6 W auxiliary power supply using ICE5GR4780AG

REF_5GR4780AG_6W1

About this document

Scope and purpose

This document is an engineering report that describes a 6 W (12 V, 500 mA) isolated flyback converter using the fifth-generation Infineon Fixed-Frequency (FF) CoolSET™ ICE5GR4780AG. The document contains power supply specification, schematic, bill-of-material, PCB layout, and performance data. This reference board is designed for users who wish to evaluate the performance of ICE5GR4780AG and its ease of use.

Intended audience

The intended audiences for this document are SMPS design/application engineers, students, etc., who wish to design low-cost and isolated flyback converter, such as auxiliary power supplies for white goods, smart metering etc.

Table of contents

1 Introduction

This engineering report describes a 6 W (12 V, 500 mA) reference board designed in an isolated flyback converter topology using the fifth-generation FF CoolSET™ ICE5GR4780AG. The target applications of ICE5GR4780AG are either auxiliary power supplies for white goods, PCs, servers or TVs, or enclosed adapters for Blu-ray players, set-top boxes, gaming consoles, smart metering etc. With the 800 V CoolMOS™ integrated into this IC, it greatly simplifies the design and layout of the PCB. The new improved digital 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 ICE5GR4780AG to protect the system and customize the IC for the chosen application.

2 Reference board

This document contains the list of features, the power-supply specifications, schematics, bill of materials (BOM), and performance data. Typical operating characteristics such as performance curve and scope waveforms are shown at the end of the report.

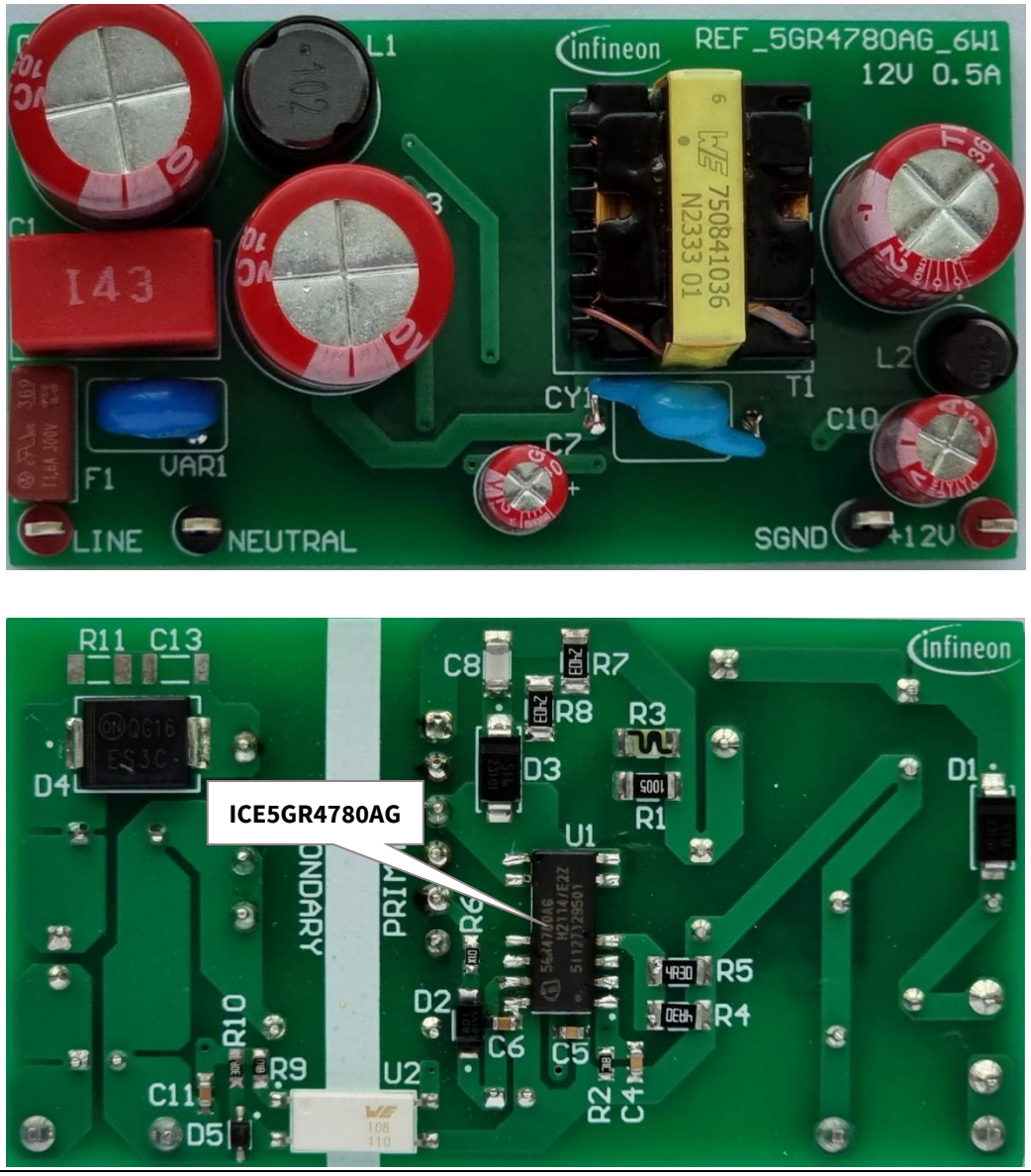


Figure 1 REF_5GR4780AG_6W1

3 Specifications of reference board

Table 1 Specifications of REF_5GR4780AG_6W1

Description	Symbol	Min.	Typ.	Max.	Unit	Comments
Input Voltage Frequency No load input power	 V_{IN} f_{LINE} P_{stby_NL}	 85 47	 50/60	 264 63 50	 V AC Hz mW	 2-wire (no P.E.)
Output Voltage Current Output power	 V_{out} I_{out} P_{out}	 	 12 	 0.5 6	 V A W	
Output voltage accuracy		< ±5%			%	
Over current protection		< 175% 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
Efficiency Full load Average (25%, 50%, 75%, and 100%)	 η_{FL} η_{ave}	 82 81	 	 	 % %	 115 V AC/ 230 V AC 115 V AC/ 230 V AC
Environmental Conducted EMI ESD • Contact discharge • Air discharge Surge immunity • Differential Mode • Common Mode	 	 6 ± 6 ± 8 ± 1 ± 2	 	 	 dB kV kV kV kV	 Margin, CISPR 22 Class B EN 61000-4-2 EN 61000-4-5
Ambient temperature	T_{amb}	–20	–	50	°C	Free convection, sea level
PCB form factor		65 × 35 × 25			mm	L × W × H

Note: The table 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 Circuit diagram

