40 W auxiliary SMPS for refrigerator using CoolSET™ ICE5QR0680BG

REF_5QR0680BG_40W1

About this document

Scope and purpose

This document describes a 40 W high-efficiency auxiliary SMPS for refrigerator with the fifth-generation quasi-resonant (QR) CoolSET™ ICE5QR0680BG PWM controller from Infineon.

This reference board is designed with a universal input compatible with most geographic regions and three outputs (isolated 12 V/3.1 A, 5 V/0.2 A, and non-isolated 15 V/0.15 A) as typically used in most home appliances.

Intended audience

This document is intended for SMPS design/application engineers, students, etc., who want to design an auxiliary power supply for refrigerators and other home appliances that are efficient, reliable, and easy-to-design.

Table of contents

1 Introduction

With the growing household trend for smart devices, the new generation of home appliances such as refrigerators are equipped with advanced features that often include communication capability, such as wireless communication, touchscreen display, and sensors. These will transform a static product into an interactive and intelligent home appliance, capable of adapting to the smart-home theme. Infineon has introduced the fifth-generation QR CoolSET™ to address this need in an efficient and cost-effective manner.

An auxiliary SMPS is needed to power the various modules and sensors, which typically operate from a stable DC voltage source. CoolSET™ PWM controller from Infineon forms the heart of the system, providing the necessary protection and AC-DC conversion from the mains to multiple regulated DC voltages to power the various blocks.

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 curves and scope waveforms are shown at the end of the report.

1.1 Reference board

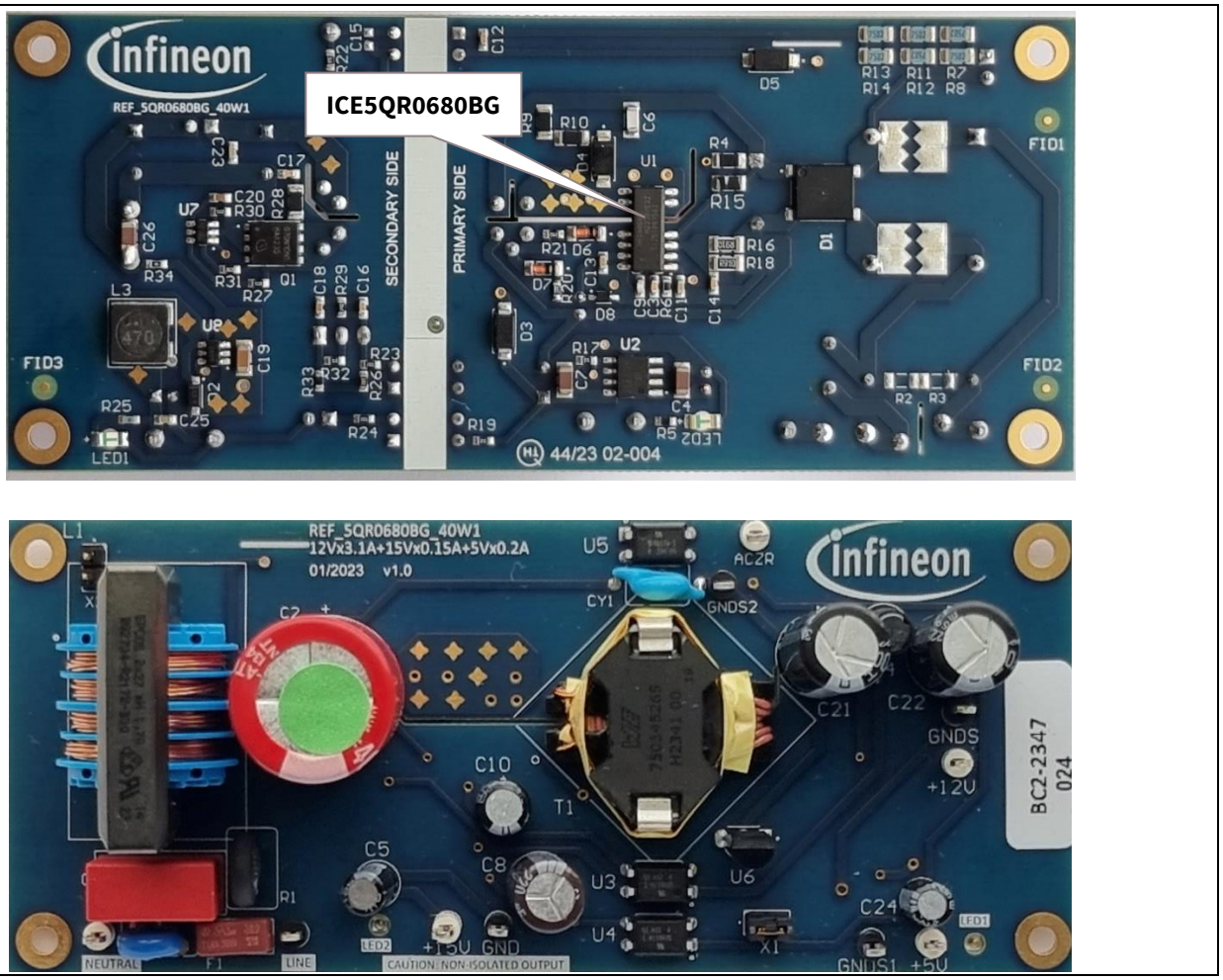

Figure 1 REF_5QR0680BG_40W1

2 Reference board specifications

Table 1 REF_5GR4780AG_6W1 specifications

Description	Symbol	Min	Typ	Max	Unit	Note/conditions
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}	–	–	500	mW	AC ZCD disabled
Output						
Output voltage 1	V_{out1}	–	12	–	V	–
Output current 1	I_{out1}	–	–	3.1	A	–
Output voltage 2	V_{out1}	–	5	–	V	DC-DC output from V_{out1}
Output current 2	I_{out1}	–	–	0.2	A	–
Output voltage 3	V_{out1}	–	15	-	V	LDO output from aux winding
Output current 3	I_{out1}	–	–	0.15	A	–
Overcurrent protection (Vout1)	I_{OCP1}	3.5	–	6	A	Full load at V_{out1} and V_{out2}
Efficiency						
Full load	η_{FL}	88	–	–	%	115 V AC/230 V AC
Average (25%, 50%, 75%, and 100%)	η_{ave}	88	-	-	%	115 V AC/230 V AC
Environmental						
Conducted EMI	–	6	–	–	dB	Margin, CISPR 22 Class B
ESD	–	–	–	–	–	EN 61000-4-2
Contact discharge	–	±6	–	–	kV	–
Air discharge	–	±8	–	–	kV	–
Surge immunity	–	–	–	–	–	EN 61000-4-5
Differential mode		±1	–	–	kV	–
Common mode		±2	–	–	kV	–
PCB form factor	–	127 × 54 × 35			mm	L × W × H

Note: The table represents the minimum acceptable performance of the design. The actual measurement results are listed in Section 8. This reference board is designed to demonstrate the maximum output current only.

3 Schematics

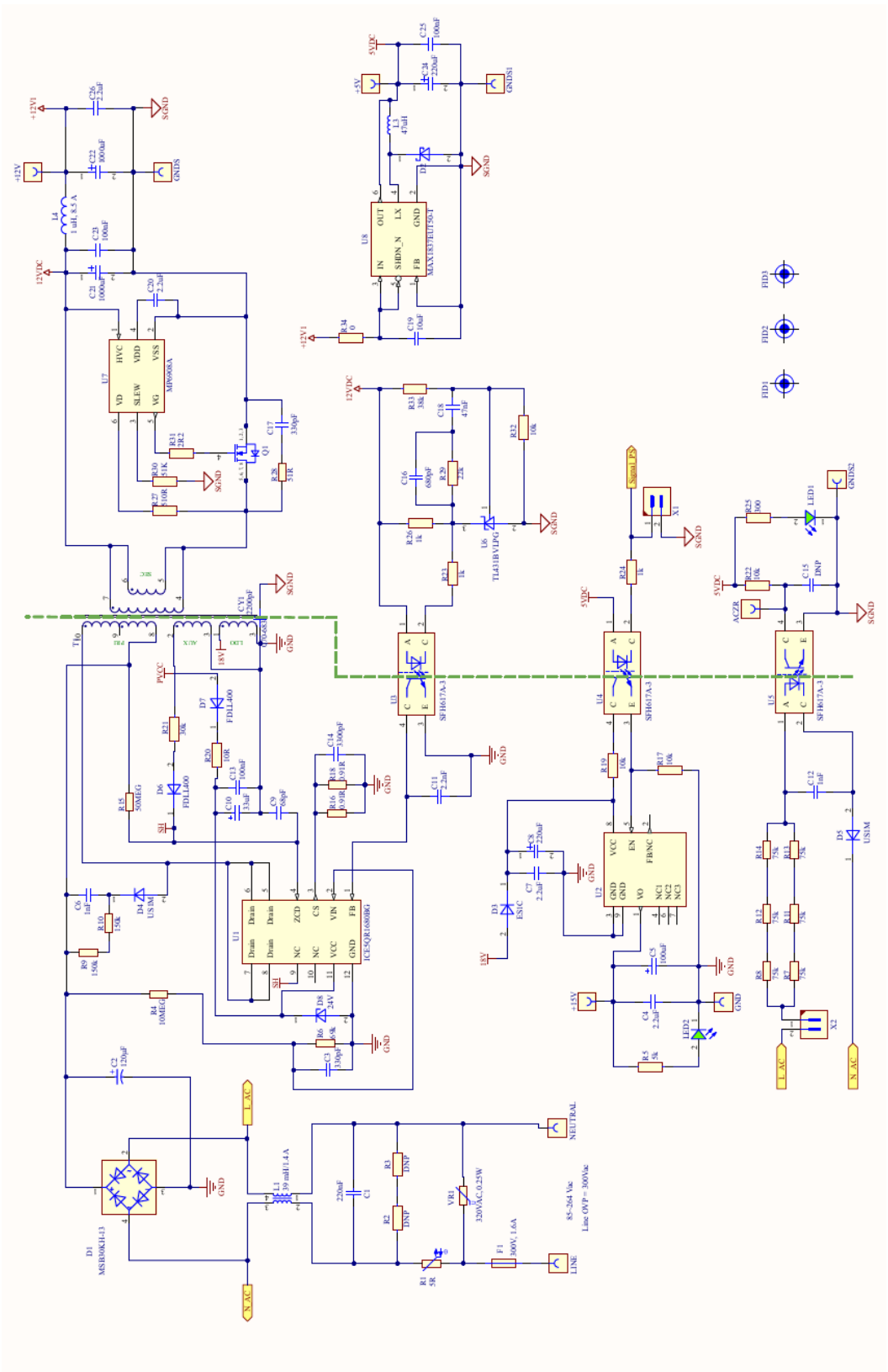

Figure 2 REF_5QR0680BG_40W1

4 Circuit description

4.1 Line input

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

- Input fuse (F1)
- Varistor (VR1)
- Inrush current limiter (R1)
- X-capacitor (C1)
- Common-mode choke (L1)
- Rectifier diode (D1)
- Capacitor (C2)

The X-capacitor (C1) and common-mode choke (L1) act as EMI suppressors.

