12 W auxiliary SMPS for energy-efficient refrigerator using ICE5QR2270AZ

REF_5QR2270AZ_12W1

About this document

Scope and purpose

This document is a reference design for a 12 W auxiliary SMPS for a refrigerator with the latest fifth-generation Infineon QR CoolSET™ ICE5QR2270AZ. The power supply is designed with a universal input compatible with most geographic regions and isolated output (+12 V/1 A) on a single-layer PCB, as typically employed in most home appliances.

Highlights of the auxiliary power supply for a refrigerator:

- High efficiency under light and heavy load conditions to meet ENERGY STAR requirements
- Simplified circuitry with good integration of power and protection features
- Single-layer PCB design for compatibility with wave-soldering process and low-cost manufacturing
- Auto-restart protection scheme to minimize interruption to enhance end-user experience

Intended audience

This document is intended for power supply design or application engineers, etc. who want to design auxiliary power supplies for refrigerators that are efficient under light and heavy load conditions, reliable and easy to design.

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1 System introduction

With the growing household trend for internet-connected devices, the new generation of home appliances such as refrigerators are equipped with advanced features which often include communication capability, such as wireless communication, touch screen display and sensors. These will transform a static product into an interactive and intelligent home appliance, capable of adapting to the smart-home theme. To support this trend, Infineon has introduced the latest 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. The Infineon CoolSET™ (as shown in Figure 1) 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.

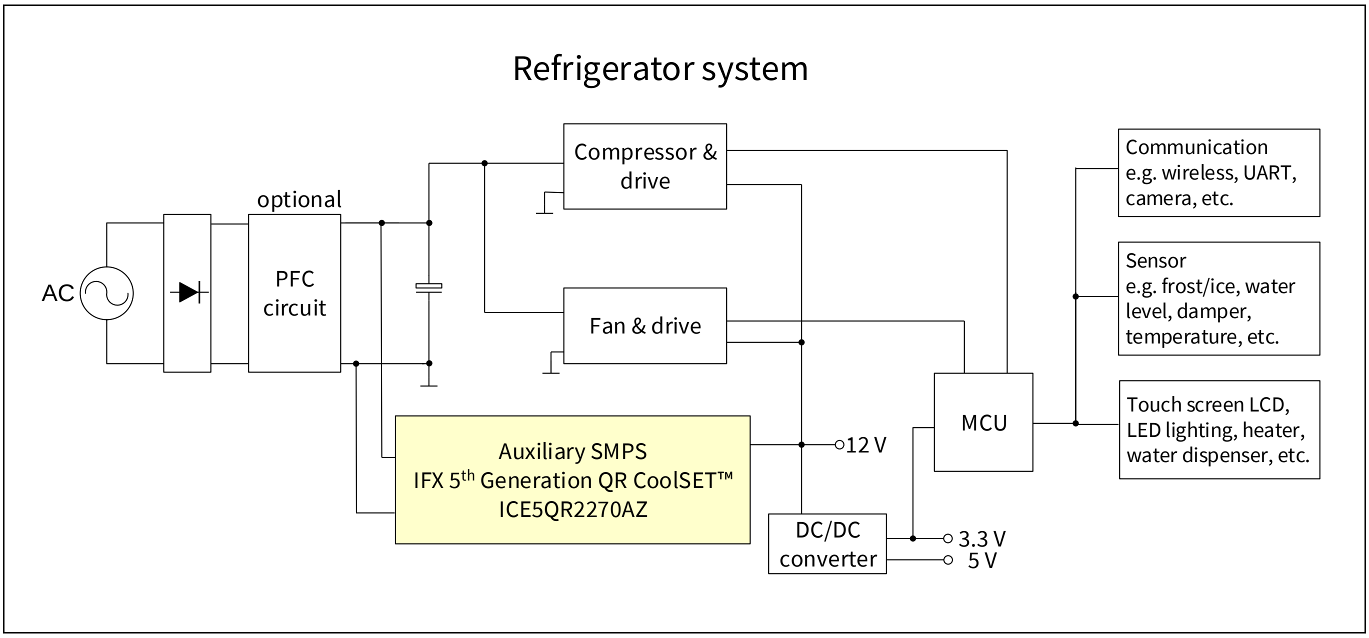


Figure 1 Simplified refrigerator system block diagram

Table 1 lists the system requirements for a refrigerator, and the corresponding Infineon solution is shown in the right-hand column.

Table 1 System requirements and Infineon solutions

	System requirement for a refrigerator	Infineon solution – ICE5QR2270AZ
1	High efficiency under light and heavy load conditions to meet ENERGY STAR requirements	New QR control and Active Burst Mode (ABM)
2	Simplified circuitry with good integration of power and protection features	Embedded 700 V MOSFET and controller in DIP-7 package
3	Auto-restart protection scheme to minimize interruption to enhance end-user experience	All protections are in auto-restart

1.1 High efficiency under light and heavy load conditions to meet ENERGY STAR requirements

During typical refrigerator operation, the power requirement fluctuates according to various use cases. However, in most cases, the refrigerator will reside in an idle state in which the loading toward the auxiliary power supply is low. It is crucial that the auxiliary power supply operates as efficiently as possible, because it will be in this particular state for a prolonged period. Under light load conditions, losses incurred with the power switch are usually dominated by the switching operation. The choice of switching scheme and frequency play a crucial role in ensuring high conversion efficiency.

In this reference design, ICE5QR2270AZ was primarily chosen due to its QR switching scheme. Compared with a traditional Flyback switching scheme, the CoolSET™ will attempt to turn on its integrated HV MOSFET in the valley of the resonant period, thereby minimizing switching losses. Additionally, the fifth-generation QR series has the highest detection rate in the industry, of up to 10 valleys, thereby lowering the switching frequency further along with a reduction in load. Therefore, an efficiency of more than 80 percent is achievable under 10 percent loading conditions.

1.2 Simplified circuitry with good integration of power and protection features

To relieve the designer of the complexity of PCB layout and circuit design, this CoolSET™ is a highly integrated device with both a controller and an HV MOSFET integrated into a single, space-saving DIP-7 package. These certainly help the designer to reduce component count as well as simplifying the layout into a single-layer PCB design for ease of manufacturing, using the traditional, cost-effective wave-soldering process.

To counter abnormal line-input conditions, CoolSET™ has integrated line-input Over-Voltage Protection (OVP) as well as brown-in/brown-out protection to increase the robustness of the auxiliary power supply. In the event of such faults, the controller within the CoolSET™ will halt the switching operation of the integrated HV MOSFET, thereby preventing permanent damage. These features allow the designer to reduce the complexity of introducing additional external circuitry and yield a saving of as many as 15 components.

Additional protection features are integrated into the CoolSET™, such as output OV, V_{CC} OV, V_{CC} Under Voltage (UV), over-load/open-loop, over-temperature and Current Sense (CS) short-to-GND. It also has limited charging current for V_{CC} short-to-GND.

1.3 Auto-restart protection scheme to minimize interruption to enhance end-user experience

For a refrigerator it would be annoying to both the end user and the manufacturer if the system were to halt and latch after protection. To minimize interruption, the CoolSET™ implements auto-restart mode for all protections.

2 Reference design board

This document provides complete design details including specifications, schematics, Bill of Materials (BOM), PCB layout, and transformer design and construction information. Performance results pertaining to line/load regulation, efficiency, transient load, thermal conditions, conducted EMI scans and so on are also included.

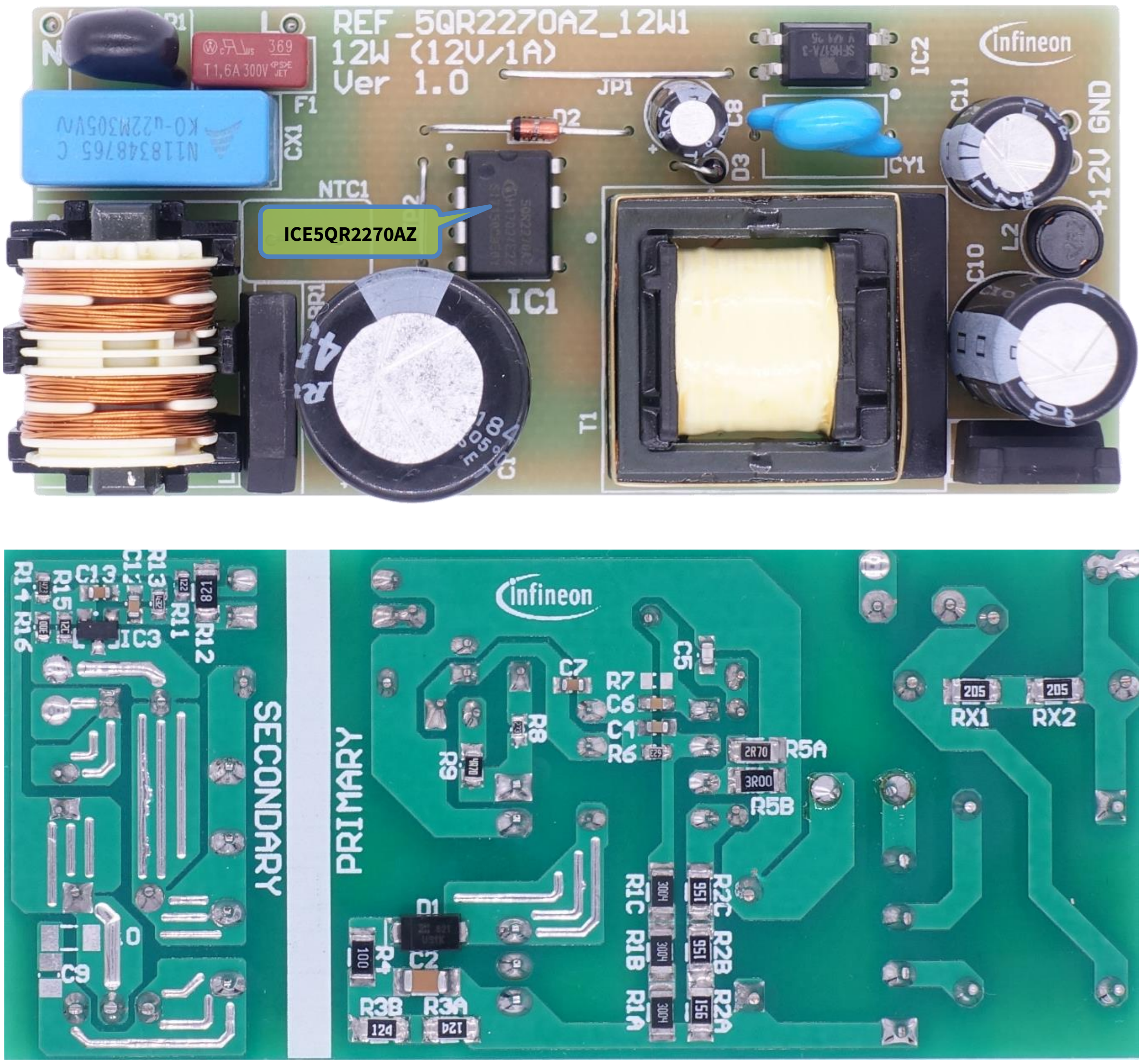


Figure 2 REF_5QR2270AZ_12W1 top and bottom

3 Power supply specifications

The table below shows the minimum acceptable performance of the design at 25°C ambient temperature. Actual performance is listed in the measurements section.

Table 2 Specifications of REF_5QR2270AZ_12W1

Description	Symbol	Min.	Typ.	Max.	Units	Comments
Input						
Voltage	V_{IN}	85	–	264	V AC	Two-wire (no P.E.)
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load input power	P_{stby_NL}	–	–	75	mW	220 V AC
Output						
Output voltage	V_{OUT}	–	12	–	V	± 1 percent
Output current	I_{OUT}	–	–	1	A	
Output power	P_{OUT_Nom}	–	–	12	W	
Output voltage ripple	V_{RIPPLE}	–	–	100	mV	20 MHz bandwidth
Output over-current protection	I_{OCP}	–	1.4	–	A	
Start-up time	t_{start_up}	–	–	250	ms	
Efficiency						
Maximum power	η	89	–	–	%	115 V AC/220 V AC
Average efficiency (25 percent, 50 percent, 75 percent and 100 percent)	η_{avg}	88	–	–	%	
10 percent load efficiency	$\eta_{10\%}$	80	–	–	%	
Environmental						
Conducted EMI			6		dB	Margin, CISPR 22 class B
ESD			±8		kV	EN 61000-4-2
Surge immunity						EN 61000-4-5
Differential Mode (DM)			± 2		kV	
Common Mode (CM)			± 4		kV	
Ambient temperature	T_{amb}	0	–	50	°C	Free convection, sea level
Form factor			80 × 36 × 30		mm^3	L × W × H

4 Circuit diagram

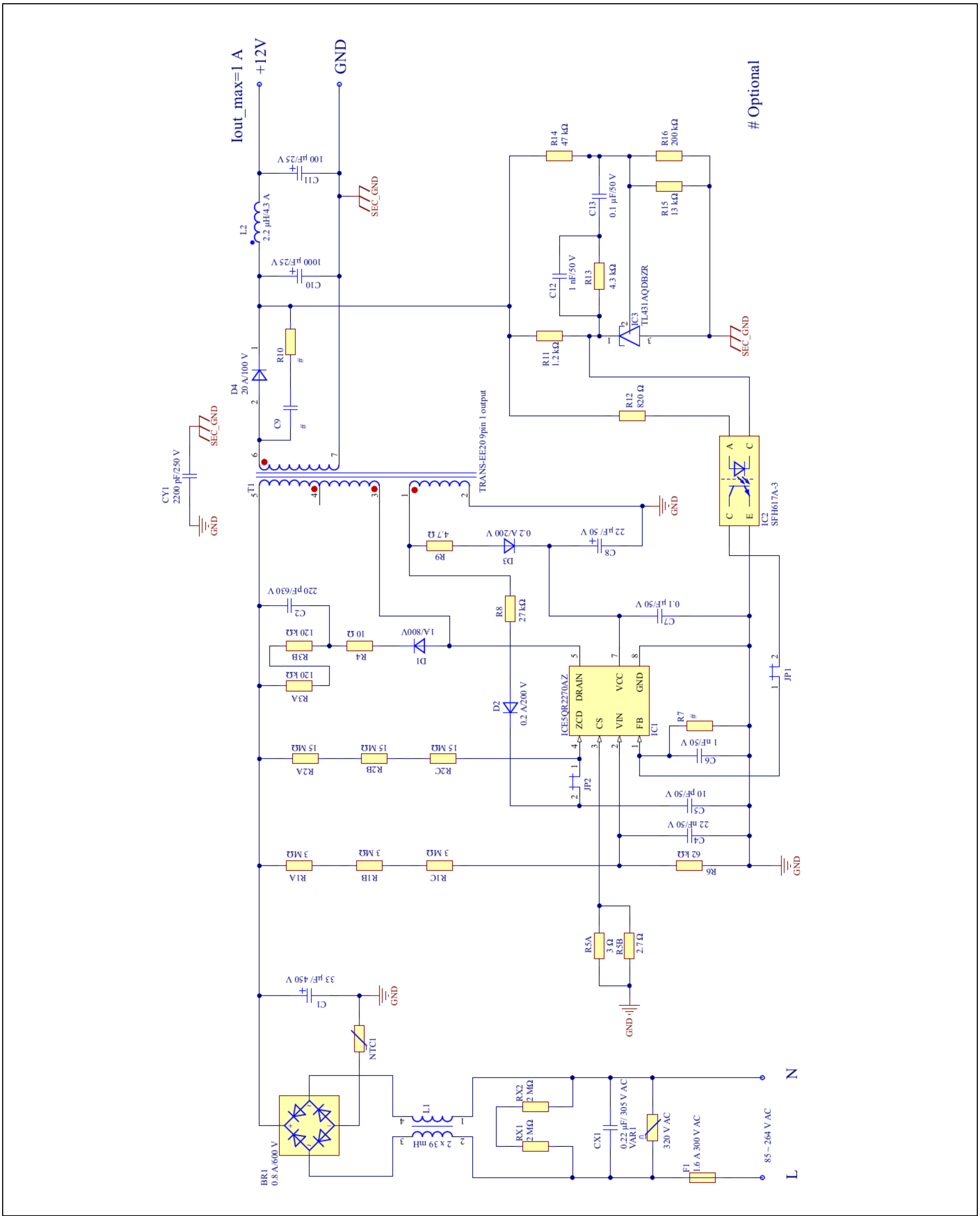


Figure 3 Schematic diagram of REF_5QR2270AZ_12W1

5 Circuit description

In this section, the reference design circuit for refrigerator auxiliary power supply will be briefly described by the different functional blocks. For details of the design procedure and component selection for the Flyback circuitry, please refer to the IC design guide [2] and calculation tool [3].

5.1 EMI filtering and line rectification

The input of the refrigerator auxiliary power unit is taken from the AC power grid, which is in the range of 85 V AC ~ 264 V AC. The fuse F1 is directly connected to the input line to protect the system in case of excess current entering the system circuit due to any fault. Following is the varistor VAR1, which is connected across L and N to absorb the line surge transient. CM choke L1 and X-capacitor CX1 are filters to attenuate the DM and CM conducted EMI noise. Resistors RX1 and RX2 are used to discharge the X-capacitor when the AC is off in order to fulfill the IEC61010-1 and UL1950 safety requirement. The bridge rectifier BR1 rectifies the AC input into DC voltage, filtered by the bulk capacitor C1.

5.2 Flyback converter power stage

The Flyback converter power stage consists of transformer T1, a primary HV MOSFET (integrated into ICE5QR2270AZ), secondary rectification diode D4 and secondary output capacitors and filtering (C10, L2 and C11).

When the integrated HV MOSFET turns on, energy is stored in the transformer. When it turns off, the stored energy is discharged to the output capacitors and into the output load.

Secondary winding is sandwiched between two layers of primary winding to reduce leakage inductance. This improves efficiency and reduces voltage spikes.

For the output rectification, lower forward voltage and ultra-fast recovery diodes can improve efficiency. Capacitor C10 stores the energy needed during output load jumps, and it should have low ESR. LC filter L2 and C11 reduces the high-frequency ripple voltage.

