45 W USB-PD SMPS reference with XDPS21071

About this document

Scope and purpose

This document is a description of the 45 W 5/9/12/15/3 A or 20 V 2.25 A, 90 V AC ~ 265 V AC input off-line Forced Frequency Resonant (FFR) Zero Voltage Switching (ZVS) Flyback converter demonstrator board using the Infineon digital FFR Flyback controller XDPS21071 and MOSFETs IPD70R360P7S, BSC0805LS and BSL606SN.

Intended audience

This document is intended for users of the XDPS21071 who wish to design a FFR ZVS Flyback converter for High Density (HD) adapters in notebooks and other computer-related applications.

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Abstract

1 Abstract

The XDPS21071 45 W HD FFR demonstrator from Infineon shows the best-in-class power density achievable with the new FFR principle for single-stage Flyback with reasonable cost added.

The demonstrator takes universal AC input and converts it to the typical 5 to 20 V DC output accepted by most modern laptops and ultrabooks. With very modest dimensions, a best-in-class power density for such a laptop adapter of 15 W/in^3 is achieved. The resonant switching transitions are exploited to virtually eliminate main MOSFET switching losses at a forced frequency. This approach enables the high switching frequency necessary to allow smaller components (e.g. transformer) while still maintaining (or even improving) the efficiency necessary to manage heat dissipation in a very small form factor. For easy SR IC selection, the XDPS21071 is implemented with guaranteed Discontinuous Conduction Mode (DCM) operation under all conditions. The XDPS21071 also implements Frequency Reduction Mode (FRM), and Burst Mode (BM) to maximize the efficiency at medium to light load. In all, the overall efficiency can be pushed to more than 90 percent in all load and line ranges.

Although not formally certified, the 45 W FFR demonstrator adapter conforms to most standard regulatory compliance requirements such as conducted EMI, isolation requirements, etc.

The XDPS21071 also has various configuration features to exploit the full function of an adapter such as propagation delay compensation (for maximum power control), adaptive current limit for variable output voltage, configurable line voltage to enable ZVS and various protection features (e.g. brown-in/brown-out, CS pin short, V_{CC} Over Voltage Protection (OVP), V_{out} OVP, Over Current Protection (OCP), Over Load Protection (OLP), Over Temperature Protection (OTP), latch enable, etc.).

2 Specifications of demonstrator board

Table 1 Specifications of DEMO-XDPS21071-45W

Input voltage	90 V AC ~ 265 V AC
Input frequency	50/60 Hz
Output load	Full load: 20 V 2.25 A ,5/9/12/15/3 A
Efficiency	EC COCV5 Tier 2 and DOELV6
Standby power (no load)	Less than 60 mW
Controller IC	XDPS21071
Main/ZVS/SR MOSFET	IPD70R360P7S/BSC0805LS/BSL606SN
Form factor (L x W x H)	55 x 26 x 25 mm = 35.75 cm^3
Power density (PCBA)	20.6 W/in^3

3 Reference board

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

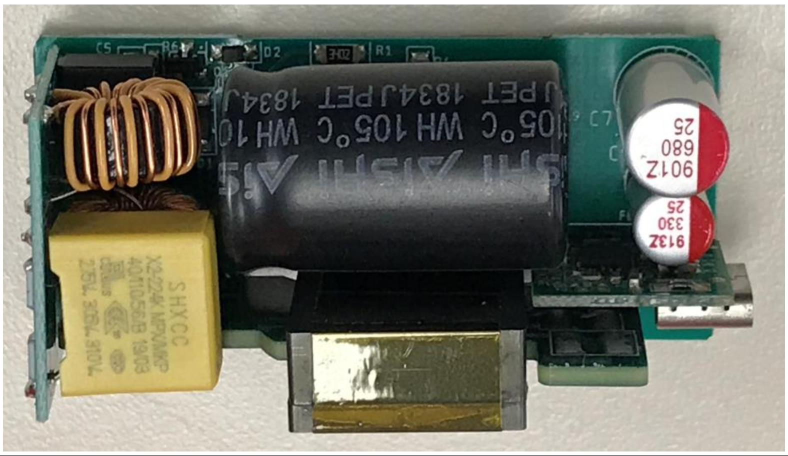


Figure 1 REF_XDPS21071_45W1 FFR ZVS Flyback converter (top view)

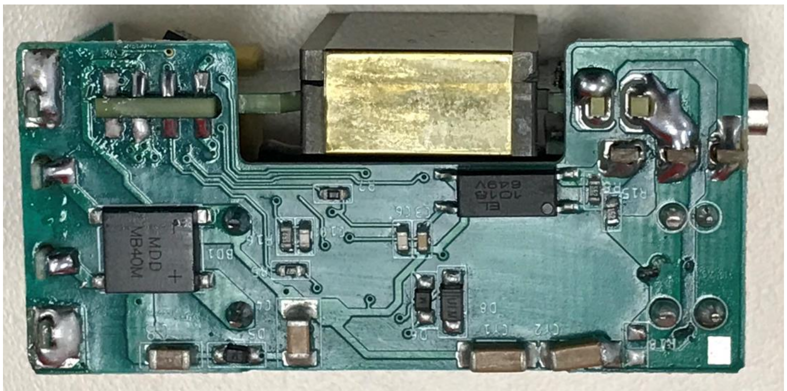


Figure 2 REF_XDPS21071_45W1 FFR ZVS Flyback converter (bottom view)

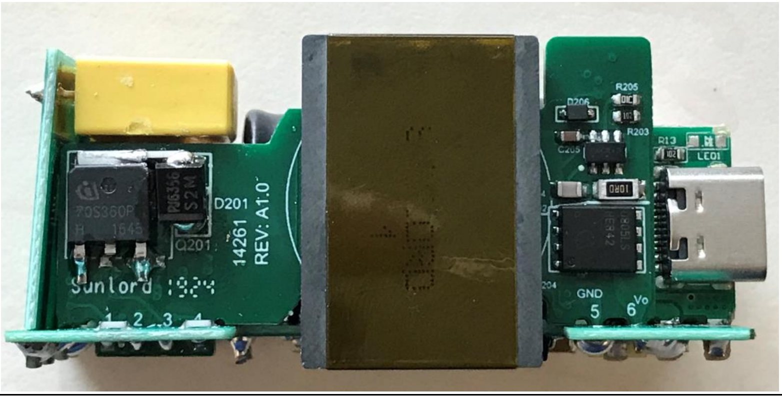


Figure 3 REF_XDPS21071_45W1 FFR ZVS Flyback converter (side view)

4 Features of XDPS21071

Table 2 Features of XDPS21071

Multi-mode operation with Active Burst Mode (ABM), DCM, FRM, Forced Frequency Resonant Mode (FFRM)
Configurable line voltage for ZVS function
Adaptive V_{CS} offset compensation for current limit
Frequency clamp for high-line and lower V_{out}
Brown-in and brown-out detection via integrated HV start-up cell
Built-in soft-start
Built-in protection modes

5 Circuit description

5.1 Introduction

The demonstrator accepts a wide input range from 90 V AC to 265 V AC, and the output is 5 to 20 V, max. 45 W. The circuit is similar to a typical Flyback converter design with SR in the secondary high-side. The XDPS21071 is a cycle-by-cycle peak current Flyback controller with secondary-side control by means of a MFIO pin. The particular design can achieve close to ZVS with the help of an additional ZVS winding and ZVS circuit driven by the GD1 pin. With the ZVS feature, the switching loss is reduced significantly at high-line so that the switching frequency can be set at around 140 kHz. For low-line, the system would run in DCM operation. Besides having high efficiency at full load, the controller can achieve high efficiency at both medium and light load by implementing FRM and ABM. The controller integrates a HV start-up cell. Connected with a resistor, R_{HV} (102 kΩ) from the bulk capacitor, it can achieve V_{CC} start-up charging and also the brown-in and brown-out features. In addition, it has various protection features to protect the system from hazards, such as OCP, V_{out} OVP, OLP, OTP, latch enable, CS pin short before power-up, etc.

