EVAL_2.5KW_CCM_4PIN

2.5 kW PFC evaluation board with CCM PFC Controller ICE3PCS01G

Authors: Franz Stückler (IFAT PMM APS SE SL)
Siu Ken (IFHK PMM SMD AP APC)

Application Note

About this document

Scope and purpose

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

Furthermore the reader will get additional Information how to use the evaluation board. Beside this he will get the information how the 600 V CoolMOS™ C7 behaves in this PFC board and what benefits will be achieved by the usage of the 4pin TO-247 package.

Intended audience

This document is intended for design engineers who want to improve their PFC applications by using 4pin devices.

Table of Contents

1 General safety instruction 3
1.1 To get started 3

2 Introduction 4
2.1 Evaluation board 4
2.2 CoolMOS™ C7 4
2.3 thinQ!™ SiC Diode Generation 5 5
2.4 CCM-PFC Controller 5
2.5 Gate Driver ICs (EiceDRIVER™ Compact) 5

3 Application 6

4 Circuit description 7
4.1 Line input 7
4.2 Power stage – boost type PFC converter 7
4.2.1 Separate source Power MOSFET 7

4.3 PWM control of boost converter 7
4.4 Thermal concept 8
4.4.1 Operate without thermal control feature 8

5 Circuit operation 10
5.1 Soft startup 10
5.2 Gate switching frequency 10
5.3 Protection features 11
5.3.1 Open loop protection (OLP) 11
5.3.2 First over-voltage protection (OVP1) 11
5.3.3 Peak current limit 11
5.3.4 IC supply under voltage lockout 11
5.3.5 Bulk voltage monitor and enable function (VBTHL_EN) 11

6 Circuit diagram 12

7 PCB layout 13

8 Component list 14

9 Boost choke layout 18

10 Source connection options 19

11 Test report 21
11.1 Conductive EMI Test 22
11.2 Startup behavior 27

12 Conclusion 29

13 References 30

1 General safety instruction

Warning: The evaluation board works with high voltage which could be deadly for the users. Furthermore all circuits on the board are not isolated from the line input. Due to the high power density, the components on the board as well as the heat sink can be heated to a very high temperature which can cause a burning risk when touched directly. The 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 lighting of the LED1. So the C21 and C24 must be first discharged untill the LED1 does not light before any directly touching of the board.

Note: The board is designed for a maximum input current of 14 A. To operate it at a main input of 90 V_{AC}, 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 stays 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 longer than 2 minutes. In this case, the device temperature of the MOSFET (DUT1) and/or Diode (DUT1) can reach above 100°C which needs to be considered for burning risk!

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 of the board is strongly dependent on the application settings and loading conditions. Users may modify the EMC filter using methods like wire shielding to make their own applications fulfill the standard. To fulfill other possible dedicated standards required by different applications, users may need to apply extra components themselves.

Note: The evaluation board is designed according to general electric rules. Nevertheless, Infineon Technologies will not guarantee any fulfillment of local certificate requirements or recommendations according to norms. Therefore, the usage of the evaluation board is on your own risk.

1.1 To get started

Step 1: Complete connections “V_{in}”, “V_{out}”, “KL01”, “J11”& “J11a”

- V_{out} : Connect with an output load which is able to operate at 400 V_{DC}
- V_{in} : Connect L, N and Earth to the 90 V_{AC}…265 V_{AC} 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 the V_{out} for the 400 V_{DC}

Step 3: For more instructions please refer to the following guideline.

2 Introduction

2.1 Evaluation board

This document describes the evaluation board EVAL_2.5KW_CCM_4PIN, which is designed for the customers 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 EVAL_2.5kW_CCM_4pin, 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_{AC}~265 V_{AC}
Input current	14 A_{eff}
Input frequency	47~63 Hz
Output voltage and current	400 V_{DC}, 6.25 A
Output power	~ 2.5 kW (at V_{in}=230 V_{AC})
Average efficiency	>95% at 115 V_{AC}
Switching Frequency	Possible Range: 40 kHz~250 kHz; Board frequency is set to 65 kHz; Changeable by R20
Power switch	4pin and 3pin MOSFET

2.2 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_{oss} reduction brings efficiency benefits at light load, the low Q_G correlates to faster switching and also lower E_{on} and E_{off} which gives efficiency benefits across the whole load range.

As well as balancing the various parameters to give the best-in-class performance also measures were taken to improve the implementation and ease of use behavior compared to other fast switching MOSFET families. Moreover, with its granular 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 $R_{DS(on)}$ per package.

2.3 thinQ!™ SiC Diode Generation 5

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 G3, is now combined with a new, more compact design and thin wafer technology. The result is a new family of products showing improved efficiency over all load conditions, coming from both the improved thermal characteristics and a lower figure of merit (Q_c*V_f). More than this it also offers improved dv/dt robustness up to 100 V/ns which enables very fast switching. This is perfect fit to the fast switching CoolMOS™ C7 family.

2.4 CCM-PFC Controller

The evaluation board presented here is a 2.5 kW power factor correction (PFC) circuit with 85~265 V_{AC} universal input and output of 400 V_{DC}. The continuous conduction mode (CCM) PFC controller ICE3PCS01G is employed in this board to achieve the unity power factor.

This ICE3PCS01G is specially designed for applications of power supplies used in PC, server, and telecom, requesting high efficiency and power factor. The voltage loop compensation is integrated digitally for better dynamic response and less design effort. Appreciated for its high integrated design, ICE3PCS01G can achieve full requirements of the PFC application implemented in the 14pin in DSO14 package. At the same time the number of peripheral components is minimized. The gate switching frequency is adjustable from 21 kHz to 250 kHz and able to synchronize with external switching frequency from 50 kHz to 150 kHz.

2.5 Gate Driver ICs (EiceDRIVER™ Compact)

Infineon EiceDRIVER™ family (IEDI60N12AF) offers a wide range of CT 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 can fully demonstrate very fast switching behavior parallel to clean gate waveforms. Base on the CT technique, the Kelvin source can be completely isolated from the power source. Higher efficiency and better system stability can be achieved.

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

The output of the driver is featured with separate positive and negative output for easy tune, the turn on and turn off behavior of the MOSFET could be changed by using different gate resistors. This is connected to the different outputs without any diode for separating turn on and turn off phase.

In the present evaluation board the two output pins are put together. This is due to the fact that the parallel design for 3- and 4pin devices causes two different changeable gate resistors. In order to keep the complexity on low level, 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.

Furthermore, this driver is the only known driver up to now, which has a CMTI (common mode transient immunity) of dv/dt =>100 V/ns which is needed for high transition noise feedback from the drain to the gate signal at fast switching mode.

3 Application

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

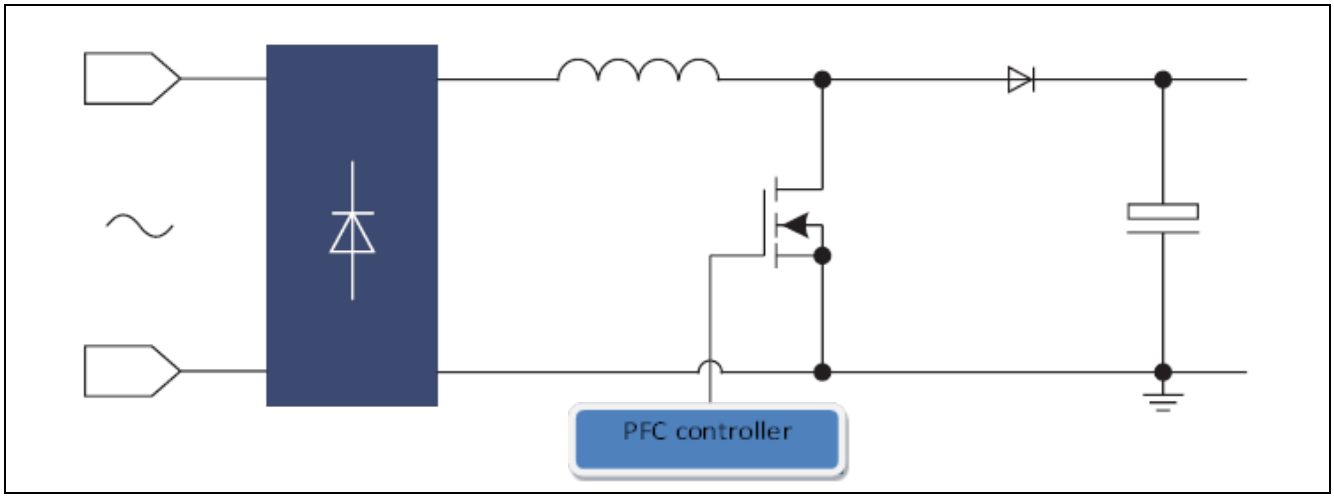


Figure 1 Schematic of the topology



Figure 2 EVAL_2.5kW_CCM_4PIN evaluation board

4 Circuit description

4.1 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 high and precise power metering. The choke L3, X2-capacitor C4/C5/C23 and Y1-capacitors C17/CY18 are used to suppress common mode noise, as well as 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.

4.2 Power stage – boost type PFC converter

After the bridge rectifier GL1 and GL2, there is a boost type PFC converter consisting of L1, IPZ65R019C7, 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 equably 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 the acceptable level and meet the hold-up time requirement.

4.2.1 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 physical same device in either 3pins or 4pins (with sense source) configuration. The standard setting of the set-up is 4pin configuration. To change the testing device to 3pins configuration, it is necessary to open the connection point J7 and connect the solder point J8 or J6. Please check chapter 10 on Page 19 for more detail information.

