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User Guide for

FEBFL7733A_L50U008A Evaluation Board

8.4 W LED Driver at Universal Line

Featured Fairchild Product: FL7733A

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 FL7733A. It should be used in conjunction with the FL7733A 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 a solution for a universal AC input voltage LED driver using the FL7733A Primary-Side Regulator (PSR) single-stage controller. The input voltage range is 90 V_{RMS} ~ 265 V_{RMS} and there is one DC output with a constant current of 350 mA at 24 V. This document contains a general description of the FL7733A, the power supply solution specification, schematic, bill of materials, and typical operating characteristics.

1.1. General Description of FL7733A

The FL7733A is an active Power Factor Correction (PFC) controller used in a single-stage flyback topology or buck-boost topology. Primary-side regulation and a single-stage topology reduce external components, such as the input bulk capacitor and feedback circuitry, minimizing cost. To improve power factor and Total Harmonic Distortion (THD), constant on-time control is utilized with an internal error amplifier and a low bandwidth compensator. Precise constant-current control regulates accurate output current, independent of input voltage and output voltage. Operating frequency is proportionally changed by output voltage to guarantee Discontinuous Current Mode (DCM) operation, resulting in high efficiency and a simple design. The FL7733A provides open-LED, short-LED, and over-temperature protections.

1.2. Controller Features

High Performance

- Cost-Effective Solution; No Input Bulk Capacitor / Secondary Feedback Circuitry
- Power Factor Correction
- THD <10% Over Universal Input Line Range
- CC Tolerance:
  < ±1% Over Universal Input Line Voltage Variation
  < ±1% by 50% ~ 100% Load Voltage Variation
  < ±1% by ±20% Magnetizing Inductance Variation
- High-Voltage Startup with VDD Regulation
- Adaptive Feedback Loop Control for No Overshoot at Startup

High Reliability

- LED Short / Open Protection
- Output Diode Short Protection
- Sensing Resistor Short / Open Protection
- V_{DD} Over-Voltage Protection (OVP)
- V_{DD} Under-Voltage Lockout (UVLO)
- Over-Temperature Protection (OTP)
- All Protections are Auto Restart
- Cycle-by-Cycle Current Limit
- Application Voltage Range: 80 V_{AC} ~ 308 V_{AC}

1.3. Controller Internal Block Diagram

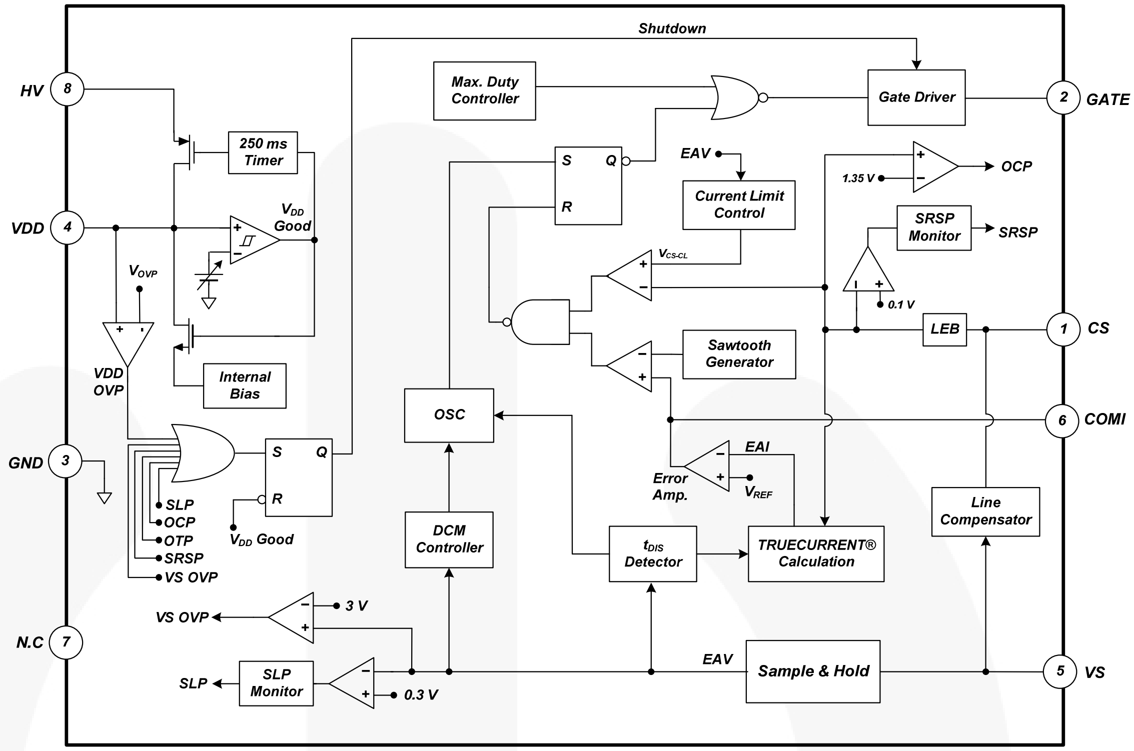

Figure 1. Block Diagram

2. Evaluation Board Specifications

Table 1. Specifications for LED Lighting Load

<table>
<tr><th colspan="2">Description</th><th>Symbol</th><th>Value</th><th>Comments</th></tr>
<tr><td rowspan="4">Input</td><td rowspan="3">Voltage</td><td>$V_{IN.MIN}$</td><td>90 V_{AC}</td><td>Minimum AC Input Voltage</td></tr>
<tr><td>$V_{IN.MAX}$</td><td>265 V_{AC}</td><td>Maximum AC Input Voltage</td></tr>
<tr><td>$V_{IN.NOMINAL}$</td><td>120 V / 230 V</td><td>Nominal AC Input Voltage</td></tr>
<tr><td>Frequency</td><td>f_{IN}</td><td>60 Hz / 50 Hz</td><td>Line Frequency</td></tr>
<tr><td rowspan="6">Output</td><td rowspan="3">Voltage</td><td>$V_{OUT.MIN}$</td><td>13 V</td><td>Minimum Output Voltage</td></tr>
<tr><td>$V_{OUT.MAX}$</td><td>28 V</td><td>Maximum Output Voltage</td></tr>
<tr><td>$V_{OUT.NOMINAL}$</td><td>24 V</td><td>Nominal Output Voltage</td></tr>
<tr><td rowspan="3">Current</td><td>$I_{OUT.NOMINAL}$</td><td>350 mA</td><td>Nominal Output Current</td></tr>
<tr><td rowspan="2">CC Deviation</td><td>< ±0.29%</td><td>Line Input Voltage Change: 90~265 V_{AC}</td></tr>
<tr><td>< ±0.72%</td><td>Output Voltage Change: 13~28 V</td></tr>
<tr><td colspan="2" rowspan="6">Efficiency</td><td>Eff_{90VAC}</td><td>86.41%</td><td>Efficiency at 90 V_{AC} Input Voltage</td></tr>
<tr><td>Eff_{120VAC}</td><td>87.88%</td><td>Efficiency at 120 V_{AC} Input Voltage</td></tr>
<tr><td>Eff_{140VAC}</td><td>88.25%</td><td>Efficiency at 140 V_{AC} Input Voltage</td></tr>
<tr><td>Eff_{180VAC}</td><td>88.68%</td><td>Efficiency at 180 V_{AC} Input Voltage</td></tr>
<tr><td>Eff_{230VAC}</td><td>88.95%</td><td>Efficiency at 230 V_{AC} Input Voltage</td></tr>
<tr><td>Eff_{265VAC}</td><td>88.96%</td><td>Efficiency at 265 V_{AC} Input Voltage</td></tr>
<tr><td colspan="2" rowspan="6">PF/THD</td><td>PF / THD_{90VAC}</td><td>0.996 / 3.85%</td><td>PF/THD at 90 V_{AC} Input Voltage</td></tr>
<tr><td>PF / THD_{120VAC}</td><td>0.992 / 3.61%</td><td>PF/THD at 120 V_{AC} Input Voltage</td></tr>
<tr><td>PF / THD_{140VAC}</td><td>0.988 / 4.16%</td><td>PF/THD at 140 V_{AC} Input Voltage</td></tr>
<tr><td>PF / THD_{180VAC}</td><td>0.975 / 4.90%</td><td>PF/THD at 180 V_{AC} Input Voltage</td></tr>
<tr><td>PF / THD_{230VAC}</td><td>0.945 / 6.01%</td><td>PF/THD at 230 V_{AC} Input Voltage</td></tr>
<tr><td>PF / THD_{265VAC}</td><td>0.914 / 7.06%</td><td>PF/THD at 265 V_{AC} Input Voltage</td></tr>
<tr><td rowspan="4">Temperature</td><td>FL7733A</td><td>$T_{FL7733A}$</td><td>52.9°C</td><td>Open-Frame Condition
(T_A = 25ºC) FL7733A Temperature</td></tr>
<tr><td>Primary MOSFET</td><td>T_{MOSFET}</td><td>61.2°C</td><td>Primary MOSFET Temperature</td></tr>
<tr><td>Secondary Diode</td><td>T_{DIODE}</td><td>52.8°C</td><td>Secondary Diode Temperature</td></tr>
<tr><td>Transformer</td><td>$T_{TRANSFORMER}$</td><td>56.0°C</td><td>Transformer Temperature</td></tr>
</table>

