

User Guide for
FEBFL7733A_L50U008A
Evaluation Board

8.4 W LED Driver at Universal Line

Featured Fairchild Product:
FL7733A

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Fairchild Semiconductor.com

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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 $90 V_{RMS} \sim 265 V_{RMS}$ 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:
 - < $\pm 1\%$ Over Universal Input Line Voltage Variation
 - < $\pm 1\%$ by 50% ~ 100% Load Voltage Variation
 - < $\pm 1\%$ by $\pm 20\%$ 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: $80 V_{AC} \sim 308 V_{AC}$

1.3. Controller Internal Block Diagram

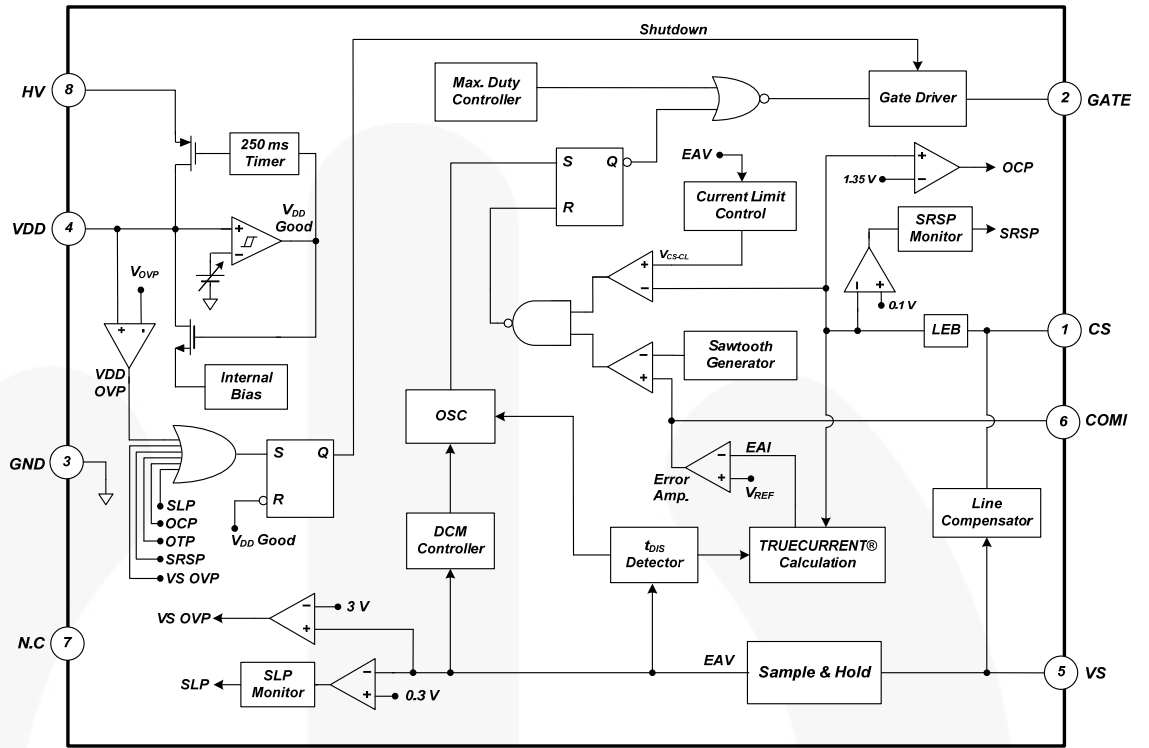


Figure 1. Block Diagram

2. Evaluation Board Specifications

Table 1. Specifications for LED Lighting Load

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

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)

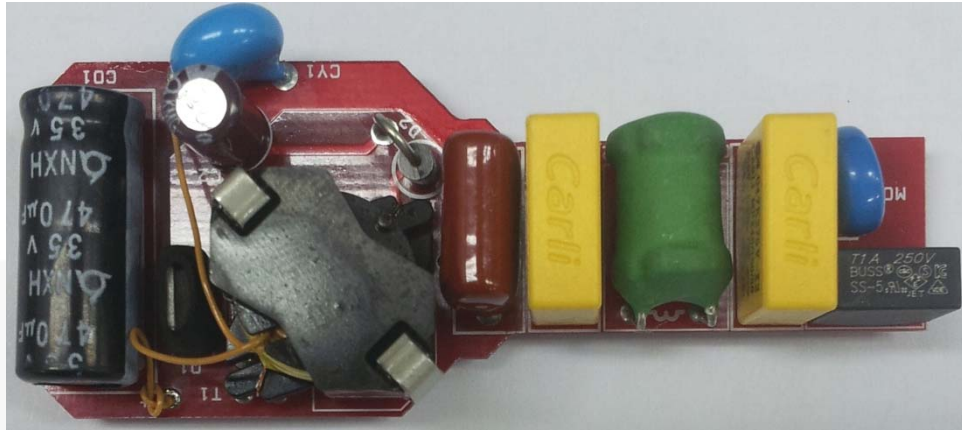


Figure 2. Top View

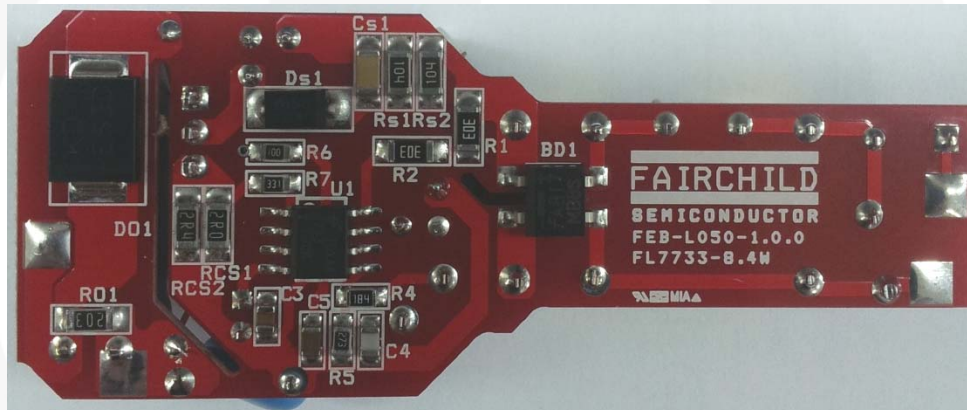


Figure 3. Bottom View

4. Evaluation Board Printed Circuit Board (PCB)

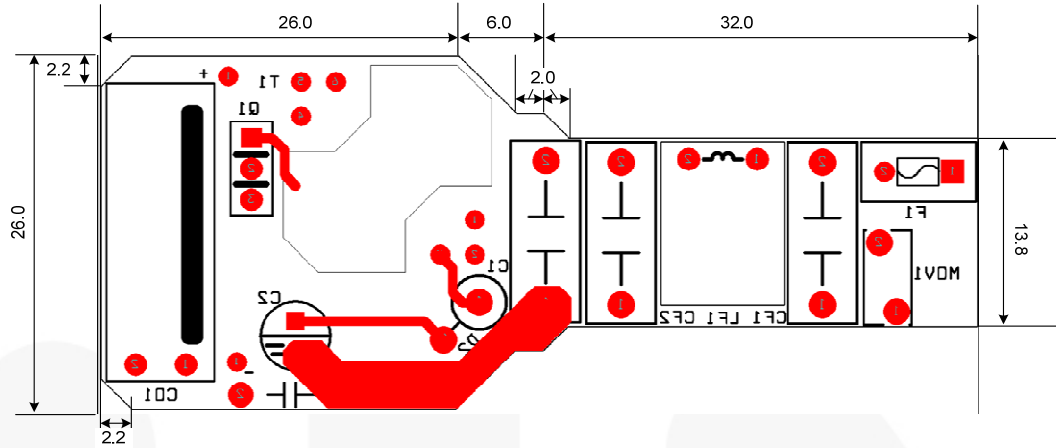


Figure 4. Top Pattern (in mm)

