45 W 20 V adapter reference board

with ICE2QS03G, IPA60R650CE, BAS21-03W and 2N7002

About this document

Scope and purpose

This document is an engineering report that describes a 45 W 20 V adapter reference design board using a quasi-resonant PWM IC ICE2QS03G (DSO-8) with a CoolMOS™ IPA60R650CE (TO220FP). The reference adapter board is designed to fit a very small form factor while having high efficiency, low standby power and various modes of protection for a highly reliable system. The board passes EMI (both conducted and radiated), ESD immunity and surge immunity tests and can be used for production by customers after final verification with minor changes.

Intended audience

This document is intended for power supply designers, application engineers, students, etc., who wish to design a high efficiency, high reliability and very small form factor 45 W 20 V AC-DC adapter in a short period of time, using Infineon's CoolMOS™ CE series and quasi-resonant PWM IC ICE2QS03G.

Table of contents

1 Abstract

This application note is an engineering report for a very small form factor reference design for a universal input 45 W 20 V adapter. The adapter uses ICE2QS03G, a second generation current mode control quasi-resonant flyback topology controller and IPA60R650CE, a CE series of high voltage power CoolMOS™ which is a price-performance optimized platform intended to target cost sensitive applications yet still meet the highest efficiency standards. The distinguishing features of this reference design are its very small form factor, best in class low standby power, high efficiency, good EMI performance and various modes of protection including a tailor-made brownout circuit for a highly reliable system.

2 Reference board

This document contains the list of features, the power supply specification, schematic, bill of material and the transformer construction documentation. Typical operating characteristics such as performance curve and scope waveforms are shown at the end of this report.

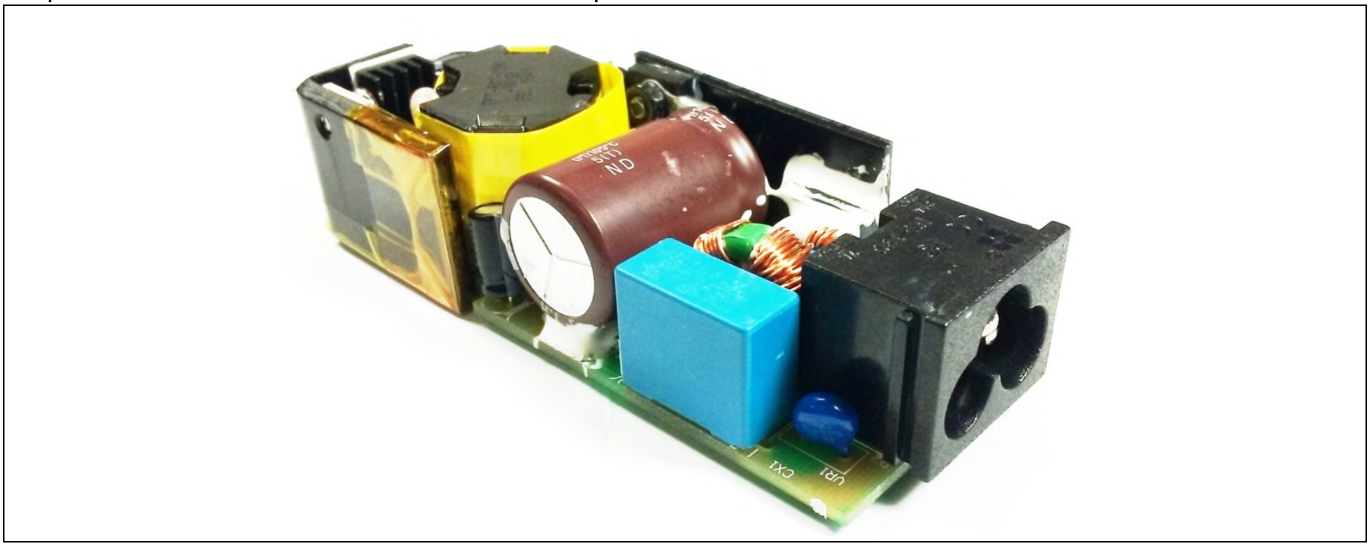


Figure 1 REF-45 W ADAPTER [PCBA dimensions L x W x H: 92 mm x 36mm x 22 mm]

Figure 2 REF-45 W ADAPTER (top view)

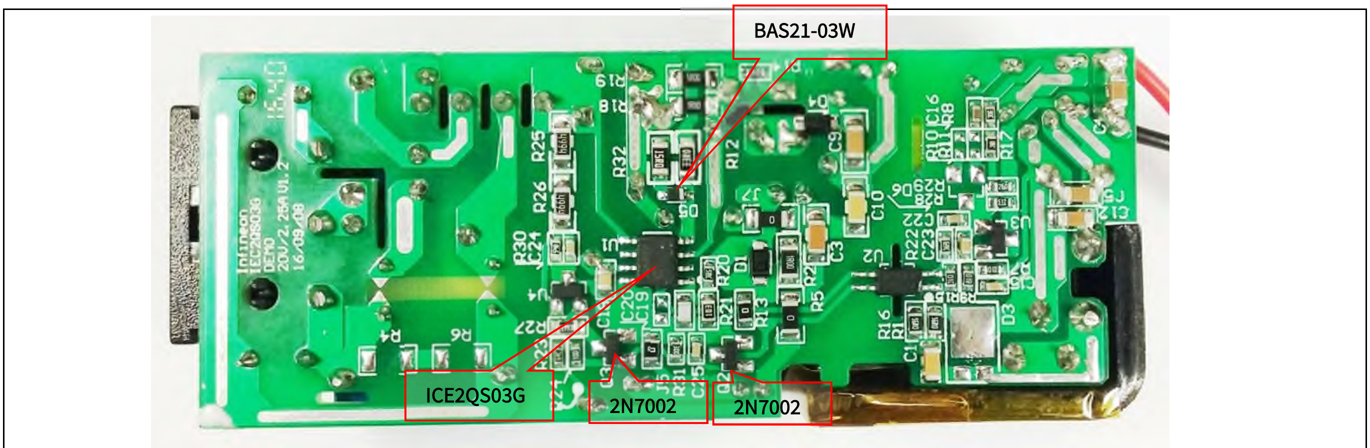


Figure 3 REF-45 W ADAPTER (bottom view)

3 Specification of reference board

Table 1 Specification of REF-45W ADAPTER

Input voltage and frequency	90 V_{AC} (60 Hz)~264 V_{AC} (50 Hz)
Output voltage, current & power	20 V/2.25 A/45 W
Brownout detect/reset voltage at full load	82/88 V_{AC}
Output over voltage protection	21 ~ 25 V
Output over current protection	2.3 ~ 3.3 A
Active mode four point average efficiency (25%,50%,75%,100% load) (EU CoC Version 5, Tier 2) No-load power consumption	>88.9% <100 mW
Conducted emissions (EN55022 class B)	Pass with 8 dB margin for QP
Radiated emissions (EN55022 class B)	Pass with 8 dB margin for QP
ESD immunity (EN61000-4-2)	Level 3 (±8 kV: contact discharge)
Surge immunity (EN61000-4-5)	Installation class 3 (2 kV: common mode and 1 kV: differential mode)
PCBA form factor (L x W x H)	(92 x 36 x 22) mm

4 Circuit description

4.1 Mains input rectification and filtering

The AC line input side includes an input fuse (F1) for over-current protection. The choke (L2), X-capacitors (CX1) and Y-capacitors (CY1, CY2 and CY3) act as EMI suppressors. The PCB spark gap and varistor (VR1) can absorb high voltage stress during a lightning surge test. After the bridge rectifier DB1 and the input bulk capacitor C11, a voltage of 90 to 373 V_{DC} is present, depending on the input line voltage.

4.2 PWM control and switching MOSFET

The PWM pulse is generated by the quasi-resonant PWM current-mode controller ICE2QS03G. This PWM pulse drives the high voltage power MOSFETs, IPA60R650CE (CoolMOS™ CE). The CoolMOS™ CE provides all of the benefits of a fast switching SJ MOSFET while not sacrificing ease of use. It achieves extremely low conduction and switching losses and can make switching applications more efficient, more compact, lighter and cooler. The PWM switch-on is determined by the zero crossing 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}. The ICE2QS03G also provides all of the necessary protection functions for flyback converters. Full details are provided in the product datasheet.

4.3 Snubber network

A snubber network comprising R3, C9 and D4 dissipates the energy of the leakage inductance and suppresses ringing on the SMPS transformer. Due to the resonant capacitor (MOSFET's drain source capacitance), the overshoot is smaller than for a fixed frequency flyback converter. Thus, the snubber resistor can be increased to reduce the snubber loss.

4.4 Output stage

On the secondary side, for a 20 V output, the power is coupled via a Schottky diode (D2). Capacitor C7 provides energy buffering following the LC filter (L1, C8) to reduce the output ripple and prevent interference between the SMPS switching frequency and the line frequency considerably. Storage capacitor C7 is selected to have as low an internal resistance (ESR) as possible to minimize the output voltage ripple caused by the triangular current.

4.5 Feedback loop

For feedback, the output is sensed by the voltage divider comprising R8, R17, R28 and R29 and compared to U3 - the TL432 internal reference voltage. C22, C23 and R22 form the compensation network. The output voltage of U3, (TL432) is converted to the current signal via optocoupler U2 and 3 resistors (R7, R9 and R15) for regulation control.

5 Circuit operation

5.1 Startup operation

As there is a built-in startup cell in the **ICE2QS03G**, there is no need for an external start up resistor, which can improve standby performance significantly. When V_{CC} reaches the turn on voltage threshold of 18 V, the IC begins with a soft-start. The soft-start implemented in the **ICE2QS03G** is a digital time-based function. The preset soft-start time is 12 ms with 4 steps. If not limited by other functions, the peak voltage on the CS pin will increase step by step from 0.32 V to 1 V. After the IC turns on, the V_{CC} voltage is supplied by the auxiliary windings of the transformer.

5.2 Normal mode operation

The secondary output voltage is generated after startup with secondary regulation control provided by the TL432 and optocoupler. The compensation network (C22, C23 and R22) creates the error amplifier for the TL432. This circuitry allows the feedback to be precisely controlled with respect to any dynamically varying load conditions, therefore providing stable control.

5.3 Primary side peak current control

The MOSFET drain-source current is sensed via the external resistors R18 and R19. Since **ICE2QS03G** is a current mode controller, it has a cycle-by-cycle primary current and feedback voltage control that can ensure that the maximum power of the converter is controlled during every switching cycle.

5.4 Digital frequency reduction

During normal operation, the switching frequency of the **ICE2QS03G** is digitally reduced with decreasing load. At light load, the CoolMOS™ **IPA60R650CE** will be turned on the nth minimum drain-source voltage time where 'n' is in range 1 to 7, depending upon the feedback voltage. The feedback voltage decreases when the output power requirement decreases, and vice versa. Therefore, the counter is set by monitoring the feedback voltage, V_{FB}. The counter will be increased for low V_{FB} and decreased for high V_{FB}. The thresholds are preset inside the IC.

5.5 Burst mode operation

At a light load condition, the SMPS enters into **Active Burst Mode**. At this stage, the controller is always active but V_{CC} must be kept above the switch off threshold. During active burst mode, the efficiency increases significantly and at the same time supports low ripple on V_{OUT} and fast response on load jump.

For determination of entering Active Burst Mode operation, three conditions apply:

1. The feedback voltage must be lower than the threshold of V_{FBEB}(1.25 V). Accordingly, the peak current sense voltage across the shunt resistor must be 0.17 V;
2. The up/down counter must be 7;
3. The blanking time t_{BEB} must be 24 ms.

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

During active burst mode, the maximum current sense voltage is reduced from 1 V to 0.34 V so as to reduce the conduction loss and the audible noise. In active burst mode, the feedback voltage has a sawtooth waveform between 3.0 and 3.6 V.

The feedback voltage immediately increases if the comparator observes a significant load jump. As the current limit is 34% during active burst mode, a certain load is needed so that the feedback voltage can exceed V_{FBLB} (4.5 V). After leaving active burst mode, maximum current can now be provided to stabilize V_{OUT}. In addition, the up/down counter will be set to 1 immediately after leaving active burst mode. This is helpful to decrease the output voltage undershoot.

6 Protection features

6.1 V_{CC} over voltage and under voltage protection

During normal operation, V_{CC} is continuously monitored. When V_{CC} increases to V_{VCCOVP} or V_{CC} falls below the under voltage lock out level V_{VCCoff}, the IC will enter auto restart mode.

6.2 Over load/open loop protection

In the case of an open control loop, the feedback voltage is pulled up with an internal block. After a fixed blanking time, the IC enters auto restart mode. In the case of a secondary short-circuit or overload, the regulation voltage, $V_{FB,}$ will also be pulled up, and the IC will auto restart.

6.3 Auto restart for over temperature protection

The IC has a built-in over temperature protection function. When the controller's temperature reaches 140°C, the IC will shut down and enter auto restart. This can protect the power MOSFET from overheating.

6.4 Adjustable output overvoltage protection

During the off-time of the power switch, the voltage at the zero-crossing pin (ZC) is monitored for output overvoltage detection. If the voltage is higher than the preset threshold of 3.7 V for a preset period of 100 µs, then the IC is latched off.

6.5 Short winding protection

The source current of the MOSFET is sensed via external resistors R18 and R19. If the voltage at the current sensing pin is higher than the preset threshold (V_{CSSW}) of 1.68 V during the on-time of the power switch, the IC is latched off giving a short winding protection. To avoid an unintentional latch off, a spike blanking time of 190 ns is integrated in the output of internal comparator.

