User Guide for

FEB-L034

Evaluation Board

Universal Line Voltage LED Ballast

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 datasheets 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 18.3W LED ballast using the FL7701. The input voltage range is $90V_{RMS}$ – $264V_{RMS}$ and there is one DC output with a constant current of 470mA at $39V_{MAX}$. 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 a Power Factor Correction (PFC) function. The special "adopted digital" technique of the IC can automatically detect input voltage condition Zero-Crossing Detector (ZCD) and send a internal reference signal for high power factor. When AC input is applied to the IC, PFC function is automatically enabled. When DC input is applied to the IC, PFC function is automatically disabled. The FL7701 does not need a bulk capacitor (electrolytic capacitor) for supply rails stability, which can significantly affect to LED lamp system.

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

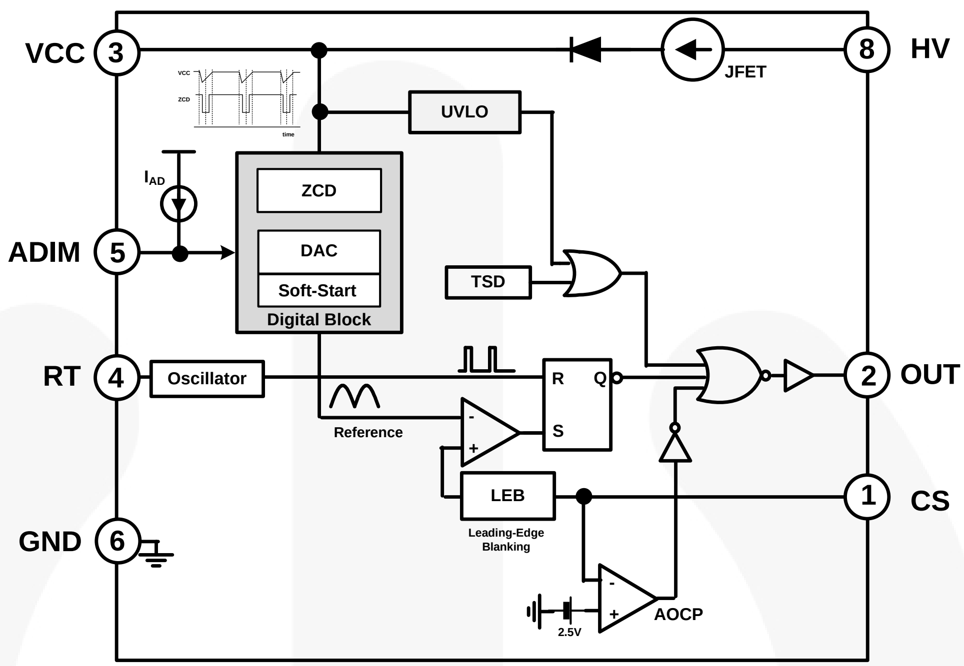

Figure 1. Block Diagram

Table 1. Pin Definitions

Pin	Name	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	**Output**. Connects to the MOSFET gate.
3	VCC	**Supply Voltage**. Supply pin for stable IC operation; ZCD signal detection used for accurate PFC function.
4	RT	**Resistor**. Programmable operating frequency using an external resistor connected to this PIN and the IC has fixed frequency when this pin is left 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 0.1µF bypass capacitor between ADIM and GND.
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 2. Summary of Features and Performance

Description	Symbol	Value	Comments
Input Voltage Range	$V_{IN.MIN}$	90V	Minimum Input Voltage
	$V_{IN.NORMAL}$	110V / 220V	Normal Input Voltage
	$V_{IN.MAX}$	264V	Maximum Input voltage
AC Input Frequency	$f_{IN.MIN}$	47Hz	Minimum Input Frequency
	$f_{IN.MAX}$	64Hz	Maximum Input Frequency
Output Voltage	$V_{OUT,MAX}$	41V	Maximum Output Voltage
	$V_{OUT,NORMAL}$	39V	Normal Output Voltage
	$V_{OUT,MIN}$	37V	Minimum Output Voltage
Output Current(1)	$I_{OUT.NORMAL}$	470mA	Normal Output Current
	CC deviation	< ±4.5%	Line Input Voltage Change: 90~264V_{AC}
Output Power(2)	Output Power	18.3W	
Efficiency		>83%	At Full Load
Temperature	T_{FL7701}	< 63°C	At full load (all at open-frame, room temperature / still air)
	$T_{DM\ filter}$	< 69°C	
	$T_{FRD,ES3J}$	< 61°C	
	T_{MOSFET}	< 68°C	
	$T_{inductor}$	< 50°C	
PCB Size			18mm (width) x 295mm (length) x 10mm (height)
Initial Application			L-Tube

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

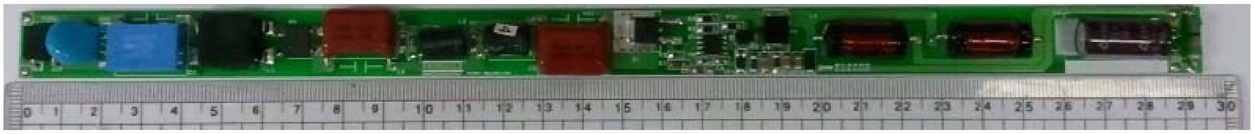

Figure 2. Top View, Length: 295mm

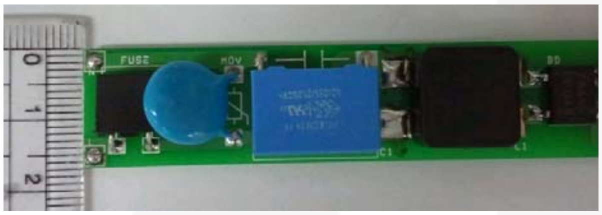

Figure 3. Width: 18mm

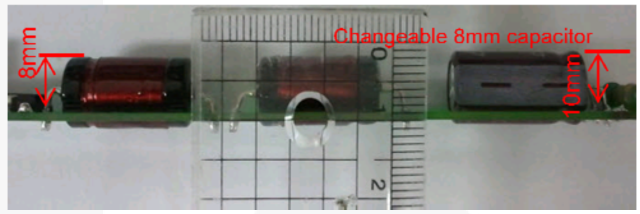

Figure 4. Height: 10mm (Include PCB)

4. Printed Circuit Board

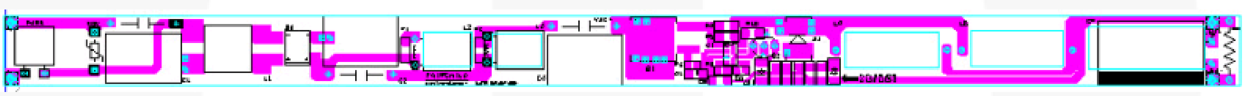

Figure 5. Top Side (18mm x 295mm)

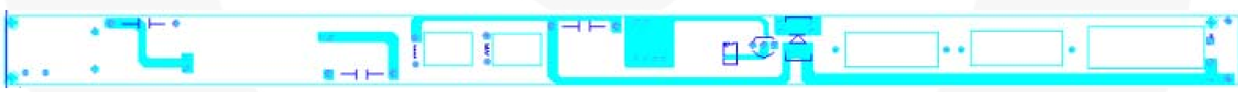

Figure 6. Bottom Side (18mm x 295mm)