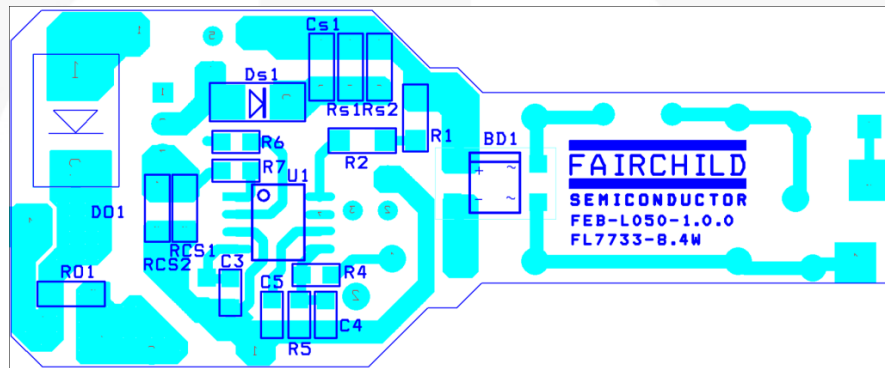


Figure 5. Bottom Pattern

5. Evaluation Board Schematic

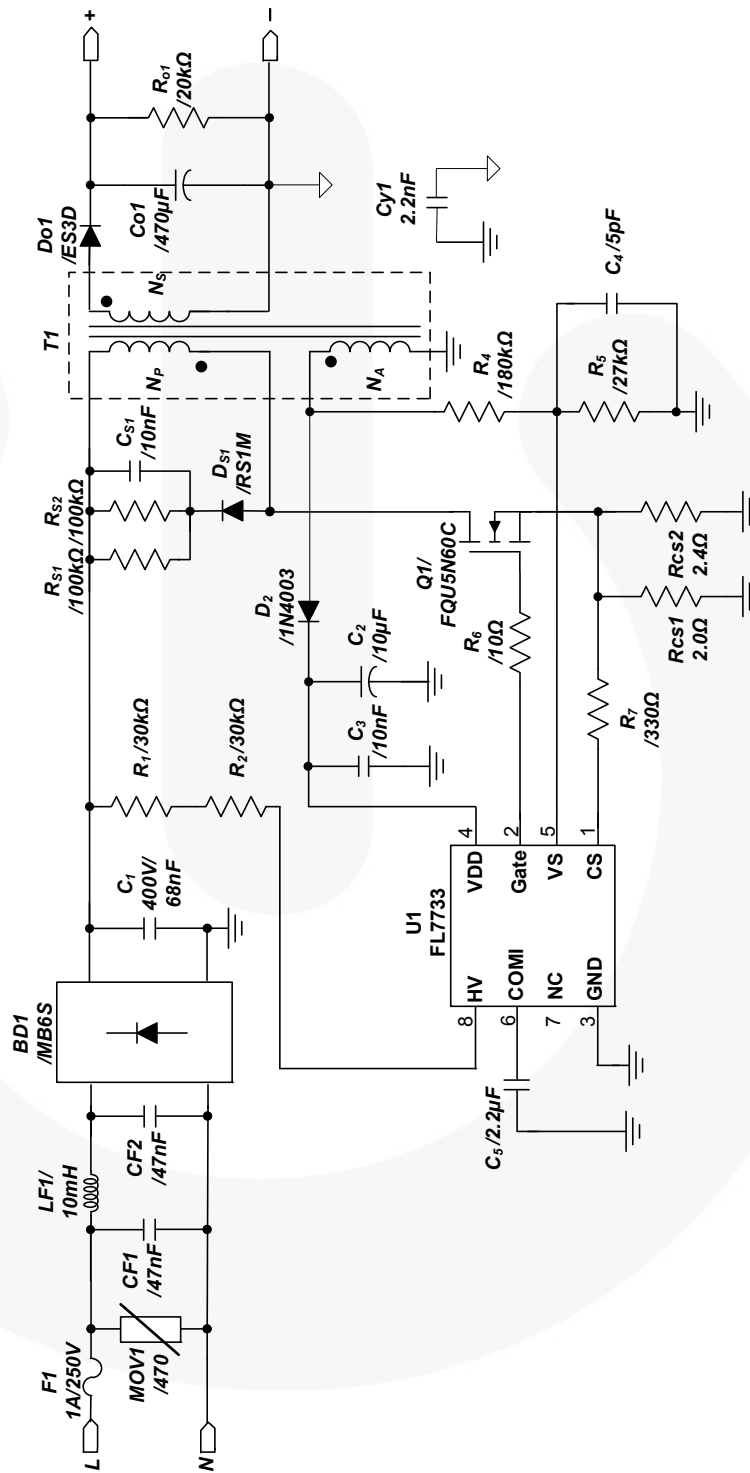


Figure 6. Schematic

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 μ F 35 V | 1 | 470 μ F / 35 V, Electrolytic Capacitor | Samyoung |
| 6 | C1 | MPE400V683K | 1 | 68 nF / 400 V, MPE Film Capacitor | Sungho |
| 7 | C2 | KMG10 μ F 35 V | 1 | 10 μ F / 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 μ F / 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, 8 \emptyset | 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 k Ω , 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 k Ω , SMD Resistor 1206 | Yageo |
| 24 | R4 | RC0805JR-07180KL | 1 | 180 k Ω , SMD Resistor 0805 | Yageo |
| 25 | R1, R2 | RC1206JR-0730KL | 2 | 30 k Ω , SMD Resistor 1206 | Yageo |
| 26 | R5 | RC0805JR-0727KL | 1 | 27 k Ω , 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

