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Design of a Converter with Anti-blinking Circuitry for T5 LED Indirect Lighting

Woo-young Kim[1], Quoc Cuong Nguyen[2], Seong-Kweon Kim[3]

[1]Ph.D. Candidate, Department of Information Technology & Media Engineering, Seoul National University of Science and Technology, Korea
[2]Assistant Professor, Faculty of Engineering, Dong Nai Technology University, Bien Hoa city, Vietnam
[3]Professor, Department of Information Technology & Media Engineering, Seoul National University of Science and Technology, Korea
[1]hero_486@hanmail.net, [2]nguyenquoccuong@dntu.edu.vn, [3]kim12632@seoultech.ac.kr

Abstract

We address the problematic issue of blinking in residential LED lighting systems—a phenomenon that has recently become a significant concern due to voltage sags caused by high-power household appliances. To combat this, we developed a two-stage LED converter with integrated anti-blinking circuitry, specifically designed for T5 LED indirect lighting fixtures. The first stage employs a Power Factor Correction (PFC) boost circuit to enhance voltage stability by aligning the voltage and current phases, thereby minimizing power losses. The second stage, a meticulously engineered DC-DC buck converter, ensures stable lighting despite electrical fluctuations. Rigorous testing has confirmed our converter's efficacy in maintaining consistent light output without blinking, thereby substantially improving user comfort and adhering to strict standards for harmonic distortion and electromagnetic compatibility. Our breakthrough provides a robust solution to a pressing issue, marking a significant advancement in LED lighting technology.

Keywords: *LED, Luminaire, Converter, Voltage sag, Two-stage circuit, Blinking, Lighting*

1. Introduction

In recent advancements within residential lighting technologies, LEDs have become central due to their energy efficiency, longevity, and environmental friendliness [1, 2]. Despite their widespread adoption, an increasingly significant issue is the occurrence of blinking in LED lighting systems. This problem, caused by abrupt and irregular light interruptions, has escalated into a notable concern due to its potential to induce stress and health issues in users, thereby necessitating prompt and effective solutions [3].

Until recently, the blinking issue in LED lights has been prematurely attributed to faults within the LEDs or their converters. Efforts to mitigate these disruptions typically involved superficial remedies such as

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Corresponding Author: kim12632@seoultech.ac.kr
Tel: +82-2-970-6432,
Professor, Department of Information Technology & Media Engineering, Seoul National University of Science and Technology, Korea

modifying the converter's PCB layout or replacing the driver ICs without a true understanding of the underlying causes. Recent investigations have revealed that the primary cause of blinking is voltage sags initiated by the use of high-power household appliances. Devices requiring significant power loads, such as electric bidet seats, heaters, induction cookers, and instant water heaters, contribute to these voltage sags. These appliances provoke sudden voltage fluctuations at the input of LED converters, leading directly to blinking. Such voltage fluctuations often result from the rapid on/off cycling of these high-demand appliances, culminating in converter malfunctions that manifest as blinking [4-6].

This issue affects not only LED lighting but also other electronic devices, although it is most visually noticeable in LED lights, significantly inconveniencing users. Consequently, major construction companies have started to mandate the incorporation of converters that are resilient to external disturbances in their lighting fixture specifications, actively combating the blinking issue [7].

Given these challenges, there is a clear demand for a reevaluation of power network designs and power usage management in residential settings. This encompasses not only technological enhancements but also a deeper comprehension of household power consumption patterns and thorough analyses of the interactions between electrical appliances and lighting systems. This paper proposes the integration of an anti-blinking circuit within a newly designed, compact, and highly efficient LED converter. Specifically developed for T5 LED fixtures, which are increasingly popular in indirect lighting applications, this solution is aimed at enhancing the usability of LED lighting and ultimately safeguarding user health and comfort.

2. Design Structure

2.1 Definition of Voltage Sag

According to IEEE-1159, a voltage sag is characterized by a decrease in RMS voltage to between 0.9 PU and 0.1 PU over durations ranging from half a cycle to one minute. This phenomenon is classified into three types based on duration: instantaneous, momentary, and temporary, as detailed in the table below [8].