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

3. Evaluation Board Photographs

Dimensions: 64 mm (L) x 26 mm (W) x 26 mm (H)

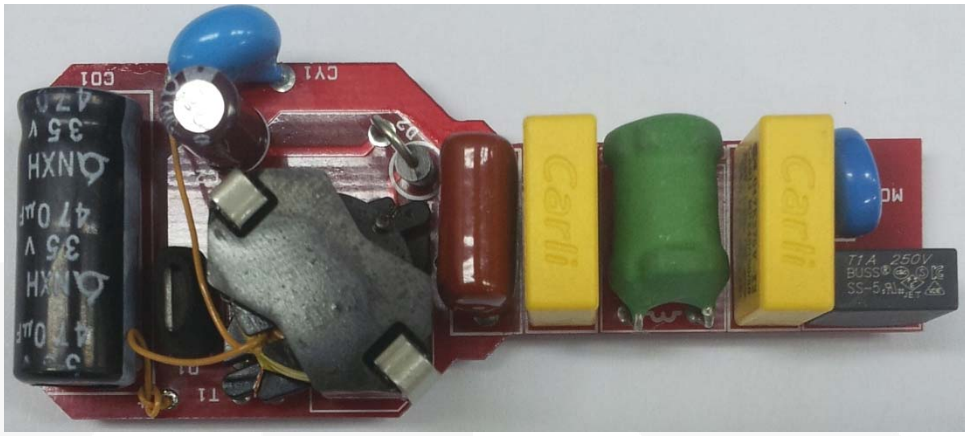

Figure 2. Top View

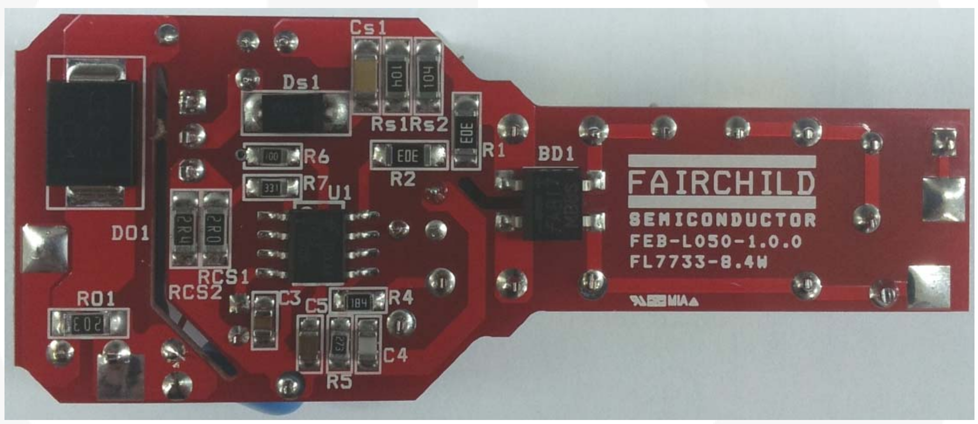

Figure 3. Bottom View

4. Evaluation Board Printed Circuit Board (PCB)

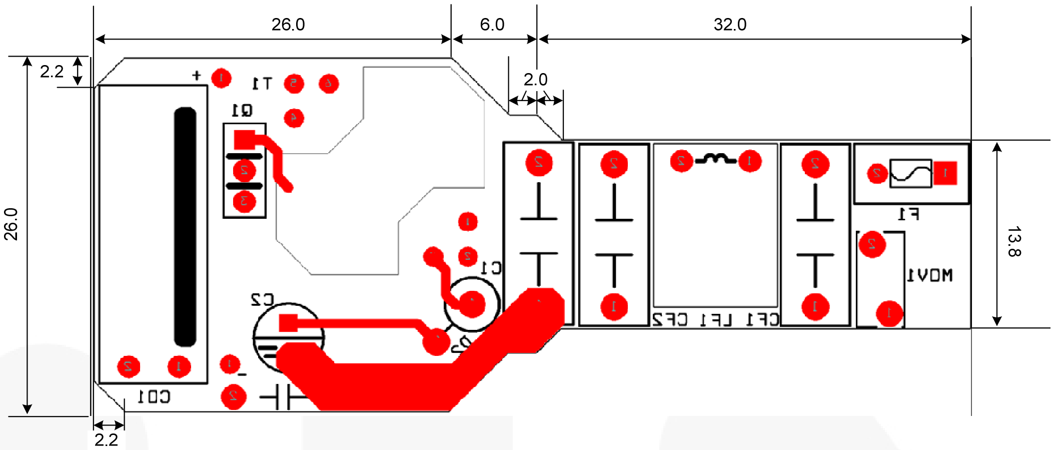

Figure 4. Top Pattern (in mm)

