User Guide for

FEBL010

Evaluation Board

Universal LED Driver using the FL6961 CRM PFC Controller

Featured Fairchild Product:

FL6961

Direct questions or comments about this evaluation board to: "Worldwide Direct Support"

Fairchild Semiconductor.com

Table of Contents

This user guide supports the evaluation kit for the FL6961. It should be used in conjunction with the FL6961 datasheet as well as Fairchild's application notes and technical support team. Please visit Fairchild's website at www.fairchildsemi.com.

1. Introduction

This document describes the proposed solution for a universal LED ballast using the FL6961 CRM PFC controller. The input voltage range is $90V_{RMS}$ – $265V_{RMS}$ and there is one DC output with a constant current of 1.25A at $24V_{MAX}$. This document contains general description of FL6961, the power supply specification, schematic, bill of materials, and the typical operating characteristics.

1.1. General Description of FL6961

The FL6961 is an active Power Factor Correction (PFC) controller for boost PFC applications that operate in Critical conduction Mode (CRM). It uses a voltage mode PWM that compares an internal ramp signal with the error amplifier output to generate the MOSFET turn-off signal. Because the voltage-mode CRM PFC controller does not need rectified AC line voltage information, it saves the power loss of the input voltage-sensing network required by the current-mode CRM PFC controller.

1.2. Features of FL6961

- Boundary Mode PFC Controller
- Low Input Current THD
- Controlled On-Time PWM
- Zero-Current Detection (ZDC)
- Cycle-by-Cycle Current Limiting
- Leading-Edge Blanking Instead of RC Filtering
- Low Startup Current: 10µA (Typical)
- Low Operating Current: 4.5mA (Typical)
- Feedback Open-Loop Protection
- Programmable Maximum On-Time (MOT)
- Output Over-Voltage Clamping Protection
- Clamped Gate Output Voltage: 16.5V

1.3. Block Diagram

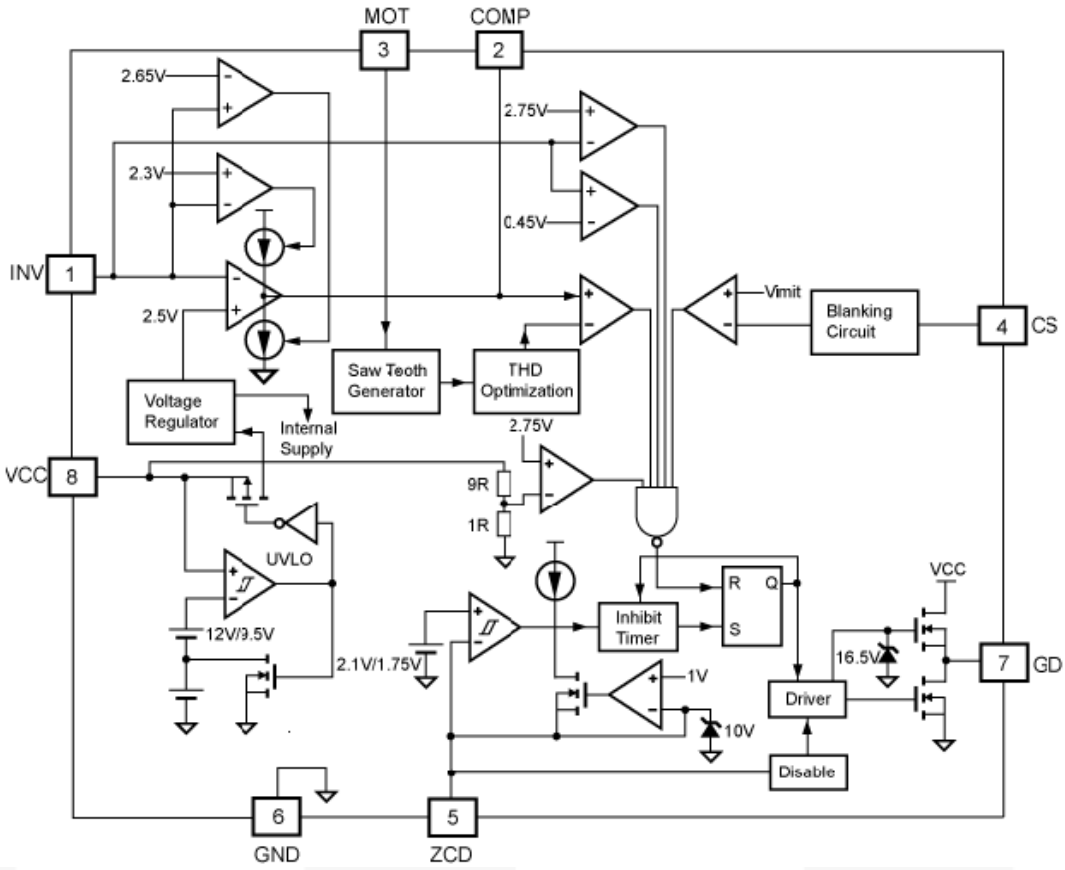

Figure 1. Internal Block Diagram of FL6961

2. General Specifications for Evaluation Board

All data of the evaluation board was measured with the board enclosed in a case and external temperature of around 25°C.

Table 1. Summary of Features and Performance

Main Controller	FL6961
Input Voltage Range	$90V_{AC}$~$265V_{AC}$
Input Voltage Frequency	47Hz~63Hz
Rated Output Power	30W
Rated Output Voltage	24V
Rated Output Current	1.25A
Application	LED Lighting

