14 W, 15 V and 5 V SMPS reference board with CoolSET™ ICE5AR4780BZS-1

REF_5AR4780BZS-1_14W1

About this document

Scope and purpose

This document describes a universal-input 14 W, 15 V and 5 V offline non-isolated flyback converter using the latest CoolSET™ 5th Generation Fixed Frequency Plus ICE5AR4780BZS-1 switching controller from Infineon that offers high-efficiency, low-standby power with selectable entry and exit standby power options, wide V_{CC} operating range with fast start-up, and various protection modes for a highly reliable system.

This reference board is designed to evaluate the performance of CoolSET™ ICE5AR4780BZS-1 switching controller for optimized efficiency, thermal performance, and electromagnetic interference (EMI).

Intended audience

This document is intended for power-supply design/application engineers and students, who wants to design low-cost and highly reliable systems for offline SMPS – either auxiliary power supplies for white goods, PCs, servers, and TVs, or enclosed adapters for gaming consoles and so on.

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

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1 Introduction

This document describes a 14 W, 15 V and 5 V reference board designed in a fixed frequency non-isolated flyback converter topology with primary-side feedback (FB) using CoolSET™ 5th Generation Fixed Frequency Plus ICE5AR4780BZS-1 switching controller.

The reference board is operated in discontinuous conduction mode (DCM) and is running at 100 kHz fixed switching frequency. The frequency reduction with soft gate driving and frequency jittering offers lower EMI and better efficiency between light load and 50 percent load. The selectable active burst mode (ABM) power enables ultra-low power consumption.

In addition, numerous adjustable protection functions have been implemented in ICE5AR4780BZS-1 switching controller to protect the system and customize the IC for the chosen application. In case of failure modes, such as VCC over voltage (OV)/under voltage (UV), open control-loop or overload, overtemperature, and VCC short-to-GND, then the device enters to the protection mode.

By cycle-by-cycle peak current limitation (PCL), the dimensions of the transformer and the current rating of the secondary diode can both be optimized. In this way, a cost-effective solution can easily be achieved.

The target applications of ICE5AR4780BZS-1 switching controller are either auxiliary power supplies for white goods, PCs, servers, and TVs, or enclosed adapters for gaming consoles and more.

This document explains the list of features, power-supply specifications, schematics, bill of materials (BOM), and transformer construction documentation of the REF_5AR4780BZS-1_14W1 reference board. Typical operating characteristics such as performance curves and oscilloscope waveforms are shown at the end of the document.

2 Reference board

Figure 1 REF_5AR4780BZS-1_14W1

2.1 Specifications of reference board

Table 1 Reference board specifications

Description	Symbol	Min.	Typ.	Max.	Units	Notes/conditions
Input						
Voltage	V_{IN}	85	–	300	V AC	Two wires (no P.E.)
Frequency	f_{LINE}	47	50/60	64	Hz	–
No-load input power	P_{stby_NL}	–		100	mW	230 V AC
Output						
Output voltage 1	V_{OUT1}	–	15	–	V	±5 percent
Output current 1	I_{OUT1}		–	830	mA	–
Output voltage ripple 1	$V_{RIPPLE1}$	–	–	150	mV	–
Output voltage 2	V_{OUT2}	–	5	–	V	±5 percent
Output current 2	I_{OUT2}		–	400	mA	–
Output voltage ripple 2	$V_{RIPPLE2}$		–	75	mV	–
Output power	P_{OUT_Nom}	–	14.4		W	–
Overcurrent protection (+15 V)	I_{OCP}	–	–	1250	mA	Full load on 5 V
Efficiency						
Average efficiency	η_{avg}	–	83	–	%	115 V AC/230 V AC
Environmental						
Conducted EMI	–	6			dB	Margin, CISPR 22 Class B
Surge immunity						
Differential mode	–	±2			kV	EN 61000-4-5
PCBA dimension	–	110 x 66 x 27			mm	L x W x H

Note: The reference board is designed for dual-output with cross-regulated loop FB. It may not regulate properly if loading is applied only to single-output. If the user wants to evaluate for single-output (e.g., 15 V only) conditions, the following changes are necessary on the board.
1. Remove D101, L101, C102, C103, R102, R103, R104, and C104 (to disable 5 V output).
2. Change R11 to 30 kΩ and R153 to 220 kΩ (full regulation FB at 15 V output).
Since the board (especially the transformer) is designed for dual-output with optimized crossregulation, single-output efficiency might not be optimized. It is only for IC functional evaluation under single-output condition.

3 Circuit description

3.1 Input filtering

The AC-line input side comprises the input fuse (F1) as overcurrent protection. The common-mode choke (CMC) (L1) and X-capacitor (CX1) act as an EMI suppressor. Optional spark-gap devices (SA1, SA2) and varistor (Z1) can absorb high-voltage stress during the lightning surge testing. A rectified DC voltage is obtained through the bridge rectifier (BR1) together with bulk capacitor (C1).

3.2 Start-up

To achieve fast and safe start-up, ICE5AR4780BZS-1 switching controller is implemented with a high-resistance start-up resistor and V_{CC} short-to-GND protection. When V_{VCC} reaches the turn-on voltage threshold V_{CC_ON}, the IC begins with a soft-start.

The soft-start implemented in ICE5AR4780BZS-1 is a digital time-based function. The preset soft-start time is around 12 ms with four steps. If not limited by other functions, the peak voltage on the CS pin will increase incrementally to V_{CS_N}. After IC turn-on, the V_{CC} voltage is supplied by auxiliary windings of the transformer. The V_{CC} short-to-GND protection is implemented during the start-up time.

3.3 Frequency reduction control

ICE5AR4780BZS-1 switching controller can be operated in either discontinuous conduction mode (DCM) or continuous conduction mode (CCM) with the frequency-reduction features.

This reference board is designed to operate in DCM. When the system is operating at maximum power, the controller will switch at the fixed frequency of 100 kHz. To achieve a better efficiency between light load and medium load, frequency reduction is implemented, and the reduction curve is shown in Figure 2. The V_{CS} is clamped by the current limitation threshold or by the PWM opamp while the switching frequency is reduced. The minimum switching frequency possible is f_{OSC4_MIN} (43 kHz) under disabled burst mode setting.

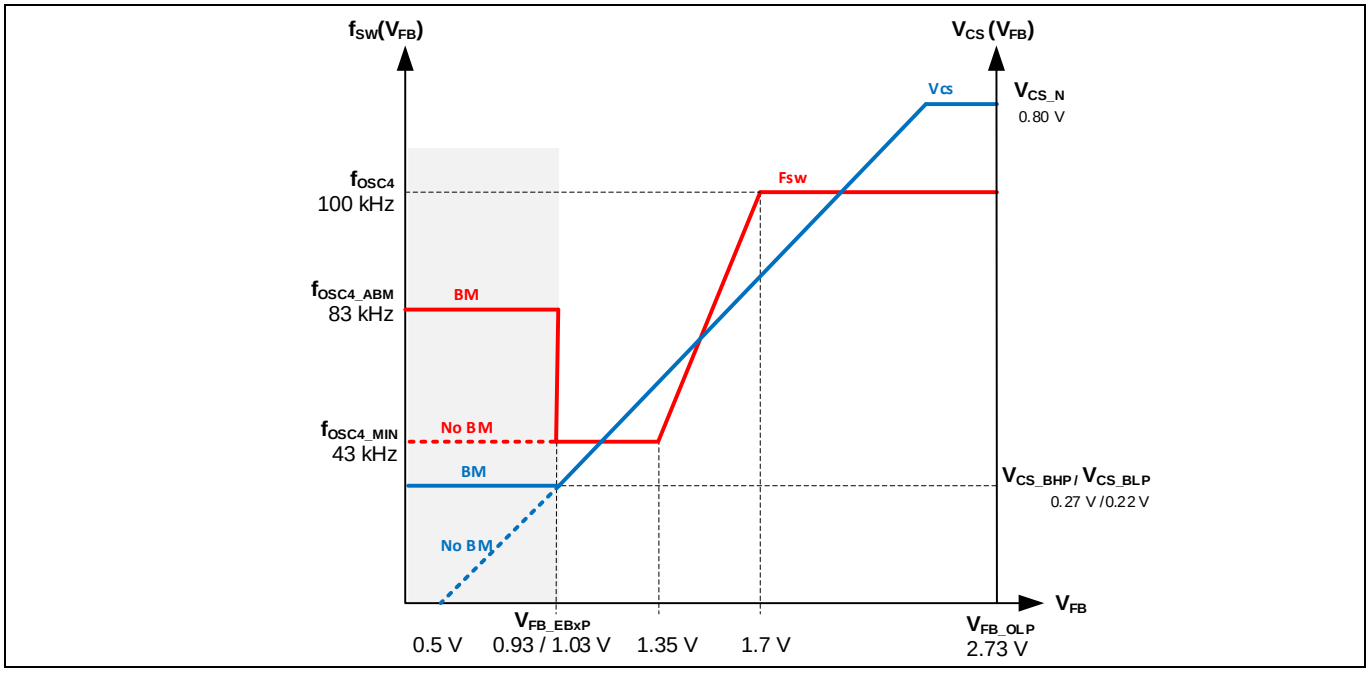

Figure 2 Frequency reduction curve

3.4 Frequency jittering with modulated gate drive

ICE5AR4780BZS-1 switching controller has a frequency jittering feature with modulated gate drive to reduce the EMI noise. The jitter frequency is internally set at 100 kHz (±4 kHz), and the jitter period is 4 ms.

3.5 RCD clamper circuit

A clamper network (R4, C2, and D1) dissipates the energy of the leakage inductance and suppresses ringing on the SMPS transformer. This is a dissipative circuit; therefore, R4 and C2 need to be fine-tuned depending on the voltage derating factor and efficiency requirement.

3.6 Output stage

There are two outputs in this converter, +15 V and +5 V. The power is coupled out via the Schottky diodes (D151 and D101). The capacitors (C152 and C102) provide energy buffering followed by the L-C filters (L151-C153) and (L101-C103) to reduce the output voltage ripple and prevent interference between SMPS switching frequency and line frequency. Storage capacitors (C152 and C102) are selected to have a very low ESR to minimize the output voltage ripple.