5.3 Control of Flyback converter through fifth-generation QR CoolSET™ ICE5QR2270AZ

5.3.1 Integrated HV power MOSFET

The ICE5QR2270AZ CoolSET™ is a seven-pin device in a DIP-7 package. It has been integrated with the new QR PWM controller and all necessary features and protections, and most importantly the 700 V power MOSFET, Infineon superjunction (SJ) CoolMOS™. Hence, the schematic is much simplified and the circuit design is made much easier.

5.3.2 Fast self-start-up and sustaining of V_{CC}

The IC uses a cascode structure to fast-charge the V_{CC} capacitor. Pull-up resistors R2A, R2B and R2C connected to the multi-function ZCD pin (pin 4) is used to initiate the start-up phase. At first, 0.2 mA is used to charge the V_{CC} capacitor from 0 V to 1.1 V. This is a protection which reduces the power dissipation of the power MOSFET during V_{CC} short-to-GND condition. Thereafter, a much higher charging current of 3.2 mA will charge the V_{CC} capacitor until the V_{CC_ON} is reached. Start-up time of less than 250 ms is achievable with a V_{CC} capacitor of 22 µF.

After start-up, the IC V_{CC} supply is sustained by the auxiliary winding of transformer T1, which needs to support the V_{CC} to be above Under-Voltage Lockout (UVLO) voltage (10 V typ.) through the rectifier circuit R9, D3 and C8.

5.3.3 QR switching with valley sensing

ICE5QR2270AZ is a QR Flyback controller, which turns the HV MOSFET on at the lowest valley point of the drain voltage to minimize the switching losses. The IC senses the valley point through the ZCD pin (pin 4), which monitors auxiliary winding voltage through R8, D2 and C5 together with the internal resistor R_{ZCD}. When the ZCD voltage drops below 100 mV (typ.), the HV MOSFET switches on.

The IC employs digital frequency reduction to avoid the inherent increasing switching frequency during load reduction of QR operation. With ICE5QR2270AZ, the HV MOSFET switches on from first to eighth valley for low-line or third to tenth valley for high-line.

5.3.4 Current Sensing (CS)

The ICE5QR2270AZ is a current mode controller. The peak current is controlled cycle-by-cycle through the CS resistors R5A and R5B in the CS pin (pin 3). Transformer saturation can be avoided through Peak Current Limitation (PCL); therefore, the system is more protected and reliable.

5.3.5 Feedback (FB) and compensation network

V_{OUT} is sensed by resistor dividers R14, R15 and R16 connected to the input of error amplifier TL431 (IC3). A type-2 compensation network (C12, C13 and R13) is connected to the input and output of IC3. The output of IC3 is coupled to the FB pin via optocoupler IC2.

The FB pin of ICE5QR2270AZ is a multi-function pin, which is used to select the entry/exit burst power level through a resistor at the FB pin (R7) and also the burst-on/burst-off sense input during ABM.

5.3.6 System robustness and reliability through protection features

Protection is one of the major factors in determining whether the system is safe and robust – therefore sufficient protection is necessary. ICE5QR2270AZ provides comprehensive protection to ensure the system is operating safely. This includes brown-in/brown-out, V_{IN} OV, V_{OUT} OV, V_{CC} OV and UV, open-loop/over-load, over-temperature, CS short-to-GND and V_{CC} short-to-GND. When those faults are found, the system will enter protection mode. Once the fault is removed, the system resumes normal operation. A list of protections and the failure conditions is shown in the table below.

Table 3 Protection functions of ICE5QR2270AZ

Protection function	Failure condition (typical values)	Protection mode
V_{CC} OV	V_{VCC} more than 25.5 V	Odd-skip auto-restart
V_{CC} UV	V_{VCC} less than 10 V	Auto-restart
V_{OUT} OV	V_{ZCD} more than 2 V for 10 consecutive pulses	Non-switch auto-restart
V_{IN} OV	V_{VIN} more than 2.9 V	Non-switch auto-restart
Brown-in/brown-out	V_{VIN_BI} less than 0.66 V/V_{VIN_BO} less than 0.40 V	Non-switch auto-restart
Open-loop/over-load	V_{FB} more than 2.75 V and lasts for 30 ms	Odd-skip auto-restart
Over-temperature	T_J more than 140°C (40°C hysteresis)	Non-switch auto-restart
CS short-to-GND	V_{CS} less than 0.1 V, lasts for 5 µs and three consecutive pulses	Odd-skip auto-restart

Protection function	Failure condition (typical values)	Protection mode
V_{CC} short-to-GND (V_{VCC} = 0 V, start-up = 50 MΩ and V_{DRAIN} = 90 V)	V_{VCC} less than 1.1 V, $I_{VCC\_Charge1}$ ≈ -0.2 mA	Cannot start up

5.4 Clamper circuit

A clamper network consisting of D1, C2, R4, R3A and R3B is used to reduce the switching voltage spikes across the DRAIN pin, which are generated from the leakage inductance of the transformer T1. This is a dissipative circuit; therefore, R3A, R3B and C2 need to be fine-tuned depending on the voltage derating factor and efficiency requirement.

5.5 PCB design tips

For a good PCB design layout, there are several points to note.

- The switching power loop needs to be as small as possible (see Figure 4). There are two power loops in the reference design; one on the primary side and one on the secondary side. The primary-side loop starts from the bulk capacitor (C1) positive terminal, primary transformer winding (pin 4 and pin 6 of T1), CoolSET™, CS resistors and back to the C1 negative terminal. The secondary-side loop starts at the secondary transformer winding (pin 8 of T1), output diode D4, output capacitor C10 and back to pin 11 of T1.

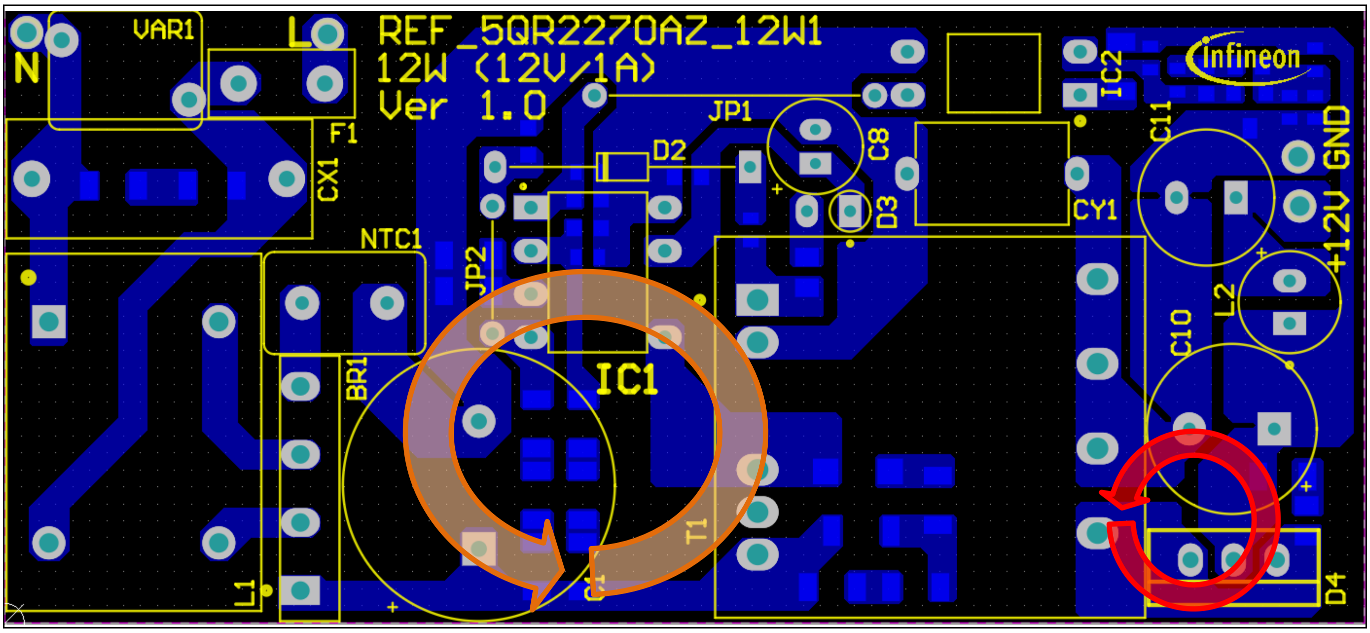


Figure 4 PCB layout tips

- Star-ground connection should be used to reduce HF noise coupling, which can affect the functional operation. The ground of the small-signal components, e.g. R6, R7, C4, C5, C6, C7, and the emitter of the optocoupler (pin 3 of IC2) should connect directly to the IC ground (pin 8 of IC1).
- Separating the HV components and LV components, e.g. clamper circuit (D1, C2, R3A, R3B and R4), at the bottom part of the PCB and the other LV components at the upper part of the PCB can reduce the spark-over chance of the high energy surge during ESD or a lightning surge test.
- Make the PCB copper pour on the DRAIN pin of the MOSFET cover as wide an area as possible to act as a heatsink.

5.6 EMI reduction tips

EMI compliance is always a challenge for the power supply designer. There are several critical points to consider in order to achieve a satisfactory EMI performance.

- A proper transformer design can significantly reduce EMI. Low leakage inductance can incur a low switching spike and HF noise. Interlaced winding technique is the most common practice to reduce leakage inductance. Winding shield, core shield and whole transformer shield are also some of the techniques used to reduce EMI.
- Input CMC and X-capacitor greatly reduce EMI, but this is costly and impractical especially for low-power applications.
- Short-switching power-loop design in the PCB (as described in section 5.5) can reduce radiated EMI due to the antenna effect.
- The Y-capacitor CY1 dampens the HF noise generated between the primary and secondary, thus reducing the EMI noise.
- The secondary diode snubber circuit (R10 and C9) can reduce HF noise.
- Ferrite beads can reduce HF noise, especially on critical nodes such as the DRAIN pin, clamper diode and secondary diode terminals. There is no ferrite bead used in this design, as this can reduce the efficiency due to additional losses, especially on the MOSFET and secondary diode.

6 PCB layout

6.1 Top side

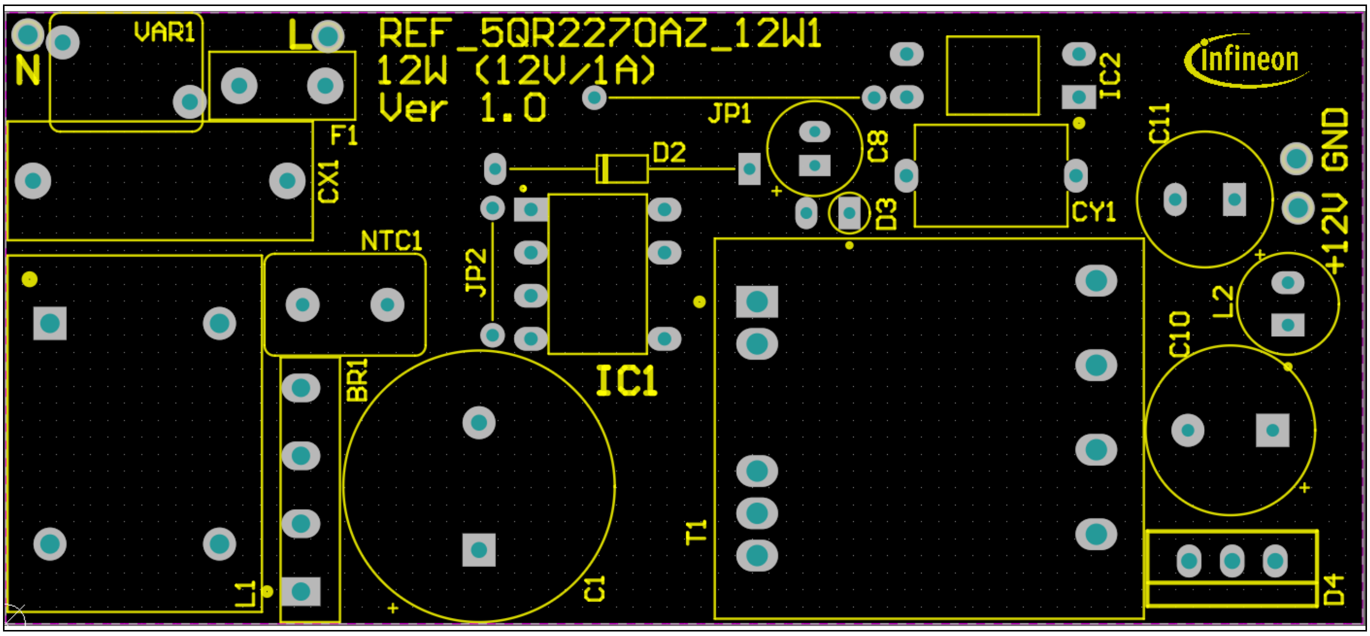


Figure 5 Top side component legend

6.2 Bottom side

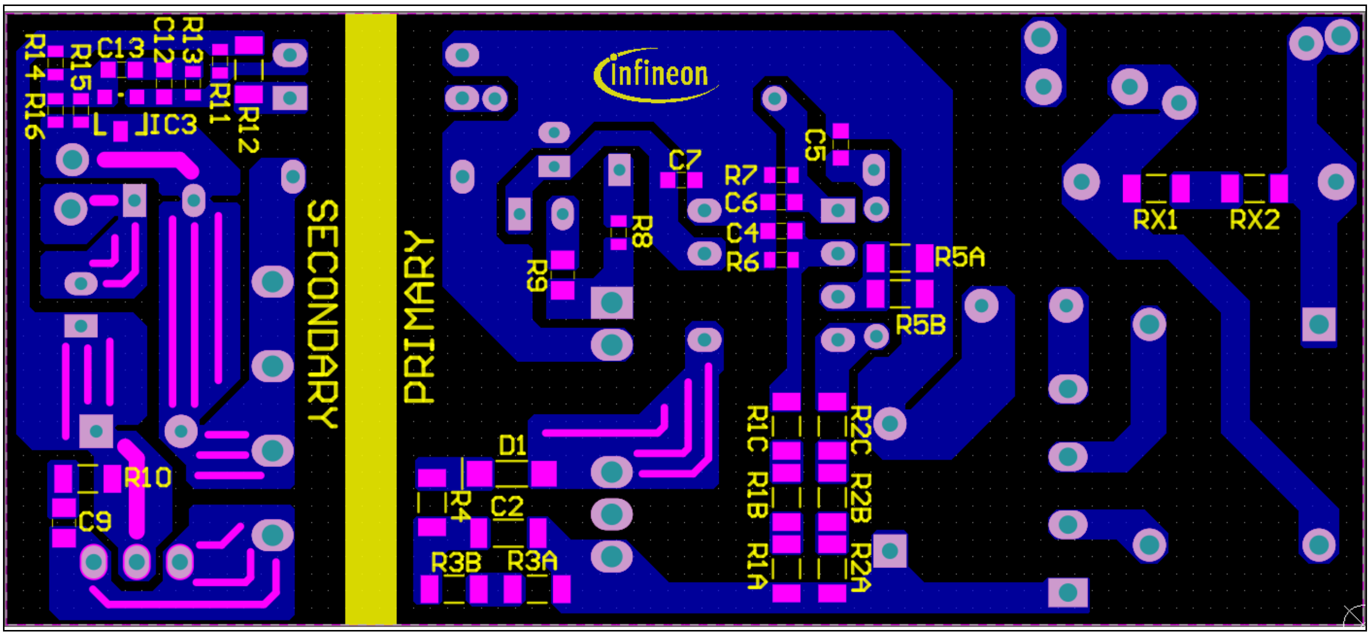


Figure 6 Bottom side copper and component legend

7 BOM

Table 4 BOM

Item	Designator	Description	Part no.	Manufacturer	Qty.
1	BR1	1 A/600 V	KBP06G	Shindengen	1
2	C1	33 µF/450 V	450BXC33MEFC16X25	Rubycon	1
3	C2	220 pF/630 V/1206			1
4	C4	22 nF/50 V/0603			1
5	C5	47 pF/50 V/0603			1
6	C6	4.7 nF/50 V/0603			1
7	C12	1 nF/50 V/0603			1
8	C7, C13	100 nF/50 V/0603			2
9	C8	22 µF/50 V	50PX22MEFC5X11	Rubycon	1
10	C10	1000 µF/25 V	25ZLH1000MEFC10X23	Rubycon	1
11	C11	220 µF/25 V	25ZLG220MEFC8X11.5	Rubycon	1
12	CX1	0.22 µF/305 V/X2	B32922C3224	Epcos	1
13	CY1	2200 pF/250 V/X1/Y1	DE1E3KX222MA4BN01F	Murata	1
14	D1	1 A/800 V	US1K-13-F		1
15	D2	0.2 A/150 V	FDH400		1
16	D3	0.2 A/200 V	1N485B		1
17	D4	20 A/100 V	STPS20M100SFP		1
18	F1	1.6 A/300 V	36911600000	Littlefuse	1
19	IC1	QR CoolSET™	ICE5QR2770AZ	Infineon	1
20	IC2	Optocoupler	SFH617A-3		1
21	IC3	2.5 V_{ref}	TL431AQDBZR		1
22	JP1, JP2		Jumper		2
23	L1	2 x 39 mH	750343586	Wurth Electronics	1
24	L2	2.2 µH/4.3 A	7447462022	Wurth Electronics	1
25	NTC1	Shorted			1
26	R1A, R1B, R1C	3 MΩ/0.25 W/1 percent/1206			3
27	R2A, R2B, R2C	15 MΩ/0.25 W/5 percent/1206			3
28	R3A, R3B	120 kΩ/0.25 W/5 percent/1206			2
29	R4	10 Ω/0.25 W/5 percent/1206			1
30	R5A	2.7 Ω/0.25 W/1 percent/1206			1
31	R5B	3 Ω/0.25 W/1 percent/1206			1
32	R6	62 kΩ/0.1 W/1 percent/0603			1
33	R8	27 kΩ/0.1 W/1 percent/0603			1
34	R9	4.7 Ω/0.1 W/5 percent/0805			1
35	R11	1.2 kΩ/0.1 W/5 percent/0603			1
36	R12	820 Ω/0.25 W/5 percent/1206			1
37	R13	4.3 kΩ/0.1 W/5 percent/0603			1
38	R14	47 kΩ/0.1 W/1 percent/0603			1
39	R15	13 kΩ/0.1 W/1 percent/0603			1