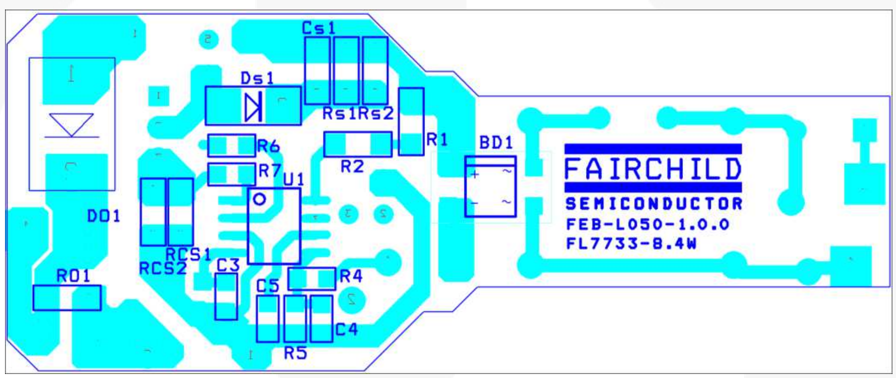

Figure 5. Bottom Pattern

5. Evaluation Board Schematic

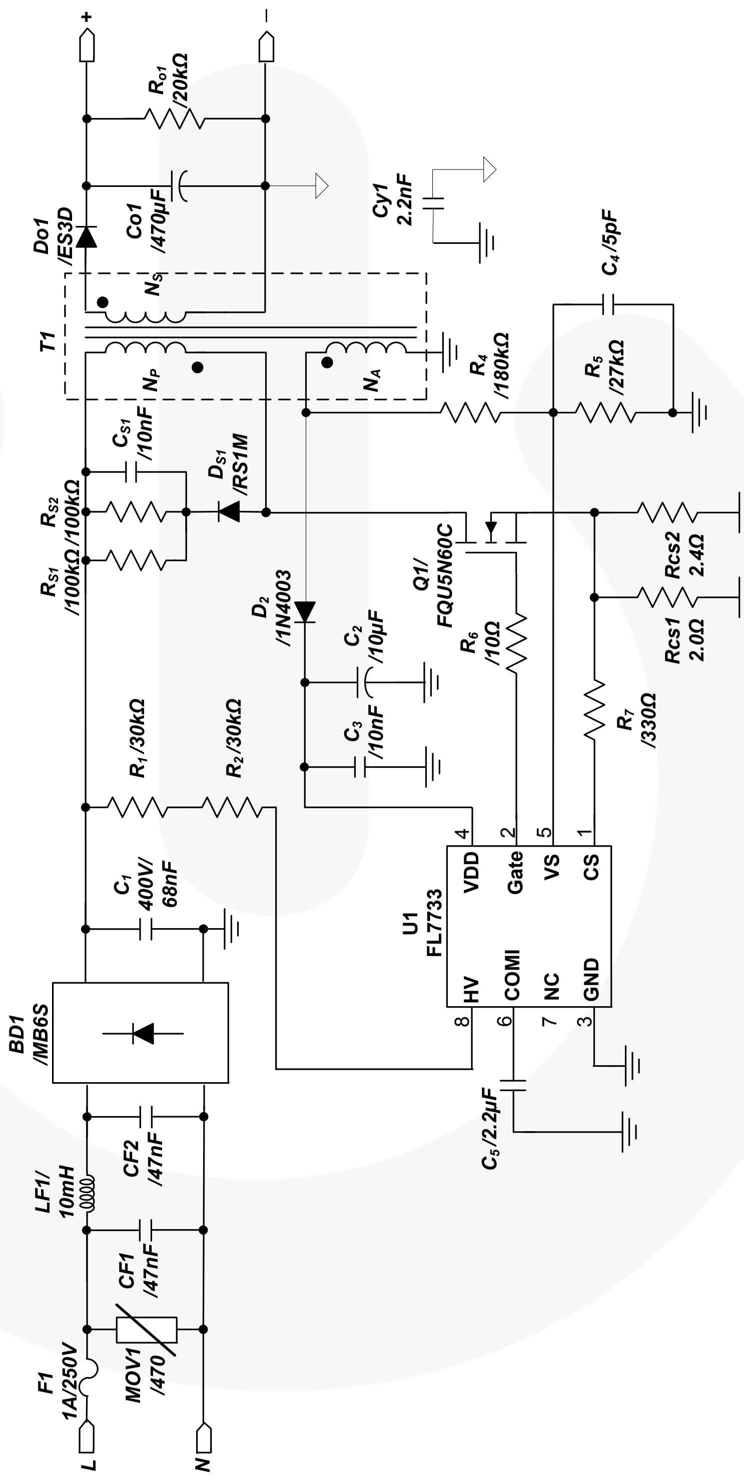

Figure 6. Schematic

6. Evaluation Board Bill of Materials (BOM)

Item No.	Part Reference	Part Number	Qty.	Description	Manufacturer
1	BD1	MB8S	1	Bridge Diode	Fairchild Semiconductor
2	CF1	MPX AC275V 473 K	2	47 nF / AC275V, X-Capacitor	Carli
3	CS1	C1206C103KDRACTU	1	10 nF / 1 kV, SMD Capacitor 1206	Kemet
4	CY1	SCFz2E222M10BW	1	2.2 nF / 250 V, Y-Capacitor	Samwha
5	Co1	NXH 470 µF 35 V	1	470 µF / 35 V, Electrolytic Capacitor	Samyoung
6	C1	MPE400V683K	1	68 nF / 400 V, MPE Film Capacitor	Sungho
7	C2	KMG10 µF 35 V	1	10 µF / 35 V, Electrolytic Capacitor	Samyoung
8	C3	C0805C104K5RACTU	1	100 nF / 50 V, SMD Capacitor 2012	Kemet
9	C4	C0805C519C3GACTU	1	5 pF / 25 V, SMD Capacitor 2012	Kemet
10	C5	C0805C225J3RACTU	1	2.2 µF / 25 V, SMD Capacitor 2012	Kemet
11	DS1	RS1M	1	1000 V / 1 A, Ultra-Fast Recovery Diode	Fairchild Semiconductor
12	Do1	ES3D	1	200 V / 3 A, Fast Rectifier	Fairchild Semiconductor
13	D2	1N4003	1	200 V / 1 A, General-Purpose Rectifier	Fairchild Semiconductor
14	F1	SS-5-1A	1	250 V / 1 A, Fuse	Bussmann
15	LF1	R10302KT00	1	10 mH, Inductor, 8Ø	Bosung
16	MOV1	SVC471D-07A	1	Metal Oxide Varistor	Samwha
17	Q1	FQU5N60C	1	600 V / 4 A, N-Channel MOSFET	Fairchild Semiconductor
18	R6	RC0805JR-0710RL	1	10 Ω, SMD Resistor 0805	Yageo
19	RS1, RS2	RC1206JR-07100KL	2	100 kΩ, SMD Resistor 1206	Yageo
20	Rcs1	RC1206JR-072RL	1	2 Ω, SMD Resistor 1206	Yageo
21	Rcs2	RC1206JR-072R4L	1	2.4 Ω, SMD Resistor 1206	Yageo
22	R7	RC0805JR-07330RL	1	330 Ω, SMD Resistor 0805	Yageo
23	Ro1	RC1206JR-0720KL	1	20 kΩ, SMD Resistor 1206	Yageo
24	R4	RC0805JR-07180KL	1	180 kΩ, SMD Resistor 0805	Yageo
25	R1, R2	RC1206JR-0730KL	2	30 kΩ, SMD Resistor 1206	Yageo
26	R5	RC0805JR-0727KL	1	27 kΩ, SMD Resistor 0805	Yageo
27	T1	RM6 Core	1	6-Pin, Transformer	TDK
28	U1	FL7733A	1	Main PSR Controller	Fairchild Semiconductor

7. Transformer Design

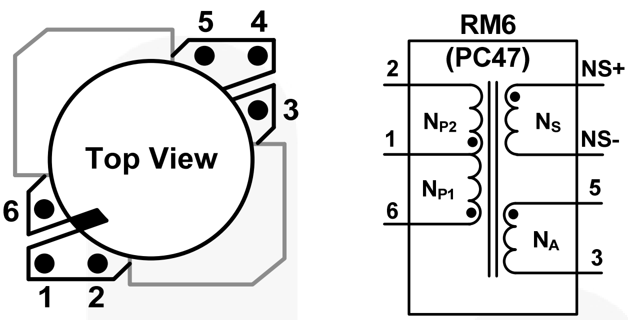

Figure 7. Transformer Bobbin Structure and Pin Configuration

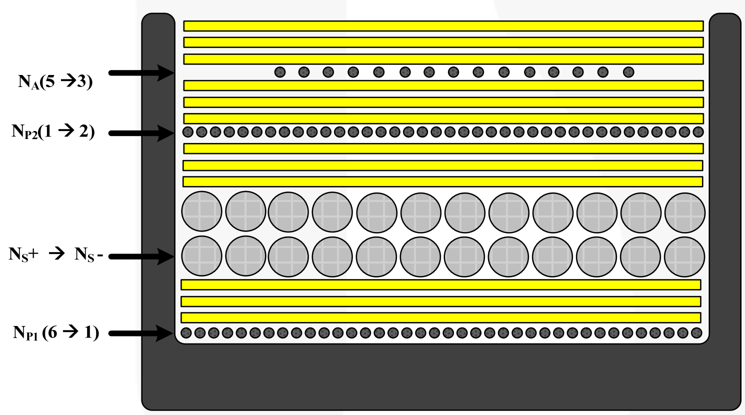

Figure 8. Transformer Winding Structure

Table 2. Winding Specifications

No.	Winding	Pin (S → F)	Wire	Turns	Winding Method
1	N_{P1}	6 → 1	0.20φ	54 Ts	Solenoid Winding
2	Insulation: Polyester Tape t = 0.025 mm, 3-Layer				
3	N_S	NS+ → NS-	0.25φ (TIW)	25 Ts	Solenoid Winding
4	Insulation: Polyester Tape t = 0.025 mm, 3-Layer				
5	N_{P2}	1 → 2	0.20φ	27 Ts	Solenoid Winding
6	Insulation: Polyester Tape t = 0.025 mm, 3-Layer				
7	N_A	5 → 3	0.20φ	17 Ts	Solenoid Winding
8	Insulation: Polyester Tape t = 0.025 mm, 3-Layer				

Table 3. Electrical Characteristics

	Pins	Specifications	Remark
Inductance	6 – 2	1.0 mH ±10%	60 kHz, 1 V
Leakage	6 – 2	10 µH	60 kHz, 1 V, Short All Output Pins

8. Evaluation Board Performance

Table 4. Test Condition & Equipment List

Ambient Temperature	T_A = 25°C
Test Equipment	AC Power Source: PCR500L by Kikusui Power Analyzer: PZ4000000 by Yokogawa Electronic Load: PLZ303WH by KIKUSUI Multi Meter: 2002 by KEITHLEY, 45 by FLUKE Oscilloscope: 104Xi by LeCroy Thermometer: Thermal CAM SC640 by FLIR SYSTEMS LED: EHP-AX08EL/GT01H-P03 (3 W) by Everlight

8.1. Startup

Figure 9 and Figure 10 show the overall startup performance at rated output load. The output load current starts flowing after about 0.2 s and 0.1 s for input voltage 90 V_{AC} and 265 V_{AC} condition when the AC input power switch turns on. CH1: V_{DD} (10 V / div), CH2: V_{IN} (100 V / div), CH3: V_{LED} (20 V / div), CH4: I_{LED} (200 mA / div), Time Scale: (100 ms / div), Load: 7 series-LEDs.

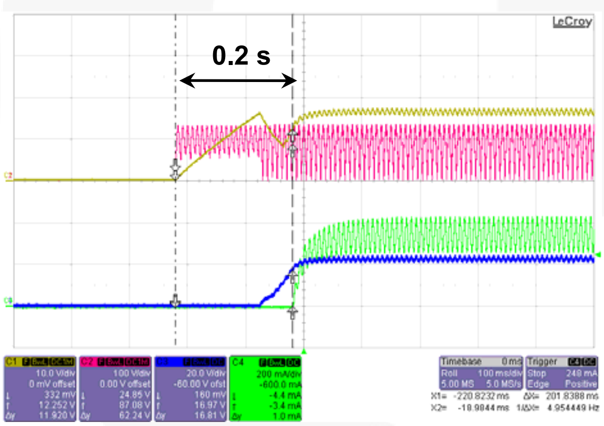

Figure 9. V_{IN} = 90 V_{AC} / 60 Hz

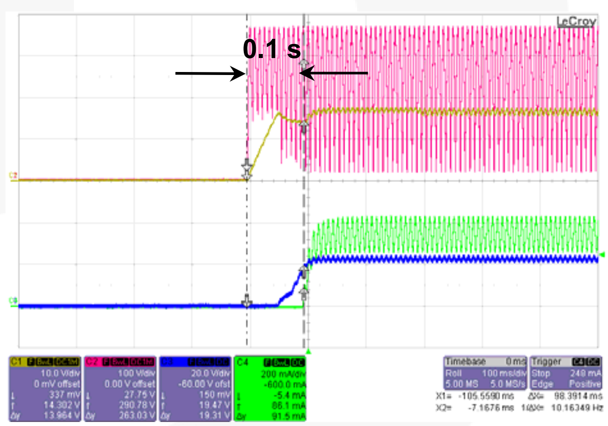

Figure 10. V_{IN} = 120 V_{AC} / 60 Hz

8.2. Operation Waveforms

Figure 11 to Figure 14 show AC input and output waveforms at rated output load. CH1: I_{IN} (200 mA / div), CH2: V_{IN} (100 V / div), CH3: V_{LED} (20 V / div), CH4: I_{LED} (200 mA / div), Time Scale: (5 ms / div), Load: 7 series LEDs.

