User Guide for

FEB-L031-1
Evaluation Board

7.8W 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, 7.8W LED ballast using the FL7701. The input voltage range is $90V_{RMS}$ – $150V_{RMS}$ and there is one DC output with a constant current of 250mA at 31V. 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: 0.85mA (Typical)
- Under-Voltage Lockout with 5V Hysteresis
- Programmable Oscillation Frequency
- Programmable LED Current
- Analog Dimming Function
- Soft-Start Function
- Precise Internal Reference: ±3%

1.3. Internal Block Diagram

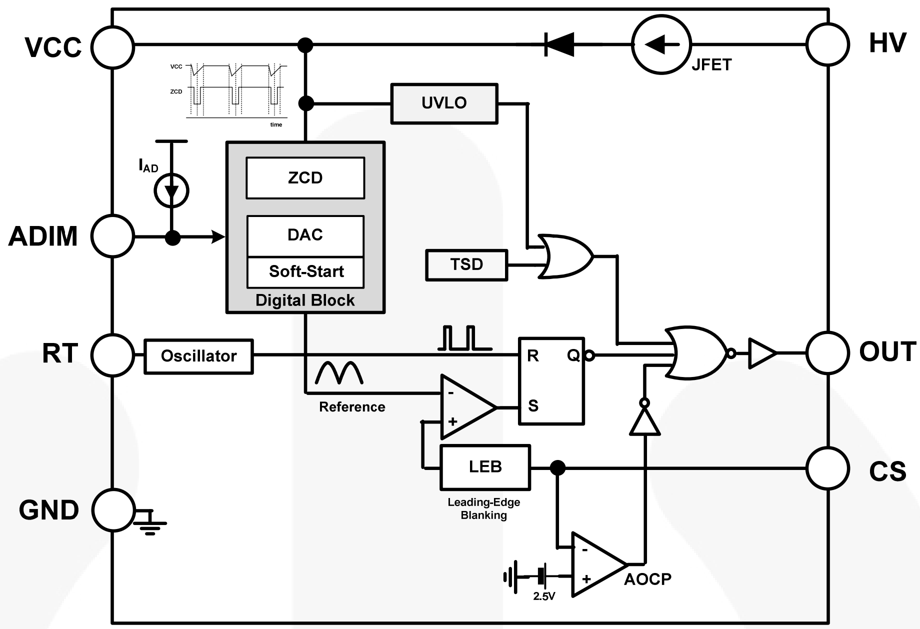


Figure 1. Block Diagram

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	$V_{IN.MIN}$	90V	Minimum Input Voltage
	$V_{IN.NORMAL}$	110V	Normal Input Voltage
	$V_{IN.MAX}$	150V	Maximum Input voltage
AC Input Frequency	$Freq_{IN.MIN}$	47Hz	Minimum Input Frequency
	$Freq_{IN.MAX}$	64Hz	Maximum Input Frequency
Output Voltage	$V_{OUT,MAX}$	33V	Maximum Output Voltage
	$V_{OUT,NORMAL}$	31V	Normal Output Voltage
	$V_{OUT,MIN}$	29V	Minimum Output Voltage
Output Current(1)	$I_{OUT.NORMAL}$	250mA	Normal Output Current
	CC Deviation	< ±1.6%	Line Input Voltage Change: 90~150V_{AC}
Output Power(2)	Output Power	7.8W	
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			28mm (width) x 52mm (length)x 20mm (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

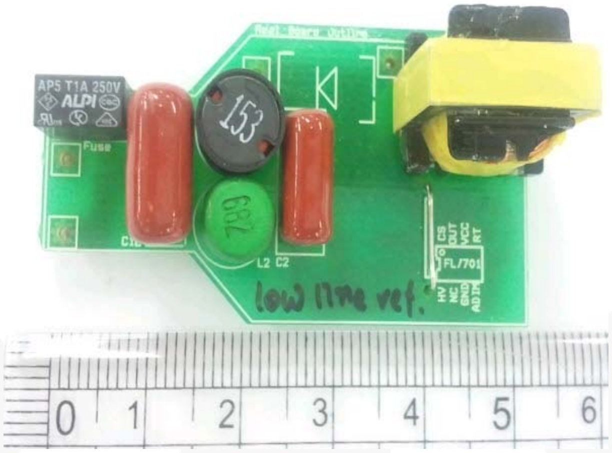


Figure 2. Top-View (28mm x 52mm)

Figure 3. Bottom-View (28mm x 52mm)

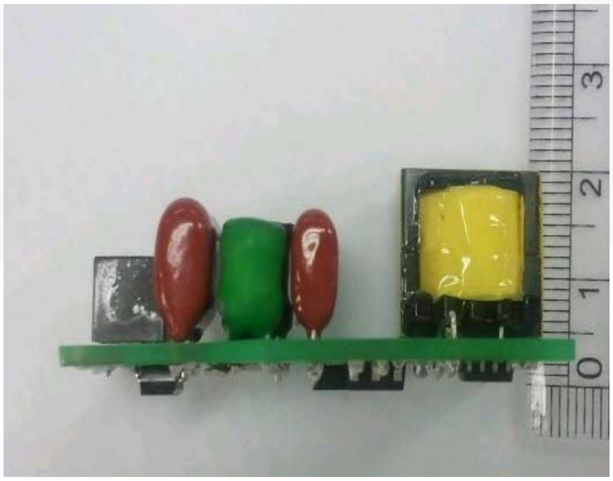


Figure 4. Side-View (20mm)

