15 W, 12 V and 5 V SMPS reference board with CoolSET™ ICE5QR4780BG-1

REF_5QR4780BG-1_15W1

About this document

Scope and purpose

This document describes a universal input 15 W, 12 V, and 5 V offline flyback converter using the CoolSET™ 5th Generation Quasi-Resonant (QR) Plus ICE5QR4780BG-1 IC from Infineon, which offers high efficiency, low standby power with selectable entry and exit standby power option, wide V_{CC} operating range with fast startup, robust line protection with input OVP, and brownout and various protections for a highly reliable system.

This reference board is designed to evaluate the performance of CoolSET™ 5th Generation QR Plus ICE5QR4780BG-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 a low-cost and high reliable offline SMPS as either auxiliary power supply for white goods, PCs, servers, and TVs, or enclosed adapters for gaming consoles.

CoolSET™

Infineon's CoolSET™ AC-DC integrated power stages in 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

Table of contents

1 Introduction

This document describes a 15 W, 12 V, and 5 V reference board designed in a quasi-resonant flyback converter topology using the CoolSET™ 5th Generation QR Plus ICE5QR4780BG-1 IC.

With the CoolMOS™ integrated in 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 ICE5QR4780BG-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 dimension of the transformer and the current rating of the secondary diode can both be optimized. Thus, a cost-effective solution can be easily achieved. The target applications of ICE5QR4780BG-1 are either auxiliary power supply of white goods, PCs, servers, and TVs, or enclosed adapters for gaming consoles, etc.

This document contains the list of features, 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

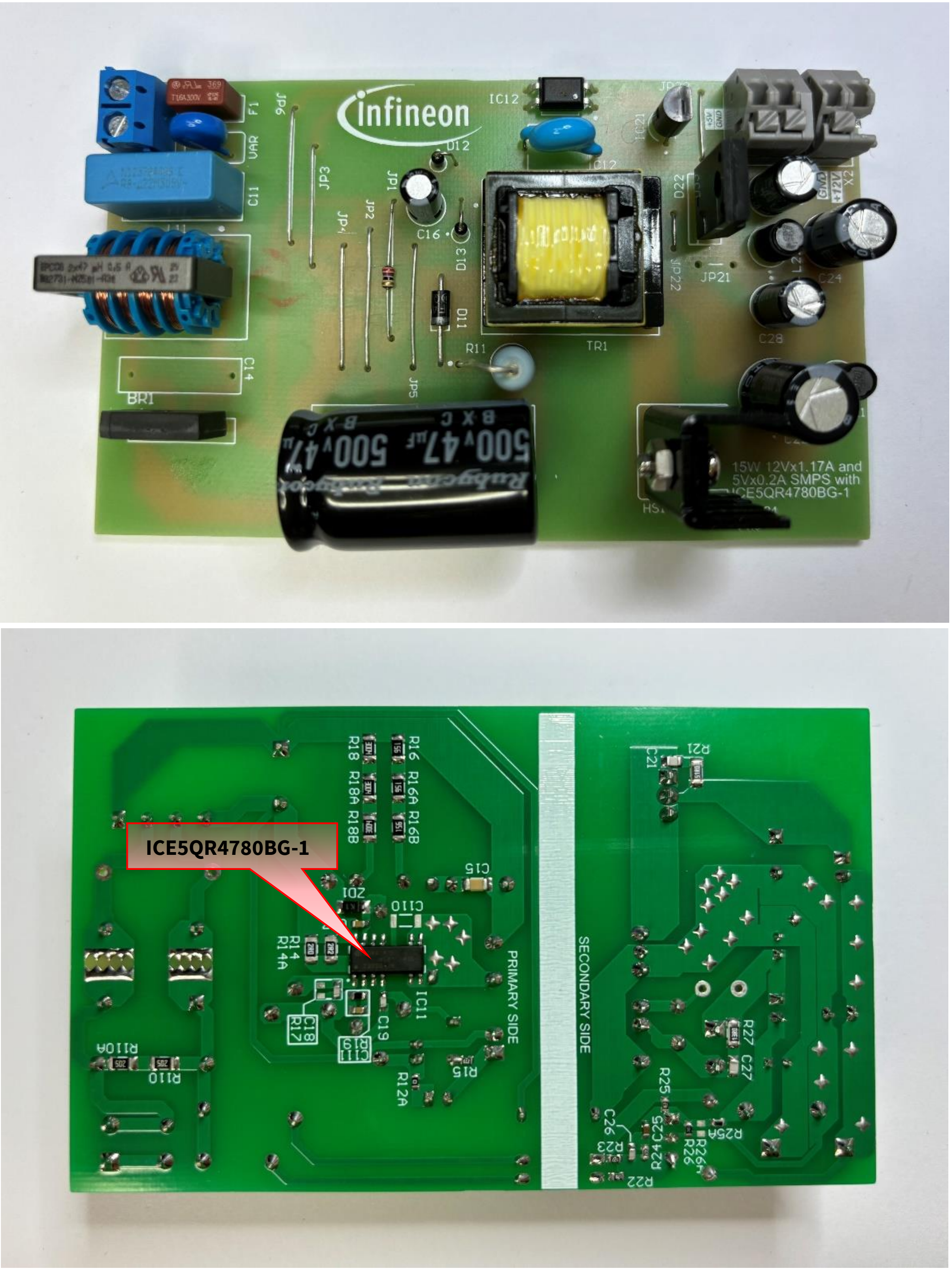


Figure 1 **REF_5QR4780BG-1_15W1**

3 Reference board specifications

Table 1 REF_5QR4780BG-1_15W1 specifications

Input voltage and frequency	85 V AC (60 Hz) ~ 300 V AC (50 Hz)
Output voltage, current, and power	(12 V x 1.16 A) +(5 V x 0.2 A) = 15 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 $V_{ripple\_p\_p}$< 100 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 (EN55022 class B)	Pass with 6 dB margin for 115 V AC and 6 dB margin for 230 V AC
ESD immunity (EN61000-4-2)	Special level (±14 kV for contact and ±16 kV air discharge)
Surge immunity (EN61000-4-5)	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)	(110 x 66 x 27) 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 the 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 condition.

4 Schematic

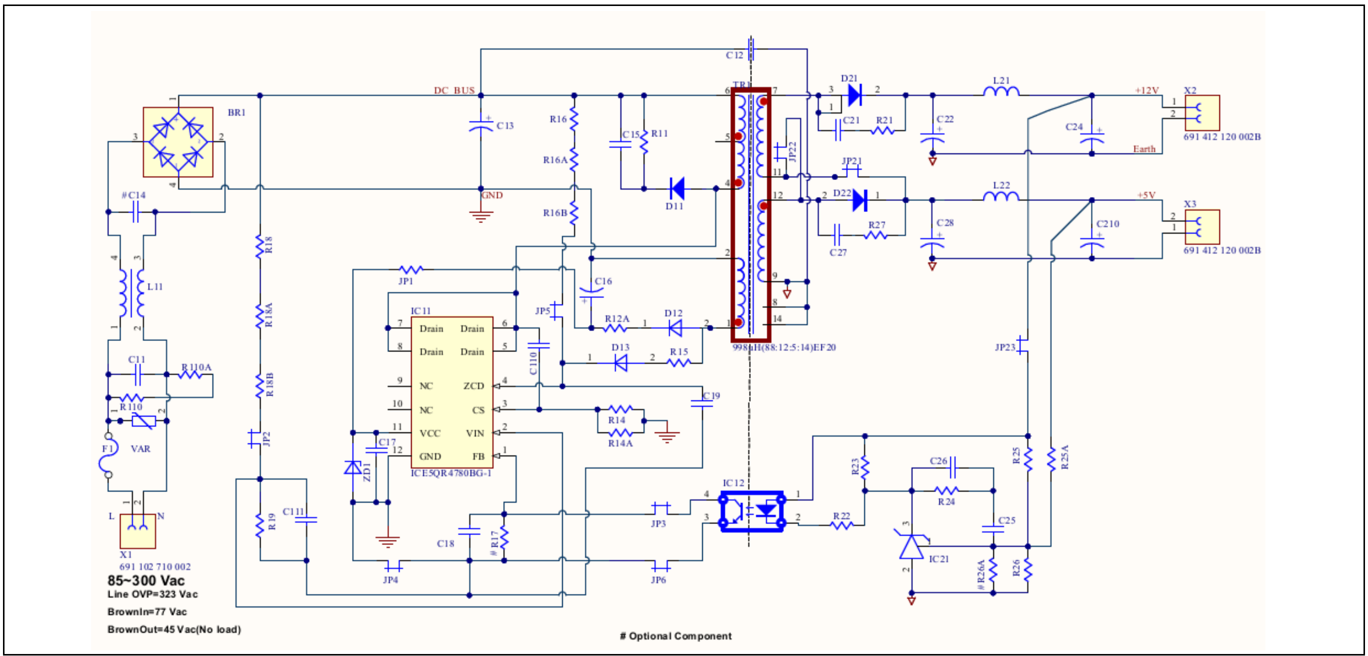


Figure 2 **Schematic of REF_5QR4780BG-1_15W1**

4.1 General guidelines for PCB layout

1. **Star ground at the bulk capacitor (C13):** Connect all primary grounds separately to the ground of the bulk capacitor (C13) at one point. This reduces the switching noise going into the sensitive pins of the CoolSET™ device effectively. The primary star ground can be split into four groups as follows:
   - Combine the signal (all small-signal grounds connecting to the GND pin of the CoolSET™ device, such as filter capacitor grounds C17, C18, C19, and C111, and optocoupler ground) and power grounds (CS resistors R14 and R14A).
   - V_{CC} ground that includes the V_{CC} capacitor ground (C16) and the auxiliary winding ground (pin 2) of the power transformer.
   - EMI return ground, which includes the Y capacitor (C12).
   - DC ground from the bridge rectifier (BR1).
2. **Filter capacitor close to the controller ground:** Place the filter capacitors (C17, C18, C19, and C111) close to the controller ground and 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 the bulk capacitor C13) to the nearby trace**: > 2.0 mm
   - **600 V traces (drain voltage of the CoolSET™ IC11) to the nearby trace**: > 2.5 mm
4. For better thermal performance, add a minimum copper area of 232 mm^2 at the drain pin on the PCB.
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 Bill of materials

No.	Designator	Description	Part Number	Manufacturer	Quantity
1	BR1	600 V/1 A	S1VBA60	Shindengen	1
2	C11	0.22 µF/305 V	B32922C3224	Epcos	1
3	C12	2.2 nF/500 V	DE1E3RA222MA4BQ	Murata	1
4	C13	47 µF/500 V	500BXC47MEFC18X31.5	Rubycon	1
5	C15	1 nF/1000 V	GRM31BR73A102KW01#	Murata	1
6	C16	22 µF/50 V	50PX22MEFC5X11	Rubycon	1
7	C17	100 nF/50 V	GRM188R71H104KA93D	Murata	1
8	C18, C26	1 nF/50 V	GRM1885C1H102GA01D	Murata	2
9	C19	120 pF/50 V	GRM1885C1H121GA01D	Murata	1
10	C111	22nF/50 V	GCM188R71H223KA37D	Murata	1
11	C21, C27	1nF/100 V	GRM2162C2A102JA01#	Murata	2
12	C22	1000 uF/16 V	16ZLH1000MEFC10X16	Rubycon	1
13	C24	470 uF/16 V	16ZLH470MEFC8X11.5	Rubycon	1
14	C25	220 nF/50 V	GRM188R71H224KAC4D	Murata	1
15	C28,C210	330 uF/10 V	10ZLH330MEFC6.3X11	Rubycon	2
16	D11	1 A/800 V	UF4006	–	1
17	D12,D13	0.2 A/200 V	1N485B	–	2
18	D21	30 A/100 V	STPS30M100SFP	–	1
19	D22	10 A/45 V	VFT1045BP	–	1
20	F1	1.6 A/300 V	36911600000	–	1
21	IC11	ICE5QR4780BG -1	ICE5QR4780BG-1	Infineon	1
22	IC12	Optocoupler	SFH617A-3	–	1
23	IC21	Shunt regulator	TL431BVLPG	–	1
24	JP2, JP3, JP4, JP5, JP6, JP22 and JP23	Jumper	–	–	7
25	L11	2X47MH 0.5A	B82731M2501A30	Epcos	1
26	L21	2.2 uH/6.3A	744 746 202 2	Würth Elektronik	1
27	L22	4.7 uH/4.2 A	744 746 204 7	Würth Elektronik	1
28	R110, R110A	2 MΩ/5%/200 V	RC1206JR-072ML		2
29	R11	68 kΩ/2 W/500 V	MO2CT631R683J	KOA Speer	1
30	R12A	0 Ω(0603)	–	–	1
31	JP1	27 Ω	–	–	1
32	R14	2.2 R/0.33 W/±1%	ERJ8BQF2R2V	Panasonic	1
33	R14A	2 R/0.33 W/±1%	ERJ8BQF2R0V	Panasonic	1