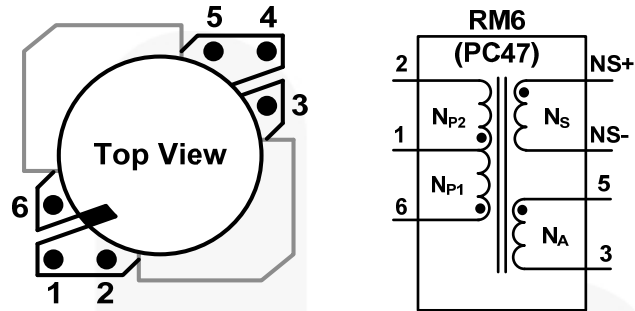


Figure 7. Transformer Bobbin Structure and Pin Configuration

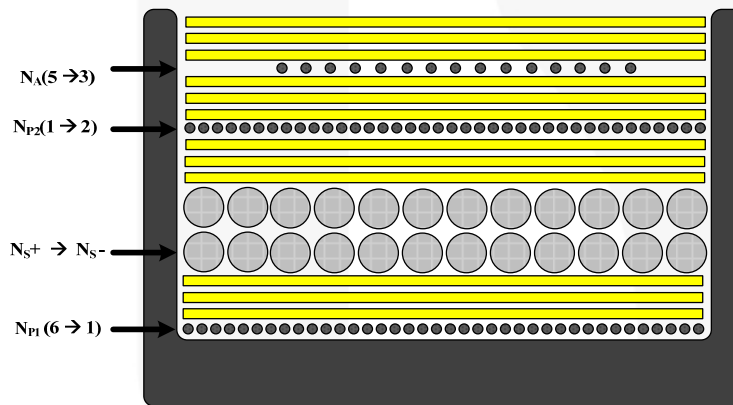


Figure 8. Transformer Winding Structure

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 | $T_A = 25^\circ\text{C}$ |
|---------------------|---|
| 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.

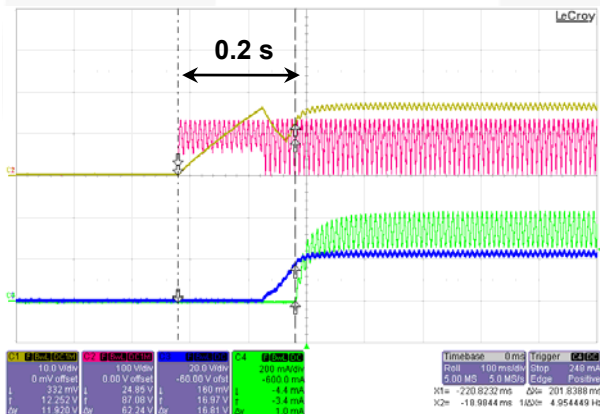


Figure 9. $V_{IN} = 90\text{ V}_{AC} / 60\text{ Hz}$

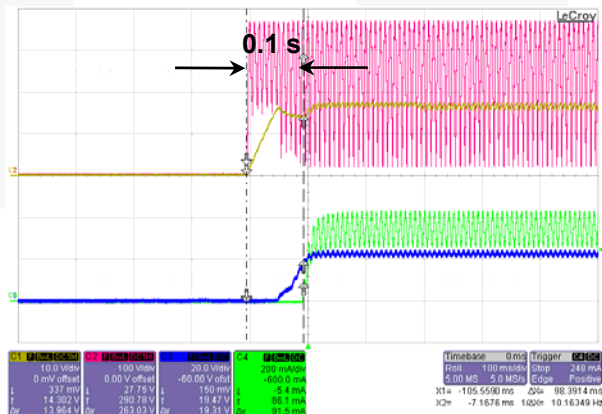


Figure 10. $V_{IN} = 120\text{ V}_{AC} / 60\text{ Hz}$

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.

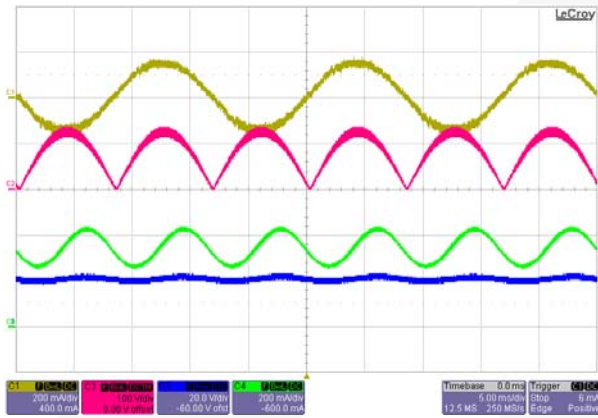


Figure 11. $V_{IN} = 90 V_{AC} / 60 \text{ Hz}$

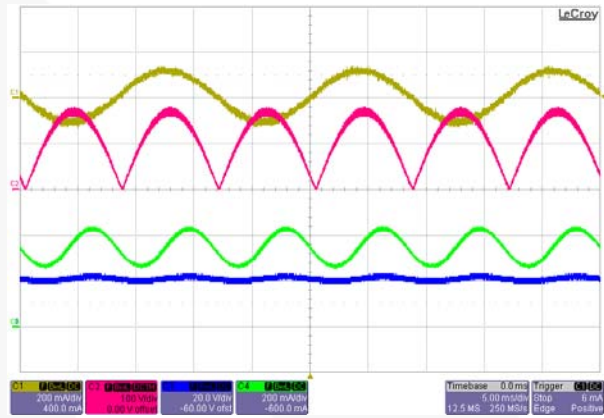


Figure 12. $V_{IN} = 120 V_{AC} / 60 \text{ Hz}$

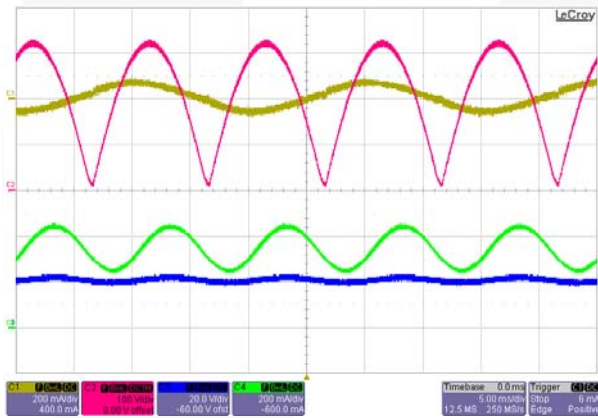


Figure 13. $V_{IN} = 230 V_{AC} / 50 \text{ Hz}$

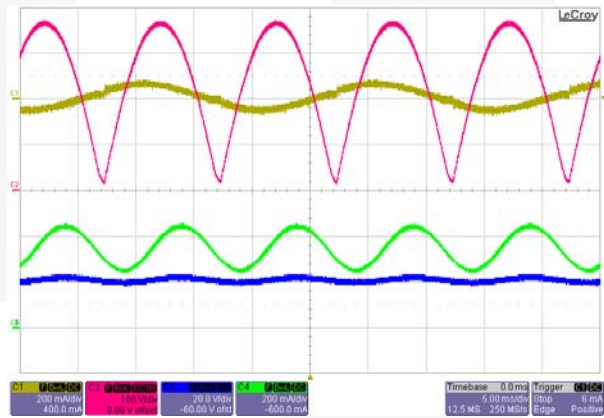


Figure 14. $V_{IN} = 265 V_{AC} / 50 \text{ Hz}$

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: $V_{SEC-Diode}$ (100 V / div), CH4: $I_{SEC-Diode}$ (2.0 A / div), Load: 7 series-LEDs.

