42 W 12 V 5 V SMPS demo board with ICE5QR0680AG

About this document

Scope and purpose

This document is an engineering report that describes a universal-input 42 W 12 V and 5 V off-line flyback converter using the latest 5th generation Infineon QR CoolSET™ ICE5QR0680AG. It offers high-efficiency, low-standby power with selectable entry and exit standby power options, wide V CC operating range with fast start-up, robust line protection with input Over Voltage Protection (OVP), and brownout and various modes of protection for a highly reliable system. This demo board is designed for users who wish to evaluate the performance of ICE5QR0680AG 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 off-line SMPS, such as auxiliary power supplies for white goods, PCs, servers and TVs, or enclosed adapters for blu-ray players, set-top boxes, games consoles, etc.

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Revision 1.0
2017-05-19

1 Abstract

This AN is an engineering report for a 42 W 12 V and 5 V demo board designed in a QR flyback converter topology using the 5th generation QR CoolSET™ ICE5QR0680AG. The target applications of ICE5QR0680AG are either auxiliary power supplies for white goods, PCs, servers or TVs, or enclosed adapters for Blu-ray players, set-top boxes, games consoles, etc. With the CoolMOS™ integrated into this IC, it greatly 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 enhanced 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, numerous adjustable protection functions have been implemented in ICE5QR0680AG to protect the system and customize the IC for the chosen application. In case of failure modes such as brownout or line over-voltage, V CC over-/under-voltage, open control-loop or over-load, output over-voltage, over-temperature, V CC short-to-ground and Current Sense (CS) 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.

2 Demo board

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

Figure 1 DEMO_5QR0680AG_42W1

3 Specifications of the demo board

Table 1 Specifications of DEMO_5QR0680AG_42W1

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% of nominal output voltage
Output ripple voltage (full-load, 85 V AC~300 V AC)	5 $V_{ripple\_p\_p}$ < 100 mV 12 $V_{ripple\_p\_p}$ < 150 mV
Active mode four-point average efficiency (25%, 50%, 75%, 100% load)	> 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: *The demo board is designed for dual output with cross-regulated loop feedback. It may not regulate properly if loading is applied only to single output. If the user wants to evaluate for single-output (12 V only) conditions, the following changes are necessary on the board.*

1. Remove D22, L22, C28, C210, 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)

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

4 Circuit description

4.1 Line input

The AC-line input side comprises the input fuse F1 as over-current protection. The choke L11, X-capacitors C11 and C14 and Y-capacitors C12, C12A and C12B act as EMI suppressors. Optional spark-gap devices SA1, SA2 and varistor VAR can absorb HV 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.

4.2 Start-up

To achieve fast and safe start-up, ICE5QR0680AG is implemented with a start-up resistor and V CC short-to-GND protection. When V_{VCC} reaches the turn-on voltage threshold 16 V, the IC begins with a soft-start. The soft-start implemented in ICE5QR0680AG is a digital time-based function. The preset soft-start time is 12 ms with four steps. If not limited by other functions, the peak voltage on the CS pin will increase in increments from 0.3 V to 1 V. After IC turn-on, the V CC voltage is supplied by auxiliary windings of the transformer. V CC short-to-GND protection is implemented during the start-up time.

4.3 Integrated MOSFET and PWM control

ICE5QR0680AG is comprised of a power MOSFET and the new proprietary QR controller, which enables higher average efficiency and low EMI. This integrated solution greatly simplifies the circuit layout and reduces the cost of PCB manufacture. The PWM switch-on is determined by the Zero Crossing Detection (ZCD) input signal and the value of the up/down counter. The PWM switch-off is determined by the feedback (FB) signal V_{FB} and the CS signal V_{CS}. ICE5QR0680AG also performs all necessary protection functions in Flyback converters. Details about the information mentioned above are illustrated in the product datasheet.

4.4 Clamper circuit

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

4.5 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 interference between SMPS switching frequency and line frequency. Storage capacitors C22, C23 and C28 are designed to have as small an internal resistance (ESR) as possible to minimize the output voltage ripple caused by the triangular current.

4.6 Feedback loop

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

4.7 Primary side peak-current control

The MOSFET drain source current is sensed via external resistors R14 and R14A. Since ICE5QR0680AG is a current mode controller, it would have a cycle-by-cycle primary current and FB 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 whole-line input voltage range. This is usually not desirable, as 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 the ICE5QR0680AG. As a result, the maximum output power can be limited against the input voltage.

4.8 Digital frequency reduction

During normal operation, the switching frequency for ICE5QR0680AG 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 FB voltage in a time-base. The FB 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.

4.9 Active Burst Mode (ABM)

ABM entry and exit power (two levels) can be selected in ICE5QR0680AG. Details are illustrated in the product datasheet. ABM power level 1 is used in this demo 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 at the same time it supports low ripple on V_{out} and fast response on load-jump.

For determination of entering ABM operation, three conditions apply:

1. The FB voltage is lower than the threshold of V_{FB_EBLX}
2. The up/down counter is 8 for low-line and 10 for high-line, and
3. 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, so that the controller enters ABM operation only when the output power is really low during the preset blanking time.

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

The FB voltage immediately increases if there is a high load-jump. This is observed by one comparator. As the current limit is 31/35% during ABM a certain load is needed so that FB 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.

5 Protection features

Protection is one of the major factors in determining whether the system is safe and robust – therefore sufficient protection is necessary. ICE5QR0680AG provides comprehensive protection to ensure the system is operating safely. This includes line over-voltage, brownout, V CC over-voltage and under-voltage, over-load, output over-voltage, over-temperature (controller junction), CS short-to-GND and V CC short-to-GND. When those faults are found, the system will go into protection mode. Once the fault is removed, the system resumes normal operation. A list of protections and failure conditions are shown in the table below.

Table 2 Protection functions of ICE5QR0680AG

Protection function	Failure condition	Protection mode
Line over-voltage	V_{VIN} > 2.9 V	Non-switch auto restart
Brownout	V_{VIN} < 0.4 V	Non-switch auto restart
V CC over-voltage	V_{VCC} > 25.5 V	Odd-skip auto restart
V CC under-voltage	V_{VCC} < 10 V	Auto restart
Over-load	V_{FB} > 2.75 V and lasts for 30 ms	Odd-skip auto restart
Output over-voltage	V_{ZCD} > 2 V and lasts for 10 consecutive pulses	Odd-skip auto restart
Over-temperature (junction temperature of controller chip only)	T_J > 140°C with 40°C hysteresis to reset	Non-switch auto restart
CS short-to-GND	V_{CS} < 0.1 V, lasts for 5 μs and 3 consecutive pulses	Odd-skip auto restart
V CC short-to-GND (V_{VCC} = 0 V, $R_{StartUp}$ = 50 MΩ and V_{Drain} = 90 V)	V_{VCC} < 1.1 V, $I_{VCC\_Charge1}$ ≈ -0.2 A	Cannot start up

6 Circuit diagram

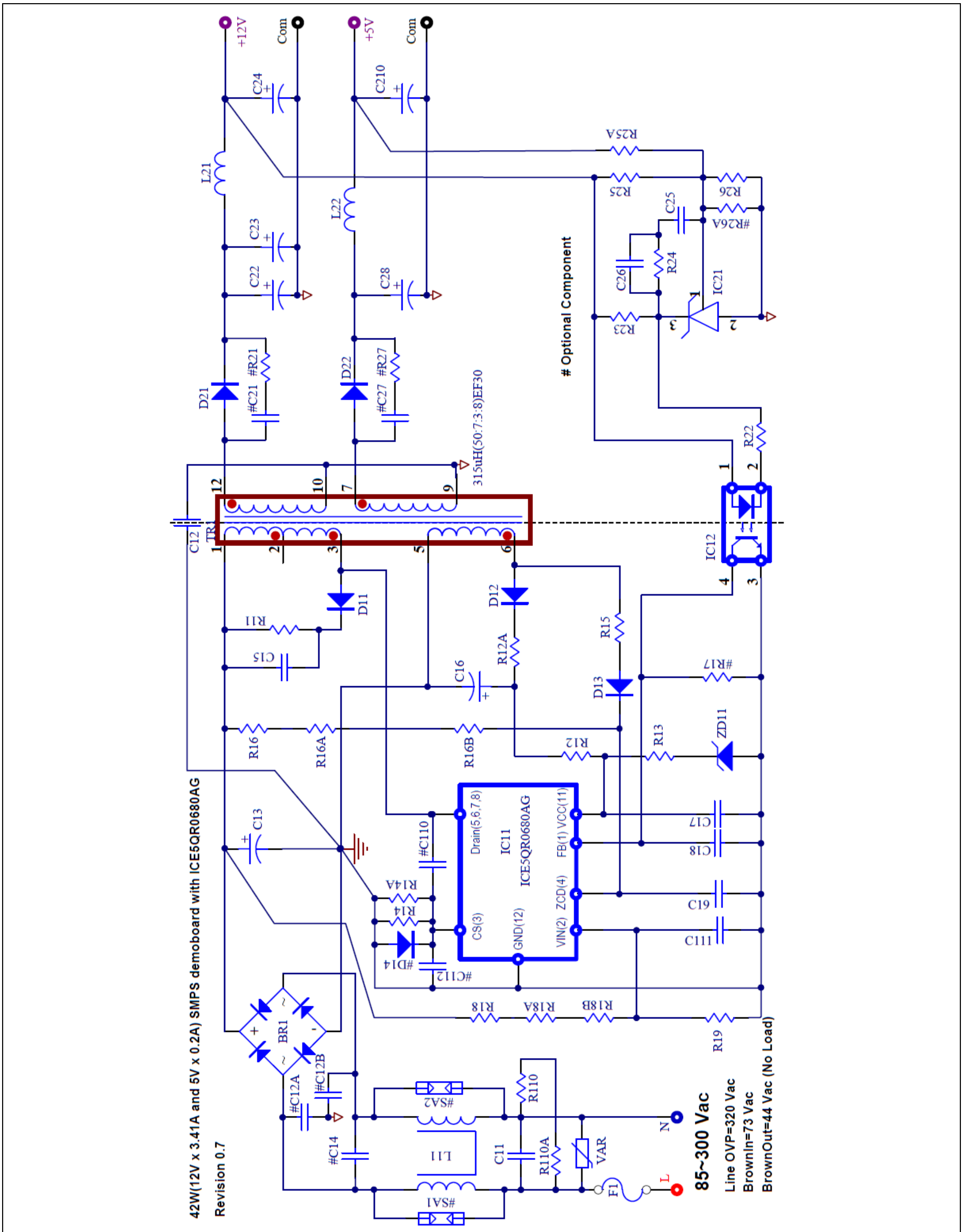


Figure 2 Schematic of DEMO_5QR0680AG_42W1

Note: *General guidelines for layout design of PCB:*

1. *Star ground at bulk capacitor C13: all primary grounds should be connected to the ground of bulk capacitor C13 separately in one point. This effectively 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:*
   i. *Combine signal (all small signal grounds connecting to the CoolSET™ GND pin, such as filter capacitor grounds C17, C18, C19, C111, C112 and optocoupler ground) and power grounds (CS resistors R14 and R14A)*
   ii. *V CC ground includes the V CC capacitor ground C16 and the auxiliary winding ground, pin 5 of the power transformer*
   iii. *EMI return ground includes Y capacitor C12*
   iv. *DC ground from bridge rectifier BR1*
2. *Filter capacitor close to the controller ground: filter capacitors C17, C18, C19, C111 and C112 should be placed as close to the controller ground and the controller pin as possible to reduce the switching noise coupled into the controller.*
3. *HV traces clearance: HV traces should retain enough spacing from the nearby traces. Otherwise, arcing could occur.*
   i. *400 V traces (positive rail of bulk capacitor C13) to nearby trace: greater than 2.0 mm*
   ii. *600 V traces (drain voltage of CoolSET™ IC11) to nearby trace: greater than 2.5 mm*
4. *Recommended minimum 232 mm^2 copper area at drain pin to add on PCB for better thermal performance.*
5. *Power-loop area (bulk capacitor C13, primary winding of the transformer TR1 (pins 1 and 3), IC11 drain pin, IC11 CS pin and CS resistor R14/R14A) should be as small as possible to minimize the switching emissions.*