4.3 PWM control of boost converter

The ICE3PCS01G is a 14pins control IC for power factor correction converters is suitable for wide range line input applications from 85 to 265 V_{AC} 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 enlargin 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 which controls the amplitude of the average input current.

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

4.4 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 effect by changing the changeable 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 galvanic 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 limitation of 3.5 A
- Set R4 accordingly to the temperature, which is intended for the devices

The control circuit will then heat up the heat sink to the adjusted temperature which is set by the variable resistor R4. Once the temperature is reached it will start the fan to coolthe system. So it is possible to operate the application with regulated heat sink temperature for the MOSFET and the DIODE.

4.4.1 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”

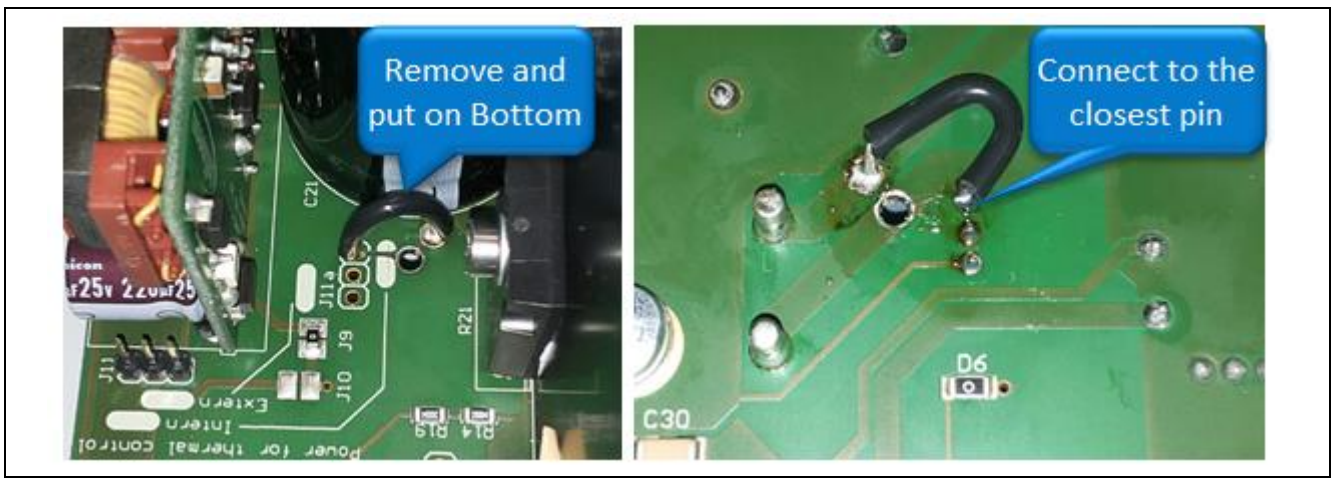


Figure 3 Wire change from top layer to bottom layer

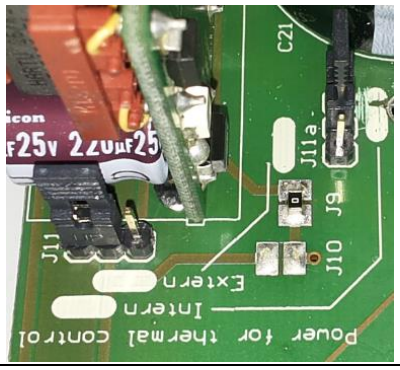


Figure 4 Setting for internal cooling powering

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 boardhas been modified as described above and one wants to investigate the efficiency testing without the thermal power losses, please set the Jumper J11 and J11a to the “external” position.

5 Circuit operation

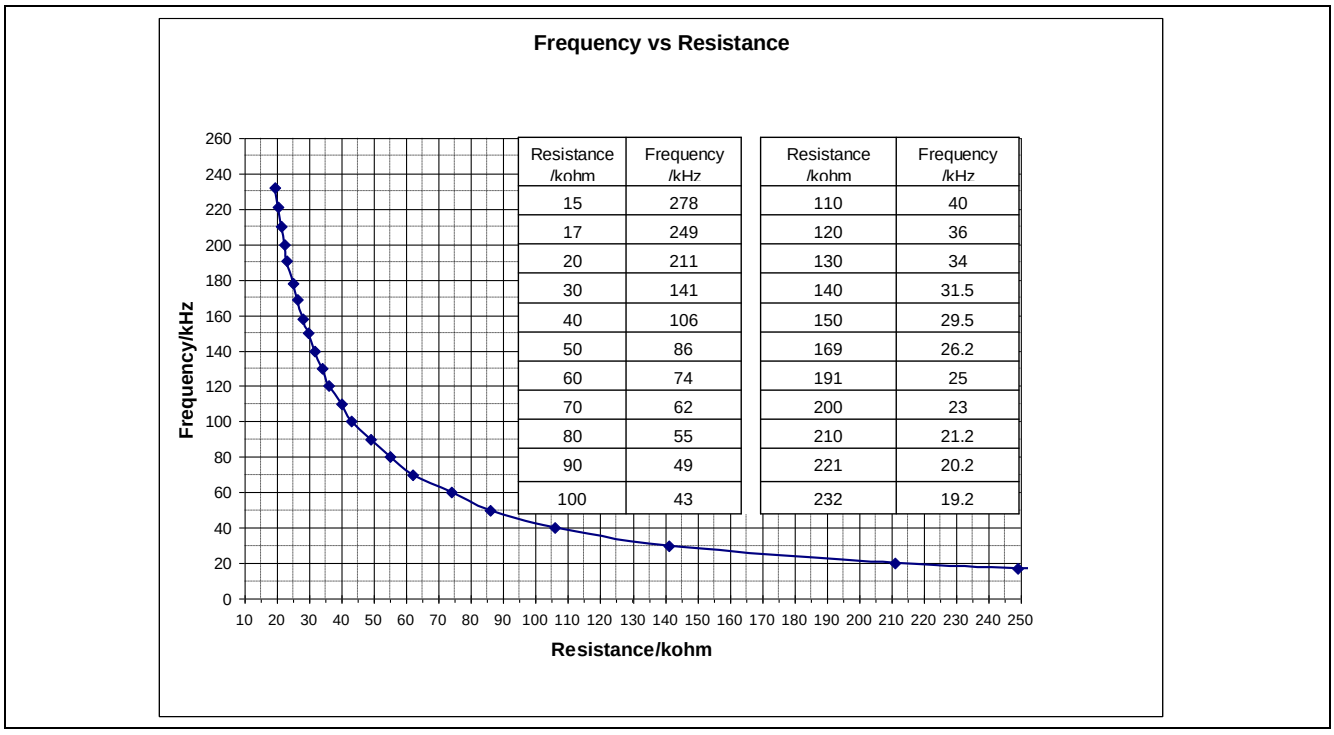
5.1 Soft startup

During power up when the V_{OUT} is less than 96% of the rated level, internal voltage loop output of the IC increases from initial voltage under the 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 VB_OK pin outputs 5 V indicating PFC output voltage in normal range.

5.2 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 in the device and the R_{FREQ}/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 kΩ at pin FREQ will typically set a switching frequency F_{SW} of 100 kHz.



Resistance /kohm	Frequency /kHz	Resistance /kohm	Frequency /kHz
15	278	110	40
17	249	120	36
20	211	130	34
30	141	140	31.5
40	106	150	29.5
50	86	169	26.2
60	74	191	25
70	62	200	23
80	55	210	21.2
90	49	221	20.2
100	43	232	19.2

Figure 5 Frequency setting

The switching frequency can be changed by the variable resistor R31. For easy adjustment please consider to use the connection pins X8 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. For using the Table and plot in Figure 3 you have to subtract 10 kΩ of the serial resistance R15. If the polarity of the measurement tool is flipped compared to the described above, please consider to subtract 23 kΩ 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!

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

5.3 Protection features

5.3.1 Open loop protection (OLP)

The open loop protection is available for this IC to safe-guard the output. Whenever voltage at pin V_{SENSE} falls below 0.5 V, or equivalently 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.

5.3.2 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 bulk voltage falls below the rated value, gate drive resumes switching again.

5.3.3 Peak current limit

The IC provides a cycle by cycle peak current limitation (PCL). It 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 deglitcher with 200 ns 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.

5.3.4 IC supply under voltage lockout

When V_{CC} voltage is below the under voltage lockout threshold V_{CCUVLO}, typical 11 V, IC is off and the gate drive is internally pull low to maintain the off state. The current consumption is down to 1.4 mA only.

5.3.5 Bulk voltage monitor and enable function (VBTHL_EN)

The IC monitors the bulk voltage status through VS_{ENSE} pin and output a TTL signal to enable PWM IC or control 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 decided by the pin VBTHL voltage adjustable externally.