2.1 Photographs of the Evaluation Board

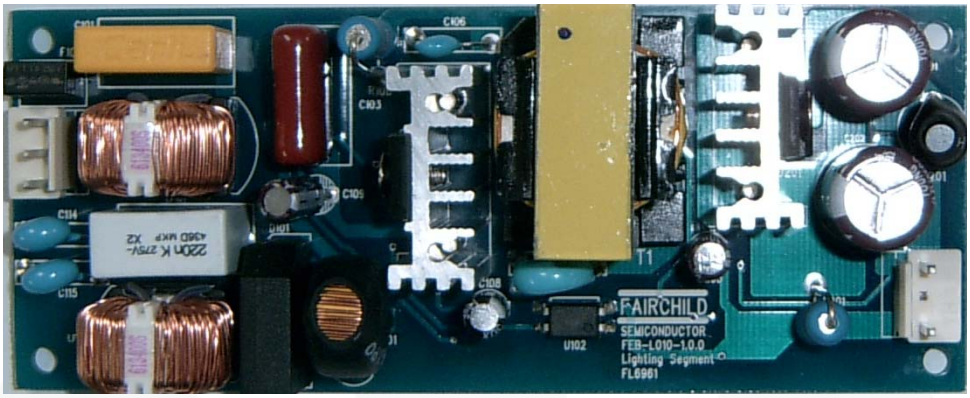

Figure 2. Photograph (125mm (W) x 41mm (H)) Top View

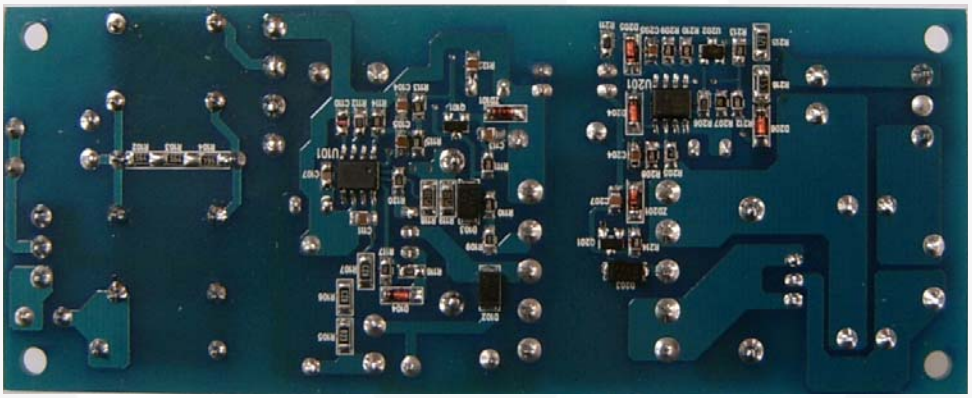

Figure 3. Photograph (125mm (W) x 41mm (H)) Bottom View

2.2 Printed Circuit Board

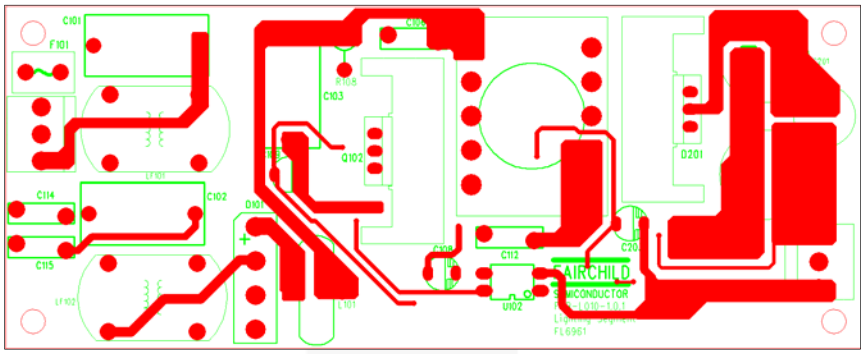

Figure 4. Printed PCB, Top Side

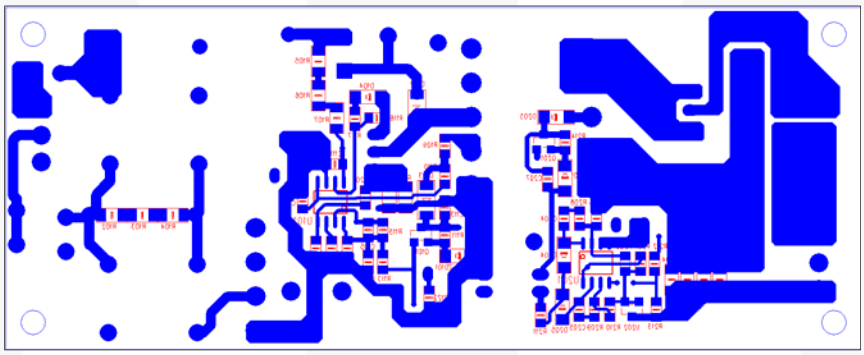

Figure 5. Printed PCB, Bottom Side

2.3 Schematic of the Evaluation Board

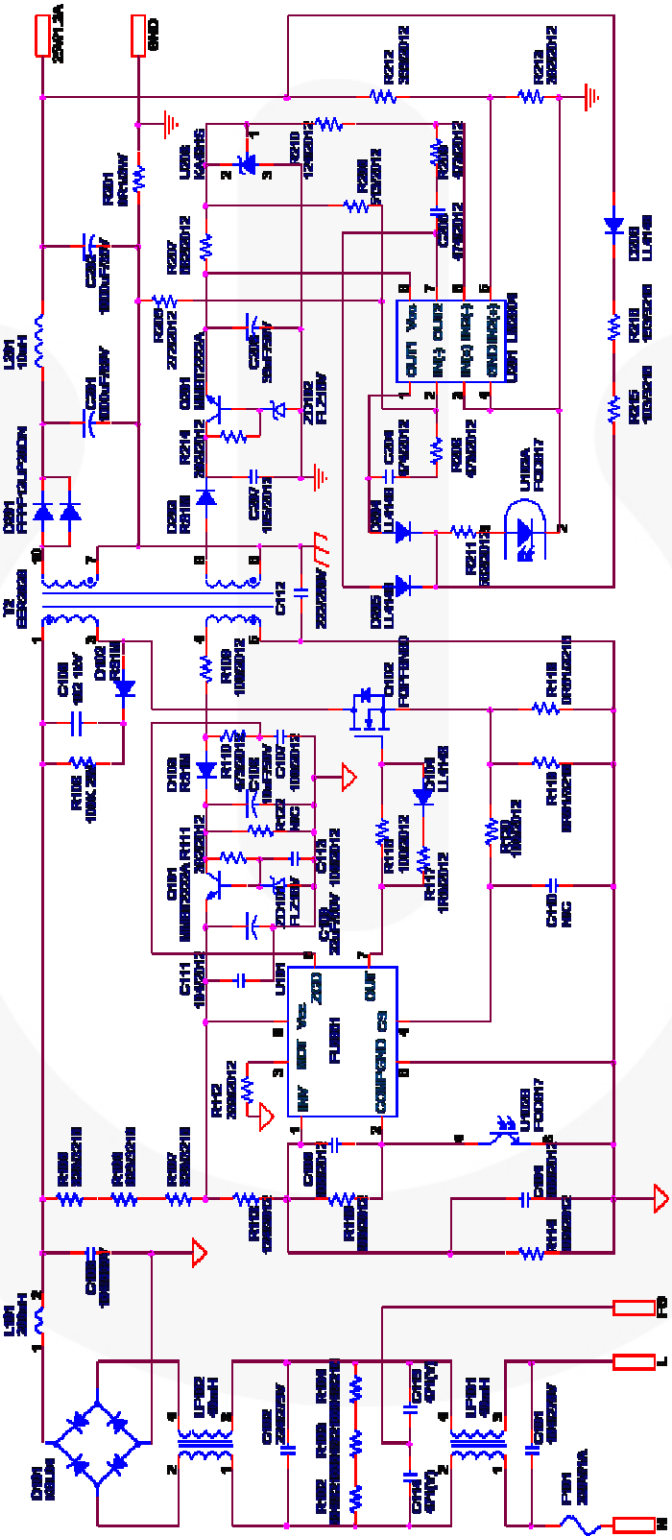

Figure 6. Schematic of Evaluation

2.4 Bill of Materials

Table 2. Bill of Materials of Evaluation Board

Item No.	Part Reference	Value	Qty	Description (Manufacturer)
1	U101	FL6961	1	CRM PFC Controller (Fairchild Product)
2	D102, D103 ,D203	RS1M	3	1000V/1A Ultra-Fast Recovery Diode (Fairchild Product)
3	Q102	FQPF8N80C	1	800V/8A MOSFET (Fairchild Product)
4	D101	KBL04	1	Bridge Diode (Fairchild Product)
5	D104, D204, D205, D206	LL4148	4	General-Purpose Diode (Fairchild Product)
6	Q101, Q201	MMBT2222A	2	General-Purpose Transistor (Fairchild Product)
7	U102	FOD817	1	Opto-Coupler (Fairchild Product)
8	U203	KA431S	1	Shunt Regulator (Fairchild Product)
9	U201	LM2904	1	Dual OP Amp (Fairchild Product)
10	D201	FFPF12UP20DN	1	Ultrafast Recovery Power Rectifier (Fairchild Product)
11	ZD101, ZD102	FLZ16V	2	Zener Diode (Fairchild Product)
12	C106	102/1kV	1	Ceramic-Capacitor
13	C101	154/275V	1	X – Capacitor
14	C102	224/275V	1	X – Capacitor
15	C112	222/250V	1	Y – Capacitor
16	C114, C115	471/250V	2	Y – Capacitor
17	C201, C202	1000µF / 35V	2	Electrolytic Capacitor
18	C108	10µF/50V	1	Electrolytic Capacitor
19	C109	22µF/50V	1	Electrolytic Capacitor
20	C203	33µF/50V	1	Electrolytic Capacitor
21	C103	154/630V	1	Film Capacitor
22	C104, C105, C113, C207	105/2012	4	SMD Capacitor 2012
23	C107	100/2012	1	SMD Capacitor 2012
24	C110	N/C	1	SMD Capacitor 2012
25	C111	104/2012	1	SMD Capacitor 2012
26	C204, C205	474/2012	2	SMD Capacitor 2012
27	F101	250V/1A	1	Fuse
28	L101	200µH	1	Inductor

Continued on the following page…

Bill of Materials (Continued)

Item No.	Part Reference	Value	Qty	Description (Manufacturer)
29	LF101, LF102	40mH	2	Line Filter
30	L201	10µH	1	Stick Inductor
31	T2	EER2828	1	Transformer, 700µH, 1kHz, 1V
32	R201	0R1/3W	1	Metal Film Resistor 3W
33	R108	100K 2W	1	Metal Oxide Film Resistor 2W
34	R122	N/C	1	SMD Resistor 2012
35	R109, R116, R120	100/2012	3	SMD Resistor 2012
36	R110, R208, R209	473/2012	3	SMD Resistor 2012
37	R111, R213, R214	392/2012	3	SMD Resistor 2012
38	R112, R212	333/2012	2	SMD Resistor 2012
39	R113, R210	124/2012	2	SMD Resistor 2012
40	R114	103/2012	1	SMD Resistor 2012
41	R115	203/2012	1	SMD Resistor 2012
42	R117	1R0/2012	1	SMD Resistor 2012
43	R205	272/2012	1	SMD Resistor 2012
44	R206	513/2012	1	SMD Resistor 2012
45	R207	682/2012	1	SMD Resistor 2012
46	R211	562/2012	1	SMD Resistor 2012
47	R102, R103, R104	564/3216	3	SMD Resistor 3216
48	R105, R106, R107	823/3216	3	SMD Resistor 3216
49	R118, R119	0R51/3216	2	SMD Resistor 3216
50	R215	103/3216	1	SMD Resistor 3216
51	R216	153/3216	1	SMD Resistor 3216

2.5 Connections Transformer and Winding Specifications

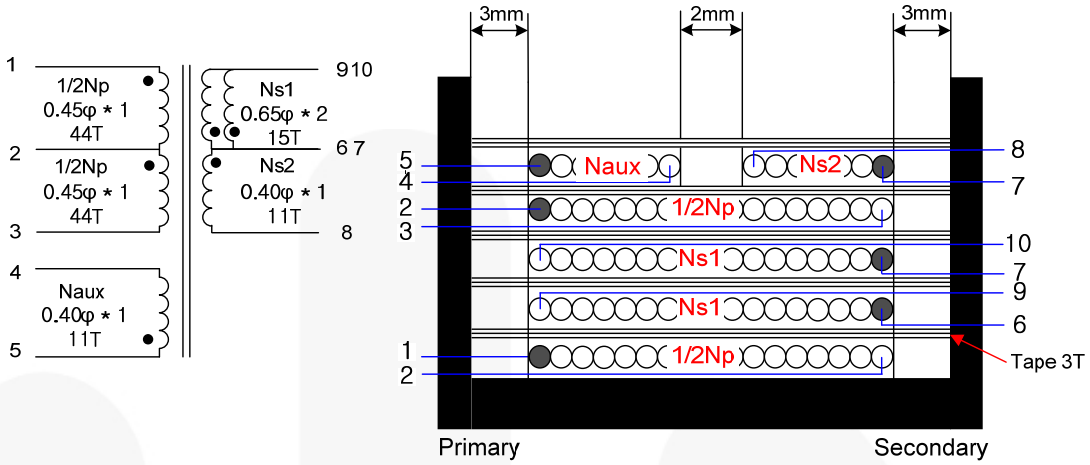

Figure 7. Transformer Specifications & Construction [EER2828]

Table 3. Winding Specifications

No	Winding	Pin (S → F)	Wire	Turns	Winding Method
1	1/2Np	1 → 2	0.45φ×1	44 Ts	Solenoid Winding
2	Insulation: Polyester Tape t = 0.025mm, 3-Layer				
3	Ns1	6 → 9	0.65φ×2	15 Ts	Solenoid Winding
4	Insulation: Polyester Tape t = 0.025mm, 3-Layer				
5	Ns1	7 → 10	0.65φ×2	15 Ts	Solenoid Winding
6	Insulation: Polyester Tape t = 0.025mm, 3Layers				
7	1/2Np	2 → 3	0.45φ×1	44 Ts	Solenoid Winding
8	Insulation: Polyester Tape t = 0.025mm, 3-Layer				
9	Naux	5 → 4	0.45φ×1	11 Ts	Solenoid Winding
	Ns1	7 → 8	0.45φ×1	11 Ts	
10	Insulation: Polyester Tape t = 0.025mm, 3-Layer				

Table 4. Electrical Characteristics

	Pin	Specifications	Remark
Inductance	1 – 3	700μH ±7%	1kHz, 1V
Leakage	1 – 3	30μH Maximum	Short All Output Pins

3 Performance of Evaluation Board

3.1 Test Condition & Items

Table 5. Test Condition & Test Equipment

Ambient Temperature	T_A = 25°C
Test Equipment	AC Power Source: PCR500L by Kikusui Power Analyzer: 2574R series by Xitron Electronic Load: PLZ303WH by KIKUSUI Multi Meter: 2002 by KEITHLEY, 45 by FLUKE Oscilloscope: 104Xi by LeCroy EMI Test Receiver: ESCS30 by ROHDE & SCHWARZ Two-Line V-Network: ENV216 by ROHDE & SCHWARZ Thermometer: Thermal CAM SC640 by FLIR SYSTEMS
Test Items	3.2. Electrical Efficiency 3.3. Power Factor 3.4. Constant Current & Constant Voltage (CC/CV) 3.5. THD Performance 3.6. Temperature Checking Results 3.7. Startup Time 3.8. Operation Waveforms 3.9 Short-Circuit Protection 3.10. Stress on MOSFET & Rectifier 3.11. EMI Result

3.2 Electrical Efficiency

Figure 8 shows at least 84% system efficiency with universal input condition at the rated output load.