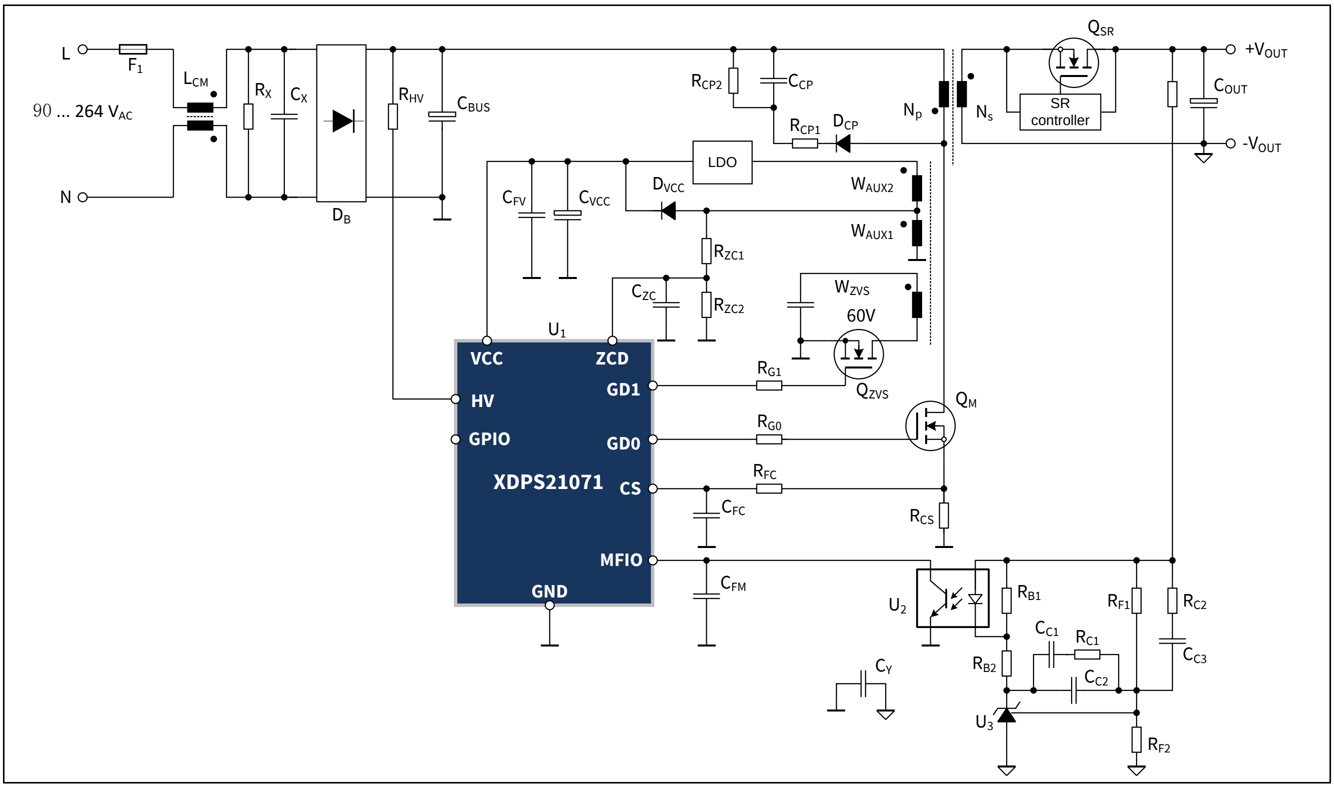


Figure 4 Simplified demonstrator circuit

6 Circuit diagram

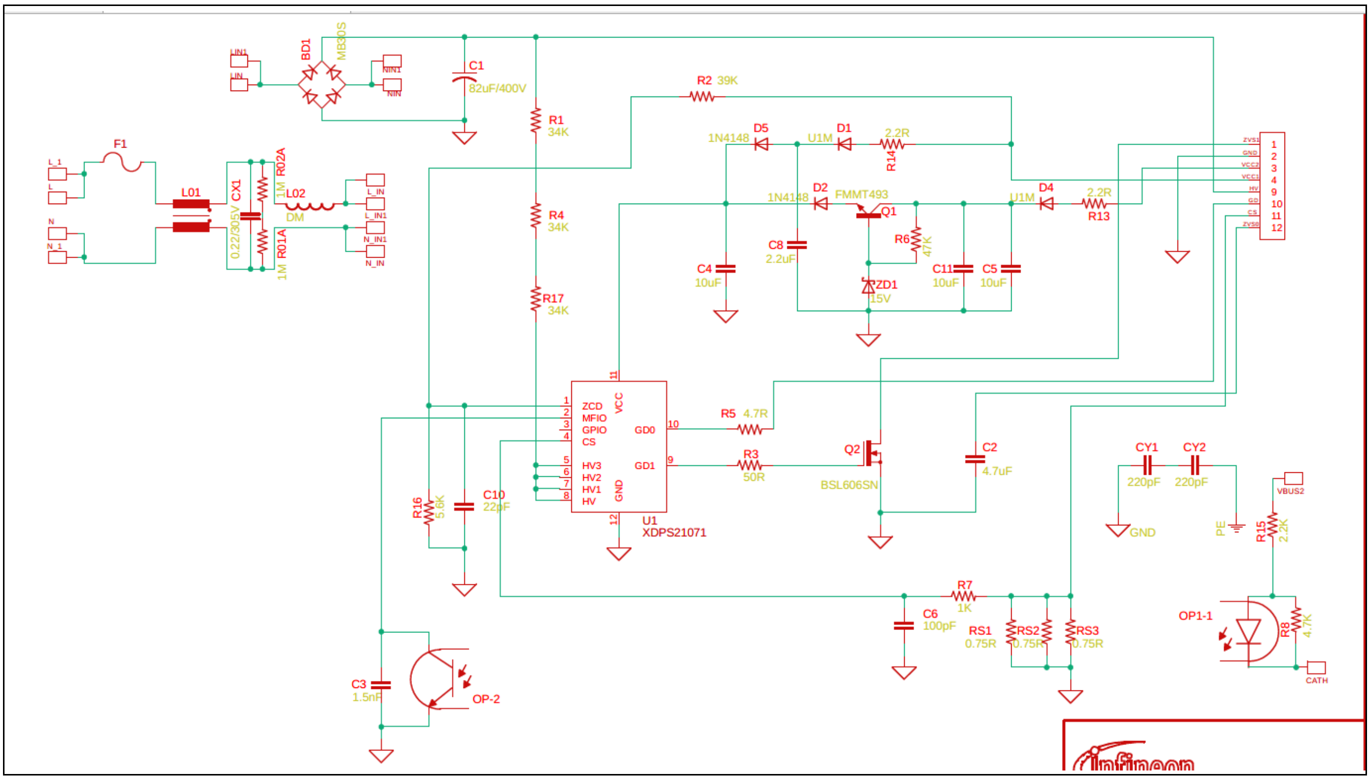


Figure 5 Schematics of 45 W FFR ZVS Flyback converter – part 1

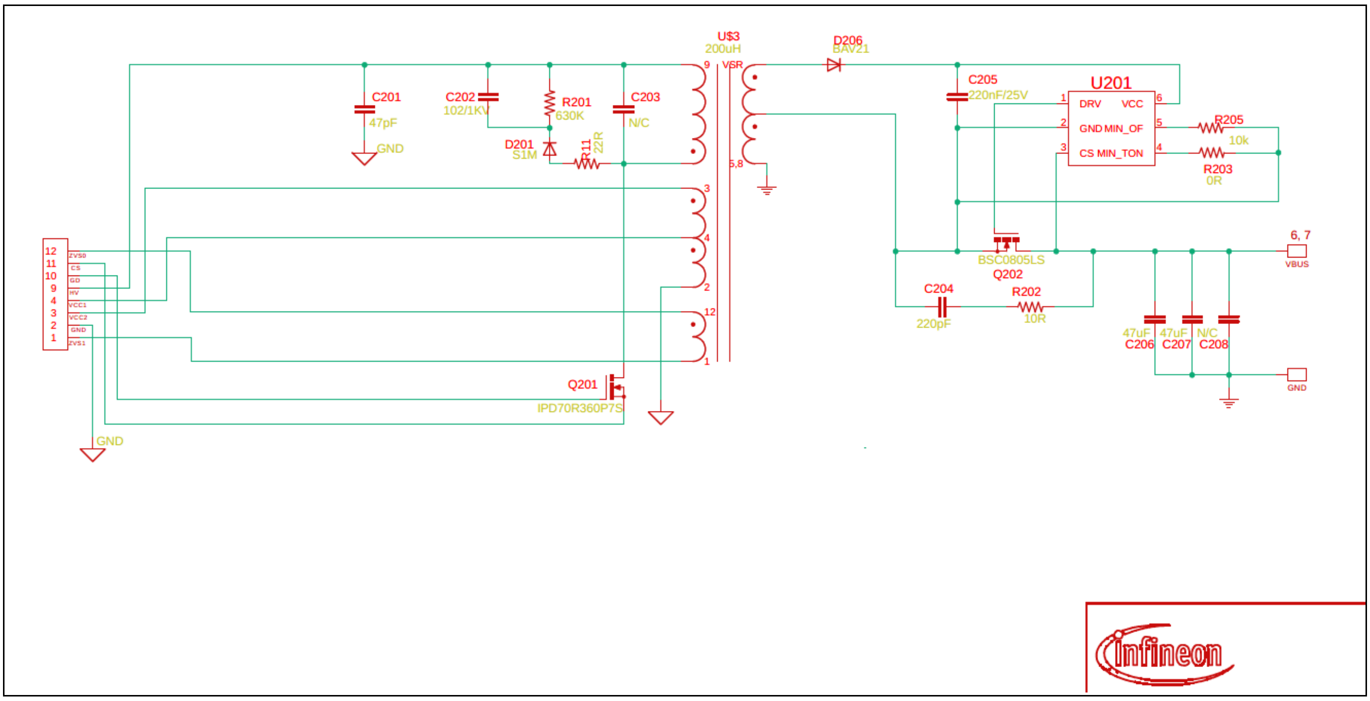


Figure 6 Schematics of 45 W FFR ZVS Flyback converter – part 2

Circuit diagram

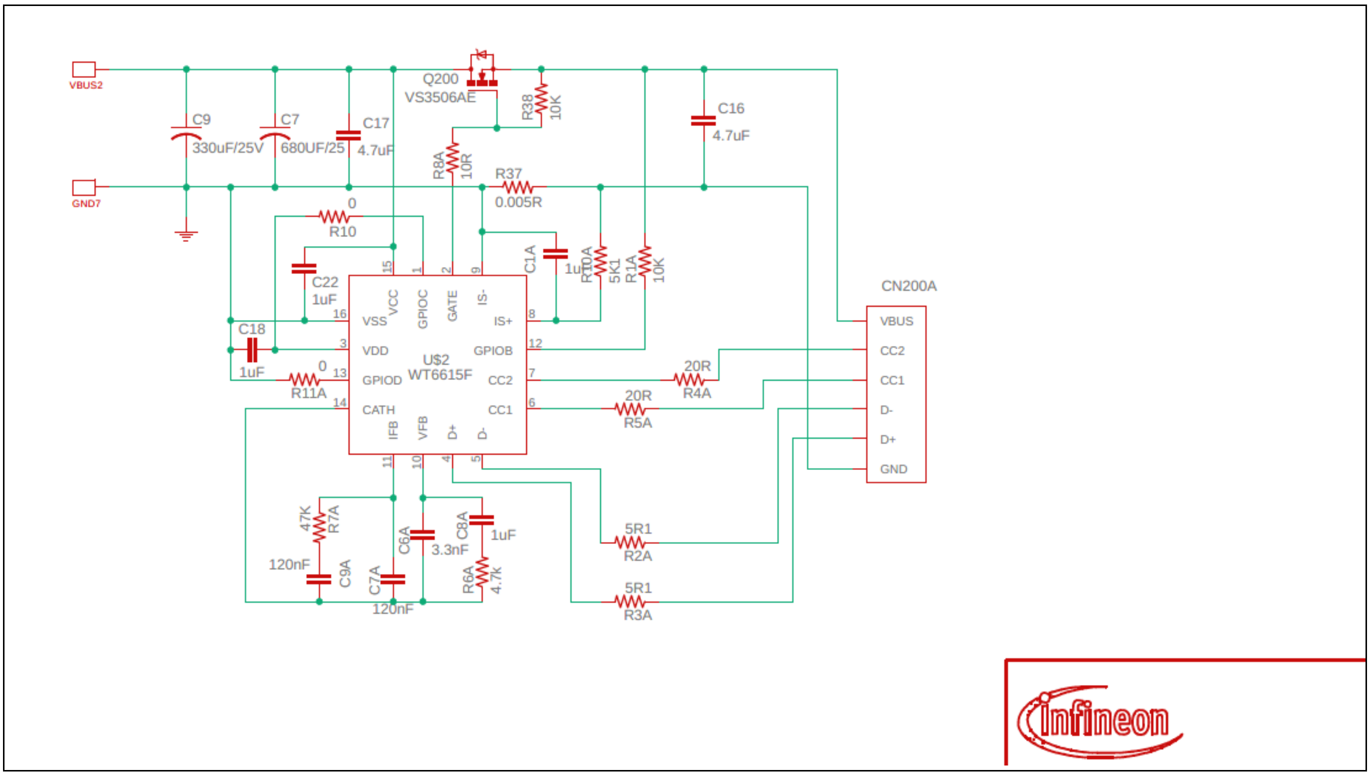


Figure 7 Schematics of 45 W FFR ZVS Flyback converter – part 3

7 PCB layout

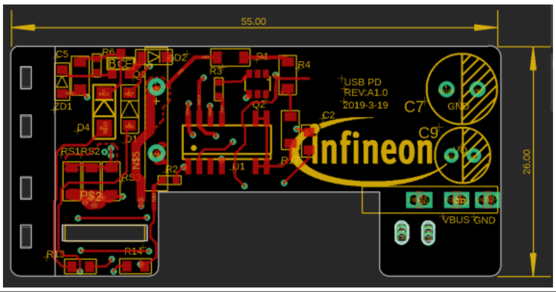


Figure 8 Top side components

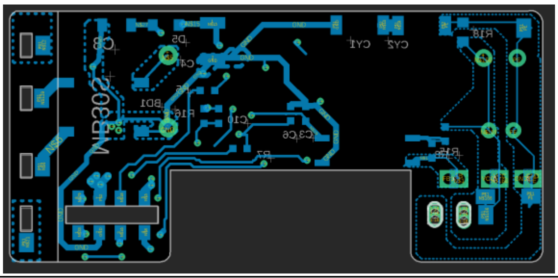


Figure 9 Bottom side components

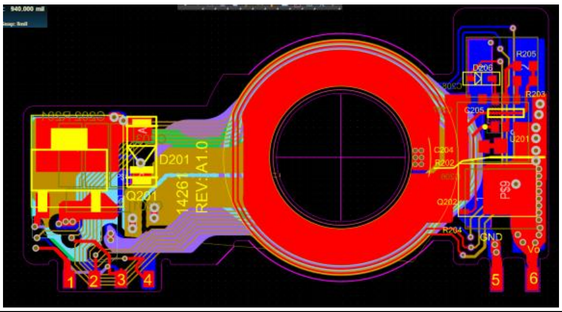


Figure 10 Transformer top view

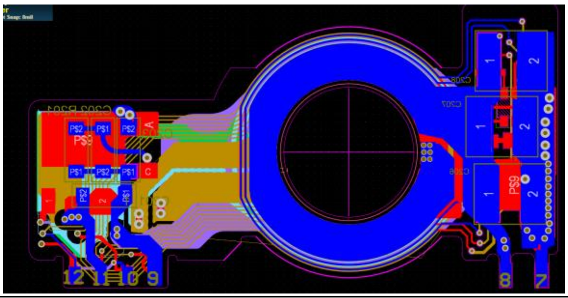


Figure 11 Transformer bottom view

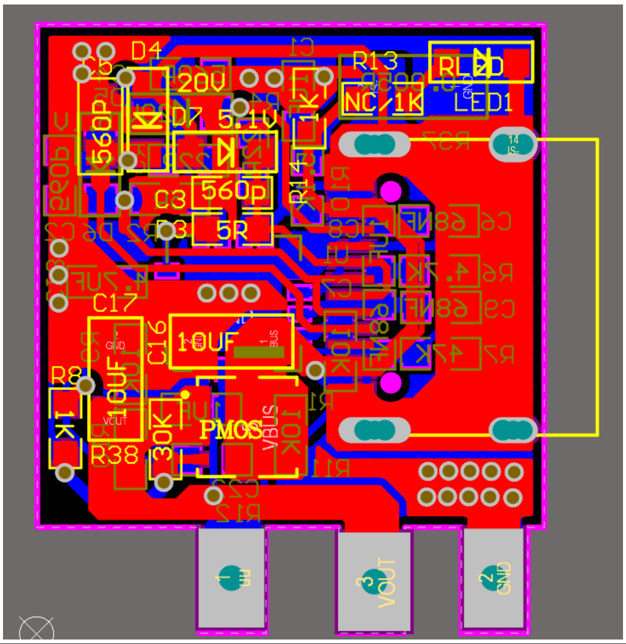


Figure 12 PD circuit top view

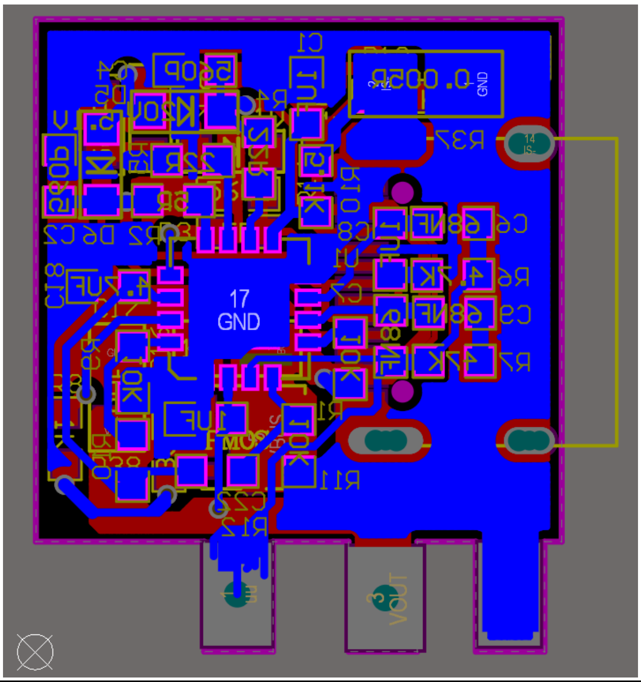


Figure 13 PD circuit bottom view

8 Bill of Materials (BOM)

Table 3 BOM

45 W main board BOM

Part	Value	Package	Description	Quantity	Manufacturer
BD1	MB30S	MB30S	Bridge rectifier	1	
C1	82 µF/400 V	16 x 25	AISHI EWH2GM820L25OT	1	
C2	4.7 µF/25 V	0805s	SMD capacitor	1	
C3	1.5 nF/25 V	0603s	SMD capacitor	1	
C4	10 µF/25 V	1206-S	SMD capacitor	1	
C6	100 pF/16 V	603	SMD capacitor	1	
C5, C11	10 µF/100 V	1206-S	SMD capacitor	2	
C8	2.2 µF/25 V	1206-S	SMD capacitor	1	
C10	22 pF/25 V	0603s	SMD capacitor	1	
C7	680 µF/25 V	8*14	DIP	1	
C9	330 µF/25 V	6*11	DIP	1	
D2, D5	1N4148	SOD-323	SMD diode	2	
D1, D4	U1M	SOD-123	SMD diode	2	
OP	EL1018	SO-4	SMD	1	
Q1	FMMT493	SOT23	SMD transistor	1	
Q2	BSL606SN	SOT23-6	N-MOS	1	Infineon
R1, R4, R17	34 k	1206	SMD resistor	3	
R2	39 k	0603s	SMD resistor	1	
R3	50 R	0603s	SMD resistor	1	
R5	4.7 R	0603s	SMD resistor	1	
R6	47 k	0603s	SMD resistor	1	
R7	1 k	0603s	SMD resistor	1	
R8	4.7 k	0603s	SMD resistor	1	
R13, R14	2.2 R	0805s	SMD resistor	2	
R15	2.2 k	0603s	SMD resistor	1	

45 W main board BOM					
R16	5.6 k	0603S	SMD resistor	1	
RS1, RS2, RS3	0.75 R	1206-S	SMD resistor	3	
U1	XDPS21071	PG-DSO-12-20	IC	1	Infineon
ZD1	15 V	SOD-323	Zener diode	1	
T1	200 µH	TPPER254609D400P	PCB planar transformer	1	Transformer: Sunlord Core: ML27D (Hitachi)
CY1, CY2	220 pF	4.5 x 2 x 2 mm	Y-cap (GA342DR7GF221KW02)	2	Murata

Transformer board BOM

Part	Value	Package	Description	Quantity	Manufacturer
C201	47 pF/1 kV	1206-S	SMD capacitor	1	
C202	102/1 kV	1206-S	SMD capacitor	1	
R201	630 k	1206	SMD resistor	1	
R11	22 R	1206	SMD resistor	1	
C203	N/C				
C204	220 pF/100 V	0805s	SMD capacitor	1	
C205	220 nF/25 V	0805s	SMD capacitor	1	
C206, C207	47 µF/25 V	CKG57X7R1E476M	SMD capacitor	2	TDK
C208	N/C				
R202	10 R	0805s	SMD resistor	1	
R203	0 R	0603s	SMD resistor	1	
R205	10 k	0603s	SMD resistor	1	
U201	NCP4306DADZZ	SOT23-6	SR IC	1	
Q202	BSC0805LS	SuperSO8	MOSFET	1	Infineon
D201	S1M	SMA	Diodes	1	
D206	BAV21	SOD-323	Diodes	1	
Q201	IPD70R360P7S	DPAK	MOSFET	1	Infineon

EMI board BOM

Part	Value	Package	Description	Quantity	Manufacturer