6.6 Foldback point protection

For a quasi-resonant flyback converter, the maximum possible output power is increased when a constant current limit value is used for all the mains input voltage range. This is usually not desired as this will increase the load on the transformer and output diode during output over power conditions.

Internal foldback protection is implemented to adjust the V_{CS} voltage limit according to the bus voltage. The input line voltage is sensed using the current flowing from the ZC pin, during the MOSFET on-time. As a result, the maximum current limit will be lower at high input voltage and the maximum output power can be limited in relation to the input voltage.

6.7 Line under voltage protection (brownout) by external circuit

When the AC line input voltage is lower than the specified voltage range, brownout mode is detected by sensing the voltage present on the REF pin (V_{REF_TYP} =2.5 V) of U4 (ATL432) through the voltage divider resistors (R25, R26, R27 and R30 in Figure 4) via bulk capacitor, C11. Q2 acts as a switch to enter or exit brownout mode by controlling the FB pin voltage. Q3, together with R27, provides voltage hysteresis for the brownout circuit and U4 (ATL432) as a comparator. The system enters the brownout mode by controlling the FB pin voltage of U1 to 0 V, when the voltage level at V_{REF} drops to 2.5 V, the MOSFETs Q2 and Q3 are "ON" and V_{FB} drops to 0 V. The system is then in auto restart mode. Once the input voltage returns to the input voltage range, V_{REF} increases to

2.5 V. At the same time MOSFETs Q2 and Q3 are "OFF" and the brownout mode is released. After that, when V_{CC} reaches 18 V, the system resumes operation. The calculation for the brownout circuit is below.

$$V_{\mathrm{REF}} = 2.5\ \mathrm{V}$$

$$\mathrm{R25} = 4.99\ \mathrm{M\Omega} \qquad \mathrm{R26} = 4.99\ \mathrm{M\Omega} \qquad \mathrm{R30} = 357\ \mathrm{k\Omega} \qquad \mathrm{R27} = 499\ \mathrm{k\Omega}$$

$$\mathrm{V}_{Bulkcap\_brownout} = \frac{(R25 + R26 + R30).V_{\mathrm{REF}}}{R30}$$

$$\mathrm{V}_{Bulkcap\_brownout} = 72.38\ V$$

$$V_{Bulkcap\_brownin} = \frac{\left[\left(\frac{R30.R27}{R30 + R27}\right) + R25 + R26\right].V_{\mathrm{REF}}}{\frac{R30.R27}{R30 + R27}}$$

$$\mathrm{V}_{Bulkcap\_brownin} = 122.38\ V$$

Since there is AC ripples atop the DC voltage at the bulk capacitor C11, the calculated $V_{Bulkcap\_brownout}$ refers to the ripple troughs and the $V_{Bulkcap\_brownin}$ refers to the ripple crests.

7 Circuit diagram

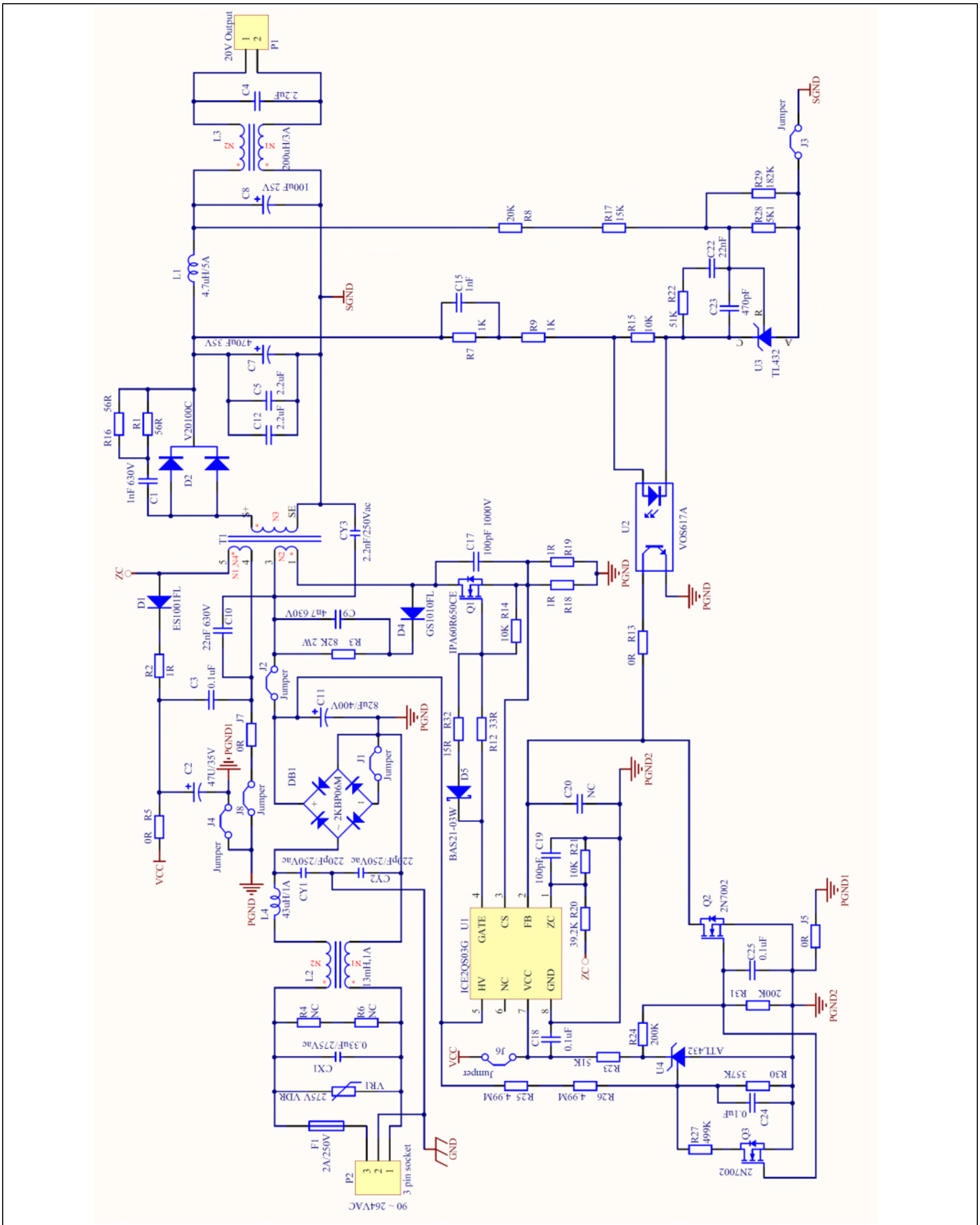


Figure 4 Schematic of REF-45 W ADAPTER

8 PCB layout

8.1 Top side

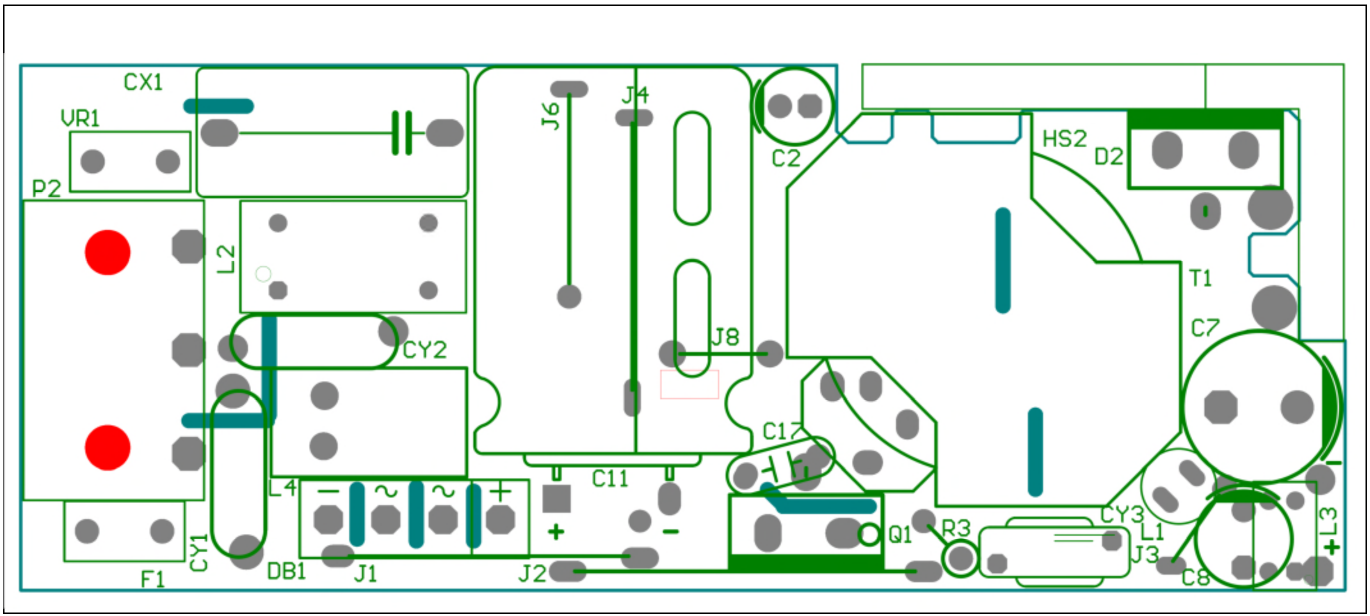


Figure 5 Top side copper and component legend

8.2 Bottom side

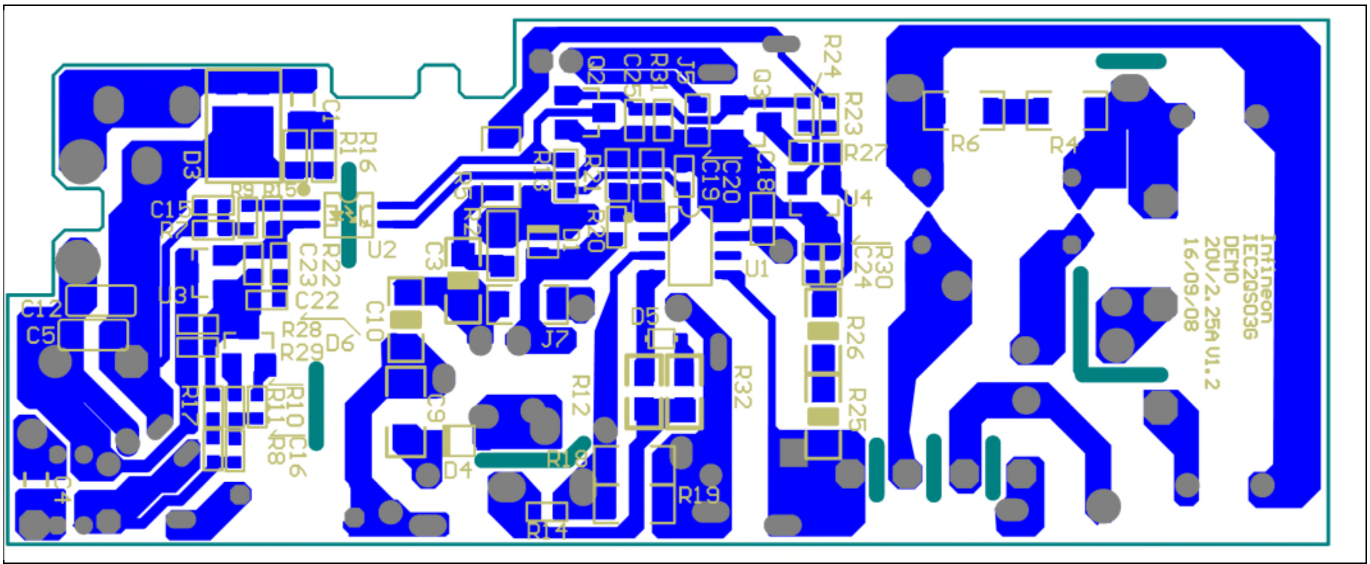


Figure 6 Bottom side copper and component legend

9 Component list

Table 2 Bill of materials

Item	Circuit code	Description	Part value	Supplier	Package / Footprint	Qty
1	C1	Output snubber cap.	1 nF 630 V (1206)		1206	1
2	C2	Vcc cap.	47 uF 35 V E-cap		5*10 mm, P=2.5 mm	1
3	C3	Filter cap.	100 nF 50 V (1206)		1206	1
4	C4	Filter cap.	2.2 uF 50 V (1206)		1206	1
5	C5	Filter cap.	2.2 uF 50 V (1206)		1206	1
6	C7	Output Cap.	470 uF 35 V low ESR E-Cap		10*16 mm, P=5.0 mm	1
7	C8	Output Cap.	100 uF 25 V low ESR E-Cap		6.3*11 mm, P=5.0mm	1
8	C9	Clamper cap.	4.7 nF 630 V (1206)		1206	1
9	C10	HV filter cap.	22 nF 630 V (1206)		1206	1
10	C11	Input bulk cap.	82 uF 400 V E-Cap (EKXG401ELL820MM25S)		18*25 mm. P=10mm	1
11	C12	Filter cap.	2.2 uF 50 V (1206)		1206	1
12	C15	Filter cap.	1 nF 50 V (0603)		0603	1
13	C17	HV Cds cap.	100 pF 1000 V		6*3 mm, P=4.0 mm	1
14	C18	Filter cap.	100 nF 50 V (0805)		0805	1
15	C22	Filter cap.	22 nF 50 V (0603)		0603	1
16	C23	Filter cap.	470 pF50 V (0603)		0603	1
17	C24	Filter cap.	100 nF 50 V (0603)		0603	1
18	C25	Filter cap.	100 nF 50 V (0603)		0603	1
19	CX1	X cap	X2-Cap 0.33 uF 305 V_{AC} (B32922D3334K)	EPCOS	X2-cap, 8.5*14.5 mm, P=15 mm	1
20	CY1	Y cap	Y2-Cap 220 pF 250 V_{AC}		Y2-cap	1
21	CY2	Y cap	Y2-Cap 22 0pF 250 V_{AC}		Y2-cap	1
22	CY3	Y cap	Y1-Cap 2.2 nF 250 V_{AC}		YI-cap	1
23	D1	Signal diode	100 V 1 A diode (ES1001FL)		SOD-123	1
24	D2	Output diode	100 V 20 A schottky diode(V20100C)		TO-220	1
25	D4	Clamper diode	100 V 1 A diode (GS1010FL)		SOD-123	1
26	D5	Signal diode	200 V 0.25 A diode (BAS21-03W)	Infineon	SOD323	1
27	DB1	Input bridge diode	600 V 2 A bridge diode (2KBP06M)			1
28	F1	Fuse	T 2 A 250 V TE5 fuse		8*4 mm, P=5 mm	1
29	HTSK1	Heatsink for Q1	42 mm x 16 mm			1
30	HTSK2	Heatsink for D2	51 mm x 21 mm L-shape			1
31	J1	Jumper	L20 mm D0.6 mm		axial	1
32	J2	Jumper	L23.7 mm D0.6 mm		axial	1
33	J3	Jumper	L6.3 mm D0.6 mm		axial	1
34	J4	Jumper	L18.5 mm D0.6 mm		axial	1
35	J5	Jumper	0R (0805)		0805	1
36	J6	Jumper	L10 mm D0.6 mm		axial	1

