ON Semiconductor

Is Now

To learn more about onsemi™, please visit our website at
www.onsemi.com

Is Now Part of

ON Semiconductor®

To learn more about ON Semiconductor, please visit our website at
www.onsemi.com

User Guide for

FEBFL7701_L31L008A

7.8 W LED Ballast at Low Line

Featured Fairchild Product:

FL7701

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 FL7701. It should be used in conjunction with the FL7701 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 low line input, 7.8 W LED ballast using the FL7701. The input voltage range is 90 V_{RMS} – 150 V_{RMS} and there is one DC output with a constant current of 250 mA at 31 V. This document contains general description of FL7701, the power supply specification, schematic, bill of materials, and the typical operating characteristics.

1.1. General Description

The FL7701 LED lamp driver is a simple IC with PFC function and integrated switching MOSFET. The special "adopted digital" technique automatically detects input voltage condition and sends an internal reference signal, resulting in high Power Factor (PF). When AC input voltage is applied to the IC, PFC function is automatically enabled. When DC input voltage is applied to the IC, PFC function is automatically disabled. The FL7701 does not require a bulk capacitor (electrolytic capacitor) for supply rail stability, which can significantly improve LED reliability.

1.2. Features

- Digitally Implemented Active PFC Function
  (No Additional Circuit Necessary for High PF)
- Built-in HV Supplying Circuit: Self Biasing
- AOCP Function with Auto-Restart Mode
- Built-in Over-Temperature Protection (OTP)
- Cycle-by-Cycle Current Limit
- Low Operating Current: 0.85 mA (Typical)
- Under-Voltage Lockout with 5 V Hysteresis
- Programmable Oscillation Frequency
- Programmable LED Current
- Analog Dimming Function
- Soft-Start Function
- Precise Internal Reference: ±3%

1.3. Internal Block Diagram

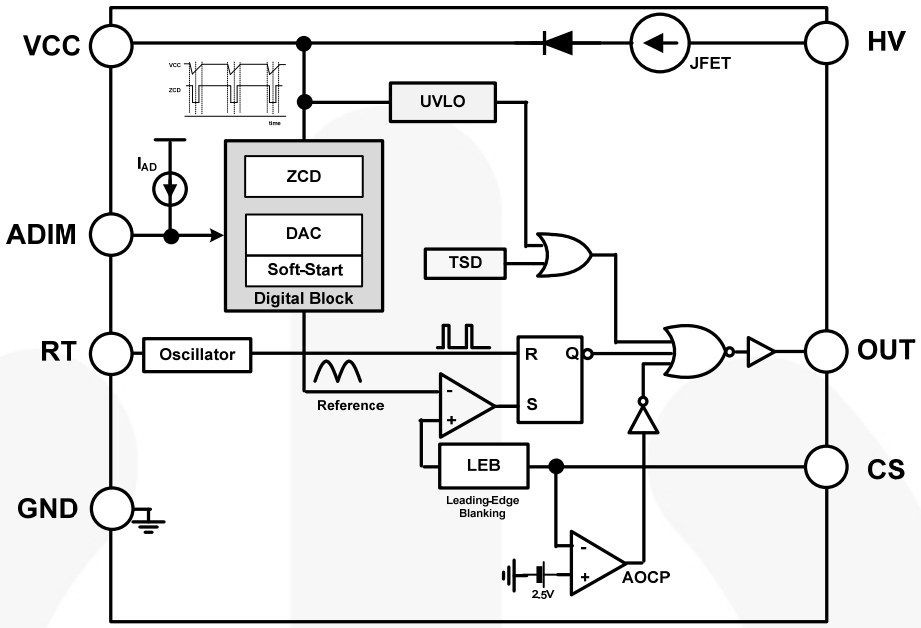


Figure 1. Block Diagram

Pin No.	Symbol	Description
1	**CS**	**Current Sense**. Limits output current depending on the sensing resistor voltage
2	**OUT**	**OUT**. Connects to the MOSFET gate.
3	**VCC**	**VCC**. Supply pin for stable IC operation and IC uses this pin for catching ZCD signal to make internal artificial reference.
4	**RT**	**RT**. Programmable operating frequency using external resistor and IC has fixed frequency even though this pin open or floating.
5	**ADIM**	**Analog Dimming**. Connect to the internal current source. Can change output current using external resistor. Connect small capacitor at non-dimming condition.
6	**GND**	**GROUND**. Ground for the IC.
7	**NC**	No Connection.
8	**HV**	**High Voltage**. Connect to the high voltage line and supply current to the IC.

2. General Specifications for Evaluation Board

All data for this table was measured at an ambient temperature of 25°C.

Table 1. Summary of Features and Performance

Description	Symbol	Value	Comments
Input Voltage Range	$V_{IN.MIN}$	90 V	Minimum Input Voltage
	$V_{IN.NORMAL}$	110 V	Normal Input Voltage
	$V_{IN.MAX}$	150 V	Maximum Input voltage
AC Input Frequency	$Freq_{IN.MIN}$	47 Hz	Minimum Input Frequency
	$Freq_{IN.MAX}$	64 Hz	Maximum Input Frequency
Output Voltage	$V_{OUT,MAX}$	33 V	Maximum Output Voltage
	$V_{OUT,NORMAL}$	31 V	Normal Output Voltage
	$V_{OUT,MIN}$	29 V	Minimum Output Voltage
Output Current(1)	$I_{OUT.NORMAL}$	250 mA	Normal Output Current
	CC Deviation	< ±1.6%	Line Input Voltage Change: 90~150 V_{AC}
Output Power(2)	Output Power	7.8 W	
Efficiency		> 82%	At Full Load
Temperature	T_{FL7701}	< 56°C	At full load (all at open-frame, room temperature / still air)
	$T_{DM\ filter}$	< 67°C	
	$T_{FRD,ES3J}$	< 53°C	
	T_{MOSFET}	< 58°C	
	$T_{inductor}$	< 46°C	
PCB Size			28 mm (width) x 52 mm (length)x 20 mm (height)
Initial Application			LED Bulb

Notes:

1. The output current has I_{LEDPK} ripple. To reduce ripple current, use a large electrolytic capacitor in parallel with the LED. Ensure the capacitor voltage rating is high enough to withstand an open-LED condition or use a Zener diode for protection.
2. The output power is not equal to the apparent power due to the slight phase shift between the output voltage and current.

3. Photographs of the Evaluation Board

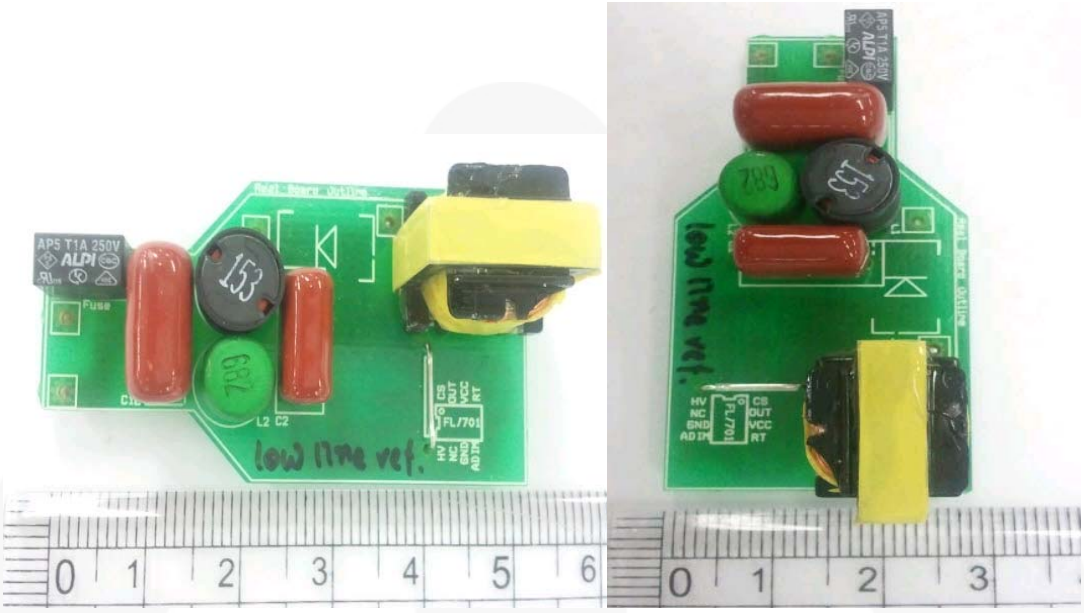


Figure 2. Top-View (28 mm x 52 mm)