5. Schematic

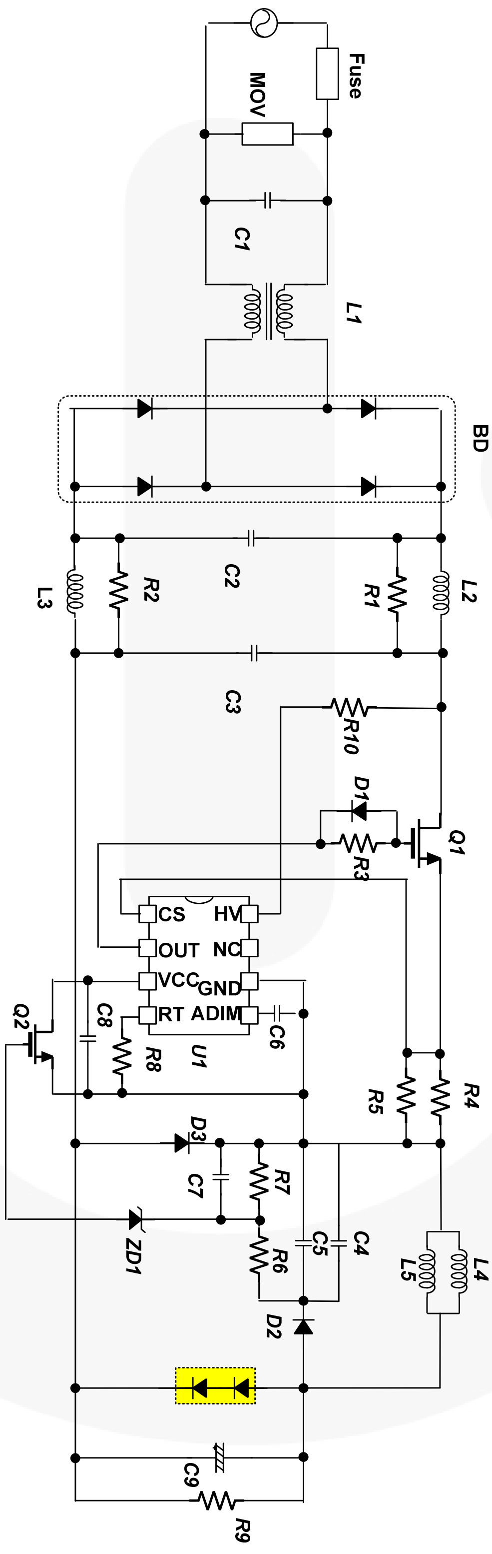

Figure 7. Schematic

6. Bill of Materials

Item No.	Part Reference	Part Number	Qty.	Description	Manufacturer
1	U1	FL7701	1	Controller	Fairchild Semiconductor
2	Fuse	SS-5-1A	1	1A/250V Fuse	Cooper Bussmann
3	MOV	MOV-10D471K	1	VARISTOR 470V 10MM RADIAL	Bourns Inc.
4	L1	LF-1480-253	1	Line Filter	Sejin Telecom (www.sejintel.com)
5	L2, L3	RFB0810-472	2	4.7mH Inductor	Coil Craft
6	L4, L5	PCH-45x-475	2	4.7mH Inductor	Coil Craft
7	BD	DF04S	1	400V / 1.5A, Bridge Rectifier	Fairchild Semiconductor
8	D1	1N4148	1	100V / 200mA, Small Signal Diode	Fairchild Semiconductor
9	D2	RS1M	1	1000V / 1A, Fast Rectifier	Fairchild Semiconductor
10	D3	ES3J	1	600V / 3A, Fast Rectifier	Fairchild Semiconductor
11	ZD1	MMSZ5230B	1	4.7V / 0.5W Zener Diode	Fairchild Semiconductor
12	Q1	FQD2N60	1	2A / 600V MOSFET	Fairchild Semiconductor
13	Q2	FQN1N50C	1	1A / 500V MOSFET	Fairchild Semiconductor
14	C1	PCX2 335M MKP 100nF	1	100nF / 275V_{AC}, X-Cap	PILKOR
15	C2	MPE 630V104K	1	0.1µF / 630V_{AC}, 10%, Polypropylene	Sungho
16	C3	MPE 400V334K	1	0.33µF / 400V_{AC}, 10%, Polypropylene	Sungho
17	C4, C5	C1206C225K5PACTU	2	2.2µF / 50V SMD Capacitor 3216	Kemet
18	C6	C0805C104K3RACTU	1	0.1µF / 25V SMD Capacitor 2012	Kemet
19	C7	C1206C102K5PACTU	1	1nF / 50V SMD Capacitor 3216	Kemet
20	C8	C1206C105K5PACTU	1	1µF / 50V SMD Capacitor 3216	Kemet
21	C9	KMG 330µF / 63V	1	330µF/63V Electrolytic Capacitor	SamYoung
22	R1, R2	RC1106JR-07151RL	2	150Ω RES, SMD, 1/4W, 3216	Yageo
23	R3	RC0805JR-07331RL	1	330Ω RES, SMD, 1/8W, 2012	Yageo
24	R4, R5	RC1106JR-070R9RL	2	0.9Ω RES, SMD, 1/4W, 3216	Yageo
25	R6	RC1106JR-07204RL	1	200kΩ RES, SMD, 1/4W, 3216	Yageo
26	R7	RC1106JR-07153RL	1	15kΩ RES, SMD, 1/4W, 3216	Yageo
27	R8	RC0805JR-07823RL	1	82kΩ RES, SMD, 1/8W, 2012	Yageo
28	R9	10.0KBZTB-ND	1	10kΩ / 1W Resistor	Yageo
29	R10	RC1106JR-07000RL	1	0Ω RES, SMD, 1/4W, 3216	Yageo

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7. Performance of Evaluation Board

Table 3. Test Condition & Equipments

Test Temperature	T_A = 25°C, Open-Flame
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

7.1. 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.

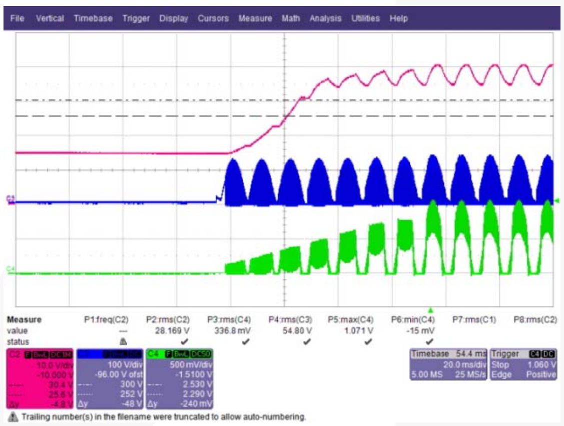

Figure 8. Soft-Start Characteristics at 90V_{AC} (47Hz) CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: $I_{INDUCTOR}$

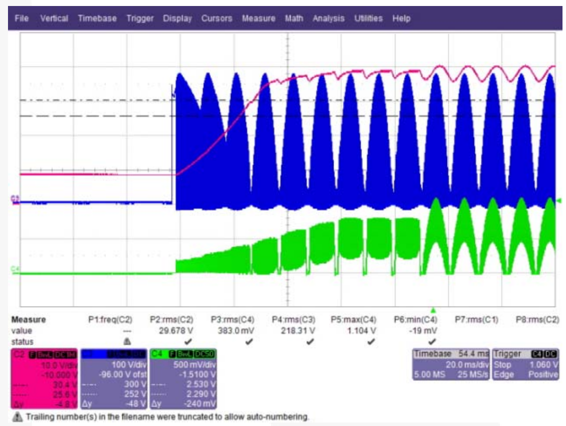

Figure 9. Soft-Start Characteristics at 264V_{AC} (47Hz), CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: $I_{INDUCTOR}$

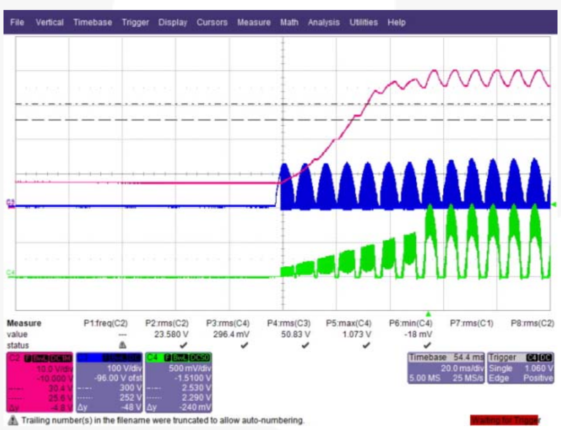

Figure 10. Soft-Start Characteristics at 90V_{DC} (64Hz), CCH2: V_{OUT}, CH3: V_{DRAIN}, CH4: $I_{INDUCTOR}$

