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User Guide for

FEBFL7701_L31H008A

7.8 W LED Ballast Using FL7701

Featured Fairchild Product:

FL7701

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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 an universal input, 2.4W LED ballast using the FL7701. The input voltage range is 187 V_{RMS} – 264 V_{RMS} and there is one DC output with a constant current of 250 mA at 31 V_{MAX}. 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
- Application Input Range: 80 V_{AC} ~ 308 V_{AC}
- AOCP Function with Auto-Restart Mode
- Built-in Over-Temperature Protection (OTP)
- Cycle-by-Cycle Current Limit
- Current-Sense Pin-Open Protection
- 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%

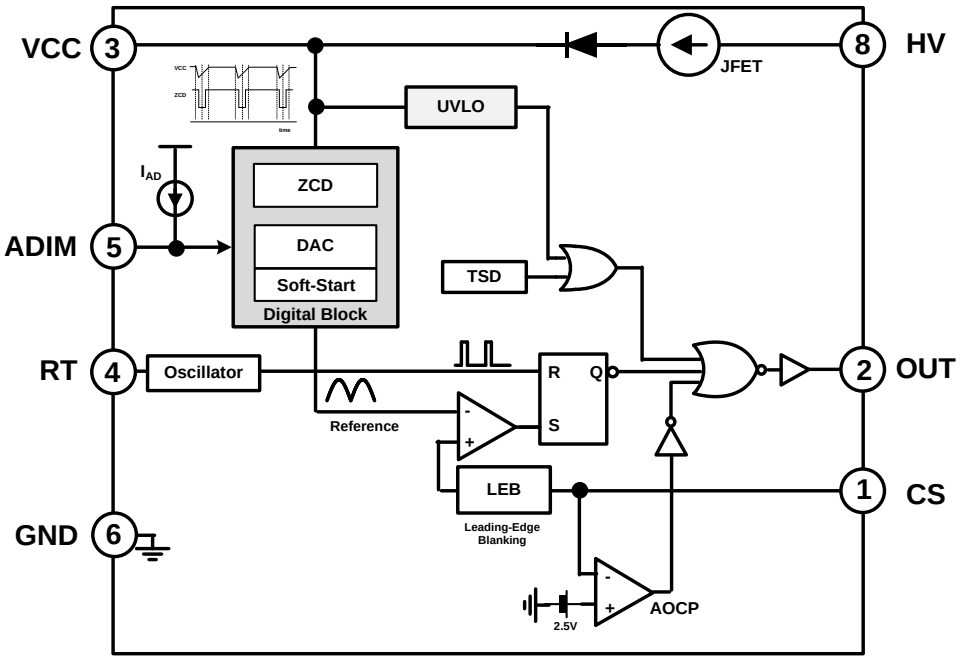


Figure 1. Block Diagram

Table 1. Pin Definitions

Pin No.	Symbol	Description
1	CS	**Current Sense**. Limits output current, depending on the sensing resistor voltage. The CS pin is also used to set the LED current regulation.
2	OUT	**OUT.** Connects to the MOSFET gate.
3	VCC	**VCC**. Supply pin for stable IC operation, ZCD signal detection, and used for accurate PFC function.
4	RT	**RT**. Programmable operating frequency using an external resistor. The IC has a fixed frequency when this pin is open or floating.
5	ADIM	**Analog Dimming**. Connects to the internal current source and can change the output current using an external resistor. If ADIM is not used, connect a 0.1 µF bypass capacitor between ADIM and GND.
6	GND	**GROUND**. Ground for the IC.
7	NC	No Connection.
8	HV	**High Voltage**. Connects to the high-voltage line and supplies 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 2. Summary of Features and Performance

Description	Symbol	Value	Comments
Input Voltage Range	$V_{IN,min}$	187 V	
	$V_{IN,nom}$	220 V	
	$V_{IN,max}$	264 V	
Input Frequency	$f_{IN,min}$	47 Hz	
	$f_{IN,max}$	64 Hz	
Output Voltage/Current(1)	V_{OUT}	31 V	
	I_{OUT}	250 mA	
Output Power(2)	Output Power	7.8 W	
Efficiency		>78%	At Full Load
Temperature	T_{FL7701}	< 72°C	At Full Load (all at open-frame, room temperature / still air)
	T_{MOSFET}	< 60°C	
	T_{DIODE}	< 66°C	
	$T_{INDUCTOR}$	< 58°C	
	$T_{HV\ RESISTOR}$	< 67°C	
PCB Size			20 mm (width) x32 mm (length) x13 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

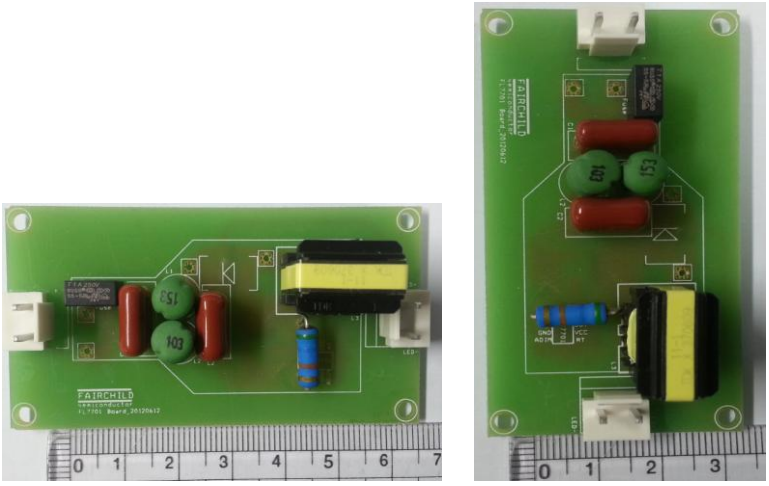


Figure 2. Top-View (PCB) (28 mmx52 mmx18 mm)

Figure 3. Top View (28 mm x 52 mm x 18 mm) (Mounted Housing)

Figure 4. Side View (28 mm x 52 mm x 18 mm)