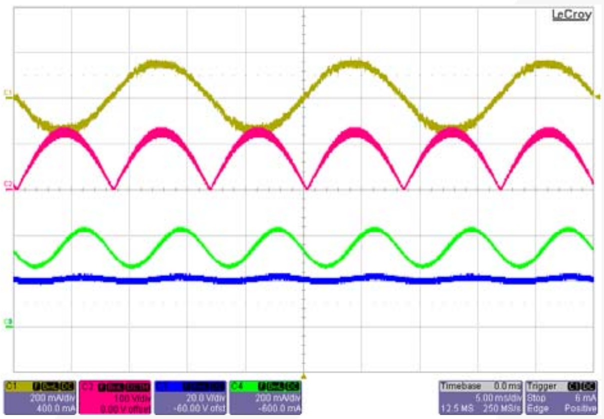

Figure 11. V_{IN} = 90 V_{AC} / 60 Hz

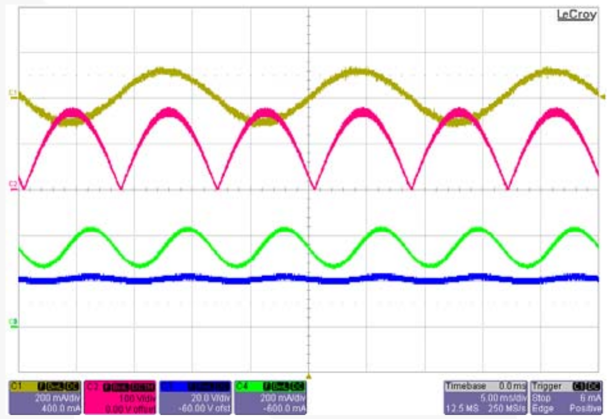

Figure 12. V_{IN} = 120 V_{AC} / 60 Hz

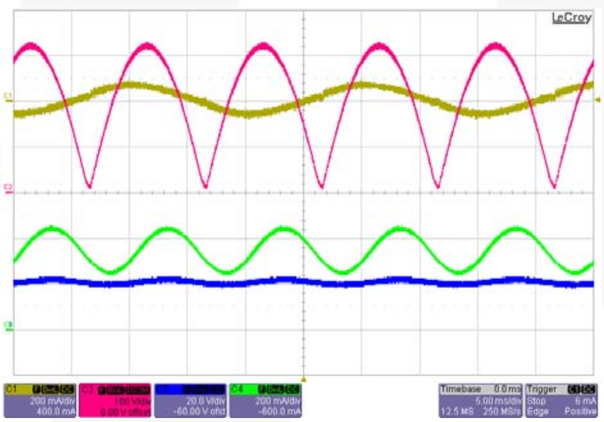

Figure 13. V_{IN} = 230 V_{AC} / 50 Hz

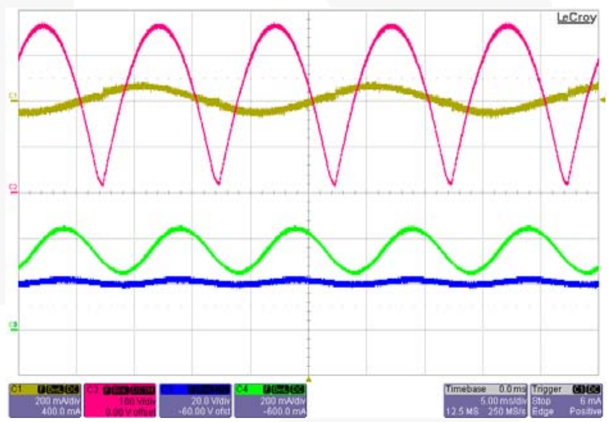

Figure 14. V_{IN} = 265 V_{AC} / 50 Hz

Figure 15 to Figure 18 show key waveforms of single-stage flyback converter operation for line voltage at rated output load. CH1: V_{CS} (500 mA / div), CH2: V_{DS} (200 V / div), CH3: $V_{SEC\text{-}Diode}$ (100 V / div), CH4: $I_{SEC\text{-}Diode}$ (2.0 A / div), Load: 7 series-LEDs.

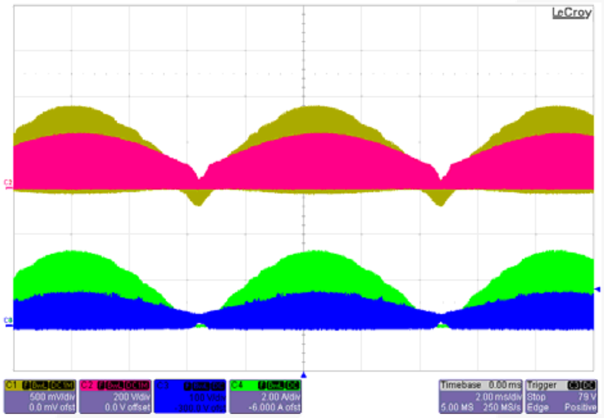

Figure 15. V_{IN} = 90 V_{AC} / 60 Hz, [2.0 ms / div]

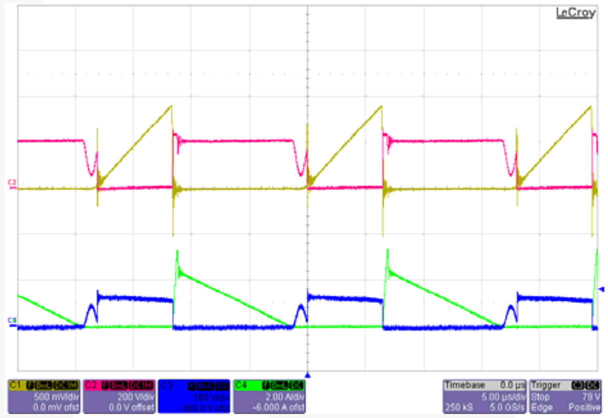

Figure 16. V_{IN} = 90 V_{AC} / 60 Hz, [5.0 µs / div]

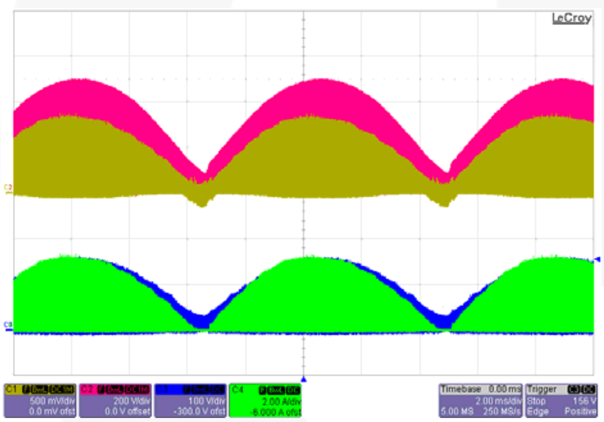

Figure 17. V_{IN} = 265 V_{AC} / 60 Hz, [2.0 ms / div]

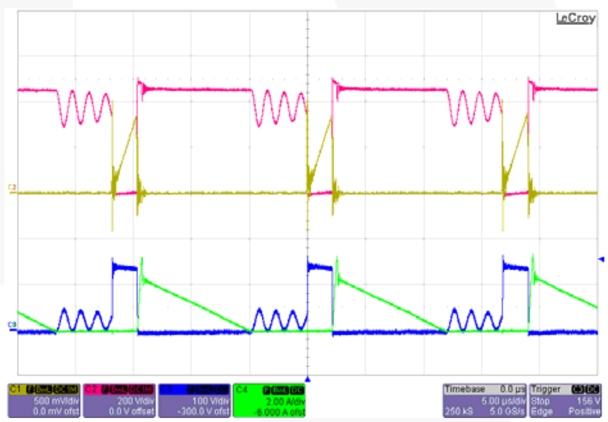

Figure 18. V_{IN} = 265 V_{AC} / 60 Hz, [5.0 µs / div]

8.3. Constant-Current Regulation

The output current deviation for wide output voltage ranges, from 13 V to 28 V, is less than ±0.8% at each line voltage. Line regulation at the rated output voltage (24 V) is less than ±0.3%. The results were measured with E-load [CR Mode].