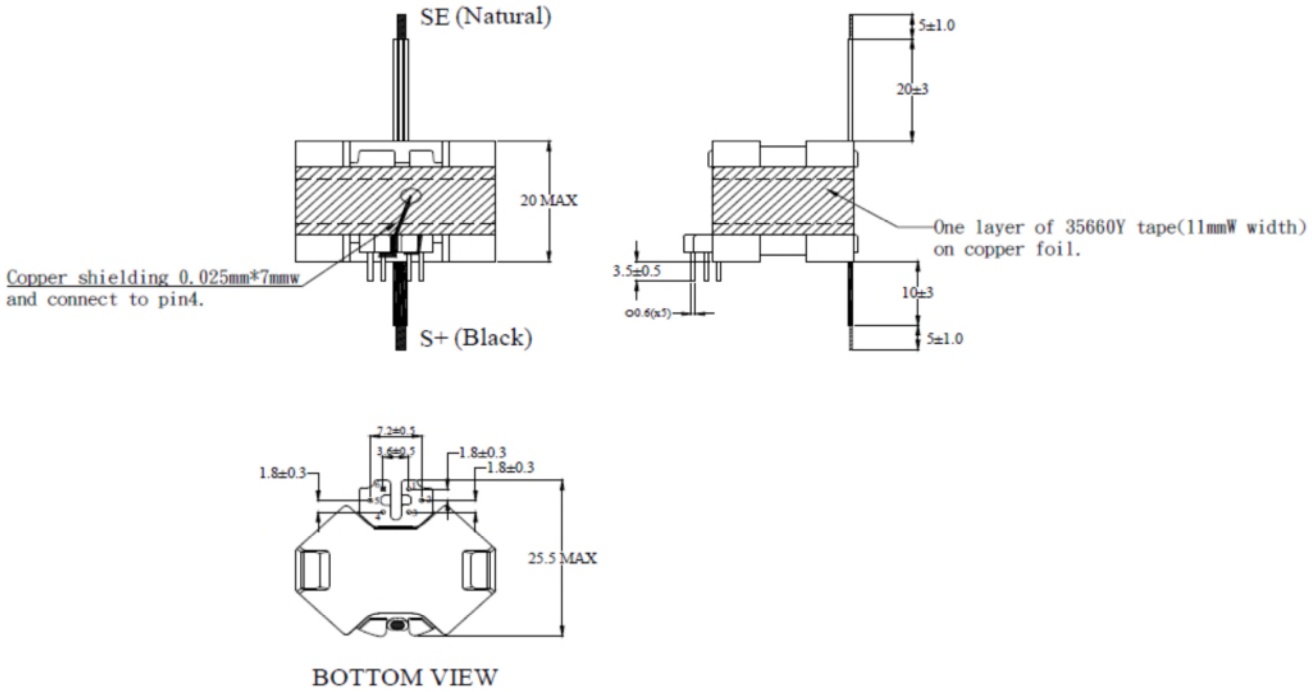
37	J7	Jumper	0R (1206)		1206	1
38	J8	Jumper	L6.5mm D0.6mm		axial	1
39	L1	Output D-choke	4.7uH/5A (B32922D3334K)	WURTH	6*8.5 mm, P=2.5 mm	1
40	L2	Input CMC	13 mH 1 A (GM-1495SH)		7*15*15mm, P=5 mm	1
41	L3	Output CMC	200 µH 1 A (GM-633-050)		4*8*8 mm, P=4 mm	1
42	L4	Input D-choke	43 µH 1 A 0.06 Ω (7447034)	WURTH	6.5*13*13.5 mm, P=4.5 mm	1
43	P1	Output wire	2 pcs φ0.6 mm			
44	P2	Input 3 pin socket	Plum blossom socket (ST-A04)			1
45	PCB	PCB	88 mm x 35 mm FR1 1.6 mm thick			1
46	Q1	Power MOSFET	N MOS 600 V 0.65 Ω (IPA60R650CE)	Infineon	TO220FP	1
47	Q2	Signal MOSFET	N MOSFET 60 V 300 mA (2N7002)	Infineon	SOT-23	1
48	Q3	Signal MOSFET	N MOSFET 60 V 300 mA (2N7002)	Infineon	SOT-23	1
49	R1	Resistor	56R (0805)		0805	1
50	R2	Resistor	1R (1206)		1206	1
51	R3	Clamper Resistor	82K 2W		axial	1
52	R5	Resistor	0R (1206)		1206	1
53	R7	Resistor	1K (0603)		0603	1
54	R8	Resistor	20K (0603)		0603	1
55	R9	Resistor	1K (0603)		0603	1
56	R12	Resistor	33R (1206)		1206	1
57	R13	Resistor	0R (0805)		0805	1
58	R14	Resistor	10K (0603)		0603	1
59	R15	Resistor	10K (0603)		0603	1
60	R16	Resistor	56R (0805)		0805	1
61	R17	Resistor	15K (0603)		0603	1
62	R18	Resistor	1R (1206)		1206	1
63	R19	Resistor	1R (1206)		1206	1
64	R20	Resistor	39K2 (0603)		0603	1
65	R21	Resistor	10K (0603)		0603	1
66	R22	Resistor	51K (0603)		0603	1
67	R23	Resistor	51K (0603)		0603	1
68	R24	Resistor	200K (0603)		0603	1
69	R25	Resistor	4.99M (1206)		1206	1
70	R26	Resistor	4.99M (1206)		1206	1
71	R27	Resistor	499K (0603)		0603	1
72	R28	Resistor	5K1 (0603)		0603	1
73	R29	Resistor	182K (0603)		0603	1
74	R30	Resistor	357K (0603)		0603	1
75	R31	Resistor	200K (0603)		0603	1
76	R32	Resistor	15R (1206)		1206	1
77	T1	Power	L_p=650 µH, RM10 P47		RM10	1

		Transformer				
78	U1	PWM controller	QR controller (ICE2QS03G)	Infineon	SO-8	1
79	U2	Opto-coupler	CTR 63% ~ 125% (VOS617A-2X001T)		SOP4	1
80	U3	Error amplier	2.5 V TL432 (TL432AIDBZR)		SOT-23	1
81	U4	Error amplier	2.5 V low current ATL432 (ATL432AIDBZR)		SOT-23	1
82	VR1	VDR	S05K075 (B72205S0271K101)	EPCOS	radial	1
83	Screw	For HTSK1 and HTSK2	M3 bolt and nut			2
84	Jumper wire	For HTSK1	φ0.6mm with M3 crimp terminal			1

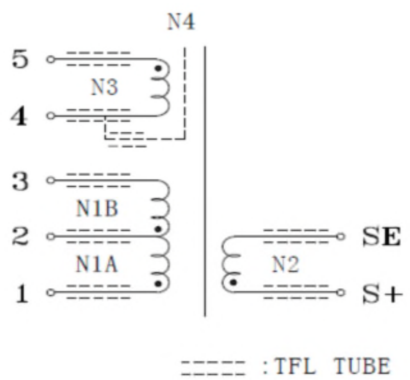
10 Transformer construction

Core and material: RM10 P47
Primary inductance, Lp=650 µH (±15 µH), measured between pin 1 and pin 3
Leakage inductance. Ll=9.5 µH max measured between pin 1 and pin 3

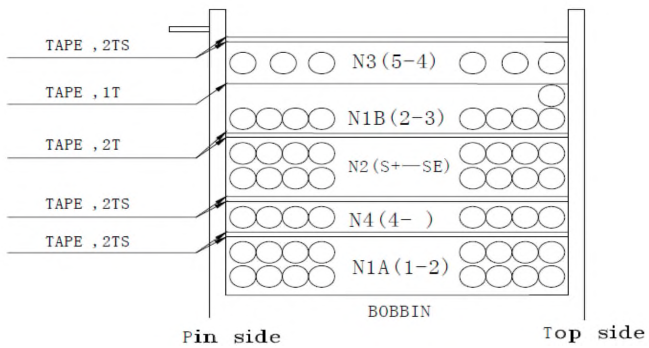
Physical Dimension :



Winding Spec. :



Winding Structure :



Winding Order :

N1A(1–2)	:0.32ϕ*2	,28TS	,Close Wound	
N4 (4–)	:0.32ϕ*2	,14TS	,Shield wind	
N2 (S+—SE)	:0.65ϕ*3	, 7TS	,Close Wound	,Triple wire
N1B(2–3)	:0.32ϕ*2	,14TS	,Close Wound	
N3 (5–4)	:0.15ϕ	, 6TS	,Space Wound	

Figure 7 Transformer structure

11 Test results

11.1 Efficiency, regulations and output ripple

Table 3 Efficiency, regulation & output ripple

Input (V_{AC}/Hz)	P_{IN} (W)	I_{OUT} (A)	V_{OUT} (V)	P_{OUT} (W)	η	Avg η	OLP P_{IN} (W)	OLP I_{OUT} (A)
90 V_{AC} / 60 Hz	50.25	2.26	19.77	44.62	88.79%	89.32%	57	2.80
	37.00	1.68	19.79	33.26	89.88%			
	24.88	1.13	19.80	22.37	89.92%			
	12.58	0.56	19.81	11.16	88.69%			
	0.05	0.00	19.82	0.00	-	-		
115 V_{AC} / 60 Hz	49.48	2.26	19.80	44.67	90.29%	90.05%	63	3.00
	36.68	1.68	19.79	33.25	90.66%			
	24.77	1.13	19.80	22.37	90.29%			
	12.54	0.56	19.81	11.15	88.97%			
	0.05	0.00	19.82	0.00	-	-		
230 V_{AC} / 50 Hz	49.26	2.26	19.78	44.63	90.61%	89.25%	65	3.08
	36.88	1.68	19.79	33.25	90.18%			
	25.01	1.13	19.80	22.36	89.40%			
	12.85	0.56	19.81	11.16	86.82%			
	0.07	0.00	19.82	0.00	-	-		
264 V_{AC} / 50 Hz	49.58	2.26	19.78	44.63	90.03%	88.42%	68	3.10
	37.16	1.68	19.79	33.25	89.48%			
	25.24	1.13	19.80	22.36	88.60%			
	13.04	0.56	19.81	11.16	85.59%			
	0.08	0.00	19.82	0.00	-	-		

