15 W auxiliary SMPS using CoolSET™ ICE5AR4770AG-1

REF_5AR4770AG-1_15W1

About this document

Scope and purpose

This document is an engineering report that describes a 15 W auxiliary SMPS with the CoolSET™ 5th Generation Fixed-Frequency (FF) ICE5AR4770AG-1 IC. The document contains power supply specifications, schematics, bill of materials, PCB layout, and performance data. This reference board is designed with a universal input compatible with most geographic regions and three outputs (isolated 12 V/1 A, 5 V/0.1 A and non-isolated 15 V/0.1 A) as typically employed in most home appliances.

Intended audience

This document is intended for SMPS design/application engineers, students, etc., who wish to design auxiliary power supply for major home appliances that are efficient, reliable, and easy to design.

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 W (isolated 12 V/1 A, 5 V/0.1 A and non-isolated 15 V/0.1 A) reference board designed in a flyback converter topology using the CoolSET™ 5th Generation Fixed-Frequency (FF) ICE5AR4770AG-1 IC. The target applications of ICE5AR4770AG-1 are;

- Auxiliary power supplies for white goods, PCs, servers or TVs
- Enclosed adapters for Blu-ray players, set-top boxes, gaming consoles, smart metering, etc.,

With the 700 V CoolMOS™ MOSFET integrated into this IC, it greatly simplifies the design and layout of the PCB. The new improved frequency reduction and frequency jitter features 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 ICE5AR4770AG-1 to protect the system and customize the IC for the chosen application.

2 Reference board

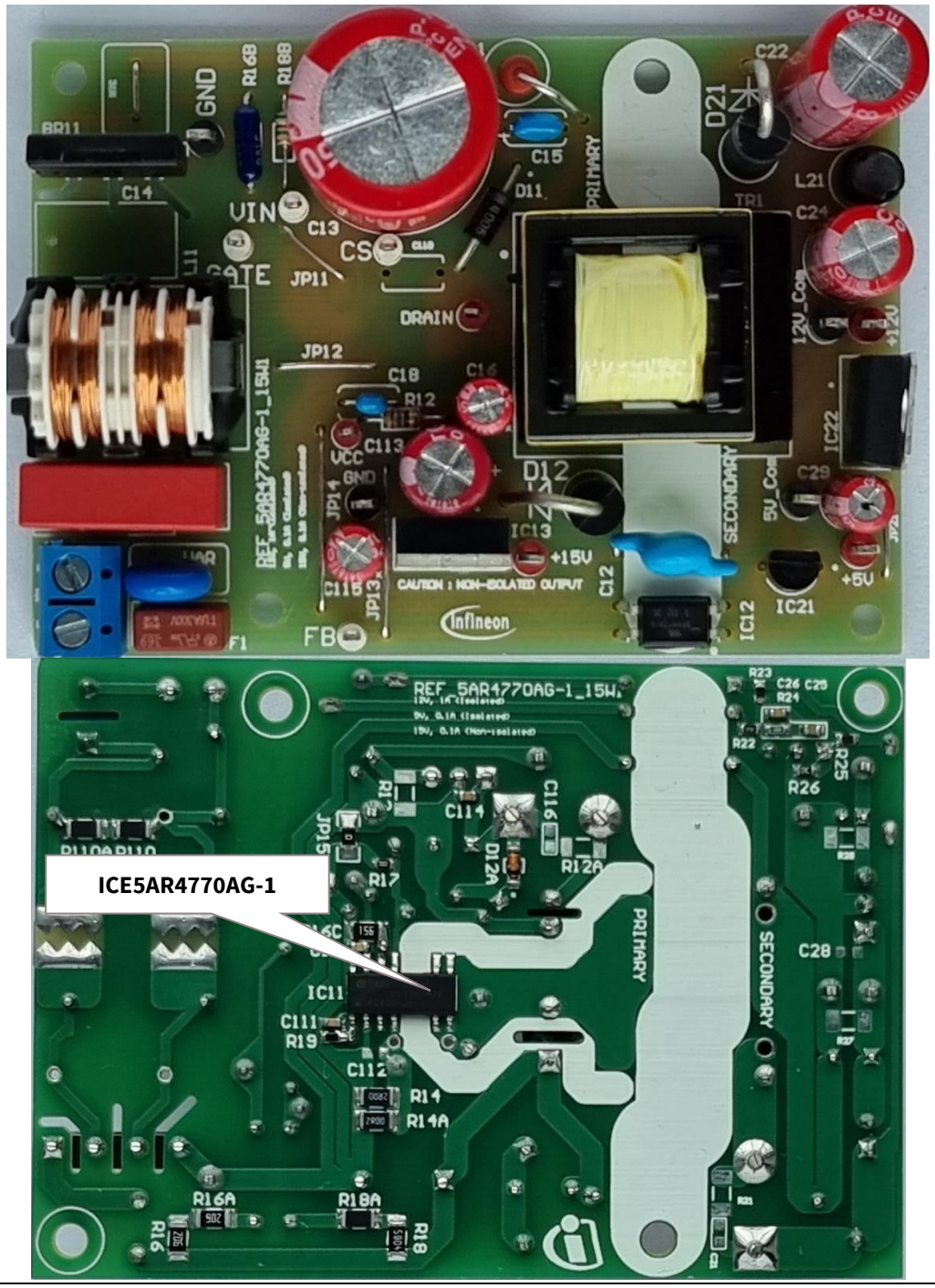


Figure 1 REF_5AR4770AG-1_15W1

3 Reference board specifications

Table 1 REF_5AR4770AG-1_15W1 specifications

Description	Symbol	Min.	Typ.	Max.	Unit	Comments
Input						
Voltage	V_{IN}	85	115/230	264	V AC	2-wire (no P.E.)
Frequency	f_{LINE}	47	50/60	63	Hz	
No load input power	P_{stby_NL}	–	–	200	mW	
Output						
Output voltage 1	V_{out1}	–	12	–	V	
Output current 1	I_{out1}	0.02	–	1	A	
Output voltage 2	V_{out1}	–	5	–	V	LDO output from Vout1
Output current 2	I_{out1}	0.01	–	0.1	A	
Output voltage 3	V_{out1}	–	15	–	V	LDO output from aux winding
Output current 3	I_{out1}	0.01	–	0.1	A	
Over current protection (V_{out1})	I_{OCP1}	1.2	–	1.7	A	Full load at Vout1 and Vout2
Efficiency						
Full load	η_{FL}	78	–	–	%	115 V AC/ 230 V AC
Average (25%, 50%, 75%, and 100%)	η_{ave}	78	–	–	%	115 V AC/ 230 V AC
Environmental						
Conducted EMI		6	–	–	dB	Margin, CISPR 22 Class B
ESD (Contact/air discharge)		± 8	–	–	kV	EN 61000-4-2
Surge immunity						EN 61000-4-5
• Differential Mode		± 2	–	–	kV	
• Common Mode		± 4	–	–	kV	
PCB form factor		57 × 80 × 30			mm	L × W × H

Note: Table 1 represents the minimum acceptable performance of the design. The actual measurement results are listed in Section 9. This reference board is designed to demonstrate the maximum output current only.

4 Schematic

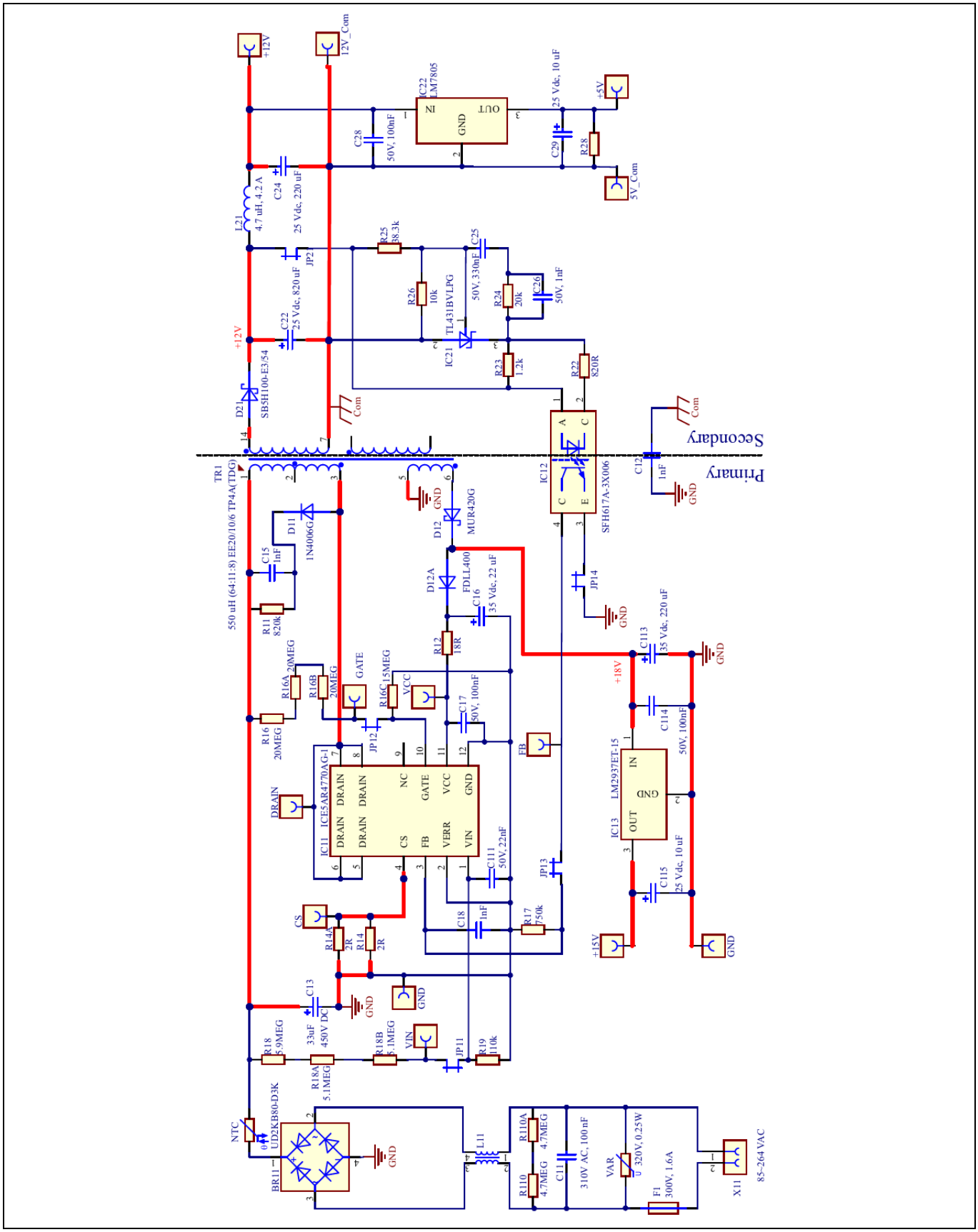


Figure 2 Schematic of REF_5AR4770AG-1_15W1

5 Circuit description

5.1 Line input

The AC-line input stage consists of the following components:

- Input fuse F1
- Varistor VAR
- X-capacitor C11
- X-capacitor discharge resistors R110 and R110A
- Common-mode choke L11
- Rectifier diode BR11
- Bulk capacitor C13

The X-capacitor C11 and common-mode choke L11 act as EMI suppressors.