Table 1. Classification of instantaneous voltage sags

Voltage Dips Classification	Instantaneous	Momentary	Temporary
Duration	0.5 ~ 30 cycles	0.5 ~ 30 cycles	3 sec. ~ 1 min.

2.2 Configuration of the Two-stage LED Converter

To address voltage sags and meet the standards of KS C IEC 61347-2-13 and KS C IEC 62384, the converter is designed as a two-stage circuit

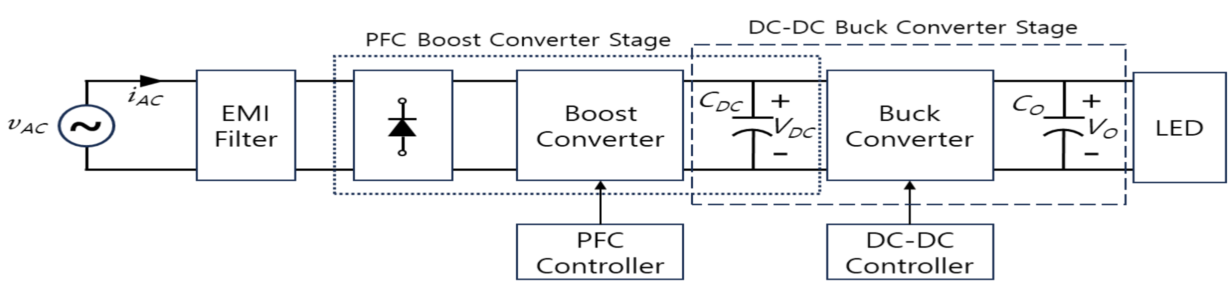

Figure 1. The conceptual diagram of the double-stage LED-driving power converter

The first stage uses a Power Factor Correction (PFC) boost circuit to align the phase angle close to zero degrees, minimizing the phase difference between voltage and current, thus approaching real power while meeting international standards for maximum allowable harmonic current [9, 10].

The second stage consists of a DC-DC buck converter that receives the boosted voltage to supply a stable output to the LED module. Given the specifications of T5 fluorescent lamp fixtures, which typically measure about 16 mm in diameter, the recent transition to LED equivalents does not demand exact dimension compliance but does require a simplified circuit due to the confined space within the converter housing [11]. Consequently, a non-isolated buck converter is designed to fit within these compact dimensions [12].

2.3 Circuit Design and Component Configuration

The control ICs selected for assembling the two-stage circuitry include built-in FETs, which help reduce the size of the circuit board while ensuring heat generated by the circuit is managed efficiently. Figure 2 illustrates the schematic of the circuit using two FET-integrated controller ICs, based on which component values are determined and PCB artwork for converter sample production is planned.