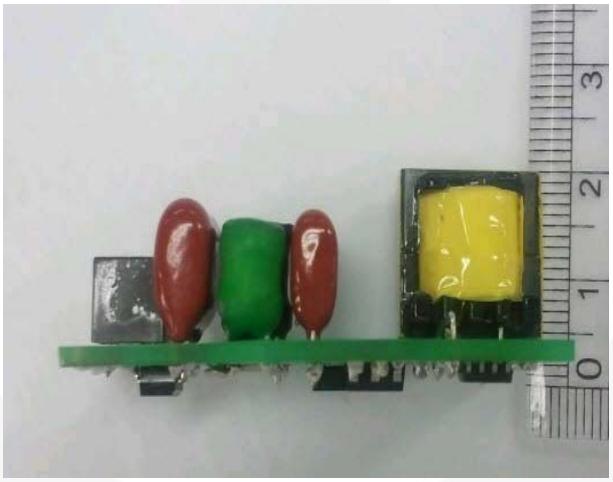


Figure 3. Side-View (20 mm)

4. Printed Circuit Board

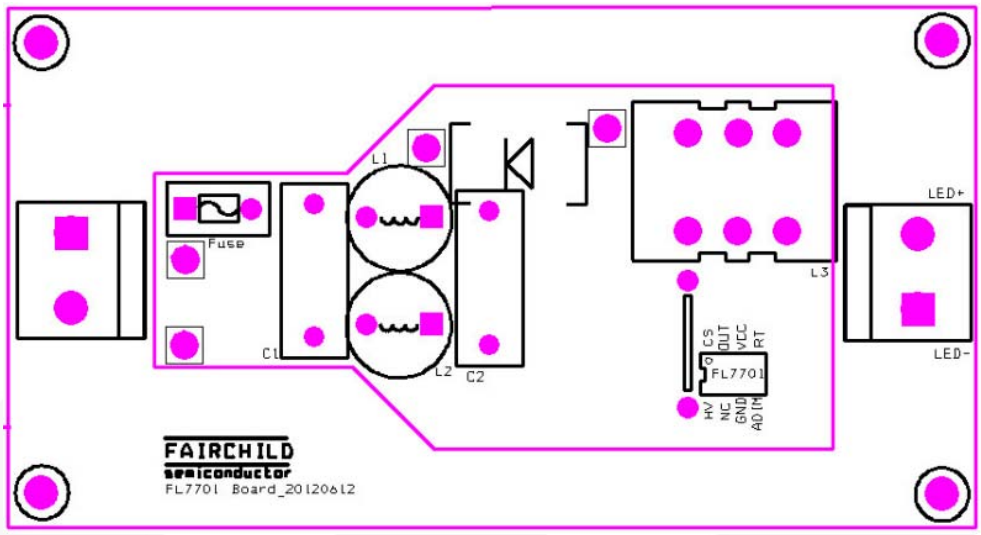


Figure 4. Top Side

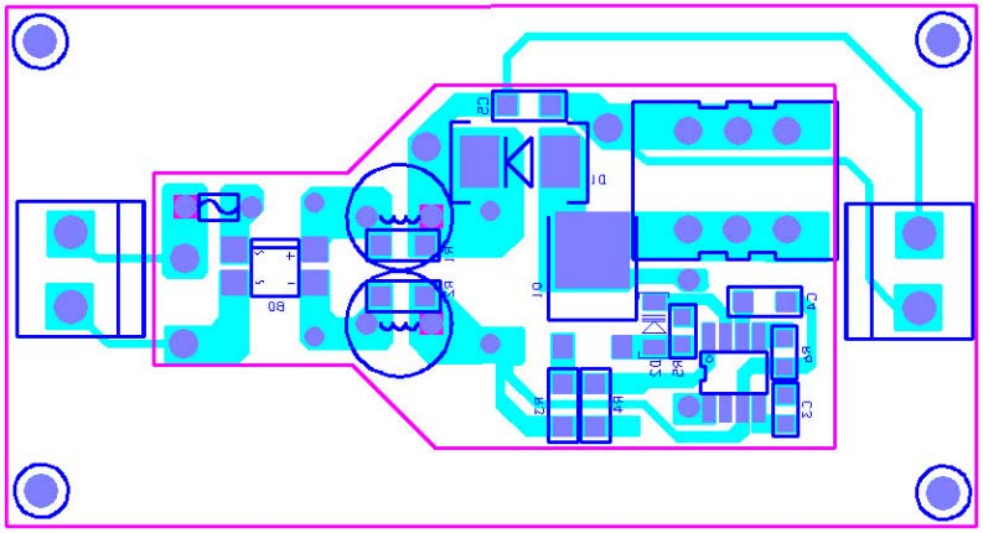


Figure 5. Bottom Side

5. Schematic

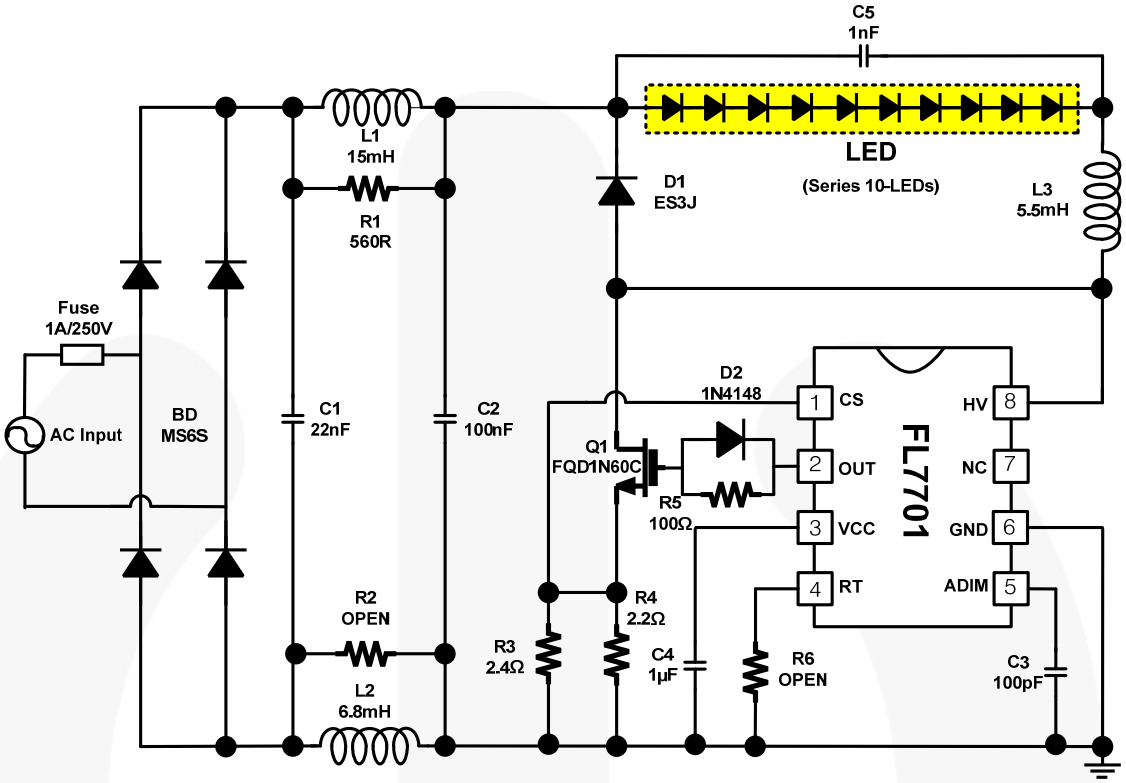


Figure 6. Schematic

6. Bill of Materials

Item No.	Part Reference	Part Number	Qty.	Description	Manufacturer
1	Fuse	SS-5-1A	1	1A / 250 V_{AC}	Bussmann
2	U1	FL7701M	1	Controller	Fairchild Semiconductor
3	BD	MB6S	1	0.5 A / 600 V, Bridge Diode	Fairchild Semiconductor
4	C1	MPE 630V223K	1	22 nF / 630 V_{AC}, Film Capacitor	Sungho
5	C2	MPE 400V104K	1	0.1 uF / 400 V_{AC}, Film Capacitor	Sungho
6	C3	C0805C101K3RACTU	1	100 pF / 25 V SMD Capacitor 2012	Kemet
7	C4	C1206C105K3PACTU	1	1 µF / 25 V SMD Capacitor 3216	Kemet
8	C5	C1206C102JBGACTU	1	1 nF / 630 V SMD Capacitor 3216	Kemet
9	Q1	FQD1N60C	1	1 A / 600 V D-PAK	Fairchild Semiconductor
10	D1	ES3J	1	3 A / 600 V, Ultra-Fast Recovery	Fairchild Semiconductor
11	D2	1N4148	1	0.2 A / 200 V Small Signal Diode	Fairchild Semiconductor
12	L1	RFB0810-153L	1	15 mH, Filter Inductor	Coilcraft
13	L2	R06682KT00	1	6.8 mH, Filter Inductor	Bosung
14	L3	EE1614	1	5.5 mH Inductor	TDK
15	R1	RC1206JR-07561RL	1	560 Ω, SMD Resistor 3216	Yageo
16	R2		0	Open	
17	R3	RC1206JR-072R4RL	1	2.4 Ω, SMD Resistor 3216	Yageo
18	R4	RC1206JR-072R2RL	1	2.2 Ω, SMD Resistor 3216	Yageo
19	R5	RC0805JR-07101RL	1	100 Ω, SMD Resistor 2012	Yageo
20	R6		0	Open	

