42 W, 12 V and 5 V SMPS reference board with ICE5QR0680BG-1

REF_5QR0680BG-1_42W1

About this document

Scope and purpose

This document describes a universal input 42 W, 12 V and 5 V offline flyback converter using the CoolSET™ 5th Generation Quasi-Resonant (QR) Plus ICE5QR0680BG-1 IC from Infineon, which offers high efficiency, low standby power with selectable entry and exit standby power options, wide V_{CC} operating range with fast startup, robust line protection with input overvoltage protection (OVP), and brownout and various modes of protection for a highly reliable system.

This reference board is designed to evaluate the performance of CoolSET™ 5th Generation QR Plus ICE5QR0680BG-1 IC and its ease of use.

Intended audience

This document is intended for power-supply design/application engineers, students, etc., who wish to design low-cost and highly reliable systems of offline SMPS, such as auxiliary power supplies for white goods, PCs, servers and TVs, or enclosed adapters for gaming consoles, etc.

CoolSET™

Infineon's CoolSET™ AC-DC integrated power stages in a quasi-resonant switching scheme offers increased robustness and outstanding performance. This family offers superior energy efficiency, comprehensive protective features, and reduced system costs and is ideally suited for auxiliary power supply applications in a wide variety of potential applications such as:

- SMPS
- Home appliances
- Server
- Telecom

Revision V 1.0
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1 Introduction

This document describes a 42 W, 12 V and 5 V reference board designed in a quasi-resonant flyback converter topology using the CoolSET™ 5th Generation QR Plus ICE5QR0680BG-1 IC.

With the CoolMOS™ integrated into this IC, it simplifies the design and layout of the PCB. The new improved digital frequency reduction with proprietary QR operation offers lower EMI and higher efficiency for a wide AC range by reducing the switching frequency difference between low- and high-line. The active burst mode (ABM) power enables flexibility in standby power operation range selection and QR operation during ABM. As a result, the system efficiency over the entire load range is significantly improved compared to a conventional free-running QR converter implemented with only maximum switching frequency limitation at light loads.

In addition, several adjustable protection functions have been implemented in ICE5QR0680BG-1 to protect the system and customize the IC for the chosen application. In case of failure modes like brownout or line overvoltage, V_{CC} overvoltage and undervoltage, open control loop or overload, output overvoltage, overtemperature, and V_{CC} short-to-ground, the device enters protection mode.

By means of the cycle-by-cycle peak current limitation (PCL), the dimensions of the transformer and the current rating of the secondary diode can both be optimized. Thus, a cost-effective solution can easily be achieved. The target applications of ICE5QR0680BG-1 are either auxiliary power supplies for white goods, PCs, servers, and TVs, or enclosed adapters for gaming consoles, etc.

This document contains the list of features, the power supply specifications, schematics, bill of materials (BOM) and transformer construction documentation. Typical operating characteristics such as performance curves and scope waveforms are shown at the end of the document.

2 Reference board

Figure 1 REF_5QR0680BG-1_42W1

3 Reference board specifications

Table 1 REF_5QR0680BG-1_42W1 specifications

Input voltage and frequency	85 V AC (60 Hz) ~ 300 V AC (50 Hz)
Output voltage, current, and power	(12 V x 3.41 A) + (5 V x 0.2 A) = 42 W
Dynamic load response (5 V at 0.2 A and 12 V load change from 10% to 100%, slew rate at 0.4 A/µs, 100 Hz)	±5 percent of nominal output voltage
Output ripple voltage (full load, 85 V AC ~ 300 V AC)	5 $V_{ripple\_p\_p}$ less than 100 mV 12 $V_{ripple\_p\_p}$ less than 150 mV
Active mode four-point average efficiency (25%, 50%, 75%, 100% load)	More than 84% at 115 V AC and 230 V AC
No-load power consumption	< 100 mW at 230 V AC
Conducted emissions (EN 55022 Class B)	Pass with 6 dB margin for 115 V AC and 230 V AC
ESD immunity (EN 61000-4-2)	Special level (±10 kV for contact and air discharge)
Surge immunity (EN 61000-4-5)	Installation Class 4 (±2 kV for line-to-line and ±4 kV for line-to-earth)
Form factor case size (L x W x H)	(140 x 66 x 40) mm^3

Note that the reference board is designed for dual-output with cross-regulated loop feedback. It may not regulate properly if loading is applied only to a single output. If you want to evaluate for a single output (12 V only) condition, make the following changes on the board:

1. Remove D22, L22, C28, C210, and R25A to disable 5 V output).
2. Change R26 to 10 kΩ and R25 to 38 kΩ to disable 5 V feedback and enable 100% weighted factor on 12 V output).

Because the board (especially the transformer) is designed for dual output with optimized cross regulation, single output efficiency might not be optimized. This configuration is only for IC functional evaluation under single output conditions.

4 Schematic

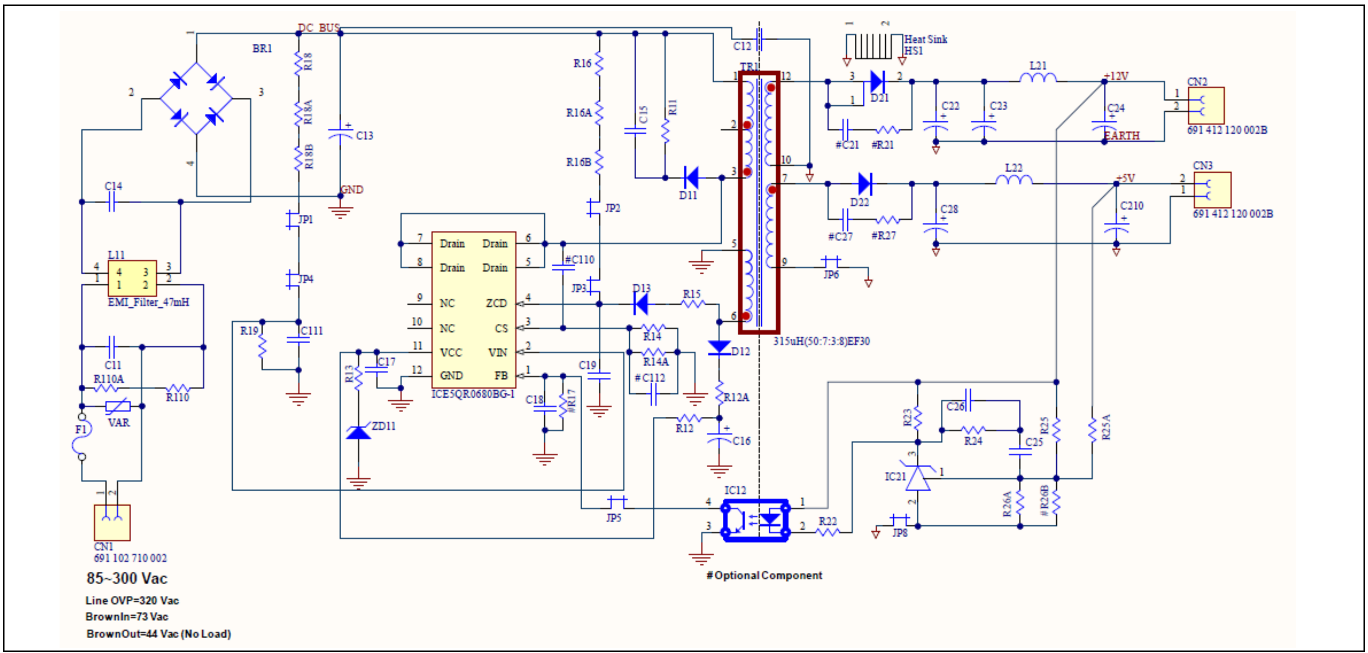


Figure 2 REF_5QR0680BG-1_42W1

4.1 General guidelines for PCB layout:

1. **Star ground at bulk capacitor (C13):** Connect all primary grounds separately to the ground of bulk capacitor (C13) at one point. This reduces the switching noise going into the sensitive pins of the CoolSET™ device. The primary star ground can be split into four groups as follows:
   - Combine the signal (all small-signal grounds connecting to the CoolSET™ GND pin, such as filter capacitor grounds C17, C18, C19, C111, and C112, and optocoupler ground) and power grounds (CS resistors R14 and R14A).
   - V_{CC} ground includes the V_{CC} capacitor ground (C16) and the auxiliary winding ground (pin 5) of the power transformer.
   - EMI return ground, which includes Y capacitor (C12).
   - DC ground from bridge rectifier (BR1).
2. **Filter capacitor close to the controller ground:** Place the filter capacitors (C17, C18, C19, C111, and C112) close to the controller ground and the controller pin to reduce the switching noise coupled into the controller.
3. **HV trace clearance:** To avoid arcing, space out the high-voltage traces far apart from the nearby traces.
   - **400 V traces (positive rail of bulk capacitor C13) to nearby trace:** > 2.0 mm.
   - **600 V traces (drain voltage of CoolSET™ IC11) to nearby trace:** < 2.5 mm.
4. For better thermal performance, add a minimum copper area of 232 mm^2 at drain pin.
5. To minimize the switching emissions, keep the following as small as possible:
   - Power-loop area (bulk capacitor C13)
   - primary winding of the transformer (TR1; pin 4 and 6)
   - IC11 drain pin
   - IC11 CS pin
   - CS resistors (R14/R14A)

5 Bill of materials

Table 2 BOM

No.	Designator	Description	Part number	Manufacturer	Quantity
1	BR1	600 V/2 A	D2SB60A	Shindengen	1
2	C11	0.47 µF/310 V	890334024005	Würth Elektronik	1
3	C12	2.2 nF/500 V	DE1E3RA222MA4BQ	Murata	1
4	C13	120 µF/450 V	ESMQ451VSN121MP30S	–	1
5	C14	0.22uF/310V	890334025027	Würth Elektronik	1
6	C15	2.2 nF/1000 V	RDE7U3A222J3K1H03	Murata	1
7	C16	33 µF/50 V	50PX33MEFC5X11	Rubycon	1
8	C17	100 nF/50 V	GRM188R71H104KA93D	Murata	1
9	C18, C26	1 nF/50 V	GRM1885C1H102GA01D	Murata	2
10	C19	68 pF/50 V	GRM1885C1H680GA01D	Murata	1
11	C111	22 nF/50 V	GCM188R71H223KA37D	Murata	1
12	C22, C23	1000 µF/16 V	16ZLH1000MEFC10X16	Rubycon	2
13	C24	470 µF/16 V	16ZLH470MEFC8X11.5	Rubycon	1
14	C25	220 nF/50 V	GRM188R71H224KAC4D	Murata	1
15	C28, C210	330 µF/10 V	10ZLH330MEFC6.3X11	Rubycon	2
16	D11	1 A/800 V	UF4006	–	1
17	D12	0.2 A/200 V	BAV20WS	–	1
18	D13	0.2 A/200 V	1N485B	–	1
19	D21	30 A/100 V	VF30100SG	–	1
20	D22	1 A/50 V	SB150	–	1
21	F1	2 A/300 V	36912000000	–	1
22	HS1	Heatsink	513002B02500G	–	1
23	IC11	ICE5QR0680BG-1	ICE5QR0680BG-1	Infineon	1
24	IC12	Optocoupler	SFH617A-3	–	1
25	IC21	Shunt regulator	TL431BVLPG	–	1
26	JP1, JP2, JP3, JP4, JP5, JP6,JP8	Jumper	–	–	7
27	L11	47 mH	B82734R2132B030 (2x47mH, 1.3A)	–	1
28	L21	2.2 µH/6 A	744772022	Würth Elektronik	1
29	L22	4.7 µH/4.2 A	7447462047	Würth Elektronik	1
30	R11	33 kR/2 W/350 V	ERG-2SJ333A	Panasonic	1
31	R12	27 Ω (0603)	–	–	1
32	R12A	0 Ω (0603)	–	–	1
33	R13	27 Ω (0603)	–	–	1
34	R14	0.81 R/0.5 W/±1 percent	RCWE1206R820FKEA	–	1
35	R14A	0.91 R/0.5 W/±1 percent	RCWE1206R910FKEA	–	1
36	R15	24 kΩ/±1 percent (0603)	–	–	1
37	R16, R16A	15 MR (1206)	RC1206JR-0715ML	–	2
38	R16B	20 MR (1206)	–	–	1
39	R18, R18A, R18B	3 MR (1206)	RC1206FR-073ML	–	2

No.	Designator	Description	Part number	Manufacturer	Quantity
40	R19	59 kR/0.5 percent (0603)	ERJ-3RBD5902V	–	1
41	R110, R110A	1.5 MΩ/200 V (1206)	–	–	2
42	R22	820 Ω (0603)	–	–	1
43	R23	1.2 kΩ (0603)	–	–	1
44	R24	12 kΩ (0603)	–	–	1
45	R25	16 kΩ (0603)	–	–	1
46	R25A	6.2 kΩ (0603)	–	–	1
47	R26A	2.49 kΩ (0603)	–	–	1
48	TR1	315 µH	750343506(R03)	Würth Elektronik	1
49	VAR	0.25 W/320 V	B72207S2321K101	Epcos	1
50	ZD11	22 V (SOD123)	MMSZ5251B-7-F	–	1
51	Con (L N)	Connector	691102710002	Würth Elektronik	1
52	Con (+12 V com), Con (+5 V com)	Connector	691 412 120 002B	Würth Elektronik	2

6 Circuit description

6.1 Line input

The AC line input side comprises the input fuse (F1) as overcurrent protection. The choke (L11), X-capacitors (C11 and C14) and Y-capacitor (C12) act as EMI suppressors. Varistor VAR will absorb the high-voltage stress during a lightning surge test. A rectified DC voltage (120 ~ 424 V DC) is obtained through the bridge rectifier (BR1) together with the bulk capacitor (C13).