3.7 Feedback loop

The output voltage is sensed by the voltage divider (R11, R103 and R153), and compared to the internal reference voltage of ICE5AR4780BZS-1 IC via the VERR pin, which is connected to the input of an integrated error amplifier internally. By connecting this pin, achieves a non-isolated application. The comparison voltage is converted to the current signal via the IC internal integrated error amplifier to the feedback pin for regulation control.

3.8 Active burst mode

The active burst mode (ABM) entry and exit power (three levels) can be selected in ICE5AR4780BZS-1 IC. For more details, see the product Datasheet [1]. At light-load condition, the SMPS enters ABM. At this stage, the controller is always active, but the V_{VCC} must be kept above V_{VCC_OFF}. During ABM, the efficiency increases significantly and at the same time it supports low ripple on V_{OUT} and fast response on load-jump condition.

To enter into the ABM, two conditions must apply:

1. The feedback voltage must be lower than the threshold of V_{FB_EBXP}
2. A blanking time must have elapsed (t_{FB_BEB} = 36 ms).

Once both conditions are fulfilled, the ABM flip-flop is set and the controller enters into the ABM operation. This dual-condition determination for entering ABM prevents mistriggering, so that the controller enters into the ABM operation only when the output power is extremely low during the preset blanking time.

During ABM, the maximum CS voltage is reduced from V_{CS_N} to V_{CS_BXP} to reduce the conduction loss and the audible noise. In the burst mode, the feedback voltage is changing like a sawtooth between $V_{FB\_Bon\_NISO}$ and $V_{FB\_Boff\_NISO}$.

The feedback voltage immediately increases if there is a sudden increment in the output load. This is observed by one comparator. When the feedback voltage can exceed V_{FB_LB}, it leaves the ABM and the peak current limit (PCL) threshold voltage will return to V_{CS_N} immediately to stabilize V_{OUT}.

4 System robustness and reliability through protection features

Protection against undervoltage, overvoltage, overload, and temperature is one of the major factors in determining whether the system is safe and robust.

ICE5AR4780BZS-1 IC provides a comprehensive protection to ensure the system is operating safely. The protections include V_{CC} OV and UV, overload, overtemperature (controller junction), and V_{CC} short-to-GND. When those faults are detected, then the system will enter to the protection mode until the fault is removed, and then resume its normal operation. A list of protections and the failure conditions are shown in Table 2.

Table 2 Protection features of ICE5AR4780BZS-1 IC

Protection function	Failure condition	Protection mode
VCC OV	V_{VCC} greater than V_{VCC_OVP}	Extended cycle skip auto restart
VCC UV	V_{VCC} less than V_{VCCoff}	Auto restart
Overload	V_{FB} greater than V_{FB_OLP} and lasts for $t_{FB\_OLP\_B}$	Extended cycle skip auto restart
Over-temperature	T_J greater than 140°C (40°C hysteresis)	Non-switch auto restart
VCC short-to-GND (VVCC = 0 V, RStartUp = 50 MΩ and VDRAIN = 90 V)	V_{VCC} less than V_{CC_SCP}, $I_{VCC\_Charge1}$ ≈ -0.2 mA	Cannot start up