5.2 Start-up

ICE5AR4770AG-1 uses a cascode structure to fast-charge the V_{CC} capacitor. The pull-up resistors R16, R16A, and R16B connected to the GATE pin (pin 10) 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 ICE5AR4770AG-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 IC turn-on, the V_{CC} voltage is supplied by the auxiliary winding of the transformer. V_{CC} short-to-GND protection is implemented during the start-up time.

5.3 Integrated MOSFET and PWM control

ICE5AR4770AG-1 comprises of a power MOSFET and an FF PWM controller with frequency reduction. Active Burst Mode (ABM) is also implemented to achieve a very low standby input power. The PWM switch-on is synchronized with the internal oscillator and the PWM switch-off is determined by the feedback signal VFB and the current sensing signal V_{CS} via resistors R14 and R14A. ICE5AR4770AG-1 also performs all necessary protection functions including V_{CC} overvoltage and undervoltage, overload, overtemperature (controller junction), line overvoltage protection and V_{CC} short-to-GND. This integrated solution greatly simplifies the circuit layout and reduces the cost of PCB manufacturing. For more information, see the product datasheet [1].

5.4 RCD clamper circuit

A clamper network (R11, C15, and D11) dissipates the energy of the leakage inductance and suppress ringing on the SMPS transformer.

5.5 Output stage

This reference board has a three output:

- Isolated 12 V output rectified by diode D21 and C22 with output filter L21 and C24
- Isolated 5 V output from LDO IC22 taken from 12 V output
- Non-isolated 15 V output via LDO IC13

5.6 Feedback control

The system uses a TL431 IC21 feedback circuit monitoring the 12 V output coupled with an optocoupler IC12 connected to FB pin of the ICE5AR4770AG-1 for output voltage control.

6 PCB layout

6.1 Top side

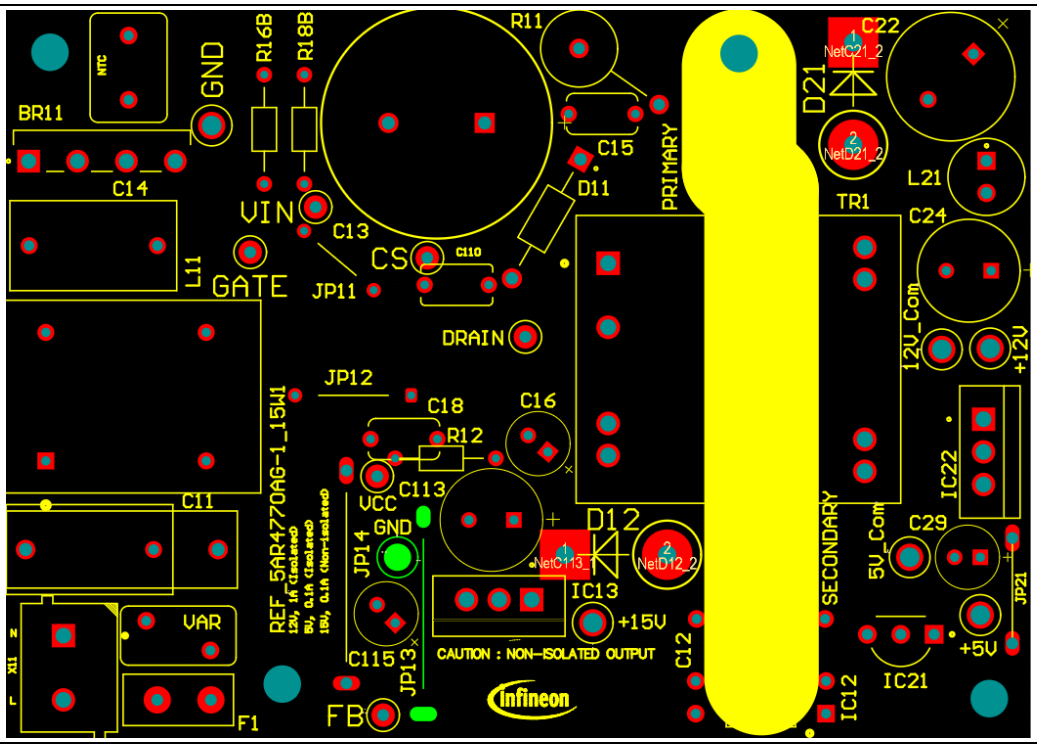


Figure 3 Top-side component legend

6.2 Bottom side

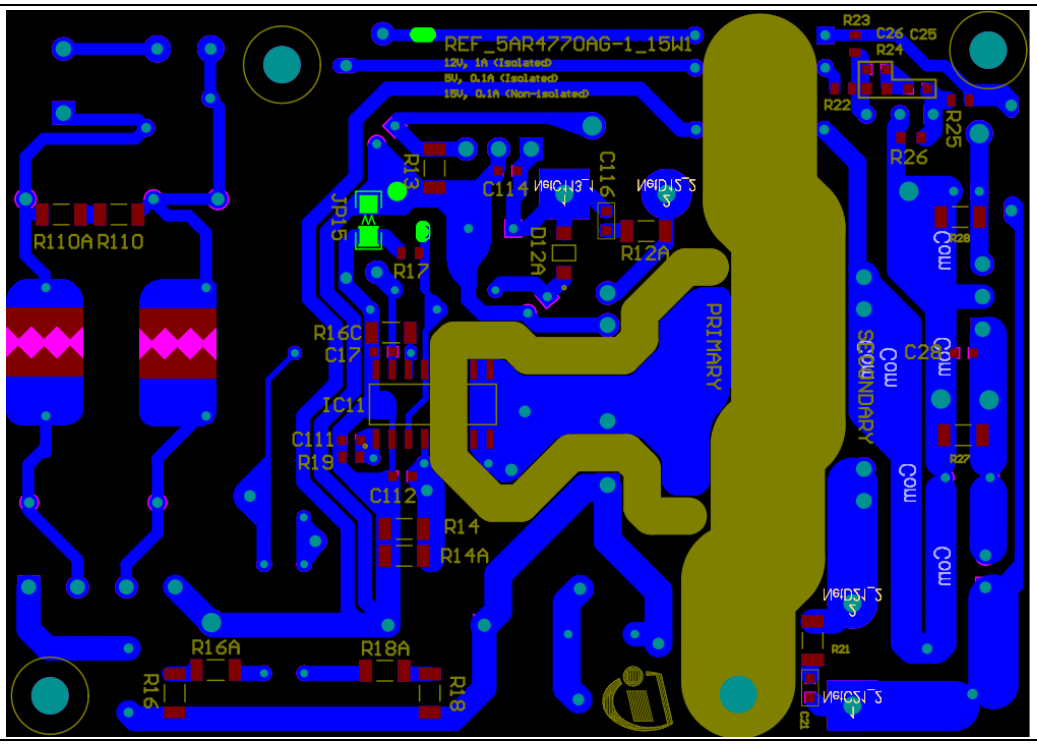


Figure 4 Bottom-side copper and component legend

7 Bill of materials

Table 2 Bill of materials

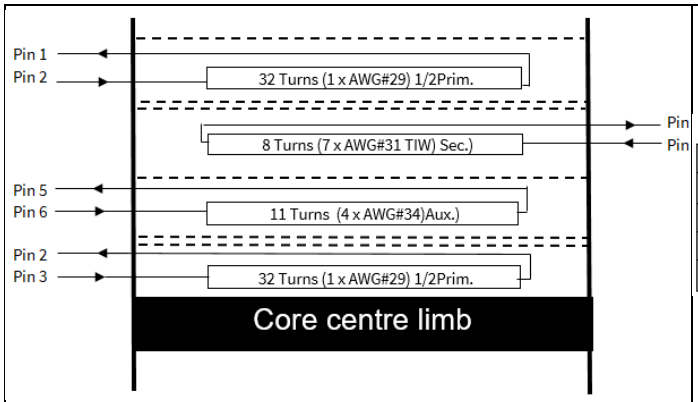
No.	Designator	Description	Part number	Manufacturer	Quantity
1	+5V, +12V, +15V	Connector	5010		3
2	C11	310 V AC, 100 nF	890334025017CS	Würth Elektronik	1
3	C12	1 nF	DE1E3RA102MA4BQ01F	Murata	1
4	C13	33 µF, 450 V	860241481006	Würth Elektronik	1
5	C15	1 nF	RDE7U3A102J2M1H03A	Murata	1
6	C16	35 Vdc, 22 µF	860010572003	Würth Elektronik	1
7	C18	50 V, 1 nF	RDE5C1H102J0K1H03B	Murata	1
8	C17, C114	50 V, 100 nF	885012206095	Würth Elektronik	2
9	C22	25 Vdc, 820 µF	860040475010	Würth Elektronik	1
10	C24	25 Vdc, 220 µF	860040474004	Würth Elektronik	1
11	C25	50 V, 330 nF	885012206121	Würth Elektronik	1
12	C26	50 V, 1 nF	885012206083	Würth Elektronik	1
13	C115, C29	25 Vdc, 10 µF	860010472002	Würth Elektronik	2
14	C111	50 V, 22 nF	885012206091	Würth Elektronik	1
15	C113	35 Vdc, 220 µF	860010574011	Würth Elektronik	1
16	5V_Com, 12V_Com, GND	Connector	5011		3
17	CS, GATE, VIN, FB	Connector	5002		4
18	D11	1N4006G	1N4006G		1
19	BR11	800 V, 1.2 A	UD2KB80-D3K	Shindengen	1
20	D12	200 V, 4 A	MUR420G		1
21	D21	100 V, 5 A	SB5H100-E3/54		1
22	D12A	150 V, 0.2 A	FDLL400		1
23	F1	300 V, 1.6 A	36911600000		1
24	IC11	CoolSET™	ICE5AR4770AG-1	Infineon Technologies AG	1
25	IC12	Optocoupler	SFH617A-3X006		1
26	IC13	15 V LDO	LM2937ET-15		1
27	IC21	2.5 V reference	TL431BVLPG		1
28	IC22	5 V LDO	LM7805ABV		1
29	JP11, JP12, JP21, JP13, JP14, NTC	JUMPER			6
30	JP15	0R, 0805			1
31	L11	43 mH, 0.4 A	7448640418	Würth Elektronik	1
32	L21	4.7 µH, 4.2 A	7447462047	Würth Elektronik	1
33	R11	820k	PR02000208203JR500		1