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

6 Circuit diagram

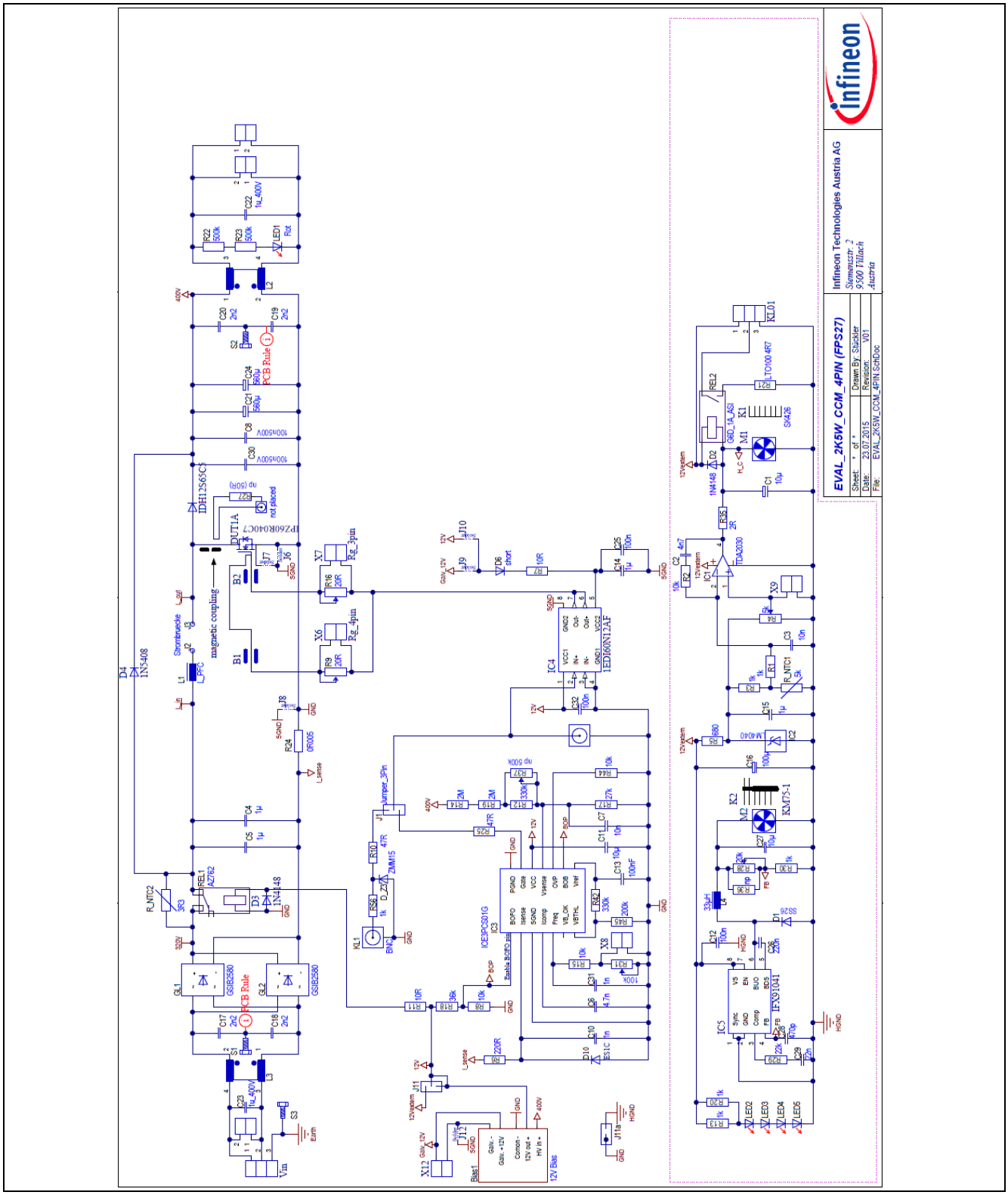


Figure 6 Whole evaluation board schematic

7 PCB layout

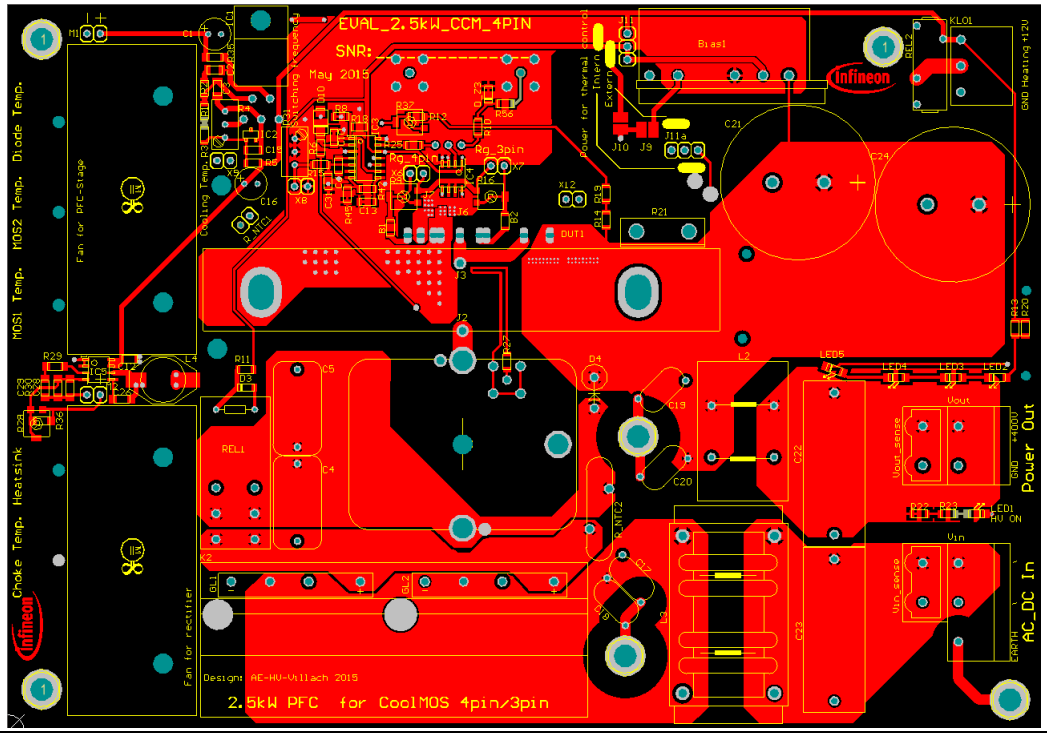


Figure 7 PCB top layer view

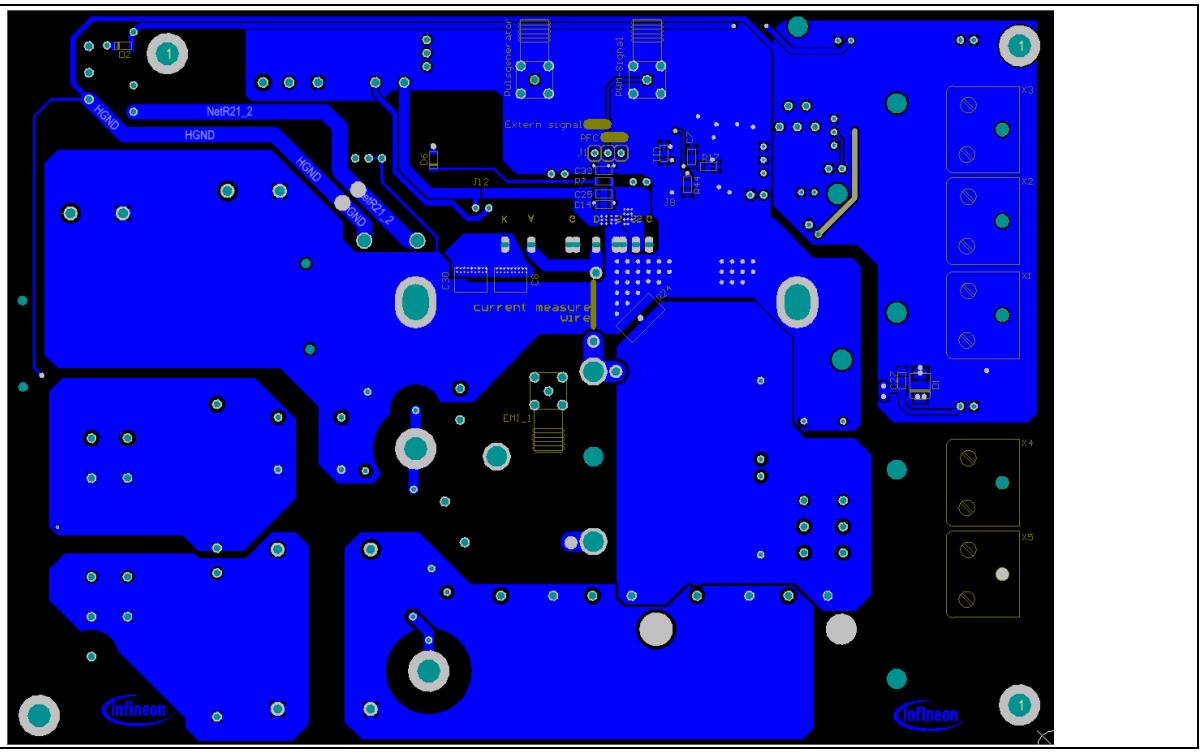


Figure 8 PCB bottom layer view

8 Component list

Table 2 Component list

Designator	Value	Description
B1, B2	closed with 0 Ohm	Placeholder for Ferrite Bead, 0Ohm resistor
Bias1	12 V Bias	Bias adapter
C1	10 µ	25 V
C2	4n7	25 V
C3	10 n	25 V
C4, C5	1 µ	x-capacitor
C6	4.7 n	25 V
C7	10 n	25 V
C8, C30	100 n 500 V	VJ1825Y104KXEAT
C10, C31	1 n	25 V
C11	10 µ	25 V
C12, C25, C32	100 n	25 V
C13	100 nF	25 V
C14, C15	1 µ	25 V
C16	100 µ	25 V
C17, C18, C19, C20	2n2	Y-capacitor
C21, C24	560 µ	EETHC2G561KA or EKMR421VSN561MR50S
C22, C23	1u_400 V	BFC237351105; Farnel 1215540
C26	220 n	25 V
C27	10 µ	25 V
C28	470 p	25 V
C29	22 n	25 V
D1	SS26	
D2, D3	1N4148	
D4	1N5408	
D6	short	0 Ohm
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