5 Schematic

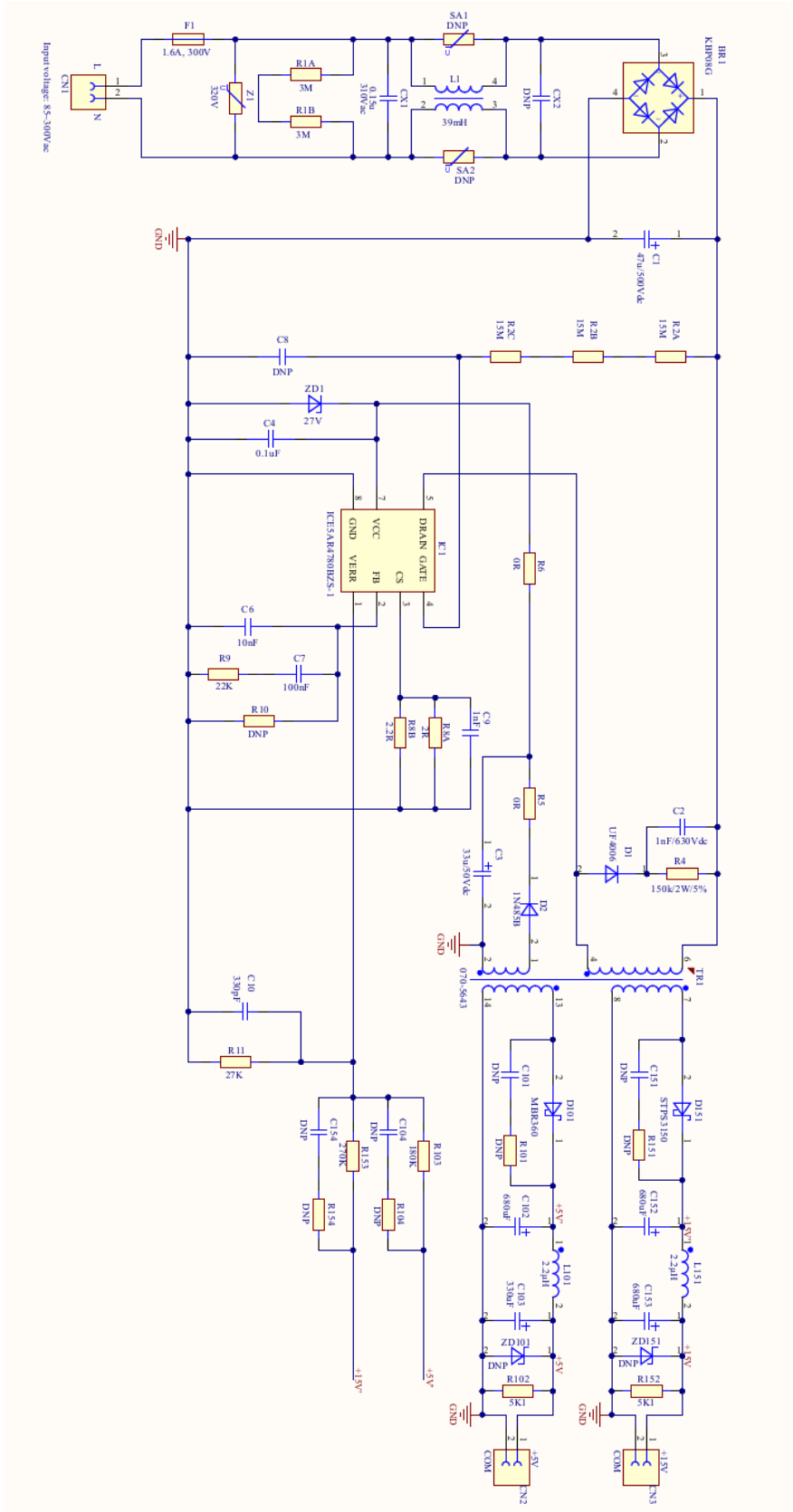

Figure 3 Schematic of REF_5AR4780BZS-1_14W1 board

6 PCB layout

6.1 Top side

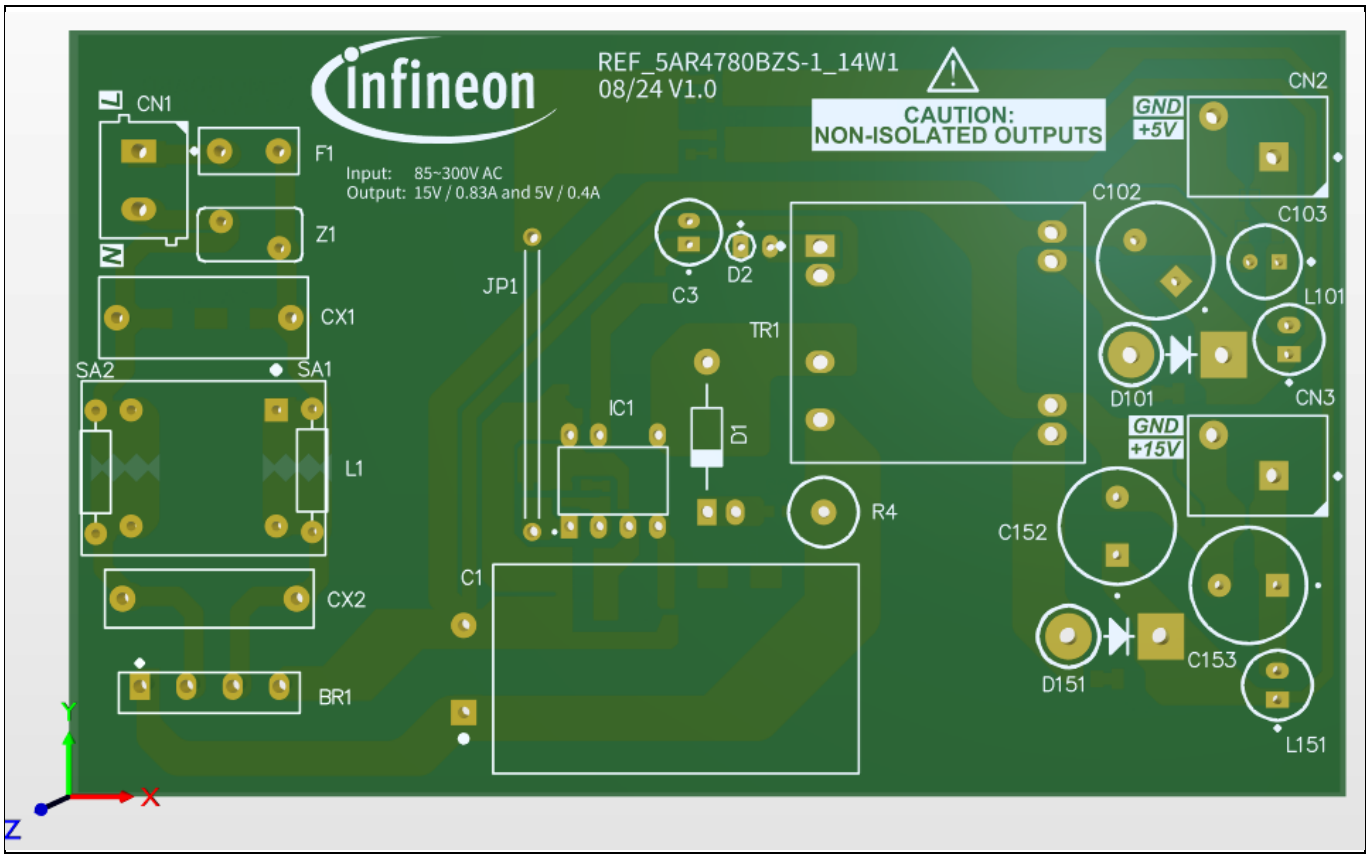

Figure 4 Top-side component legend

6.2 Bottom side

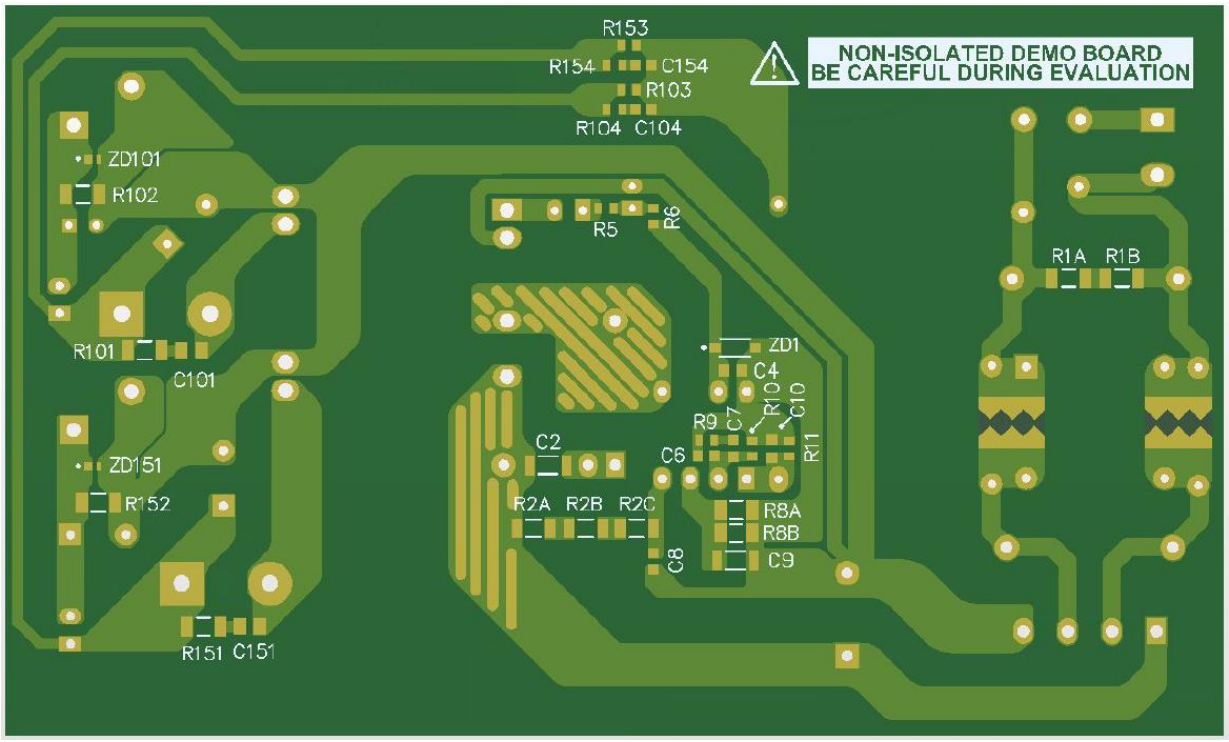

Figure 5 Bottom-side component legend

7 Bill of materials

Table 3 BOM

No.	Designator	Description	Manufacturer	Part number	Quantity
1	F1	Time-lag fuse 300 V 1.6 A	Littlefuse	36911600000	1
2	Z1	Varistor 0.3 W 320 V	Panasonic	ERZE07A511	1
3	BR1	Bridge diode 800 V 1.5 A	Diodes Incorporated	KBP08G	1
4	CX1	Film capacitor 0.15 µF 10% 310 V AC radial	TDK Electronics	B32932A3154K189	1
5	C1	Aluminum capacitor 47 µF 500 V radial	Rubycon	500BXC47MEFC18X31.5	1
6	C2	Ceramic capacitor 1000 pF 630 V U2J 1206	Murata Manufacturing	GRM31A7U2J102JW31D	1
7	C3	Aluminum capacitor 33 µF 20% 50 V radial	Rubycon	50PX33MEFC5X11	1
8	C4	Ceramic capacitor 0.1 µF 50 V X7R 0603	–	–	1
9	C6	Ceramic capacitor 10 nF 50 V X7R 0603	–	–	1
10	C7	Ceramic capacitor 100 nF 50 V X7R 0603	–	–	1
11	C9	Ceramic capacitor 1206 1 nF 25 V X7R 5%	–	–	1
12	C10	Ceramic capacitor 330 pF 50 V X7R 0603	–	–	1
13	C102	Aluminum capacitor 680 µF 20% 10 V radial	Rubycon	10ZL680MEFC8X16	1
14	C103	Aluminum capacitor 330 µF 20% 10 V radial	Rubycon	10ZLH330MEFC6.3X11	1
15	C152, C153	Aluminum capacitor 680 µF 20% 25 V radial	Rubycon	25ZLS680MEFC10X16	2
16	ZD1	Zener diode 27 V 0.5W 2%	Vishay Intertechnology	BZT52B27-E3-08	1
17	D1	General-purpose diode 800 V 1 A DO204AL	Vishay Intertechnology	UF4006-E3/54	1
18	D2	General-purpose diode 200 V 200 mA DO35	onsemi	1N485B	1
19	D151	Schottky diode 150 V 3 A DO201AD	ST	STPS3150	1
20	D101	Schottky diode 60 V 3 A DO201AD	onsemi	MBR360G	1
21	IC1	CoolSET™ Fixed Frequency 800 V	Infineon	ICE5AR4780BZS-1	1

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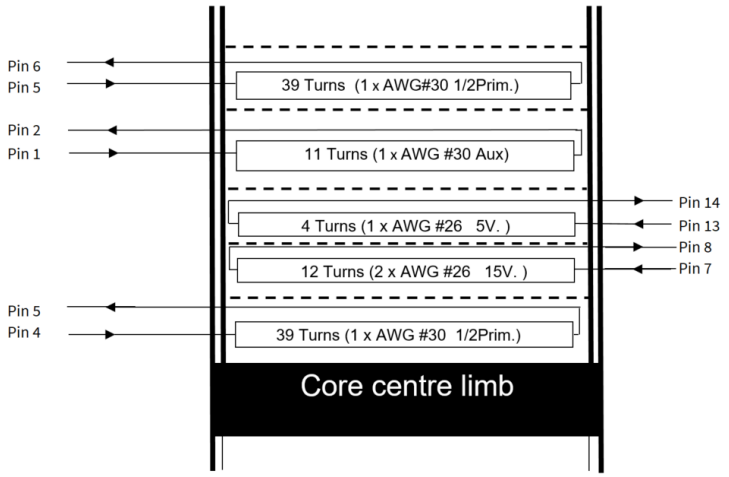
Bill of materials

No.	Designator	Description	Manufacturer	Part number	Quantity
22	L1	CMC 39 mH 700 mA 2LN TH	EPCOS	B82732R2701B030	1
23	L101, L151	Fixed inductor 2.2 µH 6.3 A 20 mΩ TH	Würth Elektronik	7447462022	2
24	R1A, R1B	Resistor 3 MΩ 5% 1/4 W 1206	–	–	2
25	R2A, R2B, R2C	Resistor 15 MΩ 5% 1/4 W 1206	Yageo	RC1206JR-0715ML	3
26	R4	Resistor 150 kΩ 5% 2 W axial	Yageo	FMP200JR-52-150K	1
27	R5, R6	Resistor 0 Ω jumper 1/10 W 0603	–	–	2
28	R8A	Resistor 2 Ω 1% 1/4 W 1206	–	–	1
29	R8B	Resistor 2.2 Ω 1% 1/4 W 1206	–	–	1
30	R9	Resistor 22 kΩ 1% 1/10 W 0603	–	–	1
31	R11	Resistor 27 kΩ 1% 1/10 W 0603	–	–	1
32	R103	Resistor 180 kΩ 1% 1/10 W 0603	–	–	1
33	R153	Resistor 270 kΩ 1% 1/10 W 0603	–	–	1
34	R102, R152	Resistor 5.1 kΩ 5% 1/4 W 1206	–	–	2
35	T1	Transformer EE20_H rev 00	Würth Elektronik	750343698	1
36	CN1	Terminal blocks WR-TBL 300 V AC 15 A 2P straight	Würth Elektronik	691102710002	1
37	CN2, CN3	Terminal blocks WR-TBL 2POS 3.5 mm 6 A 300 V	Würth Elektronik	691412120002B	2
38	JP1	Jumper	–	–	1
39	PCB	110 mm × 66 mm (L × W) single-layer 2 oz. FR-4	–	–	1

8 Transformer construction

- **Core and materials**: EE20/10/6, TP4A (TDG)
- **Bobbin**: 070-5643 (14-pin, THT, horizontal version)
- **Primary inductance**: Lp = 550 µH (±10 percent), measured between pin 4 and pin 6
- **Manufacturer and part number**: Würth Elektronik Midcom (750343698)



Start	Stop	No. of turns	Wire size	Layer
4	5	39	1 x AWG#30	1/2 Primary
7	8	12	2 x AWG #26	15V
13	14	4	1 x AWG #26	5V
1	2	11	1 x AWG#30	Auxiliary
5	6	39	1 x AWG#30	1/2 Primary