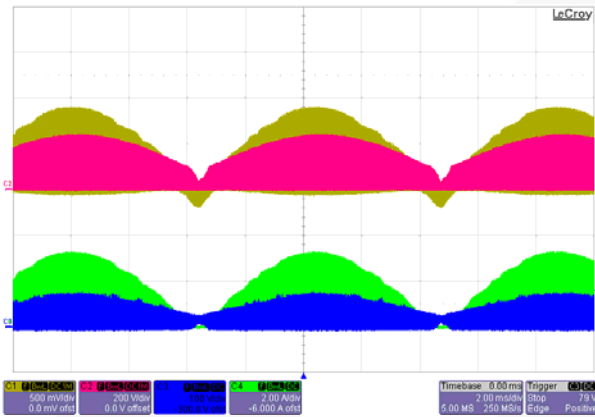


Figure 15. $V_{IN} = 90 V_{AC} / 60 \text{ Hz}$, [2.0 ms / div]

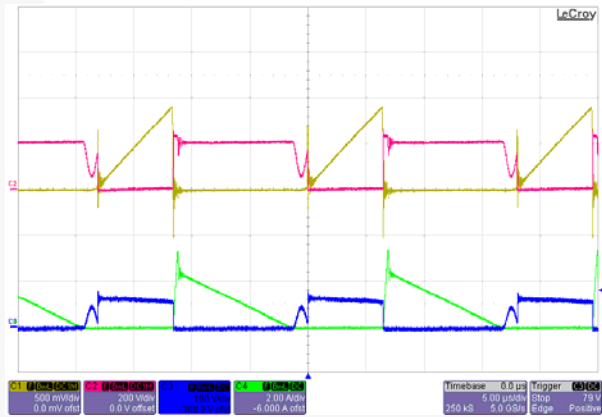


Figure 16. $V_{IN} = 90 V_{AC} / 60 \text{ Hz}$, [5.0 μs / div]

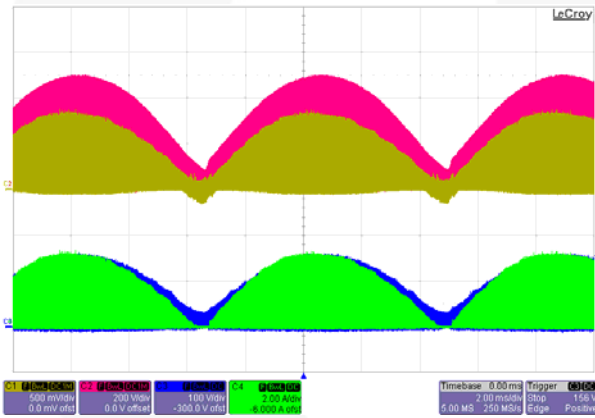


Figure 17. $V_{IN} = 265 V_{AC} / 60 \text{ Hz}$, [2.0 ms / div]

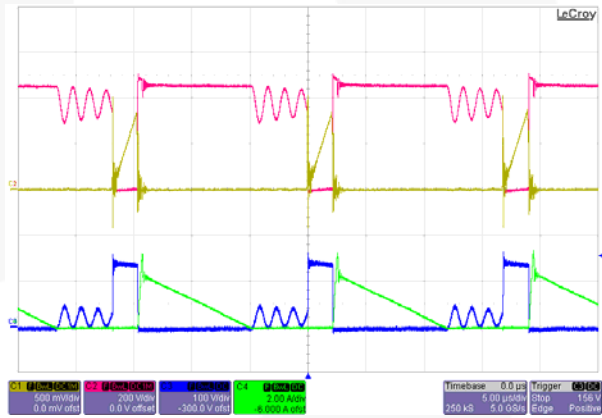


Figure 18. $V_{IN} = 265 V_{AC} / 60 \text{ Hz}$, [5.0 μs / div]

8.3. Constant-Current Regulation

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

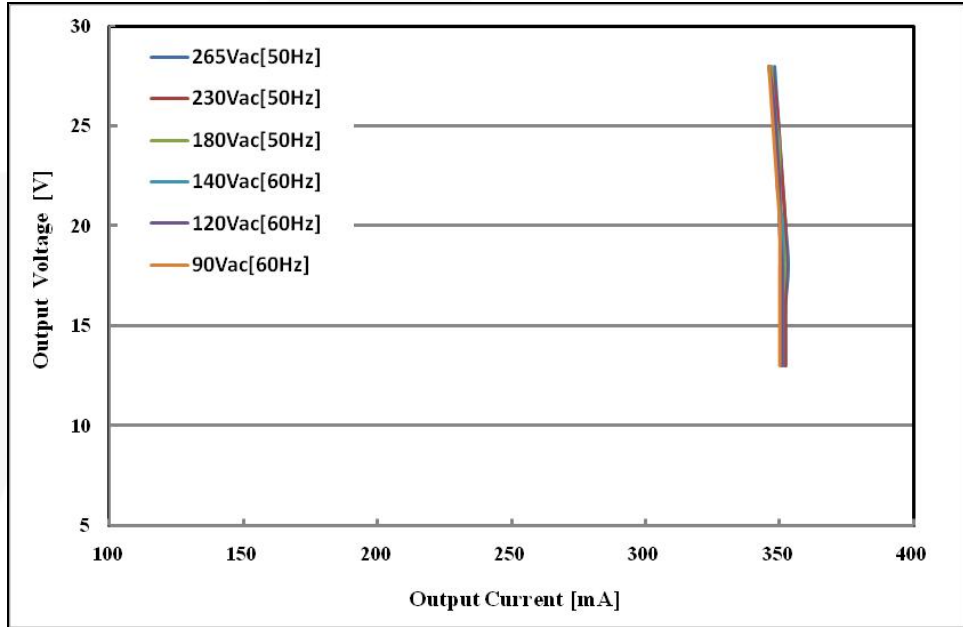


Figure 19. Constant-Current Regulation

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 | $\pm 0.57\%$ |
| 120 V _{AC} [60 Hz] | 346 | 351 | $\pm 0.72\%$ |
| 140 V _{AC} [60 Hz] | 346 | 351 | $\pm 0.72\%$ |
| 180 V _{AC} [50 Hz] | 347 | 352 | $\pm 0.72\%$ |
| 230 V _{AC} [50 Hz] | 347 | 352 | $\pm 0.72\%$ |
| 265 V _{AC} [50 Hz] | 348 | 353 | $\pm 0.71\%$ |

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 | $\pm 0.29\%$ |
| 24 V | 348 mA | 349 mA | 349 mA | 350 mA | 350 mA | 350 mA | $\pm 0.29\%$ |
| 22 V | 349 mA | 350 mA | 349 mA | 350 mA | 351 mA | 351 mA | $\pm 0.29\%$ |

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).

