AP3917B 12V/20mA + 3.8V/20mA EV3 Board User Guide

DUAL OUTPUT OFF-LINE NON-ISOLATED FLY-BACK POWER SOLUTION

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1. Introduction

1.1. General Description

The AP3917B is an off-line universal AC voltage input step-down regulator that provides accurate constant voltage (CV), outstanding low standby power, light loading efficiency, and dynamic performance. The chip supports non-isolated buck and buck-boost topology, and isolated and non-isolated flyback topology. The device is suited for cost-effective power for home appliances.

Working with a single winding inductor and integrating a 650V MOSFET when used in buck topology, the BOM cost is very low.

The AP3917B EV3 Evaluation Board contains two outputs specifications: 12V/20mA and 3.8V/20mA, both featuring non-isolation flyback. The two outputs share a three-winding transformer. The feedback circuitry samples a 3.8V output. This user guide provides design examples for dual-output power applications in home-appliance power.

1.2. Key Features

- Universal 85V to 264V V_{AC} Input
- Internal MOSFET 650V ($R_{DS(ON)}$) 10Ω max. @25℃)
- Maximum output current: 170mA typ.@5V output
- Low standby power consumption
- High light-loading efficiency and average efficiency meeting DOE IV and CoC V5 Tier 2
- Frequency modulation to suppress EMI, meeting EN55032 and FCC part 15 class B
- Rich protection features including OTP, OLP, OLD, and SCP
- Extremely low system component count.
- **Totally Lead-free & Fully RoHS Compliant (SO-7)**
- **Halogen and Antimony Free. “Green” Device**

1.3. Applications

- Non-isolated home appliances including:
  - AC fans
  - Rice cookers
  - Air conditioners
  - Coffee machines
  - Soymilk machines
- Auxiliary power to IoT devices.

1.4. Board Picture

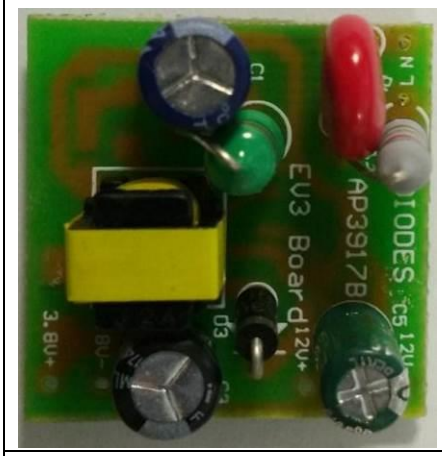

Fig.1-1, Top View

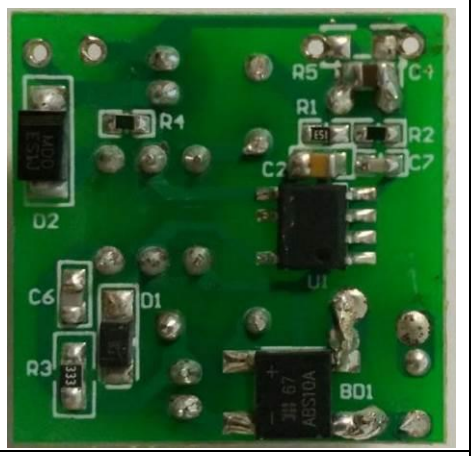

Fig. 1-2, Bottom View

2. Power Supply Specification

2.1. System Performance

The system performance specifications include input and output characteristics, EMC, protections, and more.

Items		Min.	Typ.	Max.	Comments
Input Characteristics					
Input AC Voltage Rating		100V/60Hz	115/230	240V/50Hz	Two-wire, no PE
Input AC Voltage Range		85V/60Hz	-	264V/50Hz	
Input AC Frequency Range		47Hz	50/60	63Hz	
Output Characteristics					
Output Voltage 1		11.1V	12.0V	12.9V	Test at board terminal
Output Voltage 1		3.61V	3.8V	3.99V	
Loading Current 1		0	-	20mA	mA
Loading Current 2		4	-	20mA	
Performance Specifications					
Standby Power		-		12mW	@230V/50Hz
Efficiency		-	74.32%/72.98%	-	@full load, 115V/230V
Ripple and Noise	12V	-	192mV	220mV	@full load
	3.8V	-	101mV	150mV	
Start-Up Time		-	16.8ms	20ms	@full load, 85V/60Hz
EMC Testing					
ESD Test	Air	±15kV	-	-	@full load condition
	contract	±8kV	-	-	
Surge Test		±0.5kV	-	-	Differential mode, 2Ω, 1.2/50μs
Conduction EMI	110V	6dB Margin	-	-	FCC Part 15 Class B
	230V	6dB Margin	-	-	EN55032
Protection Functions					
SCP Test		-	-	-	OK
OLP Test		-	-	-	OK
OTP Test		135℃	150℃	165℃	OK

2.2. Environment

- Operation temperature: -20℃~85℃
- Operation humidity: 20%~90% R.H.
- Storage temperature: 0~40℃
- Storage humidity: 0%~95% R.H.

3. Schematic and Bill of Materials

3.1. Schematic

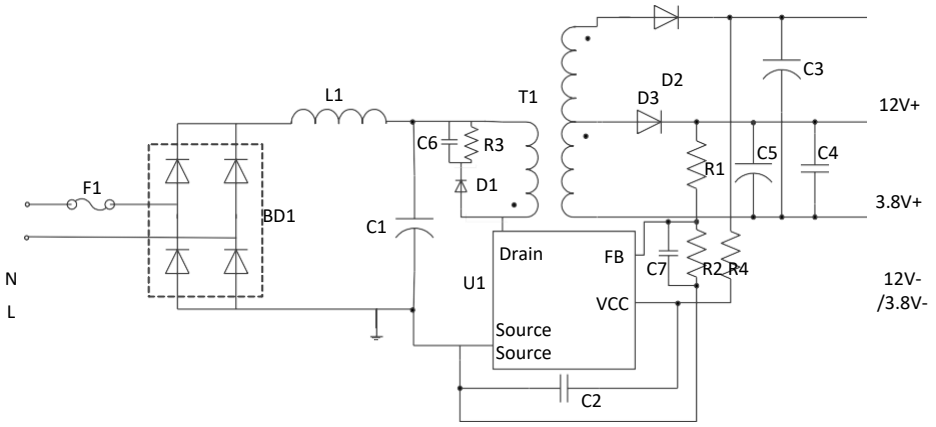

Fig. 3-1, Evaluation Board Schematic

3.2. Bill of Materials

Table 3-1, Bill of Materials

Item	Designator	Description	Footprint	Qty.	Manufacturer
1	F1	8.2R, fusible resistor	Φ3*10mm	1	OAHE
2	BD1	ABS10A, bridge diode	SOPA-4	1	Diodes
3	C1	2.2uF/400V, electrolytic capacitor	Φ6*9mm	1	Aishi
4	C2	2.2uF/25V, X7R	SMD 0805	1	Telesky
5	C3	100uF/16V, electrolytic capacitor	Φ6*7mm	1	Aishi
6	C4	10uF/16V, X7R	SMD 0805	1	Telesky
7	C5	22uF/16V, electrolytic capacitor	Φ5*10mm	1	Telesky
8	C6	470pF/500V, X7R	SMD 0805	1	Telesky
9	C7	470pF/50V, X7R	SMD 0805	1	Telesky
10	D1	S1MWF-7, slow type diode, mark F9	SOD123-FL	1	Diodes
11	D2	ES1J, 1A/600V, Trr 35ns	SMA	1	Diodes
12	D3	APD260, Schottky diode, 2A/60V	DO-41	1	Diodes
13	L1	2.2mH,choke inductor	DIP, 0406	1	Deloop
14	T1	EE8.3, Horizontal	DIP, 3+3Pin,Horizontal	1	Deloop
15	R1	13.0k, thick film	SMD 0805, 1%	1	Panasonic
16	R2	24.7k, thick film	SMD 0805, 1%	1	Panasonic
17	R3	330k, thick film	SMD 0805, 5%	1	Panasonic
18	R4	27k, thick film	SMD 0805, 5%	1	Panasonic
19	U1	AP3917B	SO-7	1	Diodes
Total		19pcs			