** When mounted on the housing, evaluation board should be cut along the silk outline.

4. Printed Circuit Board

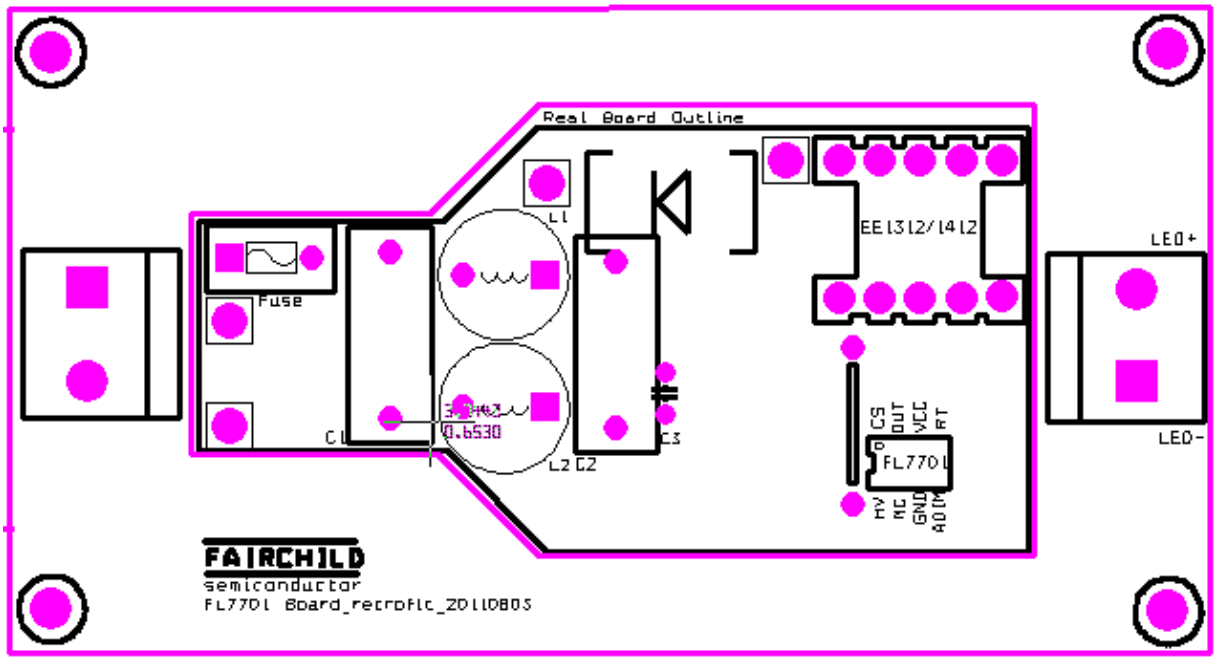


Figure 5. Top Side

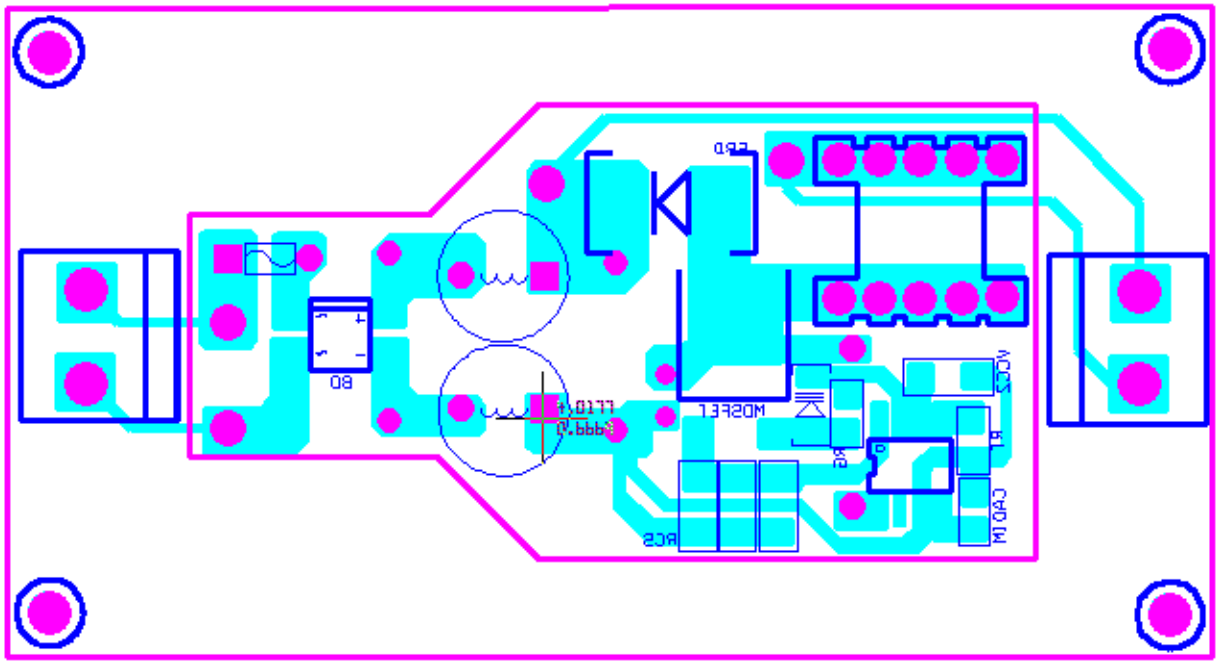


Figure 6. Bottom Side

5. Schematic

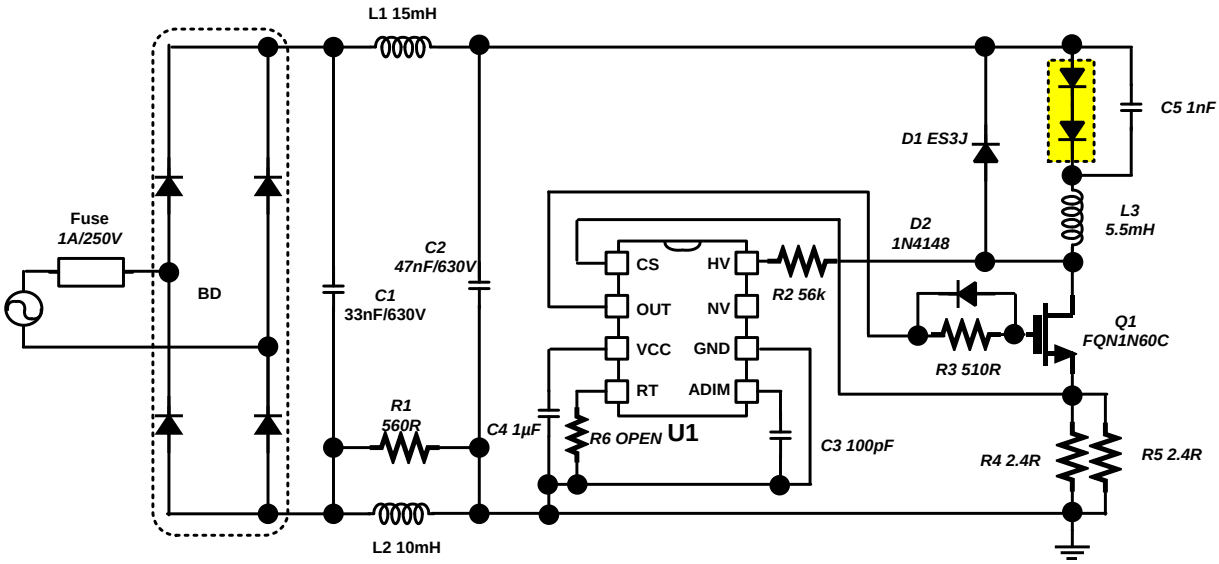


Figure 7. Schematic of Evaluation Board

6. Bill of Materials

Item No.	Part Reference	Part Number	Qty.	Description	Manufacturer
1	Fuse	SS-5-1A	1	1 A / 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 630V333K	1	33 nF / 630 V_{AC}, Film Capacitor	Sungho
5	C2	MPE 630V473K	1	47 nF / 630 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	R06153KT00	1	15 mH, Filter Inductor	Bosung
13	L2	R06103KT00	1	10 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	RSMF1JB56K0	0	56k Ω / 1 W Metal Resistor	Stackpole Elec.
17	R3	RC0805JR-07511RL	1	510 Ω, SMD Resistor 2012	Yageo
18	R4, R5	RC1206JR-072R4RL	1	2.4 Ω, SMD Resistor 3216	Yageo
19	R6		0	Open	