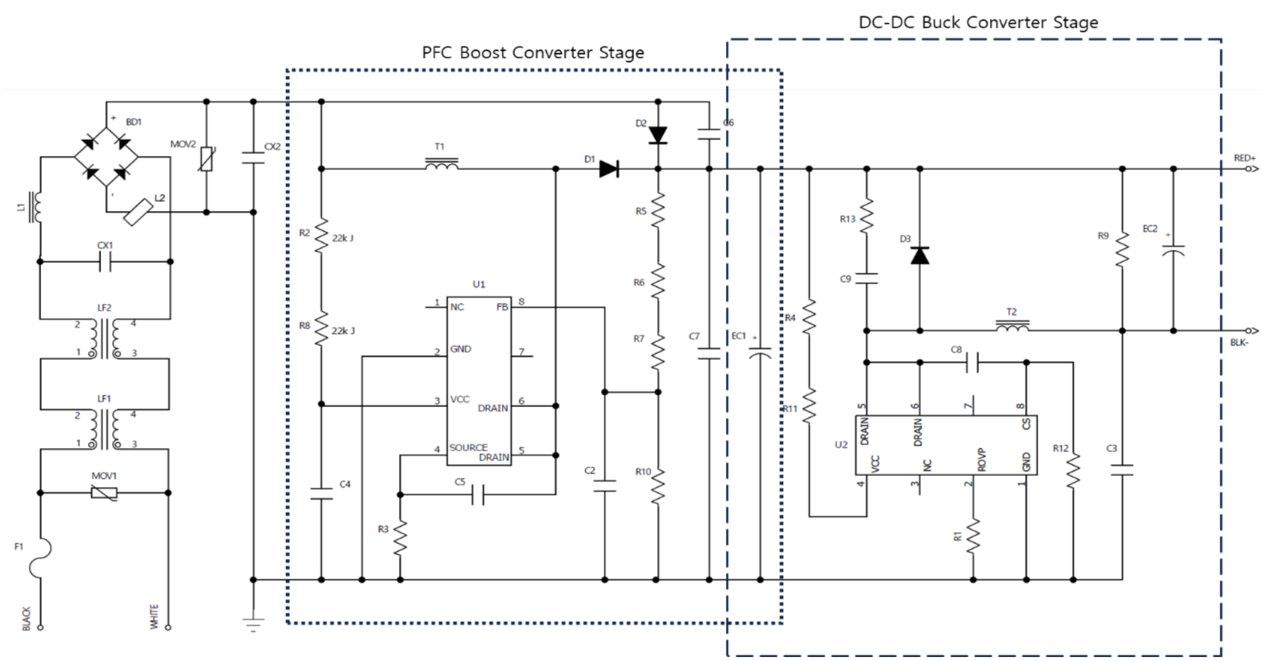

Figure 2. Schematic of a two-stage LED-driving power converter

In the AC input stage, the design incorporates an EMI filter to minimize electromagnetic interference, ensuring the converter meets electromagnetic compatibility standards. Following rectification, the voltage is boosted to 400V through the PFC controller(U1) and the switching transformer(T1). At this time, the PFC controller compares the output voltage through the FB pin to an internal high-precision 2.5 V reference to maintain a constant output voltage. In closed-loop control, the output voltage is determined by the following equation (1).

$$V_o(V) = \frac{V_{ref}}{R_{fb\_2}} \times (R_{fb\_1} + R_{fb\_2}) \quad (1)$$

In the equation above, R_{fb_1} means the Upper voltage divider resistor and R_{fb_1} means the resistor between FB pin and GND.

In the PFC stage, the rectified 400V DC voltage is fed into a DC-DC buck converter. It is then converted to a lower voltage suitable for the LED module through controller U1 and switching transformer(T2). T5 LED lighting fixtures of 1200mm length typically consume around 20 W of power. The DC-DC controller used in the buck circuit of the second stage is in QR-Buck mode, where the IC keeps the CS peak current constant and starts a new PWM cycle with valley switching. Thus, high-precision CC and high conversion efficiency can be achieved simultaneously. The average LED regulated output current is given by the following equation (2).

$$I_{cc_{out}}(mA) = \frac{1}{2} \cdot \frac{V_{cs(max)}}{R_{cs}} = \frac{300mV}{R_{cs}(\Omega)} \tag{2}$$

In the equation above, R_{CS} means the sensing resistor connected between the CS pin to IC GND. Utilizing this approach, the converter's output current was designed to maintain a constant current of 160 mA. When operating with a 114 V LED load, the converter aims for a power consumption of 20 W and an efficiency of approximately 91%. Over Voltage Protection (OVP) was set to a maximum of 155 V to accommodate voltage variations, and the design allows for a minimum power consumption of 12 W based on adjustments to the load voltage.

2.2 Artwork for the Converter PCB

Before designing the PCB, the structure of the T5 lighting fixture targeted for application was analyzed to select the appropriate size for the PCB and components, and to plan the artwork. Figure 3 is a drawing of the intended T5 fixture, which has a width of 22.5mm. However, due to the groove for the ceiling attachment bracket, the available width is confirmed to be 18.9mm, and there is a space of 17.3mm in height. Considering the cost-effectiveness and ease of obtaining product certification, an external converter design was required, and an extruded outer case made of 0.5mm thick Polypropylene (PP) material was selected. Thus, taking into account the clearance, the width was set to 16mm and the height to 14mm including the lead of the insert components on the bottom surface.