3.3. Transformer Specification

3.3.1. Electrical Diagram

Bobbin: EE8.3, 3+3Pin, Horizontal Core:
PC40, Ae=7mm^2

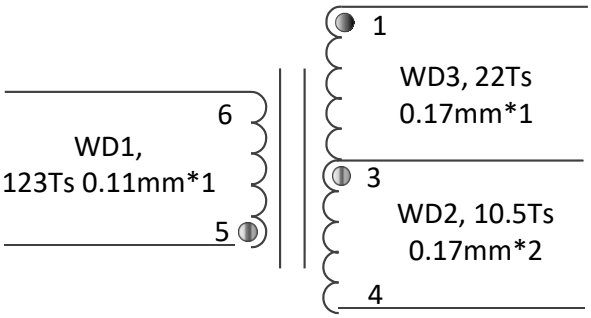

Fig. 3-2, Transformer Electrical Diagram

3.3.2. Transformer Instructions

Winding	Wire	Turns	Notes
5-6	0.11mm*1 UEW	123	Three layers with tight tension
Tape	W=5mm	2	Full layer
3-4	0.17mm*2 UEW	10.5	One layer with tight tension
Tape	W=5mm	2	Full layer
1-3	0.17mm*1 UEW	23	One layer with tight tension
Tape	W=7mm	2	Full layer

Note: The transformer must be varnished. Put the transformer in the varnish for 30min, then remove it and place in the oven at 90℃ for at least 6 hours.

3.3.3. Electrical Specifications

Item	Pins	Inductance	Conditions
Main inductance	5-6	800μH±7%	1/3/4pin open, 1V/10kHz
Leak inductance	5-6	<50μH	1/3/4pin short, 1V/10kHz

4. Evaluation Board Connections

4.1. PCB Layout

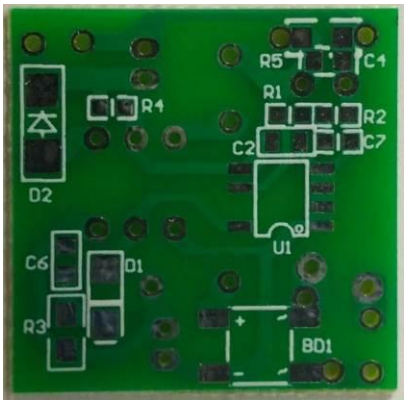

Fig. 4-1, PCB Board Layout Top View

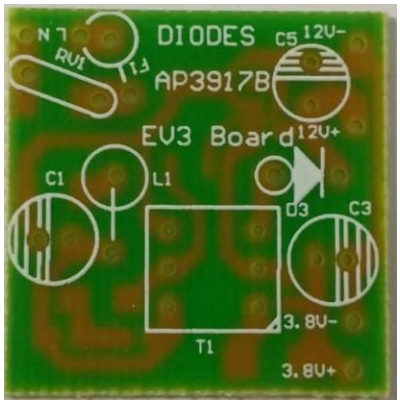

Fig. 4-2, PCB Board Layout Bottom View

4.2. Circuit Description

4.2.1. Input EMI Filtering

The input stage is composed of a fusible resistor (RF1), bridge diode (BD1), capacitor (C1), and inductor (L1). Resistor RF1 is a flame proof, fusible, wire-wound resistor. It limits inrush current to safe levels for bridge diodes, provides differential mode noise reduction, and acts as an input fuse in the event of a short circuit. Inductor L1 and capacitor C1 constitute an LC filter, which can smooth the input voltage and improve EMI conduction.

4.2.2. Control IC

The AP3917B co-packages a 650V power MOSFET and control circuitry into a cost-effective SO-8 package. The device receives its start-up current from the DRAIN pin with a small capacitor C3, connected to the BP pin when AC source is applied.

4.2.3. Flyback Block

The flyback system is coupled in a transformer and contains two outputs: 12V and 3.8V. The 3.8V output winding and 12V output winding are in series; if the turn ratio of the 12V winding to 3.8V winding is approximate to 12/3.8, the output voltage can be fixed to 12V and 3.8V.

4.2.4. Output Rectification

During the ON time of U1, current ramps up in the main inductance of transformer T1 until the current reaches the Ipk. During the OFF time, the inductor current ramps down via diodes D2 and D3. D2 and D3 must be ultra-fast diodes or Schottky diodes (Trr<50ns or lower). Capacitor C3/C5 should be selected to have an adequate ripple margin.

4.2.5. Output Feedback

The voltage across C4/C5 is quite smooth, so the divider R1 and R2 can reflect the output voltage. The output voltage dividend by R1 and R2 is sent to the feedback pin to regulate the 3.8V output voltage, thus regulating the 12V output voltage. The small capacitor C7 uses about several hundreds of pF to prevent sharp noise from sampling circuit.

4.3. Quick Start Guide

1. The evaluation board is preset at 12V/20mA+3.8V20mA from the output.
2. Ensure that the AC source is switched OFF or disconnected before doing a connection.
3. Connect the AC line wires of the power supply to “L and N” on the board’s left side.
4. Turn on the AC main switch.
5. Measure output terminals to ensure correct output voltages of Vo1 and Vo2 respectively.

5. System Test

5.1. Input & Output Characteristics

5.1.1. Input Standby Power

The standby power and output voltage were tested after 10min of burning. The voltage data was tested at the PCB terminal. All data was tested at room temperature.

Table 5-1, standby power and no load output voltage

Input Voltage	Pin (mW)	Vo1 (V)	Vo2 (V)
85V/60Hz	5.0	3.791	12.202
115V/60Hz	5.4	3.791	12.205
230V/50Hz	7.8	3.788	12.197
264V/50Hz	8.6	3.788	12.197

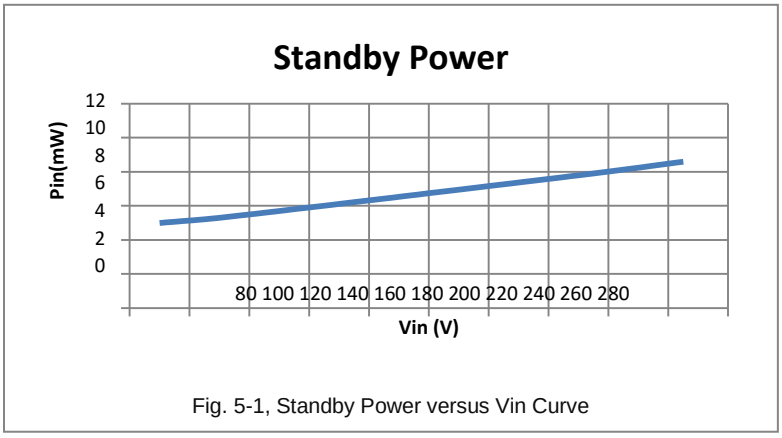

Fig. 5-1, Standby Power versus Vin Curve

5.1.2. Efficiency

The efficiency data was tested after 10min burning and at the PCB terminal. All data was tested at room temperature; 12V and 3.8V full load, input voltage ranges from 85V/60Hz to 265V/50Hz.