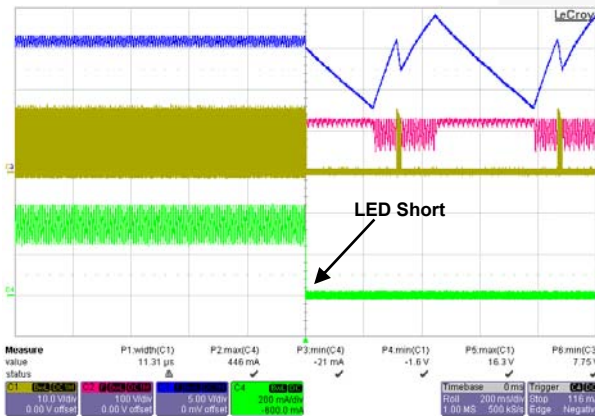


Figure 20. $V_{IN} = 90 V_{AC} / 60 \text{ Hz}$, [LED Short]

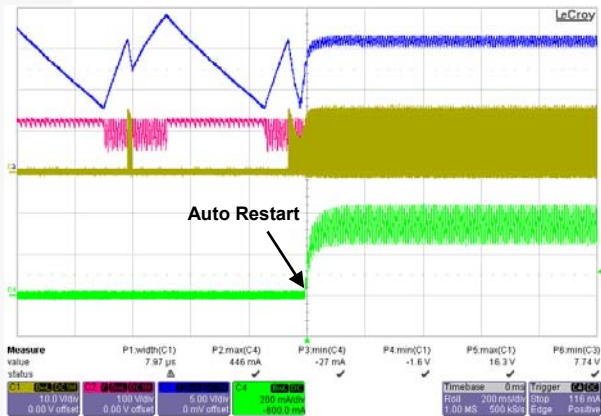


Figure 21. $V_{IN} = 90 V_{AC} / 60 \text{ Hz}$, [LED Restore]

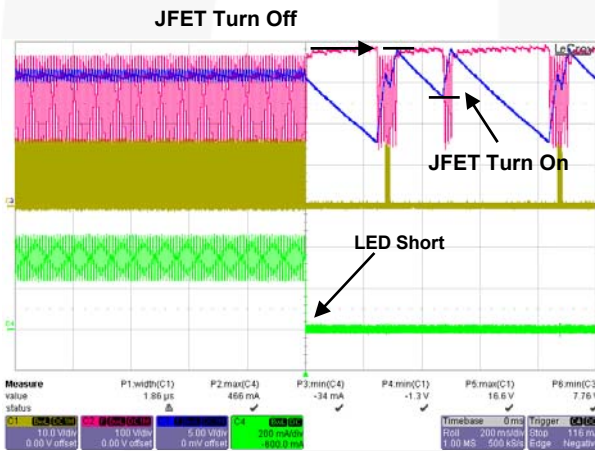


Figure 22. $V_{IN} = 265 V_{AC} / 50 \text{ Hz}$, [LED Short]

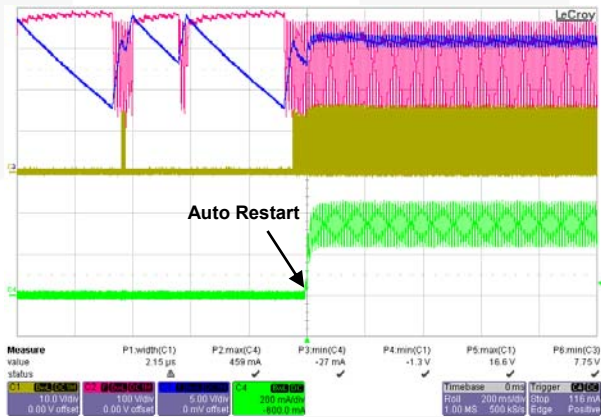


Figure 23. $V_{IN} = 265 V_{AC} / 50 \text{ Hz}$, [LED Restore]

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).

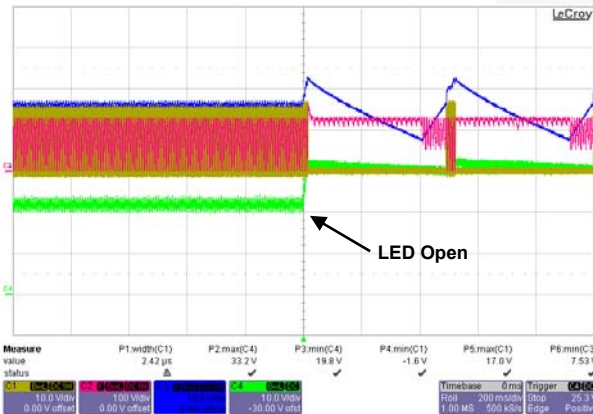


Figure 24. $V_{IN} = 90 V_{AC} / 60$ Hz, [LED Short]

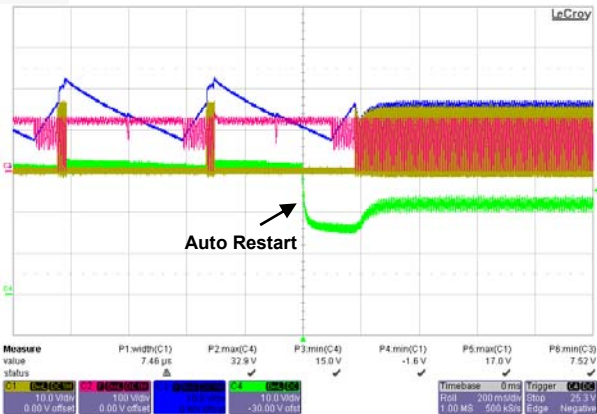


Figure 25. $V_{IN} = 90 V_{AC} / 60$ Hz, [LED Restore]

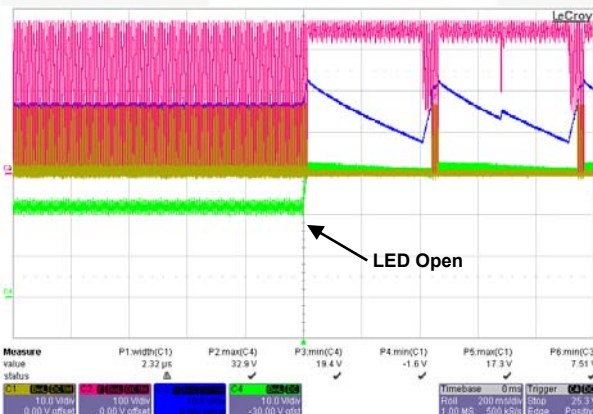


Figure 26. $V_{IN} = 265 V_{AC} / 50$ Hz, [LED Short]

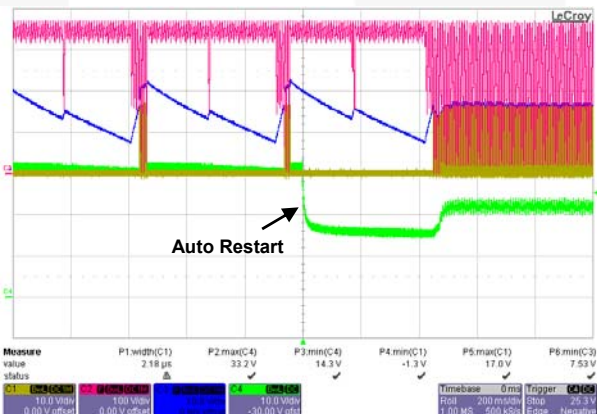


Figure 27. $V_{IN} = 265 V_{AC} / 50$ Hz, [LED Restore]

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.