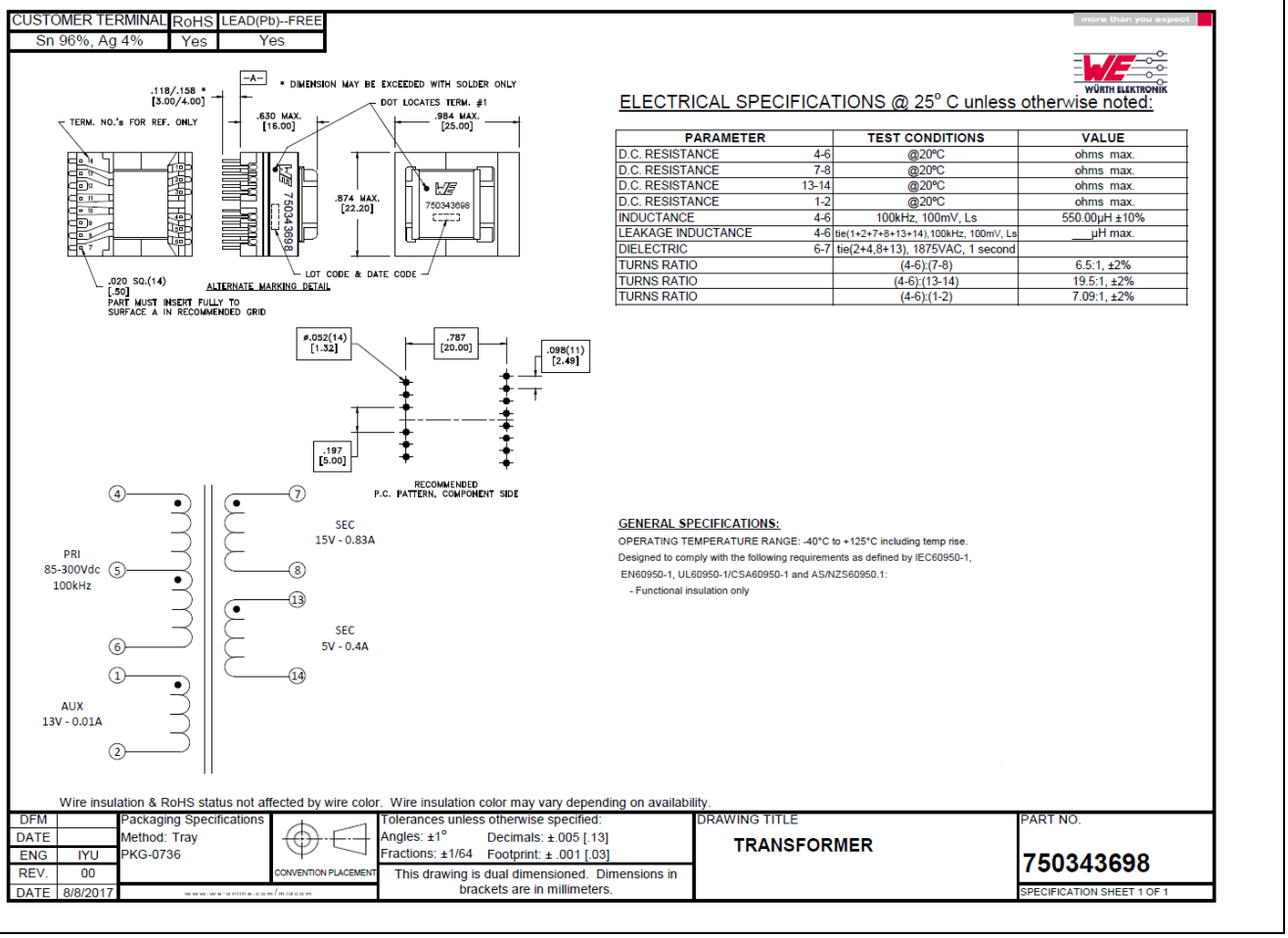


Figure 6 Transformer structure

9 Test results

9.1 Efficiency and regulation

Table 4 Electrical measurement

Input (V AC/Hz)	Load percentage	P_{IN} (W)	15 V DC (V)	I_{OUT_15V} (mA)	5 V DC (V)	I_{OUT_5V} (mA)	P_{OUT} (W)	Efficiency (%)	Average efficiency (%)	OLP pin (W)	OLP I_{OUT_15V} (fixed 5 V at 0.4 A) (A)
85 V AC/ 60 Hz	0	0.075	15.13	0.000	4.984	0.000				20.51	0.97
	25%	4.456	15.23	0.206	4.987	0.102	3.650	81.90	82.17		
	50%	8.69	15.24	0.405	4.977	0.201	7.176	82.59			
	75%	13.19	15.25	0.615	4.968	0.301	10.880	82.48			
	100%	17.83	15.25	0.825	4.959	0.401	14.570	81.71			
115 V AC/ 60 Hz	0	0.076	15.12	0.000	4.984	0.000	0.000			20.25	0.99
	25%	4.448	15.23	0.207	4.983	0.101	3.647	81.99	83.12		
	50%	8.598	15.24	0.405	4.976	0.201	7.177	83.48			
	75%	13.01	15.24	0.615	4.968	0.301	10.874	83.58			
	100%	17.46	15.25	0.825	4.960	0.401	14.570	83.45			
230 V AC/ 50 Hz	0	0.093	15.11	0.000	4.984	0.000				20.74	1.03
	25%	4.572	15.25	0.2065	4.972	0.1005	4.572	79.81	82.35		
	50%	8.773	15.24	0.4055	4.977	0.2011	8.773	81.85			
	75%	13.02	15.24	0.6155	4.968	0.301	13.020	83.53			
	100%	17.3	15.25	0.8251	4.959	0.4002	17.300	84.20			
265 V AC/ 50 Hz	0	0.098	15.09	0.000	4.984	0.000				21.30	1.06
	25%	4.632	15.25	0.207	4.968	0.101	3.650	78.80	81.69		
	50%	8.798	15.25	0.406	4.970	0.201	7.182	81.63			
	75%	13.12	15.24	0.616	4.970	0.301	10.879	82.92			
	100%	17.47	15.25	0.825	4.960	0.401	14.571	83.40			
300 V AC/ 50 Hz	0	0.107	15.11	0.000	4.984	0.000				21.91	1.09
	25%	4.717	15.25	0.207	4.969	0.101	3.650	77.39	80.73		
	50%	8.913	15.25	0.406	4.967	0.201	7.183	80.59			
	75%	13.25	15.24	0.616	4.969	0.301	10.875	82.07			
	100%	17.59	15.25	0.8250	4.963	0.401	14.573	82.85			