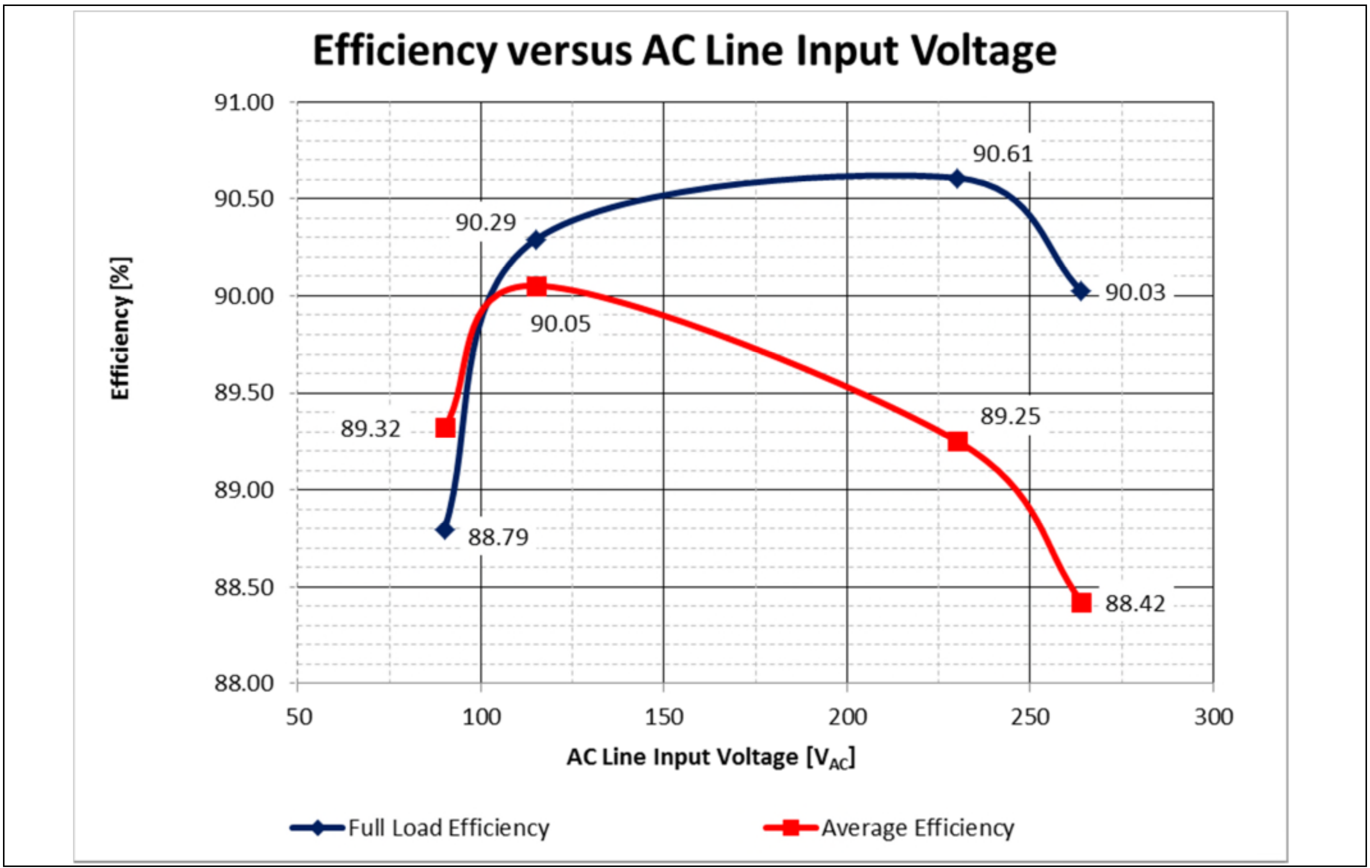


Figure 8 Efficiency vs AC line input voltage

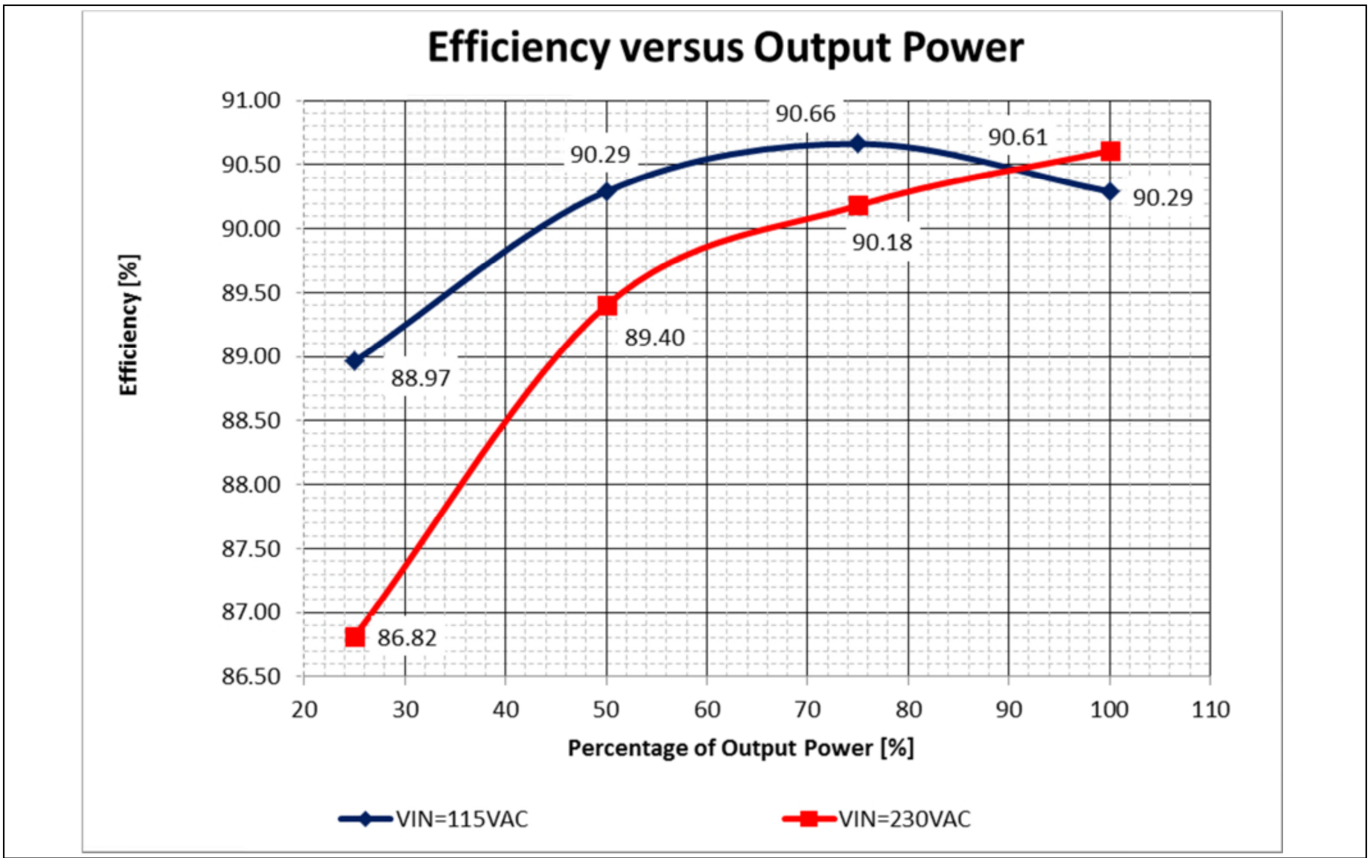


Figure 9 Efficiency vs output power at 115 V_{AC} and 230 V_{AC} line

11.2 Standby power

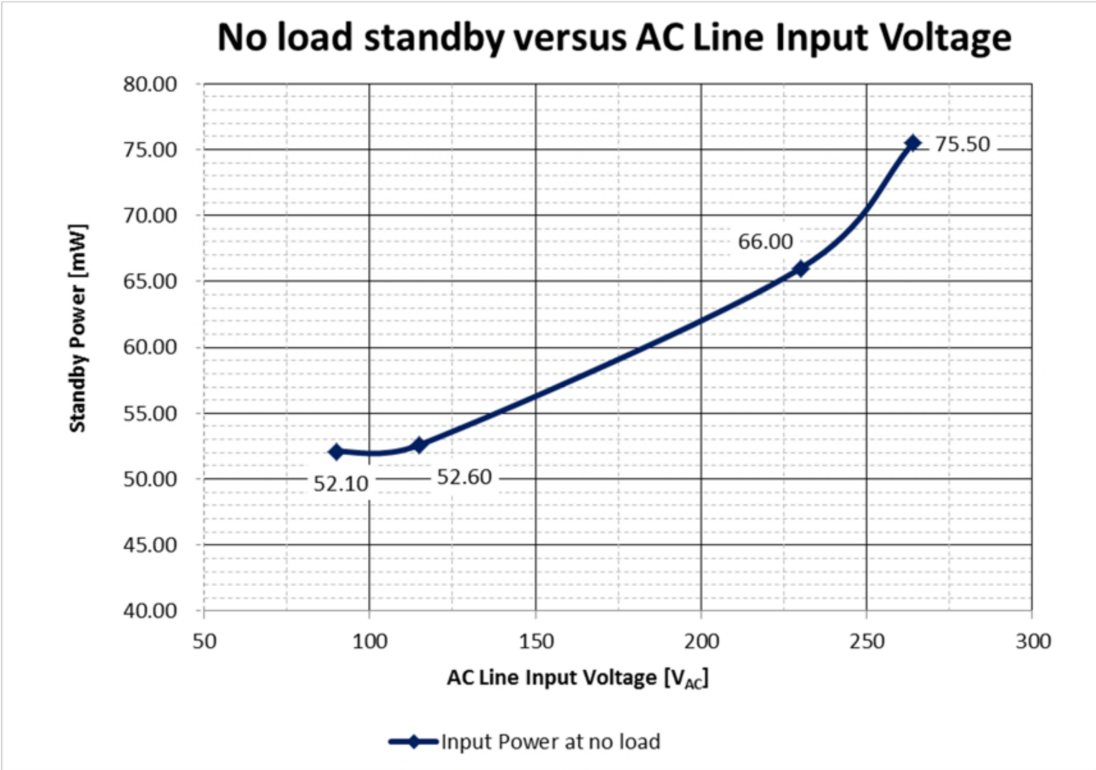


Figure 10 Standby power at no load vs AC line input voltage (measured by Yokogawa WT210 power meter - integration mode)