No.	Designator	Description	Part Number	Manufacturer	Quantity
34	R15	27 k Ω ±1% (0603)	–	–	1
35	R16, R16A, R16B	15 MΩ/0.25 W/5%	RC1206JR-0715ML	–	3
36	R18, R18A, R18B	3 MΩ/0.25 W/1%	RC1206FR-073ML	–	3
37	R19	58.3 kR/0.1 W/0.5%	RT0603DRE0758K3L	–	1
38	R21	51 R/0.25 W/±1%	ERJ8ENF51R0V	Panasonic	1
39	R22	820 Ω (0603)	–	–	1
40	R23	1.2 kΩ (0603)	–	–	1
41	R24	12 kΩ (0603)	–	–	1
42	R25	16 kΩ (0603)	–	–	1
43	R25A	6.2 kΩ (0603)	–	–	1
44	R26	2.5 kΩ (0603)	–	–	1
45	R27	13 R/0.25 W/±1%	ERJ8ENF13R0V	Panasonic	1
46	R110, R110A	2 MΩ/5%/200 V	RC1206JR-072ML		2
47	TR1	998 µH	750343074(Rev 0.2)	Würth Elektronik	1
48	VAR	Varistor	B72207S2321K101	Epcos	1
49	ZD1	22 V Zener	MMSZ5251B-7-F	Diodes Incorporated	1
50	HS1	Heatsink	577202B00000G		1
51	Con(L N)	Connector	691102710002	Würth Elektronik	1
52	Con(+12V Com), Con(+5V 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-capacitor (C11), and Y-capacitor (C12) act as EMI suppressors. 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, ICE5QR4780BG-1 is implemented with startup resistors 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 ICE5QR4780BG-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 the 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

ICE5QR4780BG-1 comprises a power 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}. ICE5QR4780BG-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 the Schottky diodes (D21 and D22). The capacitors (C22 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 the SMPS switching frequency and line frequency. Storage capacitors (C22 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 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 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 ICE5QR4780BG-1 is a current mode controller, it would have a cycle-by-cycle primary current and feedback voltage control, which ensures that the maximum power of the converter 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 line-dependent V_{CS} curve and the new proprietary QR switching, which reduces the switching frequency difference between the minimum and maximum line are implemented in ICE5QR4780BG-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 ICE5QR4780BG-1 is digitally reduced with decreasing load. At light load conditions, the MOSFET will be turned on – not at the first minimum drain-source voltage time, but on the n^{th}. The counter is in the 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 the 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 ICE5QR4780BG-1 [1]. ABM power level 1 is used in this reference board (R17 = open). At light load conditions, the SMPS enters into 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.

For determination of entering 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).

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 entering ABM operation, so that the controller enters active burst mode 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. When the current limit is 31/35% during ABM, a certain load is needed 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

ICE5QR4780BG-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 the failure conditions.

Table 3 Protection function of ICE5QR4780BG-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

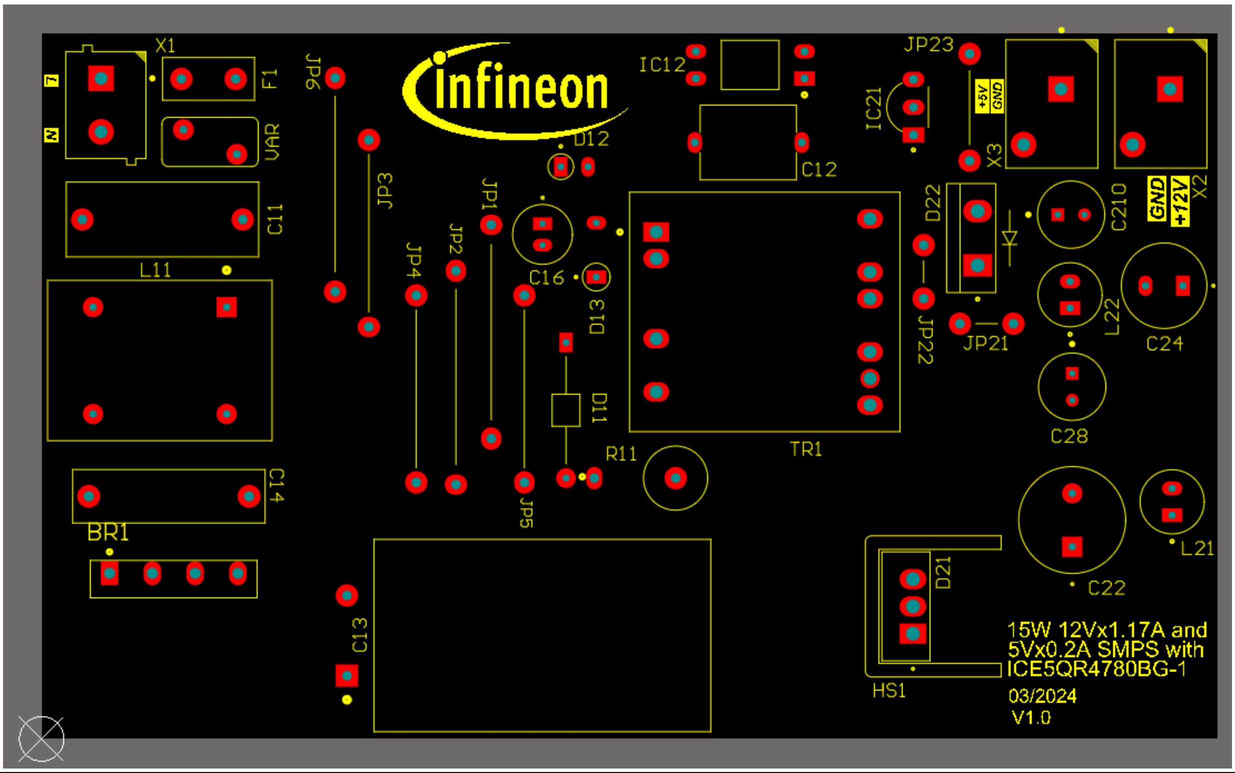


Figure 3 Top side component legend

8.2 Bottom side

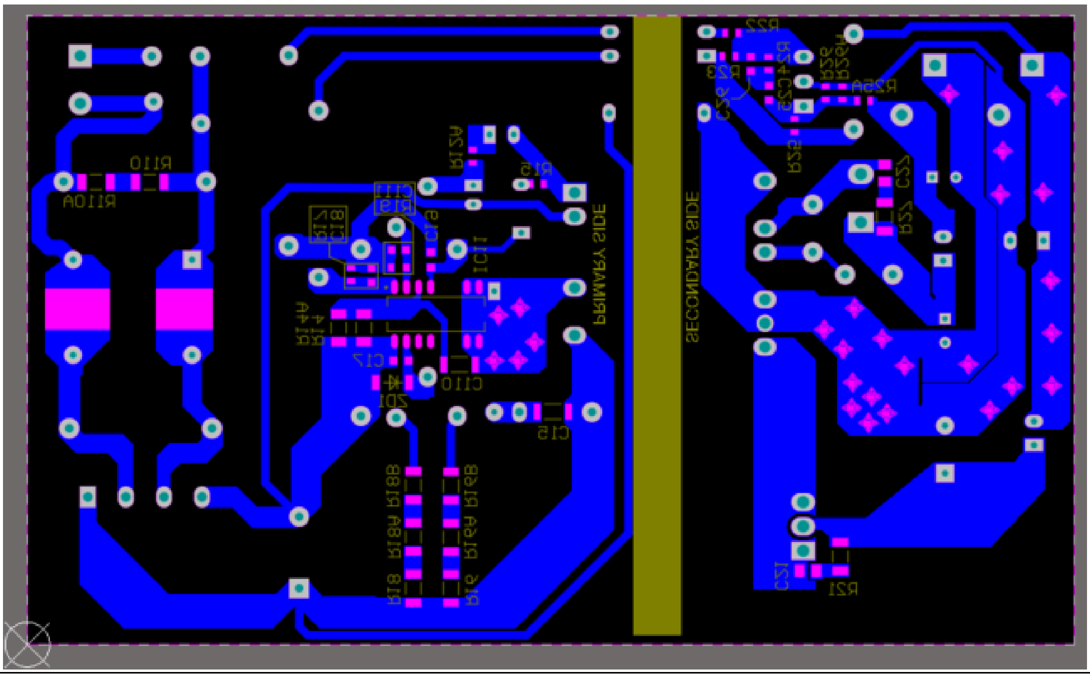


Figure 4 Bottom side component legend

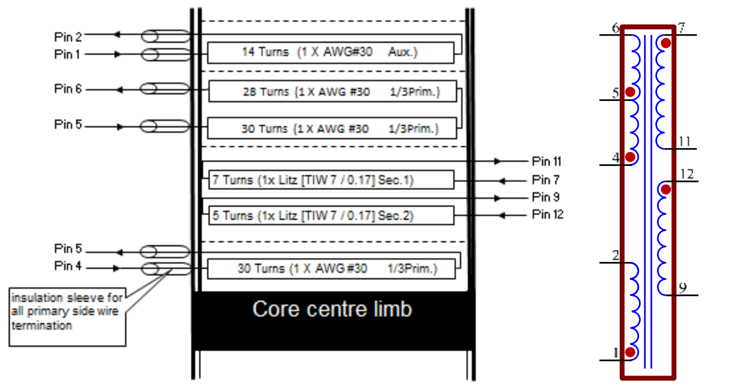
9 Transformer construction

Core and material: EE20/10/6(EF20), TP4A (TDG)

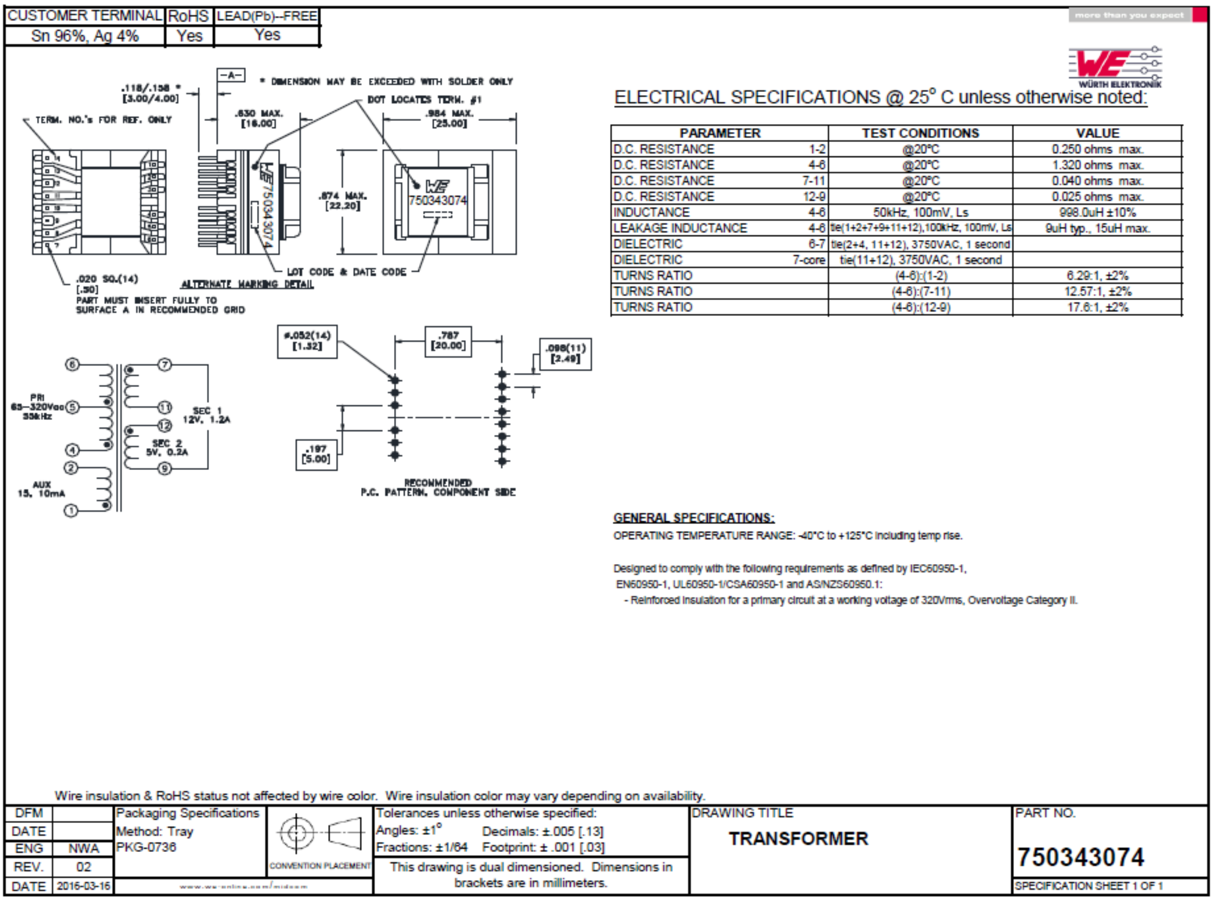
Bobbin: 070-5643 (14 Pin, THT, horizontal version)