6.2 Startup

To achieve a fast and safe startup, ICE5QR0680BG-1 is implemented with a startup resistor and V_{CC}-to-GND short-circuit protection. When V_{VCC} reaches the turn-on voltage threshold (16 V), the IC begins with a soft start.

The soft start implemented in ICE5QR0680BG-1 is a digital time-based function. The preset soft-start time is 12 ms with four steps. If not limited by other functions, the peak voltage on the CS pin will increase incrementally from 0.3 V to 1 V. After IC turns on, the V_{CC} voltage is supplied by auxiliary windings of the transformer. V_{CC}-to-GND short-circuit protection is implemented during the startup time.

6.3 Integrated CoolMOS™ MOSFET and PWM control

ICE5QR0680BG-1 comprises a power CoolMOS™ MOSFET and the proprietary novel QR controller, which enables higher average efficiency and low EMI. This integrated solution simplifies the circuit layout and reduces the cost of PCB manufacturing. The PWM switch-on is determined by the zero-crossing detection input signal and the value of the up/down counter. The PWM switch-off is determined by the feedback signal V_{FB} and the current sensing signal V_{CS}. ICE5QR0680BG-1 also performs all necessary protection functions in the flyback converters. For more details, refer to the datasheet [1].

6.4 RCD clamper circuit

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

6.5 Output stage

There are two outputs on the secondary side (12 V and 5 V). The power is coupled out via Schottky diodes (D21 and D22). The capacitors (C22, C23, and C28) provide energy buffering, followed by the L-C filters (L21-C24 and L22-C210) to reduce the output ripple and prevent the interference between the SMPS switching frequency and line frequency. Storage capacitors (C22, C23, and C28)) are designed to have the smallest possible internal resistance (ESR) to minimize the output voltage ripple caused by the triangular current.

6.6 Feedback loop

For feedback, the output is sensed by the voltage dividers (R26, R25, and R25A) and compared to the IC21 (TL431) internal reference voltage. C25, C26, and R24 form the compensation network. The output voltage of IC21 (TL431) is converted to the current signal via the optocoupler (IC12) and two resistors (R22 and R23) for regulation control.

6.7 Primary-side peak-current control

The MOSFET drain-source current is sensed via the external resistors (R14 and R14A). Because ICE5QR0680BG-1 is a current mode controller, it would have a cycle-by-cycle primary current and feedback voltage control, which ensures the converter's maximum power is controlled in every switching cycle.

For a QR flyback converter, the maximum possible output power is increased when a constant current limit value is used for the entire line input voltage range. However, this is not desirable because this will increase the cost of the transformer and output diode in case of output over-power conditions.

Internal current limitation with a line-dependent V_{CS} curve and the new proprietary QR switching, which reduces switching frequency difference between the minimum and maximum line are implemented in ICE5QR0680BG-1. As a result, the maximum output power can be limited against the input voltage.

6.8 Digital frequency reduction

During normal operation, the switching frequency for ICE5QR0680BG-1 is digitally reduced with decreasing load. At light loads, the MOSFET will be turned on – not at the first minimum drain-source voltage time, but on the n^{th}. The counter is within a range of 1 to 8 for low-line and 3 to 10 for high-line, which depends on the feedback voltage in a time base. The feedback voltage decreases when the output power requirement decreases, and vice versa. Therefore, the counter is set by monitoring voltage V_{FB}. The counter will be increased with low V_{FB} and decreased with high V_{FB}. The thresholds are preset inside the IC.

6.9 Active burst mode (ABM)

ABM entry and exit power (two levels) can be selected in ICE5QR0680BG-1 [1]. ABM power level 1 is used in this reference board (R17 = open). In light load conditions, the SMPS enters ABM with QR switching. At this stage, the controller is always active but the V_{VCC} must be kept above the switch-off threshold. During ABM, the efficiency increases significantly; and it supports low ripple on V_{out} and fast response on load-jump.

To enter ABM operation, three conditions apply:

- The feedback voltage is lower than the threshold of V_{FB_EBLX}
- The up/down counter is 8 for low-line and 10 for high-line
- A certain blanking time (t_{FB_BEB} = 20 ms) is required

Once all of these conditions are fulfilled, the ABM flip-flop is set and the controller enters ABM operation. This multi-condition determination for entering ABM operation prevents mis-triggering of ABM operation, so that the controller enters ABM operation only when the output power is really low during the preset blanking time.

During ABM, the maximum current sense voltage is reduced from V_{CS_N} to V_{CS_BLX} to reduce the conduction loss and the audible noise. During ABM operation, the feedback voltage changes like a sawtooth between V_{FB_BOFF} and V_{FB_BON}.

The feedback voltage immediately increases if there is a sudden increment in the output load, as observed by one comparator. As the current limit is 31/35% during ABM, a certain load is required so that the feedback voltage can exceed V_{FB_LB}. After leaving ABM, maximum current can now be provided to stabilize V_{out}. In addition, the up/down counter will be set to '1' (low-line) or '3' (high-line) immediately after leaving ABM. This is helpful to decrease the output voltage undershoot.

7 Protection features

ICE5QR0680BG-1 provides comprehensive protection features to ensure that the system is operating safely. \ When faults are detected, the system enters the protection mode and remains in this mode until the fault is removed, and then the system resumes normal operation. Table 3 lists the protections and failure conditions.

Table 3 Protection functions of ICE5QR0680BG-1

Protection function	Failure condition	Protection mode
Line overvoltage	$V_{VIN} > V_{VIN\_LOVP}$	Non-switch auto-restart
Brownout	$V_{VIN} < V_{VIN\_BO}$	Non-switch auto-restart
V_{CC} overvoltage	$V_{VCC} > V_{VCC\_OVP}$	Odd-skip auto-restart
V_{CC} undervoltage	$V_{VCC} < V_{VCC\_OFF}$	Auto-restart
Overload	$V_{FB} > V_{FB\_OLP}$ and lasts for 30 ms	Odd-skip auto-restart
Output overvoltage	$V_{ZCD} > V_{ZCD\_OVP}$ and lasts for 10 consecutive pulses	Odd-skip auto-restart
Overtemperature (junction temperature of controller chip only)	T_J > 140°C with 40°C hysteresis to reset	Non-switch auto-restart
V_{CC} short-to-GND (V_{VCC} = 0 V, $R_{StartUp}$ = 50 MΩ and V_{Drain} = 90 V)	$V_{VCC} < V_{VCC\_SCP}$, $I_{VCC\_Charge} = I_{VCC\_Charge1}$	Cannot start up

8 PCB layout

8.1 Top side

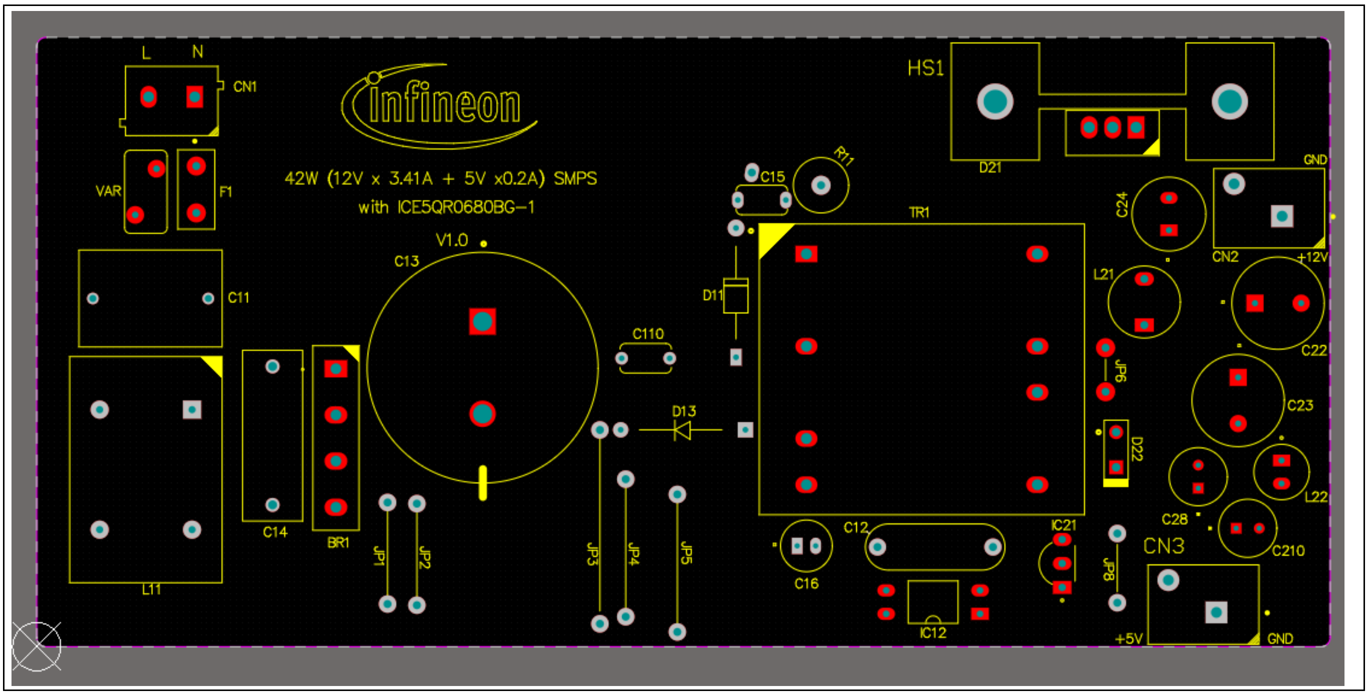


Figure 3 Top-side component legend

8.2 Bottom side

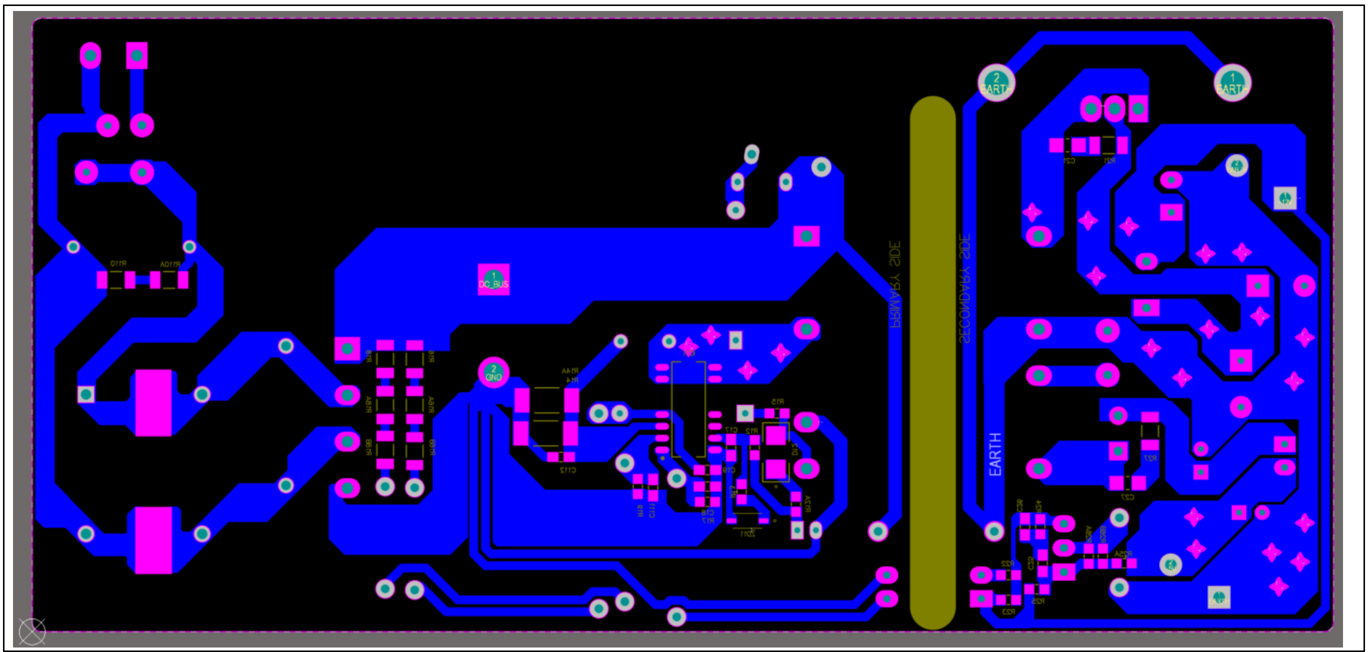
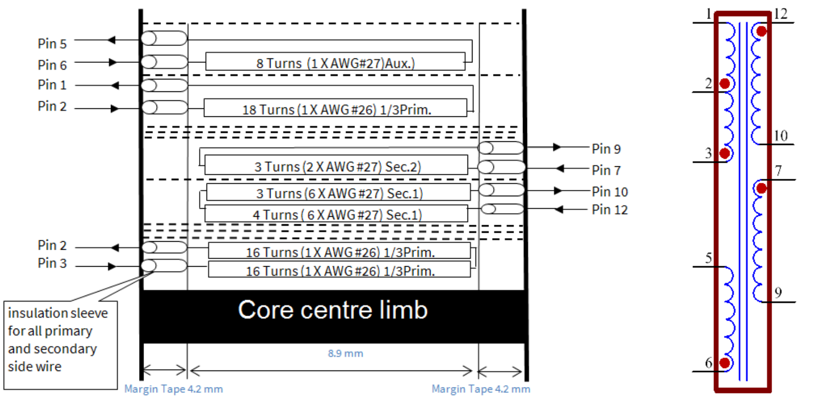


Figure 4 Bottom-side copper and component legend

9 Transformer construction

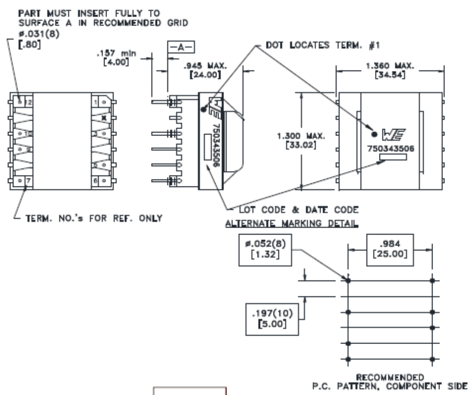
- **Core and materials:** EE30/15/7 (EF30), TP4A (TDG)
- **Bobbin:** 070-5313 (12-pin, THT, horizontal version)
- **Primary inductance:** Lp = 315 µH (±10 percent), measured between pin 1 and pin 3
- **Manufacturer and part number:** Würth Elektronik Midcom (750343506)



Start	Stop	No. of turns	Wire size	Layer
3	2	32	1XAWG#26	2/3 Primary
12	10	7	6XAWG#27	Secondary 1
7	9	3	2XAWG#27	Secondary 2
2	1	18	1XAWG#26	1/3 Primary
6	5	8	1XAWG#27	Auxiliary

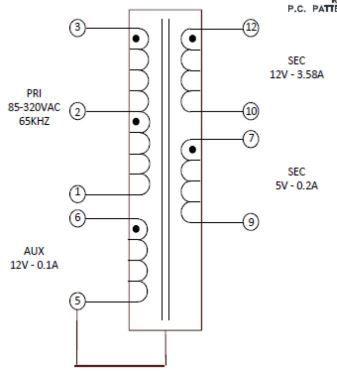
Horizontal and vertical core shields are added and tied to pin 5.