4.2 Start-up

ICE5QR0680BG uses a cascode structure to fast-charge the V_{CC} capacitor. The pull-up resistor (R15) connected to the ZCD 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 ICE5QR0680BG 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 1 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.

4.3 Integrated MOSFET and PWM control

ICE5QR0680BG comprises power MOSFET and a quasi-resonant PWM controller with digital frequency reduction. Active burst mode (ABM) is also implemented to achieve a very low standby input power. The PWM switch-on is determined by the zero crossing detection and the PWM switch-off is determined by the feedback signal VFB and the current sensing signal V_{CS} via resistors (R16 and R18). ICE5QR0680BG also performs all necessary protection functions including V_{CC} overvoltage and undervoltage, overload, output overvoltage, overtemperature (controller junction), brown-in/out protection, 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].

4.4 RCD clamper circuit

A clamper network (R9, R10, C6, and D4) dissipates the energy of the leakage inductance and suppress ringing on the SMPS transformer.

4.5 Output stage

This reference board has three outputs:

- Isolated 12 V output rectified SR MOSFET Q1 controlled by SR controller U7
- Isolated 5 V output from buck converter U8 taken from 12 V output
- Non-isolated 15 V output via LDO U2 which can be disabled by removing jumper X1

4.6 Feedback control

The system uses a TL431 feedback circuit monitoring the 12 V output coupled with an optocoupler U3 connected to FB pin of the ICE5QR0680BG for output voltage control.

4.7 AC zero-crossing detection

An AC zero-crossing detection circuit is usually required in home appliances that supply power from an AC outlet to detect the zero-cross point (which is the 0 V point of the AC waveform) to efficiently control motors. Therefore, a conventional circuit is added to output a zero-cross signal from 85 V AC to 264 V AC input at the ACZR pin. This circuit can be enabled by adding a jumper (X2).

5 PCB layout

5.1 Top side

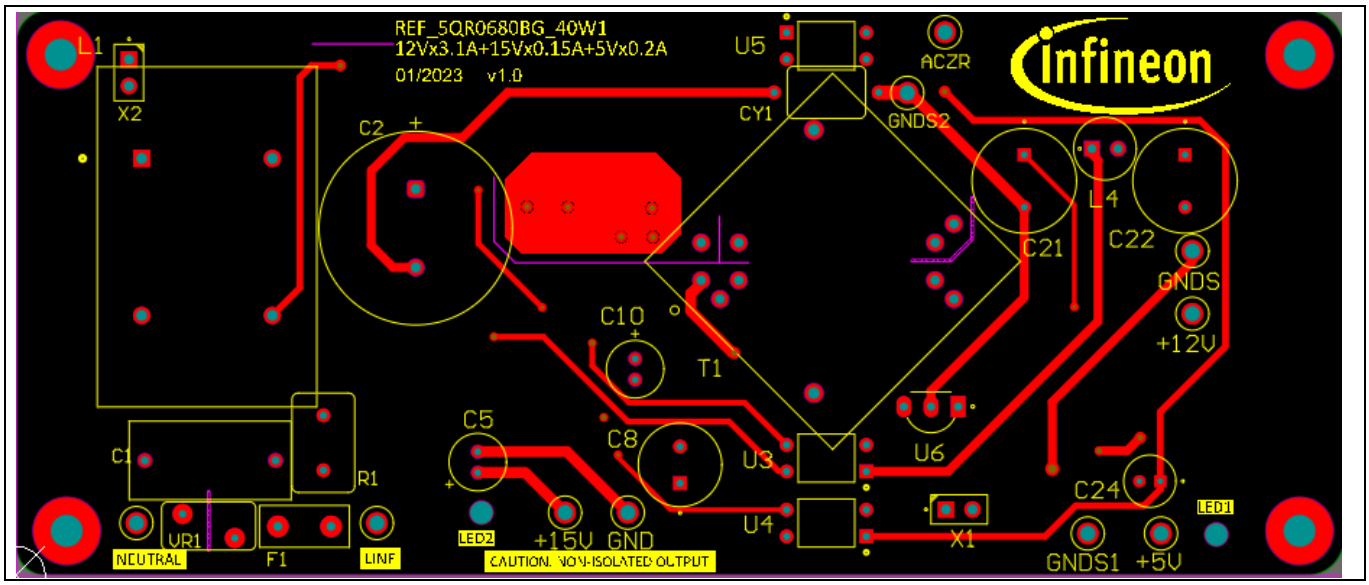

Figure 3 Top-side copper and component legend

5.2 Bottom side

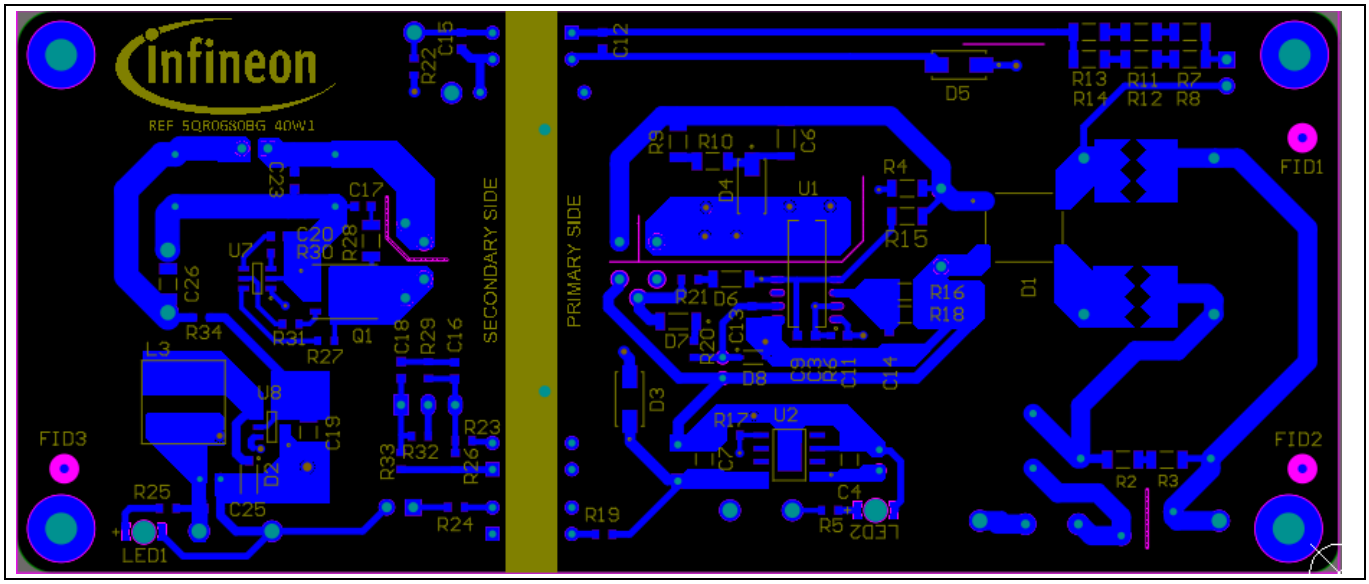

Figure 4 Bottom-side copper and component legend

6 Bill of materials

Table 2 BOM

No.	Designator	Description	Part number	Manufacturer	Quantity
1	C1	CAP FILM 0.22 µF 10% 310 VAC RAD	890334024002	Würth Elektronik	1
2	C2	CAP ALUM 120 µF 20% 400 V RADIAL	860021381021	Würth Elektronik	1
3	C3, C14	CAP CER 330 pF 100 V CH 0603	–	–	2
4	C4, C7, C26	CAP CER 2.2 µF 50 V X7R 1206	–	–	3
5	C5	CAP ALUM 100 µF 20% 25 V RADIAL	25YXJ100M5X11	Rubycon	1
6	C6	CAP CER 1206 1 nF 500 V X7R 10% FL	–	–	1
7	C8	CAP ALUM 220 µF 20% 35 V RADIAL	EKZE350ELL221MH15D	United Chemi-Con	1
8	C9	CAP CER 68 pF 50 V COG 0603	–	–	1
9	C10	CAP ALUM 33 µF 20% 35 V RADIAL	35MS733MEFC6.3X7	Rubycon	1
10	C11	CAP CER 0603 2.2 nF 16 V X7R 10%	–	–	1
11	C12	CAP CER 0603 1 nF 50 V X7R 10%	–	–	1
12	C13, C23, C25	CAP CER 100 nF 50 V X7R 0603	–	–	3
13	C16	CAP CER 680 pF 50 V X7R 0603	–	–	1
14	C17	CAP CER 330 pF 100 V CH 0603	–	–	1
15	C18	CAP CER 47 nF 16 V X7R 0603	–	–	1
16	C19	CAP CER 10 µF 25 V X7R 1206	–	–	1
17	C20	CAP CER 2.2 µF 10 V X7R 0603	–	–	1
18	C21, C22	CAP ALUM 1000 µF 20% 25 V RADIAL	25ZLH1000MEFC10X23	Rubycon	2
19	C24	CAP ALUM 220 µF 20% 10 V RADIAL	10YXJ220M5X11	Rubycon	1
20	CY1	CAP CER 2200 pF 250 V RADIAL	DE1E3KX222MA4BN01F	Murata Electronics	1
21	D1	BRIDGE RECT 1PHASE 800 V 3 A 4MSBL	MSB30KH-13	–	1
22	D2	DIODE SCHOTTKY 30 V 1 A SOD123	MBR130T3G	–	1
23	D3	DIODE GEN PURP 150 V 1 A SMA	ES1C	–	1
24	D4, D5	DIODE GEN PURP 1 kV 1 A SMA	US1M	–	2
25	D6, D7	DIODE GEN PURP 100 V 200 mA SOD80	FDLL914B	–	2
26	D8	DIODE ZENER 24 V 300 mW SOD323	BZX384-C24,115	–	1
27	F1	FUSE BOARD MNT 1.6 A 300 V AC RAD	36911600000	Littelfuse	1
28	L1	CMC 39 mH 1.4 A 2LN TH	B82734R2142B030	TDK Electronics	1
29	L3	FIXED IND 47 µH 730 mA 280 mOHM SMD	744062470	Würth Elektronik	1
33	L4	FIXED IND 1µH 8.5 A 15 mOHM TH	7447462010	Würth Elektronik	1
31	LED1, LED2	LED GREEN CLEAR 2SMD BOTTOM ENT	156120VS82500	Würth Elektronik	2