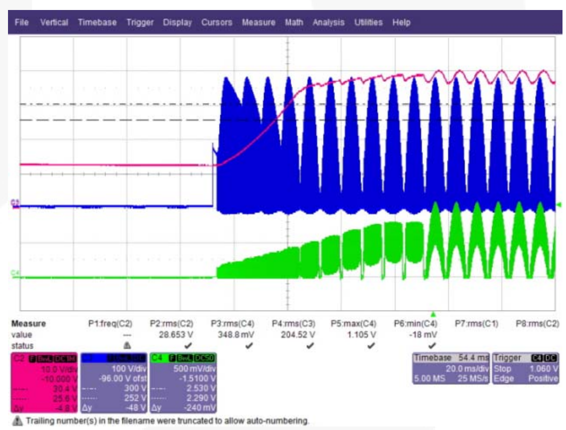

Figure 11. Soft-Start Characteristics at 264V_{DC} (64Hz), CCH2: V_{OUT}, CH3: V_{DRAIN}, CH4: $I_{INDUCTOR}$

7.2. Operating Frequency & Minimum Duty

The recommended switching frequency of FL7701 is around 20kHz ~ 250kHz and it is determined by the RT resistor and has prefixed output frequency in RT-open condition. The maximum duty ratio is fixed below 50% and pre-fixed minimum on time is around 400ns. There are two considerable points to design properly. The first, consider the minimum duty at low input voltage because the FL7701 cannot get higher than 50% duty ratio. This means the FL7701 should have duty margin. The other is minimum on-time at high input voltage condition. The FL7701 cannot control output power when the set point is smaller than on time at very high input voltage. On-time margin must be considered.

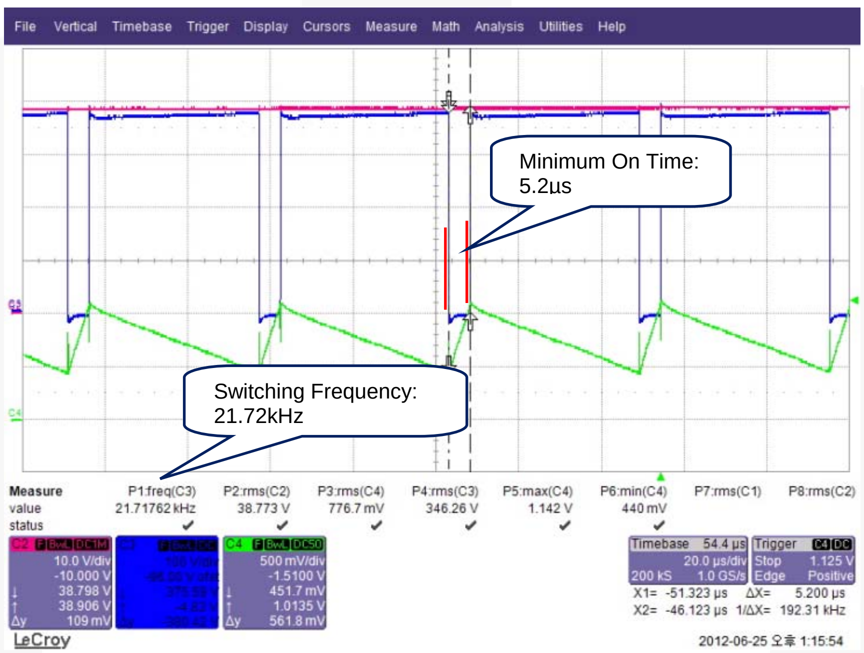

Figure 12. Operating Frequency & Minimum Duty
CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: $I_{INDUCTOR}$

7.3. Typical Waveforms: Steady State

Figure 13 through Figure 22 show the normal operation waveforms by input voltage and input frequency. The output voltage and current always keeps a certain output level with (input frequency ×2) ripple and the test results are provided in Table 5.

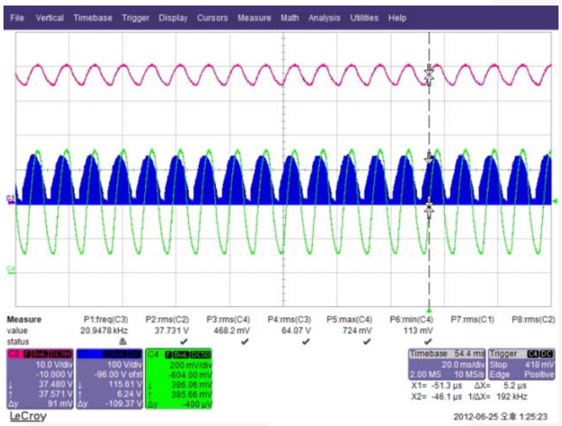

Figure 13. Input Voltage: 90V_{AC}, Input Frequency: 47Hz, CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

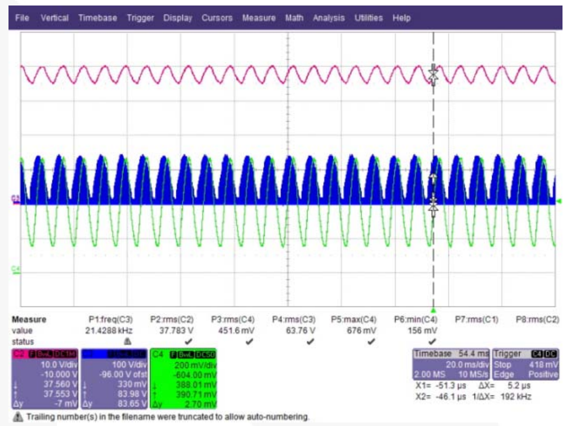

Figure 14. Input Voltage: 90V_{AC}, Input Frequency: 64Hz, CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

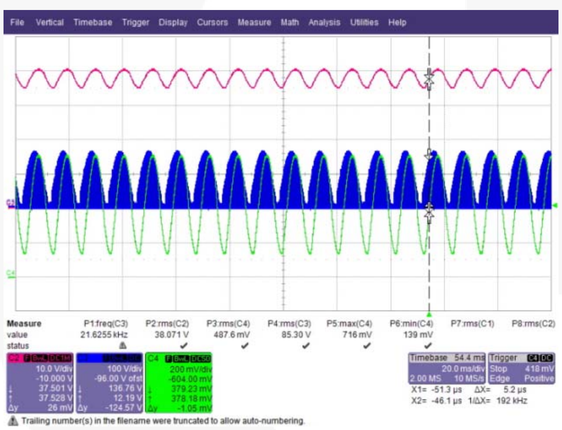

Figure 15. Input Voltage: 110V_{AC}, Input Frequency: 47Hz, CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

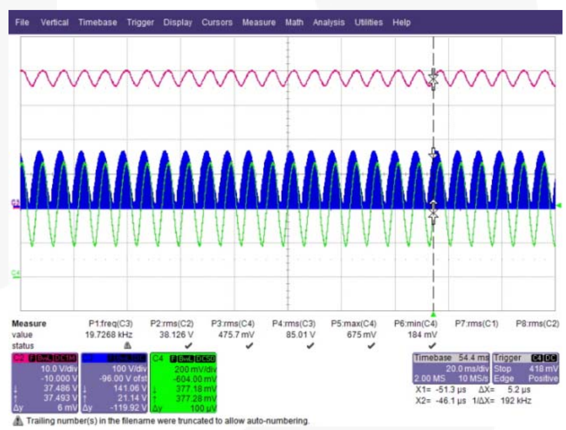

Figure 16. Input Voltage: 110V_{AC}, Input Frequency: 64Hz, CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

Figure 17. Input Voltage: 180V_{AC}, Input Frequency: 47Hz, CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

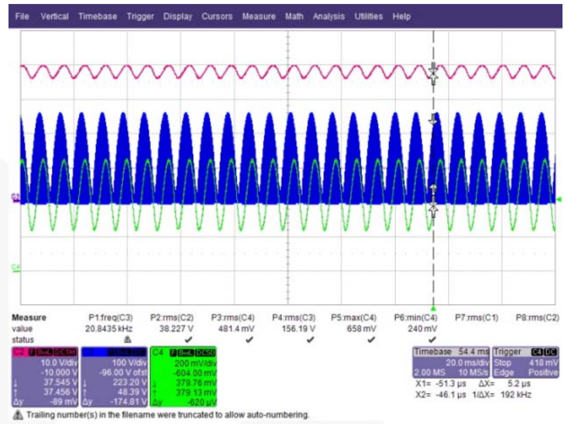

Figure 18. Input Voltage: 180V_{AC}, Input Frequency: 64Hz, CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

