EMI Mitigation in LED Driver Design: A Technology Strategy for Business Value

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Abstract
Electromagnetic interference (EMI) poses a significant challenge in the design of LED drivers, particularly in achieving compliance with electromagnetic compatibility (EMC) standards while maintaining development cost-efficiency. This paper explores a set of cost-effective EMI mitigation strategies, including using single bus architectures for universal voltage compatibility, boost converter frequency selection to avoid third harmonic issues, and jitter modulation to flatten EMI peaks in half-bridge converters. Drawing on real-world design experience, these techniques have successfully reduced EMI, lowered development costs, and accelerated time-to-market. The paper also highlights how these solutions align with broader business strategies, offering scalable, globally compliant designs that support market expansion and profitability.

Keywords: LED Driver Design, Power Supply Design, Switching Power supply, SMPS, Electromagnetic Interference (EMI), Electromagnetic Compatibility (EMC), Jitter Modulation, Frequency Selection, EMI Mitigation, Cost-Effective Design, Product Development, Time-to-Market, Business value, Strategy.

INTRODUCTION

The LED lighting industry is evolving rapidly, driven by the technology's energy efficiency, long lifespan, and environmental benefits. However, the design of LED drivers comes with challenges in terms of alignment with business needs, which drives the technology or design strategy that needs to be used. In most LED driver or home automation companies, businesses often expect a single design or product to serve the universal market, meaning it could be sold in any market. This means that product design strategy should be focused on designing products for universal compliance requirements, which often change with the country while designing for low manufacturing and development costs. The LED drivers are used mainly to power the LEDs with DC voltage and regulate current for optimal performance. However, like other power electronics components, electromagnetic compatibility is a challenge as they must meet compliance requirements like CISPR 15 EMI- Lighting Equipment [1] and other international requirements. In order to meet these requirements, the design of power supply design is crucial.

The design of power supplies, particularly switching power supplies commonly used in LED drivers, plays a pivotal role in addressing EMI issues. Unmitigated EMI can lead to significant development delays, increased costs, and damage to the reputation of the final product. This paper will explore technical strategies, specifically jitter methods and frequency selection, to mitigate EMI and ensure compliance with EMC standards. Additionally, it will highlight how these technology-driven approaches can lower development costs, accelerate time-to-market, and align with broader business goals.

Electromagnetic interference poses a persistent challenge in the design of LED drivers, as manufacturers strive to comply with rigorous electromagnetic compatibility standards while maintaining cost-efficiency and time-to-market [2]. This paper explores a suite of practical, cost-effective EMI mitigation strategies that have proven successful in real-world LED driver development, including the use of single bus architectures, strategic selection of converter switching frequencies, and the application of jitter modulation techniques to address EMI issues in half-bridge converter topologies. One key approach to reducing EMI and development costs is the adoption of single-bus architectures that offer universal voltage compatibility [3].

LITERATURE REVIEW

Some of the key considerations for LED driver design include optical, electrical, thermal, and mechanical factors, emphasizing manufacturability, cost, and reliability [4]. Addressing Electromagnetic Interference (EMI), especially in switching power supplies, in the initial designing phase can solve all the above requirements. This is true due to the increased focus on EMC compliance standards and the certifications that enhance the product's market positioning and competitive advantage. Several studies and publications explore the mechanisms of EMI generation in switching power supplies and the effectiveness of different mitigation strategies.

In his foundational work, [5] provided a comprehensive overview of EMC engineering, detailing how switching power supplies, such as those used in LED drivers, inherently generate high-frequency noise due to the rapid switching of currents and voltages. Ott highlighted the importance of optimizing circuit layout and filtering techniques to reduce EMI emissions in power converters.

F. Pareschi, R. Rovatti, and G. Setti (2015) [6] investigated the use of dithering or jitter modulation in LED driver circuits to reduce EMI. Their study demonstrated that applying a slight modulation to the switching frequency could significantly spread the noise spectrum, lowering the peak energy concentrated at specific frequencies. This method proved effective in reducing the sharp noise peaks typically generated by fixed-frequency switching in LED drivers.

In addition, research by [7] Lynch Brian T. explored the optimal way and considerations for designing the boost converter that is more suitable for single bus architecture. Other research recommended selective operating frequency to avoid third harmonic EMI issues, especially for universal voltage applications and highlighted the tradeoffs with efficiency, cost, and complexity. [8][9][3]

These studies provide a strong foundation for the technical strategies discussed in this paper, demonstrating the importance of early EMI management in power electronics design. By building on these approaches, the present paper focuses on cost-effective methods that align with the business objectives of LED lighting manufacturers, including reducing development costs and improving time-to-market.

STRATEGIES

This paper draws on the authors' practical design experience in developing cost-effective LED driver solutions that comply with EMC standards. The author concentrates on the three main technology strategies, one of which is to design power suppliers for LED drivers with reduced EMI and EMC issues, thereby meeting business needs and strategies.