Component list

Designator	Value	Description
IC3	ICE3PCS01G	PFC_CCM_Controller
IC4	1EDI60N12AF	6 A_isolated_MOSdriver
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; 4 pin as 3 pin
J7, J12	close with solder or 0 Ω resistance	Solder jumper; driver ground to SS, Solder jumper; isolated driver power
J8, J10	open	Solder jumper; 3 pin ground, Solder jumper; driver power none isolated
J9	close with solder or 0 Ω resistance	Solder jumper; isolated driver power
K1	SK426	100 mm long; mound with 2xM4x15
K2	KM75-1	KM75-1 +4clip 4597; Fischer
KL1	BNC	Osziloskope_functionsgenerator
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 µH	Würth 744824101
L3	8120-RC	BOURNS_8120-RC_2m4H_17A
L4	33 µH	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 60mm	LZ28CP
PWM-Signal	SMA	Osziloskope_Functionsgenerator
R1, R3, R13, R20, R56	1 k	5%
R2, R8, R15, R44	10 k	5%
R4	5 k	67WR20KLF
R5	680	5%
R6	220 R	5%
R7, R11	10 R	5%
R9, R16	20 R	3314G-1-200E
R10, R25	47 R	5%

Component list

Designator	Value	Description
R12, R42	330 k	5%
R14, R19	2 M	5%
R17	27 k	5%
R18	36 k	5%
R21	LTO100 4R7	include two 20F2617 Bürklin connector
R22, R23	500 k	10%
R24	0R005	FCSL90R005FE
R27	Np	
R28	20 k	23AR20KLFTR
R29	22 k	5%
R30	1 k	10 V
R31	100 k	67WR100KLF
R35	2 R	5%
R36	Np	
R37	np 500 k	5%
R45	200 k	5%
REL1	AZ762	12 V
REL2	G6D_1A_ASI	12 V
R_NTC1	5 k	B57560G502F mound in K1 under MOS
R_NTC2	3R3	R_SL22
S1, S2, S3, S4, S5, S6	SCREW_M4	3 cm Distance holder
S1, S2, S3, S4, S5, S6	Mutter M4	M4 Screw nut
S1, S2, S3, S4, S5, S6	Washer M4	washer M4
V_{in}	HV_{in}	GMSTBA 2,5/ 3-G-7,62 and GMSTB 2,5/ 3-ST-7,62
V_{out}	V_{out}	GMSTBA 2,5/ 2-G-7,62 and GMSTB 2,5/ 2-ST-7,62
V_{out_sense}	V_{out_sense}	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	Rg_4pin	SPC20485
X7	Rg_3pin	SPC20485
X8, X9	KL_STANDARD_2	SPC20485

Component list

Designator	Value	Description
X12	Np	for adapter power supply

9 Boost choke layout

The boost choke on this evaluation board is self-winded since this is not a volume production. It consists of 2 stacked “Kool Mμ” 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 µH. As the inductance and the magnetic flux optimum are depending on the switching frequency and the output power, a change might be needed if the evaluation board is used for different setting in power and frequency.

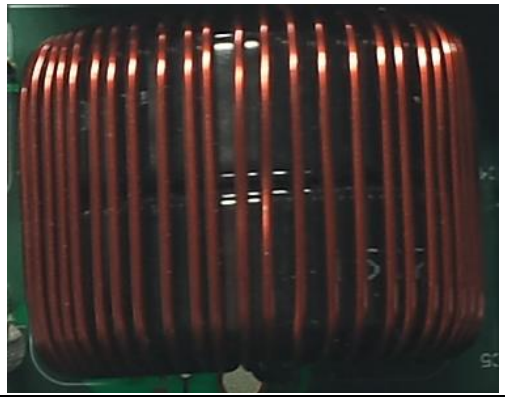


Figure 9 Main inductor

10 Source connection options

The source connection for the MOSFET-Gate drive can be set to different options. It is important to make sure that only one of the Jumper 6, 7 and 8 is closed at the same time. In Figure 10 the possibilities on top side of the PCB are shown. For Standard through hole packages one can put a 0 Ohm resistor or as much solder on the 2 surface area of J6 so that there is an electrical connection if a low inductive gate driving is wanted. For Standard gate drive inductance it is possible to close J8 (see Figure 11) on bottom side of the PCB instead J6.

To investigate the performance advantages of the 4pin solution please activate J7 on 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.

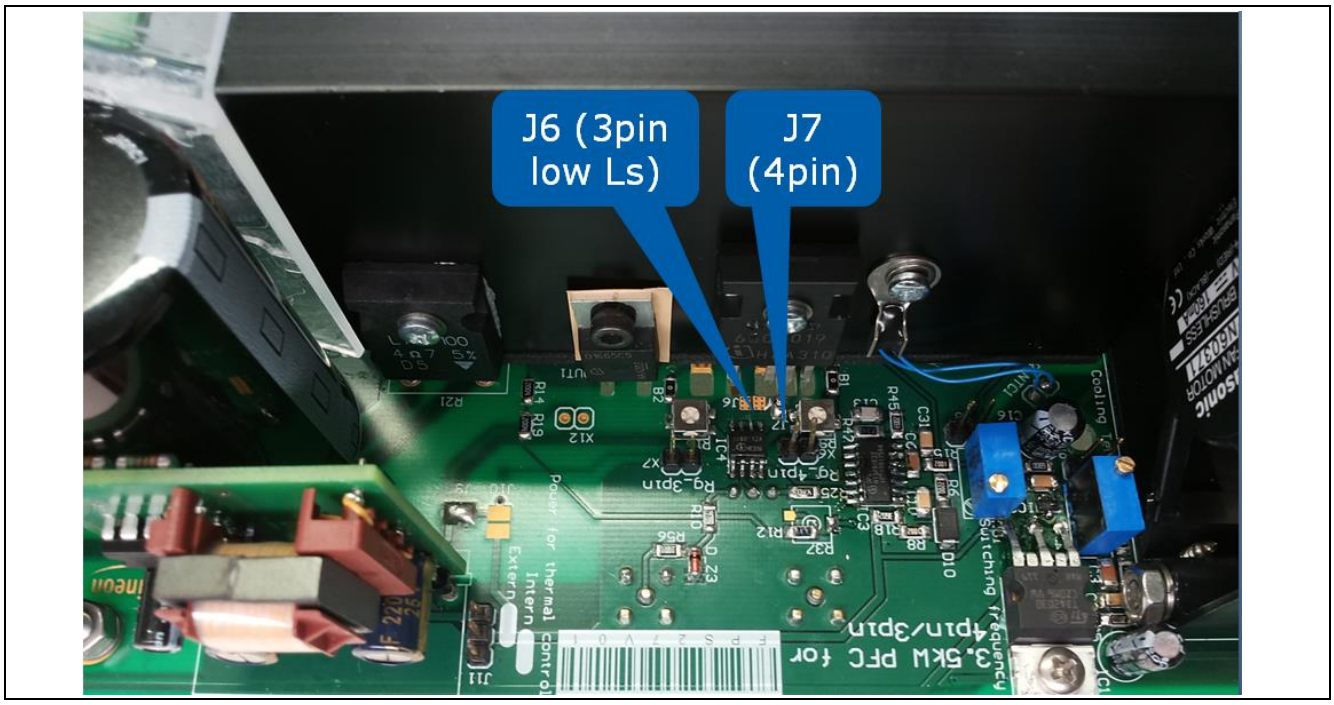


Figure 10 Source connection setting on top side for source sense and low inductance 3pin option