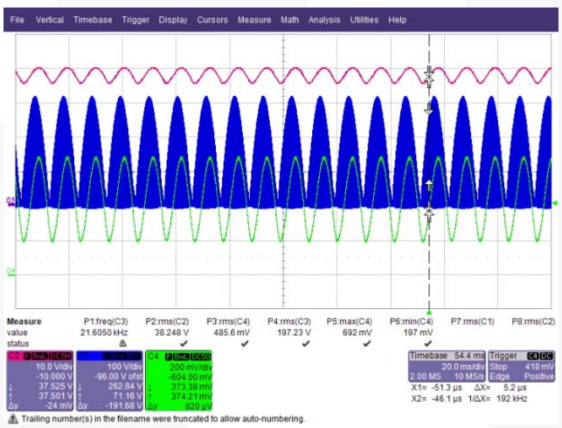

Figure 19. Input Voltage: 220V_{AC}, Input Frequency: 47Hz, CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

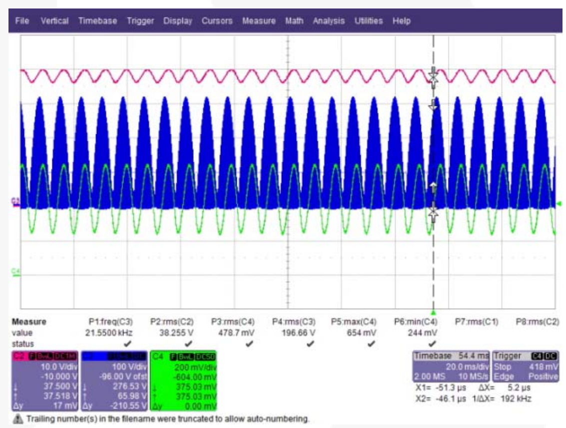

Figure 20. Input Voltage: 220V_{AC}, Input Frequency: 64Hz, CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

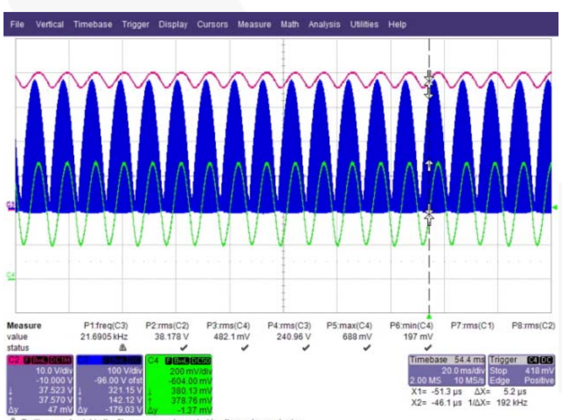

Figure 21. Input Voltage: 264V_{AC}, Input Frequency: 47Hz, CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

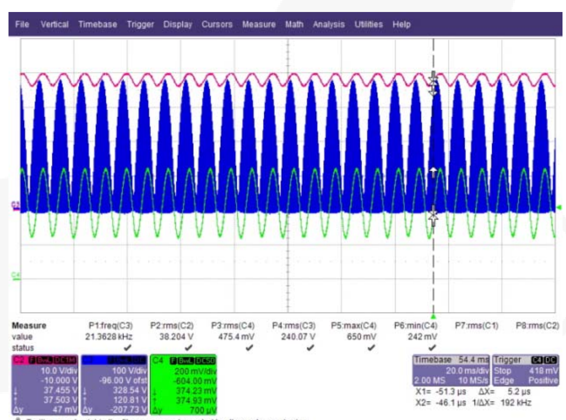

Figure 22. Input Voltage: 264V_{AC}, Input Frequency: 64Hz, CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

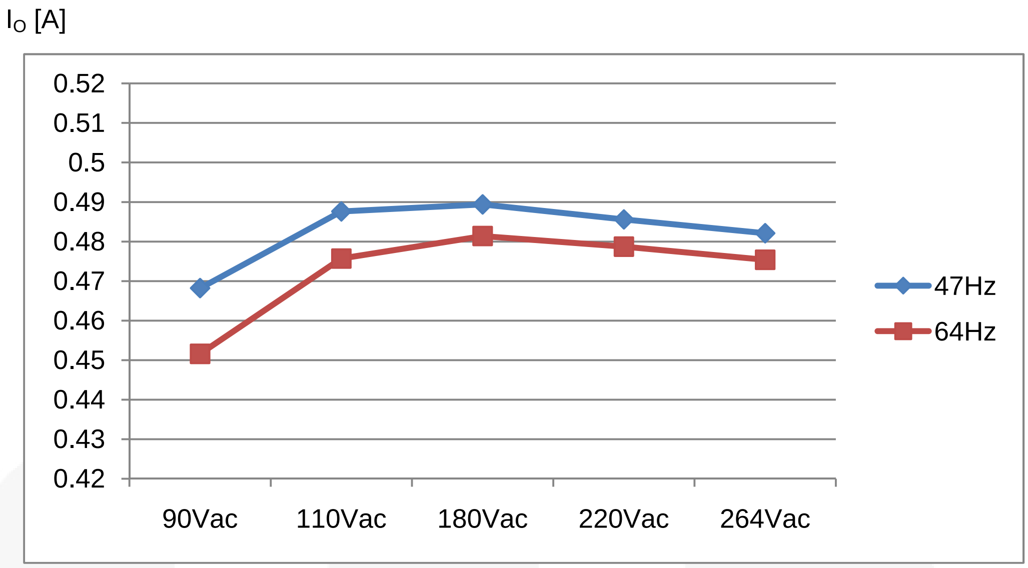

Figure 23. CC Deviation Curve

Table 4. Output Characteristics by Input Voltage & Frequency

	47Hz		**64Hz**	
	$V_{LED(RMS)}$	$I_{LED(RMS)}$	$V_{LED(RMS)}$	$I_{LED(RMS)}$
90V$_{AC}$	37.73V	468.2mA	37.78V	451.6mA
110V$_{AC}$	38.07V	487.6mA	38.13V	475.7mA
180V$_{AC}$	38.25V	489.4mA	38.23V	481.4mA
220V$_{AC}$	38.25V	485.6mA	38.26V	478.7mA
264V$_{AC}$	38.18V	482.1mA	38.20V	475.4mA
Deviation		4.33%		6.19%

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

Figure 24 shows the open-load condition test method. If the LED disconnects from the system, the output voltage increases up to match the voltage of the input source. Add the output voltage clamping circuit or the special protection circuit to protect components, especially output capacitor.

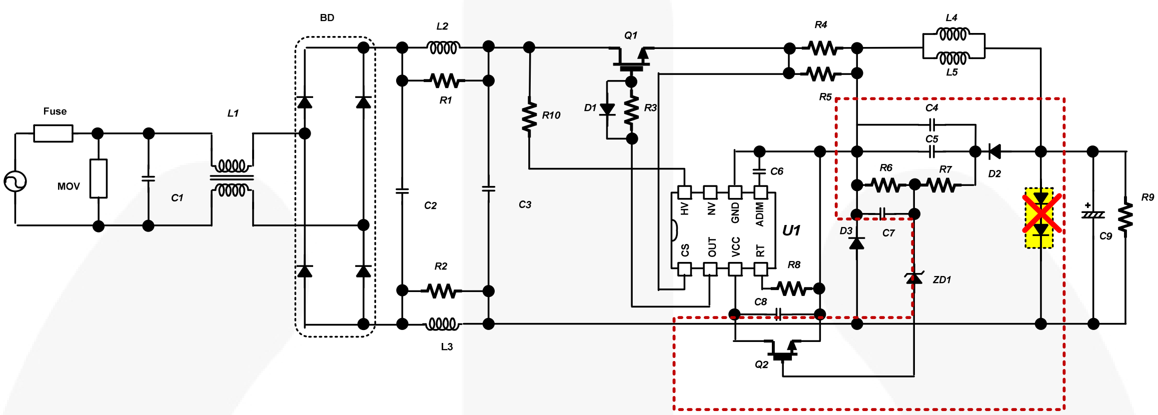

Figure 24. Open-LED Condition

The Figure 25 shows the test results of waveform in LED-open condition; the output voltage clamps a certain level.