Single Bus Architecture:

One key approach to reducing EMI and development costs is the adoption of single-bus architectures that offer universal voltage compatibility. This strategy eliminates the need for multiple power converters or complex switching topologies to handle different input voltage ranges, simplifying the overall circuit design and reducing component count [9]. By using a single power conversion stage, the EMI profile is significantly improved, as there are fewer potential noise sources and less complex switching dynamics. The input voltage across the world varies, and Japan has the lowest voltage at 100V and the highest voltage in Europe and Asia at around 230V. This provides a huge challenge to power supply designers as they need a single product to meet the same requirements with a wide range of input voltages. This might not be a challenge when it's a low-power and low-current design. However, when the power levels go higher, the design complexity increases manifold.

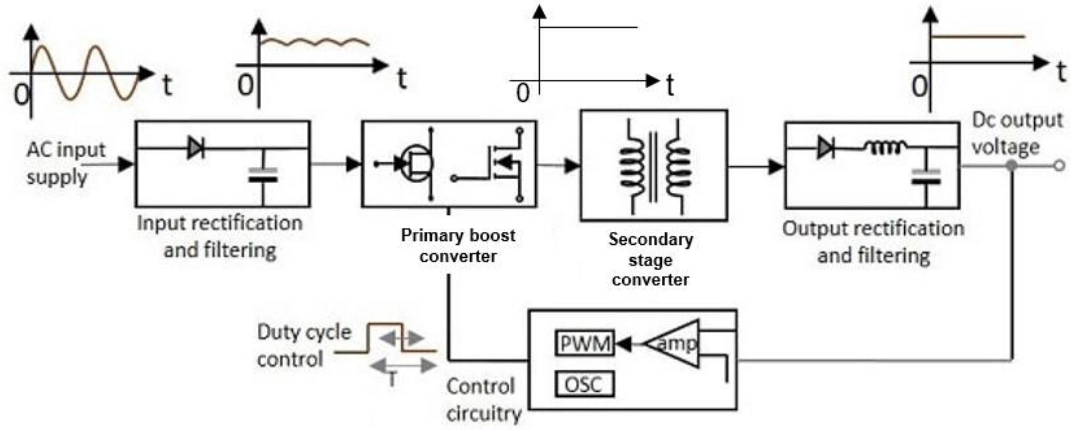


Figure 1: Concept of Single bus architecture

Using the single-bus architecture approach, the power supply can handle the wide input voltage range without needing to have specific topologies for each voltage level. A boost converter should be designed to take the input of variable voltage from 90V to 277V. This voltage is considered by applying a 10% tolerance to the universal voltage range for residential design consideration.

RMS Voltage range = $Vrms \; * \; \sqrt{2}$

So, the Single bus architecture would result in developing a boost design with an output voltage of around 400-450V for LED drive. The power of the boost design depends on the load used. This design ensures that a single input stage, irrespective of the line voltage or load voltage, can drive the LED loads efficiently and also meet the EMI and EMC requirements. However, a secondary stage voltage converter is needed to convert high voltage to class 2 isolated low voltage.

Frequency Selection:

As per the CISPR, 15 EMI- Lighting Equipment standard the testing of the for the conducting emission test has a test range of 150 kHz — 30 MHz. Using a switching frequency higher than 150 kHz causes a shift of conducted emissions above the lower limit of the CISPR 15 standard due to its direct relationship with power. In addition, the harmonic content produced by the switching converter should not coincide with the lower frequency conducted EMI range, which typically occurs around the third and fifth harmonics. Choosing the switching frequency lower than 120Hz helps. For example, selecting a switching frequency of around 70 kHz for a boost converter used in an LED driver will shift the emissions above the CISPR 15 lower limit while avoiding harmonics in the critical conducted EMI range.

Jitter Modulation:

Jitter modulation is an effective technique to spread the spectral energy of EMI in LED driver circuits. By introducing a small random or pseudo-random variation in the switching frequency, the EMI peaks can be significantly flattened, reducing the amplitude of the conducted and radiated emissions. This approach leverages the fact that the EMI profile of a fixed-frequency converter exhibits sharp spikes at the fundamental switching frequency and its harmonics. Applying jitter modulation causes the energy to be distributed across a wider frequency band, lowering the peak energy levels and helping the design meet EMC standards without requiring additional filtering. The jitter modulation can be implemented in the controller IC or using discrete components like varactor diodes. An optimum level of jitter modulation depth is required to balance the EMI reduction and potential efficiency impact. These technical strategies have been successfully applied in real-world LED driver designs, enabling cost-effective solutions that meet stringent EMC requirements.

RESULTS AND DISCUSSION

The EMI mitigation techniques described in this paper have been implemented in practical LED driver designs, demonstrating their ability to reduce conducted and radiated emissions while minimizing development costs and time-to-market.