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Bill of materials

No.	Designator	Description	Part number	Manufacturer	Quantity
32	Q1	MOSFET N-CH 100 V 80 A TDSON-8	BSC070N10NS5	Infineon	1
33	R1	ICL 5 OHM 20% 4.2 A 9.5 mm	B57235S0509M000	TDK Electronics	1
35	R4	RES SMD 10 MOHM 1% 1206	RCV120610M0FKEA	–	1
36	R5	RES SMD 5 kOHM 0.1% 1/10 W 0603	–	–	1
37	R6	RES SMD 69 kOHM 0.5% 1/10 W 0603	–	–	1
38	R7, R8, R11, R12, R13, R14	RES SMD 75 kOHM 1% 1/4 W 1206	–	–	6
39	R9, R10	RES SMD 150 kOHM 1% 1/2 W 1206	–	–	2
40	R15	RES SMD 50 MOHM 1% 1206	–	–	1
41	R16, R18	RES SMD 0.91 OHM 1% 1/2 W 1206	–	–	2
42	R17, R19, R22, R32	RES SMD 10 kOHM 1% 1/10 W 0603	–	–	4
43	R20	RES SMD 10 OHM 1% 1/10 W 0603	–	–	1
44	R21	RES SMD 27 kOHM 1% 1/10 W 0603	–	–	1
45	R23, R24, R26	RES SMD 1 kOHM 1% 1/10 W 0603	–	–	3
46	R25	RES 300 OHM 1% 1/8 W 0603	–	–	1
47	R27	RES SMD 510 OHM 1% 1/10 W 0603	–	–	1
48	R28	RES SMD 22 OHM 1% 1/4 W 1206	–	–	1
49	R29	RES SMD 24 kOHM 1% 1/10 W 0603	–	–	1
50	R30	RES SMD 51 kOHM 1% 1/10 W 0603	–	–	1
51	R31	RES SMD 2.2 OHM 1% 1/10 W 0603	–	–	1
52	R33	RES SMD 38.3 kOHM 1% 1/10 W 0603	–	–	1
53	R34	RES SMD 0 OHM 1% 1/10 W 0603	–	–	1
54	T1	TRF RM8	750345265	Würth Elektronik	1
55	U1	QUASI-RESONANT 800 V CoolSET™	ICE5QR0680BG	Infineon	1
56	U2	IC REG LINEAR 15 V 1 A 8HTSOP	BDJ5FC0WEFJ-E2	ROHM	1
57	U3, U4, U5	OPTOISOLATOR 5.3 kV TRANS 4DIP	SFH617A-3	Vishay	3
58	U6	IC VREF SHUNT ADJ 0.4% TO92-3	TL431BVLPG	–	1
59	U7	FAST TURN-OFF INTELLIGENT RECTIF	MP6908AGJ-Z	–	1
60	U8	IC REG BUCK ADJ/1.25 V 250 mA SOT6	MAX1837EUT50+T	–	1
61	VR1	VARISTOR 510 V 1.75 kA DISC 7 mm	B72207S2321K101	TDK Electronics	1
62	X1, X2	CONN HEADER VERT 2POS 2.54 mm	TSW-102-08-G-S	Samtec	2
63	X1, X2	CONN SHUNT 2POS	SNT-100-BK-G	Samtec	2
64	+5 V, +12 V, +15 V, NEUTRAL, ACZR	Test Point-Multipurpose THT, White	5012	Keystone	5

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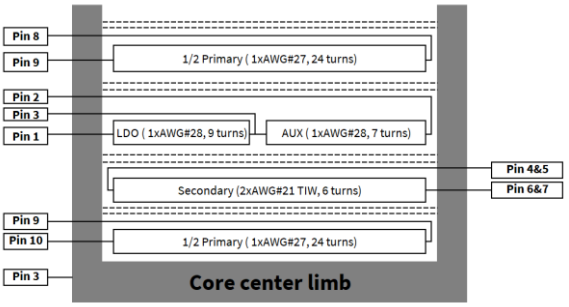
Bill of materials

No.	Designator	Description	Part number	Manufacturer	Quantity
65	GND, LINE, GNDS, GNDS1, GNDS2	Test Point-Multipurpose THT, Black	5011	Keystone	5

7 Transformer construction

- **Core and material**: 150-2623 (RM8, TP4A)
- **Bobbin**: 10 pin, THT, vertical version
- **Primary inductance**: Lp = 365 µH (±10%), measured between pin 8 and pin 10
- **Manufacturer and part number**: Würth Elektronik (750345265 Rev 00)

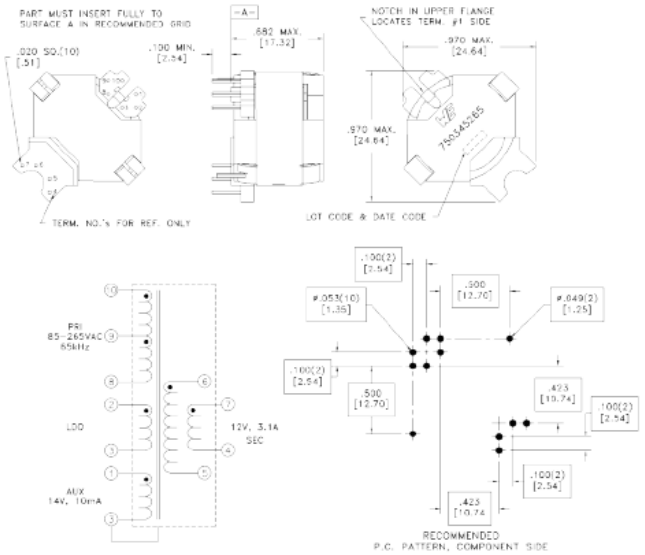


Notes:
(1) === 2 layers of tape
(2) core is shielded with a copper foil wrap around it and connected to pin 3 (core and foil shorted)

Wire size requirement :

Start	Stop	No. of turns	Wire size	Layer
Pin 10	Pin 9	24	1 x AWG#27	1/2 Primary
Pin 6&7	Pin 4&5	6	2 x AWG#21 TIW	Secondary
Pin 1	Pin 3	9	1 x AWG#28	LDO
Pin 2	Pin3	7	1 x AWG#28	Aux
Pin 9	Pin 8	24	1 x AWG#27	1/2 Primary

CUSTOMER TERMINAL	RoHS	LEAD(Pb)–FREE
Sn 96%, Ag 4%	Yes	Yes



Customer to tie terminals 4+5 and 6+7 on PC board.
Application of the transformer allows for the leadwires between terminals 4&5 and 6&7 to solder bridge.

ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	10-8	@20ºC	0.51 ohms max.
D.C. RESISTANCE	7-4	tie(4+5,6+7), @20ºC	0.02 ohms max.
D.C. RESISTANCE	2-3	@20ºC	0.15 ohms max.
D.C. RESISTANCE	1-3	@20ºC	0.19 ohms max.
INDUCTANCE	10-8	10kHz, 100mV, Ls	365.00µH ±10%
SATURATION CURRENT	10-8	20% rolloff from initial	2.5A
LEAKAGE INDUCTANCE	10-8	tie(4+5+6+7),100kHz, 100mV, Ls	5.3µH typ., 10µH max.
DIELECTRIC	10-7	tie(10+1,6+7), 3750VAC, 1 second	3000VAC, 1 minute
DIELECTRIC	10-1	625VAC, 1 second	500VAC, 1 minute
TURNS RATIO		(10-8):(7-4), tie(4+5,6+7)	8:1
TURNS RATIO		(10-8):(2-3)	6.86:1
TURNS RATIO		(10-8):(1-3)	5.33:1

GENERAL SPECIFICATIONS:
OPERATING TEMPERATURE RANGE: -40°C to +125°C including temp rise.
Designed to comply with the following requirements as defined by IEC62368-1, EN62368-1, UL62368-1/CSA62368-1 and AS/NZS62368.1:
- Reinforced insulation for a primary circuit at a working voltage of 265Vrms, 400Vpeak, OVC II, Pollution Degree 2.

Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability. Marking method, font and color may vary on preproduction samples.