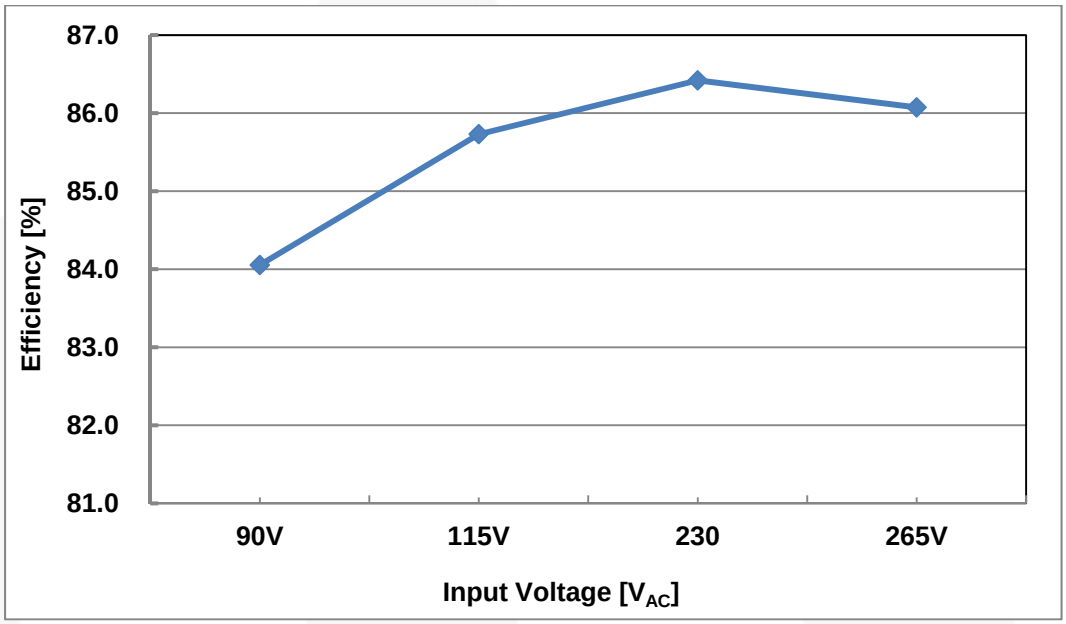

Figure 8. System Efficiency

Input Voltage	$90V_{AC}$	$115V_{AC}$	$230V_{AC}$	$265V_{AC}$
Efficiency [%]	84.05	85.73	86.42	86.07

3.3 Power Factor

Figure 9 shows over 90% PF results with universal input condition at rated output power.

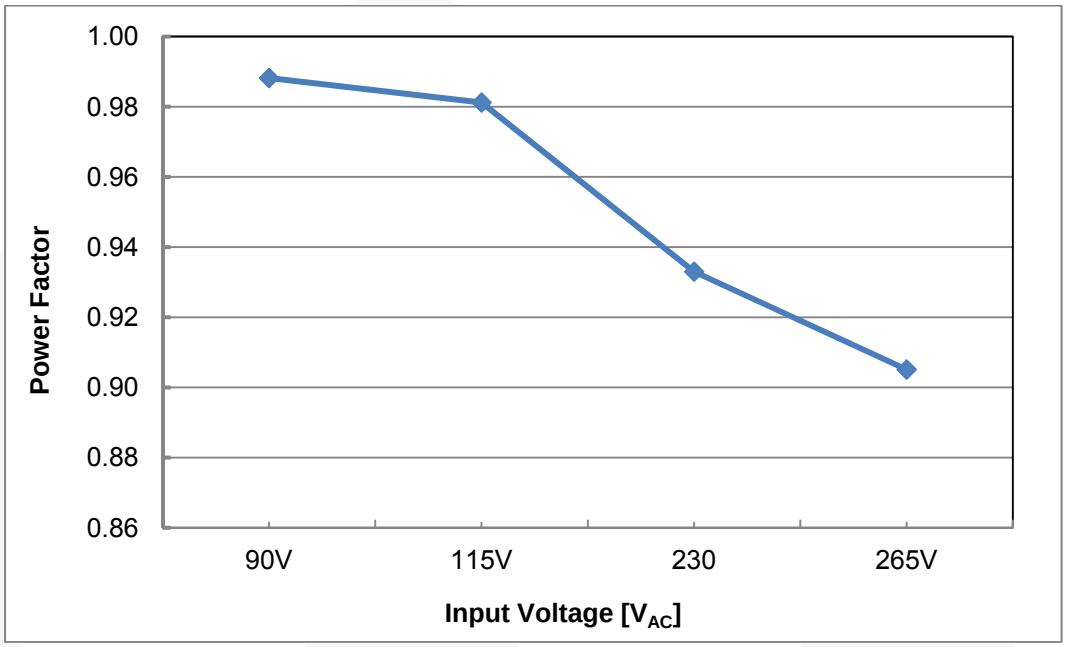

Figure 9. Power Factor

Input Voltage	$90V_{AC}$	$115V_{AC}$	$230V_{AC}$	$265V_{AC}$
PF	0.9882	0.9812	0.9330	0.9051

3.4 Constant Current & Constant Voltage (CC/CV)

Figure 10 shows the typical CC/CV performance on the board, showing very stable CC performance at $90V_{AC}$ ~ $265V_{AC}$ input conditions.

Input Voltage	Min. Current	Max. Current	Tolerance	Remark
$90V_{AC}$ / 60Hz	1.318	1.333	1.13%	< 10%
$115V_{AC}$ / 60Hz	1.308	1.321	0.98%	
$230V_{AC}$ / 60Hz	1.285	1.307	1.68%	
$230V_{AC}$ / 60Hz	1.292	1.308	1.22%	
Total	1.285	1.333	3.60%	

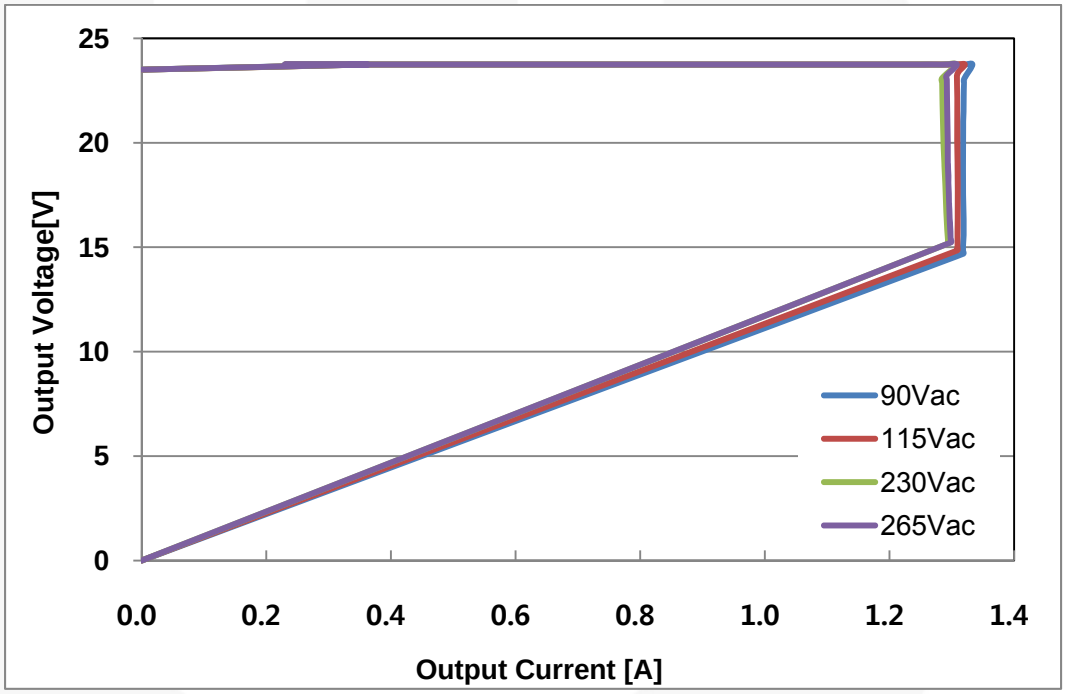

Figure 10. CC/CV Performance

Table 6. CC and CV Measured Data

$90V_{AC}$		$115V_{AC}$		$220V_{AC}$		$265V_{AC}$	
Vout	**Iout**	**Vout**	**Iout**	**Vout**	**Iout**	**Vout**	**Iout**
23.50	0.0000	23.50	0.0000	23.50	0.0000	23.50	0.0000
23.75	0.2440	23.75	0.2440	23.75	0.2440	23.74	0.2440
23.75	0.2813	23.75	0.2810	23.75	0.2810	23.74	0.2810
23.75	0.3190	23.75	0.3190	23.75	0.3190	23.74	0.3190
23.75	0.3630	23.75	0.3630	23.75	0.3630	23.74	0.3630
23.75	0.4320	23.75	0.4320	23.75	0.4320	23.74	0.4317
23.75	0.5260	23.75	0.5260	23.75	0.5260	23.74	0.5260
23.74	0.6760	23.75	0.6760	23.75	0.6760	23.74	0.6760
23.74	0.9520	23.75	0.9520	23.75	0.9520	23.74	0.9520
23.74	1.2140	23.75	1.2140	23.75	1.2140	23.74	1.2140
23.74	1.2770	23.75	1.2770	23.75	1.2770	23.74	1.2770
23.74	1.3080	23.75	1.3080	23.75	1.3067	23.74	1.3080
23.74	1.3330	23.32	1.3210	22.88	1.2847	23.00	1.2920
22.85	1.3197	22.67	1.3090	22.26	1.2850	22.38	1.2923
22.34	1.3190	22.16	1.3090	21.77	1.2853	21.88	1.2923
21.75	1.3190	21.59	1.3090	21.21	1.2857	21.32	1.2930
21.28	1.3187	21.13	1.3090	20.76	1.2863	20.87	1.2930
20.75	1.3183	20.60	1.3090	20.25	1.2867	20.35	1.2930
20.16	1.3183	20.02	1.3090	19.69	1.2873	19.78	1.2937
19.68	1.3180	19.55	1.3093	19.24	1.2880	19.32	1.2937
19.15	1.3180	19.03	1.3093	18.73	1.2887	18.81	1.2940
18.65	1.3180	18.54	1.3097	18.25	1.2893	18.32	1.2947
18.11	1.3180	18.00	1.3097	17.73	1.2903	17.79	1.2947
17.60	1.3183	17.49	1.3097	17.24	1.2907	17.30	1.2953
17.07	1.3183	16.96	1.3100	16.72	1.2913	16.78	1.2960
16.45	1.3190	16.34	1.3097	16.12	1.2923	16.18	1.2970
15.98	1.3190	15.87	1.3093	15.70	1.2930	15.75	1.2977
15.70	1.3190	15.59	1.3093	15.41	1.2940	15.45	1.2980
15.46	1.3190	15.35	1.3093	15.18	1.2947	15.22	1.2983
15.18	1.3183	15.07	1.3093	0.00	0.0000	0.00	0.0000
14.95	1.3180	14.84	1.3087			0.00	0.0000
14.81	1.3180	0.00	0.0000			0.00	0.0000
14.68	1.3180	0.00	0.0000			0.00	0.0000
0.00	0.0000	0.00	0.0000			0.00	0.0000

3.5 THD Performance

Figure 11 through Figure 14 show the test results of the FL6961 evalutaiton board. All of the results meet international regulations.