40	R16	200 kΩ/0.1 W/1 percent/0603			1
41	RX1, RX2	2 MΩ/0.25 W/5 percent/1206			2
42	T1	1.3 mH/EE20	750344229	Wurth Electronics	1
43	VAR1	Varistor, 0.3 W/320 V	ERZE07A511	Panasonic	1
44	PCB	80 mm x 36 mm(L x W), single layer, 2 oz., FR-4			1

8 Transformer specification

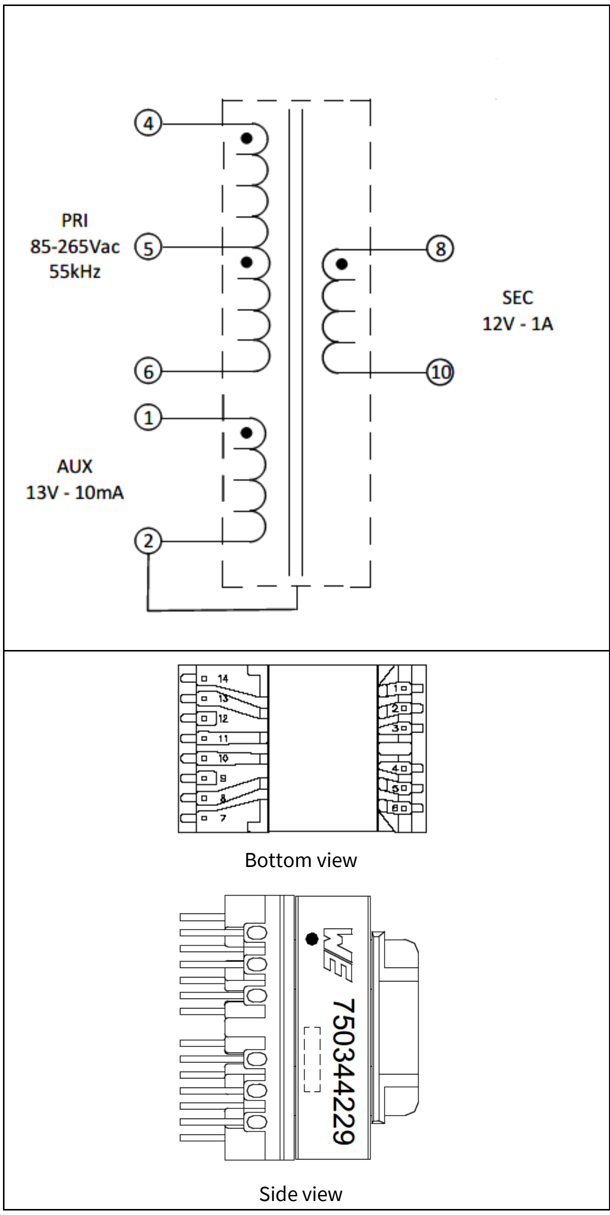
Refer to Appendix A: Transformer design and spreadsheet [3] for transformer design and Appendix B: WE transformer specification for WE transformer specification.

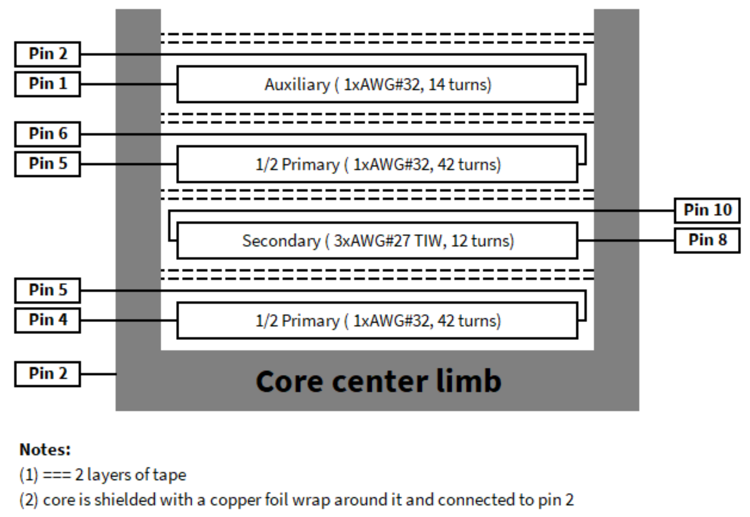
Wurth Electronics core part number: 150-1945 (EE20/10/6)

Wurth Electronics bobbin: 070-5643 (14-Pin EXT, THT, horizontal version)

Primary inductance: L_P = 1300 µH (±10 percent), measured between pin 4 and pin 6

Manufacturer and part number: Wurth Electronics Midcom (750344229)





Wire size requirement :

Start	Stop	No. of turns	Wire size	Layer
4	5	42	1 x AWG#32	1/2 Primary
8	10	12	3 x AWG#27 TIW	Secondary
5	6	42	1 x AWG#32	1/2 Primary
1	2	14	1 x AWG#32 (Spread)	Auxiliary

Figure 7 Transformer structure

9 Measurement data and graphs

Table 5 Measurement data

Input (V AC/Hz)	Loading condition	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Efficiency (%)	Average efficiency (%)	OLP P_{IN} (W)	OLP I_{OUT} (A)
85 V AC/ 60 Hz	No load	0.034	12.055	0.0000	0.00			17.11	1.24
	10 percent load	1.413	12.054	0.1000	1.21	85.29			
	25 percent load	3.404	12.052	0.2506	3.02	88.73	88.64		
	50 percent load	6.776	12.050	0.5006	6.03	89.03			
	75 percent load	10.165	12.047	0.7506	9.04	88.96			
	100 percent load	13.720	12.044	1.0006	12.05	87.84			
115 V AC/ 60 Hz	No load	0.038	12.055	0.0000	0.00			18.56	1.36
	10 percent load	1.424	12.053	0.1000	1.21	84.65			
	25 percent load	3.394	12.052	0.2506	3.02	89.00	89.51		
	50 percent load	6.730	12.049	0.5006	6.03	89.62			
	75 percent load	10.066	12.047	0.7506	9.04	89.84			
	100 percent load	13.453	12.044	1.0006	12.05	89.58			
220 V AC/ 50 Hz	No load	0.057	12.056	0.0000	0.00			19.83	1.48
	10 percent load	1.419	12.049	0.1000	1.20	84.94			
	25 percent load	3.447	12.045	0.2506	3.02	87.57	89.25		
	50 percent load	6.739	12.043	0.5006	6.03	89.46			
	75 percent load	10.051	12.039	0.7506	9.04	89.91			
	100 percent load	13.373	12.036	1.0006	12.04	90.06			
264 V AC/ 50 Hz	No load	0.069	12.055	0.0000	0.00			20.69	1.54
	10 percent load	1.445	12.049	0.1000	1.20	83.39			
	25 percent load	3.491	12.043	0.2506	3.02	86.46	88.69		
	50 percent	6.781	12.040	0.5006	6.03	88.89			

	load								
	75 percent load	10.090	12.036	0.7506	9.03	89.53			
	100 percent load	13.396	12.033	1.0006	12.04	89.88			

9.1 Efficiency curve

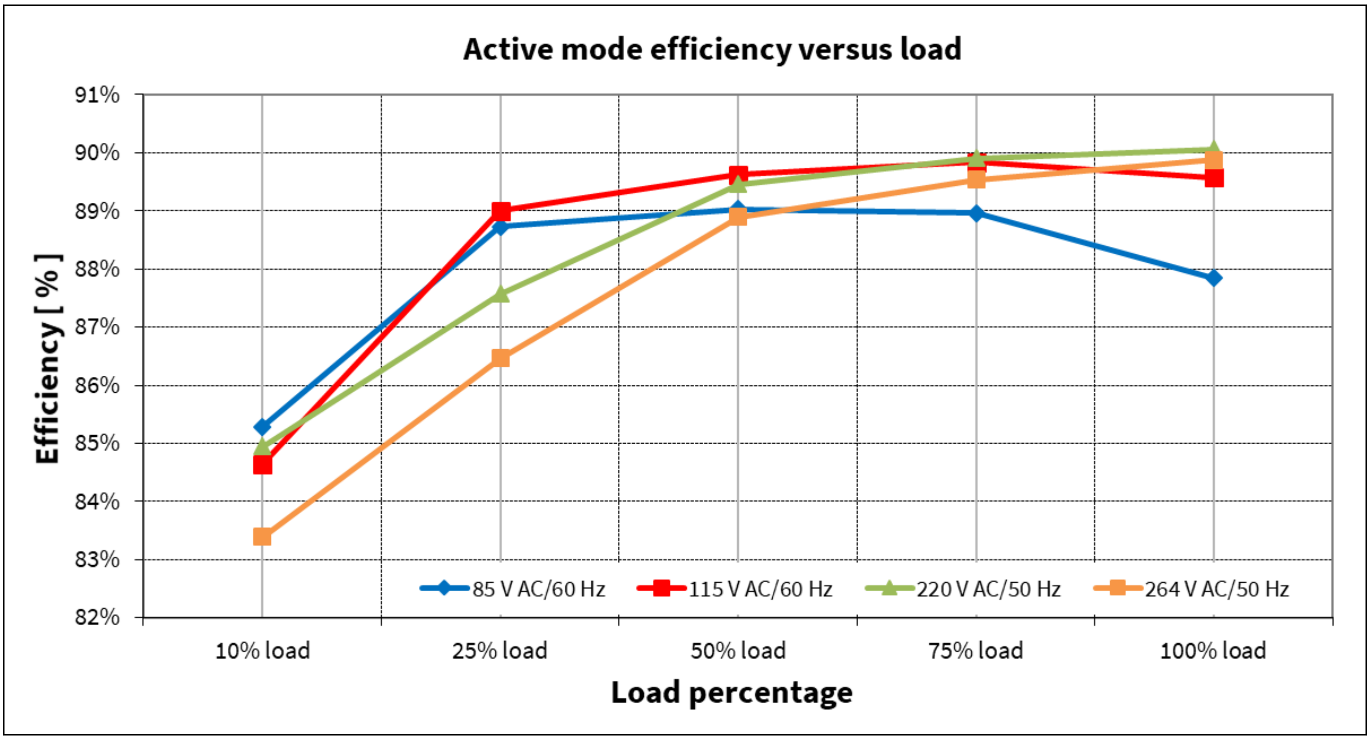


Figure 8 Active mode efficiency vs. load

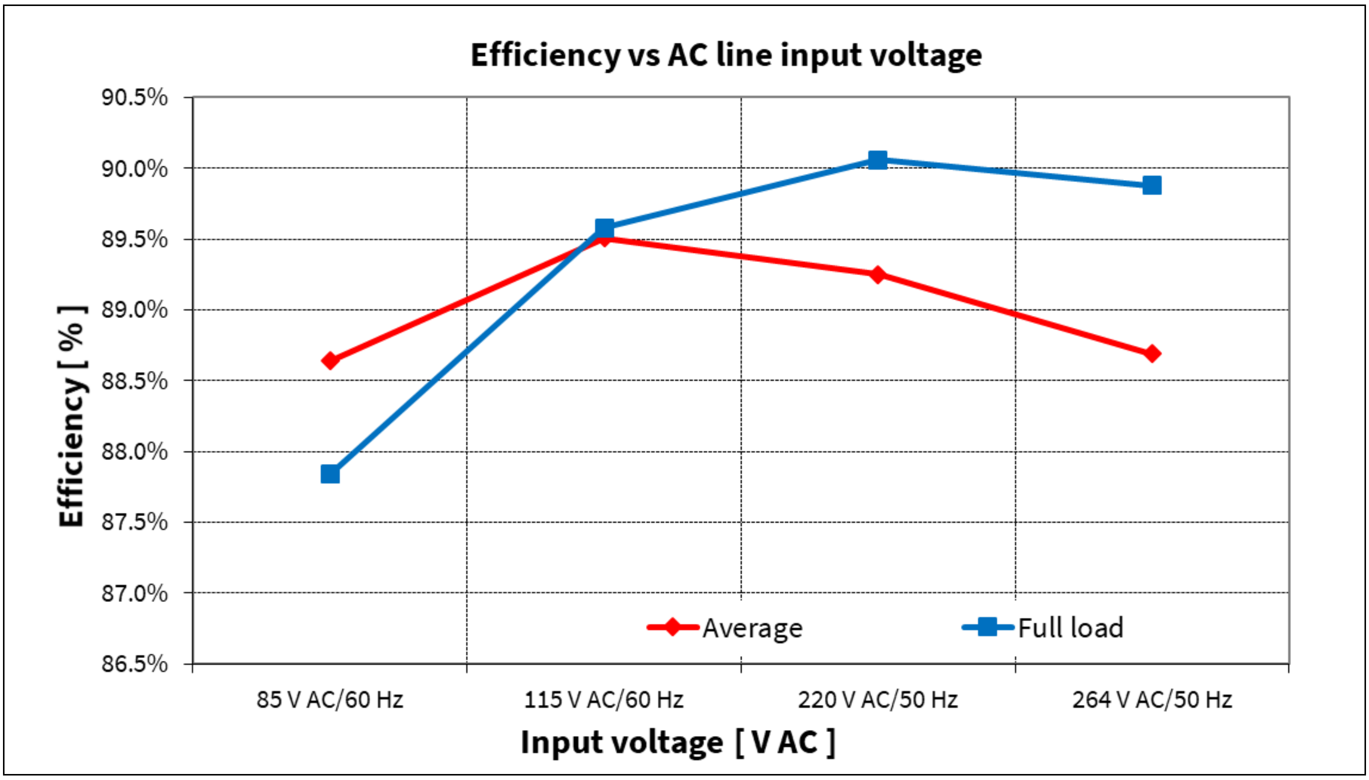


Figure 9 Efficiency vs. AC-line input voltage

9.2 Standby power

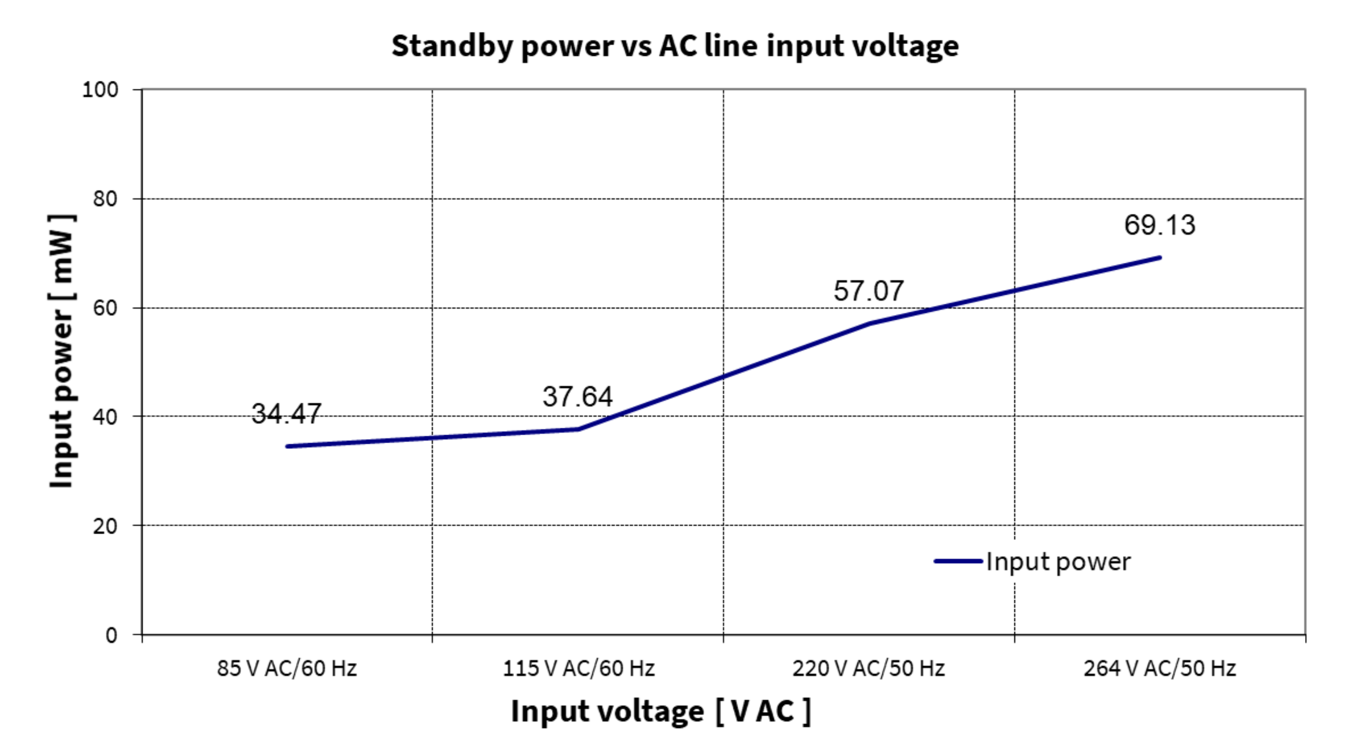


Figure 10 Standby power at no load vs. AC-line input voltage (measured by Yokogawa WT210 power meter – integration mode)