4. Printed Circuit Board

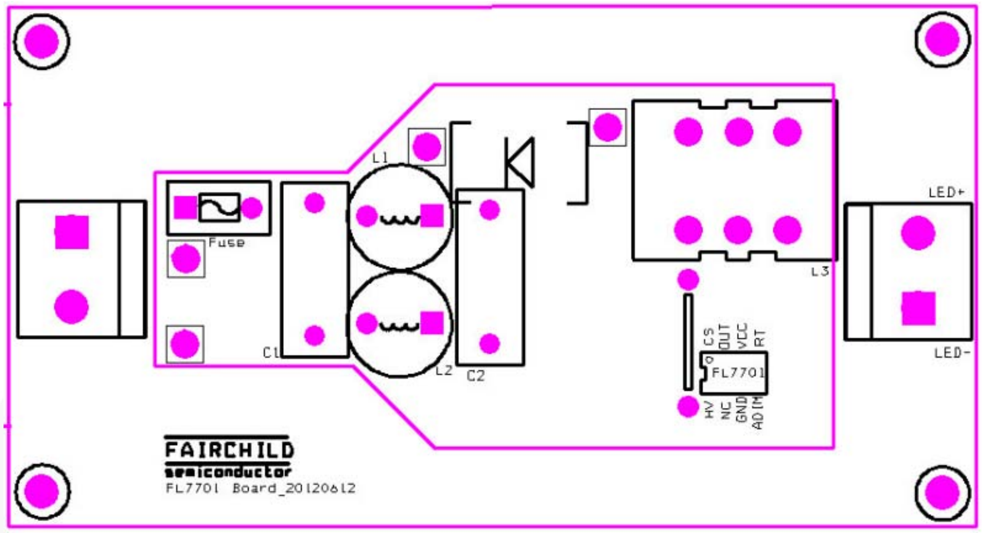


Figure 5. Top Side

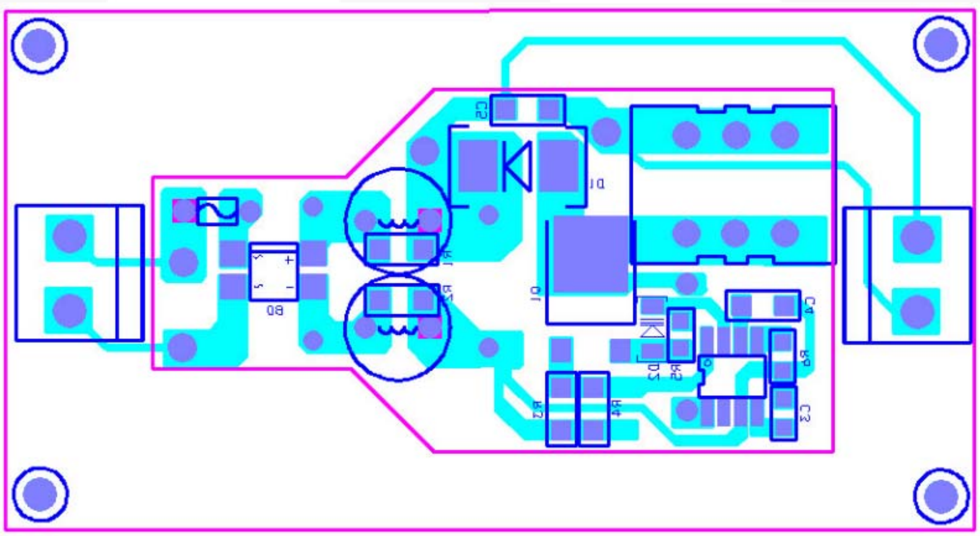


Figure 6. Bottom Side

5. Schematic

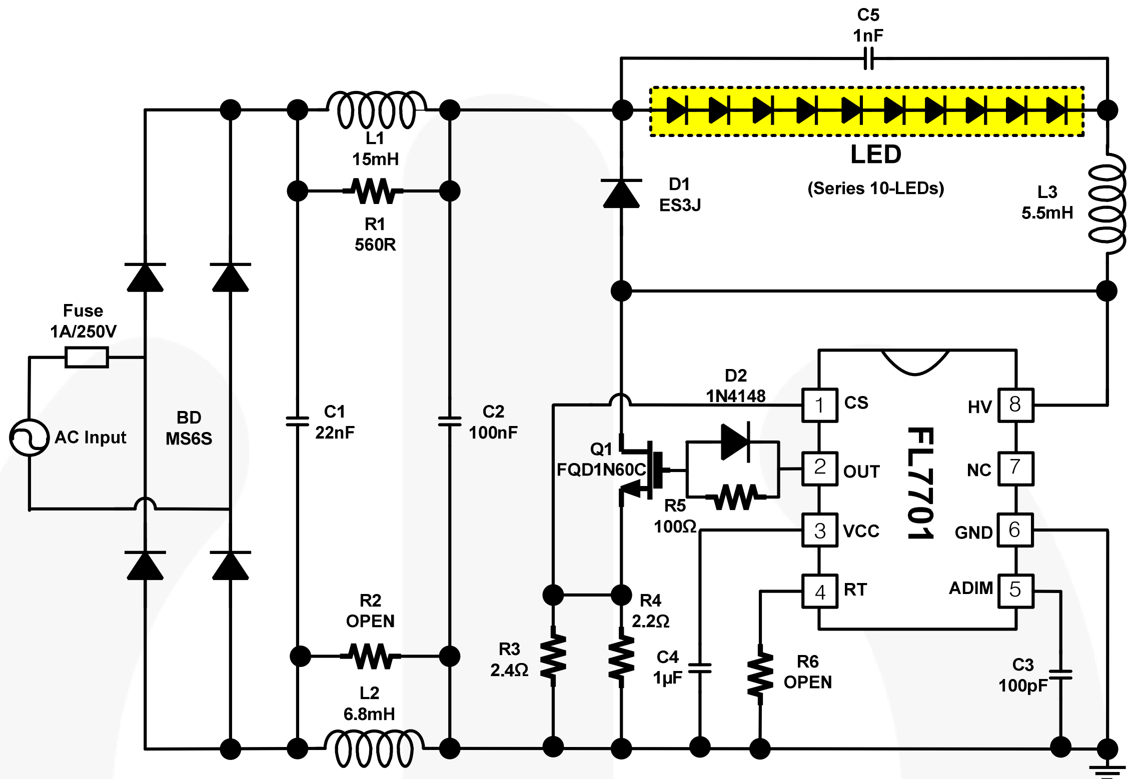


Figure 7. Schematic

6. Bill of Materials

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

7. Inductor Design

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

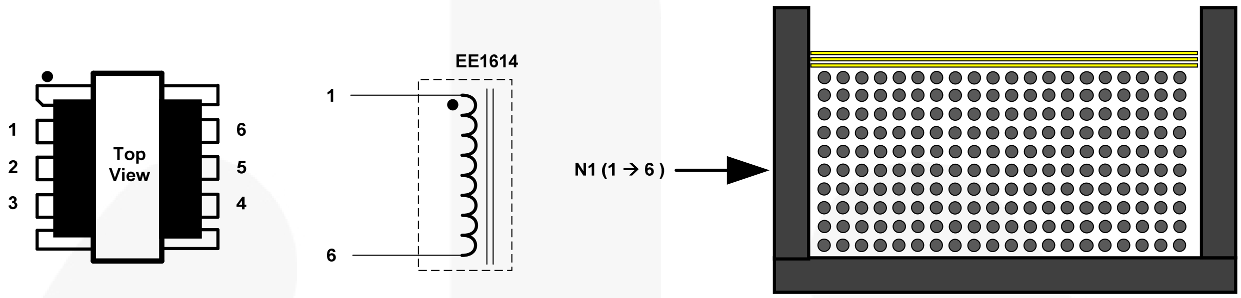


Table 2. Inductor Specification

No.	Winding	Pin (S → F)	Wire	Turns	Winding Method
1	N1	1 → 6	0.2∅	280Ts	Solenoid Winding
2	Insulation: Polyester Tape t = 0.025mm 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 (1W) 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.