Table 5-2, Full load efficiency VS Vin data

Vin	Vo1(V)	Vo2(V)	Pin(W)	Eff.
85V/60Hz	3.752	12.291	0.451	73.22%
115V/60Hz	3.746	12.280	0.452	72.98%
150V/60Hz	3.749	12.282	0.444	74.32%
180V/50Hz	3.748	12.280	0.446	73.97%
200V/50Hz	3.748	12.280	0.447	73.80%
230V/50Hz	3.746	12.280	0.452	72.98%
265V/50Hz	3.746	12.278	0.460	71.70%

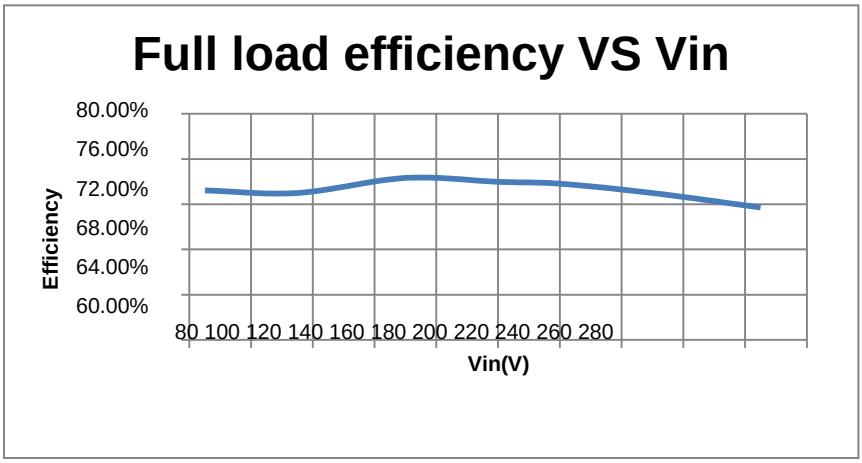

Fig. 5-2, Full load efficiency VS Vin

5.1.3. Line Regulation

The line regulation data was tested after 10min of burning. The voltage data was tested at the PCB terminal. All the data was tested at room temperature; 3.8V and 12V at full load, Vin ranges from 85V to 264V.

Table 5-3, line and load regulation data

Vin	Vo1 Output (V)	Vo2 Output (V)
85V/60Hz	3.752	12.291
115V/60Hz	3.746	12.280
150V/60Hz	3.749	12.282
180V/50Hz	3.748	12.280
200V/50Hz	3.748	12.280
230V/50Hz	3.746	12.280
265V/50Hz	3.746	12.278

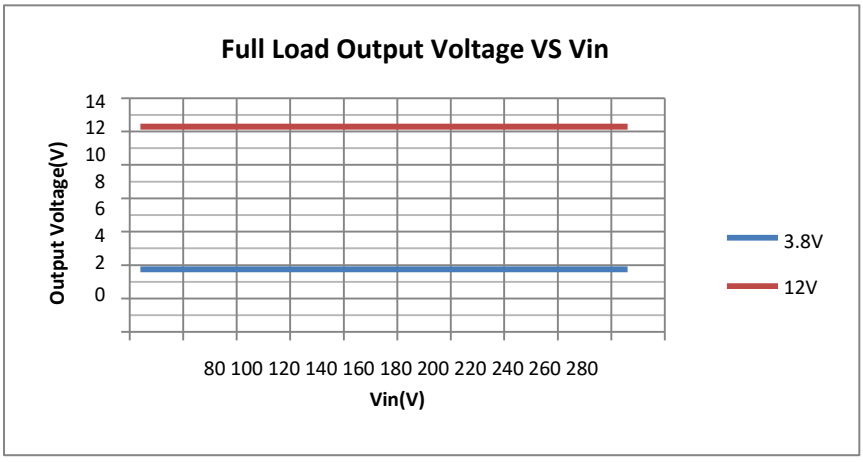

Fig 5-3, 3.8V and 12V full load, output voltage versus input voltage

5.1.4. Load Regulation

The load regulation data was tested after 10min of burning. The voltage data was tested at the PCB terminal. All data was tested at room temperature. The load of the Vo1 and Vo2 terminals both range from 10% to 100%.

Table 5-4, Vo1 and Vo2 output voltage

Vin	10%		25%		50%		75%		100%	
	Vo1(V)	Vo2(V)	Vo1(V)	Vo2(V)	Vo1(V)	Vo2(V)	Vo1(V)	Vo2(V)	Vo1(V)	Vo2(V)
85V/60Hz	3.788	11.578	3.785	11.772	3.788	11.937	3.772	12.057	3.768	12.157
115V/60Hz	3.788	11.585	3.784	3.777	3.774	11.932	3.772	12.052	3.766	12.157
230V/50Hz	3.786	11.572	3.781	11.757	3.774	11.922	3.769	12.047	3.764	12.147
265V/50Hz	3.785	11.572	3.780	11.755	3.774	11.922	3.768	12.045	3.763	12.147

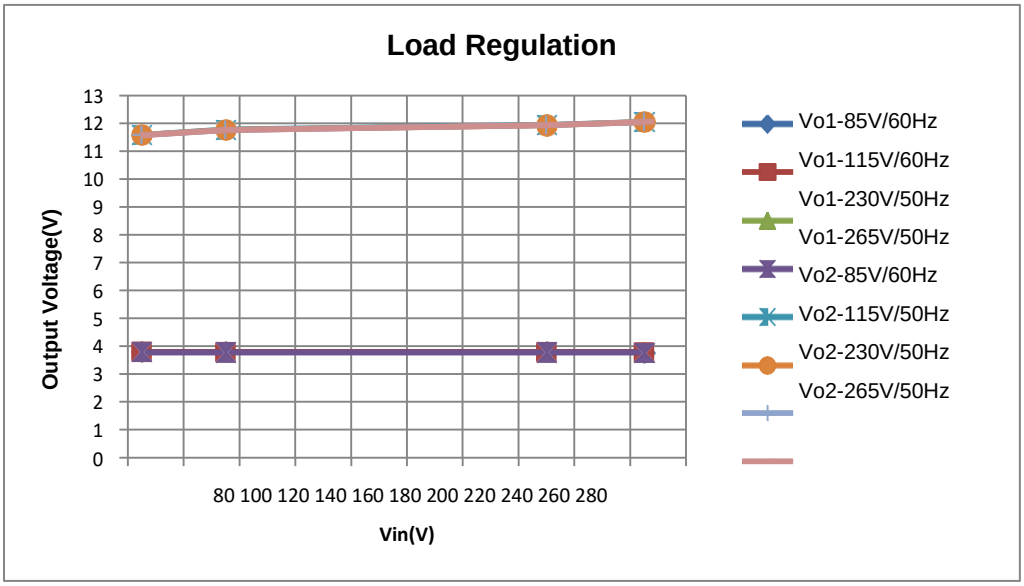

Fig. 5-4, 12V and 5V output voltage@ 3.8V no load

5.2. Key Performance Test

5.2.1. Start-Up Performance

The start-up time was measured with a differential probe clipping on the input AC source, and the common low-voltage probe clipping on the output terminal. Before start-up, the buck cap should be discharged.