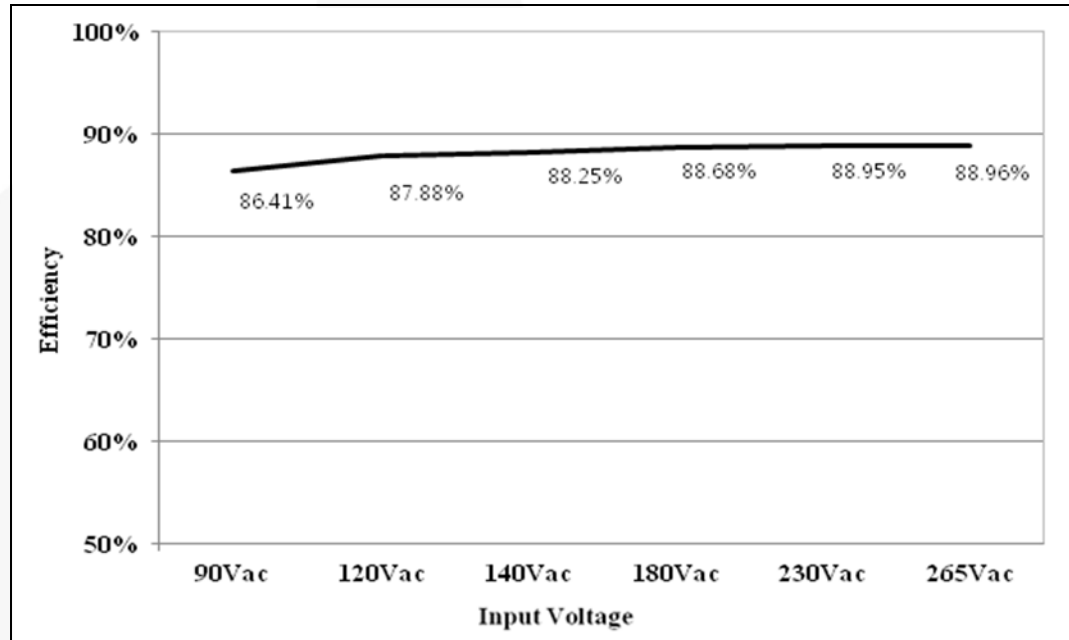


Figure 28. System Efficiency

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.

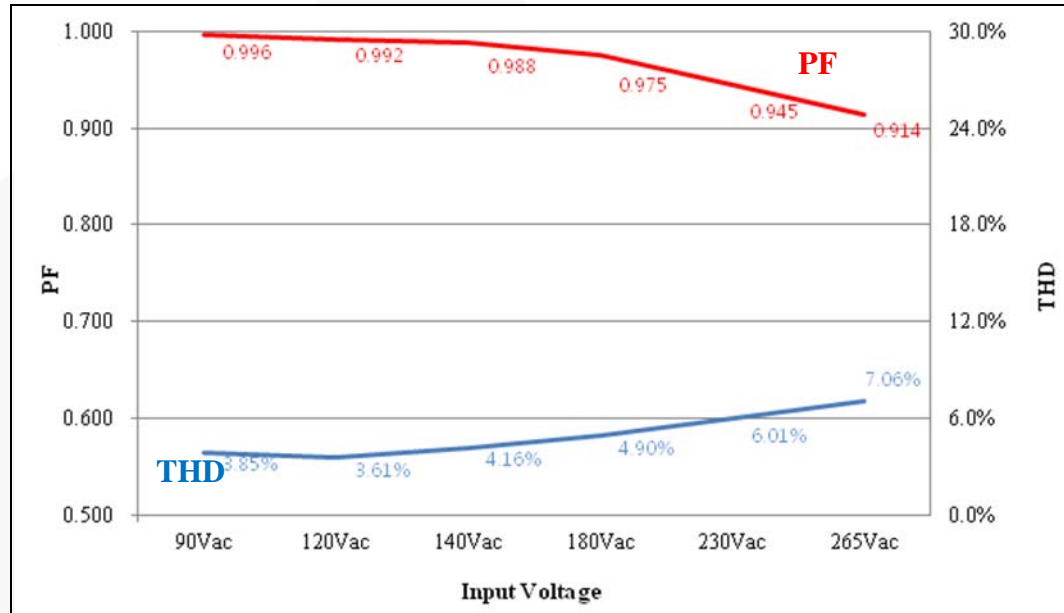


Figure 29. Power Factor & Total Harmonic Distortion

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.