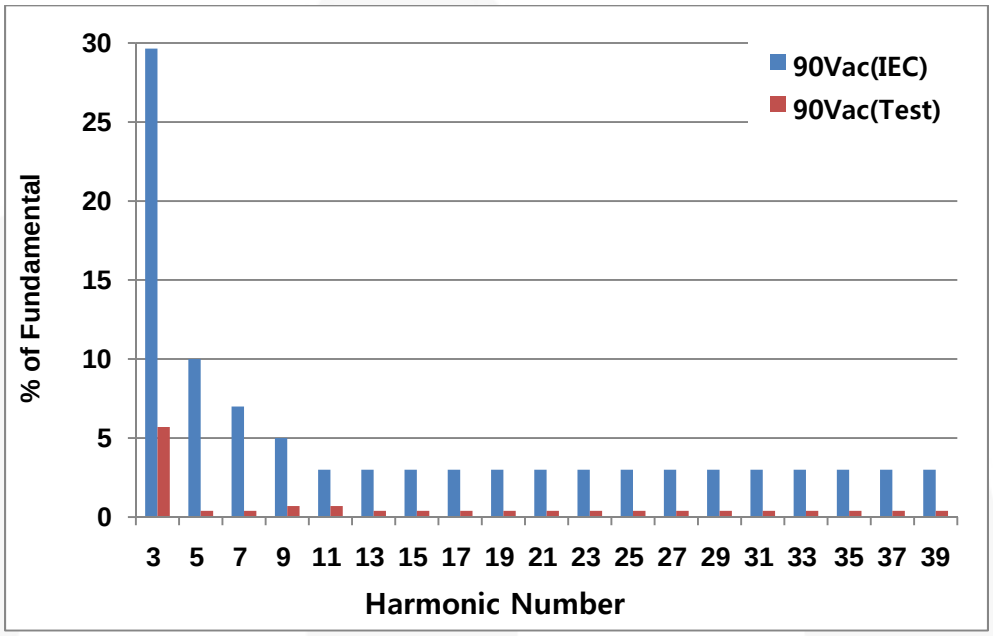

Figure 11. THD Performance Results at 90V_{AC}

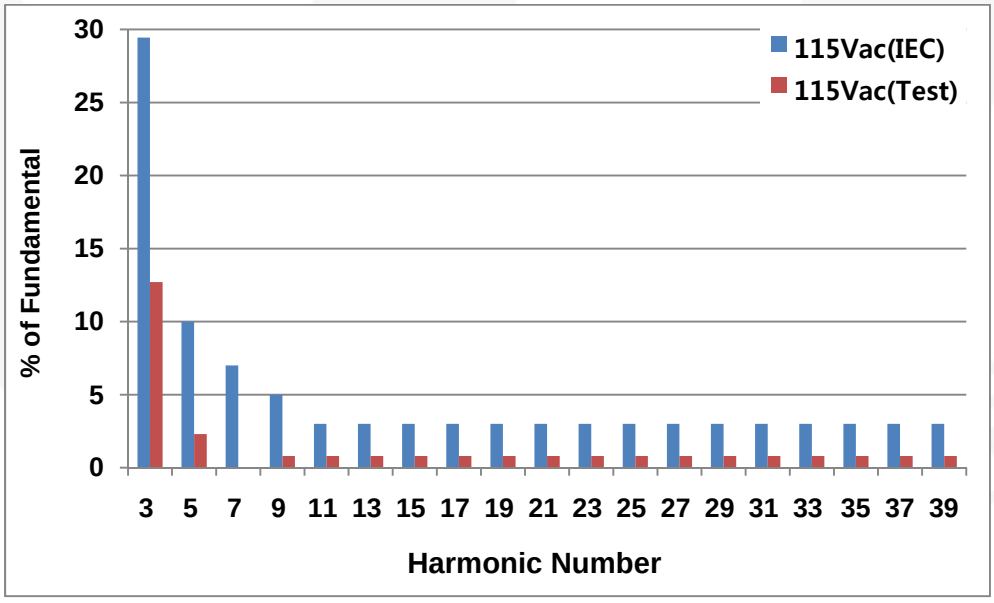

Figure 12. THD Performance Results at 115V_{AC}

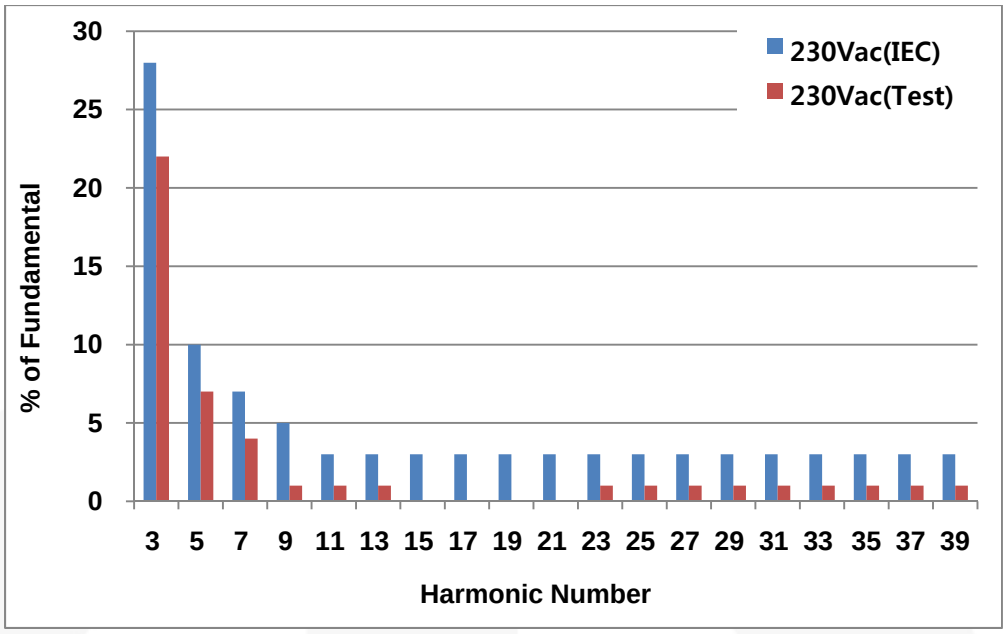

Figure 13. THD Performance Results at 230V$_{AC}$

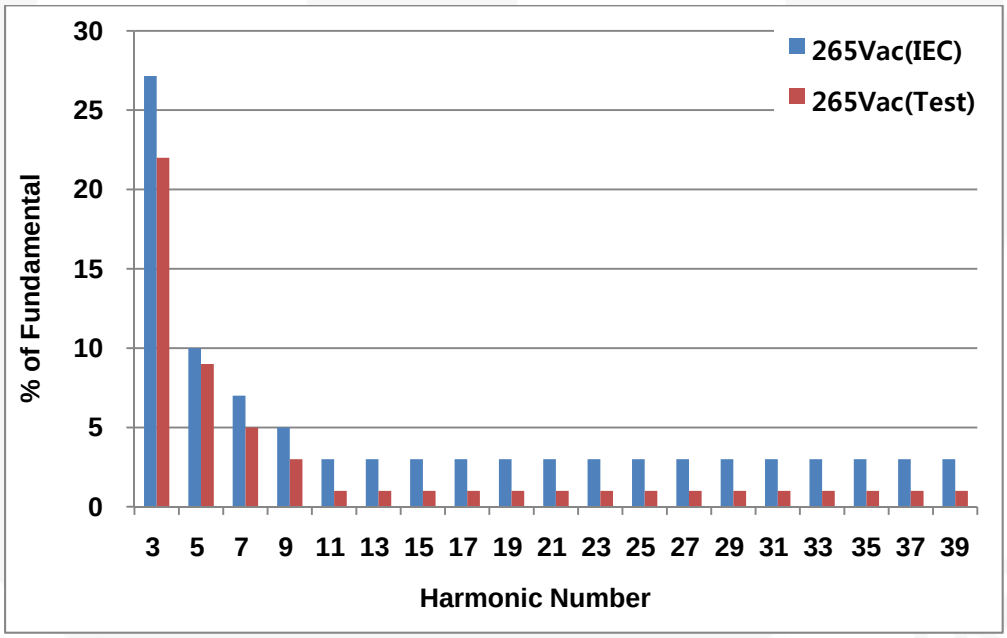

Figure 14. THD Performance Results at 265V$_{AC}$

3.6 Temperature Checking Results

Figure 15 through Figure 18 show the temperature-checking results on the board in minimum and maximum input voltage condition.

