 V  | 4.3698 A  | 1753.2 W  | 97.99888% |
|                     | 229.67 V | 8.923 A  | 2044.7 W | 401.18 V  | 4.9897 A  | 2001.6 W  | 97.89211% |
|                     | 229.61 V | 10.054 A | 2304.5 W | 401.19 V  | 5.615 A   | 2252.5 W  | 97.74355% |
|                     | 229.56 V | 11.178 A | 2561.5 W | 401.15 V  | 6.235 A   | 2500.9 W  | 97.6342%  |

In Figures 10 and 11 it can be seen that the full load efficiency is improved by simply changing from 3pin to 4pin configuration. Due to this it is possible to replace a current 3pin PFC MOSFET with a MOSFET of one step higher  $R_{DS(on)}$ . This will help to increase the efficiency all over the power range except full load at low line and will help to meet the Titanium Standard for server SMPS.

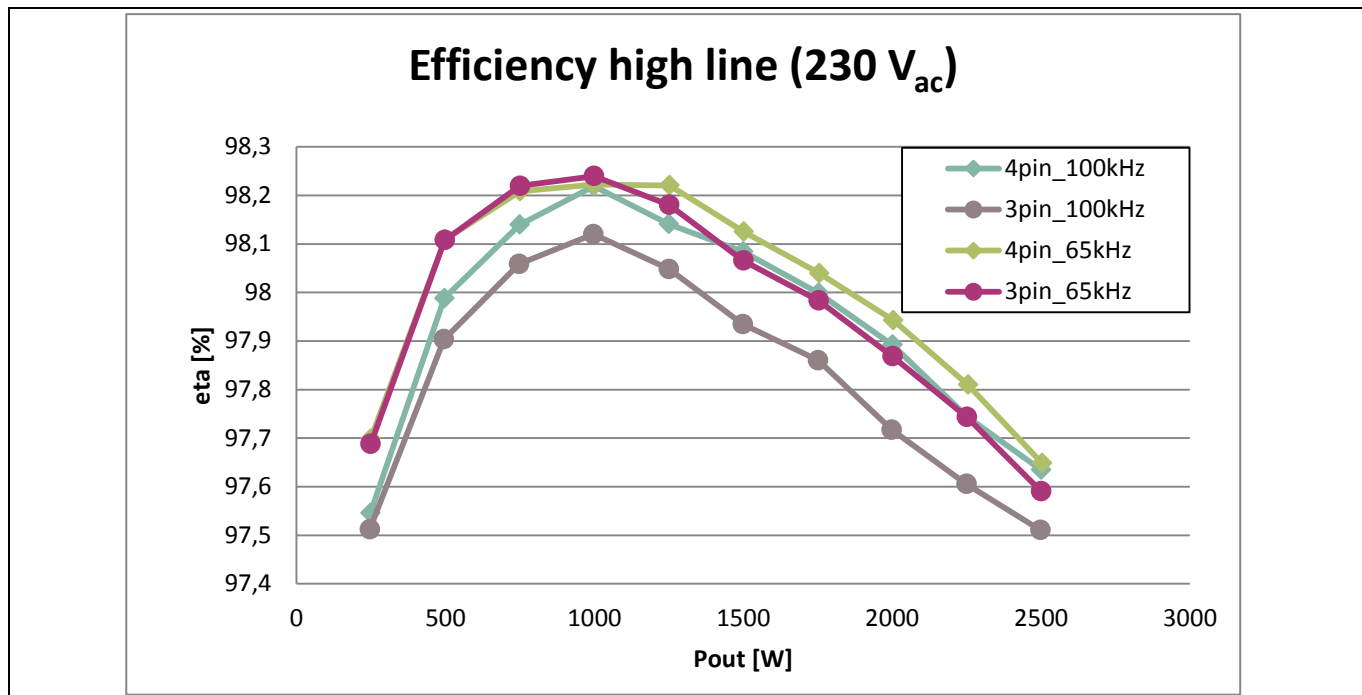


Figure 12 High line efficiency curve with the device IPZ60R040C7 & IDH16G65C5 @ 65 kHz & 100 kHz 3.3 Ω