7 PCB layout

7.1 Top side

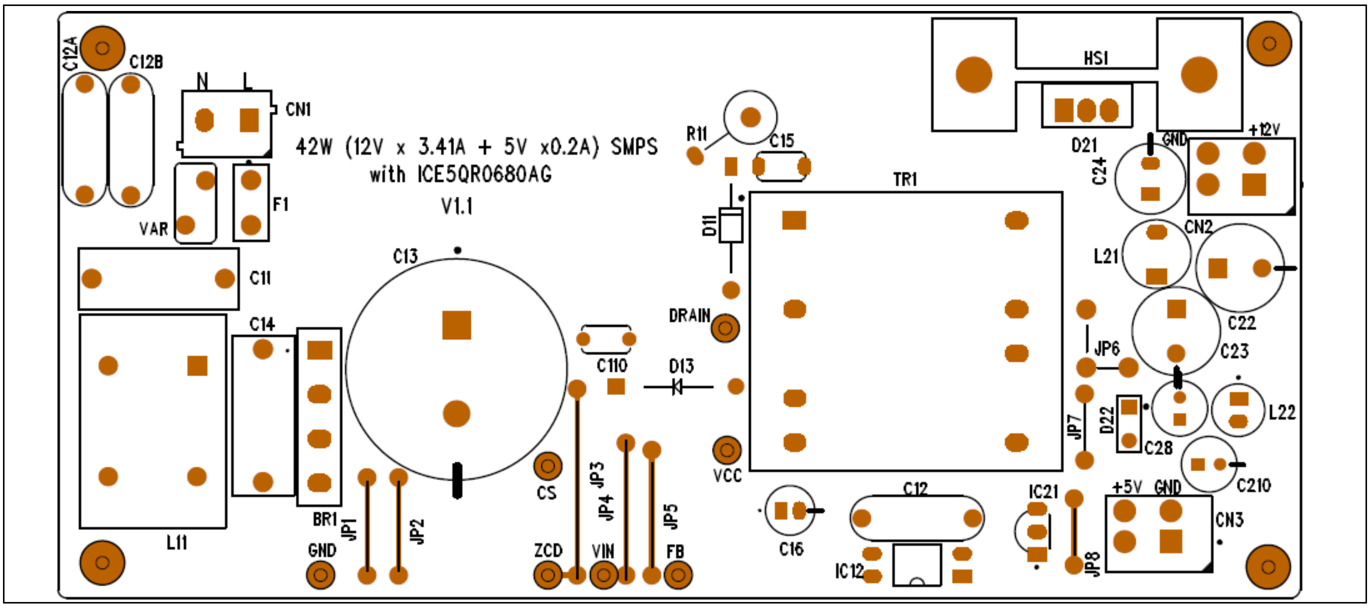


Figure 3 Top side component legend

7.2 Bottom side

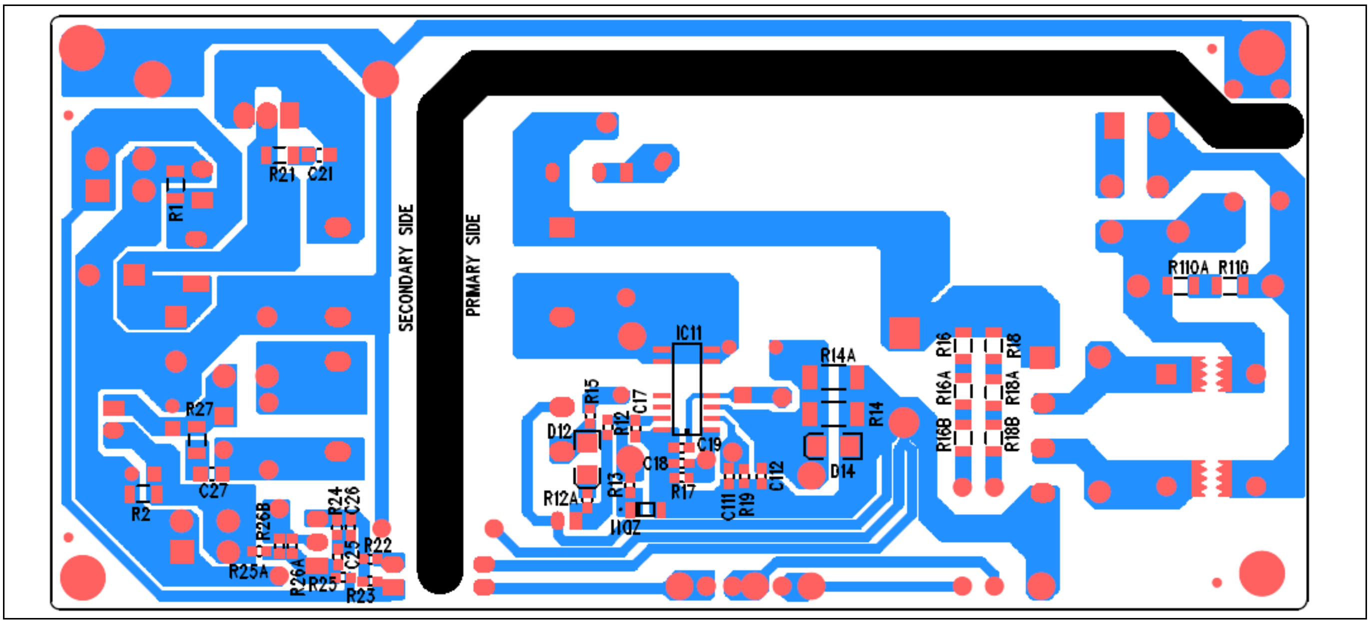


Figure 4 Bottom side copper and component legend

8 Bill of materials

Table 3 Bill of materials (R0.7)

No.	Designator	Description	Part number	Manufacturer	Quantity
1	BR1	600 V/2 A	D2SB60A	Shindengen	1
2	C11	0.33 µF/305 V	B32922C3334M***	Epcos	1
3	C12	2.2 nF/500 V	DE1E3RA222MA4BQ	Murata	1
4	C13	120 µF/450 V	ESMQ451VSN121MP30S		1
5	C15	2.2 nF/1000 V	RDE7U3A222J3K1H03	Murata	1
6	C16	33 µF/50 V	50PX33MEFC5X11	Rubycon	1
7	C17	100 nF/50 V	GRM188R71H104KA93D	Murata	1
8	C18, C26	1 nF/50 V	GRM1885C1H102GA01D	Murata	2
9	C19	68 pF/50 V	GRM1885C1H680GA01D	Murata	1
10	C111	22 nF/50 V	GCM188R71H223KA37D	Murata	1
11	C22, C22A	1000 uF/16 V	16ZLH1000MEFC10X16	Rubycon	2
12	C24	470 uF/16 V	16ZLH470MEFC8X11.5	Rubycon	1
13	C25	220 nF/50 V	GRM188R71H224KAC4D	Murata	1
14	C28, C210	330 uF/10 V	10ZLH330MEFC6.3X11	Rubycon	2
15	D11	1 A/800 V	UF4006		1
16	D12	0.2 A/200 V	BAV20WS		1
17	D13	0.2 A/150 V/50 ns	FDH400		1
18	D21	30 A/100 V	VF30100SG		1
19	D22	1 A/50 V	SB150		1
20	F1	2 A/300 V	36912000000		1
21	HS21	Heatsink	513002B02500G		1
22	IC11	ICE5QR0680AG	ICE5QR0680AG	Infineon	1
23	IC12	Optocoupler	SFH617A-3		1
24	IC21	Shunt regulator	TL431BVLPG		1
25	JP1, JP2, JP3, JP4, JP5, JP6	Jumper			7
26	L11	33 mH/1.4 A	CL4003301	MEC	1
27	L21	2.2 uH/6 A	744772022	Wurth Electronics	1
28	L22	4.7 uH/4.2 A	744 746 204 7	Wurth Electronics	1
29	R11	33 kR/2 W/350 V	ERG-2SJ333A	Panasonic	1
30	R12	27 Ω (0603)			1
31	R12A	0 Ω (0603)			1
32	R13	27 Ω (0603)			1
33	R14	0.81 R/0.5 W/±1%	RCWE1206R820FKEA		1
34	R14A	0.91 R/0.5 W/±1%	RCWE1206R910FKEA		1
35	R15	24 kΩ/±1% (0603)			1
36	R16, R16A	15 MR (1206)	RC1206JR-0715ML		2
37	R16B	20 MR (1206)			1
38	R18, R18A, R18B	3 MR (1206)	RC1206FR-073ML		2
39	R19	59 kR/0.5% (0603)	ERJ-3RBD5902V		1
40	R110, R110A	1.5 MΩ/200 V (1206)			2
41	R22	820 Ω (0603)			1

42	R23	1.2 kΩ (0603)			1
43	R24	12 kΩ (0603)			1
44	R25	16 kΩ (0603)			1
45	R25A	6.2 kΩ (0603)			1
46	R26	2.49 kΩ (0603)			1
47	TR1	315 µH	750343506(R03)	Wurth Electronics	1
48	Test point of FB, VIN, CS, ZCD, Drain, V_{cc}, GND	Test point	5010		7
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	Wurth Electronics	1
52	Con (+12 V com), Con (+5 V com)	Connector	691 412 120 002B	Wurth Electronics	2

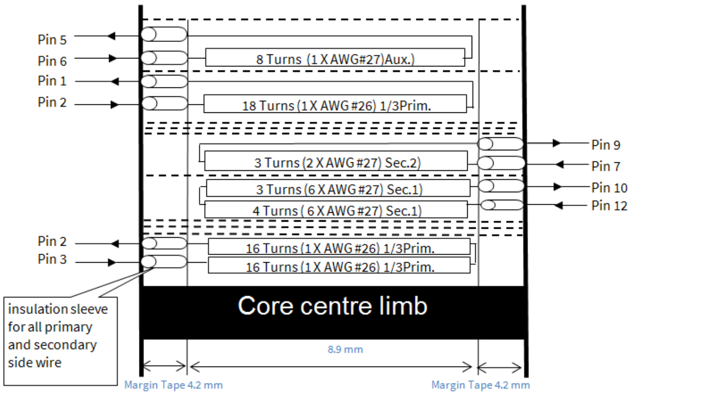
9 Transformer construction

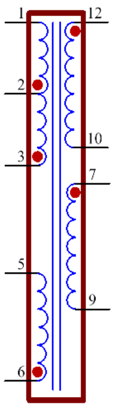
Core and materials: EE30/15/7 (EF30), TP4A (TDG)

Bobbin: 070-5313 (12-pin, THT, horizontal version)