7. Inductor Design

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

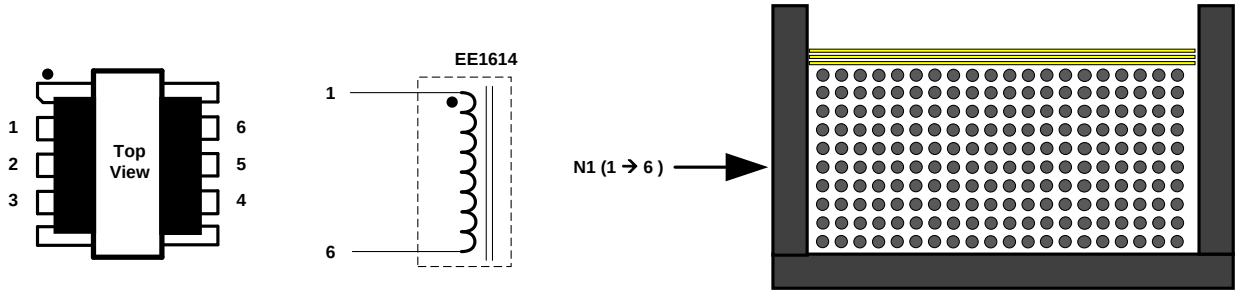


Figure 8. Transformer Structure

Table 3. 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 = 0.025 mm 3-Layer				

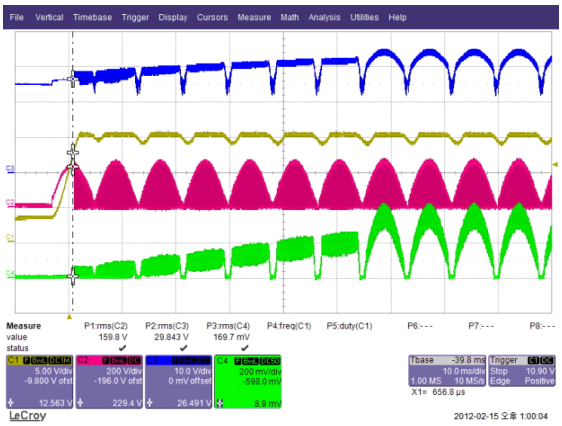
8. Performance of Evaluation Board

Table 4. 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 (3W) by Everlight

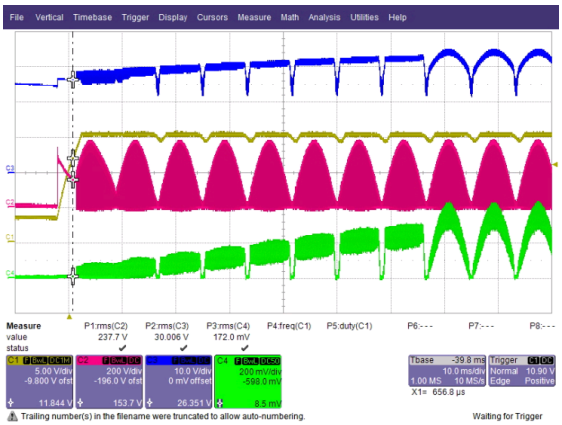
8.1. Typical Waveforms: Startup

Figure 9 through Figure 12 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 11 and Figure 12 show the soft-start characteristics when a DC input voltage is applied.



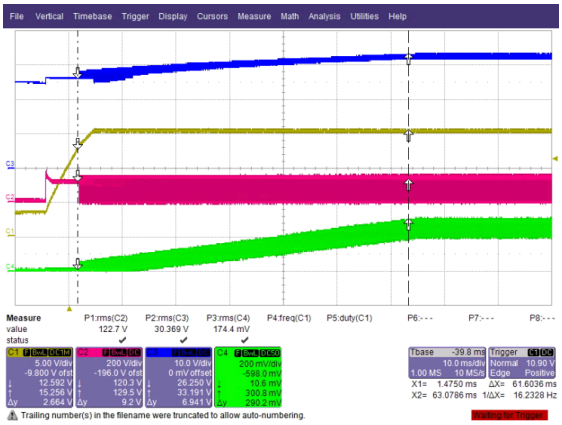
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 9. Soft-Start, AC Mode, 187 V_{AC}



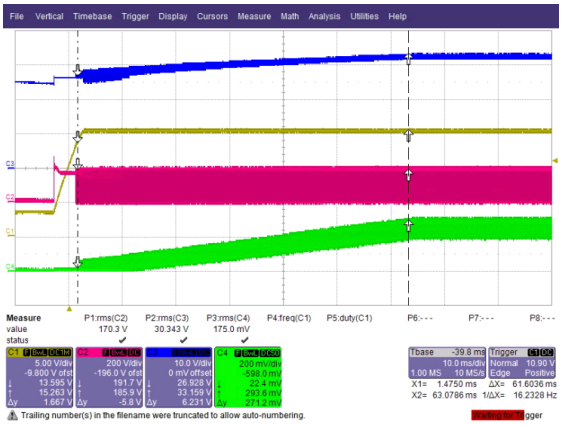
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 10. Soft-Start, AC Mode, 264 V_{AC}



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

Figure 11. Soft-Start, DC Mode, 150 V_{DC}



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

Figure 12. Soft-Start, DC Mode, 200 V_{DC}

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.

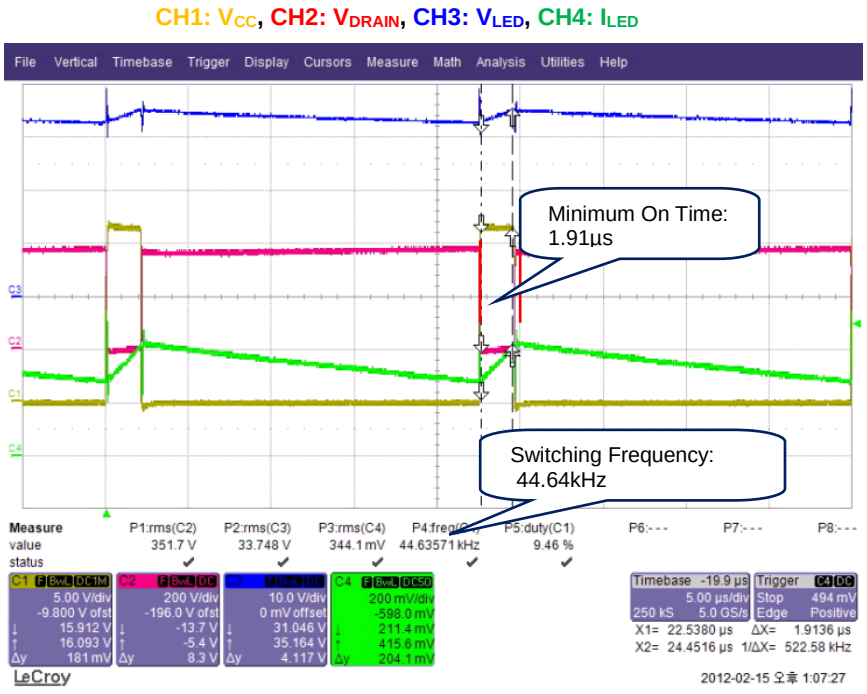
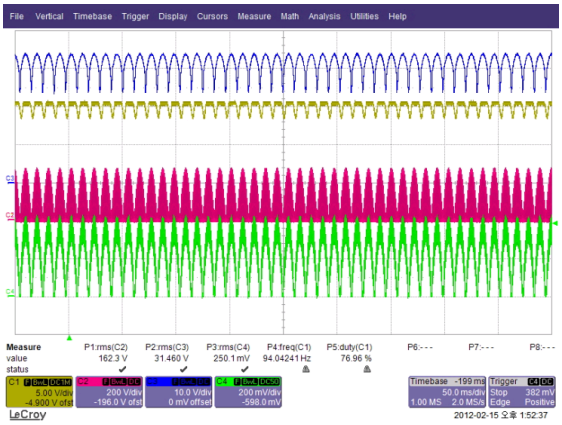