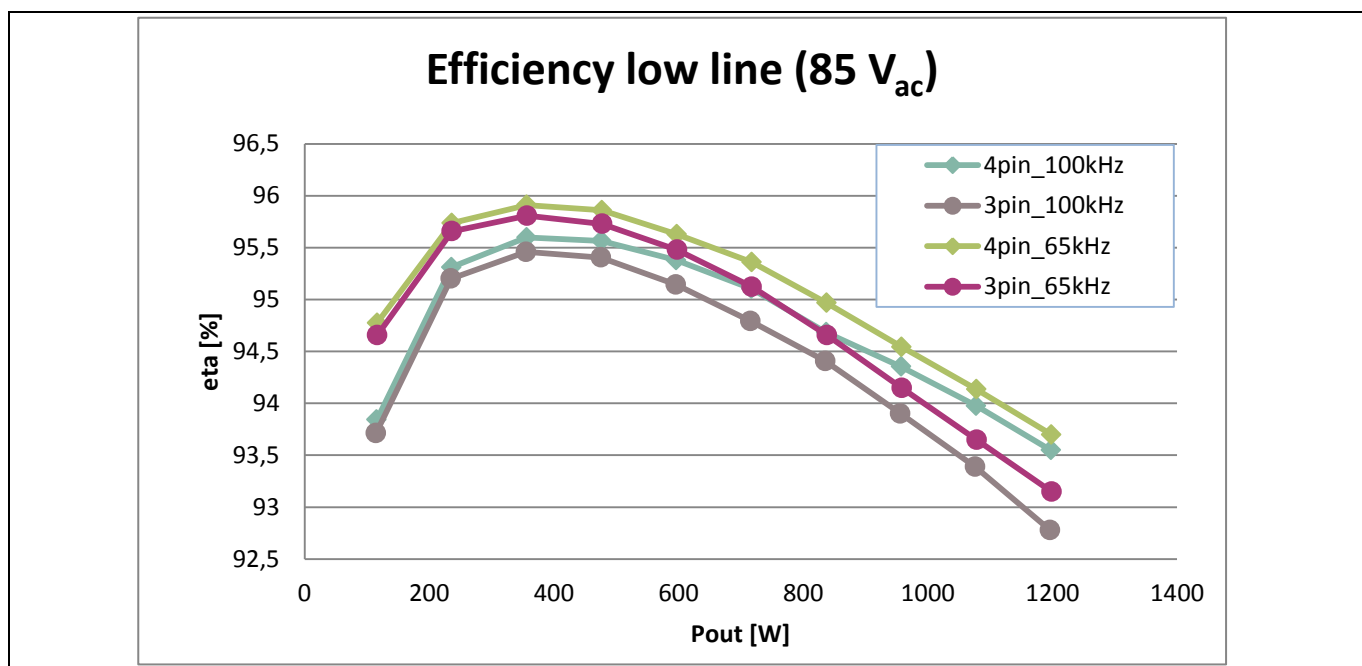


Figure 13 Low line efficiency curve with the device IPZ60R040C7 & IDH16G65C5 @ 65 kHz & 100 kHz 3.3 Ω

## 10.1 Conductive EMI test

EMI is a very important quality factor for a power supply. The EMI data includes the whole spectrum of the SMPS behavior and is split into radiated and conducted EMI. It is most important to investigate the conducted EMI behavior for the described evaluation PFC board, as it is the input stage of any SMPS below a certain power range.