9.3 Line and load regulation

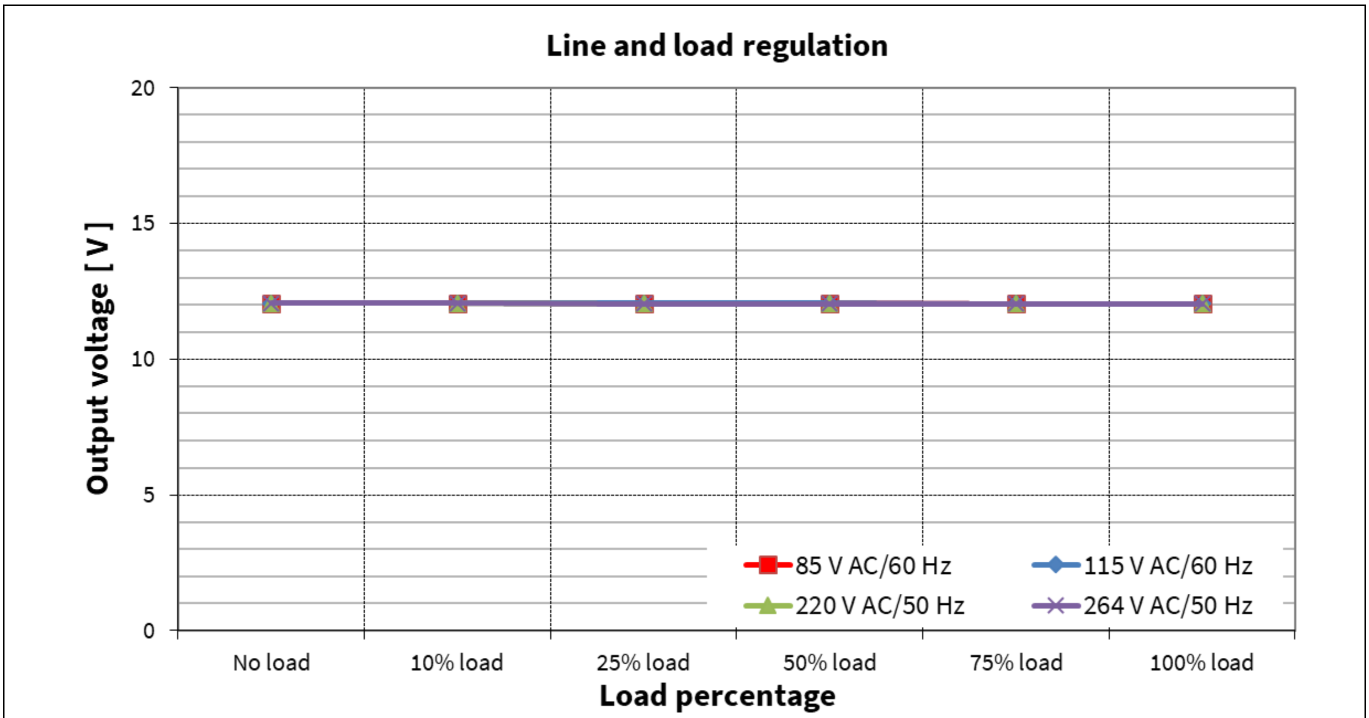


Figure 11 Output regulation vs. load at different AC-line input voltages

9.4 Maximum input power

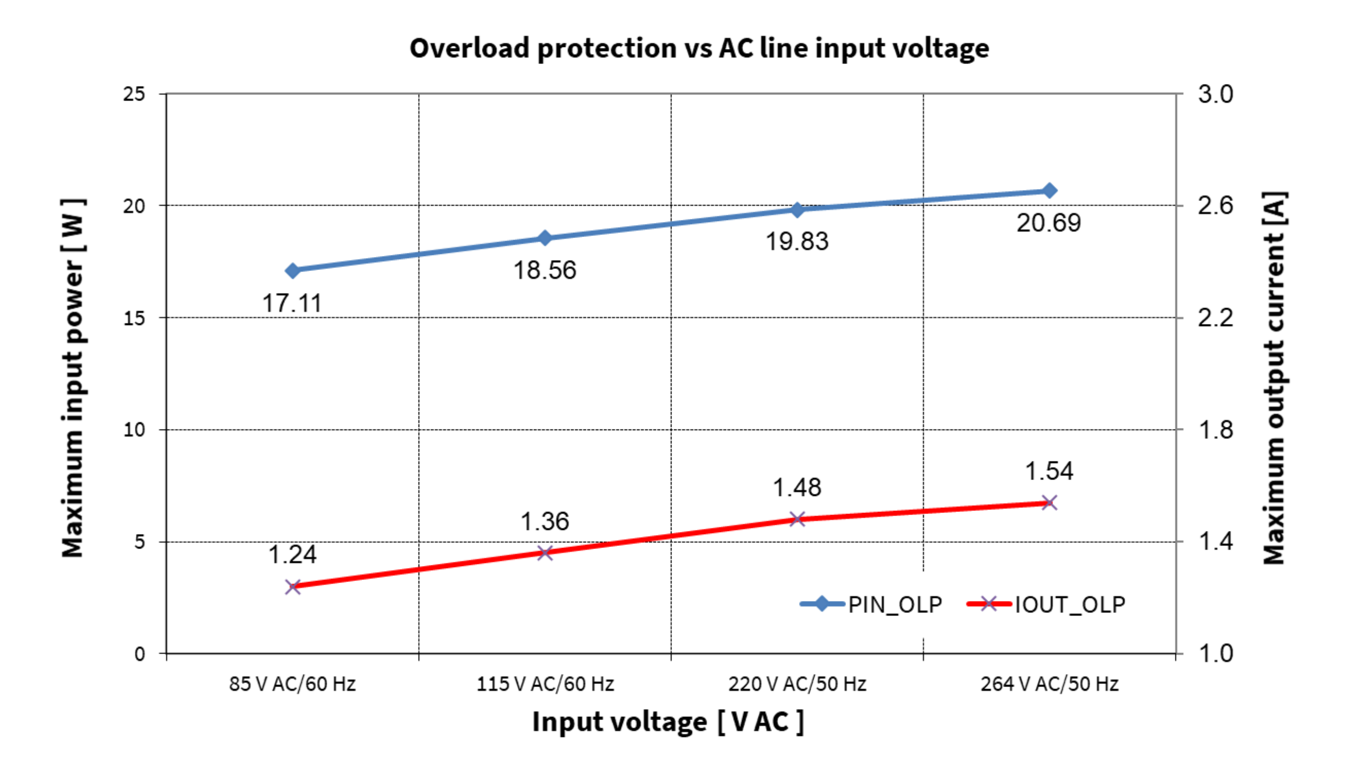


Figure 12 Maximum input power and output current (before over-load protection) vs. AC-line input voltage

9.5 Switching frequency through digital frequency reduction

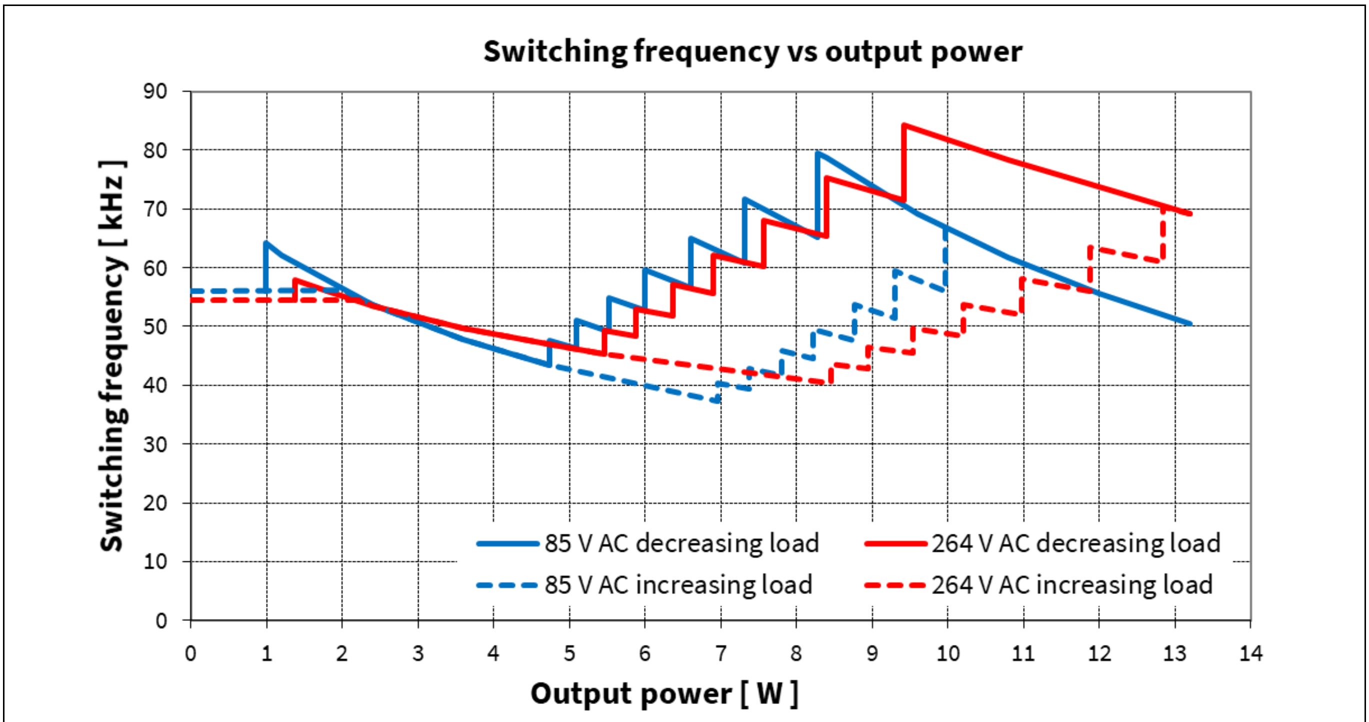


Figure 13 Switching frequency vs. output load

9.6 ESD immunity (EN 61000-4-2)

The reference board was subjected to a ±8 kV contact and air discharge ESD test according to EN 61000-4-2. It was tested at full load (12 W) using resistive load (12 Ω) at an input voltage of 115 V AC and 220 V AC. A test failure was defined as non-recoverable and/or system auto-restart.

- ±8 kV contact discharge: pass
- ±8 kV air discharge: pass

Table 6 System ESD test result

Description	ESD test	Level	Number of strikes		Test result
			+12 V_{OUT}	GND	
115 V AC, 12 W (12 Ω R_{LOAD})	Contact	+8 kV	10	10	Pass
		-8 kV	10	10	Pass
	Air	+8 kV	10	10	Pass
		-8 kV	10	10	Pass
220 V AC, 12 W (12 Ω R_{LOAD})	Contact	+8 kV	10	10	Pass
		-8 kV	10	10	Pass
	Air	+8 kV	10	10	Pass
		-8 kV	10	10	Pass

9.7 Surge immunity (EN 61000-4-5)

The reference board 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 (12 W) using resistive load (12 Ω) at an input voltage of 220 V AC. Output GND is connected to P.E. during testing. A test failure was defined as non-recoverable.

- ±2 kV DM: pass
- ±4 kV CM: pass

Table 7 System surge immunity test result

Description	Test	Level		Number of strikes				Test result
				0 degrees	90 degrees	180 degrees	270 degrees	
220 V AC, 12 W (12 Ω R_{LOAD})	DM	+2 kV	L → N	3	3	3	3	Pass
		-2 kV	L → N	3	3	3	3	Pass
	CM	+4 kV	L → GND	3	3	3	3	Pass
		+4 kV	N → GND	3	3	3	3	Pass
		-4 kV	L → GND	3	3	3	3	Pass
		-4 kV	N → GND	3	3	3	3	Pass

9.8 Conducted emissions (EN 55022 class B)

The conducted EMI was measured by Schaffner (SMR4503) and followed the test standard of EN55022 (CISPR 22) class B. The reference board was tested at full load (12 W) using resistive load (12 Ω) at an input voltage of 115 V AC and 220 V AC.

- 115 V AC: pass with more than 9 dB margin
- 220 V AC: pass with more than 9 dB margin