11.3 Line regulation

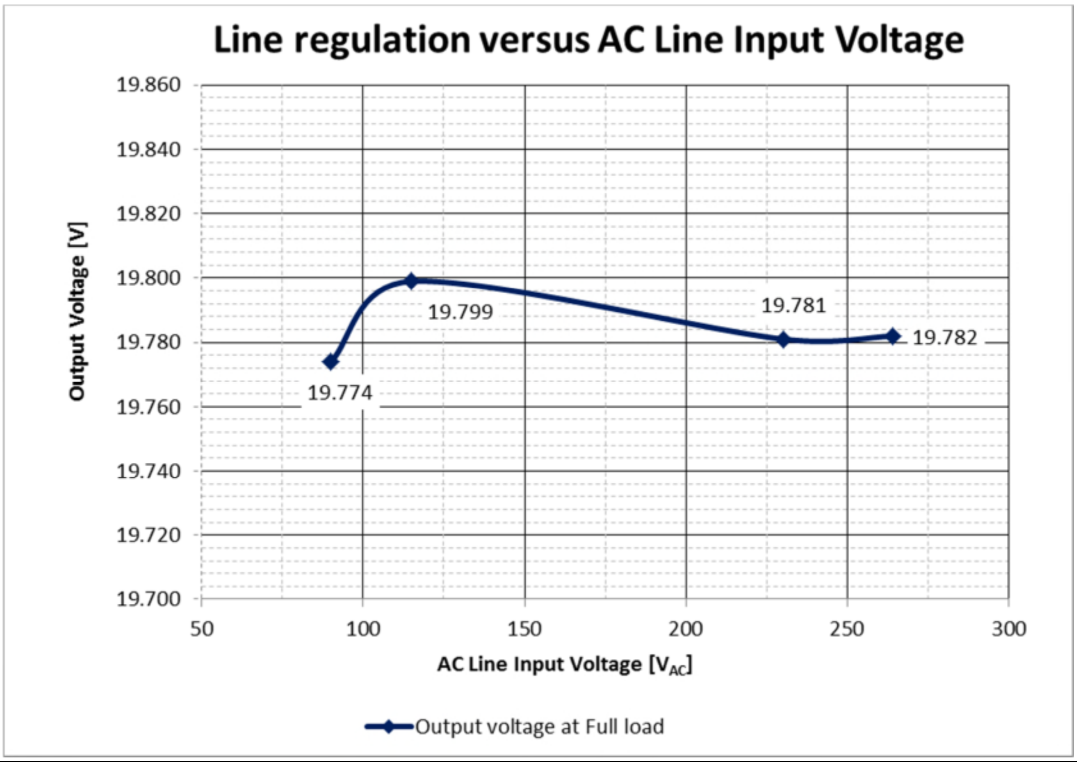


Figure 11 Line regulation V_{OUT} at full load vs AC line input voltage

11.4 Load regulation

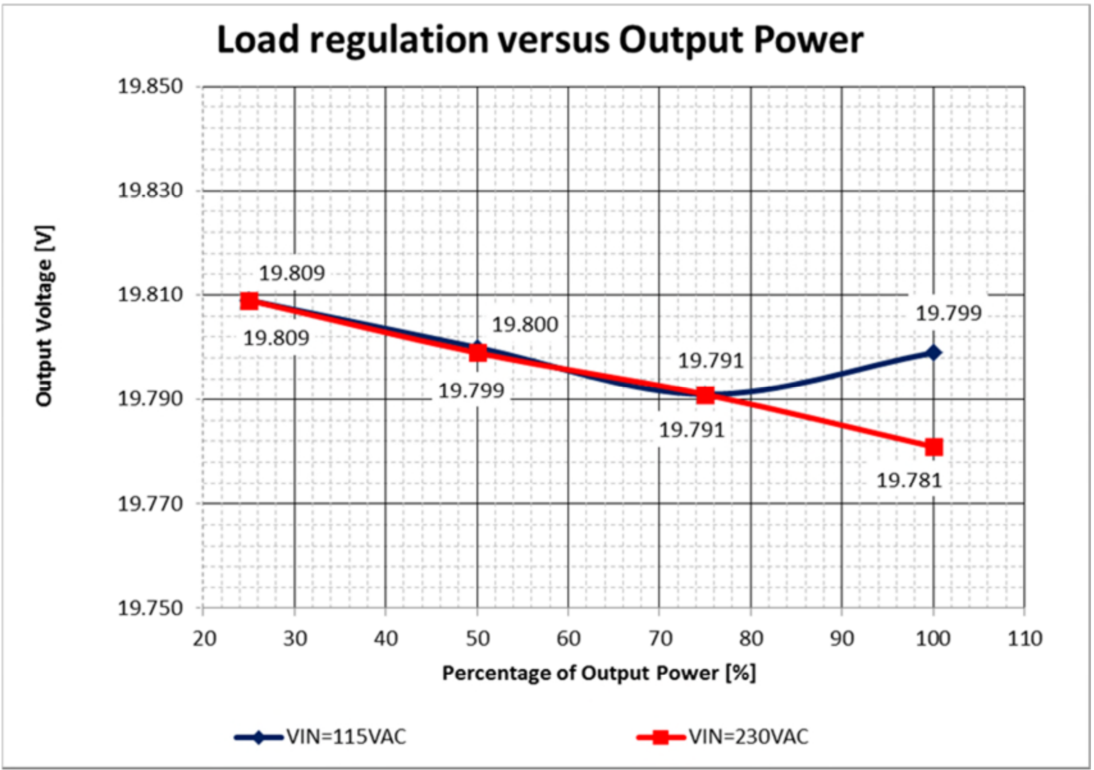


Figure 12 Load regulation V_{OUT} vs output power

11.5 Maximum output current / input power

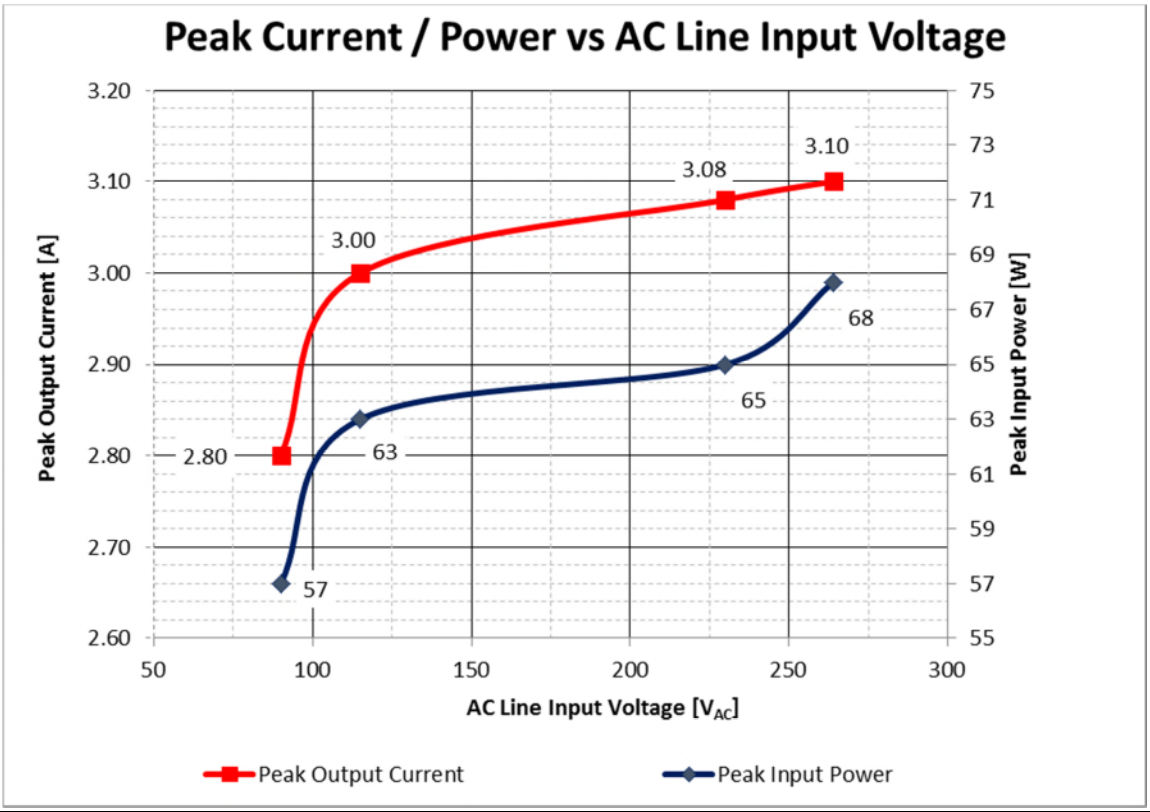


Figure 13 Maximum output current / input power vs AC line input voltage

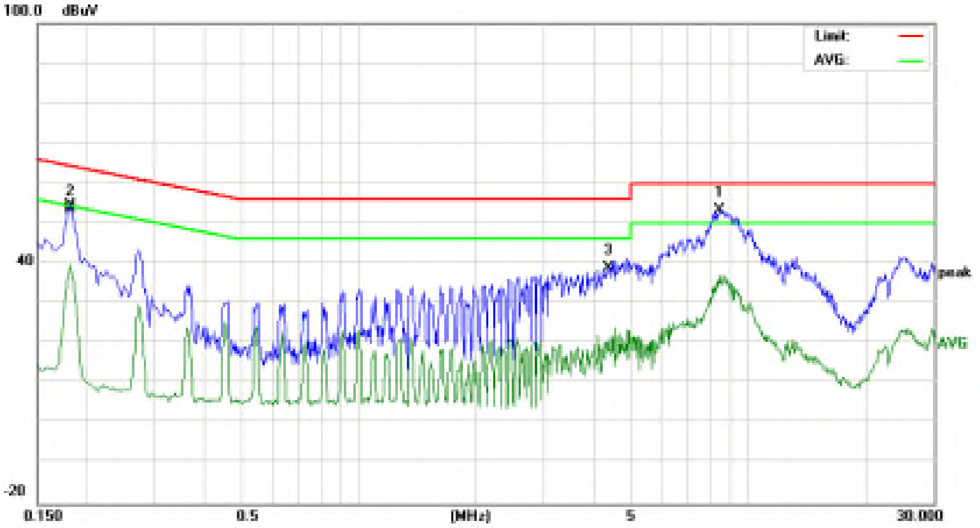
11.6 Conducted emissions (EN55022 class B)

The conducted EMI was measured by a certified laboratory (NTEK Testing Technologies Co., Ltd) and met EN55022 (CISPR 22) class B. The demo board was set up at full load (45 W) with an input voltage of 115 V_{AC} and 230 V_{AC}.
Pass conducted emissions EN55022 (CISPR 22) class B with 8 dB margin.

NTEK Testing Technology Co., Ltd.
Fenda Science Park,Sanwei Community,Xixiang Street,Bao'an District,Shenzhen
Tel: (86)-0755-61156588 Fax: (86)-0755-61156599 http://www.ntek.org.cn

Conducted Emission Measurement

File :CE0914 Data :#18 Date: 2016/09/14 Time: PM 04:40:32



Site CONDUCTION #1 Phase: L1 Temperature: 22
Limit: EN55022_Class B_(0.15-30MHz) _Main_QP Power: AC 230V/50Hz Humidity: 51 %
EUT:
M/N: 45W
Mode:
Note: 2#

No.	Mk.	Freq.	Reading Level	Correct Factor	Measure-ment	Limit	Over	Detector	Comment
		MHz	dBuV	dB	dBuV	dBuV	dB	Detector	Comment
1	*	8.4540	43.47	9.86	53.33	60.00	-6.67	peak	
2		0.1825	43.55	10.13	53.68	64.37	-10.69	peak	
3		4.4020	29.04	9.81	38.85	56.00	-17.15	peak	
4		0.1819	29.72	10.13	39.85	54.39	-14.54	AVG	
5		8.4540	27.20	9.86	37.06	50.00	-12.94	AVG	

Figure 14 Conducted emissions (line) at 115 V_{AC} and full load

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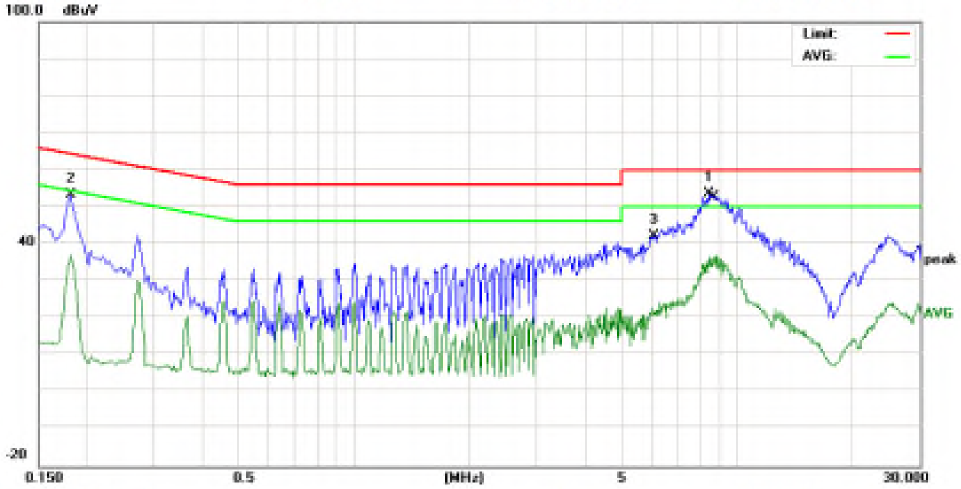
Conducted Emission Measurement

File :CE0914 Data :#19 Date: 2016/09/14 Time: PM 04:42:19



Site CONDUCTION #1 Phase: N Temperature: 22
Limit: EN55022_Class B_(0.15-30MHz) _Main_QP Power: AC 230V/50Hz Humidity: 51 %
EUT:
M/N: 45W
Mode:
Note: 2#

No.	Mk.	Freq.	Reading Level	Correct Factor	Measure-ment	Limit	Over	Detector	Comment
		MHz	dBuV	dB	dBuV	dBuV	dB		
1	*	8.4420	43.82	9.84	53.66	60.00	-6.34	peak	
2		0.1819	43.17	10.04	53.21	64.39	-11.18	peak	
3		6.0620	32.49	9.81	42.30	60.00	-17.70	peak	
4		0.1819	27.26	10.04	37.30	54.39	-17.09	AVG	
5		8.8060	27.11	9.84	36.95	50.00	-13.05	AVG	

Figure 15 Conducted emissions (neutral) at 115 V_{AC} and full load

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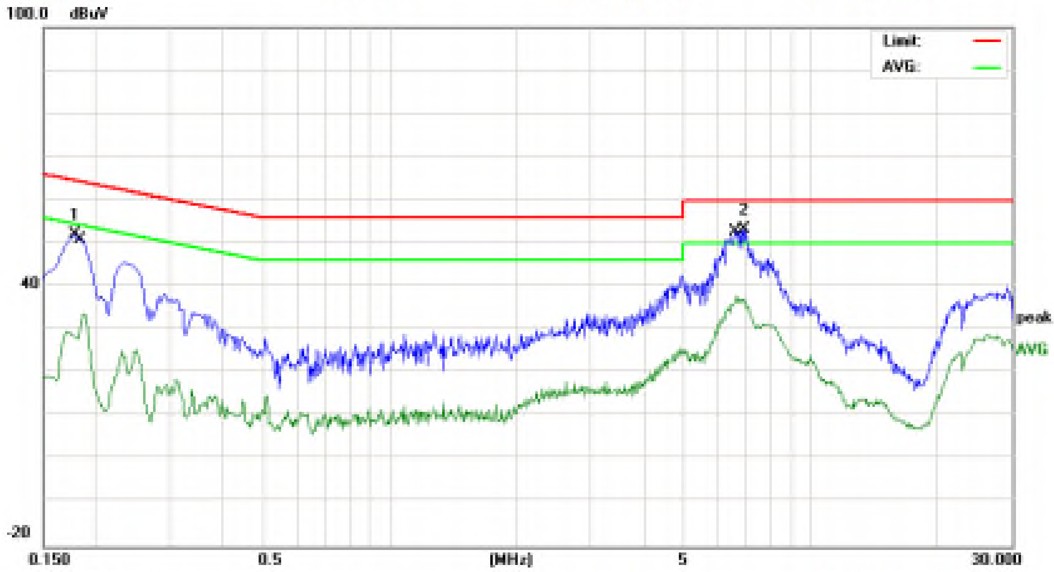
Tel: (86)-0755-61156588 Fax: (86)-0755-61156599 http://www.ntek.org.cn

Conducted Emission Measurement

File :CE0914 Data :#17 Date: 2016/09/14 Time: PM 04:38:04



Site CONDUCTION #1 Phase: L1 Temperature: 22
Limit: FCC Part 15B_(0.15-30MHz) _Main_QP Power: AC 120V/60Hz Humidity: 51 %
EUT:
M/N: 45W
Mode:
Note: 2#

No.	Mk.	Freq.	Reading Level	Correct Factor	Measure-ment	Limit	Over	Detector	Comment
		MHz	dBuV	dB	dBuV	dBuV	dB		
1		0.1780	42.10	10.13	52.23	64.57	-12.34	peak	
2	*	6.9180	43.48	9.85	53.33	60.00	-6.67	peak	
3		0.1860	23.74	10.13	33.87	54.21	-20.34	AVG	
4		6.6540	27.89	9.85	37.74	50.00	-12.26	AVG	

