# 700 mA non-isolated high-voltage buck evaluation board using CoolSET™ ICE5BR2280BZ-1

## EVAL_5BR2280BZ-1_700mA1

## About this document

### Scope and purpose

This document describes a non-isolated 15 V, 700 mA high-voltage (HV) buck converter using the latest CoolSET™ 5th Generation Fixed Frequency Plus ICE5BR2280BZ-1 switching controller from Infineon. The document contains power supply specifications, schematics, bill of materials (BOM), PCB layout, and performance data.
This evaluation board is designed to evaluate the performance of CoolSET™ ICE5BR2280BZ-1 switching controller for its ease of use.

### Intended audience

This document is intended for SMPS design/application engineers, students, etc., who wish to design low-cost and non-isolated buck converters for applications such as auxiliary power supplies for white goods, smart metering, etc.

### CoolSET™

Infineon's CoolSET™ AC-DC integrated power stages in fixed-frequency switching scheme offers increased robustness and outstanding performance. This family offers superior energy efficiency, comprehensive protective features, and reduced system costs and is ideally suited for auxiliary power supply applications in a wide variety of potential applications such as:

- SMPS
- Home appliances
- Server
- Telecom

# Table of contents

# 1 Introduction

This document describes a 15 V, 700 mA evaluation board designed in a buck converter topology using the CoolSET™ 5th Generation Fixed Frequency Plus ICE5BR2280BZ-1 switching controller. The target applications of the ICE5BR2280BZ-1 switching controller are either auxiliary power supplies for white goods, PCs, servers or TVs, or enclosed adapters for games consoles and smart metering, etc. The 800 V CoolMOS™ integrated into this IC greatly simplifies the design and layout of the PCB. The new improved digital frequency reduction and frequency jitter feature offer lower EMI and higher efficiency. The enhanced active burst mode (ABM) power enables flexibility in standby power operation range selection. In addition, numerous adjustable protection functions have been implemented in ICE5BR2280BZ-1 switching controller to protect the system and customize the IC for the chosen application.

# 2 Evaluation board

Typical operating characteristics such as performance curve and scope waveforms are shown at the end of the report.

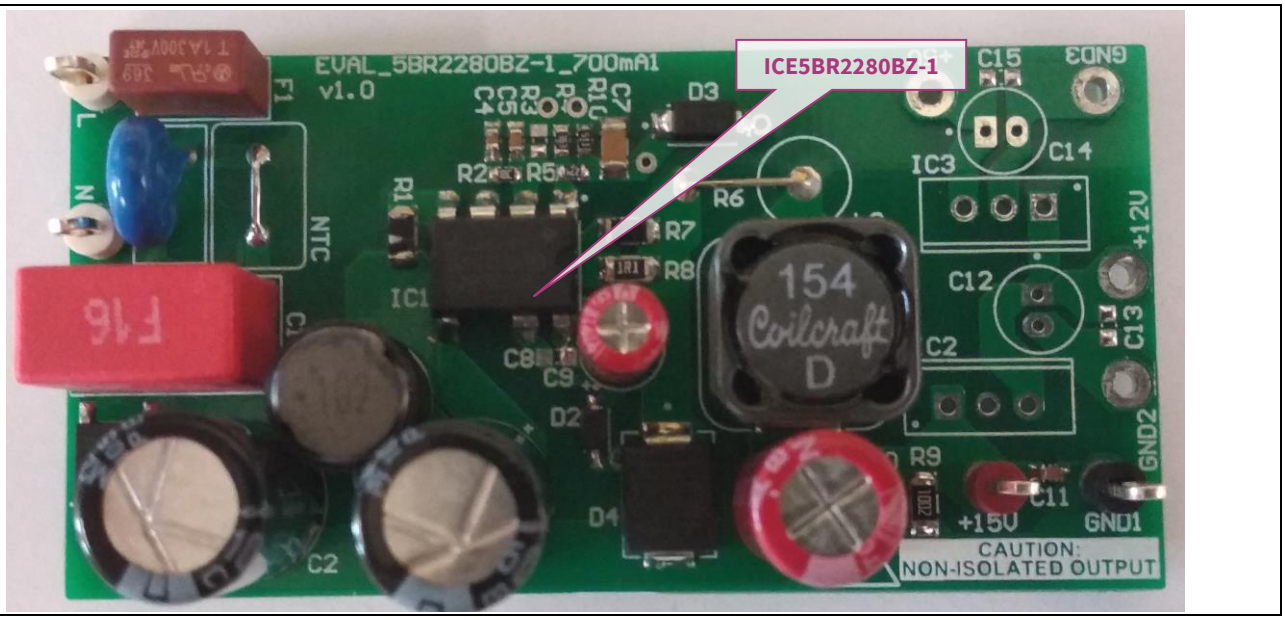



**Figure 1 EVAL_5BR2280BZ-1_700mA1**

# 3 Specifications of evaluation board

**Table 1 Specifications of EVAL_5BR2280BZ-1_700mA1**

| Description | Symbol | Min. | Typ. | Max. | Unit | Comments |
|---|---|---|---|---|---|---|
| **Input** | | | | | | |
| Voltage | $V_{IN}$ | 85 | – | 264 | V AC | 2-wire (no P.E.) |
| Frequency | $f_{LINE}$ | 47 | 50/60 | 63 | Hz | |
| **Output** | | | | | | |
| Voltage | $V_{OUT}$ | 15 | | | V | – |
| Current | $I_{OUT}$ | 0.7 | | | A | – |
| Output power | $P_{OUT}$ | 10.5 | | | W | – |
| **Output voltage accuracy** | – | < ±5% | | | % | – |
| **Overcurrent protection** | – | < 150% of rated current | | | A | – |
| **Ripple and noise voltage** | $V_{pk-pk}$ | < 1% (20 MHz bandwidth) | | | mV | With 10 µF e-cap and 0.1 µF MLCC |
| **Environmental** | | | | | | |
| Conducted EMI | – | 6 | | | dB | Margin, CISPR 22 Class B |
| **Surge immunity** | | | | | | |
| Differential mode (DM) | | ± 1 | | | kV | EN 61000-4-5 |
| Ambient temperature | $T_{ambw}$ | -20 | – | 50 | °C | Free convection, sea level |
| **PCB form factor** | – | 70 × 35 × 23 | | | mm | L × W × H |

*Note: The table above represents the minimum acceptable performance of the design; actual measurement results are given in the test results section. This evaluation board is designed to demonstrate the maximum output current only.*