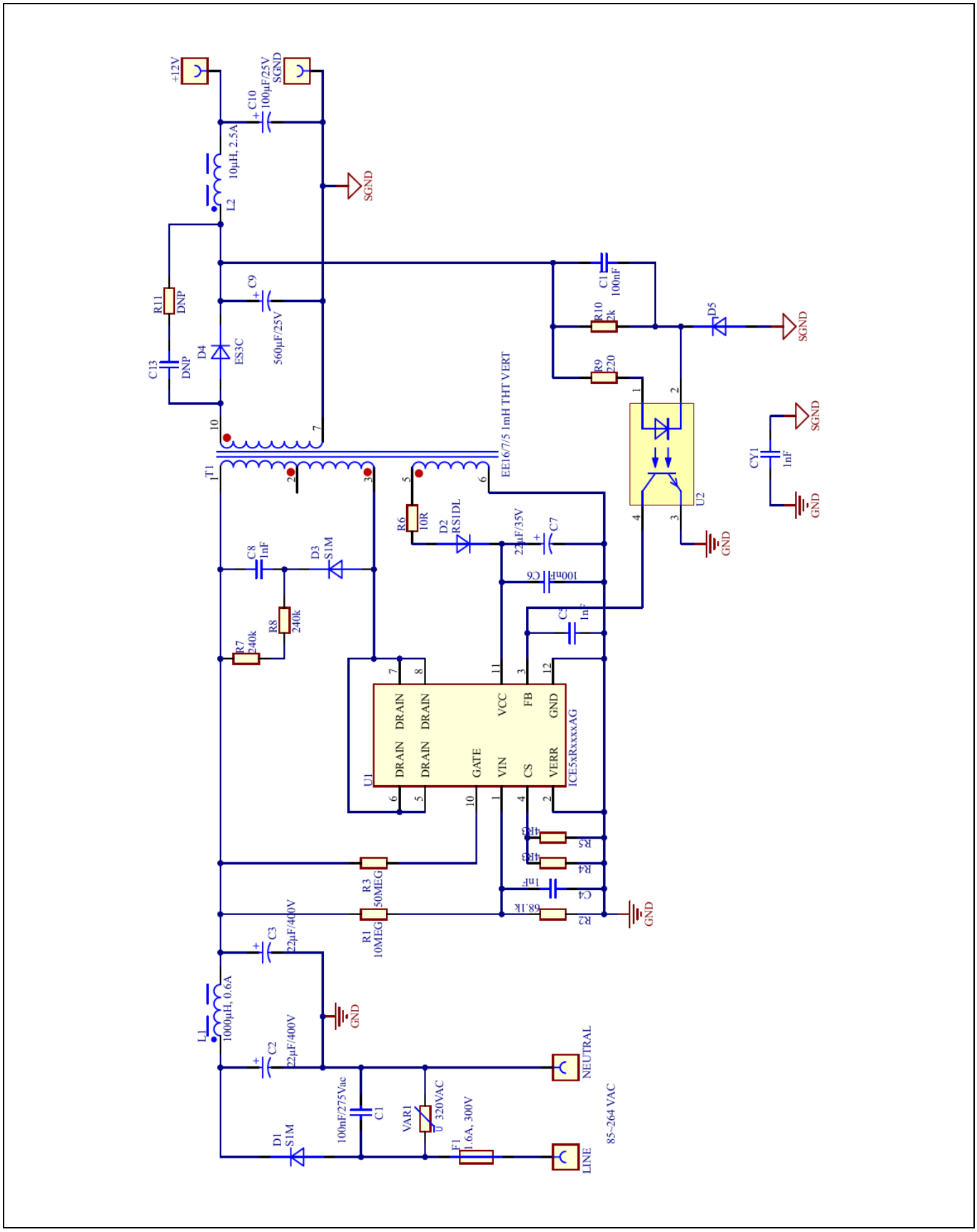


Figure 2 Schematic of REF_5GR4780AG_6W1

5 Circuit description

5.1 Line input

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

- Input fuse F1
- Varistor VAR1
- X-capacitor C1
- Rectifier diode D1
- Capacitors C2 and C3
- Inductor L1

The X-capacitor C1 and π-filter C2, L1, and C3 act as EMI suppressors.

5.2 Start-up

ICE5GR4780AG uses a cascode structure to fast-charge the V_{CC} capacitor. The pull-up resistor R3 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 ICE5GR4780AG 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

ICE5GR4780AG comprises of a power MOSFET and a 125 kHz fixed-frequency PWM controller with frequency reduction from medium to light load. The frequency jittering feature is implemented to enable higher average efficiency and low EMI. Active Burst Mode (ABM) is also implemented to achieve a very low standby input power. The PWM switch-on is determined by the 125 kHz fixed frequency and the PWM switch-off is determined by the feedback signal VFB and the current sensing signal V_{CS} via resistors R4 and R5. ICE5GR4780AG also performs all necessary protection functions including VCC overvoltage and undervoltage, overload, output overvoltage, overtemperature (controller junction) and VCC 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 (R7, R8, C8, and D3) dissipates the energy of the leakage inductance and suppress ringing on the SMPS transformer.

5.5 Output stage

This has a single isolated 12 V output converter. It is rectified by an ultrafast diode D4. The low ESR capacitor C9 provides energy buffering and is followed by the L-C filter L2-C10 to reduce the output voltage ripple.

5.6 Feedback control

For cost down consideration, the system uses a simple Zener diode D5 coupled with an optocoupler U2 connected to FB pin of the ICE5GR4780AG for output voltage control.