Figure 16 Conducted emissions (line) at 230 V_{AC} and full load

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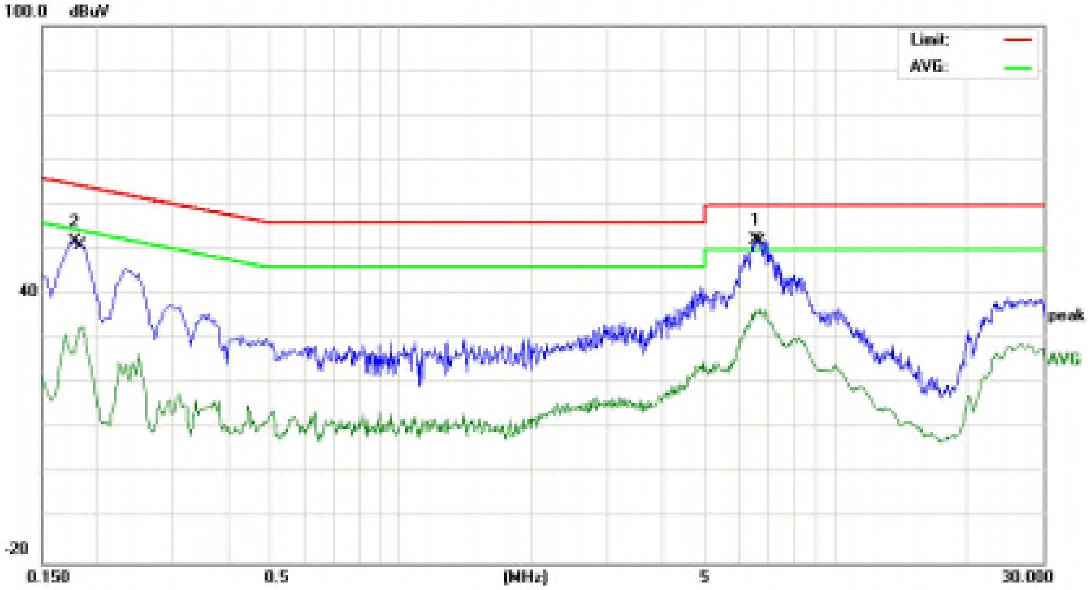
Conducted Emission Measurement

File :CE0914 Data :#16 Date: 2016/09/14 Time: PM 04:36:16



Site CONDUCTION #1 Phase: N Temperature: 22
Limit: FCC Part 15B_(0.15-30MHz) _Main_QP Power: AC 120V/60Hz Humidity: 51 %
EUT:
M/N: 45W
Mode:
Note: 2#

No.	Mk.	Freq.	Reading Level	Correct Factor	Measure-ment	Limit	Over		
		MHz	dBuV	dB	dBuV	dBuV	dB	Detector	Comment
1	*	6.5260	42.28	9.82	52.10	60.00	-7.90	peak	
2		0.1780	41.90	10.05	51.95	64.57	-12.62	peak	
3		0.1860	22.82	10.04	32.86	54.21	-21.35	AVG	
4		6.6980	26.96	9.82	36.78	50.00	-13.22	AVG	

Figure 17 Conducted emissions (neutral) at 230 V_{AC} and full load

11.7 Radiated emissions (EN55022 class B)

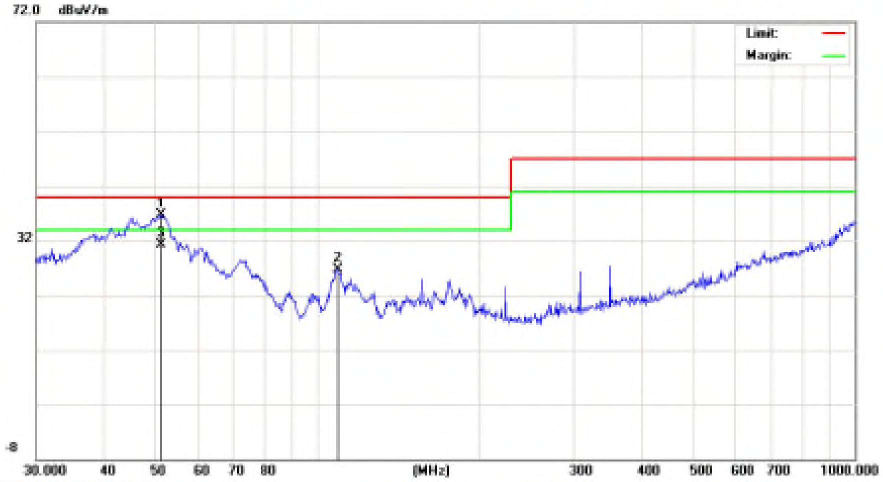
The radiated EMI was measured by a certified laboratory (NTEK Testing Technologies Co., Ltd) and met EN55022 (CISPR 22) class B (230 V_{AC}). The demo board was set up at full load (45 W) with an input voltage of 230 V_{AC}.
Pass radiated emissions EN55022 (CISPR 22) class B with 8 dB margin.

NTEK 北测检测机构 EMC Testing Centre

NTEK Testing Technology Co., Ltd.
Fenda Science Park,Sanwei Community,Xixiang Street,Bao'an
Tel: (86)-0755-61156588 Fax: (86)-0755-61156599

Radiated Emission Measurement

File :RE0914 Data :#1 Date: 2016/09/14 Time: PM 02:27:21



Site NTEK 9*6*6 Chamber #1 Polarization: *Vertical* Temperature: 24
Limit: EN55022 _ClassB_QP Power: AC 230V/50Hz Humidity: 50 %
EUT: ADAPTER Distance: 3m
M/N: 45w 1#
Mode: FULL LOAD
Note: 不接排插 滑动变阻器

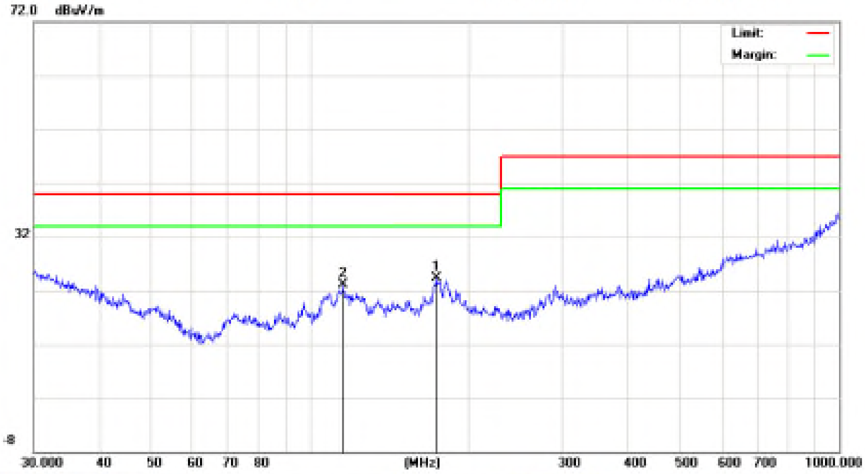
No.	Mk.	Freq.	Reading Level	Correct Factor	Measure-ment	Limit	Over		Antenna Height	Table Degree	
		MHz	dBuV	dB	dBuV/m	dBuV/m	dB	Detector	cm	degree	Comment
1	*	51.3005	26.99	9.81	36.80	40.00	-3.20	peak			
2		109.0286	15.37	11.31	26.68	40.00	-13.32	peak			
3		51.3005	21.49	9.81	31.30	40.00	-8.70	QP			

Figure 18 Radiated emissions (vertical) at 230 V_{AC} and full load

NTEK Testing Technology Co., Ltd.
Fenda Science Park,Sanwei Community,Xixiang Street,Bao'an
Tel: (86)-0755-61156588 Fax: (86)-0755-61156599

Radiated Emission Measurement

File :RE0914 Data :#2 Date: 2016/09/14 Time: PM 02:32:02



Site NTEK 9*6*6 Chamber #1 Polarization: *Horizontal* Temperature: 24
Limit: EN55022 _ClassB_QP Power: AC 230V/50Hz Humidity: 50 %
EUT: ADAPTER Distance: 3m
M/N: 45w 1#
Mode: FULL LOAD
Note: 不接排插 滑动变阻器

No.	Mk.	Freq.	Reading Level	Correct Factor	Measure-ment	Limit	Over	Detector	Antenna Height	Table Degree	Comment
		MHz	dBuV	dB	dBuV/m	dBuV/m	dB	Detector	cm	degree	Comment
1	*	173.2051	10.87	13.52	24.39	40.00	-15.61	peak			
2		115.7256	11.73	11.33	23.06	40.00	-16.94	peak			

Figure 19 Radiated emissions (horizontal) at 230 V_{AC} and full load

11.8 ESD immunity (EN61000-4-2)

The electrostatic discharge test was measured by a certified laboratory (NTEK Testing Technologies Co., Ltd) and met EN61000-4-2. The demo board was set up at full load (45 W) with an input voltage of 230 V_{AC}.
Pass EN61000-4-2 contact discharge ±8 kV.

11.9 Surge immunity (IEC61000-4-5)

The surge immunity test was measured by a certified laboratory (NTEK Testing Technologies Co., Ltd) and met IEC61000-4-5. The demo board was set up at full load (45 W) with an input voltage of 230 V_{AC}.
Pass IEC61000-4-5 installation class 3; differential mode > ±1 kV and common mode > ±2 kV.

11.10 Thermal measurement

The reference adapter's open frame thermal test was performed with a thermal infrared camera (TVS-500EX) at an ambient temperature of 25^{0}C. The thermal measurements were taken after one hour running at full load.

Table 4 Thermal measurement of REF-45W ADAPTER

No.	Component	100 V_{AC} & 45 W load (°C)
1	DB1 (Bridge diode)	74.0
2	Q1 (Primary MOSFET)	63.7
3	T1 (Transformer)	75.4
4	D2 (Secondary diode)	71.2
5	Ambient	30.9

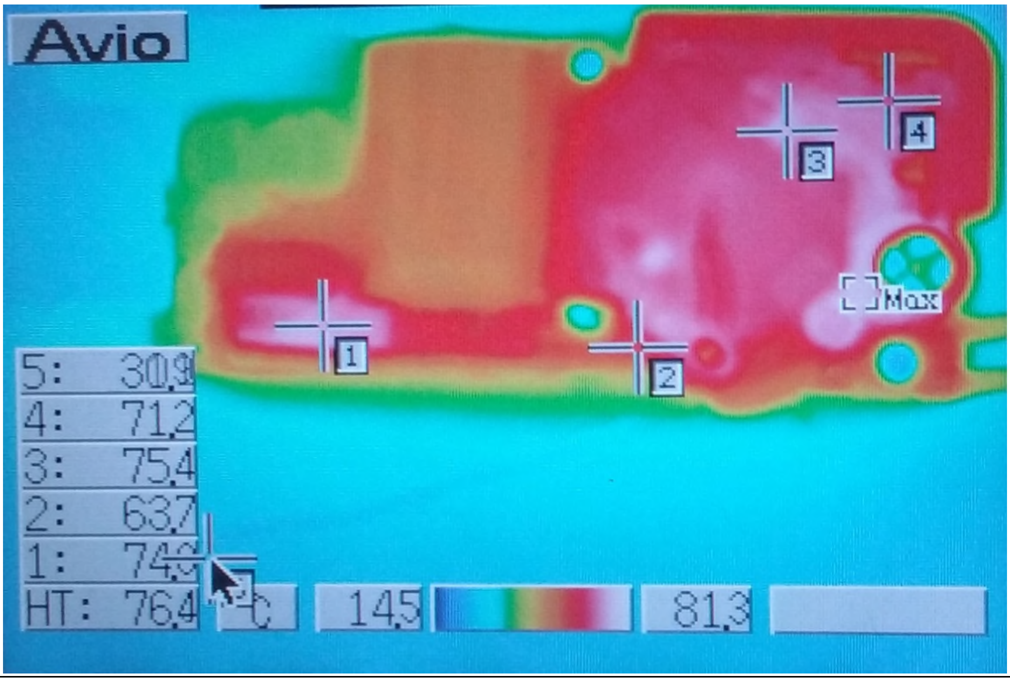
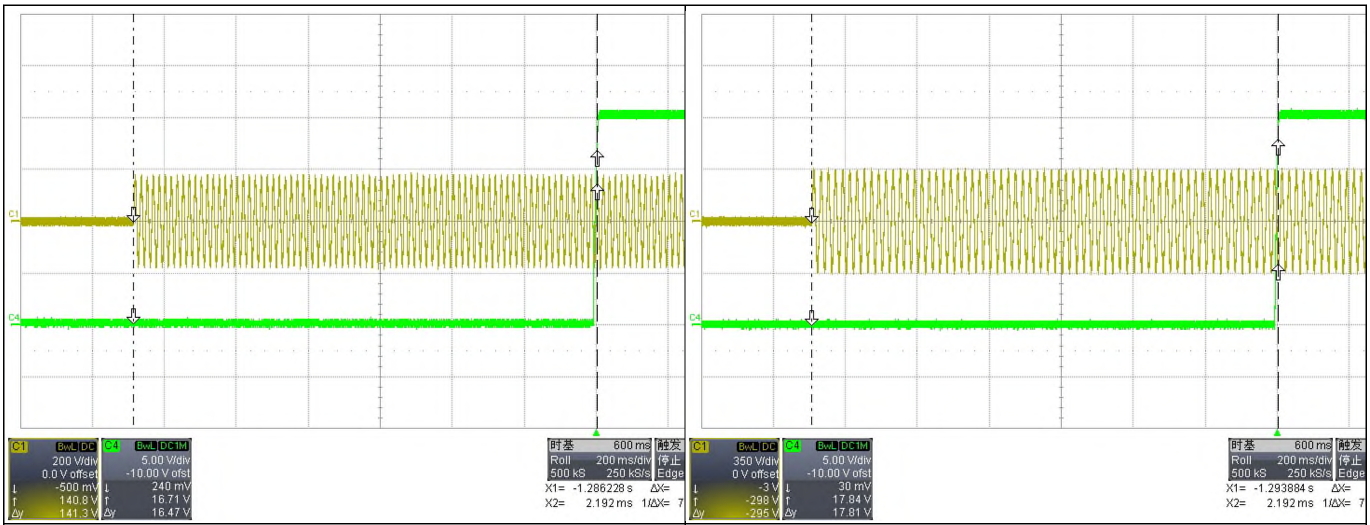


Figure 20 Infrared thermal image of REF-45 W ADAPTER (PCB top side, 100 V_{AC} & full load)

12 Waveforms and scope plots

All waveforms and scope plots were recorded with a Lecroy Wavesurfer 24Xs-A.