Figure 13. Operating Frequency & Minimum Duty

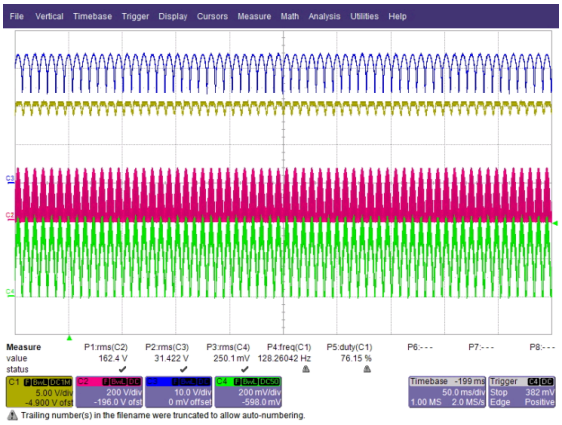
8.3. Typical Waveforms: Steady State

Figure 14 through 19 show normal operation waveforms 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 the Table 5.



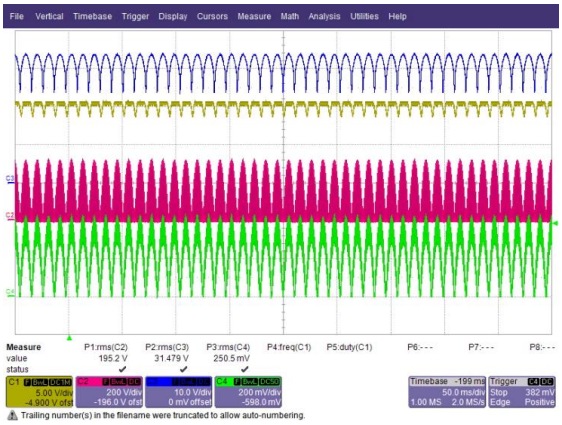
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 14. Input Voltage: 187 V_{AC}, Input Frequency: 47 Hz



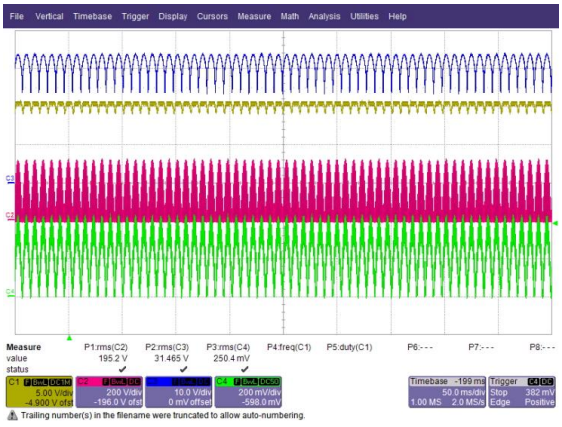
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 15. Input Voltage: 187 V_{AC}, Input Frequency: 64 Hz



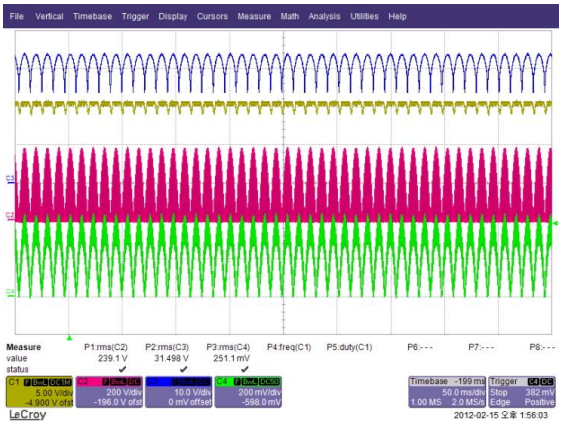
H1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 16. Input Voltage: 220 V_{AC}, Input Frequency: 47 Hz



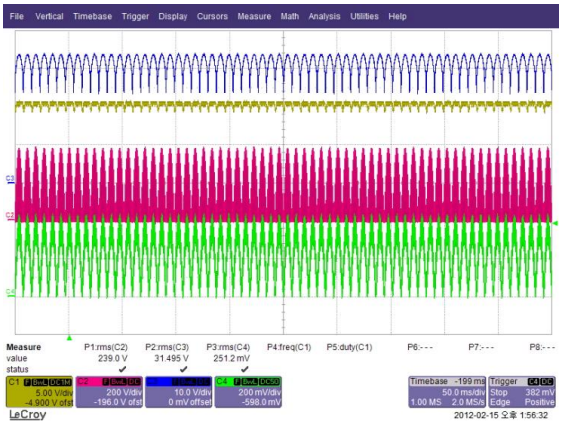
H1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 17. Input Voltage: 220 V_{AC}, Input Frequency: 64 Hz



H1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 18. Input Voltage: 264 V_{AC}, Input Frequency: 47 Hz



H1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 19. Input Voltage: 264 V_{AC}, Input Frequency: 64 Hz

Table 5. Output Characteristics by Input Voltage & Frequency

	47 Hz		64 Hz	
	$V_{LED(RMS)}$	$I_{LED(RMS)}$	$V_{LED(RMS)}$	$I_{LED(RMS)}$
187 V_{AC}	31.46 V	250.1 mA	31.42 V	250.1 mA
220 V_{AC}	31.48V	250.5 mA	31.47 V	250.4 mA
264 V_{AC}	31.49 V	251.1 mA	31.49 V	251.2 mA

8.4. Typical Waveforms: Abnormal Mode (LED Open)

Figure 20 and Figure 21 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.