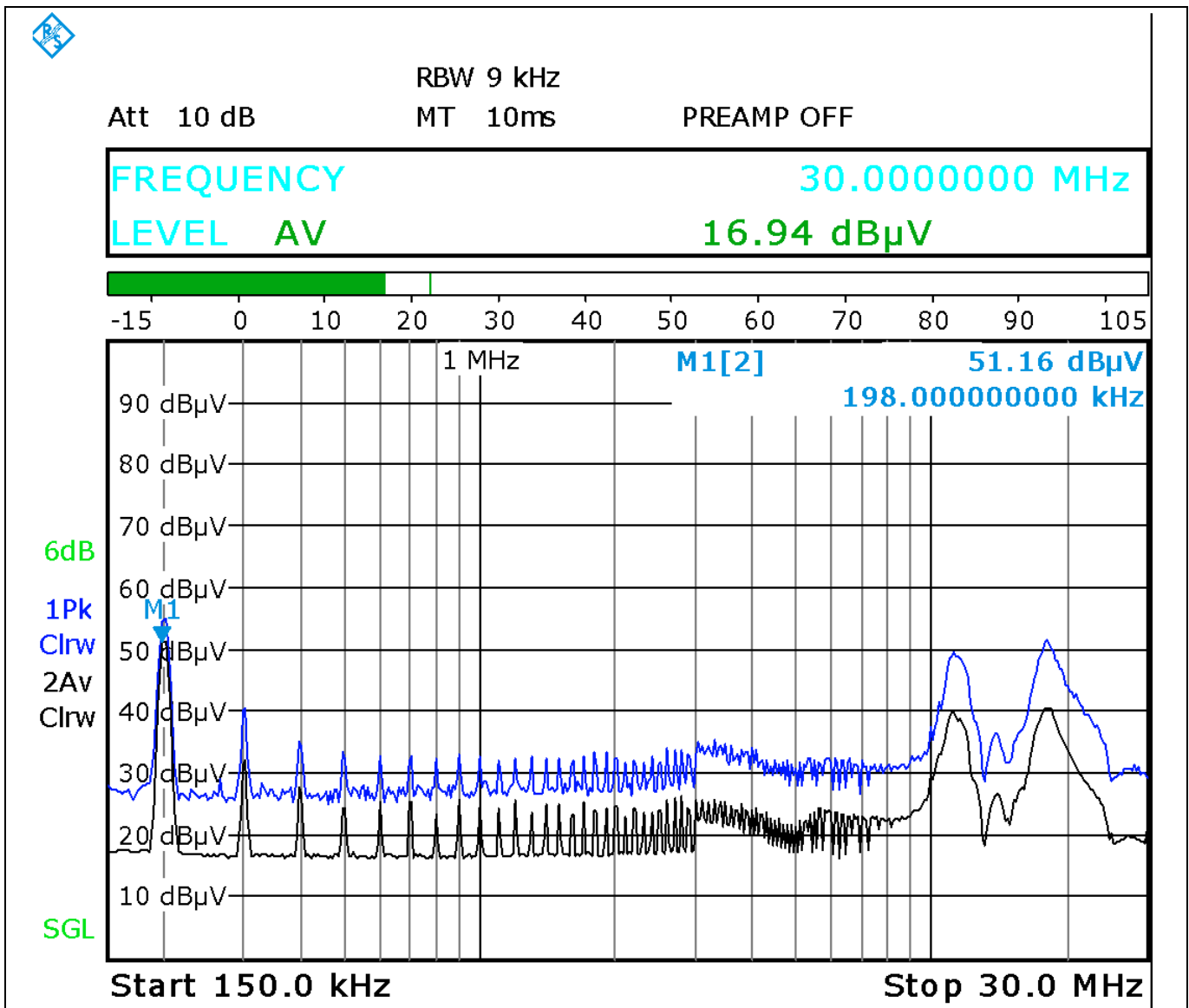


Figure 14 Conductive EMI measurement of the evaluation board at 100 kHz with a resistive load (4 pin configuration)

Based on the EN55022 standard, the line filter can be modified as shown in Figure 15, in order to further improve the EMI quality and provide enough design margin (6 dB) under the standard line requirement:

- Change the X2-capacitor C23 from value 1  $\mu$ F to 1.5  $\mu$ F

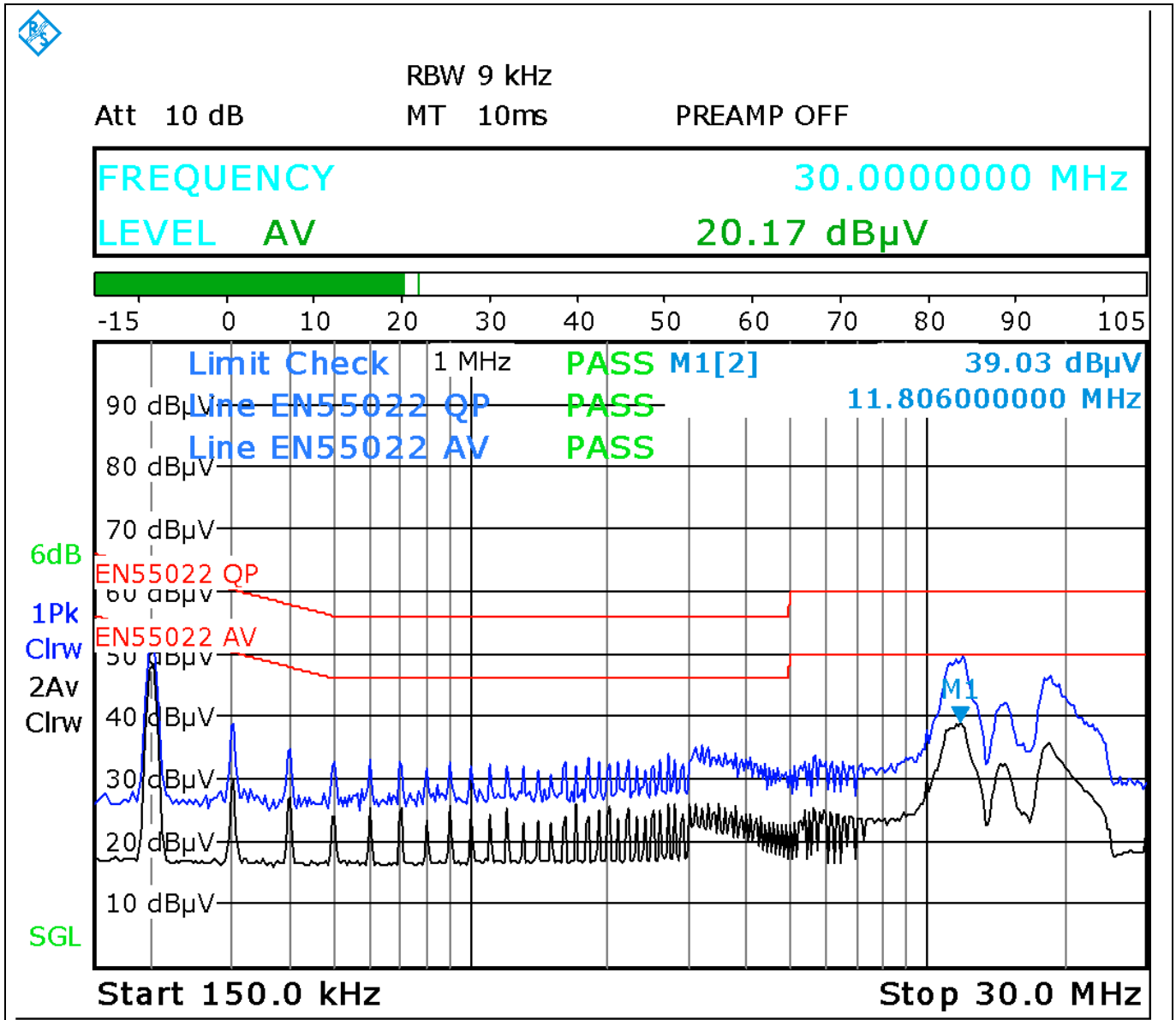


Figure 15 Conductive EMI measurement of the evaluation board at 100 kHz with a resistive load and filter modification (4pin configuration)