Table 5-5, start-up performance

Input Voltage	Start-Up Time	Figures
85V/60Hz	16.8ms	Fig. 15
115V/50Hz	16.1ms	Fig. 16
230V/50Hz	15.3ms	Fig. 17
264V/60Hz	14.6ms	Fig. 18

Turn on Waveforms

CH1: Vin; CH2: 3.8V output; CH3:12V output

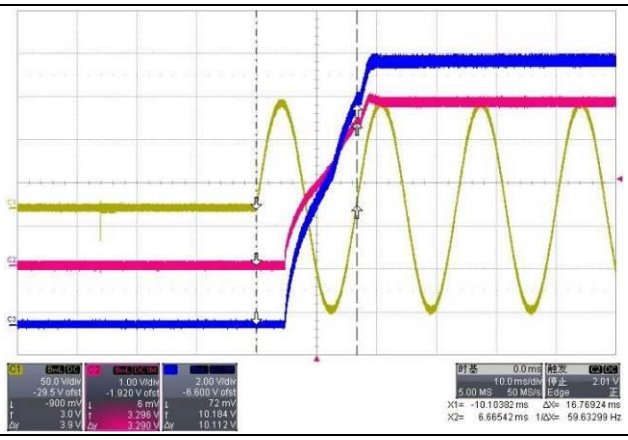

Fig. 5-5, Start-up time is 16.8ms @full load, 85V/60Hz

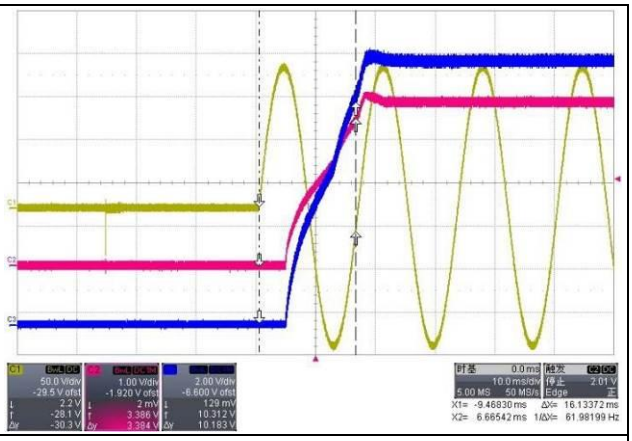

Fig 5-6, Start-up time is 16.1ms @full load, 115V/60Hz

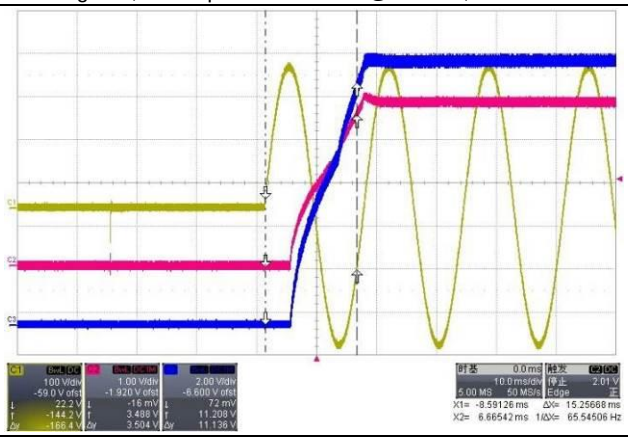

Fig. 5-7, Start-up time is 15.3ms @full load, 230V/50Hz

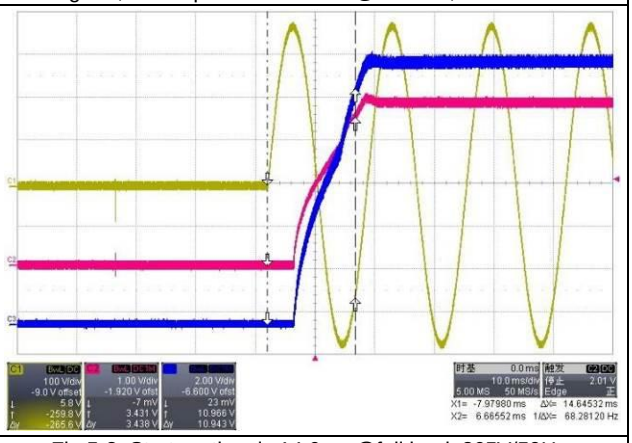

Fig 5-8, Start-up time is 14.6ms @full load, 265V/50Hz

5.2.2. Voltage Stress

The voltage tested below was between the source and the drain pin of IC. The test need use differential probe. The Vak voltage is tested between the anode and cathode of flyback diode D2/D3.

Table 5-6, MOSFET drain-source and flyback diodes Vak voltage stress

Input Voltage	Voltage Stress			Figures
	Vds(V)	Vak1(V)	Vak2(V)	
85V/60Hz	221	17	57	Fig. 19
115V/50Hz	265	21	65	-
230V/50Hz	429	37	119	-
264V/60Hz	484	42	129	Fig. 22

