Next-Gen LED Lighting Designs Driven by SiC Devices

As LED lighting designs move into higher power applications, power electronics engineers can achieve simplified architectures, higher reliability, and lower cost through the benefits of Silicon Carbide power devices. **Marcelo Schupbach, PhD., Technical Marketing Manager, Edgar Ayerbe, Product Marketing Engineer, Wolfspeed (formerly Cree Power & RF), Durham, USA**

When compared to conventional lighting sources, the benefits of solid-state lighting (LEDs) are well documented, and include long life, high efficacy, high light output with no mercury, and much lower thermal characteristics. LEDs are also relatively easy to control; however, as they are increasingly deployed in higher power, higher voltage applications, such as stadium illumination or high bay lighting fixtures, careful consideration must be paid to power architectures and topologies to ensure that they are capable of delivering high reliability, high voltage drivers that contribute to lower overall system weight, volume, complexity, and cost. One especially effective method to achieve these goals is to replace conventional Silicon (Si) switching devices with Silicon Carbide (SiC) power MOSFETs and Schottky diodes when developing these new high power systems.

LED driver designs are crucial for cost reduction

While converting lighting designs to LEDs helps achieve higher performance and cost reduction, the LED components themselves typically represent just 25 % of the overall system cost. As seen in Figure 1, more significant savings can be achieved in the optics, the thermal management components, and the driver elements of the lighting system. To realize these savings, careful consideration must be given to the topology employed for the power conversion platform of the LED driver, which, in turn, will have implications for the thermal management elements.

When using conventional Si power switching devices (typically MOSFETs or IGBTs) at power levels above 100 W, it is not possible to implement a single-stage topology due to the switching frequency limitations of the Si devices. This forces design engineers to employ two-stage topologies, which increase cost due to their inherently greater complexity and higher part count. An example of this design is shown in the power factor

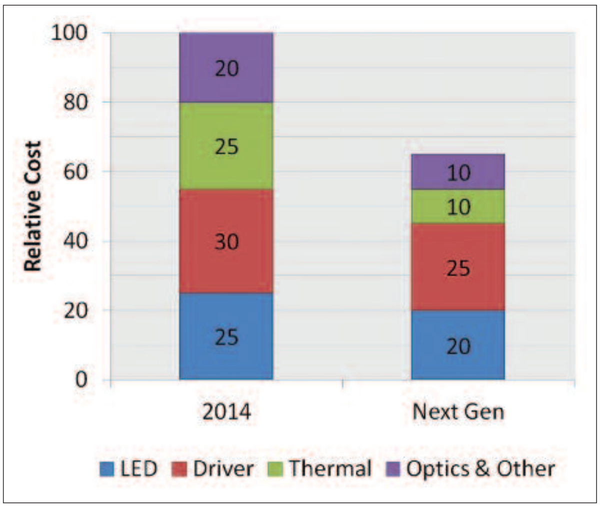


Figure 1: Relative cost comparison of next-generation high-bay lighting

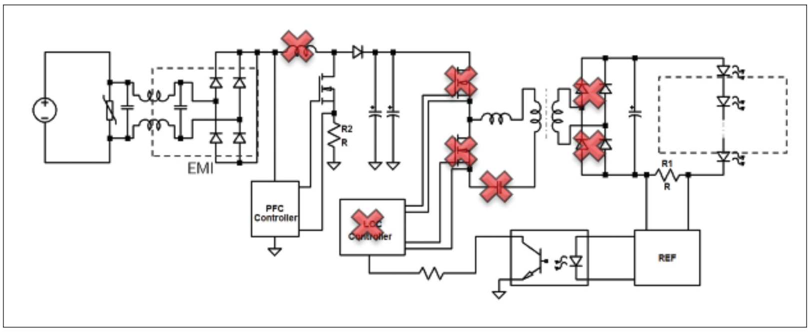


Figure 2: Two-stage driver topology using a boost PFC and LLC half bridge - the red “X” marks illustrate the additional complexity and parts required for a two-stage topology