Bill of materials

No.	Designator	Description	Part number	Manufacturer	Quantity
34	R12	18R	CFR-12JR-52-18R		1
35	R14, R14A	2R	CRCW12062R00FKTA		2
36	R16, R16A	20MEG	RC1206JR-0715ML		2
37	R16B	20MEG	RN55D2005FB14		1
38	R16C	15MEG	RC1206JR-0715ML		1
39	R17	750k	CRCW0603750KFK		1
40	R18	5.9MEG	CRCW12065M90FK		1
41	R18A	5.1MEG	CRCW12065M10FK		1
42	R18B	5.1MEG	299-5.1M-RC		1
43	R19	110k	CRCW0603110KFK		1
44	R22	820R	CRCW0603820RFK		1
45	R23	1.2k	CRCW06031K20FK		1
46	R24	20k	TNPW060320K0BY		1
47	R25	38.3k	CRCW060338K3FK		1
48	R26	10k	RC0603FR-0710KL		1
49	R110, R110A	4.7MEG	CRCW12064M70FK		2
50	TR1	550 µH (64:11:8) EE20/10/6 TP4A(TDG)	750344251 (R01)	Würth Elektronik	1
51	VAR	320 V, 0.25 W	B72207S2321K101	TDK Corporation	1
52	VCC, DRAIN	Connector	5000		2
53	X11	Connector	691 102 710 002	Würth Elektronik	1
54	PCB	80 mm × 57 mm (L x W) single layer, 2 oz., FR-4			1

8 Transformer construction

- Core and material: EE20/10/6, TP4A (TDG)
- Bobbin: 14 pin, THT, horizontal version
- Primary Inductance: Lp = 550 µH (±10%), measured between pin 1 and pin 3
- Manufacturer and part number: Würth Elektronik (750344251 Rev.01)



Wire size requirement :

Start	Stop	Turns	Wire size	Layer
3	2	32	1 x AWG#29	1/2 Primary
6	5	11	4 x AWG#34	Auxiliary
14	7	8	7 x AWG#31 TIW	Secondary
2	1	32	1 x AWG#29	1/2 Primary

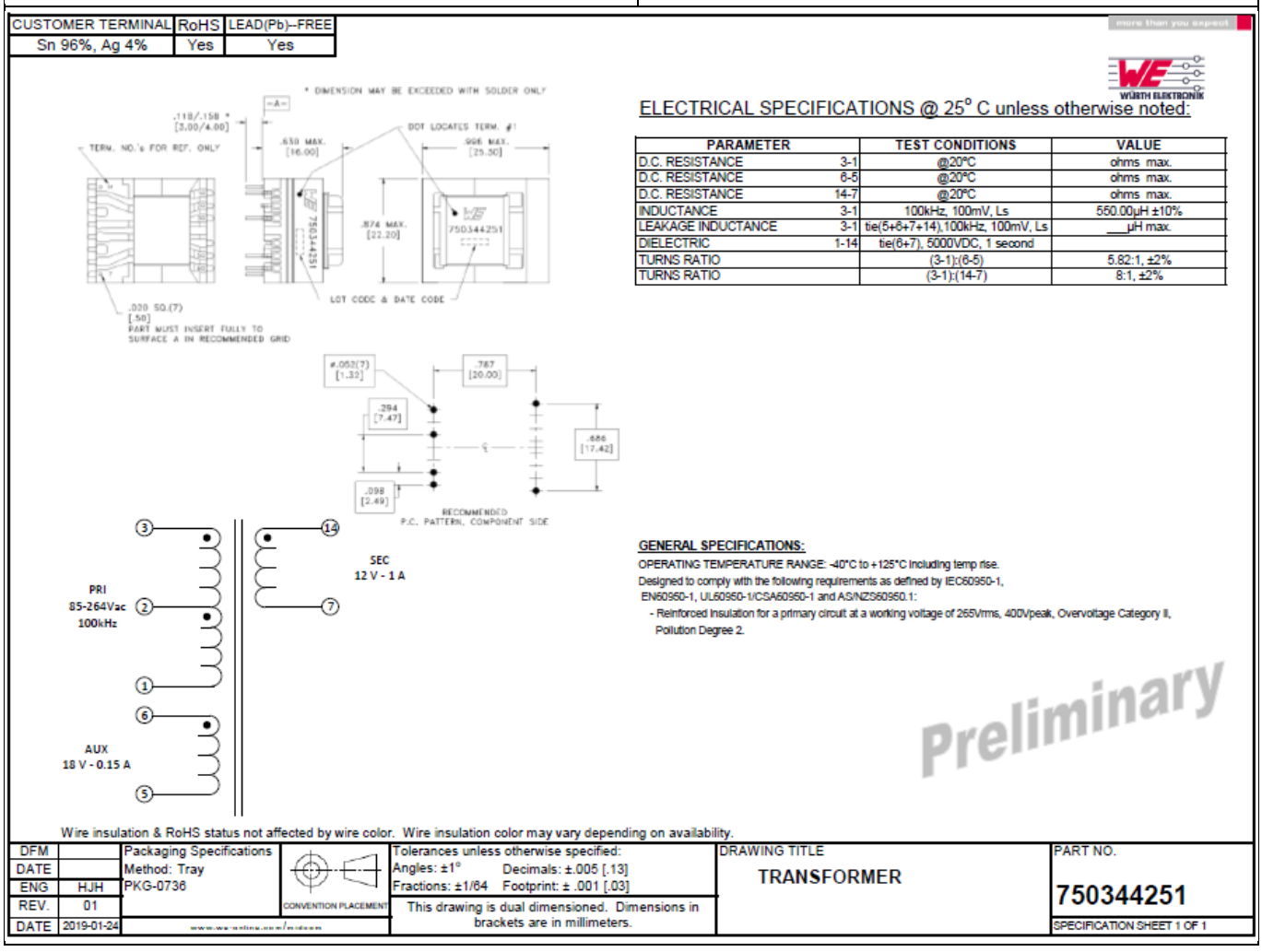


Figure 5 Transformer structure

9 Test results

9.1 Efficiency

Table 3 Efficiency

Input (V AC/Hz)	Loading percentage	Pin (W)	Vout1 (V)	Iout1 (A)	Vout2 (V)	Iout2 (A)	Vout3 (V)	Iout3 (A)	Pout (W)	Efficiency (%)	Average efficiency (%)
85 V AC/60 Hz	No load	0.136	12.020	0.000	4.975	0.000	14.914	0.000	0.00		
	Min. load	0.808	12.010	0.020	4.970	0.010	14.914	0.010	0.44	54.34%	
	25% load	4.523	12.005	0.250	4.970	0.025	14.914	0.025	3.50	77.35%	77.47%
	50% load	8.906	11.995	0.500	4.963	0.050	14.914	0.050	6.99	78.50%	
	75% load	13.515	11.990	0.750	4.963	0.075	14.914	0.075	10.48	77.57%	
	100% load	18.276	11.985	1.000	4.963	0.100	14.914	0.100	13.97	76.45%	
115 V AC/60 Hz	No load	0.139	12.012	0.000	4.975	0.000	14.914	0.000	0.00		
	Min. load	0.814	12.010	0.020	4.970	0.010	14.914	0.010	0.44	53.94%	
	25% load	4.481	12.002	0.250	4.970	0.025	14.914	0.025	3.50	78.05%	79.03%
	50% load	8.773	11.995	0.500	4.963	0.050	14.914	0.050	6.99	79.69%	
	75% load	13.205	11.987	0.750	4.963	0.075	14.914	0.075	10.48	79.37%	
	100% load	17.684	11.980	1.000	4.963	0.100	14.914	0.100	13.97	78.98%	
230 V AC/50 Hz	No load	0.160	12.010	0.000	4.975	0.000	14.914	0.000	0.00		
	Min. load	0.860	12.010	0.020	4.970	0.010	14.914	0.010	0.44	51.05%	
	25% load	4.535	12.002	0.250	4.970	0.025	14.914	0.025	3.50	77.12%	79.44%
	50% load	8.760	11.995	0.500	4.963	0.050	14.914	0.050	6.99	79.81%	
	75% load	13.065	11.987	0.750	4.963	0.075	14.914	0.075	10.48	80.22%	
	100% load	17.330	11.980	1.000	4.963	0.100	14.914	0.100	13.97	80.60%	
264 V AC/50 Hz	No load	0.170	12.012	0.000	4.975	0.000	14.914	0.000	0.00		
	Min. load	0.890	12.010	0.020	4.970	0.010	14.914	0.010	0.44	49.33%	
	25% load	4.572	12.002	0.250	4.970	0.025	14.914	0.025	3.50	76.50%	79.03%
	50% load	8.812	11.992	0.500	4.963	0.050	14.914	0.050	6.99	79.32%	
	75% load	13.119	11.985	0.750	4.963	0.075	14.914	0.075	10.48	79.88%	
	100% load	17.370	11.980	1.000	4.963	0.100	14.914	0.100	13.97	80.41%	

