User Guide for

FEBFL7701_L30U003A

2.4W LED Ballast Using FL7701

Featured Fairchild Product:

FL7701

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Fairchild Semiconductor.com

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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 a universal-input 2.4W LED ballast using the FL7701. The input voltage range is $90V_{RMS}$ – $265V_{RMS}$ and there is one DC output with a constant current of 85mA at $28V_{MAX}$. 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. The special "adopted digital" technique automatically detects input voltage condition and sends an internal reference signal, resulting in high power factor. When an AC input voltage is applied to the IC, the PFC function is automatically enabled. Otherwise, when a DC input is applied to the IC, the PFC function is automatically disabled. The FL7701 does not require a bulk capacitor (electrolytic capacitor) for supply rail stability, which can significantly affect LED reliability.

1.2. Key Features

- Digitally Implemented Active PFC Function
- Built-in Self-Biasing HV Startup Circuit
- Application Input Range: $80V_{AC}$ ~ $308V_{AC}$
- AOCP Function with Auto-Restart Mode
- Built-in Over-Temperature Protection
- Cycle-by-Cycle Current Limit
- Current-Sense Pin Open Protection
- Low Operating Current: 0.85mA (Typical)
- Under-Voltage Lockout with 5V Hysteresis
- Programmable Oscillator Frequency
- Programmable LED Current
- Analog Dimming Function
- Fixed Soft-Start Function
- Precise Internal Reference: ±3%

1.3. Internal Block Diagram

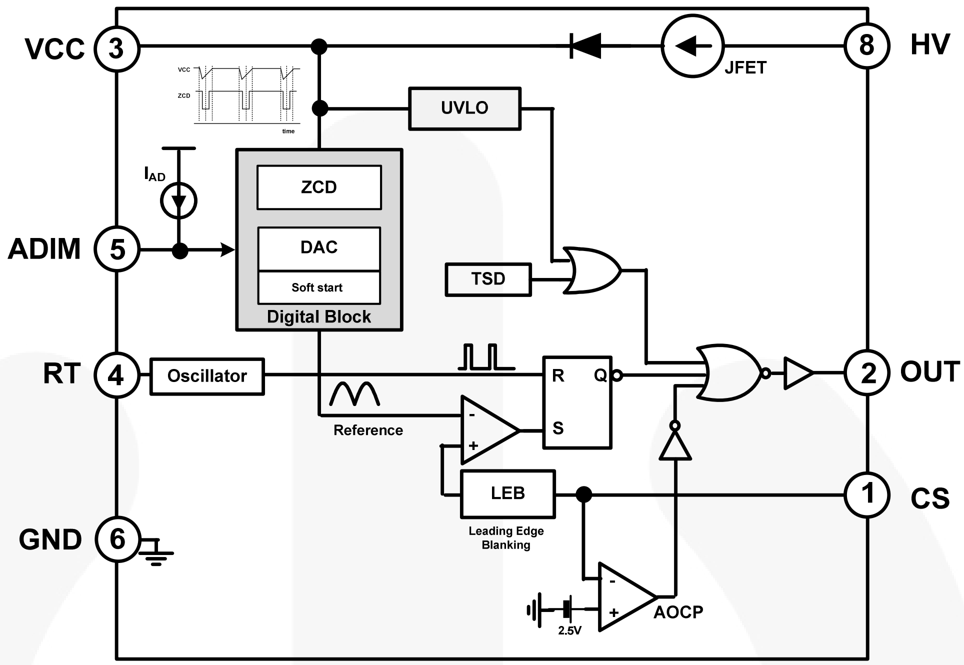


Figure 1. Internal Block Diagram

Pin Descriptions

Pin	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	**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 1. Summary of Features and Performance

Description	Symbol	Value	Comments
Input Voltage Range	$V_{IN,min}$	90V	
	$V_{IN,nom}$	220V	
	$V_{IN,max}$	265V	
AC Input Frequency	$f_{IN,min}$	47Hz	
	$f_{IN,max}$	64Hz	
Output Voltage/Current	V_{OUT}	28V	Note 1
	I_{OUT}	85mA	
Output Power	Output Power	2.41W	Note 2
Efficiency		>78%	At full load
Temperature	T_{FL7701}	< 71.5°C	At full load (all at open frame, room temperature / still air)
	T_{MOSFET}	< 59.5°C	
	$T_{INDUCTOR}$	< 57.5°C	
PCB Size			20mm (width) x 32mm (length) x 13mm (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

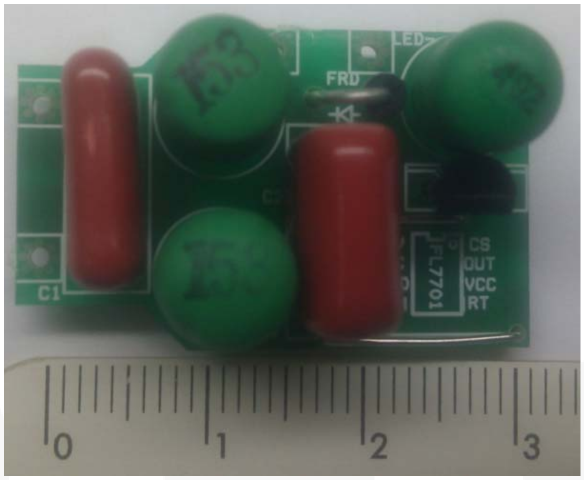


Figure 2. Photograph Top View (20mm x 32mm x 13mm)

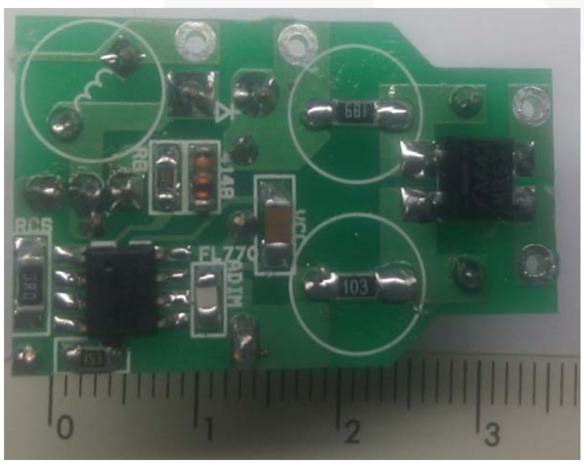


Figure 3. Photograph Bottom View (20mm x 32mm x 13mm)

Figure 4. Photograph Side View (20mm x 32mm x 13mm)