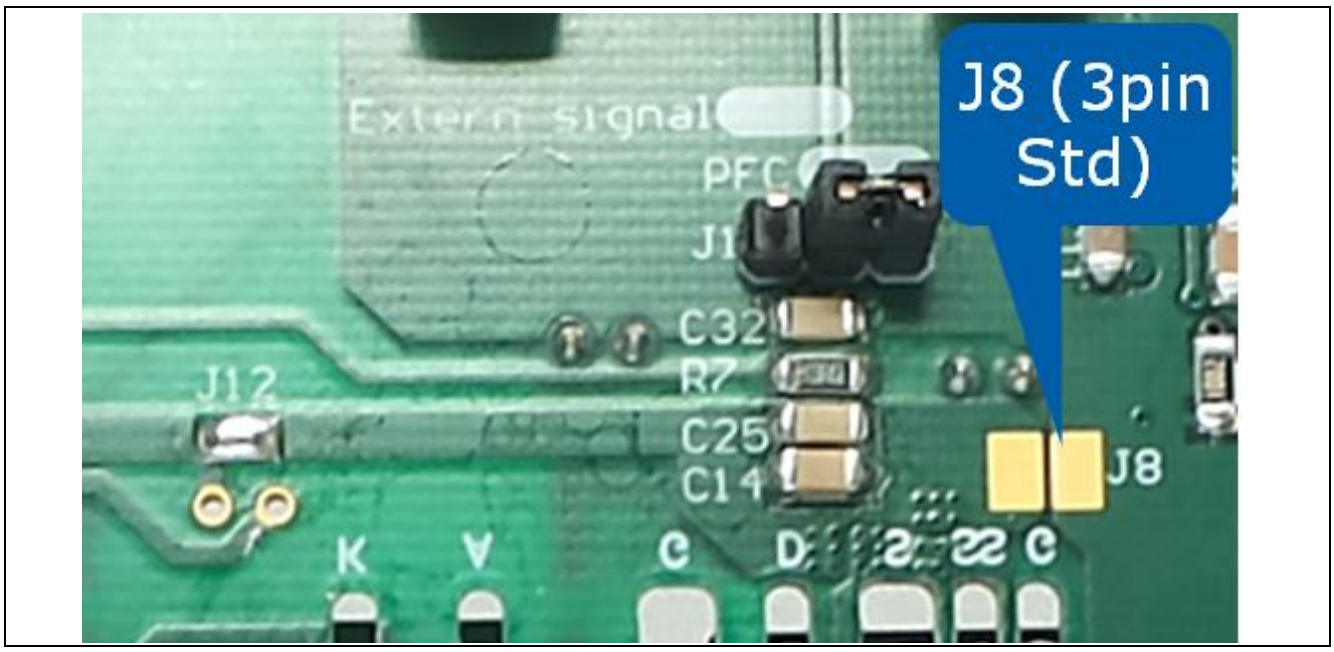


Figure 11 Source connection setting on bottom side for standard 3pin

11 Test report

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

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

In Figure 10 and 11 can see that the full load efficiency is improved by only changing from 3pin to 4pin configuration. Due to this advantage it can be 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 beside full load at low line. Therefore it will help to enter into the TITANUM Standard for server SMPS.

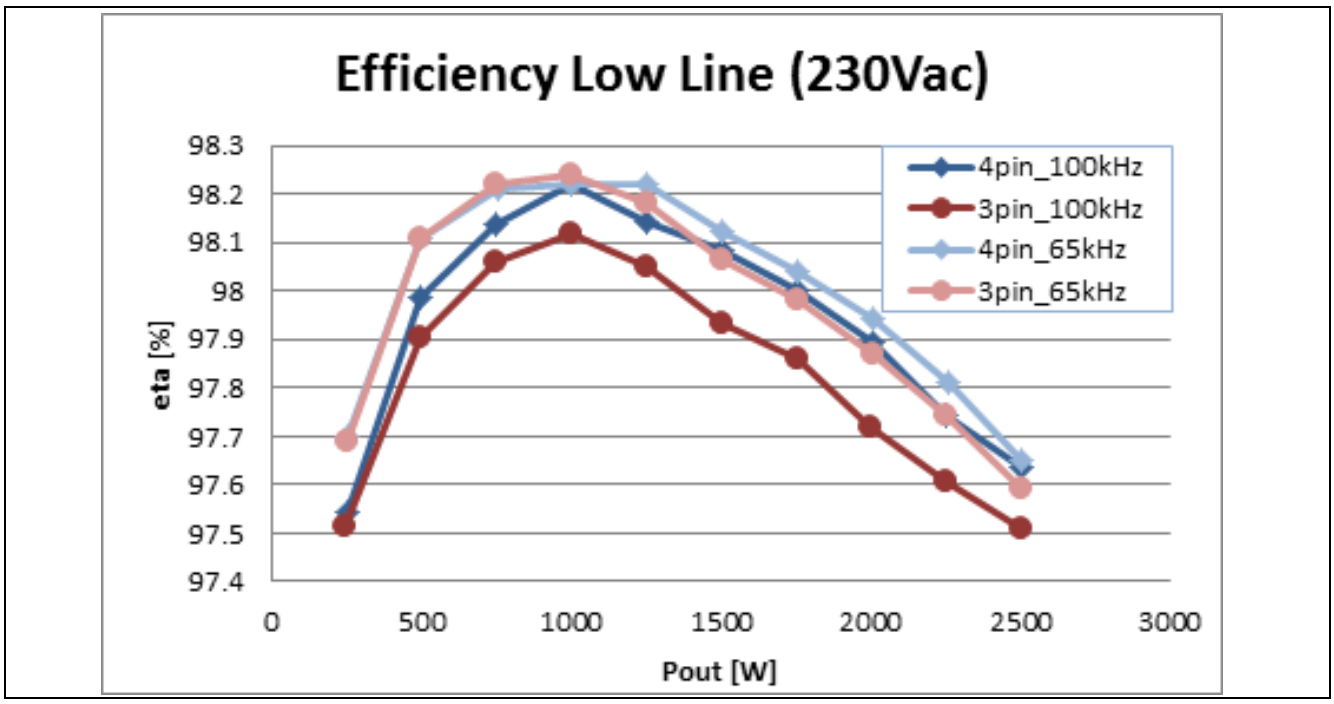


Figure 12 High line efficiency curve with the device IPZ60R040C7 & IDH16G65C5 @ 65 kHz & 100 kHz 3.3 ohms

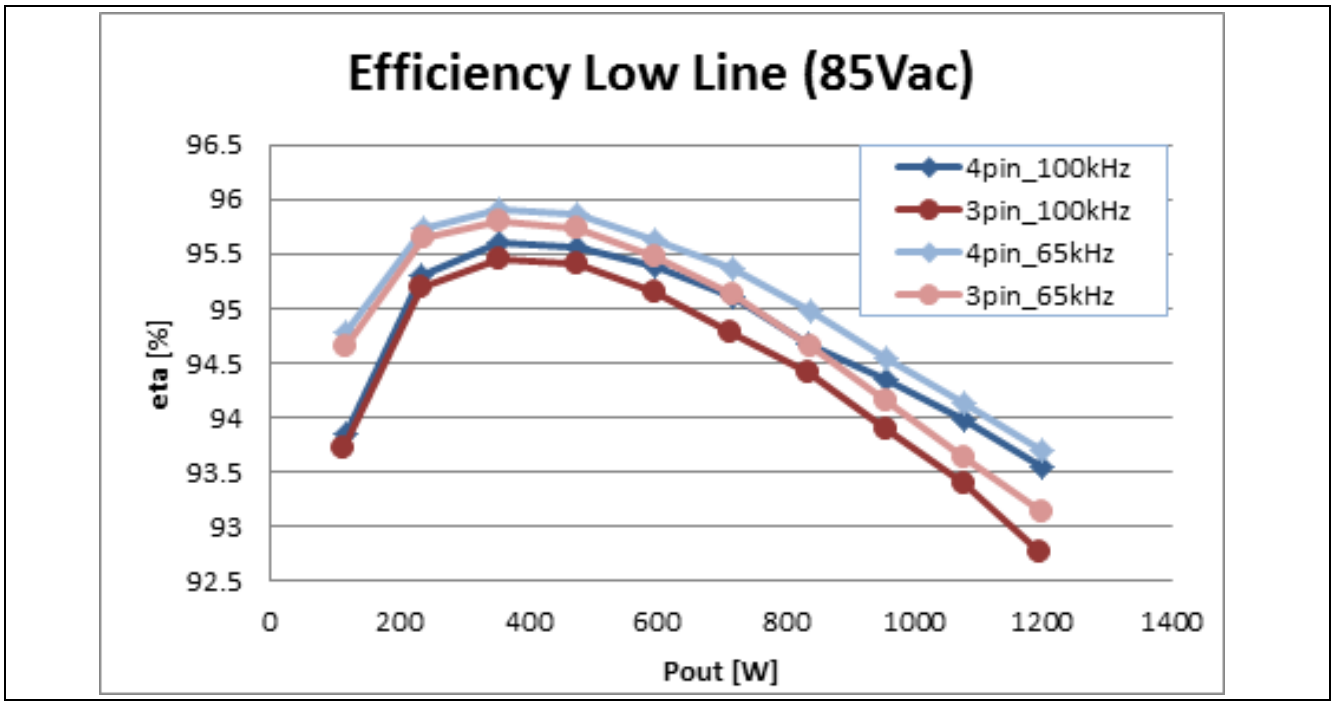


Figure 13 Low line efficiency curve with the device IPZ60R040C7 & IDH16G65C5 @ 65 kHz & 100 kHz 3.3 ohms

11.1 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 conductive EMI. It is most important to investigate on the

conducted EMI behavior, for the described evaluation PFC board, since it is the input stage of any SMPS below a certain power range.