# 4 Schematic

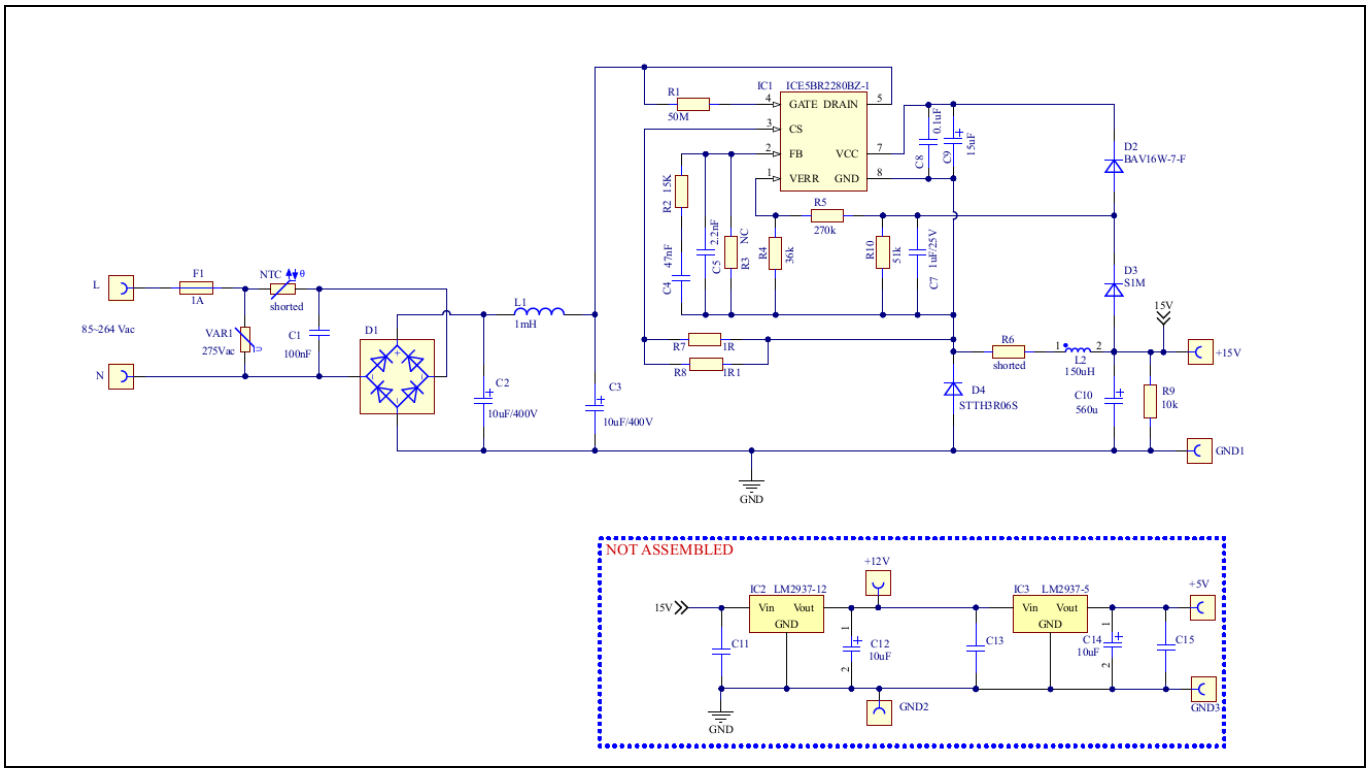



**Figure 2 EVAL_5BR2280BZ-1_700mA1**

# 5 Circuit description

## 5.1 Line input

The AC-line input stage comprises the input fuse (F1), varistor (VAR1), X-capacitor (C1), rectifier diode bridge (D1), capacitors (C2 and C3), and inductor (L1). The X-capacitor (C1) and π-filter (C2, L1, and C3) act as EMI suppressors.

## 5.2 Start-up

ICE5BR2280BZ-1 uses a cascode structure to fast-charge the $V_{CC}$ capacitor. Pull-up resistor (R1) connected to the GATE pin (pin 4) is used to initiate the start-up phase. When $V_{CC}$ reaches the turn-on voltage threshold 16 V, the IC begins with a soft-start.
The soft-start implemented in ICE5BR2280BZ-1 switching controller is a digital time-based function. The preset soft-start time is 12 ms with four steps. If not limited by other functions, the peak voltage on the CS pin will increase in increments from 0.3 V to 0.8 V. After IC turn-on, the $V_{CC}$ voltage is supplied by output voltage. The $V_{CC}$ short-to-GND protection is implemented during the start-up time.

## 5.3 Integrated MOSFET and PWM control

ICE5BR2280BZ-1 comprises a power MOSFET and the controller, which simplifies the circuit layout and reduces the cost of PCB manufacture. The controller together with the MOSFET is placed at the high-side of the converter with a floating ground at the cathode of freewheeling diode (D4). An ultra-fast recovery diode (D4) is used to allow the inductor demagnetizing current to flow through it and limit the spike current through the power MOSFET, especially when the buck converter operates in CCM mode. Thus, output voltage is sensed only during freewheeling diode conduction time.

## 5.4 Output stage

The maximum output voltage ripple is determined by the output capacitance and the equivalent series resistance (ESR) of the output capacitor. Selection of a low-ESR capacitor helps to reduce ripple. The dummy load resistor (R9) helps output voltage regulation at light-load condition.

## 5.5 Feedback control

ICE5BR2280BZ-1 switching controller integrates a transconductance amplifier for feedback (FB) control. The output is sensed by the voltage divider (R4 and R5) and compared with an internal reference voltage at the VERR pin. An external compensation network (C4, C5, and R2) is recommended on the FB pin to control output voltage.

## 5.6 Primary-side peak-current control

The MOSFET drain-source current is sensed via external resistors (R7 and R8). ICE5BR2280BZ-1 switching controller is a current mode controller and has a cycle-by-cycle primary current and FB voltage control, which ensures the converter's maximum power is controlled in every switching cycle. To avoid mis-triggering caused by MOSFET switch-on transient voltage spikes, a leading-edge blanking (LEB) time ($t_{CS\_LEB}$) is integrated in the current sensing (CS) path.

## 5.7 Frequency reduction

Frequency reduction is implemented in ICE5BR2280BZ-1 switching controller to achieve better efficiency at light load. At light load, the reduced switching frequency $F_{SW}$ improves efficiency by reducing the switching losses. When load decreases, $V_{FB}$ and $F_{SW}$ decrease. Typically, $F_{SW}$ at high load is 65 kHz and starts to decrease at $V_{FB}$ = 1.7 V. There is no further frequency reduction once it reaches the $f_{OSCx\_MIN}$ even if the load is further reduced.

## 5.8 Active burst mode

ABM entry and exit power (two levels) can be selected in ICE5BR2280BZ-1 IC. Details are illustrated in the product datasheet. ABM power level 1 is used in this evaluation board (R3 = open).

## 5.9 Protection features

ICE5BR2280BZ-1 switching controller provides comprehensive protections to ensure safe system operation. This includes $V_{CC}$ overvoltage (OV) and undervoltage (UV), overload, output OV, overtemperature (controller junction), and $V_{CC}$ short-to-GND. When those faults are found, the system will enter protection mode. Once the fault is removed, the system resumes normal operation.

To protect ICE5BR2280BZ-1 switching controller from excess thermal stress during auto-restart protection, a 15 µF $V_{CC}$ capacitor (C9) is used to extend the total auto-restart off-time to around 2s, as shown in Figure 17.