9.2 Efficiency curve

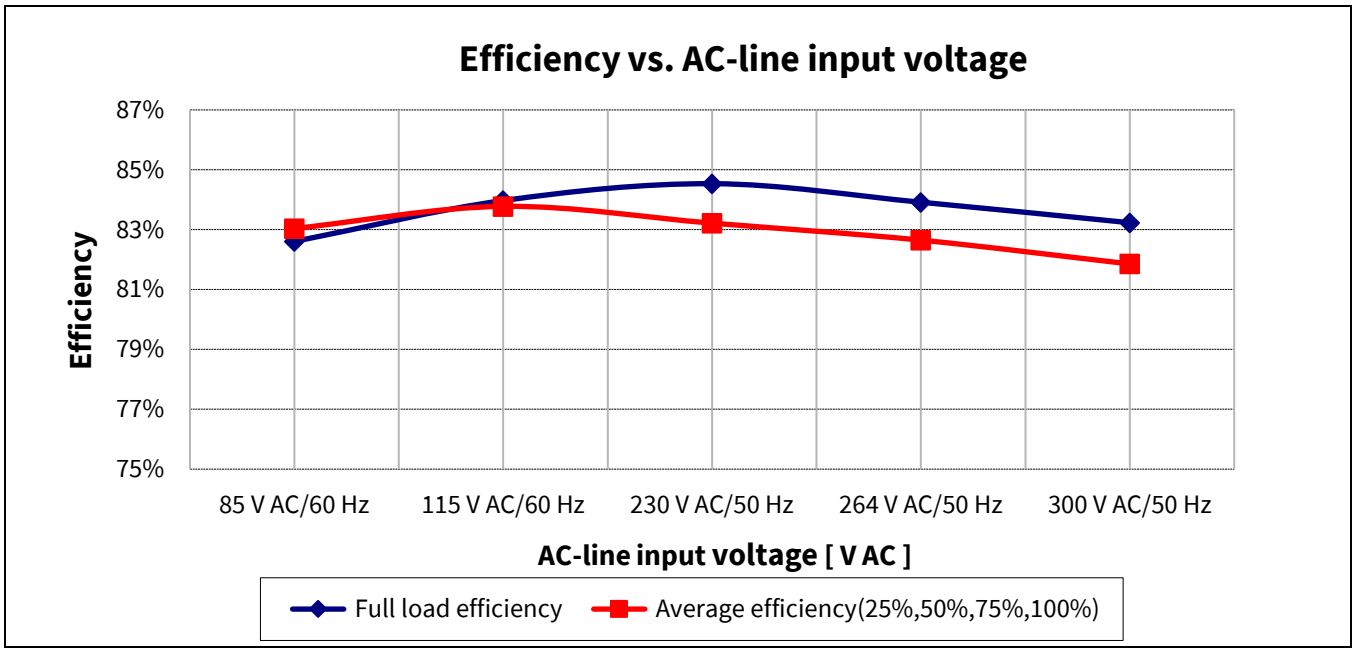


Figure 7 Efficiency vs. output load

9.3 Standby power

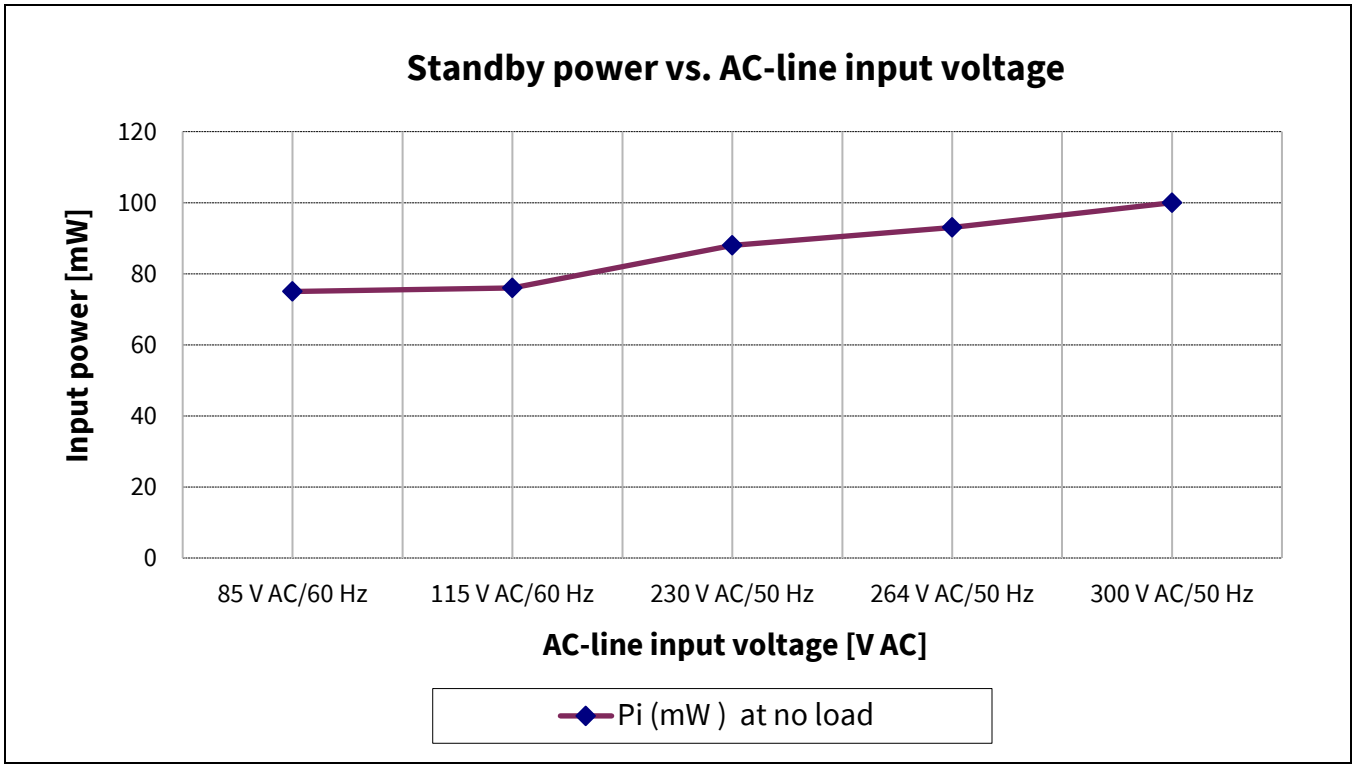


Figure 8 Standby power vs. AC-line input voltage

9.4 Line regulation

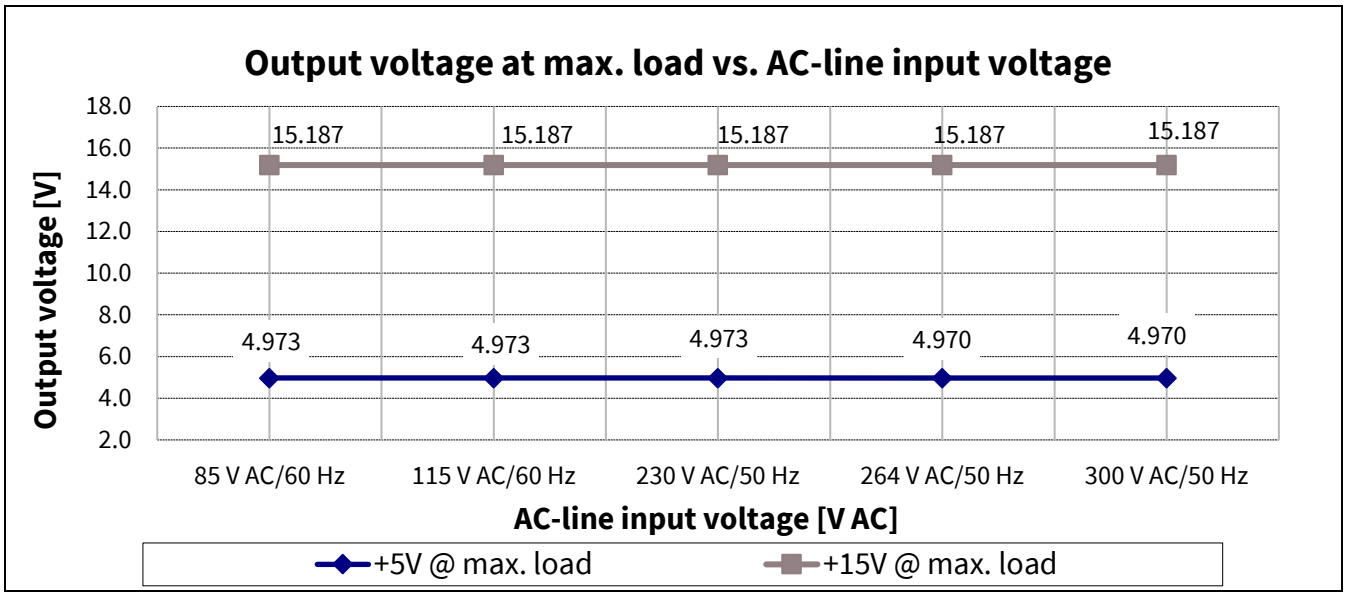


Figure 9 Output regulation at full load vs. AC-line input voltage

9.5 Load regulation

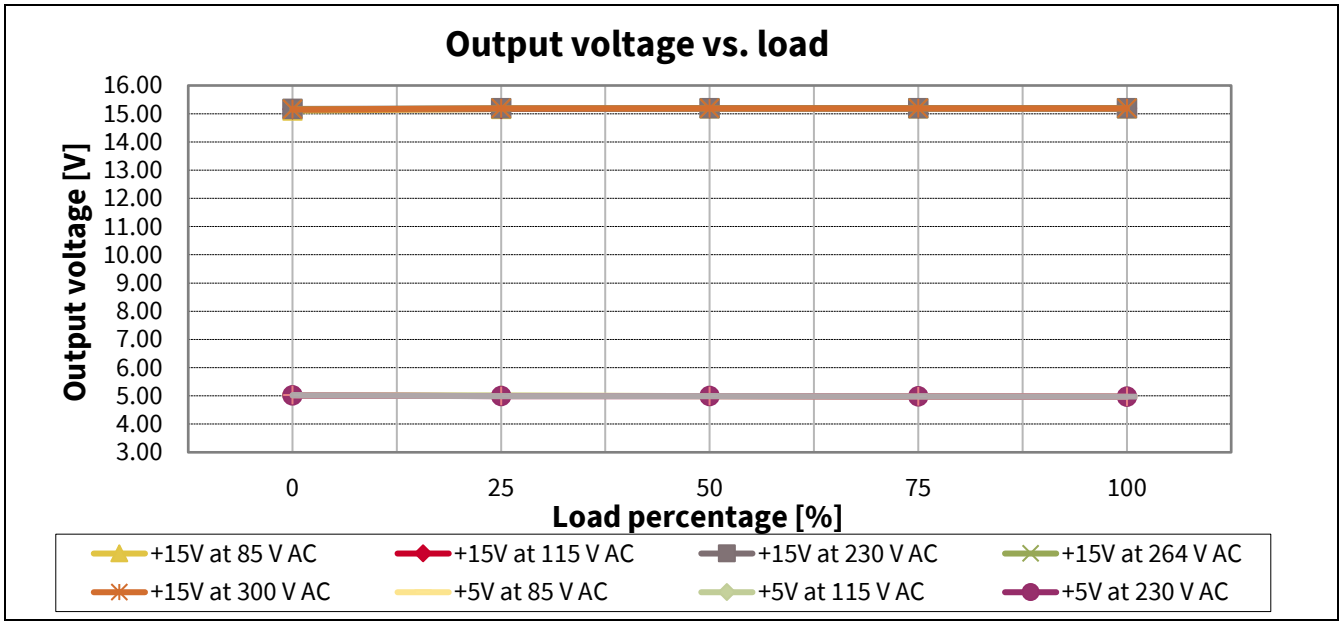


Figure 10 Output regulation vs. load

9.6 Maximum input power

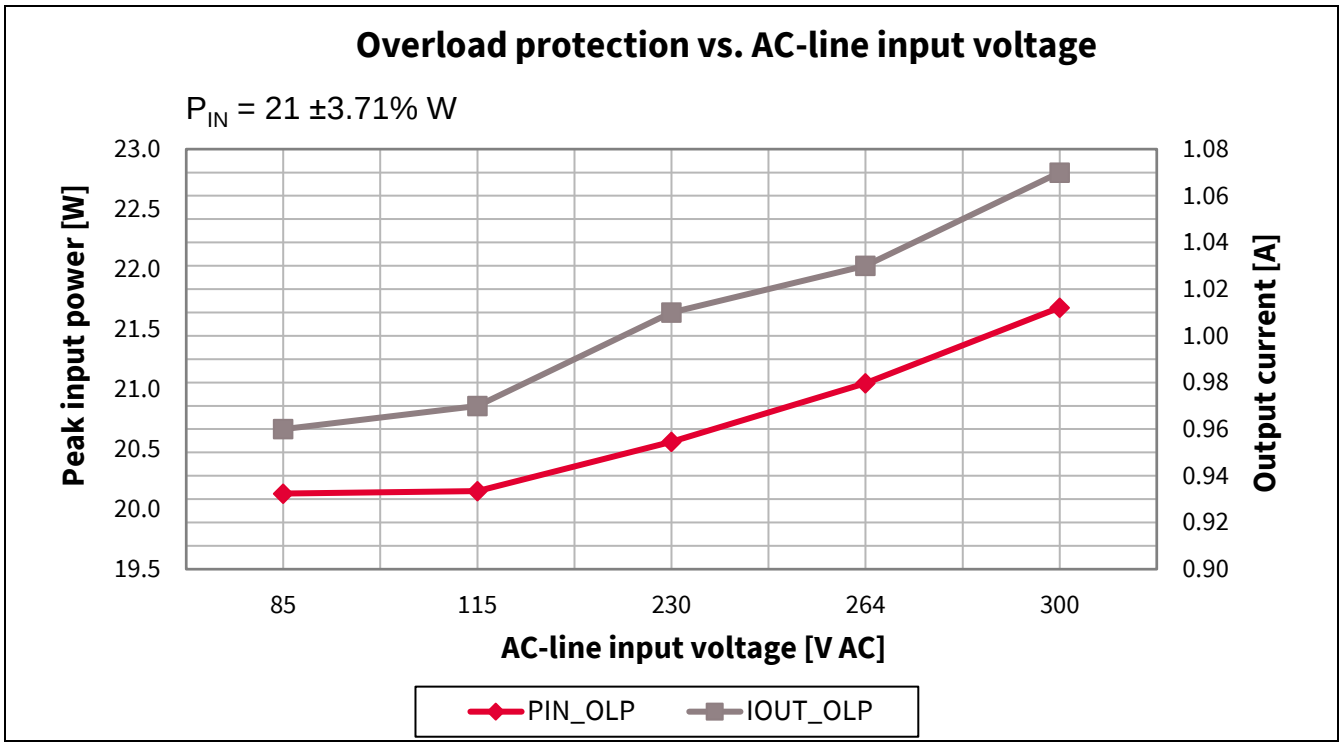


Figure 11 **Maximum input power and output current (before overload protection) vs. AC-line input voltage**

9.7 Surge immunity (EN 61000-4-5)

Pass EN 61000-4-5 installation class 4 (±2 kV for line-to-line).