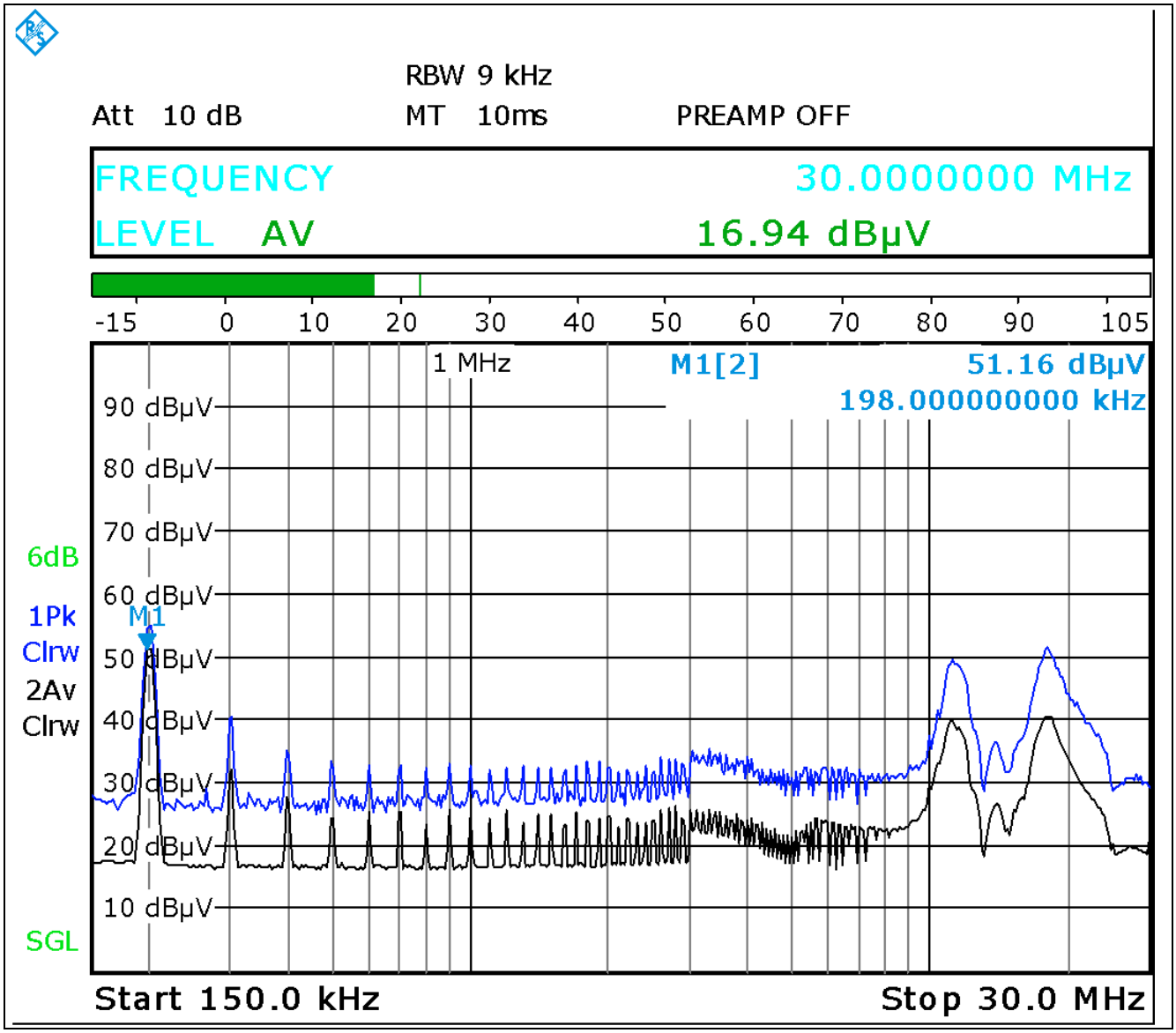


Figure 14 Conductive EMI measurement of the evaluation board at 100 kHz with a resistive load (4 pins configuration)

Base 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 margins (6 dB) under the standard line requirement:

- Change the X2-capacitor C23 from value 1 uF to 1.5 uF

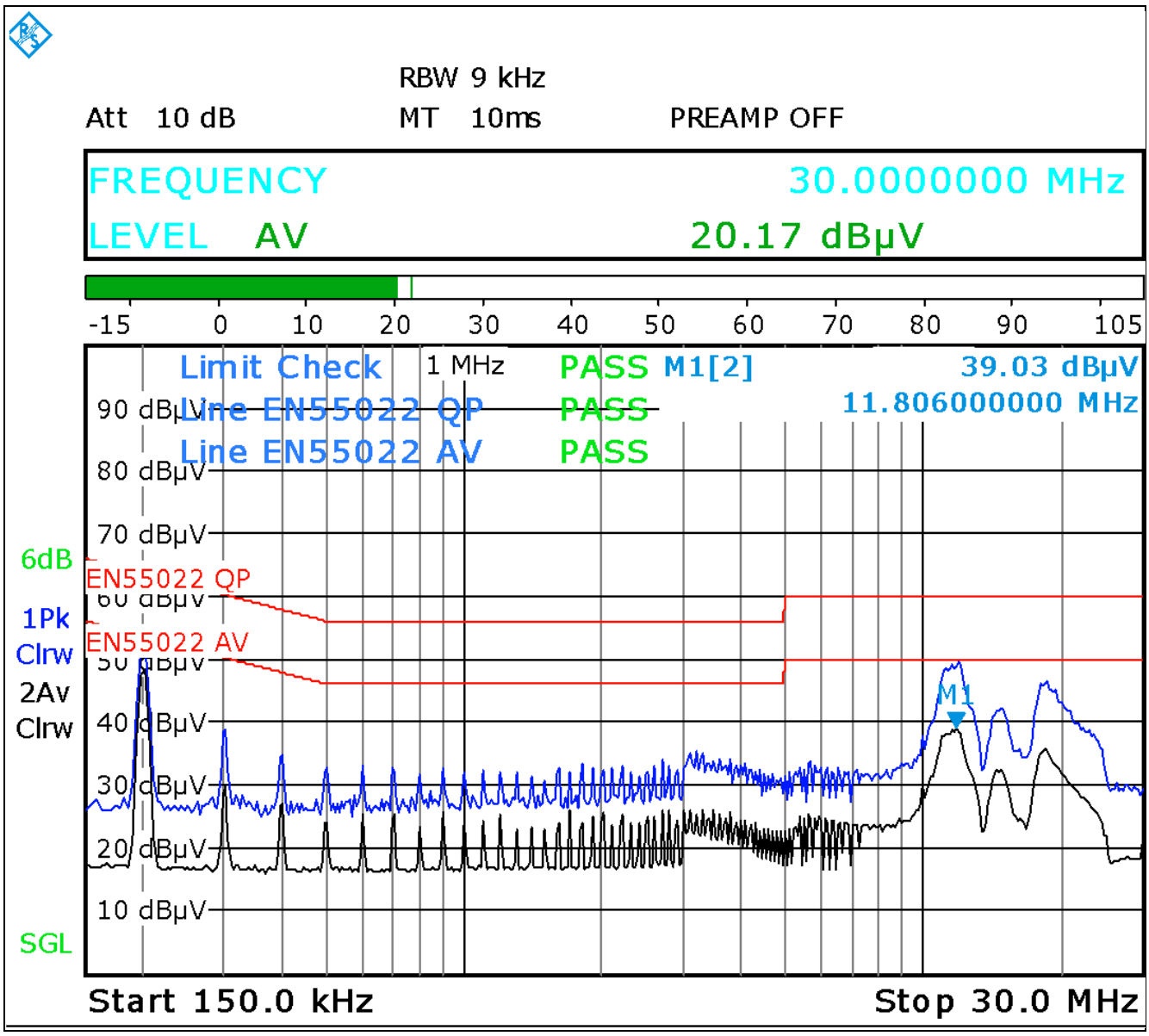


Figure 15 Conductive EMI measurement of the evaluation board at 100 kHz with a resistive load and filter modification (4pins configuration)

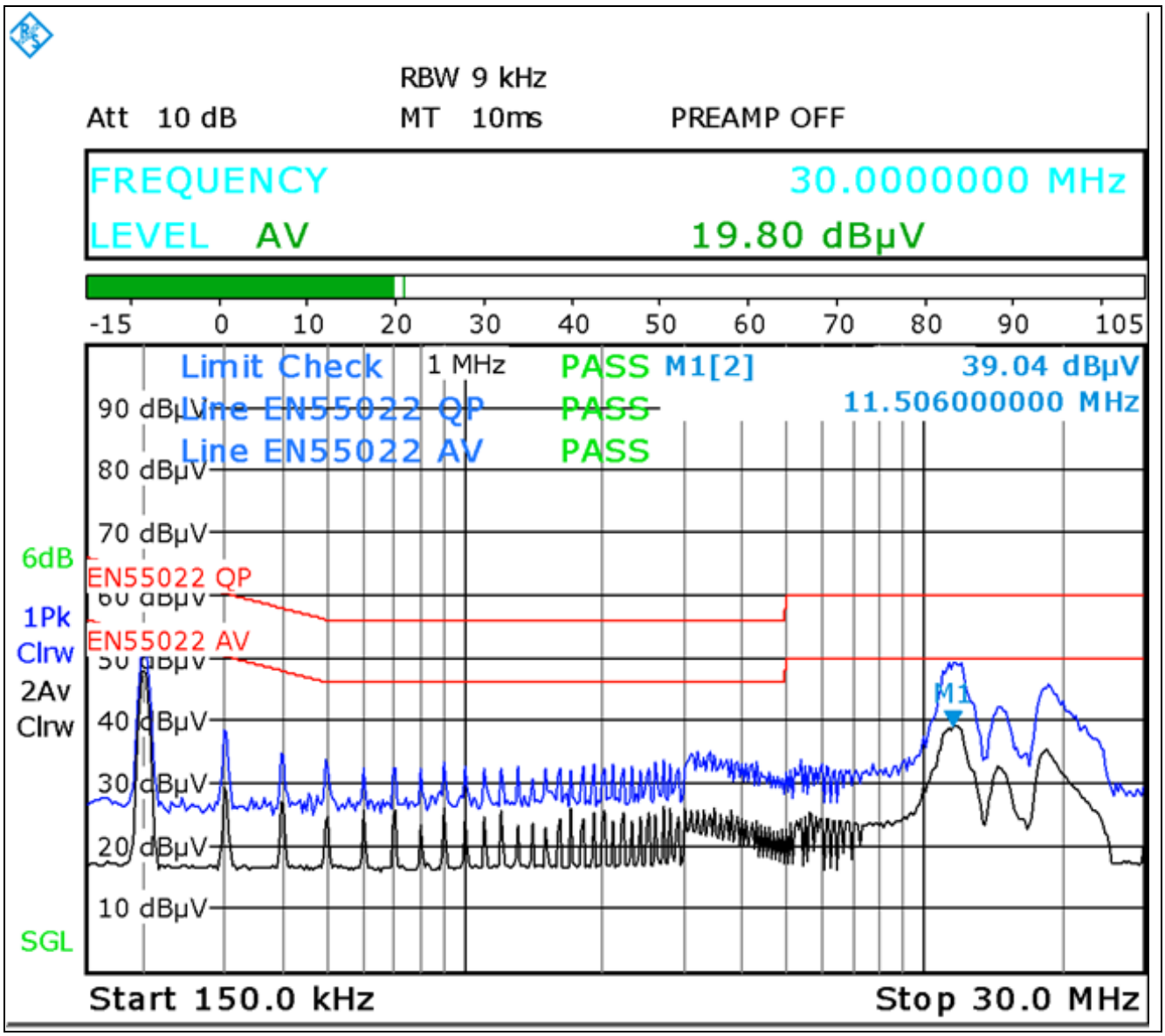


Figure 16 Conductive EMI measurement of the evaluation board at 100 kHz with a resistive load and filter modification (3pins configuration)