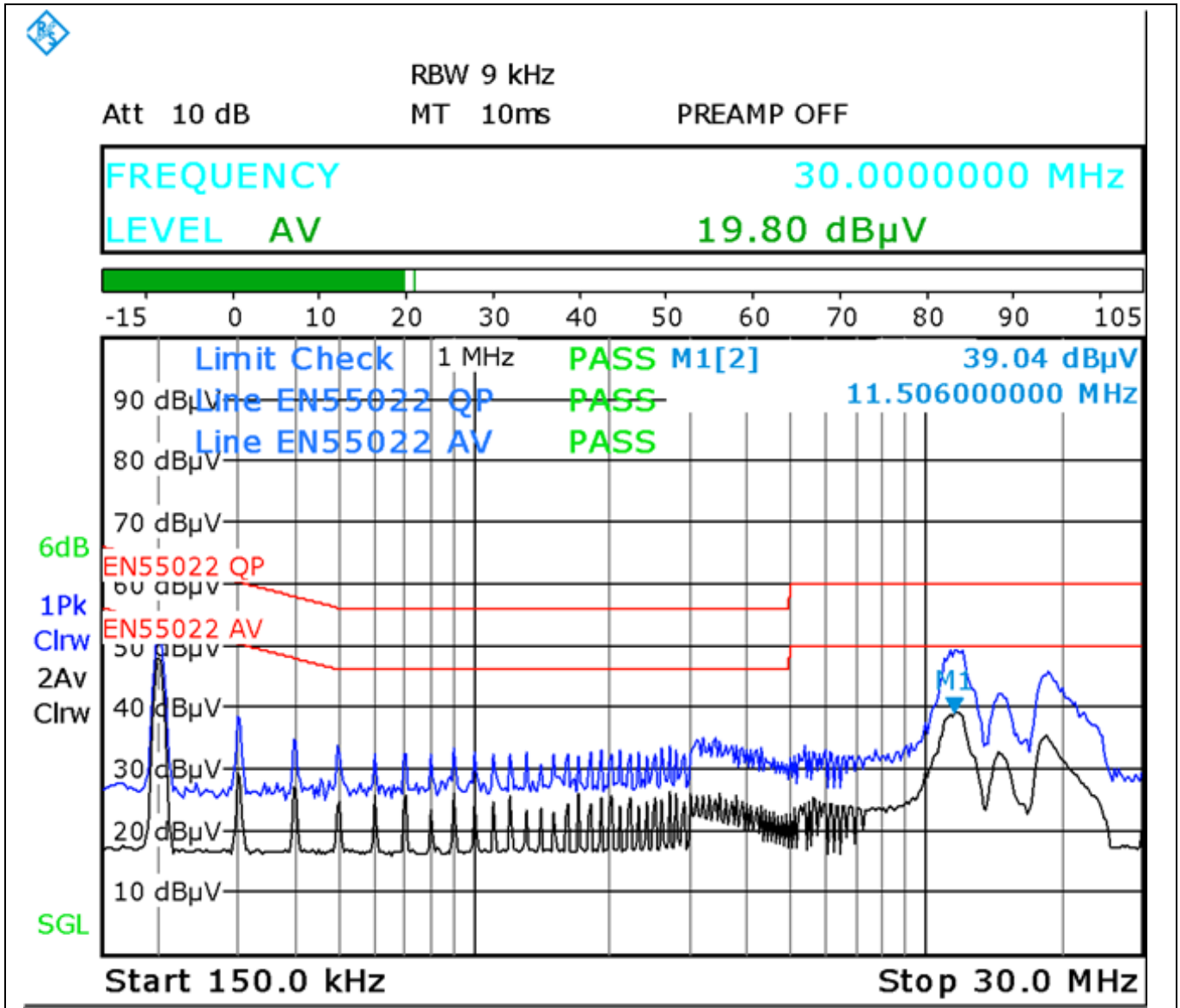


Figure 16 Conductive EMI measurement of the evaluation board at 100 kHz with a resistive load and filter modification (3pin configuration)