Primary inductance: Lp = 315 µH (±10%), measured between pin 1 and pin 3

Manufacturer and part number: Wurth Electronics Midcom (750343506)

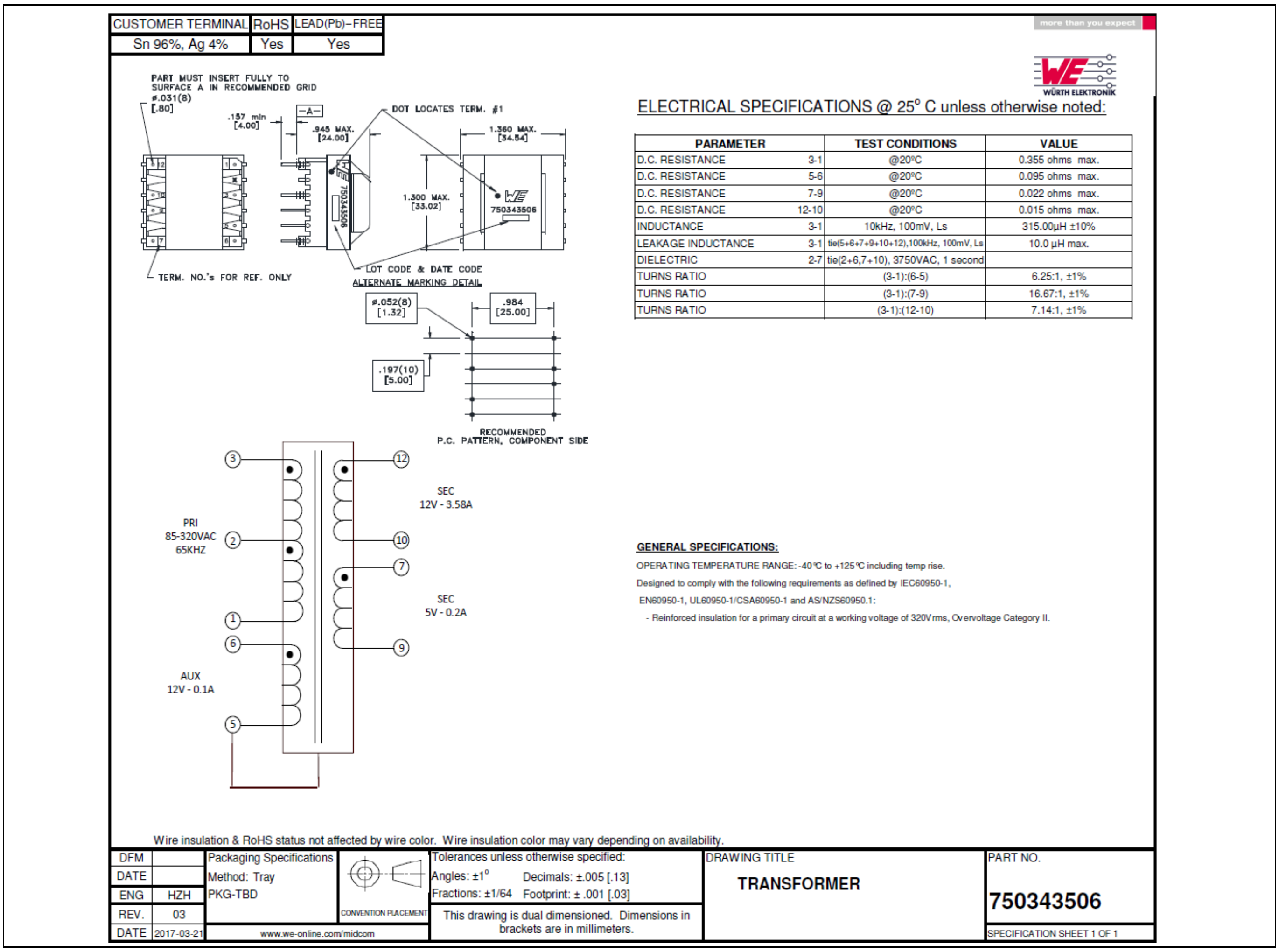




Start	Stop	No. of turns	Wire size	Layer
3	2	32	1XAWG#26	^{2}/3 Primary
12	10	7	6XAWG#27	Secondary 1
7	9	3	2XAWG#27	Secondary 2
2	1	18	1XAWG#26	^{1}/3 Primary
6	5	8	1XAWG#27	Auxiliary

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

Transformer construction



PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	3-1	@20°C	0.355 ohms max.
D.C. RESISTANCE	5-6	@20°C	0.095 ohms max.
D.C. RESISTANCE	7-9	@20°C	0.022 ohms max.
D.C. RESISTANCE	12-10	@20°C	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	Tolerances unless otherwise specified:	DRAWING TITLE	PART NO.
DATE		Method: Tray	Angles: ±1° Decimals: ±.005 [.13]	TRANSFORMER	750343506
ENG	HZH	PKG-TBD	Fractions: ±1/64 Footprint: ± .001 [.03]		
REV.	03	CONVENTION PLACEMENT	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_5 (V DC)	I_5 (A)	V_{5RPP} (mV)	V_{12} (V DC)	I_{12} (A)	V_{12RPP} (mV)	P_{out} (W)	Efficiency η (%)	Average η (%)	OLP P_{in} (W)	OLP I_{out12V} (fixed 5 V at 0.2 A) (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		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

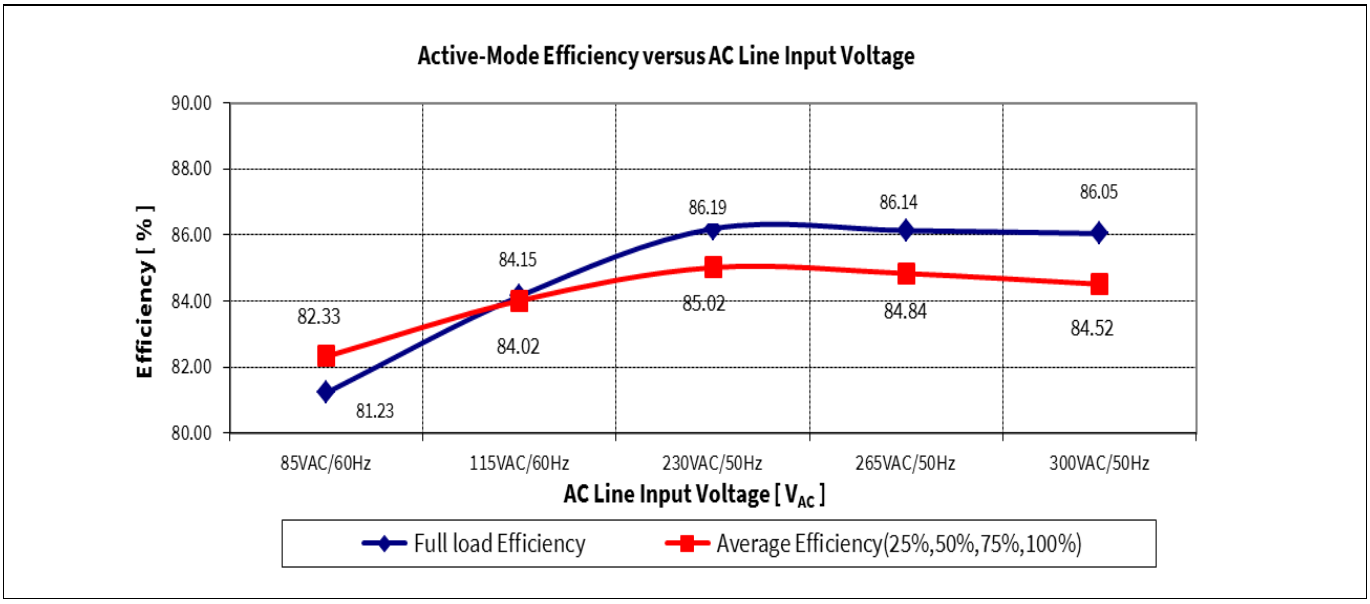


Figure 6 Efficiency vs AC-line input voltage

10.2 Standby power

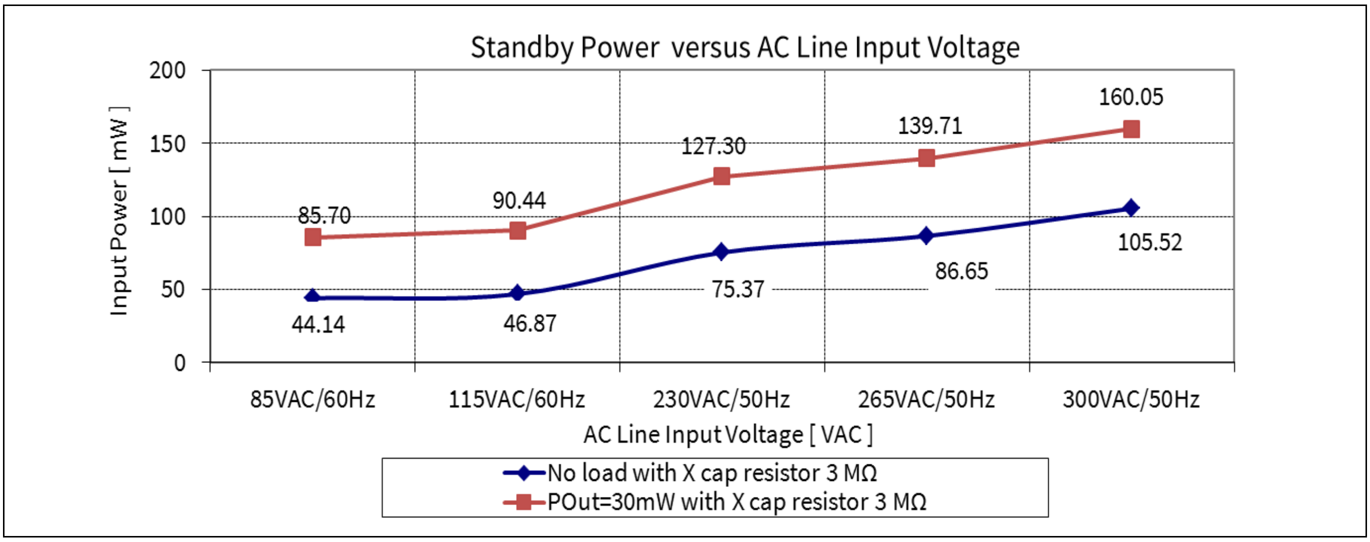


Figure 7 Standby power at no-load and 30 mW load vs AC-line input voltage (measured by Yokogawa WT210 power meter – integration mode)