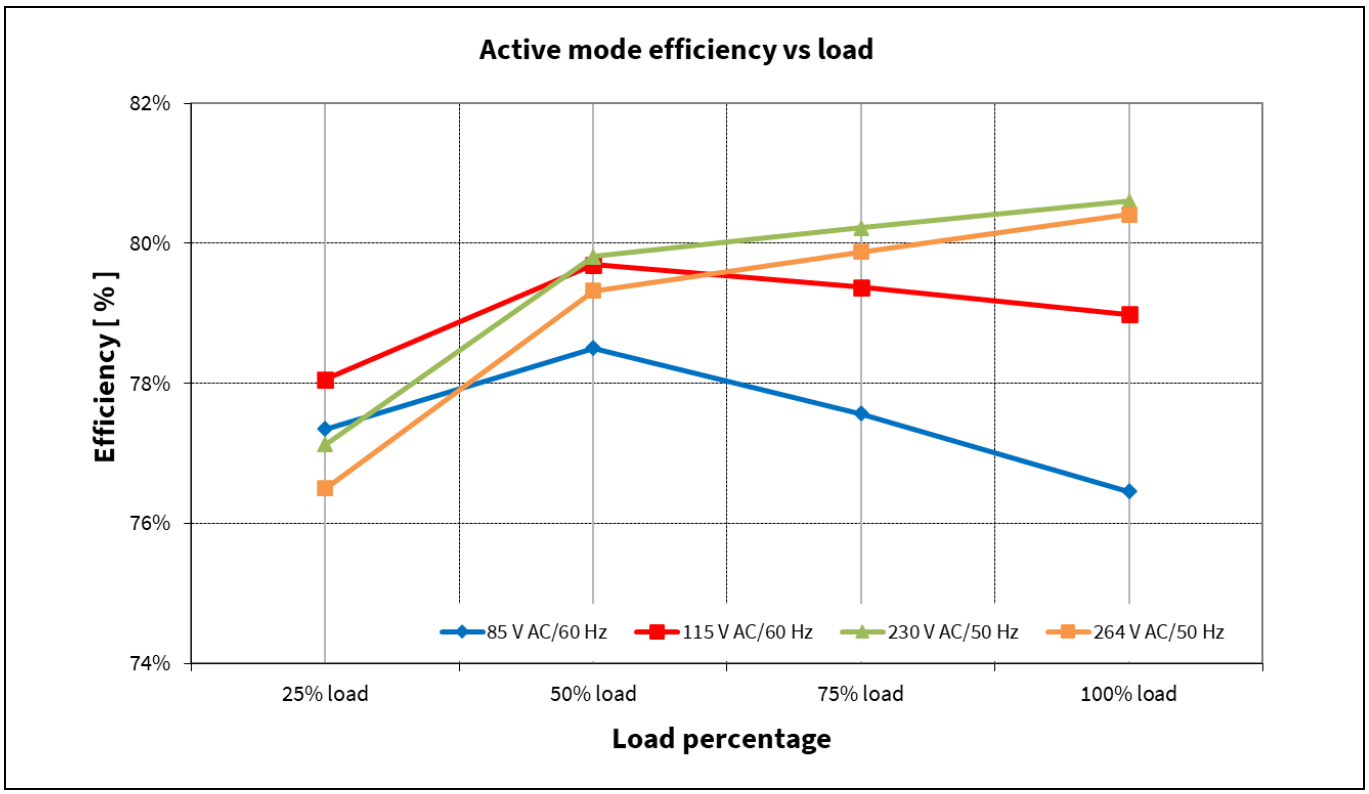


Figure 6 Efficiency vs. AC-line input voltage

9.2 Standby power

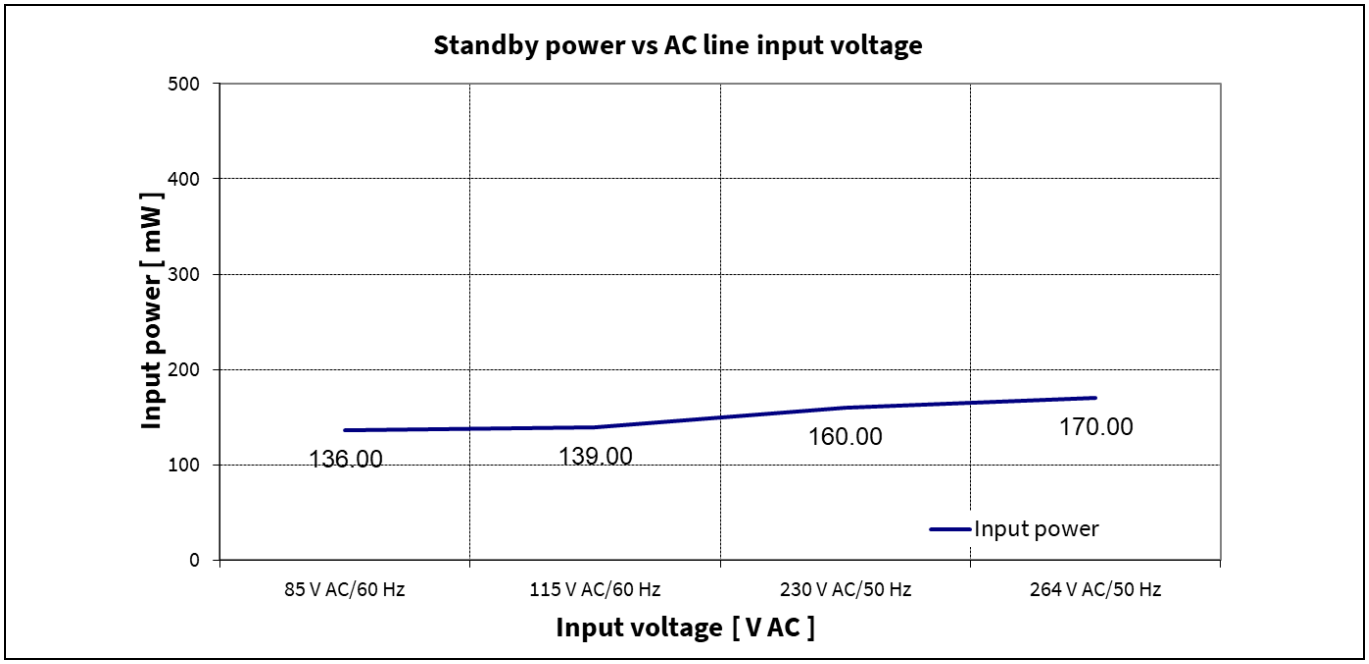


Figure 7 Standby power vs. AC-line input voltage

9.3 Line and load regulation

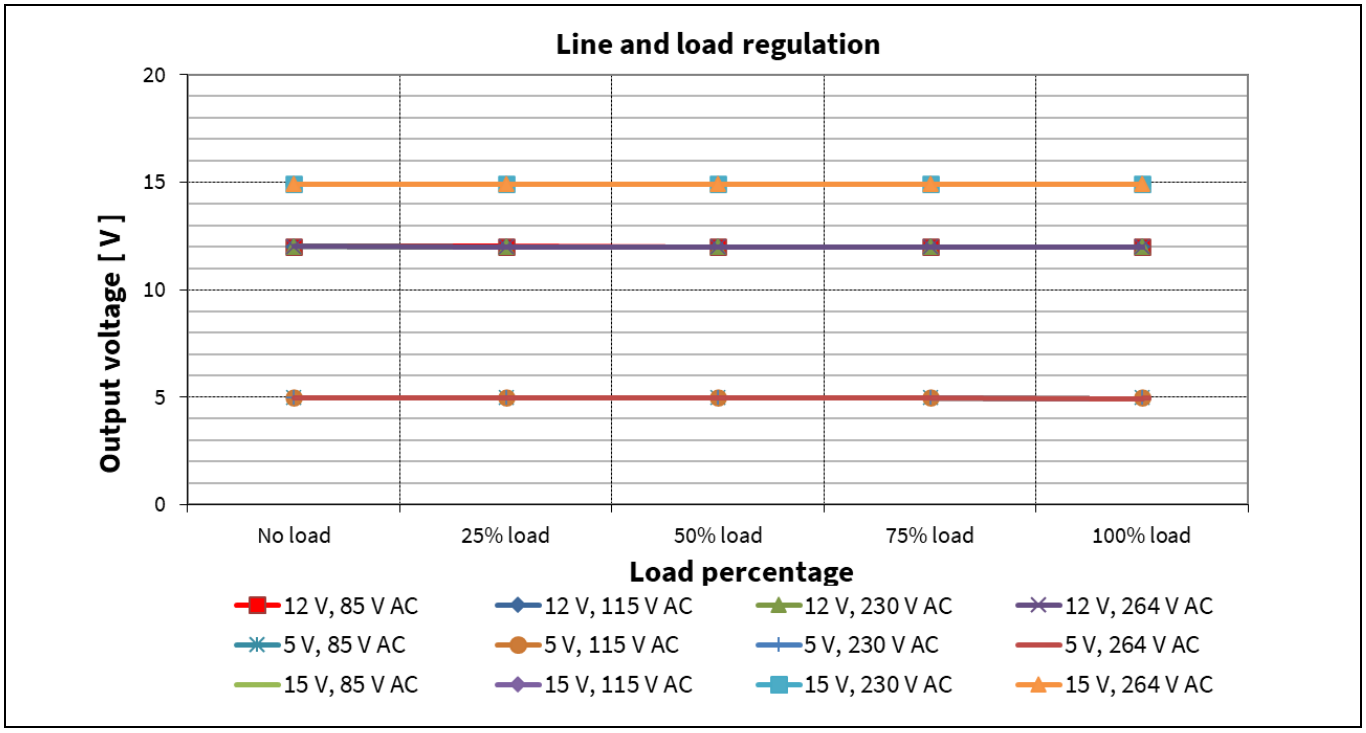


Figure 8 Line and load regulation

9.4 Maximum input power

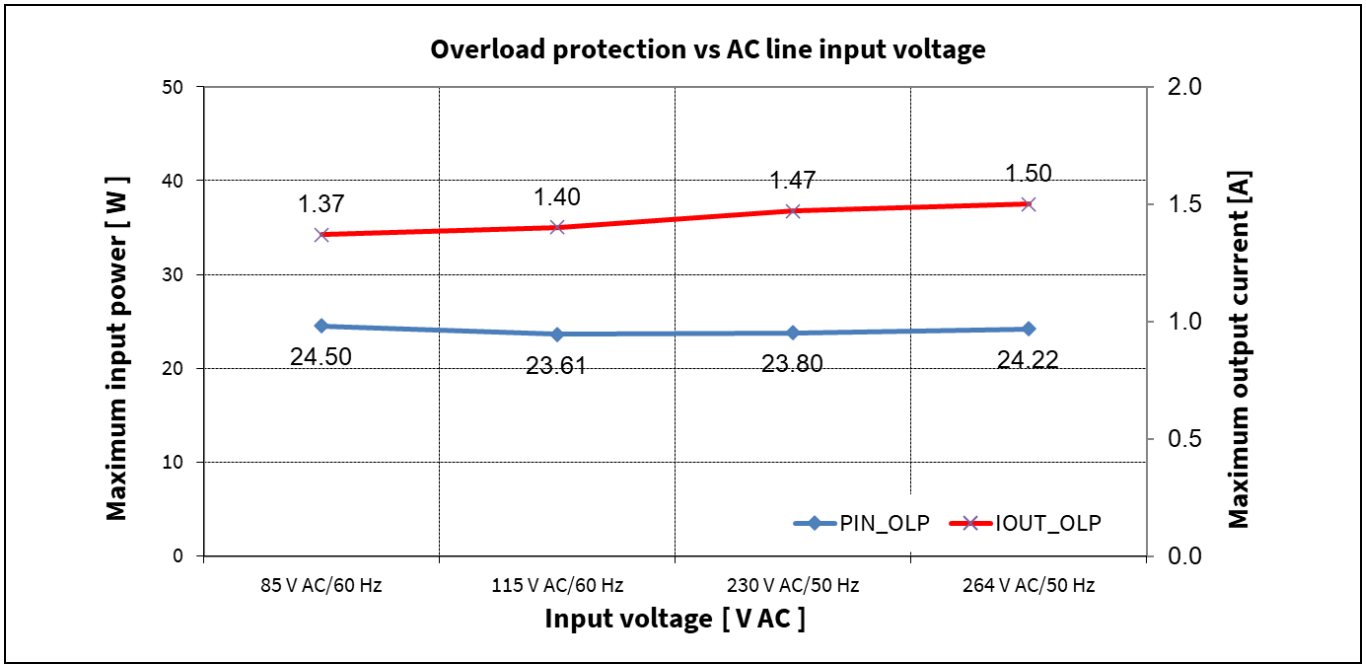


Figure 9 Maximum input power and maximum output current at 12 V output vs. AC line input voltage (15 V and 5 V output at full load condition)

9.5 ESD immunity (EN61000-4-2)

This system was subjected to a ±8 kV ESD test according to EN 61000-4-2 for both contact and air discharge. It was tested at full load with a resistive load. A test failure was defined as non-recoverable.

- Contact discharge: pass ±8 kV; air discharge: pass ±8 kV

Table 4 System ESD test result

Description	ESD test	Level	Number of strikes		Test result
			V_{OUT1}	$-V_{OUT}$	
115 V AC, full load	Contact	+8 kV	10	10	PASS
		-8 kV	10	10	PASS
	Air	+8 kV	10	10	PASS
		-8 kV	10	10	PASS
230 V AC, full load	Contact	+8 kV	10	10	PASS
		-8 kV	10	10	PASS
	Air	+8 kV	10	10	PASS
		-8 kV	10	10	PASS

9.6 Surge immunity (EN 61000-4-5)