# 6 PCB layout

## 6.1 Top side

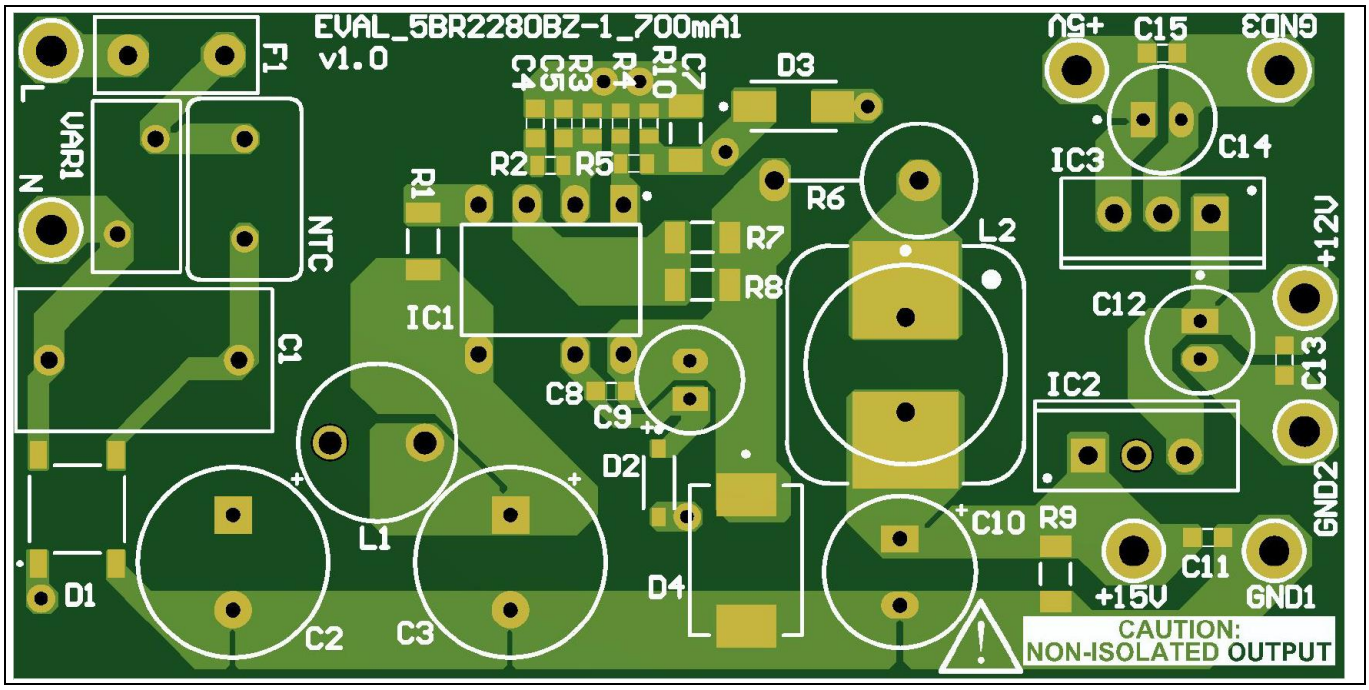



**Figure 3 Top-side copper and component legend**

## 6.2 Bottom side

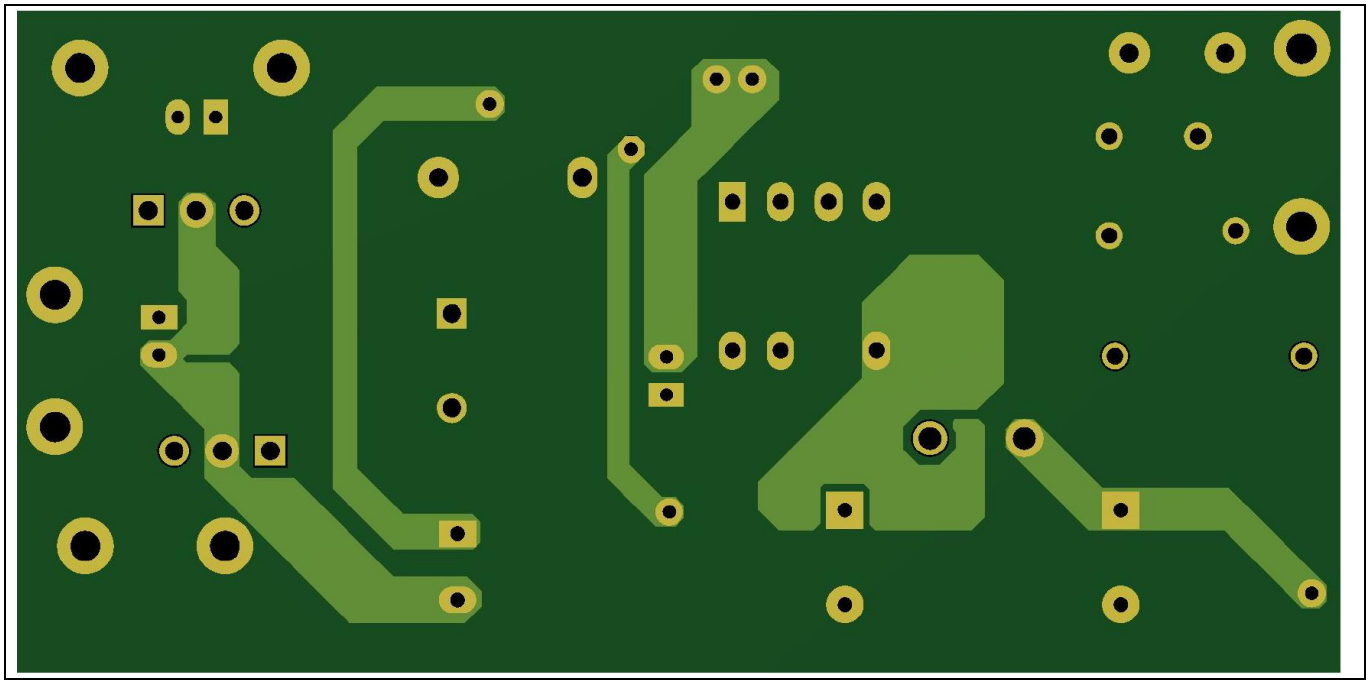


**Figure 4 Bottom-side copper**

# 7 Bill of materials

**Table 2 BOM**

| No | Designator | Description | Manufacturer | Manufacturer order number | Quantity |
|---|---|---|---|---|---|
| 1 | C1 | CAP FILM 0.1UF 10% 310VAC RADIAL | Würth Elektronik | 890334023023 | 1 |
| 2 | C2, C3 | CAP ALUM 10UF 20% 450V RADIAL | Rubycon | 450BXC10MEFC10X20 | 2 |
| 3 | C4 | CAP CER 47nF 25V X7R 0603 | – | – | 1 |
| 4 | C5 | CAP CER 2.2nF 25V X7R 0603 | – | – | 1 |
| 5 | C7 | CAP CER 1uF 25V X7R 1206 | – | – | 1 |
| 6 | C9 | CAP ALUM 15uF 20% 50V RADIAL | Würth Elektronik | 8.60161E+11 | 1 |
| 7 | C10 | CAP ALUM 560UF 20% 25V RADIAL | Würth Elektronik | 860160474023 | 1 |
| 8 | C11, C13, C15 | CAP CER 0.1UF 50V X7R 0603 | – | – | 3 |
| 9 | C12, C14 | CAP ALUM 10UF 20% 50V RADIAL | Rubycon | 50PX10MEFC5X11 | 2 |
| 10 | D1 | BRIDGE RECT 1PHASE 1KV 1A 4SOPA | Diodes Incorporated | ABS10A-13 | 1 |
| 11 | D2 | DIODE GEN PURP 100V 150MA SOD123 | Diodes Incorporated | BAV16W-7-F | 1 |
| 12 | D3 | DIODE GEN PURP 1KV 1A SMA DO-214AC | Vishay | S1M | 1 |
| 13 | D4 | Surface Mount Ultrafast Power Rectifier | STMicroelectronics | STTH3R06S | 1 |
| 14 | F1 | FUSE BOARD MNT 1A 300VAC RADIAL | – | – | 1 |
| 15 | IC1 | CoolSET™ Gen5 Fixed Frequency DIP7 | Infineon Technologies | ICE5BR2280BZ-1 | 1 |
| 16 | IC2 | IC REG LINEAR 12V 1.5A TO220AB | STMicroelectronics | L7812CV | 1 |
| 17 | IC3 | IC REG LINEAR 5V 1.5A TO220AB | STMicroelectronics | L7805CV | 1 |
| 18 | L1 | FIXED IND 1000UH 0.6A 1.27 OHM | Würth Elektronik | 7447452102 | 1 |
| 19 | L2 | FIXED IND 150UH 2.5A | Coilcraft | MSS1210-154KED | 1 |
| 20 | NTC | ICL 5 OHM 20% 4.2A 9.5MM | TDK | B57235S0509M000 | Short |

## EVAL_5BR2280BZ-1_700mA1

### Bill of materials

| No | Designator | Description | Manufacturer | Manufacturer order number | Quantity |
|---|---|---|---|---|---|
| 21 | R1 | RES 50 MOhms 300mW 1206 | – | CRHA1206AF50M0FKEF | 1 |
| 22 | R2 | RES SMD 15K OHM 1% 1/10W 0603 | – | – | 1 |
| 23 | R4 | RES SMD 36K OHM 1% 1/10W 0603 | – | – | 1 |
| 24 | R5 | RES SMD 270K OHM 1% 1/10W 0603 | – | – | 1 |
| 25 | R6 | RES 2 OHM 3W TH | – | MCKNP03UJ020JB00 | 1 |
| 26 | R7 | RES SMD 1 OHM 1% 1/2W 1206 | – | – | 1 |
| 27 | R8 | RES SMD 1.1 OHM 1% 1/2W 1206 | – | – | 1 |
| 28 | R9 | RES SMD 10K OHM 1% 1/4W 1206 | – | – | 1 |
| 29 | R10 | RES SMD 51K OHM 1% 1/10W 0603 | – | – | 1 |
| 30 | VAR1 | S07K275E2/275VAC/10% | Epcos | B72207S2271K101 | 1 |
| 31 | Line, Neutral | PC Test Point-Multipurpose THT, White | Keystone | 5012 | 2 |
| 32 | GND1, GND2, GND3 | PC Test Point-Multipurpose THT, Black | Keystone | 5011 | 3 |
| 33 | +5V, +12V, +15V | PC Test Point-Multipurpose THT, Red | Keystone | 5010 | 3 |