6 PCB layout

6.1 Top side

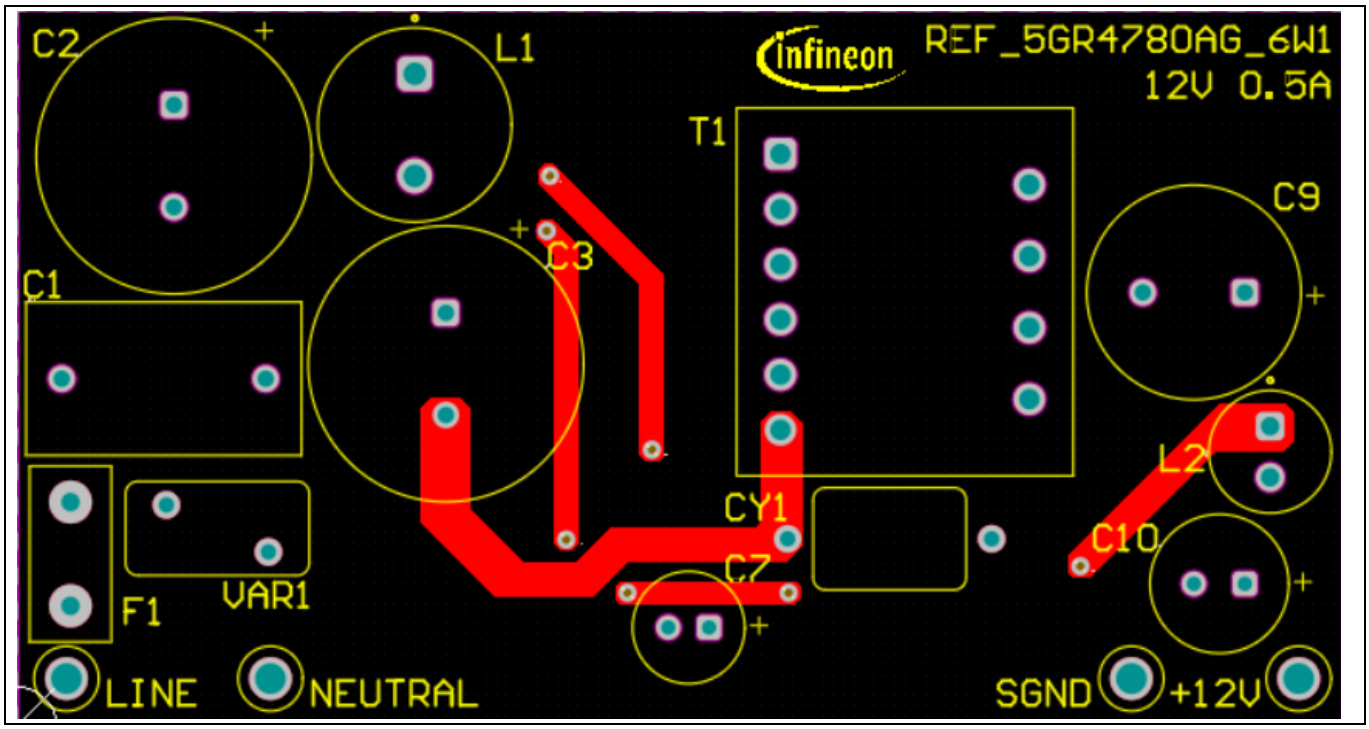


Figure 3 Top-side copper and component legend

6.2 Bottom side

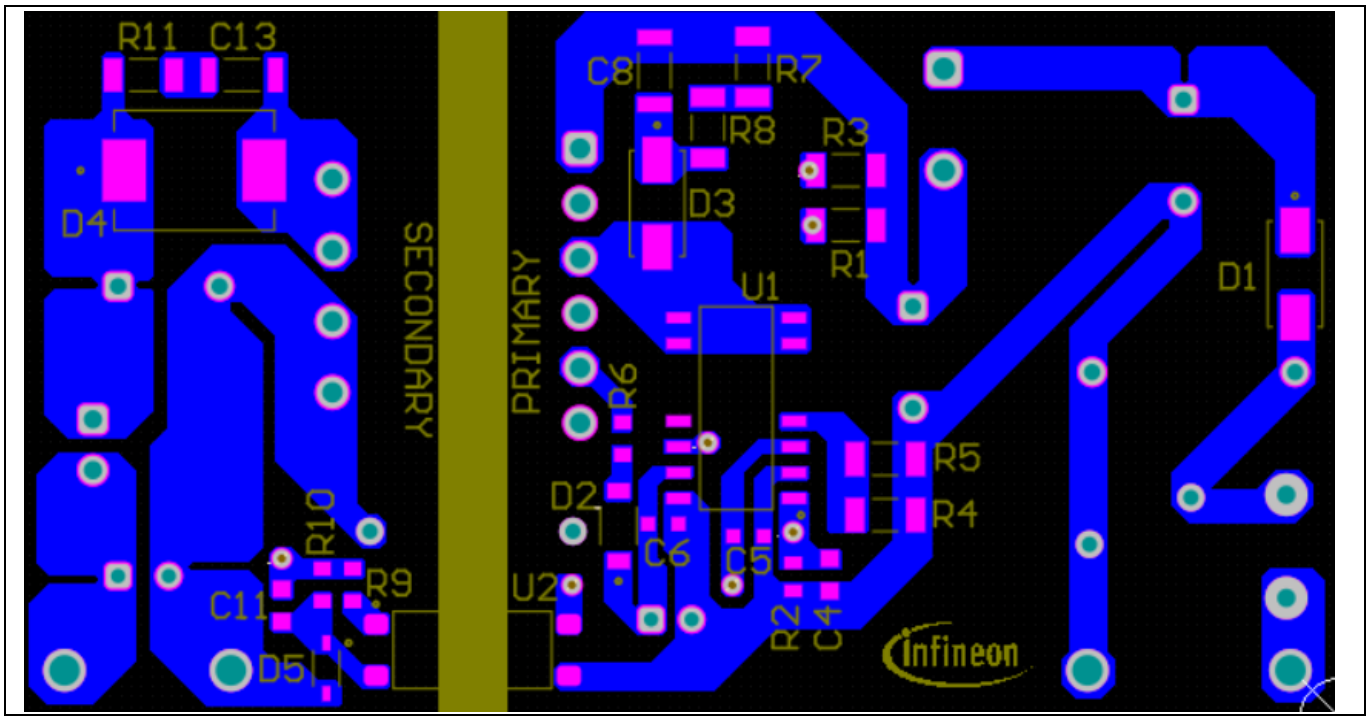


Figure 4 Bottom-side copper and component legend

7 Bill of materials

Table 2 BOM

No.	Designator	Description	Part number	Manufacturer	Quantity
1	C1	CAP FILM 0.1 µF 10% 275 VAC RADIAL	890324023023	Würth Elektronik	1
2	C2,C3	CAP ALUM 22 µF 20% 400 V RADIAL	860021378013	Würth Elektronik	2
3	C4, C5	CAP CER 1 nF 50 V X7R 0603			2
4	C6, C11	CAP CER 0.1 µF 50 V X7R 0603			2
5	C7	CAP ALUM 22 UF 20% 35 V RADIAL	860020572004	Würth Elektronik	1
6	C8	CAP CER 1 nF 500 V X7R 1206			1
7	C9	CAP ALUM 560 µF 20% 25 V RADIAL	860080475017	Würth Elektronik	1
8	C10	CAP ALUM 100 µF 20% 25 V RADIAL	860080473006	Würth Elektronik	1
9	CY1	CAP CER 1000 pF 250 V RADIAL	DE1E3KX102MA4BN01F		1
10	D1, D3	DIODE GEN PURP 1 KV 1A SMA	S1M		2
11	D2	DIODE GEN PURP 200 V 0.8 A SOD123	RS1DL		1
12	D4	DIODE GEN PURP 150 V 3 A SMC	ES3C		1
13	D5	DIODE ZNR 11 V 0.3 W SOD323	MM3Z11VST1G		1
14	F1	TIME LAG FUSE 300 V 1.6 A	36911600000	Littelfuse	1
15	L1	INDUCTOR 1 mH 0.6 A RADIAL	7447452102	Würth Elektronik	1
16	L2	INDUCTOR 10 µH 2.5 A RADIAL	7447462100	Würth Elektronik	1
17	R1	RES SMD 10 MΩ 1% 0.25 W 1206	LHVC1206-10MFT5		1
18	R2	RES SMD 68.1 kΩ 1% 0.1 W 0603			1
19	R3	RES SMD 50 MΩ 1% 0.25 W 1206	CRHV1206AF50M0FKFT	Vishay	1
20	R4, R5	RES SMD 4.3 Ω 1% 0.25 W 1206			2
21	R6	RES SMD 10 Ω 1% 0.1 W 0603			1
22	R7, R8	RES SMD 240 kΩ 1% 0.25 W 1206			2
23	R9	RES SMD 220 Ω 1% 0.1 W 0603			1
24	R10	RES SMD 2 kΩ 1% 0.1 W 0603			1
25	T1	EE16/7/5 1 mH THT VERTICAL		Würth Elektronik	1
26	U1	800 V FF CoolSET™	ICE5GR4780AG	Infineon	1
27	U2	OPTOCOUPLER	140108146000	Würth Elektronik	1
28	VAR1	S07K320E2 320 VAC 10%	B72207S2321K101	TDK Electronics	1
29	LINE, +12 V	CONNECTOR RED	5010	Keystone	2
30	NEUTRAL, SGND	CONNECTOR BLACK	5011	Keystone	2

8 Transformer construction

- Core and material: 150-2115 (EE16/7/5, TP4A)
- Bobbin: 070-5278 (10 Pin, THT, vertical version)
- Primary Inductance: Lp=1000 µH (±10%), measured between pin 1 and pin 3
- Manufacturer and part number: Würth Elektronik Midcom (750841036 Rev 01)