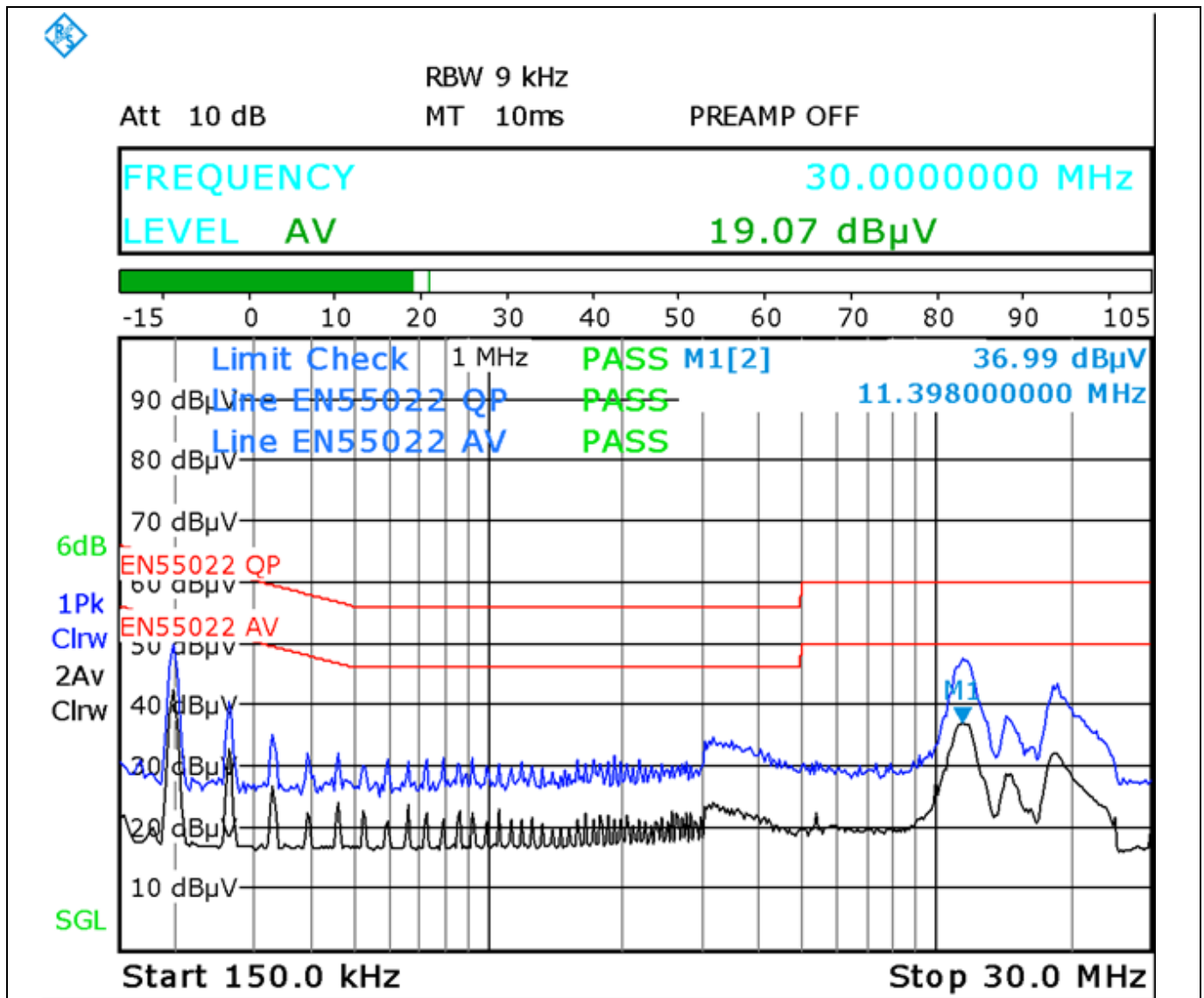


Figure 17 Conductive EMI measurement of the evaluation board at 65 kHz with a resistive load and filter modification (4pin configuration)