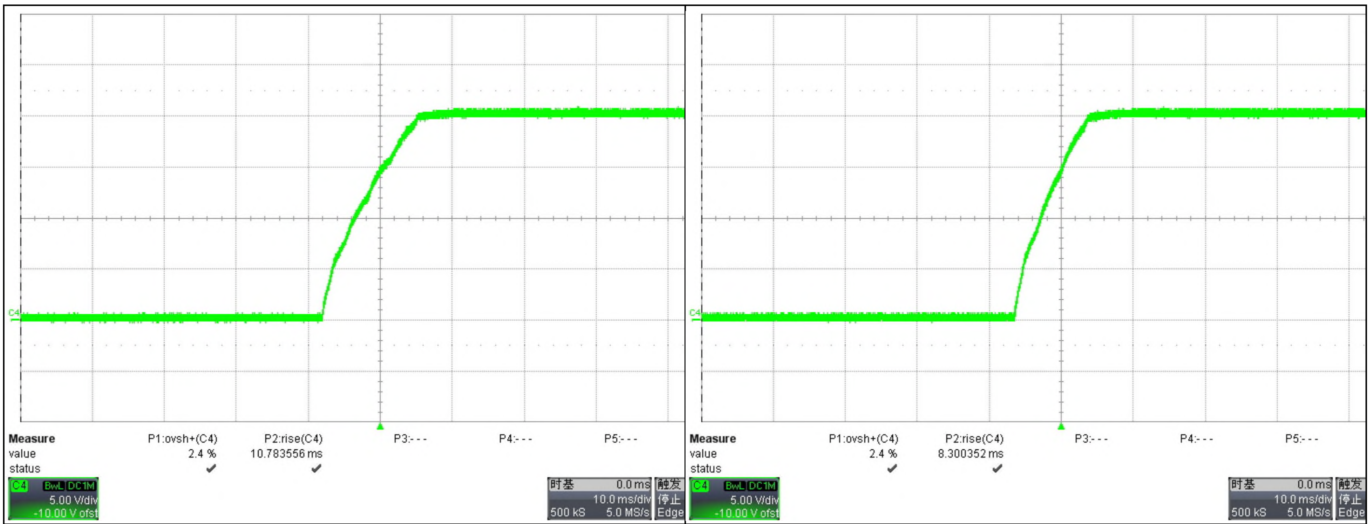
12.1 Start up delay



C1 (Yellow) : Input voltage C4 (Green) : Output voltage(V_{OUT})	C1 (Yellow) : Input voltage C4 (Green) : Output voltage(V_{OUT})
Startup time at 115 V_{AC} & ful lload ≈ 1.29 s	Startup time at 230 V_{AC} & full load ≈ 1.29 s

Figure 21 Start up delay

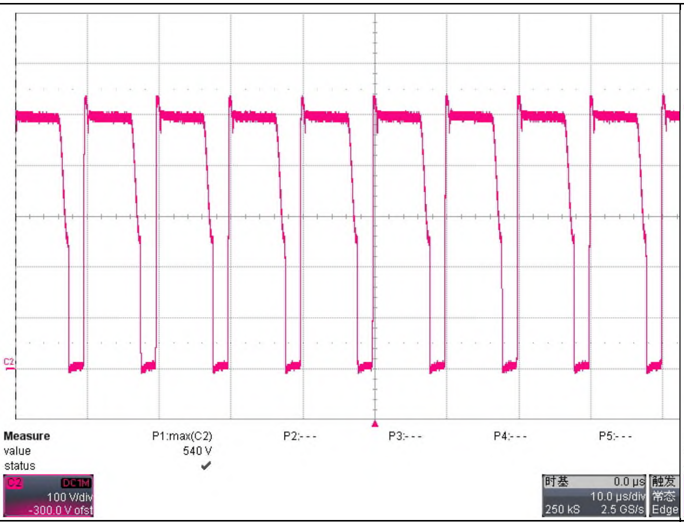
12.2 Output rise time

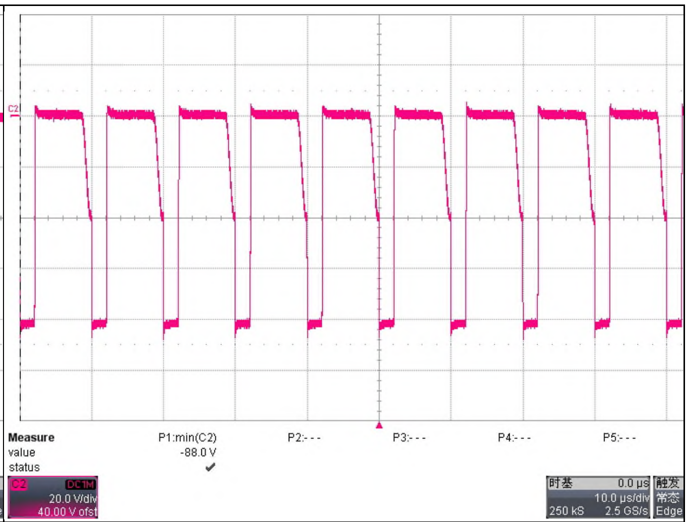


C4 (Green) : Output voltage(V_{OUT})	C4 (Green) : Output voltage(V_{OUT})
Output rise time at 115 V_{AC} and full load ≈ 10.8 ms	Output rise time at 230 V_{AC} and full load ≈ 8.3 ms

Figure 22 Output rise time

12.3 Voltage stress of main MOSFET and output diode at full load

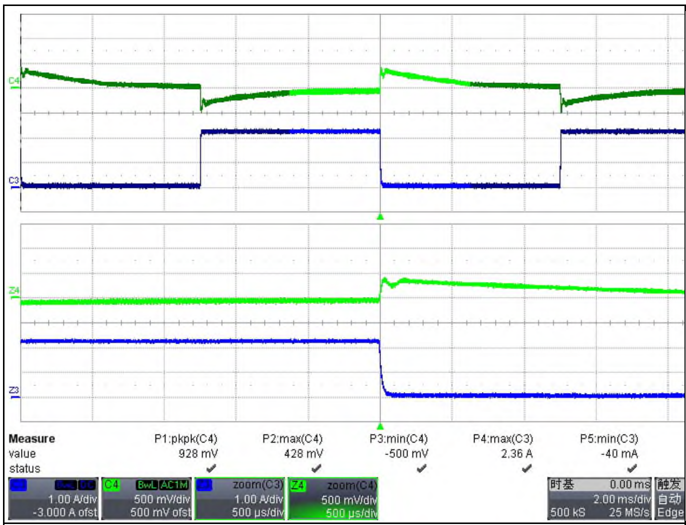


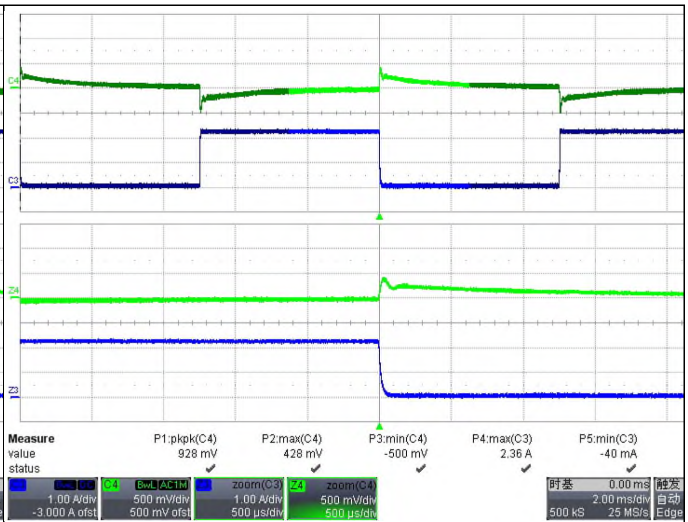


C2 (Red) : Drain Source voltage of Q1	C2 (Red) : Reverse voltage of D2
At 264 V_{AC}, full load : $V_{Drain\_source\_max}$ ≈ 540 V	At 264 V_{AC}, full load : V_{r_max} ≈ 88 V

Figure 23 Drain and current sense voltage at full load

12.4 Load transient response (dynamic load)

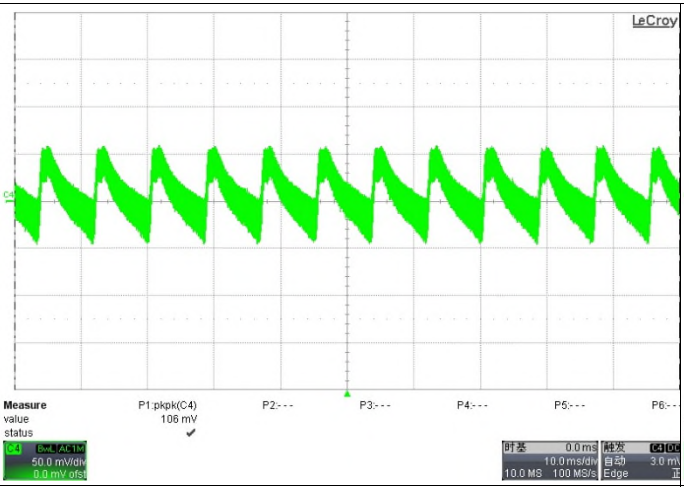


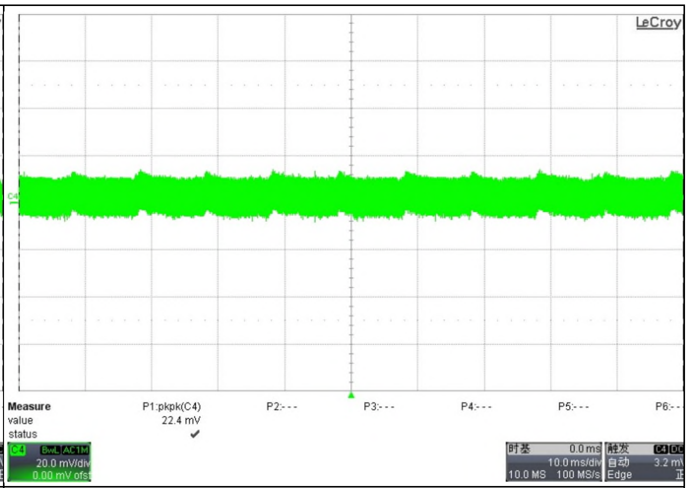


C3 (Blue) : Output current (I_{OUT}) C4 (Green) : Output ripple voltage (V_{out_ripple})	C3 (Blue) : Output current (I_{OUT}) C4 (Green) : Output ripple voltage (V_{out_ripple})
At 90 V_{AC}, Io=0.05 ⟷ 2.25 A 1.5 A/µs, $V_{ripple\_pk\_pk}$ ≈ 428 mV Scope set at 20 MHz bandwidth	At 264 V_{AC}, Io=0.05 ⟷ 2.25 A 1.5 A/µs, $V_{ripple\_pk\_pk}$ ≈ 428 mV Scope set at 20 MHz bandwidth

Figure 24 Load transient response

12.5 Output ripple voltage at full load

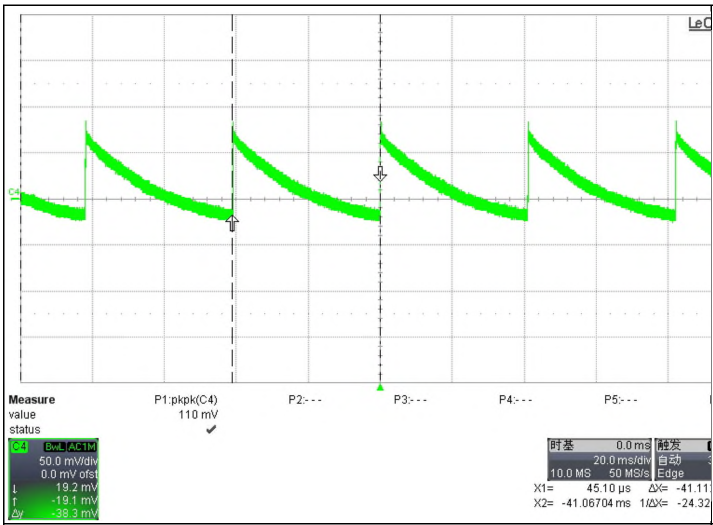


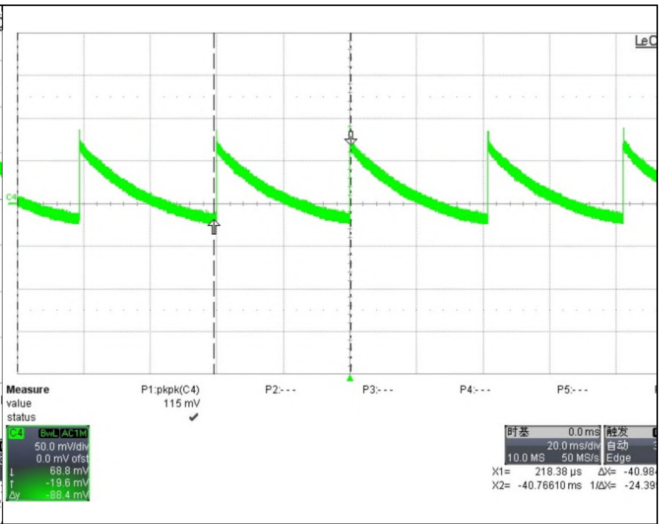


C4 (Green) : Output ripple voltage (V_{out_ripple})	C4 (Green) : Output ripple voltage (V_{out_ripple})
At 90 $V_{AC,}$ full load $V_{ripple\_pk\_pk}$ ≈ 106 mV Scope set at 20 MHz bandwidth	At 264 $V_{AC,}$ full load $V_{ripple\_pk\_pk}$ ≈ 22.4 mV Scope set at 20 MHz bandwidth