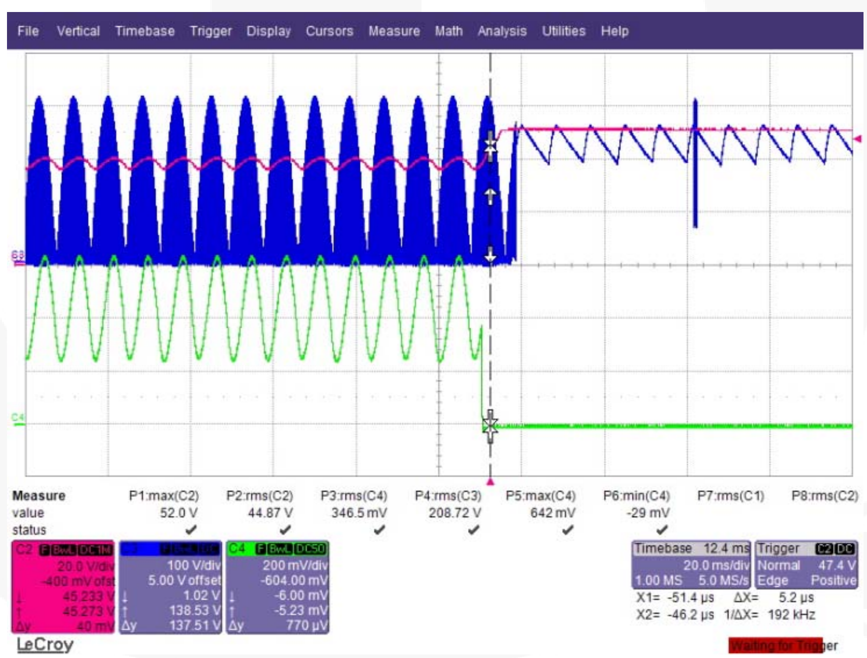

Figure 25. Output Waveforms at LED-OPEN Condition
CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

7.5. Typical Waveforms: Abnormal Mode (Inductor Short)

Figure 26 and Figure 27 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.

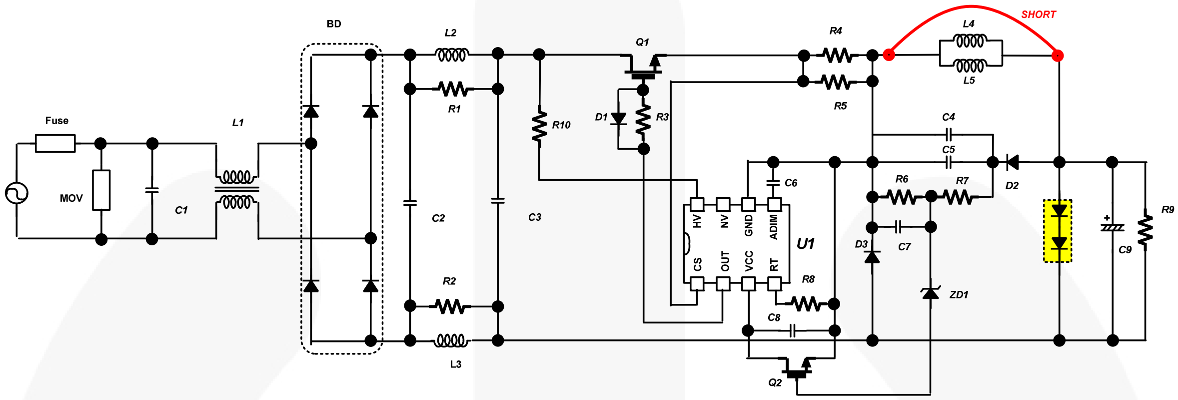

Figure 26. Inductor Short Condition

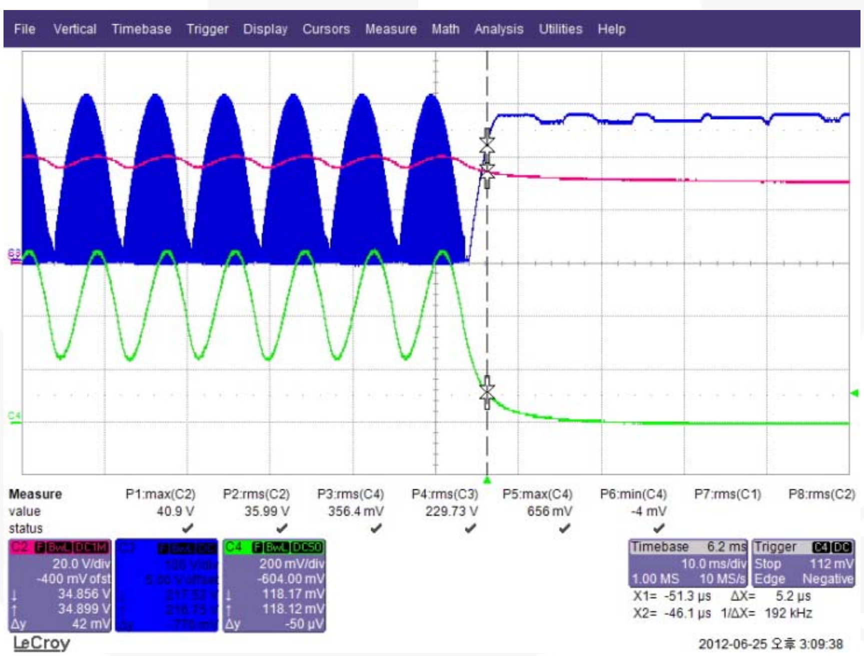

Figure 27. Test Result of Inductor Short Condition
CH2: V_{OUT}, CH3: V_{DRAIN}, CH4: I_{LED}

7.6. System Efficiency

Figure 28 shows system efficiency results for different AC input voltage frequency conditions. As shown, the input frequency has negligible effect on system efficiency.

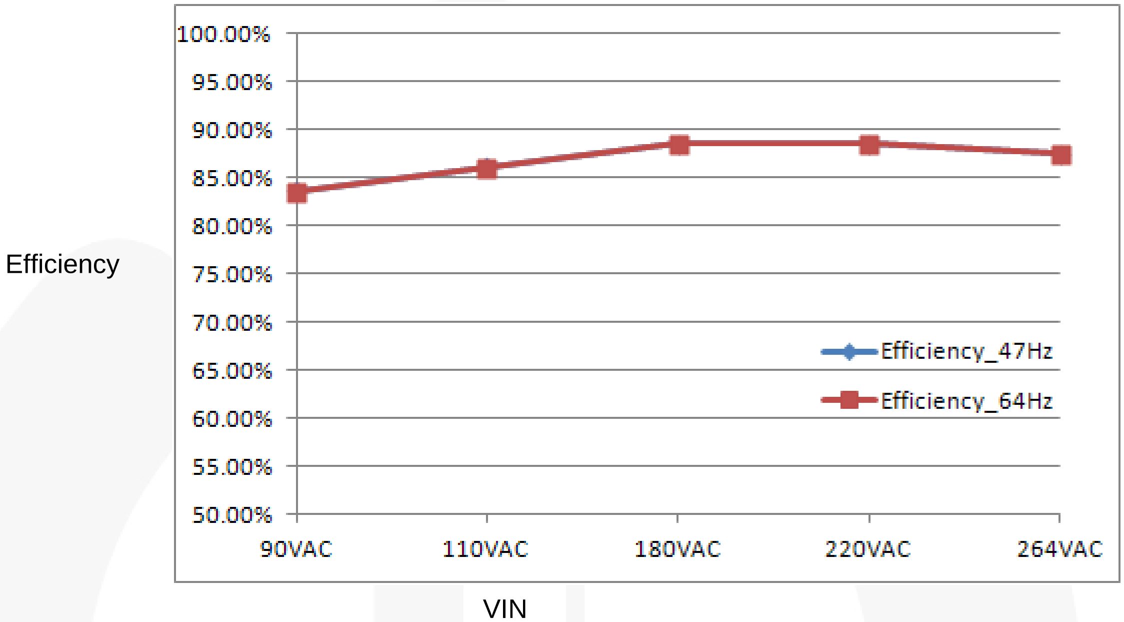

Figure 28. System Efficiency

Table 5. Test Result of System Efficiency

Input Voltage		Efficiency (%)
$90V_{AC}$	47Hz	83.63
	64Hz	83.55
$110V_{AC}$	47Hz	86.18
	64Hz	86.06
$180V_{AC}$	47Hz	88.52
	64Hz	88.56
$220V_{AC}$	47Hz	88.58
	64Hz	88.52
$264V_{AC}$	47Hz	87.53
	64Hz	87.51

7.7. Power Factor at Rated Load Condition

Figure 29 shows the system Power Factor (PF) performance for the entire input voltage range ($90V_{AC}$ to $264V_{AC}$) at different input frequency conditions (47Hz, 64Hz). The PF changes slightly according to the input frequency.