F1	2 A/250 V		Fuse	1	
CX1	0.22 µF/275 V	14 x 5 x 11	X-cap pin: 12.5 mm	1	

45 W main board BOM					
L01	10T 3.5 mH	R10 x 5 x 5	Common mode choke	1	
L02	45T 200 µH	R10 x 5 x 5	Differential mode choke	1	
R01A, R02A	1 M	1206-S	SMD resistor	1	

PD board BOM

Part	Value	Package	Description	Quantity	Manufacturer
R10, R11A	0	0603s		2	
R37	0.005 R	0805s		1	
R1A, R38	10 k	0603s		2	
R8A	10 R	0603s		1	
R4A, R5 A	20 R	0603s		2	
R6A	4.7 k	0603s		1	
R7A	47 k	0603s		1	
R10A	5.1 k	0603s		1	
R2A, R3A	5.1 R	0603s		2	
C1A	1 µF/25 V	0603s		1	
C7A	120 nF/25 V	0603s		1	
C9A	120 nF/25 V	0603s		1	
C16	4.7 µF/25 V	0805s		1	
C17	4.7 µF/25 V	0805s		1	
C18	1 µF/25 V	0603s		1	
C22	1 µF/25 V	0603s		1	
C8A	1 µF	0603s		1	
C6A	3.3 nF	0603s		1	
Q200	VS3506AE			1	
U2	WT6615F	QFN	PD chip	1	Weltrend
CN200A	TYPE C			1	

* SMD capacitor in X7R or, better, SMD resistor in 1 percent

9 Transformer construction

9.1 Input CMC, L01

Core: Nano-crystalline toroidal core

Inductance: 5.5 mH at 1 kHz

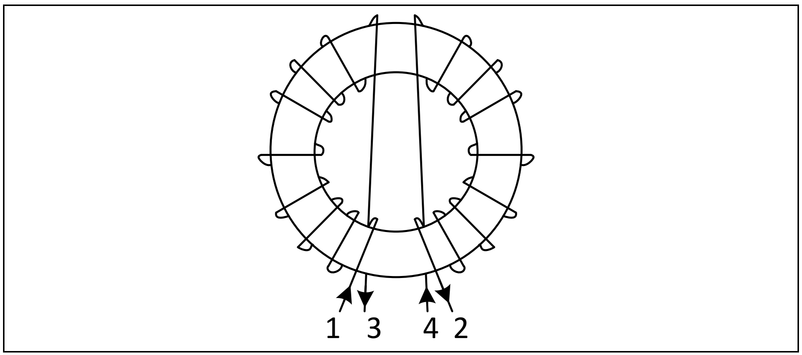


Figure 14 CMC choke electrical diagram (top view)

9.2 Input DMC, L02

Inductance: 190 µH at 1 kHz

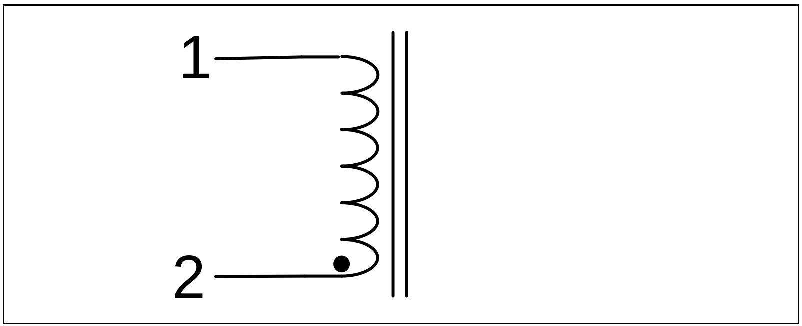


Figure 15 DMC choke electrical diagram (top view)

9.3 FFR ZVS Flyback transformer

The transformer uses a six-layer PCB. The details of the transformer are shown in the table and diagrams below. The SR IC and SR MOSFET are on the transformer board too, and there is another SR V_{CC} winding in the transformer, which is not shown in the diagram below.

Transformer construction

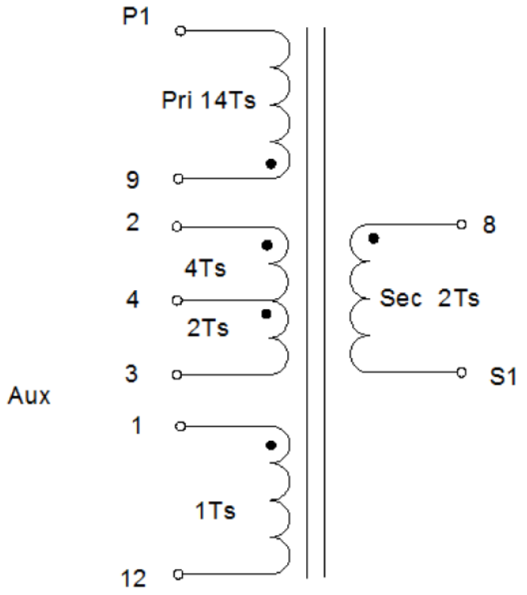


Figure 16 Flyback transformer electrical view

Table 4 Flyback transformer winding characteristics

ITEM	TEST TERMINAL	TEST SPECIFICATION	TEST CONDITION	TESTER
INDUCTANCE	Pin(9-P1)	210uH±10%	140KHz ,0.1V	Agilent E4980A
LEAKAGE INDUCTANCE	Pin(9-P1), shorted other Pin	2.0uH Max.	140KHz ,0.1V	Agilent E4980A
D.C.R	Pin(9-P1)	400 mΩ Max.	AT 25±5℃	HIOKI3541
	Pin(1-12)	350 mΩ Max.		
	Pin(4-3)	1000 mΩ Max.		
	Pin(2-4)	550 mΩ Max.		
	Pin(8-S1)	8 mΩ Max.		
HI-POT	Pri to Sec	No breakdown	3750Vac/50Hz/1mA/3Sec	CH333
	Pri to Core	No breakdown	3750Vac/50Hz/1mA/3Sec	
TURNS RATIO	Pin(9-P1):(1-12):(4-3):(2-4):(8-S1)	14:1:2:4:2±0.5Ts	15.75KHz, 1.0V	CH3302
Test Condition: T=25±5℃， RH=65%±20% OPERATING TEMPERATURE: -40℃ to +125℃.				

Transformer construction

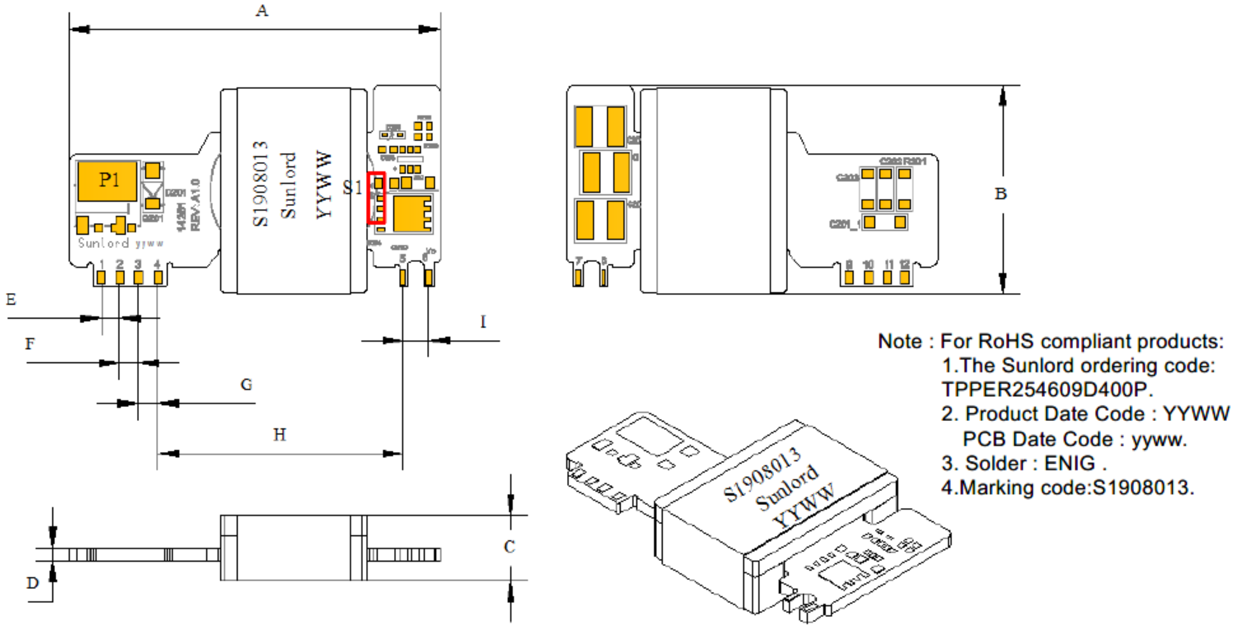


FIG-1 : Shape

3.2 Dimensions (Unit: mm)

ITEM	A	B	C	D	E	F	G	H	I
LIMIT	46.5 Max.	27.0 Max.	9.0 Max.	1.7 Typ	2.3±0.3	2.3±0.3	2.3±0.3	30.2±0.2	3.15±0.2

Figure 17 Flyback transformer board drawing – Sunlord TPPER254609D400P

10 Measurement results

10.1 Efficiency

Efficiency was measured with the unit outside of the enclosure and by sensing the output voltage directly on the PCB terminals. The input AC voltage was fed to the DUT by a Chroma AC voltage source. An electronic load was used in Constant Current (CC) mode.

