450 mA non-isolated high-voltage buck evaluation board using CoolSET™ ICE5BR4780BZ-1

EVAL_5BR4780BZ-1_450mA1

About this document

Scope and purpose

This document describes a non-isolated 15 V/450 mA high-voltage buck converter using the latest CoolSET™ 5th Generation Fixed Frequency Plus ICE5BR4780BZ-1 enhanced switching controller from Infineon. The document contains power supply specifications, schematics, BOM, PCB layout and performance data. This evaluation board is designed to evaluate the performance of CoolSET™ ICE5BR4780BZ-1 switching controller and 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/450 mA evaluation board designed in a buck converter topology using the CoolSET™ 5th Generation Fixed Frequency Plus ICE5BR4780BZ-1 switching controller. ICE5BR4780BZ-1 is targeted at auxiliary power supplies for white goods, PCs, servers and TVs, or enclosed adapters, gaming consoles, smart metering, etc.

The CoolMOS™ 800 V SJ MOSFET 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 ICE5BR4780BZ-1 to protect the system and customize the IC for the chosen application.

This document describes the list of features, power supply specifications, schematics, BOM, and performance data. Typical operating characteristics such as performance curves and scope waveforms are provided at the end of this document.

2 Evaluation board

Figure 1 EVAL_5BR4780BZ-1_450mA1

2.1 Evaluation board specifications

Table 1 Specifications of EVAL_5BR4780BZ-1_450mA1

Description	Symbol	Min	Typ	Max	Unit	Notes/conditions
Input						
Voltage	V_{IN}	85	–	264	V AC	Two-wire (no P.E.)
Frequency	f_{LINE}	47	50/60	63	Hz	–
Output						
Voltage	V_{OUT}	15			V	–
Current	I_{OUT}	0.45			A	–
Output power	P_{OUT}	6.75			W	–
Output voltage accuracy	–	< ±5%			%	–
Over current protection	–	< 150% of rated current			A	–

Description	Symbol	Min	Typ	Max	Unit	Notes/conditions
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_{amb}	-20	–	50	°C	Free convection, sea level
PCB form factor	–	70 x 35 x 23			mm	L X W X H

Note: Table 1 represents the minimum acceptable performance of the design. Actual measurement results are listed in the Test results section. This evaluation board is designed to demonstrate the maximum output current only.

3 Schematic

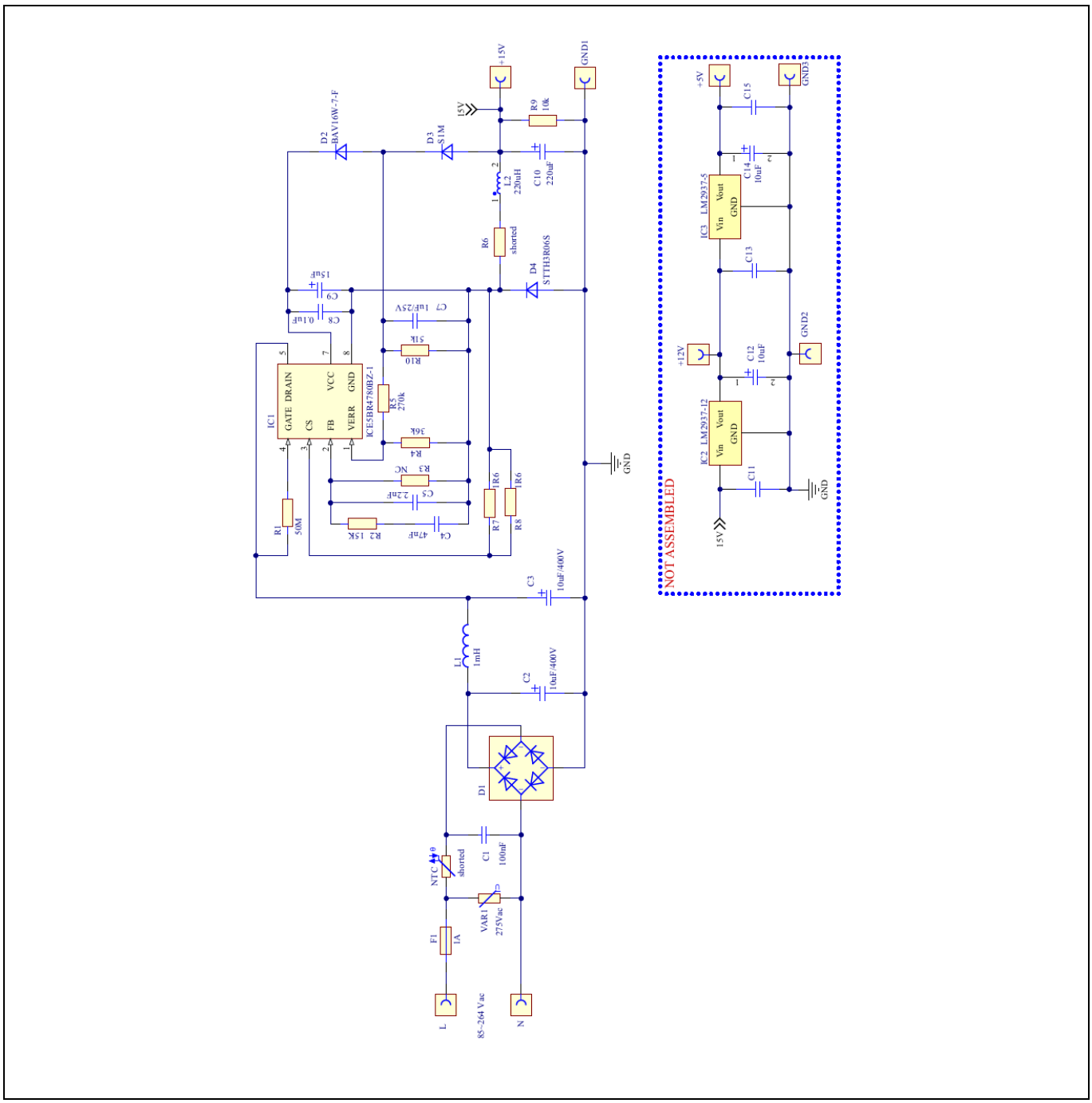


Figure 2 EVAL_5BR4780BZ-1_450mA1

4 Circuit description

4.1 Line input

The AC line input stage comprises an 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.

4.2 Start-up

The CoolSET™ ICE5BR4780BZ-1 switching controller 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_{VCC} reaches the turn-on voltage threshold 16 V, the IC begins with a soft-start. The soft-start implemented in ICE5BR4780BZ-1 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 the IC turn-on, the V_{CC} voltage is supplied by the output voltage. V_{CC} short-to-GND protection is implemented during the startup time.

4.3 Integrated MOSFET and PWM control

The CoolSET™ ICE5BR4780BZ-1 switching controller comprises a power MOSFET and a controller that simplify the circuit layout and reduce the PCB manufacturing cost. ICE5BR4780BZ-1 together with the MOSFET is placed at the high side of the converter with a floating ground at the cathode of the 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 continuous conduction mode (CCM). Therefore, the output voltage is sensed only during the freewheeling diode conduction time.