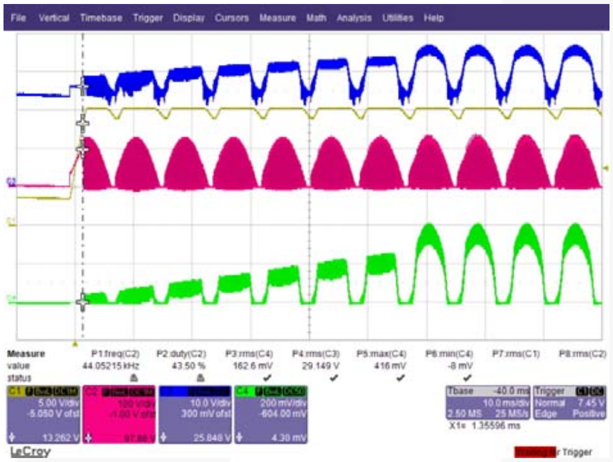


Figure 8. Soft-Start, AC Mode, 90V_{AC}
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

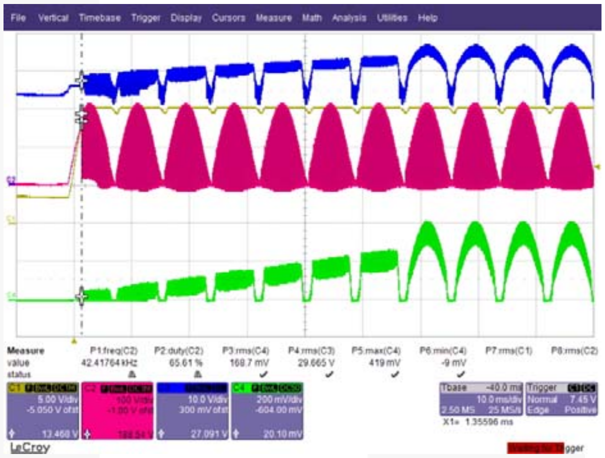


Figure 9. Soft-Start, AC Mode, 150V_{AC}
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

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

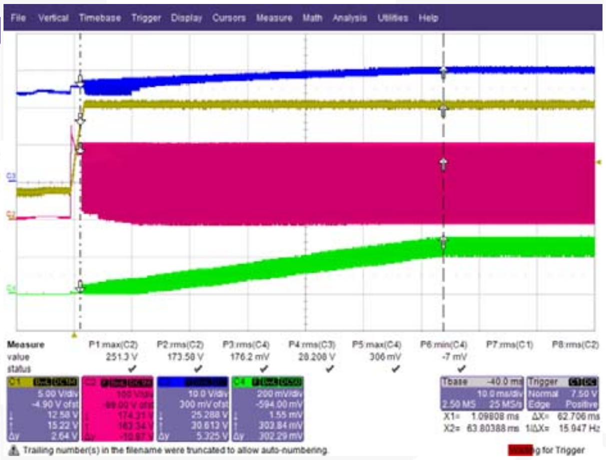
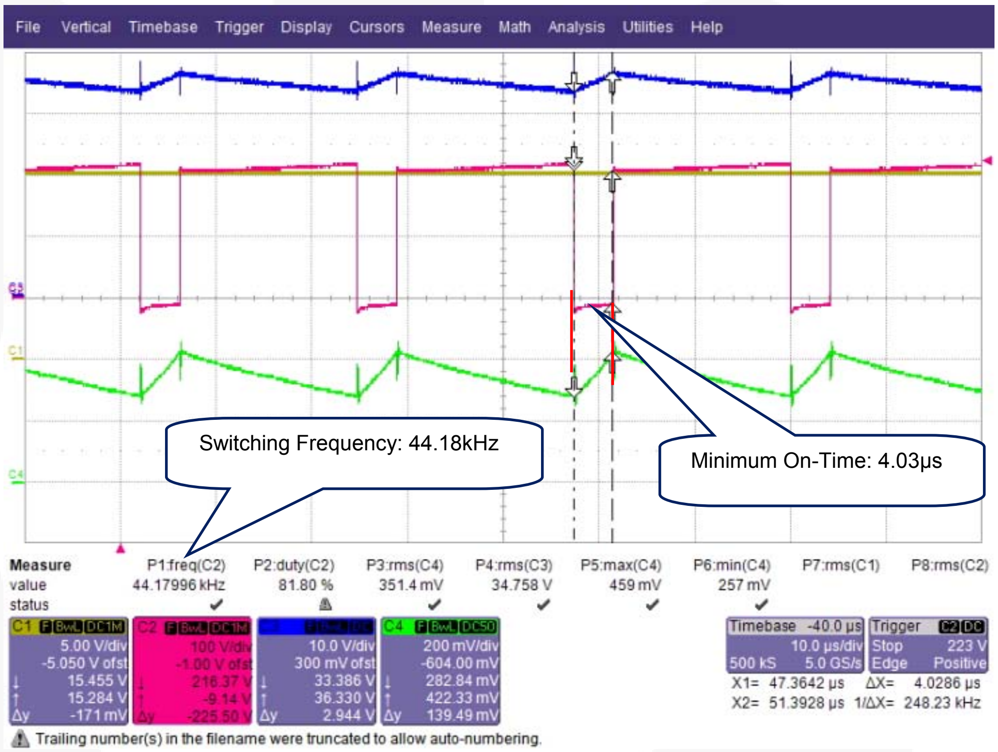


Figure 11. Soft-Start, DC Mode, 200V_{DC}
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

8.2. Operating Frequency & Minimum Duty

The programmable switching frequency is between 20kHz ~ 250kHz, determined by selecting the RT resistor value. If no RT resistor is used (RT pin OPEN), the FL7701 default switching frequency is set to 45kHz. The maximum duty ratio is fixed below 50% and has a fixed minimum typical on-time of 400ns. 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 400ns 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 120Hz ripple, as shown in the test results in Table 4.

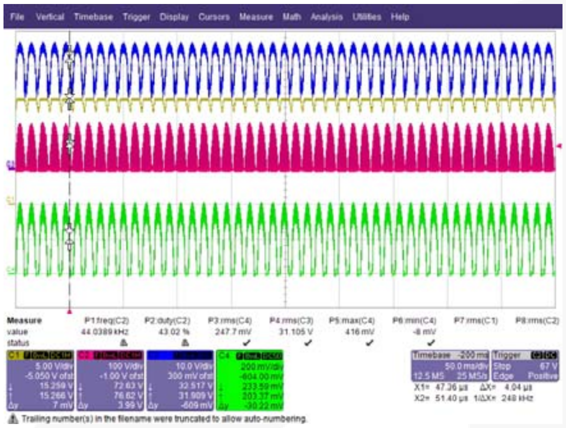


Figure 13. Input Voltage: 90V$_{AC}$, Input Frequency: 47Hz, CH1: V$_{CC}$, CH2: V$_{DRAIN}$, CH3: V$_{LED}$, CH4: I$_{LED}$