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	3-1	@20ºC	0.355 ohms max.
D.C. RESISTANCE	5-6	@20ºC	0.095 ohms max.
D.C. RESISTANCE	7-9	@20ºC	0.022 ohms max.
D.C. RESISTANCE	12-10	@20ºC	0.015 ohms max.
INDUCTANCE	3-1	10kHz, 100mV, Ls	315.00µH ±10%
LEAKAGE INDUCTANCE	3-1	tie(5+6+7+9+10+12),100kHz, 100mV, Ls	10.0 µH max.
DIELECTRIC	2-7	tie(2+6,7+10), 3750VAC, 1 second	
TURNS RATIO		(3-1):(6-5)	6.25:1, ±1%
TURNS RATIO		(3-1):(7-9)	16.67:1, ±1%
TURNS RATIO		(3-1):(12-10)	7.14:1, ±1%



GENERAL SPECIFICATIONS:

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

Designed to comply with the following requirements as defined by IEC60950-1, EN60950-1, UL60950-1/CSA60950-1 and AS/NZS60950.1:

- Reinforced insulation for a primary circuit at a working voltage of 320Vrms, Overvoltage Category II.

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

DFM		Packaging Specifications Method: Tray PKG-TBD	CONVENTION PLACEMENT	Tolerances unless otherwise specified: Angles: ±1° Decimals: ±.005 [.13] Fractions: ±1/64 Footprint: ± .001 [.03]	DRAWING TITLE TRANSFORMER	PART NO. 750343506
DATE						
ENG	HZH					
REV.	03			This drawing is dual dimensioned. Dimensions in brackets are in millimeters.		
DATE	2017-03-21	www.we-online.com/midcom				SPECIFICATION SHEET 1 OF 1

Figure 5 Transformer structure

10 Test results

10.1 Efficiency, regulation, and output ripple

Table 4 Efficiency, regulation, and output ripple

Input (V AC/Hz)	P_{in} (W)	V_{o1} (V DC)	I_{o1} (A)	V_{o1RPP} (mV)	V_{o2} (V DC)	I_{o2} (A)	V_{o2RPP} (mV)	P_{out} (W)	Efficiency η (percent)	Average η (percent)	OLP P_{in} (W)	OLP I_{outo1V} (A) (fixed 5 V at 0.2 A)
85 V AC/60 Hz	0.04	4.99	0.000	37	12.15	0.000	107				59.30	3.93
	0.09	4.61	0.006	71	13.03	0.000	47	0.03	32.28			
	14.72	5.06	0.060	17	11.90	1.000	44	12.20	82.88			
	12.53	5.06	0.050	16	11.89	0.853	39	10.39	82.93	82.33		
	25.00	5.07	0.100	21	11.87	1.705	60	20.74	82.98			
	37.82	5.08	0.150	26	11.85	2.559	78	31.08	82.17			
	50.98	5.08	0.200	30	11.84	3.412	93	41.41	81.23			
115 V AC/60 Hz	0.05	4.96	0.000	37	12.15	0.000	58				66.70	4.59
	0.09	4.60	0.006	80	13.06	0.000	53	0.03	30.52			
	14.60	5.05	0.060	17	11.91	1.000	41	12.21	83.65			
	12.45	5.06	0.050	16	11.90	0.853	38	10.40	83.53	84.02		
	24.58	5.06	0.100	20	11.89	1.705	58	20.77	84.50			
	37.06	5.07	0.150	25	11.85	2.559	73	31.09	83.89			
	49.27	5.07	0.200	26	11.86	3.412	83	41.46	84.15			
230 V AC/50 Hz	0.08	4.95	0.000	37	12.17	0.000	63				75.00	5.29
	0.13	4.52	0.006	81	13.25	0.000	53	0.03	21.30			
	14.66	5.04	0.060	16	11.94	1.000	41	12.24	83.49			
	12.54	5.05	0.050	16	11.93	0.853	39	10.42	83.09	85.02		
	24.36	5.05	0.100	19	11.91	1.705	58	20.81	85.41			
	36.49	5.06	0.150	21	11.88	2.559	71	31.15	85.37			
	48.20	5.06	0.200	22	11.88	3.412	71	41.54	86.19			
265 V AC/50 Hz	0.09	4.95	0.000	40	12.16	0.000	66				76.70	5.49
	0.14	4.51	0.006	83	13.26	0.000	56	0.03	19.37			
	14.77	5.04	0.060	17	11.94	1.000	41	12.24	82.89			
	12.62	5.05	0.050	16	11.93	0.853	39	10.42	82.57	84.84		
	24.42	5.05	0.100	21	11.91	1.705	61	20.81	85.24			
	36.50	5.06	0.150	21	11.89	2.559	71	31.17	85.40			
	48.25	5.06	0.200	21	11.89	3.412	68	41.56	86.14			
300 V AC/50 Hz	0.11	4.95	0.000	42	12.17	0.000	68				78.90	5.67
	0.16	4.50	0.006	90	13.28	0.000	57	0.03	16.87			
	14.87	5.04	0.060	16	11.94	1.000	41	12.24	82.33			
	12.73	5.04	0.050	16	11.93	0.853	38	10.42	81.87	84.52		
	24.53	5.05	0.100	20	11.92	1.705	58	20.82	84.89			
	36.58	5.06	0.150	27	11.89	2.559	70	31.19	85.25			
	48.32	5.06	0.200	22	11.89	3.412	66	41.58	86.05			

- **Minimum load condition:** 5 V at 6 mA
- **Typical load condition:** 5 V at 60 mA and 12 V at 1 A
- **Maximum load condition:** 5 V at 200 mA and 12 V at 3.41 A

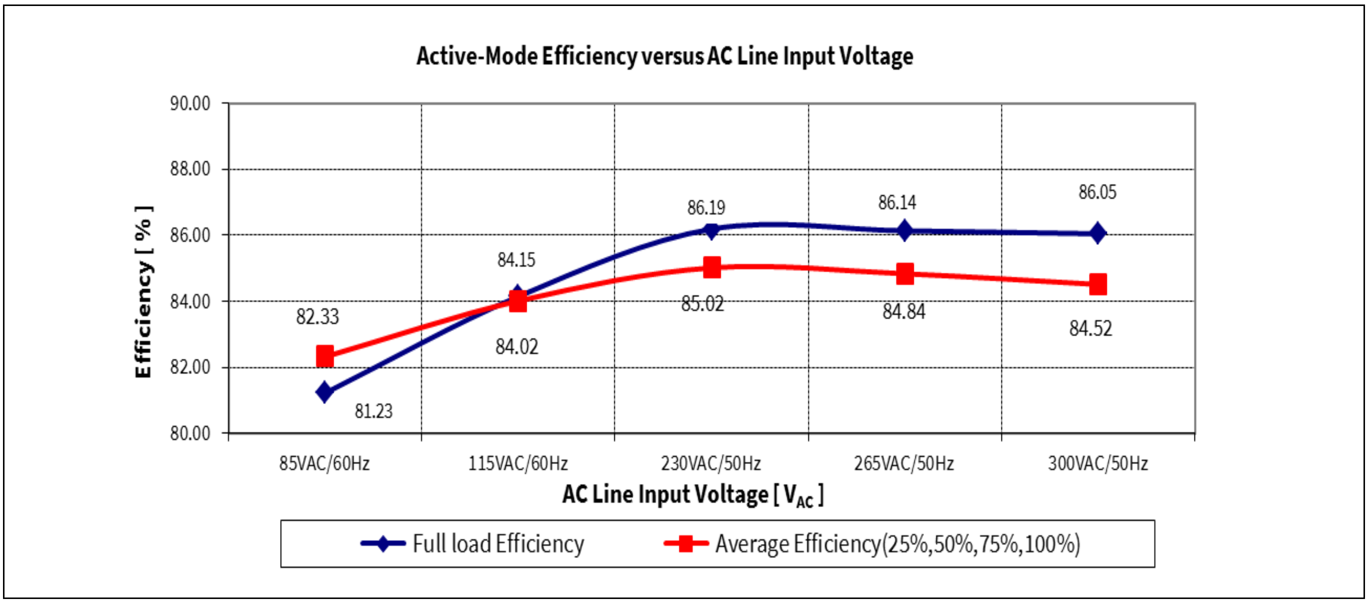


Figure 6 **Efficiency vs. AC-line input voltage**

10.2 Standby power

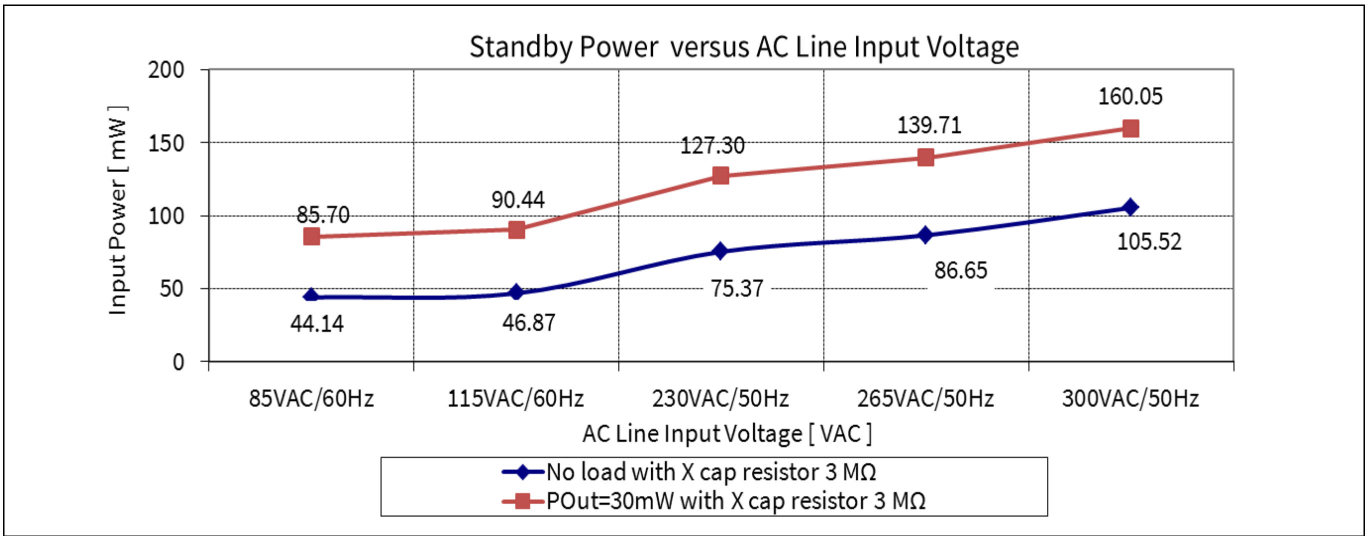


Figure 7 **Standby power at no load and 30 mW load vs. AC-line input voltage (measured by Yokogawa WT210 power meter – integration mode)**