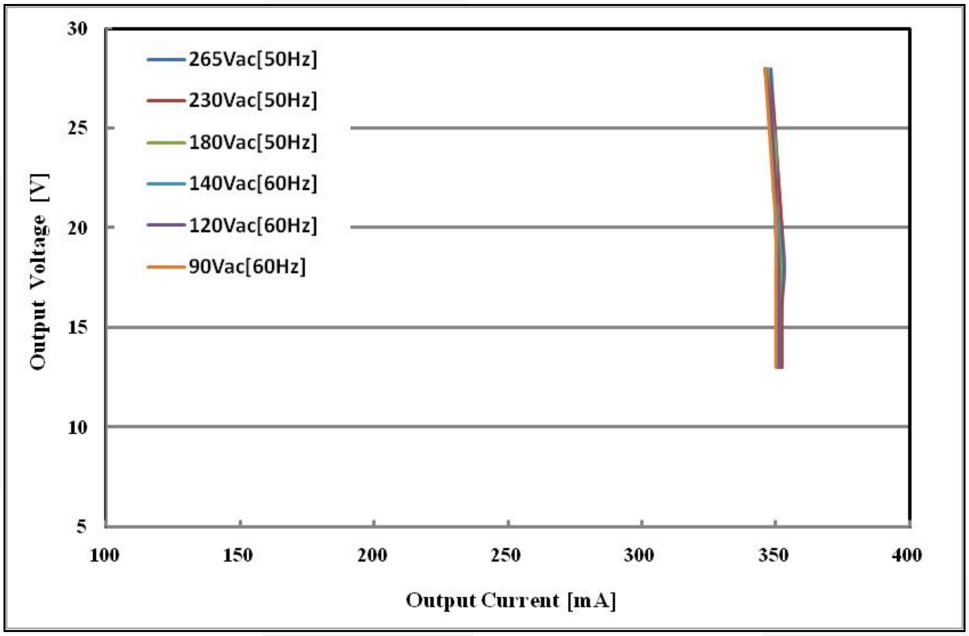

Figure 19. Constant-Current Regulation

Table 5. Constant-Current Regulation by Output Voltage Change (13 ~ 28 V)

Input Voltage	Min. Current [mA]	Max. Current [mA]	Tolerance
90 V_{AC} [60 Hz]	346	350	±0.57%
120 V_{AC} [60 Hz]	346	351	±0.72%
140 V_{AC} [60 Hz]	346	351	±0.72%
180 V_{AC} [50 Hz]	347	352	±0.72%
230 V_{AC} [50 Hz]	347	352	±0.72%
265 V_{AC} [50 Hz]	348	353	±0.71%

Table 6. Constant-Current Regulation by Line Voltage Change (90 ~ 265 V_{AC})

Output Voltage	90 V_{AC} [60 Hz]	120 V_{AC} [60 Hz]	140 V_{AC} [60 Hz]	180 V_{AC} [50 Hz]	230 V_{AC} [50 Hz]	265 V_{AC} [50 Hz]	Tolerance
26 V	347 mA	348 mA	348 mA	348 mA	349 mA	349 mA	±0.29%
24 V	348 mA	349 mA	349 mA	350 mA	350 mA	350 mA	±0.29%
22 V	349 mA	350 mA	349 mA	350 mA	351 mA	351 mA	±0.29%

8.4. Short- / Open-LED Protections

Figure 20 to Figure 23 show waveforms for protections operated when the LED is shorted and recovered. Once the LED short occurs, SCP is triggered and VDD starts hiccup mode with JFET regulation times [250 ms]. This lasts until the fault condition is eliminated. Systems can restart automatically when returned to normal condition. CH1: V_{GATE} (10 V / div), CH2: V_{IN} (100 V / div), CH3: V_{DD} (5 V / div), I_{OUT} (200 mA / div), Time Scale: (200 ms / div).

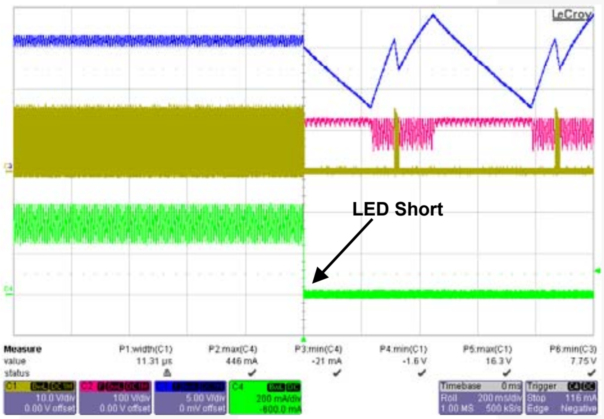

Figure 20. V_{IN} = 90 V_{AC} / 60 Hz, [LED Short]

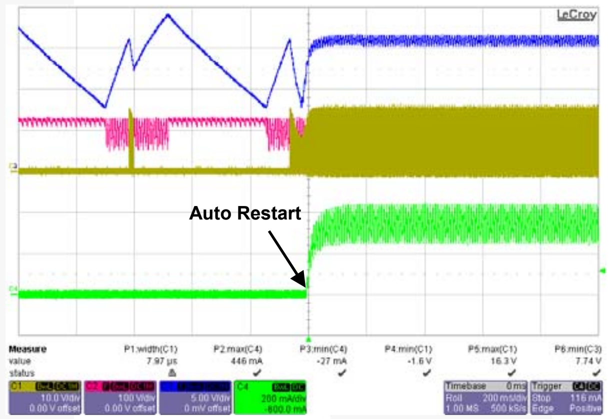

Figure 21. V_{IN} = 90 V_{AC} / 60 Hz, [LED Restore]

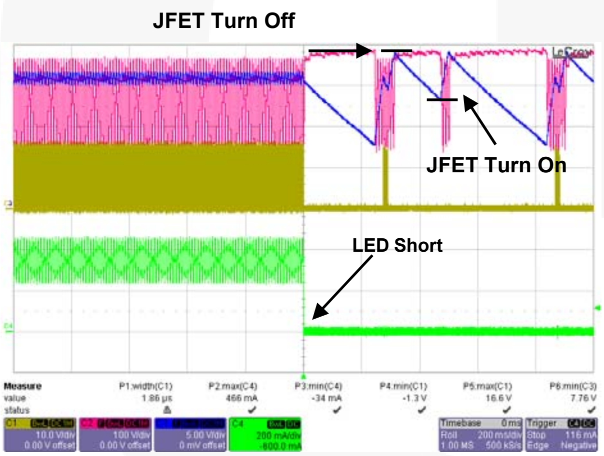

Figure 22. V_{IN} = 265 V_{AC} / 50 Hz, [LED Short]

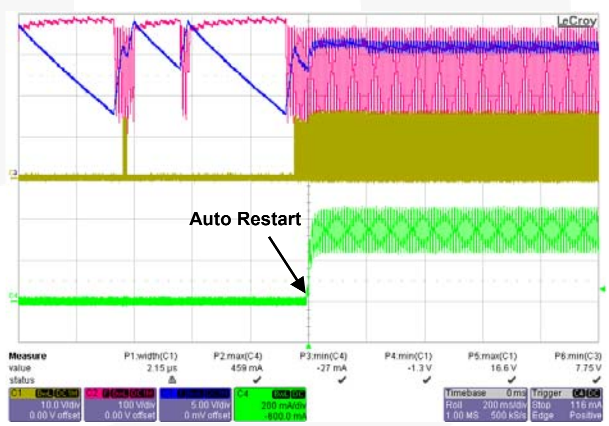

Figure 23. V_{IN} = 265 V_{AC} / 50 Hz, [LED Restore]

Figure 24 to Figure 27 show waveforms for protections operated when the LED is opened and recovered. Once the LED has opened, V_S OVP or V_{DD} OVP are triggered and V_{DD} starts "Hiccup" Mode with JFET regulation times [250 ms]. This lasts until the fault condition is eliminated. Systems can restart automatically when returned to normal condition. V_{GATE} (10 V / div), CH2: V_{IN} (100 V / div), CH3: V_{DD} (10 V / div), V_{OUT} (10 V / div), Time Scale: (200 ms / div).