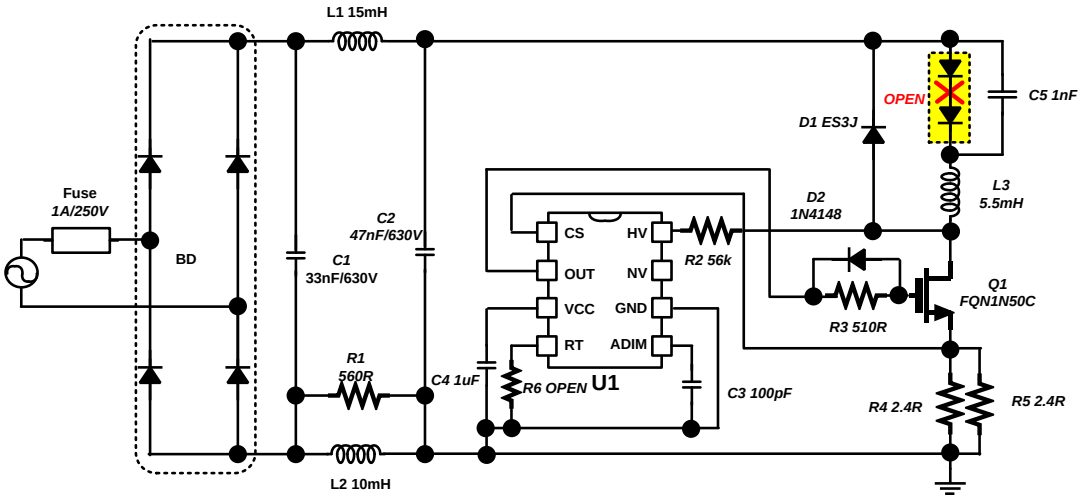
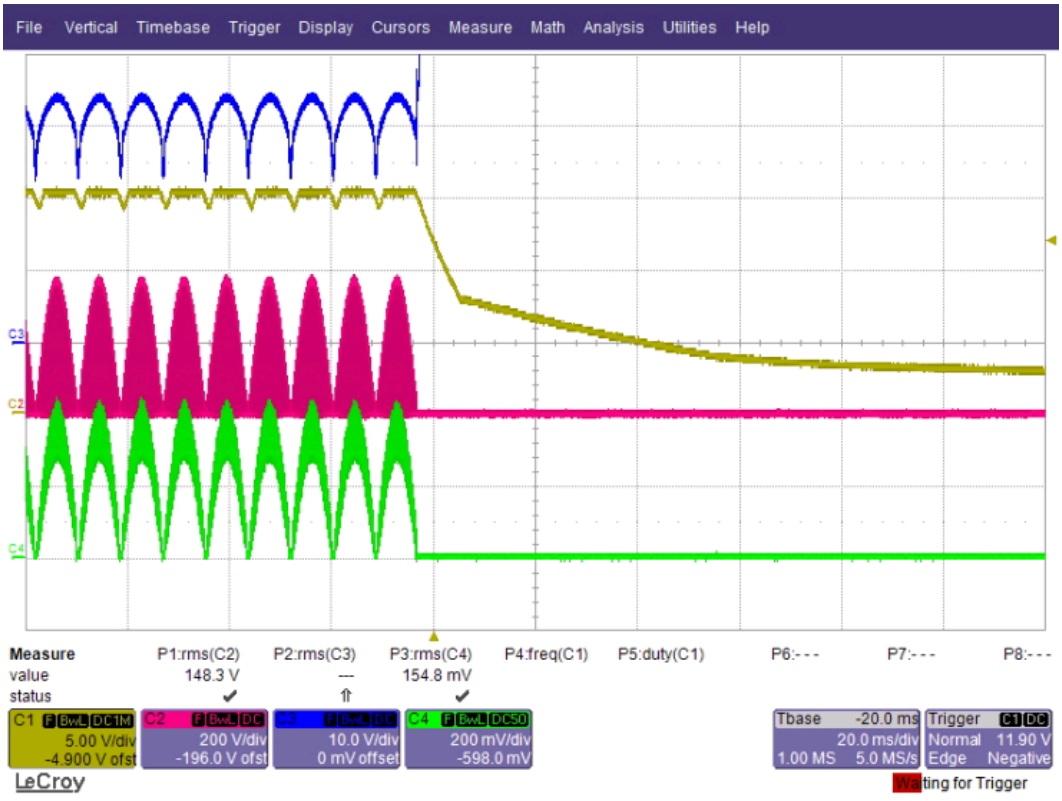


Figure 20. Open-Load Condition Test



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

Figure 21. Test Results of Open-Load Condition

8.5. Typical Waveforms: Abnormal Mode (Inductor Short)

The Figure 22 and Figure 23 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.

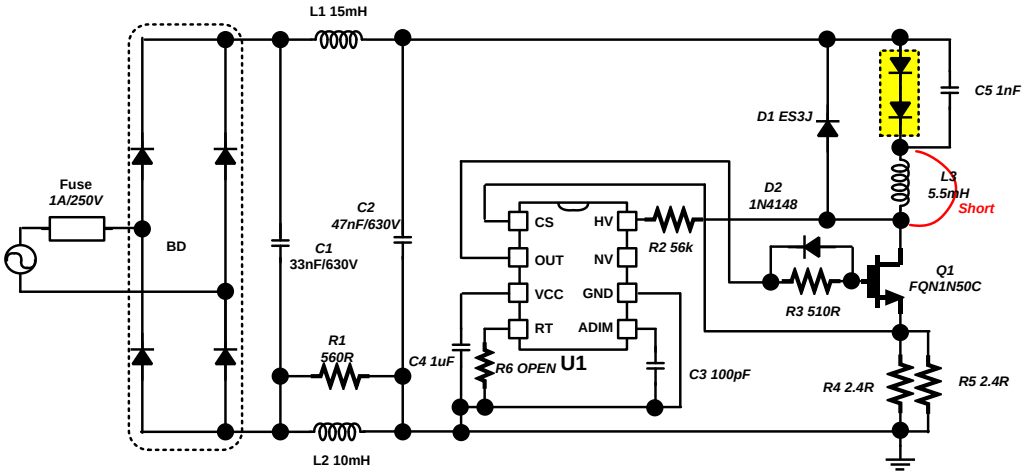
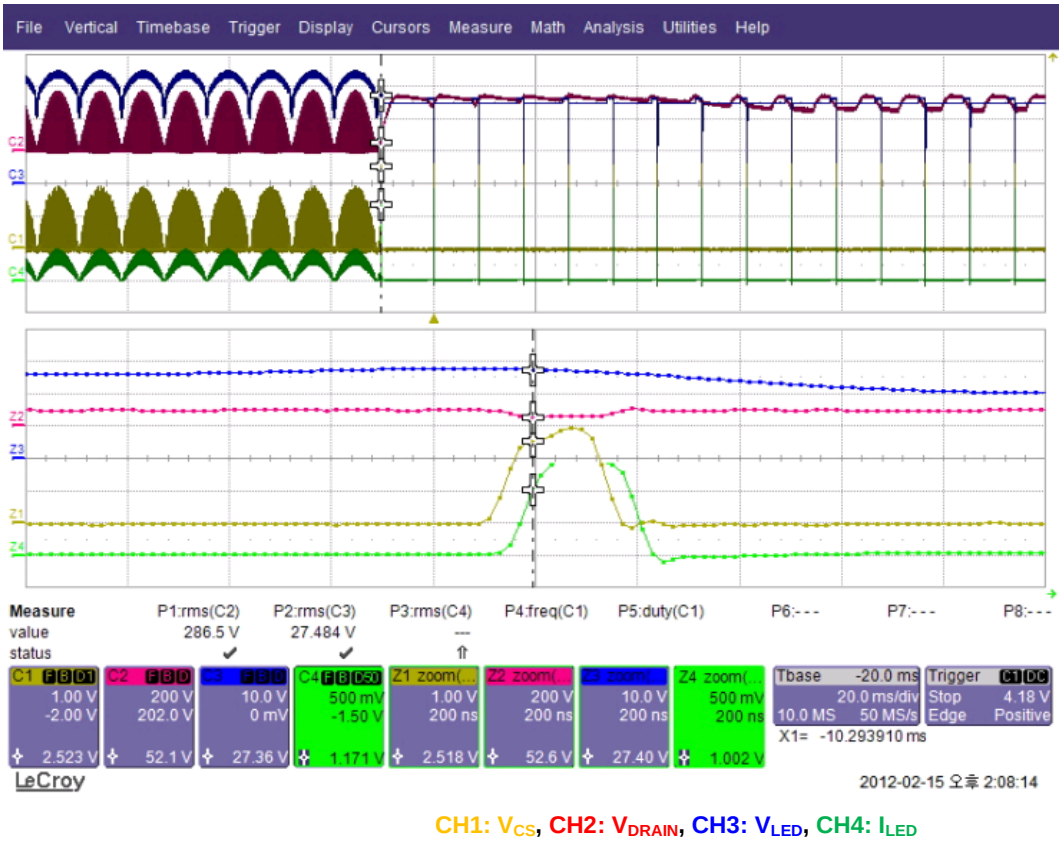