10.3 Line regulation

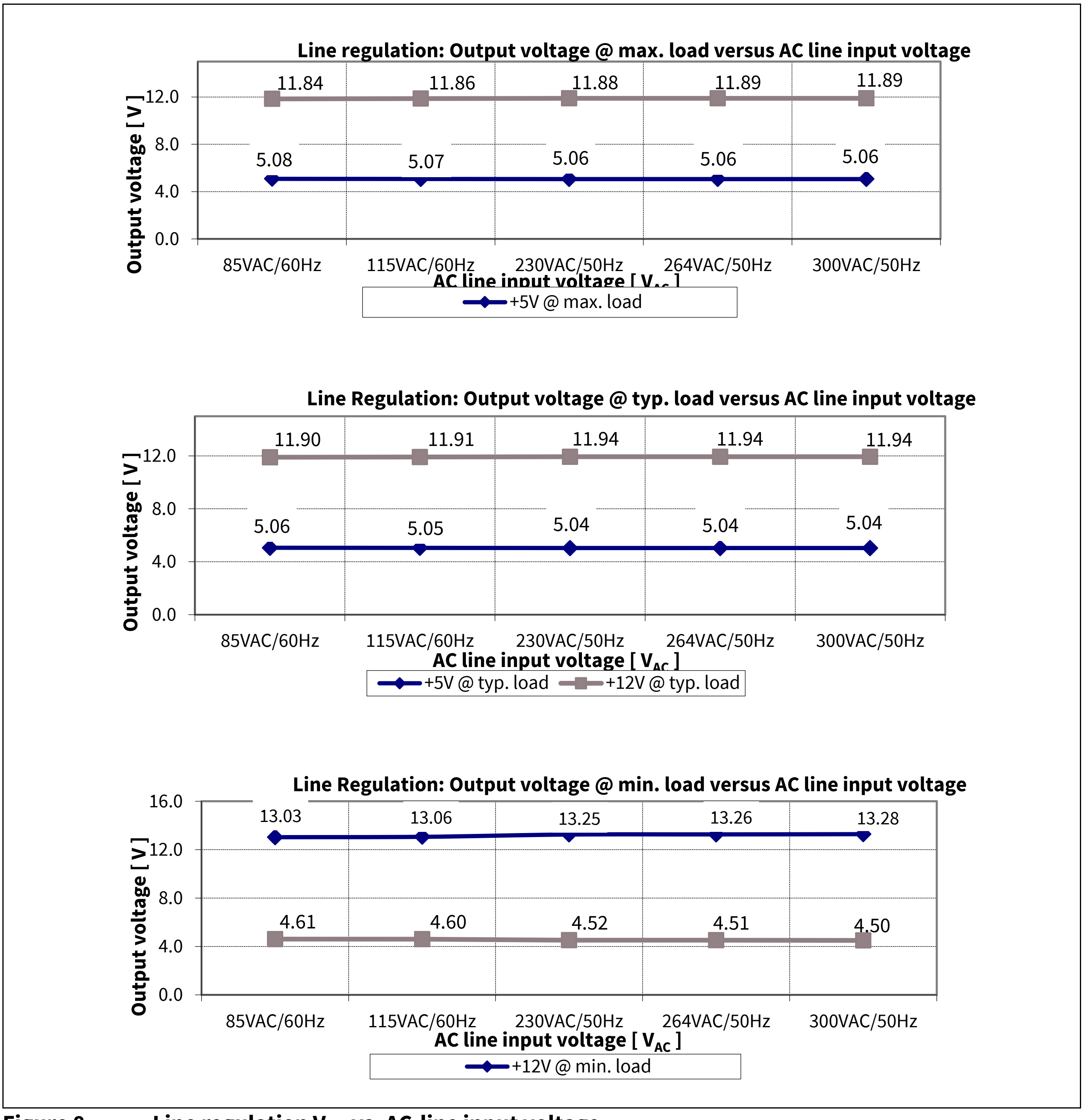


Figure 8 Line regulation V_{out} vs. AC-line input voltage

10.4 Load regulation

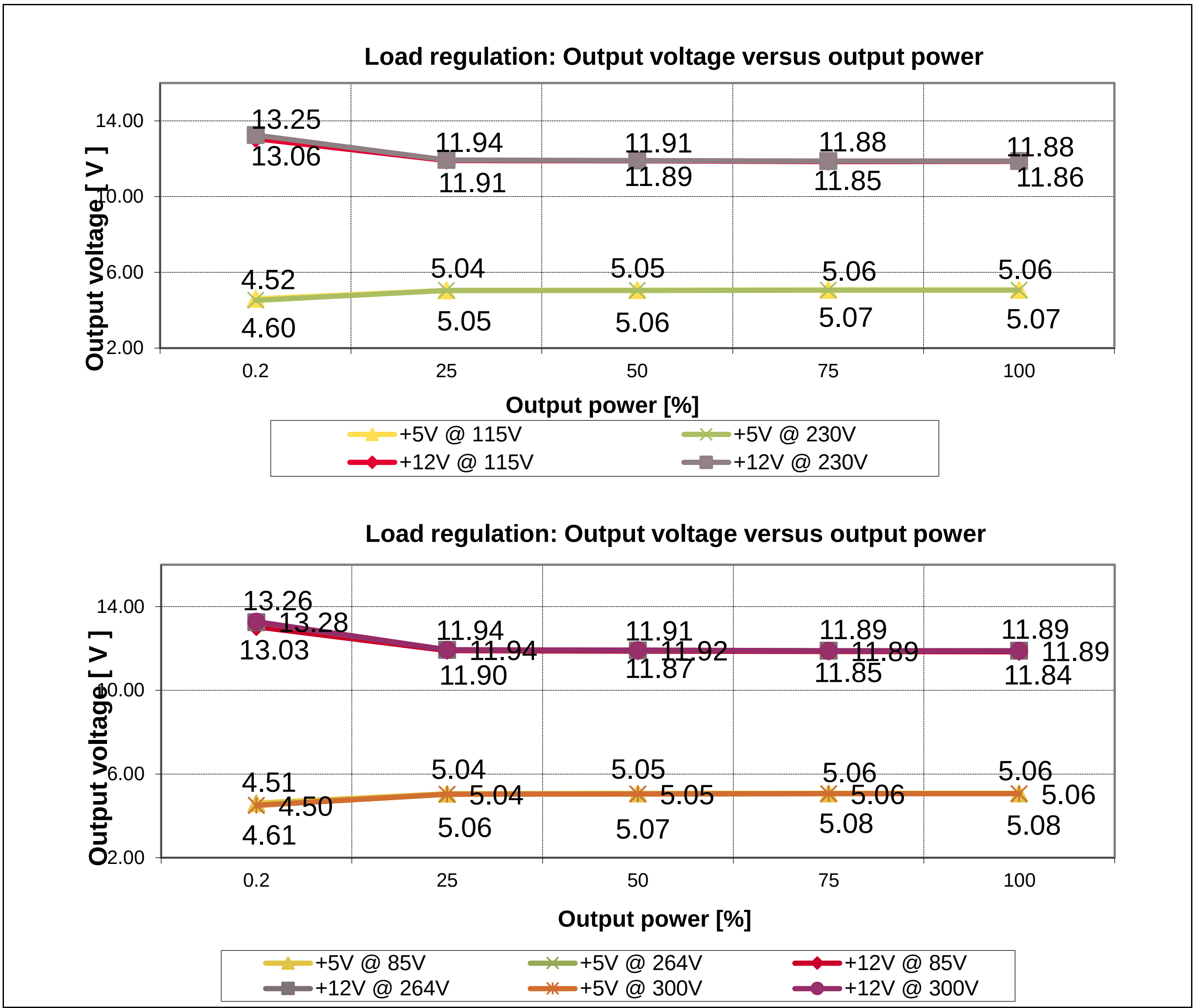


Figure 9 **Load regulation V_{out} vs. output power**

10.5 Maximum input power

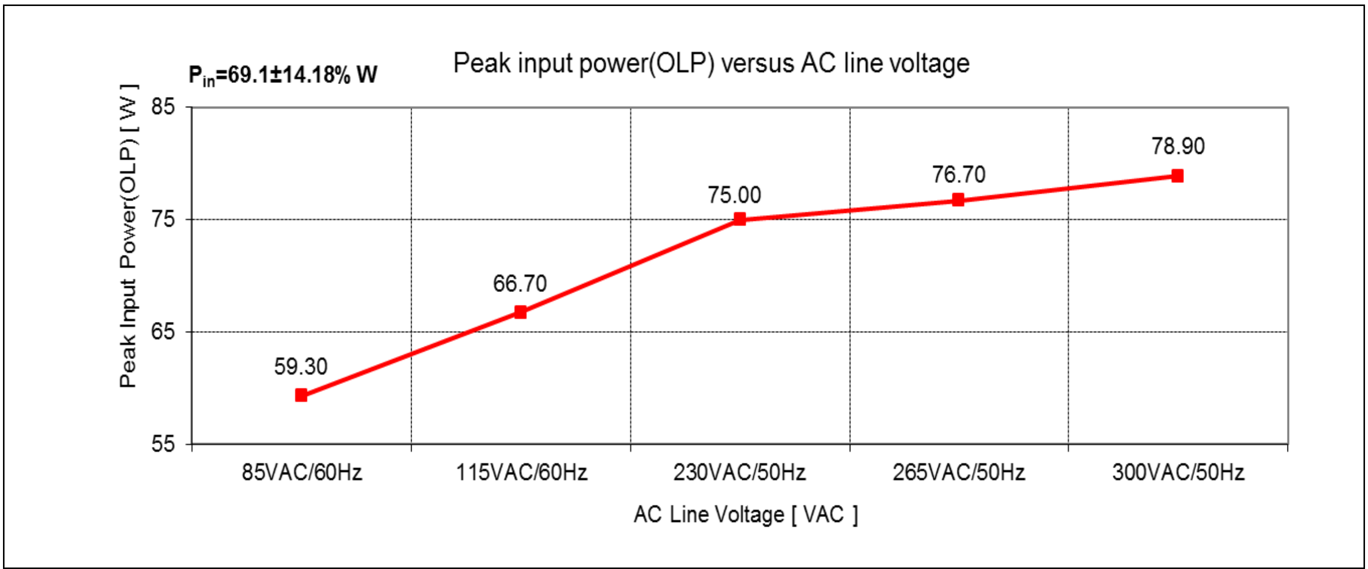


Figure 10 Maximum input power (before overload protection) vs. AC-line input voltage

10.6 ESD immunity (EN 61000-4-2)

Pass EN 61000-4-2 special level (±10 kV for both contact and air discharge).

10.7 Surge immunity (EN 61000-4-5)

Pass EN 61000-4-5 installation Class 4 (±2 kV for line-to-line and ±4 kV for line-to-earth).[1]

10.8 Conducted emissions (EN 55022 Class B)

The conducted EMI is measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) Class B. The reference board is set up at maximum load (42 W) with an input voltage of 115 V AC and 230 V AC.

[1] PCB spark-gap distance needs to reduce to 0.5 mm.