10.3 Line regulation

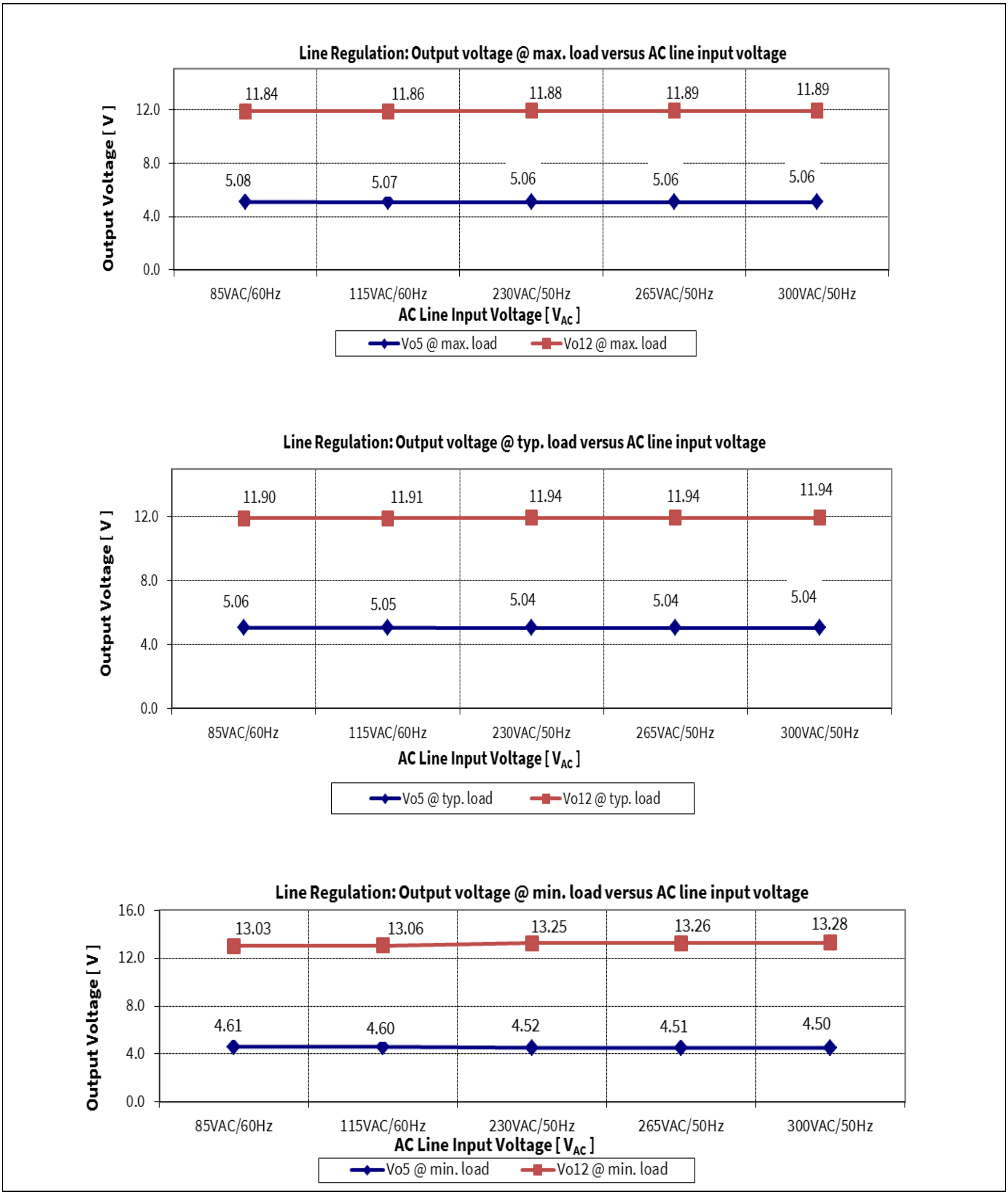


Figure 8 Line regulation V_{Out} vs AC-line input voltage

10.4 Load regulation

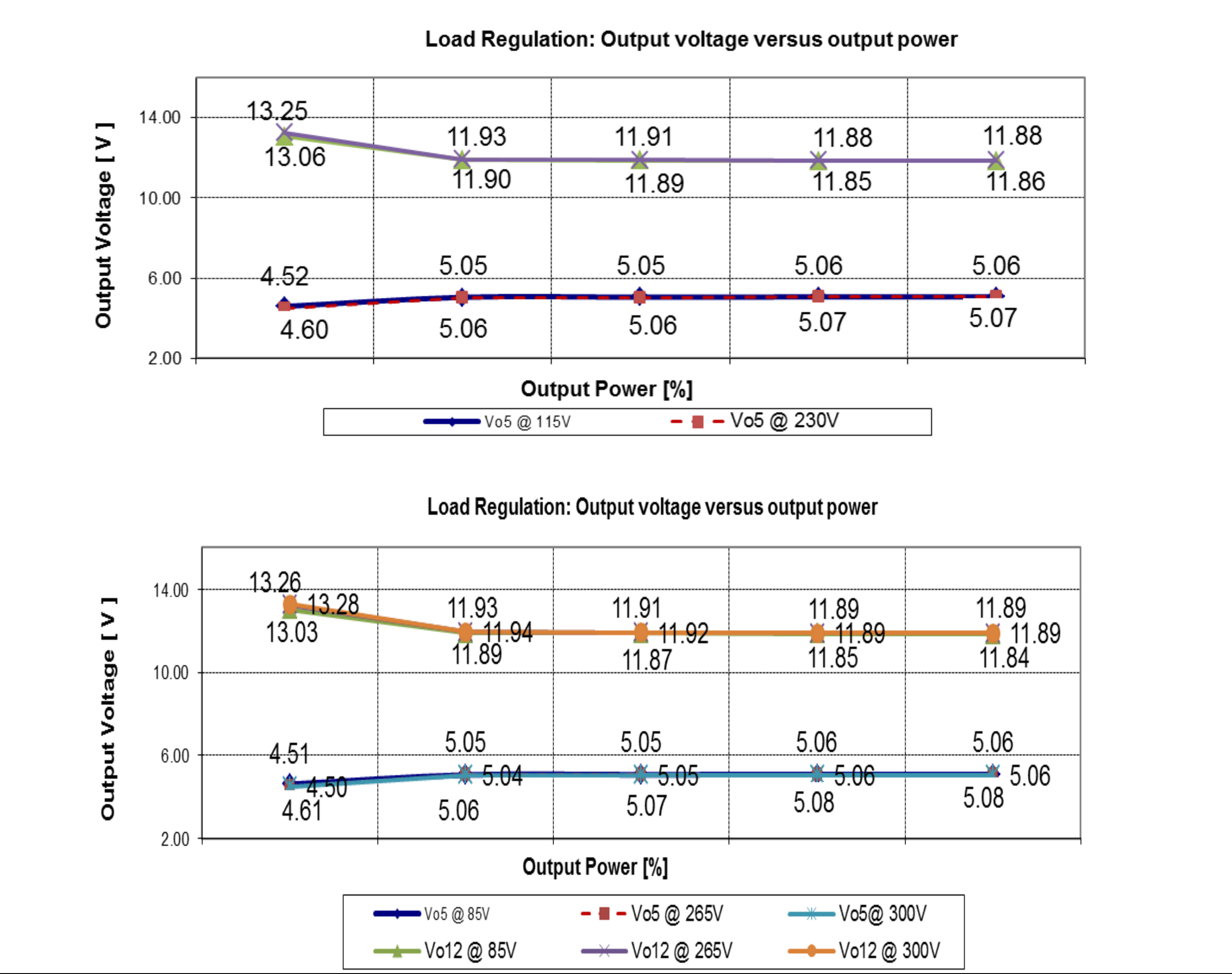


Figure 9 Load regulation V_{Out} vs output power

10.5 Maximum input power

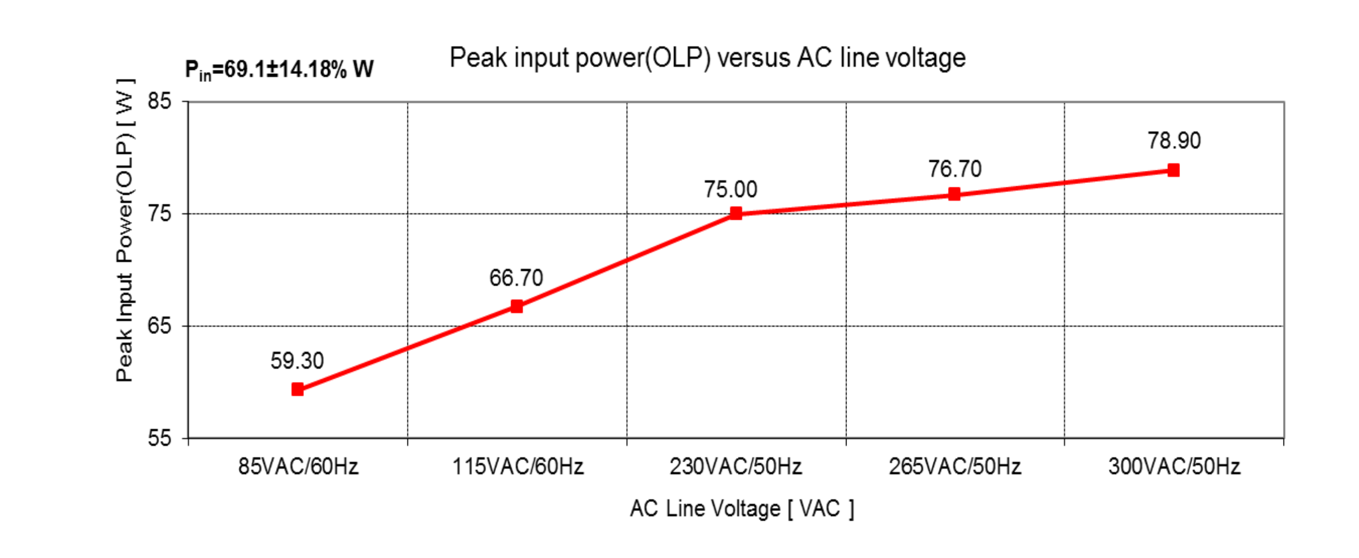


Figure 10 Maximum input power (before over-load protection) vs AC-line input voltage

10.6 ESD immunity (EN 61000-4-2)

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

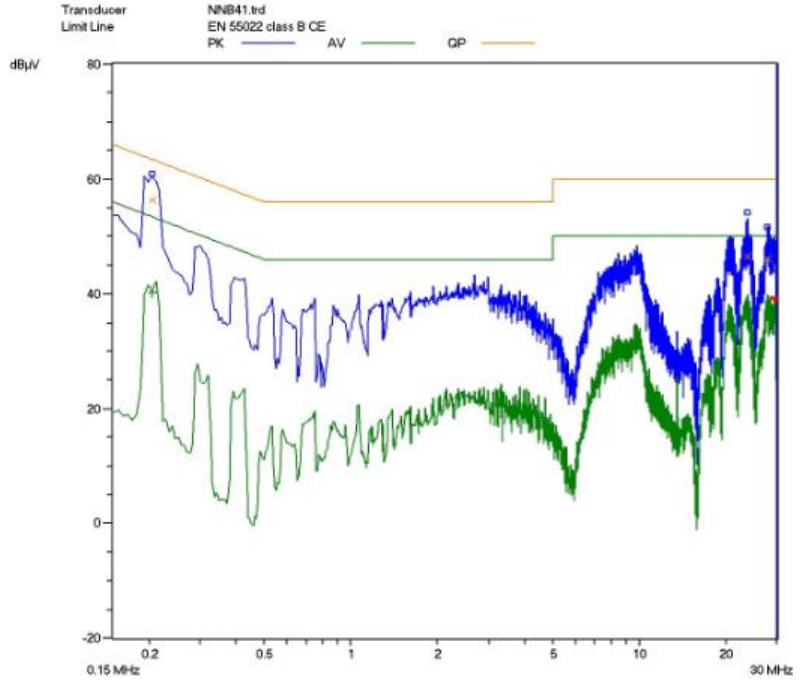
10.7 Surge immunity (EN 61000-4-5)

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)