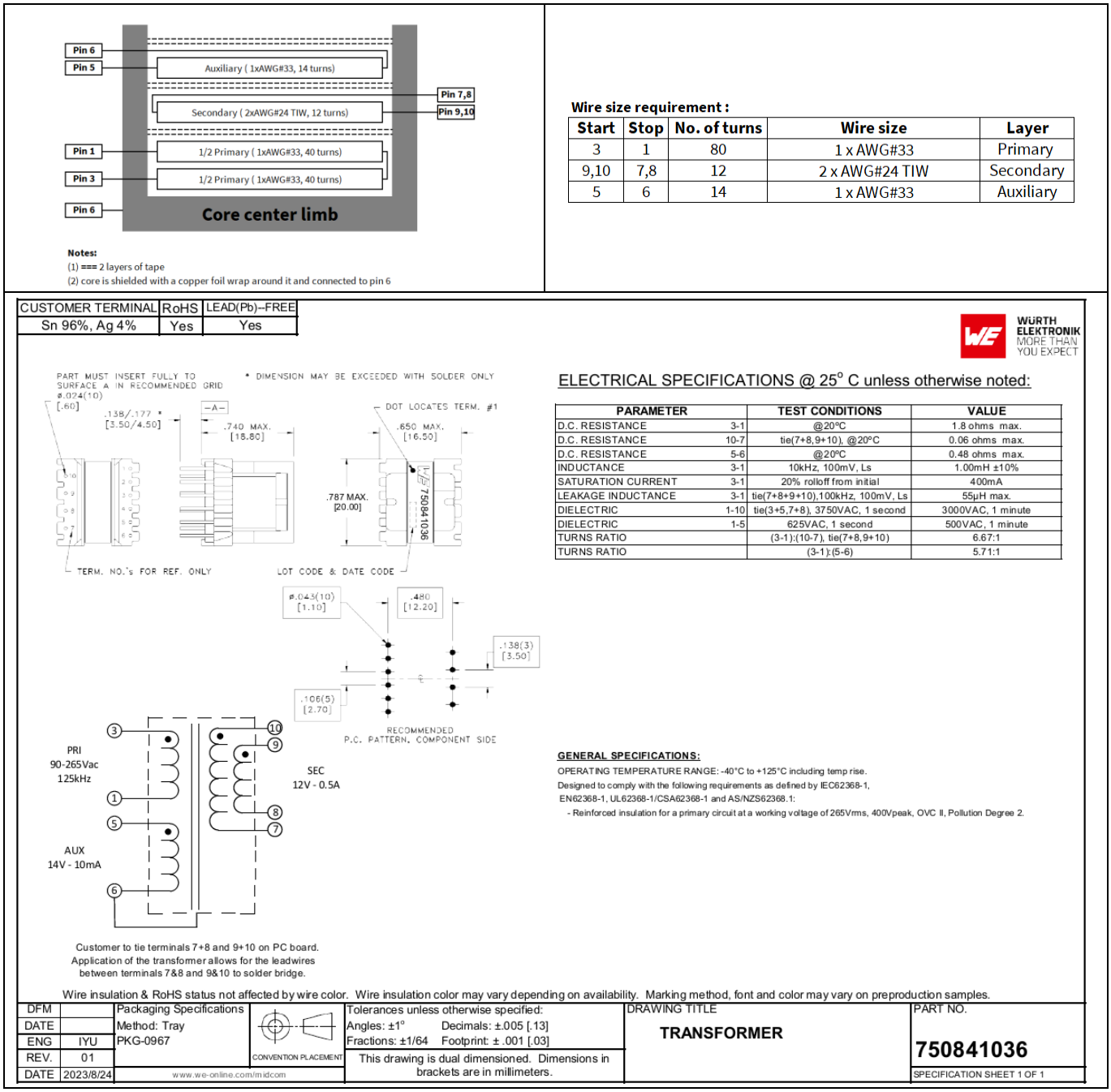


Figure 5 Transformer structure

9 Test results

9.1 Efficiency

Table 3 Efficiency

Input (V AC/Hz)	Load percentage (%)	Pin (W)	Vo (V DC)	Io (A)	Pout (W)	Efficiency η (%)	Average η (%)
85 V AC/60 Hz	No load	0.024	12.316	0.000			
	10% load	0.791	12.355	0.050	0.62	78.10%	
	25% load	1.880	12.350	0.125	1.54	82.11%	82.90%
	50% load	3.710	12.335	0.250	3.08	83.12%	
	75% load	5.548	12.311	0.375	4.62	83.21%	
	100% load	7.382	12.279	0.500	6.14	83.17%	
115 V AC/60 Hz	No load	0.025	12.314	0.000			
	10% load	0.800	12.355	0.050	0.62	77.22%	
	25% load	1.887	12.349	0.125	1.54	81.80%	83.02%
	50% load	3.710	12.331	0.250	3.08	83.09%	
	75% load	5.519	12.307	0.375	4.62	83.62%	
	100% load	7.349	12.279	0.500	6.14	83.54%	
230 V AC/50 Hz	No load	0.040	12.330	0.000			
	10% load	0.879	12.374	0.050	0.62	70.39%	
	25% load	1.968	12.361	0.125	1.55	78.51%	81.05%
	50% load	3.777	12.347	0.250	3.09	81.72%	
	75% load	5.655	12.325	0.375	4.62	81.73%	
	100% load	7.477	12.294	0.500	6.15	82.21%	
264 V AC/50 Hz	No load	0.047	12.330	0.000			
	10% load	0.914	12.378	0.050	0.62	67.71%	
	25% load	2.003	12.367	0.125	1.55	77.18%	79.70%
	50% load	3.875	12.354	0.250	3.09	79.70%	
	75% load	5.740	12.330	0.375	4.62	80.55%	
	100% load	7.557	12.297	0.500	6.15	81.36%	