4.4 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 reduce the ripple. The dummy load resistor (R9) helps in output voltage regulation at light-load condition.

4.5 Feedback control

ICE5BR4780BZ-1 integrates a transconductance amplifier for feedback 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 the output voltage.

4.6 Primary-side peak-current control

The MOSFET drain-source current is sensed via external resistors (R7 and R8). ICE5BR4780BZ-1 is a current mode controller that has a cycle-by-cycle primary current and FB voltage control which ensures that the converter's maximum power is controlled in every switching cycle. To avoid mistriggering caused by the MOSFET switch-on transient voltage spikes, a leading-edge blanking (LEB) time (t_{CS_LEB}) is integrated into the current sensing (CS) path.

4.7 Frequency reduction

Frequency reduction is implemented in ICE5BR4780BZ-1 to achieve better efficiency during light load. At light-load conditions, the reduced switching frequency (F_{SW}) improves the 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.

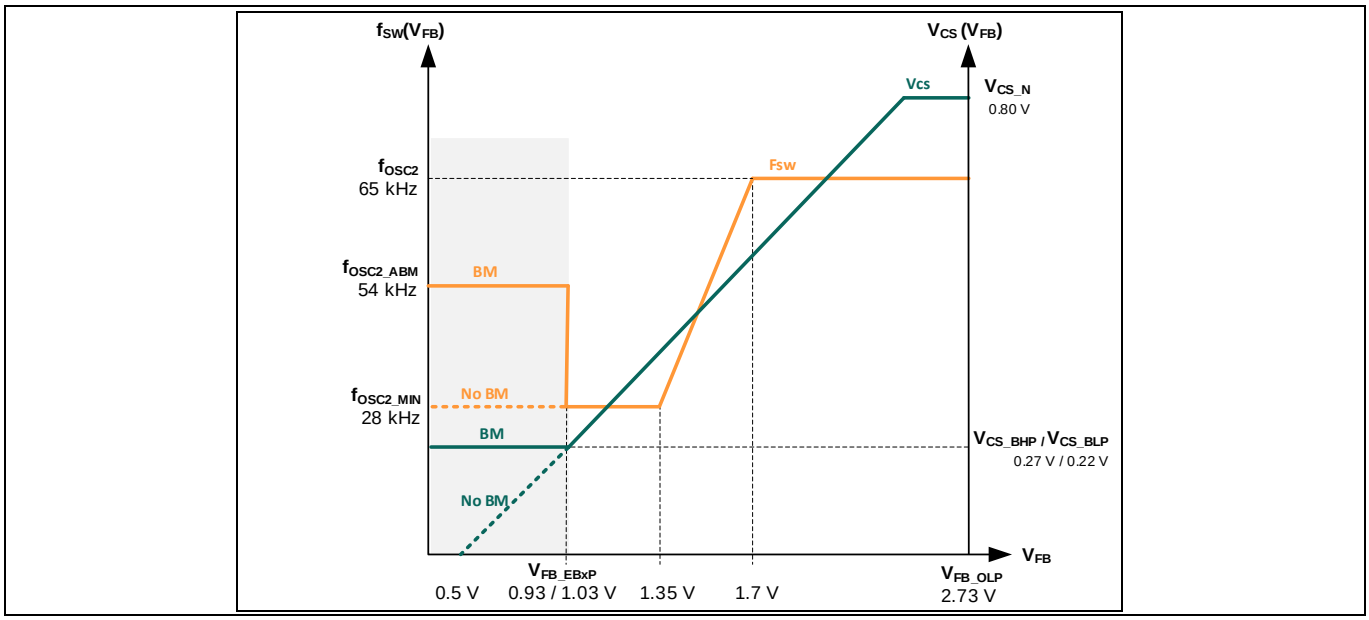


Figure 3 Frequency reduction curve

4.8 Active burst mode (ABM)

The ABM entry and exit power levels (two levels) can be selected in ICE5BR4780BZ-1. See the product datasheet [1] for more details. ABM power level 3 is used in this evaluation board (R3 = open).

4.9 Protection features

ICE5BR4780BZ-1 provides comprehensive protection features to ensure a safe operation of the system. This includes V_{CC} overvoltage (OV) and undervoltage (UV), overload, overtemperature (controller junction) and V_{CC} short-to-GND. When those faults are detected, the system enters protection mode. Once the fault is removed, the system resumes normal operation.