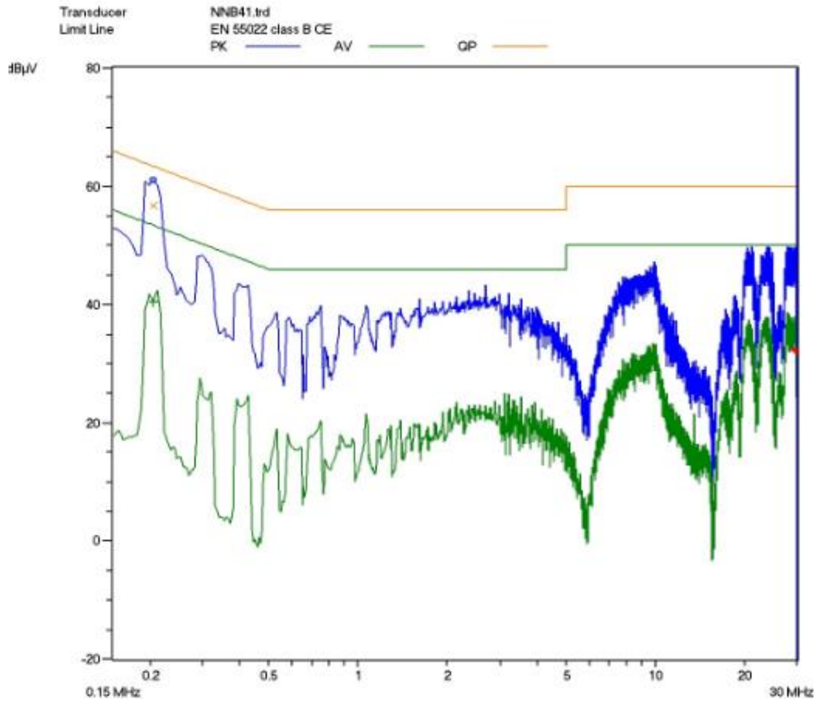
The conducted EMI was measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) class B. The demo board was set up at maximum load (42 W) with input voltage of 115 V AC and 230 V AC.

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



Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP
0.2040	L	60.9	L	40.2	L	56.3	53.4	63.4
23.7360	L	54.3	L	37.3	L	46.5	50.0	60.0
27.7360	L	51.6	L	37.2	L	46.2	50.0	60.0

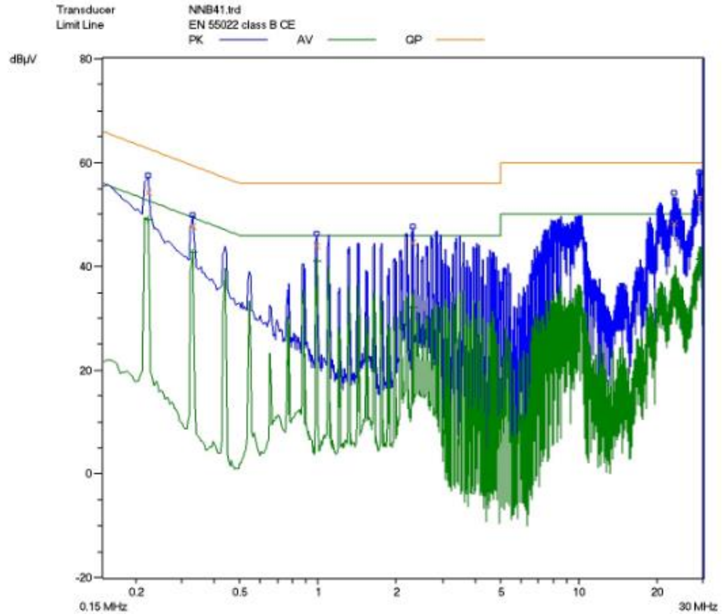
Figure 11 Conducted emissions (line) at 115 V AC and maximum load



Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP
0.2040	N	61.2	N	40.4	N	56.7	53.4	63.4

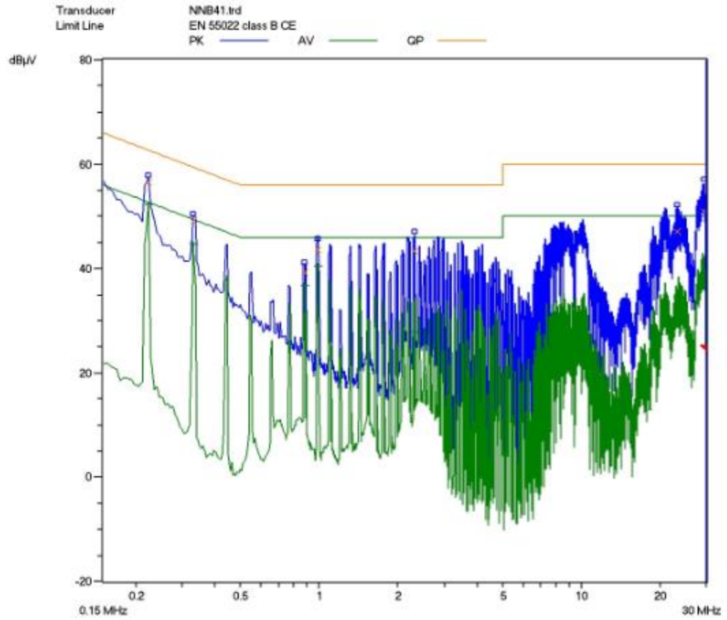
Figure 12 Conducted emissions (neutral) at 115 V AC and maximum load

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



Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP
0.2220	L	57.6	L	49.2	L	54.2	52.7	62.7
0.3300	L	49.8	L	42.9	L	47.6	49.5	59.5
0.9840	L	46.3	L	41.0	L	44.0	46.0	56.0
2.3040	L	47.7	L	32.1	L	44.6	46.0	56.0
23.2080	L	54.1	L	35.1	L	48.4	50.0	60.0
29.1120	L	58.2	L	41.5	L	53.1	50.0	60.0

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



Frequency		Level Pk		Level AV		Level QP	Limit AV	Limit QP
0.2220	N	57.9	N	52.2	N	56.6	52.7	62.7
0.3300	N	50.5	N	44.8	N	49.2	49.5	59.5
0.8760	N	41.2	N	36.7	N	39.2	46.0	56.0
0.9840	N	45.7	N	40.5	N	43.6	46.0	56.0
2.3100	N	47.1	N	27.9	N	43.4	46.0	56.0
23.1840	N	52.3	N	34.5	N	47.1	50.0	60.0
29.2400	N	57.1	N	39.2	N	51.0	50.0	60.0

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 test of the open-frame demo board was done using an infrared thermography camera (FLIR-T62101) at an ambient temperature of 25°C. The measurements were taken after one hour running at full-load.

Table 5 Hottest temperature of demo board

No.	Major component	85 V AC (°C)	300 V AC (°C)
1	IC11 (ICE5QR0680AG)	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

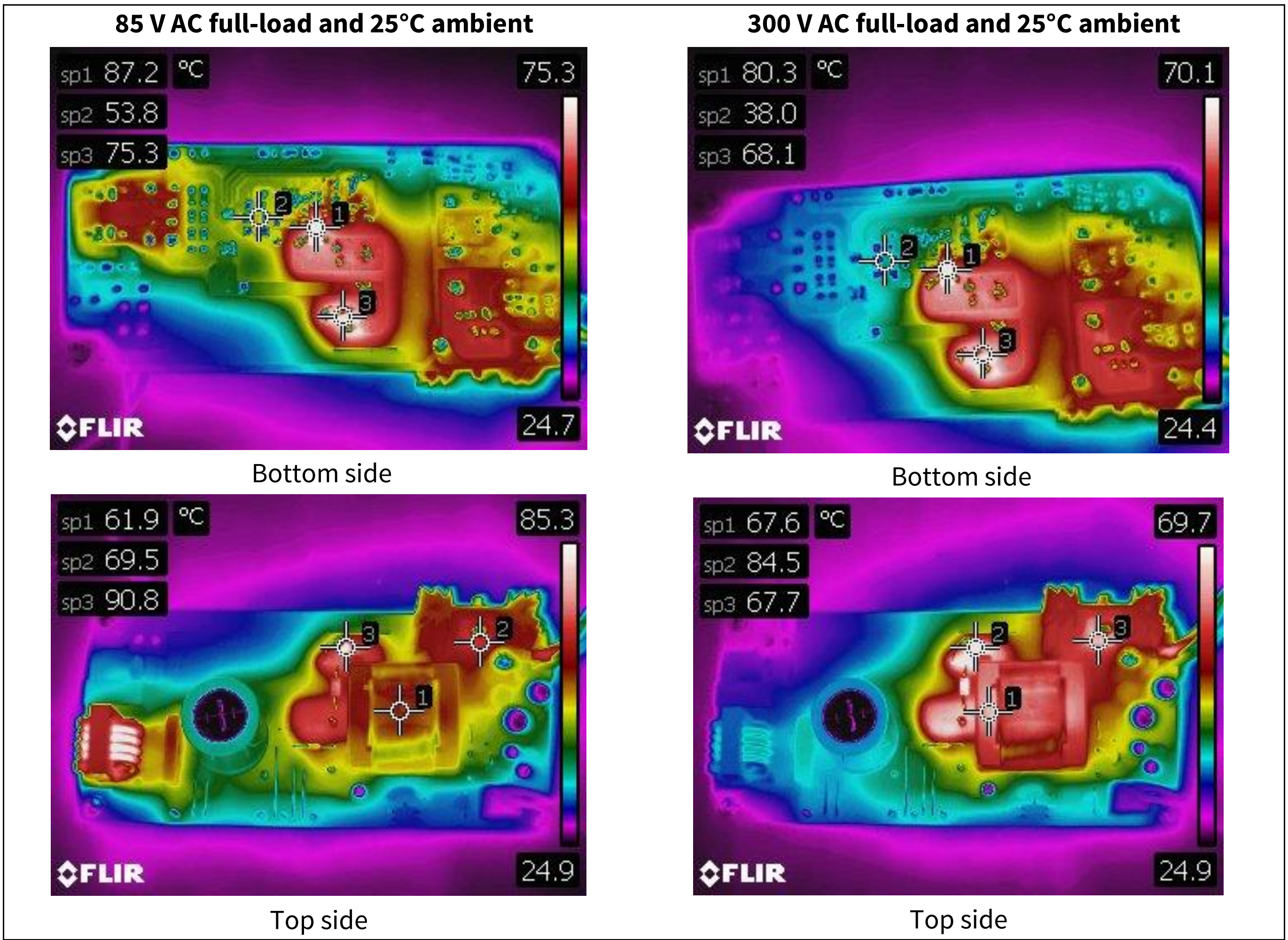


Figure 15 Infrared thermal image of DEMO_5QR0680AG_42W1

11 Waveforms and scope plots

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

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

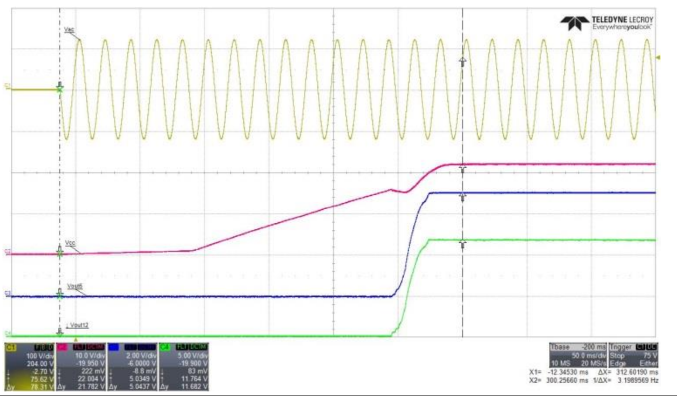
	
C1 (yellow) : AC-line voltage (V AC) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : 5 V output voltage (V_{Out5}) C4 (green) : 12 V output voltage (V_{Out12})	C1 (yellow) : AC-line voltage (V AC) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : 5 V output voltage (V_{Out5}) C4 (green) : 12 V output voltage (V_{Out12})
Start-up time at 85 V AC and maximum load ≈ 312 ms	Start-up time at 300 V AC and maximum load ≈ 262 ms