Figure 22. Inductor-Short Condition



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

Figure 23. Test Results of Inductor-Short Condition

8.6. System Efficiency

The Figure 24 shows system efficiency results for different AC input voltage frequency conditions. As shown, the input frequency has negligible effect on system efficiency.

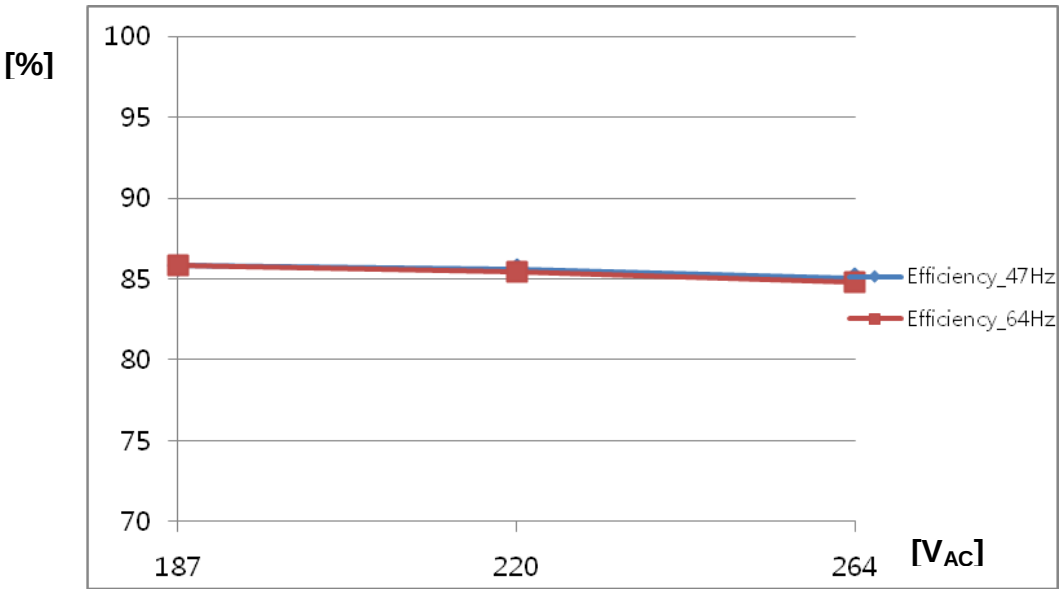


Figure 24. System Efficiency

Table 6. Test Results

Input Voltage		Efficiency
187 V_{AC}	47 Hz	85.80
	64 Hz	85.85
220 V_{AC}	47 Hz	85.60
	64 Hz	85.44
264 V_{AC}	47 Hz	85.00
	64 Hz	84.80

8.7. Power Factor at Rated Load Condition

The Figure 25 shows the system Power Factor (PF) performance for the entire input voltage range (187 V to 264 V) at different input frequency conditions (47 Hz, 64 Hz). The PF changes slightly according to the input frequency, but can achieve over 86% at 264 V_{AC} condition.

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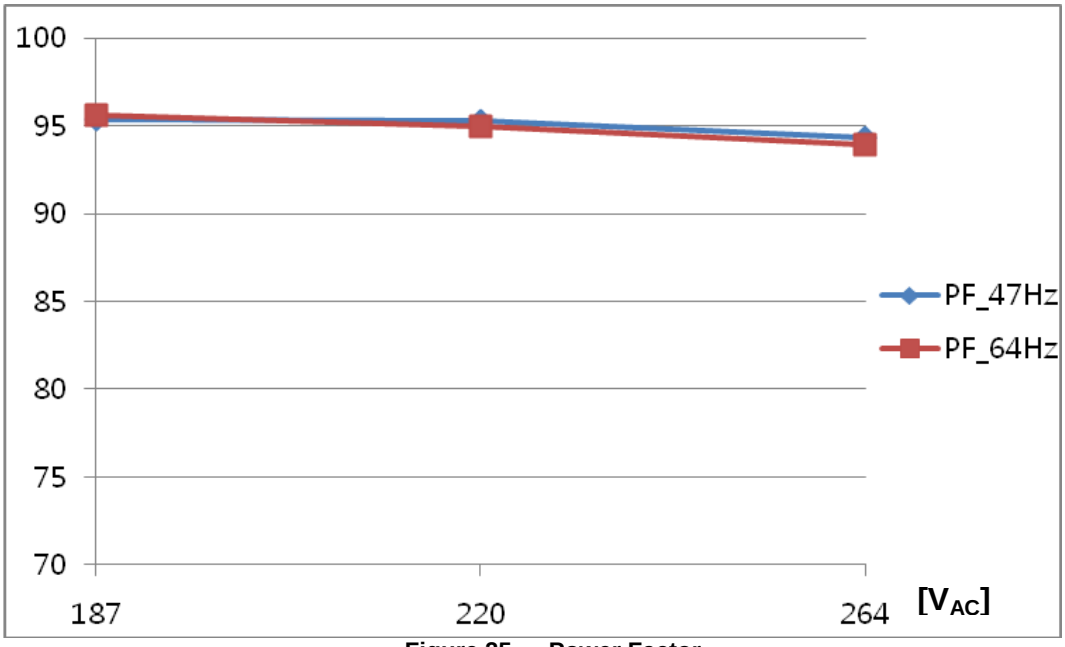

Figure 25. Power Factor

Table 7. Test Results

Input Voltage		Power Factor
187 V_{AC}	47 Hz	95.37
	64 Hz	95.59
220 V_{AC}	47 Hz	95.28
	64 Hz	94.98
264 V_{AC}	47 Hz	94.31
	64 Hz	93.91

8.8. Total Harmonic Discharge (THD) Performance

The Figure 26 shows the Total Harmonic Discharge (THD) performance at different input frequencies. Test results are quite similar, but meet international regulations (under 30%).