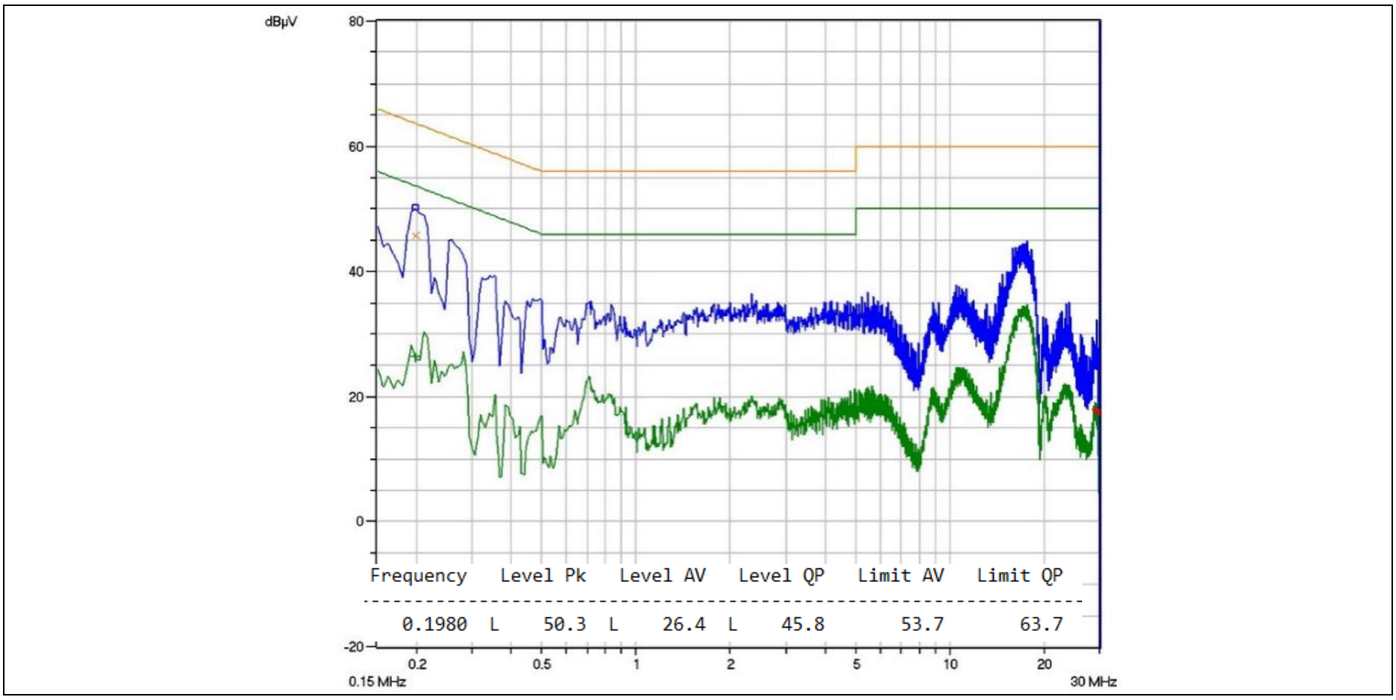


Figure 14 Conducted emissions (line) at 115 V AC and full load

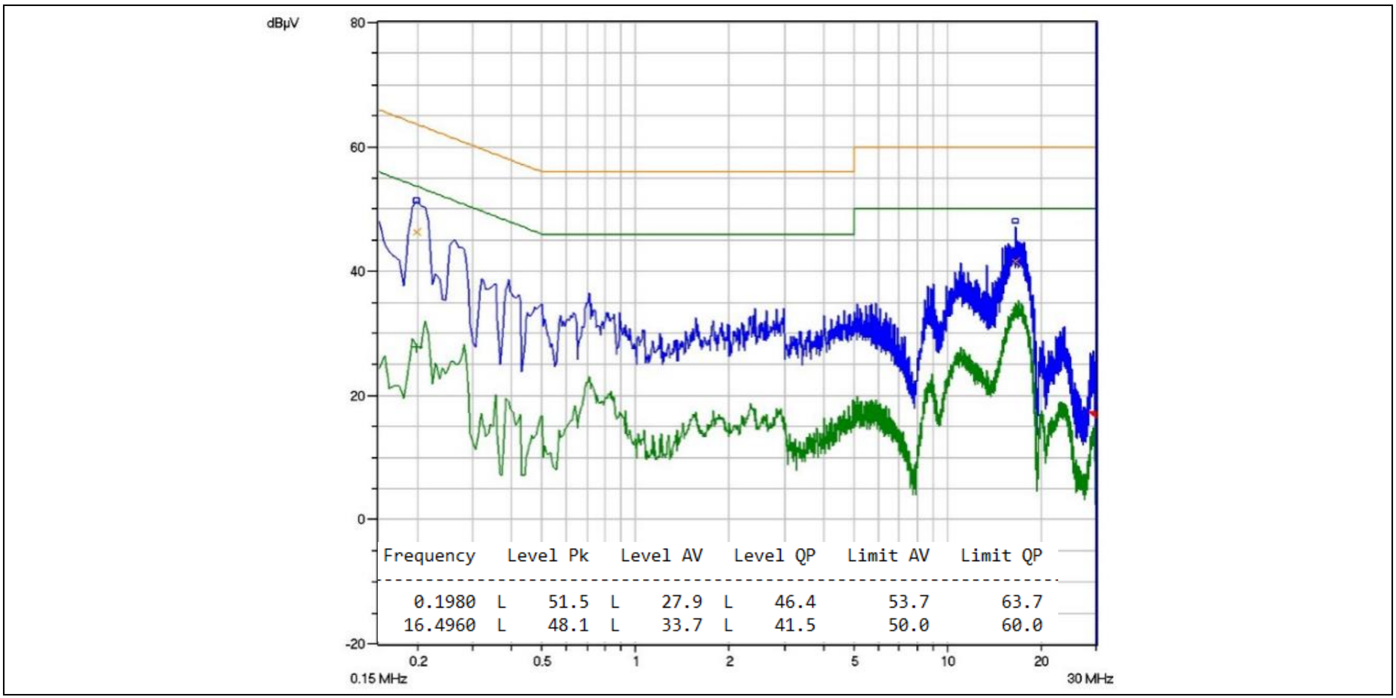


Figure 15 Conducted emissions (neutral) at 115 V AC and full load

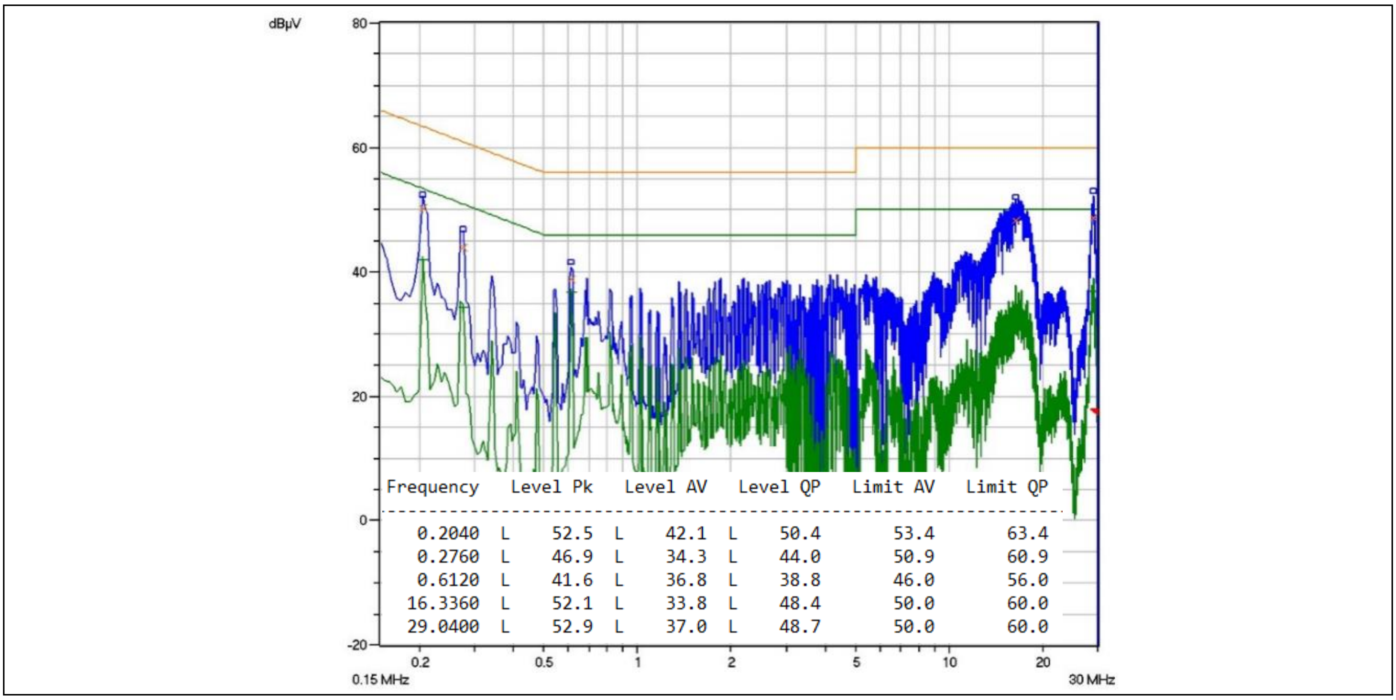


Figure 16 Conducted emissions (line) at 220 V AC and full load

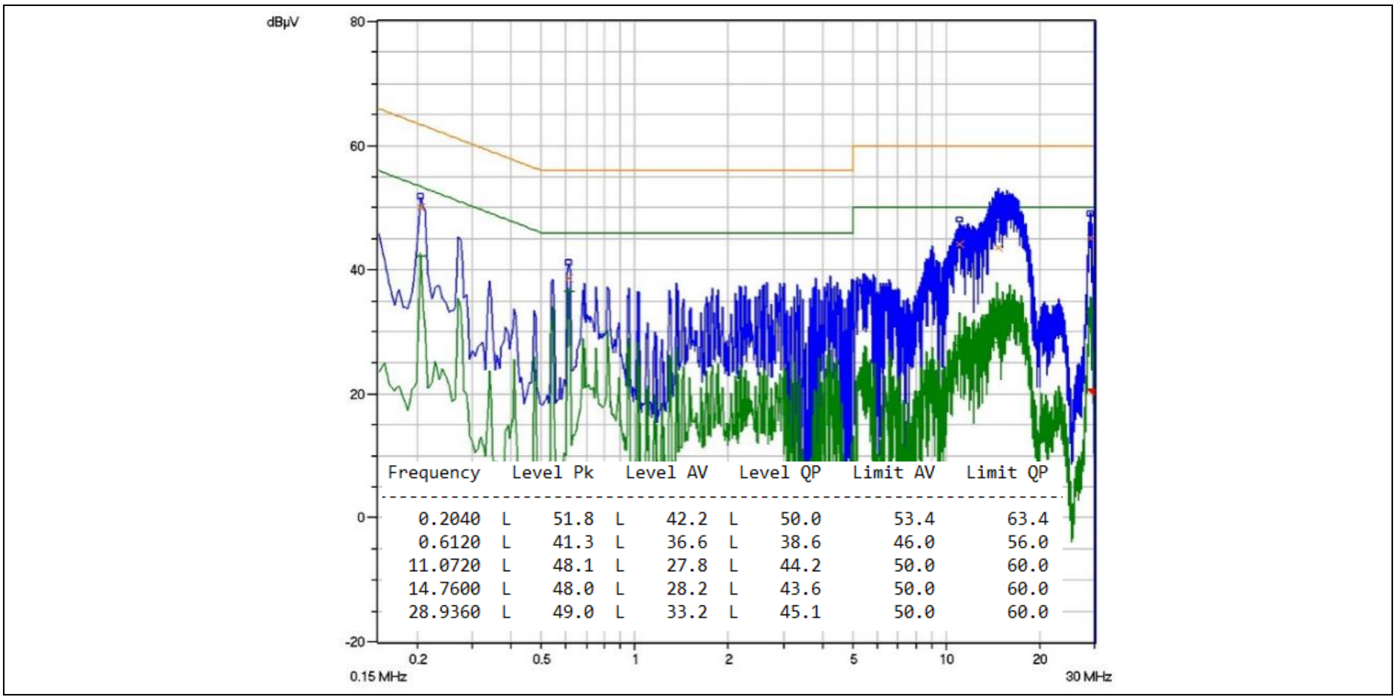


Figure 17 Conducted emissions (neutral) at 220 V AC and full load

9.9 Thermal measurement

Thermal measurement was done using an infrared thermography camera (FLIR-T62101) at an ambient temperature of 25°C, after one hour running at full load. The temperature of the components was taken in an open-frame set-up.

Table 8 Thermal measurement on components (open frame)

No.	Component	Temperature at 85 V AC (°C)	Temperature at 264 V AC (°C)
1	D4 (secondary diode)	53.4	53.1
2	T1 (transformer)	49.3	50.1
3	IC1 (ICE5QR2270AZ)	46.1	43.4
4	PCB (under secondary diode)	47.7	47.4

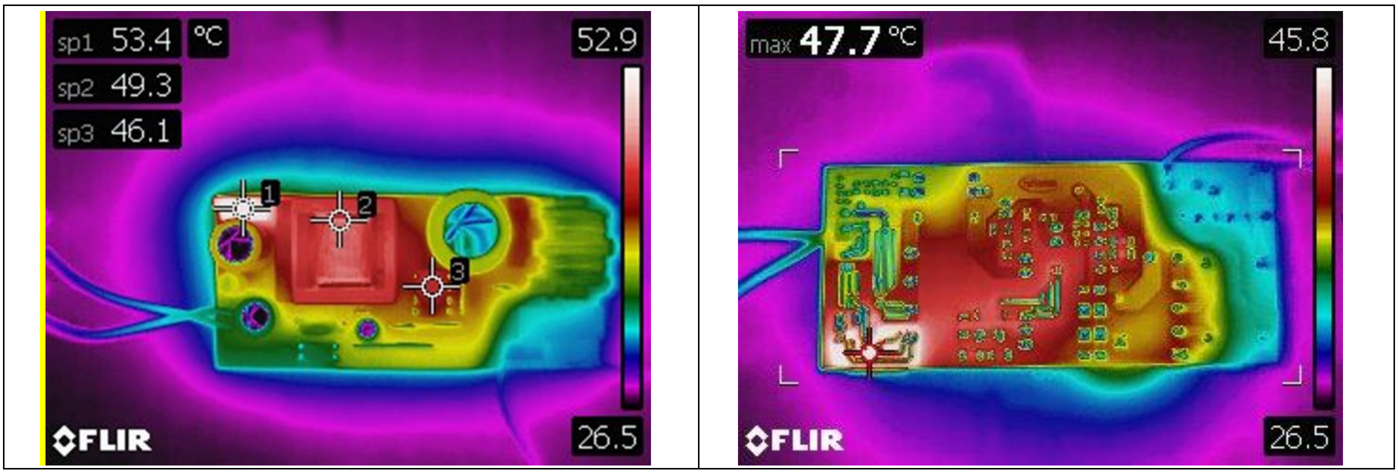


Figure 18 Top layer (left) and bottom layer (right) thermal image at 85 V AC input voltage

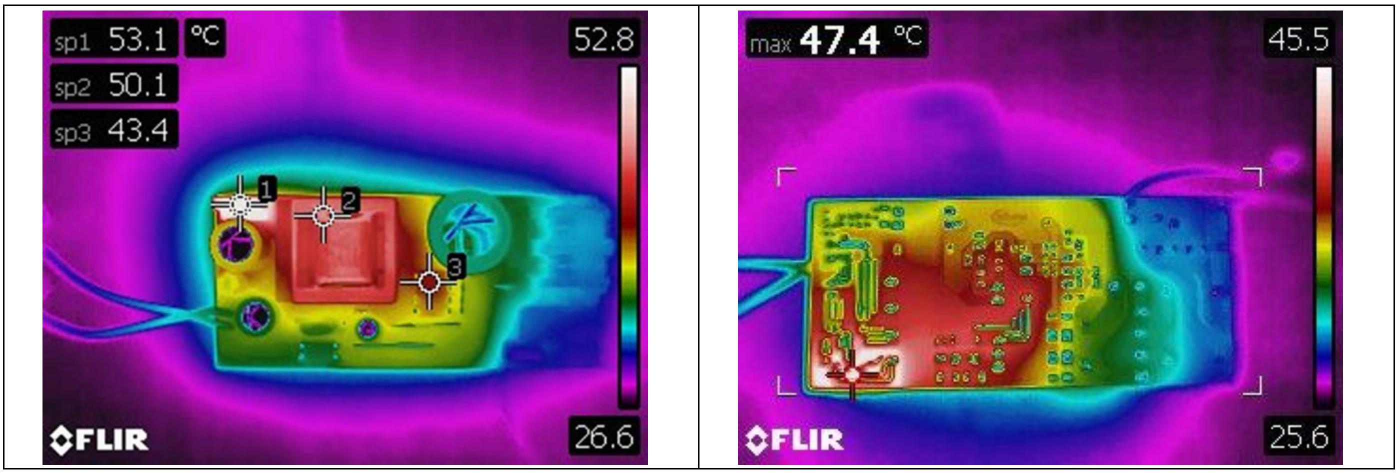


Figure 19 Top layer (left) and bottom layer (right) thermal image at 264 V AC input voltage

10 Waveforms and oscilloscope plots

All waveforms and scope plots were recorded with a LeCroy 44Xi oscilloscope.

10.1 Start-up at full load

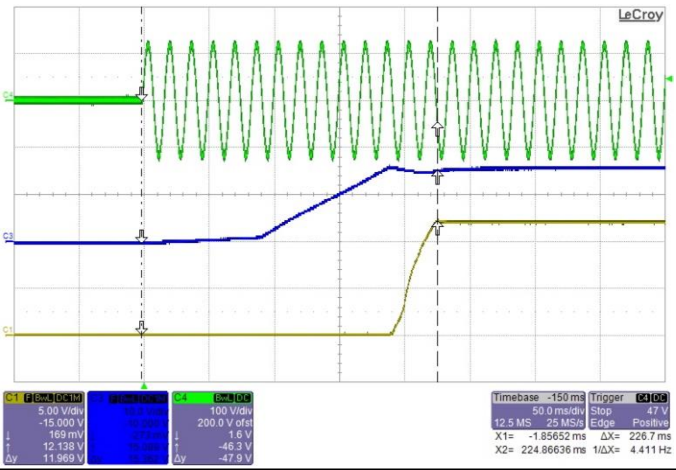
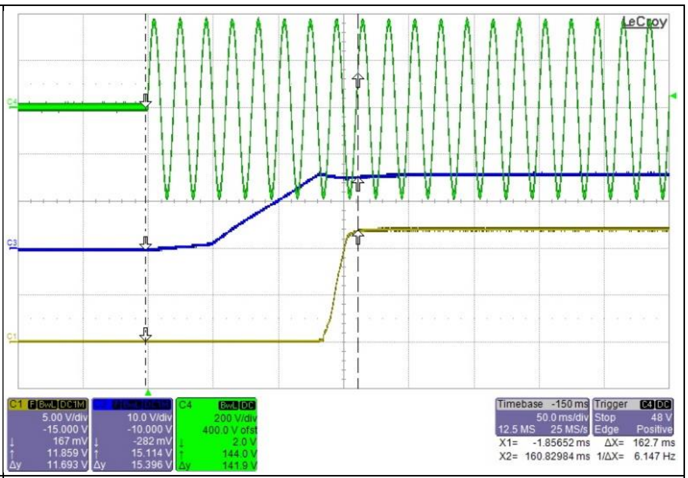
	
C1 (yellow) : +12 V output voltage C3 (blue) : V_{CC} voltage C4 (green) : AC-line voltage	C1 (yellow) : +12 V output voltage C3 (blue) : V_{CC} voltage C4 (green) : AC-line voltage
85 V AC start-up time at full load is less than 230 ms	264 V AC start-up time at full load is less than 170 ms

Figure 20 Start-up

10.2 Soft-start at full load

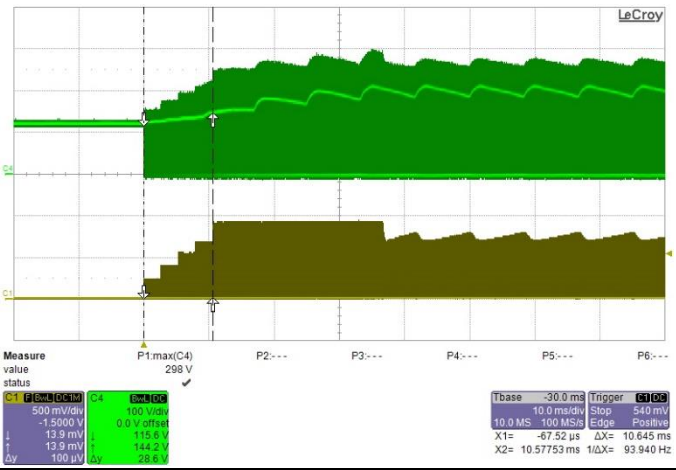
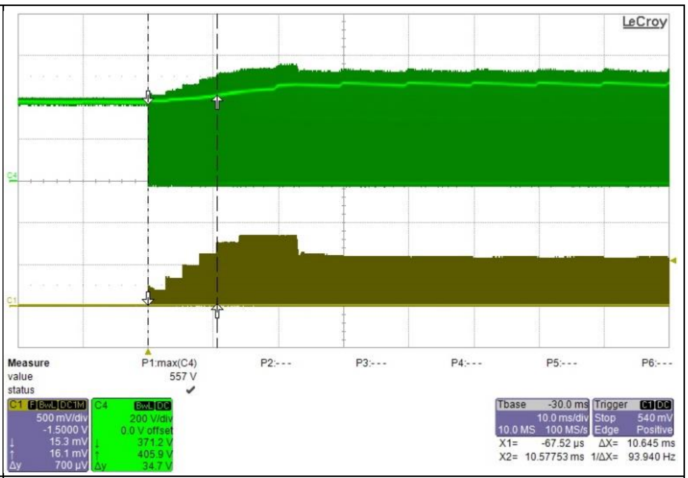
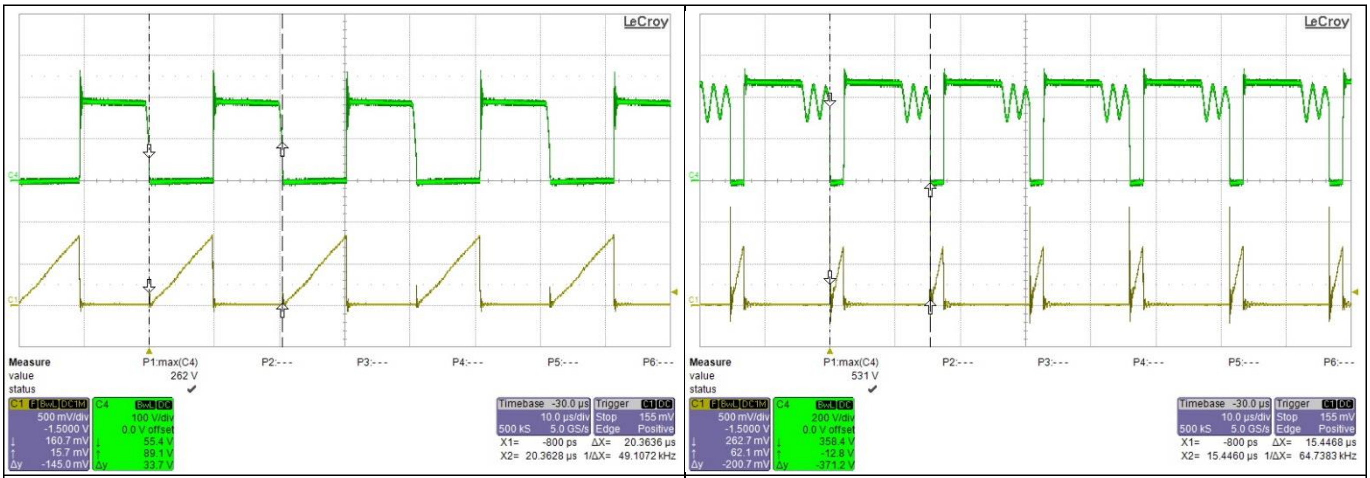
	
C1 (yellow) : CS voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C4 (green) : Drain voltage
85 V AC soft-start time at full load is ~11 ms	264 V AC soft-start time at full load is ~11 ms