CH1: Vds/Vak2; CH2: Vak1

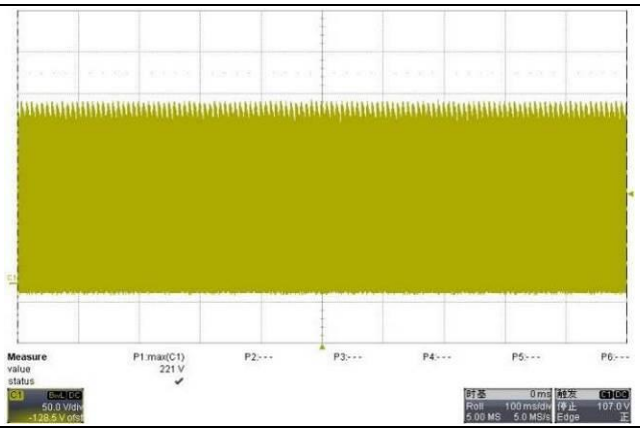

Fig. 5-9, MOS drain-source 221V@85V/60Hz, full load

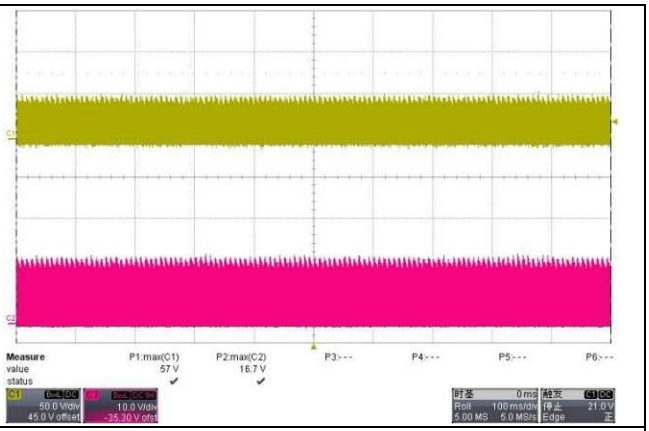

Fig. 5-10, Vo1 terminal Vak 17V, Vo2 Vak 57V@85V/60Hz, full load

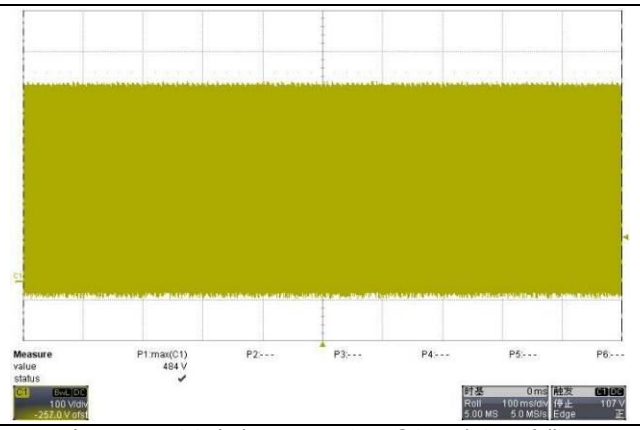

Fig. 5-11, MOS drain-source 484V @265V/50Hz, full load

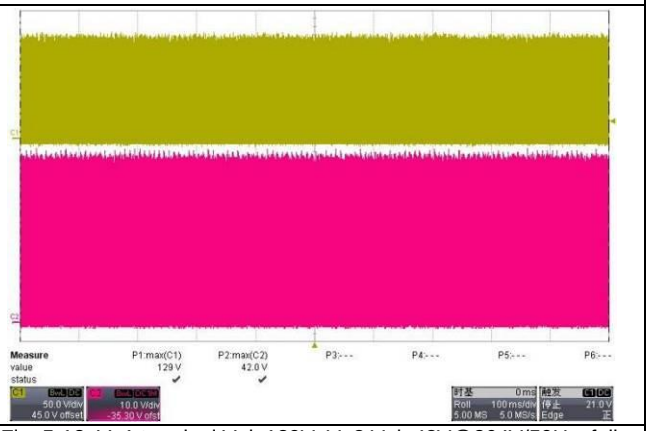

Fig. 5-12, Vo1 terminal Vak 129V, Vo2 Vak 42V@264V/50Hz, full load

5.2.3. Output Ripple & Noise

The ripple and noise were tested at a PCB terminal using a coaxial cable (1:1). The bandwidth was limited to 20MHz. A 10μF electrolytic capacitor and a 104 ceramic capacitor should be parallel to the output terminal.

Table 5-7, ripple & noise

Conditions	Input voltage	R&N(mV)		Figures
		Vo1 terminal	Vo2 terminal	
3.8V full load, 12V full load	85V/60Hz	96	184	Fig. 23
	115V/50Hz	96	184	-
	230V/50Hz	101	192	-
	264V/60Hz	101	190	Fig. 24

CH1:Vo1 output; CH4:Vo2 output

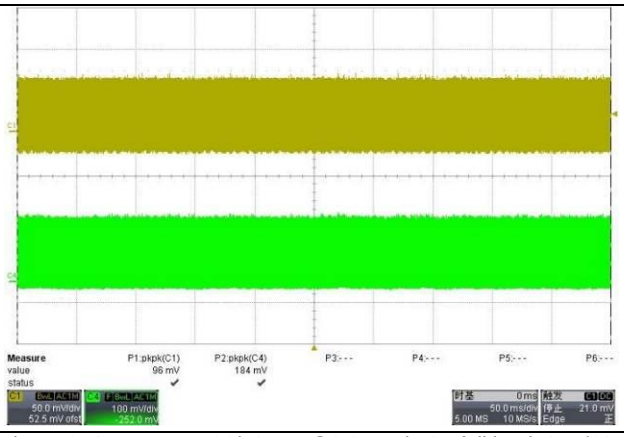

Fig.5-13, Output R&N 96/184mV@3.8Vand 12V full load, 85V/60Hz

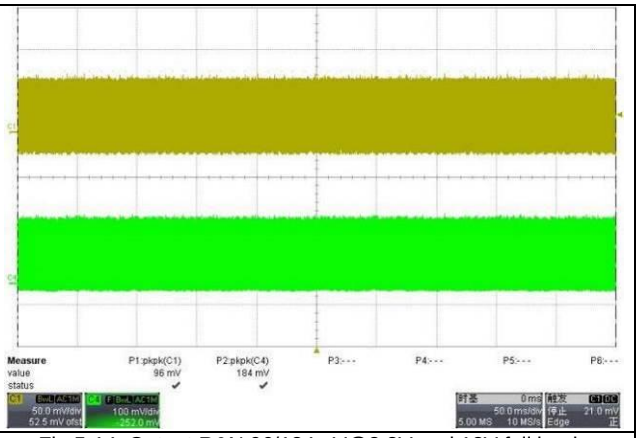

Fig.5-14, Output R&N 96/184mV@3.8V and 12V full load, 115V/60Hz

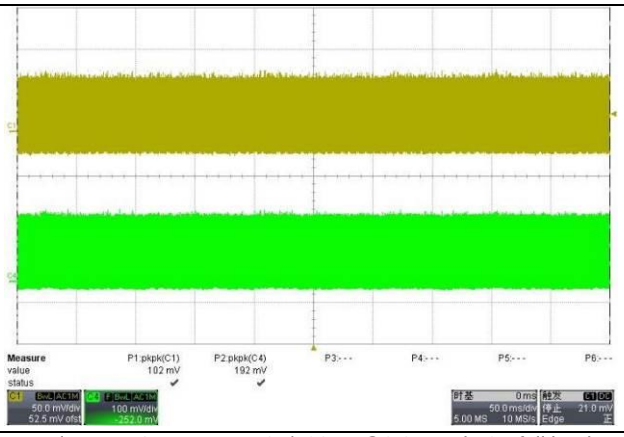

Fig.5-15, Output R&N101/192mV@3.8V and 12V full load, 230V/50Hz

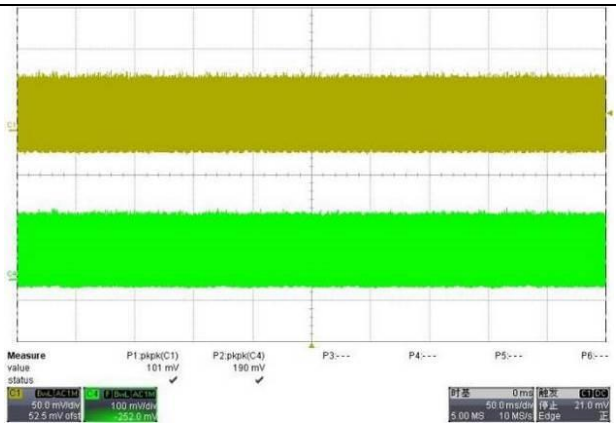

Fig.5-16, Output R&N 101/190mV@3.8Vand 12V full load, 265V/50Hz

5.2.4. Dynamic Response

The dynamic response output voltage was tested at a PCB terminal, and the bandwidth was limited to 20MHz. The loading is set 0mA as low load and 20mA as high load, lasting for 0.1s. The ramp is set at 40mA/μs.