# 8 Test results

## 8.1 Efficiency

**Table 3 Efficiency**

| Input (V AC/Hz) | Load percentage (%) | $P_{IN}$ (W) | $V_{OUT}$ (V DC) | $I_{OUT}$ (A) | $P_{OUT}$ (W) | Efficiency η (%) | Average η (%) |
|---|---|---|---|---|---|---|---|
| 85 V AC/60 Hz | No load | 0.062 | 16.500 | 0.000 | | | |
| | 25 | 3.225 | 15.175 | 0.175 | 2.65 | 82.25% | 82.75% |
| | 50 | 6.368 | 15.108 | 0.350 | 5.28 | 82.99% | |
| | 75 | 9.512 | 15.074 | 0.525 | 7.91 | 83.12% | |
| | 100 | 12.742 | 15.051 | 0.700 | 10.53 | 82.63% | |
| 115 V AC/60 Hz | No load | 0.063 | 16.500 | 0.000 | | | |
| | 25 | 3.242 | 15.188 | 0.175 | 2.65 | 81.89% | 82.69% |
| | 50 | 6.386 | 15.120 | 0.350 | 5.29 | 82.82% | |
| | 75 | 9.513 | 15.087 | 0.525 | 7.91 | 83.18% | |
| | 100 | 12.704 | 15.051 | 0.700 | 10.53 | 82.87% | |
| 230 V AC/50 Hz | No load | 0.066 | 16.600 | 0.000 | | | |
| | 25 | 3.328 | 15.178 | 0.175 | 2.65 | 79.72% | 81.09% |
| | 50 | 6.528 | 15.120 | 0.350 | 5.29 | 81.02% | |
| | 75 | 9.682 | 15.095 | 0.525 | 7.92 | 81.77% | |
| | 100 | 12.865 | 15.055 | 0.700 | 10.53 | 81.86% | |
| 264 V AC/50 Hz | No load | 0.069 | 16.700 | 0.000 | | | |
| | 25 | 3.355 | 15.170 | 0.175 | 2.65 | 79.04% | 80.54% |
| | 50 | 6.574 | 15.115 | 0.350 | 5.29 | 80.43% | |
| | 75 | 9.742 | 15.088 | 0.525 | 7.91 | 81.23% | |
| | 100 | 12.931 | 15.057 | 0.700 | 10.53 | 81.45% | |