4. Printed Circuit Board

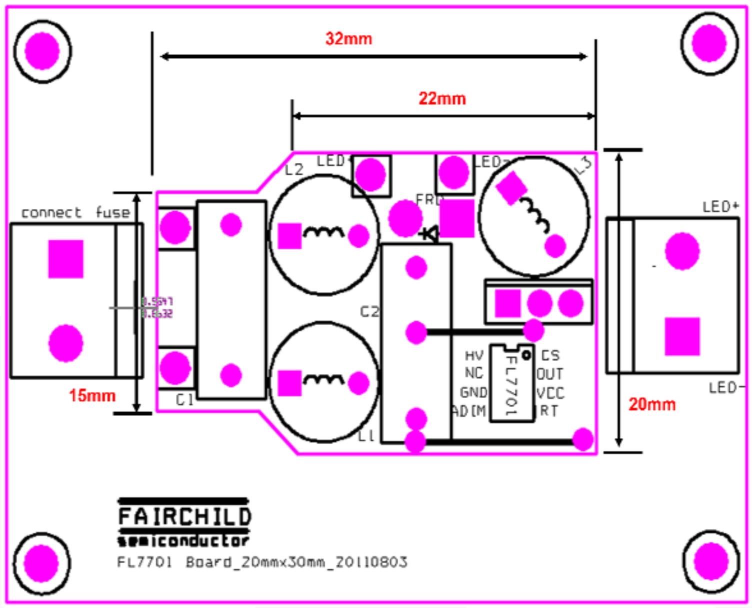


Figure 5. PCB, Top Side

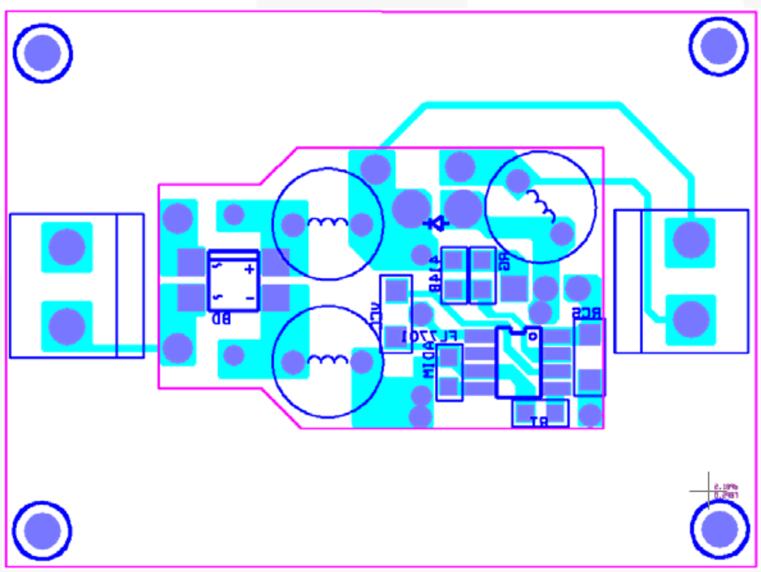


Figure 6. PCB, Bottom Side

5. Schematic

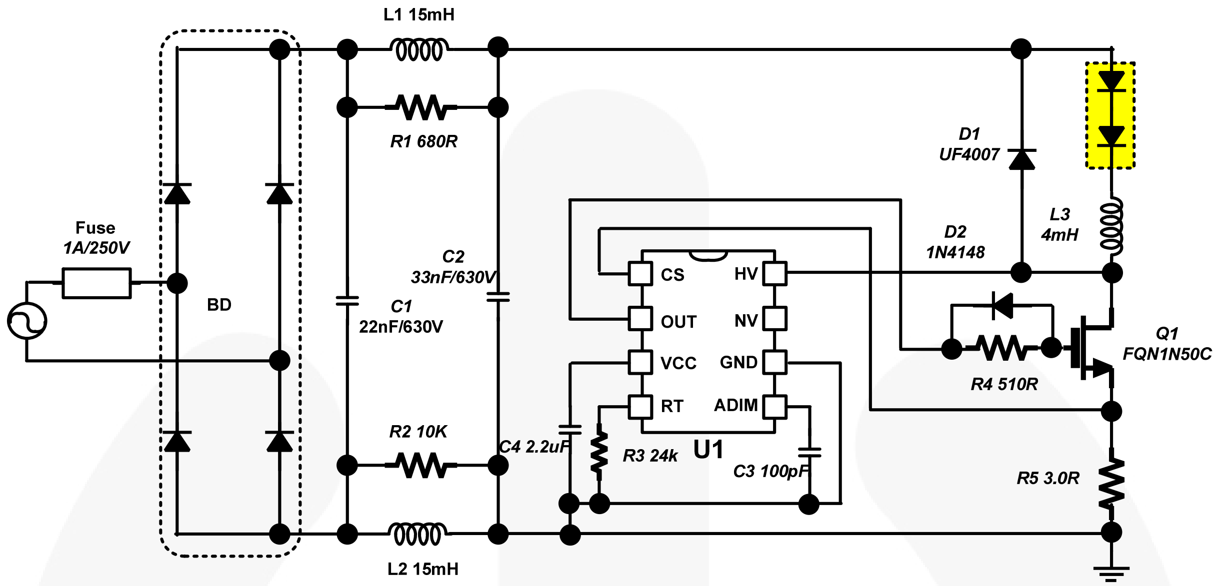


Figure 7. Schematic of Evaluation

6. Bill of Materials

Qty	Reference	Part Number	Value	Description	Manufacturer	PCB Silkscreen
1	U1	FL7701		Controller	Fairchild Semiconductor	
1	BD	MB6S	0.5A / 600V	Diode, Bridge, 600V, 0.5A	Fairchild Semiconductor	
1	C1	MPE 630V223K	22nF	Capacitor, 630V_{AC}, 10%, Polypropylene	Sungho	C1
1	C2	MPE 630V333K	33nF	Capacitor, 630V_{AC}, 10%, Polypropylene	Sungho	C2
1	C3	C0805C101K3RACTU	100pF	Capacitor, SMD, Ceramic, 25V, X7R	Kemet	ADIM
1	C4	C1206C225K3PACTU	2.2µF	Capacitor, SMD, Ceramic, 25V, X7R	Kemet	VCC
1	D1	UF4007	1A / 1kV	Diode, 1kV, 1A Ultra-Fast Recovery	Fairchild Semiconductor	FRD
1	D2	1N4148	1A / 100V	100V/1A, Small-Signal Diode	Fairchild Semiconductor	4148
2	L1, L2	R06153KT00	15mH	Inductor, Radial, R6.5x7.5	Bosung	L1, L2
1	L3	R06402KT00	4mH	Inductor, Radial, R6.5x7.5	Bosung	L3
1	R1	RC1206JR-07680RL	680R	Resistor,SMD,1/4W,1206	Yageo	
1	R2	RC1206JR-0710KL	10k	Resistor,SMD,1/4W,1206	Yageo	
1	R3	RC0805JR-0724KL	24k	Resistor,SMD,1/8W,0805	Yageo	RT
1	R4	RC0805JR-07510RL	510R	Resistor,SMD,1/8W,0805	Yageo	RG
1	R5	RC1206JR-073RL	3.0R	Resistor,SMD,1/4W,1206	Yageo	RCS

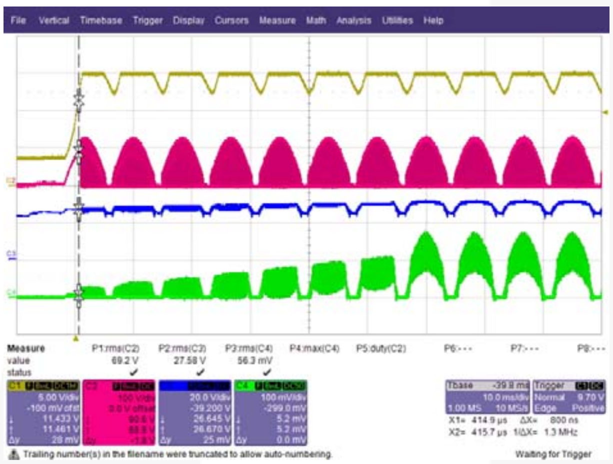
7. Test Condition & Test Equipment

Evaluation Board	FEBFL7701_L30U003A
Test Date	2012.01.19
Test Temperature	T_A = 25°C
Test Equipments	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. Test Waveforms

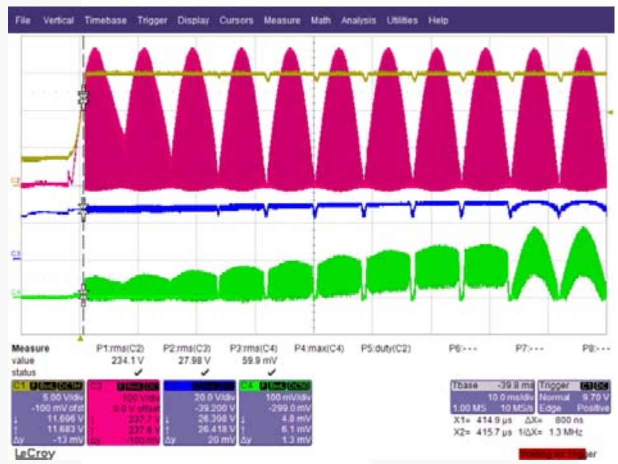
8.1. Typical Waveforms: Startup

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.