5 PCB layout

5.1 Top side

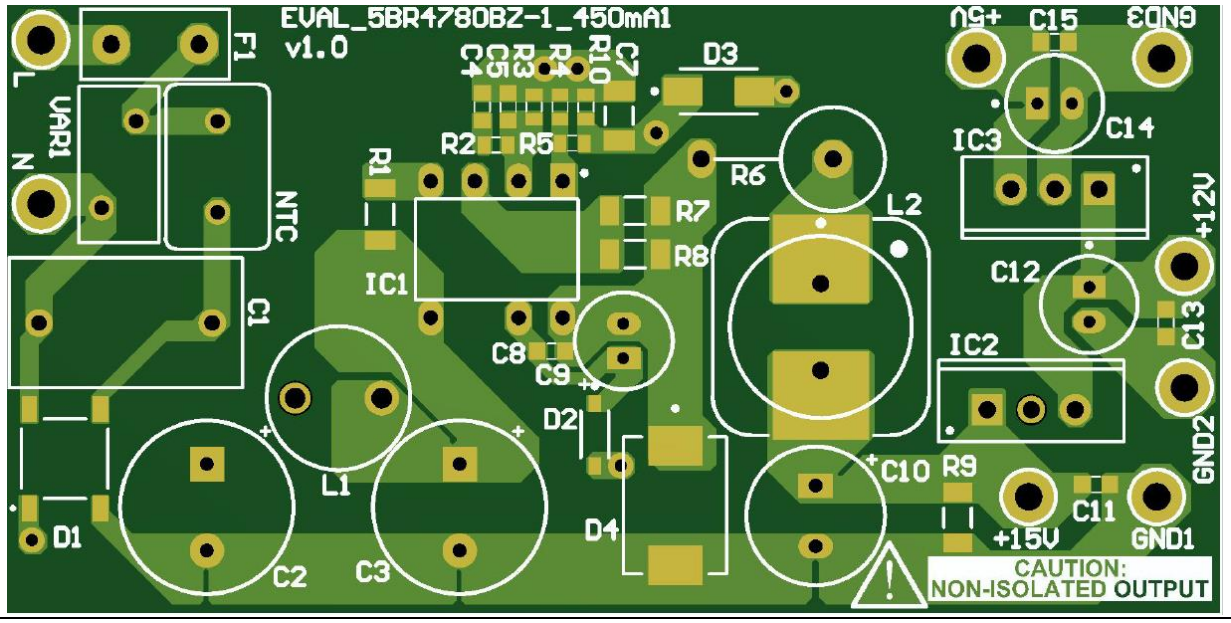


Figure 4 Top-side copper and component legend

5.2 Bottom side

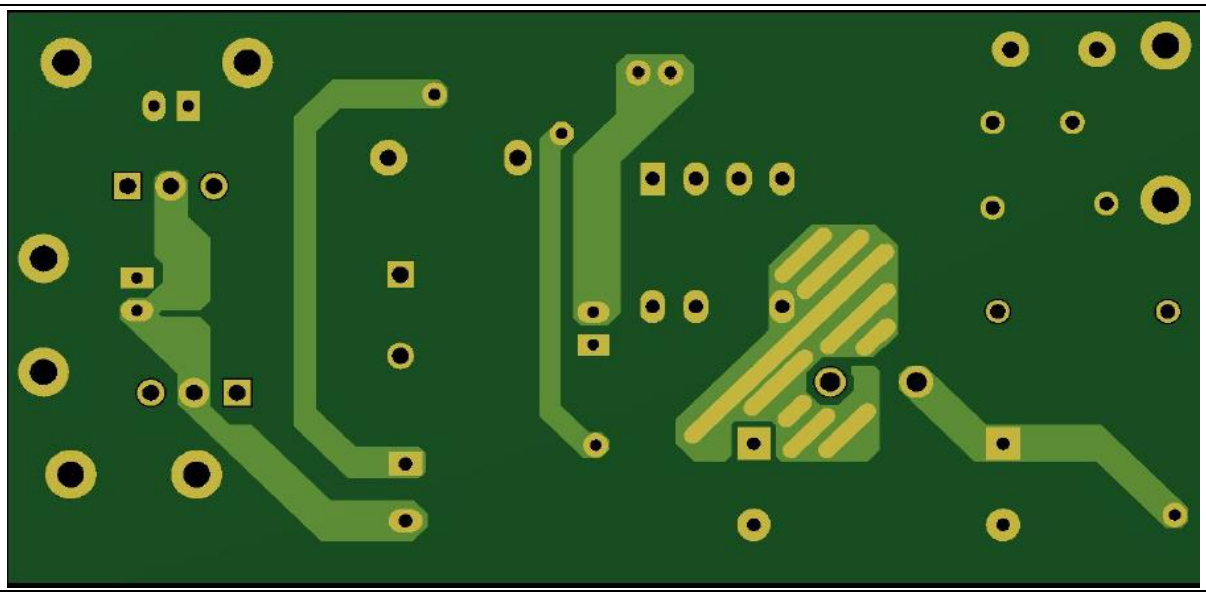


Figure 5 Bottom-side copper

6 Bill of materials

Table 2 BOM

No.	Designator	Description	Manufacturer	Part number	Qty
1	C1	CAP FILM 0.1 UF 10% 310 V AC RADIAL	Würth Elektronik	890334023023	1
2	C2, C3	CAP ALUM 10 UF 20% 450 V RADIAL	Rubycon	450BXF10M10X16	2
3	C4	CAP CER 47 nF 25 V X7R 0603	–	–	1
4	C5	CAP CER 2.2 nF 25 V X7R 0603	–	–	1
5	C7	CAP CER 1 uF 25 V X7R 1206	–	–	1
6	C9	CAP ALUM 15 uF 20% 50 V RADIAL	–	–	1
7	C10	CAP ALUM 220 UF 20% 25 V RADIAL	–	–	1
8	C8, C11, C13, C15	CAP CER 0.1 UF 50 V X7R 0603	–	–	4
9	C12, C14	CAP ALUM 10 UF 20% 50 V RADIAL	Rubycon	50PX10MEFC5X11	2
10	D1	BRIDGE RECT 1PHASE 1KV 1A 4SOPA	Diodes Incorporated	ABS10A-13	1
11	D2	DIODE GEN PURP 100 V 150 MA SOD123	Diodes Incorporated	BAV16W-7-F	1
12	D3	DIODE GEN PURP 1 KV 1A SMA DO-214AC	Vishay	S1M	1
13	D4	Surface Mount Ultrafast Power Rectifier	STMicroelectronics	STTH3R06S	1
14	F1	FUSE BOARD MNT 1A 300 V AC RADIAL	–	–	1
15	IC1	CoolSET™	Infineon Technologies	ICE5BR4780BZ-1	1
16	IC2	IC REG LINEAR 12 V 1.5 A TO220AB	STMicroelectronics	L7812CV	1
17	IC3	IC REG LINEAR 5 V 1.5 A TO220AB	STMicroelectronics	L7805CV	1
18	L1	FIXED IND 1000 UH 0.6A 1.27 OHM	Würth Elektronik	7447452102	1
19	L2	FIXED IND 220 UH 1.7A	Bourns	SRR1210-221M	1
20	NTC	ICL 5 OHM 20% 4.2A 9.5MM	TDK	B57235S0509M000	Short
21	R1	RES 50 MOhms 300mW 1206	–	CRHA1206AF50M0FKEF	1

EVAL_5BR4780BZ-1_450mA1

Bill of materials

No.	Designator	Description	Manufacturer	Part number	Qty
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 3.3 OHM 3W TH	–	MCKNP03SJ033JA19	Short
26	R7	RES SMD 1.6 OHM 1% 1/2 W 1206	–	–	1
27	R8	RES SMD 1.6 OHM 1% 1/2 W 1206	–	–	1
28	R9	RES SMD 10K OHM 1% 1/4 W 1206	–	–	1
29	R10	RES SMD 51K OHM 1% 1/10 W 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	+5 V, +12 V, +15 V	PC Test Point-Multipurpose THT, Red	Keystone	5010	3

7 Test results

7.1 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	0.066	15.962	0.000			
	25	2.083	15.056	0.112	1.69	81.17%	81.81%
	50	4.097	14.973	0.225	3.37	82.16%	
	75	6.127	14.923	0.337	5.03	82.15%	
	100	8.187	14.891	0.450	6.69	81.78%	
115 V AC/60 Hz	No load	0.071	15.954	0.000			
	25	2.094	15.061	0.112	1.69	80.77%	81.86%
	50	4.107	14.988	0.225	3.37	82.04%	
	75	6.119	14.935	0.337	5.04	82.33%	
	100	8.138	14.896	0.450	6.70	82.30%	
230 V AC/50 Hz	No load	0.071	16.097	0.000			
	25	2.176	15.052	0.112	1.69	77.68%	79.86%
	50	4.227	14.980	0.225	3.37	79.67%	
	75	6.241	14.940	0.337	5.04	80.74%	
	100	8.238	14.906	0.450	6.70	81.35%	
264 V AC/50 Hz	No load	0.074	16.195	0.000			
	25	2.202	15.044	0.112	1.69	76.72%	79.07%
	50	4.273	14.970	0.225	3.37	78.76%	
	75	6.294	14.933	0.337	5.04	80.03%	
	100	8.293	14.897	0.450	6.70	80.76%	