Table 5-8, Dynamic Response

Conditions	Vin	Output Voltage (V)				Figures
		Vo1		Vo2		
		Max (V)	Min (V)	Max (V)	Min (V)	
12V full load, 3.8V loading 0~100%	85V/60Hz	4.16	3.62	12.94	8.65	Fig. 27
	115V/60Hz	4.10	3.65	12.87	8.52	-
	230V/50Hz	4.06	3.65	12.87	8.71	-
	264V/50Hz	4.10	3.65	12.94	8.31	Fig. 28
3.8V full load, 12V loading 0~100%	85V/60Hz	3.98	3.63	15.01	12.00	Fig. 29
	115V/60Hz	3.95	3.63	15.01	11.94	-
	230V/50Hz	4.02	3.63	15.01	11.94	-
	264V/50Hz	4.02	3.63	15.07	11.94	Fig. 30

CH3:12V output; CH2:3.8V output

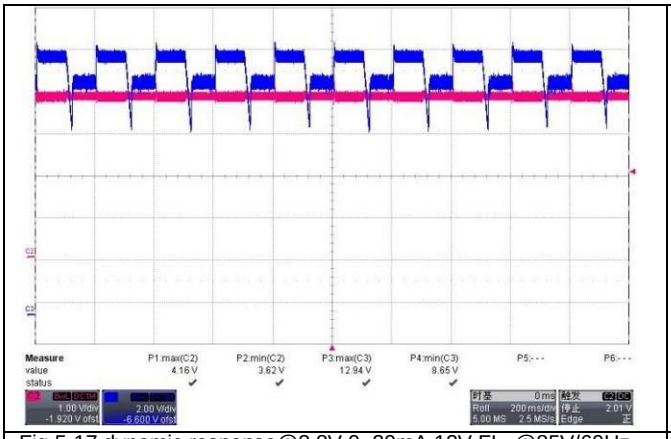

Fig.5-17 dynamic response@3.8V 0~20mA,12V FL, @85V/60Hz

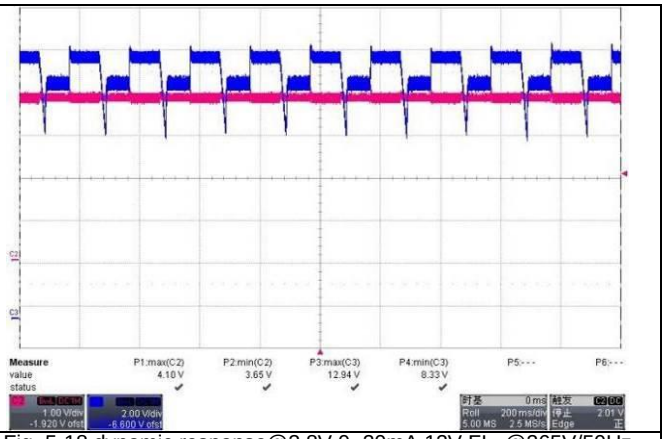

Fig. 5-18 dynamic response@3.8V 0~20mA,12V FL, @265V/50Hz

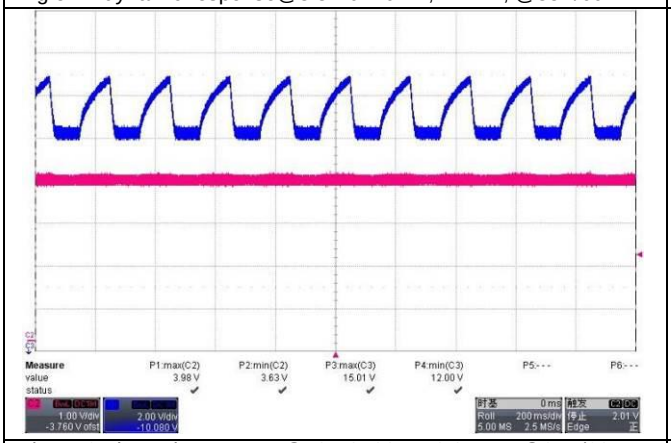

Fig.5-19, dynamic response@12V 0~20mA,3.8V FL, @85V/60Hz

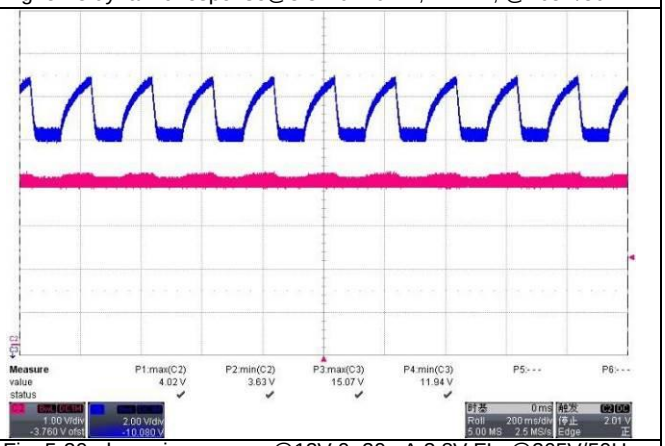

Fig. 5-20, dynamic response@12V 0~20mA,3.8V FL, @265V/50Hz

5.3. Protection (SCP) Test

The SCP test was measured under the conditions of the output cable terminal short circuit.

Table 5-9, the short circuit protection test

Condition	Vin	Vo1 max(V)	Vo2 max(V)	Figures
12V terminal output short	85V/60Hz	0.416	0.508	Fig. 31
	115V/60Hz	0.425	0.512	-
	230V/50Hz	0.463	0.503	-
	264V/50Hz	0.480	0.508	Fig. 32
3.8V terminal output short	85V/60Hz	0.544	2.81	Fig. 33
	115V/60Hz	0.562	2.90	-
	230V/50Hz	0.588	3.05	-
	264V/50Hz	0.608	3.07	Fig. 34