DFM		Packaging Specifications	Tolerances unless otherwise specified: Angles: ±1° Decimals: ±.005 [.13] Fractions: ±1/64 Footprint: ± .001 [.03]
DATE		Method: Tray	DRAWING TITLE: TRANSFORMER
ENG	IYU	PKG-0002	PART NO.: 750345265
REV.	00		This drawing is dual dimensioned. Dimensions in brackets are in millimeters.
DATE	2022/11/4	www.we-online.com/midcom	SPECIFICATION SHEET 1 OF 1

CONVENTION PLACEMENT

Figure 5 Transformer structure

8 Test results

8.1 Efficiency

Table 3 Efficiency

Input (V AC/Hz)	Loading Percentage	Pin (W)	V_{out1} (V)	I_{out1} (A)	V_{out2} (V)	I_{out2} (A)	V_{out3} (V)	I_{out3} (A)	P_{out} (W)	Efficiency (%)	Average Efficiency (%)
85 V AC 60 Hz	No load	0.214	12.067	0.000	5.007	0.000	15.145	0.000			
	25% load	11.712	12.061	0.775	5.015	0.050	15.109	0.038	10.16	86.79%	86.72%
	50% load	23.300	12.052	1.550	5.022	0.100	15.098	0.075	20.32	87.19%	
	75% load	35.000	12.042	2.325	5.025	0.150	15.086	0.113	30.45	87.00%	
	100% load	47.200	12.028	3.100	5.025	0.200	15.082	0.150	40.55	85.92%	
115 V AC 60 Hz	No load	0.215	12.067	0.000	5.007	0.000	15.145	0.000			
	25% load	11.632	12.060	0.775	5.015	0.050	15.105	0.038	10.16	87.38%	88.15%
	50% load	22.960	12.051	1.550	5.022	0.100	15.094	0.075	20.31	88.47%	
	75% load	34.400	12.042	2.325	5.025	0.150	15.086	0.113	30.45	88.51%	
	100% load	45.970	12.028	3.100	5.025	0.200	15.082	0.150	40.55	88.22%	
230 V AC 50 Hz	No load	0.230	12.067	0.000	5.007	0.000	15.145	0.000			
	25% load	11.704	12.061	0.775	5.015	0.050	15.109	0.038	10.16	86.85%	88.95%
	50% load	22.750	12.052	1.550	5.022	0.100	15.098	0.075	20.32	89.30%	
	75% load	33.900	12.042	2.325	5.025	0.150	15.086	0.113	30.45	89.82%	
	100% load	45.140	12.030	3.100	5.025	0.200	15.082	0.150	40.56	89.85%	
264 V AC 50 Hz	No load	0.237	12.067	0.000	5.007	0.000	15.145	0.000			
	25% load	11.796	12.061	0.775	5.015	0.050	15.109	0.038	10.16	86.17%	88.67%
	50% load	22.820	12.052	1.550	5.022	0.100	15.098	0.075	20.32	89.02%	
	75% load	34.000	12.042	2.325	5.025	0.150	15.086	0.113	30.45	89.55%	
	100% load	45.100	12.030	3.100	5.025	0.200	15.082	0.150	40.56	89.93%	

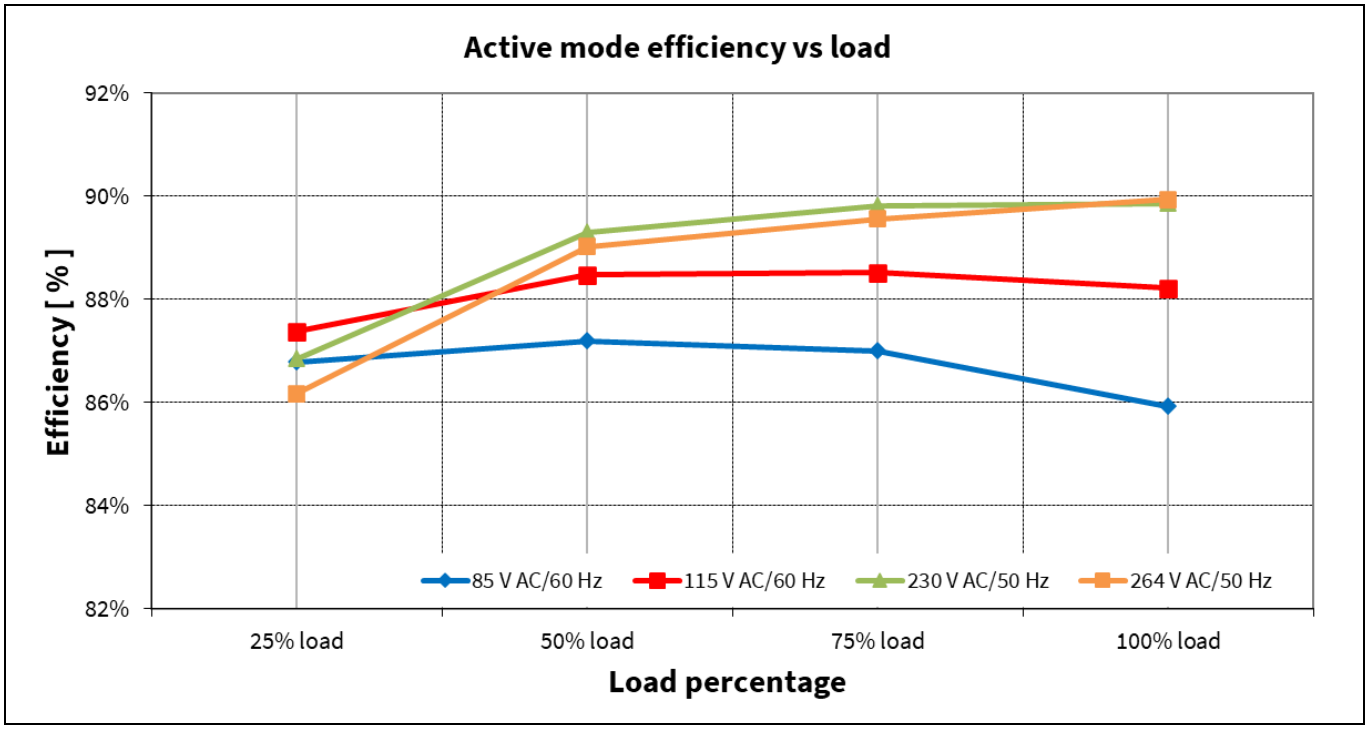


Figure 6 Efficiency vs. AC-line input voltage

8.2 Standby power

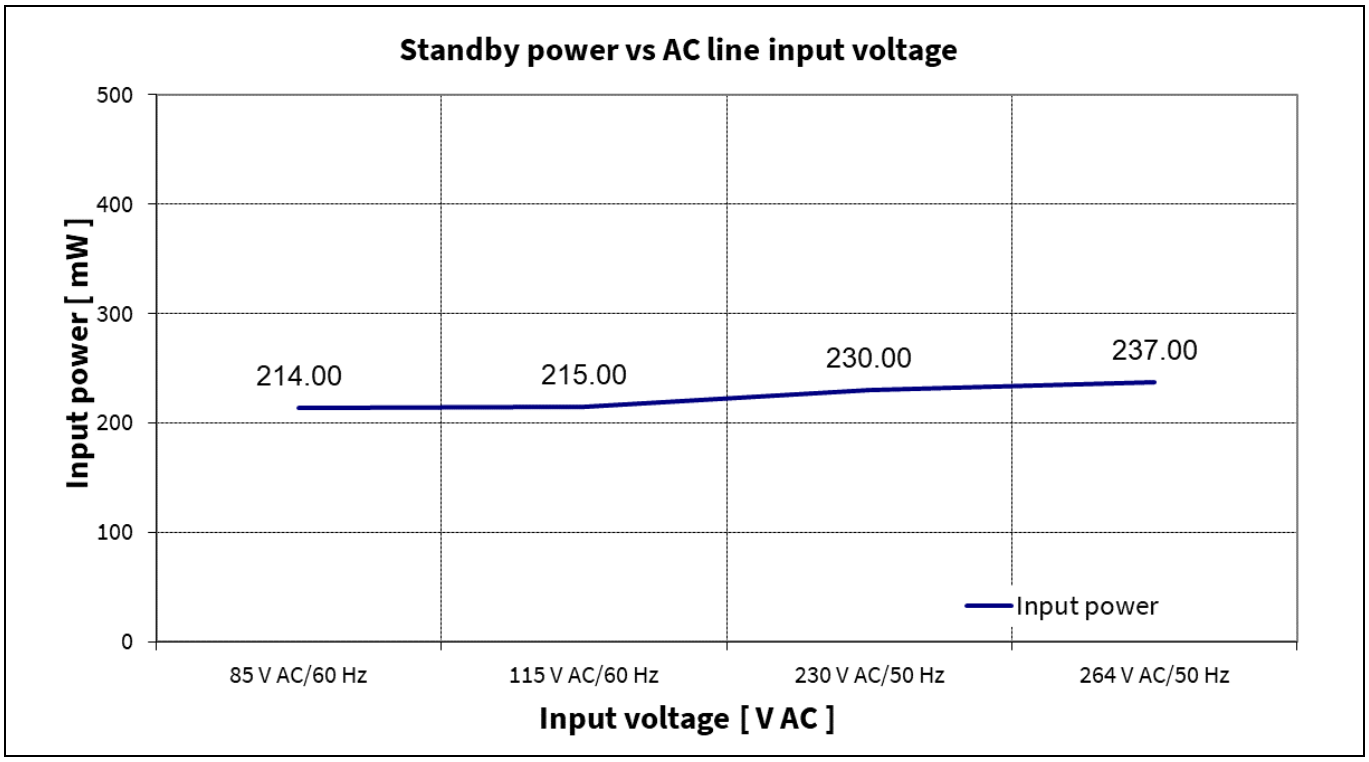


Figure 7 Standby power vs. AC-line input voltage (AC ZCD disabled)