The efficiency of 10 percent, 25 percent, 50 percent, 75 percent and 100 percent load is measured at 115 V AC and 230 V AC. The average efficiency of 25 percent, 50 percent, 75 percent and 100 percent is calculated.

Table 5 Measured efficiency over line and load range at PCB end

115 V AC

I_{out} (A)	V_{out} (V)	P_{in} (W)	P_{out} (W)	Effi.	Criteria
0.3	4.9571	1.79	1.48713	83.08%	74.50%
0.75	4.9507	4.20108	3.713025	88.38%	
1.5	4.9378	8.2884	7.4067	89.36%	
2.25	4.925	12.35	11.08125	89.73%	
3	4.9133	16.41	14.7399	89.82%	
			avg	89.32%	84.50%
0.3	8.8631	3.15204	2.65893	84.36%	77.30%
0.75	8.8546	7.4604	6.64095	89.02%	
1.5	8.8417	14.71	13.26255	90.16%	
2.25	8.83	21.99	19.8675	90.35%	
3	8.8161	29.25	26.4483	90.42%	
			avg	89.99%	87.30%
0.3	11.77	4.19046	3.531	84.26%	78.30%
0.75	11.759	9.9324	8.81925	88.79%	
1.5	11.747	19.55	17.6205	90.13%	
2.25	11.733	29.14	26.39925	90.59%	
3	11.719	38.99	35.157	90.17%	
			avg	89.92%	88.30%
0.3	14.866	5.316	4.4598	83.89%	78.85%
0.75	14.859	12.57	11.14425	88.66%	
1.5	14.847	24.8	22.2705	89.80%	
2.25	14.837	36.98	33.38325	90.27%	
3	14.825	49.4	44.475	90.03%	
			avg	89.69%	88.85%
0.225	19.602	5.21676	4.41045	84.54%	78.85%
0.5625	19.592	12.4	11.0205	88.88%	
1.125	19.586	24.5	22.03425	89.94%	
1.6875	19.575	36.59	33.03281	90.28%	

230 V AC

I_{out} (A)	V_{out} (V)	P_{in} (W)	P_{out} (W)	Effi.	Criteria
0.3	4.956	1.913	1.4868	77.72%	74.50%
0.75	4.9485	4.301	3.711375	86.29%	
1.5	4.9336	8.3874	7.4004	88.23%	
2.25	4.9218	12.4938	11.07405	88.64%	
3	4.9079	16.5792	14.7237	88.81%	
			avg	87.99%	84.50%
0.3	8.8599	3.251	2.65797	81.76%	77.30%
0.75	8.8503	7.542	6.637725	88.01%	
1.5	8.8353	14.8062	13.25295	89.51%	
2.25	8.8225	22.173	19.85063	89.53%	
3	8.8086	29.24	26.4258	90.38%	
			avg	89.36%	87.30%
0.3	11.77	4.278	3.531	82.54%	78.30%
0.75	11.76	9.996	8.82	88.24%	
1.5	11.751	19.6692	17.6265	89.61%	
2.25	11.738	29.3	26.4105	90.14%	
3	11.726	38.91	35.178	90.41%	
			avg	89.60%	88.30%
0.3	14.866	5.3868	4.4598	82.79%	78.85%
0.75	14.855	12.6084	11.14125	88.36%	
1.5	14.84	24.7908	22.26	89.79%	
2.25	14.832	36.93	33.372	90.37%	
3	14.82	49.33	44.46	90.13%	
			avg	89.66%	88.85%
0.225	19.599	5.27742	4.409775	83.56%	78.85%
0.5625	19.593	12.3906	11.02106	88.95%	
1.125	19.577	24.444	22.02413	90.10%	
1.6875	19.574	36.36	33.03113	90.84%	
2.25	19.568	48.63	44.028	90.54%	

115 V AC

2.25	19.568	48.81	44.028	90.20%	
			avg	89.82%	88.85%

230 V AC

			avg	90.11%	88.85%

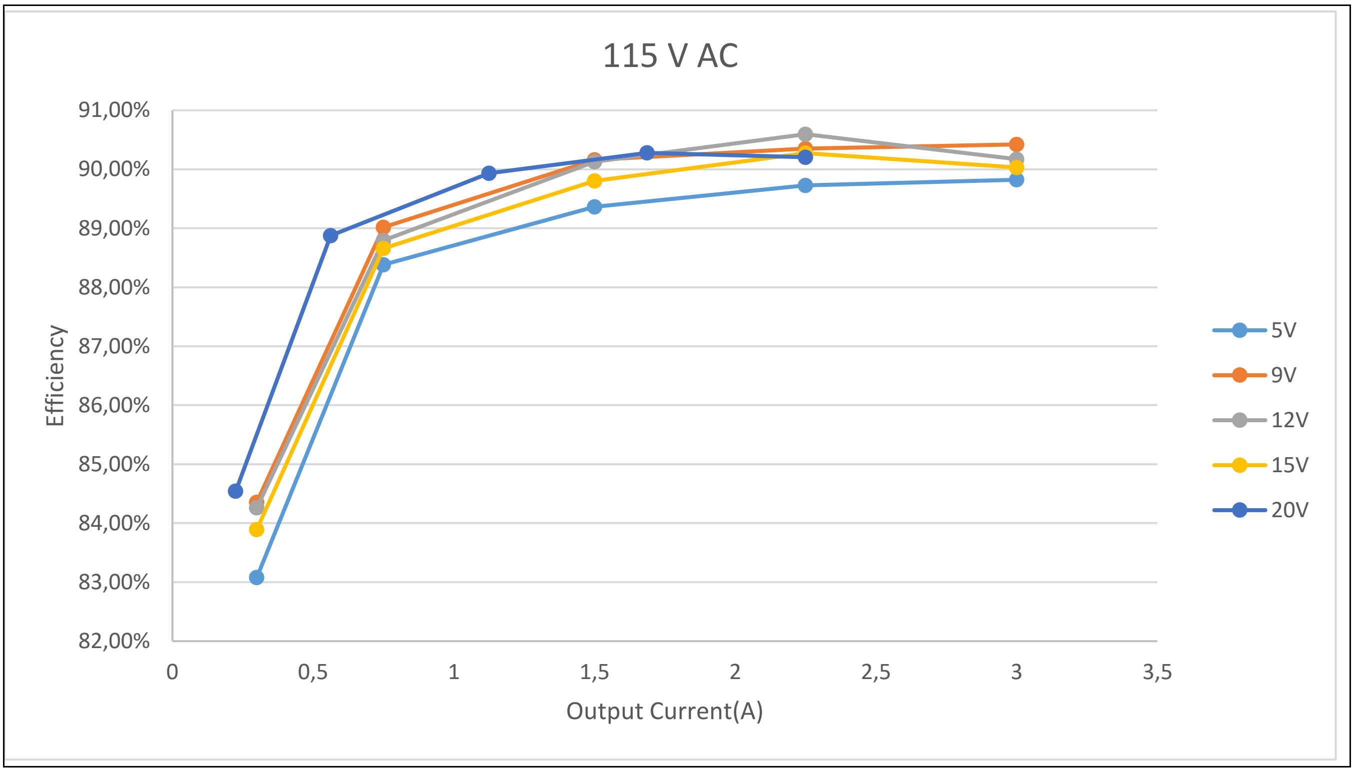


Figure 18 Efficiency curves over load range under 115 V AC

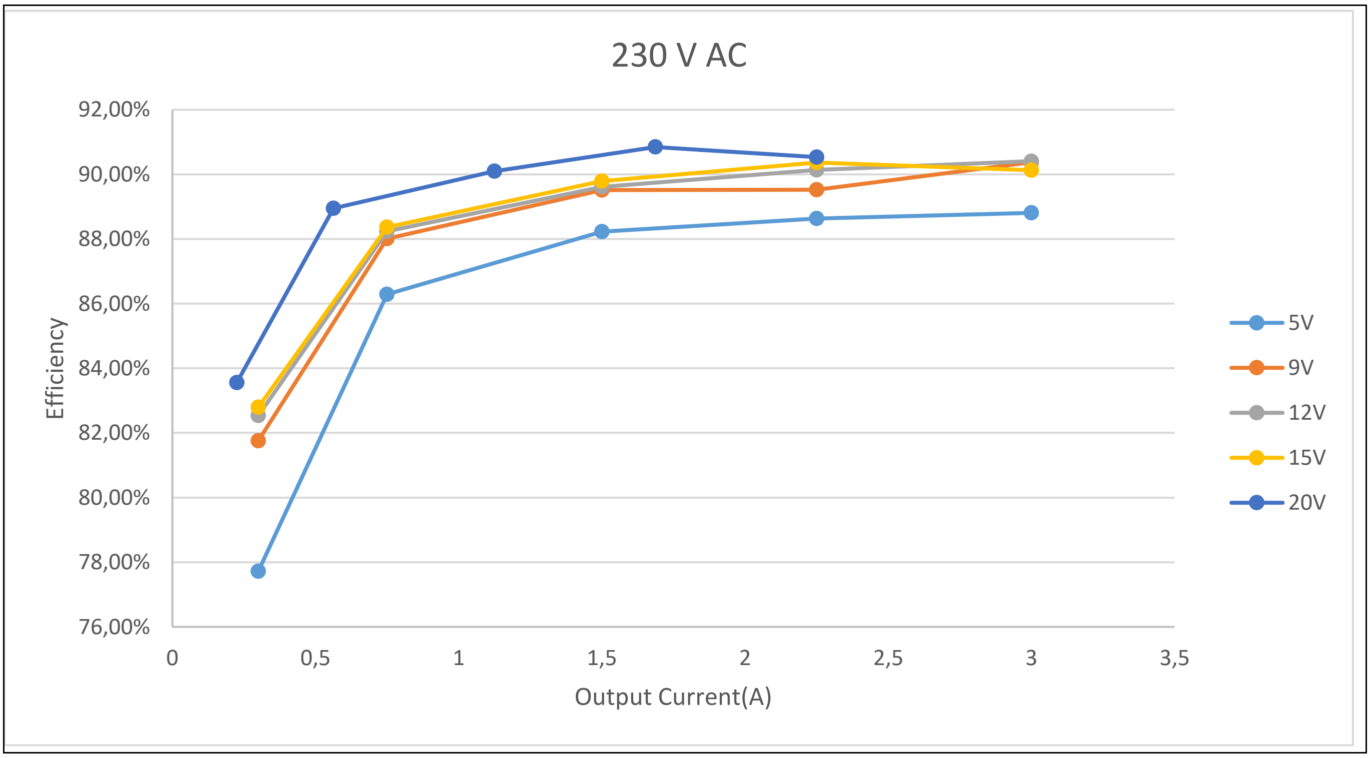


Figure 19 Efficiency curves over load range under 230 V AC

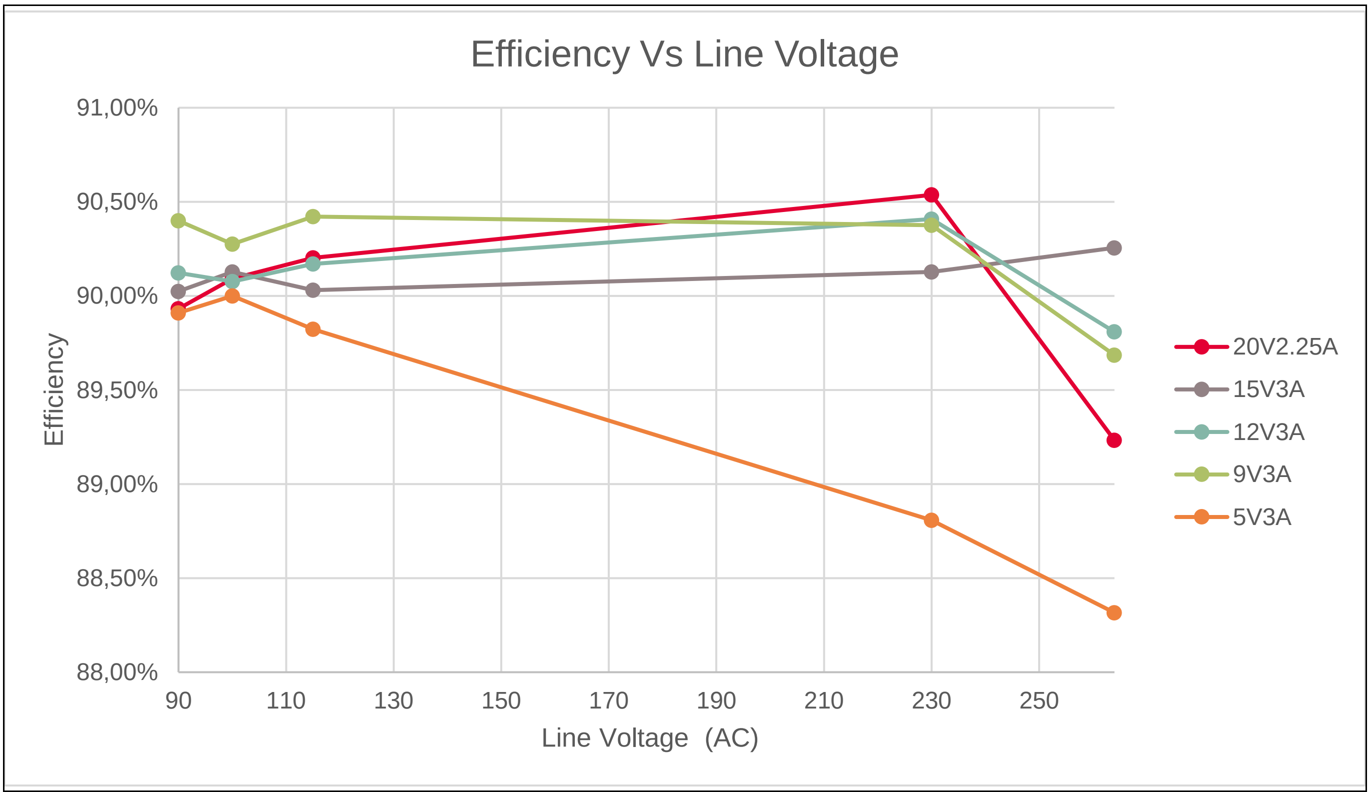


Figure 20 Efficiency curves at full load from 90 V AC to 264 V AC with different output voltages

10.2 Standby power

The standby power consumptions are measured from 90 V AC to 264 V AC at default 5 V output. They are less than 30 mW. Standby power is measured with a Yokogawa power meter WT210 and integrated one minute.