Primary Inductance: Lp = 998 µH (±10%), measured between pin 4 and pin 6

Manufacturer and part number: Würth Electronik Midcom (750343074)



Start	Stop	No. of turns	Wire size	Layer
4	5	30	1XAWG#30	1/3 Primary
12	9	5	1 x Litz [TIW 7 / 0.17]	Secondary 2
7	11	7	1 x Litz [TIW 7 / 0.17]	Secondary 1
5	6	58	1XAWG#30	2/3 Primary
1	2	14	1XAWG#30	Auxiliary



PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	1-2	@20°C	0.250 ohms max.
D.C. RESISTANCE	4-6	@20°C	1.320 ohms max.
D.C. RESISTANCE	7-11	@20°C	0.040 ohms max.
D.C. RESISTANCE	12-9	@20°C	0.025 ohms max.
INDUCTANCE	4-6	50kHz, 100mV, Ls	998.0uH ±10%
LEAKAGE INDUCTANCE	4-6	tie(1+2+7+9+11+12),100kHz, 100mV, Ls	9uH typ., 15uH max.
DIELECTRIC	6-7	tie(2+4, 11+12), 3750VAC, 1 second	
DIELECTRIC	7-core	tie(11+12), 3750VAC, 1 second	
TURNS RATIO		(4-6):(1-2)	6.29:1, ±2%
TURNS RATIO		(4-6):(7-11)	12.57:1, ±2%
TURNS RATIO		(4-6):(12-9)	17.6:1, ±2%

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_{out1} (V_{DC})	I_{out1} (A)	V_{ORPP1} (mV)	V_{out2} (V_{DC})	I_{out2} (A)	V_{ORPP2} (mV)	P_{out} (W)	Efficiency η (%)	Average η (%)	OLP P_{in} (W)	OLP I_{out12V} (Fixed 5 V at 0.2 A) (A)
85V AC/ 60Hz	0.043	4.92	0.000	10.9	12.16	0.000	44.8				25.18	1.52
	0.083	4.79	0.006	38.4	12.50	0.000	28.2	0.03				
	9.172	4.96	0.060	9.0	12.05	0.600	26.9	7.53	82.07			
	4.562	4.93	0.050	9.1	12.14	0.290	21.1	3.77	82.54	82.76		
	9.030	4.93	0.100	9.6	12.14	0.580	42.2	7.53	83.40			
	13.667	4.92	0.150	10.2	12.15	0.880	38.4	11.43	83.60			
	18.620	4.93	0.200	11.5	12.13	1.170	41.6	15.18	81.51			
115V AC/ 60Hz	0.046	4.92	0.000	10.9	12.16	0.000	46.7				27.97	1.79
	0.092	4.79	0.006	38.4	12.50	0.000	26.9	0.03				
	8.973	4.96	0.060	8.3	12.06	0.600	31.4	7.53	83.96			
	4.563	4.93	0.050	8.3	12.13	0.290	18.6	3.76	82.49	83.16		
	9.018	4.94	0.100	8.3	12.10	0.580	22.4	7.51	83.30			
	13.692	4.94	0.150	9.0	12.11	0.880	21.3	11.40	83.24			
	18.142	4.93	0.200	8.3	12.12	1.170	24.3	15.17	83.60			
230V AC/ 50Hz	0.071	4.92	0.000	11.5	12.17	0.000	49.9				28.68	1.87
	0.118	4.79	0.006	30.1	12.51	0.000	21.1	0.03				
	9.020	4.96	0.060	10.2	12.05	0.600	27.5	7.53	83.45			
	4.612	4.94	0.050	10.2	12.12	0.290	44.8	3.76	81.57	83.35		
	9.050	4.93	0.100	9.6	12.13	0.580	32.6	7.53	83.19			
	13.580	4.93	0.150	10.2	12.15	0.880	38.4	11.43	84.18			
	17.970	4.94	0.200	9.6	12.13	1.170	30.1	15.18	84.47			
265V AC/ 50Hz	0.083	4.92	0.000	12.8	12.17	0.000	49.3				29.57	1.95
	0.131	4.78	0.006	41.0	12.52	0.000	30.7	0.03				
	9.161	4.96	0.060	10.2	12.05	0.600	27.0	7.53	82.17			
	4.672	4.94	0.050	10.2	12.11	0.290	43.5	3.76	80.46	82.52		
	9.151	4.93	0.100	9.6	12.13	0.580	32.6	7.53	82.27			
	13.670	4.93	0.150	10.2	12.13	0.880	36.5	11.41	83.50			
	18.087	4.93	0.200	9.6	12.12	1.170	30.7	15.17	83.85			
300V AC/ 50Hz	0.098	4.92	0.000	12.8	12.17	0.000	50.6				30.35	1.99
	0.139	4.79	0.006	39.0	12.50	0.000	30.1	0.03				
	9.215	4.96	0.060	9.6	12.06	0.600	28.8	7.53	81.75			
	4.868	4.93	0.050	10.2	12.16	0.290	23.7	3.77	77.50	81.20		
	9.267	4.94	0.100	9.6	12.12	0.580	32.0	7.52	81.19			
	13.806	4.93	0.150	10.2	12.14	0.880	35.8	11.42	82.74			
	18.192	4.94	0.200	10.2	12.12	1.170	30.1	15.17	83.38			

- **Minimum load condition:** 5 V at 6 mA
- **Typical load condition:** 5 V at 60 mA and 12 V at 0.6 A
- **Maximum load condition:** 5 V at 200 mA and 12 V at 1.17 A

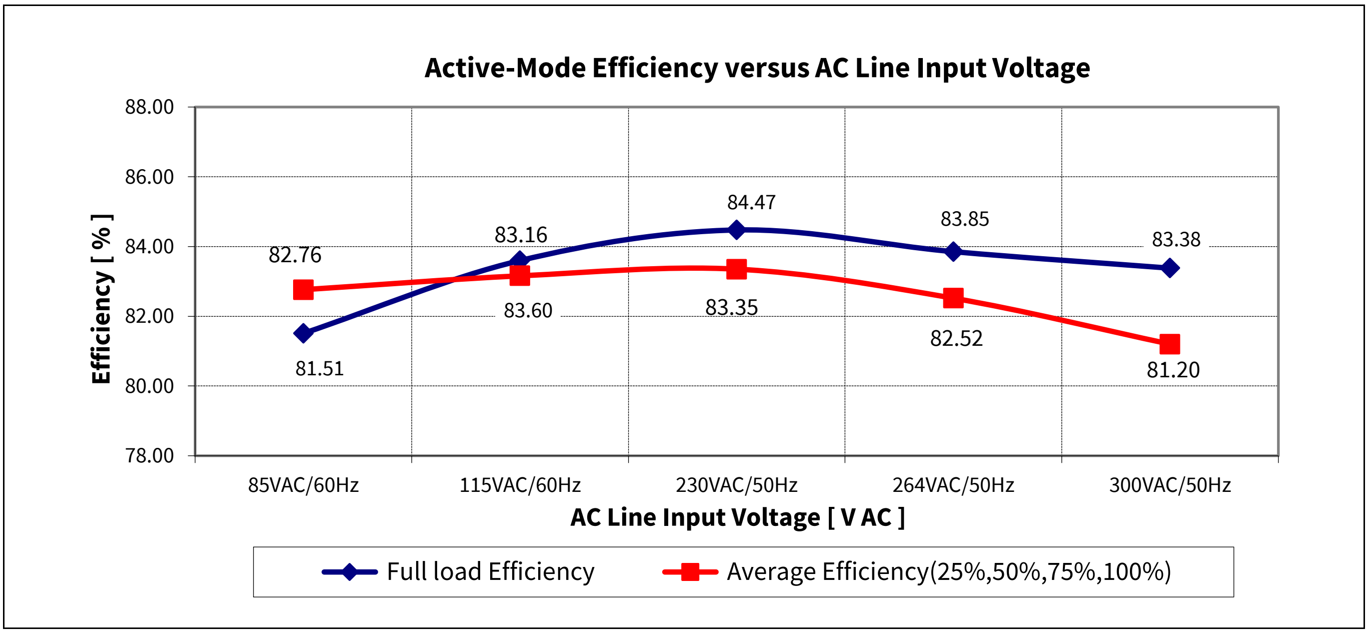


Figure 6 **Efficiency vs. AC line input voltage**

10.2 Standby power

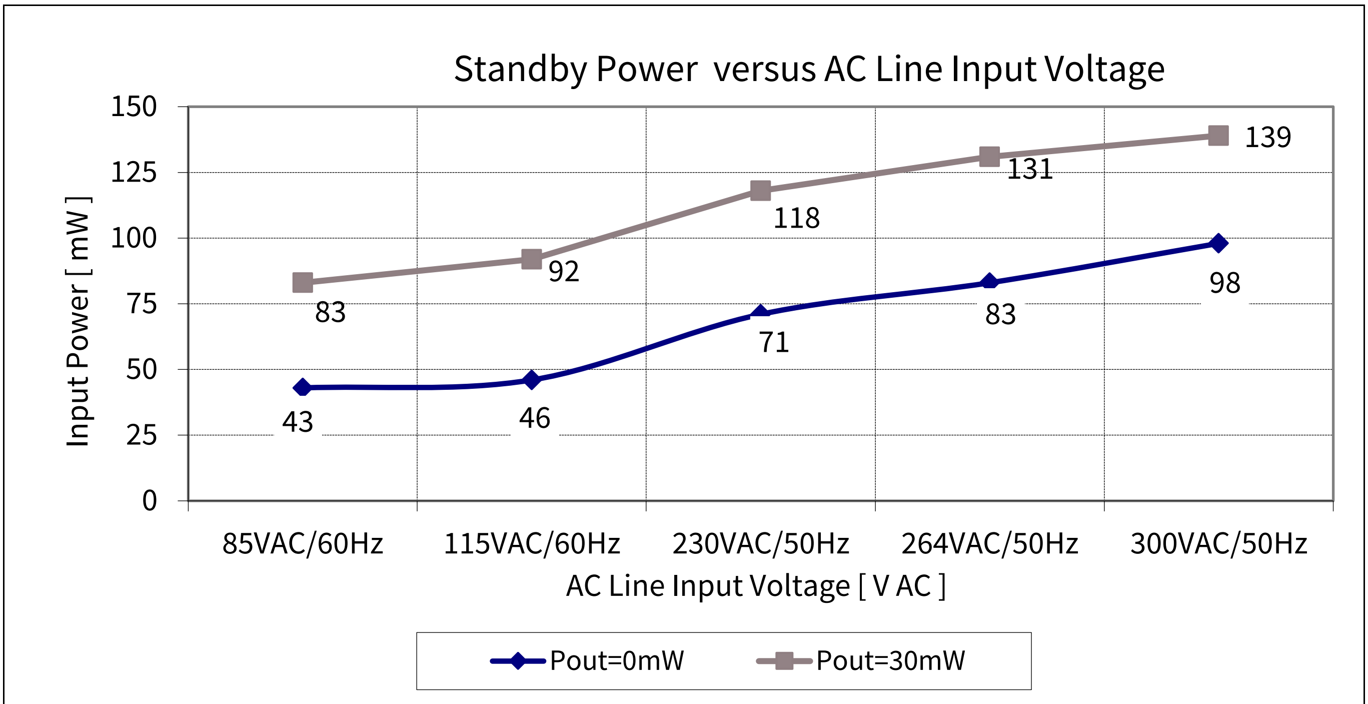


Figure 7 **Standby power at no load and 30 mW load vs. AC line input voltage (measured by Yokogawa WT210 power meter - integration mode)**