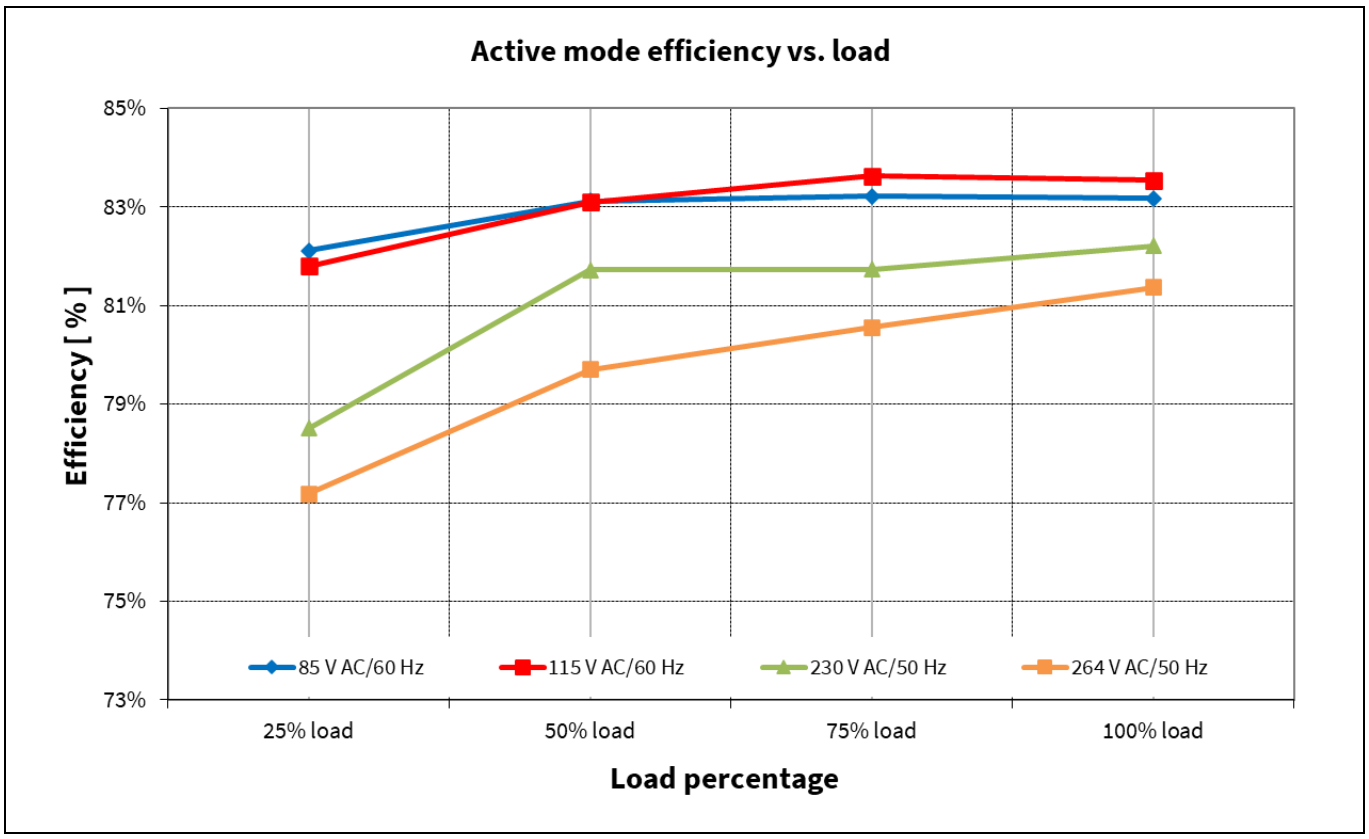


Figure 6 Efficiency vs. AC-line input voltage

9.2 Standby power

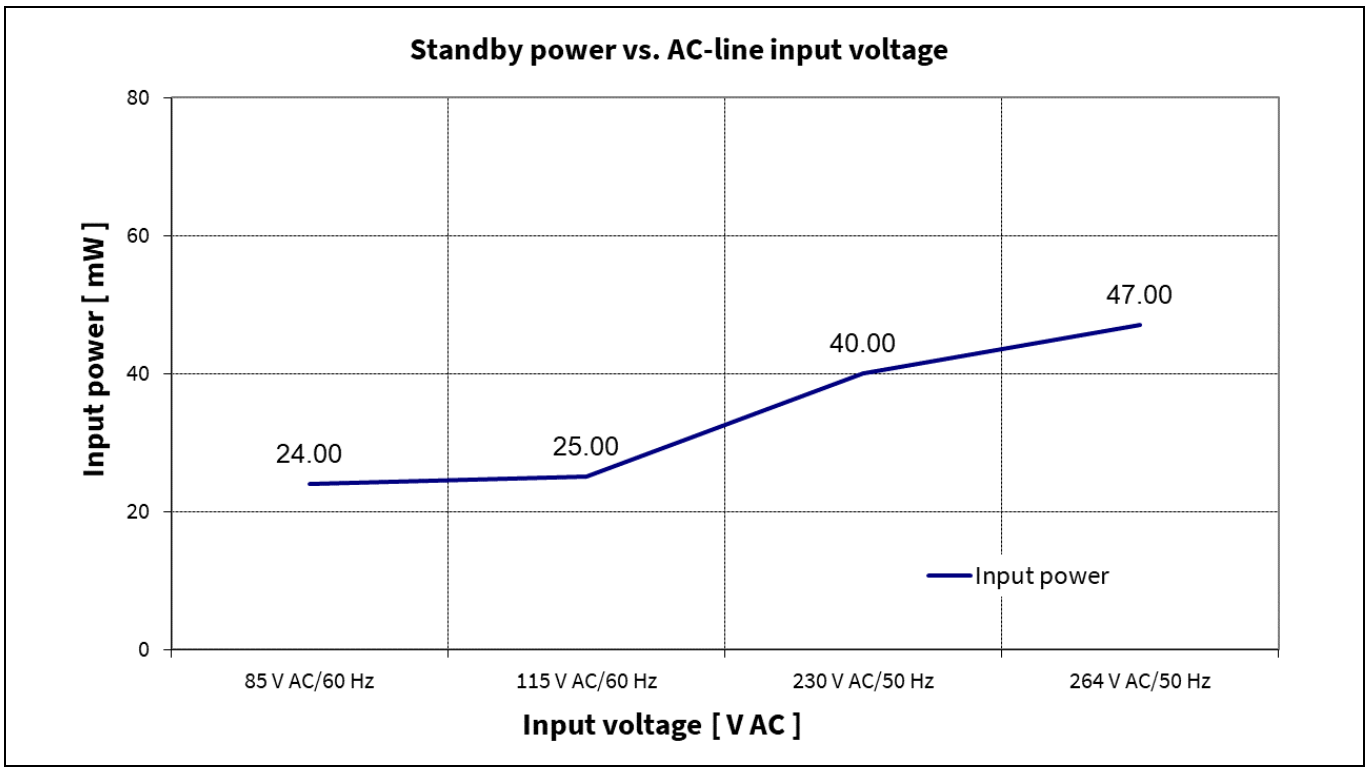


Figure 7 Standby power vs. AC-line input voltage

9.3 Line and load regulation

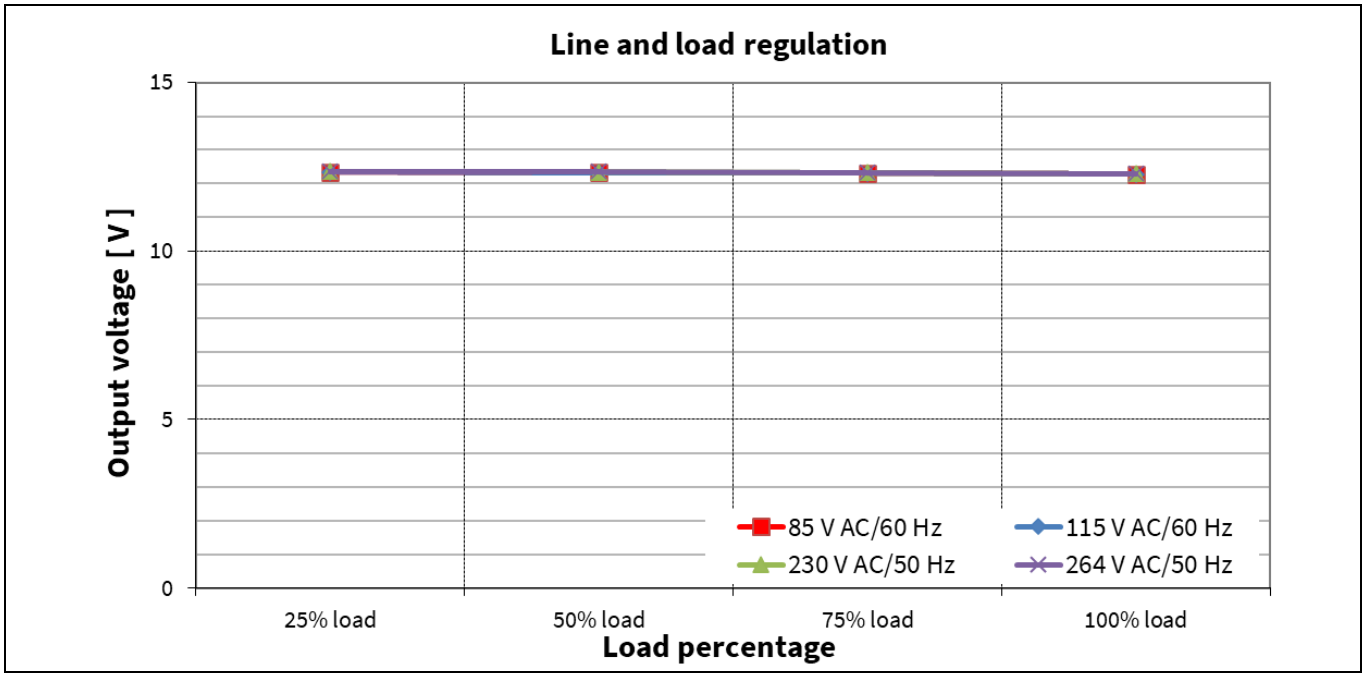


Figure 8 Line and load regulation

9.4 Maximum input power

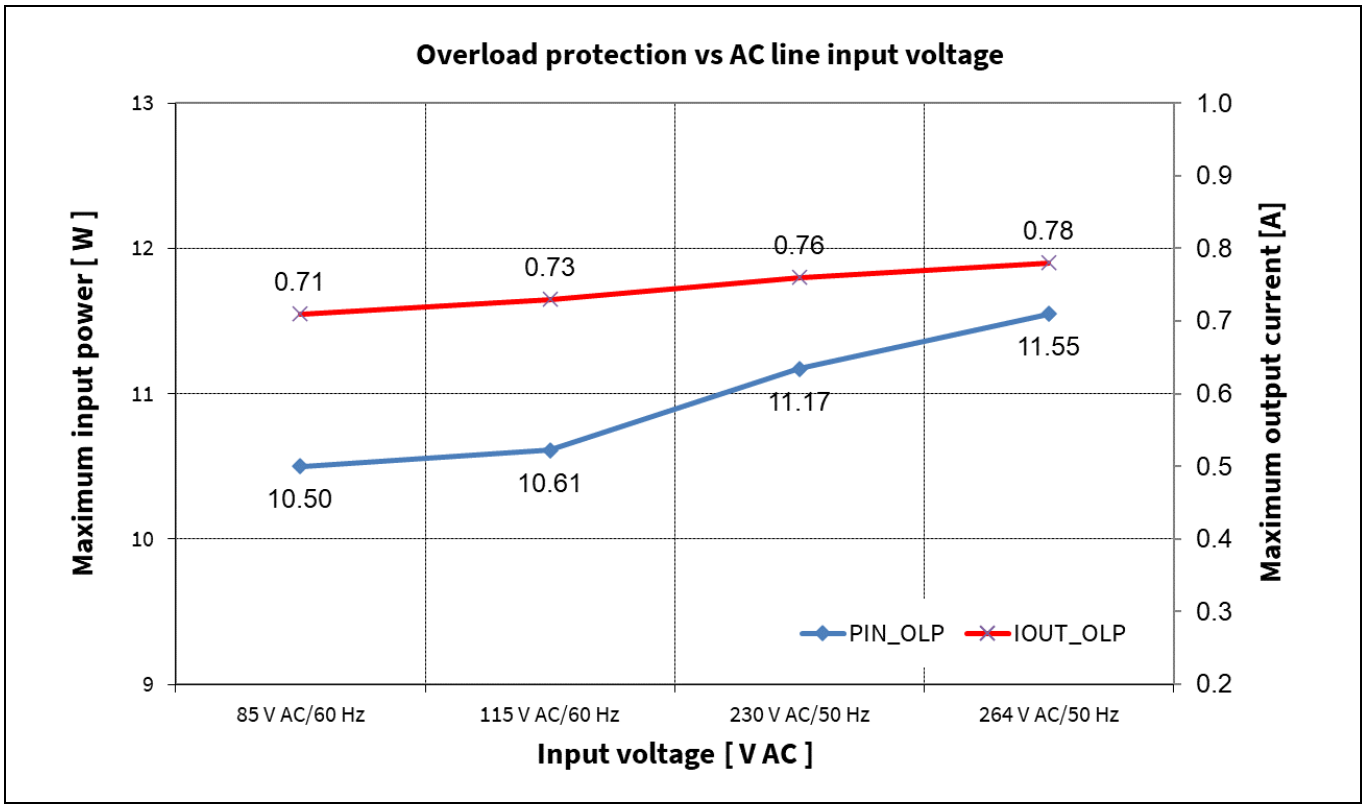


Figure 9 Maximum input power and maximum output current vs. AC line input voltage

9.5 ESD immunity (EN61000-4-2)

This system was subjected to level 3 ESD test according to EN 61000-4-2 (±6 kV contact and ±8 kV air discharge). A test failure was defined as non-recoverable.

- Contact discharge: pass ±6 kV; air discharge: pass ±8 kV.

Table 4 System ESD test result

Description	ESD test	Level	Number of strikes		Test result
			$+V_{OUT}$	$-V_{OUT}$	
115 V AC, 6 W (12 V/24 Ω)	Contact	+6 kV	10	10	PASS
		-6 kV	10	10	PASS
	Air	+8 kV	10	10	PASS
		-8 kV	10	10	PASS
230 V AC, 6 W (12 V/24 Ω)	Contact	+6 kV	10	10	PASS
		-6 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 (±1 kV DM and ±2 kV CM) according to EN 61000-4-5. A test failure was defined as a non-recoverable.