Figure 21 Soft-start

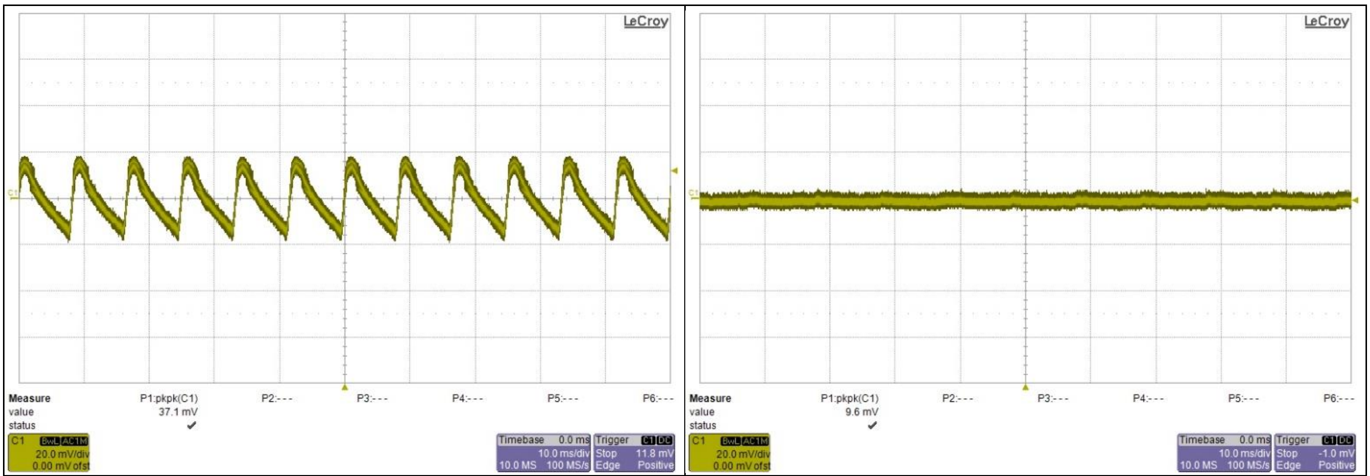
10.3 Drain and CS voltage at full load



C1 (yellow) : CS voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C4 (green) : Drain voltage
85 V AC maximum drain voltage at full load is ~262 V	264 V AC maximum drain voltage at full load is ~531 V

Figure 22 Drain and CS voltage

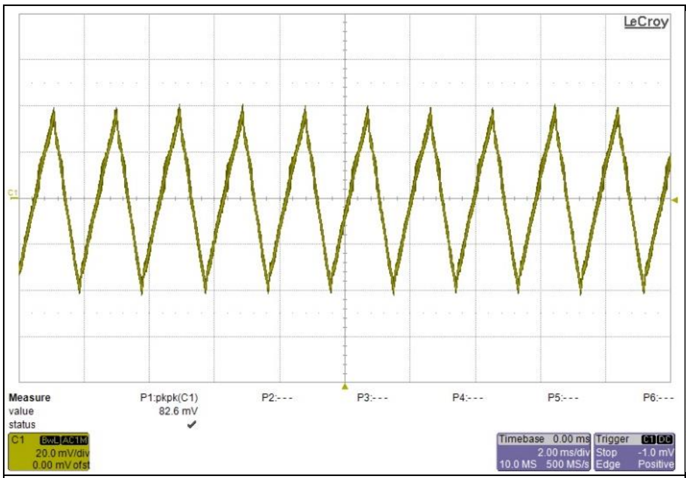
10.4 Output ripple voltage at full load

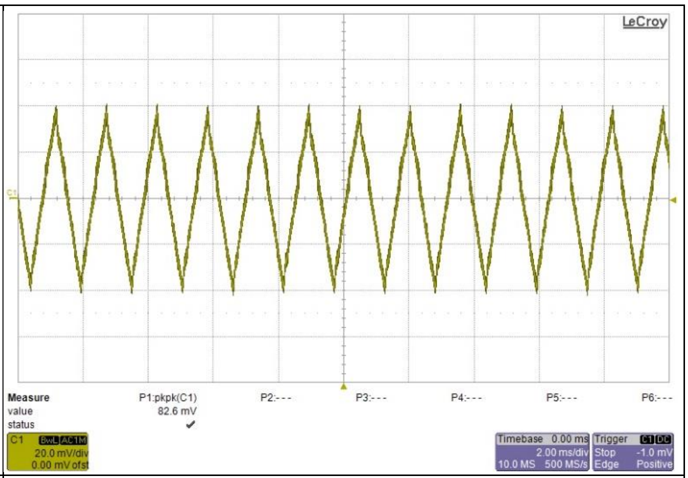


C1 (yellow) : +12 V output voltage	C1 (yellow) : +12 V output voltage
85 V AC +12 V output voltage $V_{ripple\_pk\_pk}$ is ~37 mV	264 V AC +12 V output voltage $V_{ripple\_pk\_pk}$ is ~10 mV

Figure 23 Output ripple voltage at full load. Probe terminals are connected on the PCB end and decoupled with 1 µF electrolytic and 0.1 µF ceramic capacitors. Oscilloscope is bandwidth filter limited to 20 MHz.

10.5 Output ripple voltage at ABM (100 mA load)

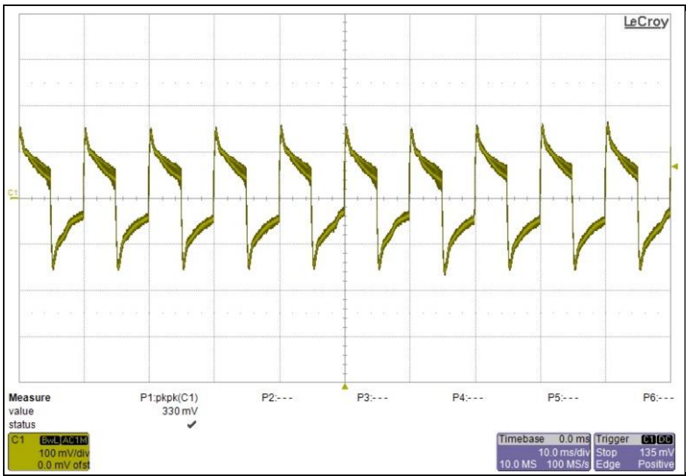


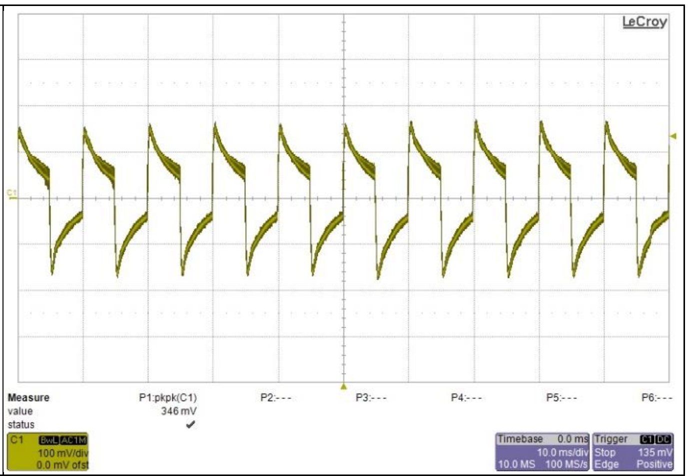


C1 (yellow) : +12 V output voltage	C1 (yellow) : +12 V output voltage
85 V AC +12 V output voltage $V_{ripple\_pk\_pk}$ is ~83 mV	264 V AC +12 V output voltage $V_{ripple\_pk\_pk}$ is ~83 mV

Figure 24 Output ripple voltage at 100 mA load. Probe terminals are connected on the PCB end and decoupled with 1 µF electrolytic and 0.1 µF ceramic capacitors. Oscilloscope is bandwidth filter limited to 20 MHz.

10.6 Load transient response (dynamic load from 10 percent to 100 percent)





C1 (yellow) : +12 V output voltage	C1 (yellow) : +12 V output voltage
85 V AC +12 V output voltage $V_{ripple\_pk\_pk}$ is ~330 mV	264 V AC +12 V output voltage $V_{ripple\_pk\_pk}$ is ~346 mV

Figure 25 Load transient response with +12 V output load change from 10 percent to 100 percent at 0.4 A/µs slew rate, 100 Hz. Probe terminals are connected on the PCB end and decoupled with 1 µF electrolytic and 0.1 µF ceramic capacitors. Oscilloscope is bandwidth filter limited to 20 MHz.

10.7 Entering ABM

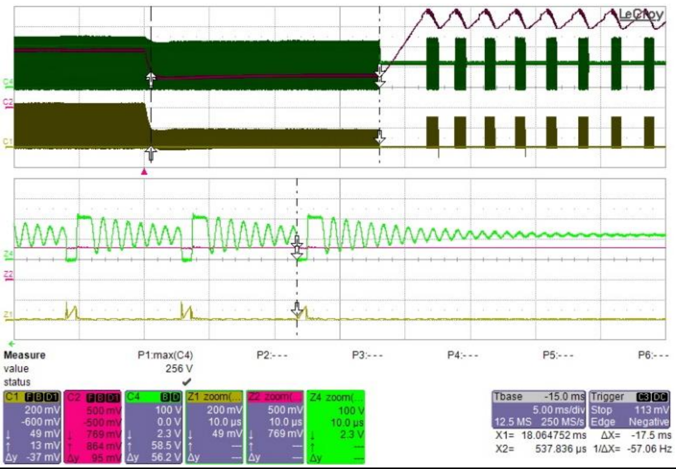
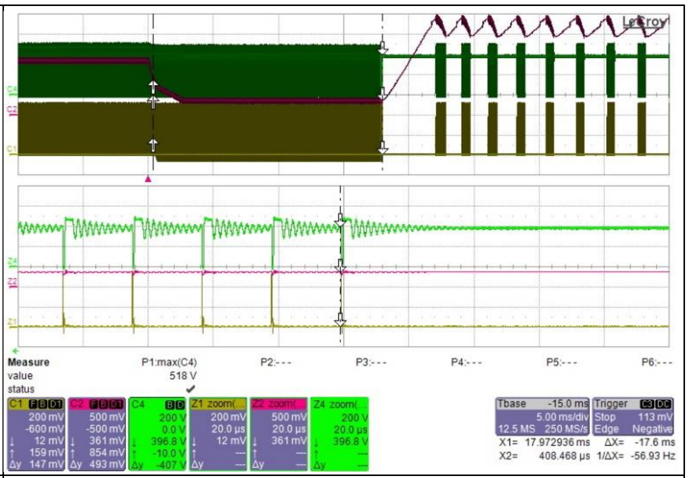
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage
85 V AC 3 W to 0.5 W load. Enter ABM at FB pin voltage less than 1.05 V (V_{FB_EBL2}) and eighth valley for more than 20 ms (t_{FB_BEB}).	264 V AC 3 W to 0.5 W load. Enter ABM at FB pin voltage less than 1.05 V (V_{FB_EBL2}) and tenth valley for more than 20 ms (t_{FB_BEB}).

Figure 26 Entering ABM. Output at 3 W to 0.5 W load.

10.8 During ABM

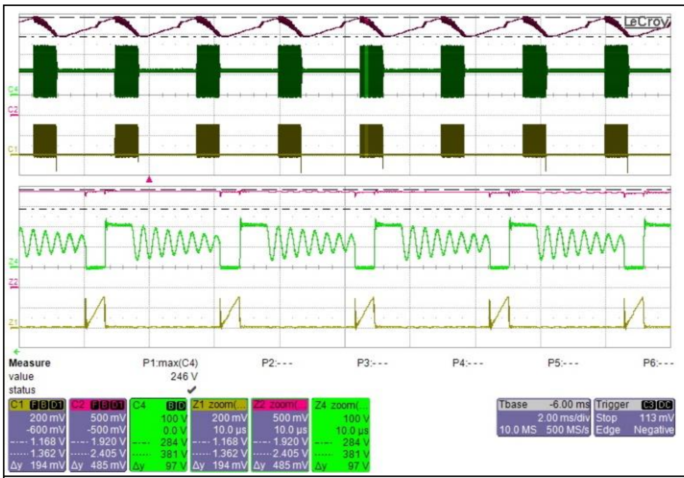
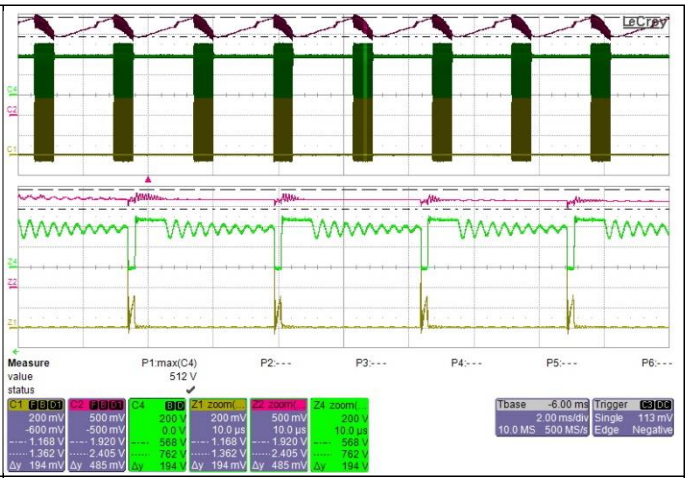
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage
85 V AC at 0.5 W load. Burst-on at FB voltage 2.4 V (V_{FB_BOn}) and burst-off at 2 V (V_{FB_BOff}). CS voltage at 0.35 V (V_{CS_BL2}). Switching at eighth valley.	264 V AC at 0.5 W load. Burst-on at FB voltage 2.4 V (V_{FB_BOn}) and burst-off at 2 V (V_{FB_BOff}). CS voltage at 0.35 V (V_{CS_BL2}). Switching at tenth valley.

Figure 27 During ABM. Output at 0.5 W load.

10.9 Leaving ABM

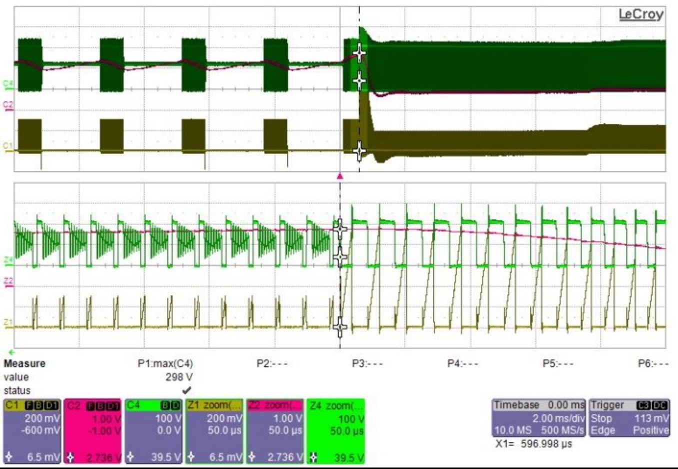
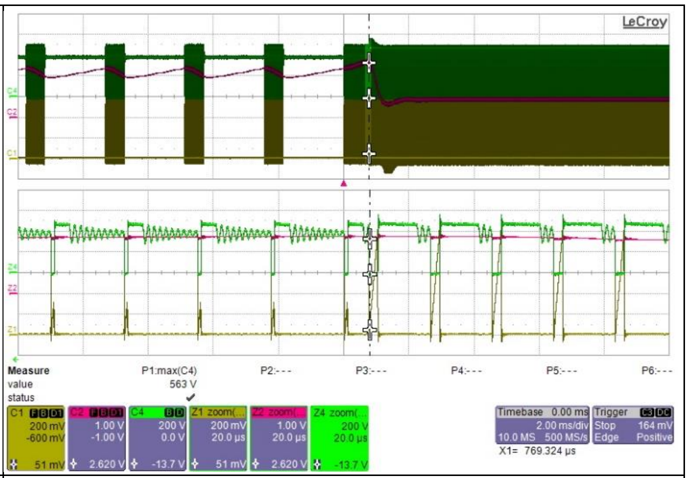
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C4 (green) : Drain voltage
85 V AC at 0.5 W load to 3 W load. Leave ABM at FB voltage more than 2.75 V (V_{FB_LB}).	264 V AC at 0.5 W load to 3 W load. Leave ABM at FB voltage more than 2.75 V (V_{FB_LB}).

Figure 28 Leaving ABM. Output at 0.5 W load to 3 W load.

10.10 Over-load protection

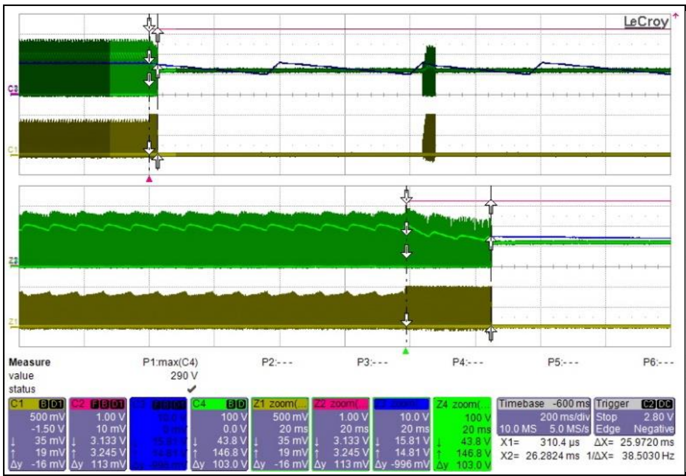
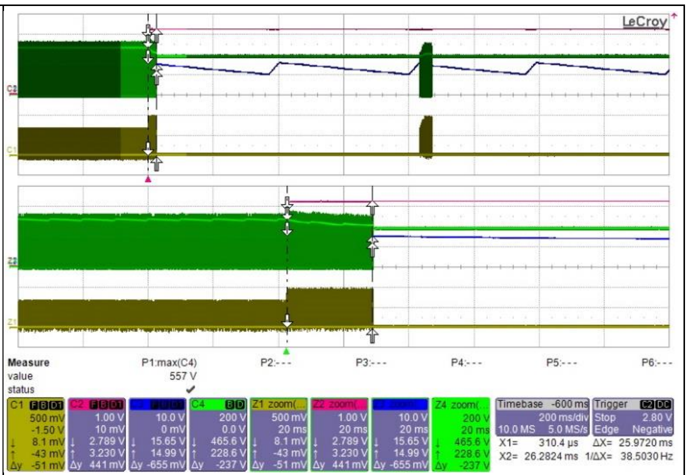
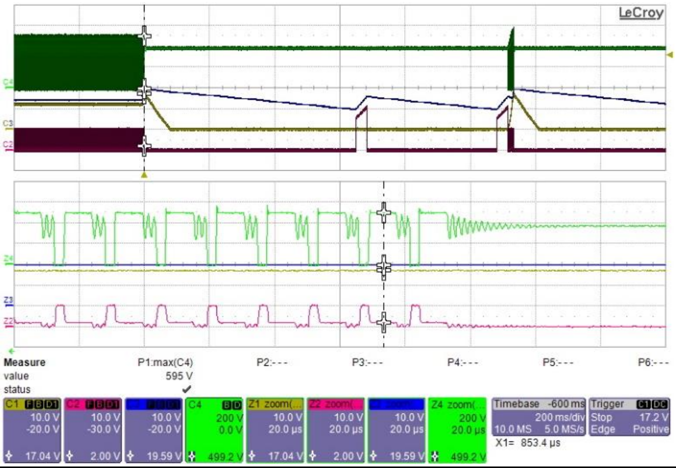
	
C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : V_{CC} voltage C4 (green) : Drain voltage	C1 (yellow) : CS voltage C2 (purple) : FB pin voltage C3 (blue) : V_{CC} voltage C4 (green) : Drain voltage
85 V AC at full load to 2 A load. Trigger protection at FB pin voltage more than 2.75 V (V_{FB_OLP}) for more than 30 ms ($t_{FB\_OLP\_B}$). Odd-skip auto-restart mode.	264 V AC at full load to 2 A load. Trigger protection at FB pin voltage more than 2.75 V (V_{FB_OLP}) for more than 30 ms ($t_{FB\_OLP\_B}$). Odd-skip auto-restart mode.