Figure 16 Start-up

11.2 Soft-start

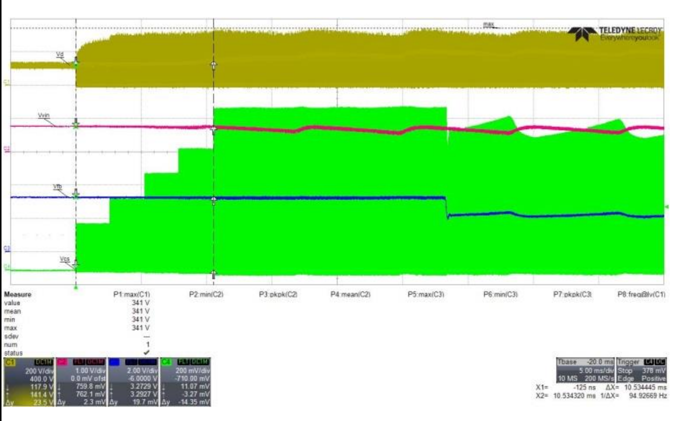
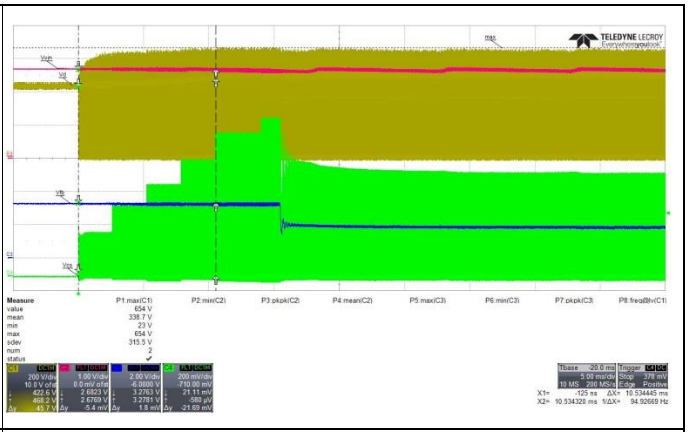
	
C1 (yellow) : Drain voltage (V_D) C2 (purple) : VIN voltage (V_{VIN}) C3 (blue) : Feedback voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C2 (purple) : VIN voltage (V_{VIN}) C3 (blue) : Feedback voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})
Soft-start time at 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

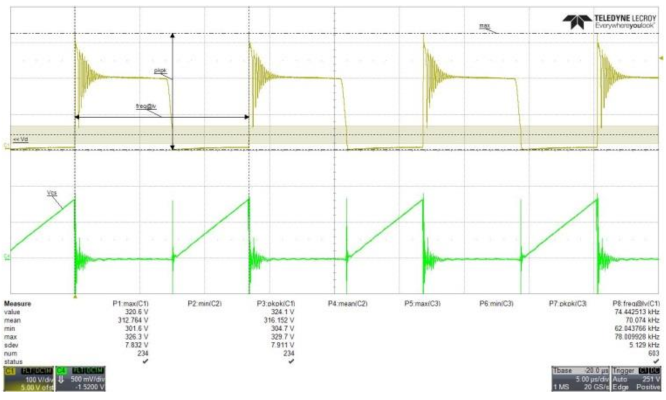
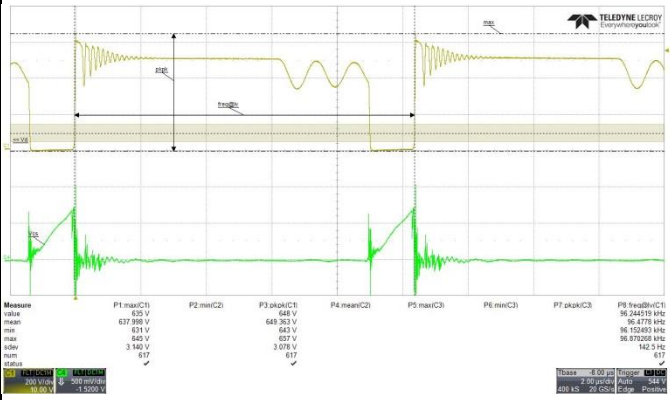
	
C1 (yellow) : Drain voltage (V_D) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C4 (green) : CS voltage (V_{CS})
V_{Drain_peak} at 85 V AC ≈ 326 V with 1st ZC and f_{S_Min} ≈ 62 kHz	V_{Drain_peak} at 300 V AC ≈ 657 V with 3rd ZC and f_{S_Min} ≈ 96 kHz

Figure 18 Drain and CS voltage at maximum load

11.4 Zero crossing point during normal operation

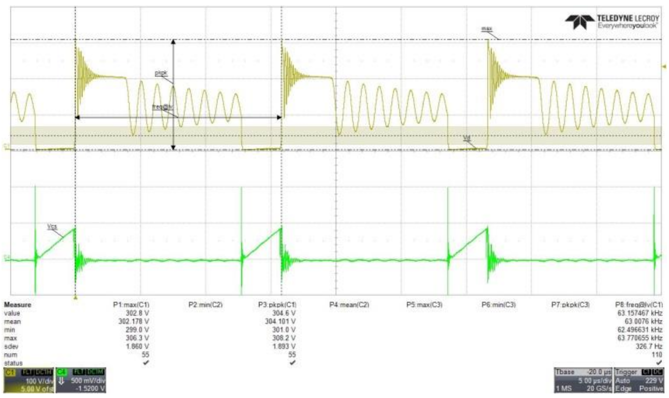
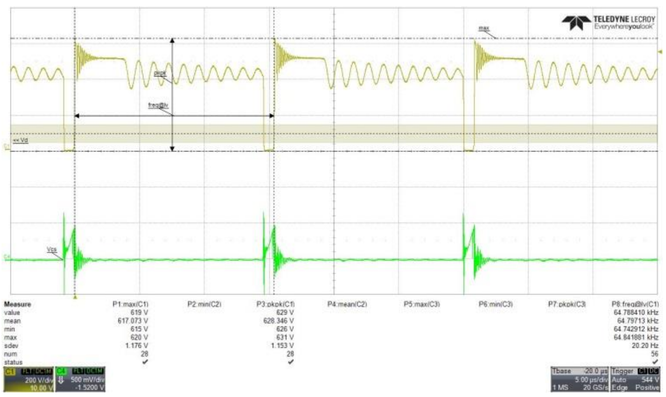
	
C1 (yellow) : Drain voltage (V_D) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C4 (green) : CS voltage (V_{CS})
8th ZC at 85 V AC and 25% load (5 V x 0.05 A + 12 V x 0.853 A) (ZC varies from 1~8 for low-line)	10th ZC at 300 V AC and 25% load (5 V x 0.05 A + 12 V x 0.853 A) (ZC varies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

Figure 19 Zero Crossing (ZC)

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

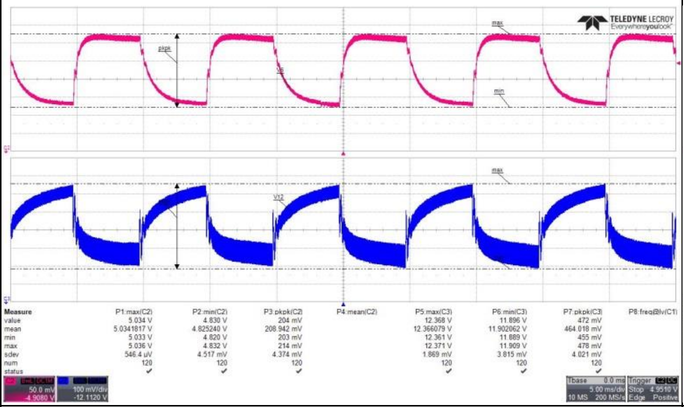
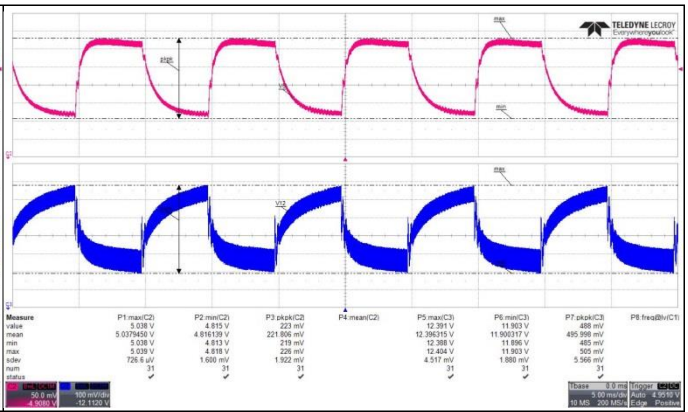
	
C2 (purple) : 5 V output ripple voltage (V_{Out5}) C3 (blue) : 12 V output ripple voltage (V_{Out12})	C2 (purple) : 5 V output ripple voltage (V_{Out5}) C3 (blue) : 12 V output ripple voltage (V_{Out12})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 214 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 478 mV (85 V AC, 12 V load change from 10% to 100% 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% to 100% 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

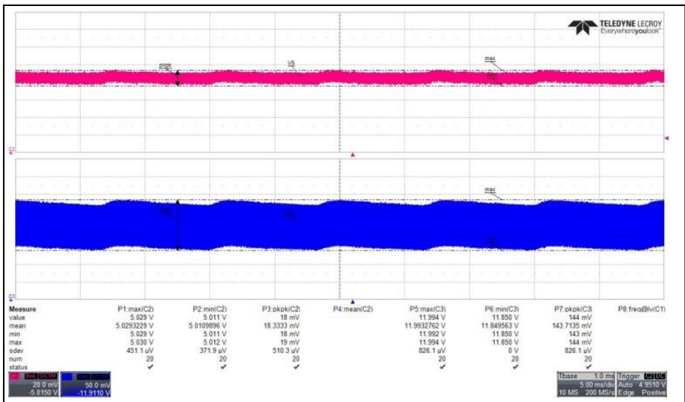
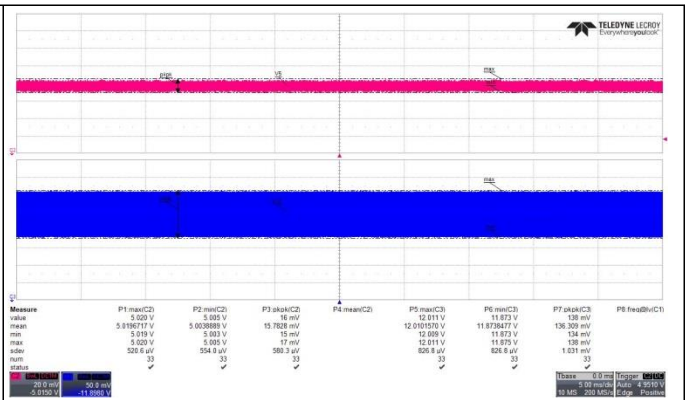
	