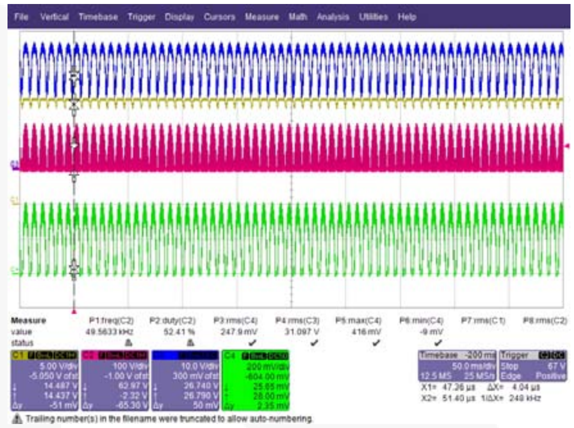


Figure 14. Input Voltage: 90V$_{AC}$, Input Frequency: 64Hz, CH1: V$_{CC}$, CH2: V$_{DRAIN}$, CH3: V$_{LED}$, CH4: I$_{LED}$

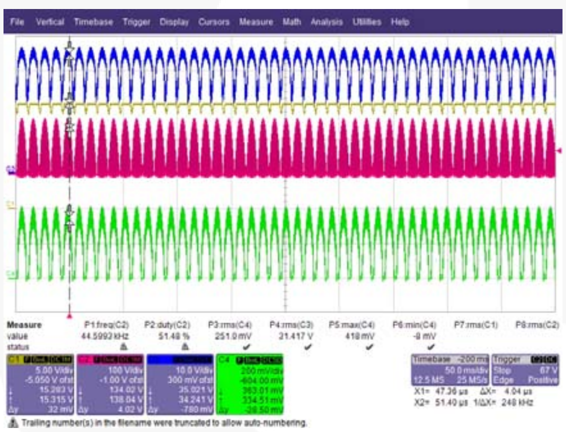


Figure 15. Input Voltage: 110V$_{AC}$, Input Frequency: 47Hz, H1: V$_{CC}$, CH2: V$_{DRAIN}$, CH3: V$_{LED}$, CH4: I$_{LED}$

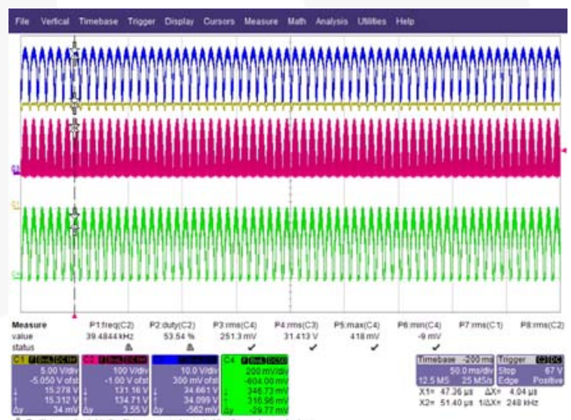


Figure 16. Input Voltage: 110V$_{AC}$, Input Frequency: 64Hz, H1: V$_{CC}$, CH2: V$_{DRAIN}$, CH3: V$_{LED}$, CH4: I$_{LED}$

8.4. Typical Operating Waveforms: Output Characteristics

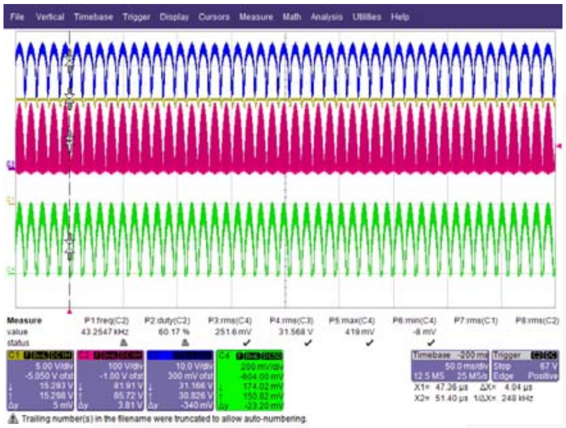


Figure 17. Input Voltage: 130V$_{AC}$, Input Frequency: 47Hz, CH1: V$_{CC}$, CH2: V$_{DRAIN}$, CH3: V$_{LED}$, CH4: I$_{LED}$

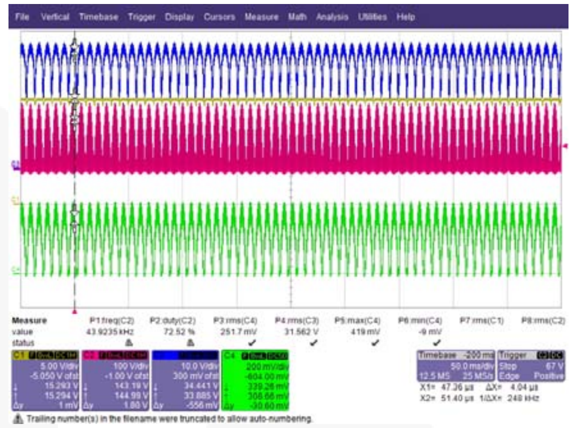


Figure 18. Input Voltage: 130V$_{AC}$, Input Frequency: 64Hz, CH1: V$_{CC}$, CH2: V$_{DRAIN}$, CH3: V$_{LED}$, CH4: I$_{LED}$

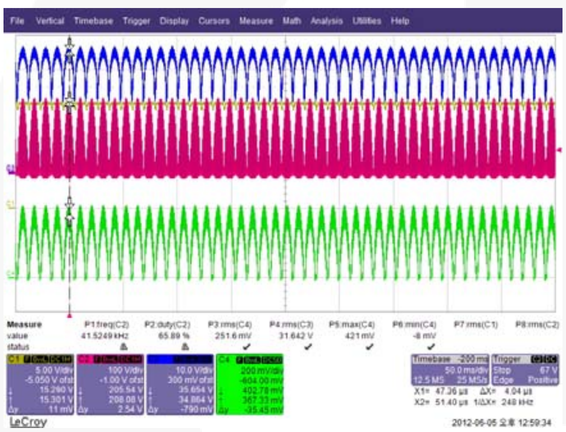


Figure 19. Input Voltage: 150V$_{AC}$, Input Frequency: 47Hz, CH1: V$_{CC}$, CH2: V$_{DRAIN}$, CH3: V$_{LED}$, CH4: I$_{LED}$

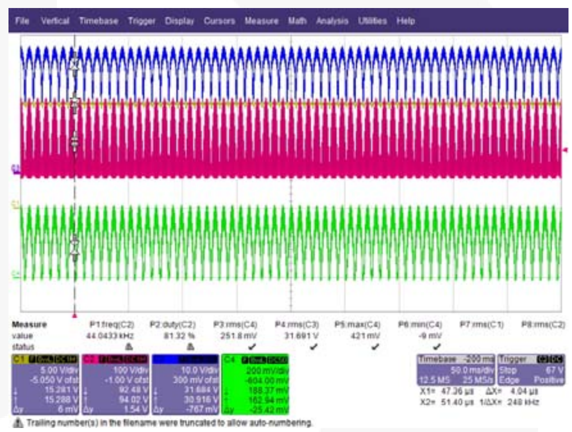


Figure 20. Input Voltage: 150V$_{AC}$, Input Frequency: 64Hz, CH1: V$_{CC}$, CH2: V$_{DRAIN}$, CH3: V$_{LED}$, CH4: I$_{LED}$

Table 4. Output Characteristics by Input Voltage and Frequency

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

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.