Table 6 Standby power consumption

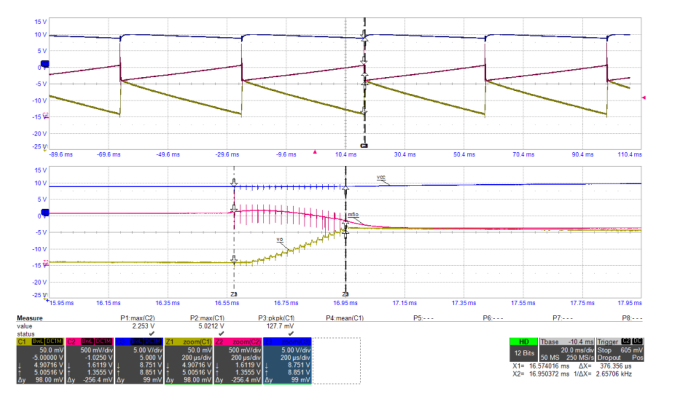
V_{out} (V)	Load (A)	Input voltage (AC)	Input power (mW)
5	0	90	19
		115	19.6
		230	20
		264	22

10.3 Output ripple – steady-state operation

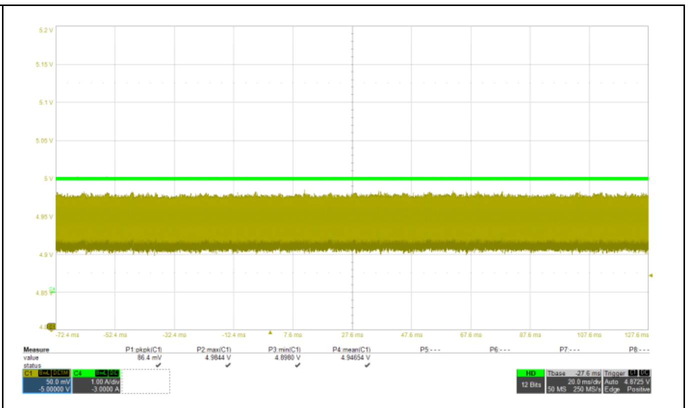
The output ripple is measured at the PCB end at 0 A, and at full load with input voltages of 90 V AC and 264 V AC. 0.1 µF and 10 µF electric capacitors are used. The ripple in BM is controlled by the V_{pause} parameter and loop gain.

Table 7 Measured output ripple voltage in steady-state (DC load current)

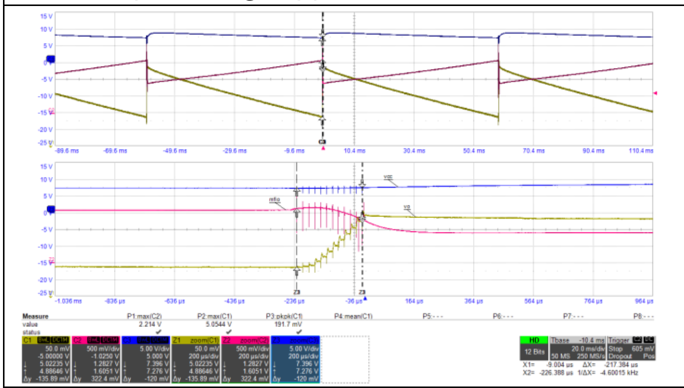
V_{out} (V)	V_{in} (AC)	I_{out} (A)	V_{out_ripple} (mV)
5	90	0	127.7
		3	86.4
	264	0	191.7
		3	92.1
9	90	0	116.3
		3	112.8
	264	0	151.8
		3	121.5
12	90	0	110.3
		3	190.4
	264	0	143.2
		3	105.6
20	90	0	107.4
		3	258.9
	264	0	134.5
		3	123.5



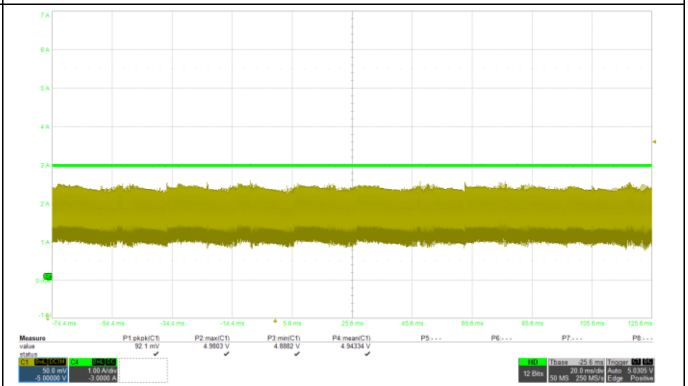
5 V output voltage ripple at V_{in} = 90 V AC no load



5 V output voltage ripple at V_{in} = 90 V AC 3 A load

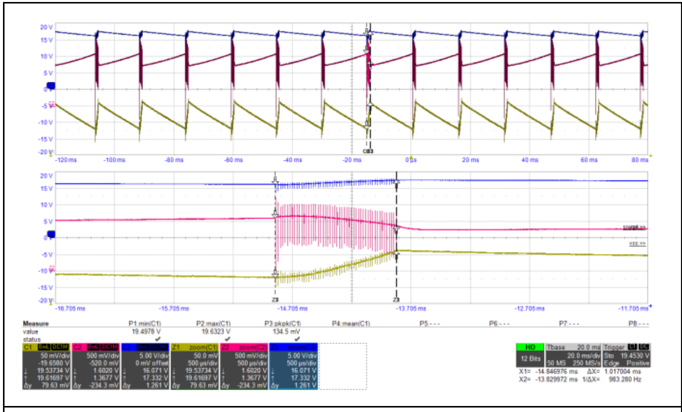


5 V output voltage ripple at V_{in} = 264 V AC no load

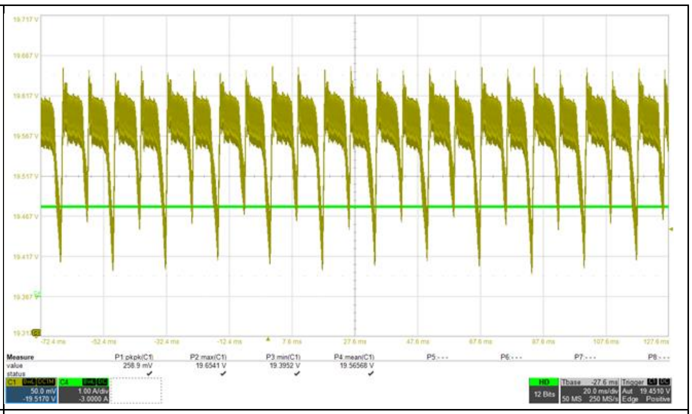


5 V output voltage ripple at V_{in} =264 V AC 3 A load

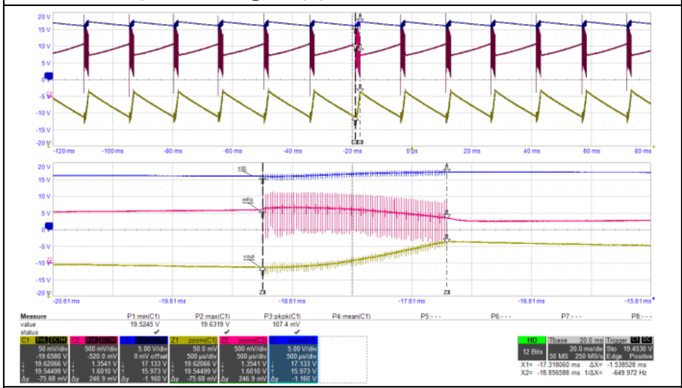
Figure 21 5 V output voltage ripple



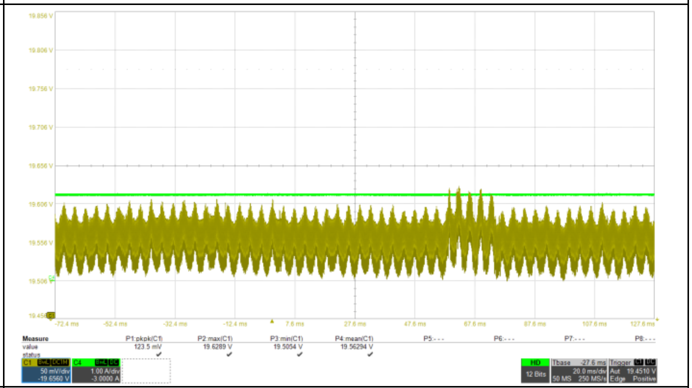
20 V output voltage ripple at V_{in} = 90 V AC no load



20 V output voltage ripple at V_{in} = 90 V AC 2.25 A load



20 V output voltage ripple at V_{in} = 264 V AC no load



20 V output voltage ripple at V_{in} =264 V AC 2.25 A load

Figure 22 20 V output voltage ripple

10.4 Regulation under different loads

The steady-state output regulation is checked under various loadings and different input voltages, which pass +/-5 percent specification.

Table 8 Regulation check under 100 V AC with different loadings

100 V AC	No load	50 percent load	Full load
5 V	4.95	4.94	4.92
9 V	8.86	8.84	8.82
12 V	11.78	11.76	11.75
15 V	14.84	14.82	14.80
20 V	19.62	19.61	19.59

Table 9 Regulation check under 100 V AC with different loadings

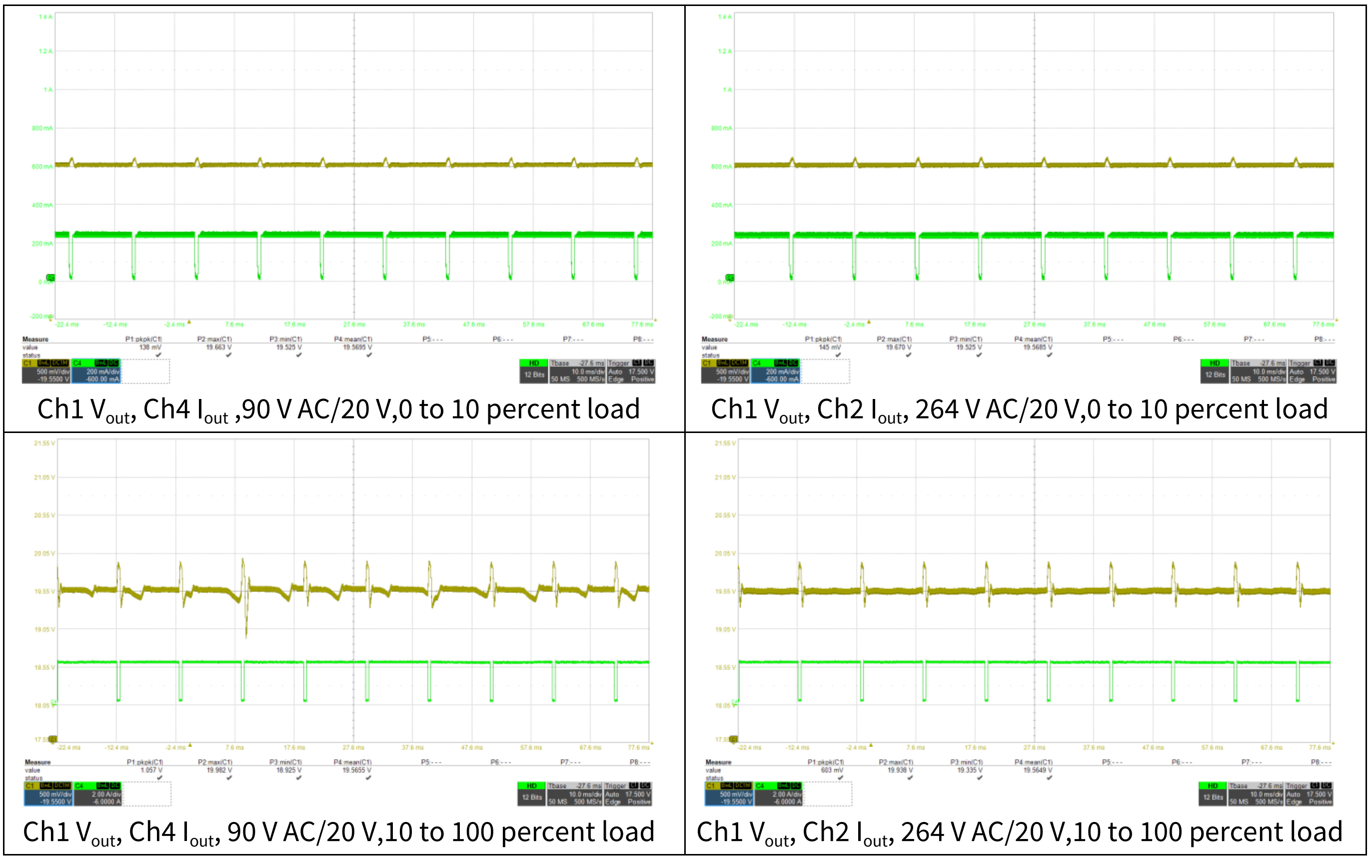
100 V AC	No load	50 percent load	Full load
5 V	4.95	4.93	4.91
9 V	8.85	8.83	8.82
12 V	11.77	11.76	11.74
15 V	14.83	14.82	14.80
20 V	19.60	19.59	19.59

10.5 Dynamic load step

The dynamic load step from 0 A to 0.225 A, 0.225 A to 2.25 A at 0.8 A/µs are measured at 90 V AC and 264 V AC. They are less than 0.725 percent at 0 A to 0.225 A step and less than 5.3 percent at 0.225 A to 2.25 A step.