8.3 Line and load regulation

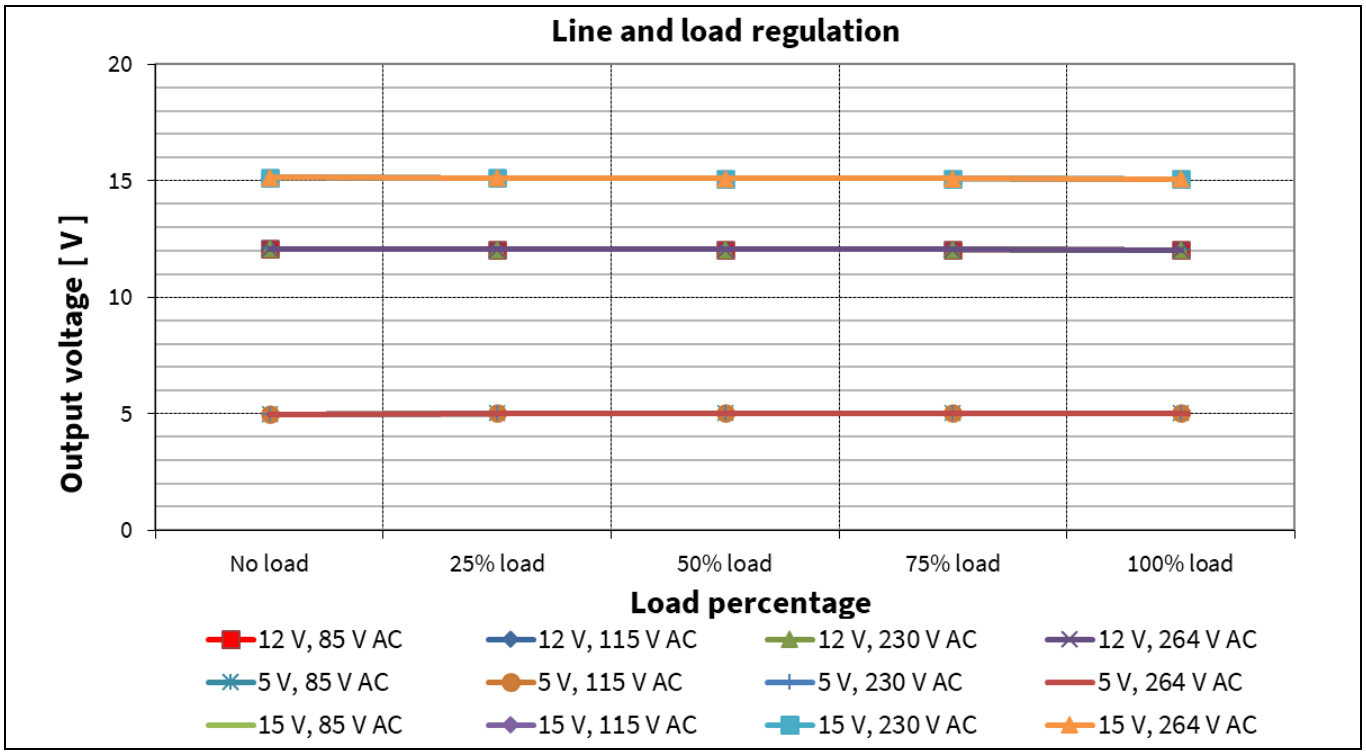


Figure 8 Line and load regulation

8.4 Maximum input power

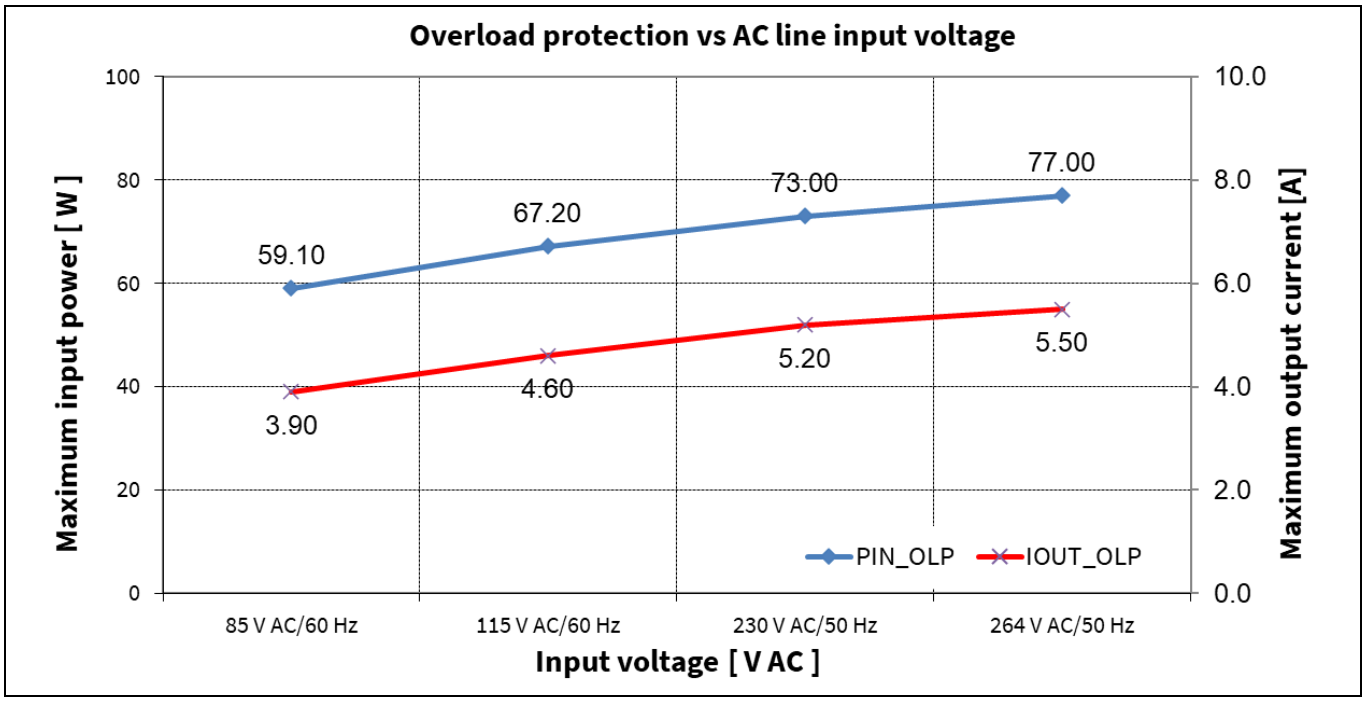


Figure 9 Maximum input power and maximum output current at 12 V output vs. AC line input voltage (15 V and 5 V output at full load condition)

8.5 ESD immunity (EN61000-4-2)

This system is subjected to level 3 ESD test according to EN 61000-4-2 (±6 kV contact and ±8 kV air discharge). It is tested at full load with a resistive load. A test failure is 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_{OUT1}	$-V_{OUT}$	
115 V AC, 40.45 W	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, 40.45 W	Contact	+6 kV	10	10	PASS
		-6 kV	10	10	PASS
	Air	+8 kV	10	10	PASS
		-8 kV	10	10	PASS

8.6 Surge immunity (EN 61000-4-5)

This system is subjected to a surge immunity test (±2 kV DM and ±4 kV CM) according to EN 61000-4-5. It is tested at full load with a resistive load. A test failure is defined as a non-recoverable.

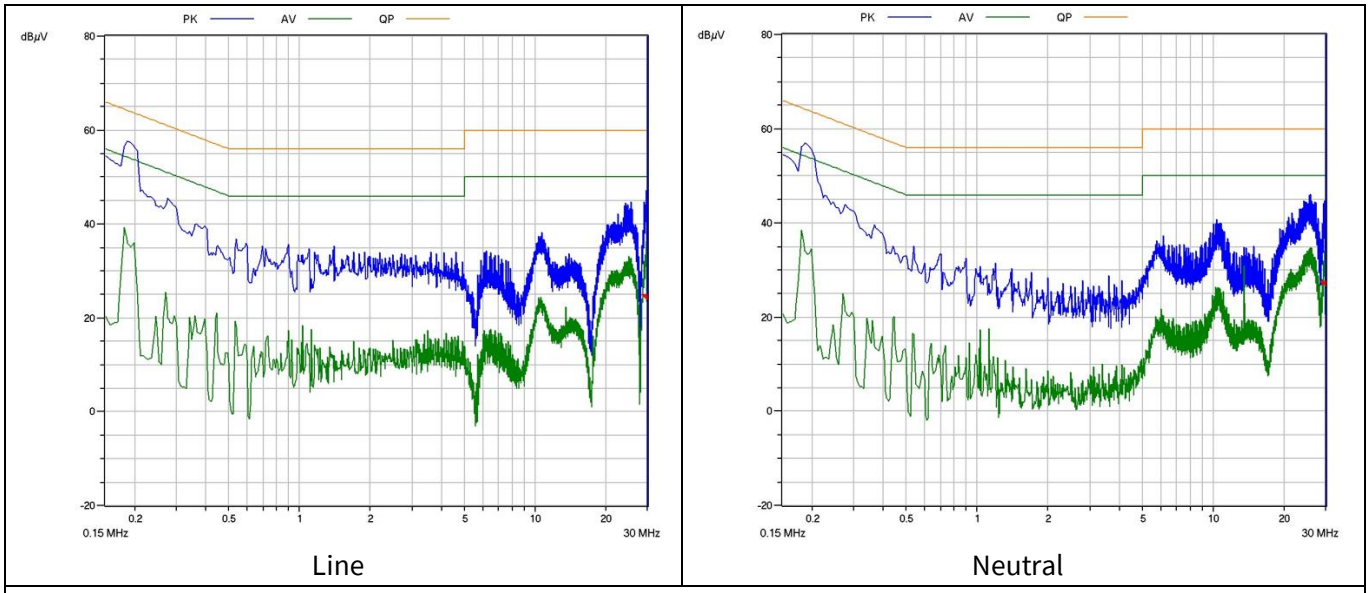
- DM: pass ±2 kV; CM: pass ±4 kV

Table 5 System surge immunity test result

Description	Test	Level		Number of strikes				Test result
				0°	90°	180°	270°	
115 V AC, 40.45 W	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, 40.45 W	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

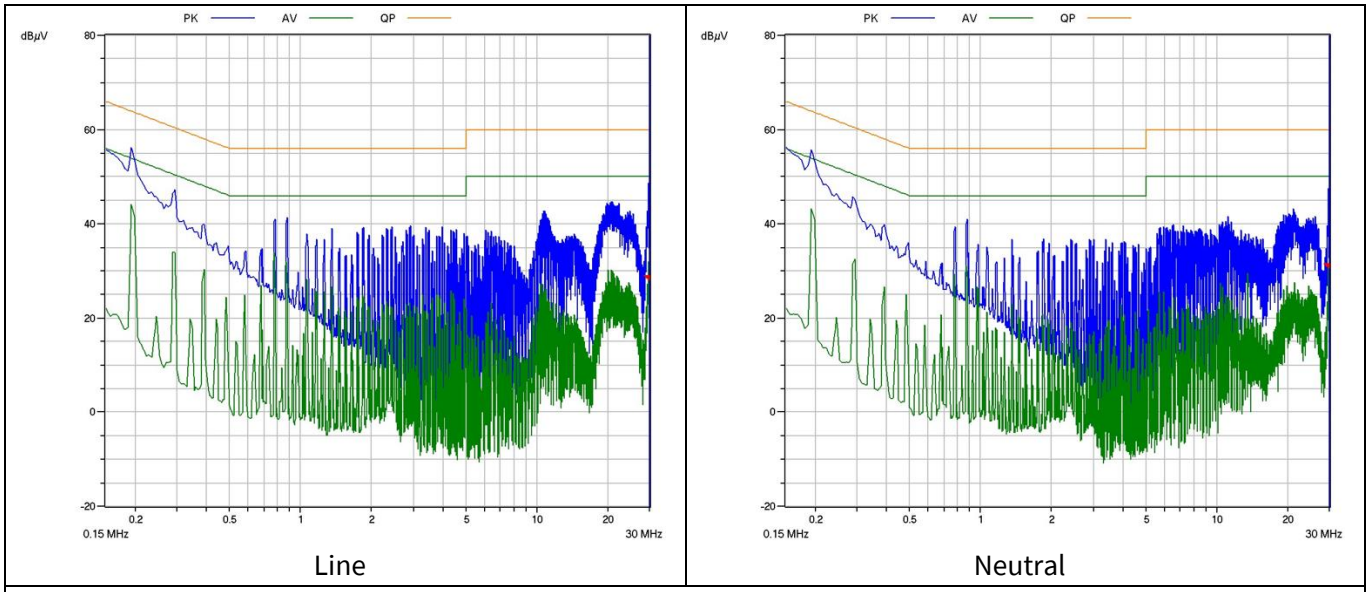
8.7 Conducted emissions (EN 55022 class B)

Conducted EMI is measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) class B. Reference board is connected to a resistive load 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

8.8 Thermal measurement

The thermal test of the open-frame reference 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 conditions.