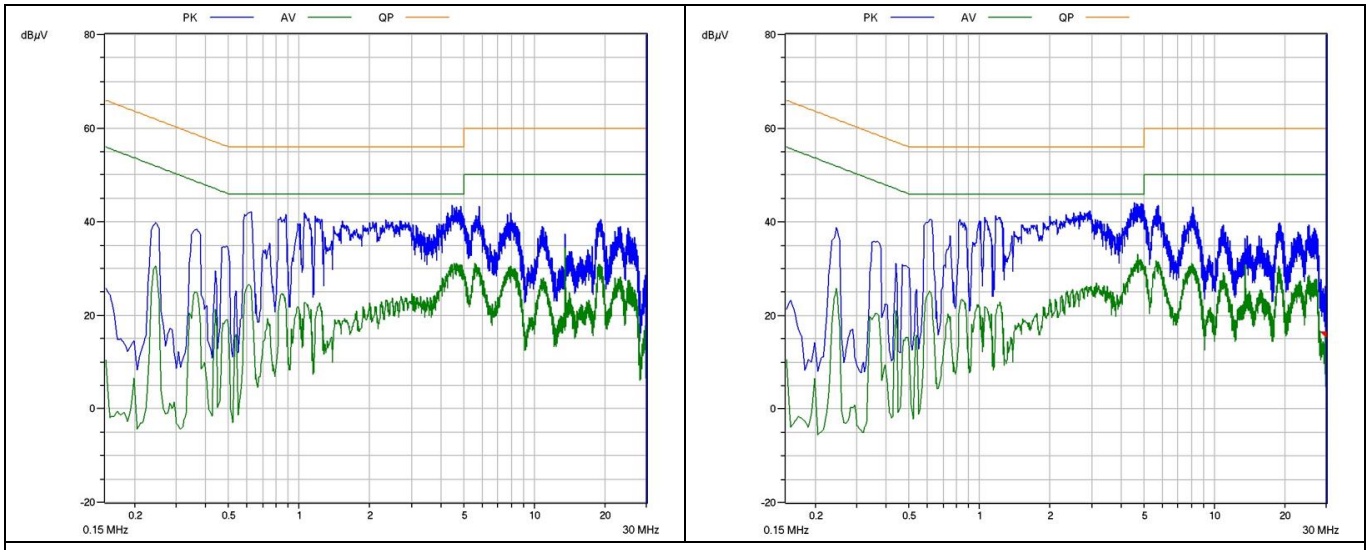
- DM: pass ±1 kV; CM: pass ±2 kV

Table 5 System surge immunity test result

Description	Test	Level		Number of strikes				Test result
				0°	90°	180°	270°	
115 V AC, 6 W (12 V/24 Ω)	DM	+1 kV	L → N	3	3	3	3	PASS
		-1 kV	L → N	3	3	3	3	PASS
	CM	+2 kV	L → G	3	3	3	3	PASS
		+2 kV	N → G	3	3	3	3	PASS
		-2 kV	L → G	3	3	3	3	PASS
		-2 kV	N → G	3	3	3	3	PASS
230 V AC, 6 W (12 V/24 Ω)	DM	+1 kV	L → N	3	3	3	3	PASS
		-1 kV	L → N	3	3	3	3	PASS
	CM	+2 kV	L → G	3	3	3	3	PASS
		+2 kV	N → G	3	3	3	3	PASS
		-2 kV	L → G	3	3	3	3	PASS
		-2 kV	N → G	3	3	3	3	PASS

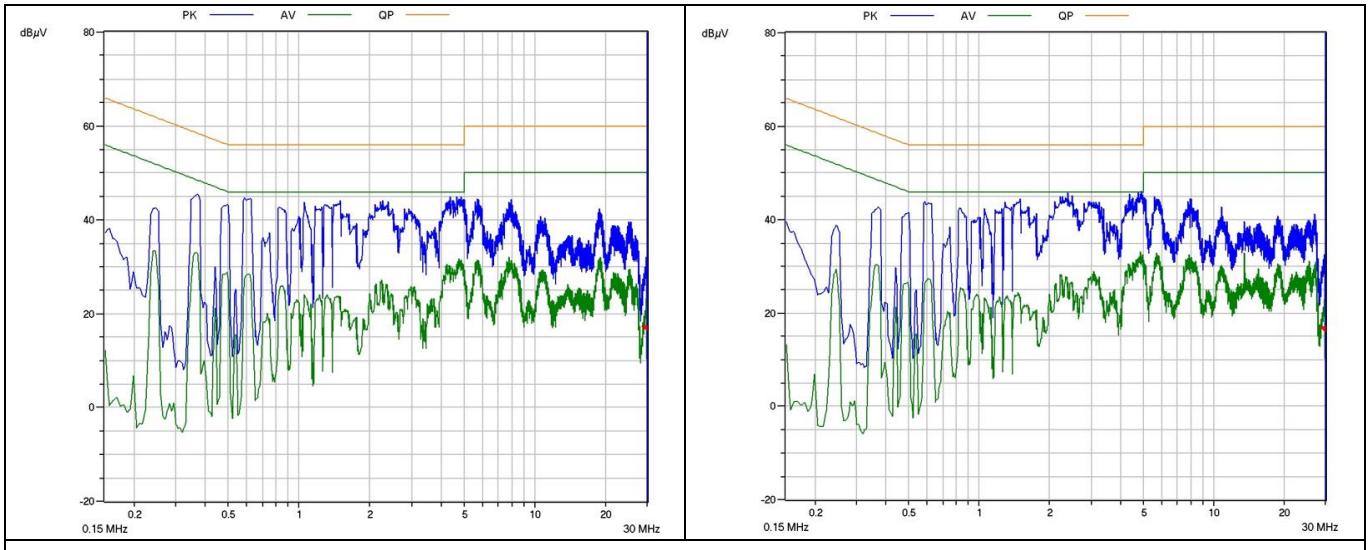
9.7 Conducted emissions (EN 55022 class B)

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 (24 Ω) with input voltage of 115 V AC and 230 V AC.



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



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	T1 (Transformer)	50.6	56.0
2	L1 (Input filter inductor)	34.0	32.5
3	D4 (Output rectifier diode)	55.1	55.9
4	U1 (ICE5GR4780AG)	49.4	61.4
5	D1 (Input rectifier diode)	36.1	31.3

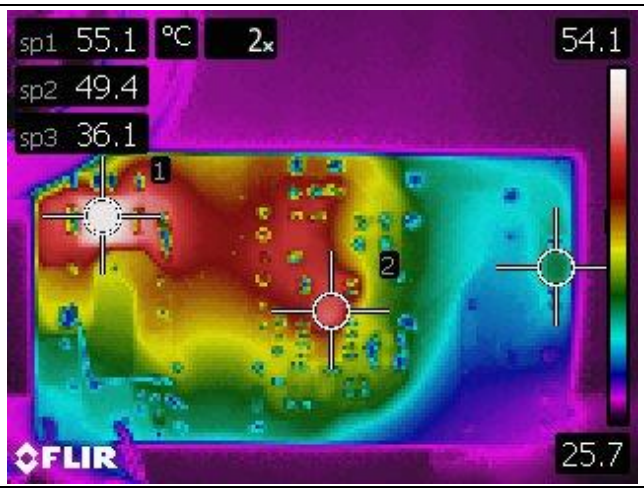
Top side	Bottom side
	

Figure 12 Infrared thermal image of REF_5GR4780AG_6W1 at 85 V AC

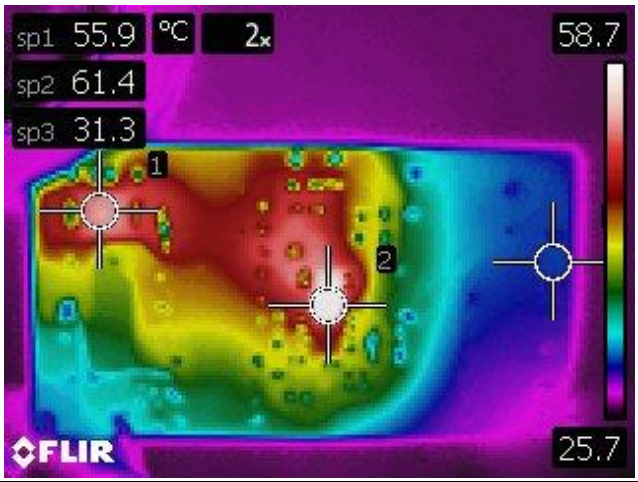
Top side	Bottom side
	

Figure 13 Infrared thermal image of REF_5GR4780AG_6W1 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

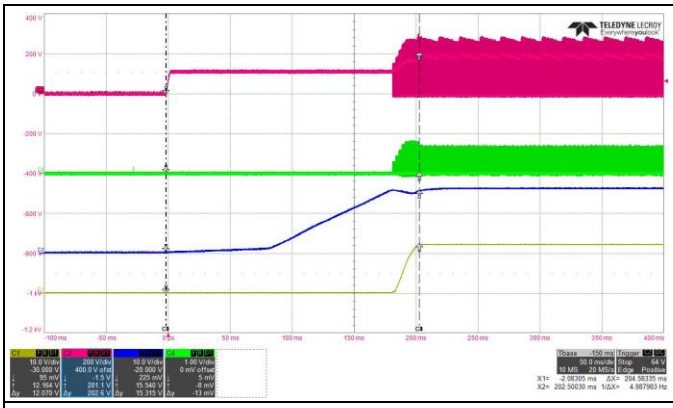
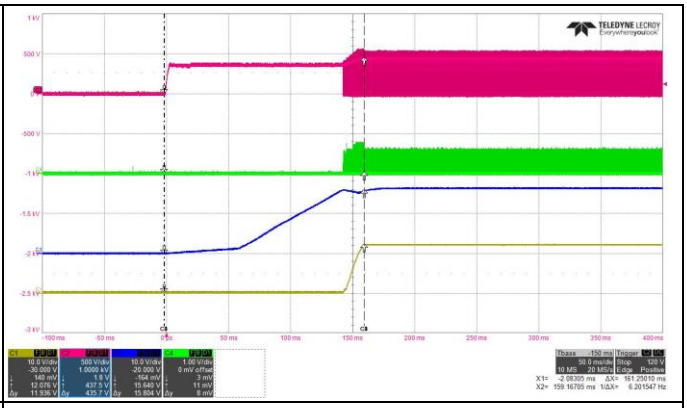
	