10.3 Line regulation

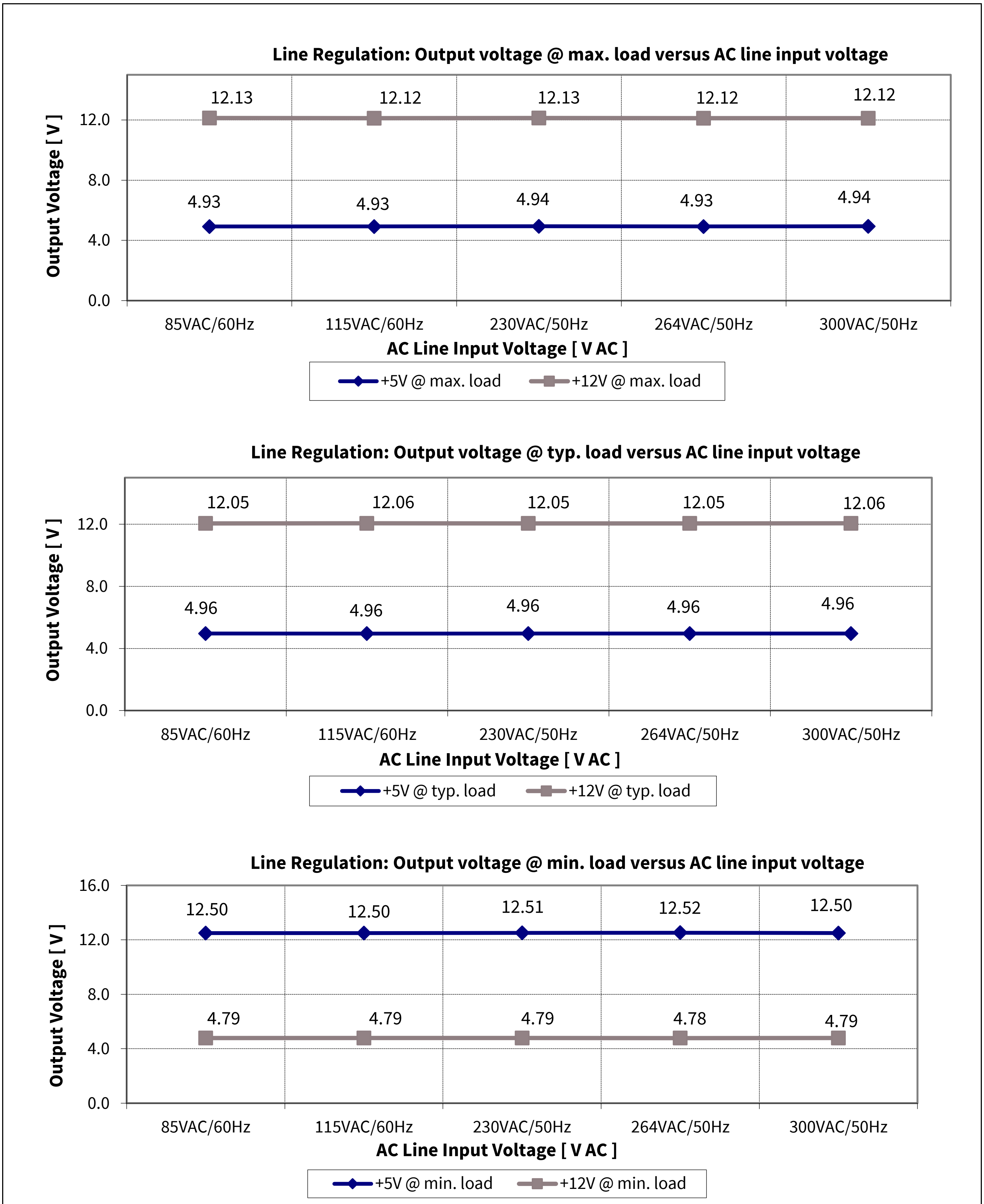


Figure 8 Line regulation V_{Out} at full load vs. AC line input voltage

10.4 Load regulation

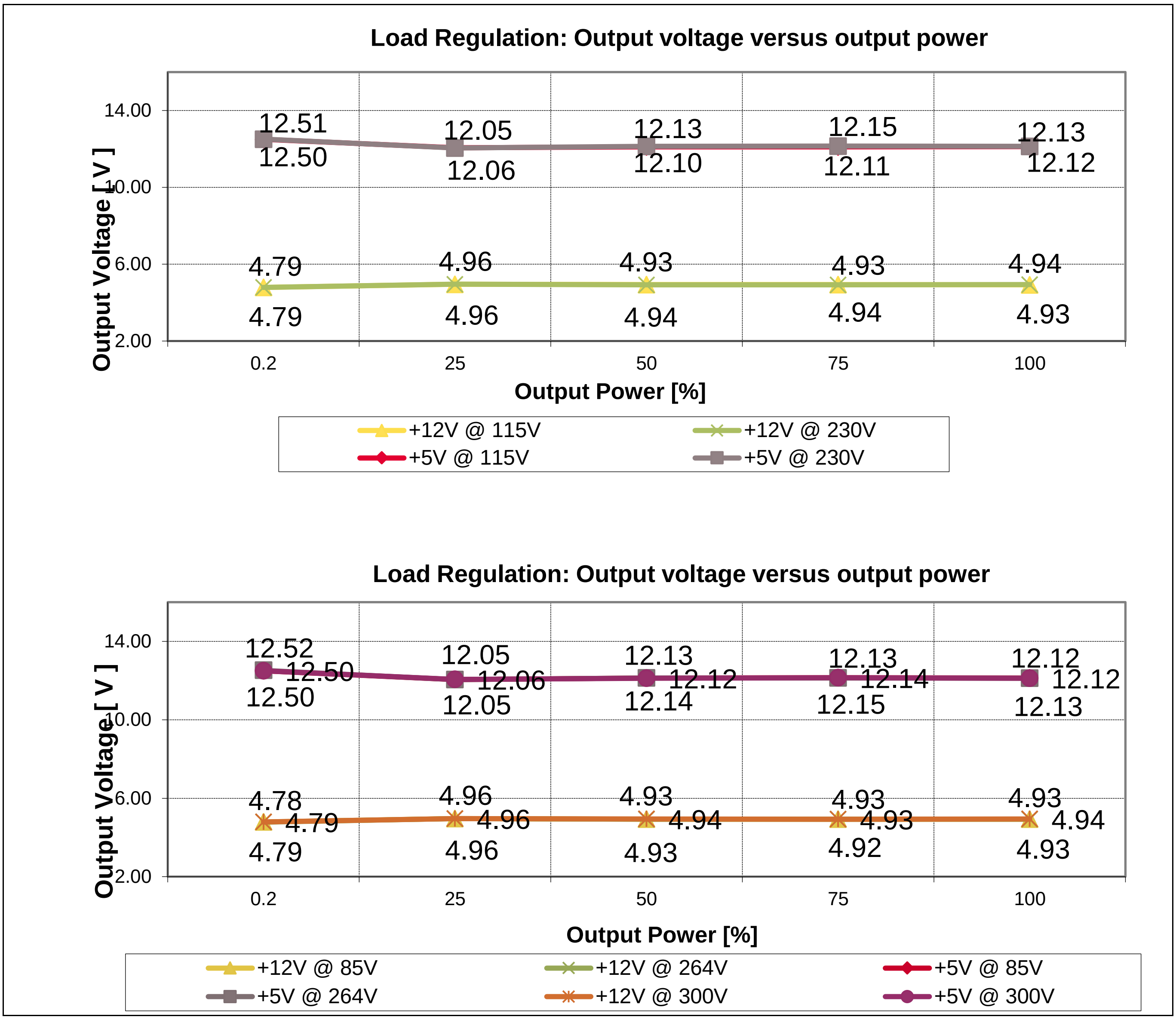


Figure 9 Load regulation V_{out} vs. output power

10.5 Maximum input power

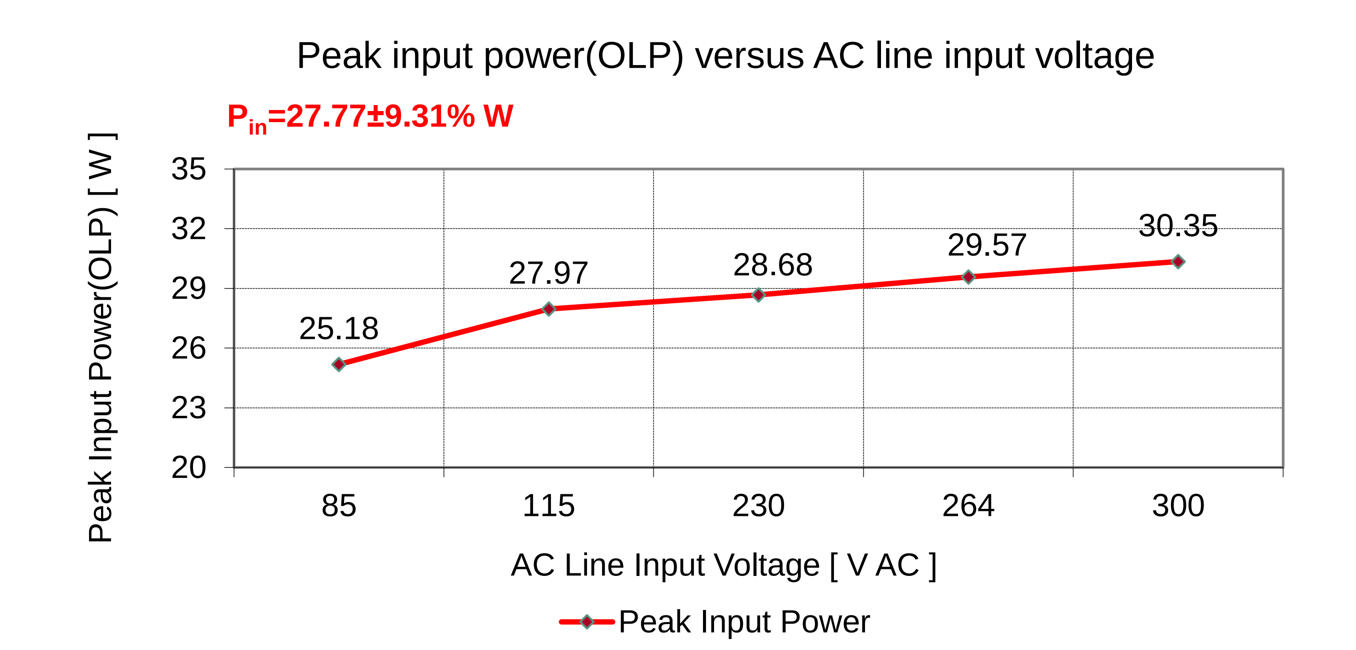


Figure 10 Maximum input power (before overload protection) vs. AC line input voltage

10.6 ESD immunity (EN61000-4-2)

Pass EN 61000-4-2 special level (±14 kV for contact discharge and (±16 kV air discharge).

10.7 Surge immunity (EN61000-4-5)

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

[1] PCB spark gap distance needs to reduce to 0.5 mm and C13 change to 120 µF.

10.8 Conducted emissions (EN55022 Class B)

The conducted EMI was measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) Class B. The reference board was set up at maximum load (15 W) with the input voltage of 115 V AC and 230 V AC.