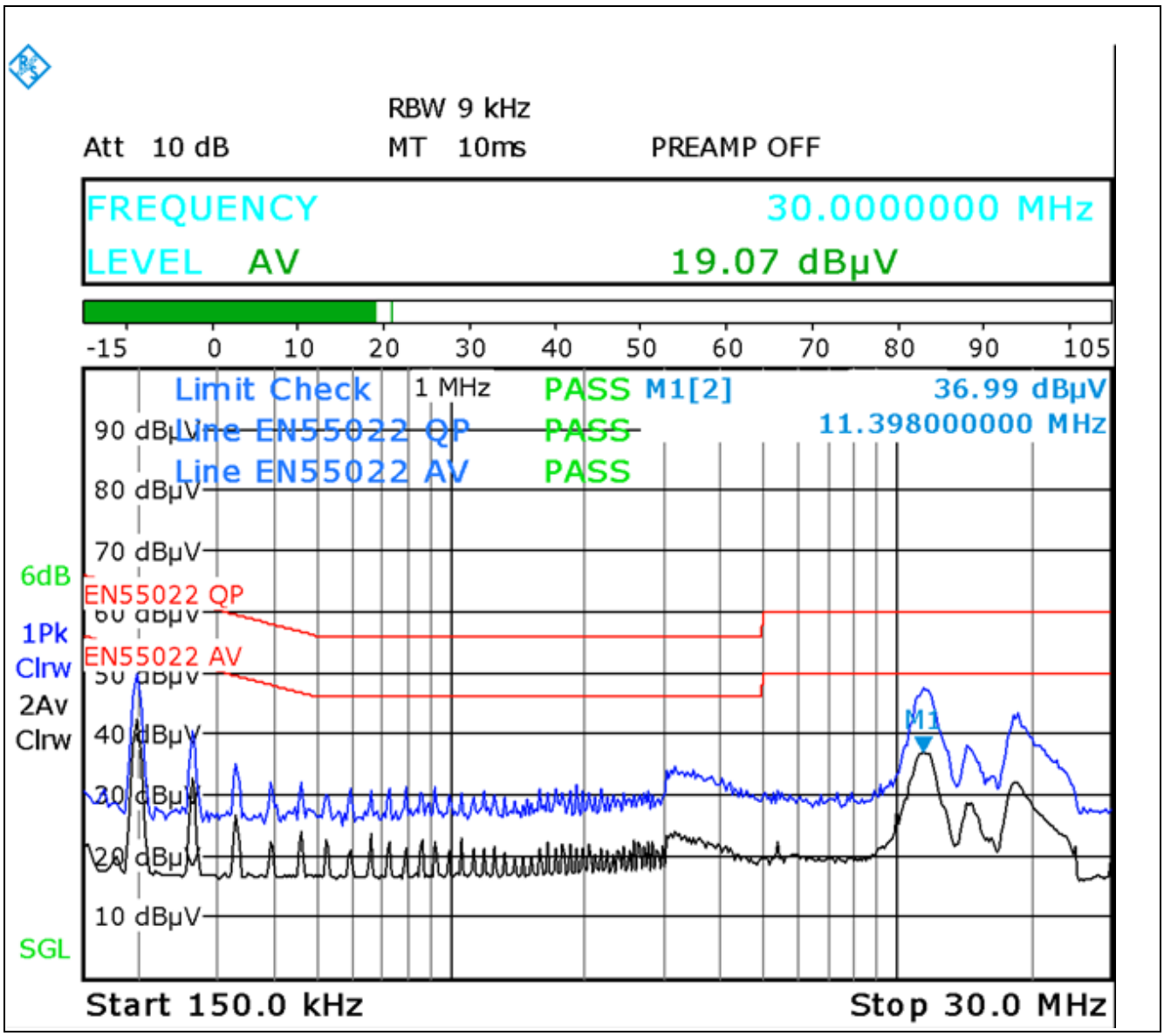


Figure 17 Conductive EMI measurement of the evaluation board at 65 kHz with a resistive load and filter modification (4pins configuration)

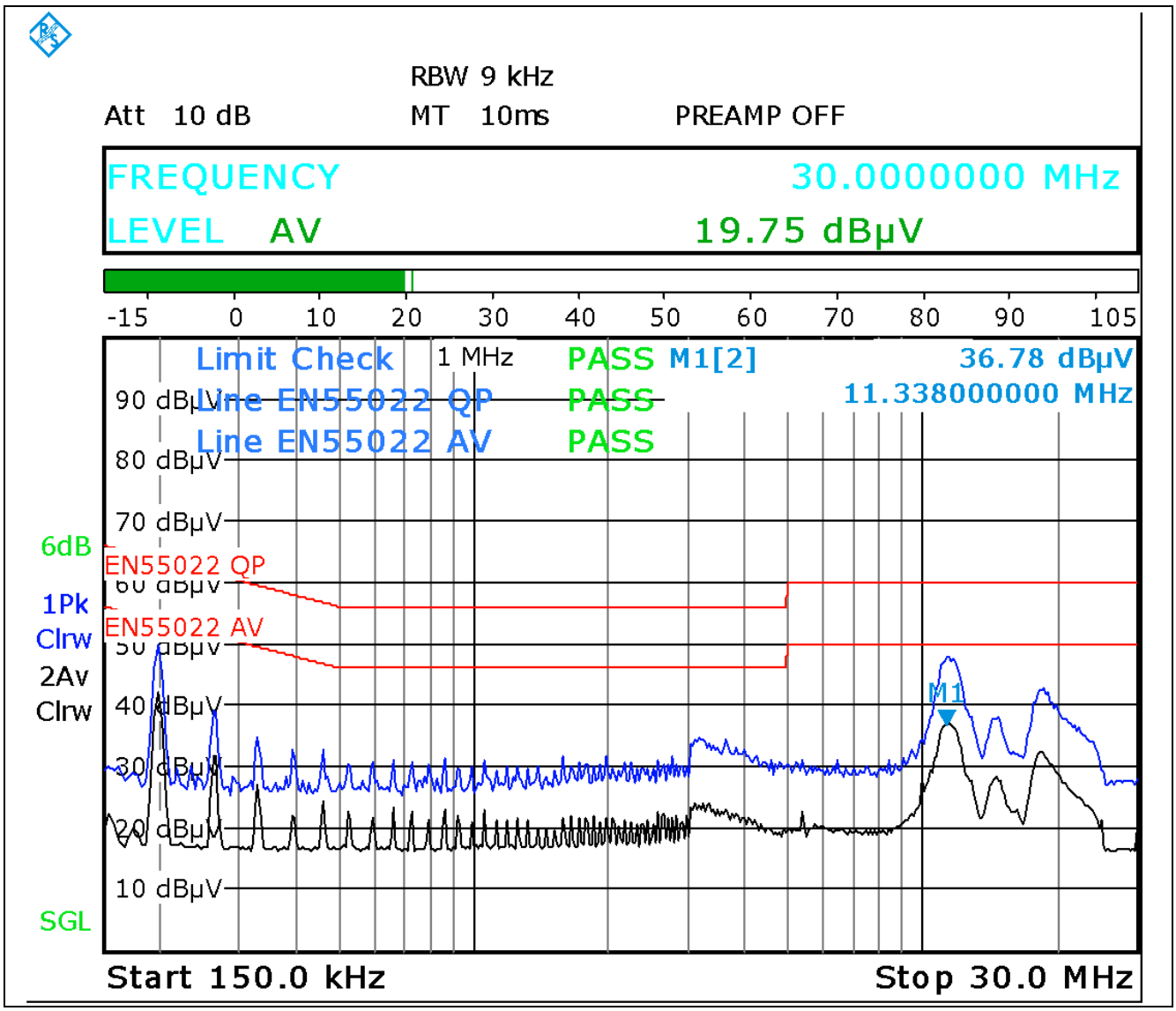


Figure 18 Conductive EMI measurement of the evaluation board at 65 kHz with a resistive load and filter modification (3pins configuration)

11.2 Startup behavior

During power up, when the V_{OUT} is less than 96% of the rated level, internal voltage loop of the IC increases from the initial voltage under the 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 on the yellow wave shape in Figure 19.