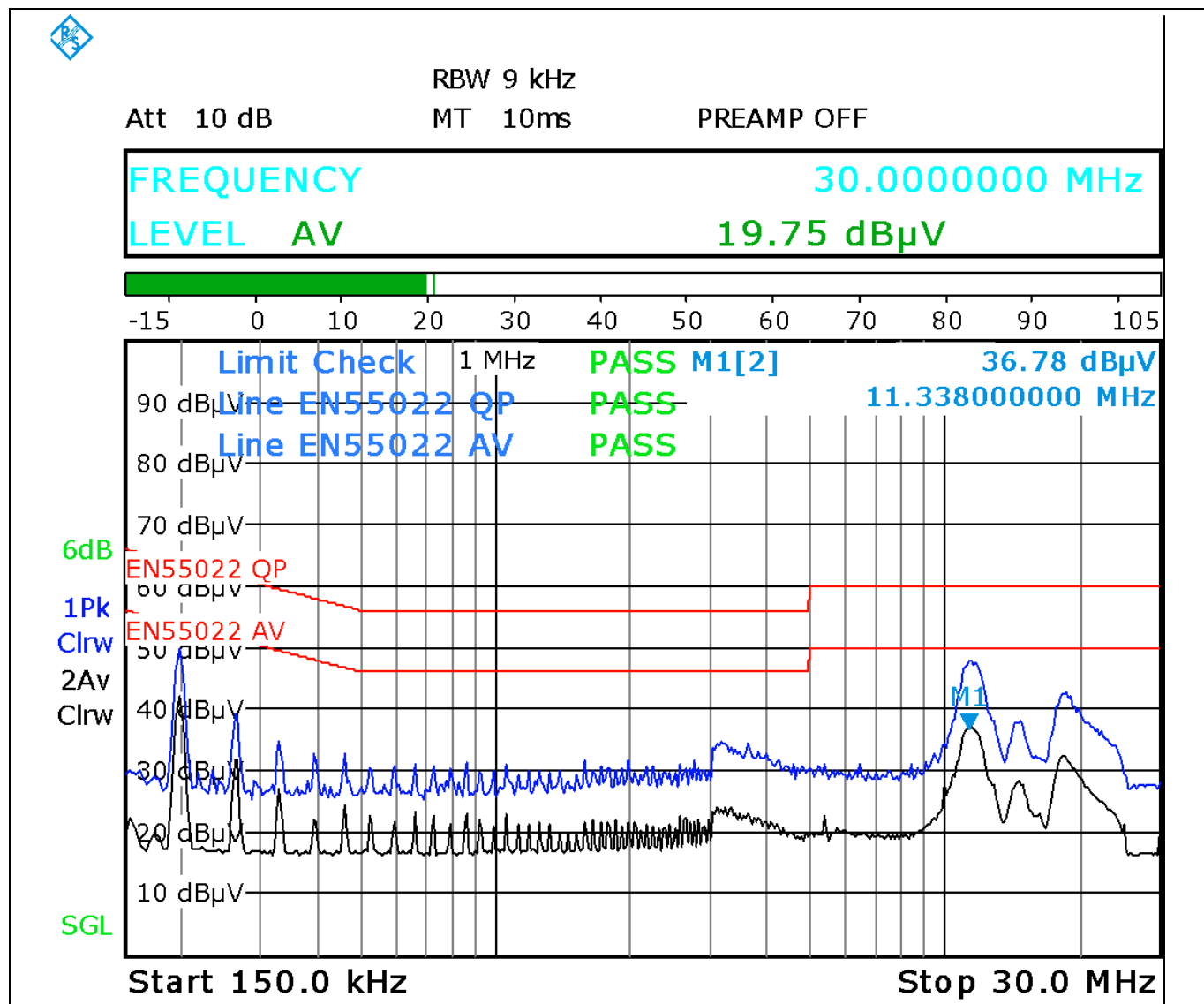


Figure 18 Conductive EMI measurement of the evaluation board at 65 kHz with a resistive load and filter modification (3pin configuration)

## 10.2 Startup behavior

During power up, when  $V_{OUT}$  is less than 96% of the rated level, the internal voltage loop of the IC increases from the initial voltage under soft-start control. This results in a controlled linear increase of the input current from 0 A, thus reducing the current stress in the power components as can be seen in the yellow waveform in Figure 19.