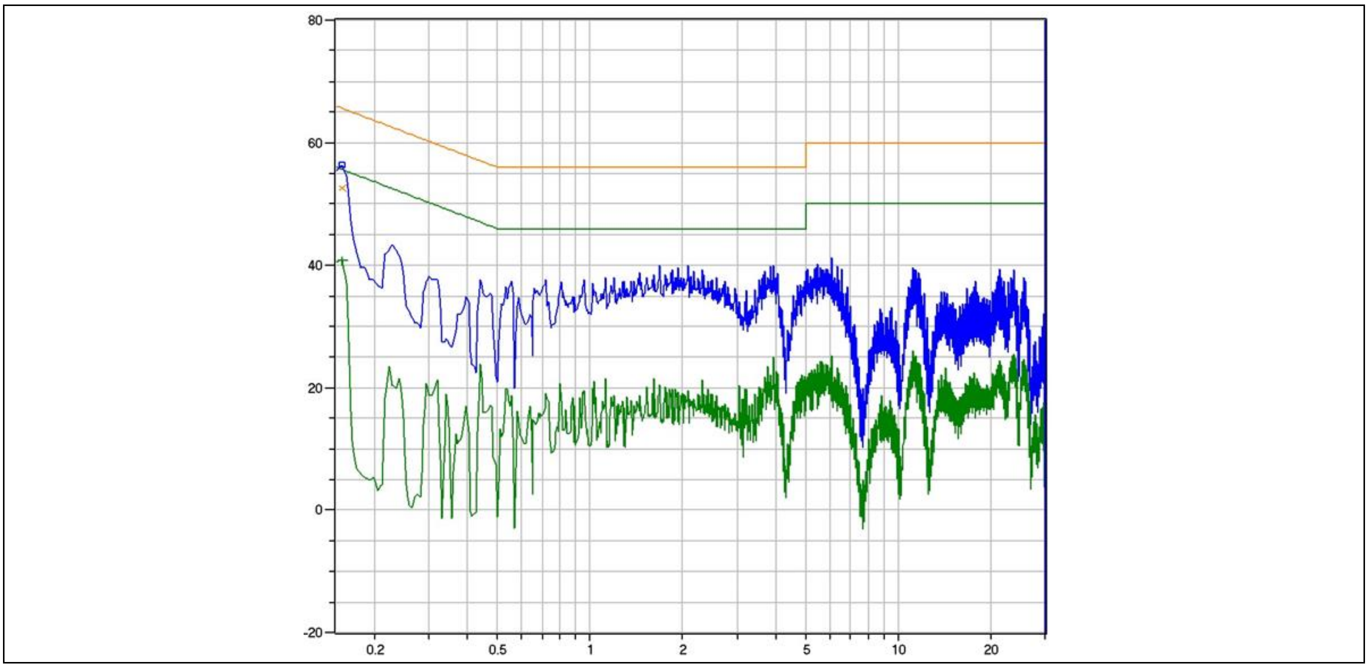


Figure 11 Conducted emissions (line) at 115 V AC and maximum load

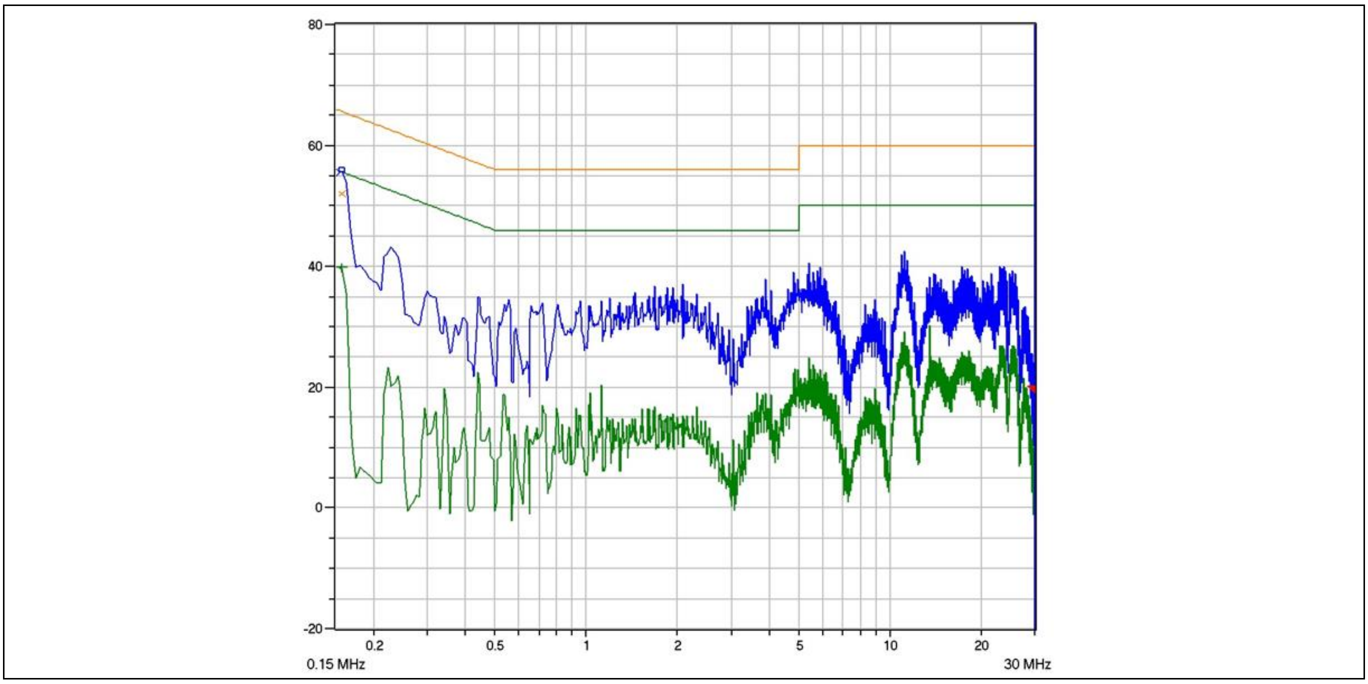


Figure 12 Conducted emissions (neutral) at 115 V AC and maximum load

Pass conducted emissions EN 55022 (CISPR 22) Class B with 10 dB margin for quasi-peak measurement at low-line (115 V AC).

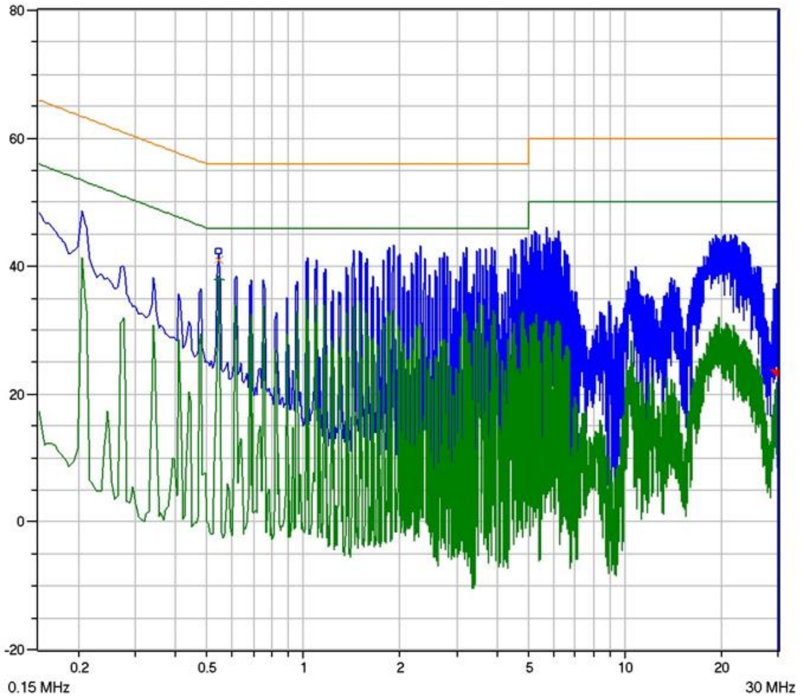


Figure 13 Conducted emissions (line) at 230 V AC and maximum load

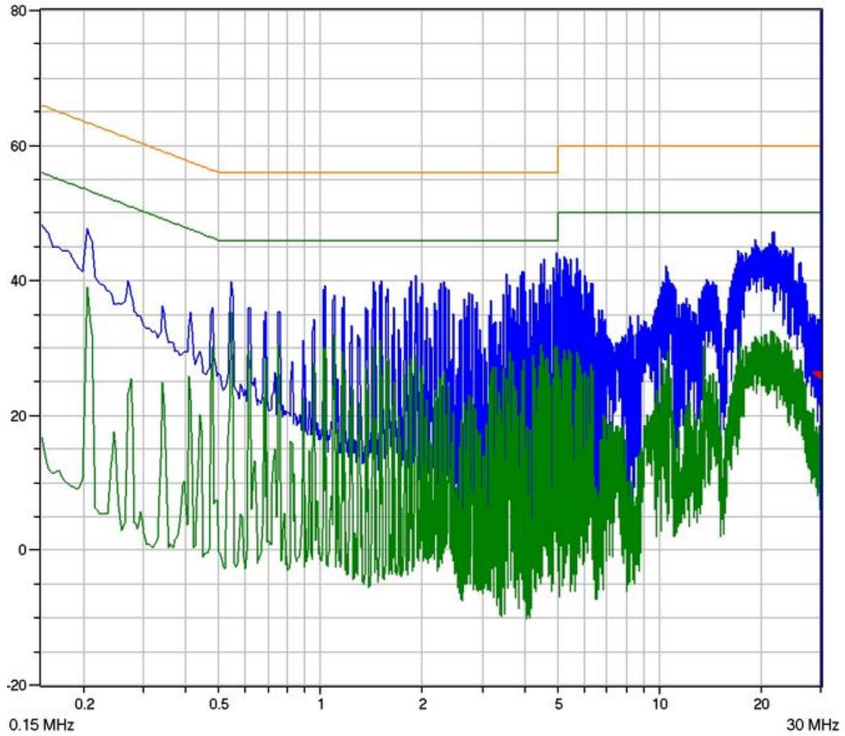


Figure 14 Conducted emissions (neutral) at 230 V AC and maximum load

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

Table 5 Hottest temperature of reference board

No.	Major component	85 V AC (°C)	300 V sAC (°C)
1	IC11 (ICE5QR4780BG-1)	75.9	54.9
2	R14A (current sense resistor)	49.6	43.5
3	TR1 (transformer)	51.7	61.3
4	BR1 (bridge diode)	46.8	30.5
5	R11(clamper resistor)	49.1	51.3
6	L11 (choke)	43.8	28.7
7	D21 (Secondary diode)	43.9	50.8
8	D22 (Secondary diode)	37.4	40.3
9	Ambient	25.0	25.0

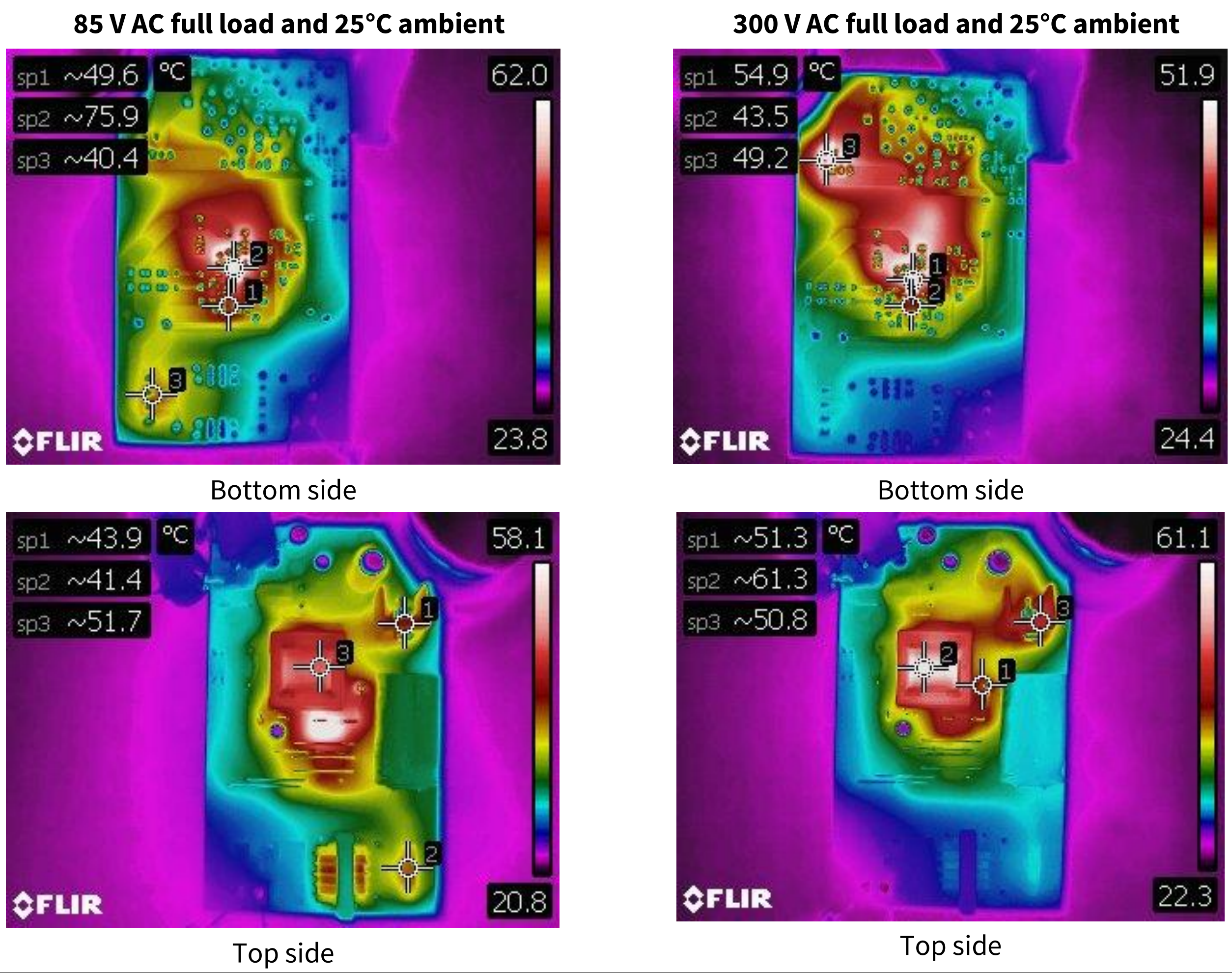


Figure 15 **Infrared thermal image of REF_5QR4780BG-1_15W1**

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

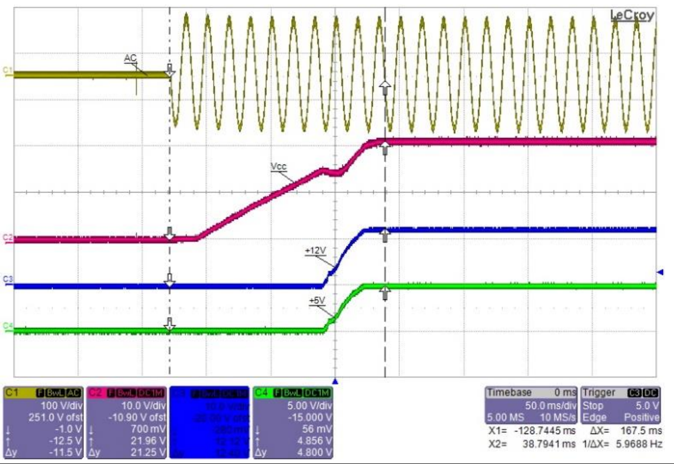
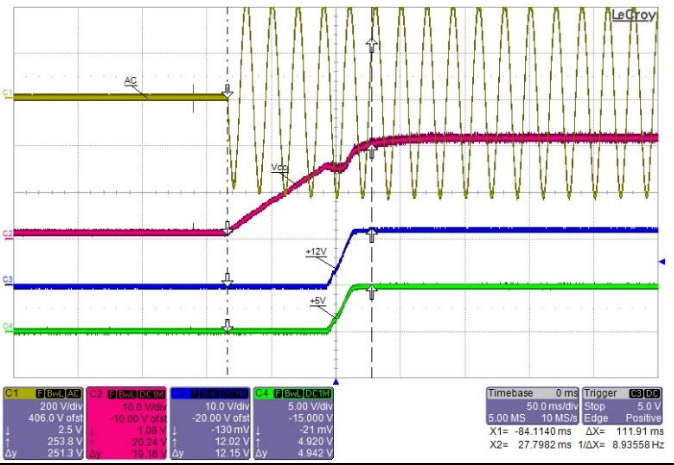
	