Table 10 Dynamic load step performance for load jumps

Test conditions	Output ripple peak to peak (mV)	
	90 V AC	264 V AC
0 to 10 percent load, 0.8 A/µs, 20 V_{out}	138	145
10 to 100 percent load, 0.8 A/µs, 20 V_{out}	1057	603



Ch1 V_{out}, Ch4 I_{out} ,90 V AC/20 V,0 to 10 percent load

Ch1 V_{out}, Ch2 I_{out}, 264 V AC/20 V,0 to 10 percent load

Ch1 V_{out}, Ch4 I_{out}, 90 V AC/20 V,10 to 100 percent load

Ch1 V_{out}, Ch2 I_{out}, 264 V AC/20 V,10 to 100 percent load

Figure 23 Dynamic load test

10.6 Burst Mode (BM) entry/leaving power

IC will enter BM based on V_{MFIO} voltage; for XDPS21071, different thresholds per output voltage are used to keep the BM entry power more consistent. Below is the measured BM entry/leaving power at different line voltages and different output voltages.

Table 11 BM entry power

	5 V	9 V	12 V	15 V	20 V
90 V AC	0.185 A	0.096 A	0.097 A	0.048 A	0.038 A
115 V AC	0.179 A	0.091 A	0.109 A	0.051 A	0.044 A
230 V AC	0.218 A	0.097 A	0.110 A	0.030 A	0.027 A
264 V AC	0.273 A	0.096 A	0.116 A	0.038 A	0.032 A

Table 12 BM leaving power

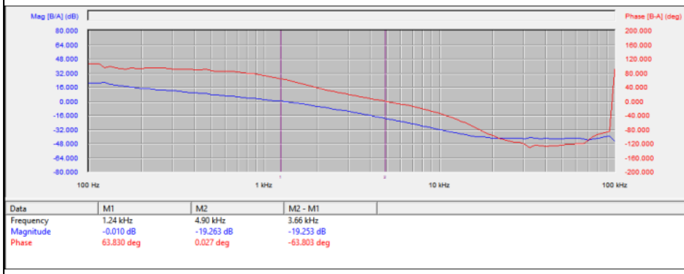
	5 V	9 V	12 V	15 V	20 V
90 V AC	0.388 A	0.196 A	0.148 A	0.112 A	0.103 A
115 V AC	0.388 A	0.212 A	0.170 A	0.113 A	0.081 A
230 V AC	0.455 A	0.238 A	0.170 A	0.112 A	0.094 A
264 V AC	0.561 A	0.316 A	0.224 A	0.163 A	0.126 A

10.7 Loop stability

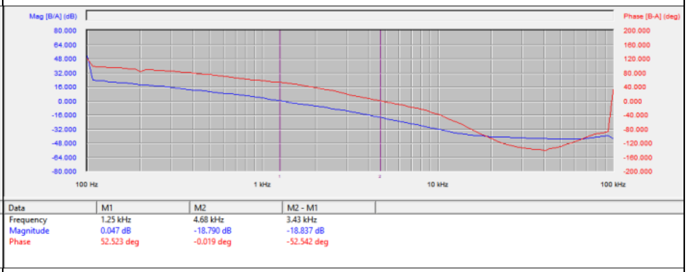
Bode plots were performed using industry-standard small-signal techniques.

Table 13 Loop bandwidth (BW), Gain Margin (GM) and Phase Margin (PM) for 90 V AC and 264 V AC

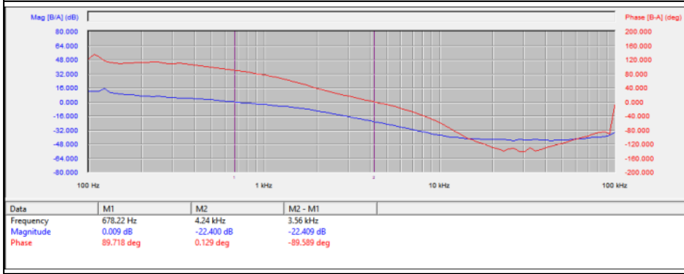
Items	Output	90 V AC	264 V AC
BW (kHz)	5 V/3 A	2.68	2.72
Phase (deg.)		20.3	23.4
Gain (dB)		-6.5	-9.6
BW (kHz)	9 V/3 A	1.12	1.85
Phase (deg.)		59.5	34
Gain (dB)		-21.6	-12.1
BW (kHz)	12 V/3 A	0.991	1.85
Phase (deg.)		62.8	36.2
Gain (dB)		-20.8	-14.3
BW (kHz)	15 V/3 A	0.678	1.67
Phase (deg.)		89.7	39.1
Gain (dB)		-22.4	-15.8
BW (kHz)	20 V/2.25 A	1.24	1.25
Phase (deg.)		63.8	52.5
Gain (dB)		-19.3	-18.8



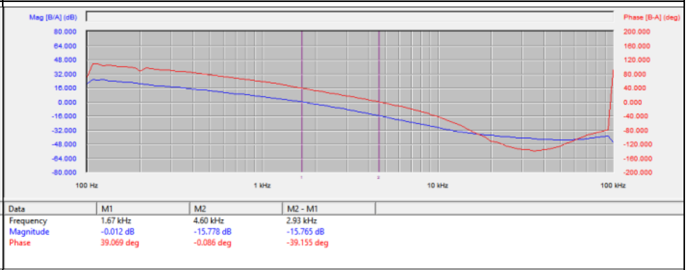
Bode plot at V_{in} = 90 V AC, 20 V/2.25 A



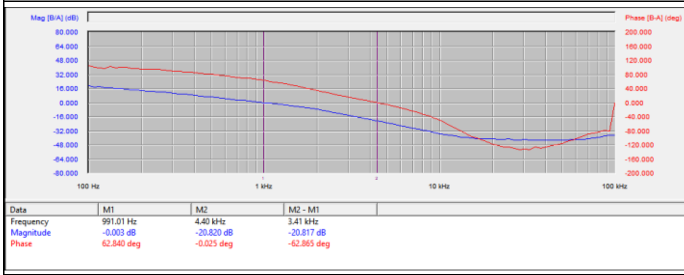
Bode plot at V_{in} = 264 V AC, 20 V/2.25 A



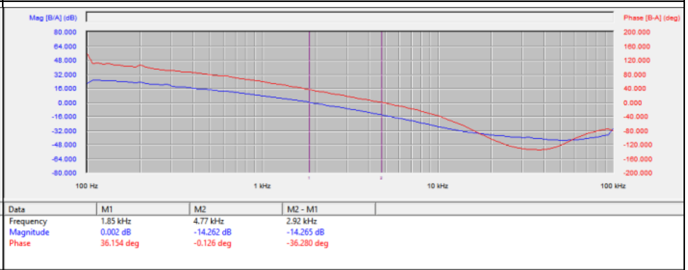
Bode plot at V_{in} = 90 V AC, 15 V/3 A



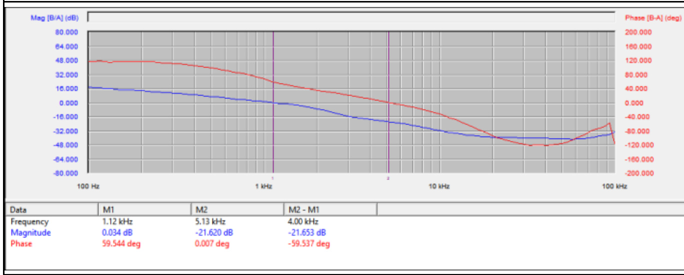
Bode plot at V_{in} = 264 V AC, 15 V/3 A



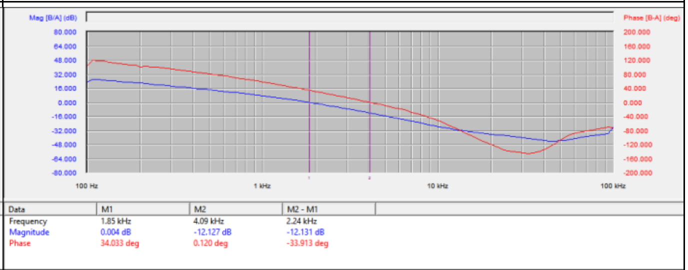
Bode plot at V_{in} = 90 V AC, 12 V/3 A



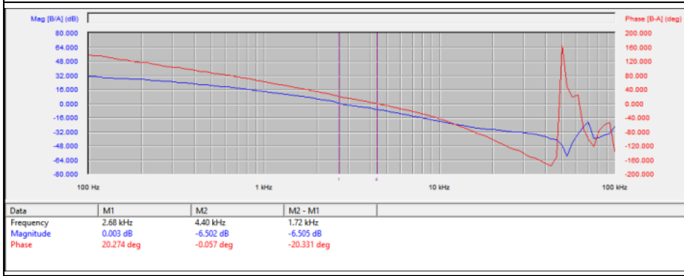
Bode plot at V_{in} = 264 V AC, 12 V/3 A



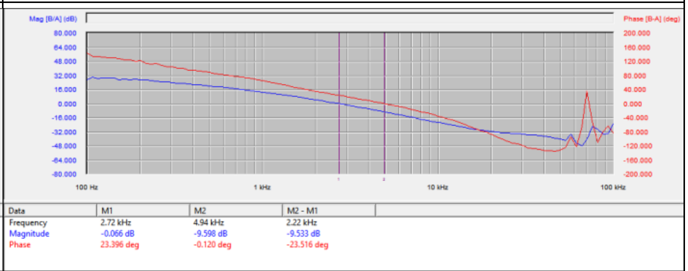
Bode plot at V_{in} = 90 V AC, 9 V/3 A



Bode plot at V_{in} = 264 V AC, 9 V/3 A



Bode plot at V_{in} = 90 V AC, 5 V/3 A



Bode plot at V_{in} = 264 V AC, 5 V/3 A

Figure 24 Bode plots

10.8 Thermal measurement results

Thermal results were checked at different input voltages at 20 V/2.25 A after three hours' burn-in in an open frame at room temperature. SR IC was covered by a thermal pad. A thermal coupler was used to measure the temperature of different components.

Table 14 Thermal results

	90 V AC	115 V AC	230 V AC	264 V AC
SR MOSFET	91.0°C	92.3°C	97.4°C	98.0°C
Primary main MOSFET	97.0°C	98.3°C	92.7°C	93.6°C
Transformer core	88.0°C	88.8°C	96.6°C	99.0°C
Transformer copper	83.0°C	83.8°C	86.2°C	87.0°C
Input rectifier	83.6°C	77.4°C	68.6°C	67.8°C
XDPS21071	71.2°C	71.0°C	72.4°C	72.8°C
SR IC	77.1°C	78.1°C	84.2°C	85.3°C
Primary MOSFET snubber diode	84.8°C	87.0°C	84.0°C	84.0°C
Secondary MOSFET snubber resistor	76.0°C	77.3°C	83.6°C	85.0°C

10.9 Conducted emissions (EN 55022 class B)

The conducted EMI was measured by a certified safety laboratory according to the test standard of EN 55022 (CISPR 22) class B. The demo board was set up at a different output full load with an input voltage of 110 V AC and 230 V AC. The system passes CISPR 22 class B. A copper heaksink was used to cover the main MOSFET to improve the EMI test as it is close to the input pin.