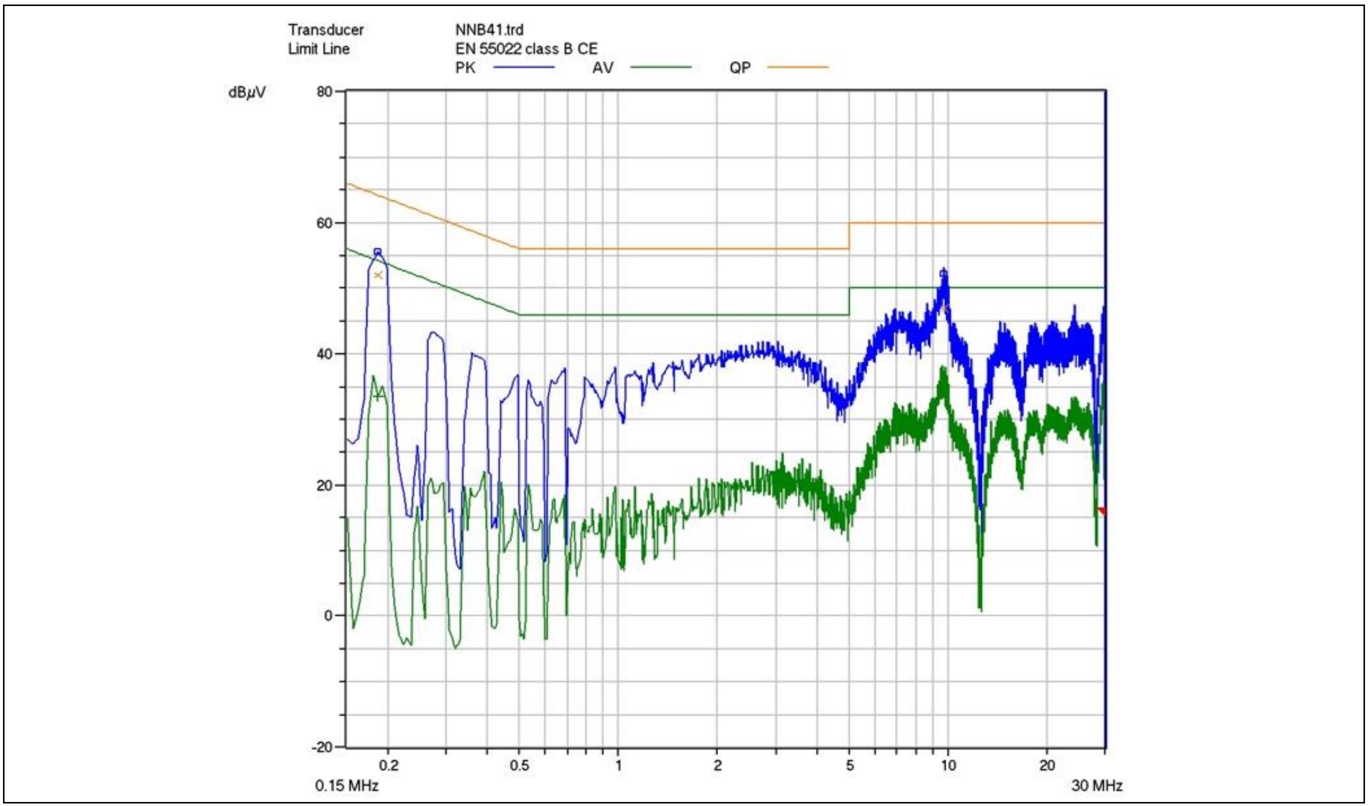


Figure 11 Conducted emissions (line) at 115 V AC and maximum load

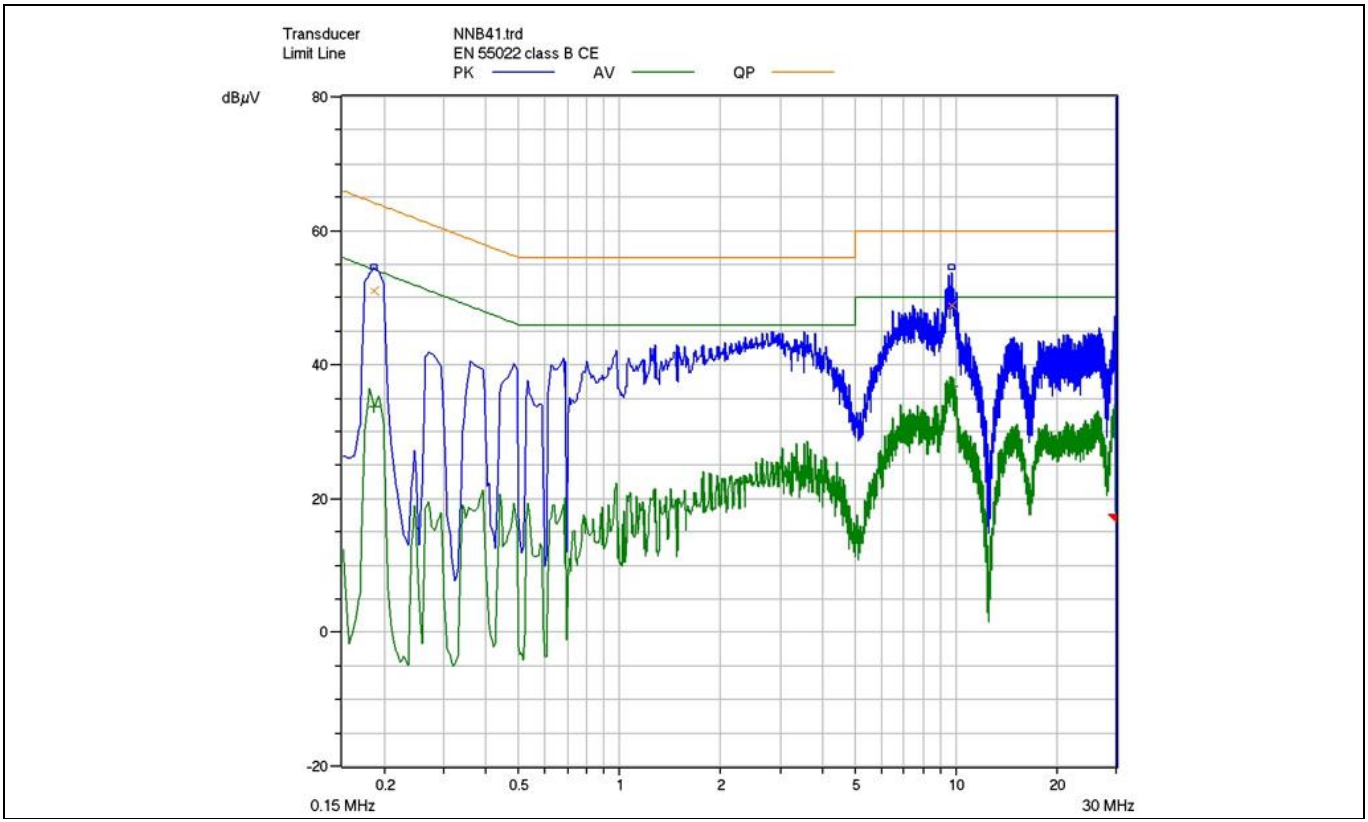


Figure 12 Conducted emissions (neutral) at 115 V AC and maximum load

Pass conducted emissions EN 55022 (CISPR 22) Class B with 6 dB margin for quasi-peak measurement at low-line (115 V AC).

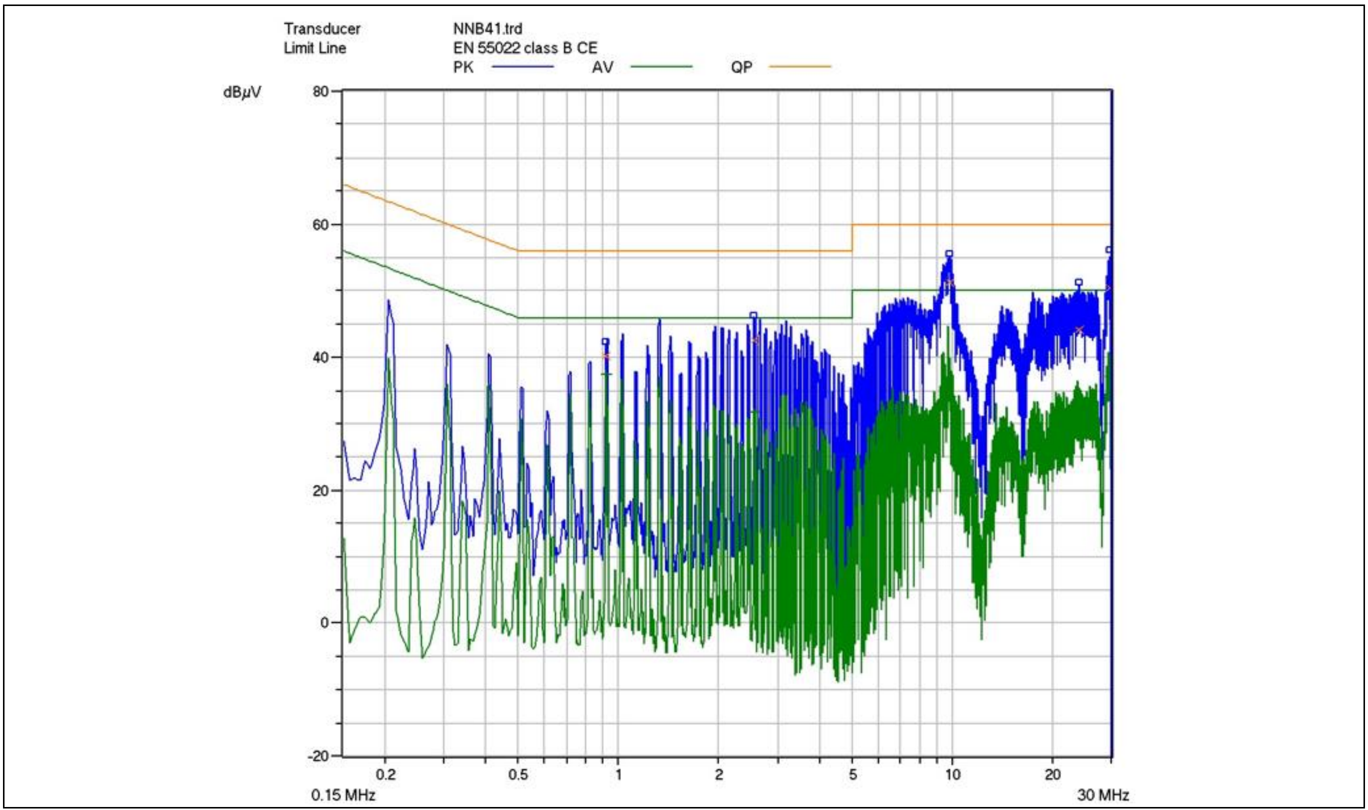


Figure 13 **Conducted emissions (line) at 230 V AC and maximum load**

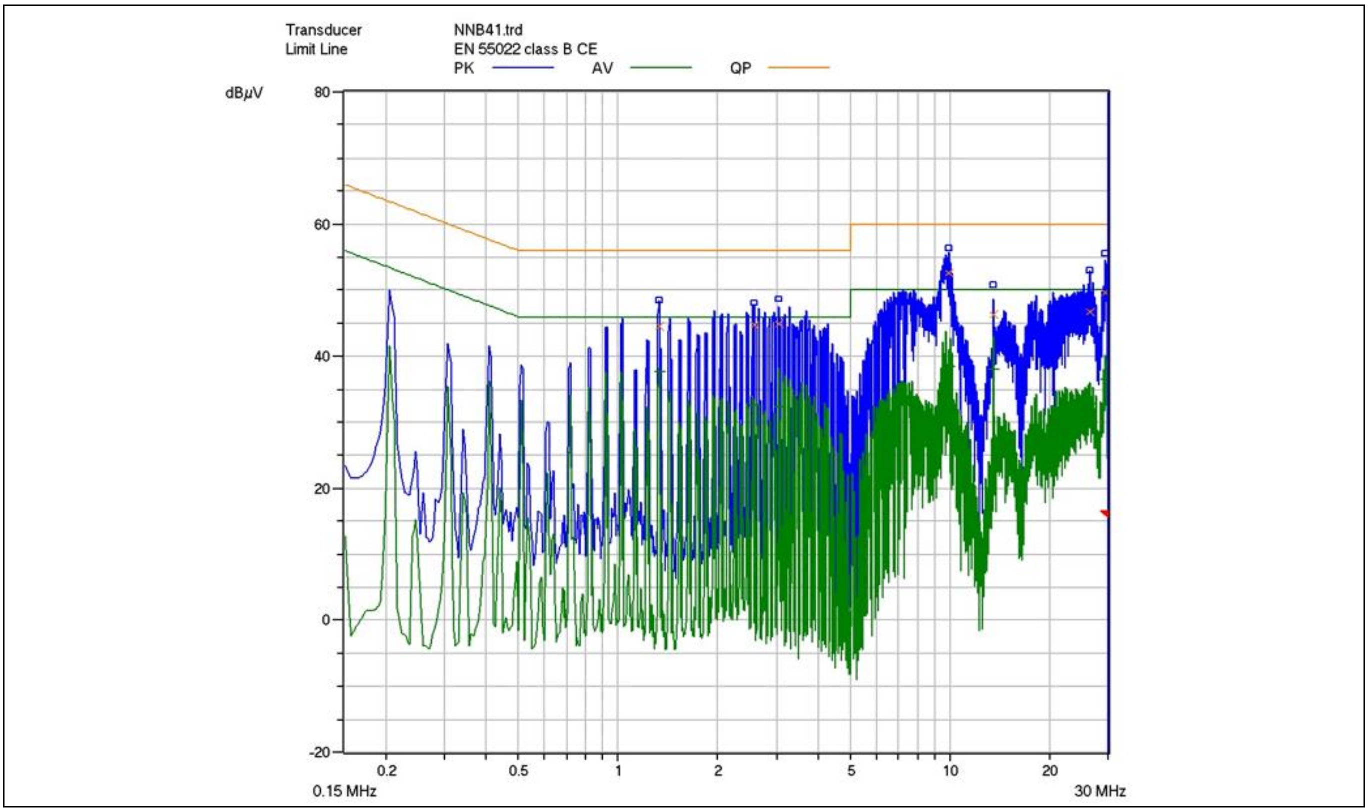


Figure 14 **Conducted emissions (neutral) at 230 V AC and maximum load**

Pass conducted emissions EN 55022 (CISPR 22) Class B with 6 dB margin for quasi-peak measurement at high-line (230 V AC).

10.9 Thermal measurement

The thermal testing 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 condition.

Table 5 Hottest temperature of reference board

No.	Major component	85 V AC (°C)	300 V AC (°C)
1	IC11 (ICE5QR0680BG-1)	87.2	80.3
2	R14 (CS resistor)	53.8	38
3	TR1 (transformer)	61.9	67.6
4	BR1 (bridge diode)	62.9	36.9
5	R11 (clamper)	90.8	84.5
6	L11 (choke)	92.0	36.5
7	D21 (secondary diode)	69.5	67.7
8	D22 (secondary diode)	50.8	50.5
9	Ambient	25.0	25.0

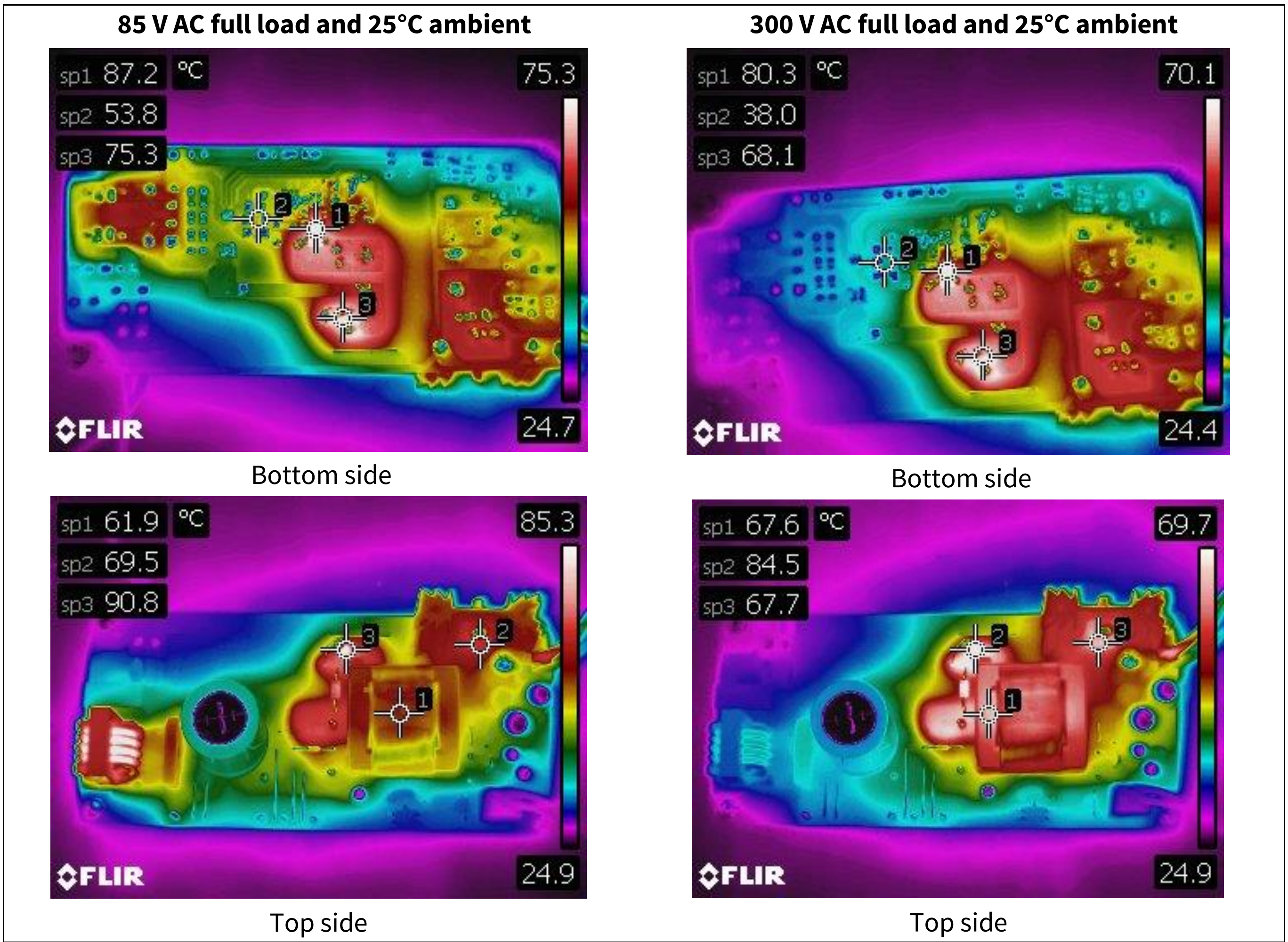


Figure 15 Infrared thermal image of REF_5QR0680BG-1_42W1

11 Waveforms and scope plots

All waveforms and scope plots were recorded with a Teledyne LeCroy 606Zi oscilloscope.