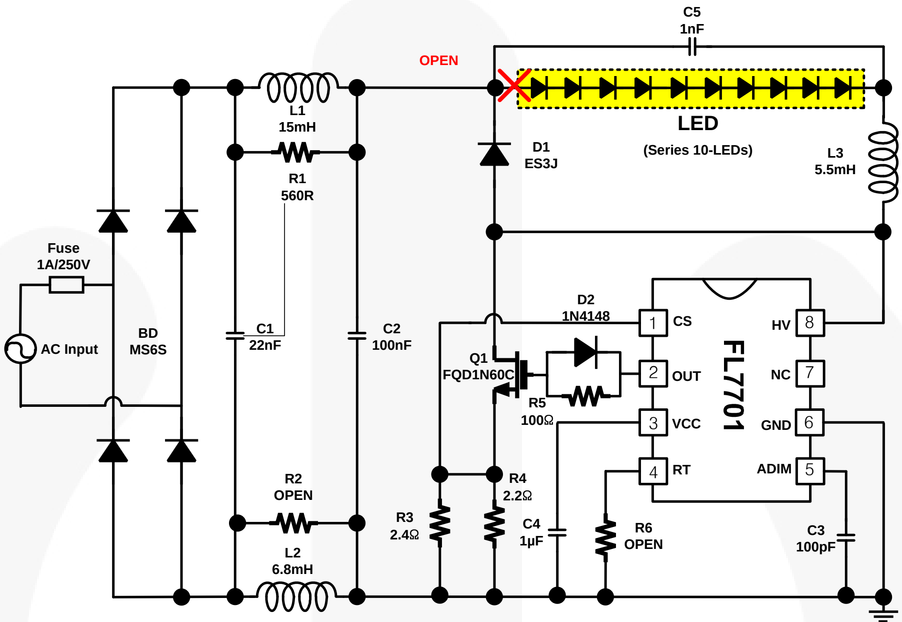
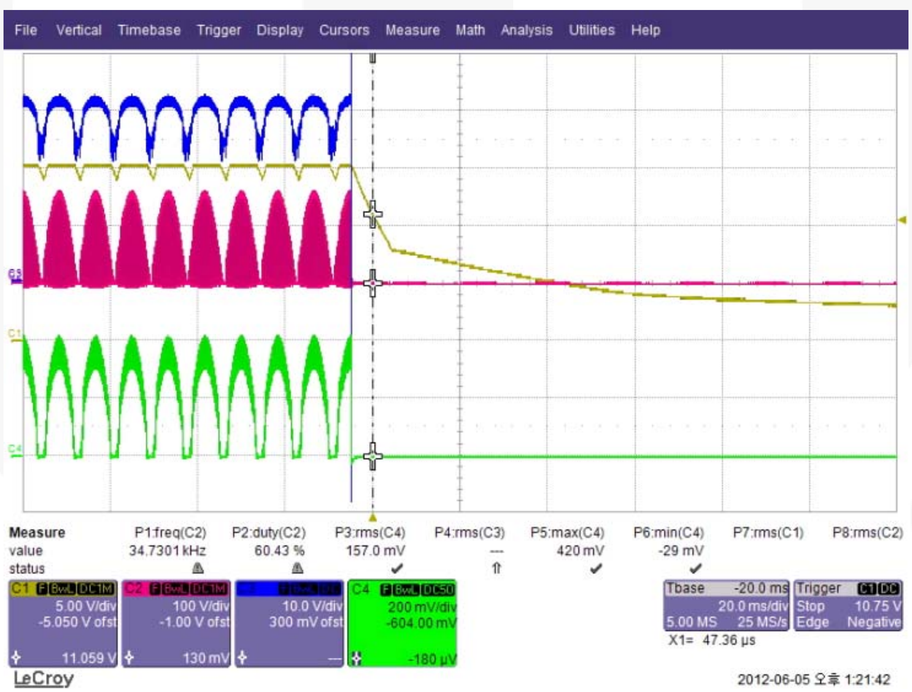


Figure 21. Open-Load Condition Test



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.

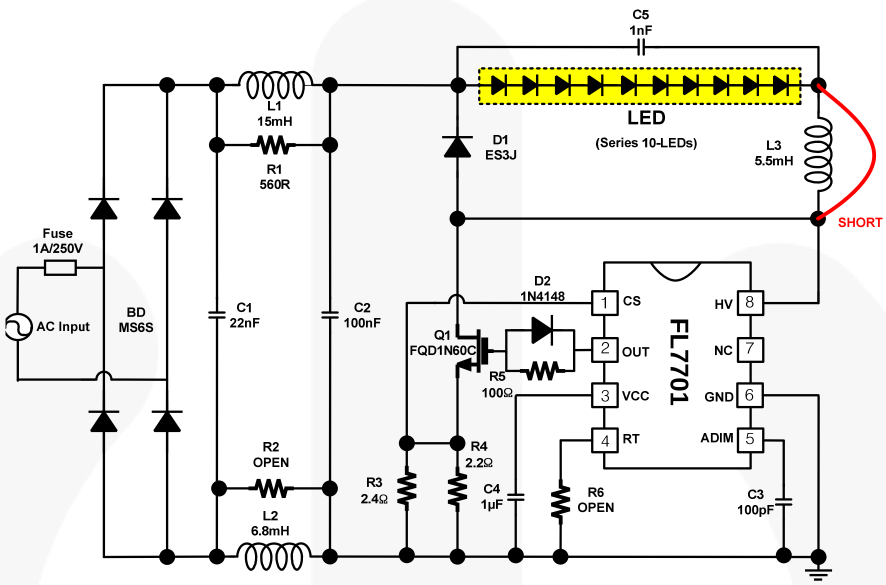
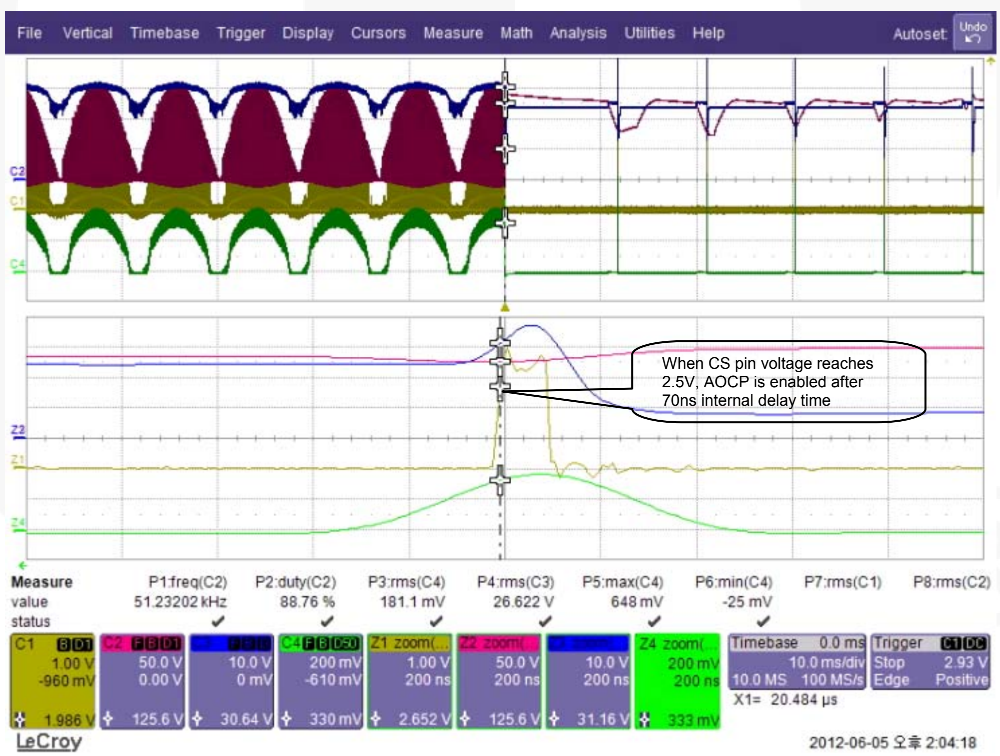