Figure 29 Over-load protection. Load increased from full load to 2 A load to trigger protection.

10.11 Output over-voltage protection

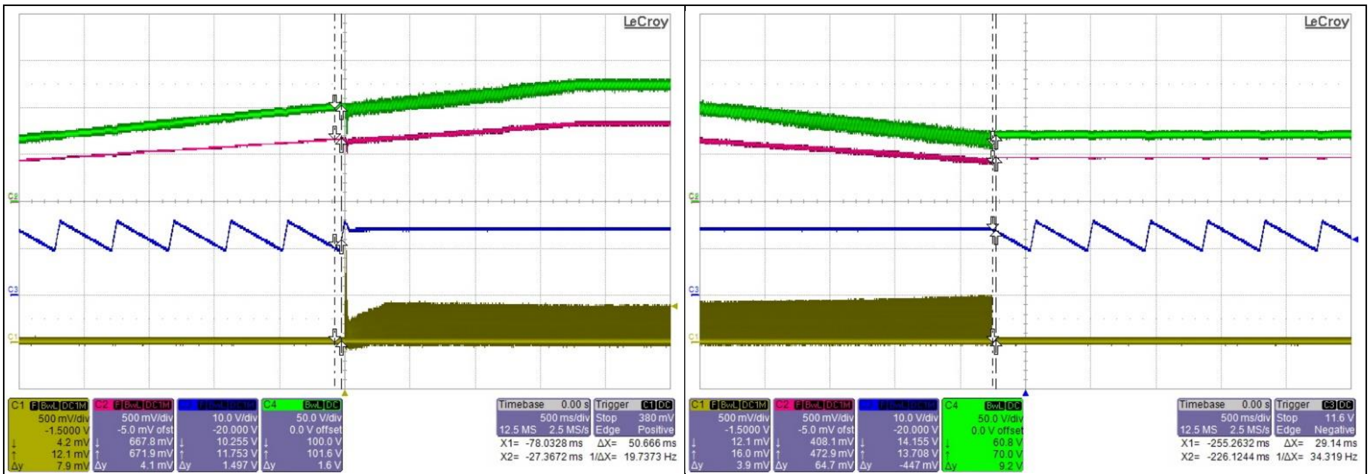


C1 (yellow)	: +12 V output voltage
C2 (purple)	: ZCD pin voltage
C3 (blue)	: V_{CC} voltage
C4 (green)	: Drain voltage

264 V AC 3 W load output over-voltage at ZCD more than 2 V (V_{ZCD_OVP}) for 10 consecutive pulses. Protection triggered at ~17 V output voltage and V_{CC} voltage at ~19.6 V. Odd-skip auto-restart mode.

Figure 30 Output over-voltage protection

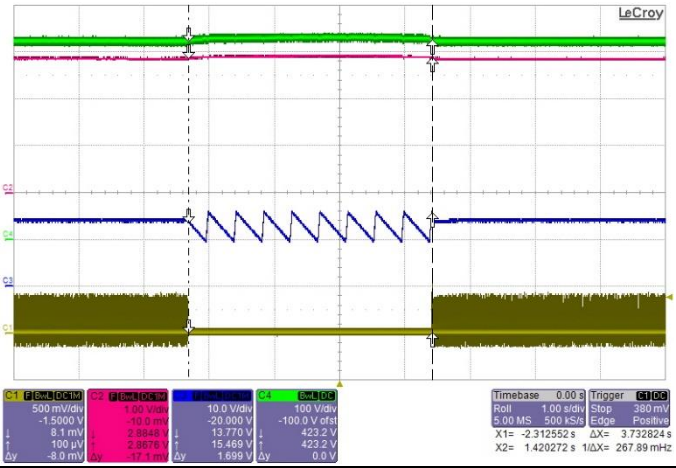
10.12 Brown-in/brown-out protection



C1 (yellow) : CS voltage C2 (purple) : VIN pin voltage C3 (blue) : V_{CC} voltage C4 (green) : V_{BUS} voltage	C1 (yellow) : CS voltage C2 (purple) : VIN pin voltage C3 (blue) : V_{CC} voltage C4 (green) : V_{BUS} voltage
AC voltage increasing at 3 W load. Start-up at VIN voltage more than 0.66 V (V_{VIN_BI}) and V_{BUS} at 100 V (71 V AC). Non-switch auto-restart mode.	AC voltage decreasing at 3 W load. Shut-down at VIN voltage less than 0.4 V (V_{VIN_BO}) and V_{BUS} at 70 V (50 V AC). Non-switch auto-restart mode.

Figure 31 Brown-in/brown-out at 3 W

10.13 Input line OVP



C1 (yellow)	: CS voltage
C2 (purple)	: VIN pin voltage
C3 (blue)	: V_{CC} voltage
C4 (green)	: V_{BUS} voltage

AC voltage increasing and decreasing at 3 W load. Shut-down and restart at VIN voltage 2.9 V (V_{VIN_LOVP}) and V_{BUS} at 423 V (300 V AC). Non-switch auto-restart mode.

Figure 32 Input line over-voltage protection at 3 W

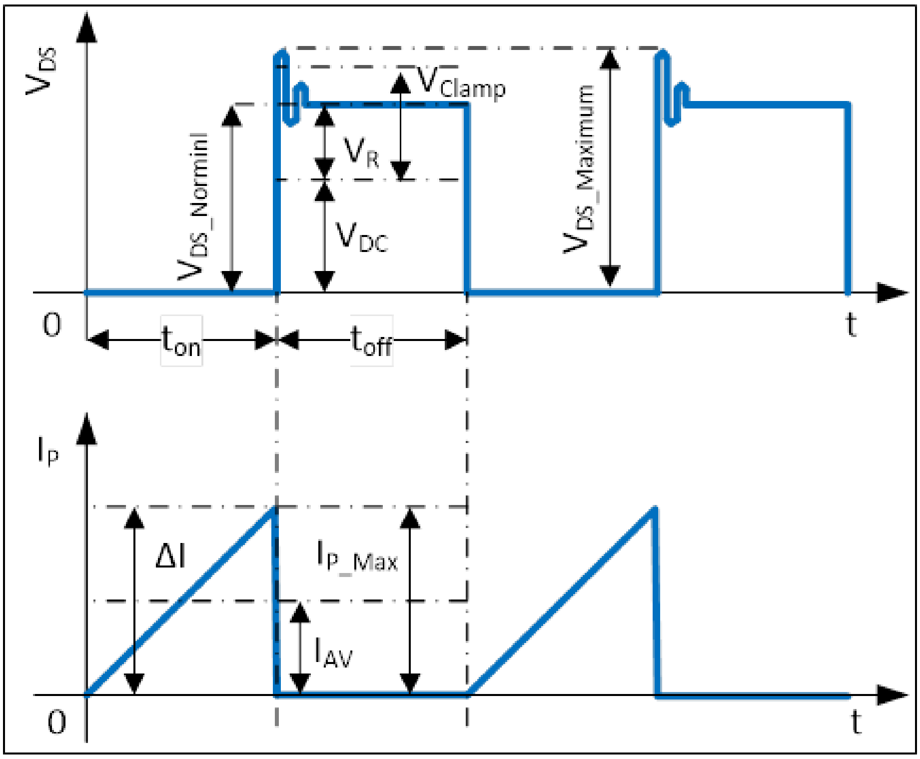
11 Appendix A: Transformer design and spreadsheet [3]

Design procedure for QR Flyback converter using Q5 CoolSET™ 5QrxxxxAx (version 1.1)

Project:	**12 W auxiliary SMPS for refrigerator using ICE5QR2270AZ**
Application:	**85 to 264 V AC, 12 V/1 A single-output FB**
CoolSET:	**ICE5QR2270AZ**
Date:	
Revision:	

Enter design variables in orange colored cells
Read design results in green colored cells
Equation numbers are according to the application note

			Unit	Value
Input	**Minimum AC input voltage**	$V_{AC\ Min}$	[V]	**85**
Input	**Maximum AC input voltage**	$V_{AC\ Max}$	[V]	**264**
Input	**Line frequency**	f_{AC}	[Hz]	**60**
Input	**Bus capacitor (C13) DC ripple voltage**	$V_{DC\ Ripple}$	[V]	**26**
Input	**Output voltage 1**	V_{Out1}	[V]	**12**
Input	**Output currnet 1**	I_{Out1}	[A]	**1.00**
Input	**Forward voltage of output diode (D21)**	$V_{F\ Out1}$	[V]	**0.3**
Input	**Output ripple voltage**	$V_{Out\ Ripple}$	[V]	**0.24**
Input	**Maximum output power for start-up, transient response and OLP**	$P_{Out\ Max}$	[W]	**12**
Result	**Nominal output power**	$P_{Out\ Nor}$	[W]	12.00
Input	**Minimum output power**	$P_{Out\ Min}$	[W]	**3**
Input	**Efficency**	**H**		**0.88**
Result	**Drain-to-source capacitance of MOSFET (including $C_{o(er)}$ of MOSFET)**	$C_{DS}+Co_{(er)}$	[pF]	10.00



Input	**Reflection voltage**	V_R	[V]	**85**
Input	**V_{CC} voltage**	V_{Vcc}	[V]	**14**
Input	**Forward voltage of V_{CC} diode (D12)**	$V_{F\,Vcc}$	[V]	**0.6**
Result	**CoolSET™**	**CoolSET™ Q5**		**ICE5QR2270AZ**
Input	**Low-line min. switching frequency**	f_S	[Hz]	**55000**
Input	**Targeted max. drain source voltage**	$V_{DS\,Max}$	[V]	**600**
Input	**Max. ambient temperature**	T_a	[°C]	**50**
Diode bridge (BR1)				
Result	**Eq 1**	$P_{In\,Max}$	[W]	13.64
Result	**Eq 2**	$I_{AC\,RMS}$	[A]	0.267
Result	**Eq 3**	$V_{DC\,Max\,Pk}$	[V]	373.35
Result	**Eq 4**	$V_{DC\,Min\,Pk}$	[V]	120.21
Result	**Eq 10**	$V_{DC\,Min}$	[V]	95.04
Result	**Eq 6**	T_D	[ms]	6.56
Result	**Eq 7**	W_{In}	[Ws]	0.09
Result	**Eq 11**	D_{Max}		0.4721
Input capacitor (C13)				
Result	**Eq 8**	C_{In} (C13)	[µF]	32.07
Input	**Select input capacitor**	**C_{In} (C13)**	[µF]	**33**
Transformer (TR1)				
Result	**Eq 12**	L_P	[H]	1.290E-03
Result	**Eq 13**	I_{AV}	[A]	0.30
Result	**Eq 14**	ΔI	[A]	0.632
Result	**Eq 15**	$I_{P\,Max}$	[A]	0.62
Result	**Eq 16**	I_{Valley}	[A]	0.0
Result	**Eq 17**	$I_{P\,RMS}$	[A]	0.24
Select core type				
Input	**Select core type**			**1**
Result		Core type		**EE20/10/6**
Result		Core material		**TP4A(TDG)**
Result	**Maximum flux density**	B_{Max}	[T]	**0.3**
Result	**Effective magnetic cross-section**	A_e	[mm²]	**32**
Result	**Bobbin width**	BW	[mm]	**11**
Result	**Winding cross-section**	A_N	[mm²]	**34**
Result	**Average length of turn**	l_N	[mm]	**41.2**
Winding calculation				
Result	**Eq 18**	N_P	Turns	83.33
Input	**Choose number of primary turns**	N_P	Turns	**84**
Result	**Eq 19**	N_{S1}	Turns	12.16
Input	**Choose number of secondary turns**	N_{S1}	Turns	**12**
Result	**Eq 20**	N_{Vcc}	Turns	14.24
Input	**Choose number of auxiliary turns**	N_{Vcc}	Turns	**14**
Result	**Auxiliary supply voltage (Eq 21)**	V_{Vcc}	[V]	**13.75**
Post calculation				
Result	**Eq 23**	V_R	[V]	**86.10**
Result	**Eq 24**	D_{Max}		**0.47**
Result	**Eq 25**	D_{Max}'		**0.52**
Result	**Eq 26**	B_{Max}	[T]	**0.298**

CS resistor (R14)

Appendix A: Transformer design and spreadsheet [3]

Input	**CS threshold value from datasheet**	**V_{csth}**	[V]	**1**
Result	**Eq 21**	R_{Sense} (R14)	[Ω]	1.61
Result	**Eq 22**	P_{SR}	[W]	**0.10**
Input	**PWM-OP gain from datasheet**	**A_V**		**2.05**
Result	**Eq 94**	Z_{PWM}	[V/A]	**3.3**

Transformer winding design

Input	**Margin according to safety standard**	**M**	[mm]	**0**
Input	**Copper space factor**	**f_{Cu}**		**0.4**

Primary

Input	**Insulation thickness**	**INS**	[mm]	**0.02**
Result	**Eq 32**	A_P (area of primary wire)	[mm²]	0.08
Result	**Eq 36**	d (diameter of primary wire)	[mm]	0.32
Result	**Eq 35**	AWG		28
Input	**Selected wire size**	**AWG**		**32**
Input	**Number of parallel wires**	**Np**		**1**
Result	**Eq 37**	d (diameter of primary wire)	[mm]	0.20
Result	**Eq 38**	(Eff. copper area of primary)	[mm²]	0.0326
Result	**Eq 39**	Sp (primary current density)	[A/mm²]	7.47
Result	**Eq 30**	BW_e (effective bobbin width)	[mm]	11.0
Result	**Eq 40**	Od_p (diameter of primary wire including insulation)	[mm]	0.24
Result	**Eq 41**	NL_P (max. primary turns/layer)	Turns/layer	45
Result	**Eq 42**	Ln_P (primary layers)	layers	2

Secondary

Input	**Insulation thickness**	**INS**	[mm]	**0.02**
Result	**Eq 33**	A_S (area of secondary wire)	[mm²]	0.51
Result	**Eq 36**	d (diameter of secondary wire)	[mm]	0.81
Result	**Eq 35**	AWG		20
Input	**Selected wire size**	**AWG**		**27**
Input	**Number of parallel wires**	**Np**		**3**
Result	**Eq 37**	dia (diameter of secondary wire)	[mm]	0.36
Result	**Eq 38**	(Eff. copper area of secondary)	[mm²]	0.3103
Result	**Eq 39**	S_S (secondary current density)	[A/mm²]	5.81
Result	**Eq 30**	BW_E (effective bobbin width)	[mm]	11.0
Result	**Eq 40**	Od_S (diameter of secondary wire including insulation)	[mm]	0.40
Result	**Eq 41**	NL_S (max. secondary turns/layer)	Turns/layer	9
Result	**Eq 42**	Ln_S (secondary layers)	Layers	2

Leakage inductance

Input		**Leakage Inductance as percentage of L_P**	[%]	**1**
Result	**Eq 45**	L_{LK}	[H]	1.29E-05

RCD clamper circuit (D11, R11 and C15)

Result	**Eq 44**	V_{Clamp}	[V]	140.55
Result	**Eq 46**	C_{clamp} (C15)	[nF]	0.2
Input	**Selected C_{clamp} capacitor value**	**C_{clamp} (C15)**	[nF]	**0.22**
Result	**Eq 47**	R_{clamp} (R11)	[kΩ]	322.2
Input	**Selected R_{clamp} value**	**R_{clamp} (R11)**	[kΩ]	**240**

Output and V_{CC} diode (D21, D22 and D12)