C1 (yellow) : 12 V output voltage (V_{out}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : VCC voltage (V_{CC}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : 12 V output voltage (V_{out}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : VCC voltage (V_{CC}) C4 (green) : CS voltage (V_{CS})
Start-up time at 85 V AC and maximum load ≈ 205 ms	Start-up time at 264 V AC and maximum load ≈ 161 ms

Figure 14 Start-up

10.2 Soft-start

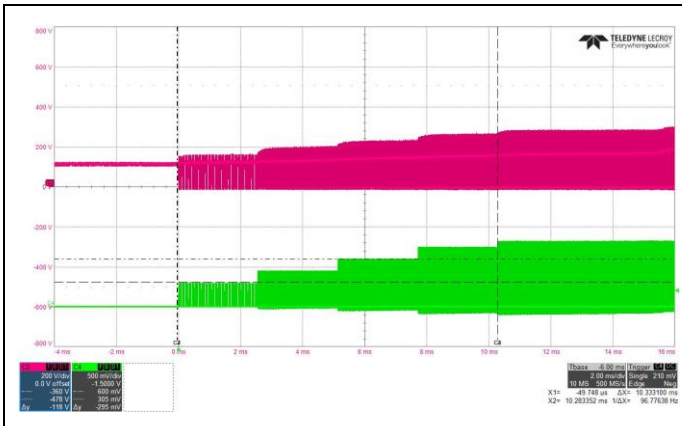
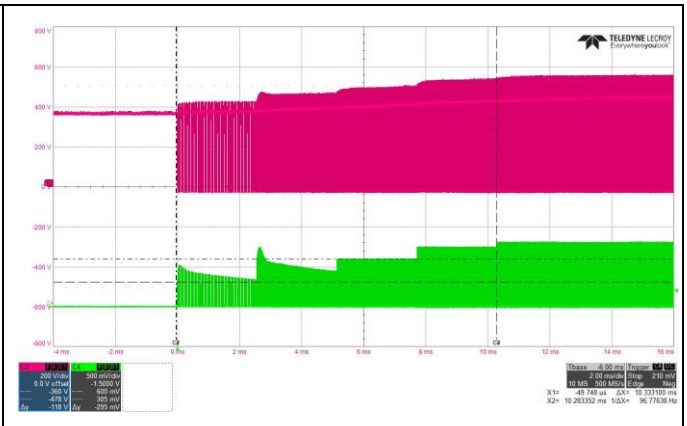
	
C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})	C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})
Soft-start time at 85 V AC and maximum load ≈ 10 ms	Soft-start time at 264 V AC and maximum load ≈ 10 ms

Figure 15 Soft-start

10.3 Drain and CS voltage at maximum load

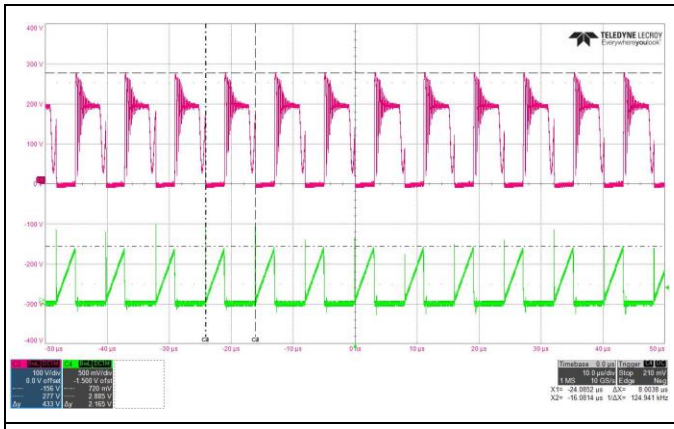
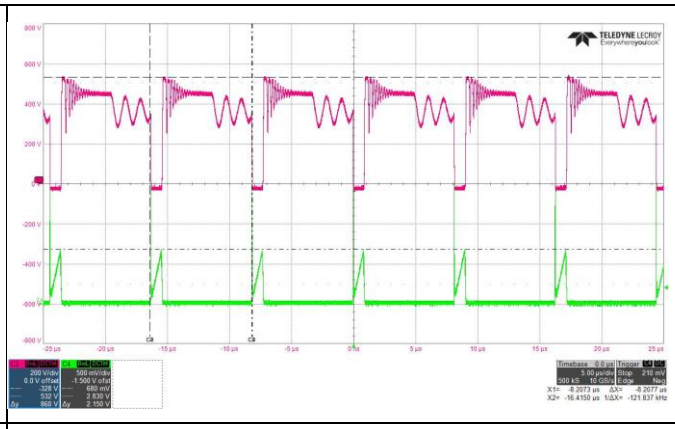
	
C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})	C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})
V_{Drain_peak} at 85 V AC ≈ 277 V V_{CS_peak} at 85 V AC ≈ 720 mA	V_{Drain_peak} at 264 V AC ≈ 532 V V_{CS_peak} at 264 V AC ≈ 680 mA

Figure 16 Drain and CS voltage at maximum load

10.4 Output ripple voltage at maximum load

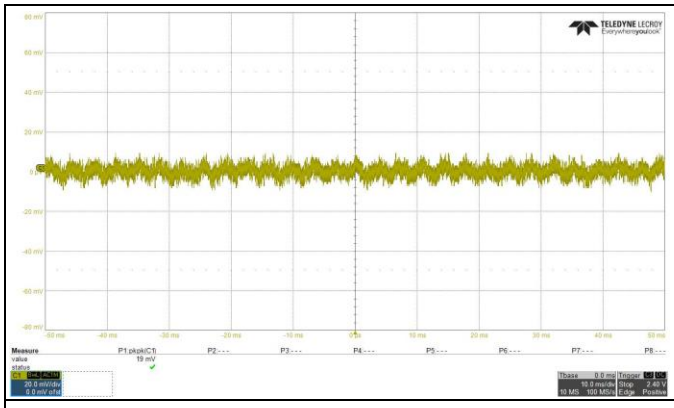
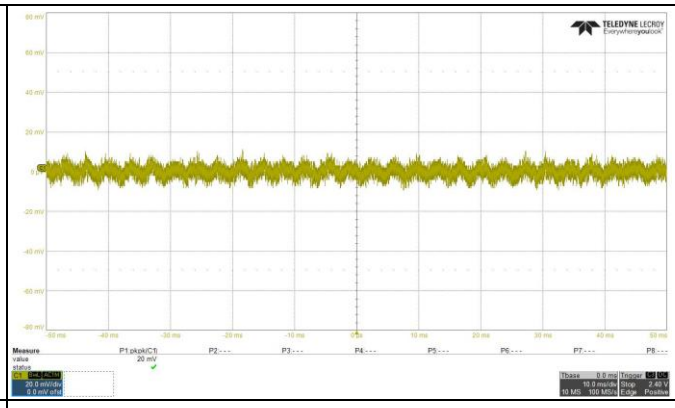
	
C1 (yellow) : 12 V output ripple voltage (V_{out})	C1 (yellow) : 12 V output ripple voltage (V_{out})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 19 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW	12 $V_{ripple\_pk\_pk}$ at 264 V AC ≈ 20 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW

Figure 17 Output ripple voltage at maximum load

10.5 Output ripple voltage at ABM

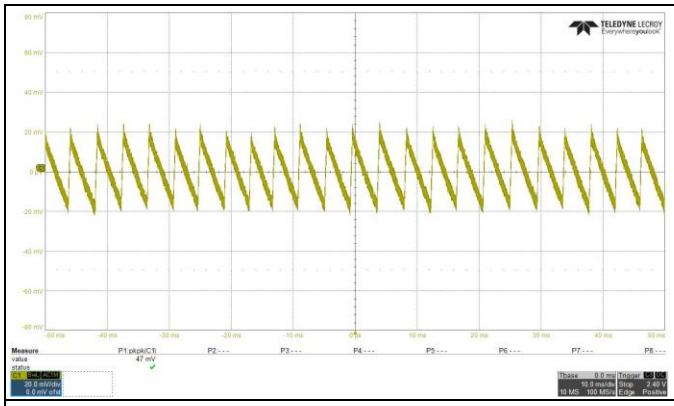
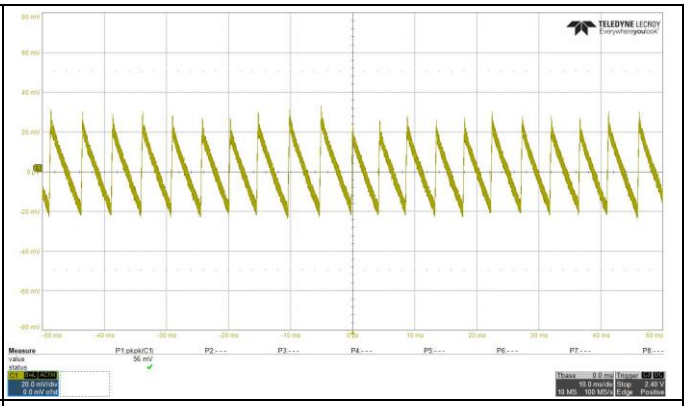
	