This system was subjected to a surge immunity test (±2 kV DM and ±4 kV CM) according to EN 61000-4-5. It was tested at full load with a resistive load with LOVP disabled (add 2.4 V Zener diode at VIN pin to GND pin). A test failure was defined as a non-recoverable.

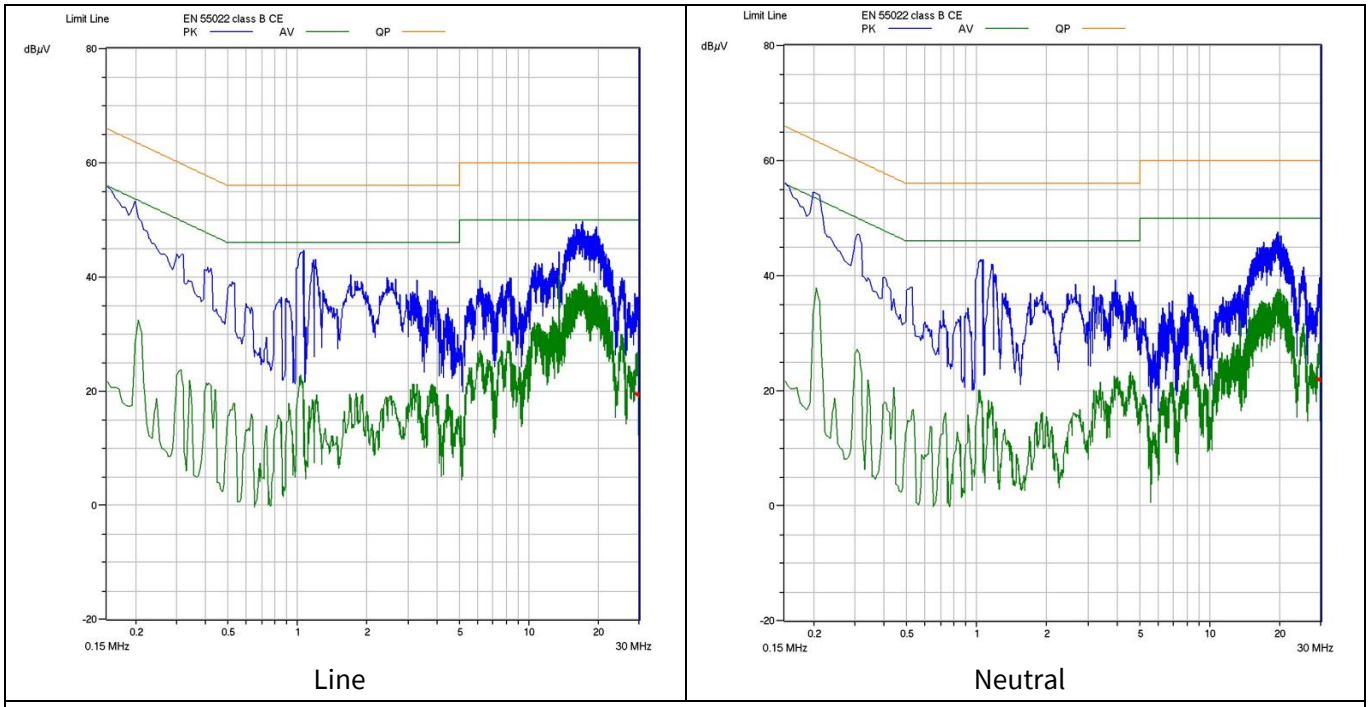
- DM: pass ±2 kV; CM: pass ±4 kV

Table 5 System surge immunity test result

Description	Test	Level		Number of strikes				Test result
				0°	90°	180°	270°	
115 V AC, full load	DM	+2 kV	L → N	3	3	3	3	PASS
		-2 kV	L → N	3	3	3	3	PASS
	CM	+4 kV	L → G	3	3	3	3	PASS
		+4 kV	N → G	3	3	3	3	PASS
		-4 kV	L → G	3	3	3	3	PASS
		-4 kV	N → G	3	3	3	3	PASS
230 V AC, full load	DM	+2 kV	L → N	3	3	3	3	PASS
		-2 kV	L → N	3	3	3	3	PASS
	CM	+4 kV	L → G	3	3	3	3	PASS
		+4 kV	N → G	3	3	3	3	PASS
		-4 kV	L → G	3	3	3	3	PASS
		-4 kV	N → G	3	3	3	3	PASS

9.7 Conducted emissions (EN 55022 class B)

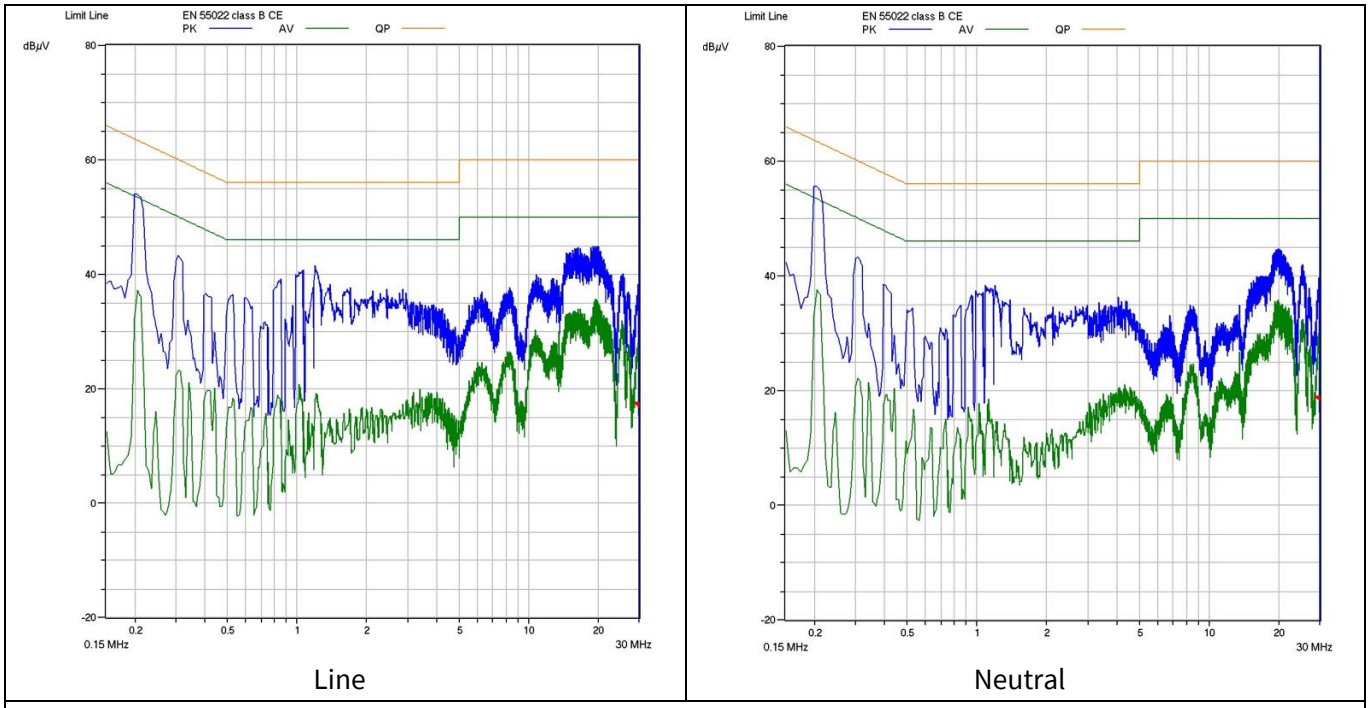
Conducted EMI was measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) class B. Reference board was connected to a resistive load with input voltage of 115 V AC and 230 V AC.



Line | Neutral

Passed with more than 6 dB margin for quasi-peak measurement at lowline (115 V AC).