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

Figure 8. Soft-Start Characteristics, AC Mode, 90V_{AC}

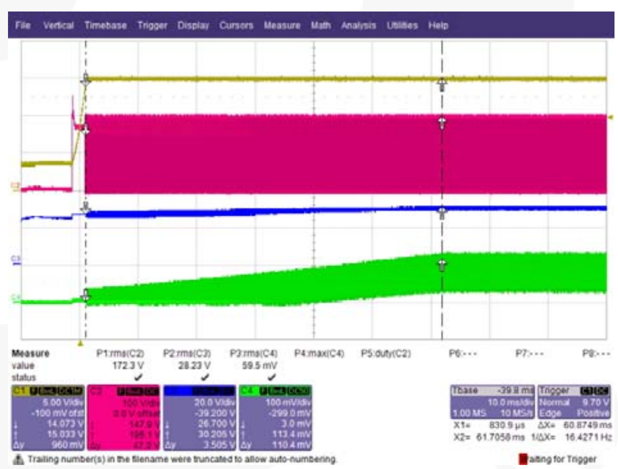


CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 9. Soft-Start Characteristics, AC Mode, 265V_{AC}

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

Figure 10. Soft-Start Characteristics, DC Mode, 100V_{DC}

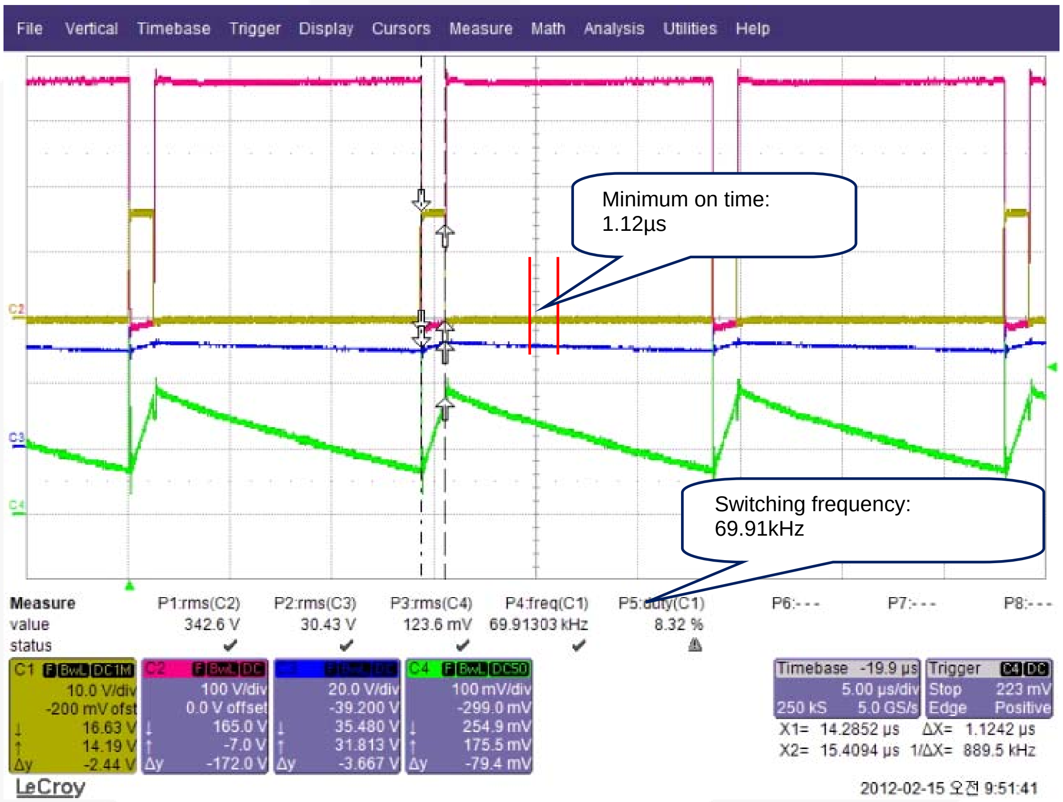


CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 11. Soft-Start Characteristics, DC Mode, 200V_{DC}

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.

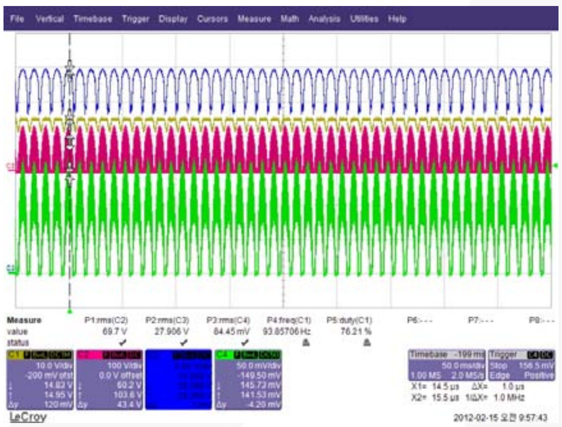


CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 12. Operating Frequency & Minimum Duty

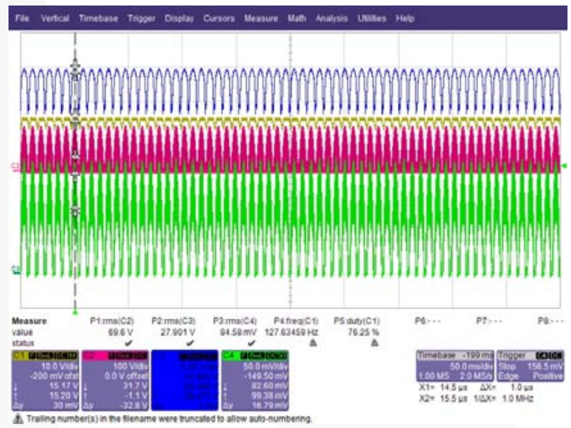
8.3. Typical Waveforms: Steady State

Figure 13 through Figure 22 show the normal operation waveform by input voltage & input frequency. The output voltage and current maintains a certain output level with 120Hz ripple, as shown in the test results in Table 2.



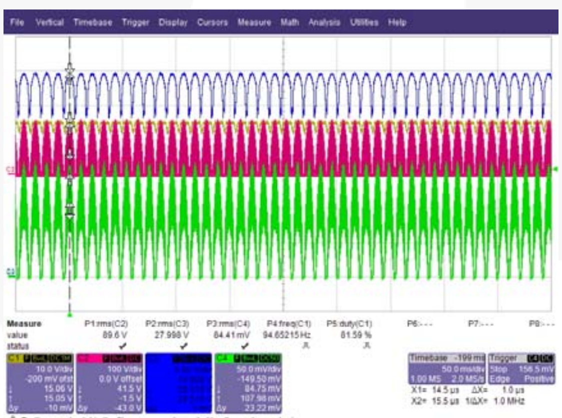
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 13. Input Voltage: 90V_{AC}, Input Frequency: 47Hz



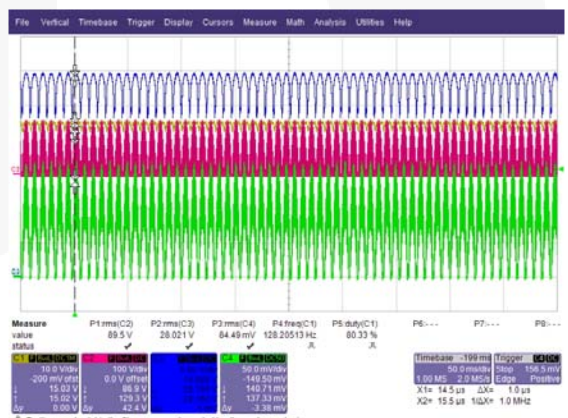
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 14. Input Voltage: 90V_{AC}, Input Frequency: 64Hz



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

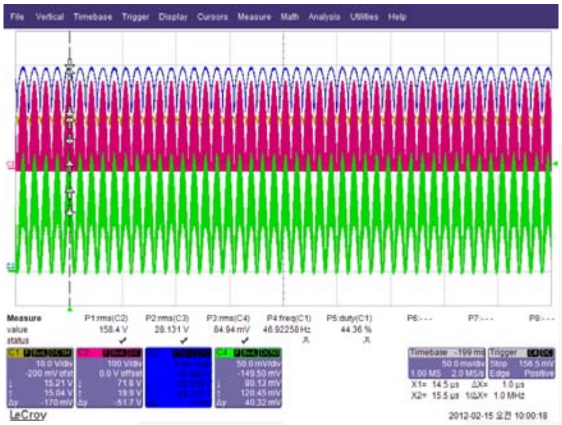
Figure 15. Input Voltage: 110V_{AC}, Input Frequency: 47Hz