11.1 Start up at low/high AC-line input voltage with maximum load

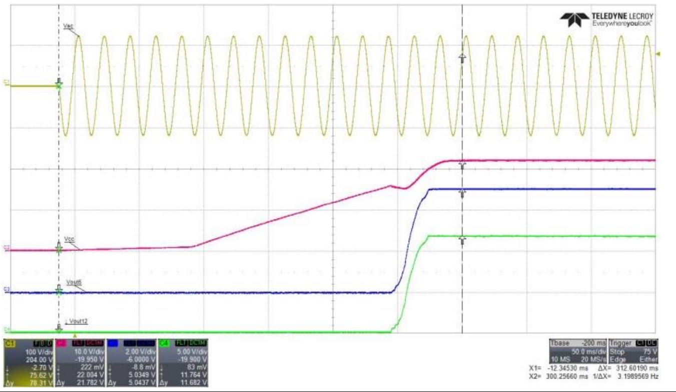
	
C1 (yellow): AC-line voltage (V AC) **C2 (purple):** Supply voltage (V_{VCC}) **C3 (blue):** 5 V output voltage (V_{out5}) **C4 (green):** 12 V output voltage (V_{out12})	**C1 (yellow):** AC-line voltage (V AC) **C2 (purple):** Supply voltage (V_{VCC}) **C3 (blue):** 5 V output voltage (V_{out5}) **C4 (green):** 12 V output voltage (V_{out12})
Startup time at 85 V AC and maximum load ≈ 312 ms	Startup time at 300 V AC and maximum load ≈ 262 ms

Figure 16 Startup

11.2 Soft start

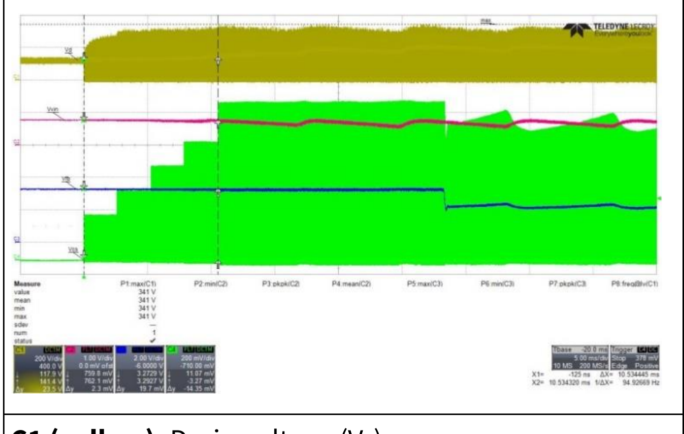
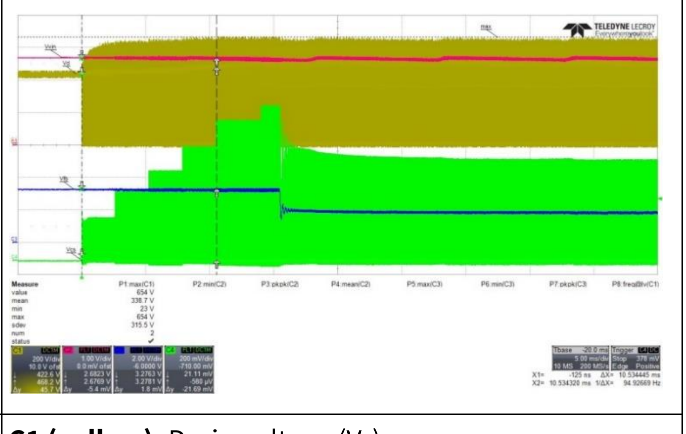
	
C1 (yellow): Drain voltage (V_D) **C2 (purple):** V_{IN} voltage (V_{VIN}) **C3 (blue):** Feedback voltage (V_{FB}) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Drain voltage (V_D) **C2 (purple):** V_{IN} voltage (V_{VIN}) **C3 (blue):** Feedback voltage (V_{FB}) **C4 (green):** CS voltage (V_{CS})
Soft-start time at 85 V AC and maximum load ≈ 10 ms	Soft-start time at 300 V AC and maximum load ≈ 10 ms

Figure 17 Soft start

11.3 Drain and CS voltage at maximum load

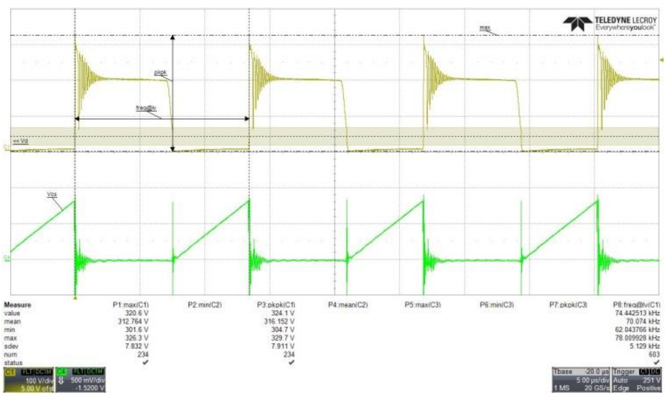
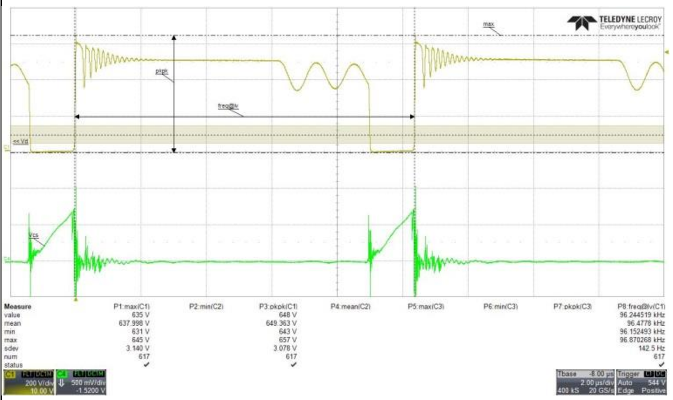
	
C1 (yellow): Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})
V_{Drain_peak} at 85 V AC ≈ 326 V with first zero crossing and f_{S_Min} ≈ 62 kHz	V_{Drain_peak} at 300 V AC ≈ 657 V with third zero crossing and f_{S_Min} ≈ 96 kHz

Figure 18 Drain and CS voltage at maximum load

11.4 Zero crossing point during normal operation

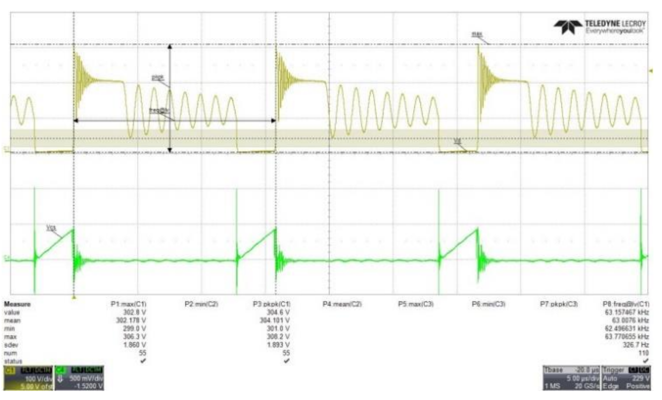
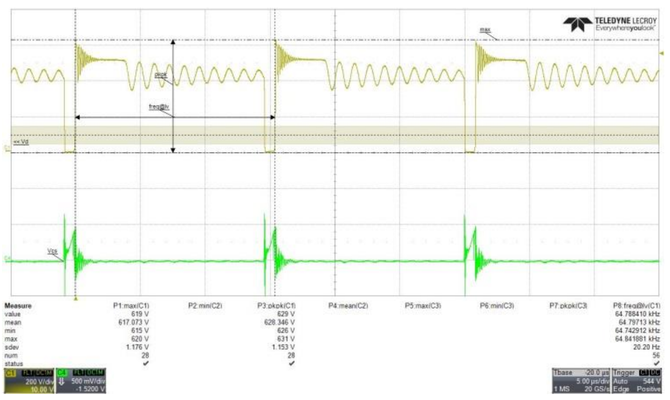
	
C1 (yellow): Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Drain voltage (V_D) **C4 (green):** CS voltage (V_{CS})
Eighth zero crossing at 85 V AC and 25 percent load (5 V x 0.05 A + 12 V x 0.853 A) (Zero crossing varies from 1 ~ 8 for low-line)	Tenth zero crossing at 300 V AC and 25 percent load (5 V x 0.05 A + 12 V x 0.853 A) (Zero crossing varies from 3 ~ 10 for high-line)

Figure 19 Zero crossing

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

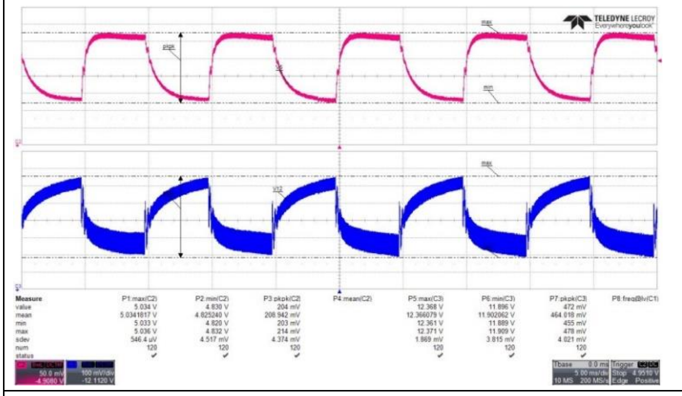
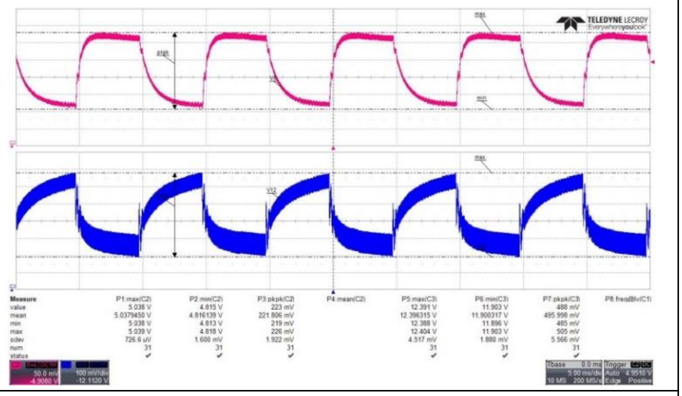
	
C2 (purple): 5 V output ripple voltage (V_{out5}) **C3 (blue):** 12 V output ripple voltage (V_{out12})	**C2 (purple):** 5 V output ripple voltage (V_{out5}) **C3 (blue):** 12 V output ripple voltage (V_{out12})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 214 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 478 mV (85 V AC, 12 V load change from 10 percent to 100 percent and 5 V at 200 mA load, 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 BW	5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 226 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 505 mV (300 V AC, 12 V load change from 10 percent to 100 percent and 5 V at 200 mA load, 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 BW