C2 (purple) : 5 V output ripple voltage (V_{Out5}) C3 (blue) : 12 V output ripple voltage (V_{Out12})	C2 (purple) : 5 V output ripple voltage (V_{Out5}) C3 (blue) : 12 V output ripple voltage (V_{Out12})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 20 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 146 mV Probe terminal 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

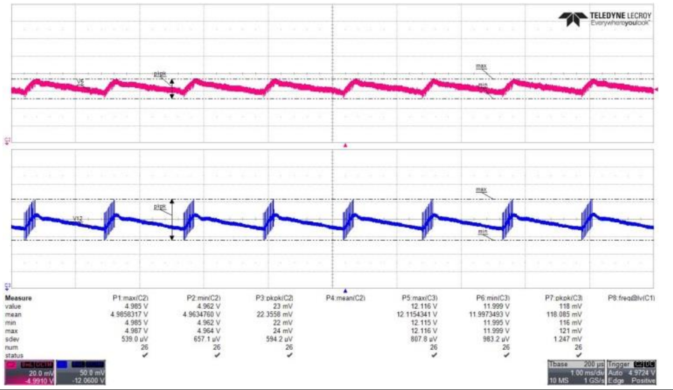
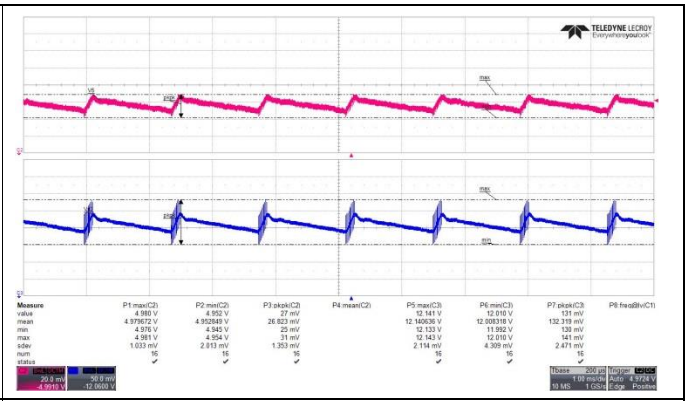
	
C2 (purple) : 5 V output ripple voltage (V_{Out5}) C3 (blue) : 12 V output ripple voltage (V_{Out12})	C2 (purple) : 5 V output ripple voltage (V_{Out5}) C3 (blue) : 12 V output ripple voltage (V_{Out12})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 24 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 121 mV Load: 5 V at 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

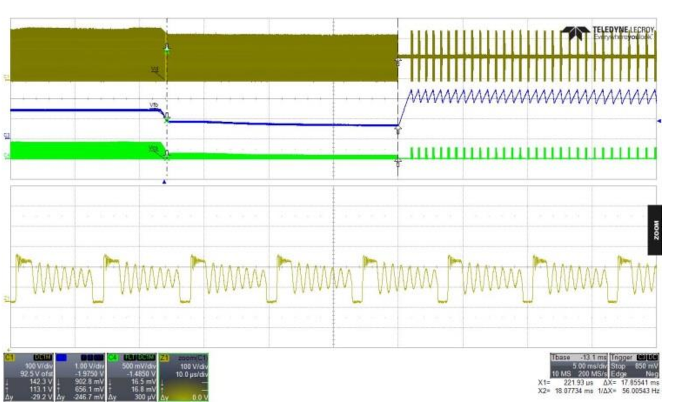
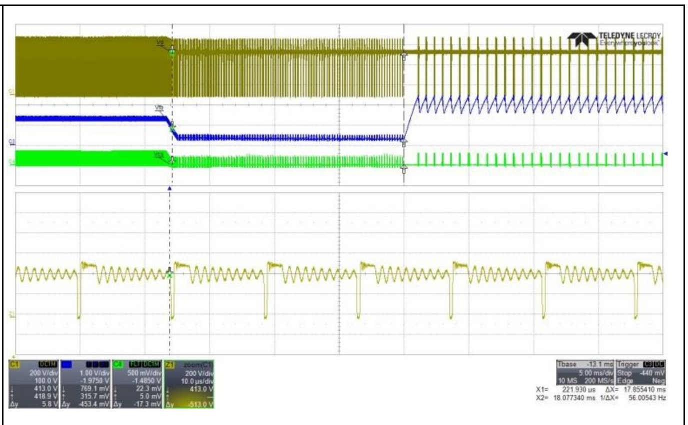
	
C1 (yellow) : Drain voltage (V_D) C3 (blue) : Feedback voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C3 (blue) : Feedback voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})
Condition to enter ABM level 1: V_{FB} < 0.9 V, N_{ZC} = 8 and $t_{blanking}$ = 20 ms (85 V 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} < 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

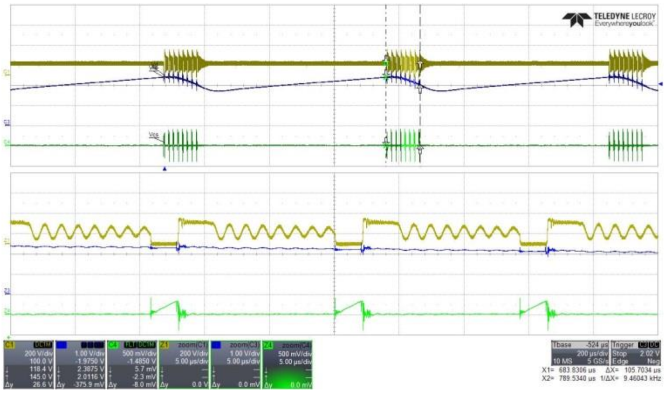
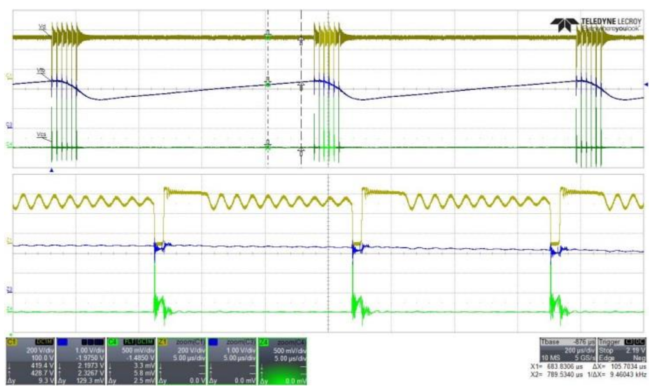
	
C1 (yellow) : Drain voltage (V_D) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})
During ABM level 1: V_{FB_BOn} = 2.4 V, V_{FB_BOff} = 2.0 V, V_{CSBLP} = 0.31 V, N_{ZC} = 8 85 V AC, 1 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

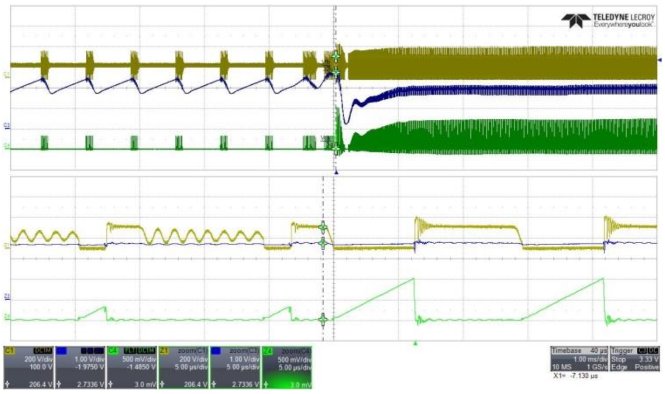
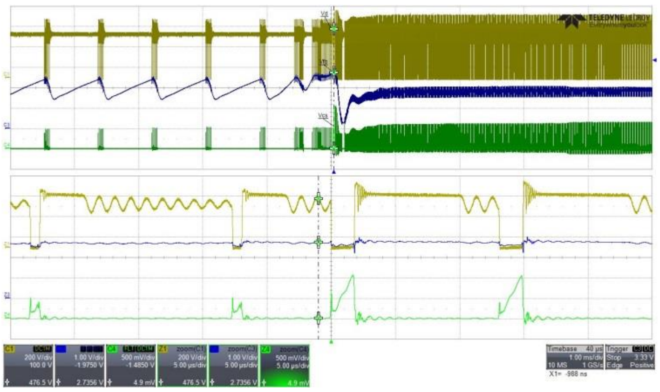
	
C1 (yellow) : Drain voltage (V_D) C3 (blue) : FB voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Drain voltage (V_D) C3 (blue) : Feedback voltage (V_{FB}) C4 (green) : CS voltage (V_{CS})
Condition to leave ABM level 1: V_{FB} > 2.75 V 85 V AC, load change from 1 W to 41.25 W (5 V x 50 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} > 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)

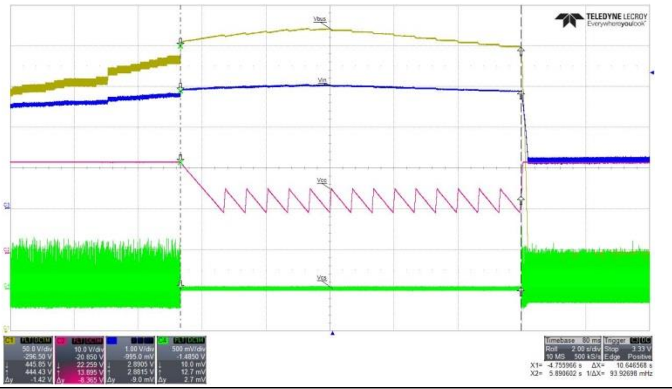
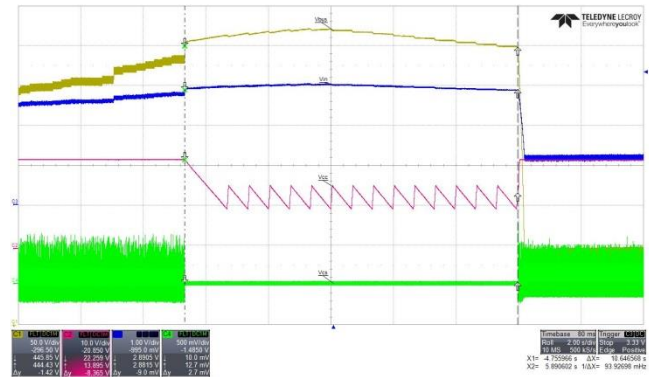
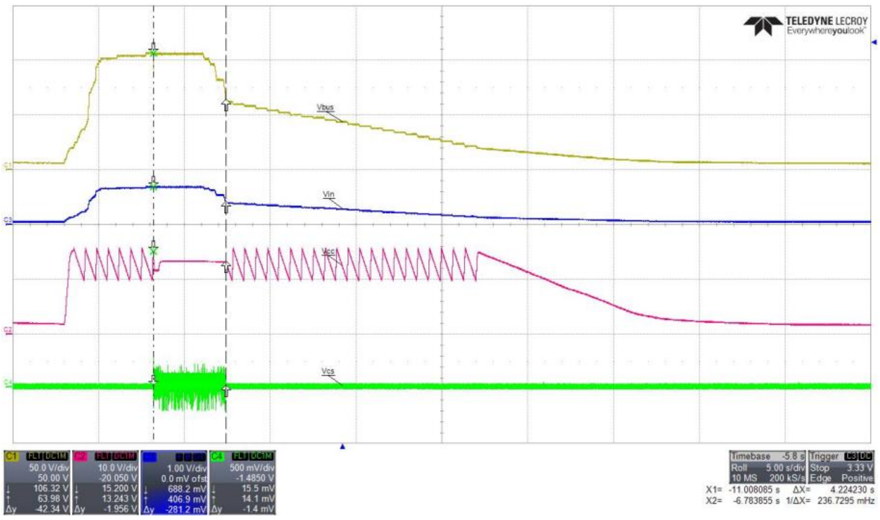
	