C1 (Yellow): AC line voltage (V AC) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** 12 V output voltage (V_{Out12}) **C4 (Green):** 5 V output voltage (V_{Out5})	**C1 (Yellow):** AC line voltage (V AC) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** 12 V output voltage (V_{Out12}) **C4 (Green):** 5 V output voltage (V_{Out5})
Startup time at 85 V AC and maximum load ≈ 168 ms	Startup time at 300 V AC and maximum load ≈ 112 ms

Figure 16 Startup

11.2 Soft start

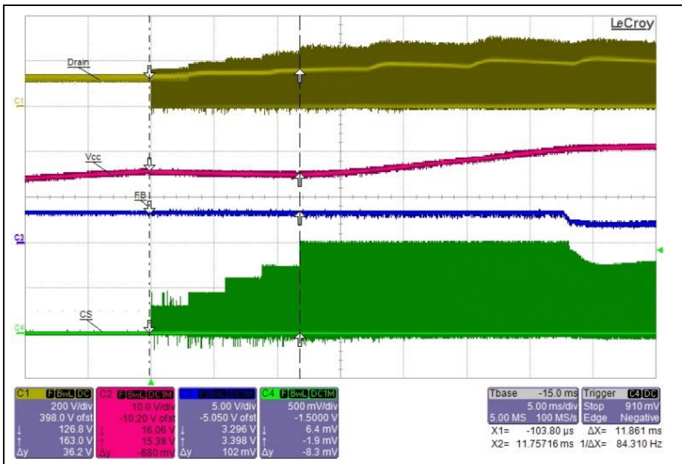
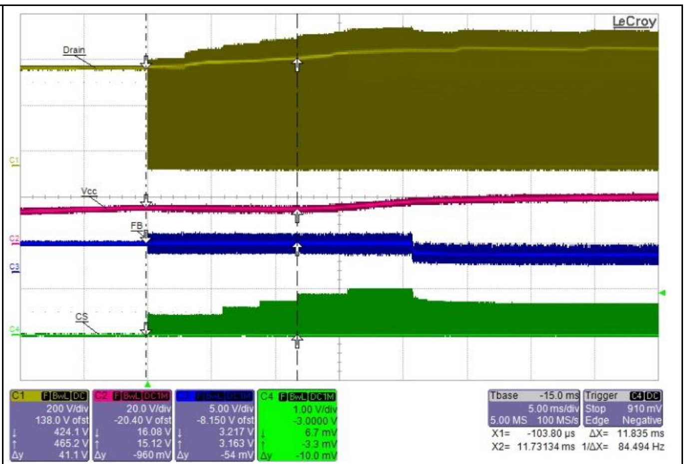
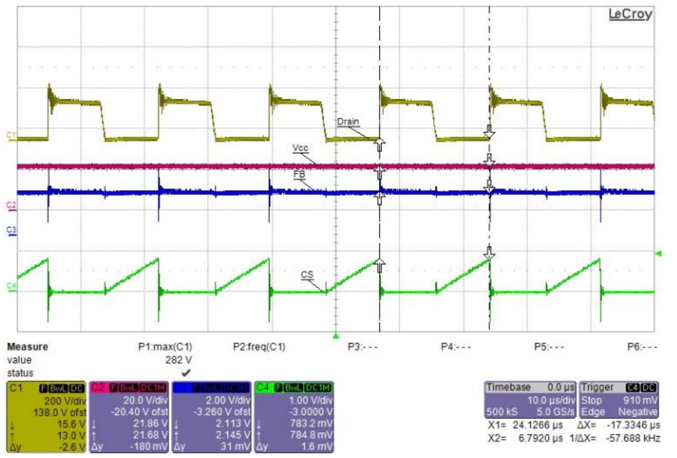
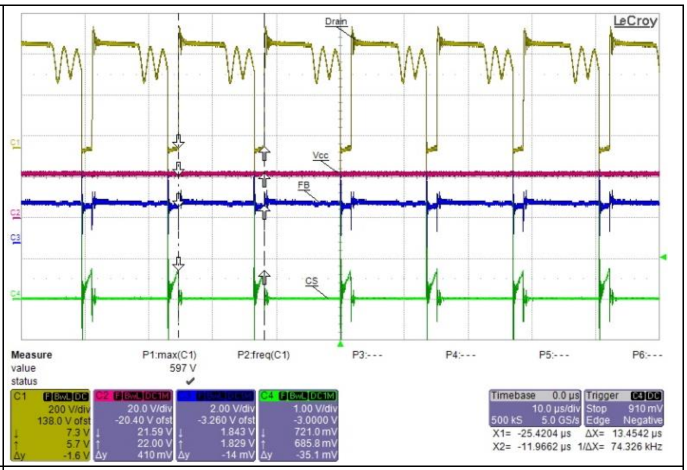
	
C1 (Yellow): Drain voltage (V_D) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** Feedback voltage (V_{FB}) **C4 (Green):** Current sense voltage (V_{CS})	**C1 (Yellow):** Drain voltage (V_D) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** Feedback voltage (V_{FB}) **C4 (Green):** Current sense voltage (V_{CS})
Soft-start time at 85 V AC and maximum load ≈ 12 ms	Soft-start time at 300 V AC and maximum load ≈ 12 ms

Figure 17 Soft start

11.3 Drain and current sense voltage at maximum load

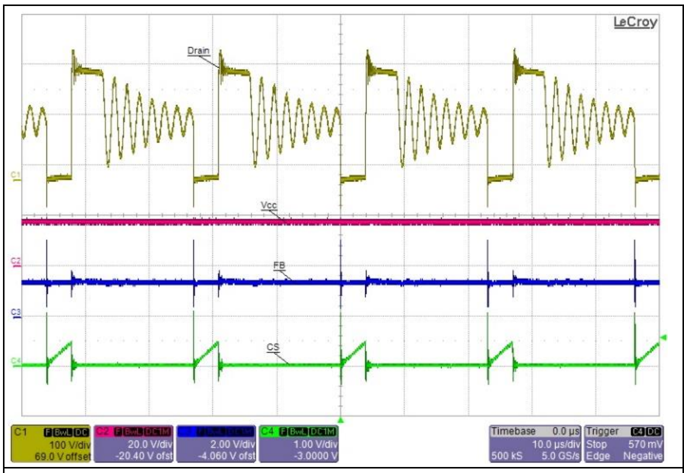


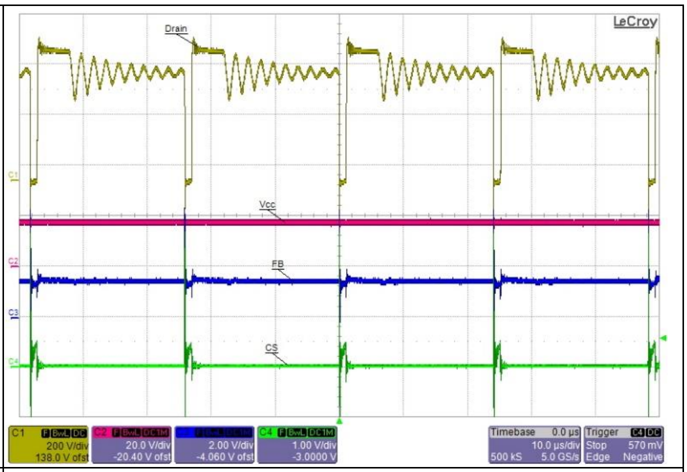


C1 (Yellow): Drain voltage (V_D) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** Feedback voltage (V_{FB}) **C4 (Green):** Current sense voltage (V_{CS})	**C1 (Yellow):** Drain voltage (V_D) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** Feedback voltage (V_{FB}) **C4 (Green):** Current sense voltage (V_{CS})
V_{Drain_peak} at 85 V AC ≈ 282 V with 1st ZC and f_S ≈ 58 kHz	V_{Drain_peak} at 300 V AC ≈ 597 V with 3rd ZC and f_S ≈ 74 kHz

Figure 18 Drain and current sense voltage at maximum load

11.4 Zero crossing point during normal operation





C1 (Yellow): Drain voltage (V_D) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** Feedback voltage (V_{FB}) **C4 (Green):** Current sense voltage (V_{CS})	**C1 (Yellow):** Drain voltage (V_D) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** Feedback voltage (V_{FB}) **C4 (Green):** Current sense voltage (V_{CS})
8th zero crossing at 85 V AC and 25% load (5 V x 0.05 A +12 V x 0.29 A) (zero crossing varies from 1~8 for low line)	10th zero crossing at 300 V AC and 25% load (5 V x 0.05 A +12 V x 0.29 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%)

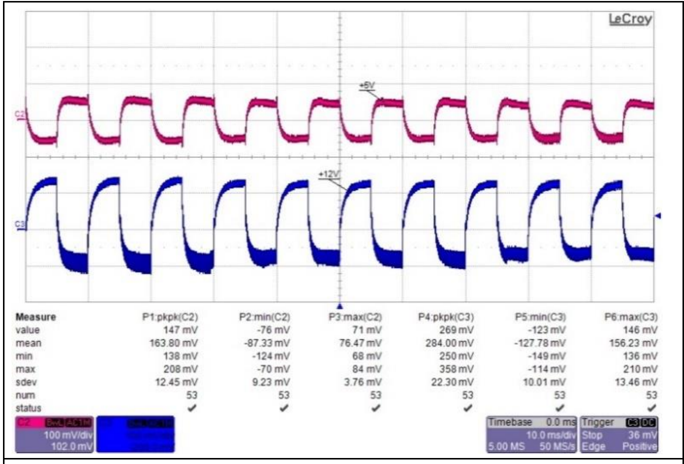
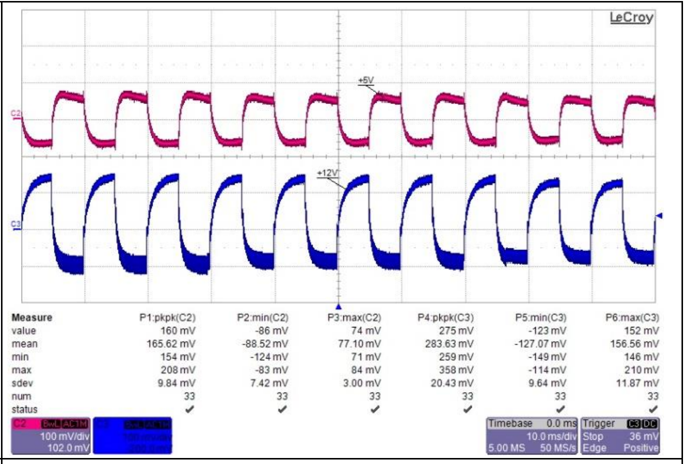
	
C2 (Purple): 5 V Output ripple voltage (V_{Out5}) **C3 (Blue):** 12 V Output ripple voltage (V_{Out12})	**C2 (Purple):** 5 V Output ripple voltage (V_{Out5}) **C3 (Blue):** 12 V Output ripple voltage (V_{Out12})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 147 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 269 mV (85 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 filter	5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 160 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 275 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 filter

Figure 20 Load transient response

11.6 Output ripple voltage at maximum load

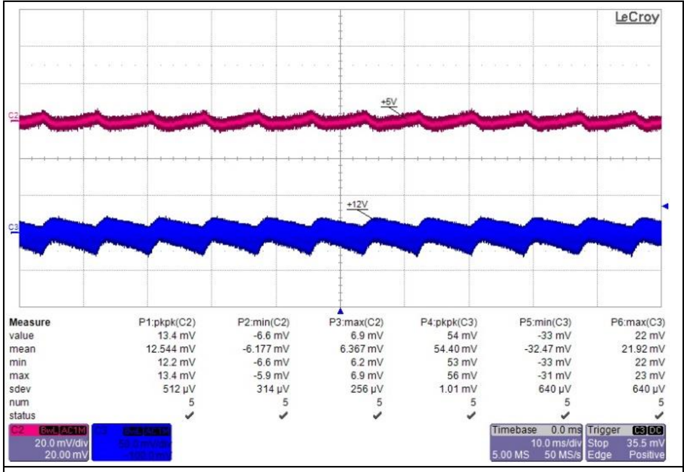
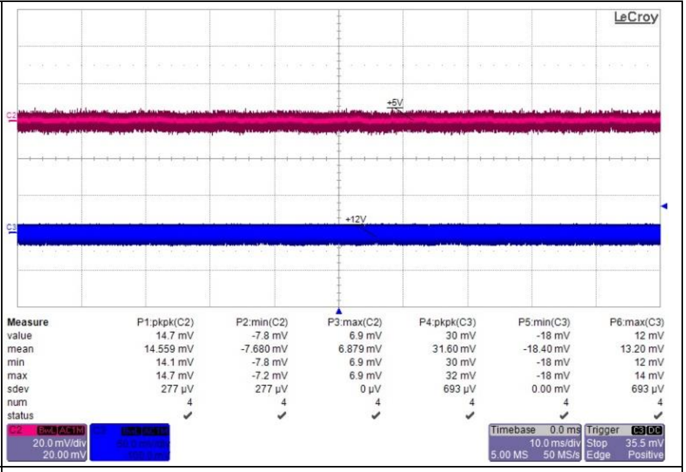
	