Table 5 **System surge immunity test result**

Description	Test	Level		Number of strikes				Test result
				0°	90°	180°	270°	
115 V AC, 14 W	DM	+2 kV	L → N	3	3	3	3	PASS
		-2 kV	L → N	3	3	3	3	PASS
230 V AC, 14 W	DM	+2 kV	L → N	3	3	3	3	PASS
		-2 kV	L → N	3	3	3	3	PASS

9.8 Conducted emissions (EN 55022 class B)

The conducted EMI was measured by Schaffner (SMR4503) test equipment and followed the test standard of EN 55022 (CISPR 22) class B. The reference board was tested at resistive full load with input voltage of 115 V AC and 230 V AC.

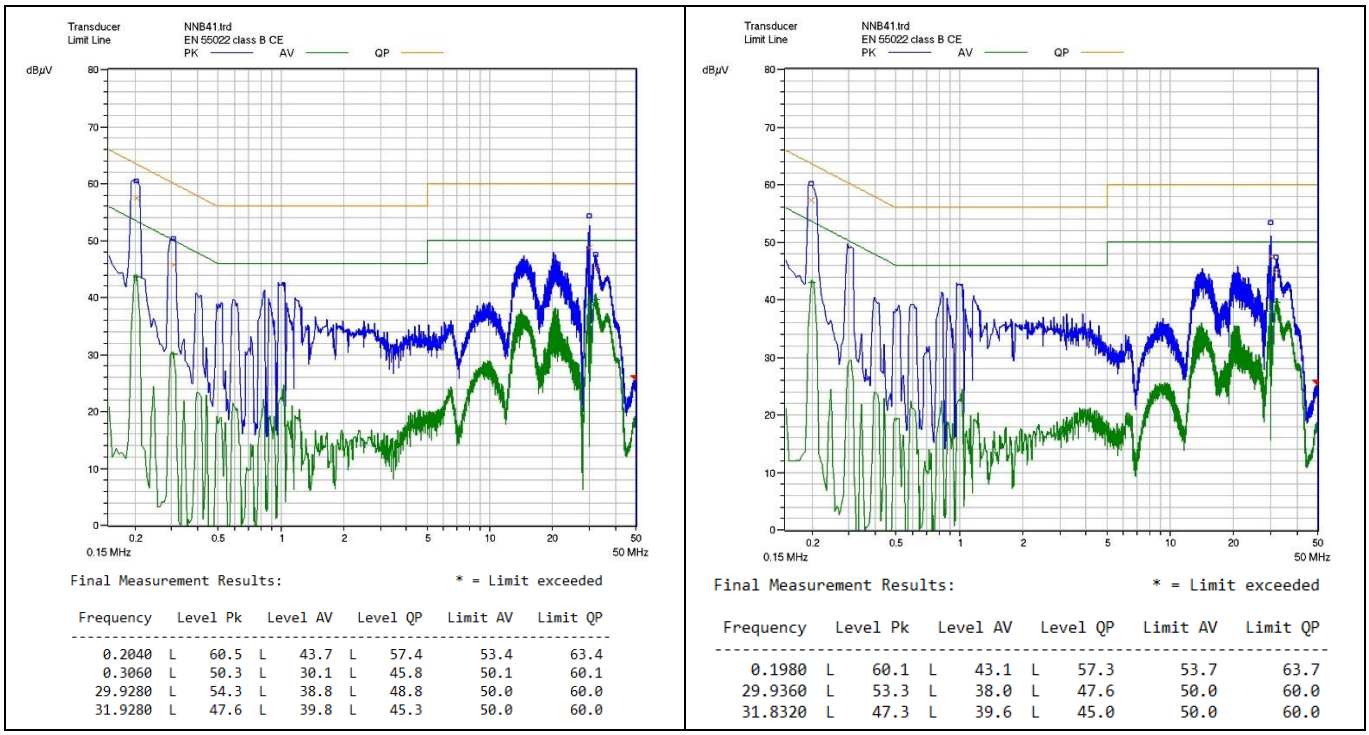


Figure 12 Conducted emissions at 115 V AC and full load on-line (left) and neutral (right)

Test results

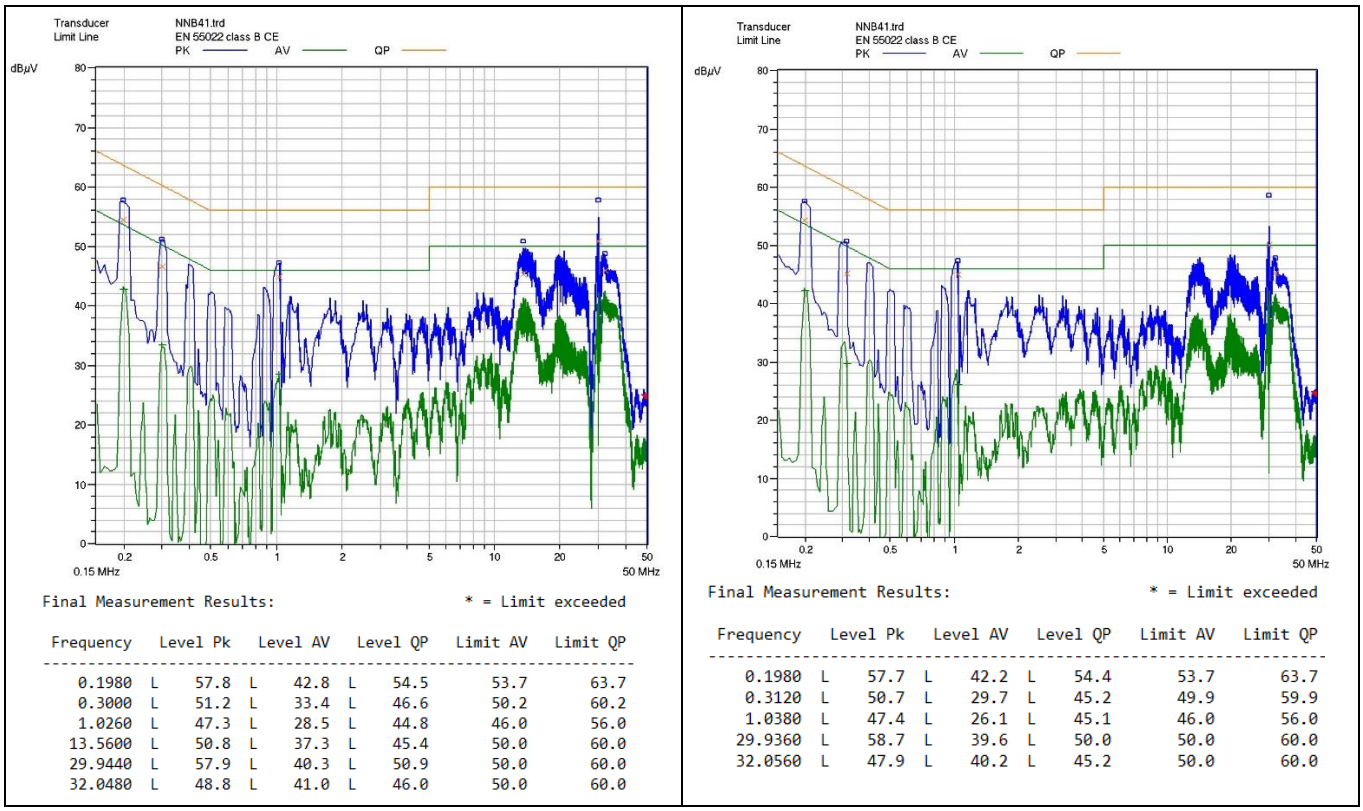


Figure 13 Conducted emissions at 230 V AC and full load on-line (left) and neutral (right)

9.9 Thermal measurements

The thermal testing of the open-frame reference 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 condition.

Table 6 Hottest components on the reference board

No.	Components	Temperature at 85 V AC (°C)	Temperature at 300 V AC (°C)
1	D151 (15 V diode)	54.6	60.2
2	TR1 (transformer)	52.3	64.7
3	IC1 (ICE5AR4780BZS-1)	61.7	63.3

Top side – 85 V AC	Top side – 300 V AC
	

Figure 14 Infrared thermal image of REF_5AR4780BZS-1 at full load

10 Waveforms and oscilloscope plots

All waveforms and scope plots were recorded with a Teledyne LeCroy 9054 oscilloscope.