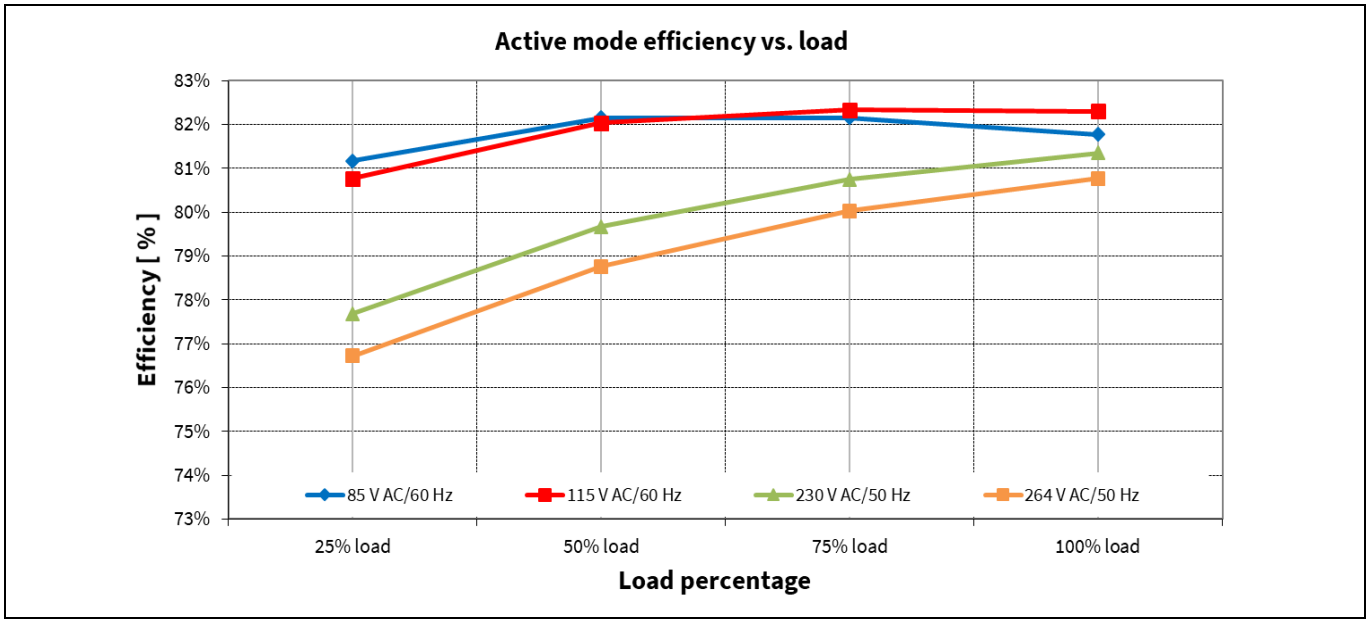


Figure 6 **Efficiency vs. AC line input voltage**

7.2 Standby power

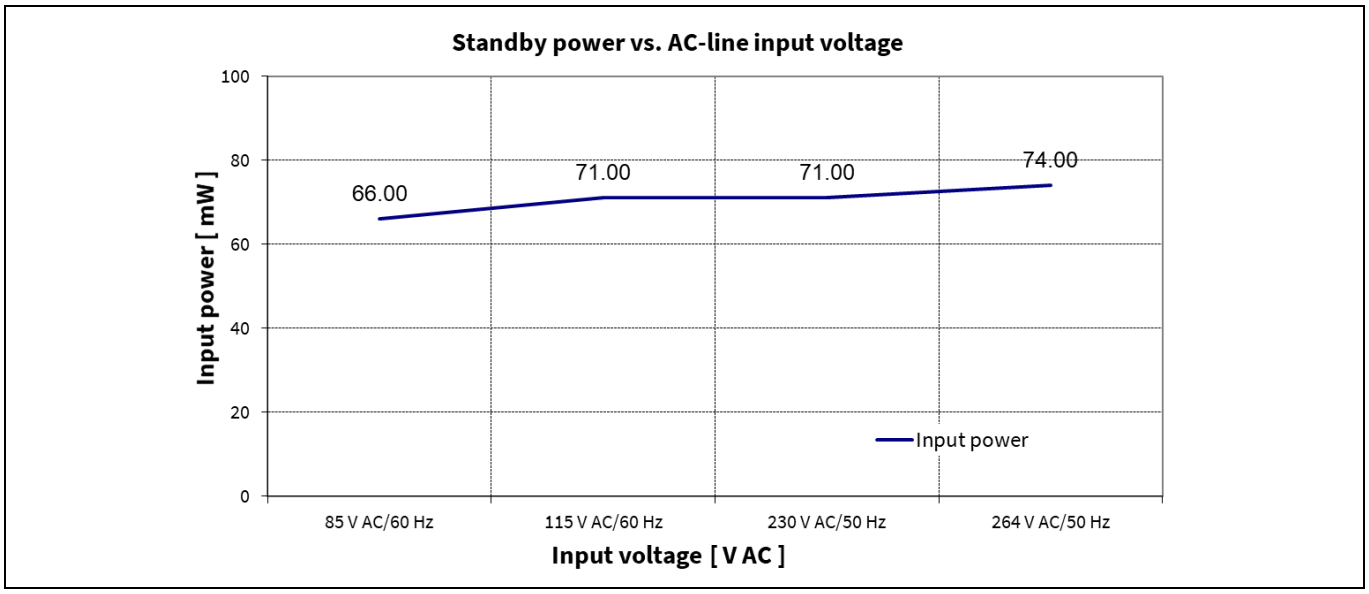


Figure 7 **Standby power at 10 kΩ R9 (22 mW) vs. AC line input voltage. Bleeder resistor (R9) prevents the output voltage from increasing during no-load conditions.**