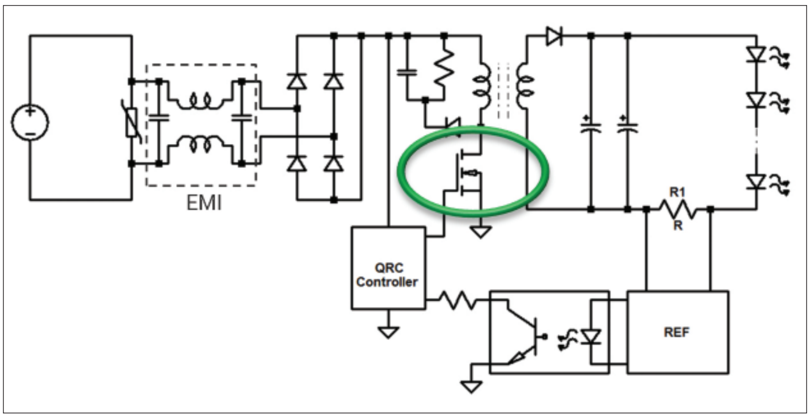


Figure 3: Single-stage flyback-based LED driver topology - the green mark represents the location of the single SiC MOSFET required for a single-stage topology

correction (PFC) boost converter plus LLC resonant half-bridge in Figure 2.

In contrast to the complexity and higher cost of the two-stage topology, a single-stage topology, such as the quasi-resonant flyback shown in Figure 3, delivers lower costs and a simplified design (i.e., lower part count). However, the limitations of traditional silicon switching devices make it impractical to design single-stage topology converters above 100 W. The demands imposed on power MOSFETs are typically higher in single-stage topologies than two-stage topologies, and these demands are further increased when wider input and output voltages are required. These demands have a significant impact on the converter's overall efficiency, the rating of the power MOSFET employed in the design, and, ultimately, the system cost. This is the primary reason why single-stage topologies have previously been limited to low power designs.

However, the latest generation SiC MOSFETs significantly outperforms Si devices, boasting figures of merit (FOM) that are 15–30x better than the best commercially-available 900V Si Superjunction MOSFETs. As such, employing SiC MOSFETs in single-stage topology converters increases their power output by approximately 3x, while delivering efficiencies and operating voltages that are equivalent to those obtained with two-stage Si-based topologies. This enables the design of single-stage topology converters with power up to 250 W–300 W that can deliver performance usually found in two-stage topologies while maintaining the cost structure of a single-stage topology converter.

By employing the latest 900 V SiC MOSFETs, these single-stage LED drivers significantly increase power density by delivering volume reduction in the 40–50 % range and weight reduction in the 60–75 % range when compared to traditional Silicon-based drivers of similar power output (see Figure 4). These dramatic weight and volume reductions further add to the overall system cost savings, reducing both the size and weight of the mechanical structural components of the light fixture. Through this reduction in complexity and parts count, overall system cost in the converter is on the order of 15–20 %.

Additionally, higher voltage SiC MOSFETs such as the 1200V family can also be used to improve the efficiency and power density of LED drivers with two-stage topologies that are focused on lighting applications with power requirements above 300 W, input voltages up to 528 VAC, or wide input voltage ranges from 90–528 VAC, in addition to lighting drivers that demand efficiencies of 95 % or higher.