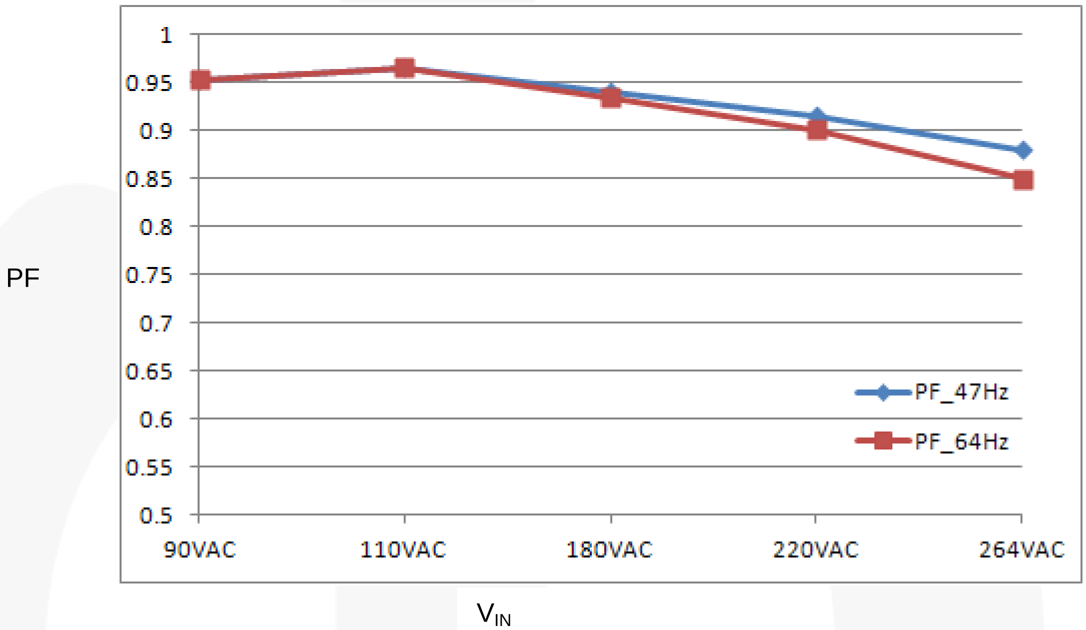

Figure 29. Power Factor

Table 6. Power Factor Test Results

Input Voltage		Power Factor
$90V_{AC}$	47Hz	0.95
	64Hz	0.95
$110V_{AC}$	47Hz	0.96
	64Hz	0.96
$180V_{AC}$	47Hz	0.94
	64Hz	0.93
$220V_{AC}$	47Hz	0.91
	64Hz	0.90
$264V_{AC}$	47Hz	0.88
	64Hz	0.85

7.8. THD Performance at Rated Load Condition

Figure 30 shows the Total Harmonic Distortion (THD) performance at different input frequencies. Test results are similar; THD meets international regulations (under 30%).

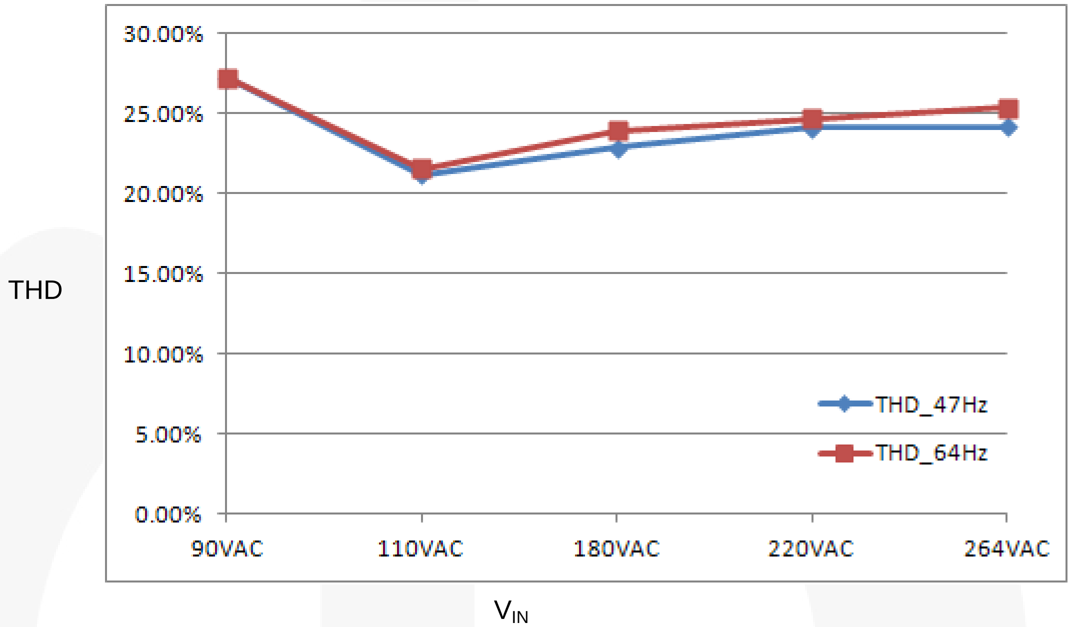

Figure 30. Total Harmonic Distortion Performance

Table 7. THD Test Result

Input Voltage		**THD (%)**
$90V_{AC}$	47Hz	27.24
	64Hz	27.25
$110V_{AC}$	47Hz	21.18
	64Hz	21.54
$180V_{AC}$	47Hz	22.88
	64Hz	23.97
$220V_{AC}$	47Hz	24.10
	64Hz	24.71
$264V_{AC}$	47Hz	24.19
	64Hz	25.40

7.9. Thermal Performance at Rated Load Condition

The Figure 31 through Figure 35 show the temperature checking results on the board, depending on different input voltage conditions. All of the components temperatures are below 69°C in whole input voltage condition.