7. Inductor Design

- Follow Safe Standard
- Inductor Core: EE1614 (TDK)
- N1: 280 Turns
- Inductance Value (1 → 6): 5.5 mH

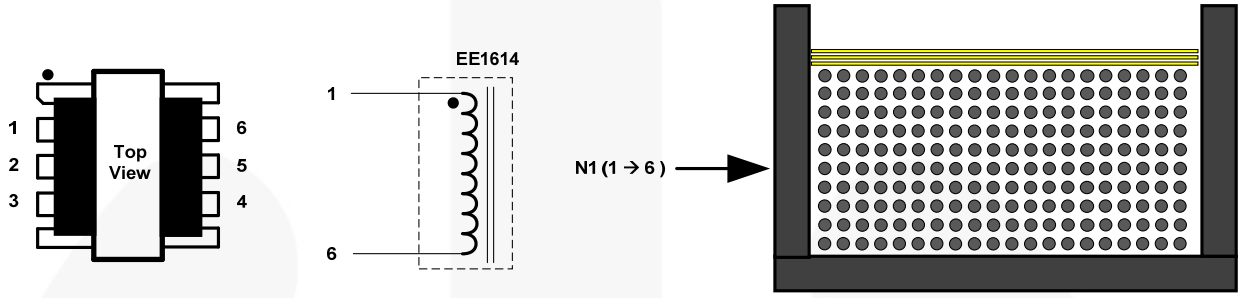


Figure 7. Transformer Structure

Table 2. Inductor Specification

No.	Winding	Pin (S → F)	Wire	Turns	Winding Method
1	N1	1 → 6	0.2Ø	280Ts	Solenoid Winding
2	Insulation: Polyester Tape t = 0.02 5mm 3-Layer				

8. Performance of Evaluation Board

Table 3. Test Condition & Equipments

Test Temperature	T_A = 25°C
Test Equipment	AC Source : PCR500L by Kikusui Power Meter : PZ4000 by Yokogawa Oscilloscope : Waverunner 64Xi by LeCroy EMI Test Receiver: ESCS30 by ROHDE & SCHWARZ Two-Line V-Network: ENV216 by ROHDE & SCHWARZ Thermometer : CAM SC640 by FLIR SYSTEMS LED: EHP-AX08EL/GT01H-P03 (1 W) by Everlight

8.1. Typical Waveforms: Startup

Figure 8 through Figure 11 show the typical startup performance at different input voltage conditions. When AC input voltage is applied to the system, the FL7701 automatically operates in AC Mode after finishing an internally fixed, seven-cycle, soft-start period. Figure 10 and Figure 11 show the soft-start characteristics when a DC input voltage is applied.

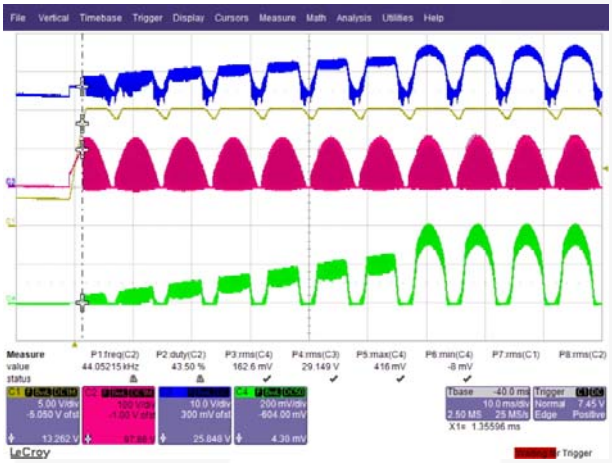


Figure 8. Soft-Start, AC Mode, 90 V_{AC}
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

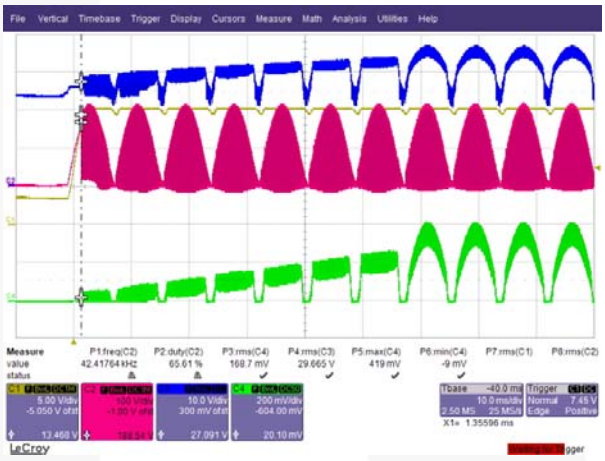


Figure 9. Soft-Start, AC Mode, 150 V_{AC}
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 10. Soft-Start, DC Mode, 100 V_{DC}
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

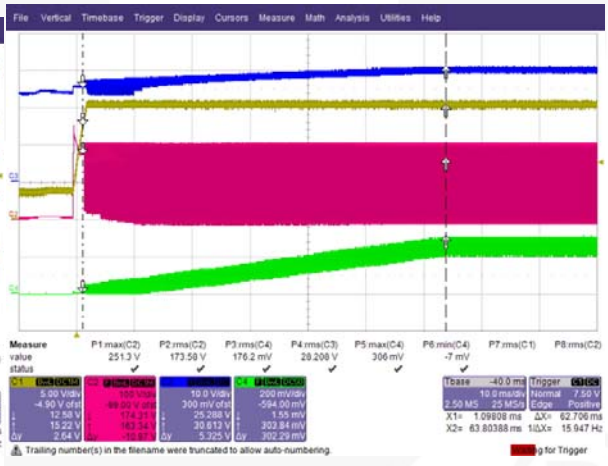
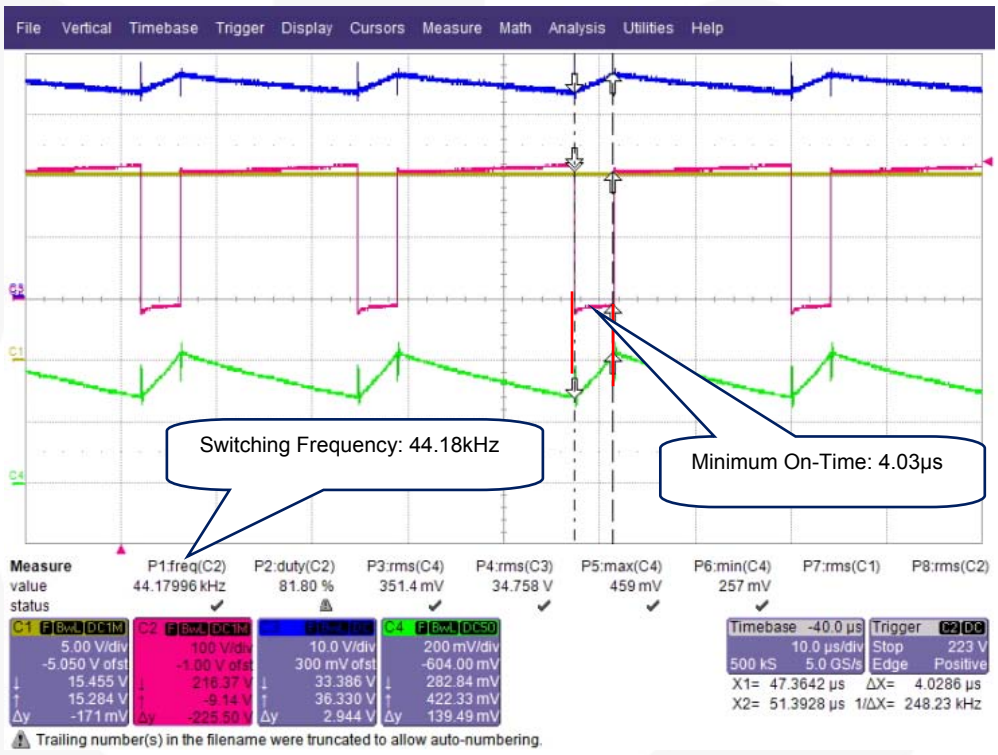


Figure 11. Soft-Start, DC Mode, 200 V_{DC}
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

8.2. Operating Frequency & Minimum Duty

The programmable switching frequency is between 20 kHz ~ 250 kHz, determined by selecting the RT resistor value. If no RT resistor is used (RT pin OPEN), the FL7701 default switching frequency is set to 45 kHz. The maximum duty ratio is fixed below 50% and has a fixed minimum typical on-time of 400 ns. There are two crucial points to design properly. The first is consideration of the minimum duty ratio at minimum input voltage because the FL7701 is limited to 50% duty ratio. The second consideration is minimum on-time at maximum input voltage condition. The FL7701 cannot control output power when the operating conditions are such that the required on-time is less than the 400 ns minimum on-time.



CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 12. Operating Frequency & Minimum Duty Ratio

8.3. Typical Waveforms: Steady State

Figure 13 through Figure 20 show the normal operation waveform by input voltage and input frequency. The output voltage and current maintains a certain output level with 120 Hz ripple, as shown in the test results in Table 4.

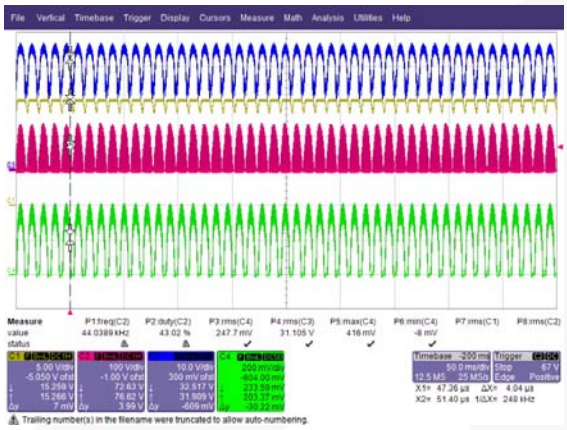


Figure 13. Input Voltage: 90 V_{AC}, Input Frequency: 47 Hz, CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

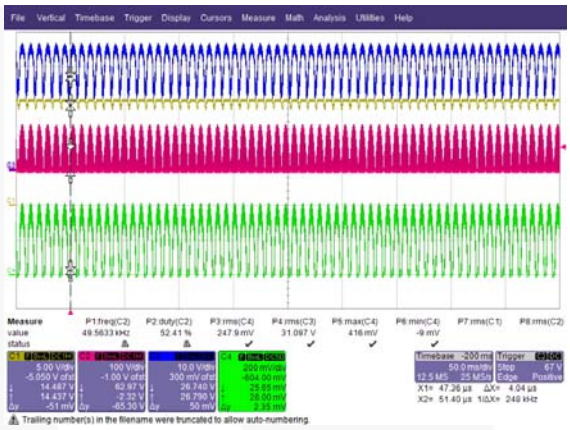


Figure 14. Input Voltage: 90 V_{AC}, Input Frequency: 64 Hz, CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

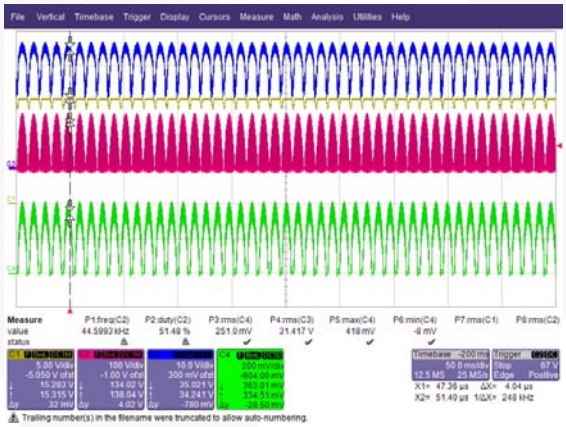


Figure 15. Input Voltage: 110 V_{AC}, Input Frequency: 47 Hz, H1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

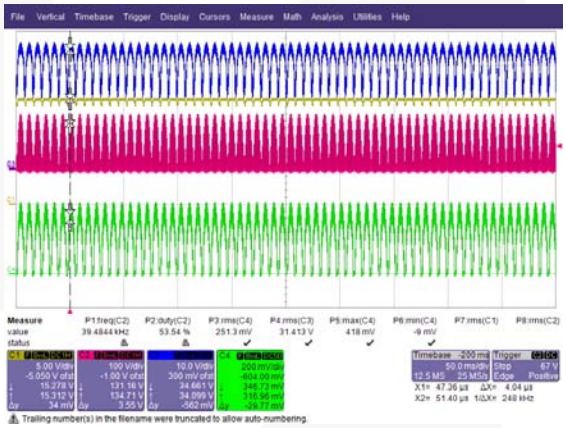


Figure 16. Input Voltage: 110 V_{AC}, Input Frequency: 64 Hz, H1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

8.4. Typical Operating Waveforms: Output Characteristics

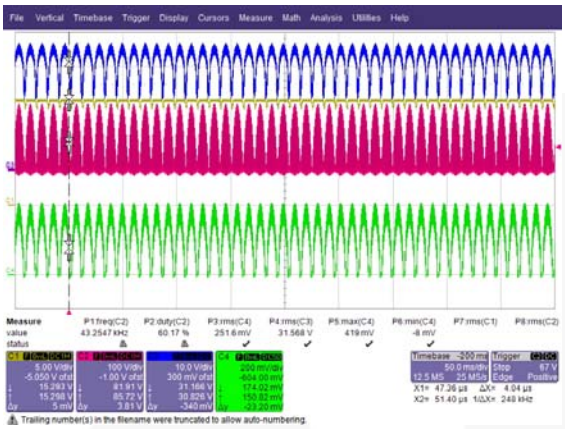


Figure 17. Input Voltage: 130 V_{AC}, Input Frequency: 47 Hz, CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

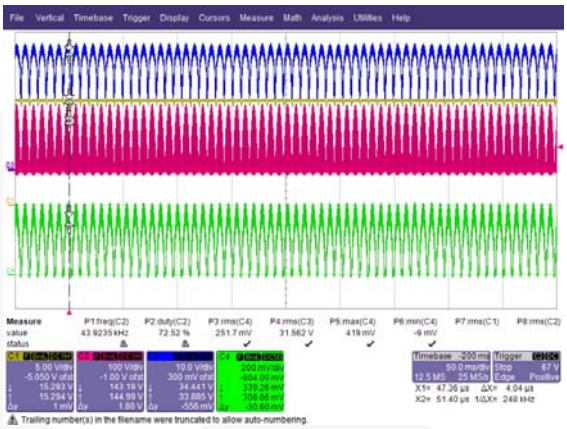


Figure 18. Input Voltage: 130 V_{AC}, Input Frequency: 64 Hz, CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

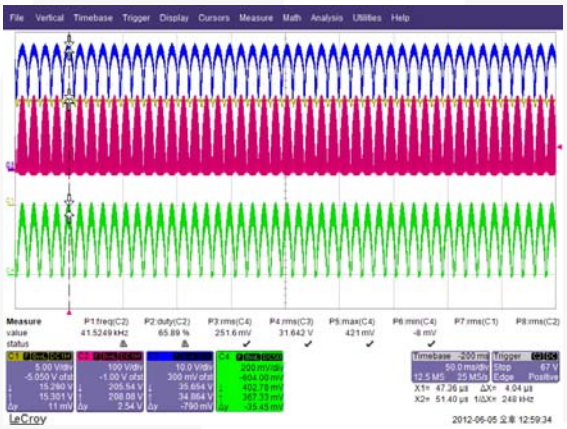


Figure 19. Input Voltage: 150 V_{AC}, Input Frequency: 47 Hz, CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