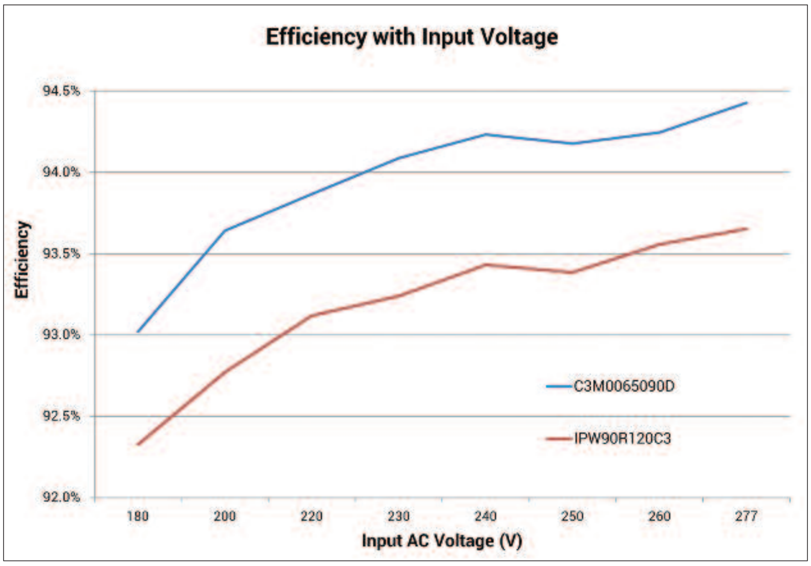
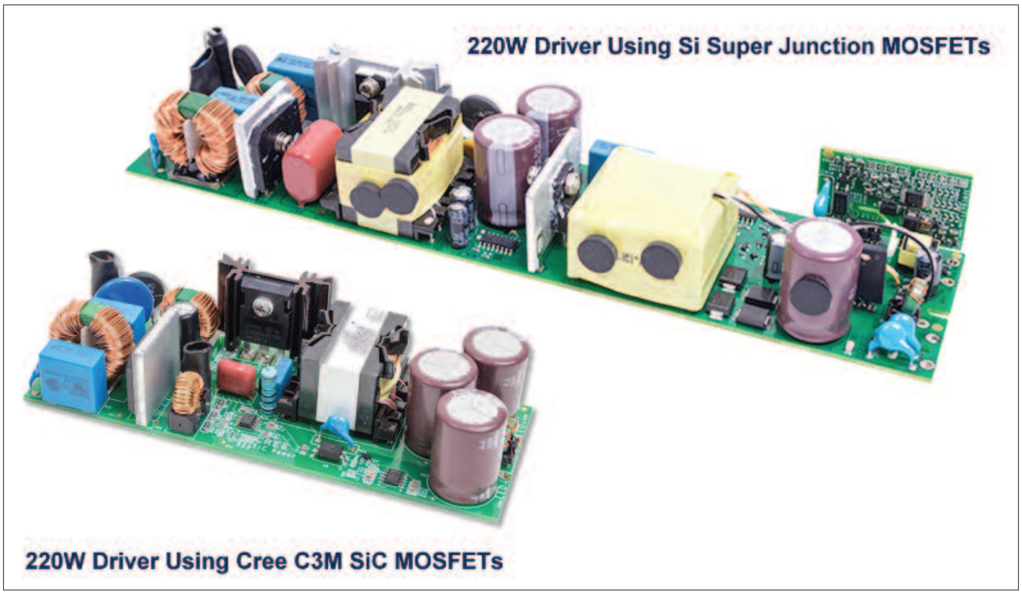


Figure 5: Efficiency vs. input voltage of a single-stage flyback driver using a Cree® 900V C3M™ SiC MOSFET vs. a two-stage topology converter using 900V Si MOSFETs

SiC MOSFET technology is critical

In many cases, employing SiC MOSFETs as switching devices is one of the keys to overcoming common design limitations when implementing a single-stage topology in a high power LED lighting application. The design of a single-stage topology power converter imposes higher voltage and current stresses to the switching devices than in a two-stage topology design, and these stresses are increased as the input voltage range is widened. The cumulative effect of these stresses impacts the overall converter efficiency, as well as the rating (and hence the cost) of the power MOSFET used in the design.

SiC MOSFETs exhibit superior efficiency over a wider input voltage range than Si



RIGHT Figure 4: Comparison of 200 W LED drivers: one using Si superjunction MOSFETs in a two-stage topology, the other using a Cree® SiC MOSFET in a single-stage topology

MOSFETs, as shown in Figure 5, which shows the efficiency vs. input voltage of two 220 W LED drivers: a two-stage topology with Si MOSFETs, and a single-stage topology with SiC MOSFETs. Both drivers have equivalent operating voltage windows (120–277 VAC), but the single-stage driver using C3M0065090D SiC MOSFETs exhibits superior efficiency, higher power density, and lower cost.

Reducing the cost of EMI filter components

Typically, the EMI signature of a single-stage flyback converter configuration is higher than that of a continuous conduction mode (CCM) boost PFC, and hence requires more expensive EMI filters. However, using a quasi-resonant converter (QRC) flyback configuration with a variable switching frequency generates reduced EMI emission, since it spreads the RF emission over a wider frequency range.

Although the switching frequency of the first stage in a two-stage topology converter is limited to 60–150 kHz to stay within the lower EMI frequency limit (150 kHz), more complex two-stage EMI filters are usually required in the second stage to reduce harmonics for EMI compliance. The higher operating frequency (>200 kHz) that is enabled by SiC MOSFETs with the same EMI filter design delivers significantly improved harmonics, thus enabling this design to reach EMI compliance without additional cost.

Figure 6 shows the theoretical EMI signature of a two-stage topology converter (Si switching devices) with a DCM boost PFC first stage, while Figure 7 shows the same EMI measurement of a single-stage topology converter (SiC switching devices) using the same EMI filter components.