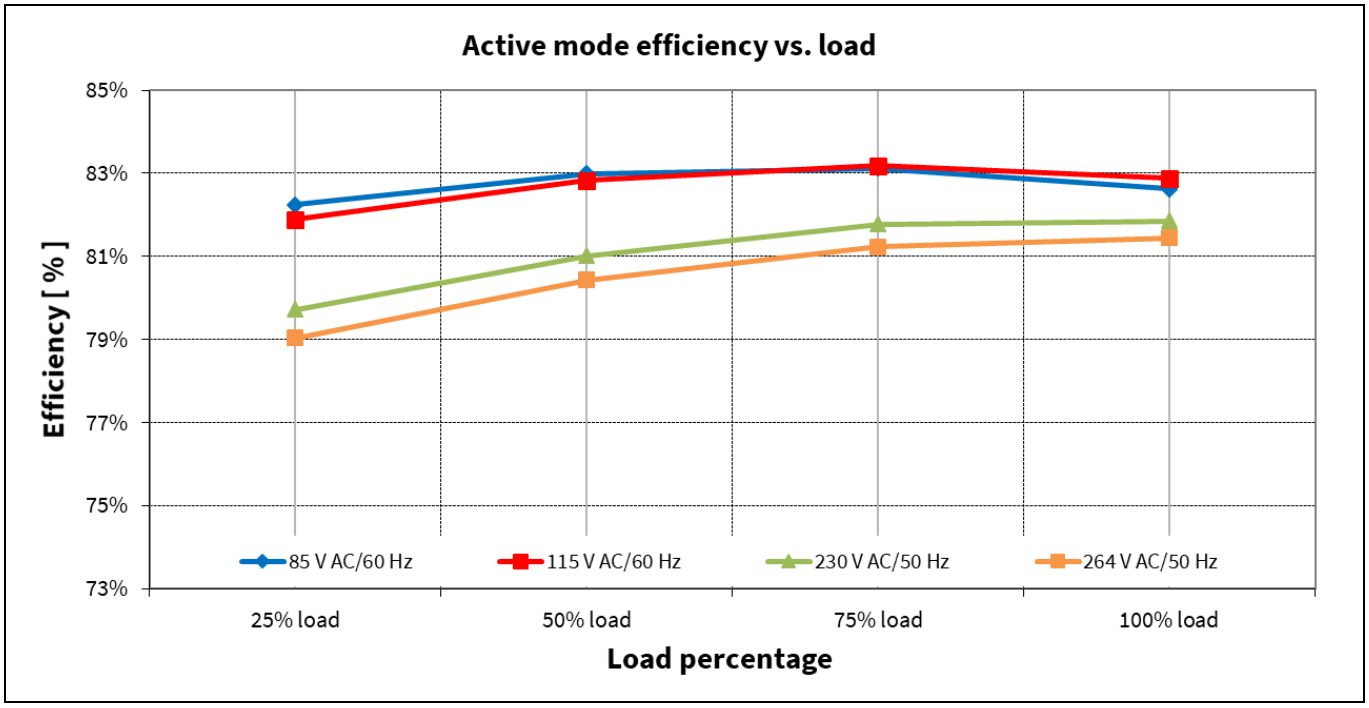



**Figure 5** **Efficiency vs. AC-line input voltage**

## 8.2 Standby power

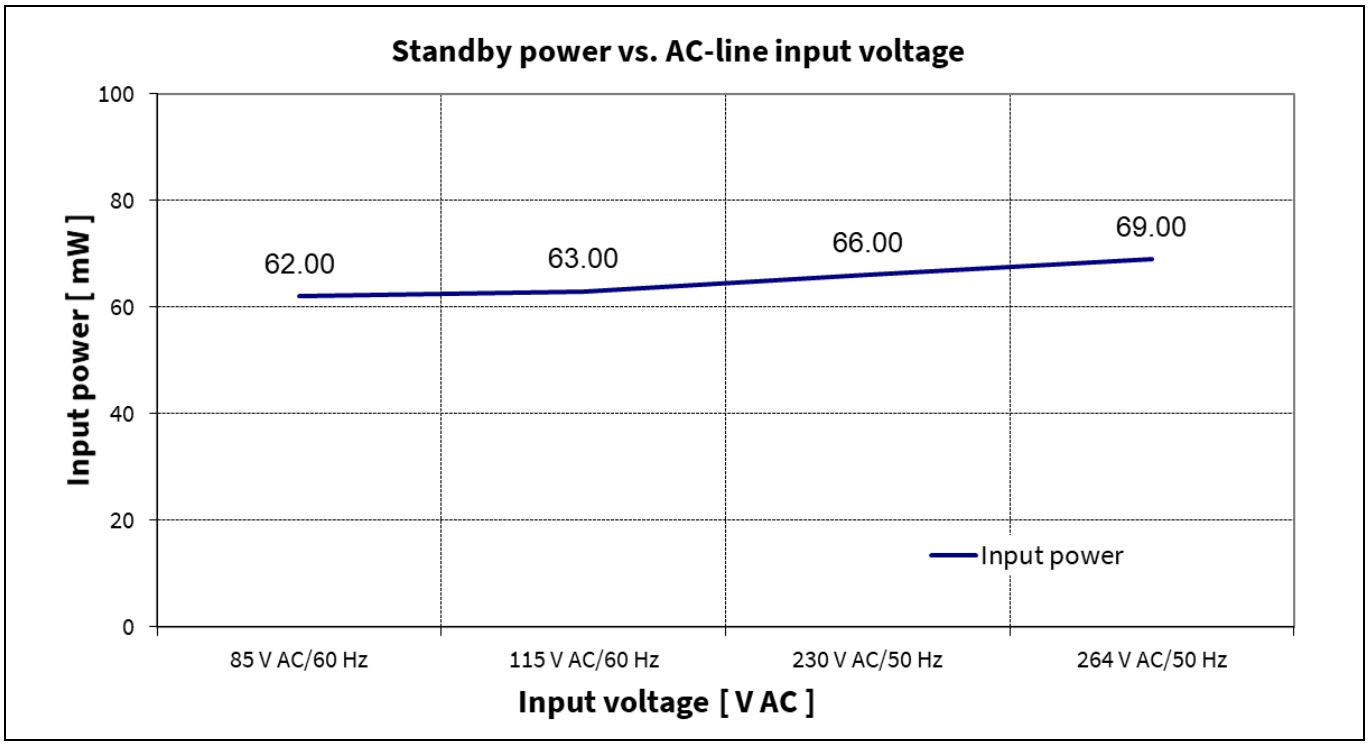



**Figure 6** **Standby power at 10 kΩ R9 (22 mW) vs. AC-line input voltage. Bleeder resistor R9 prevents output voltage to increase during no load.**

## 8.3 Line and load regulation

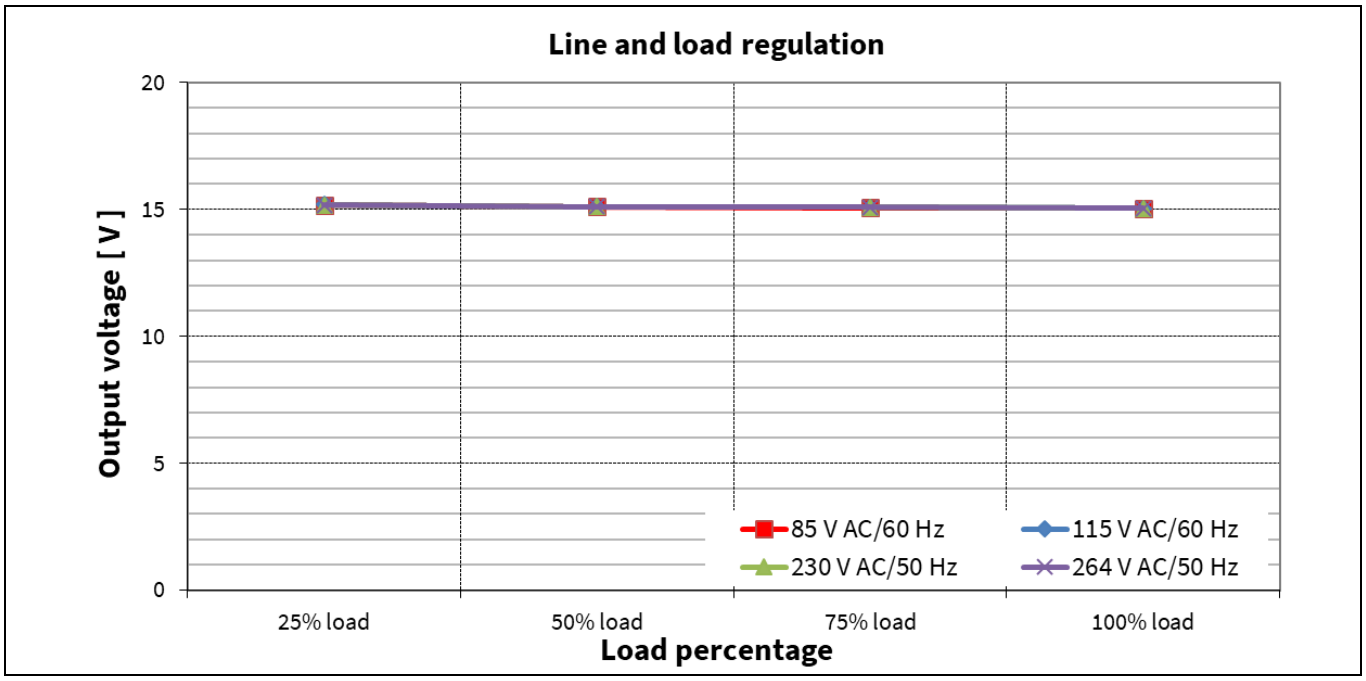



**Figure 7 Line and load regulation**

## 8.4 Surge immunity (EN 61000-4-5)

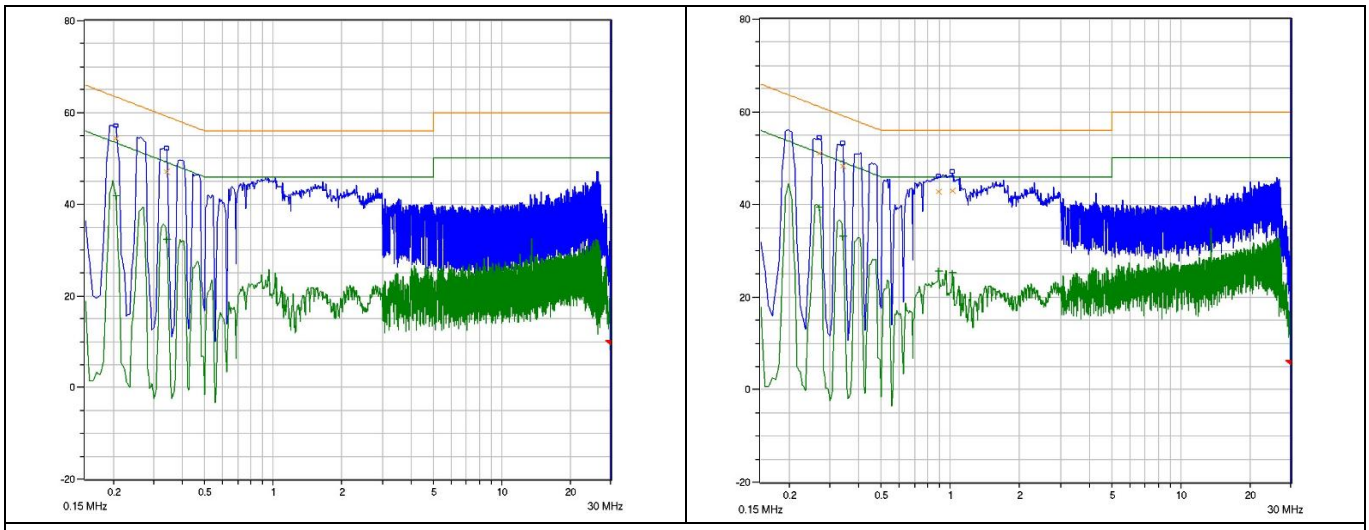
EN 61000-4-5 installation class 3 (±1 kV for line-to-line DM). A test failure is defined as a non-recoverable and/or system auto-restart.