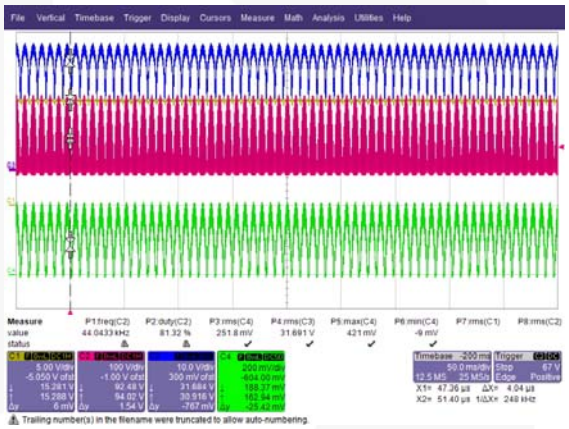


Figure 20. Input Voltage: 150 V_{AC}, Input Frequency: 64 Hz, CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Table 4. Output Characteristics by Input Voltage and Frequency

	47 Hz		64 Hz	
	$V_{LED(RMS)}$	$I_{LED(RMS)}$	$V_{LED(RMS)}$	$I_{LED(RMS)}$
90 V_{AC}	31.11 V	247.7 mA	31.10 V	247.9 mA
110 V_{AC}	31.42 V	251.0 mA	31.41 V	251.3 mA
130 V_{AC}	31.57 V	251.6 mA	31.56 V	251.7 mA
150 V_{AC}	31.64 V	251.6 mA	31.69 V	251.8 mA

8.5. Typical Waveforms: Abnormal Mode (LED-Open)

Figure 21 and Figure 22 show the open-load condition test method and result. When the LED disconnects from the system, the IC cannot operate because the HV pin is disconnected.

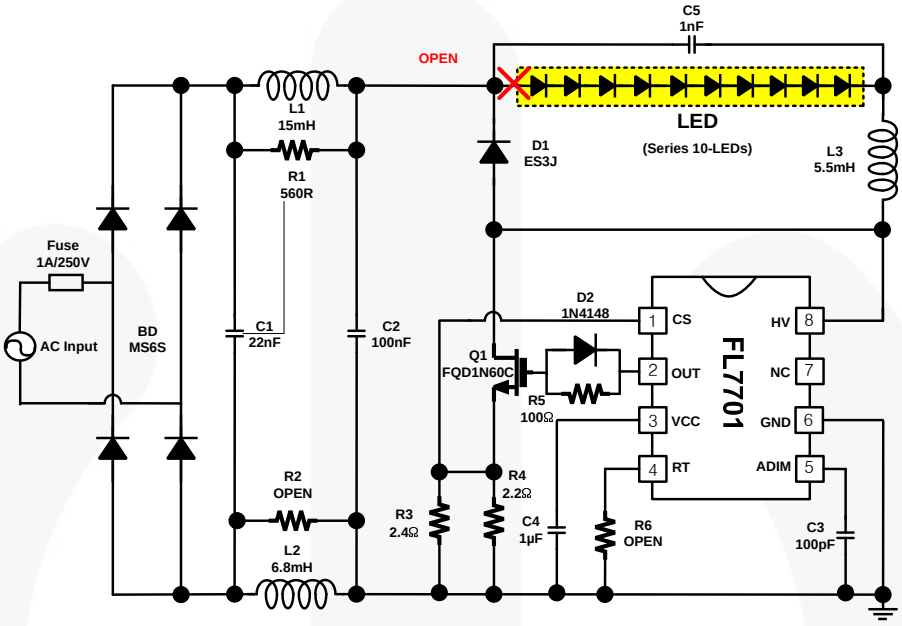
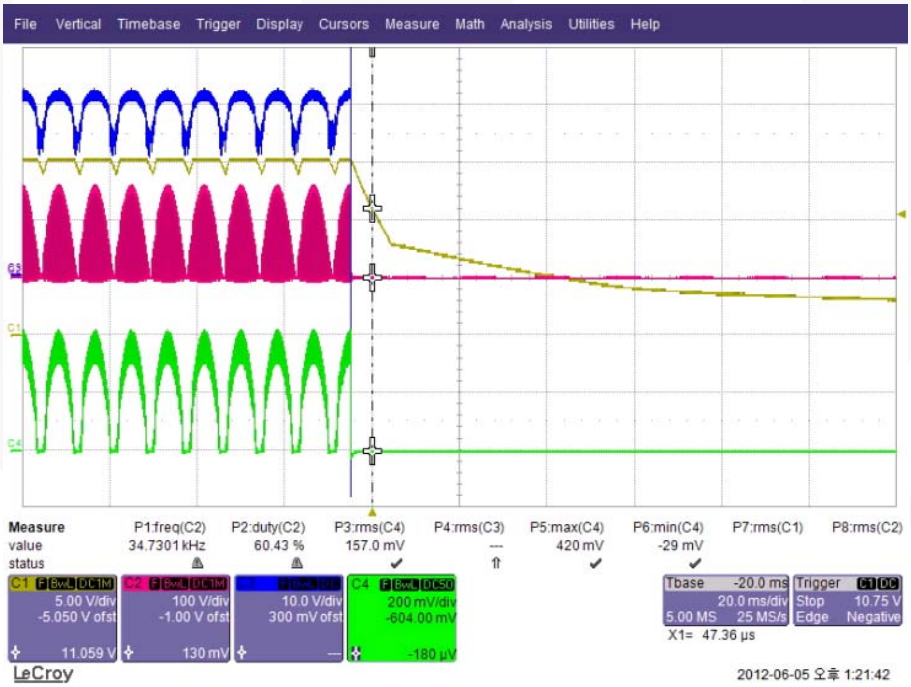


Figure 21. Open-Load Condition Test



CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 22. Test Results of Open-Load Condition

8.6. Typical Waveforms: Abnormal Mode (Inductor Short)

Figure 23 and Figure 24 show the test method and result of an inductor short. The FL7701 uses an abnormal over-current protection (AOCP) function, limiting the current on RCS in the event of an inductor short.

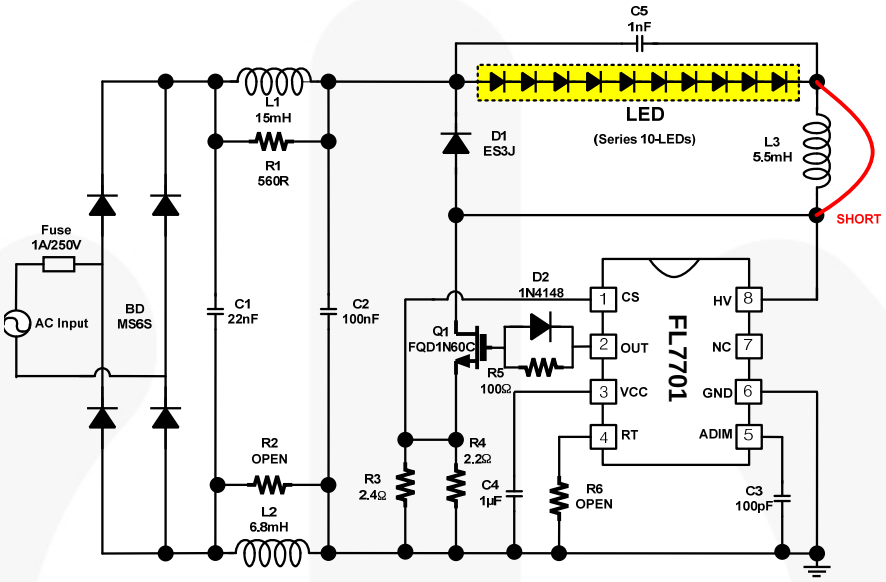
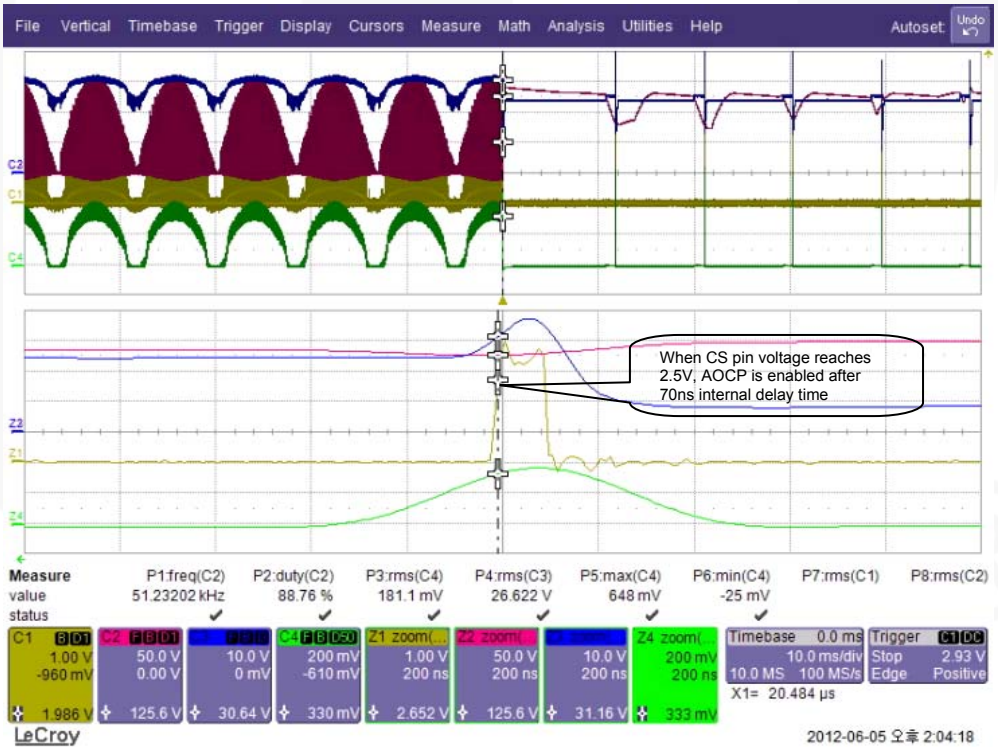