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

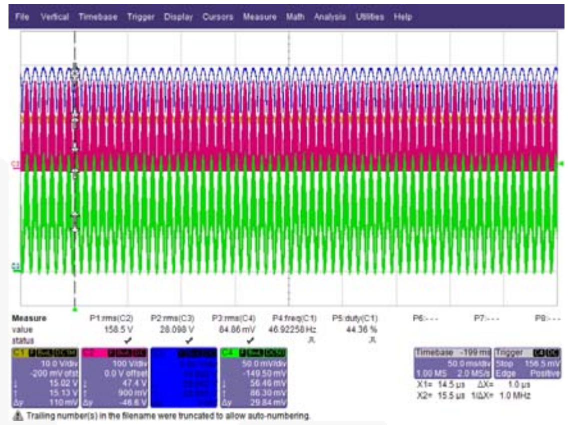
Figure 16. Input Voltage: 110V_{AC}, Input Frequency: 64Hz

Typical Operating Waveforms: Output Characteristics



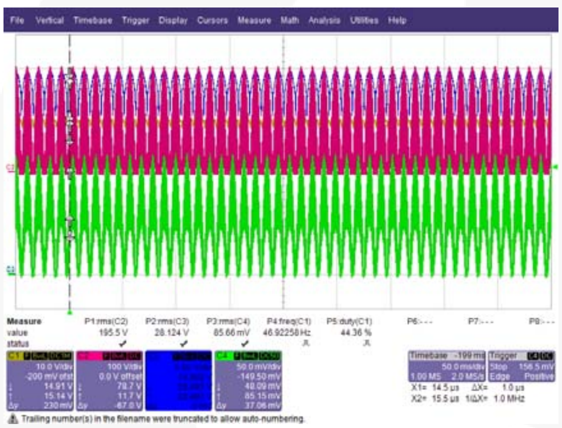
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 17. Input Voltage: 180V_{AC}, Input Frequency: 47Hz



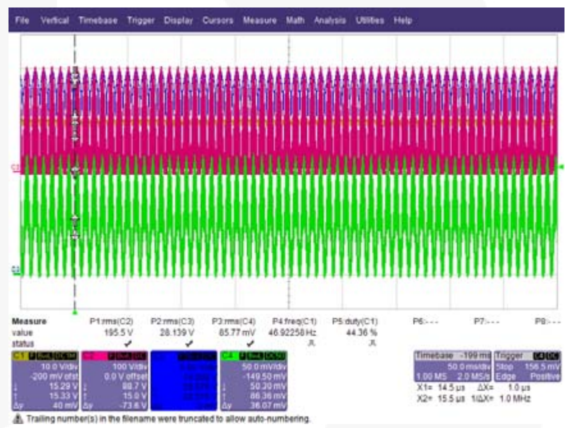
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 18. Input Voltage: 180V_{AC}, Input Frequency: 64Hz



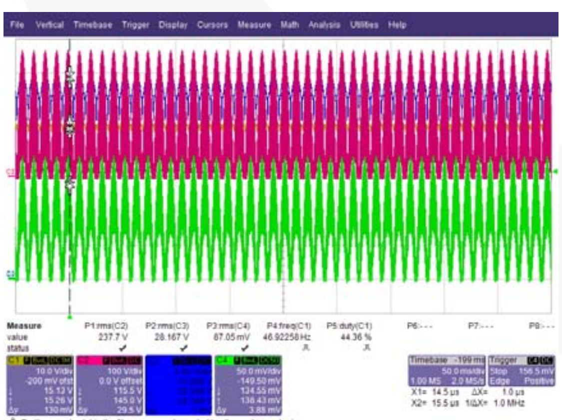
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 19. Input Voltage: 220V_{AC}, Input Frequency: 47Hz



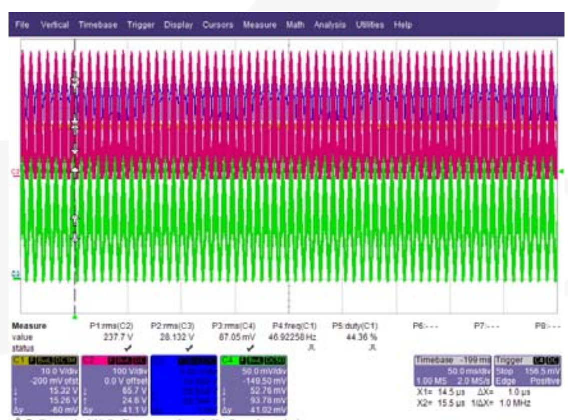
CH1: V_{CC}, CH2: V_{DRAIN}, CH3: V_{LED}, CH4: I_{LED}

Figure 20. Input Voltage: 220V_{AC}, Input Frequency: 64Hz



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

Figure 21. Input Voltage: 265V_{AC}, Input Frequency: 47Hz



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

Figure 22. Input Voltage: 265V_{AC}, Input Frequency: 64Hz

Table 2. Output Characteristics by Input Voltage & Frequency

	47Hz		64Hz	
	$V_{LED(RMS)}$	$I_{LED(RMS)}$	$V_{LED(RMS)}$	$I_{LED(RMS)}$
$90V_{AC}$	27.91V	84.45mA	27.90V	84.58mA
$110V_{AC}$	27.99V	84.41mA	28.02V	84.49mA
$180V_{AC}$	28.13V	84.94mA	28.10V	84.86mA
$220V_{AC}$	28.12V	85.66mA	28.14V	85.77mA
$265V_{AC}$	28.17V	87.05mA	28.13V	87.05mA

8.4. Typical Waveforms: Abnormal Mode (LED Open)

Figure 23 and Figure 24 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.

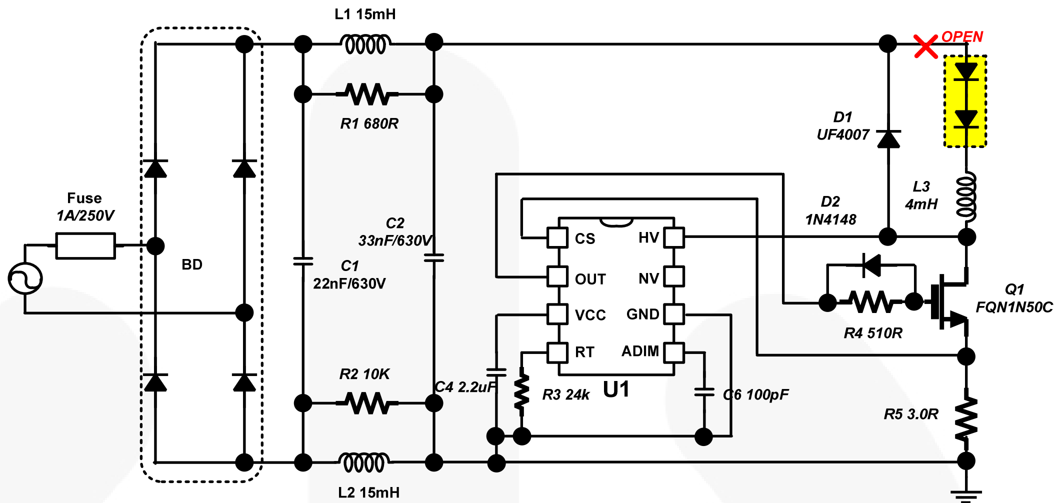
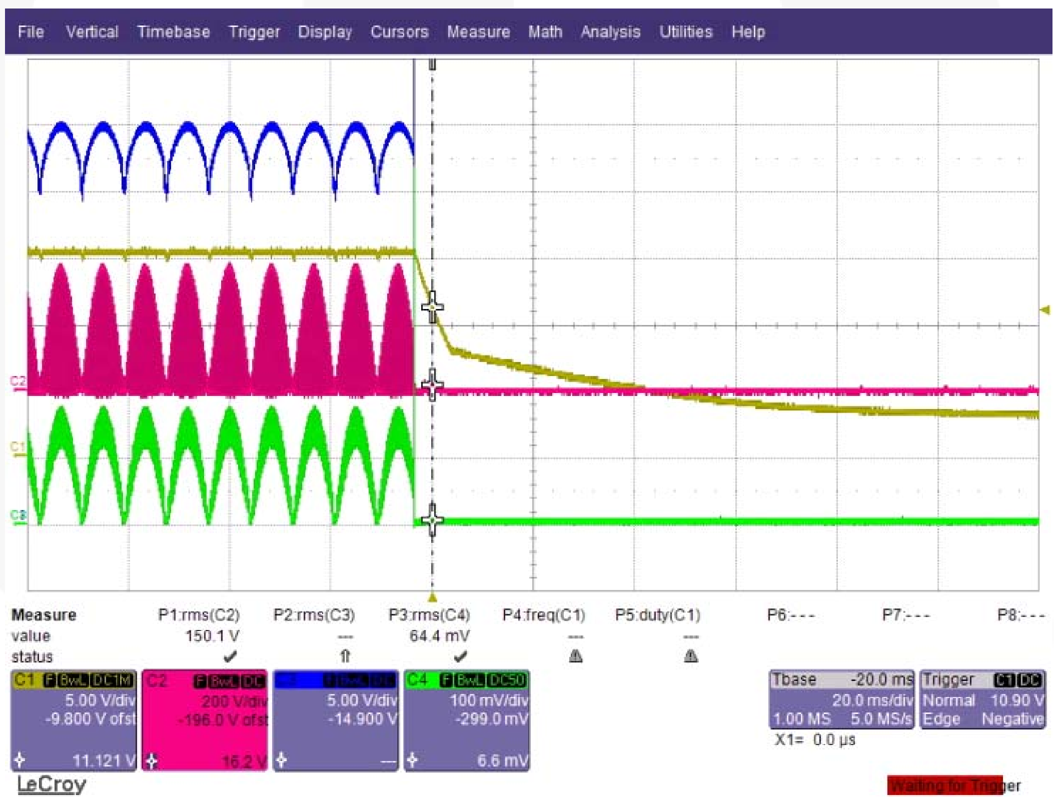