Adopting a single bus architecture with a boost converter topology has simplified the power circuit, reduced component count, and improved the overall EMI profile.

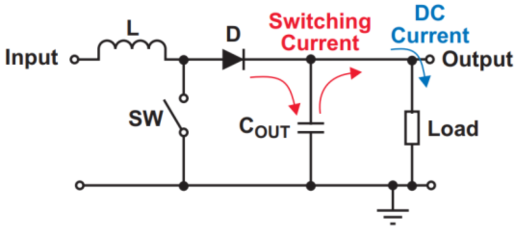


Figure 2: Boost Concept

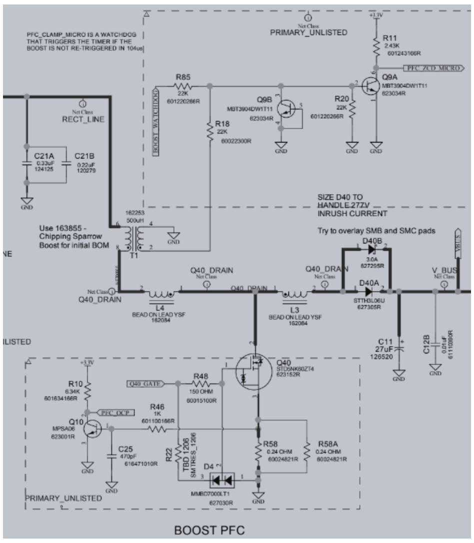


Figure 3: Boost design for practical design

A microcontroller is used to control the switching frequency of the boost converter, which is programmed to switch around 66kHz base frequency. A frequency dithering formula is incorporated in the programming to vary the frequency variation for testing it. The following table shows the results measured. Figure 4 shows the values recorded.

An electromagnetic compliance test is done in a certified lab with the help of a certified technician as per the CRISP 15 requirement. This testing is typically done after the product has been developed completely. A careful observation can be made with the two test reports given in Figure 5. Figure 5A represents the EMC results without dithering, showing the peaks of the switching frequency crossing the peak around the third harmonic peaking while the same harmonics are reduced in peak in Figure 5B with dithering enabled.

Procedure					
	OS/PAR:			5.11/14.3	
Step	Min	Max	Measured	Measured	Unit
Set load to Pmax at any line voltage					
Probe Q6 or Q7 gate drive signals at Micro					
Use Oscilloscope Math function to display Track (Period (Q6/Q7 signal))					
Measure step size	60	100		83.0	ns
Measure signal ON time				15.64	mS
Measure signal OFF time				23.8	mS

a. Measure in time

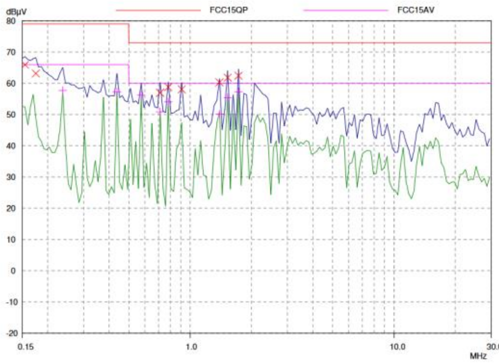
b. Waveform for the measurement

Figure 4: Frequency dithering measurements

BUSINESS VALUE

Solving for EMI in the earlier phase of the development saves an organization and product development team both effort and budget. Any complexity in the LED driver design increases the development cost and time to market. Once the PCB is developed, the cost of changing the design and spinning the PCB will be significantly higher. At these stages of development using, software solutions like dithering frequency and PWM modulation are used. Adopting techniques such as frequency selection, jitter modulation, and single bus architectures not only improves the EMI performance of LED drivers but also provides significant business benefits. On average, 20-30% EMI filter cost reduction can be achieved through these techniques [3].

Beyond the direct cost savings, the EMI mitigation approaches discussed here also enable LED driver designs that are globally compliant, scalable, and future-proof. By anticipating and addressing EMI challenges early in the design process, manufacturers can accelerate time-to-market, enhance product reliability, and position their offerings as more competitive and attractive to customers across diverse regional markets.



a. EMC report without dithering enabled

b. EMC report without dithering enabled

Figure 5. EMC test results

CONCLUSION

LED driver design comes with significant EMI challenges that must be addressed to meet electromagnetic compatibility standards and requirements. Often, the business strategy is to produce a product variant for the entire market while targeting the entire market segment. A well-considered technological and architectural strategy can help save significant money and effort for both the development team and engineers. Technical strategies like single bus architectures, optimized switching frequency selection, and jitter modulation have proven effective in reducing conducted and radiated emissions in real-world LED driver applications. The paper clearly indicates that optimal results can be achieved using these strategies.

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