Figure 23. Inductor-Short Condition



CH1: V_{CS}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 24. Test Results of Inductor Short Condition

8.7. System Efficiency

Figure 25 shows system efficiency results for different AC input voltage frequency conditions. As shown, the input frequency has negligible effect on system efficiency.

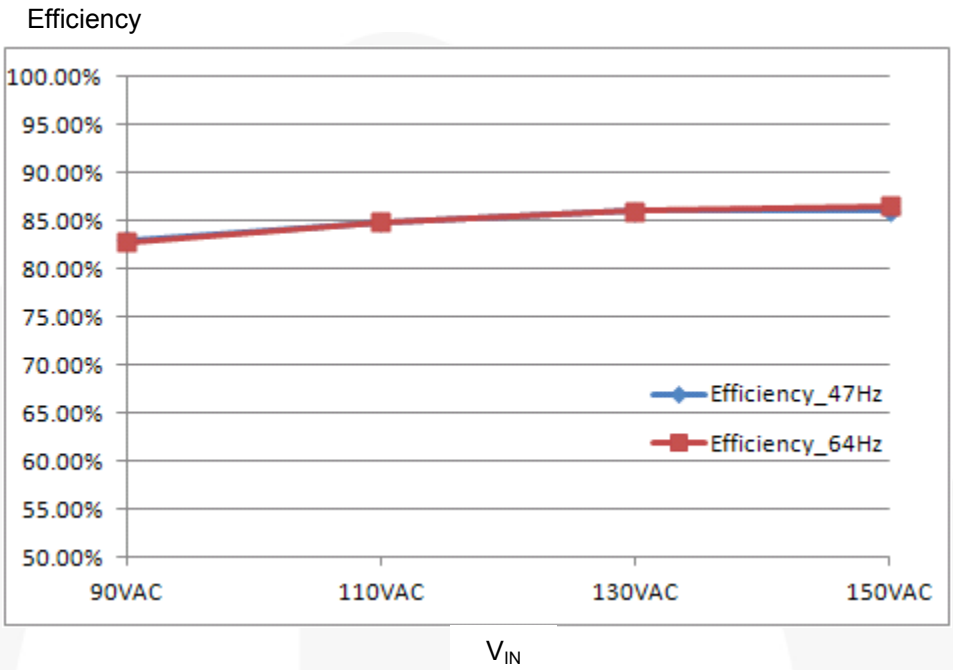


Figure 25. System Efficiency

Table 5. System Efficiency Test Result

Input Voltage		Efficiency (%)
90 V_{AC}	47 Hz	82.97
	64 Hz	82.81
110 V_{AC}	47 Hz	84..87
	64 Hz	84.88
130 V_{AC}	47 Hz	86.04
	64 Hz	86.08
150 V_{AC}	47 Hz	86.50
	64 Hz	86.61

8.8. Power Factor at Rated Load Condition

Figure 26 shows the system Power Factor (PF) performance for the entire input voltage range (90 V_{AC} to 150 V_{AC}) at different input frequency conditions (47 Hz, 64 Hz). The PF changes slightly according to the input frequency.

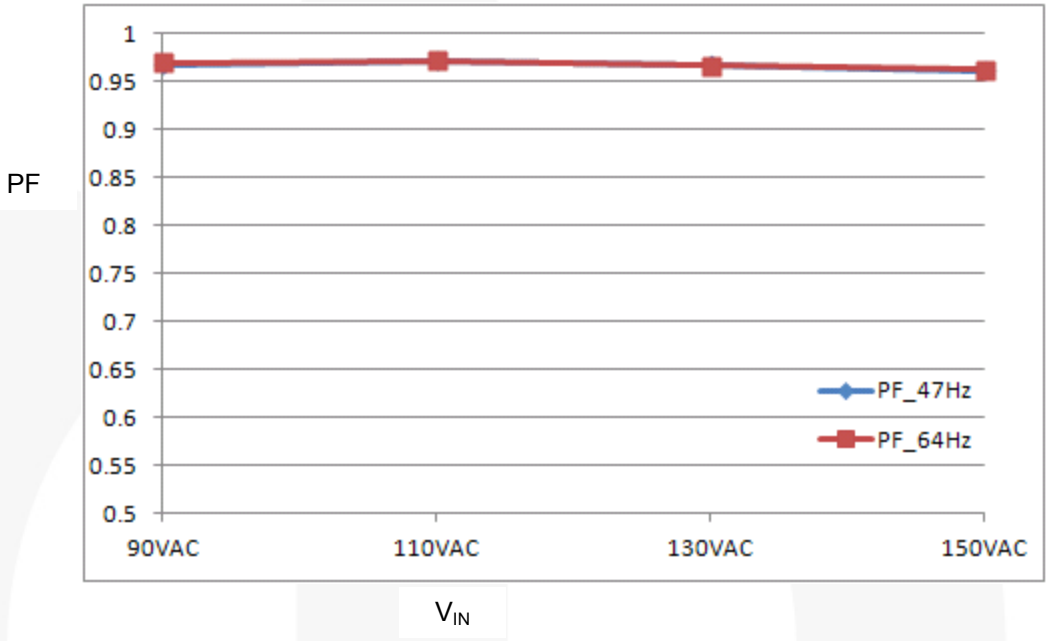


Figure 26. Power Factor

Table 6. Power Factor Test Results

Input Voltage (V_{AC})	Frequency (Hz)	PF
90 V_{AC}	47 Hz	0.97
	64 Hz	0.97
110 V_{AC}	47 Hz	0.97
	64 Hz	0.97
130 V_{AC}	47 Hz	0.97
	64 Hz	0.97
150 V_{AC}	47 Hz	0.96
	64 Hz	0.96

8.9. Total Harmonic Distortion (THD) Performance

Figure 27 shows the Total Harmonic Distortion (THD) performance at different input frequencies. Test results meet international regulations (under 30%).

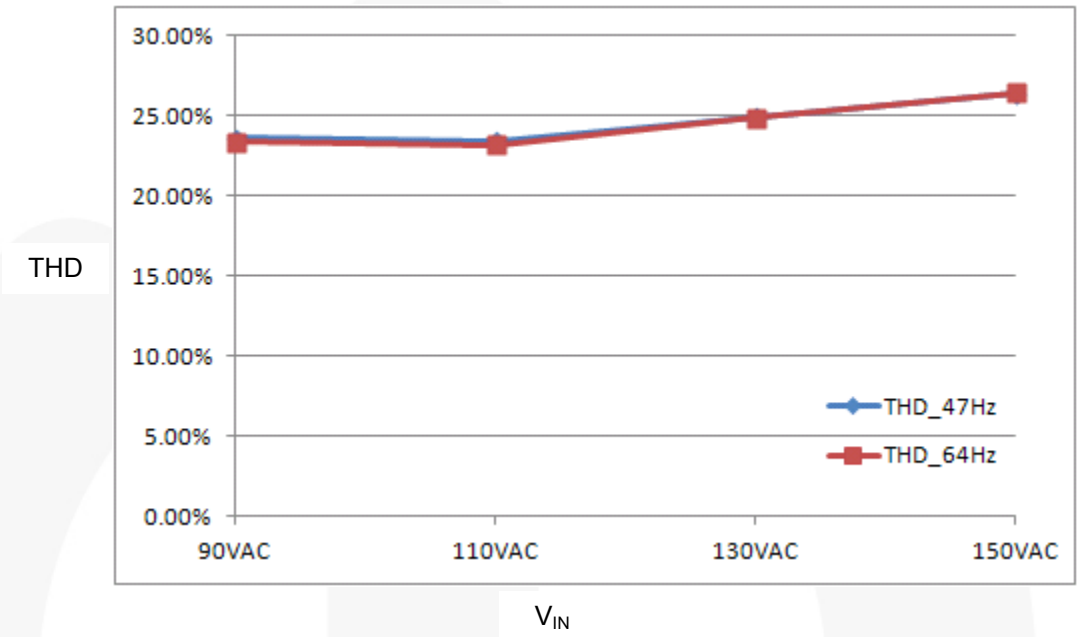


Figure 27. Total Harmonic Distortion Performance

Table 7. Total Harmonic Distortion Test Results

Input Voltage (V_{AC})	Frequency (Hz)	THD (%)
90 V_{AC}	47 Hz	23.60
	64 Hz	23.39
110 V_{AC}	47 Hz	23.45
	64 Hz	23.17
130 V_{AC}	47 Hz	24.92
	64 Hz	24.90
150 V_{AC}	47 Hz	26.40
	64 Hz	26.46