Figure 23. Open-Load Condition Test



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

Figure 24. Test Results of Open-Load Condition

8.5. Typical Waveforms: Abnormal Mode (Inductor Short Condition)

Figure 25 and Figure 26 show the test method and result of an inductor short condition. The FL7701 uses an abnormal over-current protection (AOCP) function, limiting the current on RCS in the event of an inductor short condition.

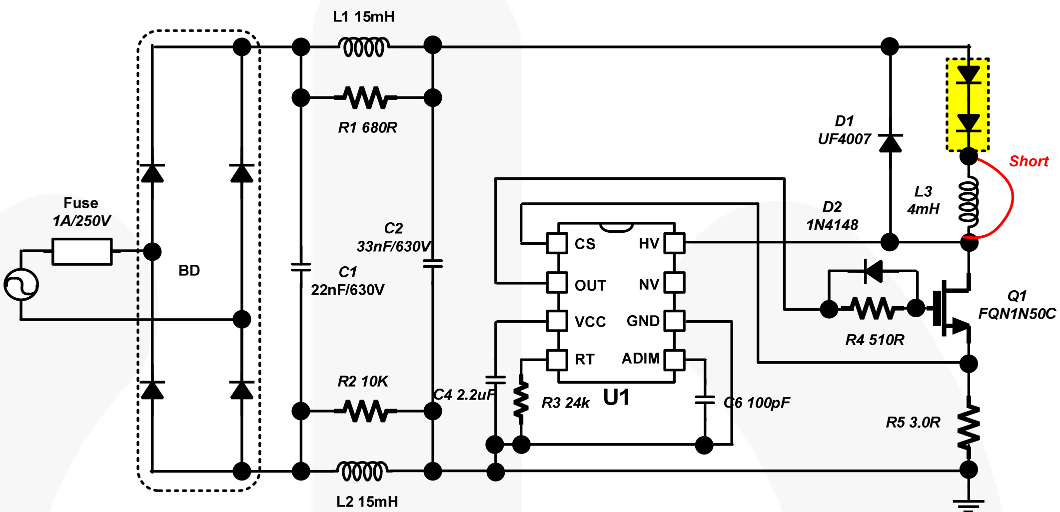
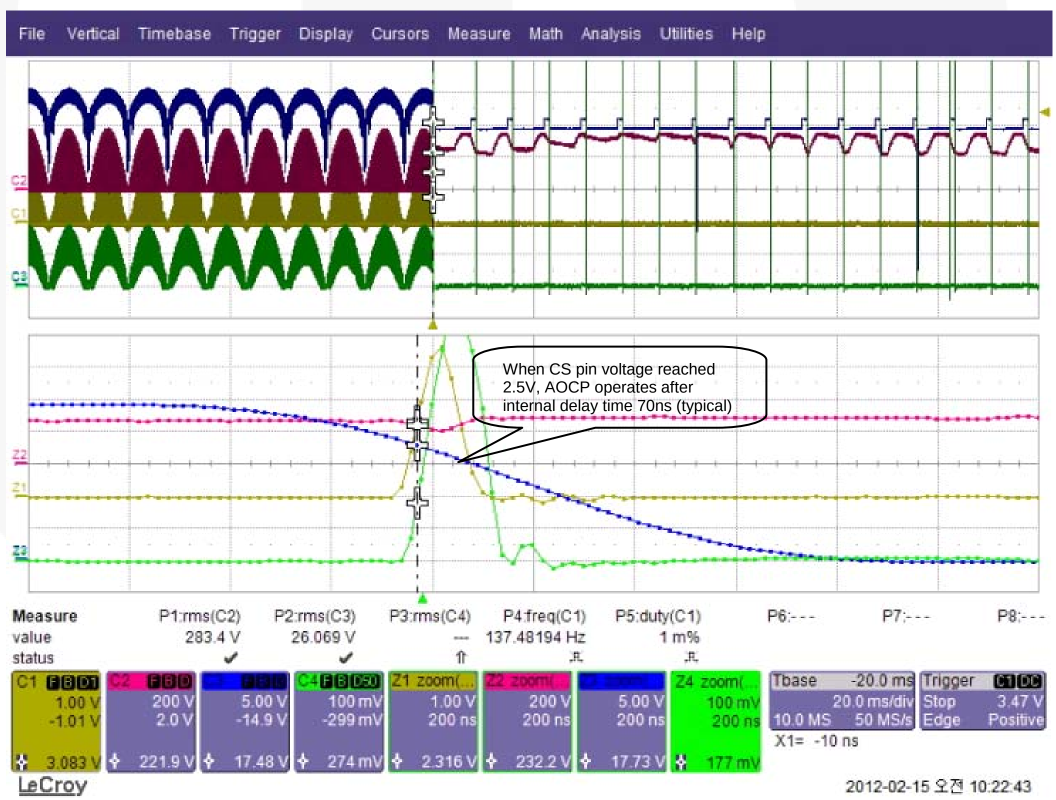


Figure 25. Inductor Short Condition



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

Figure 26. Test Results of Inductor Short Condition

9. Performance of Evaluation Board

9.1. Power Factor at Rated Load Condition

Figure 27 shows the system PF performance for the entire input voltage range (90V to 265V) at different input frequency conditions (47Hz, 64Hz). The PF slightly changes according to the input frequency but can achieve over 86% at 265V_{AC} condition.

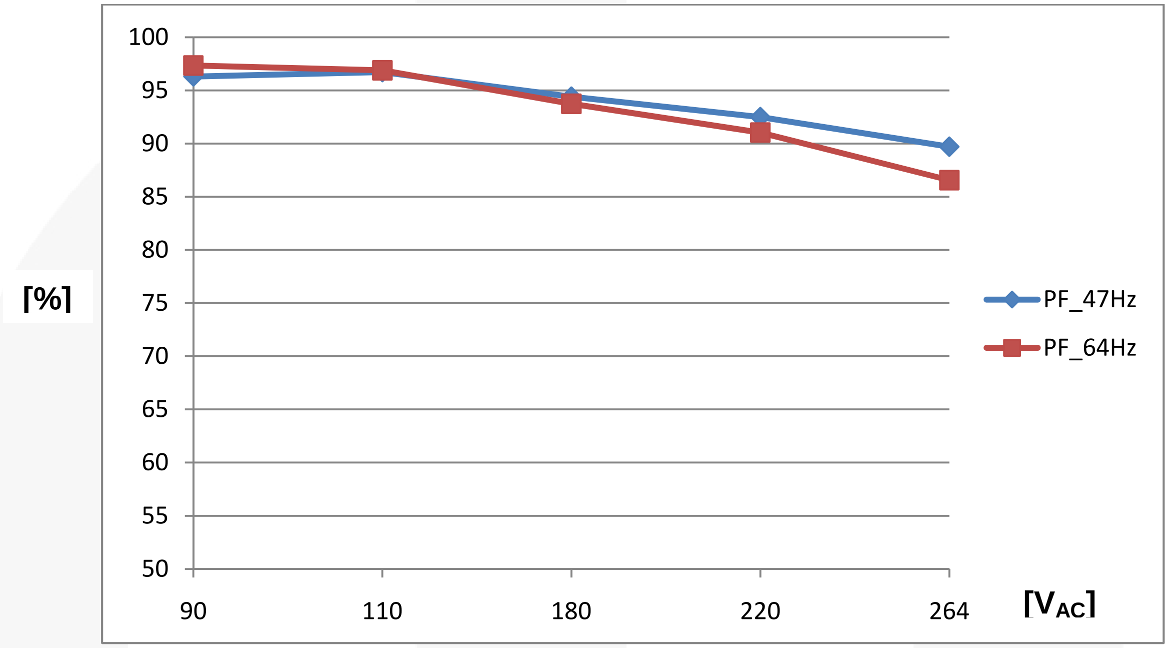


Figure 27. Power Factor

Table 3. PF Test Results

Input Voltage		Power Factor
90V_{AC}	47Hz	96.31
	64Hz	97.34
110V_{AC}	47Hz	96.72
	64Hz	96.89
180V_{AC}	47Hz	94.41
	64Hz	93.74
220V_{AC}	47Hz	92.49
	64Hz	91.09
265V_{AC}	47Hz	89.71
	64Hz	86.56

9.2. 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.

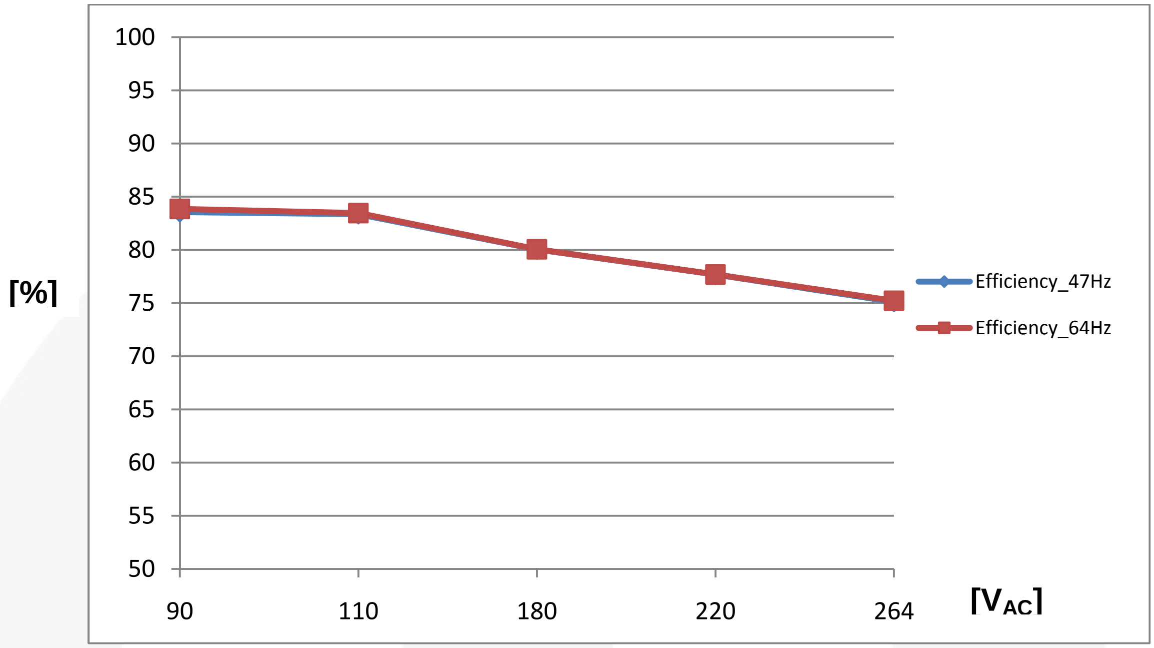


Figure 28. System Efficiency

Table 4. Efficiency Test Results

Input Voltage	Frequency	Efficiency (%)
$90V_{AC}$	47Hz	83.56
	64Hz	83.83
$110V_{AC}$	47Hz	83.36
	64Hz	83.46
$180V_{AC}$	47Hz	80.04
	64Hz	80.06
$220V_{AC}$	47Hz	77.68
	64Hz	77.69
$265V_{AC}$	47Hz	75.11
	64Hz	75.22

9.3. THD Performance

Figure 29 shows the THD performance at different input frequencies. Test results are quite similar, except the 90V_{AC} condition, but meets international regulations (under 30%).

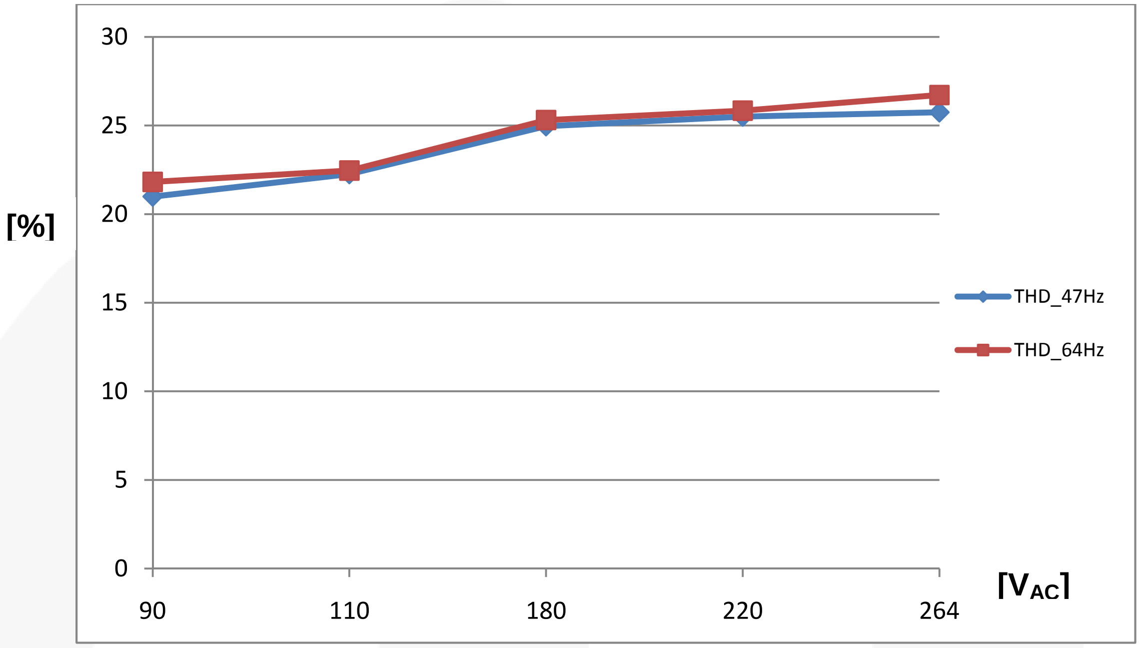


Figure 29. THD Performance

Table 5. THD Test Results

Input Voltage	Frequency	THD (%)
90V_{AC}	47Hz	20.99
	64Hz	21.82
110V_{AC}	47Hz	22.26
	64Hz	22.46
180V_{AC}	47Hz	24.96
	64Hz	25.31
220V_{AC}	47Hz	25.50
	64Hz	25.84
265V_{AC}	47Hz	25.75
	64Hz	26.72

9.4. Thermal Performance

Figure 30 through Figure 37 show the steady-state thermal 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 220V$_{AC}$ input condition.