7.3 Line and load regulation

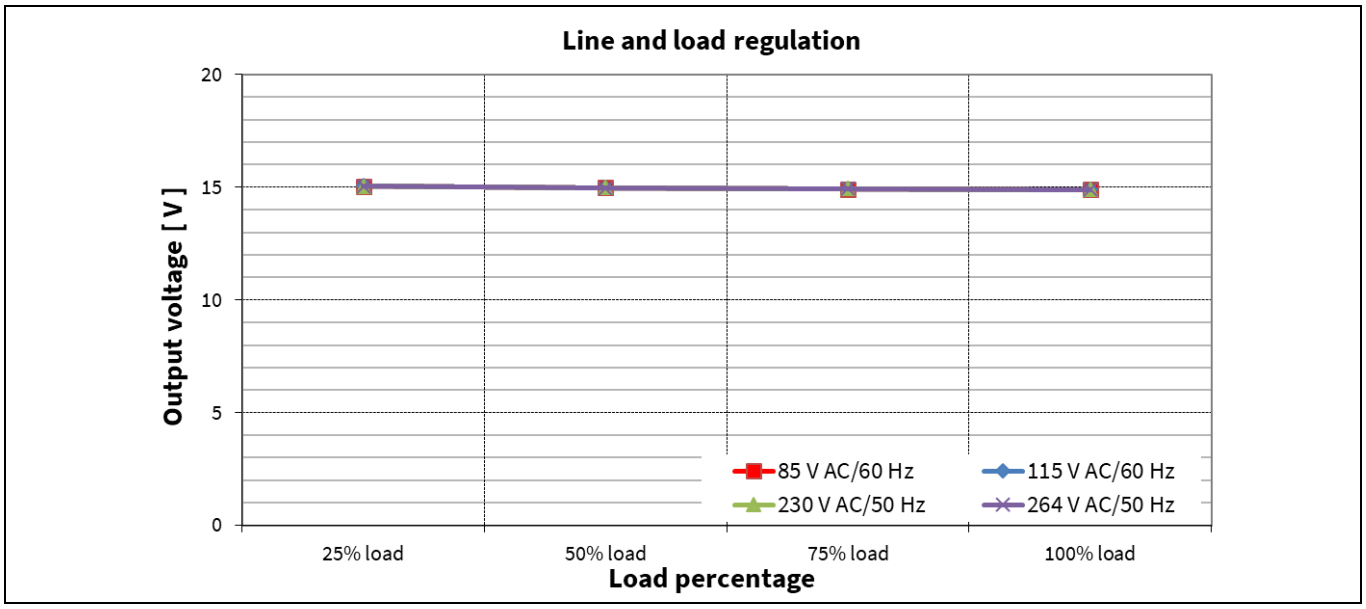


Figure 8 Line and load regulation

7.4 Surge immunity (EN 61000-4-5)

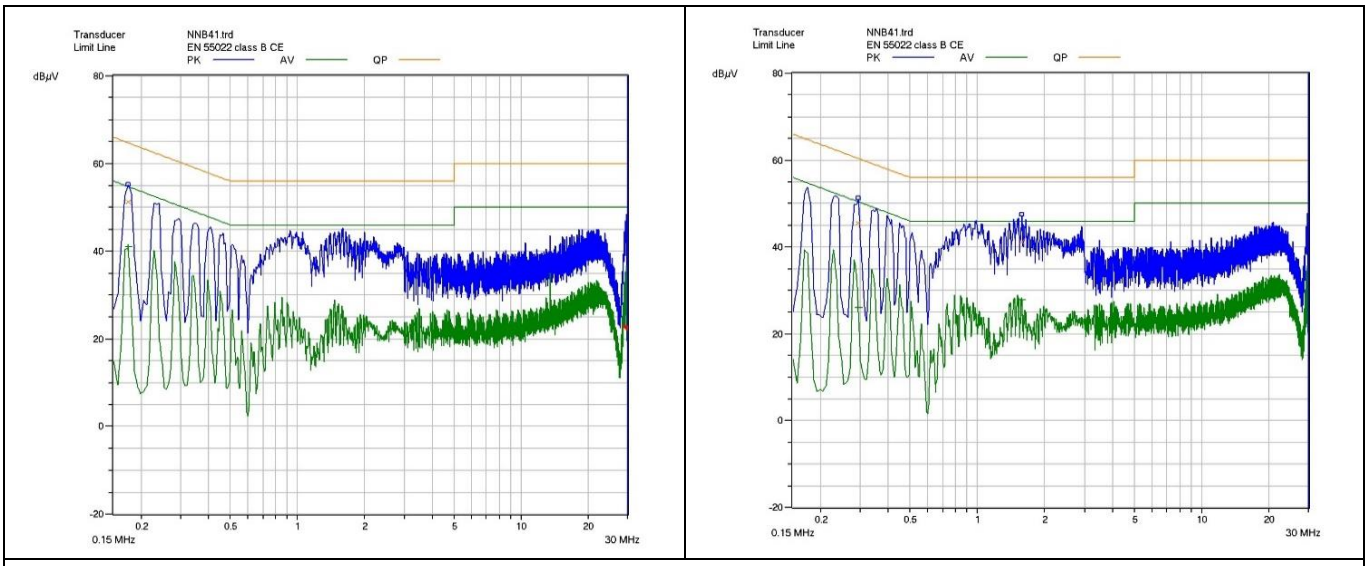
This board passes the EN 61000-4-5 installation Class 3 (±1 kV for line-to-line DM) test. A test failure is defined as a non-recoverable system auto-restart.

Table 4 Surge immunity test result

Description	Test	Level		Number of strikes				Test result
				0°	90°	180°	270°	
115/230 V AC, 450 mA	DM	+/-1 kV	L → N	3	3	3	3	Pass

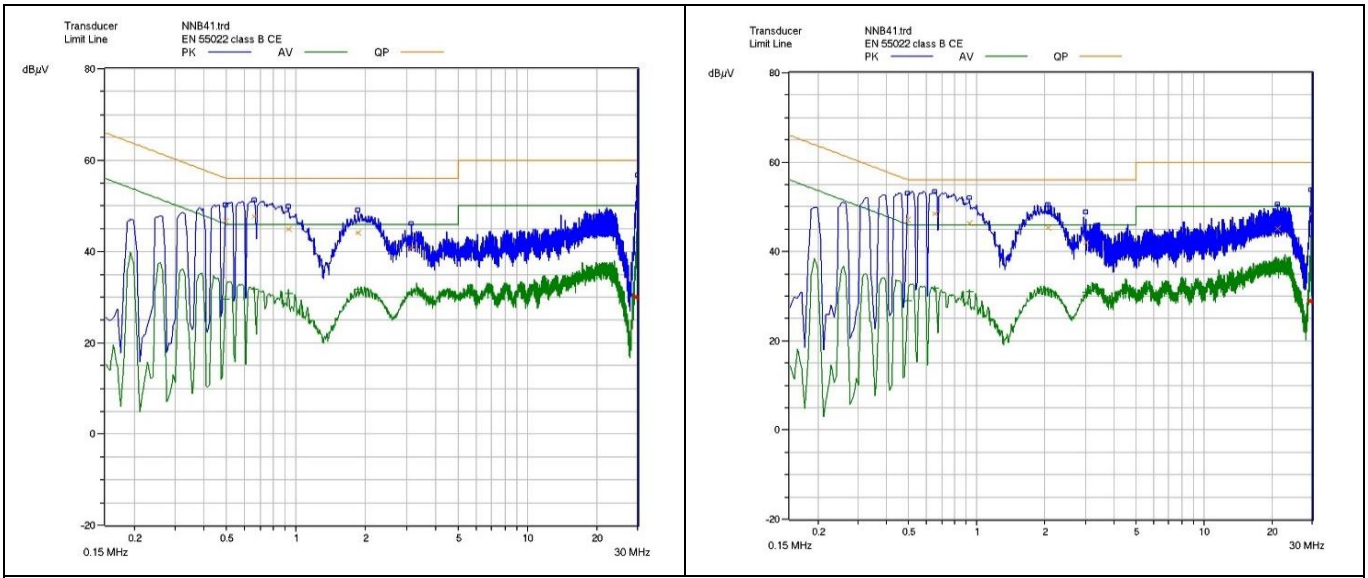
7.5 Conducted emissions (EN 55022 Class B)

Conducted EMI was measured by Schaffner (SMR4503) EMI measuring receiver and followed the test standard of EN 55022 (CISPR 22) Class B. The evaluation board is connected to a resistive load (450 mA) with an 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 9 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 10 Conducted emissions at 230 V AC with full load

7.6 Thermal measurement

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

Table 5 Hottest components of the evaluation board

No.	Major component	85 V AC (°C)	264 V AC (°C)
1	ICE5BR4780BZ-1 (IC1)	61.0	56.4
2	Buck inductor (L2)	59.4	72.4
3	Buck diode (D4)	63.5	67.0