Figure 10 Conducted emissions at 115 V AC with full load



Line | Neutral

Passed with more than 6 dB margin for quasi-peak measurement at highline (230 V AC).

Figure 11 Conducted emissions at 230 V AC with full load

9.8 Thermal measurement

The thermal test 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.

Table 6 Hottest temperature of reference board

No.	Major component	85 V AC (°C)	264 V AC (°C)
1	IC22 (5 V LDO)	72.9	73.7
2	D21 (output diode)	68.0	69.6
3	TR1 (transformer)	61.2	64.5
4	U1 (ICE5QR0680BG CoolSET™)	89.2	65.2

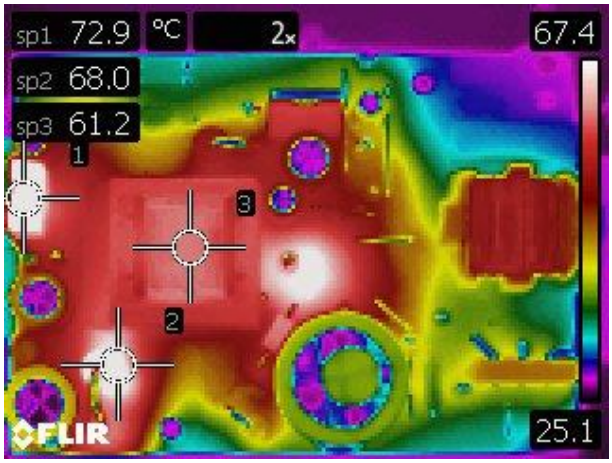
Top side	Bottom side
	

Figure 12 Infrared thermal image at 85 V AC

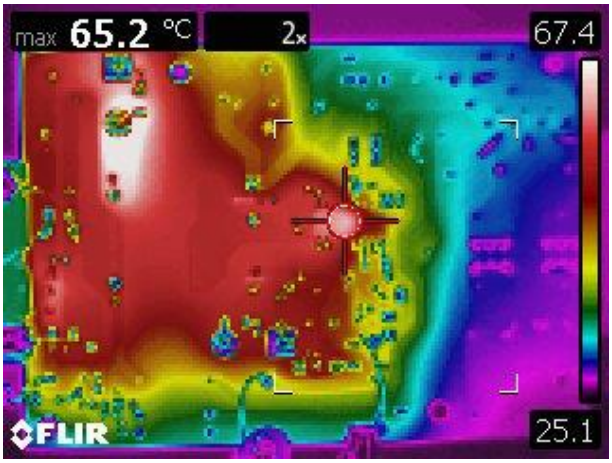
Top side	Bottom side
	

Figure 13 Infrared thermal image of at 264 V AC

10 Waveforms and scope plots

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

10.1 Start-up with maximum load

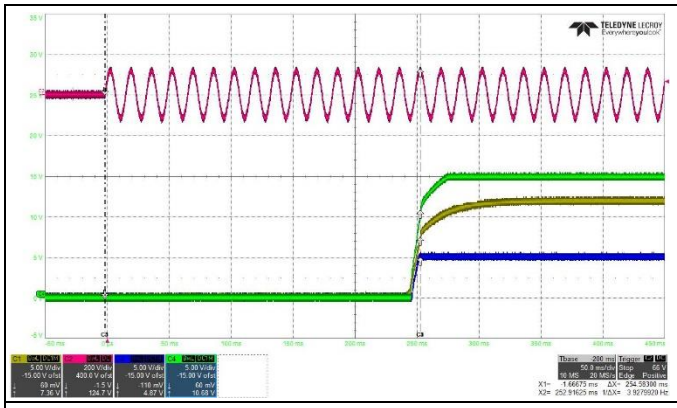
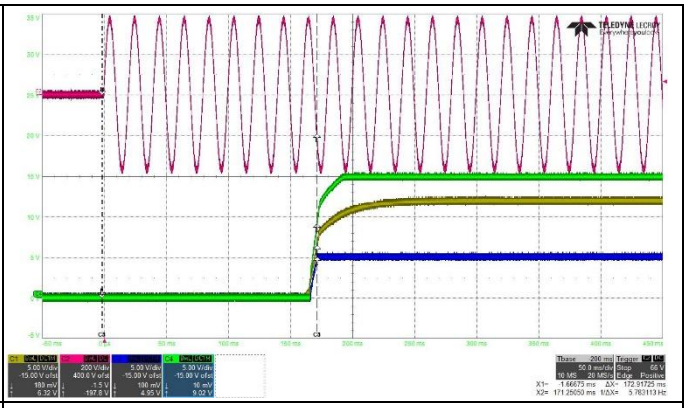
	
C1 (yellow) : 12 V output voltage (V_{out1}) C2 (purple) : Input AC voltage (V AC) C3 (blue) : 5 V output voltage (V_{out2}) C4 (green) : 15 V output voltage (V_{out3})	C1 (yellow) : 12 V output voltage (V_{out1}) C2 (purple) : Input AC voltage (V AC) C3 (blue) : 5 V output voltage (V_{out2}) C4 (green) : 15 V output voltage (V_{out3})
Start-up time at 85 V AC and maximum load ≈ 255 ms	Start-up time at 264 V AC and maximum load ≈ 173 ms

Figure 14 Start-up

10.2 Soft-start

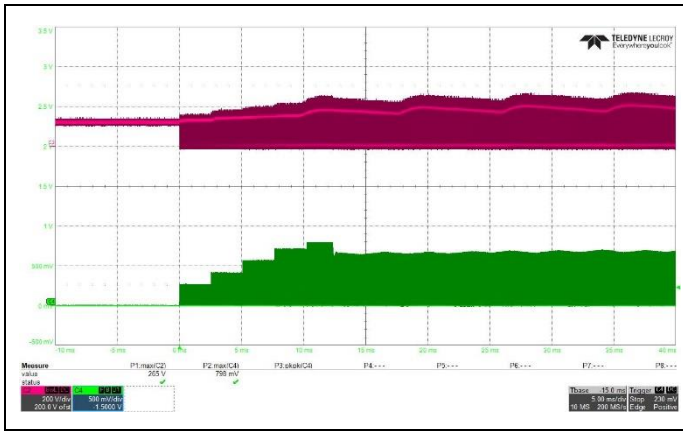
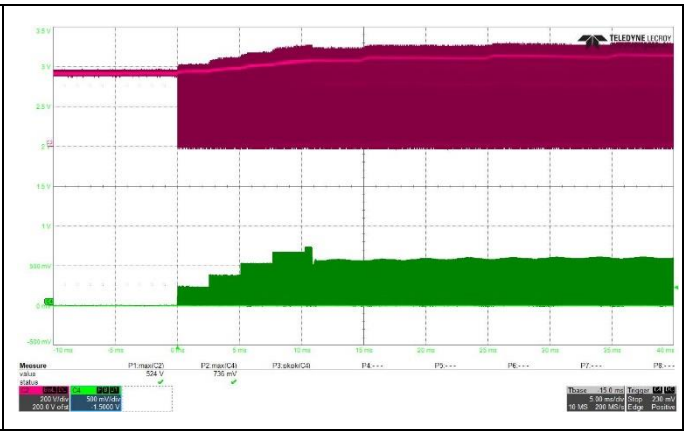
	
C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})	C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})
Soft-start time at 85 V AC and maximum load ≈ 11 ms	Soft-start time at 264 V AC and maximum load ≈ 11 ms

Figure 15 Soft-start

10.3 Drain and CS voltage at maximum load

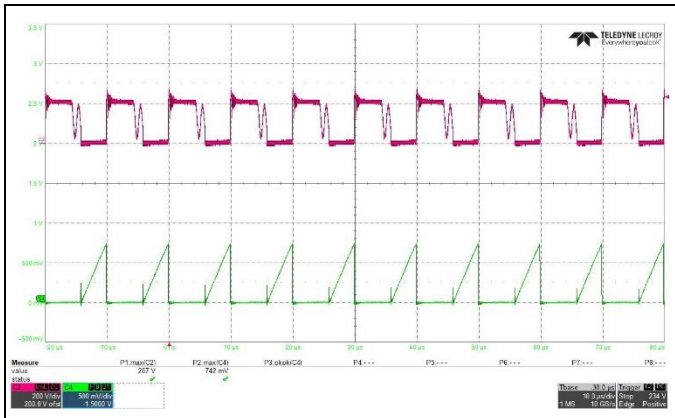
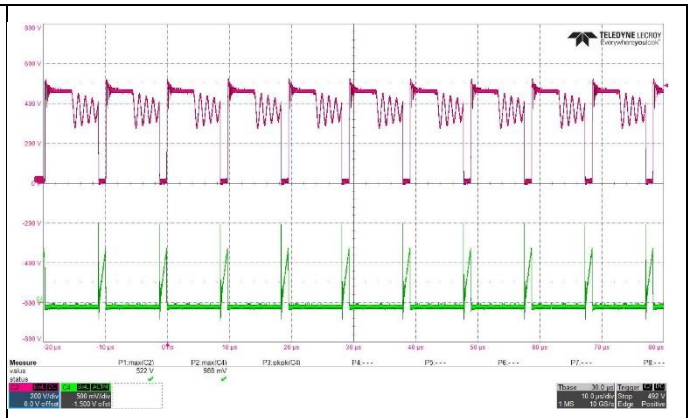
	
C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})	C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})
V_{DRAIN_PEAK} at 85 V AC ≈ 267 V	V_{DRAIN_PEAK} at 264 V AC ≈ 520 V

Figure 16 Drain and CS voltage at maximum load

10.4 Output ripple voltage at maximum load

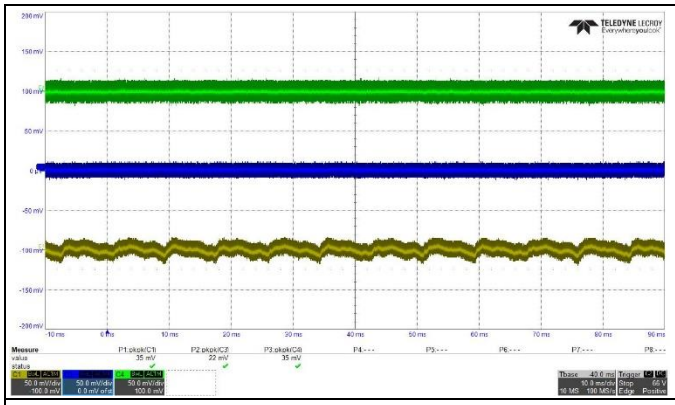
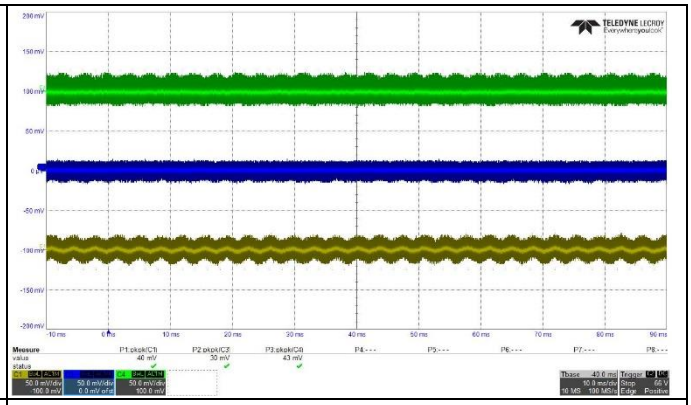
	