**Table 4 Surge immunity test result**

| Description | Test | Level | | Number of strikes | | | | Test result |
|---|---|---|---|---|---|---|---|---|
| | | | | 0° | 90° | 180° | 270° | |
| 115/230 V AC, 700 mA | DM | +/-1 kV | L → N | 3 | 3 | 3 | 3 | Pass |

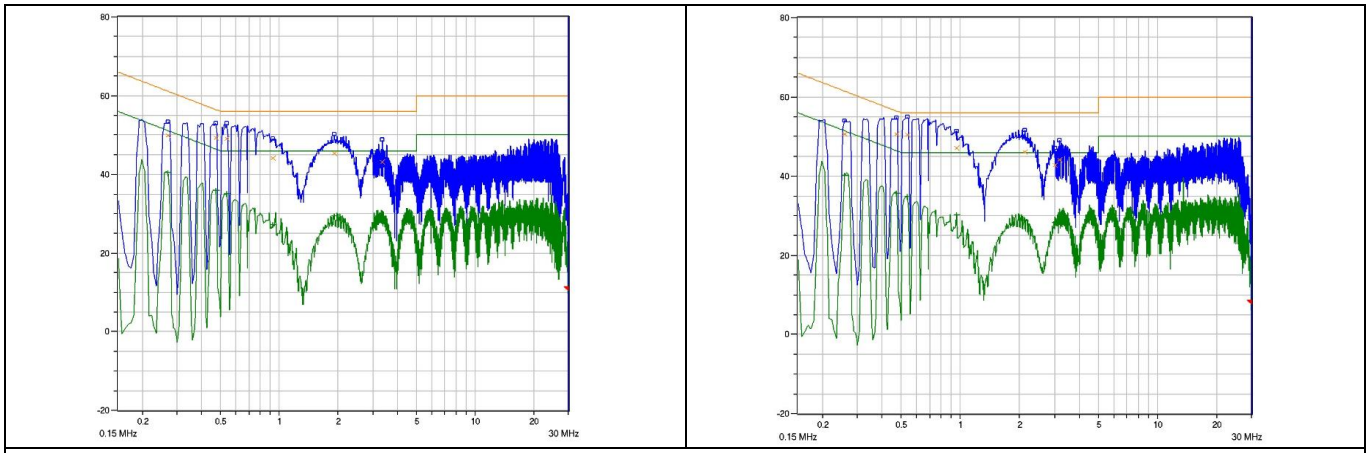
## 8.5 Conducted emissions (EN 55022 class B)

Conducted EMI was measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) class B. The evaluation board was connected to resistive load (700 mA) with input voltage of 115 V AC and 230 V AC.




Passed with 6 dB margin for quasi-peak measurement at low-line (115 V AC).

**Figure 8 Conducted emissions at 115 V AC with full load**




Passed with 6 dB margin for quasi-peak measurement at high-line (230 V AC).

**Figure 9 Conducted emissions at 230 V AC with full load**

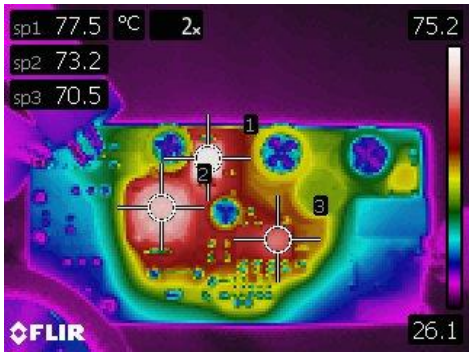
## 8.6 Thermal measurement

The thermal test of the open-frame evaluation board was done using an infrared thermography camera (FLIR-T62101) at an ambient temperature of 25°C. The measurements were taken after one hour running at full load.

**Table 5 Hottest temperature of evaluation board**

| No. | Major component | 85 V AC (°C) | 264 V AC (°C) |
|---|---|---|---|
| 1 | D4 (buck diode) | 77.5 | 81.9 |
| 2 | L2 (buck inductor) | 73.2 | 96.2 |
| 3 | IC1 (ICE5BR2280BZ-1) | 70.5 | 68.3 |

**85 V AC full load and 25°C ambient**




Top side

**264 V AC full load and 25°C ambient**


Top side

**Figure 10 Infrared thermal image of EVAL_5BR2280BZ-1_700mA1**

# 9 Waveforms and scope plots

All waveforms and scope plots were recorded with a Teledyne LeCroy 8054 oscilloscope.

## 9.1 Start-up with maximum load

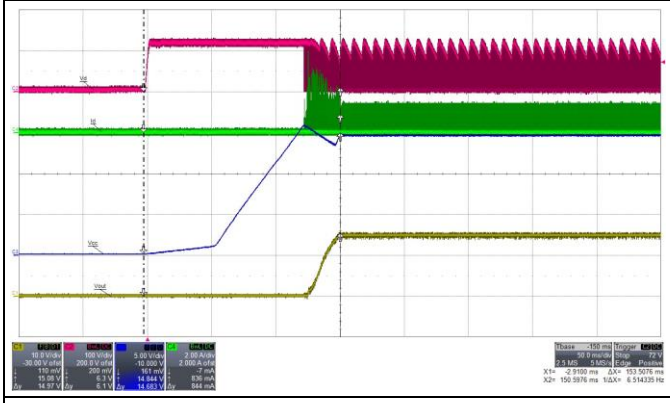
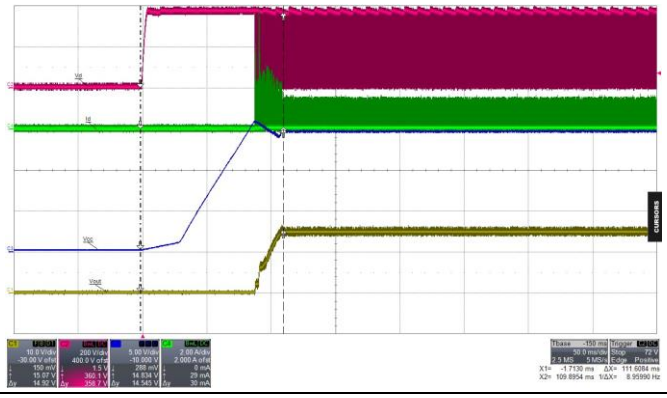
| | |
|---|---|
|  |  |
| C1:15 $V_{out}$ C2:$V_{DS}$ C3:$V_{CC}$ C4:$I_{DS}$ | C1:15 $V_{out}$ C2:$V_{DS}$ C3:$V_{CC}$ C4:$I_{DS}$ |
| Start-up time at 85 V AC and maximum load ≈ 154 ms | Start-up time at 264 V AC and maximum load ≈ 112 ms |

**Figure 11 Start-up**

## 9.2 Soft-start

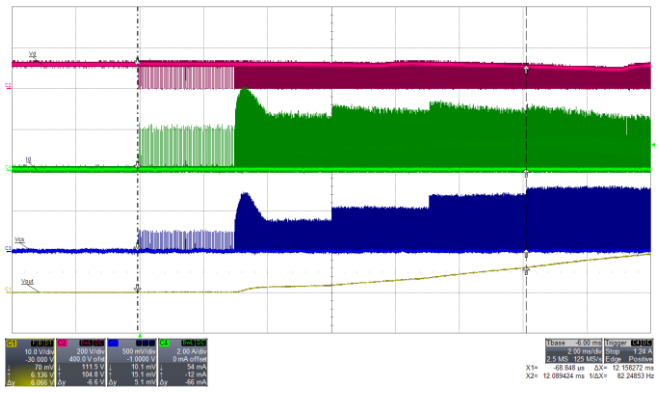
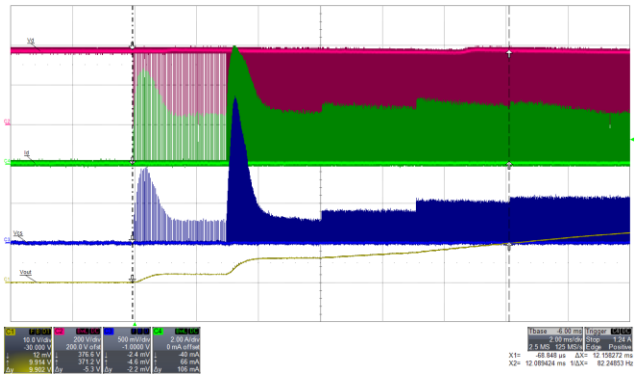
| | |
|---|---|
|  |  |
| C1:15 $V_{out}$ C2:$V_{DS}$ C3:$V_{CS}$ C4:$I_{DS}$ | C1:15 $V_{out}$ C2:$V_{DS}$ C3:$V_{CS}$ C4:$I_{DS}$ |
| Soft-start time at 85 V AC and maximum load ≈ 12 ms | Soft-start time at 264 V AC and maximum load ≈ 12 ms |