8.10. Thermal Performance

Figure 28 through Figure 35 show the steady-state thermal test results with different input voltage conditions. Filter inductor L2 has the highest temperature on the top side of the PCB due to copper resistance. The switching MOSFET has the highest temperature on the bottom side of the PCB. The IC temperature is 56.4°C for 150 V_{AC} input condition.

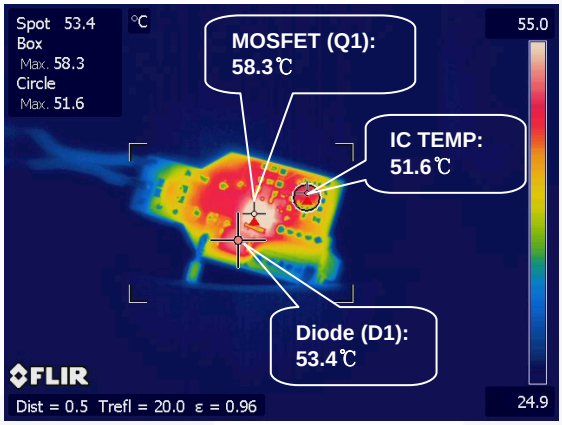


Figure 28. Bottom-Side Temperature at 90 V_{AC} Condition (IC)

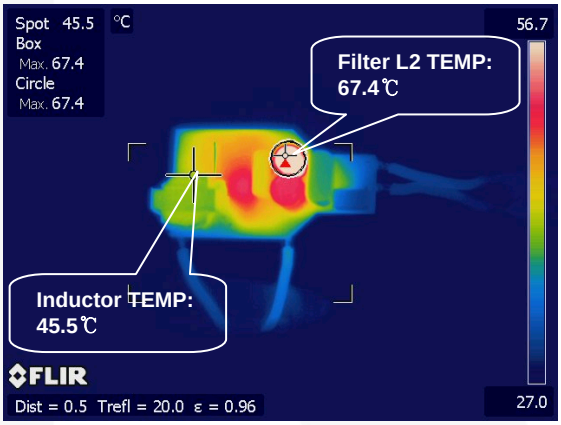


Figure 29. Top-Side Temperature at 90 V_{AC} Condition (Inductor)

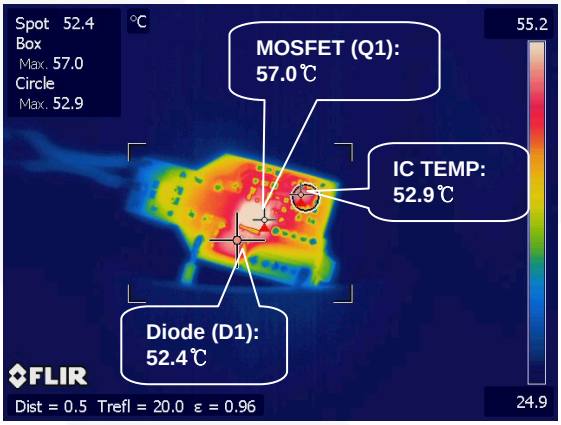


Figure 30. Bottom-Side Temperature at 110 V_{AC} Condition (IC)

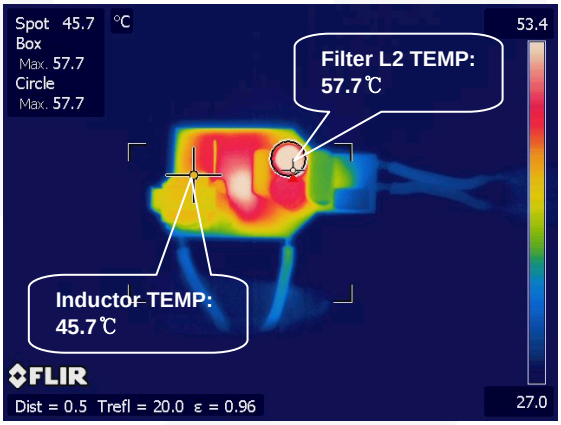


Figure 31. Top-Side Temperature at 110 V_{AC} Condition (Inductor)

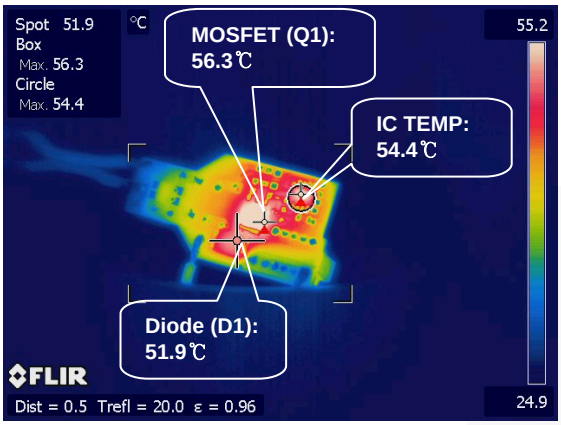


Figure 32. Bottom-Side Temperature at 130 V_{AC} Condition (IC)

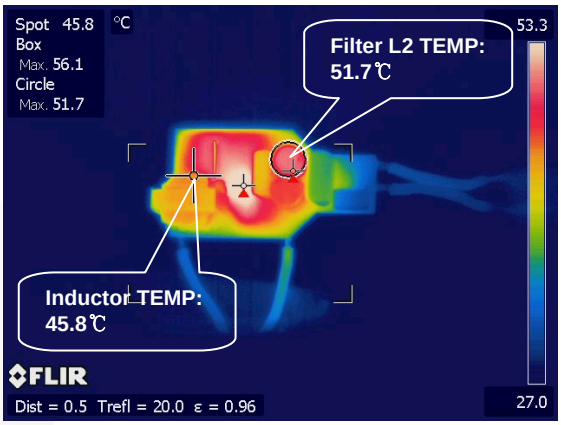


Figure 33. Top-Side Temperature at 130 V_{AC} Condition (Inductor)

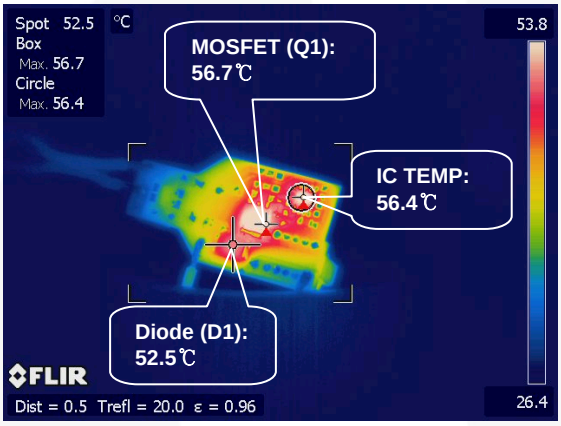


Figure 34. Bottom-Side Temperature at 150 V_{AC} Condition (IC)

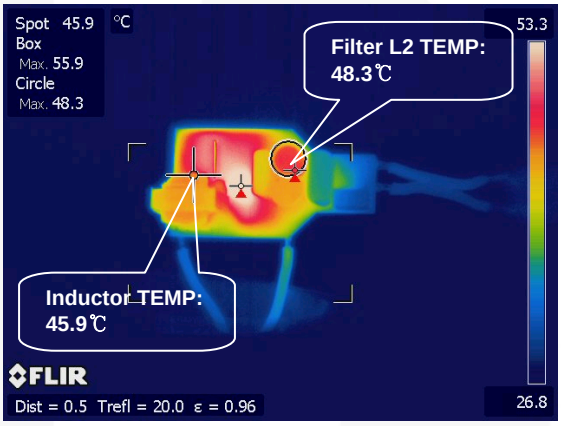


Figure 35. Top-Side Temperature at 150 V_{AC} Condition (Inductor)

Table 8. Temperature Performance by Input Voltage

Input Voltage (V_{AC})	T_{IC}	T_{MOSFET}	$T_{FILTER\ L2}$
90 V_{AC}	51.6°C	58.3°C	67.4°C
110 V_{AC}	52.9°C	57.0°C	57.7°C
130 V_{AC}	54.4°C	56.3°C	51.7°C
150 V_{AC}	56.4°C	56.7°C	48.3°C

8.11. Electromagnetic Interference (EMI) Test Results

EMI test measurements were conducted in observance of CISPR22 criteria, which has stricter limits than CISPR15 for lighting applications.