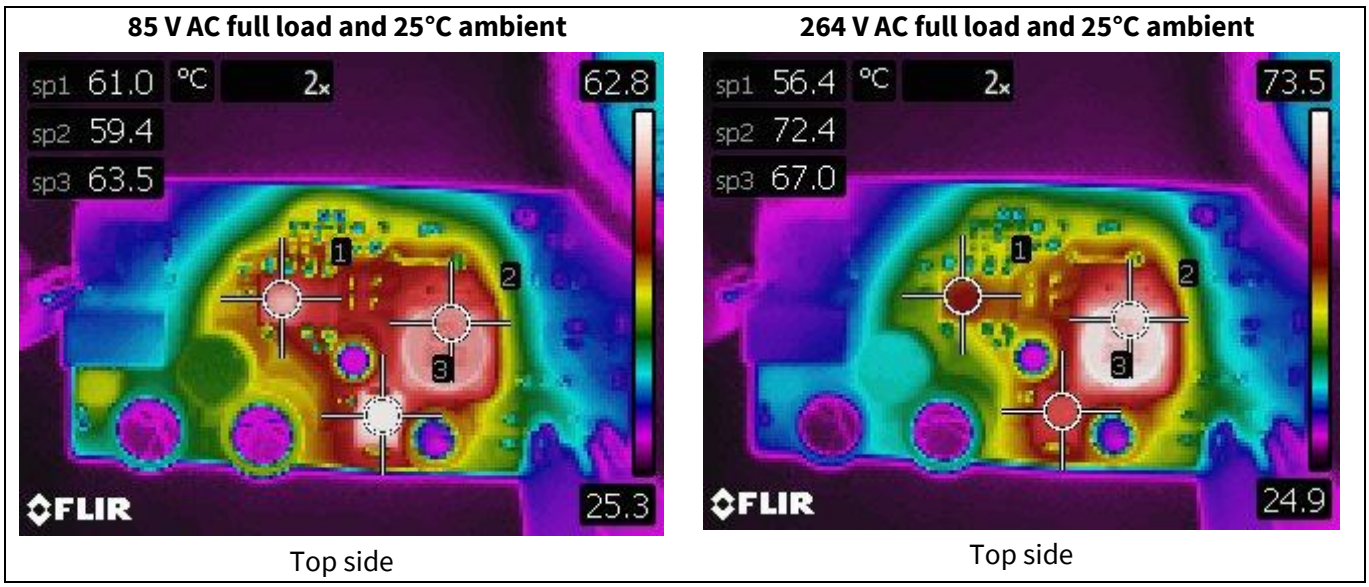


Figure 11 Infrared thermal image of EVAL_5BR4780BZ-1_450mA1

8 Waveforms and scope plots

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

8.1 Start-up with maximum load

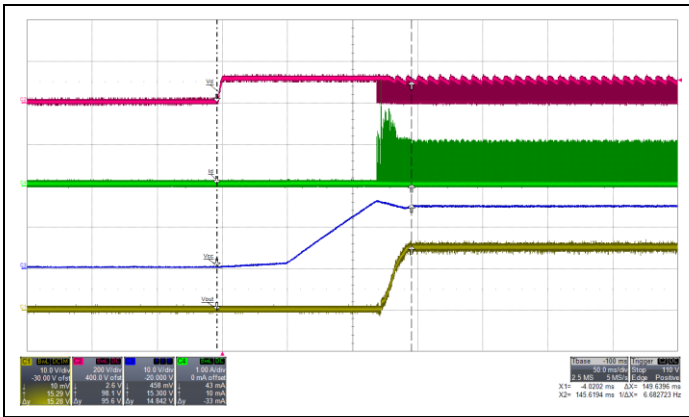
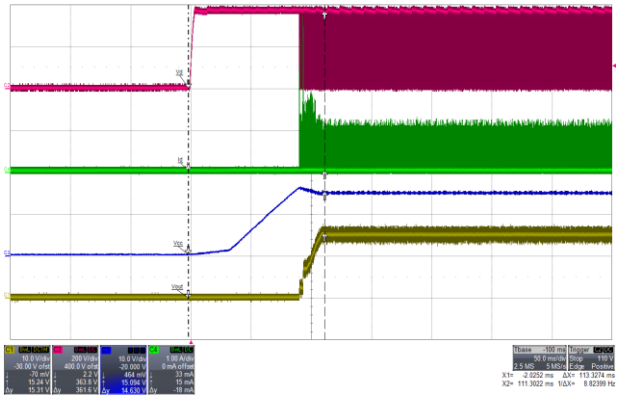
	
C1: $15V_{out}$ C2:V_{DS} C3:V_{CC} C4:Drain Current	C1: $15V_{out}$ C2:V_{DS} C3:V_{CC} C4:Drain Current
Start-up time at 85 V AC and maximum load ≈ 150 ms	Start-up time at 264 V AC and maximum load ≈ 113 ms

Figure 12 Start-up

8.2 Soft-start

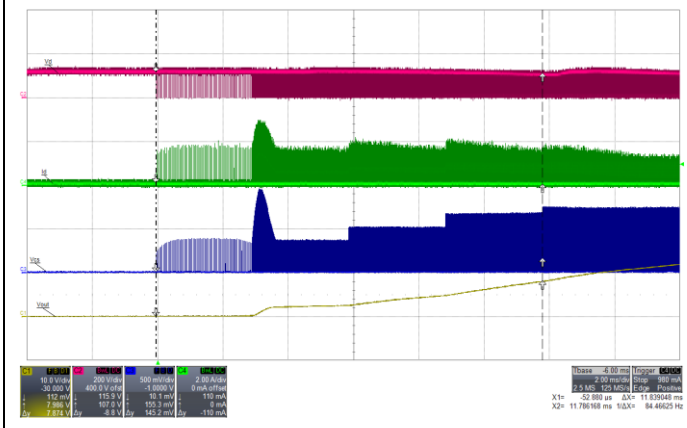
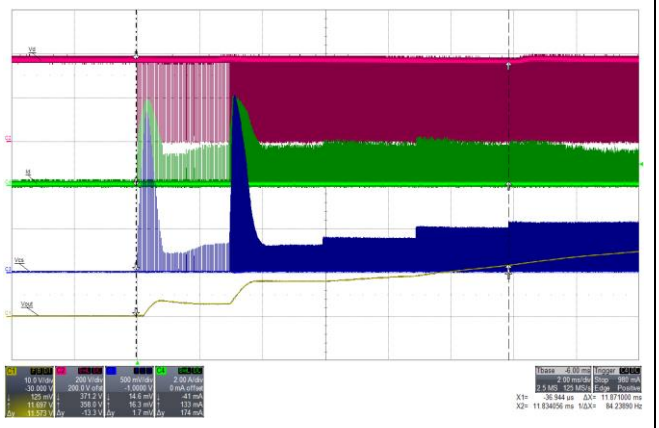
	
C1: $15V_{out}$ C2:V_{DS} C3:CS C4:Drain Current	C1: $15V_{out}$ C2:V_{DS} C3:CS C4:Drain Current
Soft-start time at 85 V AC and maximum load ≈ 12 ms	Soft-start time at 264 V AC and maximum load ≈ 12 ms

Figure 13 Soft-start

8.3 Drain voltage and current at maximum load

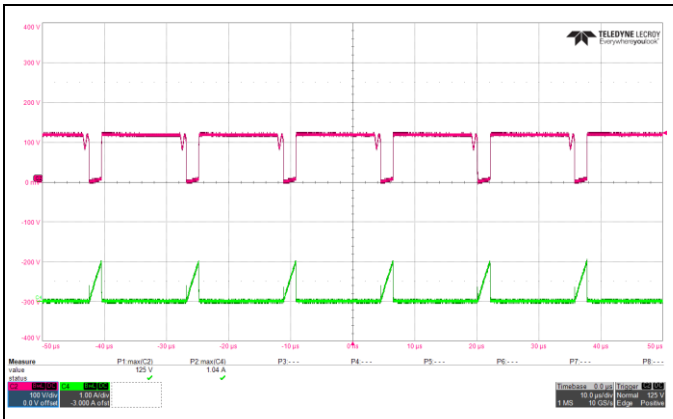
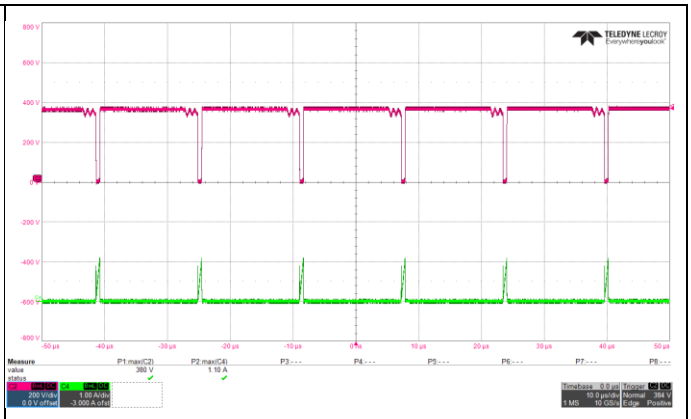
	
C2:V_{DS} C4:Drain Current	**C2:V_{DS} C4:Drain Current**
V_{Drain_peak} at 85 V AC ≈ 125 V I_{DRAIN} at 85 V AC ≈ 1.04 A	V_{Drain_peak} at 264 V AC ≈ 380 V I_{DRAIN} at 264 V AC ≈ 1.10 A

Figure 14 Drain voltage and current at maximum load

8.4 Output ripple voltage at maximum load

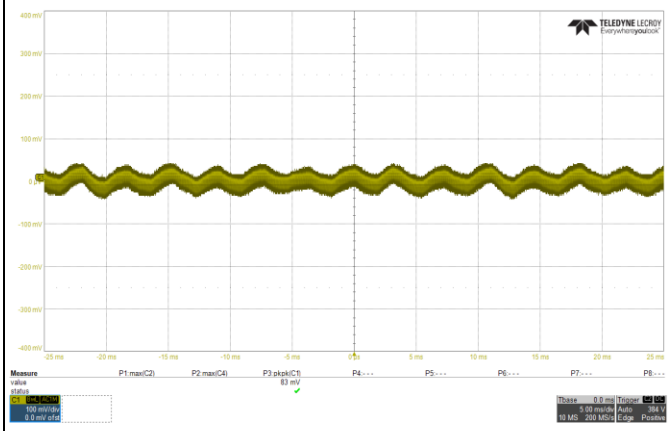
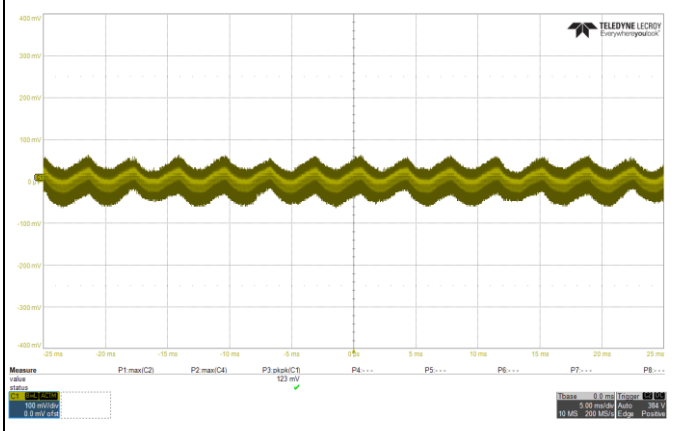
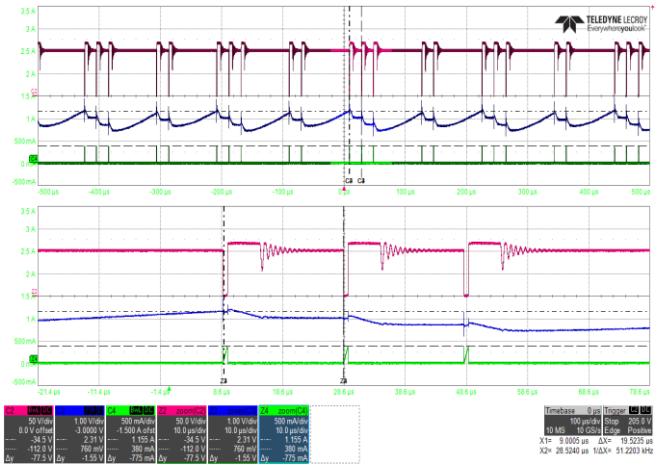
	
C1: 15V_{out} (AC Coupled)	**C1: 15V_{out} (AC Coupled)**
15 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 83 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW	15 $V_{ripple\_pk\_pk}$ at 264 V AC ≈ 123 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW