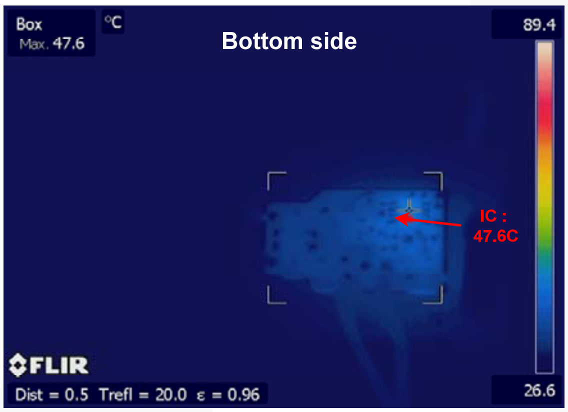


Figure 30. Thermal Test Result, Bottom-Side Temperature at 90V$_{AC}$ Condition (IC)

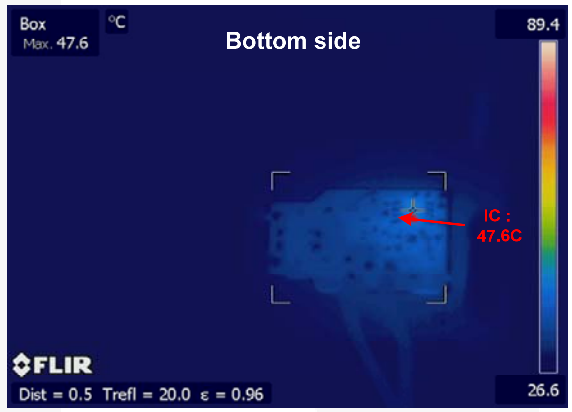


Figure 31. Thermal Test Result, Top-Side Temperature at 90V$_{AC}$ Condition (Inductor)

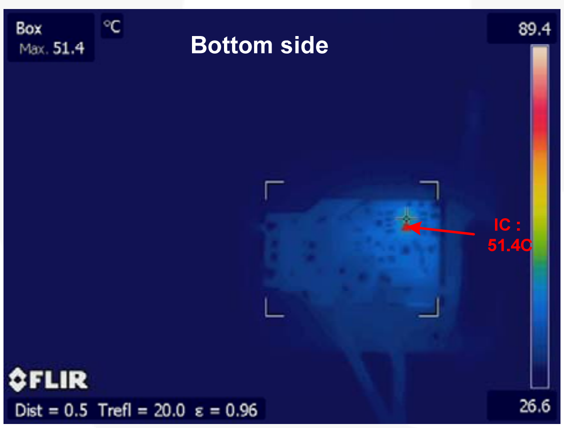


Figure 32. Thermal Test Result, Bottom-Side Temperature at 110V$_{AC}$ Condition (IC)

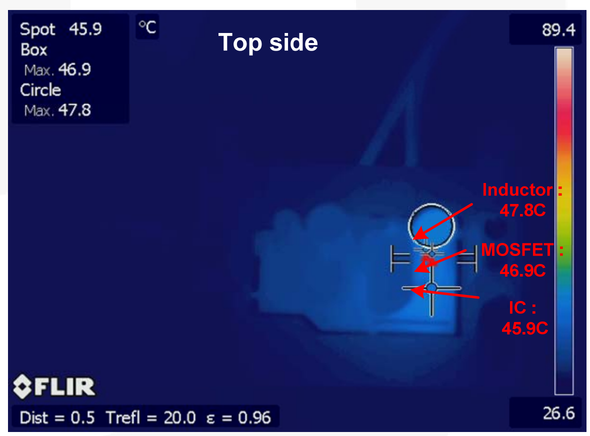


Figure 33. Thermal Test Result, Top-Side Temperature at 110V$_{AC}$ Condition (Inductor)

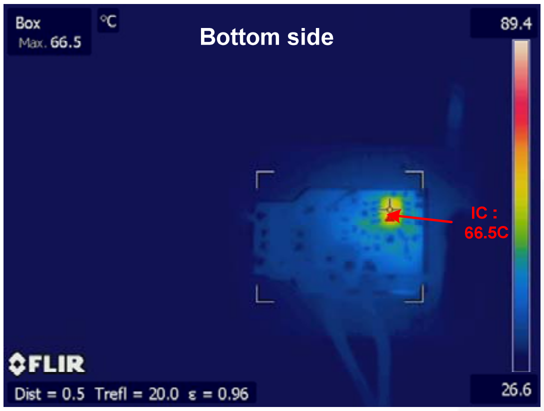


Figure 34. Thermal Test Result, Bottom-Side Temperature at 220V_{AC} Condition (IC)

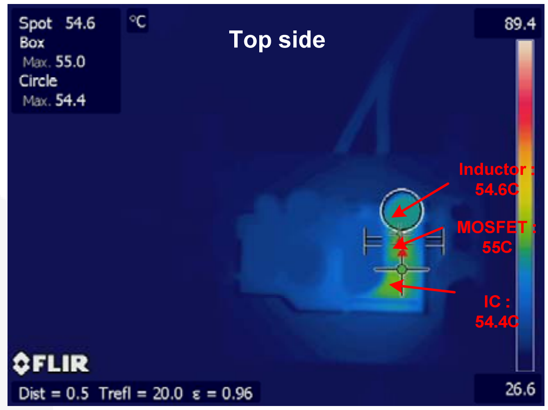


Figure 35. Thermal Test Result, Top-Side Temperature at 220V_{AC} Condition (Inductor)

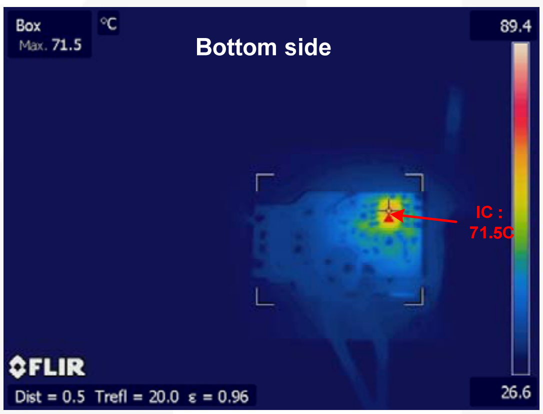


Figure 36. Thermal Test Result, Bottom-Side Temperature at 264V_{AC} Condition (IC)

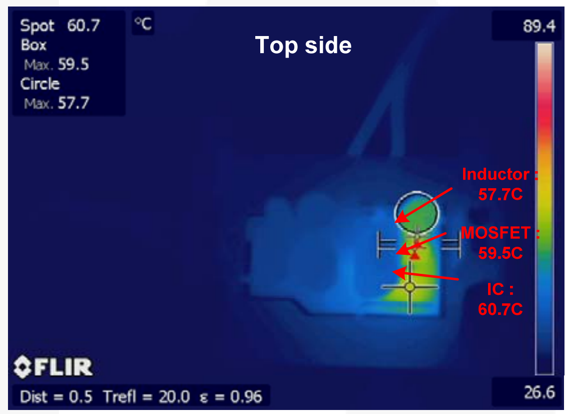


Figure 37. Thermal Test Result, Top-Side Temperature at 264V_{AC} Condition (Inductor)

Table 6. Temperature performance by Input voltage

Input Voltage	T_{IC}	T_{MOSFET}	$T_{INDUCTOR}$
90V_{AC}	47.6°C	46.2°C	47.8°C
110V_{AC}	51.4°C	46.9°C	47.8°C
220V_{AC}	66.5°C	55.0°C	54.6°C
265V_{AC}	71.5°C	59.5°C	57.7°C

9.5. EMI Results

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

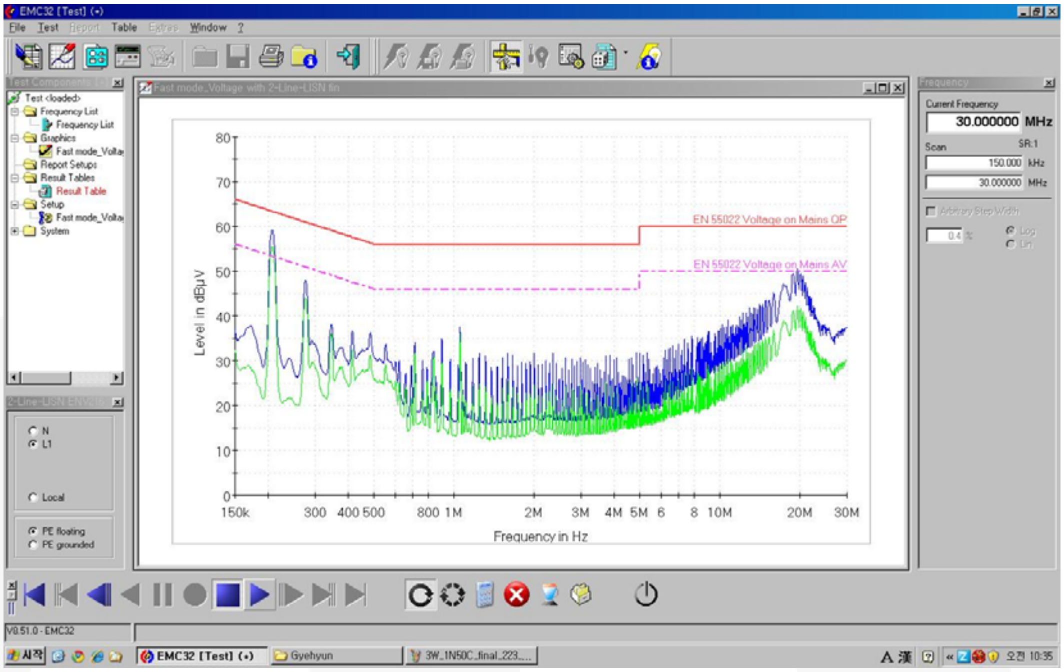


Figure 38. EMI Test Results, Conducted Emission-Line at 110V_{AC} Input Condition, Full Load (10-LED Series)