	90V_{AC} / 60Hz	265V_{AC} / 60Hz	Remark
Bridge Diode	62.8°C	53.8°C	Top Side Circle
Transformer	54.6°C	54.8°C	Top Side Line
FET	61.1°C	53.8°C	Top Side Spot
Rectifier	64.7°C	62.3°C	Top Side Box

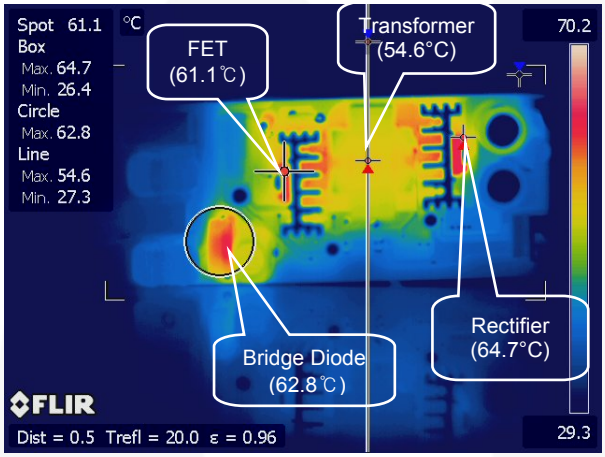

Figure 15. 90V_{AC} / 60Hz; Top Side

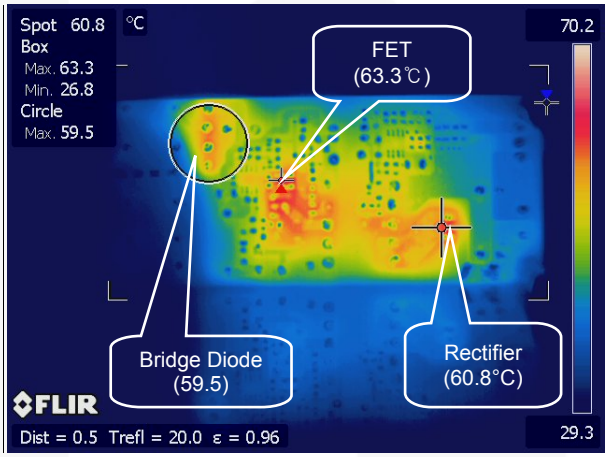

Figure 16. 90V_{AC} / 60Hz; Bottom Side

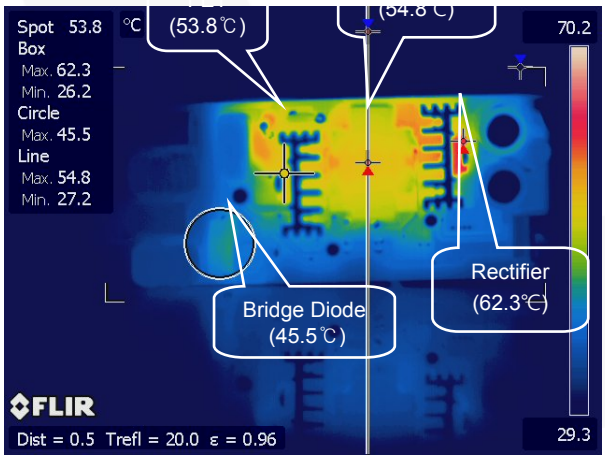

Figure 17. 265V_{AC} / 60Hz; Top Side

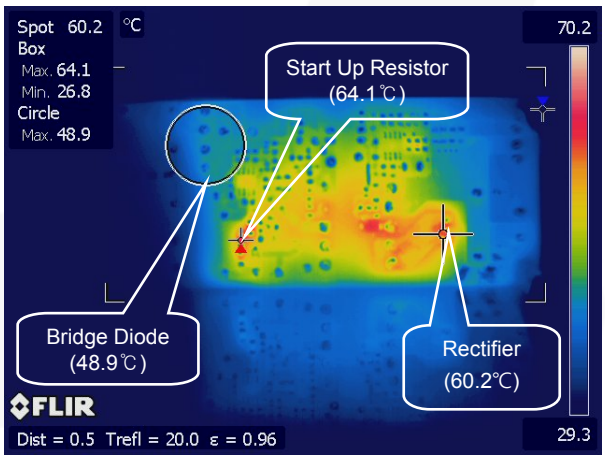

Figure 18. 265V_{AC} / 60Hz; Bottom Side

3.7 Startup Time

Figure 19 and Figure 20 show the typical startup performance of the board. A longer startup time to release the UVLO function can be achieved at $90V_{AC}$ condition rather than $265V_{AC}$ condition. This time normally depends on the starting resistor and capacitor on the board.

Input Voltage	Turn-On Time	Remark
$90V_{AC}$ / 60Hz	0.936s	< 1s
$265V_{AC}$ / 60Hz	0.279s	

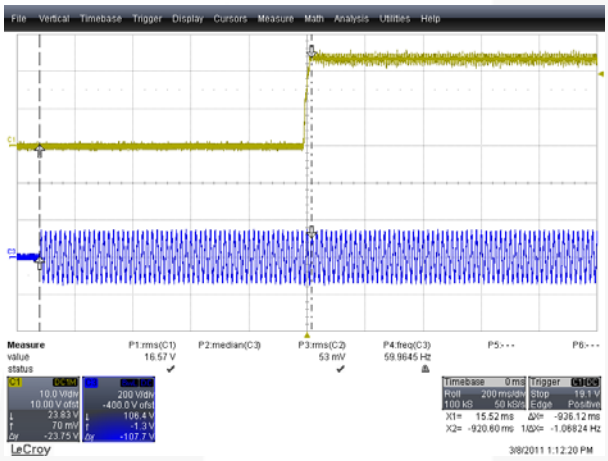

Figure 19. $90V_{AC}$ / 60Hz CH1 (Yellow): V_{OUT}, CH3 (Blue): V_{IN}

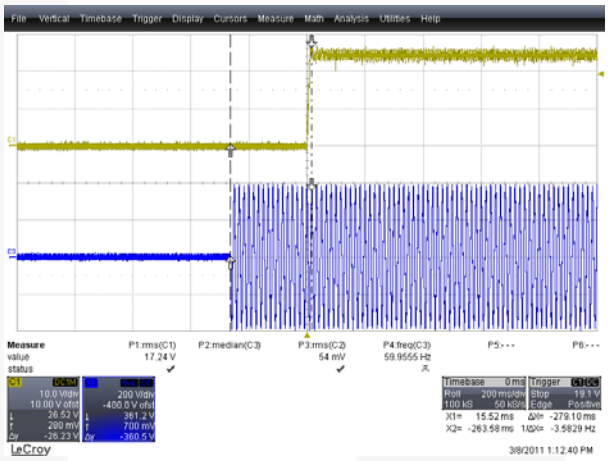

Figure 20. $265V_{AC}$ / 60Hz CH1 (Yellow): V_{OUT}, CH3 (Blue): V_{IN}

Figure 21 through Figure 24 show the typical startup performance of the Flyback circuit on the board.

Input Voltage	Turn-On Time	Remark
90V_{AC} / 60Hz	0.922s	< 1s
115V_{AC} / 60Hz	0.669s	
230V_{AC} / 60Hz	0.309s	
265V_{AC} / 60Hz	0.263s	

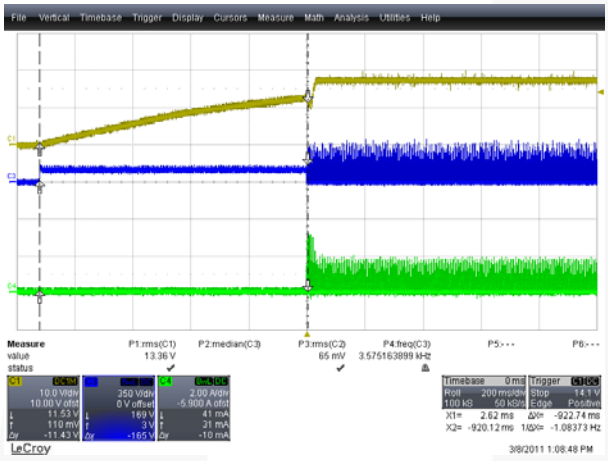

Figure 21. 90V_{AC} / 60Hz, CH1 (Yellow): V_{CC}, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

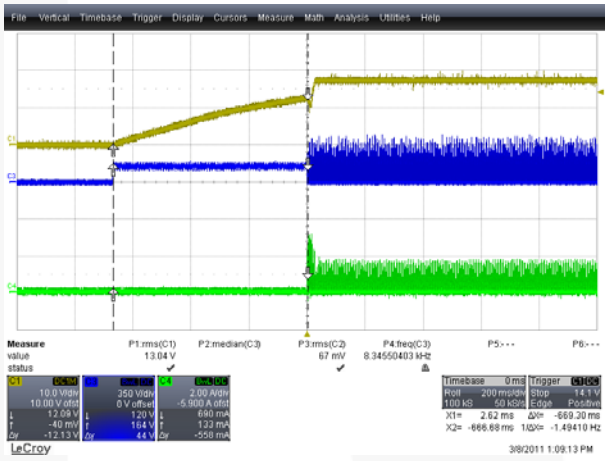

Figure 22. 115V_{AC} / 60Hz, CH1 (Yellow): V_{CC}, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

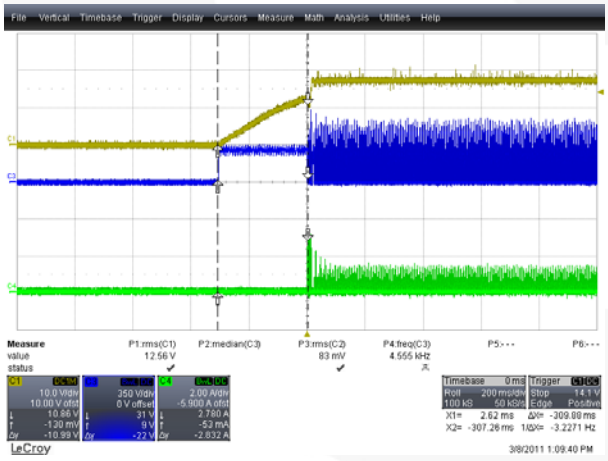

Figure 23. 230V_{AC} / 60Hz CH1 (Yellow): V_{CC}, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

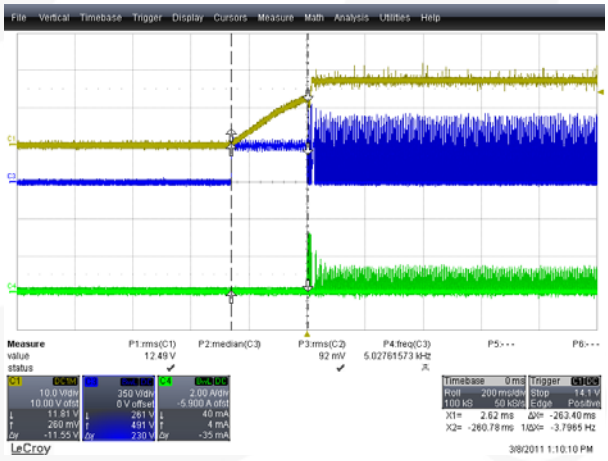

Figure 24. 265V_{AC} / 60Hz ,CH1 (Yellow): V_{CC}, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

3.8 Operation Waveforms

Figure 25 through Figure 28 show the normal operation waveforms on the board at different input voltage conditions. The output voltage maintains the output level with 120Hz ripple voltage.