C1 (yellow) : 12 V output ripple voltage (V_{out})	C1 (yellow) : 12 V output ripple voltage (V_{out})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 47 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW	12 $V_{ripple\_pk\_pk}$ at 264 V AC ≈ 56 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW

Figure 18 Output ripple voltage at ABM (5 mA load)

10.6 Load transient response (Dynamic load from 10% to 100%)

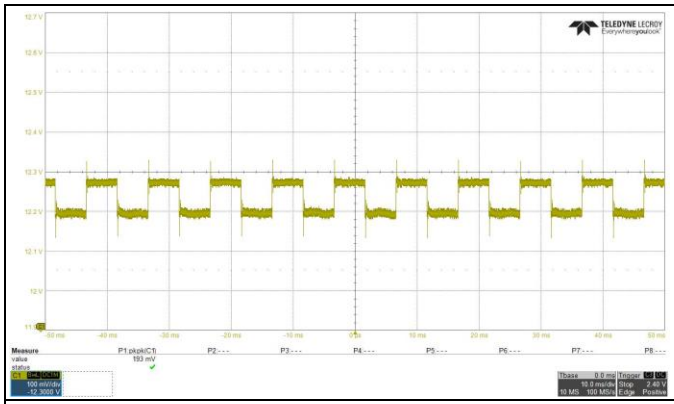
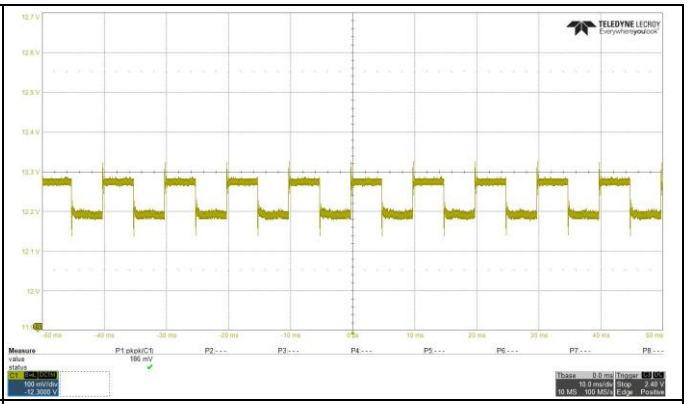
	
C1 (yellow) : 12 V output ripple voltage (V_{out})	C1 (yellow) : 12 V output ripple voltage (V_{out})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 193 mV (Load change from 10% to 100% at 85 V AC, 100 Hz, 0.8 A/µs slew rate) Probe terminal end with decoupling capacitor of 0.1 µF(ceramic) and 1 µF(Electrolytic), 20 MHz filter	12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 186 mV (Load change from 10% to 100% at 264 V AC, 100 Hz, 0.8 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

10.7 ABM operation

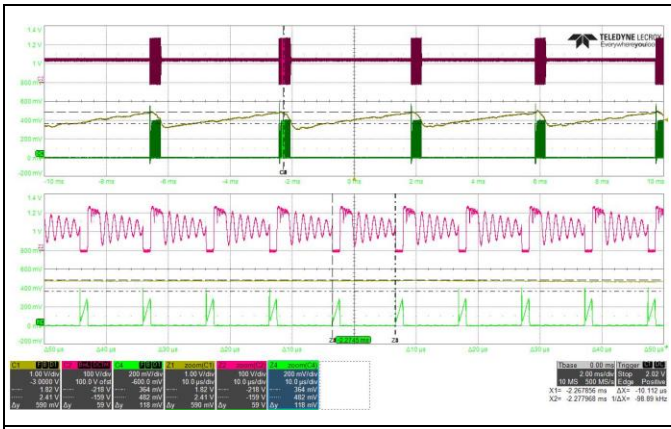
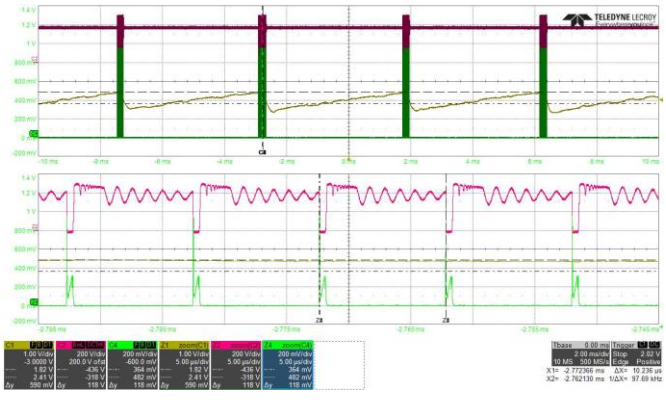
	
C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})
85 V AC, 5 mA load Operation at f_{osc2_ABM} = 100 kHz, I_{PK} = 290 mA, V_{FB_ON} = 2.4 V, V_{FB_OFF} = 1.9 V	264 V AC, 5 mA load Operation at f_{osc2_ABM} = 100 kHz, I_{PK} = 290 mA, V_{FB_ON} = 2.4 V, V_{FB_OFF} = 1.9 V

Figure 20 ABM operation

10.8 Overload protection (odd-skip auto-restart)

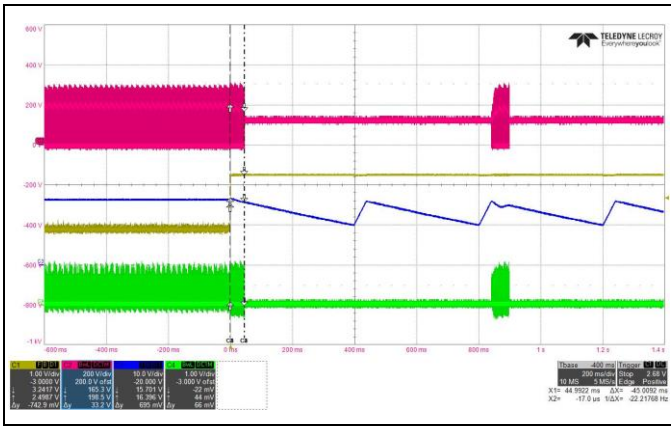
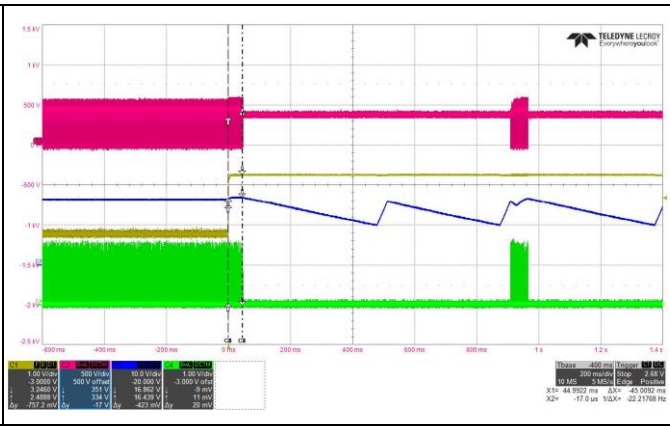
	
C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : VCC voltage (V_{VCC}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : FB voltage (V_{FB}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : VCC voltage (V_{VCC}) C4 (green) : CS voltage (V_{CS})
Condition to enter overload protection: V_{FB} more than 2.75 V and lasts for ~55 ms blanking time. 12 V output load change from full load to overload (0.8 A).	

Figure 21 Overload protection

References

[1] Infineon Technologies AG: *ICE5xRxxxxAG datasheet*; Available online

[2] Infineon Technologies AG: *Design guide 5th generation fixed-frequency ICE5xSAG and ICE5xRxxxxAG*; Available online

[3] Infineon Technologies AG: *Calculation tool - ICE5xSAG and ICE5xRxxxxAG*; Available online

Revision history

Document revision	Date	Description of changes
V 1.0	2023-12-13	Initial release

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