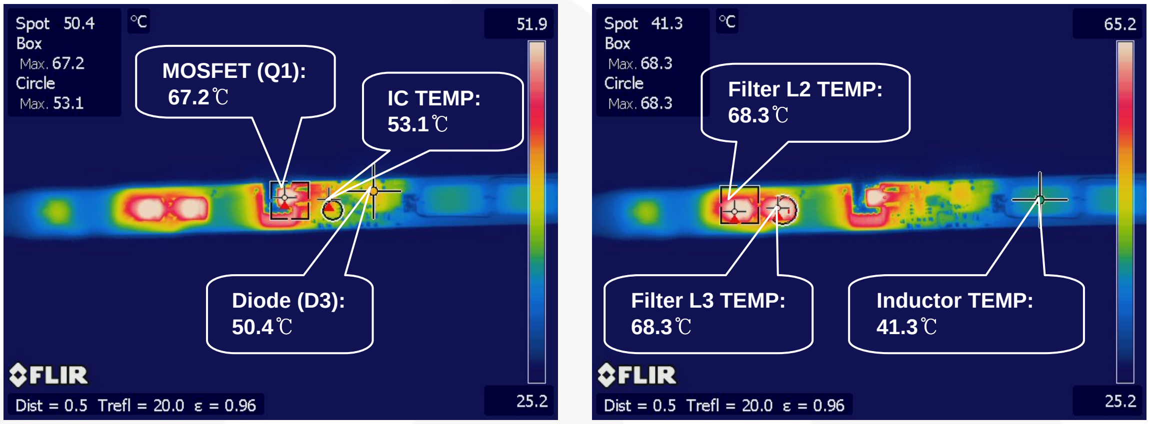

Figure 31. Thermal Test Result at 90V_{AC} Condition

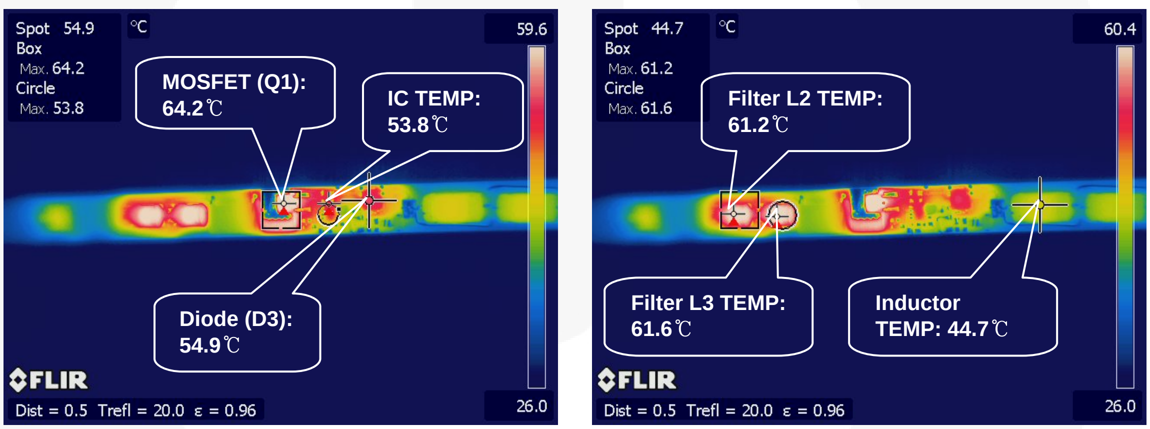

Figure 32. Thermal Test Result at 110V_{AC} Condition

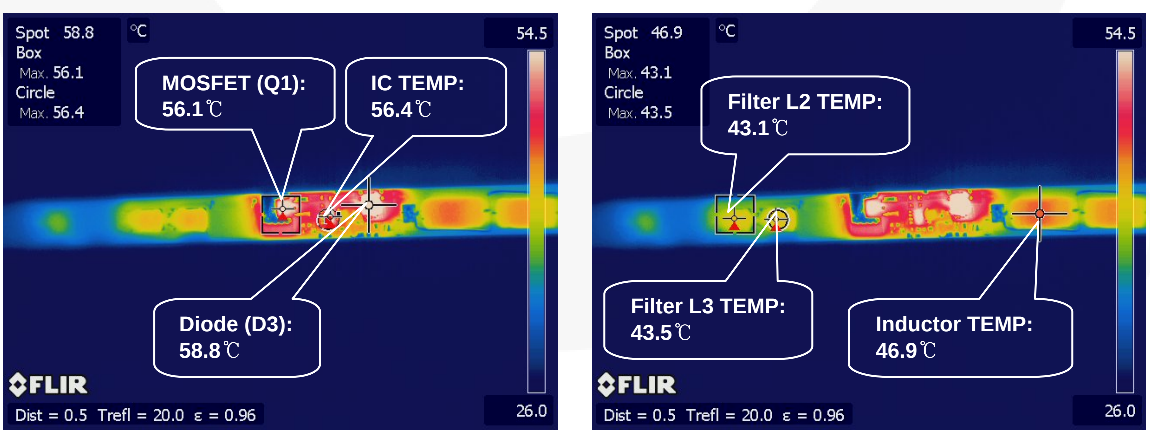

Figure 33. Thermal Test Result at 180V_{AC} Condition

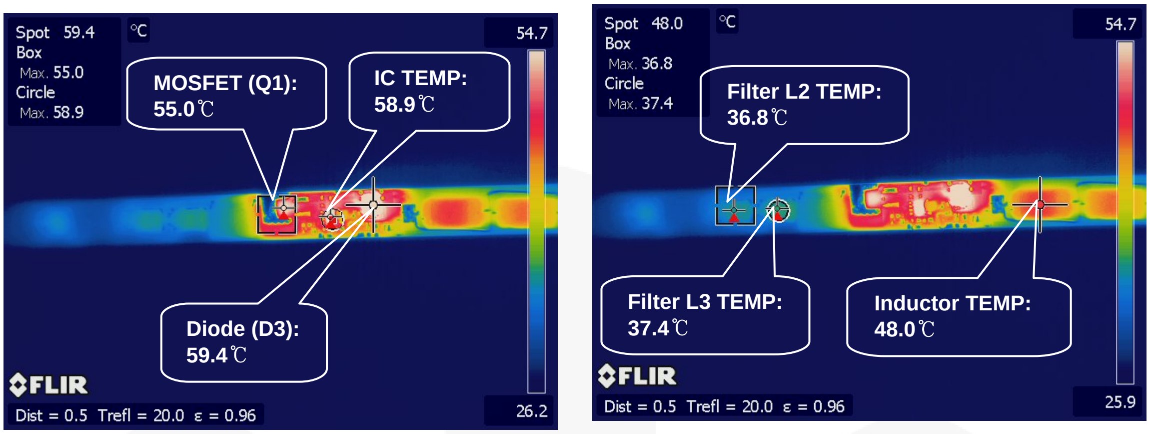

Figure 34. Thermal Test Result at 220V_{AC} Condition

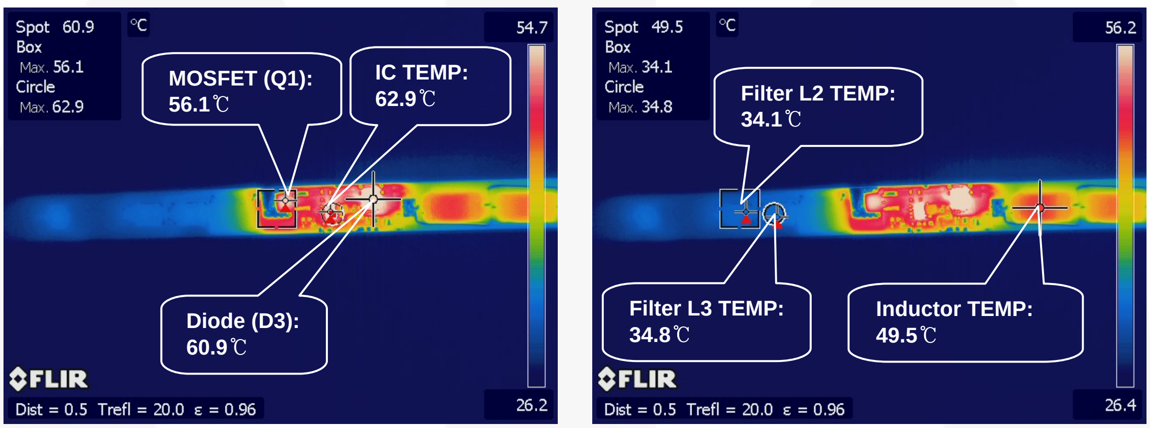

Figure 35. Thermal Test Result at 264V_{AC} Condition

Table 8. Temperature Performance by Input Voltage

	IC	MOSFET (Q1)	Diode (D3)	Filter L2	Filter L3	Inductor
90V_{AC}	53.1°C	67.2°C	50.4°C	68.3°C	68.3°C	41.3°C
110V_{AC}	53.8°C	64.2°C	54.9°C	61.2°C	61.6°C	44.7°C
180V_{AC}	56.4°C	56.1°C	58.8°C	43.1°C	43.5°C	46.9°C
220V_{AC}	58.9°C	55.0°C	59.4°C	36.8°C	37.4°C	48.0°C
264V_{AC}	62.9°C	56.1°C	60.9°C	34.1°C	34.8°C	49.5°C

7.10. Electromagnetic Interference (EMI) Result

All measurement was conducted in observance of CISPR22 criteria. This regulation is tighter than the CISPR15 regulation for lighting applications.