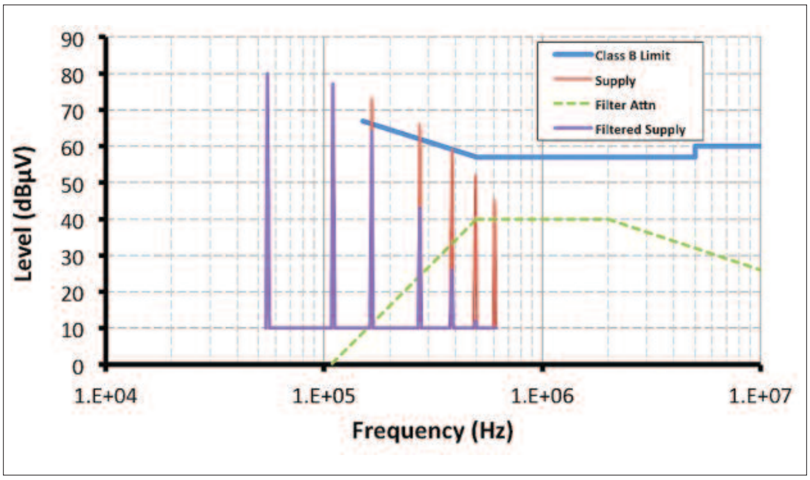


Figure 6: Typical EMI filter design for a conventional two-stage converter with Class B conducted EMI limit, theoretical EMI signature of the unfiltered supply (Supply), EMI filter attenuation (Filter Attn), and EMI signature of the filtered supply (Filtered Supply)

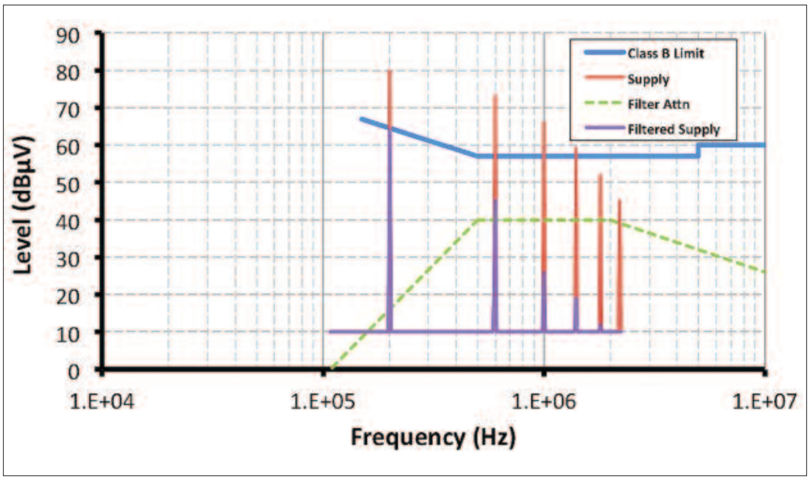


Figure 7: An EMI filter design for a single-stage high-frequency converter showing Class B conducted EMI limit, theoretical EMI signature of the unfiltered supply (Supply), EMI filter attenuation (Filter Attn), and EMI signature of the filtered supply (Filtered Supply)

Conclusions

Advances in SiC MOSFET technology have enabled power system designers to take full advantage of the benefits of single-stage topologies in high power lighting applications. With superior performance compared to Si superjunction MOSFETs, SiC MOSFETs have raised the output limit boundaries of single-stage topologies to 250–300 W from the 75–100 W range. New 900 V SiC MOSFETs also significantly increase the value proposition of single-stage topologies for these lighting applications by enabling lower cost, smaller size, and reduced weight. Thus, by employing SiC MOSFETs in single-stage topologies, lighting systems designers can now deliver lower cost designs than two-stage approaches while boosting performance. These single-stage topologies deliver LED driver solutions with comparable performance and lower cost than two-stage topologies at higher power levels using Si switching devices.

Additionally, SiC MOSFET technology is not limited to 150–300 W LED drivers. Implemented in two-stage topology converter designs, these devices can be used to develop even higher power LED drivers with outputs up to 1,000 W, ultra-wide input voltage ranges up to 528 VAC at the higher end, and efficiencies of 95 % and above, with even high power density. Thus, SiC MOSFET technology is poised to become the device of choice for LED drivers.