C1 (yellow) : 12 V output voltage (V_{out1}) C3 (blue) : 5 V output voltage (V_{out2}) C4 (green) : 15 V output voltage (V_{out3})	C1 (yellow) : 12 V output voltage (V_{out1}) C3 (blue) : 5 V output voltage (V_{out2}) C4 (green) : 15 V output voltage (V_{out3})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 35 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW	12 $V_{ripple\_pk\_pk}$ at 264 V AC ≈ 40 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW

Figure 17 Output ripple voltage at full load

10.5 Output ripple voltage at ABM

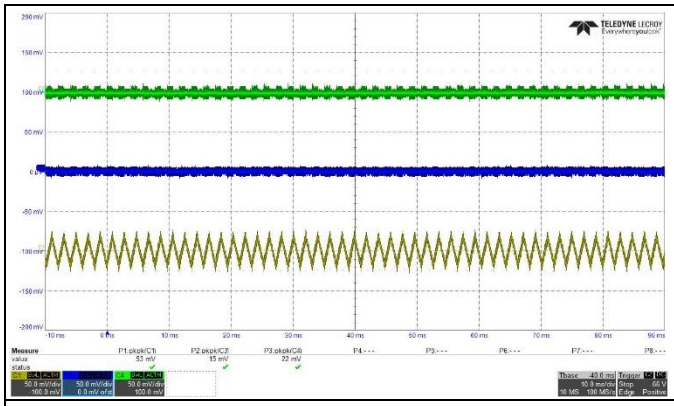
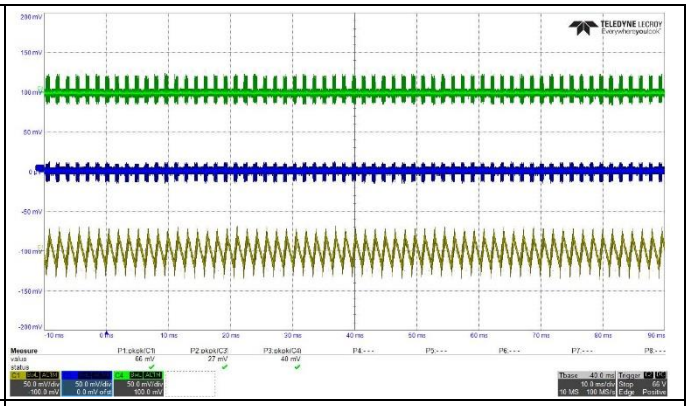
	
C1 (yellow) : 12 V output voltage (V_{out1}) C3 (blue) : 5 V output voltage (V_{out2}) C4 (green) : 15 V output voltage (V_{out3})	C1 (yellow) : 12 V output voltage (V_{out1}) C3 (blue) : 5 V output voltage (V_{out2}) C4 (green) : 15 V output voltage (V_{out3})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 53 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW	12 $V_{ripple\_pk\_pk}$ at 264 V AC ≈ 66 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW

Figure 18 Output ripple voltage at ABM (no load)

10.6 Load transient response (Dynamic load from minimum load to 100%)

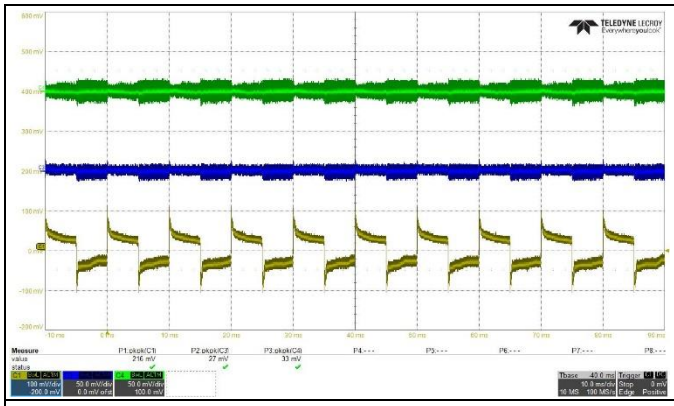
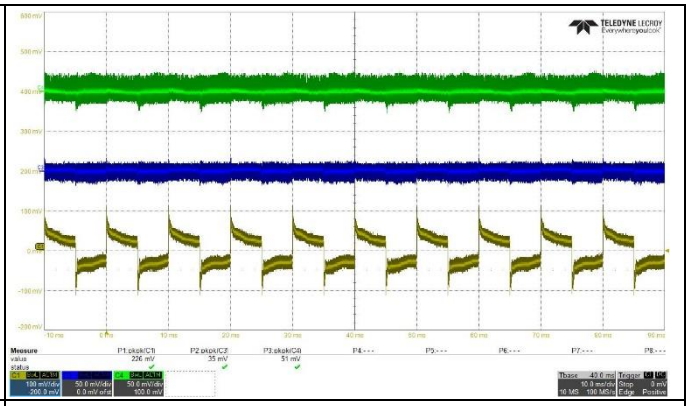
	
C1 (yellow) : 12 V output voltage (V_{out1}) C3 (blue) : 5 V output voltage (V_{out2}) C4 (green) : 15 V output voltage (V_{out3})	C1 (yellow) : 12 V output voltage (V_{out1}) C3 (blue) : 5 V output voltage (V_{out2}) C4 (green) : 15 V output voltage (V_{out3})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 216 mV (Load change from minimum load to 100% at 85 V AC, 100 Hz, 0.4 A/µs slew rate) Probe terminal end with decoupling capacitor of 0.1 µF(ceramic) and 1 µF(Electrolytic), 20 MHz filter	12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 226 mV (Load change from minimum load to 100% at 264 V AC, 100 Hz, 0.4 A/µs slew rate) Probe terminal end with decoupling capacitor of 0.1 µF(ceramic) and 1 µF(Electrolytic), 20 MHz filter

Figure 19 Load transient response at 12 V output (5 V and 15 V at full load)

10.7 Entering ABM operation

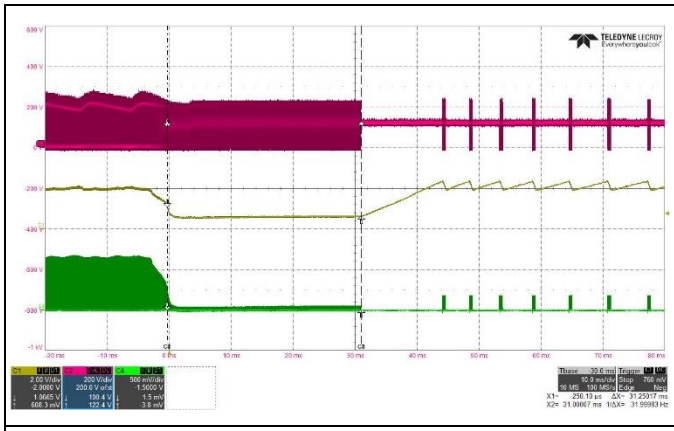
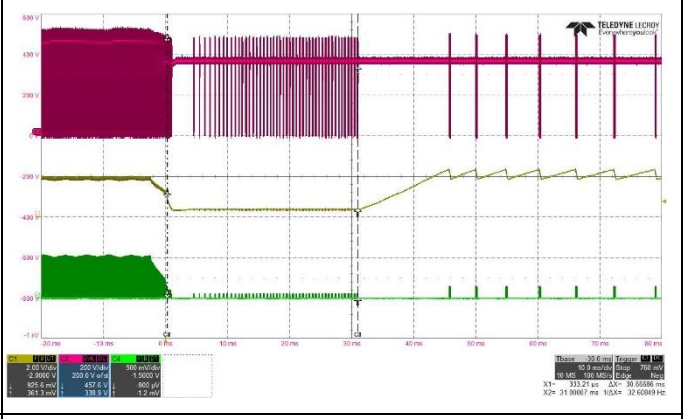
	
C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})
85 V AC, 100% load to no load Enter ABM at V_{FB} < 1.03 V and $t_{blanking}$ = 32 ms	264 V AC, 100% load to no load Enter ABM at V_{FB} < 1.03 V and $t_{blanking}$ = 32 ms

Figure 20 Entering ABM operation

10.8 During ABM operation

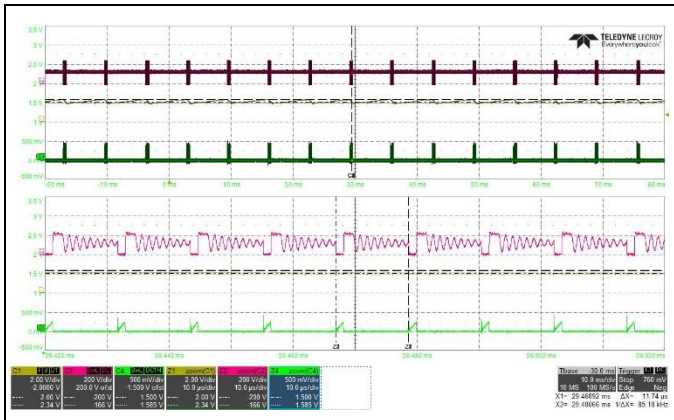
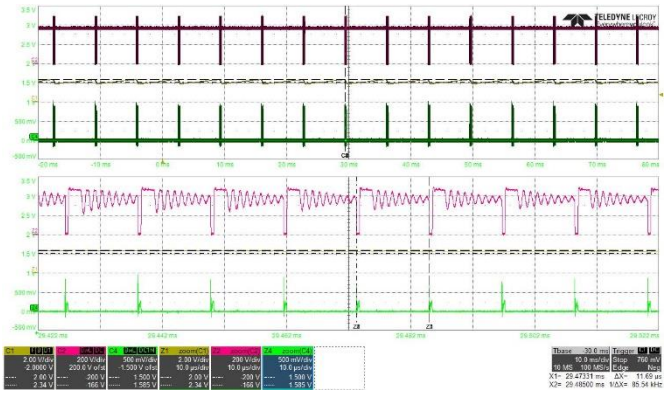
	