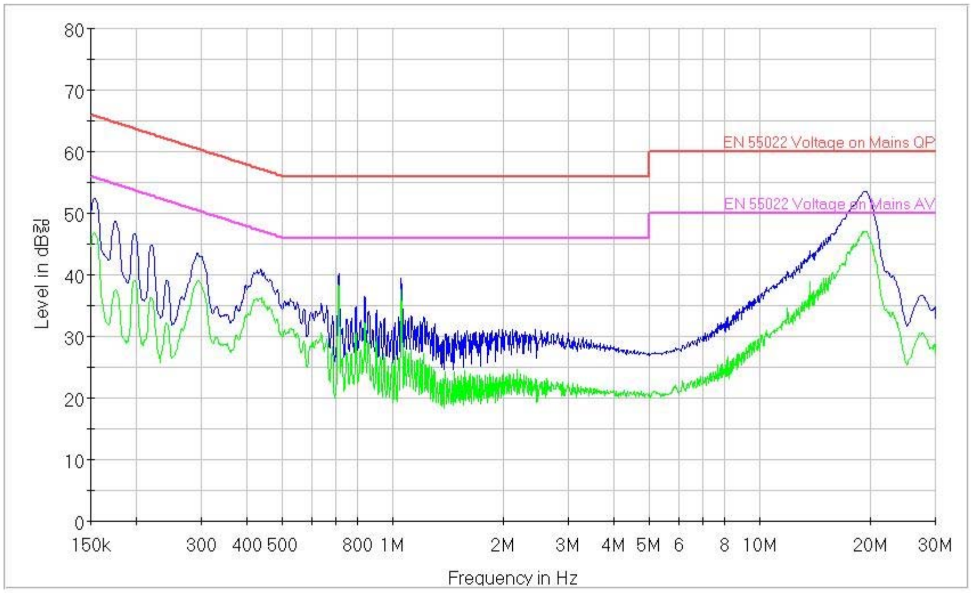

Figure 36. Conducted Emission-Line at 110V$_{AC}$, Full Load (10-LED in Series)

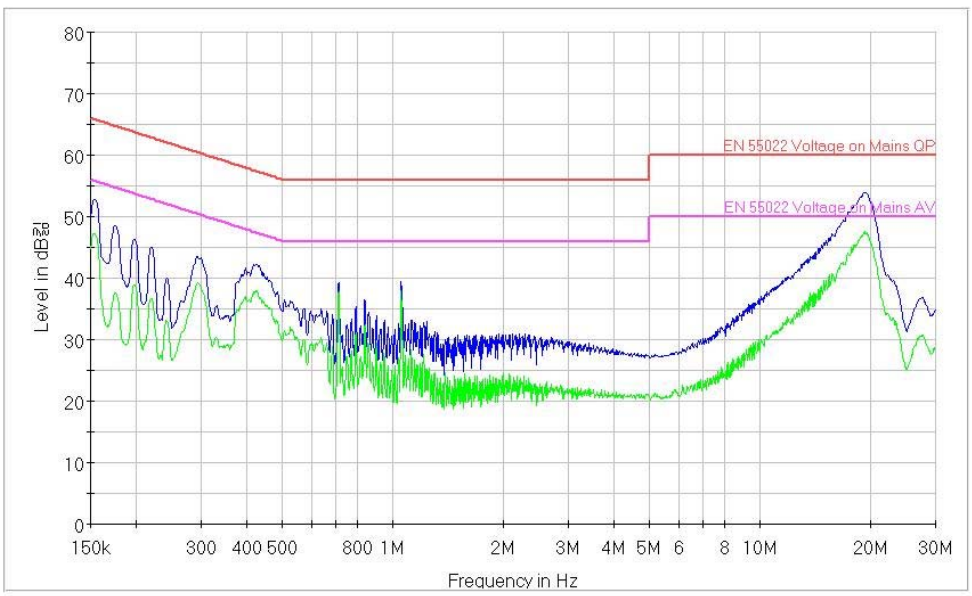

Figure 37. Conducted Emission-Neutral at 110V$_{AC}$, Full Load (10-LED in Series)

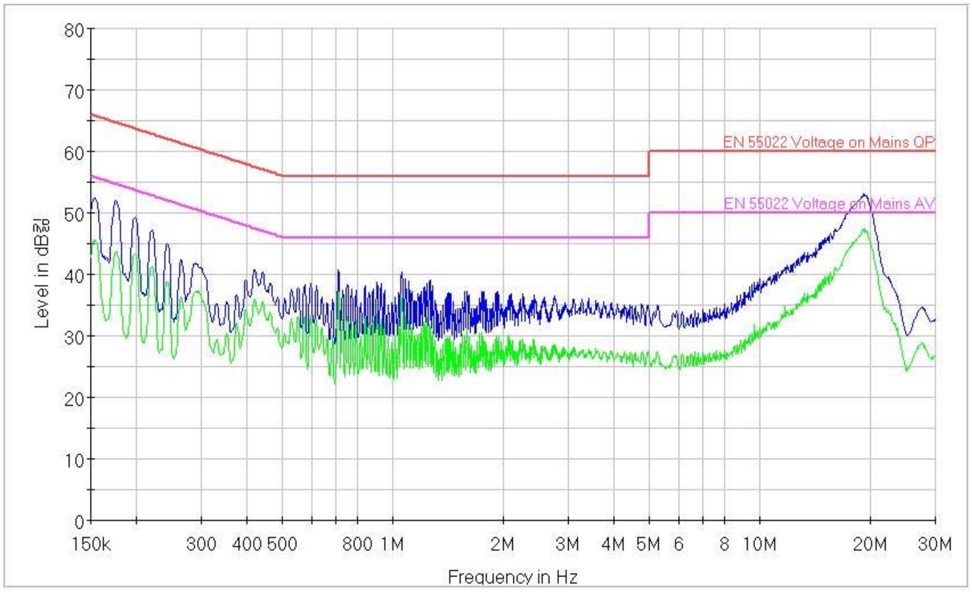

Figure 38. Conducted Emission-Line at $220V_{AC}$, Full Load (10-LED in Series)

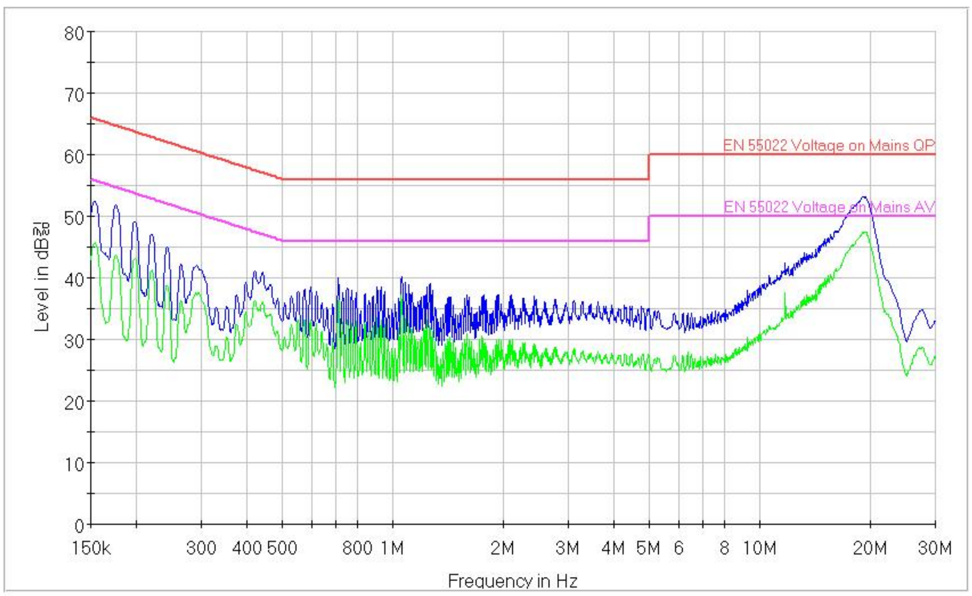

Figure 39. Conducted Emission-Neutral at $220V_{AC}$, Full Load (10-LED in Series)

8. Revision History

Rev.	Date	Description
1.0.0	July 2012	Initial Release

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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.

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