Figure 23. Inductor-Short Condition



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.

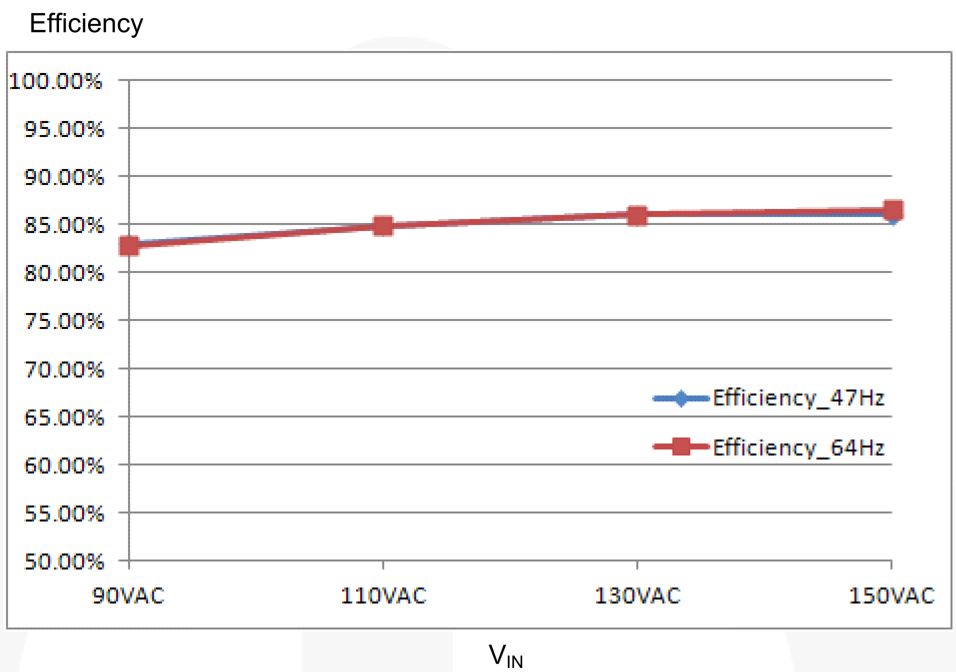


Figure 25. System Efficiency

Table 5. System Efficiency Test Result

Input Voltage		**Efficiency (%)**
$90V_{AC}$	47Hz	82.97
	64Hz	82.81
$110V_{AC}$	47Hz	84..87
	64Hz	84.88
$130V_{AC}$	47Hz	86.04
	64Hz	86.08
$150V_{AC}$	47Hz	86.50
	64Hz	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 ($90V_{AC}$ to $150V_{AC}$) at different input frequency conditions (47Hz, 64Hz). The PF changes slightly according to the input frequency.