CH2:3.8V output; CH3:12V output

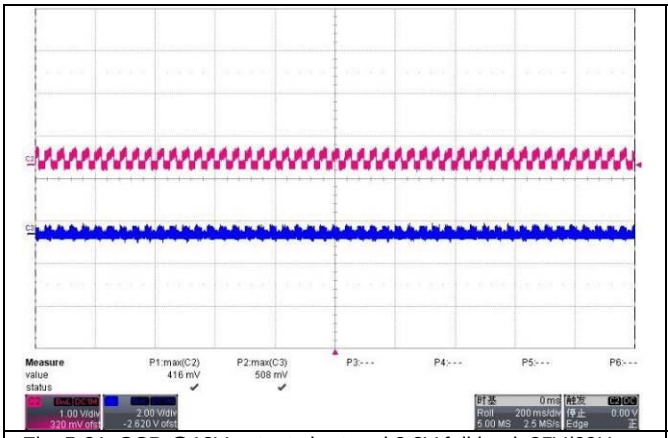

Fig. 5-21, SCP @12V output short and 3.8V full load, 85V/60Hz

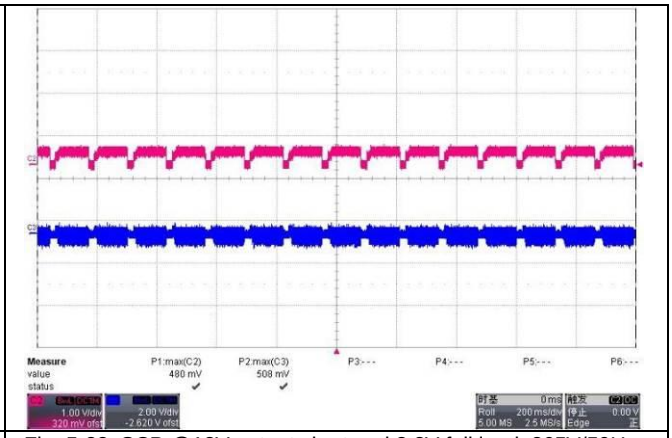

Fig. 5-22, SCP @12V output short and 3.8V full load, 265V/50Hz

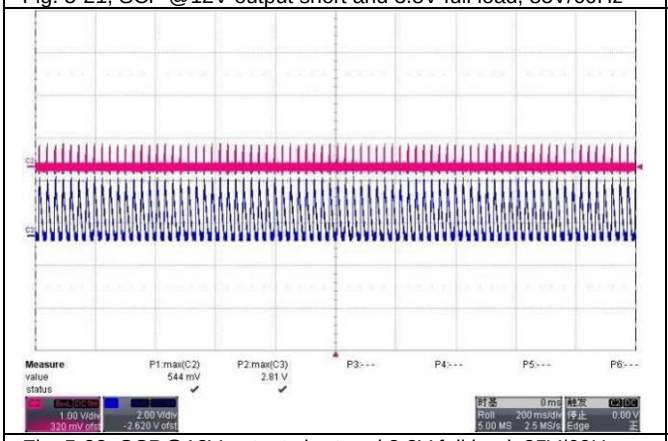

Fig. 5-23, SCP@12V output short and 3.8V full load, 85V/60Hz

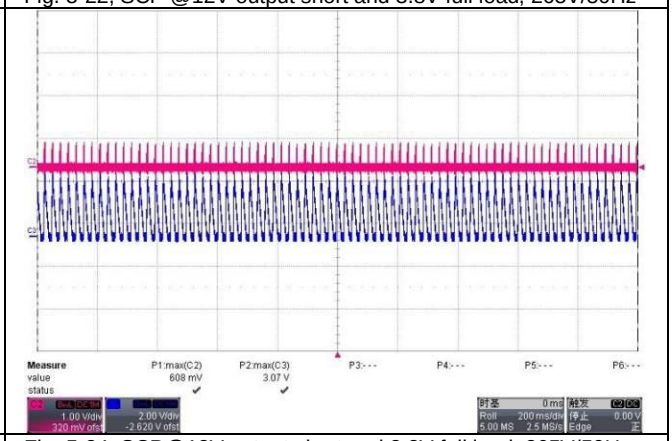

Fig. 5-24, SCP@12V output short and 3.8V full load, 265V/50Hz

5.4. Thermal Test

The thermal test was under room temperature after burning for 1 hour. The board has no case. Below shows the usage of a thermal imager to observe the IC's surface temperature.

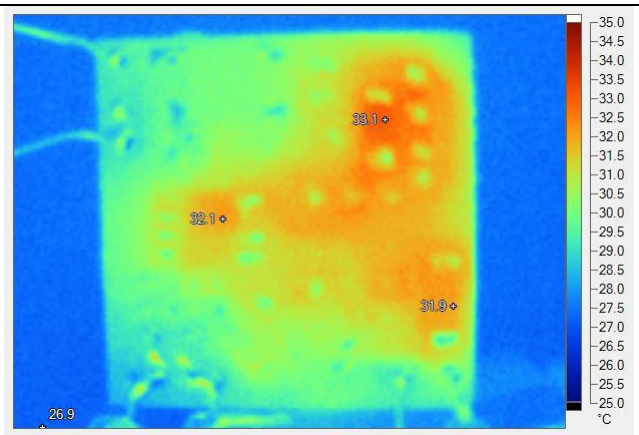

Fig. 5-25, IC 32.1℃, 12V flyback diode 31.9℃, RCD diode 33.1℃@full load, 85V/60Hz, ambient temperature 26.9℃.

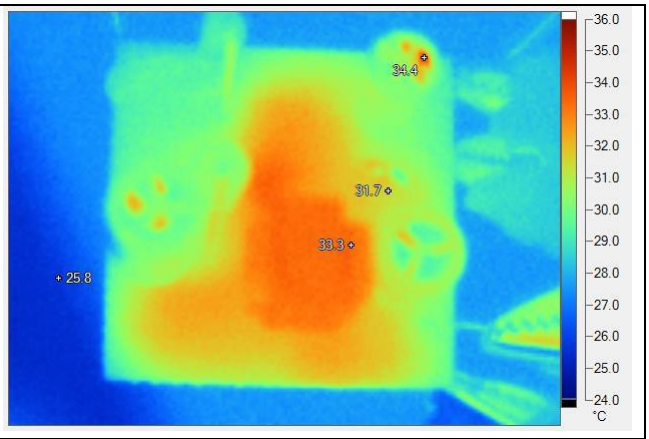

Fig. 5-26, Transformer 33.3℃, 3.8V flyback diode 31.7℃@full load, 264V/50Hz, ambient temperature 25.8℃.

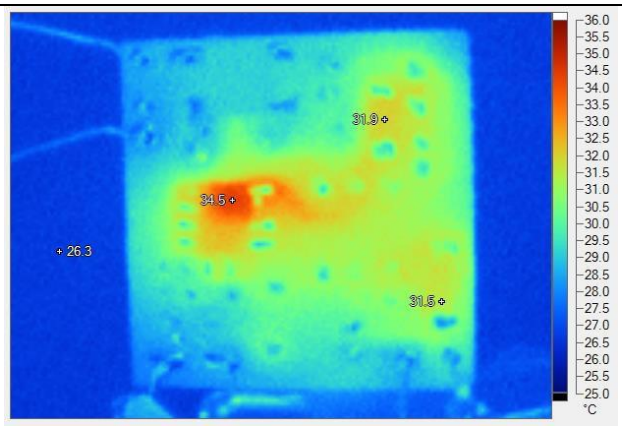

Fig. 5-27, IC 34.5℃, 12V flyback diode 31.5℃, RCD diode 31.9℃@full load, 265V/50Hz, ambient temperature 26.3℃.

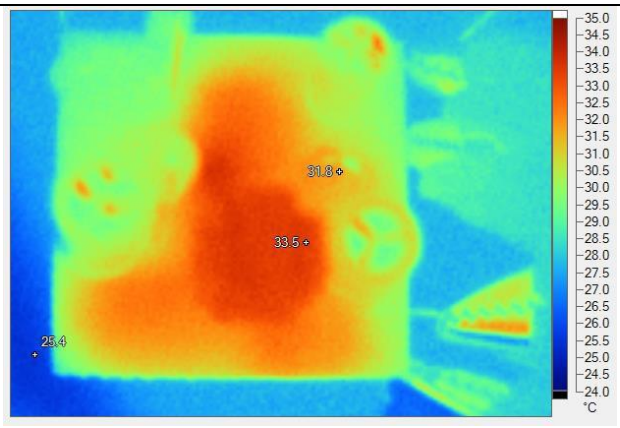

Fig. 5-28, Transformer 33.5℃, 3.8V flyback diode 31.8℃@full load, 264V/50Hz, ambient temperature 25.4℃.

5.5. System EMI Scan

The power supply passed EN55022 Class B (for 230V input) and FCC part 15 (for 110V input) EMI requirements with more than a 6dB margin.

5.5.1. Conduction EMI Test of 230V @Full Load

The test result passes EN55022 Class B limitation with more than a 6dB margin.