C2 (Purple): 5 V Output ripple voltage (V_{Out5}) **C3 (Blue):** 12 V Output ripple voltage (V_{Out12})	**C2 (Purple):** 5 V Output ripple voltage (V_{Out5}) **C3 (Blue):** 12 V Output ripple voltage (V_{Out12})
5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 13.4 mV 12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 54 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (Electrolytic), 20 MHz filter	5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 14.7 mV 12 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 30 mV Probe terminal end with decoupling capacitor of 0.1 µF (ceramic) and 1 µF (Electrolytic), 20 MHz filter

Figure 21 Output ripple voltage at maximum load

11.7 Output ripple voltage at ABM 1 W load

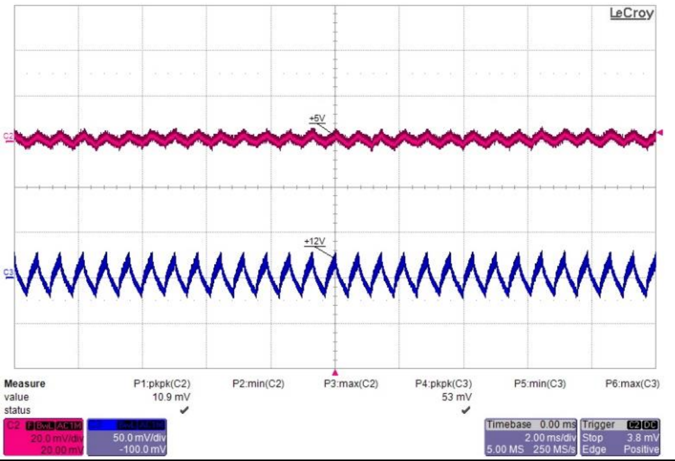
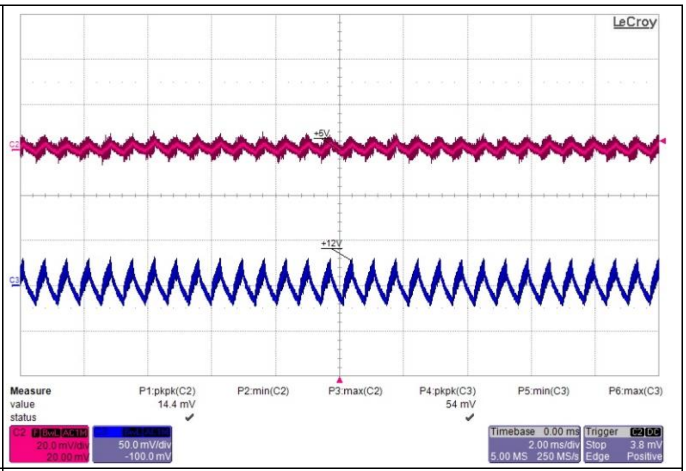
<table>
<tr><td>
</td><td>
</td></tr>
<tr><td>C2 (Purple): 5 V Output ripple voltage (V_{Out5})
C3 (Blue): 12 V Output ripple voltage (V_{Out12})</td><td>C2 (Purple): 5 V Output ripple voltage (V_{Out5})
C3 (Blue): 12 V Output ripple voltage (V_{Out12})</td></tr>
<tr><td>5 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 10.9 mV
12 $V_{ripple\_pk\_pk}$ at 85 V AC ≈ 53 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 filter</td><td>5 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 14.4 mV
12 $V_{ripple\_pk\_pk}$ at 300 V AC ≈ 54 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 filter</td></tr>
</table>

Figure 22 Output ripple voltage at ABM 1 W load

11.8 Entering active burst mode

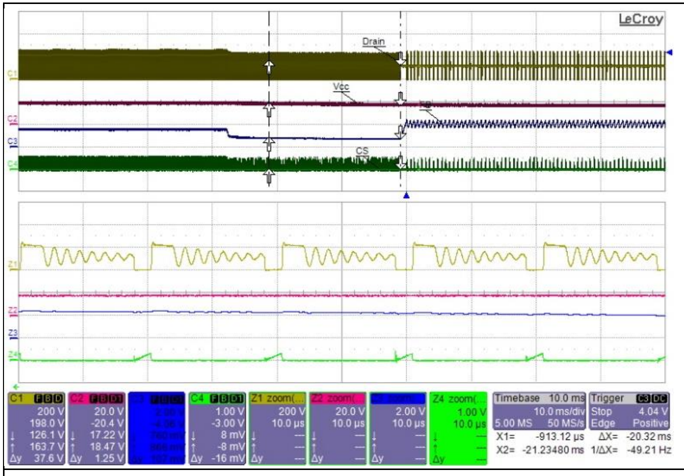
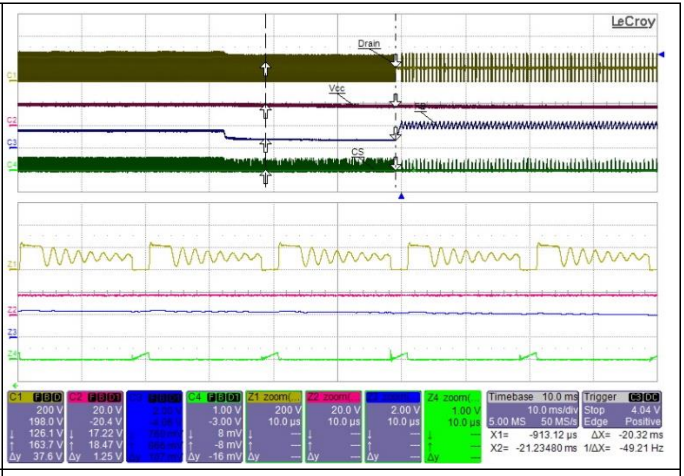
<table>
<tr><td>
</td><td>
</td></tr>
<tr><td>C1 (Yellow): Drain voltage (V_D)
C2 (Purple): Supply voltage (V_{VCC})
C3 (Blue): Feedback voltage (V_{FB})
C4 (Green): Current sense voltage (V_{CS})</td><td>C1 (Yellow): Drain voltage (V_D)
C2 (Purple): Supply voltage (V_{VCC})
C3 (Blue): Feedback voltage (V_{FB})
C4 (Green): Current sense voltage (V_{CS})</td></tr>
<tr><td>Condition to enter burst mode level 1: V_{FB} < 0.9 V, N_{ZC} = 8 and $t_{blanking}$ = 20 ms
(load change form 5 W to 0.5 W at 85 V AC)</td><td>Condition to enter burst mode level 1: V_{FB} < 0.9 V, N_{ZC} = 10 and $t_{blanking}$ = 20 ms
(load change form 5 W to 0.5 W at 300 V AC)</td></tr>
</table>

Figure 23 Entering ABM

11.9 During active burst mode

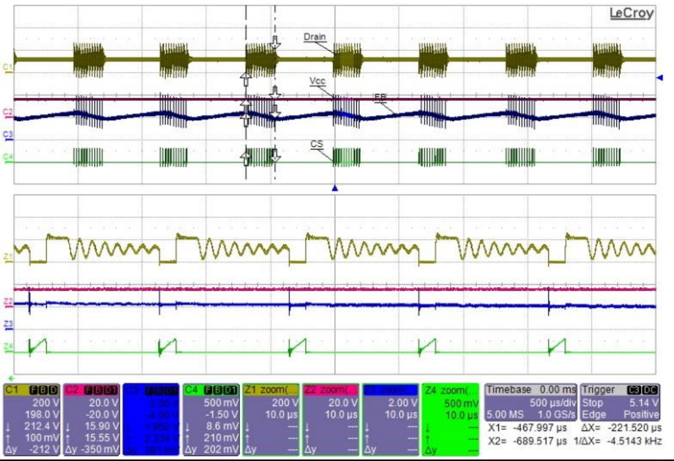
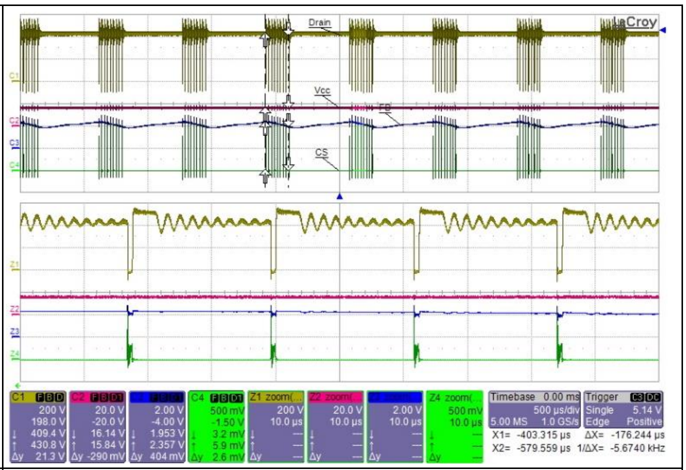
	
C1 (Yellow): Drain voltage (V_D) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** Feedback voltage (V_{FB}) **C4 (Green):** Current sense voltage (V_{CS})	**C1 (Yellow):** Drain voltage (V_D) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** Feedback voltage (V_{FB}) **C4 (Green):** Current sense 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 (0.5 W at 85 V AC)	**During ABM level 1:** V_{FB_Bon} = 2.4 V, V_{FB_BOff} = 2.0 V, V_{CSBLP} = 0.31 V, N_{ZC} = 10 (0.5 W at 300 V AC)

Figure 24 During ABM

11.10 Leaving active burst mode

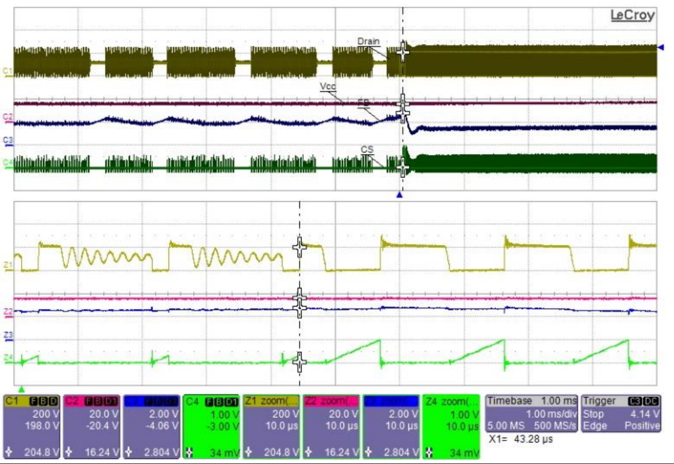
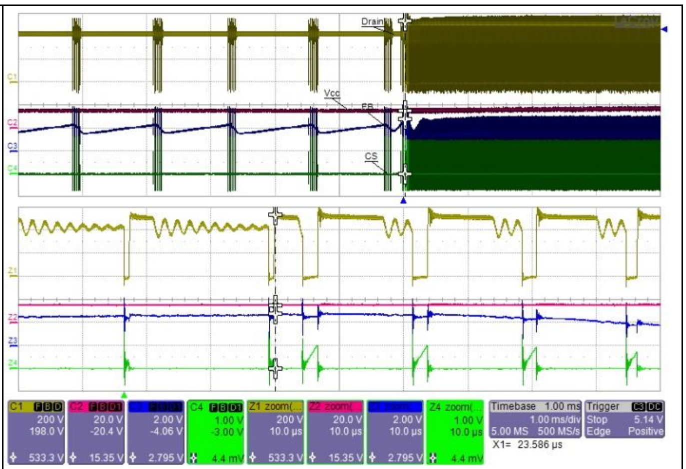
	
C1 (Yellow): Drain voltage (V_D) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** Feedback voltage (V_{FB}) **C4 (Green):** Current sense voltage (V_{CS})	**C1 (Yellow):** Drain voltage (V_D) **C2 (Purple):** Supply voltage (V_{VCC}) **C3 (Blue):** Feedback voltage (V_{FB}) **C4 (Green):** Current sense voltage (V_{CS})
Condition to leave burst mode level 1: V_{FB} >2.75 V (load change form 0.5 W full load at 85 V AC)	**Condition to leave burst mode level 1:** V_{FB} >2.75 V (load change form 0.5 W full load at 300 V AC)