Table 15 EMI test results under different output full loads

Output voltage (V)	120 V/L	120 V/N	230 V/L	230 V/N
5	Pass	Pass	Pass	Pass
9	Pass	Pass	Pass	Pass
12	Pass	Pass	Pass	Pass
15	Pass	Pass	Pass	Pass
20	Pass	Pass	Pass	Pass

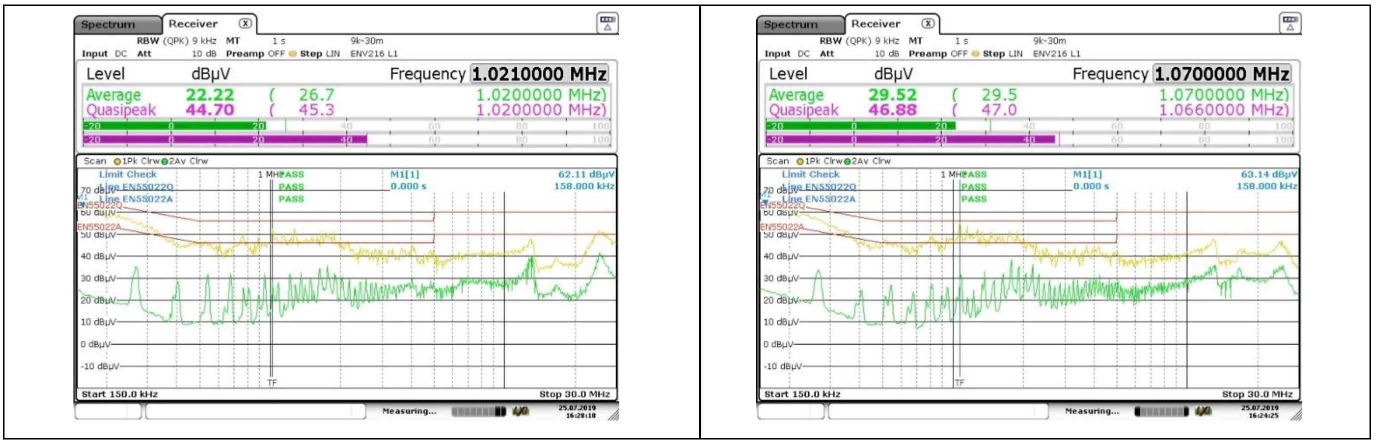


Figure 25 Conducted emissions at 120 V AC and 20 V/2.25 A load; neutral (left), line (right)

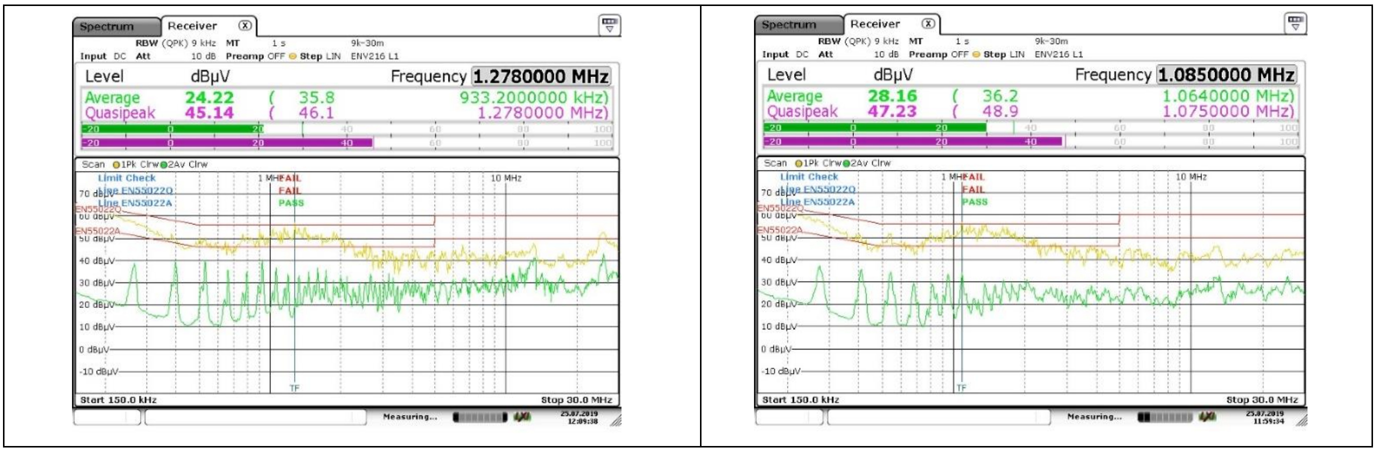


Figure 26 Conducted emissions at 230 V AC and 20 V/2.25 A load; neutral (left), line (right)

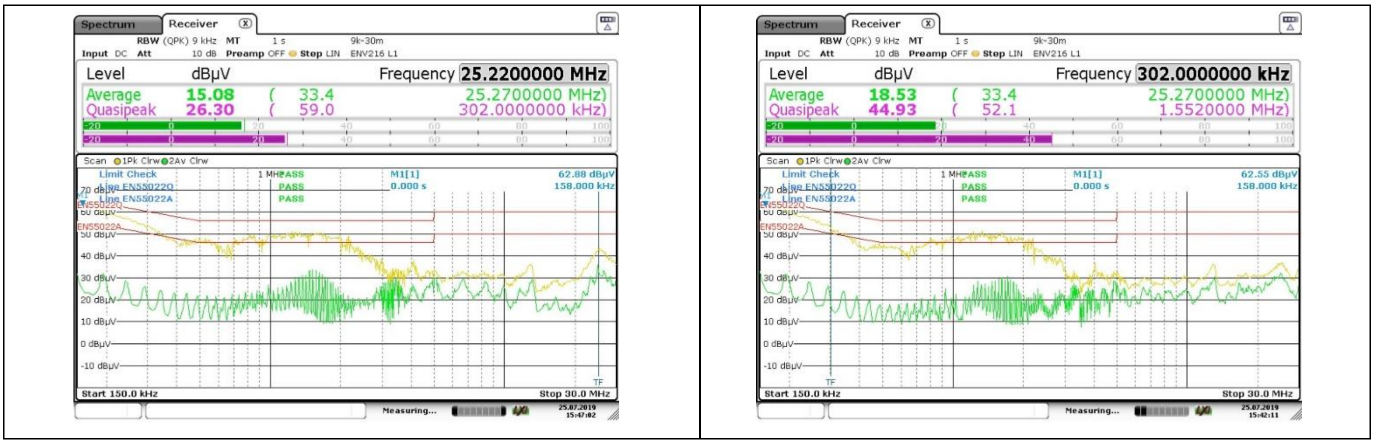


Figure 27 Conducted emissions at 120 V AC and 5 V/3 A load; neutral (left), line (right)

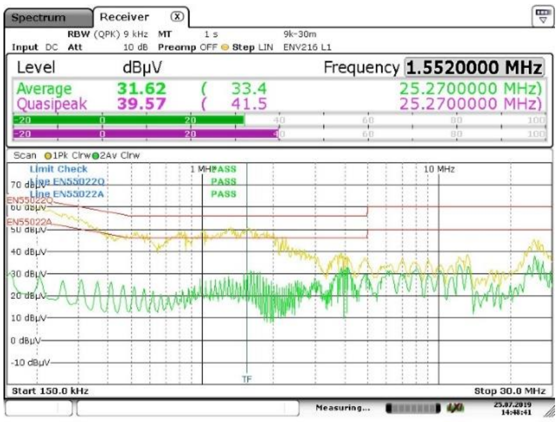
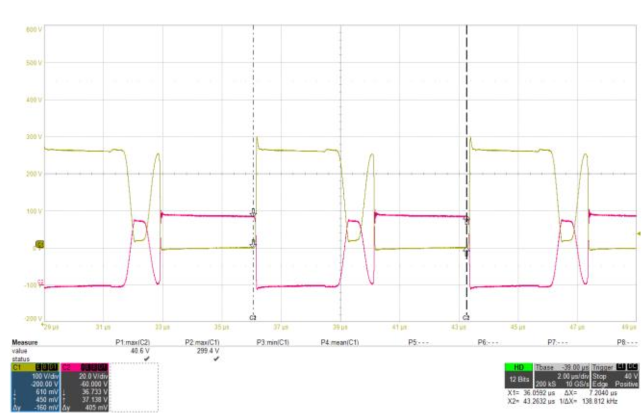


Figure 28 Conducted emissions at 230 V AC and 5 V/3 A load; neutral (left), line (right)

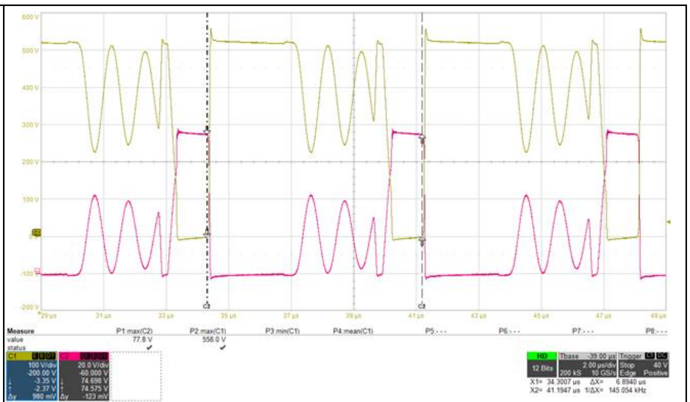
10.10 Operational waveforms

10.10.1 ZVS switching waveform at high-line

The ZVS switching is achieved by ZVS winding where there is a low-voltage MOSFET Q2. During DCM before the main MOSFET, Q201 turns on, the ZVS MOSFET Q2 turns on for a short time (the turn-on time depends on input voltage) so that the drain-source voltage of the main MOSFET would drop to a lower voltage before it turns on in order to achieve ZVS switching. Ch1 is the V_{ds} of the primary main MOSFET, 558 V peak voltage, Ch2 is the V_{ds} of the secondary main MOSFET, 77.8 V peak voltage.



Ch1 V_{ds_Pri} MOS, Ch2 V_{ds_SR} switching waveform at V AC = 90 V AC and 20 V/2.25 A

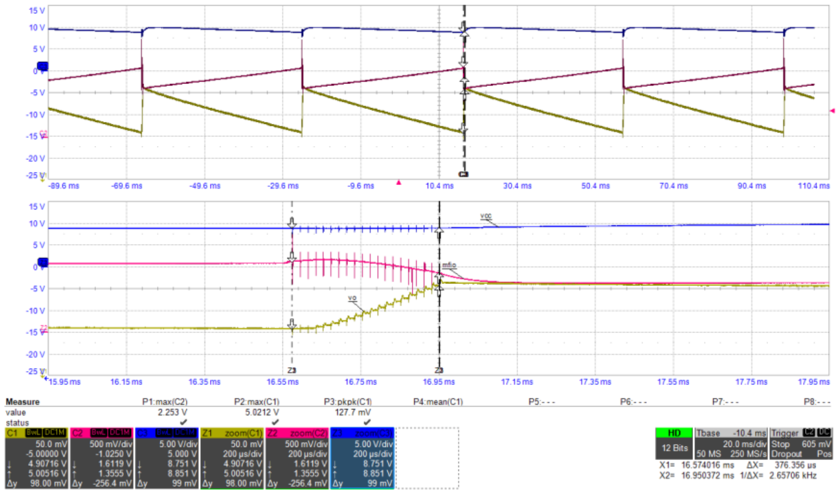


Ch1 V_{ds_Pri} MOS, Ch2 V_{ds_SR} ZVS switching waveform at V AC = 264 V AC and 20 V/2.25 A

Figure 29 Switching waveforms

10.10.2 Burst Mode (BM) waveform

When the system is running at light load, the controller will enter BM where the controller will only turn on the main MOSFET when the output voltage drops to a certain level corresponding to V_{MFIO} = 1.6 V, and will turn off when the output voltage rises to a certain level corresponding to V_{MFIO} = 1.35 V. During MOSFET turn-on, the switching frequency is set at 50 kHz. Whenever a heavy load comes, the MFIO rises. When V_{MFIO} reaches 2.0 V, the control will resume normal mode.