Result	**Eq 43a**	$V_{RDiode1}$ (for output diode D21)	[V]	65.34

Result	**Eq 28**	$I_{S\ Max1}$	[A]	4.34
Result	**Eq 29**	$I_{S\ RMS1}$	[A]	1.80
Result	**Eq 43b**	V_{Rdiode} (for V_{CC} diode)	[V]	76.23
Output capacitor (C22 and C23)				
Input	**Max. voltage overshoot at output capacitor (C22, C23)**	**ΔV_{Out}**	[V]	**0.36**
Input	**Number of clock periods**	**n_{cp}**		**20**
Result	**Eq 49**	I_{Ripple}	[A]	1.50
Result	**Eq 50**	C_{Out}	[µF]	1010
Zero frequency of output capacitor (C22 and C23) and associated ESR				
Input	**Selected output capacitor value**	**C22**	[µF]	**1000**
Input	**ESR (Z_{max}) value from datasheet at 100 kHz**	**ESR**	[Ω]	**0.018**
Input	**I_{ACmax} value from datasheet at 100 kHz**	**I_{acmax}**	[Arms]	**1.76**
Input	**Number of parallel capacitors**	**n_c**		**1**
Result	**Eq 51**	f_{ZCOut}	[kHz]	8.84
Ripple voltage first stage				
Result	**Eq 52**	$V_{Ripple\ 1}$	[V]	0.08
Input	**Selected LC filter inductor value**	**L_{out} (L21)**	[µH]	**2.2**
Calculating the necessary capacitance for the output LC-filter (C24)				
Result	**Eq 53**	C_{LC} (C24)	[µF]	147.3
Input	**Selected output inductance value**	**C_{LC} (C24)**	[µF]	**220**
Result	**Eq 54**	f_{LC}	[kHz]	7.23
Ripple voltage second stage				
Result	**Eq 55**	$V_{Ripple\ 2}$	[mV]	1.33
Soft-start time				
Input	**Chosen soft-start time from datasheet**	**$t_{softstart}$**	[ms]	**12**
V_{CC} capacitor (C16) and start-up time				
Input	**Chosen $I_{VCC,Charge3}$ from datasheet**	**$I_{VCC,Charge3}$**	[mA]	**3**
Input	**Chosen V_{VCChys} from datasheet**	**V_{VCChys}**	[mV]	**6**
Result	**Eq 56A**	C_{VCC}	[µF]	6.00
Input	**Select V_{CC} capacitor**	**C_{Vcc} (C16)**	[µF]	**22**
Input	**Select $V_{VCC,STG}$ from datasheet**	**$V_{VCC,STG}$**	[V]	**1.1**
Input	**Select $I_{VCC,Charge1}$ from datasheet**	**$I_{VCC,Charge1}$**	[mA]	**0.2**
Input	**Select $V_{VCC,ON}$ from datasheet**	**$V_{VCC,ON}$**	[V]	**16**
Result	**Eq 56B**	$t_{StartUp}$	[ms]	238.333
Calculation of losses				
Input diode bridge				
Result	**Eq 57**	P_{DIN}	[W]	0.53
Transformer copper losses				
Result	**Eq 58**	R_{PCu}	[mΩ]	1826.18
Result	**Eq 58**	R_{SCu}	[mΩ]	27.40
Result	**Eq 59**	P_{PCu}	[mW]	108.37
Result	**Eq 60**	P_{SCu}	[mW]	89.09
Result	**Eq 61**	P_{Cu}	[W]	0.1975
Output rectifier diode				
Result	**Eq 62**	$P_{Out\ DIODE}$ (D21)	[W]	0.54
RCD clamper circuit				
Result	**Eq 63**	$P_{Clamper}$	[W]	0.22
MOSFET				
Input	**$R_{DS(on)}$ from datasheet**	**$R_{DS(on)}$ at T_A = 125°C**	[Ω]	**4.31**

Input	**$C_{o(er)}$ from datasheet**	**$C_{o(er)}$**	[pF]	**10**
Input	**External drain-to-source capacitance of MOSFET**	**C_{DS}**	[pF]	**0**
MOSFET losses at V_{ACmin} + P_{max}				
Result	**Eq 65**	P_{SON}	[W]	0.000021967
Result	**Eq 66**	P_{cond}	[W]	0.2558
Result	**Eq 67**	MOSFET losses	[W]	0.2558
MOSFET losses at V_{ACmax} + P_{max}				
Result	**Eq 68**	P_{SON}	[W]	0.0295
Result	**Eq 69**	P_{cond}	[W]	0.0846
Result	**Eq 70**	MOSFET losses	[W]	0.1141
Temperature calculation				
Input	**Enter MOSFET losses**	**MOSFET losses**	[W]	0.26
Input	**Enter thermal resistance junction – ambient**	**R_{th}**	[°K/W]	103.0
Result	**Eq 74**	ΔT	[°K]	26.3
Result	**Eq 75**	T_{jmax}	°C	76.3
Controller				
Result	**$I_{VCC,Normal}$xV_{VCC}**	Controller losses	[W]	0.0124
Sum of losses				
Result	**Eq 77**	P_{Losses}	[W]	1.76
Efficiency after losses				
Result	**Eq 78**	η_L		0.8720
Calculation of the regulation loop (R22, R23, R24, R25, R26, C25, C26)				
Input	**Min. current for TL431 reference**	I_{KAmin}	[mA]	**1**
Input	**Optocoupler gain**	G_C (200 percent)		**1.5**
Input	**Max. current for optocoupler diode**	I_{Fmax}	[mA]	**10**
Input	**Second resistor of TL431 voltage divider**	R26	[kΩ]	**12.2**
Input	**0 db crossover frequency**	Fg	[kHz]	**3**
Result	**Eq 81**	R25	[kΩ]	46.36
Input	**Selected value of R25**	**R25**	[kΩ]	**47**
Result	**Eq 82**	R22	[kΩ]	0.8250
Input	**Selected value of R22**	**R22**	[kΩ]	**0.82**
Input	**V_{REF} from datasheet**	V_{REF}	[V]	**3.3**
Input	**$V_{FB,OLP}$ from datasheet (over-load/open-loop detection limit at FB pin)**	$V_{FB,OLP}$	[V]	**2.75**
Input	**R_{FB} from datasheet**	R_{FB}	[kΩ]	**15**
Result	**Eq 83**	R23	[kΩ]	1.27
Input	**Selected value of R23**	**R23**	[kΩ]	**1.2**
Result	**Eq 84**	V_{Out_RL}	[V]	**12.1**
Result	**Eq 85**	K_{FB}		27.44
Result	**Eq 86**	G_{FB}	[db]	28.77
Result	**Eq 87**	K_{VD}		0.21
Result	**Eq 88**	G_{VD}	[db]	-13.72
Result	**Eq 89**	R_{LH}	[Ω]	12.00
Result	**Eq 90**	R_{LL}	[Ω]	48.00
Result	**Eq 91**	f_{OH}	[Hz]	26.53
Result	**Eq 92**	f_{OL}	[Hz]	6.63
Result	**Eq 93**	f_{OM}	[Hz]	13.26
Result	**Eq 95**	$\lvert F_{PWR}(fg)\rvert$		0.052
Result	**Eq 96**	$G_{PWR}(fg)$	[db]	-25.72
Result	**Eq 99**	Gr	[db]	10.671

Result	**Eq 100**	R24	[kΩ]	33.09
Input	**Selected value of R24**	**R24**	[kΩ]	**33**
Result	**Eq 101**	C26	[nF]	1.608
Input	**Selected value of C26**	**C26**	[nF]	**1**
Result	**Eq 102**	C25	[nF]	362.64
Input	**Selected value of C25**	**C25**	[nF]	**470**
Zero crossing detection and output OVP calculation				
Input	**Designed V_{OUT_OVP}**	V_{OUT_OVP}	[V]	**16**
Input	**$V_{ZC\_OVP\_MIN}$ from datasheet**	$V_{ZC\_OVP\_MIN}$	[V]	**1.9**
Input	**R_{ZCD_MIN} from datasheet**	R_{ZCD}	[kΩ]	**3**
Result	**Eq 103**	R_{ZC} (R15)	[kΩ]	27.03
Input	**Selected value of R15**	**R_{ZC} (R15)**	[kΩ]	**27**
Input	**f_{OSC2} by measurement**	f_{OSC2}	[kHz]	**1000**
Result	**Eq 104**	C_{ZC} (C19)	[pF]	81
Input	**Selected value of C_{ZC} (C19)**	C_{ZC} (C19)	[pF]	47
Line OVP is the first priority and its associated brown-out, brown-in and line selection				
Input		**R_{l1} (R18)**	[Ω]	**9,000,000**
Input		Line over-voltage (V_{OVP_AC})	[V_{AC}]	**300**
Input		**$V_{DC\ Ripple}$**	[V]	**26**
Result	**Eq 105A**	R_{l2}(R19)	[Ω]	61,942
Input	**Selected value of R19 (R_{l2})**	**R_{l2}(R19)**	[Ω]	**62,000**
Result	**Eq 106**	Brown-in voltage ($V_{Brownin\_AC}$)	[V AC]	68
Result	**Eq 107**	Brown-out voltage for full load which considers $V_{DC\ RIPPLE}$ ($V_{Brownout\_AC}$)	[V AC]	60
Result	**Eq 107**	Brown-out voltage for light load which neglects $V_{DC\ RIPPLE}$ ($V_{Brownout\_AC}$)	[V AC]	41
Result	**Eq 108**	Line selection threshold with $V_{DC\ RIPPLE}$ (V_{VIN} = 1.52 V)	[V AC]	175
Result	**Eq 108**	Line selection threshold without $V_{DC\ RIPPLE}$ (V_{VIN} = 1.52 V)	[V AC]	157
Brown-out is the first priority and its associated line OVP and line selection				
Input		**R_{l1} (R18)**	[Ω]	**9,000,000**
Input		Brown-in voltage (V_{OVP_AC})	[V AC]	**70**
Input		**$V_{DC\ Ripple}$**	[V]	**26**
Result	**Eq 105B**	R_{l2} (R19)	[Ω]	60,406
Input	**Selected value of R19(R_{l2})**	**R_{l2} (R19)**	[Ω]	**62**
Result	**Eq 107**	Brown-out voltage for full load which considers $V_{DC\ RIPPLE}$ ($V_{Brownout\_AC}$)	[V AC]	41076
Result	**Eq 107**	Brown-out voltage for light load which neglects $V_{DC\ RIPPLE}$ ($V_{Brownout\_AC}$)	[V AC]	41058
Result	**Eq 114**	Line over-voltage (V_{OVP_AC})	[V AC]	297671
Result	**Eq 108**	Line selection threshold with $V_{DC\ RIPPLE}$ (V_{VIN} = 1.52 V)	[V AC]	156039
Result	**Eq 108**	Line selection threshold without $V_{DC\ RIPPLE}$ (V_{VIN} = 1.52 V)	[V AC]	156021

Electrical

Minimum AC voltage		[V]	**85**
Maximum AC voltage		[V]	**264**
Maximum input current		[A]	**0.16**
Minimum DC voltage		[V]	**95**
Maximum DC voltage		[V]	**373**
Maximum output power		[W]	**12.0**
Output voltage		[V]	**12.0**

Output ripple voltage		[mV]	**1.3**
Inductor peak current		[A]	**0.62**
Maximum duty cycle			**0.47**
Reflected output voltage		[V]	**86**
Copper losses		[W]	**0.20**
MOSFET losses		[W]	**0.26**
Sum of losses		[W]	**1.76**
Efficiency			**0.87**

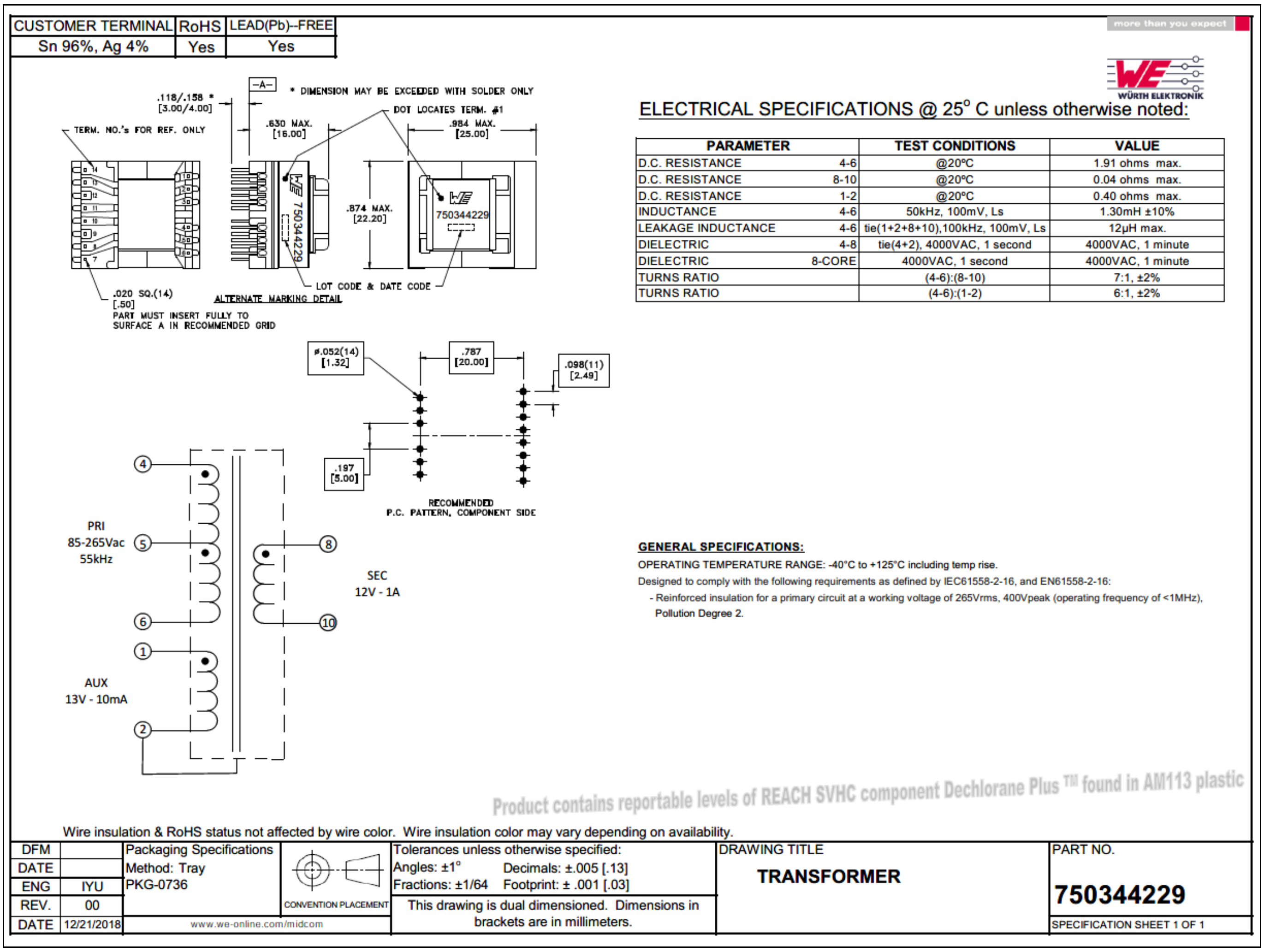
Transformer

Core type			**EE20/10/6**
Core material			**TP4A(TDG)**
Effective core area		[mm^2]	**32**
Maximum flux density		[mT]	**298**
Inductance		[µH]	**1290**
Magin		[mm]	**0**
Primary turns		Turns	**84**
Primary copper wire size		AWG	**32**
Secondary turns (N_{S1})		Turns	**12**
Secondary copper wire size		AWG	**27**
Number of parallel secondary wires			**3**
Auxiliary turns		Turns	**14**
Leakage inductance		[µH]	**12.9**
Turns ratio			**7.00**
Primary layers		Layer	**2**
Secondary layers		Layer	**2**

Components

Input capacitor	C13	[µF]	**33.0**
Output capacitor	C22	[µF]	**1000.0**
LC filter capacitor	C24	[µF]	**220.0**
LC filter inductor	L21	[µH]	**2.2**
V_{CC} capacitor	C16	[µH]	**22.0**
ZC capacitor	C19	[pF]	**47**
ZC resistor	R15	[kΩ]	**27**
Sense resistor	R14	[Ω]	**1.61**
Clamping resistor	R11	[kΩ]	**240.0**
Clamping capacitor	C15	[nF]	**0.22**
Voltage divider	R25	[kΩ]	**46.4**
Voltage divider	R26	[kΩ]	**12.2**
Regulator component	R22	[kΩ]	**0.82**
Regulator component	R23	[kΩ]	**1.2**
Regulator component	R24	[kΩ]	**33.0**
Regulator component	C25	[nF]	**470.0**
Regulator component	C26	[nF]	**1.00**

12 Appendix B: WE transformer specification



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

ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	4-6	@20ºC	1.91 ohms max.
D.C. RESISTANCE	8-10	@20ºC	0.04 ohms max.
D.C. RESISTANCE	1-2	@20ºC	0.40 ohms max.
INDUCTANCE	4-6	50kHz, 100mV, Ls	1.30mH ±10%
LEAKAGE INDUCTANCE	4-6	tie(1+2+8+10),100kHz, 100mV, Ls	12µH max.
DIELECTRIC	4-8	tie(4+2), 4000VAC, 1 second	4000VAC, 1 minute
DIELECTRIC	8-CORE	4000VAC, 1 second	4000VAC, 1 minute
TURNS RATIO		(4-6):(8-10)	7:1, ±2%
TURNS RATIO		(4-6):(1-2)	6:1, ±2%

GENERAL SPECIFICATIONS:

OPERATING TEMPERATURE RANGE: -40°C to +125°C including temp rise.

Designed to comply with the following requirements as defined by IEC61558-2-16, and EN61558-2-16:

- Reinforced insulation for a primary circuit at a working voltage of 265Vrms, 400Vpeak (operating frequency of <1MHz), Pollution Degree 2.

Product contains reportable levels of REACH SVHC component Dechlorane Plus ™ found in AM113 plastic

Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability.

DFM		Packaging Specifications		Tolerances unless otherwise specified:	DRAWING TITLE	PART NO.
DATE		Method: Tray		Angles: ±1° Decimals: ±.005 [.13]	TRANSFORMER	
ENG	IYU	PKG-0736		Fractions: ±1/64 Footprint: ± .001 [.03]		750344229
REV.	00		CONVENTION PLACEMENT	This drawing is dual dimensioned. Dimensions in brackets are in millimeters.		
DATE	12/21/2018	www.we-online.com/midcom				SPECIFICATION SHEET 1 OF 1

Figure 33 WE transformer specification

13 References

[1] ICE5QRxxxxAx datasheet, Infineon Technologies AG

[2] AN-201609_PL83_026-5th Generation QR Design Guide

[3] Calculation Tool Quasi Resonant CoolSET™ Generation 5

Revision history

Document version	Date of release	Description of changes
Rev. 1.0	2019-03-26	First release

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