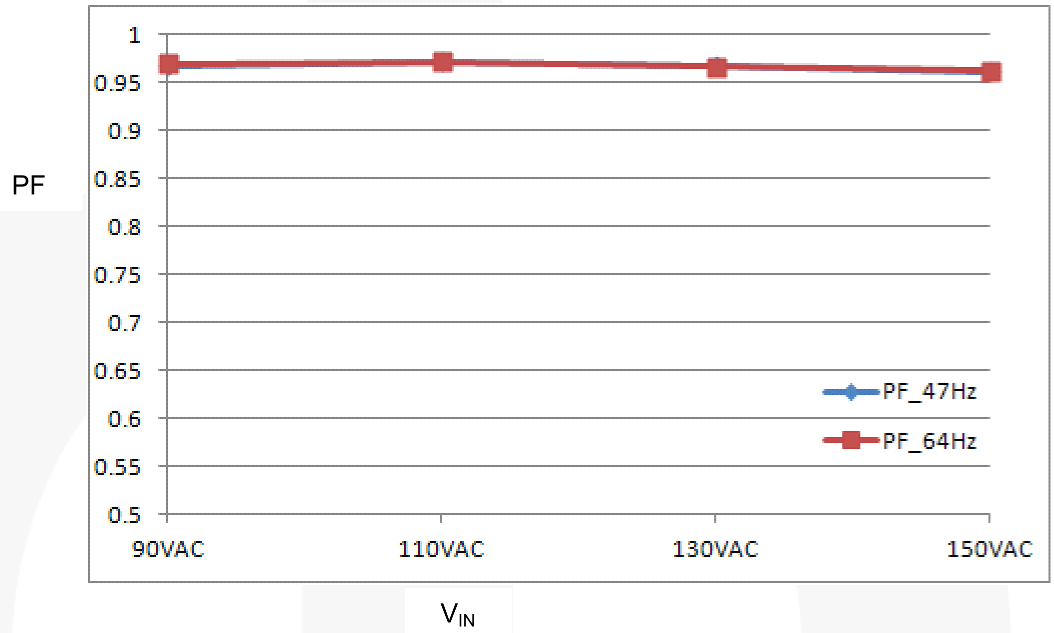


Figure 26. Power Factor

Table 6. Power Factor Test Results

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

8.9. Total Harmonic Distortion Performance

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

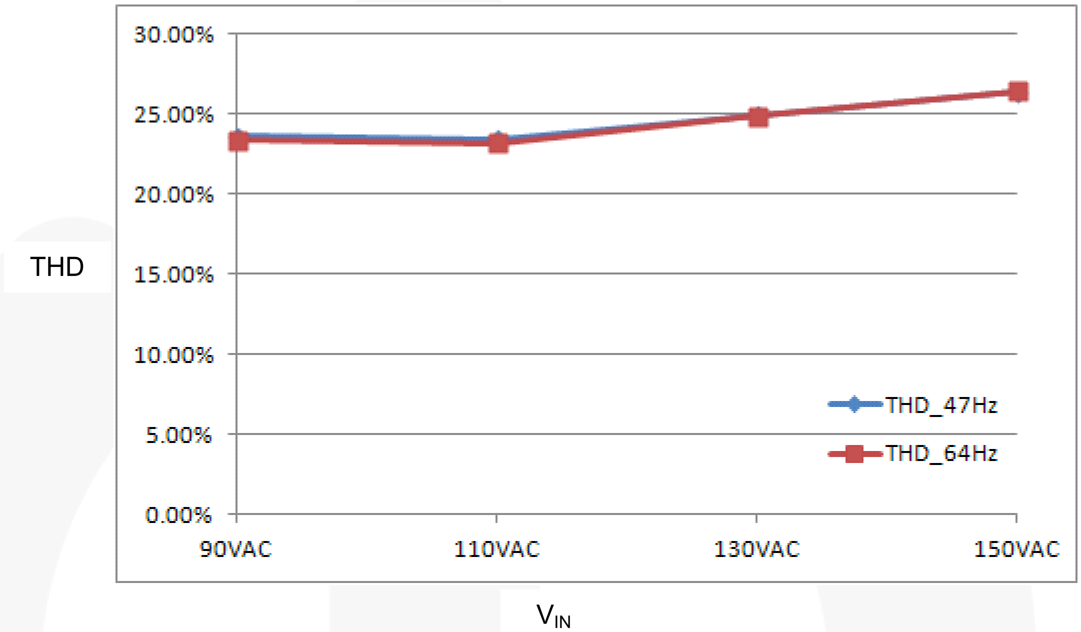


Figure 27. Total Harmonic Distortion Performance

Table 7. Total Harmonic Distortion Test Results

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

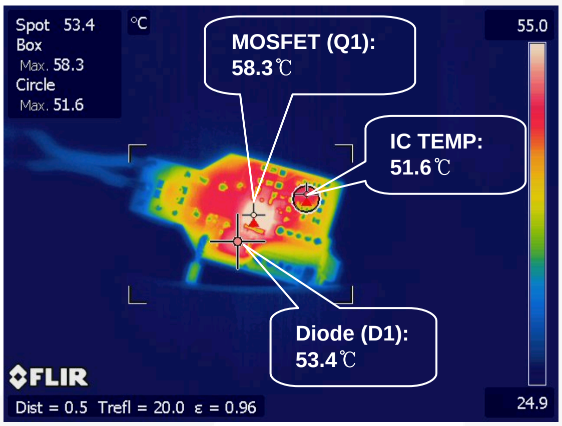


Figure 28. Bottom-Side Temperature at 90V_{AC} Condition (IC)

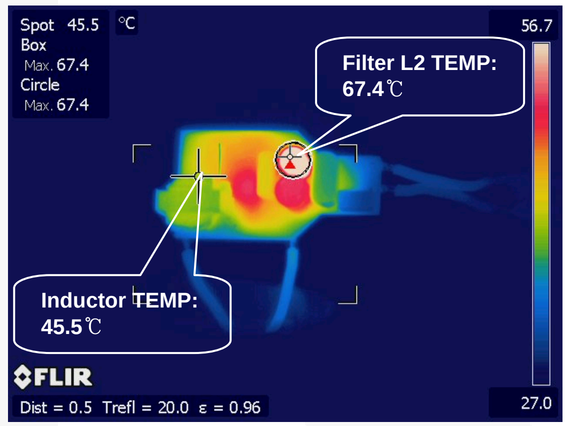


Figure 29. Top-Side Temperature at 90V_{AC} Condition (Inductor)

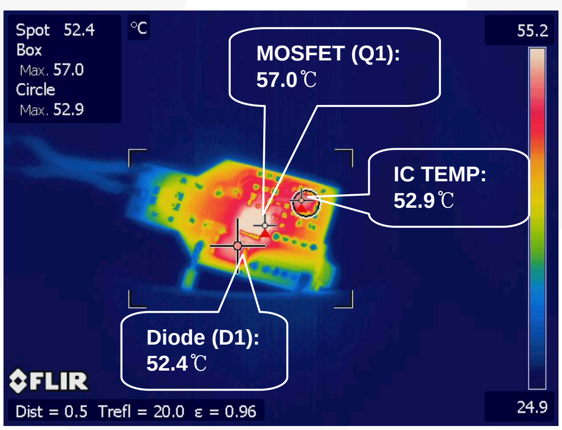


Figure 30. Bottom-Side Temperature at 110V_{AC} Condition (IC)

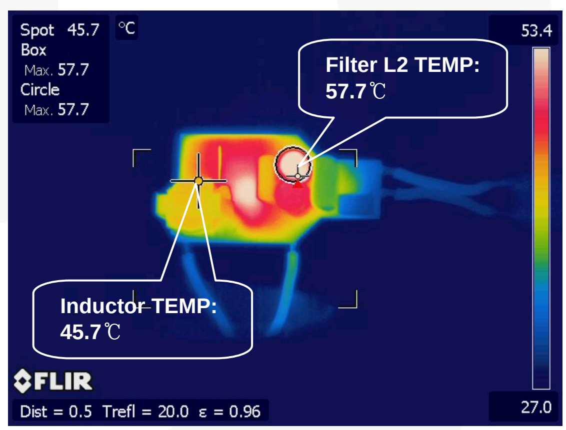


Figure 31. Top-Side Temperature at 110V_{AC} Condition (Inductor)

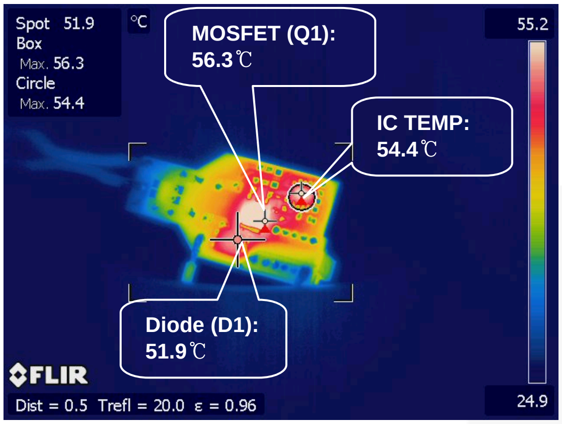


Figure 32. Bottom-Side Temperature at 130V_{AC} Condition (IC)