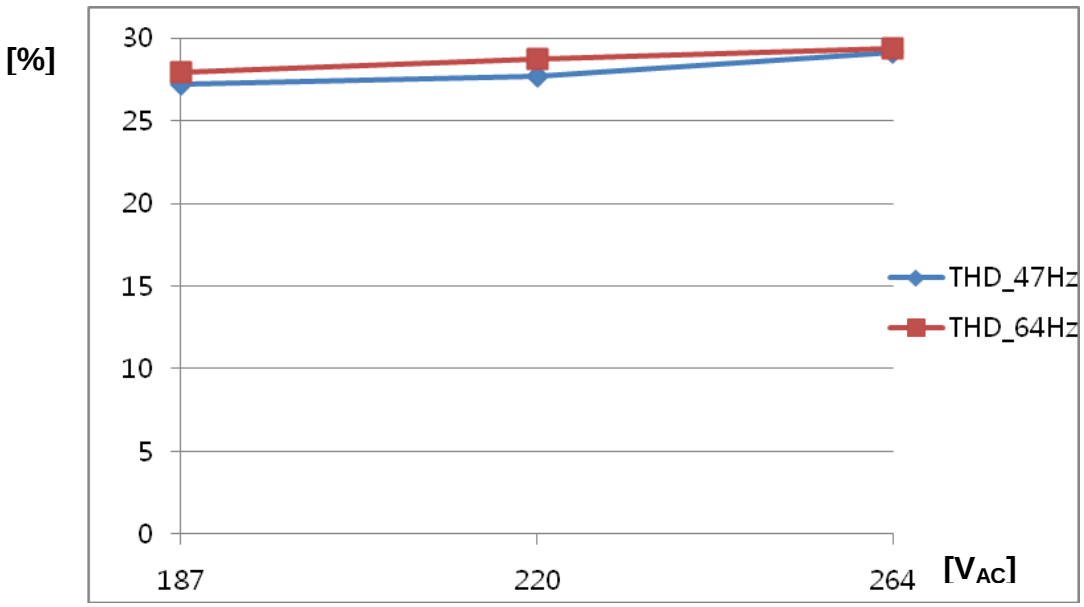

Figure 26. Total Harmonic Discharge Performance

Table 8. Test Results

Input Voltage		THD
187 V_{AC}	47 Hz	27.18
	64 Hz	27.94
220 V_{AC}	47 Hz	27.72
	64 Hz	28.72
264 V_{AC}	47 Hz	29.10
	64 Hz	29.40

8.9. Thermal Performance

Figure 27 through Figure 32 show the steady-state thermal test results with different input voltage conditions. Inductor L3 has the highest temperature on the top side of the PCB due to copper resistance. The FL7701 has the highest temperature on the bottom side of the PCB due to power loss associated with the high-voltage device. The IC temperature is 66.5°C for the 220 V_{AC} input condition.

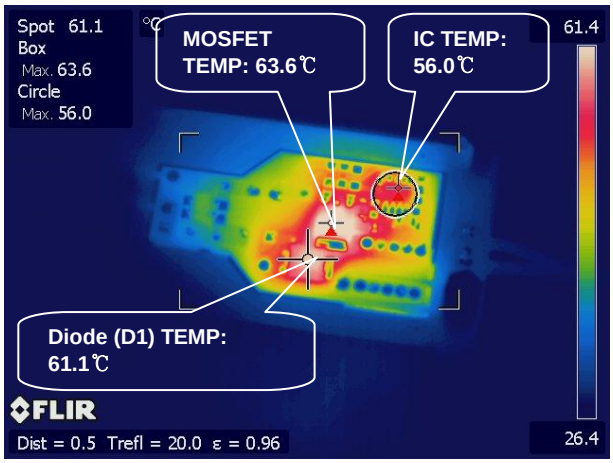

Figure 27. Bottom-Side Temperature at 187 V_{AC} Condition (IC)

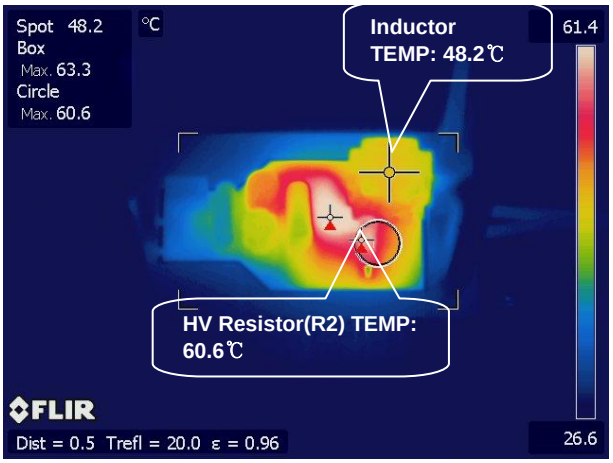

Figure 28. Top-Side Temperature at 187 V_{AC} Condition (Inductor)

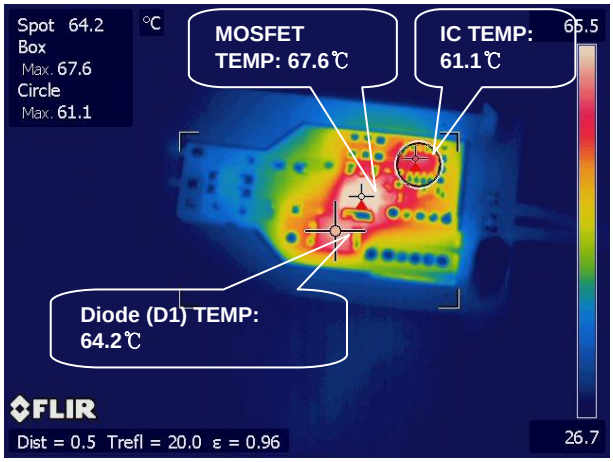

Figure 29. Bottom-Side Temperature at 220 V_{AC} Condition (IC)