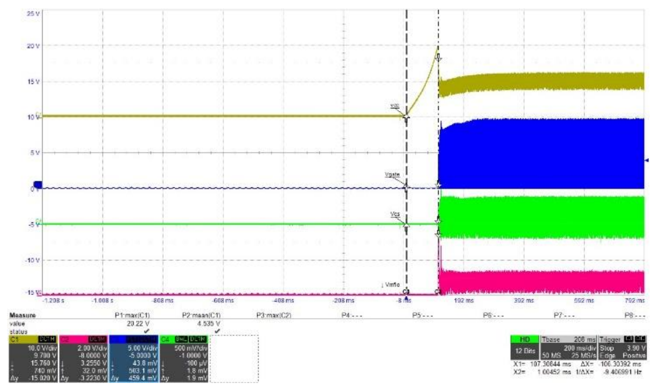


BM waveform, Ch1 V_{out}, Ch2, V_{MFIO}, Ch3 V_{CC} -90 V AC 5 V 0 A

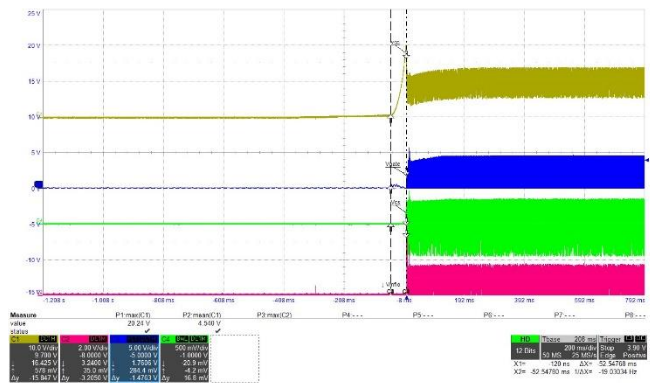
Figure 30 Burst mode waveform

10.11 V_{CC} charge time

The XDPS21071 will charge up the V_{CC} from the HV pin through the R_{HV} resistors tapping from the bulk capacitor. Since there is a R_{HV} resistor, the charging current is changed with different input voltage. The measured start-up at 90 V AC is 0.1 s and at 230 V AC is 0.05 s.



Start-up at V_{in} = 90 V AC at 5 V 1 A load, $t_{Startup}$ = 0.1 s

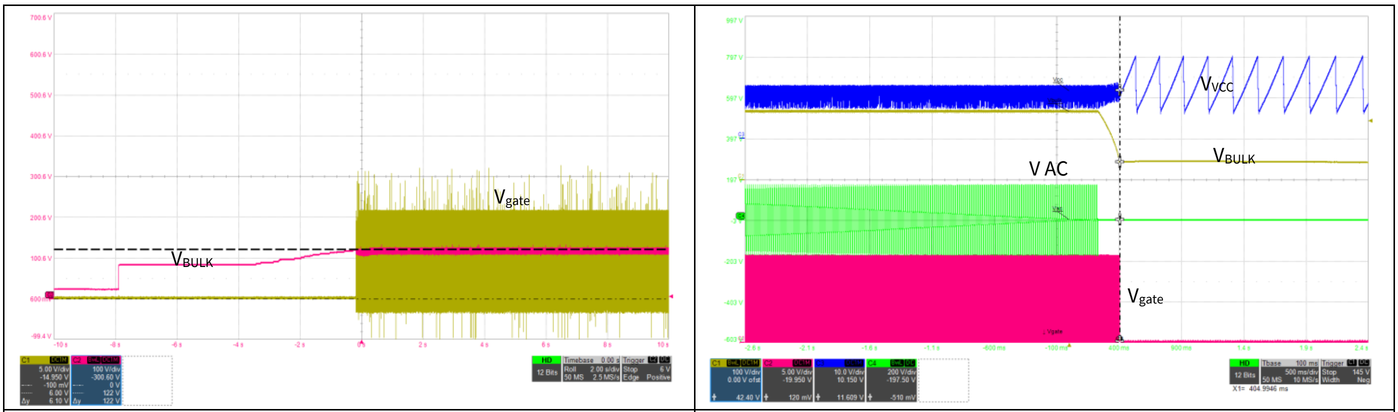


Start-up at V_{in} = 230 V AC at 5 V 1 A load, $t_{Startup}$ = 0.05 s

Figure 31 V_{CC} charge time waveforms

10.12 Brown-in/brown-out

The brown-in and brown-out control is through the sensing from the HV pin with an external resistor R_{HV} (102 kΩ) tapping from the bulk capacitor C1. The measured brown-in voltage is 119 V DC and the brown-out voltage is 43 V DC.

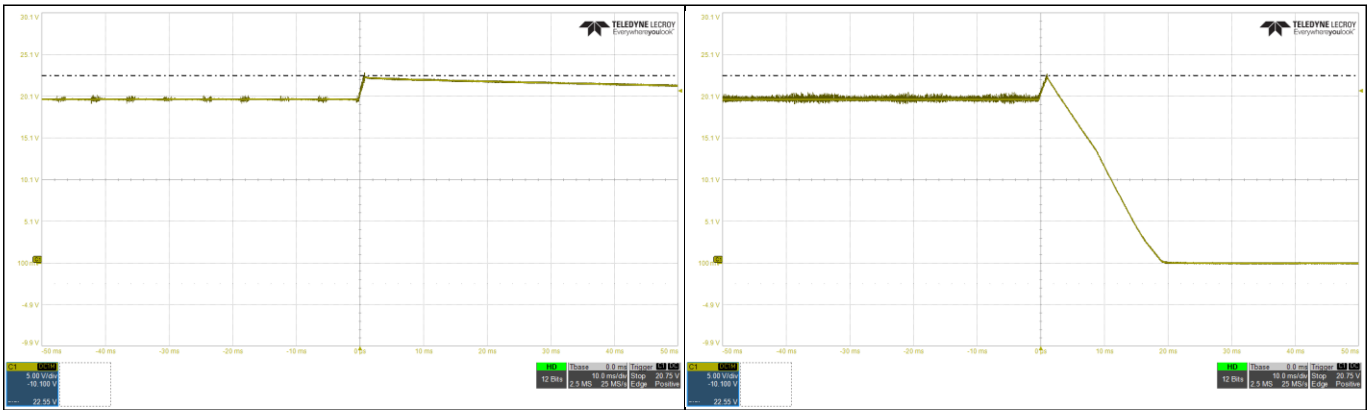


Brown-in voltage is V_{BULK} = 120 V DC at 5 V 1 A load | Brown-out voltage is V_{BULK} = 43 V DC at 3 A load

Figure 32 Brown-in/brown-out waveform

10.13 V_{out} OVP protection

V_{out} OVP is realized in the ZCD pin by sensing the ZCD winding where there is a voltage divider R16 and R2. The ZCD winding is a direct couple of the output winding. Therefore, whenever there is an output over-voltage, it would be reflected to the ZCD pin. The V_{out} OVP trigger level at the ZCD pin is 2.75 V. V_{out} output OVP is triggered by shorting the optocoupler on the secondary side. Figure 33 shows the OVP level of 22.55 V.



V_{out} OVP at V_{in} = 90 V AC 0 A load | V_{out} OVP at V_{in} = 90 V AC 1 A load

Figure 33 V_{out} OVP waveforms

10.14 Over-Load Protection (OLP)

OLP or output short-circuit protection prevents the output current from being too high, causing components to over-heat and become damaged. The function is realized by the counter when V_{CS} reaches internal V_{CS_max} during output over-load. When the blanking time 30 ms is passed, the system would enter auto-restart mode. The below tests were performed with a secondary-side PD CS resistor shorted.

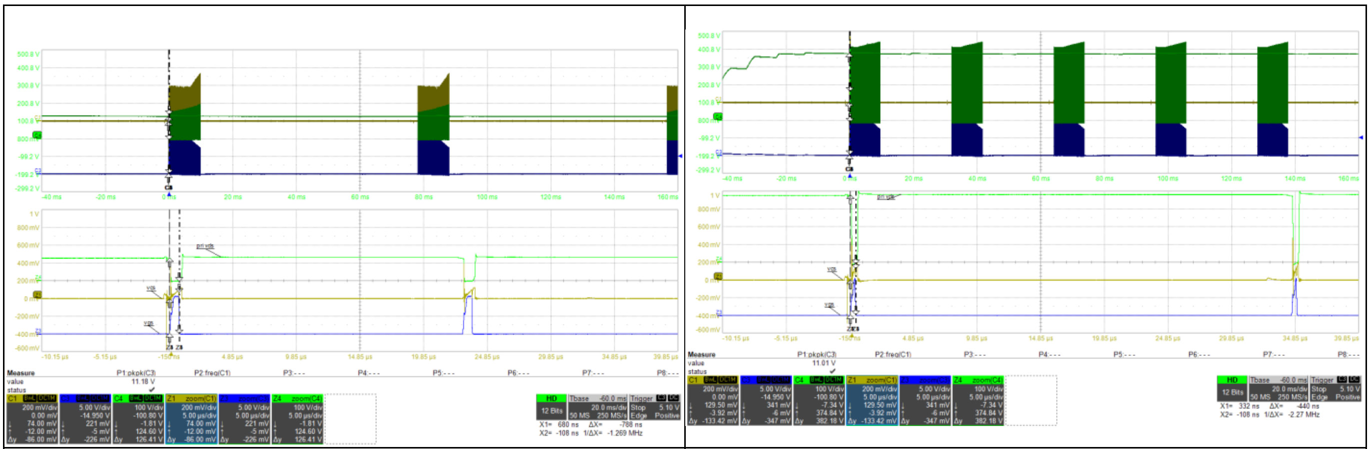
Table 16 OLP current limit at different line conditions

V_{out} (V)	V_{in} (AC) / I_{out} (A)	90	115	230	264
5		4.71	5.09	5.50	5.37
9		3.81	4.33	4.11	3.96

V_{out} (V) / V_{in} (AC) / I_{out} (A)	90	115	230	264
12	3.46	4.16	4.32	4.47
15	3.15	3.96	4.42	4.32
20	2.62	3.38	3.32	3.28

10.15 Output short-circuit protection

During full-load operation, shorting the output with E_{load}, the IC enters auto-restart mode. The tests below show that the secondary-side PD IC protection is triggered first, as the restart timer is not 3 s, which is the auto-restart timer of the primary-side PWM chip.



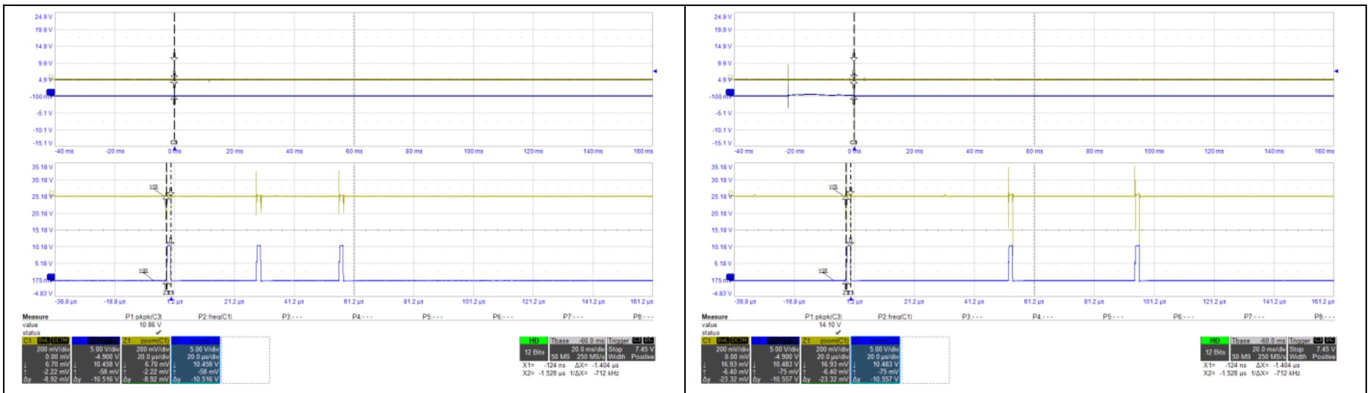
Output short-circuit at V_{in} = 90 V AC
Ch1 V_{CS}, Ch3 V_{gs}, Ch4 V_{ds}

Output short-circuit at V_{in} = 264 V AC
Ch1 V_{CS}, Ch3 V_{gs}, Ch4 V_{ds}

Figure 34 Output short-circuit protection waveforms

10.16 Current Sense (CS) resistor short protection

During start-up, if the PWM main gate signal is longer than 1.4 µs for a continuous three cycles, the IC will enter auto-restart protection. The results below show R_{CS} short protection under 90 V AC and 264 V AC power-up.



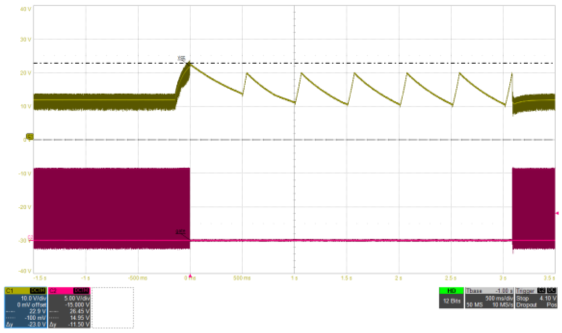
90 V AC Ch1 V_{CS}, Ch3 GD0

264 V AC Ch1 V_{CS}, Ch3 GD0

Figure 35 R_{CS} short protection waveforms

10.17 V_{CC} OVP

If V_{CC} reaches 23 V during operation, IC will enter auto-restart mode with 3 s timer. This test is performed with LDO short.



Ch1 V_{CC}, Ch2 GD0

Figure 36 V_{CC} OVP waveforms

11 References

[1] XDPS21071 datasheet V1.0, Infineon Technologies AG, 2019

[2] IPD70R360P7S datasheet, Infineon Technologies AG, 2019

[3] BSC0805LS datasheet, Infineon Technologies AG, 2019

[4] BSL606SN datasheet, Infineon Technologies AG, 2013

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Major changes since the last revision

Page or reference	Description of change

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