10.1 Start-up at full load

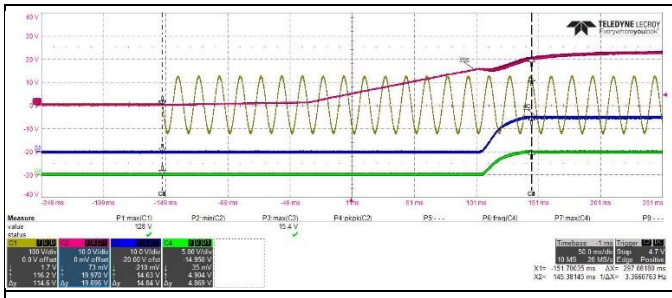
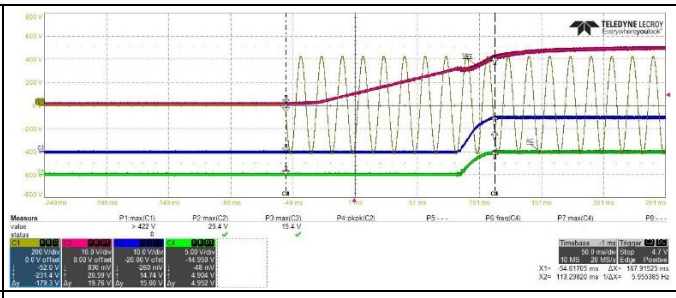
	
C1: AC Line C2: V_{CC} C3:15 Vout C4: 5 Vout	C1: AC Line C2: V_{CC} C3:15 Vout C4: 5 Vout
85 V AC start-up time at full load is around 297 ms	300 V AC start-up time at full load is around 147 ms

Figure 15 Start-up

10.2 Soft-start at full load

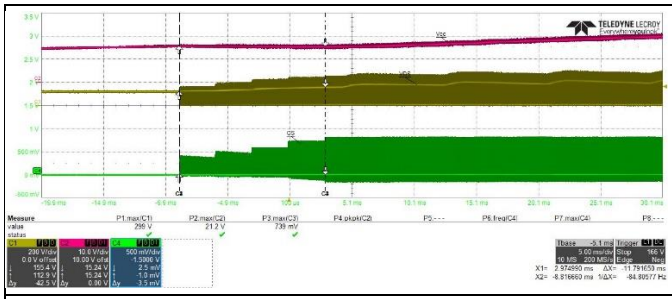
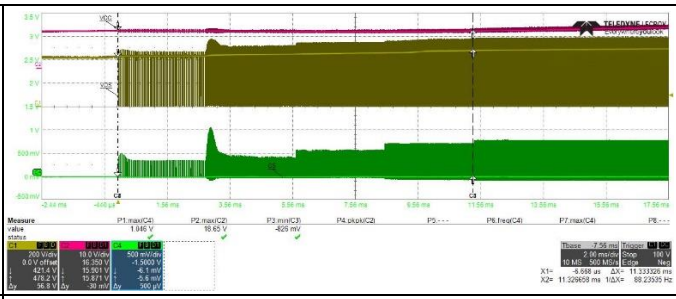
	
C1: V_{DS} C2: V_{CC} C4: VCS	C1: V_{DS} C2: V_{CC} C4:V_{CS}
85 V AC soft-start time at full load is around 11.7 ms	300 V AC soft-start time at full load is around 11.3 ms

Figure 16 Soft start

10.3 Drain and CS voltage at full load

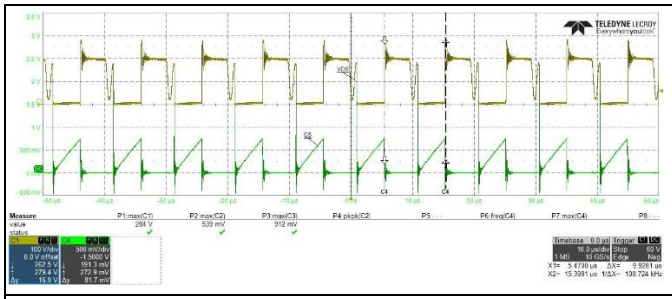
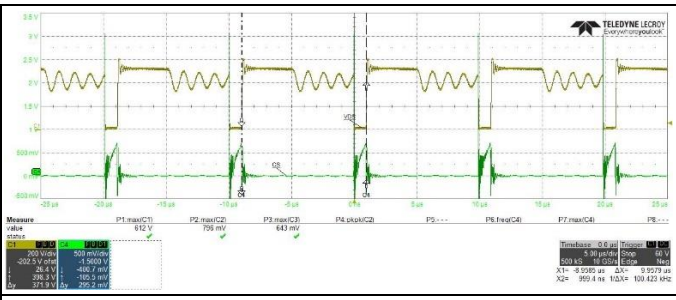
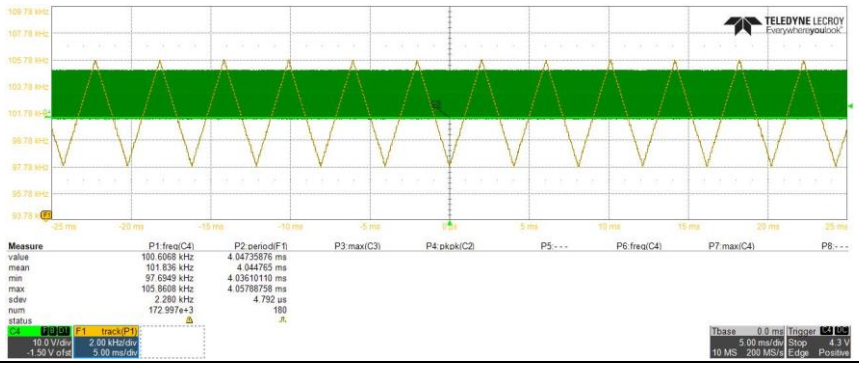
	
C1: V_{DS} C4: VCS	C1: V_{DS} C4: VCS
85 V AC maximum drain voltage at full load is 284 V	300 V AC maximum drain voltage at full load is 612 V

Figure 17 Drain and CS voltage

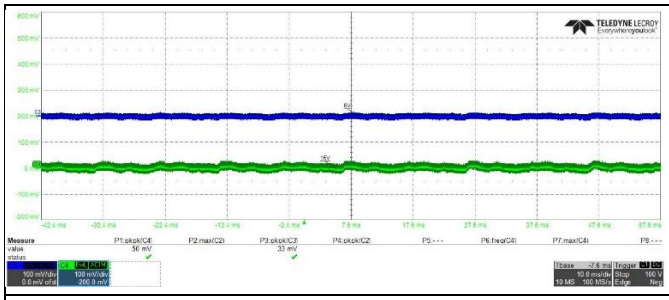
10.4 Frequency jittering



F1: Frequency trend C4: Gate Voltage
85 V AC frequency jittering at full load is from ~97.69 kHz to ~105.86 kHz

Figure 18 Frequency jittering

10.5 Output ripple voltage at full load



C3:5 Vout (AC Coupled) C4: 15 Vout (AC Coupled)	C3:5 Vout (AC Coupled) C4: 15 Vout (AC Coupled)
85 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is 50 mV 85 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is 33 mV	300 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is 56 mV 300 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is 33 mV

Figure 19 Output ripple voltage at full load. Probe terminals are decoupled with a 10 µF electrolytic capacitor and a 0.1 µF ceramic capacitor. Oscilloscope bandwidth is limited to 20 MHz.

10.6 Output ripple voltage at ABM

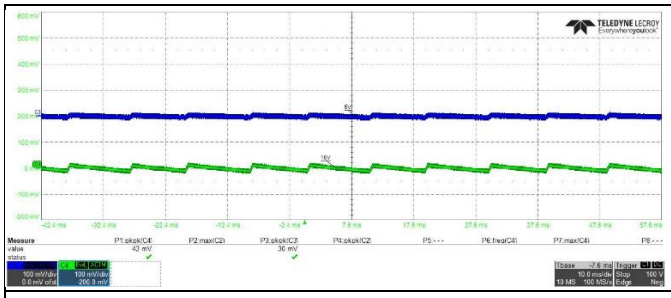
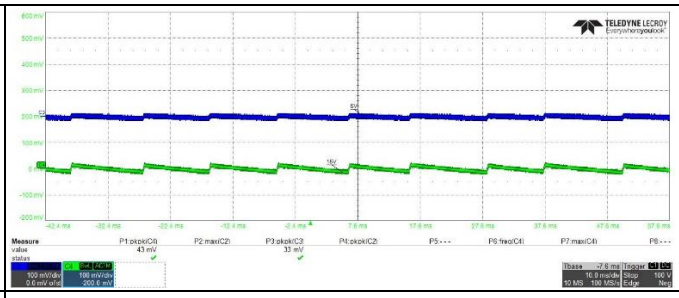
	
C3:5 Vout (AC Coupled) C4:15 Vout (AC Coupled)	C3:5 Vout (AC Coupled) C4:15 Vout (AC Coupled)
85 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is 43 mV 85 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is 30 mV	300 V AC +15 V output voltage $V_{ripple\_pk\_pk}$ is 43 mV 300 V AC +5 V output voltage $V_{ripple\_pk\_pk}$ is 33 mV

Figure 20 Output ripple voltage at no load. Probe terminals are decoupled with a 10 µF electrolytic capacitor and a 0.1 µF ceramic capacitor. Oscilloscope bandwidth is limited to 20 MHz.

10.7 Entering ABM

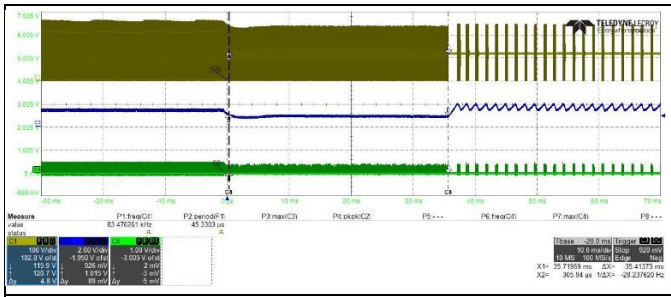
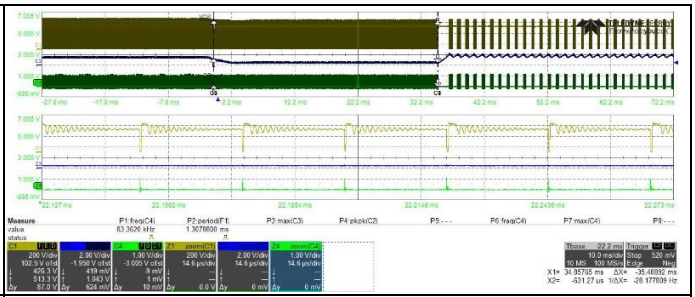
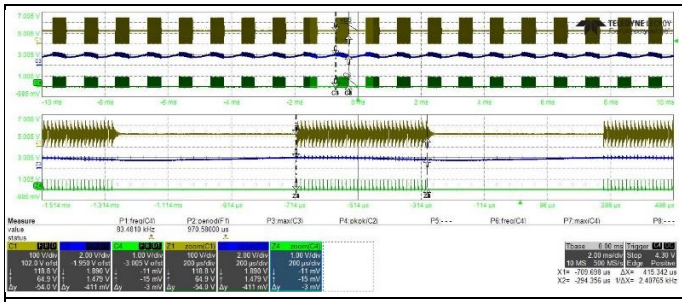
	
C1: V_{DS} C3: V_{FB} C4: V_{CS}	C1: V_{DS} C3: V_{FB} C4: V_{CS}
85 V AC full load to 0.5 W load. Enter ABM at FB pin voltage less than 1.03 V (V_{FB_EBHP}) for more than 36 ms (t_{FB_BEB}).	300 V AC full load to 0.5 W load. Enter ABM at FB pin voltage less than 1.03 V (V_{FB_EBHP}) for more than 36 ms (t_{FB_BEB}).