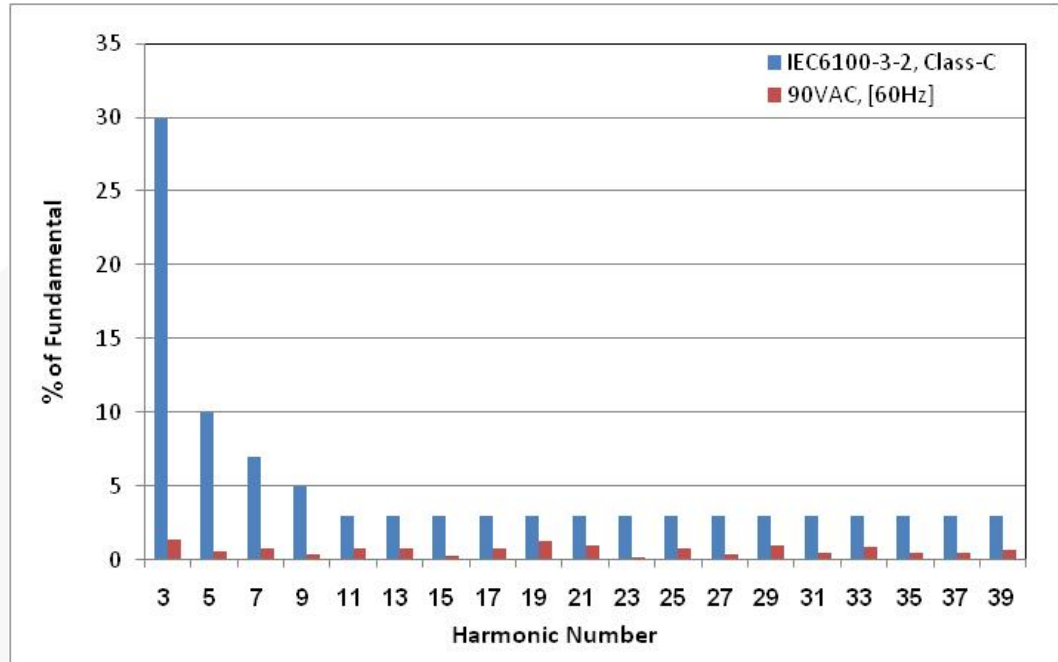


Figure 30. $V_{IN} = 90 V_{AC} / 60 \text{ Hz}$

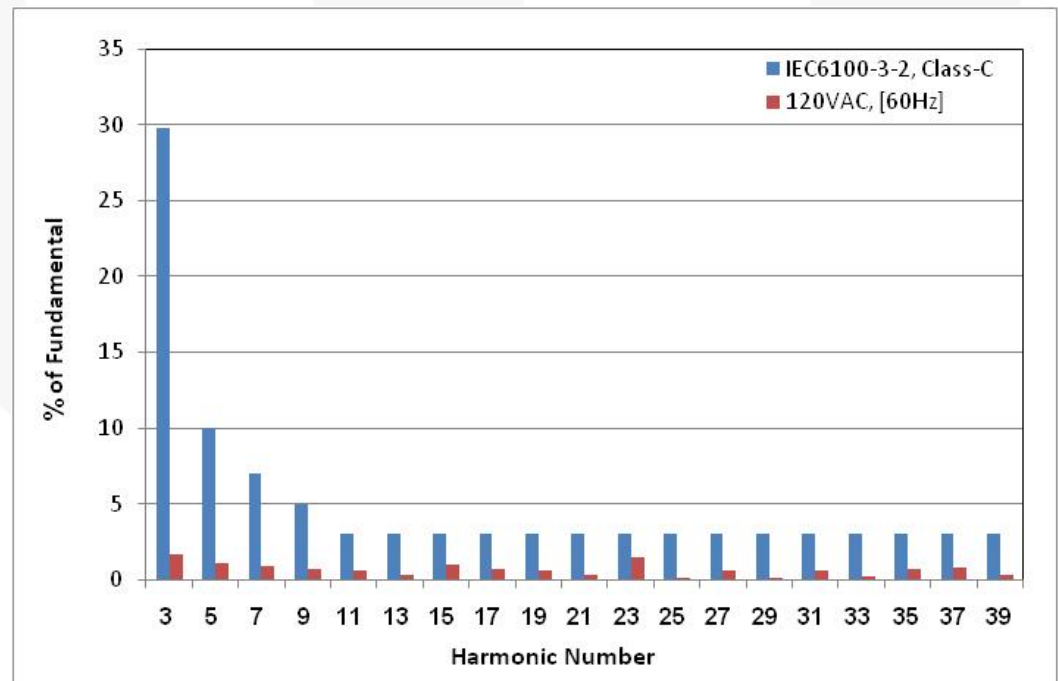


Figure 31. $V_{IN} = 120 V_{AC} / 60 \text{ Hz}$

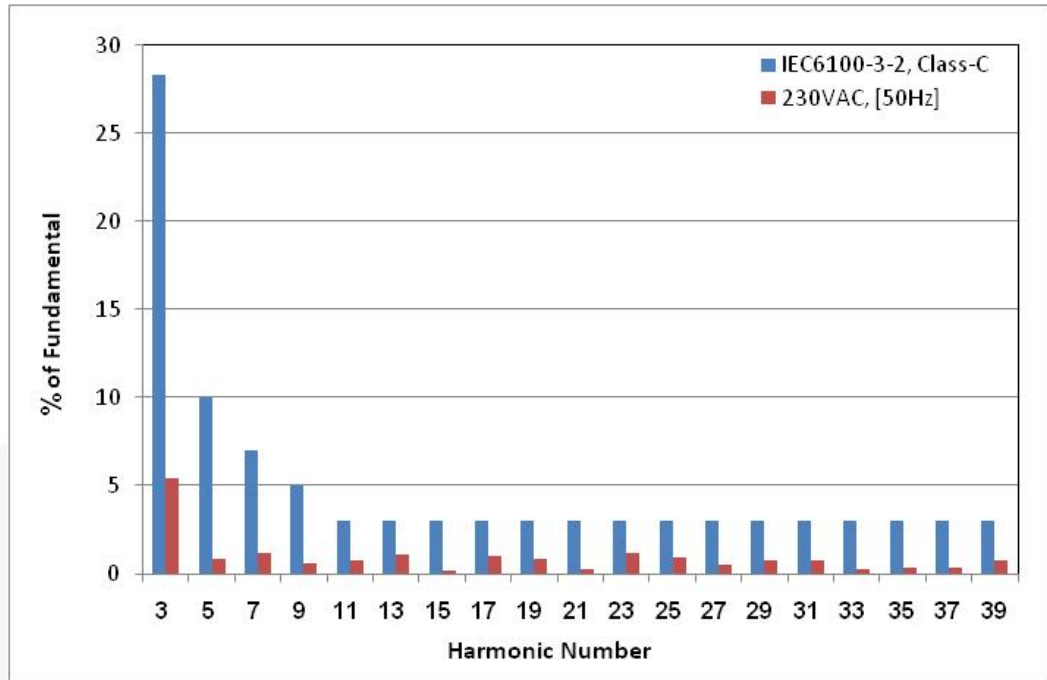


Figure 32. $V_{IN} = 230 V_{AC} / 50 \text{ Hz}$

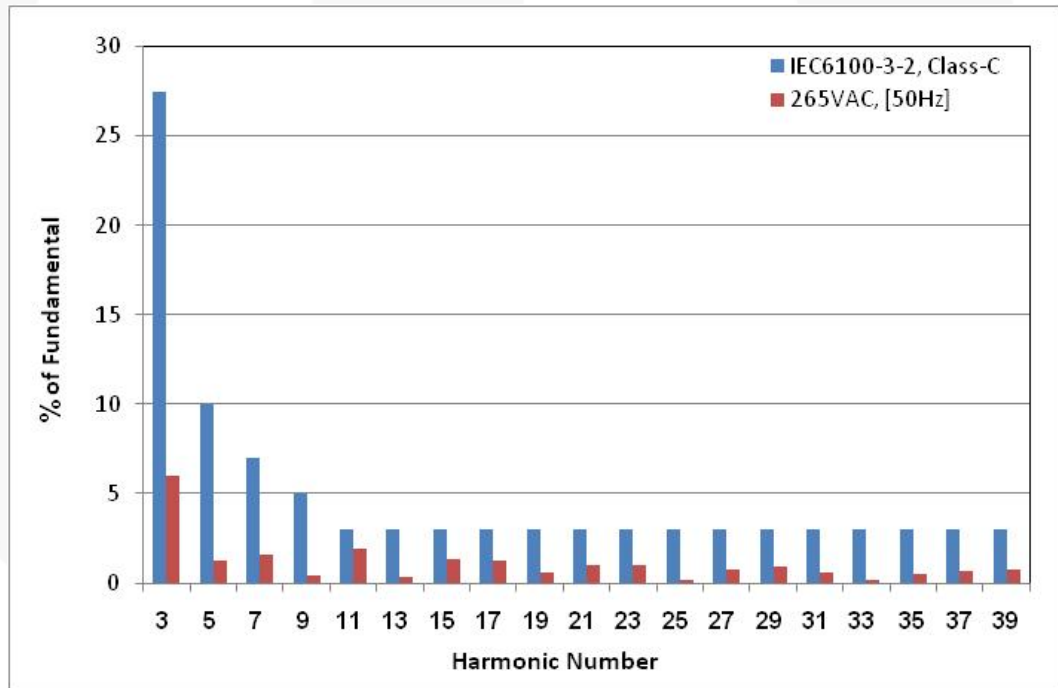


Figure 33. $V_{IN} = 265 V_{AC} / 50 \text{ Hz}$

8.8. Operating Temperature

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

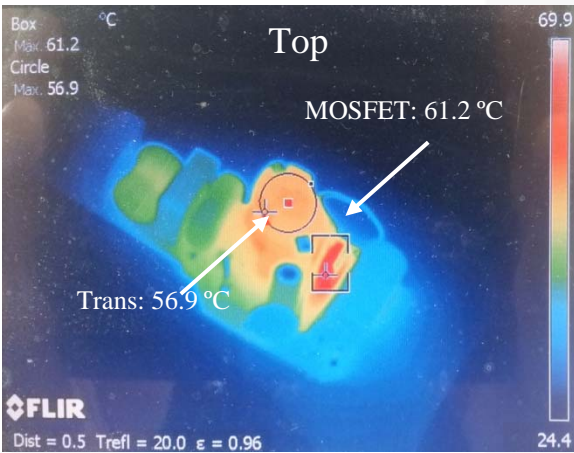


Figure 34. $V_{IN} = 90 V_{AC} / 60 \text{ Hz}$

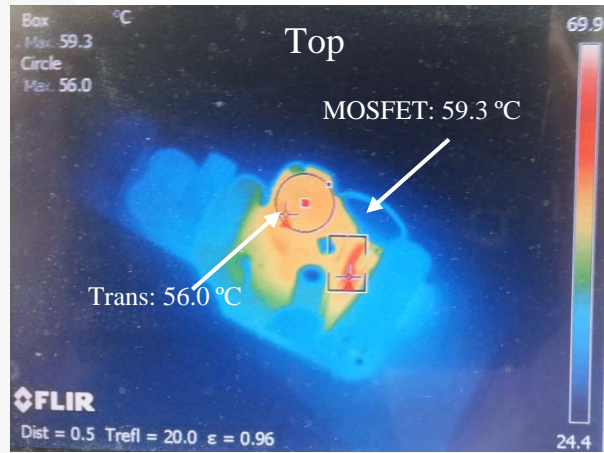


Figure 35. $V_{IN} = 265 V_{AC} / 50 \text{ Hz}$