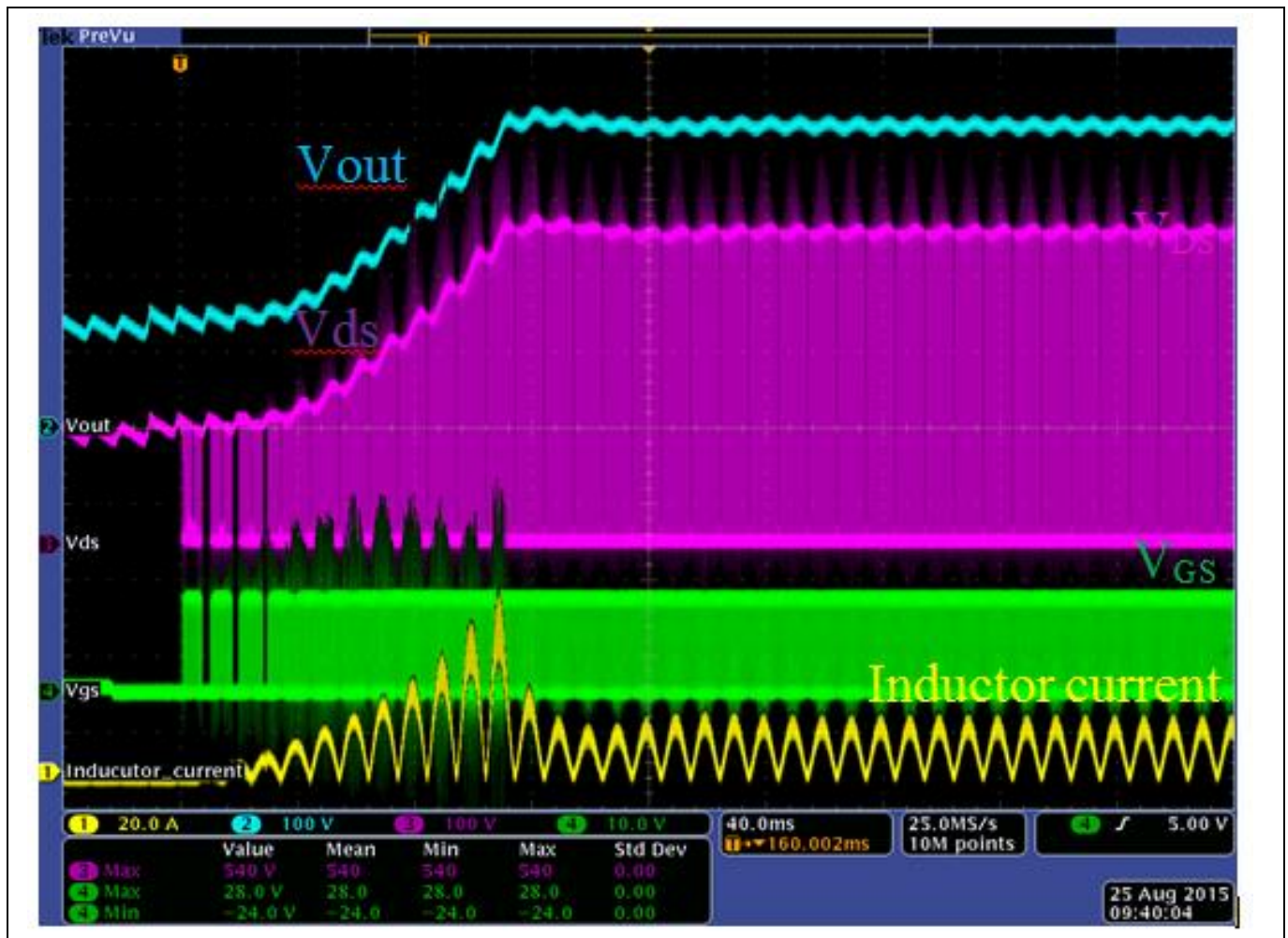


Figure 19 Soft startup at low line with 1 kW output power

## 11 Conclusion

The 2.5 kW PFC evaluation board described in this document is aimed at analyzing the switching performance of different variants of packages in a very commonly used PFC topology. It helps to understand the switching behavior and parasitic influences. With the various option settings via jumpers it is possible to modify the circuit without changing the PCB layout. Therefore the evaluation board offers several investigation opportunities. Furthermore, it shows how to boost the efficiency in a standard PFC topology.



## 12 References

1. [ICE3PCS01G](#) datasheet, Infineon Technologies AG, 2010.
2. [600V CoolMOS™ C7 Power MOSFET](#), Product Brief, Infineon Technologies AG, 2013.
3. [IDH16G65C5](#), datasheet, Infineon Technologies AG, 2012.

## Revision History

### Major changes since the last revision

| Page or Reference | Description of change |
|-------------------|-----------------------|
| --                | First Release         |
|                   |                       |
|                   |                       |

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