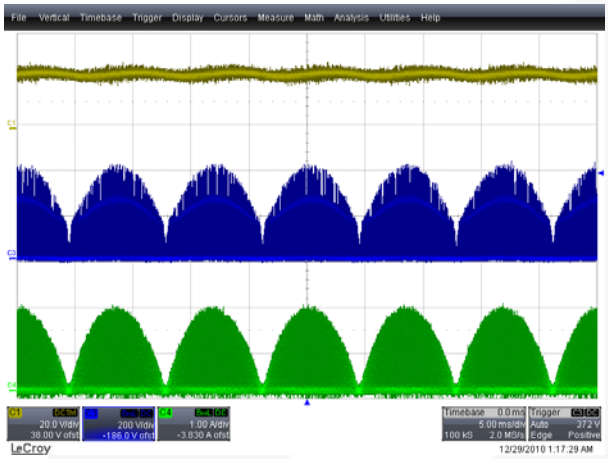

Figure 25. 90V_{AC} / 60Hz, CH1 (Yellow): V_O, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

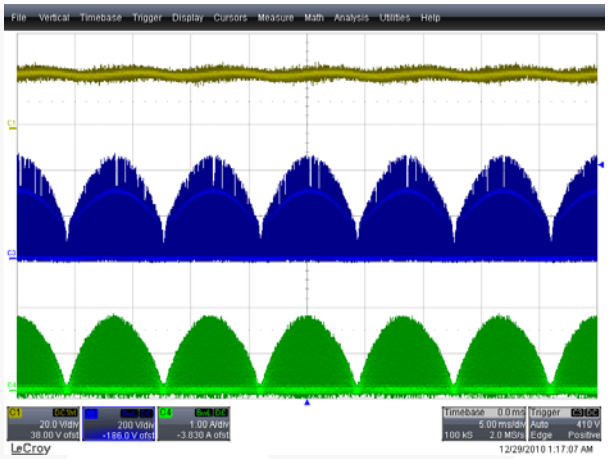

Figure 26. 115V_{AC} / 60Hz, CH1 (Yellow): V_O, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

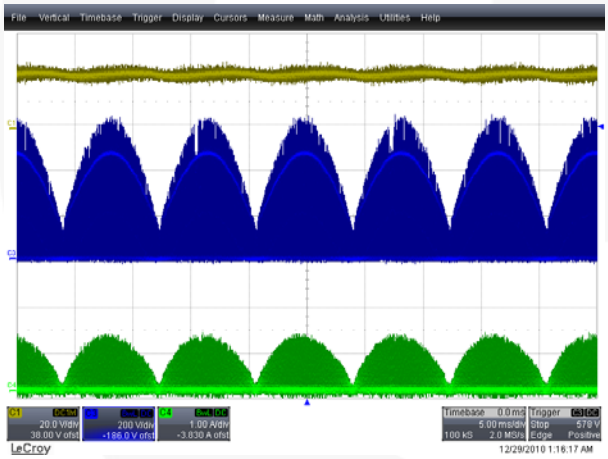

Figure 27. 230V_{AC} / 60Hz, CH1 (Yellow): V_O, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

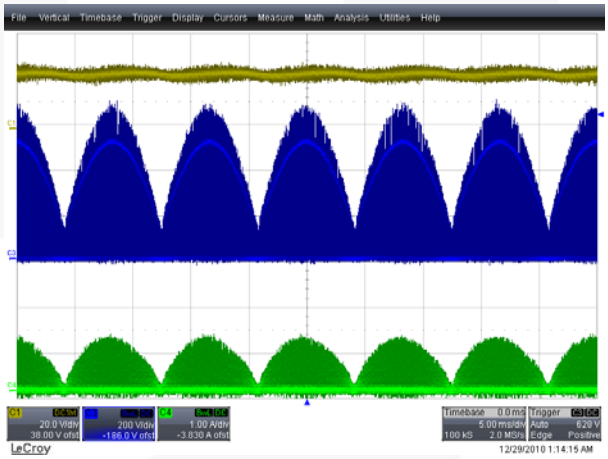

Figure 28. 265V_{AC} / 60Hz, CH1 (Yellow): V_O, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

Figure 29 through Figure 32 show the input current waveforms on the board at different input voltage conditions.

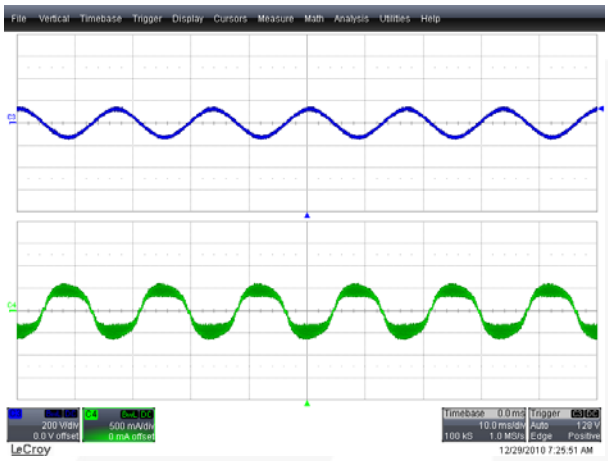

Figure 29. 90V_{AC} / 60Hz, CH3 (Blue): V_{IN}, CH4 (Green): I_{IN}

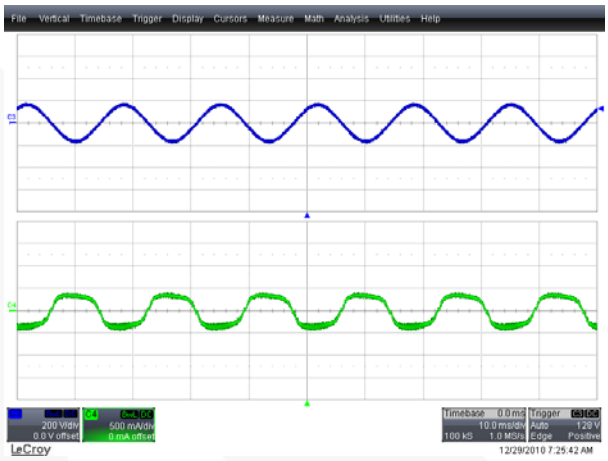

Figure 30. 115V_{AC} / 60Hz, CH3 (Blue): V_{IN}, CH4 (Green): I_{IN}

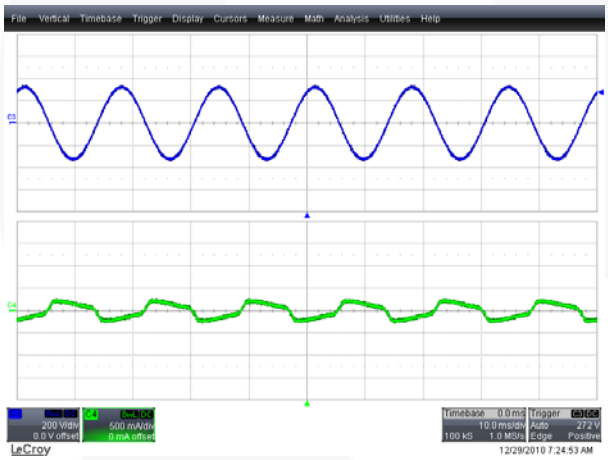

Figure 31. 230V_{AC} / 60Hz, CH3 (Blue): V_{IN}, CH4 (Green): I_{IN}

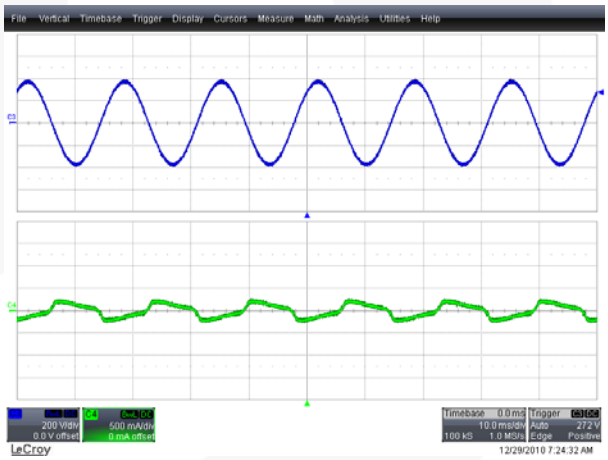

Figure 32. 265V_{AC} / 60Hz, CH3 (Blue): V_{IN}, CH4 (Green): I_{IN}

3.9 Short-Circuit Protection

Figure 33 through Figure 36 show the typical output waveforms at short load condition. The IC repeats ON and OFF functions in this mode.