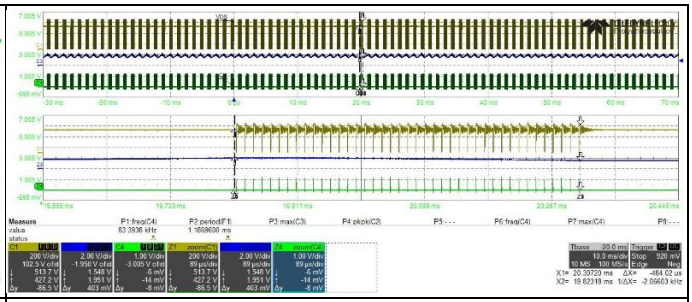
Figure 21 Entering ABM

10.8 During ABM



C1: V_{DS} C3: V_{FB} C4: V_{CS}

85 V AC at 0.5 W load. Burst on at FB voltage 1.95 V ($V_{FB\_Bon\_NISO}$) and burst off at 1.55 V ($V_{FB\_BOff\_NISO}$). CS voltage at 0.27 V (V_{CS_BHP}). Switching frequency at 86 kHz (f_{OSC2_ABM}).

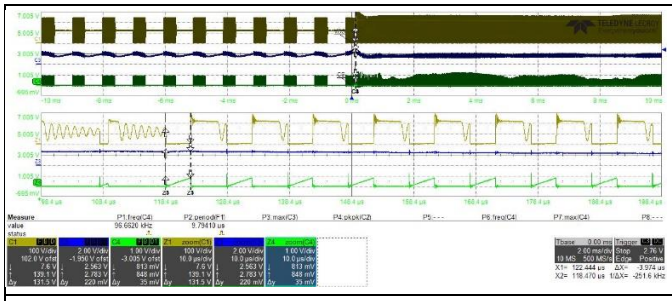


C1: V_{DS} C3: V_{FB} C4: V_{CS}

300 V AC at 0.5 W load. Burst on at FB voltage 1.95 V ($V_{FB\_Bon\_NISO}$) and burst off at 1.55 V ($V_{FB\_BOff\_NISO}$). CS voltage at 0.27 V (V_{CS_BHP}). Switching frequency at 86 kHz (f_{OSC2_ABM}).

Figure 22 During ABM

10.9 Leaving ABM



C1: V_{DS} C3: V_{FB} C4: V_{CS}

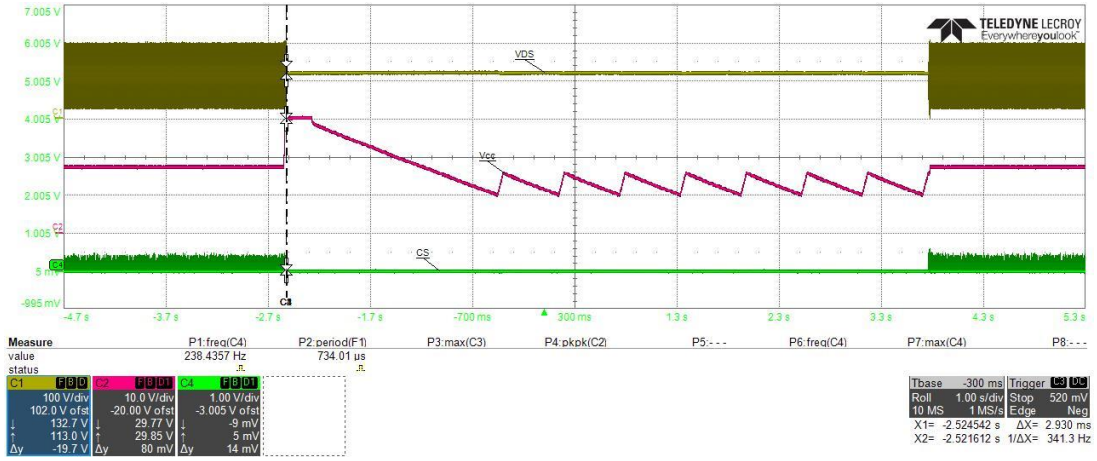
85 V AC at 0.5 W load to full load. Leave ABM at FB voltage more than 2.73 V (V_{FB_LB}).

C1: V_{DS} C3: V_{FB} C4: V_{CS}

300 V AC at 0.5 W load to full load. Leave ABM at FB voltage more than 2.73 V (V_{FB_LB}).

Figure 23 Leaving ABM

10.10 V_{CC} Over-voltage protection

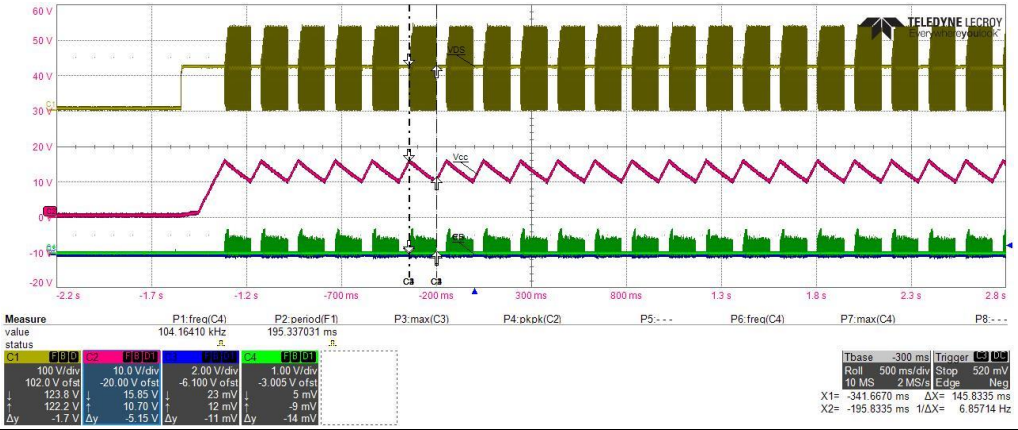


C1: V_{DS} C2: V_{CC} C4: V_{CS}

85 V AC at full load. Removed ZD1. Trigger V_{CC} OV protection at V_{CC} voltage more than ~30.5 V (V_{VCC_OVP}). Extended cycle-skip auto-restart mode.

Figure 24 V_{CC} OV protection

10.11 V_{CC} Under-voltage protection



C1: V_{DS} C2: V_{CC} C4: V_{CS}

85 V AC at full load. Removed R6. Trigger V_{CC} UV protection at V_{CC} voltage less than ~10 V (V_{VCC_OFF}). Auto-restart mode.

Figure 25 V_{CC} UV protection

10.12 Overload protection

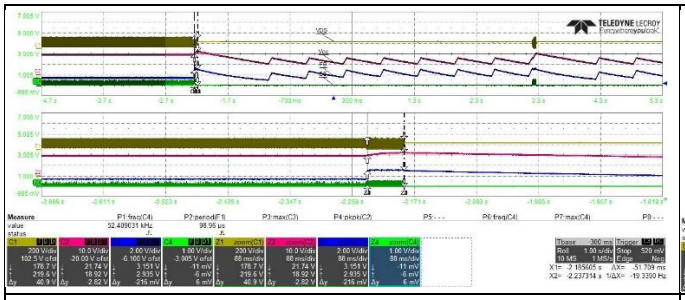
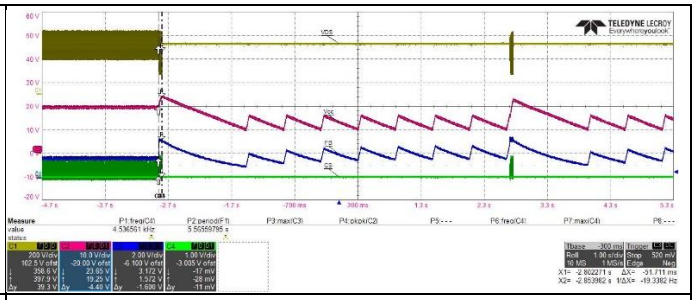
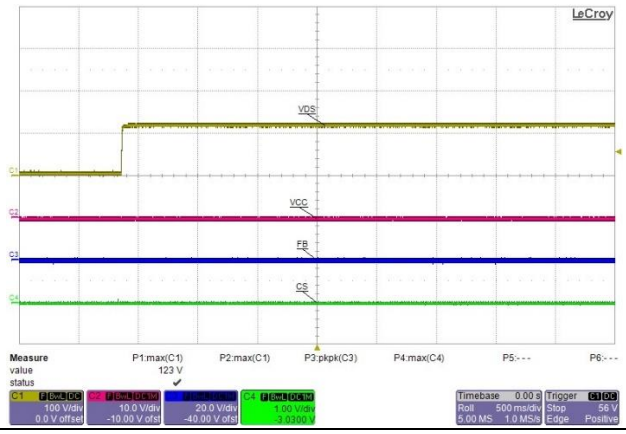
	
C1: V_{DS} C2: V_{CC} C3: V_{FB} C4: V_{CS}	C1: V_{DS} C2: V_{CC} C3: V_{FB} C4: V_{CS}
85 V AC at full load to overload. Trigger protection at feedback pin voltage more than 2.73 V (V_{FB_OLP}) for more than 54 ms ($t_{FB\_OLP\_B}$). Extended cycle-skip auto-restart mode.	300 V AC at full load to overload. Trigger protection at feedback pin voltage more than 2.73 V (V_{FB_OLP}) for more than 54 ms ($t_{FB\_OLP\_B}$). Extended cycle-skip auto-restart mode.

Figure 26 Overload protection

10.13 V_{CC} short-to-GND



C1: V_{DS} C2: V_{CC} C3: V_{FB} C4: V_{CS}

Input 85 V AC. short V_{CC} to ground, measured $I_{VCC\_Charge1}$ = 279 µA with input power around 0.03 W.
(V_{CC} charging current was measured with a digital multimeter.)

Figure 27 V_{CC} short-to-GND

References

[1] Infineon Technologies AG: *ICE5xRxxxxBZx-1 datasheet*; Available online

[2] Infineon Technologies AG: *CoolSET™ 5th Generation Fixed Frequency Plus flyback design guide;* Available online

[3] Infineon Technologies AG: *CoolSET™ 5th Generation Fixed Frequency Plus calculation tool for flyback*; Available online

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Revision history

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

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Edition 2024-08-23

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Infineon Technologies AG

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AN062913

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