Figure 25 Output ripple voltage at full load

12.6 Output ripple voltage at no load (burst mode)





CH4 (Green) : Output current (I_{OUT})	CH4 (Green) : Output current (I_{OUT})
At 90 $V_{AC,}$ no load $V_{ripple\_pk\_pk}$ ≈ 110 mV Scope set at 20 MHz bandwidth	At 264 $V_{AC,}$ no load $V_{ripple\_pk\_pk}$ ≈ 115 mV Scope set at 20 MHz bandwidth

Figure 26 Output ripple voltage at no load (burst mode)

12.7 Active burst mode waveforms

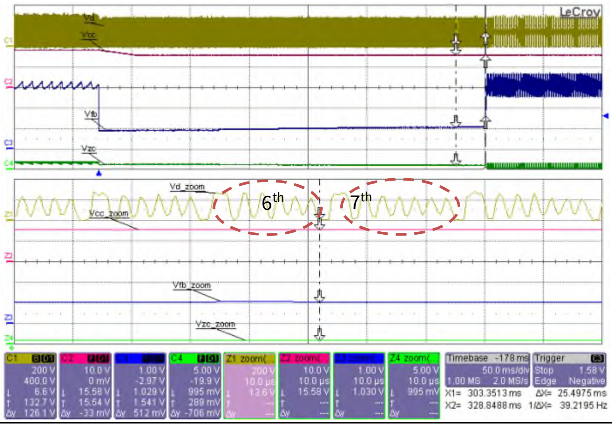
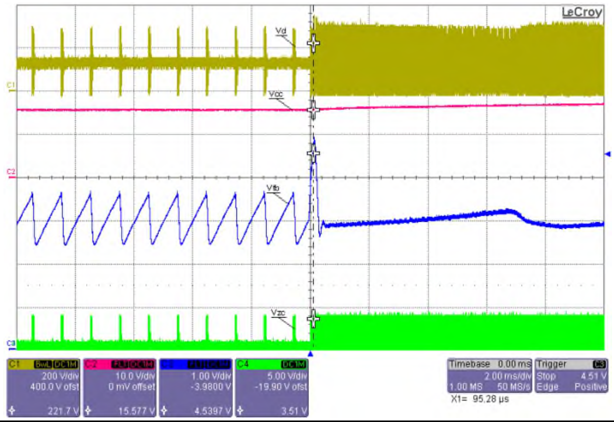
	
CH1 (Yellow) : Drain voltage (V_D) CH2 (Purple) : Supply voltage (V_{VCC}) CH3 (Blue) : Feedback voltage (V_{FB}) CH4 (Green) : Zero crossing voltage (V_{ZC})	CH1 (Yellow) : Current sense voltage (V_{CS}) CH2 (Purple) : Supply voltage (V_{VCC}) CH3 (Blue) : Feedback voltage (V_{FB}) CH4 (Green) : Zero crossing voltage (V_{ZC})
Condition: V_{FB}<1.2 V, N_{ZC}=7 and $t_{blanking}$ =24 ms (load change from full load to 1 W load)	Condition: V_{FB} > 4.5 V (load change from 1 W load to full load)

Figure 27 Active burst mode at 90 V_{AC}

12.8 Over load protection (auto restart mode)

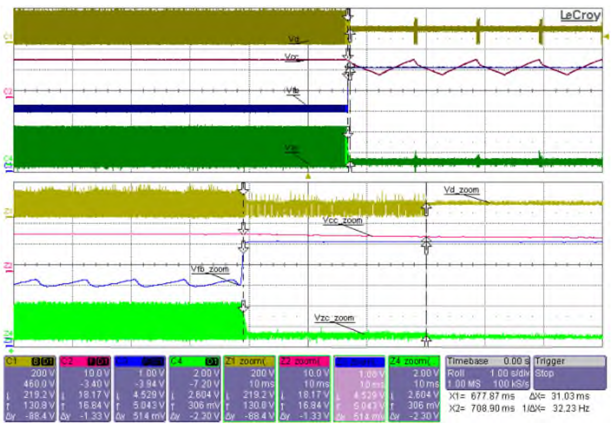
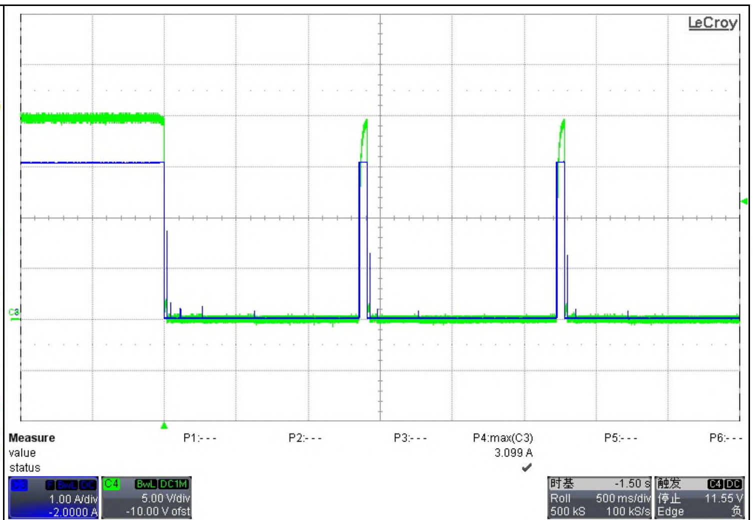
	
CH1 (Yellow) : Drain voltage (V_D) CH2 (Purple) : Supply voltage (V_{VCC}) CH3 (Blue) : Feedback voltage (V_{FB}) CH4 (Green) : Zero crossing voltage (V_{ZC})	CH3 (Blue) : Drain voltage (V_D) CH4 (Green) : Output voltage (V_{OUT})
Condition: V_{FB} > 4.5 V & 30 ms blanking time At 90 V_{AC}, short output from full load, Result: system enters auto restart mode.	At 230 V_{AC}, increase load until OLP. Result: system enters auto restart mode at I_O = 3.1 A.

Figure 28 Over load protection

12.9 Output overvoltage protection (latched mode)

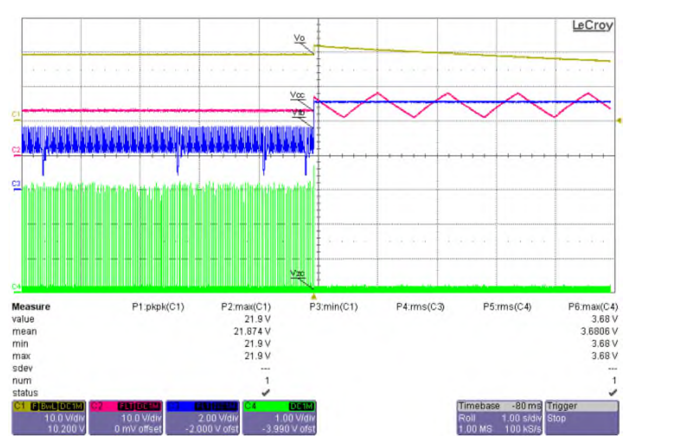
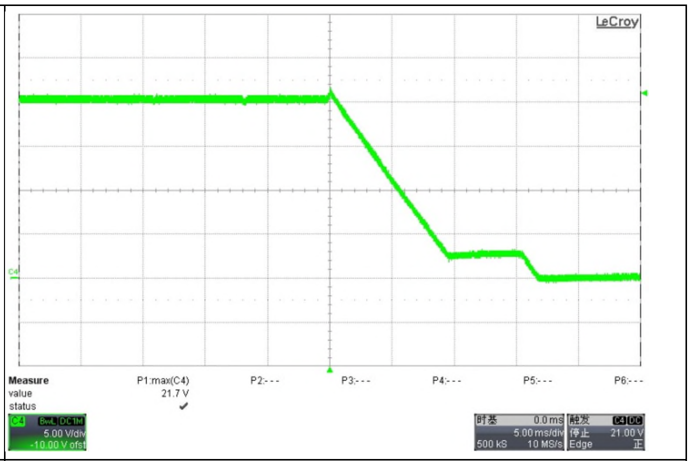
	
CH1 (Yellow) : 20 V output voltage (V_{OUT}) CH2 (Purple) : Supply voltage (V_{VCC}) CH3 (Blue) : Feedback voltage (V_{ZC}) CH4 (Green) : Zero crossing voltage (V_{ZC})	CH4 (Green) : 20 V output voltage (V_{OUT}) *Note:*
Condition: V_{ZC}>3.7 V, latch At 90 V_{AC} no load, short R15 during system operation, V_{OUT} reaches 21.9 V and enter OVP latch protection.	Condition: V_{ZC}>3.7 V, latch At 230 V_{AC} 1.125 A load, short R15 during system operation, V_{OUT} reaches 21.7 V and enter OVP latch protection.

Figure 29 Output overvoltage protection

12.10 Brownin/brownout protection

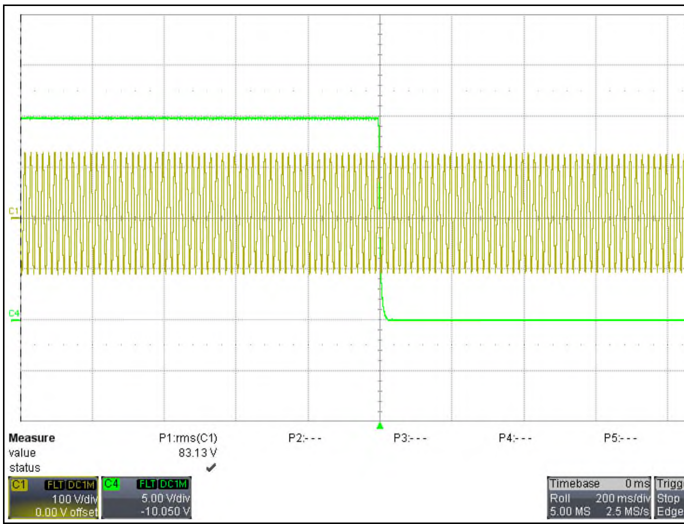
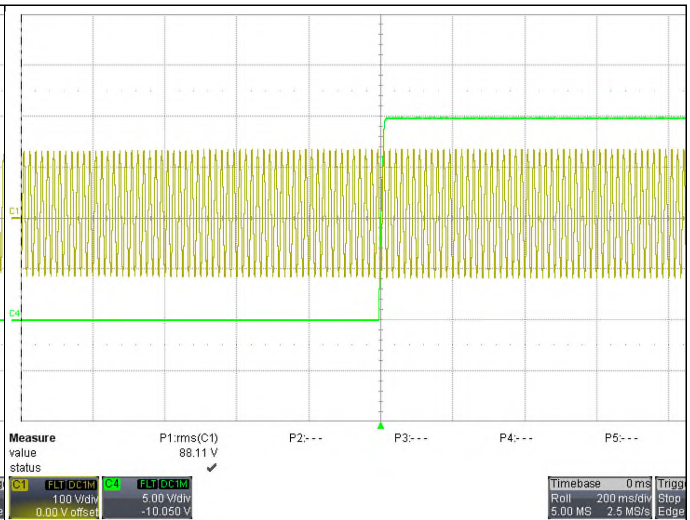
	
CH1 (Yellow) : Input voltage (V_{IN}) CH4 (Green) : Output voltage (V_{OUT})	CH1 (Yellow) : Input voltage (V_{IN}) CH4 (Green) : Output voltage (V_{OUT})
Increase input voltage until output starts up to operate, full load. Brownin voltage : 88.11 V_{AC}	Decrease input voltage until output voltage drops to 0V, full load. Brownout voltage : 83.13 V_{AC}

Figure 30 Bronwin/brownout protection

13 References

[1] ICE2QS03G data sheet, Infineon Technologies AG
[2] IPA60R650CE data sheet, 650V CoolMOS™ CE Power Transistor, Infineon Technologies AG
[3] 2N7002 data sheet, Infineon Technologies AG
[4] BAS21-03W data sheet, Infineon Technologies AG
[5] ICE2QS03G design guide. [ANPS0027]

Revision history

Major changes since the last revision

Page or reference	Description of change
--	First release

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