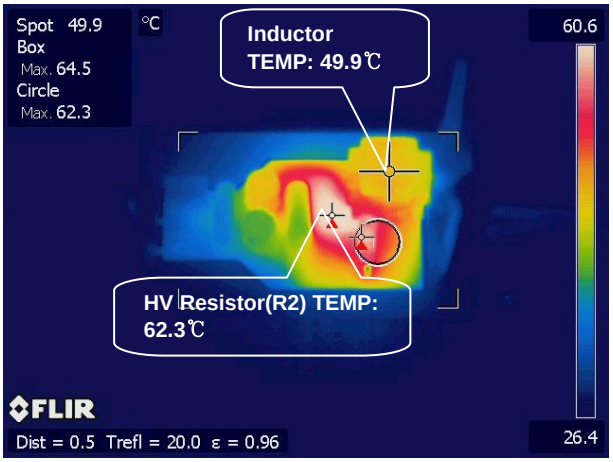

Figure 30. Top-Side Temperature at 220 V_{AC} Condition (Inductor)

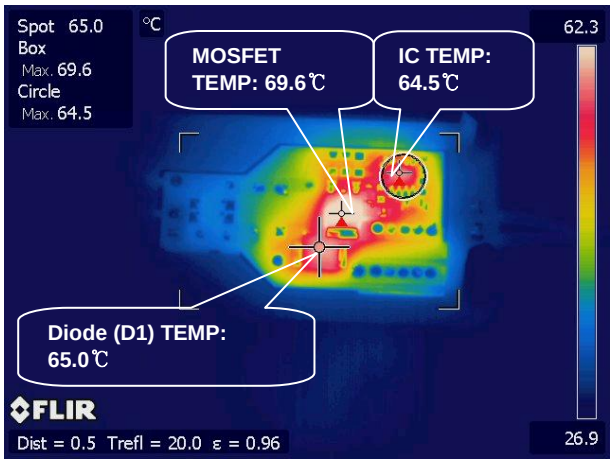

Figure 31. Bottom-Side Temperature at 264 V_{AC} Condition (IC)

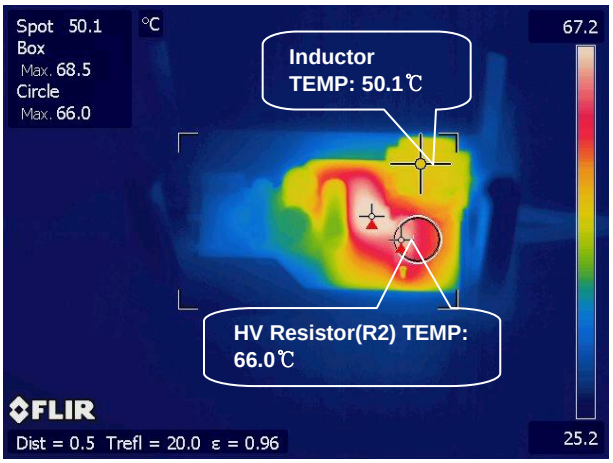

Figure 32. Top-Side Temperature at 264 V_{AC} Condition (Inductor)

Table 9. Temperature Performance by Input Voltage

	IC	MOSFET	Diode	Inductor	HV Resistor
187 V_{AC}	56.0°C	63.6°C	61.1°C	48.2°C	60.6°C
220 V_{AC}	66.5°C	55.0°C	64.2°C	54.6°C	62.3°C
264 V_{AC}	71.5°C	59.5°C	65.0°C	57.7°C	66.0°C

8.10. EMI Test Results

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

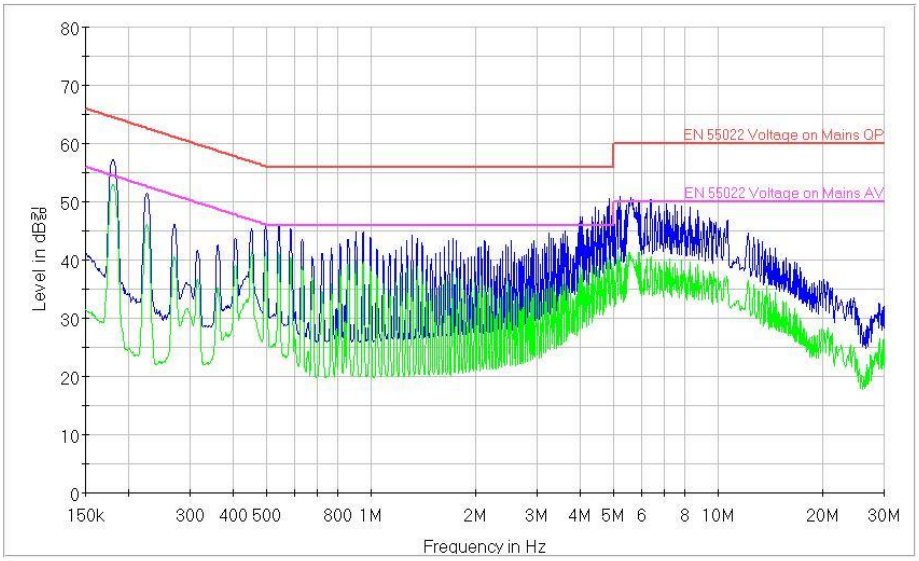

Figure 33. Conducted Emission-Line at 220 V_{AC} Input Condition, Full Load (10-LED Series)

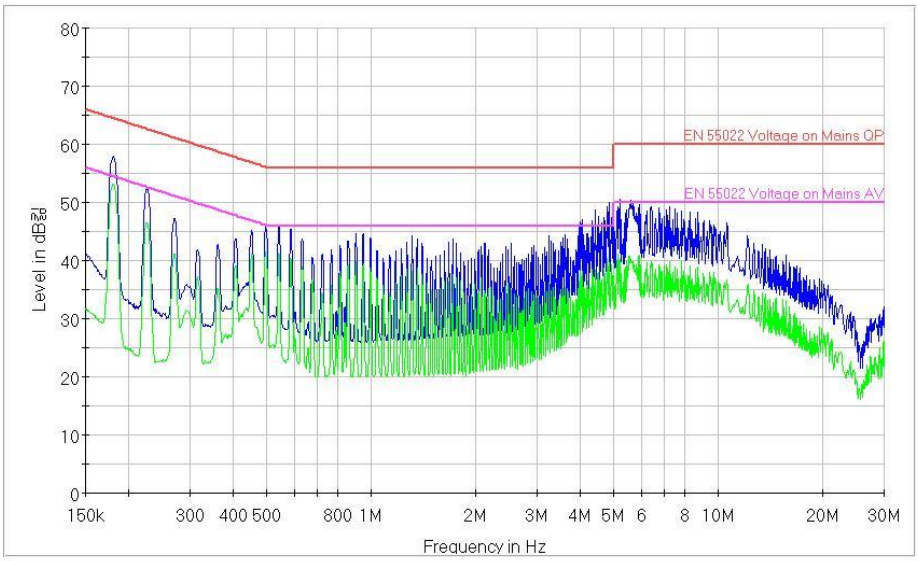

Figure 34. Conducted Emission-Neutral at 220 V_{AC} Input Condition, Full Load (10-LED Series)

9. Revision History

Rev.	Date	Description
0.0.1	Jan. 2012.	First issue
1.0.1	Feb. 2012.	Modified, edited, formatted document
1.0.2	Sep. 2012.	Modified, edited, formatted document, Changed User Guide number from FEB-L031-2 to FEBFL7701_H31L008A
1.3	Jan. 2015	Figure 2 changed

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