C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})
85 V AC, no load f_{SW} = 85 kHz, I_{PK} = 270 mA, V_{FB_ON} = 2.4 V, V_{FB_OFF} = 2.0 V	264 V AC, no load f_{SW} = 85 kHz, I_{PK} = 270 mA, V_{FB_ON} = 2.4 V, V_{FB_OFF} = 2.0 V

Figure 21 During ABM operation

10.9 Leaving ABM operation

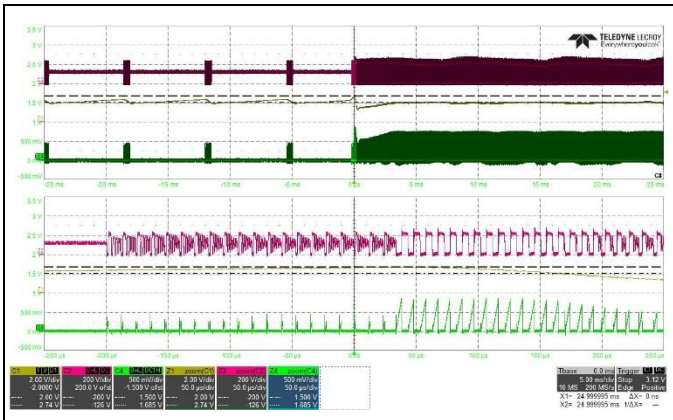
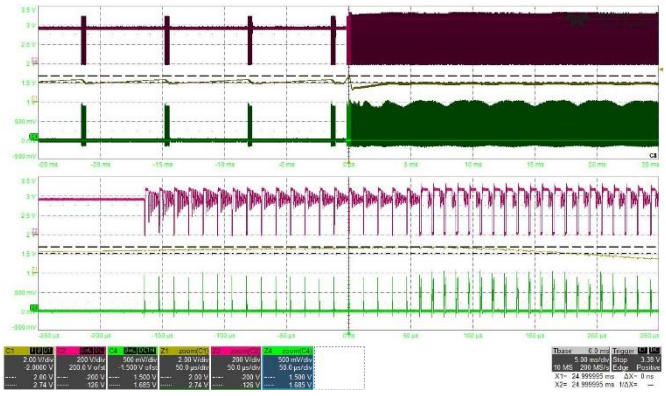
	
C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})
85 V AC, 12 V load from no load to 100% load, 5 V and 15 V at minimum load V_{FB} > 2.73 V	264 V AC, 12 V load from no load to 100% load, 5 V and 15 V at minimum load V_{FB} > 2.73 V

Figure 22 Leaving ABM operation

10.10 Overload protection (odd-skip auto-restart)

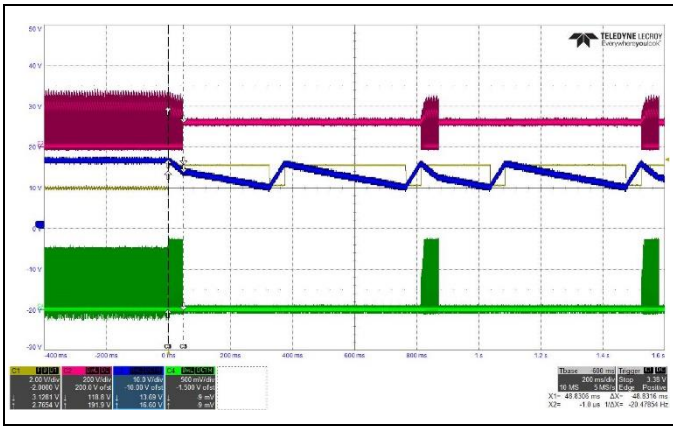
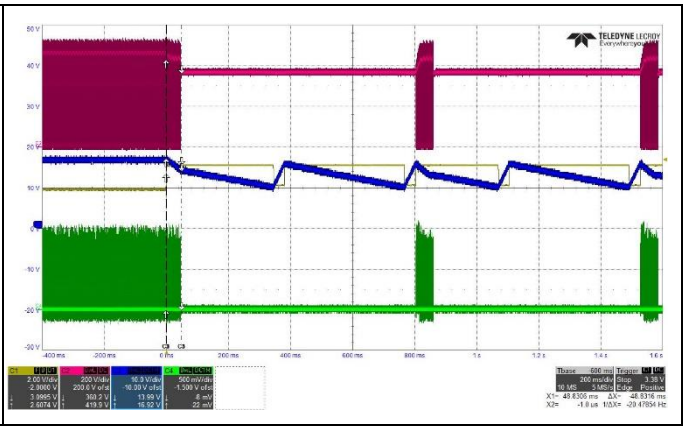
	
C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : VCC voltage (V_{VCC}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : VCC voltage (V_{VCC}) C4 (green) : CS voltage (V_{CS})
Condition to enter overload protection: V_{FB} more than 2.73 V and lasts for ~50 ms blanking time. 12 V output load change from full load to 2 A (5 V and 15 V output at full load).	

Figure 23 Overload protection

10.11 V_{CC} OV/UV protection

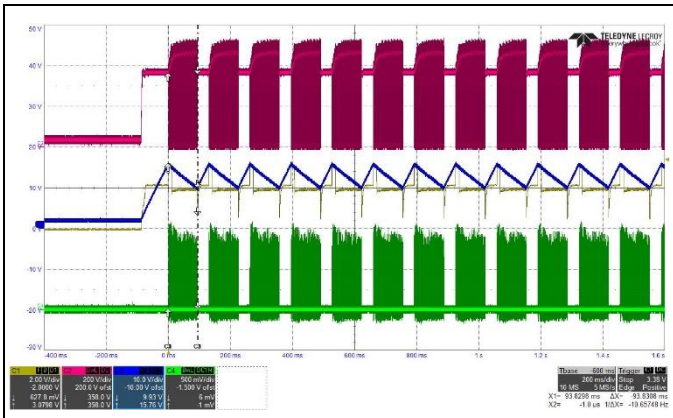
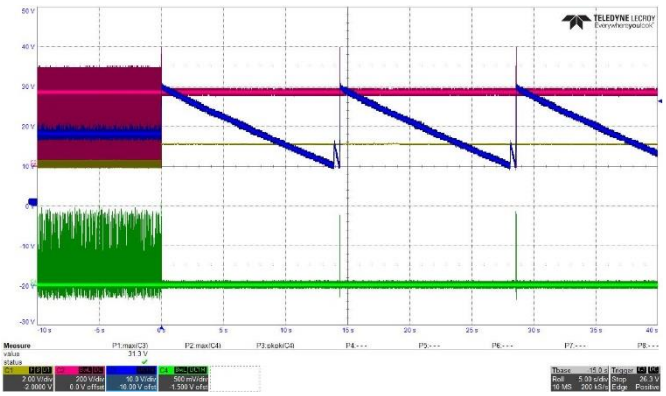
	
C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : VCC voltage (V_{VCC}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : VCC voltage (V_{VCC}) C4 (green) : CS voltage (V_{CS})
264 V AC at 100% load and open D12A. Trigger V_{CC} UVP at V_{CC} voltage less than 10 V (V_{VCC_OFF}). Auto-restart mode.	264 V AC at minimum load and short R26. Trigger V_{CC} OVP at V_{CC} voltage more than 30.5 V (V_{VCC_OVP}). Odd-skip auto-restart mode.

Figure 24 V_{CC} OV/UV protection

10.12 Brown-in protection and LOVP

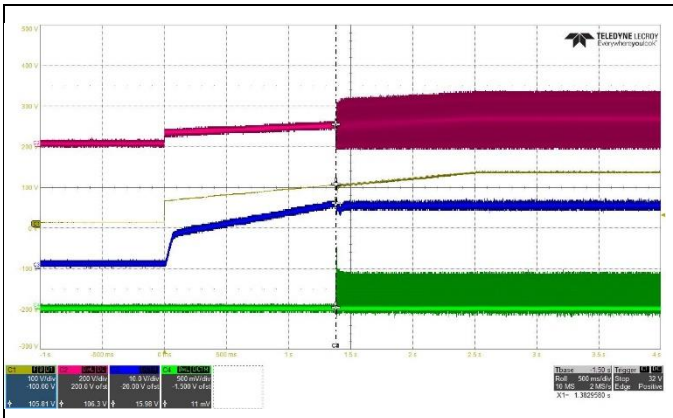
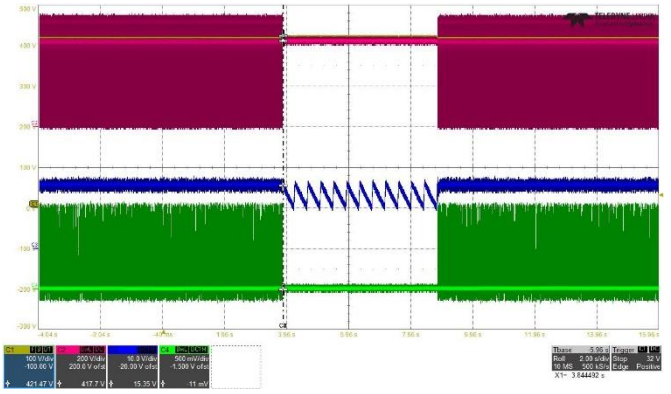
	
C1 (yellow) : Bulk voltage (V_{BULK}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : VCC voltage (V_{VCC}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Bulk voltage (V_{BULK}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : VCC voltage (V_{VCC}) C4 (green) : CS voltage (V_{CS})
Brown-in at V_{BULK} more 106 V	LOVP at V_{BULK} more 420 V

Figure 25 Brown-in protection and LOVP

References

[1] Infineon Technologies AG: *ICE5AR4770AG Fixed Frequency 700 V/800 V CoolSET™ - in DSO-12 Package*; Available online

[2] Infineon Technologies AG: *ICE5AR4770AG-1 datasheet*

[3] Infineon Technologies AG: *Fifth-generation FF design guide*

[4] Infineon Technologies AG: *Calculation Tool Fixed-frequency CoolSET™ Generation 5*

Revision history

Document revision	Date	Description of changes
V 1.0	2025-05-28	Initial release

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