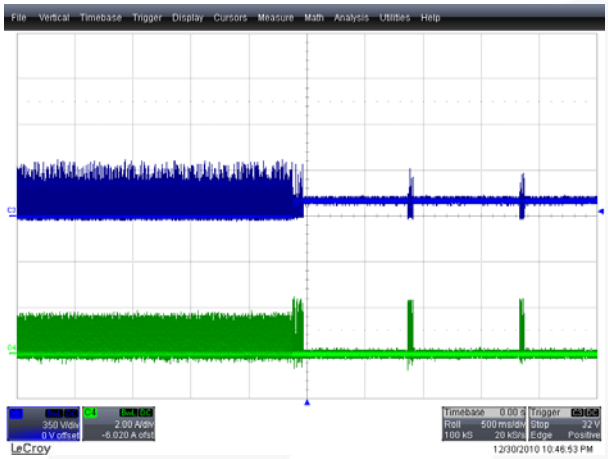

Figure 33. 90V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

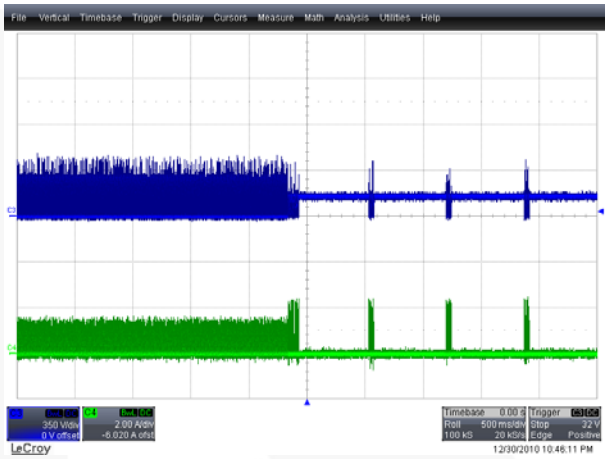

Figure 34. 115V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

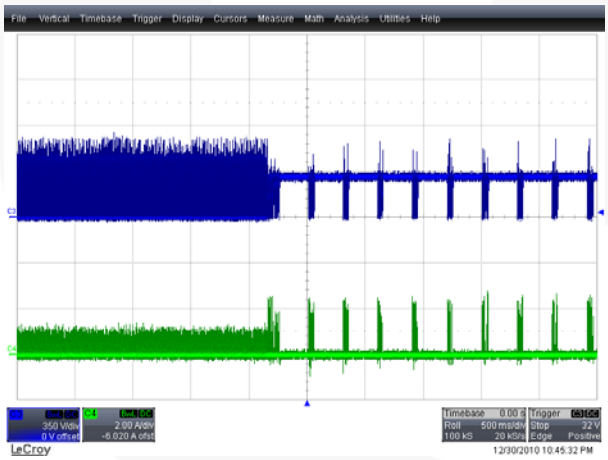

Figure 35. 230V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

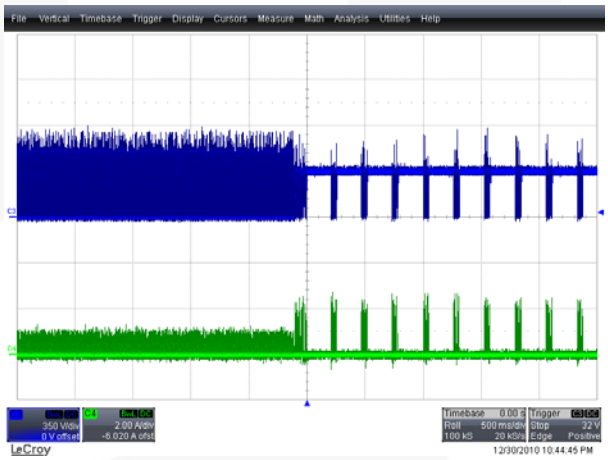

Figure 36. 265V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

3.10 Stress of the MOSFET & Rectifier

Figure 37 through Figure 40 show the voltage stress on the MOSFET at startup with the rated load condition.

	90V_{AC} / 60Hz	115V_{AC} / 60Hz	230V_{AC} / 60Hz	265V_{AC} / 60Hz
MOSFET (V_{DS})	442V	462V	644V	728V
MOSFET (I_{DS})	2.36A	2.38A	2.46A	2.42A
Rectifier (V_{AK})	54.5V	60.5V	84.5V	90.5V
Rectifier (I_{AK})	3.50A	3.32A	3.54A	3.42A

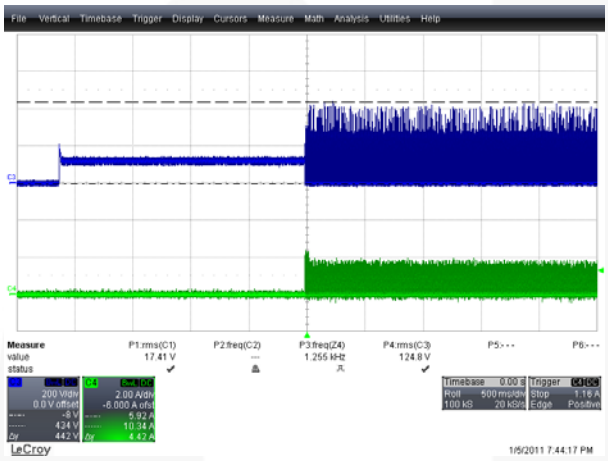

Figure 37. 90V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

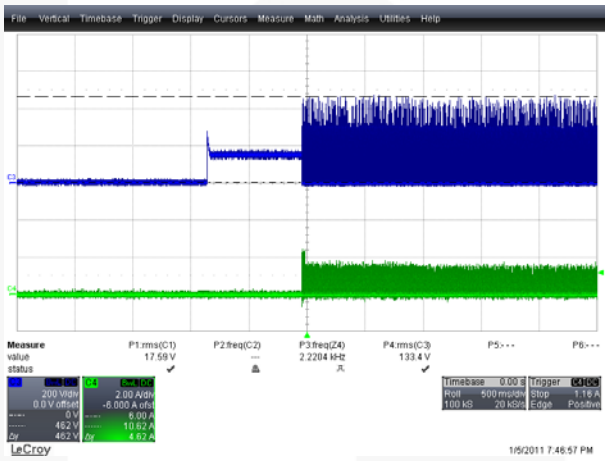

Figure 38. 115V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

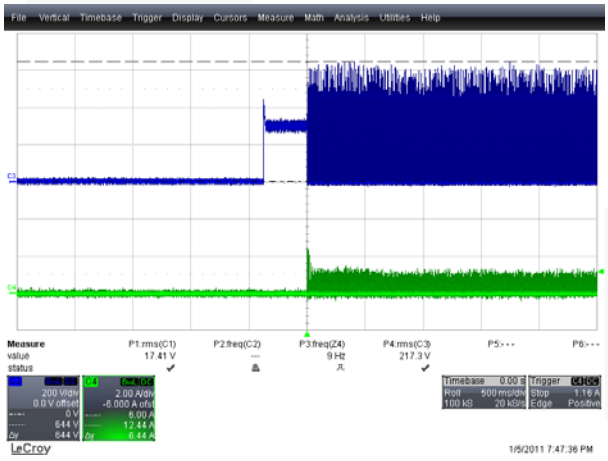

Figure 39. 230V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

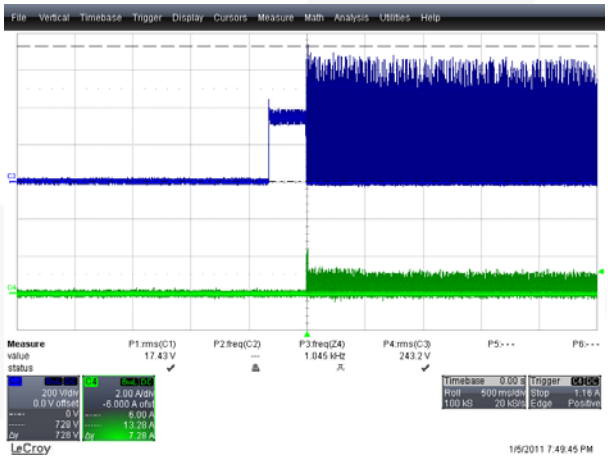

Figure 40. 265V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

Figure 41 through Figure 44 show the current stress on the MOSFET at startup with the rated load condition.

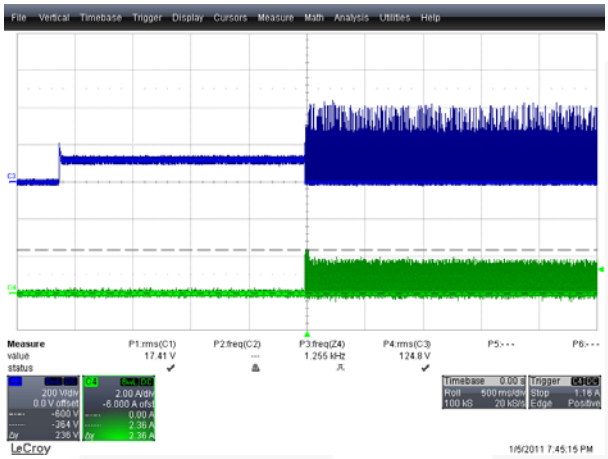

Figure 41. 90V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

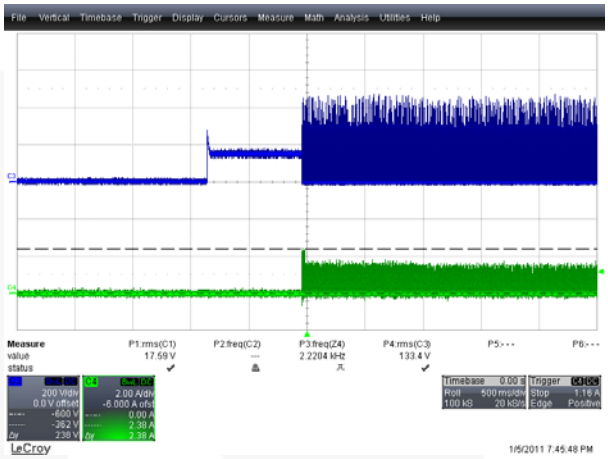

Figure 42. 115V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

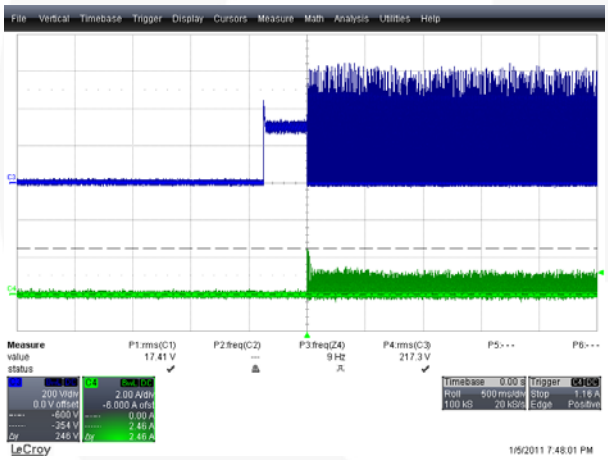

Figure 43. 230V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

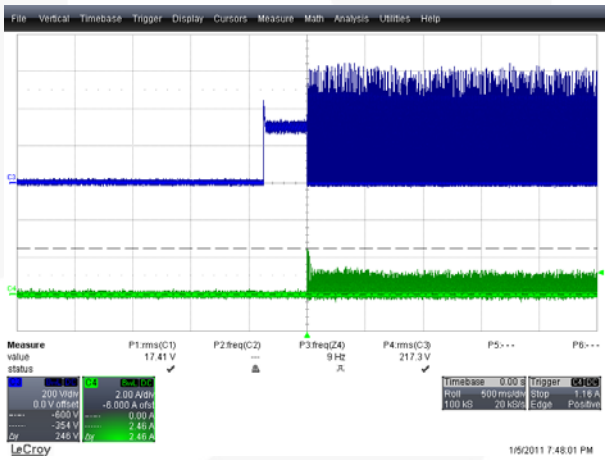

Figure 44. 265V_{AC} / 60Hz, CH3 (Blue): V_{DS}, CH4 (Green): I_{DS}

Figure 45 through Figure 48 show the voltage stress on the output rectifier at startup with the rated load condition.