Figure 20 Load transient response

11.6 Output ripple voltage at maximum load

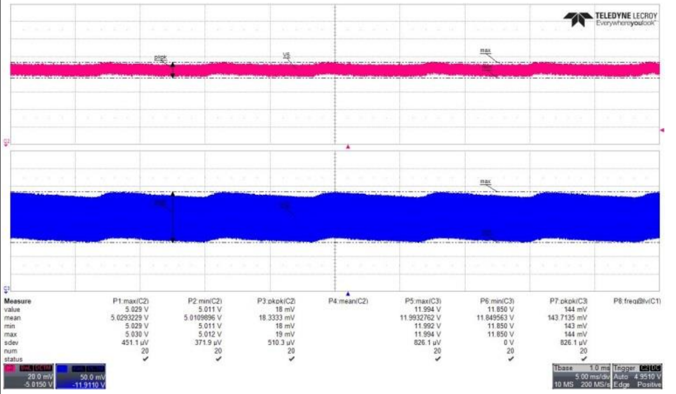
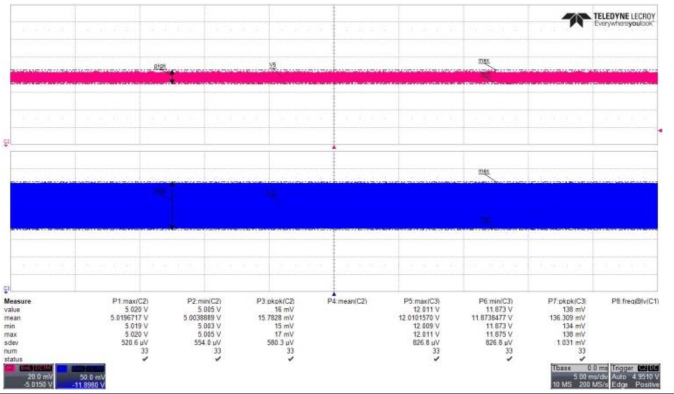
	
C2 (purple): 5 V output ripple voltage (V_{out5}) **C3 (blue):** 12 V output ripple voltage (V_{out12})	**C2 (purple):** 5 V output ripple voltage (V_{out5}) **C3 (blue):** 12 V output ripple voltage (V_{out12})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 20 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 146 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz BW	5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 17 mV 12 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 138 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz BW

Figure 21 Output ripple voltage at maximum load

11.7 Output ripple voltage at ABM 1 W load

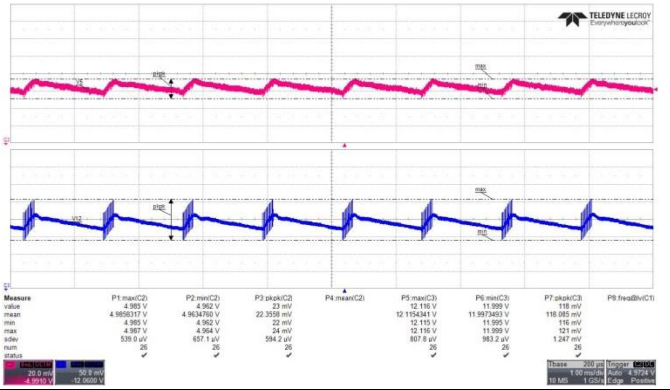
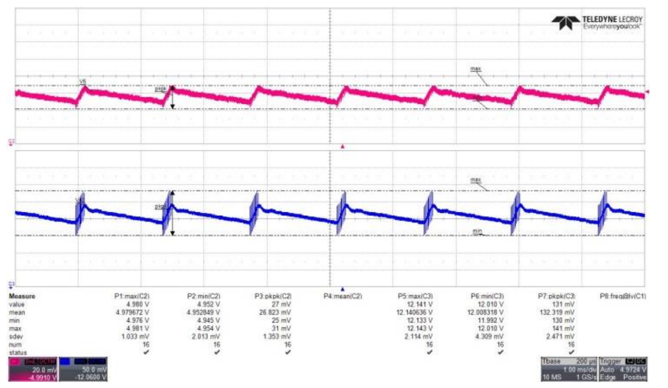
	
C2 (purple): 5 V output ripple voltage (V_{out5}) **C3 (blue):** 12 V output ripple voltage (V_{out12})	**C2 (purple):** 5 V output ripple voltage (V_{out5}) **C3 (blue):** 12 V output ripple voltage (V_{out12})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 24 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 121 mV Load: 5 V at 6 mA and 12 V at 80 mA Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz BW	5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 31 mV 12 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 141 mV Load: 5 V at 6 mA and 12 V at 80 mA Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (electrolytic), 20 MHz BW

Figure 22 Output ripple voltage at ABM 1 W load

11.8 Entering ABM

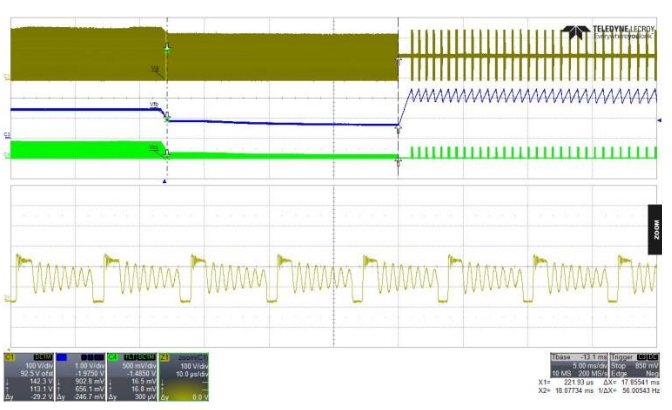
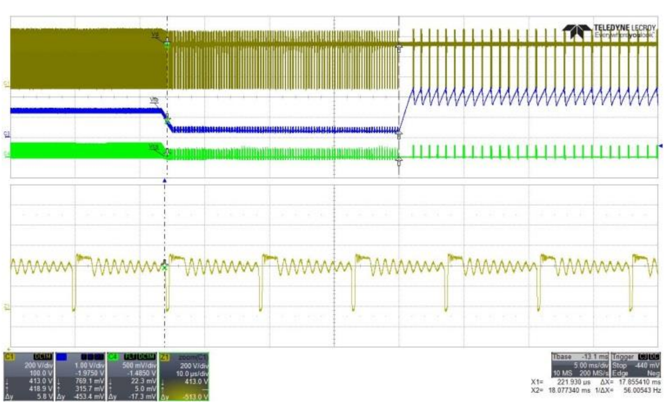
	
C1 (yellow): Drain voltage (V_D) **C3 (blue):** FB voltage (V_{FB}) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Drain voltage (V_D) **C3 (blue):** FB voltage (V_{FB}) **C4 (green):** CS voltage (V_{CS})
Condition to enter ABM level 1: V_{FB} less than 0.9 V, N_{ZC} = 8 and $t_{blanking}$ = 20 ms (85 V AC, load change from 10.5 W to 1 W) (5 V x 50 mA + 12 V x 0.853 A) to (5 V x 50 mA + 12 V x 0.0.062 A)	**Condition to enter ABM level 1:** V_{FB} less than 0.9 V, N_{ZC} = 10 and $t_{blanking}$ = 20 ms (300 V AC, load change from 10.5 W to 1 W) (5 V x 50 mA + 12 V x 0.853 A) to (5 V x 50 mA + 12 V x 0.0.062 A)

Figure 23 Entering ABM

11.9 During ABM

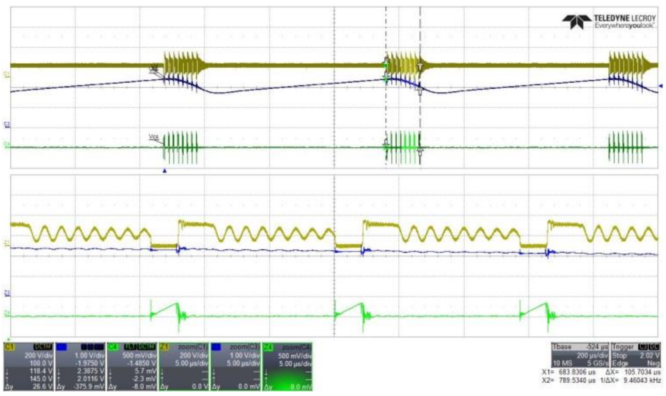
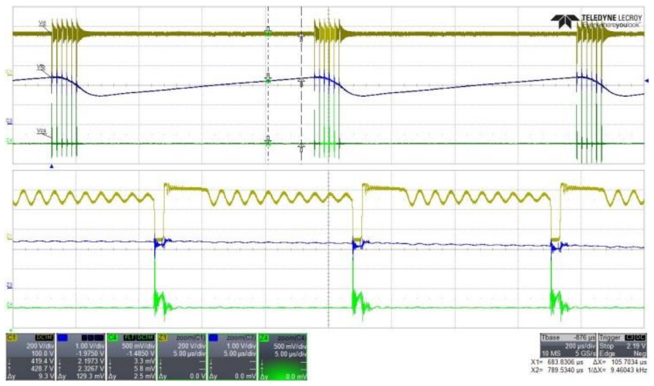
	
C1 (yellow): Drain voltage (V_D) **C3 (blue):** FB voltage (V_{FB}) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Drain voltage (V_D) **C3 (blue):** FB voltage (V_{FB}) **C4 (green):** CS voltage (V_{CS})
During ABM level 1: V_{FB_BOn} = 2.4 V, V_{FB_BOff} = 2.0 V, V_{CSBLP} = 0.31 V, N_{ZC} = 8 85 V AC, 1 W (5 V x 50 mA + 12 V x 0.062 A)	**During ABM level 1:** V_{FB_BOn} = 2.4 V, V_{FB_BOff} = 2.0 V, V_{CSBLP} = 0.31 V, N_{ZC} = 10 300 V AC, 1 W (5 V x 50 mA + 12 V x 0.062 A)

Figure 24 **During ABM**

11.10 Leaving ABM

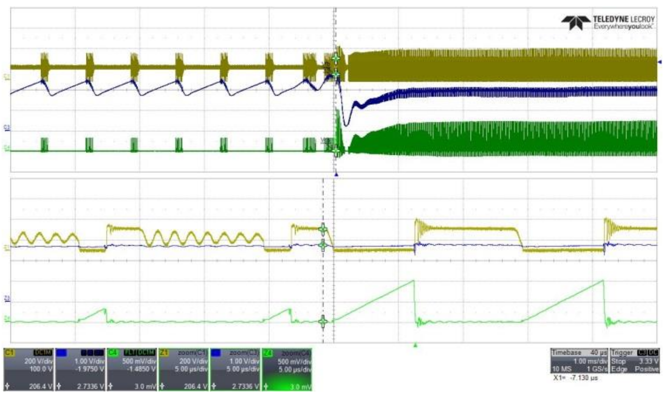
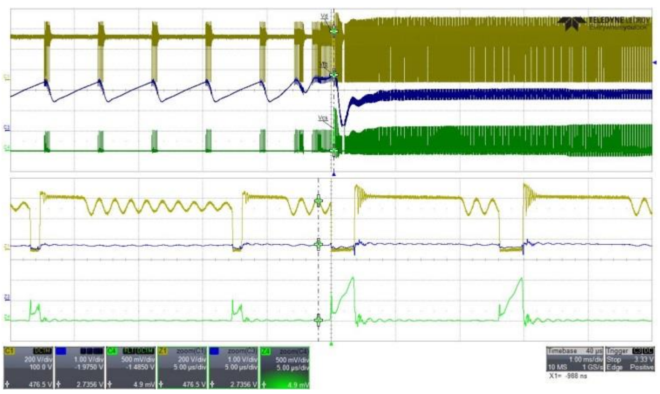
	
C1 (yellow): Drain voltage (V_D) **C3 (blue):** FB voltage (V_{FB}) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Drain voltage (V_D) **C3 (blue):** FB voltage (V_{FB}) **C4 (green):** CS voltage (V_{CS})
Condition to leave ABM level 1: V_{FB} more than 2.75 V 85 V AC, load change from 1 W to 41.25 W (5 V x 50 mA + 12 V x 0.0.062 A) to (5 V x 50 mA + 12 V x 3.41 A)	**Condition to leave ABM level 1:** V_{FB} more than 2.75 V 300 V AC, load change from 1 W to 41.25 W (5 V x 50 mA + 12 V x 0.0.062 A) to (5 V x 50 mA + 12 V x 3.41 A)