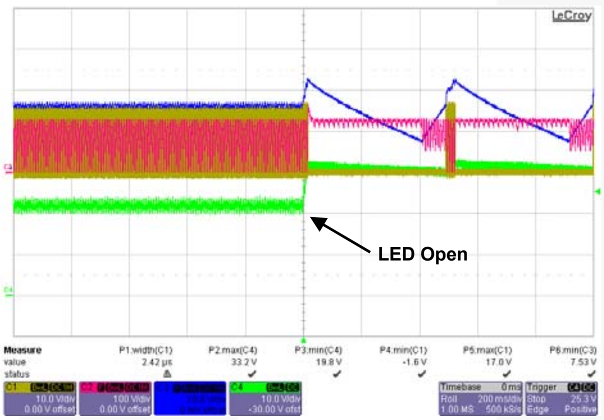

Figure 24. V_{IN} = 90 V_{AC} / 60 Hz, [LED Short]

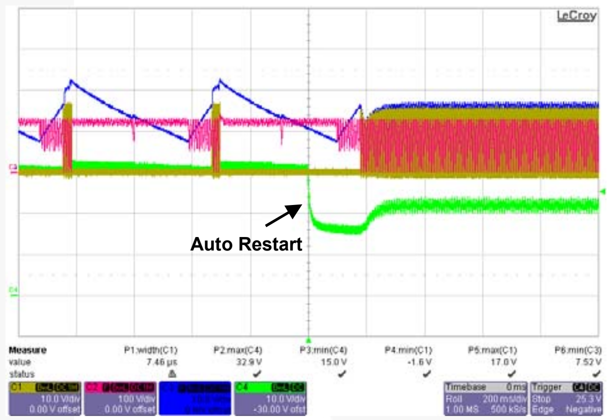

Figure 25. V_{IN} = 90 V_{AC} / 60 Hz, [LED Restore]

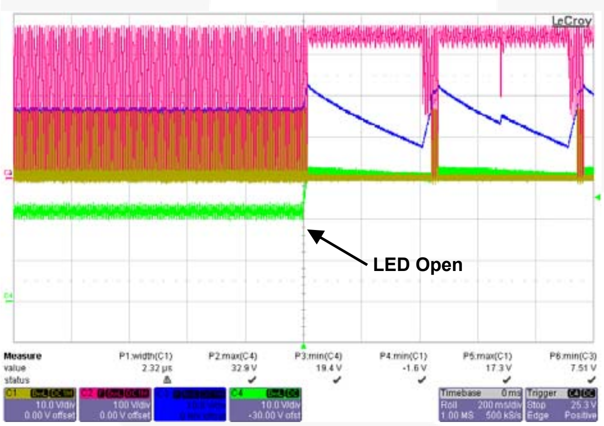

Figure 26. V_{IN} = 265 V_{AC} / 50 Hz, [LED Short]

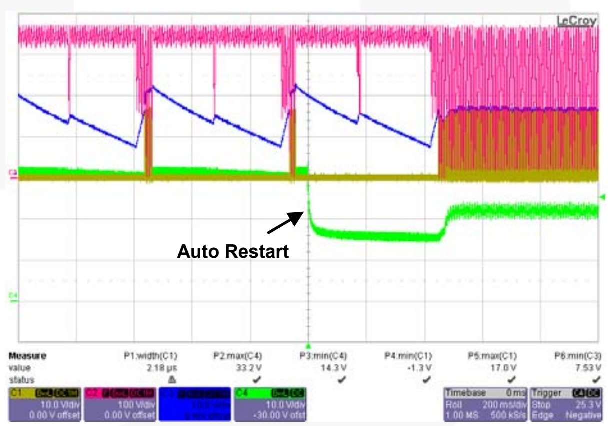

Figure 27. V_{IN} = 265 V_{AC} / 50 Hz, [LED Restore]

If the LED load is re-connected after an open-LED condition, the output capacitor is quickly discharged through the LED load and the inrush current by the discharge could destroy LED load.

8.5. Efficiency

System efficiency is 86.41% ~ 88.96% over input voltages 90 ~ 265 V_{AC}. The results were measured using actual, rated LED loads 30 minutes after startup.

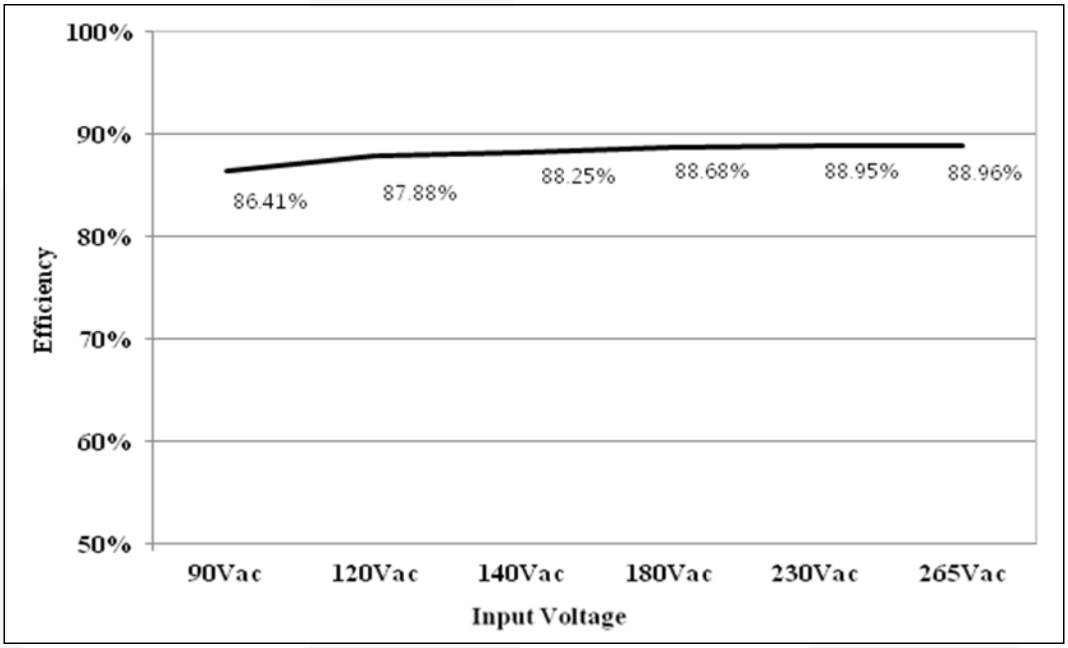

Figure 28. System Efficiency

Table 7. System Efficiency

Input Voltage	Input Power	Output Current	Output Voltage	Output Power	Efficiency
90 V_{AC} [60 Hz]	9.52 W	0.351 A	23.43 V	8.23 W	86.41%
120 V_{AC} [60 Hz]	9.39 W	0.352 A	23.45 V	8.25 W	87.88%
140 V_{AC} [60 Hz]	9.38 W	0.352 A	23.49 V	8.28 W	88.25%
180 V_{AC} [50 Hz]	9.33 W	0.354 A	23.40 V	8.27 W	88.68%
230 V_{AC} [50 Hz]	9.35 W	0.355 A	23.42 V	8.32 W	88.95%
265 V_{AC} [50 Hz]	9.38 W	0.356 A	23.46 V	8.34 W	88.96%

8.6. Power Factor (PF) & Total Harmonic Distortion (THD)

The FL7733A evaluation board shows excellent THD performance, much less than 10%. The results were measured using actual, rated LED loads ten (10) minutes after startup.

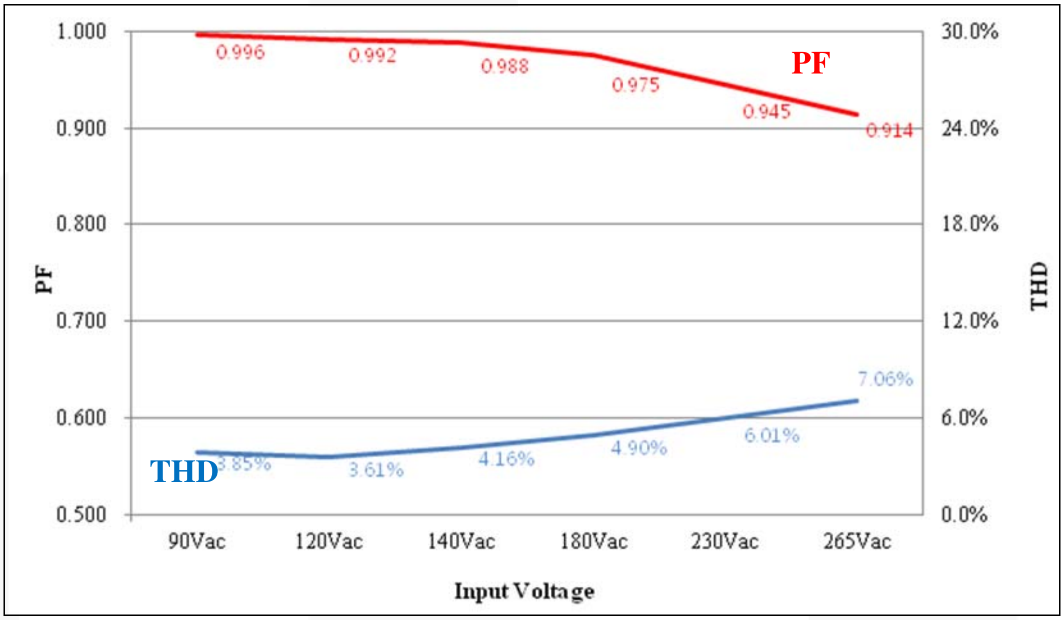

Figure 29. Power Factor & Total Harmonic Distortion

Table 8. Power Factor & Total Harmonic Distortion

Input Voltage	Output Current	Output Voltage	Power Factor	THD
90 V_{AC} [60 Hz]	0.351 A	23.43 V	0.996	3.85%
120 V_{AC} [60 Hz]	0.352 A	23.45 V	0.992	3.61%
140 V_{AC} [60 Hz]	0.352 A	23.49 V	0.988	4.16%
180 V_{AC} [50 Hz]	0.354 A	23.40 V	0.975	4.90%
230 V_{AC} [50 Hz]	0.355 A	23.42 V	0.945	6.01%
265 V_{AC} [50 Hz]	0.356 A	23.46 V	0.914	7.06%

8.7. Harmonics

Figure 30 to Figure 33 show current harmonics measured using actual, rated LED loads.