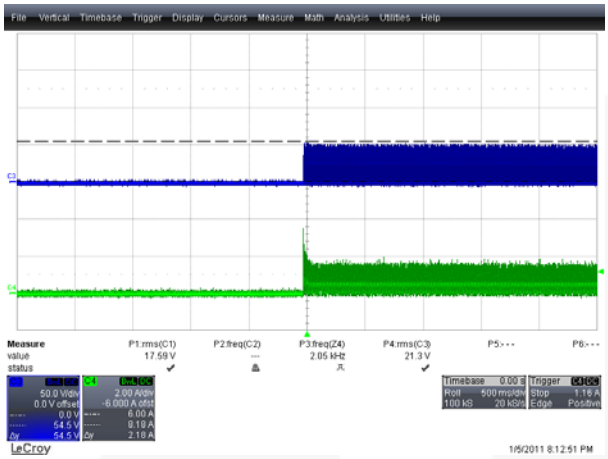

Figure 45. 90V_{AC} / 60Hz, CH3 (Blue): V_{AK}, CH4 (Green): I_{AK}

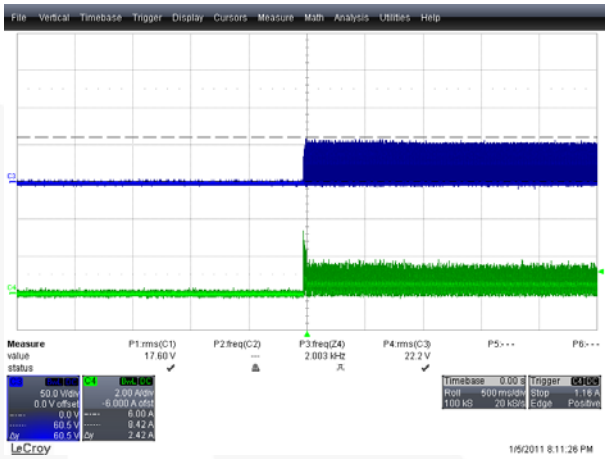

Figure 46. 115V_{AC} / 60Hz, CH3 (Blue): V_{AK}, CH4 (Green): I_{AK}

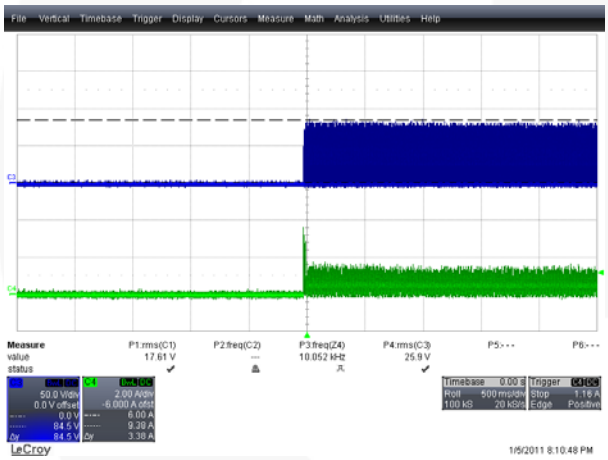

Figure 47. 230V_{AC} / 60Hz, CH3 (Blue): V_{AK}, CH4 (Green): I_{AK}

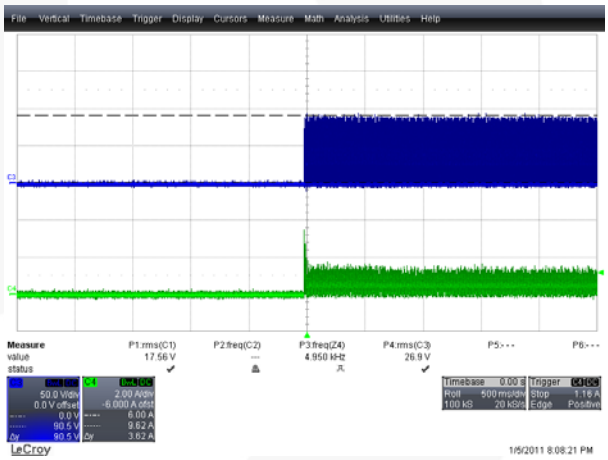

Figure 48. 265V_{AC} / 60Hz, CH3 (Blue): V_{AK}, CH4 (Green): I_{AK}

Figure 49 throgh Figure 52 show the current stress on the output rectifier at startup with the rated load condition.

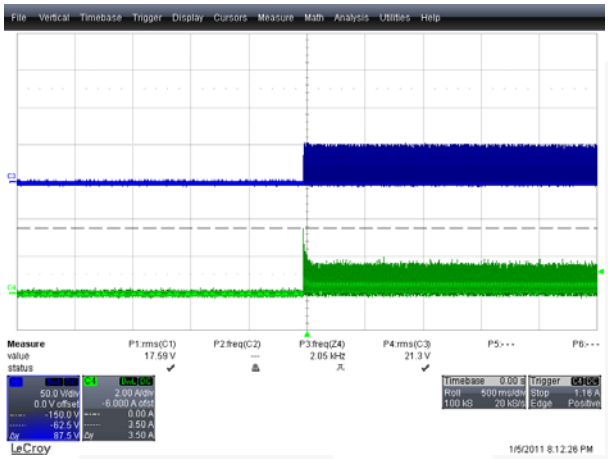

Figure 49. 90V_{AC} / 60Hz, CH3 (Blue): V_{AK}, CH4 (Green): I_{AK}

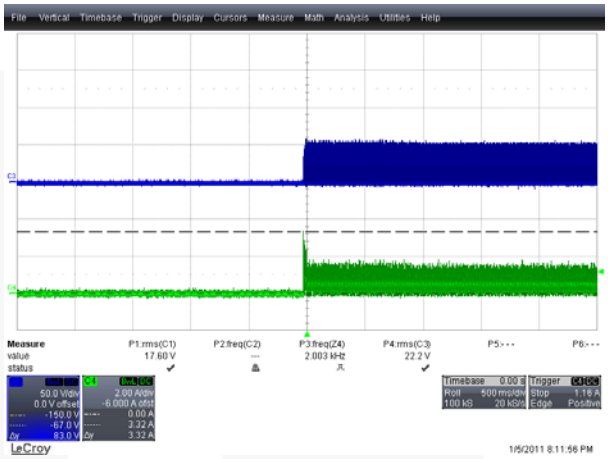

Figure 50. 115V_{AC} / 60Hz, CH3 (Blue): V_{AK}, CH4 (Green): I_{AK}

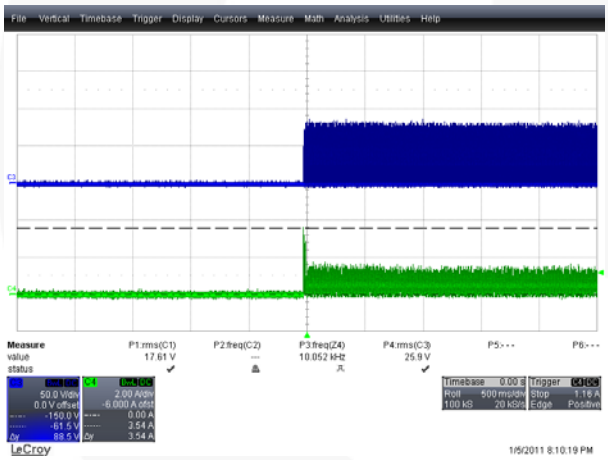

Figure 51. 230V_{AC} / 60Hz, CH3 (Blue): V_{AK}, CH4 (Green): I_{AK}

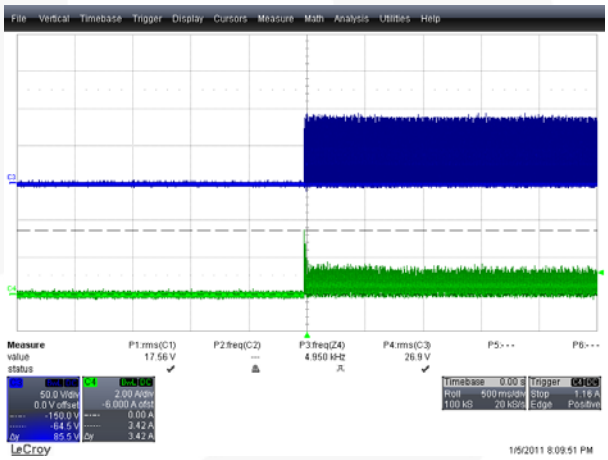

Figure 52. 265V_{AC} / 60Hz, CH3 (Blue): V_{AK}, CH4 (Green): I_{AK}

3.11 Stress of the MOSFET & Rectifier

All measurements were conducted in observance of CISPR22 criteria.

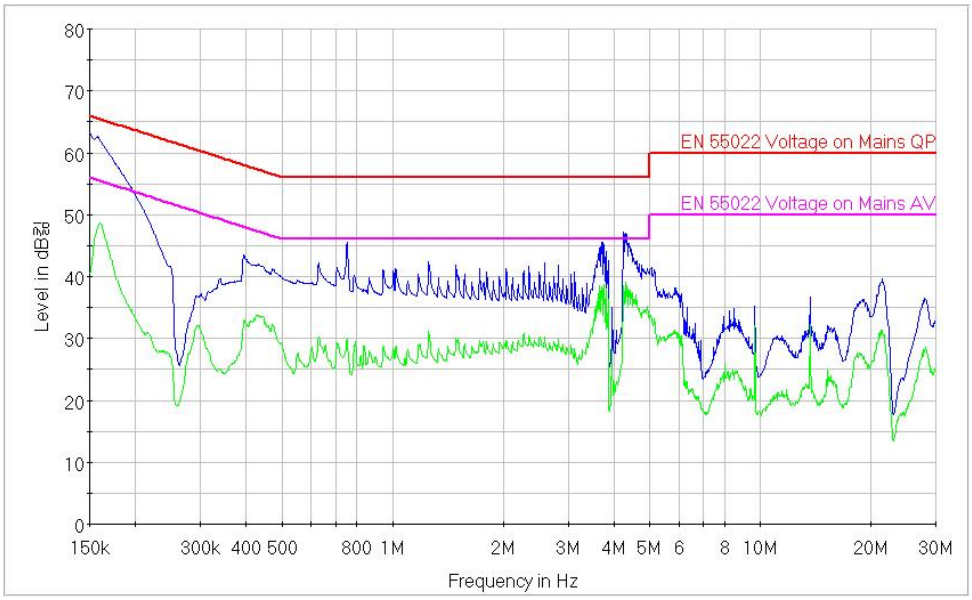

Figure 53. EMI Results, Conducted Emission-Line at 230V_{AC}, Full Load (24V/1.25A; 6 Series, 2 Parallel LEDs)

4. Revision History

Rev.	Date	Description
1.0.0	5/22/12	Initial Release

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Replace components on the Evaluation Board only with those parts shown on the parts list (or Bill of Materials) in the Users' Guide. Contact an authorized Fairchild representative with any questions.

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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