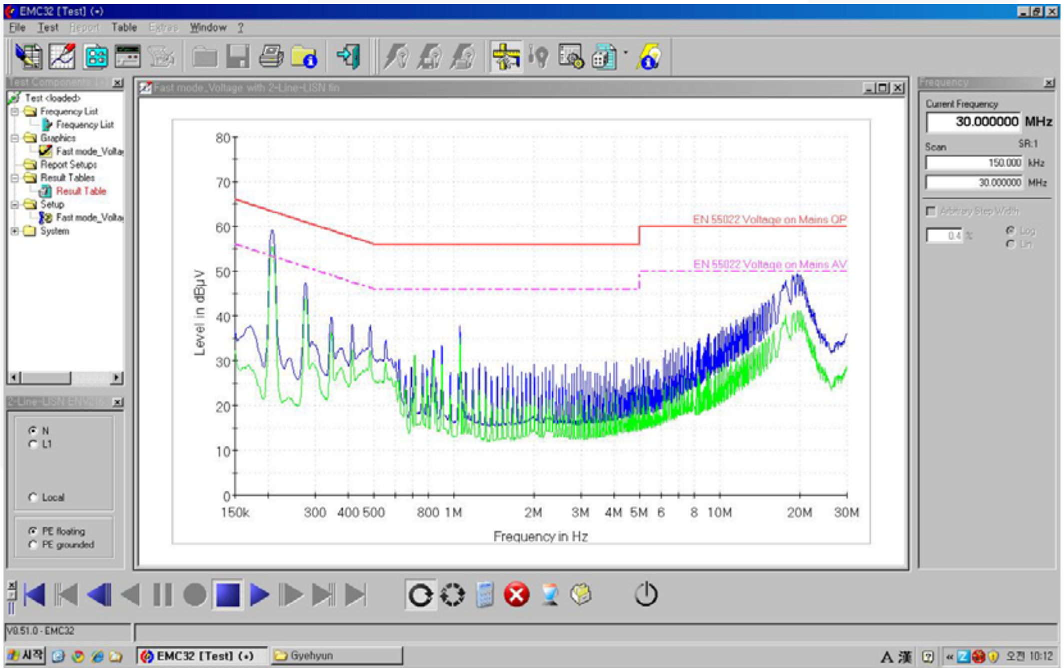


Figure 39. EMI Test Results, Conducted Emission-Neutral at 110V_{AC} Input Condition, Full Load (10-LED Series)

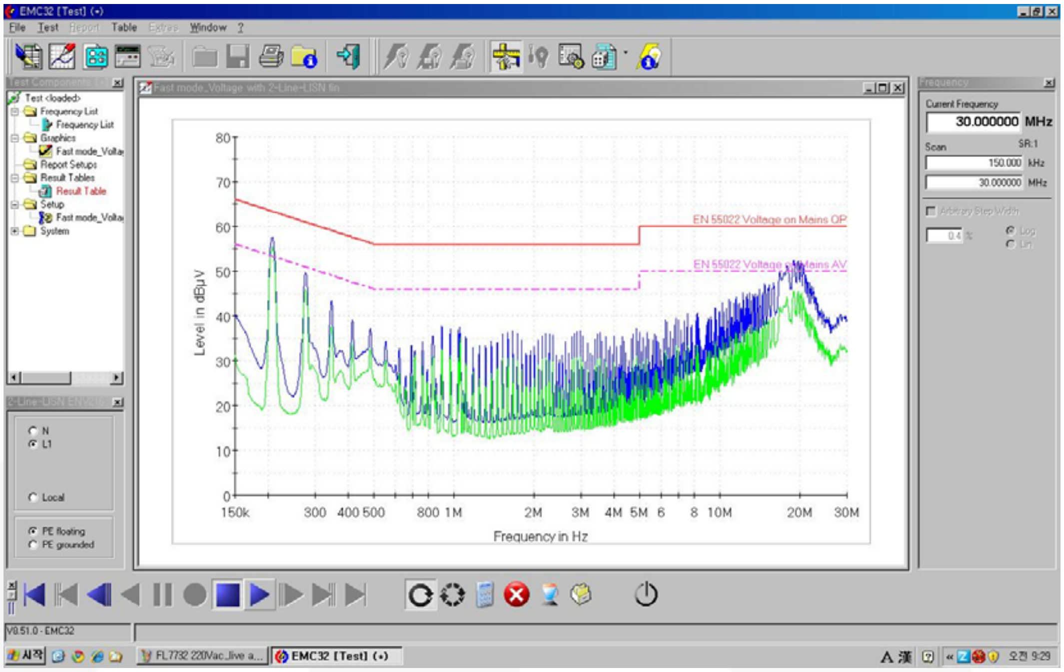


Figure 40. EMI Test Results, Conducted Emission-Neutral at 220V$_{AC}$ Input Condition, Full Load (10-LED Series)

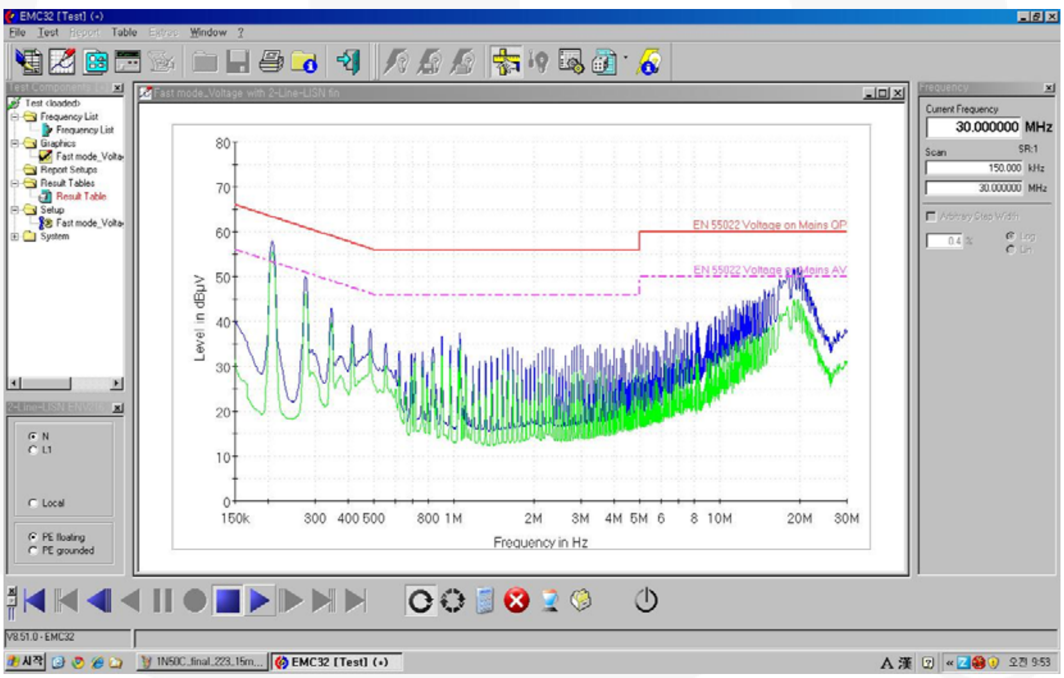


Figure 41. EMI Test Results, Conducted Emission-Neutral at 220V$_{AC}$ Input Condition, Full Load (10-LED Series)

10. Revision History

Rev.	Date	Description
0.0.1	2011.11.16	First issue
1.0.1	2011.11.30	Update IC temperature
1.0.2	2012.2.20	Modified, edited, formatted document. Changed User Guide number from FEB_L030 to FEBFL7701_L30U003A