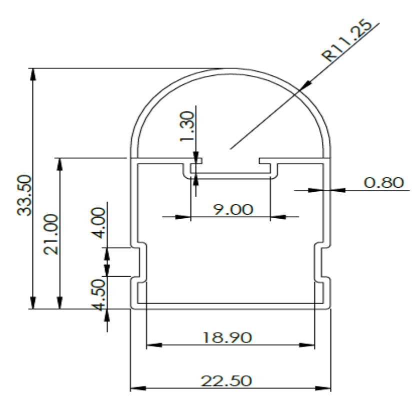

Figure 3. Structural diagram of the T5 LED fixture for the designed converter

Based on the design described above, the PCB for the Converter was created as shown in Figure 4. The material was set to FR-4 with a thickness of 1.2T and 1 oz of copper to satisfy both heat dissipation and thickness requirements, and was designed as a double layer to mount all components on the top layer for improved productivity.

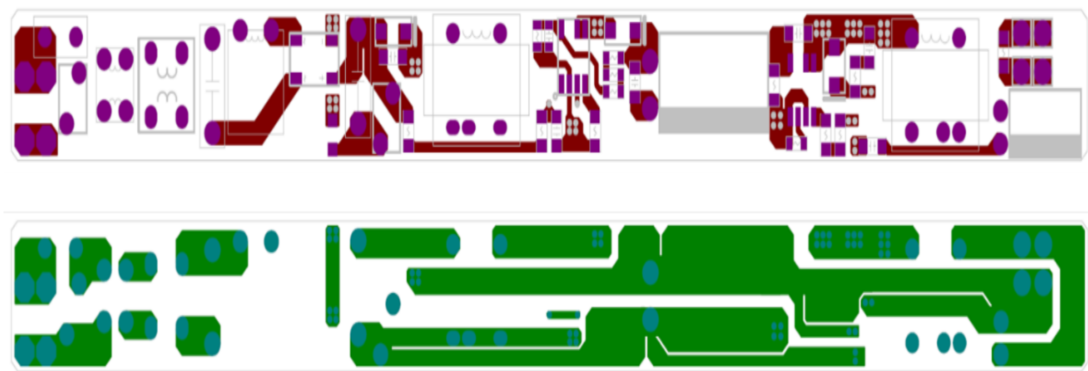

Figure 4. Top and bottom layers of the designed PCB for the converter

Considering the characteristics of T5 LED fixtures, which are connected to a single AC power source, the AC input line was designed to accommodate two sets of inserts. Since both the fixture and the converter housing are made of PP material, and the converter is mounted inside the housing, frame ground was not designed.

3. Result and Discussion

The images below showcase the top and bottom layers of the prototype converter. Within the 16 mm width of the PCB, all components were securely mounted and the spacing between patterns met all the necessary safety standards, as can be seen in Figure 5.