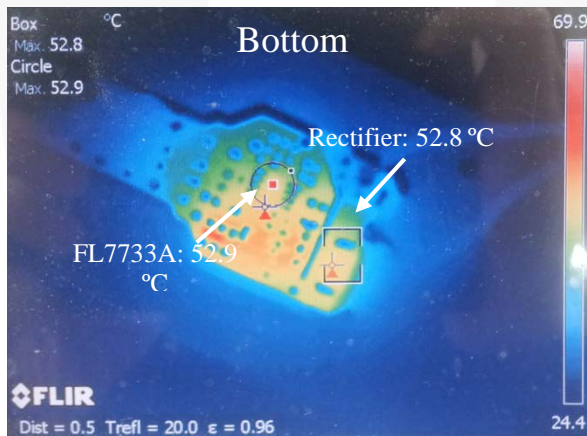


Figure 36. $V_{IN} = 90 V_{AC} / 60 \text{ Hz}$

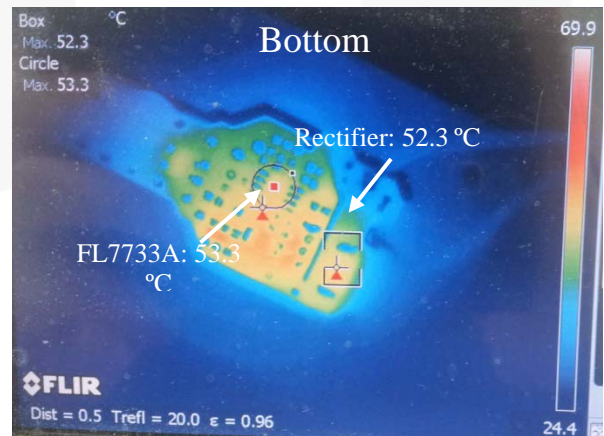


Figure 37. $V_{IN} = 265 V_{AC} / 50 \text{ Hz}$

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.

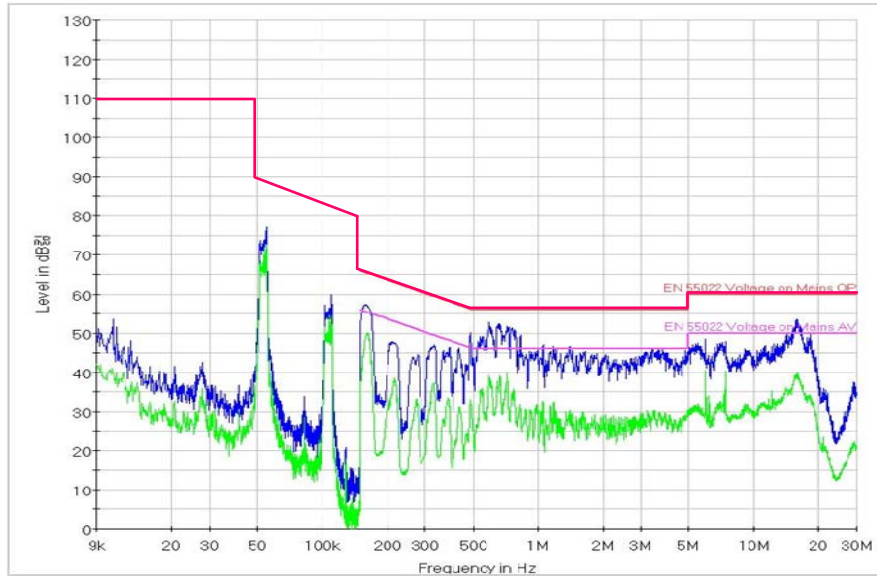


Figure 38. V_{IN} [110 V_{AC}, LIVE]

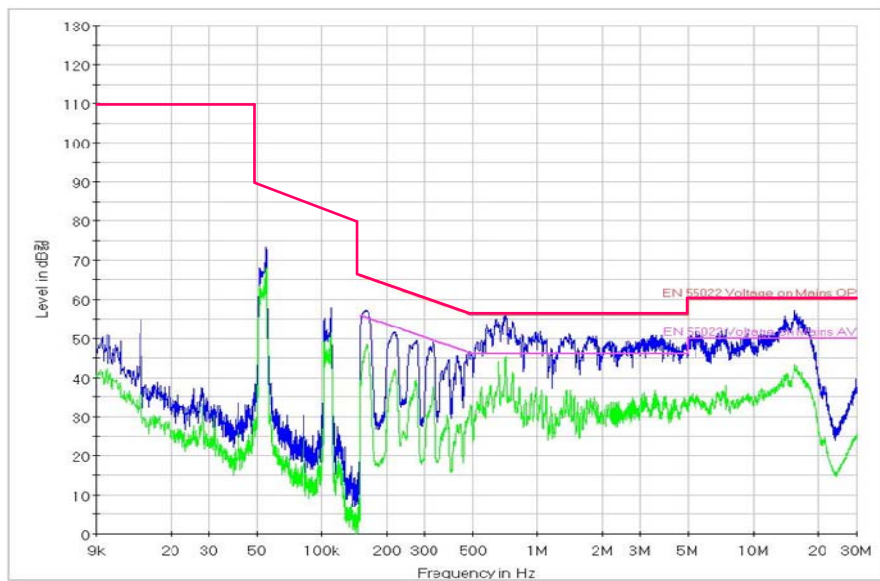


Figure 39. V_{IN} [220 V_{AC}, Neutral]



9. Revision History

| Rev. | Date | Description |
|------|-----------|-----------------|
| 1.0 | Oct. 2014 | Initial Release |
| | | |
| | | |
| | | |
| | | |

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