Table 6 Hottest temperature of reference board

No.	Major component	85 V AC (°C)	264 V AC (°C)
1	R1 (Inrush current limiter)	99.9	61.1
2	T1 (Transformer)	79.2	83.5
3	L1 (Common-mode choke)	67.5	39.3
4	D1 (Input rectifier diode bridge)	82.2	49.1
5	U1 (ICE5QR0680BG CoolSET™)	93.6	89.2
6	U2 (15 V LDO)	80.9	73.7
7	Q1 (SR MOSFET)	68.0	69.5

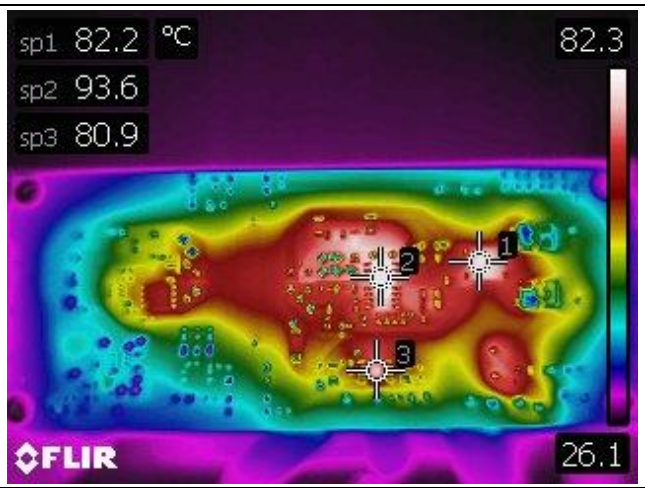
Top side	Bottom side
	

Figure 12 Infrared thermal image at 85 V AC

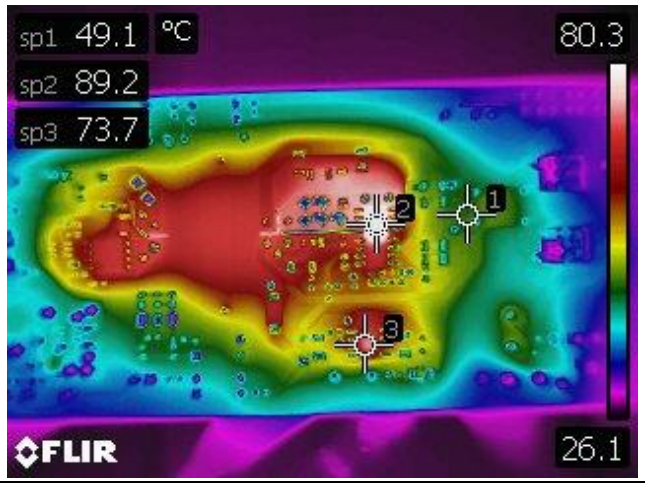
Top side	Bottom side
	

Figure 13 Infrared thermal image of at 264 V AC

9 Waveforms and scope plots

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

9.1 Start-up with maximum load

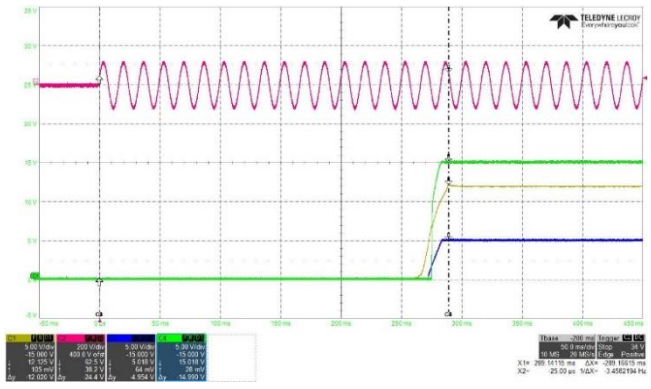
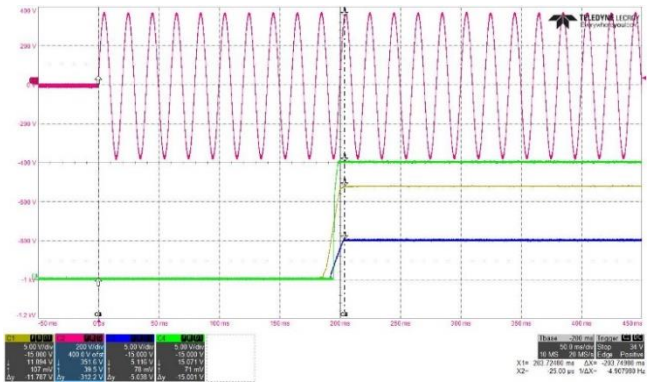
	
C1 (yellow) : 12 V output voltage (V_{out1}) C2 (purple) : Input AC voltage (V AC) C3 (blue) : 5 V output voltage (V_{out2}) C4 (green) : 15 V output voltage (V_{out3})	C1 (yellow) : 12 V output voltage (V_{out1}) C2 (purple) : Input AC voltage (V AC) C3 (blue) : 5 V output voltage (V_{out2}) C4 (green) : 15 V output voltage (V_{out3})
Start-up time at 85 V AC and maximum load ≈ 290 ms	Start-up time at 264 V AC and maximum load ≈ 204 ms

Figure 14 Start-up

9.2 Soft-start

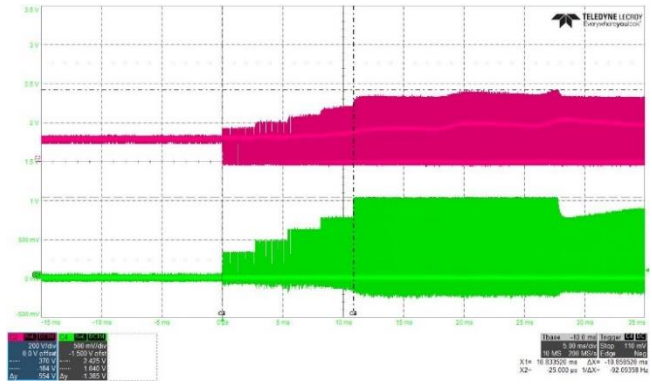
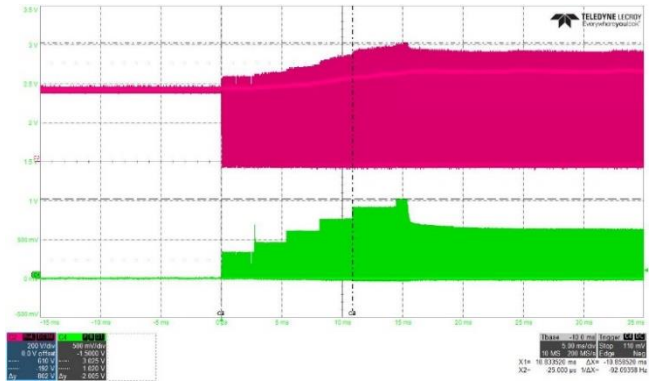
	
C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})	C2 (purple) : Drain voltage (V_{DRAIN}) C4 (green) : CS voltage (V_{CS})
Soft-start time at 85 V AC and maximum load ≈ 11 ms	Soft-start time at 264 V AC and maximum load ≈ 11 ms

Figure 15 Soft-start

9.3 Drain and CS voltage at maximum load

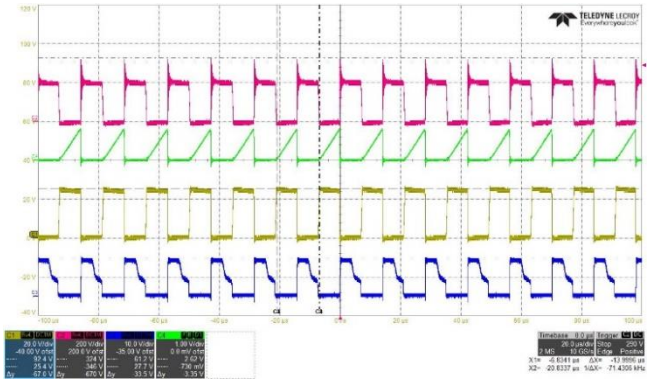
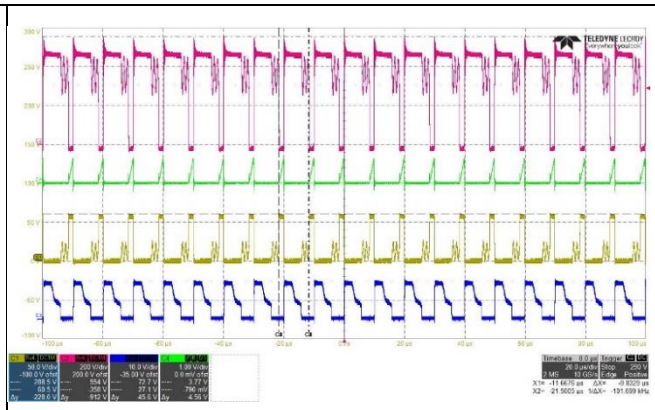
	