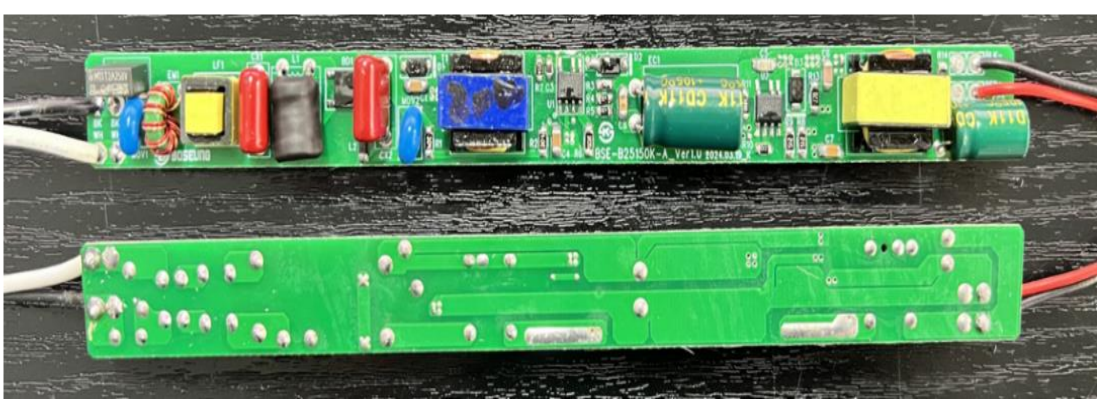

Figure 5. Top and bottom layers of the prototype converter

3.1 Voltage and Current Waveform Analysis

To verify the proper functioning of the anti-blinking circuitry targeted in this paper, we compared it with products using conventional isolated converters designed with typical flyback circuits. Notably, we tested a hot-plate known to induce blinking, which was purchased off the shelf. An oscilloscope was used to set up as depicted in Figure 6 and to measure the output current waveform with respect to Voltage sag.

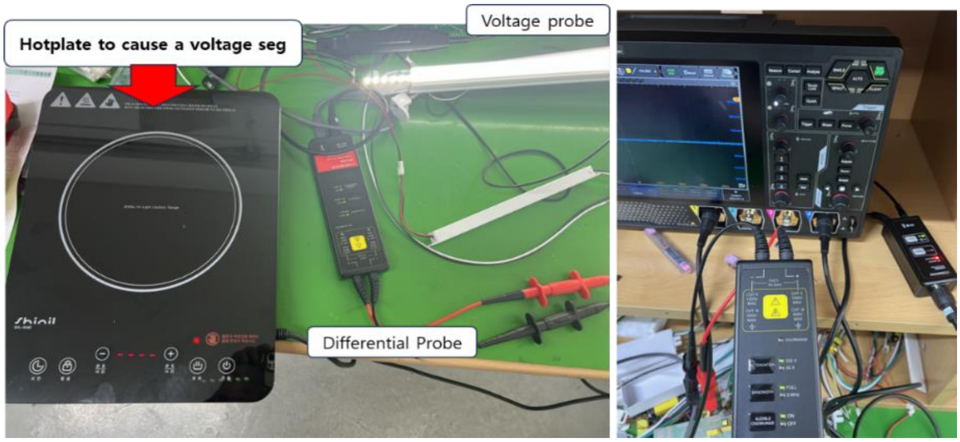

Figure 6. Setup for measuring the converter's voltage and current waveform

Figure 7 illustrates the changes in voltage/current waveforms of a typical converter before (left) and after (right) the operation of the hot plate. The yellow represents the voltage waveform, and the blue represents the current waveform. Even in a normal state, current flickering can be observed. On the right image, marked with red arrows, Voltage sag occurrence can be seen, which also leads to fluctuations in the current waveform. This results in an uneven current supply to the LEDs, thereby causing the blinking problem.