Figure 15 Output ripple voltage at maximum load

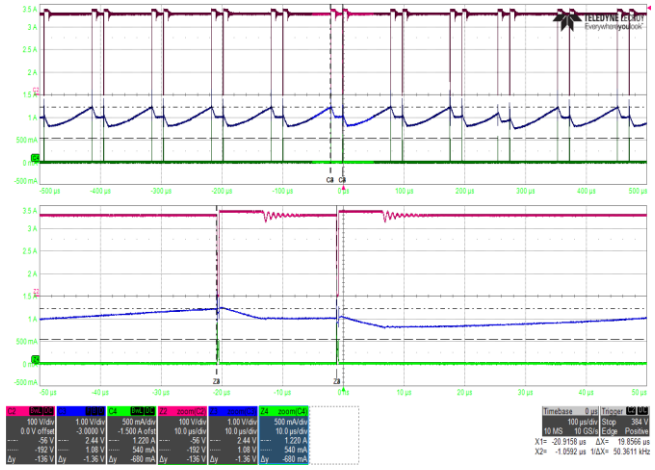
8.5 ABM operation



C2:V_{DS} C3:V_{FB} C4:Drain Current

85 V AC, 20 mA load

Operation at f_{osc2_ABM} = 51 kHz, I_{PK} = 380 mA, V_{FB_ON} = 2.3 V



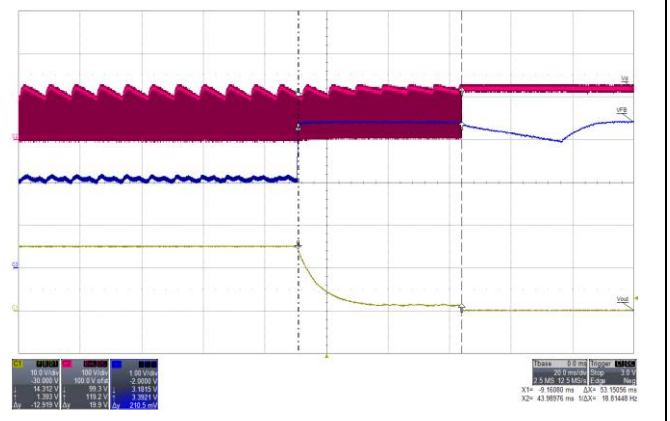
C2:V_{DS} C3:V_{FB} C4:Drain Current

264 V AC, 40 mA load

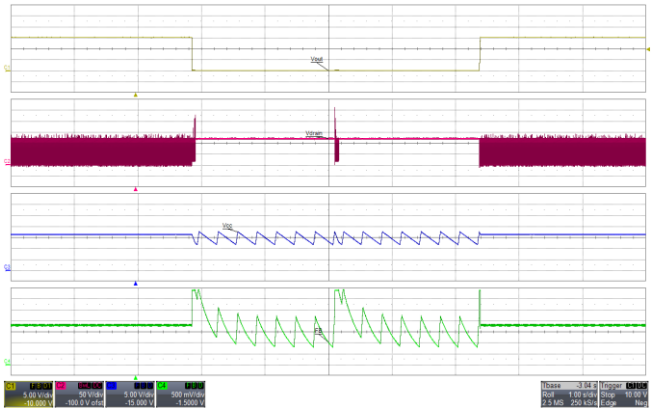
Operation at f_{osc2_ABM} = 51 kHz, I_{PK} = 540 mA, V_{FB_ON} = 2.4 V

Figure 16 ABM operation

8.6 Overload protection (extended cycle skip auto-restart)



C1: 15V_{out} C2:V_{DS} C3:V_{FB}



C1: 15V_{out} C2:V_{DS} C3:V_{FB}

Condition to enter overload protection: V_{FB} more than 2.73 V and lasts for ~54 ms blanking time.

(15V output load change from full load to overload with input 85 V AC or 264 V AC)

Figure 17 Overload protection

8.7 Output short test

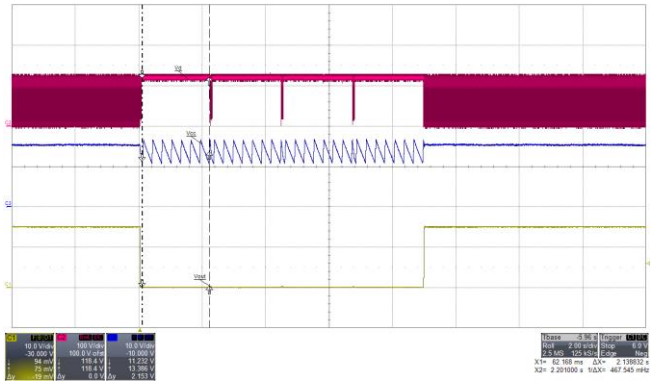
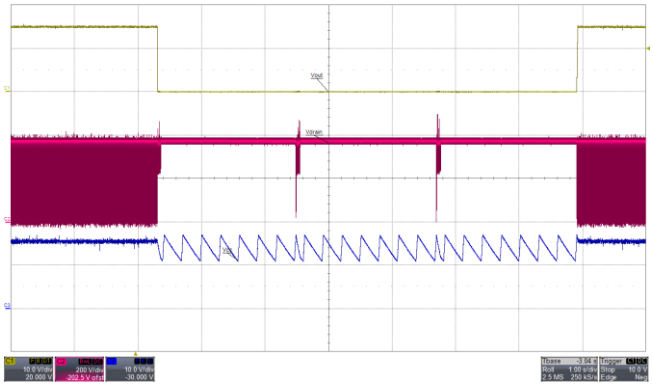
<table>
<tr><td>  </td><td>  </td></tr>
<tr><td>C1: 15V_{out} C2:V_{DS} C3:V_{CC}</td><td>C1: 15V_{out} C2:V_{DS} C3:V_{CC}</td></tr>
<tr><td colspan="2">IC enters into overload protection in extended cycle skip auto-restart mode and recovers when fault is removed</td></tr>
</table>

Figure 18 Output short test

9 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 19. The 12 V output regulated by IC2 is capable of supplying up to 250 mA. The 5 V output regulated by IC3 is capable of supplying up to 100 mA.

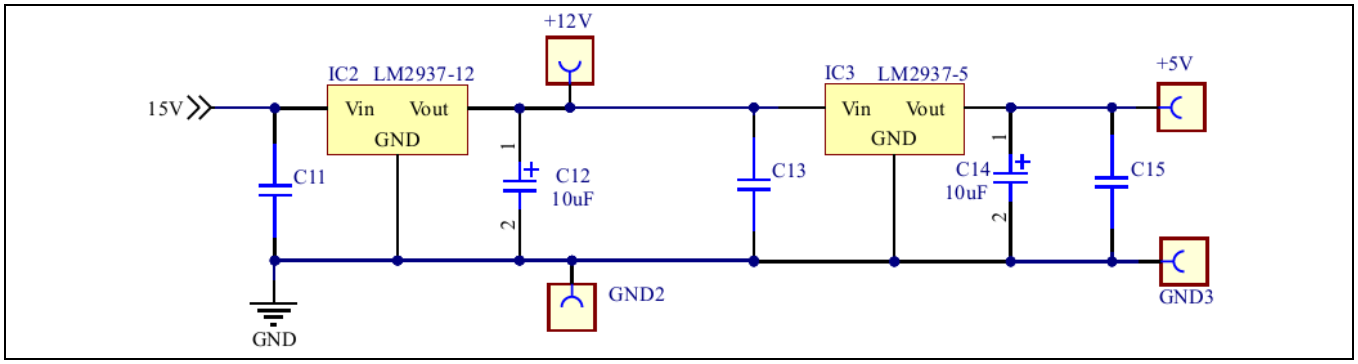


Figure 19 Additional circuit for design example A

Note: Components in the additional circuit shown in Figure 19 are not mounted on the evaluation board.

9.1 Specification of design example A

Because 12 V output and 5 V output are derived from the main output (15 V), the total output current must not exceed the maximum capacity of the main output current. The specification of this design example is shown in Table 6.

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}	0.1 A	–
Output voltage 2 (via LDO)	V_{O2}	12 V	Derived from 15 V output
Max. output current 2	I_{O2}	0.25 A	–
Output voltage 3 (via LDO)	V_{O3}	5 V	Derived from 12 V output
Max. output current 3	I_{O3}	0.1 A	

9.2 Full-load efficiency

Additional power loss caused by LDO circuits reduces the overall efficiency.

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	8.355	14.991	0.10	11.787	0.25	4.982	0.10	4.944	59.2%
115 V AC/60 Hz	8.316	15.010	0.10	11.787	0.25	4.982	0.10	4.946	59.5%
230 V AC/50 Hz	8.410	15.020	0.10	11.787	0.25	4.982	0.10	4.947	58.8%
264 V AC/50 Hz	8.465	15.020	0.10	11.787	0.25	4.982	0.10	4.947	58.4%

References

[1] Infineon Technologies AG: *ICE5BR4780BZx-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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Document revision	Date	Description of changes
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