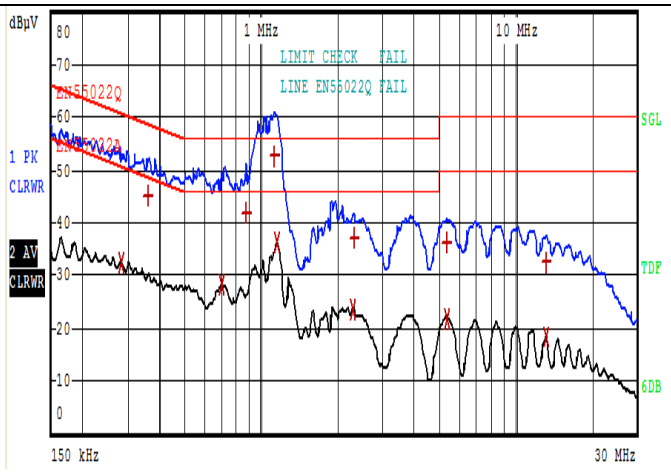

Fig. 5-29, L line conduction waveform@230V, full load.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
2	Average	298.034163623 kHz	31.85	-18.44
1	Quasi Peak	346.008411606 kHz	45.26	-13.79
1	Quasi Peak	413.877088109 kHz	42.76	-14.80
2	Average	495.058034186 kHz	28.95	-17.12
1	Quasi Peak	1.13065507631 MHz	47.41	-8.58
2	Average	1.27405044044 MHz	33.95	-12.04
1	Quasi Peak	2.29164676133 MHz	35.82	-20.18
2	Average	2.29164676133 MHz	22.64	-23.35
1	Quasi Peak	5.28619370567 MHz	34.67	-25.32
2	Average	5.33905564273 MHz	20.39	-29.60
1	Quasi Peak	13.0733860985 MHz	31.45	-28.54
2	Average	13.0733860985 MHz	17.42	-32.57

Fig. 5-30, L line conduction data@230V, full load.

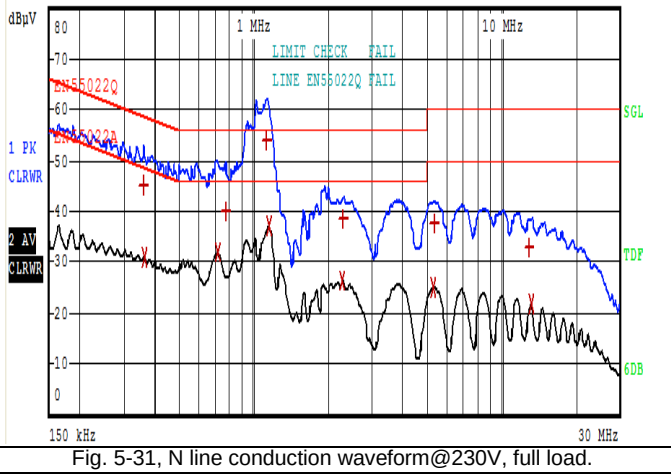

Fig. 5-31, N line conduction waveform@230V, full load.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
1	Quasi Peak	259.278686021 kHz	49.14	-12.30
2	Average	356.492812486 kHz	31.05	-17.75
1	Quasi Peak	541.437681113 kHz	39.90	-16.09
2	Average	708.31358138 kHz	29.66	-16.33
1	Quasi Peak	1.1194604716 MHz	49.21	-6.78
2	Average	1.27405044044 MHz	34.67	-11.32
1	Quasi Peak	2.29164676133 MHz	37.63	-18.36
2	Average	2.29164676133 MHz	25.37	-20.62
2	Average	5.28619370567 MHz	24.26	-25.73
1	Quasi Peak	5.44637066114 MHz	36.07	-23.92
1	Quasi Peak	12.9439466322 MHz	32.81	-27.18
2	Average	13.0733860985 MHz	20.99	-29.00

Fig. 5-32, N line conduction data@230V, full load.

5.5.2. Conduction EMI Test of 110V @Full Load

The test result passes FCC part 15 limitation with more than a 6dB margin.

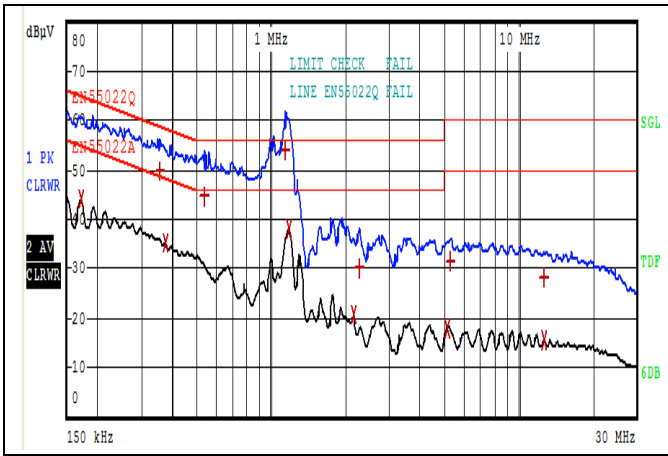

Fig. 5-33, L line conduction waveform@110V, full load.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
2	Average	169.02375452 kHz	44.54	-10.46
1	Quasi Peak	322.728292586 kHz	52.28	-7.35
2	Average	374.677528711 kHz	36.25	-12.14
1	Quasi Peak	452.651275966 kHz	47.73	-9.09
1	Quasi Peak	1.03380296375 MHz	46.09	-9.90
2	Average	1.28679094484 MHz	33.81	-12.18
1	Quasi Peak	2.1374603093 MHz	31.90	-24.09
2	Average	2.1374603093 MHz	20.71	-25.28
2	Average	5.28619370567 MHz	17.54	-32.45
1	Quasi Peak	6.26046263072 MHz	30.20	-29.79
1	Quasi Peak	12.9439466322 MHz	27.84	-32.16
2	Average	12.9439466322 MHz	15.44	-34.55

Fig. 5-34, L line conduction data@110V, full load.

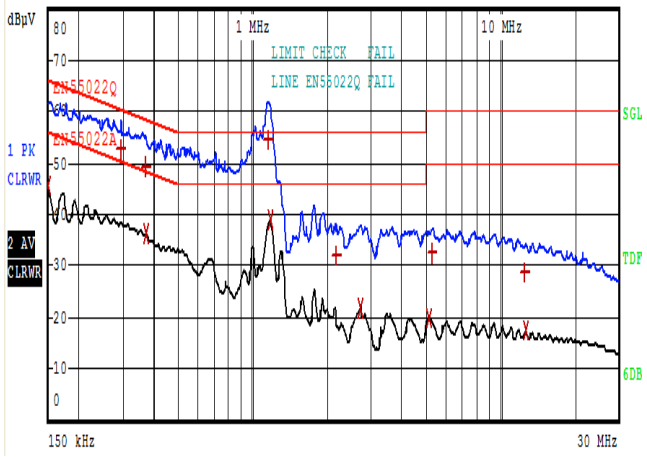

Fig. 5-35, N line conduction waveform@110V, full load.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
2	Average	169.02375452 kHz	43.74	-11.26
1	Quasi Peak	289.269022958 kHz	52.70	-7.84
2	Average	370.967850209 kHz	36.13	-12.34
1	Quasi Peak	413.877088109 kHz	48.25	-9.31
1	Quasi Peak	1.02356729084 MHz	47.22	-8.77
2	Average	1.28679094484 MHz	34.10	-11.90
2	Average	2.1374603093 MHz	22.24	-23.75
1	Quasi Peak	2.1588349124 MHz	33.49	-22.50
2	Average	5.28619370567 MHz	19.44	-30.55
1	Quasi Peak	5.50083436776 MHz	31.41	-28.58
2	Average	12.9439466322 MHz	16.83	-33.16
1	Quasi Peak	13.0733860985 MHz	28.80	-31.19

Fig. 5-36, N line conduction data@110V, full load.

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