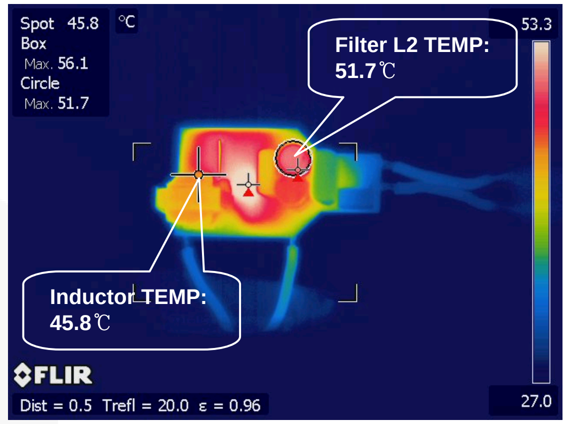


Figure 33. Top-Side Temperature at 130V_{AC} Condition (Inductor)

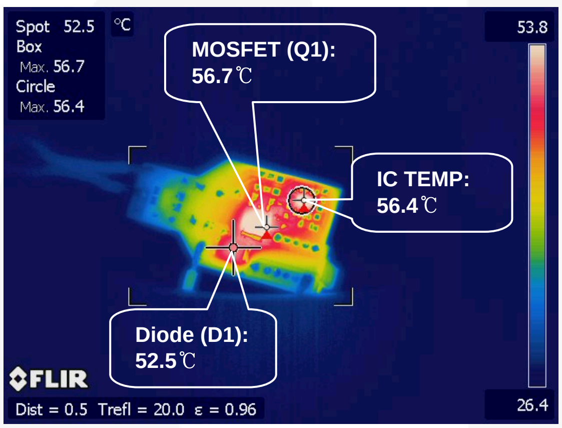


Figure 34. Bottom-Side Temperature at 150V_{AC} Condition (IC)

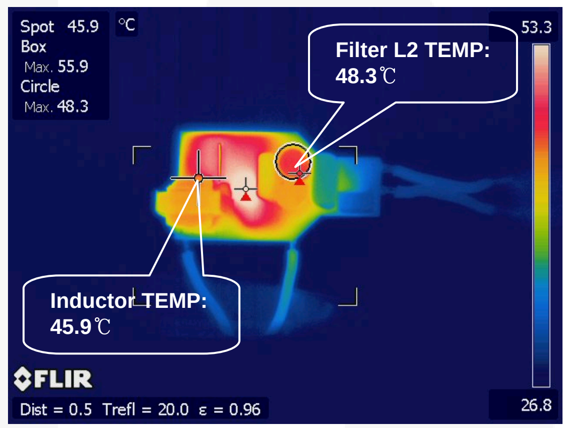


Figure 35. Top-Side Temperature at 150V_{AC} Condition (Inductor)

Table 8. Temperature Performance by Input Voltage

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

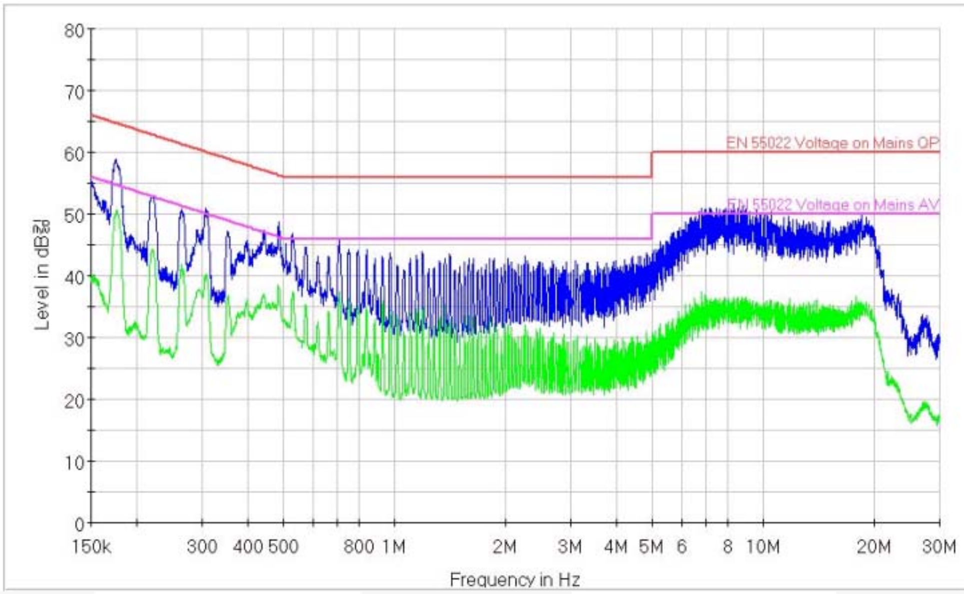


Figure 36. Conducted Emission - Line at 110V$_{AC}$ Input Condition, Full Load (10-LED Series)

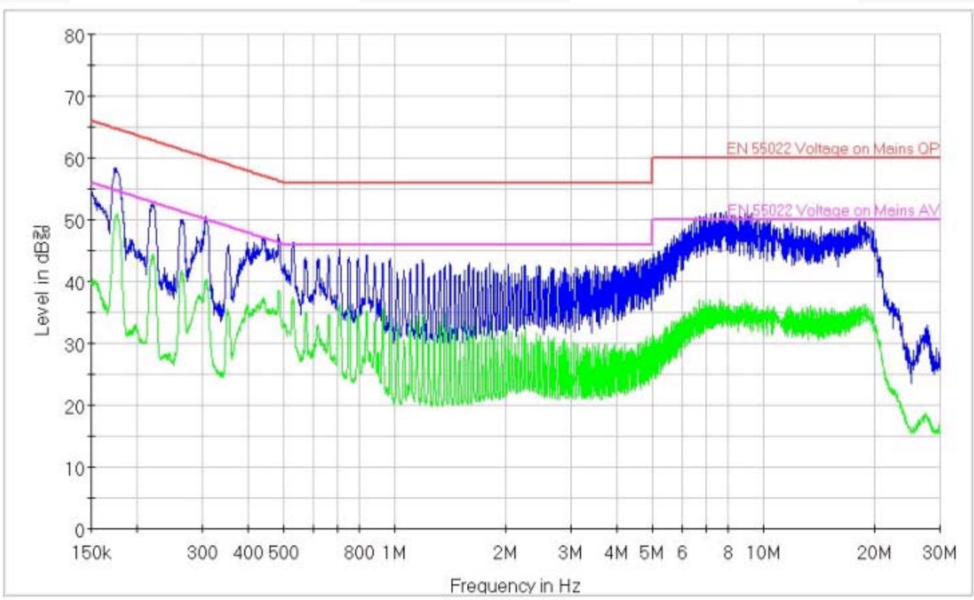


Figure 37. Conducted Emission - Neutral at 110V$_{AC}$ Input Condition, Full Load (10-LED Series)

9. Revision History

Rev.	Date	Description
1.0.0	July 2012	First Release