C1 (yellow) : SR MOSFET Drain voltage (V_{DRAIN_SR}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : SR MOSFET Gate voltage (V_{GATE_SR}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : SR MOSFET Drain voltage (V_{DRAIN_SR}) C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : SR MOSFET Gate voltage (V_{GATE_SR}) C4 (green) : CS voltage (V_{CS})
V_{DRAIN_PEAK} at 85 V AC ≈ 324 V $V_{DRAIN\_SR\_PEAK}$ at 85 V AC ≈ 25.4 V	V_{DRAIN_PEAK} at 264 V AC ≈ 554 V $V_{DRAIN\_SR\_PEAK}$ at 264 V AC ≈ 60.5 V

Figure 16 Drain and CS voltage at maximum load

9.4 Output ripple voltage at maximum load

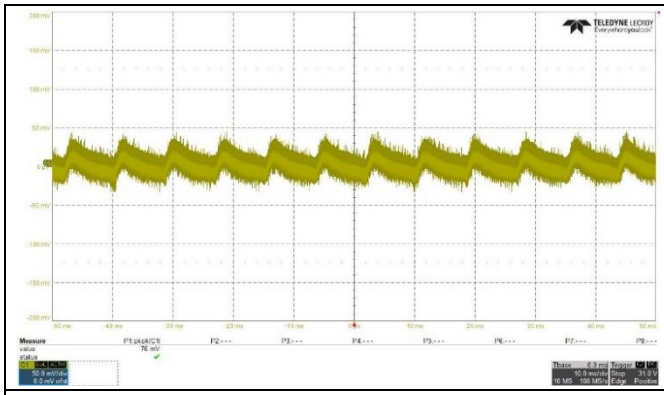
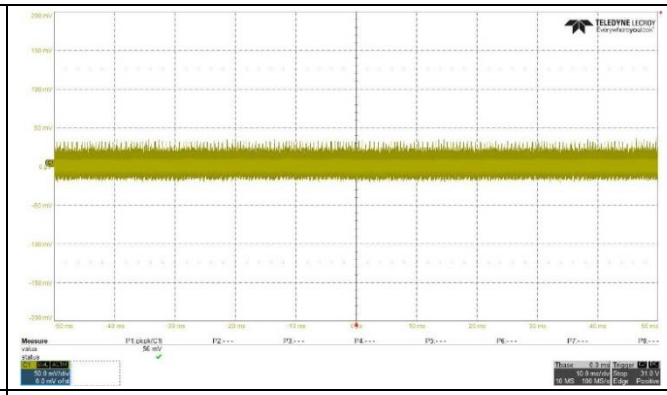
	
C1 (yellow) : 12 V output ripple voltage (V_{out1})	C1 (yellow) : 12 V output ripple voltage (V_{out1})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 76 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW	12 $V_{ripple\_pk\_pk}$ at 264 V AC ≈ 56 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW

Figure 17 12 V output ripple voltage at full load

9.5 Output ripple voltage at ABM

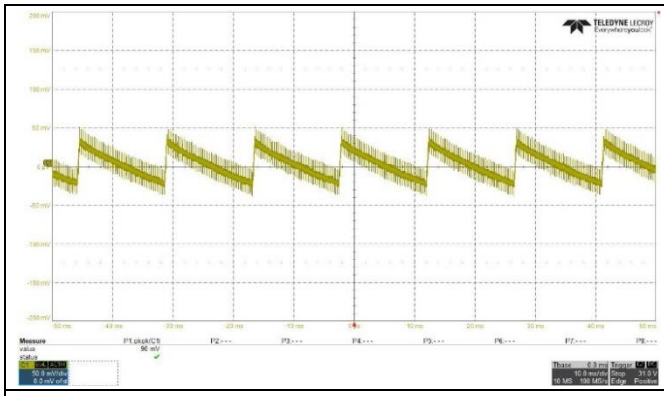
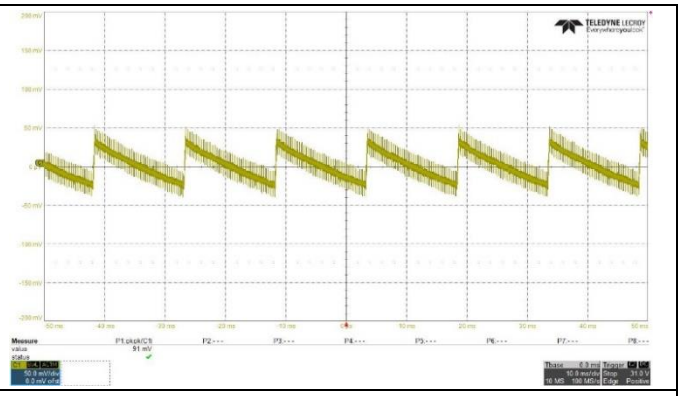
	
C1 (yellow) : 12 V output ripple voltage (V_{out1})	C1 (yellow) : 12 V output ripple voltage (V_{out1})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 90 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW	12 $V_{ripple\_pk\_pk}$ at 264 V AC ≈ 91 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 10 µF (electrolytic), 20 MHz BW

Figure 18 12 V output ripple voltage at ABM (no load)

9.6 Load transient response (dynamic load from 10% to 100%)

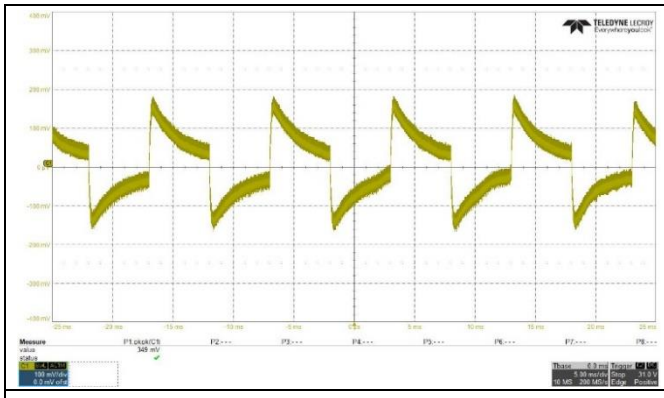
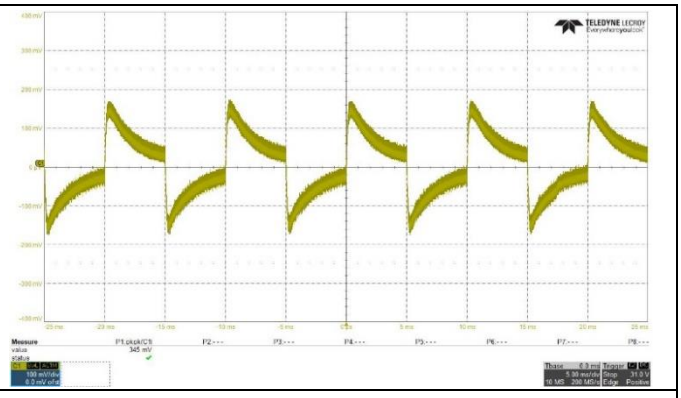
	
C1 (yellow) : 12 V output ripple voltage (V_{out1})	C1 (yellow) : 12 V output ripple voltage (V_{out1})
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 349 mV (Load change from 10% to 100% at 85 V AC, 100 Hz, 0.4 A/µs slew rate) Probe terminal end with decoupling capacitor of 0.1 µF(ceramic) and 1 µF(Electrolytic), 20 MHz filter	12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 345 mV (Load change from 10% 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)

9.7 Entering ABM operation

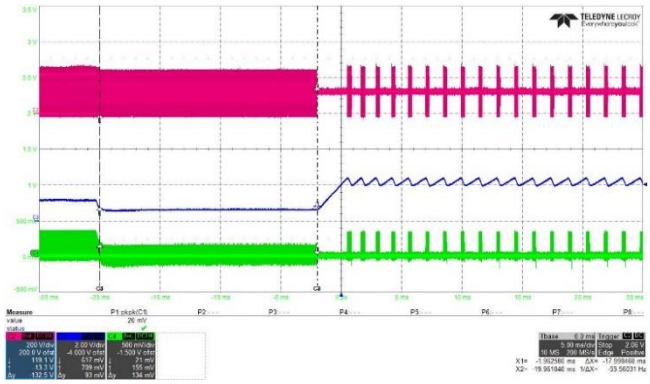
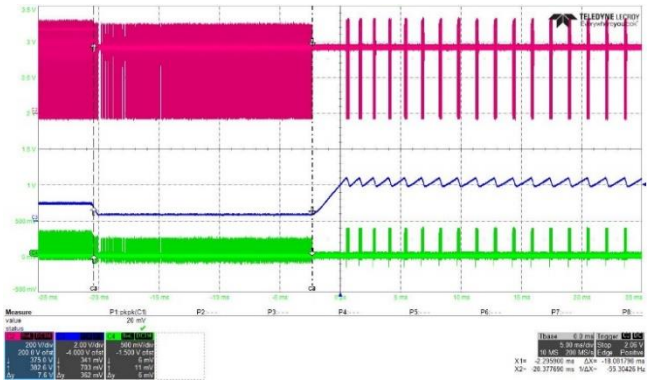
	
C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})	C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})
85 V AC, 12 V load from 0.6 A to 0.1 A Enter ABM at V_{FB} < 1 V, N_{CZ} = 8 and $t_{blanking}$ = 20 ms	264 V AC, 12 V load from 1 A to 0.1 A Enter ABM at V_{FB} < 1 V, N_{CZ} = 8 and $t_{blanking}$ = 20 ms