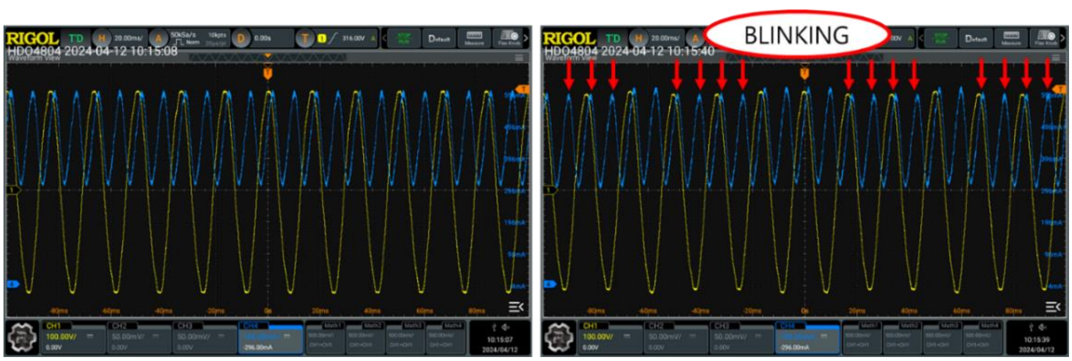

Figure 7. Changes in voltage waveform due to voltage sag

Figure 8 displays the voltage and current waveforms of the converter designed in this study. The left image shows the waveforms under typical conditions, where it can be observed that the two-stage circuit inherently does not produce flickering. The right image presents the waveforms after inducing a voltage sag. Here, distortion can be seen in the voltage waveform due to the voltage sag, yet the current waveform remains stable. Thus, it is confirmed that the designed converter effectively resolves both flickering and blinking issues.

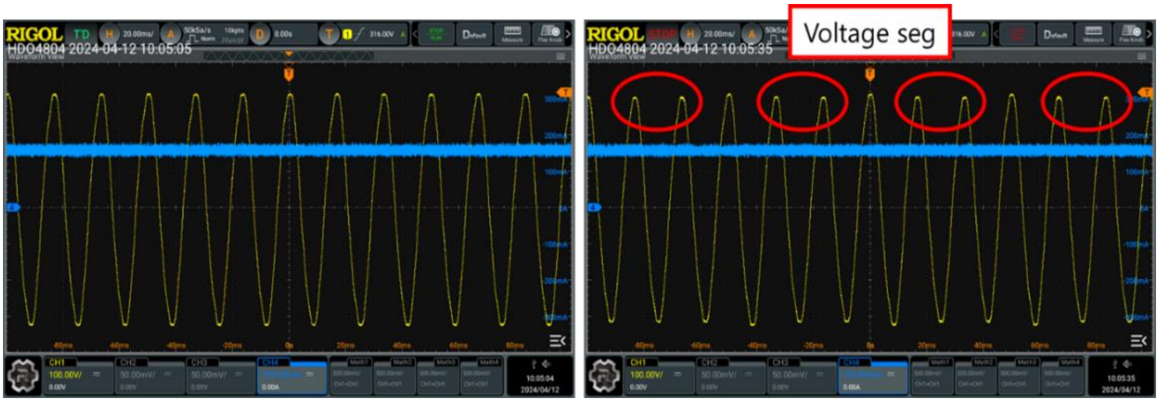

Figure 8. Voltage and current waveform graphs of the developed converter

3.2 Electrical Characteristics Analysis

The designed converter successfully outputted the targeted constant current of 0.16 mA. However, due to voltage variations in the load LEDs, the output voltage was observed to be 106 V, lower than the targeted 114 V, consequently reducing the power consumption to 18.4 W. Despite this reduction, the converter achieved a high efficiency of 92.2% with an output power of 17 W relative to the input power. The power factor was measured at 0.98, meeting all the criteria of the KS C 7655 standard.

Figure 9 displays the harmonic content of the designed converter. The harmonic currents, expressed in mA, divided by the power consumption of 18.4 W, are detailed in Table 2. A comparison of these figures against the harmonic current standards specified in KS C IEC 61347-2-13 and KS C IEC 62384 for fixtures with a rated input power of 25 W or less confirms that the converter comfortably meets these standards.