Figure 25 Leaving ABM

11.11 Line overvoltage protection (non-switch auto-restart)

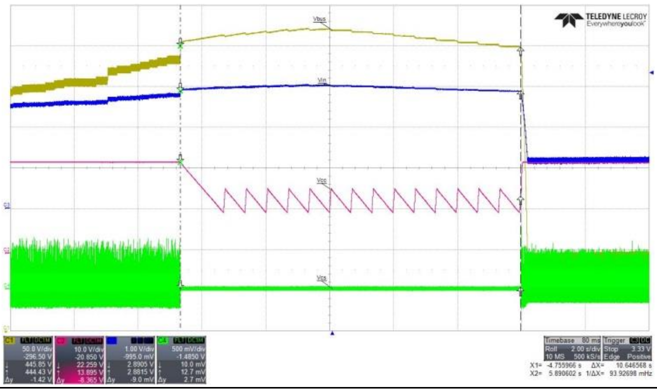
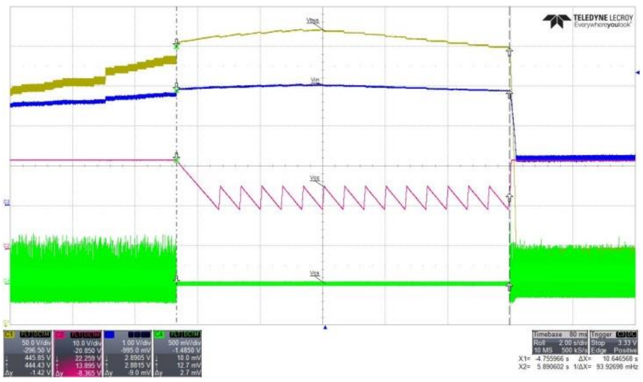
	
C1 (yellow): Bus voltage (V_{Bus}) **C2 (purple):** Supply voltage (V_{VCC}) **C3 (blue):** V_{IN} voltage (V_{VIN}) **C4 (green):** CS voltage (V_{CS})	**C1 (yellow):** Bus voltage (V_{Bus}) **C2 (purple):** Supply voltage (V_{VCC}) **C3 (blue):** V_{IN} voltage (V_{VIN}) **C4 (green):** CS voltage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

11.12 Brownout protection (non-switch auto-restart)

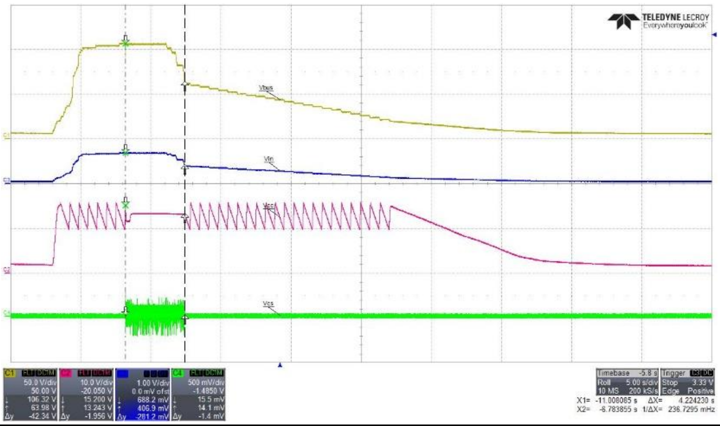
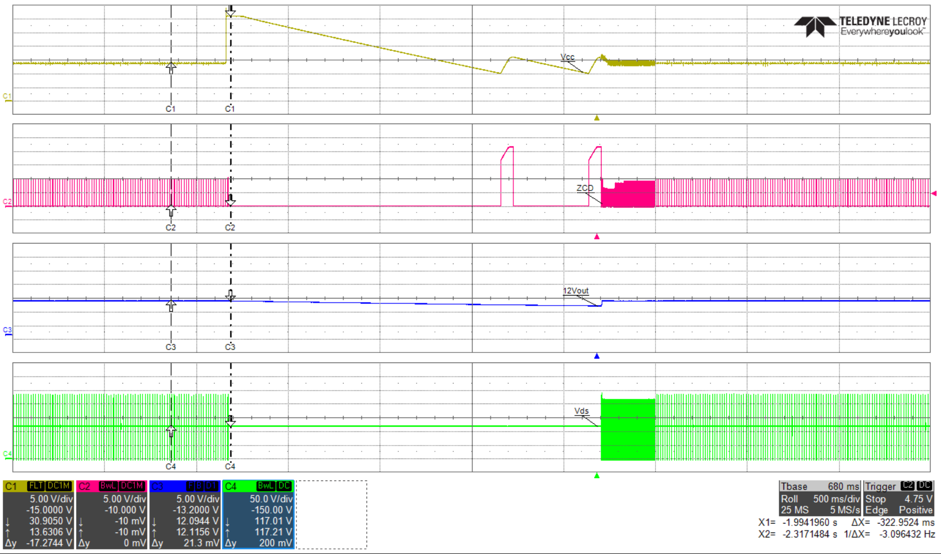

C1 (yellow): Bus voltage (V_{Bus}) **C2 (purple):** Supply voltage (V_{VCC}) **C3 (blue):** V_{IN} voltage (V_{VIN}) **C4 (green):** CS voltage (V_{CS})
Condition to reset brownout protection (brownin): V_{VIN} more than 0.66 V (V_{BULK} more than 106 V DC [≈ 75 V AC]) **Condition to detect brownout 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 brownout detect)

Figure 27 Brownout protection

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

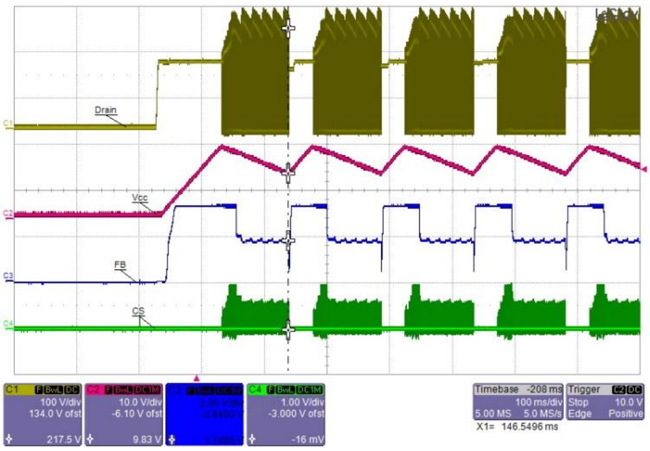


C1 (yellow): V_{CC} voltage (V_{VCC})
C2 (purple): ZCD voltage (V_{ZCD})
C3 (blue): 12 V output voltage (V_{O12})
C4 (green): VDS voltage (V_{DS})

Condition to enter V_{VCC} 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} overvoltage protection

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

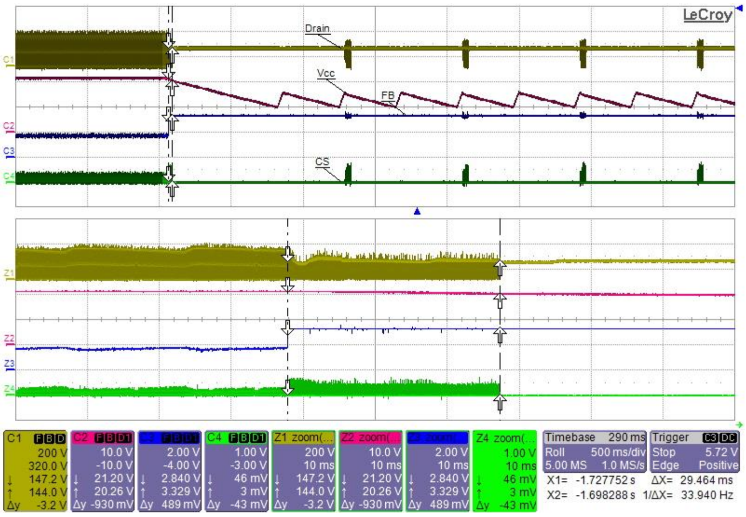


C1 (Yellow): Drain voltage (V_D)
C2 (Purple): Supply voltage (V_{VCC})
C3 (Blue): Feedback voltage (V_{FB})
C4 (Green): CS voltage (V_{CS})

Condition to enter V_{CC} undervoltage protection: V_{CC} < 10 V
(Remove R12A and power on the system with full load at 85 V AC)

Figure 29 V_{CC} under voltage protection

11.15 Overload protection (odd-skip auto-restart)

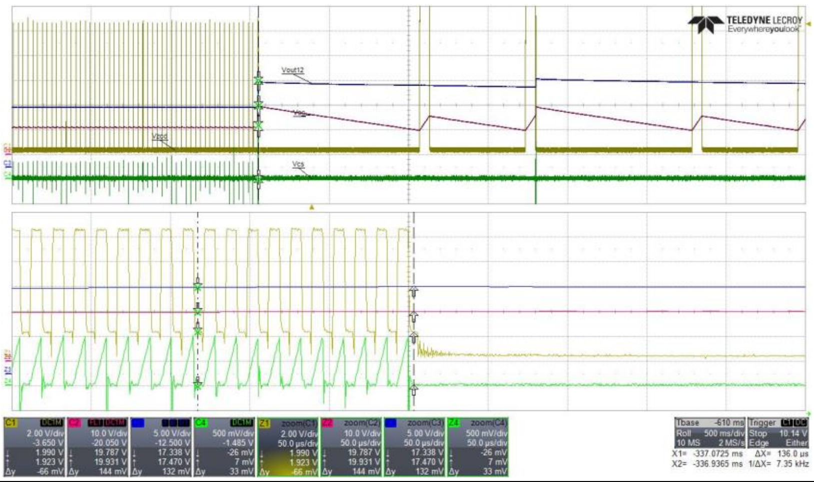


C1 (Yellow): Drain voltage (V_D)
C2 (Purple): Supply voltage (V_{VCC})
C3 (Blue): Feedback voltage (V_{FB})
C4 (Green): CS voltage (V_{CS})

Condition to enter overload protection: V_{FB} > 2.75 V and last 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 overvoltage protection (odd-skip auto-restart)

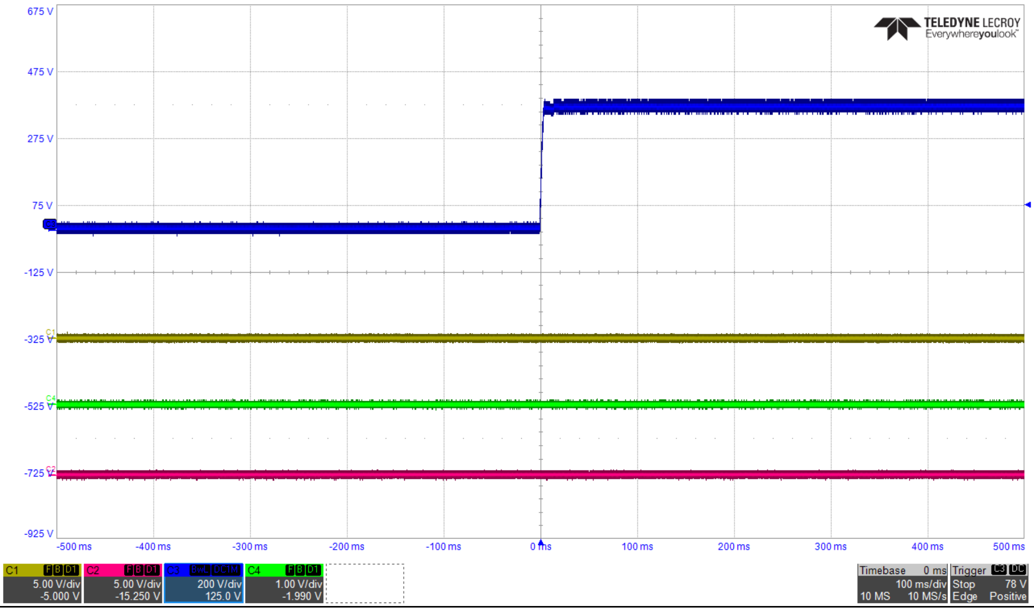


C1 (yellow): ZCD voltage (V_{ZCD})
C2 (purple): Supply voltage (V_{VCC})
C3 (blue): 12 V output voltage (V_{O12})
C4 (green): CS voltage (V_{CS})

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 overvoltage protection

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 $V_{CC} < V_{VCC\_SCP}$ I_{VCC} = $I_{VCC\_Charge1}$
(Short V_{CC} pin to GND and measure the AC input current, $I_{in} \approx$ 22.4 mA and input power is ≈ 38.6 mW at 264 V AC)

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

[3] Infineon Technologies AG: *CoolSET™ 5th Generation Quasi-Resonant Plus calculation tool for flyback*; Available online

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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