Figure 20 Entering ABM operation

9.8 During ABM operation

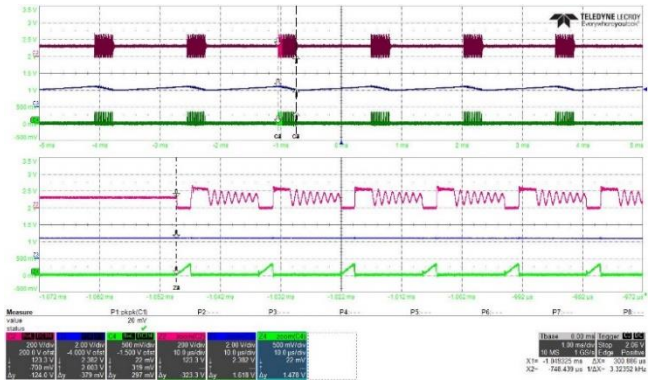
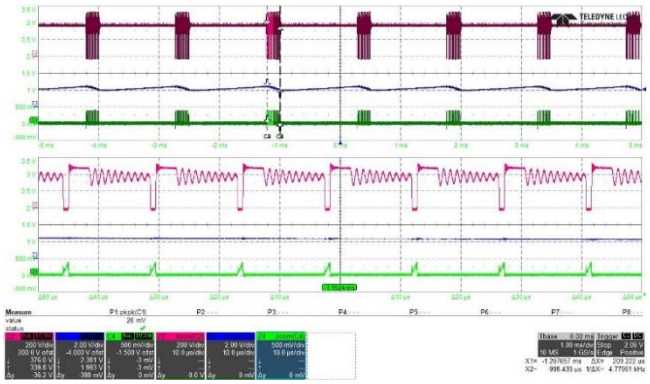
	
C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})	C2 (purple) : Drain voltage (V_{DRAIN}) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})
85 V AC, 12 V load at 0.1 A N_{ZC} =8, I_{PK} = 350 mA, V_{FB_ON} = 2.4 V, V_{FB_OFF} = 2.0 V	264 V AC, 12 V load at 0.1 A N_{ZC} =8, I_{PK} = 350 mA, V_{FB_ON} = 2.4 V, V_{FB_OFF} = 2.0 V

Figure 21 During ABM operation

9.9 Leaving ABM operation

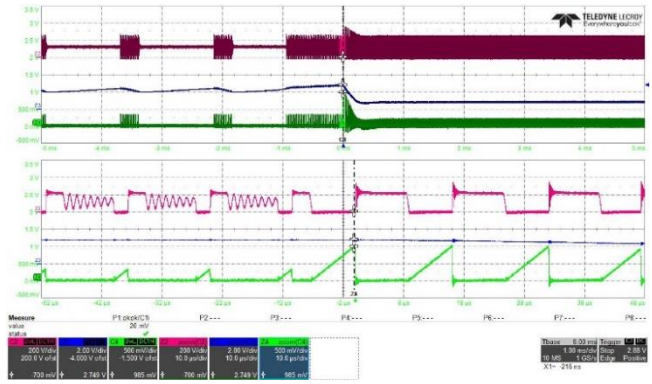
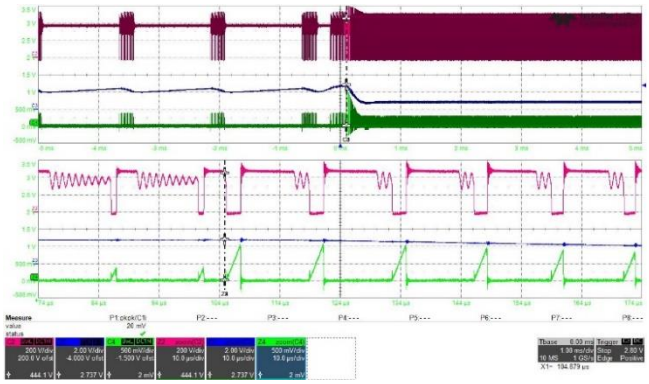
<table>
<tr><td>  </td><td>  </td></tr>
<tr><td>C2 (purple) : Drain voltage (V_{DRAIN})
C3 (blue) : FB voltage (V_{FB})
C4 (green) : CS voltage (V_{CS})</td><td>C2 (purple) : Drain voltage (V_{DRAIN})
C3 (blue) : FB voltage (V_{FB})
C4 (green) : CS voltage (V_{CS})</td></tr>
<tr><td>85 V AC, 12 V load from 0.1 A to 1 A
V_{FB} > 2.75 V</td><td>264 V AC, 12 V load from 0.1 A to 1 A
V_{FB} > 2.75 V</td></tr>
</table>

Figure 22 Leaving ABM operation

9.10 Overload protection (odd-skip auto-restart)

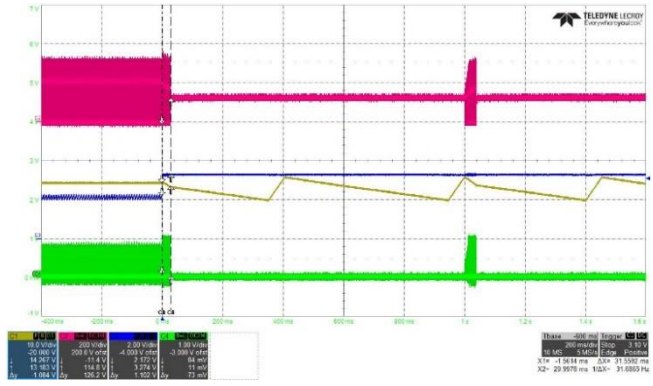
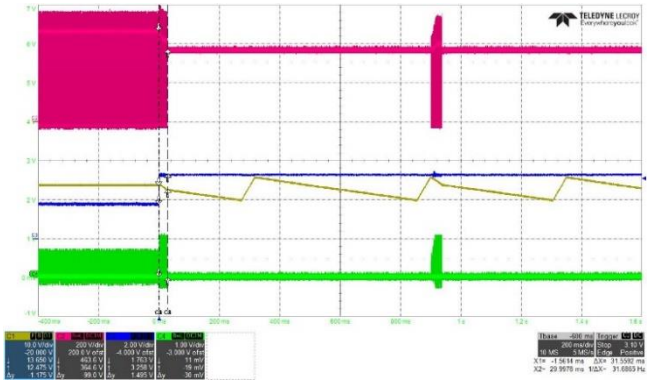
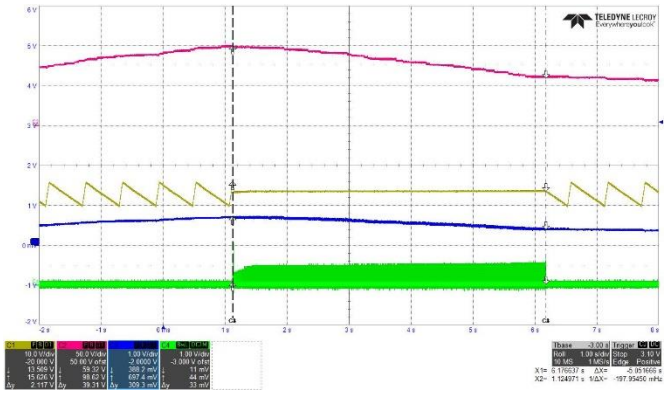
<table>
<tr><td>  </td><td>  </td></tr>
<tr><td>C1 (yellow) : VCC voltage (V_{VCC})
C2 (purple) : Drain voltage (V_{DRAIN})
C3 (blue) : FB voltage (V_{FB})
C4 (green) : CS voltage (V_{CS})</td><td>C1 (yellow) : VCC voltage (V_{VCC})
C2 (purple) : Drain voltage (V_{DRAIN})
C3 (blue) : FB voltage (V_{FB})
C4 (green) : CS voltage (V_{CS})</td></tr>
<tr><td colspan="2">Condition to enter overload protection: V_{FB} more than 2.75 V and lasts for ~30 ms blanking time.
12 V output load change from full load to 6 A (5 V and 15 V output at full load).</td></tr>
</table>

Figure 23 Overload protection

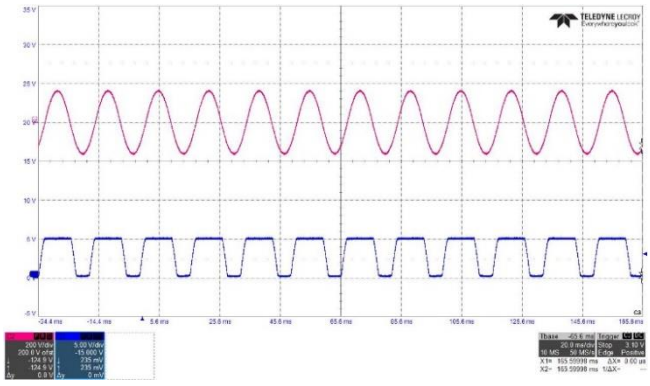
9.11 Brown-in/out protection (auto-restart)

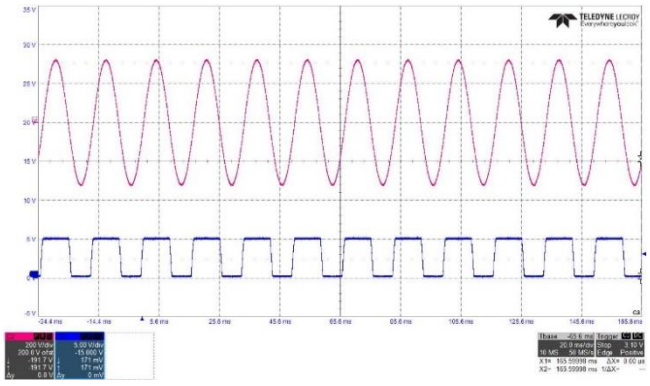


C1 (yellow)	: VCC voltage (V_{VCC})
C2 (purple)	: Bus voltage (V_{BUS})
C3 (blue)	: VIN voltage (V_{VIN})
C4 (green)	: CS voltage (V_{CS})
Brown-in at V_{VIN} more than 0.66 V (V_{BUS} = 100 V) and brown-out at V_{VIN} less than 0.4 V (V_{BUS} = 60 V)	

Figure 24 Brown-in/out protection

9.12 AC zero crossing





C2 (purple)	: Input AC voltage (V_{AC_IN})	C2 (purple)	: Input AC voltage (V_{AC_IN})
C3 (blue)	: ACZR voltage (V_{ACZR})	C3 (blue)	: ACZR voltage (V_{ACZR})
AC zero crossing signal ACZR when enabled via jumper X2			

Figure 25 AC zero crossing

References

[1] Infineon Technologies AG: *30 W high-efficiency auxiliary SMPS for refrigerator using ICE5QR1680BG*; Available online

[2] Infineon Technologies AG: *ICE5QRxx80BG datasheet*; Available online

[3] Infineon Technologies AG: *Fifth-generation QR design guide*; Available online

[4] Infineon Technologies AG: *Calculation tool quasi resonant CoolSET™ generation 5*; Available online

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Document revision	Date	Description of changes
V 1.0	2024-02-27	Initial release

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