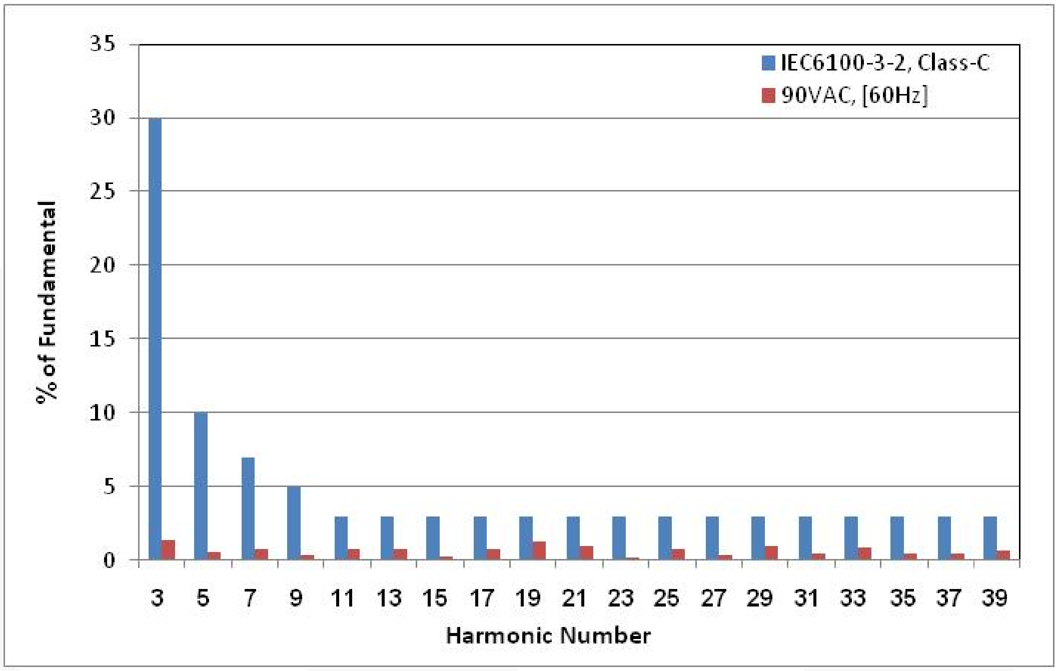

Figure 30. V_{IN} = 90 V_{AC} / 60 Hz

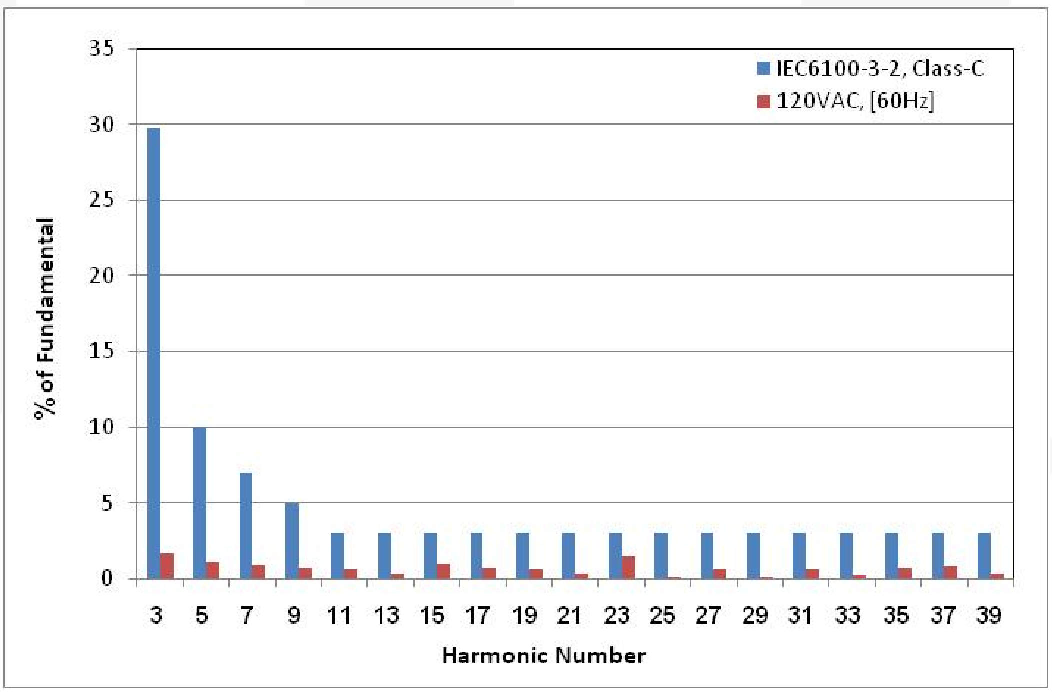

Figure 31. V_{IN} = 120 V_{AC} / 60 Hz

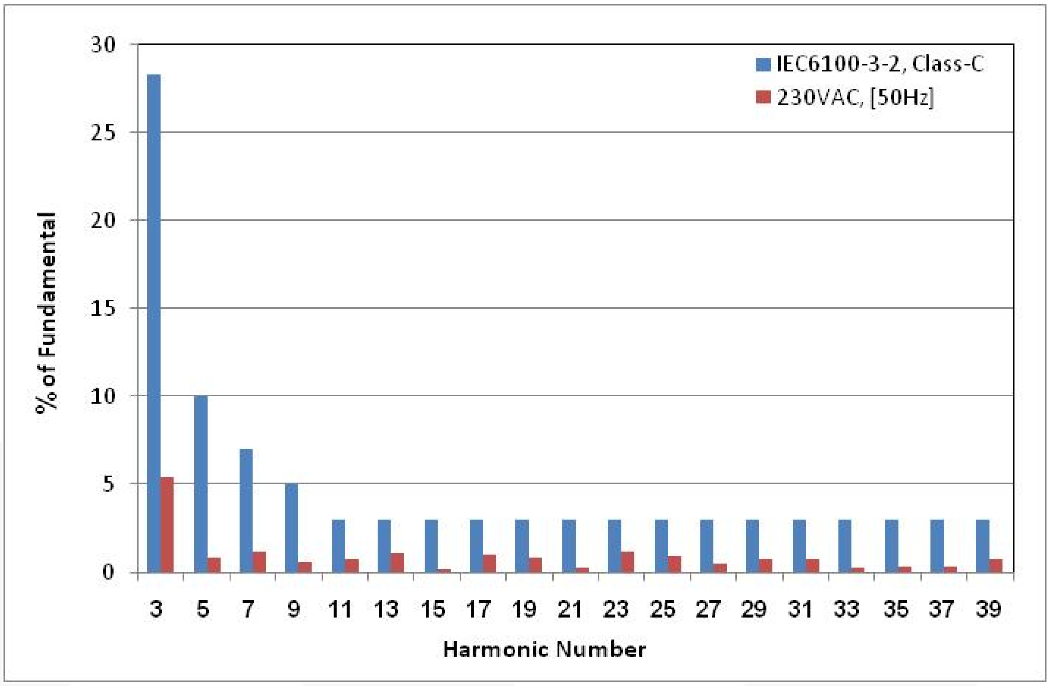

Figure 32. V_{IN} = 230 V_{AC} / 50 Hz

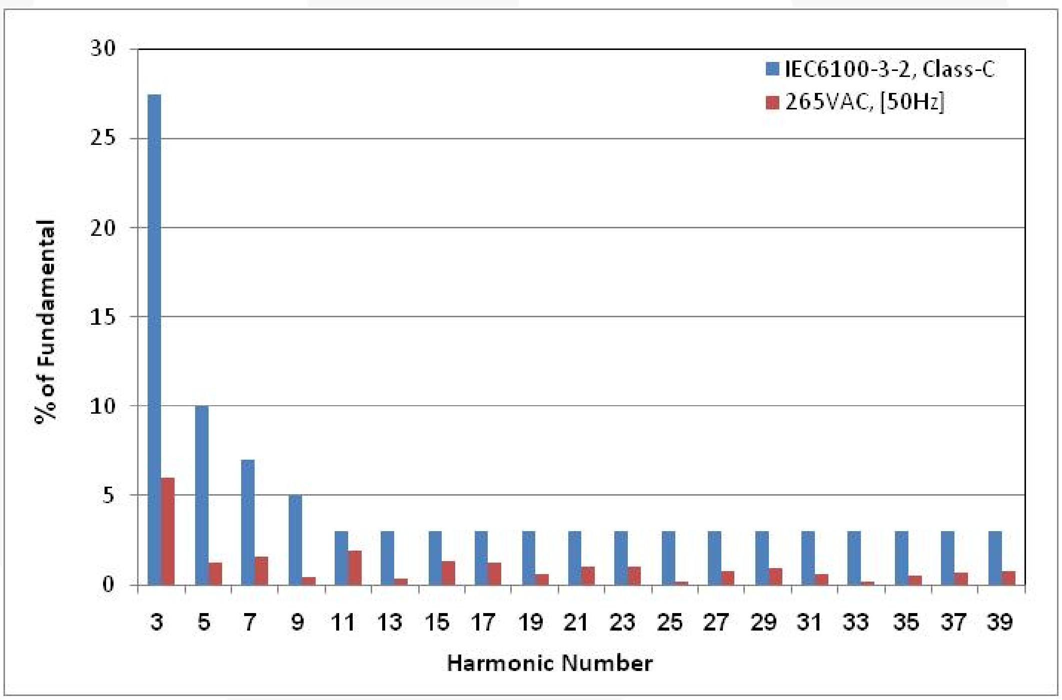

Figure 33. V_{IN} = 265 V_{AC} / 50 Hz

8.8. Operating Temperature

Temperatures on all components for this board are less than 62ºC. The results were measured using actual, rated LED loads 60 minutes after startup.

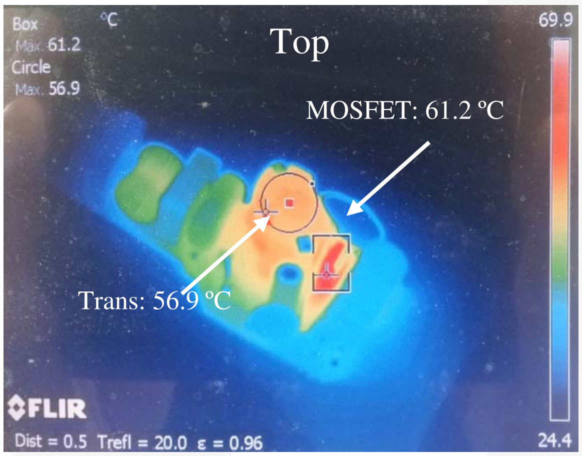

Figure 34. V_{IN} = 90 V_{AC} / 60 Hz

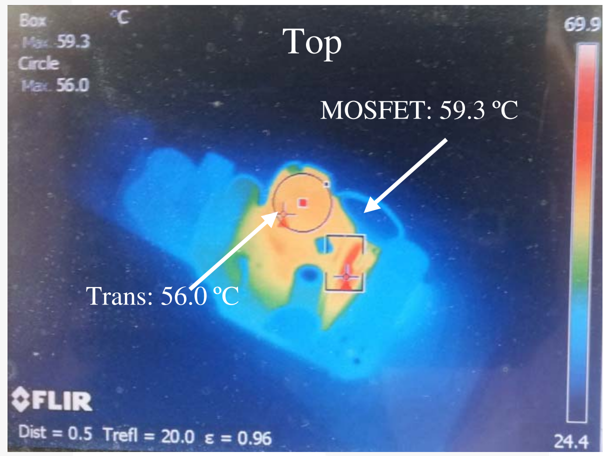

Figure 35. V_{IN} = 265 V_{AC} / 50 Hz