Figure 25 **Leaving ABM**

11.11 Line OVP (non-switch auto-restart)

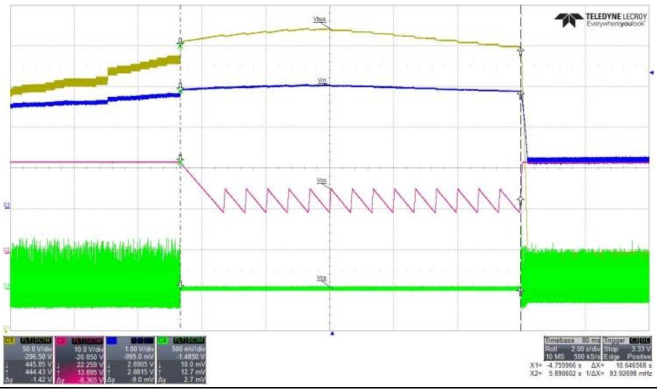
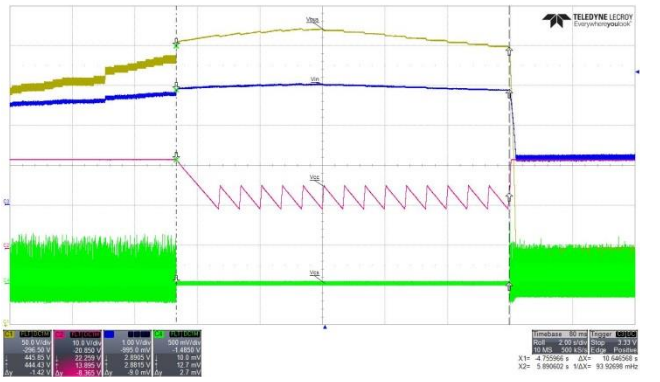
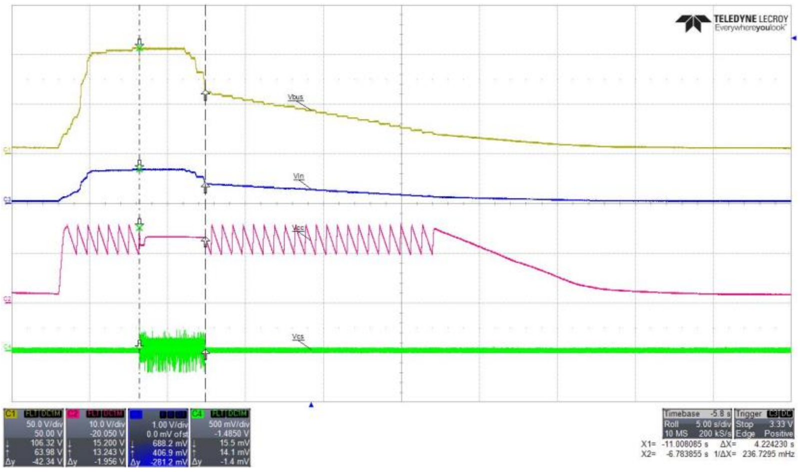
<table>
<tr><td></td><td></td></tr>
<tr><td>C1 (yellow): Bus voltage (V_{Bus})
C2 (purple): Supply voltage (V_{VCC})
C3 (blue): V_{IN} voltage (V_{VIN})
C4 (green): CS voltage (V_{CS})</td><td>C1 (yellow): Bus voltage (V_{Bus})
C2 (purple): Supply voltage (V_{VCC})
C3 (blue): V_{IN} voltage (V_{VIN})
C4 (green): CS voltage (V_{CS})</td></tr>
<tr><td colspan="2">Condition to detect line OVP: V_{VIN} more than 2.9 V (V_{BULK} more than 445 V DC [≈ 320 V AC])
Condition to reset line OVP: V_{VIN} less than 2.9 V (V_{BULK} less than 445 V)</td></tr>
<tr><td>(Gradually increase AC-line voltage at full load until line OVP detect and decrease AC-line until line OVP reset)</td><td>(Gradually increase AC-line voltage at 1 W load (ABM) until line OVP detect and decrease AC-line until line OVP reset)</td></tr>
</table>

Figure 26 Line OVP

11.12 Brownout protection (non-switch auto-restart)



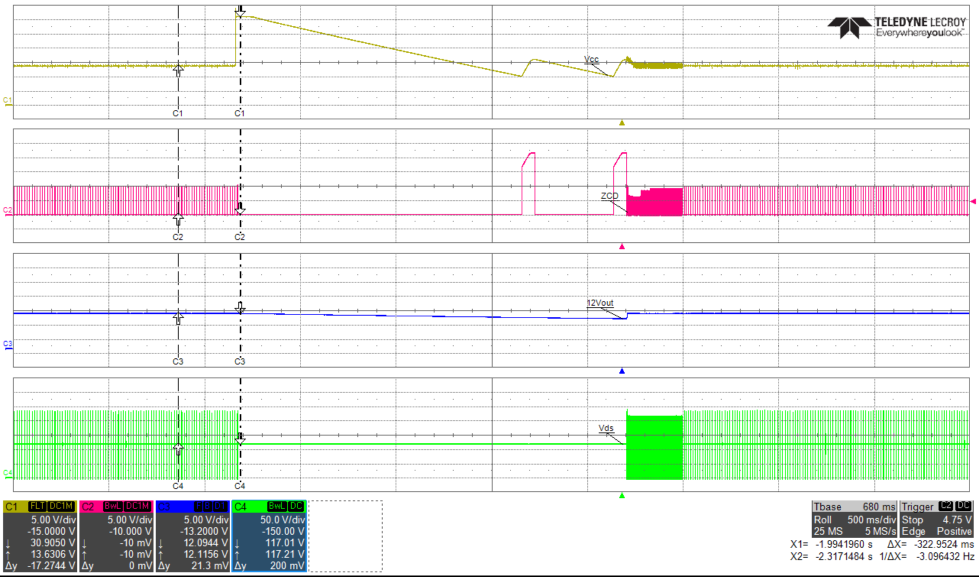
C1 (yellow): Bus voltage (V_{Bus})
C2 (purple): Supply voltage (V_{VCC})
C3 (blue): V_{IN} voltage (V_{VIN})
C4 (green): CS voltage (V_{CS})

Condition to reset brownout protection (brown-in): V_{VIN} more than 0.66 V (V_{BULK} more than 106 V DC [≈ 75 V AC])
Condition to detect brownout protection: V_{VIN} less than 0.4 V (V_{BULK} less than 63 V DC [≈ 43 V AC])

(Gradually increase AC-line voltage at 1 W (5 V at 6 mA and 12 V at 80 mA) load until system starts and reduce the line until brown-out detect)

Figure 27 Brownout protection

11.13 V_{CC} OVP (odd-skip auto-restart)



C1 (yellow): V_{CC} voltage (V_{VCC})

C2 (purple): ZCD voltage (V_{ZCD})

C3 (blue): 12 V output voltage (V_{O12})

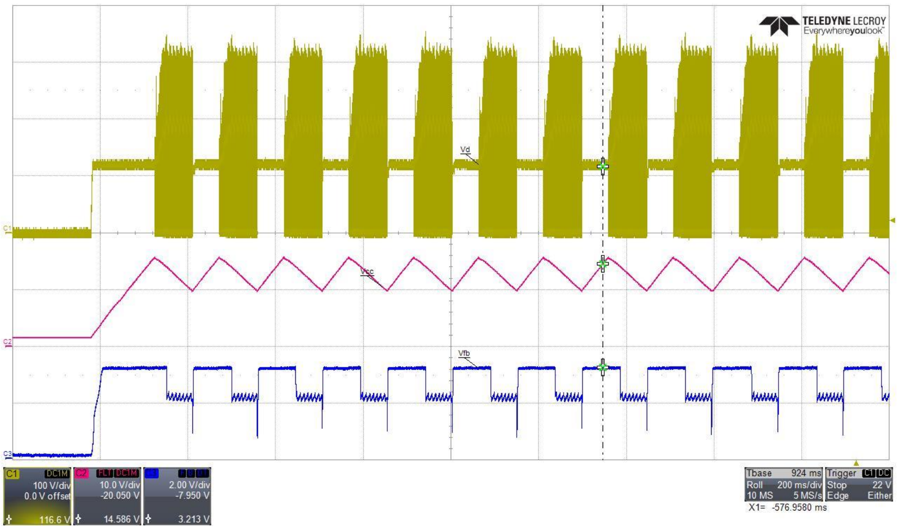
C4 (green): VDS voltage (V_{DS})

Condition to enter V_{CC} OVP: V_{VCC} more than 30.5 V

(at 85 V_{ac}, no load. Apply externally a DC Pulse at V_{CC} pin > V_{VCC_OVP}.

Figure 28 V_{CC} OVP

11.14 V_{CC} undervoltage protection (UVP) (auto-restart)



C1 (yellow): Drain voltage (V_D)

C2 (purple): Supply voltage (V_{VCC})

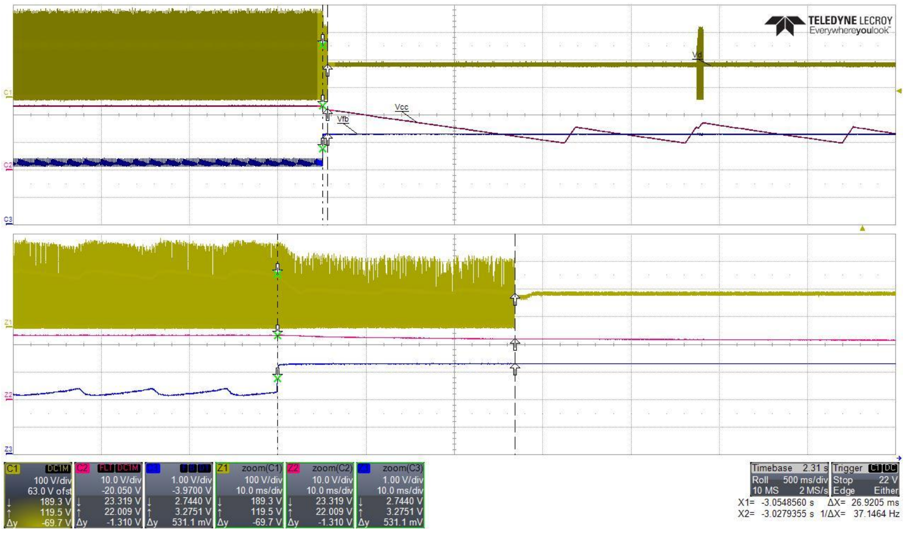
C3 (blue): Feedback voltage (V_{FB})

Condition to enter V_{CC} UVP: V_{CC} less than 10 V

(Remove R12 A and power on the system with full load at 85 V AC)

Figure 29 V_{CC} UVP

11.15 Overload protection (odd-skip auto-restart)

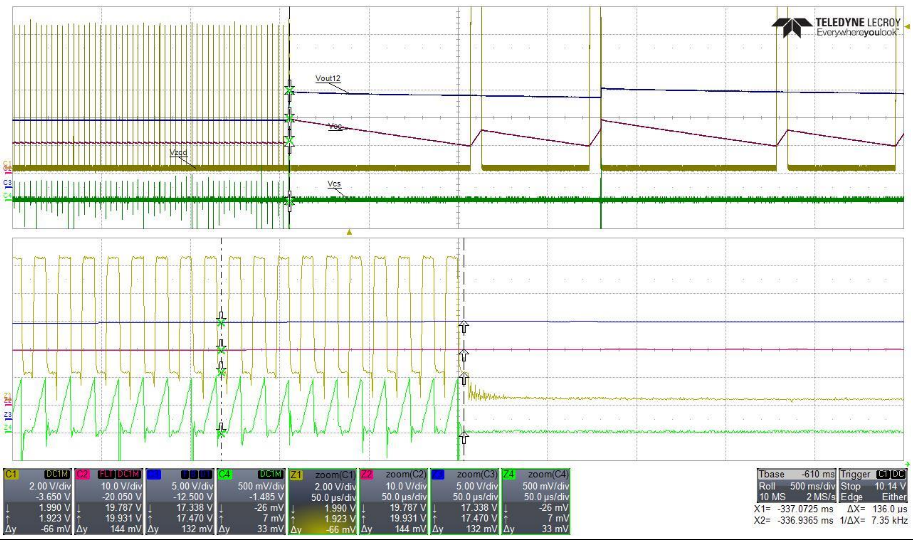


C1 (yellow): Drain voltage (V_D)
C2 (purple): Supply voltage (V_{VCC})
C3 (blue): Feedback voltage (V_{FB})

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 short at 85 V AC)

Figure 30 Overload protection

11.16 Output OVP (odd-skip auto-restart)

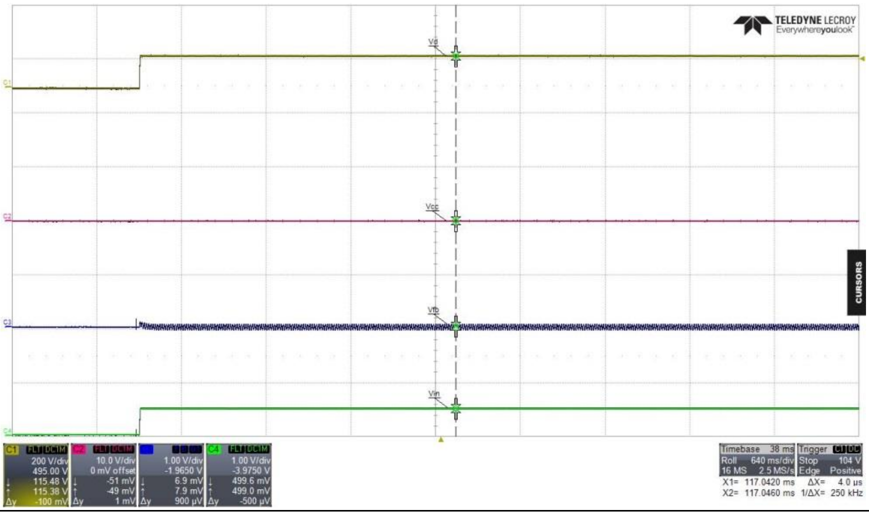


C1 (yellow): ZCD voltage (V_{ZCD})
C2 (purple): Supply voltage (V_{VCC})
C3 (blue): 12 V output voltage (V_{O12})
C4 (green): CS voltage (V_{CS})

Condition to enter output OVP: V_{ZCD} more than 1.9 V
(85 V AC, short R26 during system operation at no load)

Figure 31 Output OVP

11.17 V_{CC} short-to-GND protection



C1 (yellow): Drain voltage (V_D)
C2 (purple): V_{CC} voltage (V_{VCC})
C3 (blue): Feedback voltage (V_{FB})
C4 (green): V_{IN} voltage (V_{VIN})

Condition to enter V_{CC} short-to-GND: if V_{CC} is less than V_{VCC_SCP} $I_{VCC} = I_{VCC\_Charge1}$
(Short V_{CC} pin-to-GND by multimeter and measure the current, I_{VCC} ≈ 280 µA and input power is ≈ 50 mW at 85 V AC and full load)

Figure 32 V_{CC} short-to-GND protection

References

[1] Infineon Technologies AG: *ICE5QRxx80BG-1 datasheet*; Available online

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

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Design support

Developer community

For a wider discussion with peers from industry to trade ideas regarding Infineon products, we welcome you to actively participate on the Infineon Developer Community.

Technical support

Have technical queries? Consult experts from Infineon to get a fast turn-around by raising a request on the Technical Support page or a local sales representative.

Revision history

Document revision	Date	Description of changes
V 1.0	2024-11-19	Initial release

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