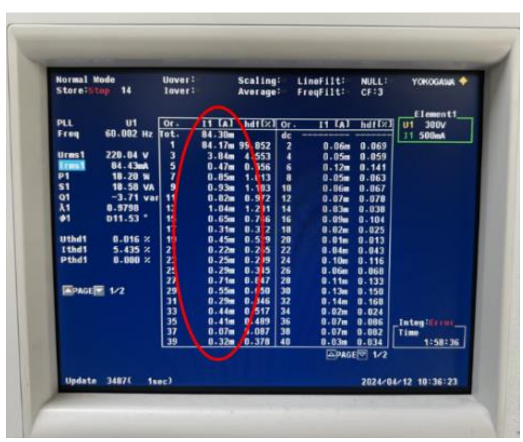

Figure 9. Measurement of harmonic content by order

Table 2. Harmonic current standards with an input power rating of 25W or less

Maximum Allowable Harmonic Current (mA)									
2nd	N/A	**3rd**	3.4 or less	**5th**	1.9 or less	**7th**	1 or less	**9th**	0.5 or less
11th	0.35 or less	**13th**	0.296 or less	**15th**	0.257 or less	**17th**	0.226 or less	**19th**	0.203 or less
21st	0.183 or less	**23rd**	0.167 or less	**25th**	0.154 or less	**27th**	0.143 or less	**29th**	0.133 or less
31st	0.124 or less	**33rd**	0.117 or less	**35th**	0.11 or less	**37th**	0.104 or less	**39th**	0.099 or less

3.3 Electromagnetic Disturbance Test

Figure 10 presents the graphs for the conducted emissions test (left) and the radiated emissions test (right). The tests were carried out inside a 10 m chamber at an accredited certification agency. Both tests were passed with a considerable margin, confirming that the product meets the standards and is clear for commercialization without any issues related to electromagnetic interference.

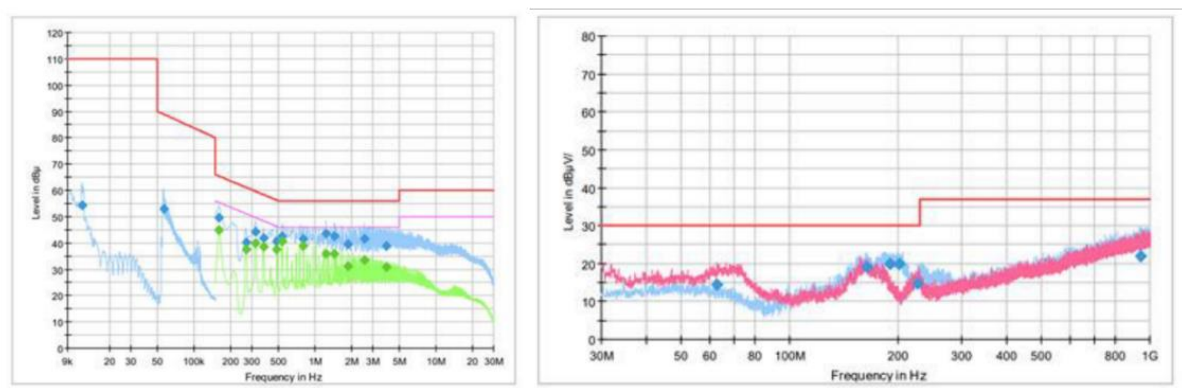

Figure 10. Graphs of conducted and radiated electromagnetic interference tests

4. Conclusion

We have presented a novel design and validation of a compact converter specifically engineered to address the pervasive issue of blinking in LED lighting, particularly suited for T5 LED indirect lighting applications. Through our development of a two-stage circuit, we have effectively countered the blinking effect that plagues many residential environments. Our approach integrates a PFC Boost circuit in the first stage, which not only adheres to the stringent power factor and harmonic standards set by KS criteria but also plays a crucial role in stabilizing voltage to prevent blinking. The second stage incorporates a DC-DC Buck converter that ensures a constant current flow, thereby mitigating the risk of flickering even during significant voltage sags.

Our extensive testing regime has demonstrated that our converter achieves an operational efficiency exceeding 92%, thereby meeting the high standards required for energy-efficient equipment certification. Moreover, the successful passing of all electromagnetic compatibility tests confirms that our converter is ready for commercialization, providing an optimal solution that enhances the quality and reliability of LED lighting systems. By applying this design across various LED fixture standards and configurations, we offer a highly effective remedy to the prevalent issue of LED light blinking, thereby enhancing user comfort and reducing energy consumption.

In conclusion, our work not only advances the technological application in lighting but also sets a new benchmark in the design of energy-efficient, stable LED lighting solutions that can significantly improve user experience and environmental impact.

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