**Figure 12 Soft-start**

## 9.3 Drain voltage and Drain current at maximum load

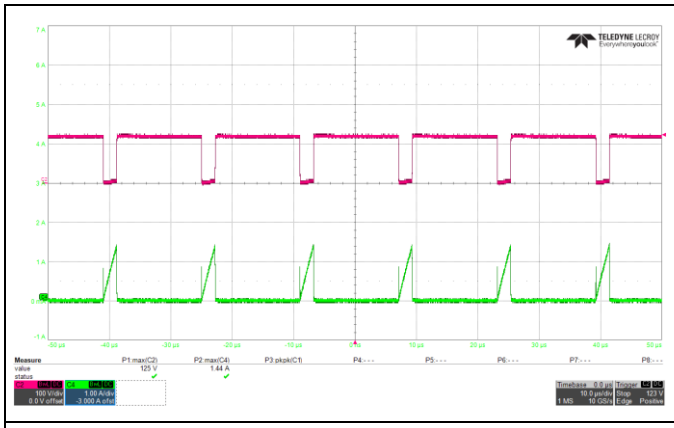
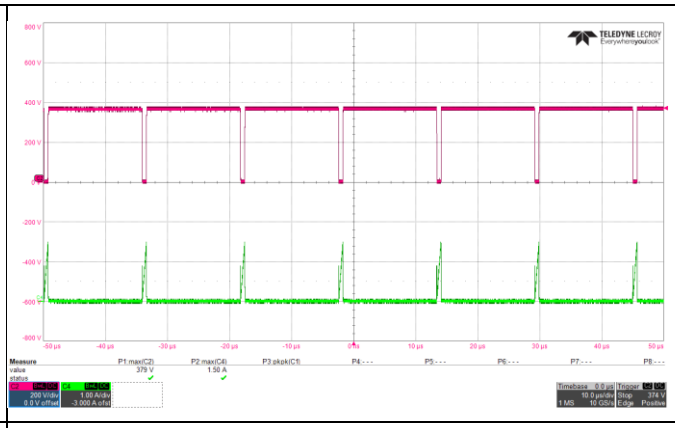
| | |
|---|---|
|  |  |
| **C2:$V_{DS}$ C4:$I_{DS}$** | **C2:$V_{DS}$ C4:$I_{DS}$** |
| $V_{Drain\_peak}$ at 85 V AC ≈ 125 V<br>$I_{DRAIN}$ at 85 V AC ≈ 1.44 A | $V_{Drain\_peak}$ at 264 V AC ≈ 380 V<br>$I_{DRAIN}$ at 264 V AC ≈ 1.50 A |

**Figure 13 Drain and CS voltage at maximum load**

## 9.4 Output ripple voltage at maximum load

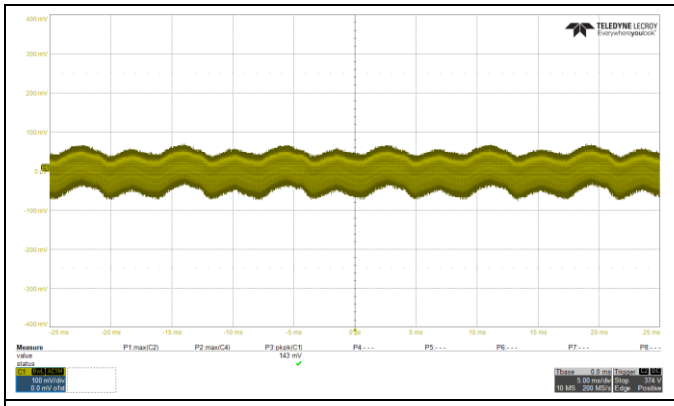
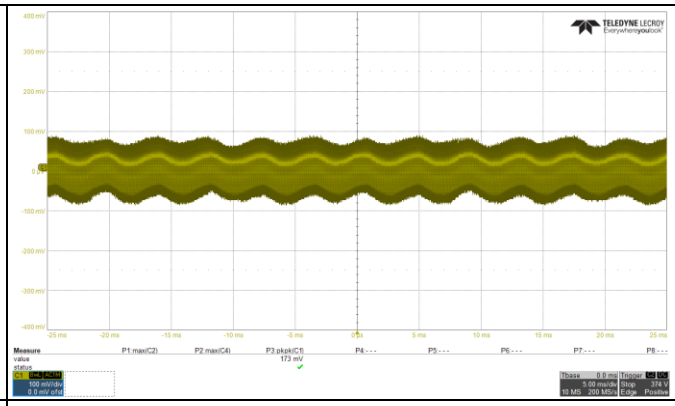
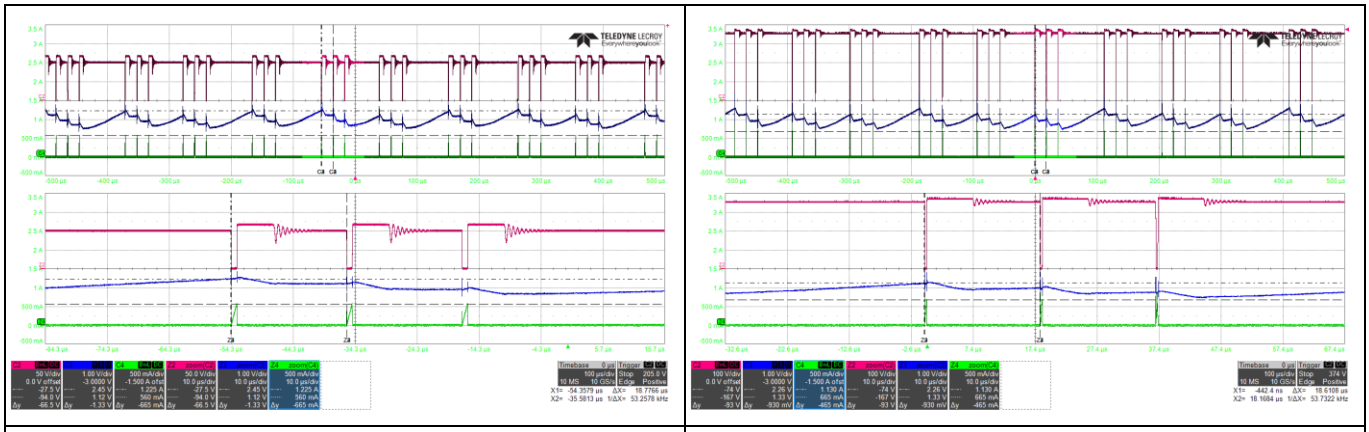
| | |
|---|---|
|  |  |
| **C1:15 $V_{out}$ (AC Coupled)** | **C1:15 $V_{out}$ (AC Coupled)** |
| 15 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 143 mV<br>Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW | 15 $V_{ripple\_pk\_pk}$ at 264 V AC ≈ 173 mV<br>Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW |

**Figure 14 Output ripple voltage at maximum load**

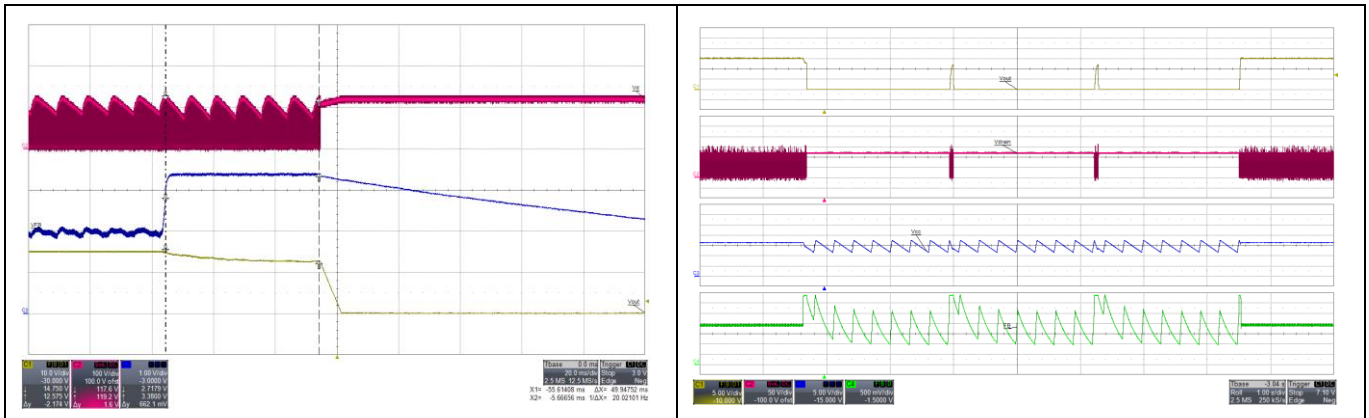
## 9.5 ABM operation



| C2:$V_{DS}$ C3:$V_{FB}$ C4:$I_{DS}$ | C2:$V_{DS}$ C3:$V_{FB}$ C4:$I_{DS}$ |
|---|---|
| 85 V AC, 50 mA load<br>Operation at $f_{osc2\_ABM}$ = 53 kHz, $I_{PK}$ = 560 mA, $V_{FB\_ON}$ = 2.4 V | 264 V AC, 40 mA load<br>Operation at $f_{osc2\_ABM}$ = 53 kHz, $I_{PK}$ = 660 mA, $V_{FB\_ON}$ = 2.3 V |