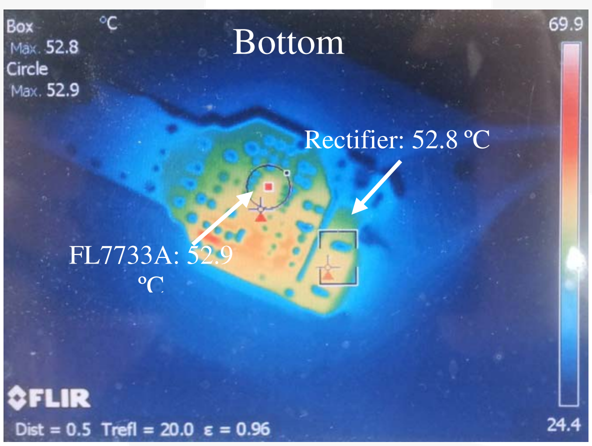

Figure 36. V_{IN} = 90 V_{AC} / 60 Hz

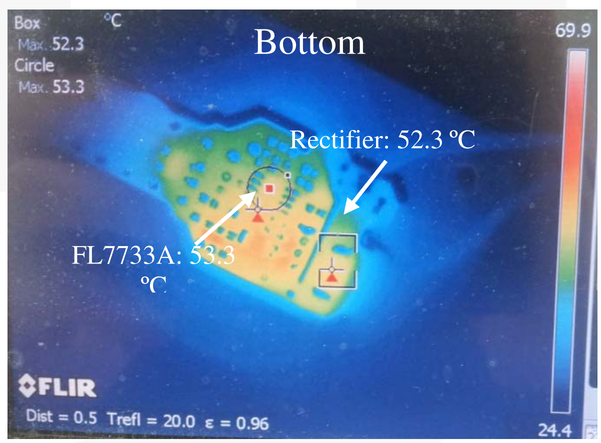

Figure 37. V_{IN} = 265 V_{AC} / 50 Hz

The IC temperature can be improved by the PCB layout.

8.9. Electromagnetic Interference (EMI)

All measurements were conducted in observance of EN55022 criteria. The results were measured using actual, rated LED loads 30 minutes after startup.

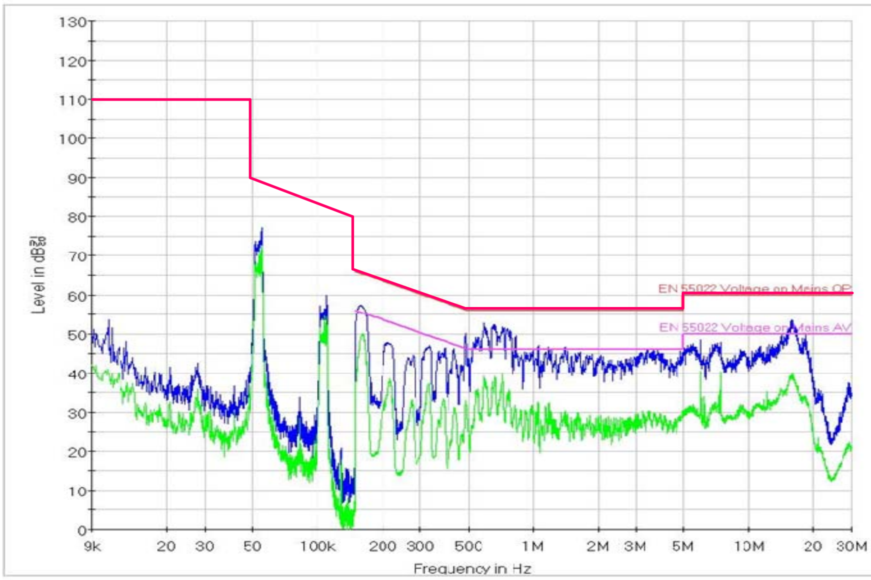

Figure 38. V_{IN} [110 V_{AC}, LIVE]

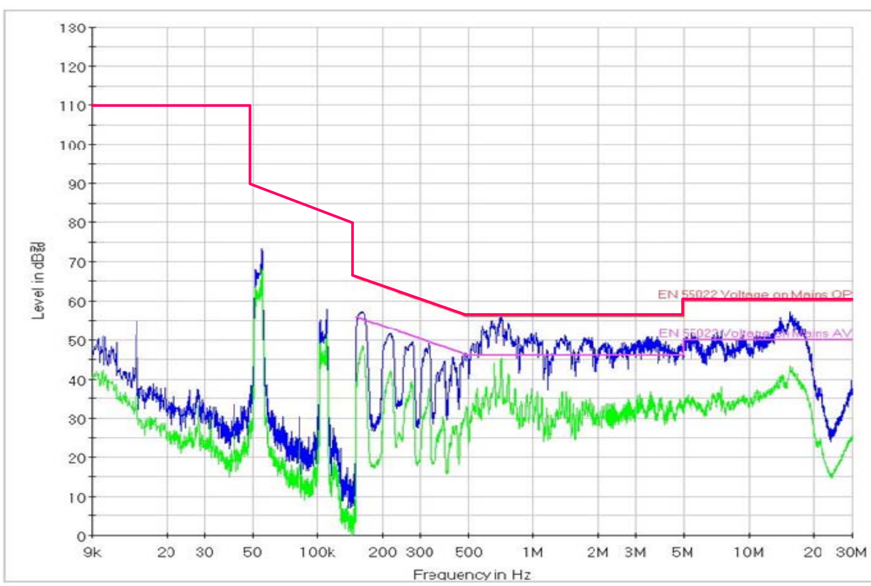

Figure 39. V_{IN} [220 V_{AC}, Neutral]

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9. Revision History

Rev.	Date	Description
1.0	Oct. 2014	Initial Release