C1 (yellow) : Bus voltage (V_{Bus}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : VIN voltage (V_{VIN}) C4 (green) : CS voltage (V_{CS})	C1 (yellow) : Bus voltage (V_{Bus}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : VIN voltage (V_{VIN}) C4 (green) : CS voltage (V_{CS})
Condition to detect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

Figure 26 Line OVP

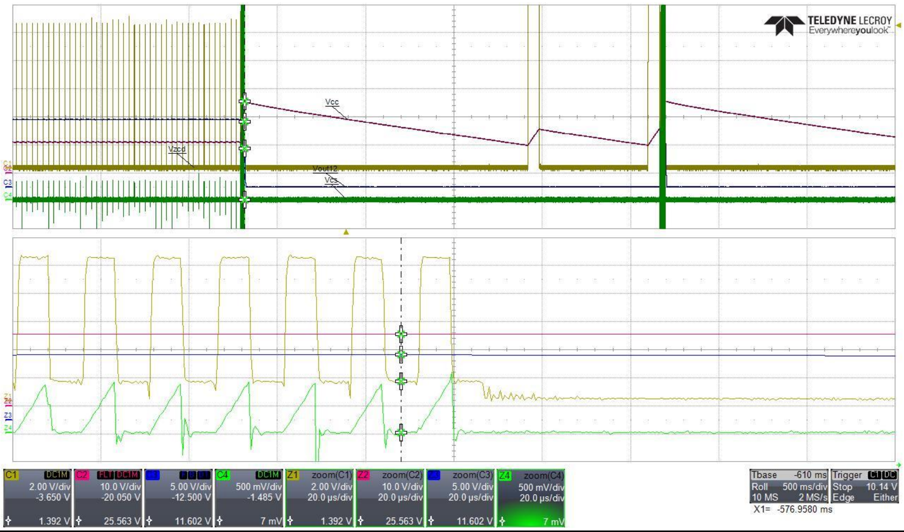
11.12 Brownout protection (non-switch auto restart)



C1 (yellow) : Bus voltage (V_{Bus}) C2 (purple) : Supply voltage (V_{VCC}) C3 (blue) : VIN voltage (V_{VIN}) C4 (green) : CS voltage (V_{CS})
Condition to reset brownout protection (brownin) : V_{VIN} > 0.66 V (V_{BULK} > 106 V DC [≈ 75 V AC]) Condition to detect brownout protection : V_{VIN} < 0.4 V (V_{BULK} < 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 start and reduce the line until brownout detect)

Figure 27 Brownout protection

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

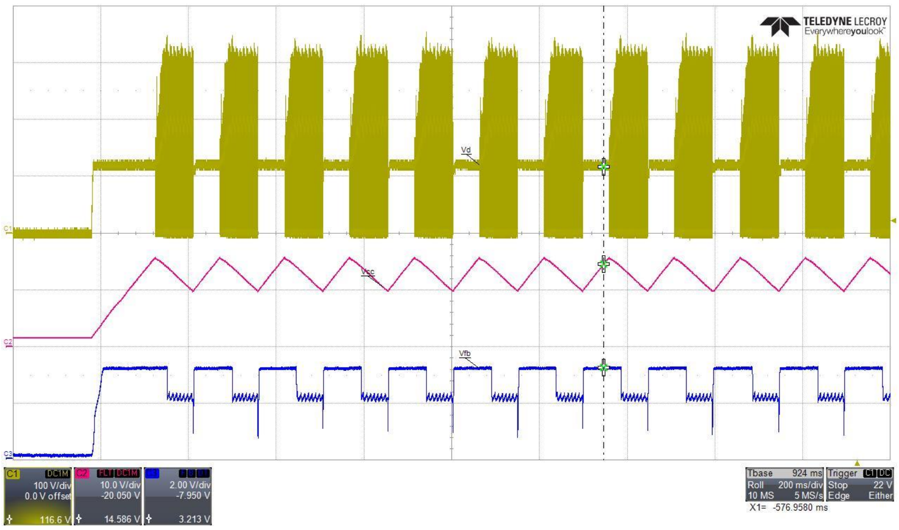


C1 (yellow) : ZCD voltage (V_{ZCD})
C2 (purple) : Supply voltage (V_{VCC})
C3 (blue) : 12 V output voltage (V_{O12})
C4 (green) : CS voltage (V_{CS})

Condition to enter V_{VCC} OVP: V_{VCC} > 25.5 V
(85 V AC, remove R13 and load change from no-load to full-load)

Figure 28 V_{CC} OVP

11.14 V_{CC} under-voltage protection (auto restart)

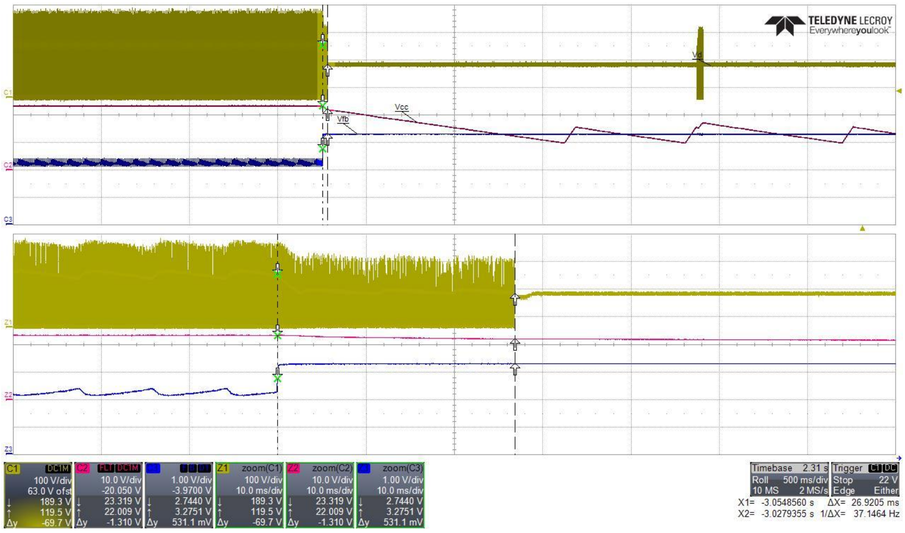


C1 (yellow) : Drain voltage (V_D)
C2 (purple) : Supply voltage (V_{VCC})
C3 (blue) : Feedback voltage (V_{FB})

Condition to enter V CC under-voltage protection: V_{CC} < 10 V
(Remove R12 A and power on the system with full-load at 85 V AC)

Figure 29 V_{CC} under-voltage protection

11.15 Over-load protection (odd-skip auto restart)

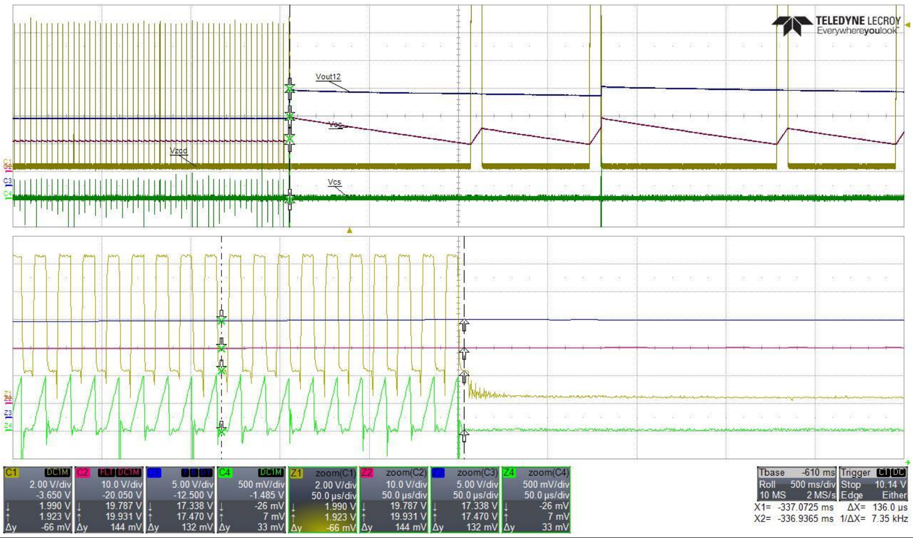


C1 (yellow) : drain voltage (V_D)
C2 (purple) : supply voltage (V_{VCC})
C3 (blue) : FB voltage (V_{FB})

Condition to enter over-load protection: V_{FB} > 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 Over-load protection

11.16 Output OVP (odd-skip auto restart)

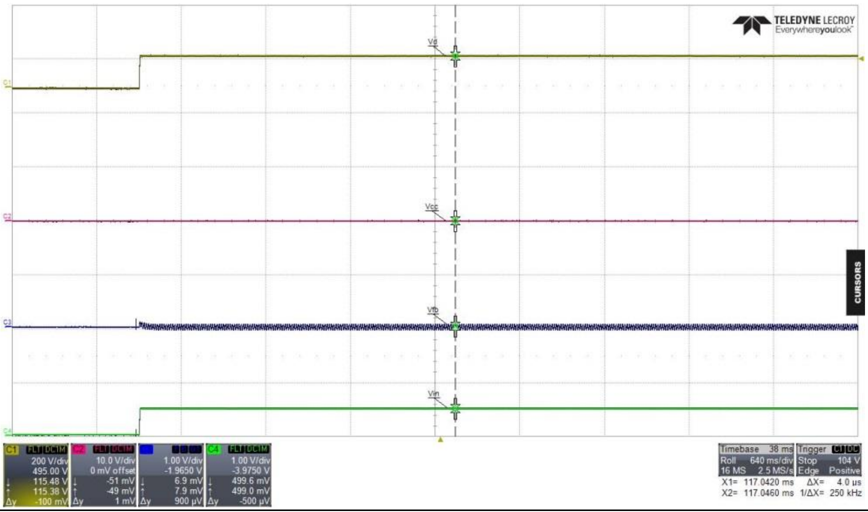


C1 (yellow) : ZCD voltage (V_{ZCD})
C2 (purple) : Supply voltage (V_{VCC})
C3 (blue) : 12 V output voltage (V_{O12})
C4 (green) : CS voltage (V_{CS})

Condition to enter output OVP: V_{O12} > V (V_{ZCD} > 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)	: VIN voltage (V_{VIN})

Condition to enter V_{CC} short-to-GND: if $V_{CC} < V_{VCC\_SCP} \rightarrow I_{VCC} = I_{VCC\_Charge1}$

(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

12 References

[1] ICE5QRxxxxAx datasheet, Infineon Technologies AG

[2] AN-201609_PL83_026-Fifth-Generation QR Design Guide

[3] Calculation Tool QRt CoolSET™ Generation 5

Revision history

Major changes since the last revision

Page or reference	Description of change
--	First release

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