**Figure 15 ABM operation**

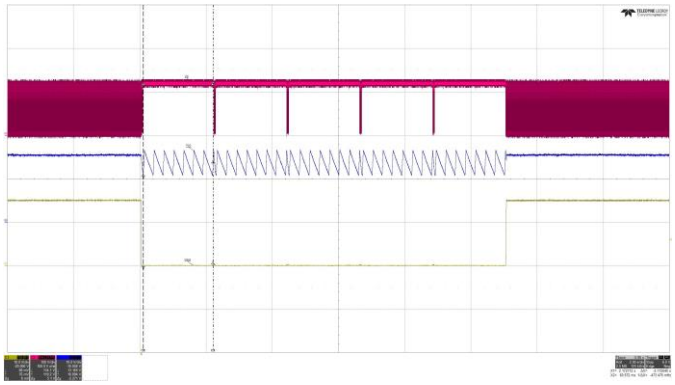
## 9.6 Overload protection (extended cycle skip auto-restart)



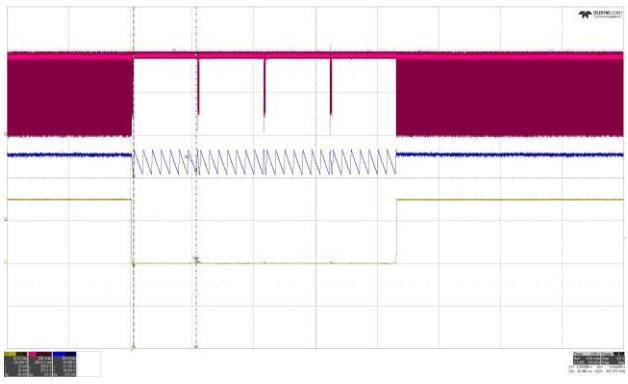
| C1:15 $V_{out}$ C2:$V_{DS}$ C3:$V_{FB}$ | C1:15 $V_{out}$ C2:$V_{DS}$ C3:$V_{CC}$ C4:$V_{FB}$ |
|---|---|
| Condition to enter overload protection: $V_{FB}$ more than 2.73 V and lasts for ~54 ms blanking time.<br>(15 V output load change from full load to overload with input 85 V AC or 264 V AC) | |

**Figure 16 Overload protection**

## 9.7 Output short test



C1:15 $V_{out}$ C2:$V_{DS}$ C3:$V_{CC}$



C1:15 $V_{out}$ C2:$V_{DS}$ C3:$V_{CC}$

IC enters into overload protection in extended cycle skip auto-restart mode and recovers when fault is removed.

**Figure 17 Output short test**

# 10 Design example A

In this evaluation board, there is a component placeholder for two low dropout (LDO) regulators connected in series as shown in Figure 18. The 12 V output regulated by IC2 can supply up to 350 mA and the 5 V output regulated by IC3 can supply up to 200 mA.

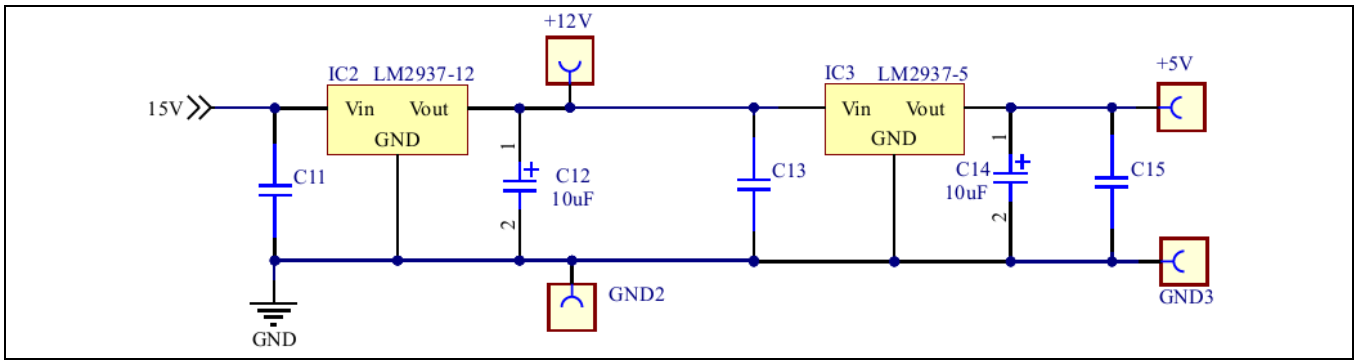



**Figure 18 Additional circuit for design example A**

*Note: Components in the additional circuit shown in Figure 18 are not mounted on the evaluation board.*

## 10.1 Specification of design example A

Since 12 V output and 5 V output are derived from the main output 15 V, the total output current should not exceed maximum capacity of the main output current. See Table 6 for the specification of this design.

**Table 6 Specification of design example A**

| Description | Symbol | Value | Comments |
|---|---|---|---|
| Output voltage 1 | $V_{O1}$ | 15 V | Main output |
| Max. output current 1 | $I_{O1}$ | 0.15 A | – |
| Output voltage 2 (via LDO) | $V_{O2}$ | 12 V | Derived from 15 V output |
| Max. output current 2 | $I_{O2}$ | 0.35 A | – |
| Output voltage 3 (via LDO) | $V_{O3}$ | 5 V | Derived from 12 V output |
| Max. output current 3 | $I_{O3}$ | 0.2 A | – |

## 10.2 Full-load efficiency

Additional power loss caused by LDO circuits will reduce overall efficiency. LDOs are mounted on the heatsink.

**Table 7 Full-load efficiency – example A**

| Input (V AC/Hz) | $P_{IN}$ (W) | $V_{O1}$ (V DC) | $I_{O1}$ (A) | $V_{O2}$ (V DC) | $I_{O2}$ (A) | $V_{O3}$ (V DC) | $I_{O3}$ (A) | $P_{OUT}$ (W) | Efficiency η (%) |
|---|---|---|---|---|---|---|---|---|---|
| 85 V AC/60 Hz | 12.974 | 15.10 | 0.15 | 11.793 | 0.35 | 4.982 | 0.2 | 7.389 | 56.95% |
| 115 V AC/60 Hz | 12.894 | 15.12 | 0.15 | 11.793 | 0.35 | 4.982 | 0.2 | 7.392 | 57.33% |
| 230 V AC/50 Hz | 13.060 | 15.13 | 0.15 | 11.793 | 0.35 | 4.982 | 0.2 | 7.393 | 56.61% |
| 264 V AC/50 Hz | 13.100 | 15.14 | 0.15 | 11.793 | 0.35 | 4.982 | 0.2 | 7.394 | 56.44% |

# References

[1] Infineon Technologies AG: *ICE5xRxxxxBZx-1 datasheet*; Available online
[2] Infineon Technologies AG: *CoolSET™ 5th Generation Fixed Frequency Plus buck design guide*; Available online
[3] Infineon Technologies AG: *CoolSET™ 5th Generation Fixed Frequency Plus calculation tool for buck*; Available online

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## Revision history

| Document version | Date of release | Description of changes |
|---|---|---|
| V 1.0 | 2024-08-23 | Initial release |

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**Edition 2024-08-23**

**Published by**

**Infineon Technologies AG**

**81726 Munich, Germany**



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**Document reference**

**AN074527**

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