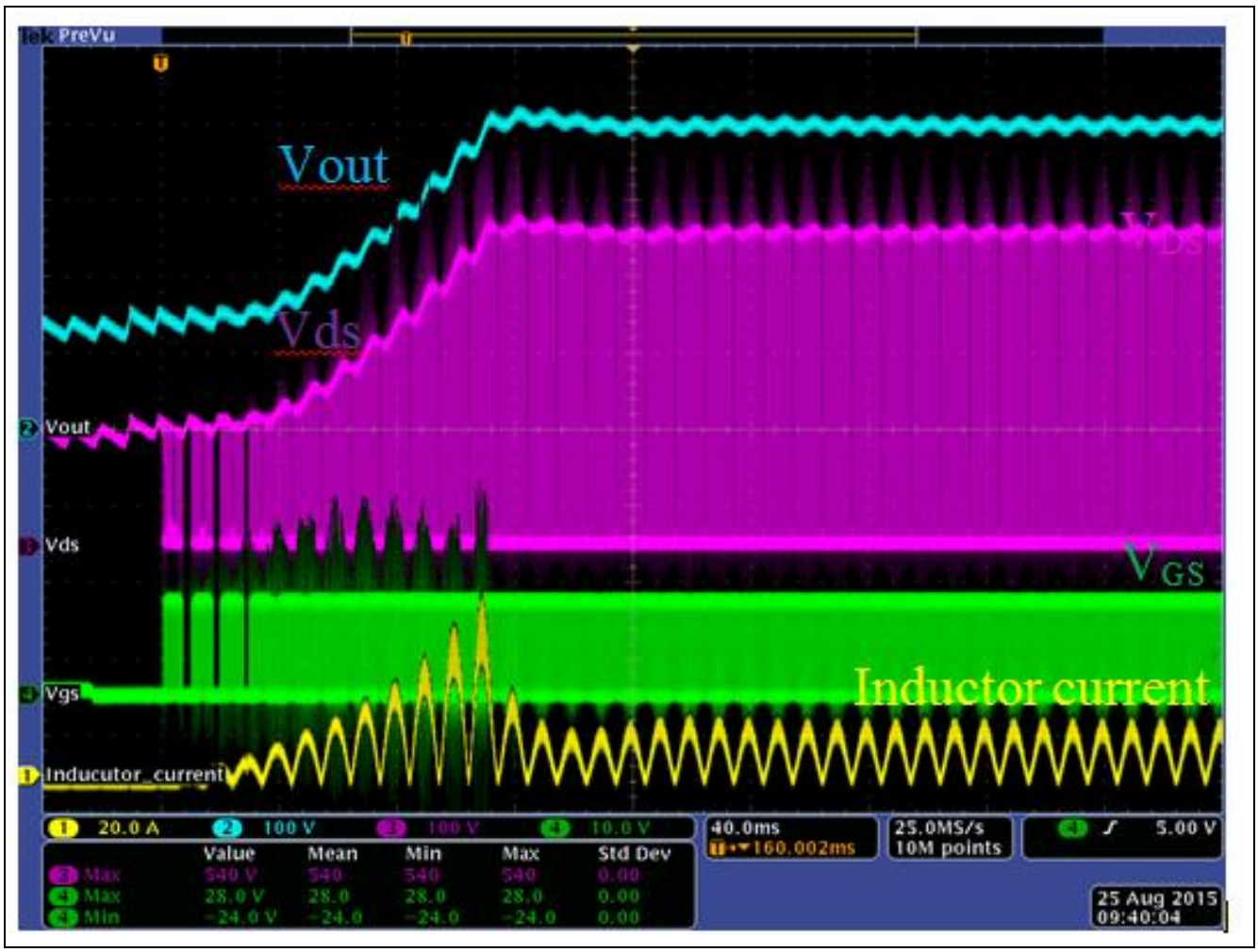


Figure 19 Soft startup at low line with 1 kW output power

12 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 common used PFC topology. It helps to understand the switching behavior and parasitic influences. With the various option settings via “solder jumper” it is possible to modify the circuit without changing any layout. Therefore the evaluation board offers plenty investigation variants. Furthermore, it shows how to boost the efficiency in a standard PFC topology.

13 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

Trademarks of Infineon Technologies AG

AURIX™, C166™, CanPAK™, CIPOS™, CIPURSE™, CoolGaN™, CoolMOS™, CoolSET™, CoolSiC™, CORECONTROL™, CROSSAVE™, DAVE™, DI-POL™, DrBLADE™, EasyPIM™, EconoBRIDGE™, EconoDUAL™, EconoPACK™, EconoPIM™, EiceDRIVER™, eupec™, FCOS™, HITFET™, HybridPACK™, ISOFACE™, IsoPACK™, i-Wafer™, MIPAQ™, ModSTACK™, my-d™, NovalithIC™, OmniTune™, OPTIGA™, OptiMOS™, ORIGA™, POWERCODE™, PRIMARION™, PrimePACK™, PrimeSTACK™, PROFET™, PRO-SIL™, RASIC™, REAL3™, ReverSave™, SatRIC™, SIEGET™, SIPMOS™, SmartLEWIS™, SOLID FLASH™, SPOC™, TEMPFET™, thinQ!™, TRENCHSTOP™, TriCore™.

Other Trademarks

Advance Design System™ (ADS) of Agilent Technologies, AMBA™, ARM™, MULTI-ICE™, KEIL™, PRIMECELL™, REALVIEW™, THUMB™, µVision™ of ARM Limited, UK. ANSI™ of American National Standards Institute. AUTOSAR™ of AUTOSAR development partnership. Bluetooth™ of Bluetooth SIG Inc. CAT-iq™ of DECT Forum. COLOSSUS™, FirstGPS™ of Trimble Navigation Ltd. EMV™ of EMVCo, LLC (Visa Holdings Inc.). EPCOS™ of Epcos AG. FLEXGO™ of Microsoft Corporation. HYPERTERMINAL™ of Hilgraeve Incorporated. MCS™ of Intel Corp. IEC™ of Commission Electrotechnique Internationale. IrDA™ of Infrared Data Association Corporation. ISO™ of INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. MATLAB™ of MathWorks, Inc. MAXIM™ of Maxim Integrated Products, Inc. MICROTEC™, NUCLEUS™ of Mentor Graphics Corporation. MIPI™ of MIPI Alliance, Inc. MIPS™ of MIPS Technologies, Inc., USA. muRata™ of MURATA MANUFACTURING CO., MICROWAVE OFFICE™ (MWO) of Applied Wave Research Inc., OmniVision™ of OmniVision Technologies, Inc. Openwave™ of Openwave Systems Inc. RED HAT™ of Red Hat, Inc. RFMD™ of RF Micro Devices, Inc. SIRIUS™ of Sirius Satellite Radio Inc. SOLARIS™ of Sun Microsystems, Inc. SPANSION™ of Spansion LLC Ltd. Symbian™ of Symbian Software Limited. TAIYO YUDEN™ of Taiyo Yuden Co. TEAKLITE™ of CEVA, Inc. TEKTRONIX™ of Tektronix Inc. TOKO™ of TOKO KABUSHIKI KAISHA TA. UNIX™ of X/Open Company Limited. VERILOG™, PALLADIUM™ of Cadence Design Systems, Inc. VLYNQ™ of Texas Instruments Incorporated. VXWORKS™, WIND RIVER™ of WIND RIVER SYSTEMS, INC. ZETEX™ of Diodes Zetex Limited.

Last Trademarks Update 2014-07-17

www.infineon.com

Edition 2015-09-07

Published by

Infineon Technologies AG

81726 Munich, Germany

© 2015 Infineon Technologies AG.
All Rights Reserved.

Do you have a question about any aspect of this document?

Email: erratum@infineon.com

Document reference

Legal Disclaimer

THE INFORMATION GIVEN IN THIS APPLICATION NOTE (INCLUDING BUT NOT LIMITED TO CONTENTS OF REFERENCED WEBSITES) IS GIVEN AS A HINT FOR THE IMPLEMENTATION OF THE INFINEON TECHNOLOGIES COMPONENT ONLY AND SHALL NOT BE REGARDED AS ANY DESCRIPTION OR WARRANTY OF A CERTAIN FUNCTIONALITY, CONDITION OR QUALITY OF THE INFINEON TECHNOLOGIES COMPONENT. THE RECIPIENT OF THIS APPLICATION NOTE MUST VERIFY ANY FUNCTION DESCRIBED HEREIN IN THE REAL APPLICATION. INFINEON TECHNOLOGIES HEREBY DISCLAIMS ANY AND ALL WARRANTIES AND LIABILITIES OF ANY KIND (INCLUDING WITHOUT LIMITATION WARRANTIES OF NON-INFRINGEMENT OF INTELLECTUAL PROPERTY RIGHTS OF ANY THIRD PARTY) WITH RESPECT TO ANY AND ALL INFORMATION GIVEN IN THIS APPLICATION NOTE.

Information

For further information on technology, delivery terms and conditions and prices, please contact the nearest Infineon Technologies Office (www.infineon.com).

Warnings

Due to technical requirements, components may contain dangerous substances. For information on the types in question, please contact the nearest Infineon Technologies Office. Infineon Technologies components may be used in life-support devices or systems only with the express written approval of Infineon Technologies, if a failure of such components can reasonably be expected to cause the failure of that life-support device or system or to affect the safety or effectiveness of that device or system. Life support devices or systems are intended to be implanted in the human body or to support and/or maintain and sustain and/or protect human life. If they fail, it is reasonable to assume that the health of the user or other persons may be endangered.