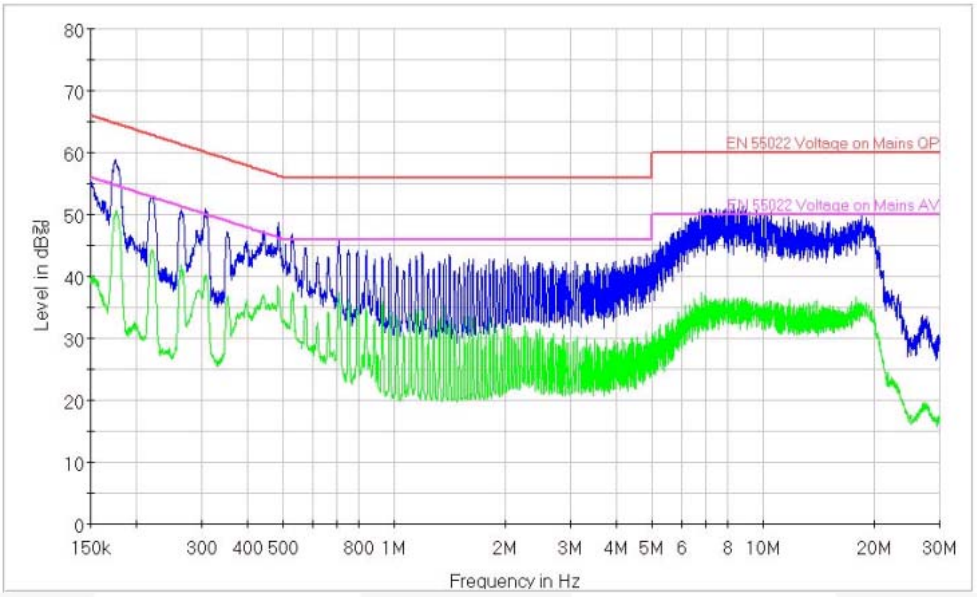


Figure 36. Conducted Emission - Line at 110 V_{AC} Input Condition, Full Load (10-LED Series)

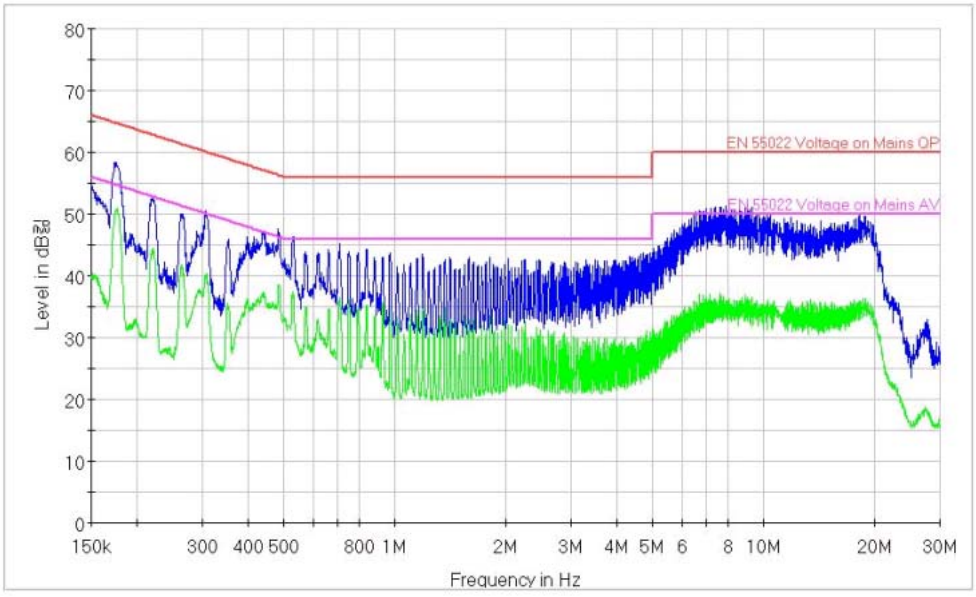


Figure 37. Conducted Emission - Neutral at 110 V_{AC} Input Condition, Full Load (10-LED Series)

9. Revision History

Rev.	Date	Description
1.0.0	July 2012	First Release
1.0.1	Sep. 2012.	Changed User Guide number from FEB-L031-1 to FEBFL7701_L31L008A

WARNING AND DISCLAIMER

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.

This board is intended to be used by certified professionals, in a lab environment, following proper safety procedures. Use at your own risk. The Evaluation board (or kit) is for demonstration purposes only and neither the Board nor this User's Guide constitute a sales contract or create any kind of warranty, whether express or implied, as to the applications or products involved. Fairchild warrantees that its products meet Fairchild's published specifications, but does not guarantee that its products work in any specific application. Fairchild reserves the right to make changes without notice to any products described herein to improve reliability, function, or design. Either the applicable sales contract signed by Fairchild and Buyer or, if no contract exists, Fairchild's standard Terms and Conditions on the back of Fairchild invoices, govern the terms of sale of the products described herein.

DISCLAIMER

FAIRCHILD SEMICONDUCTOR RESERVES THE RIGHT TO MAKE CHANGES WITHOUT FURTHER NOTICE TO ANY PRODUCTS HEREIN TO IMPROVE RELIABILITY, FUNCTION, OR DESIGN. FAIRCHILD DOES NOT ASSUME ANY LIABILITY ARISING OUT OF THE APPLICATION OR USE OF ANY PRODUCT OR CIRCUIT DESCRIBED HEREIN; NEITHER DOES IT CONVEY ANY LICENSE UNDER ITS PATENT RIGHTS, NOR THE RIGHTS OF OTHERS.

LIFE SUPPORT POLICY

FAIRCHILD'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF FAIRCHILD SEMICONDUCTOR CORPORATION.

As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, or (c) whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in significant injury to the user.
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.

ANTI-COUNTERFEITING POLICY

Fairchild Semiconductor Corporation's Anti-Counterfeiting Policy. Fairchild's Anti-Counterfeiting Policy is also stated on our external website, www.fairchildsemi.com, under Sales Support.

Counterfeiting of semiconductor parts is a growing problem in the industry. All manufacturers of semiconductor products are experiencing counterfeiting of their parts. Customers who inadvertently purchase counterfeit parts experience many problems such as loss of brand reputation, substandard performance, failed applications, and increased cost of production and manufacturing delays. Fairchild is taking strong measures to protect ourselves and our customers from the proliferation of counterfeit parts. Fairchild strongly encourages customers to purchase Fairchild parts either directly from Fairchild or from Authorized Fairchild Distributors who are listed by country on our web page cited above. Products customers buy either from Fairchild directly or from Authorized Fairchild Distributors are genuine parts, have full traceability, meet Fairchild's quality standards for handling and storage and provide access to Fairchild's full range of up-to-date technical and product information. Fairchild and our Authorized Distributors will stand behind all warranties and will appropriately address any warranty issues that may arise. Fairchild will not provide any warranty coverage or other assistance for parts bought from Unauthorized Sources. Fairchild is committed to combat this global problem and encourage our customers to do their part in stopping this practice by buying direct or from authorized distributors.

EXPORT COMPLIANCE STATEMENT

These commodities, technology, or software were exported from the United States in accordance with the Export Administration Regulations for the ultimate destination listed on the commercial invoice. Diversion contrary to U.S. law is prohibited.

U.S. origin products and products made with U.S. origin technology are subject to U.S Re-export laws. In the event of re-export, the user will be responsible to ensure the appropriate U.S. export regulations are followed.

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
19521 E. 32nd Pkwy, Aurora, Colorado 80011 USA
Phone: 303−675−2175 or 800−344−3860 Toll Free USA/Canada
Fax: 303−675−2176 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81−3−5817−1050

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative