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2022 Solid-State Lighting R&D Opportunities

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Table 3.4 Driver performance parameters for a conventional two-stage driver with silicon MOSFETs and a single stage driver with SiC MOSFETs. The driver with SiC components provides smaller size, higher efficiency, and a lower cost. [156]

220 W LED Driver	650V Si Based Two-Stage	900V SiC Based Single-Stage
Input voltage Range	120-277V AC	120-277V AC
Output Voltage Range	150-210V DC	150-210V DC
Max Output Current	1.45 A	1.45 A
Peak Efficiency	93.50%	94.40%
Input THD	< 20%	< 20%
Output Current Ripple	>0.95	>0.95
Output Current Ripple	±5 %	±10 %
Size	220×52×30 mm	140×50×30 mm
Weight	2.7 lbs / 1.3 kg	1.1 lbs / 0.5 kg
Relative cost	1	0.85

While the benefit of wide bandgap devices has been demonstrated in LED drivers, other industries are driving the implementation of wide bandgap devices in products such as electric vehicles (SiC devices) and for rapid phone chargers (GaN devices). This market pull is improving the availability and cost of wide bandgap devices overall and can help drive implementation into LED drivers. Smaller more compact drivers can be designed using the high frequency available with wide bandgap components and coupling that with high frequency planar magnetics (low profile devices). Planar magnetics also allow for a more automated manufacturing process that can reduce labor costs (eliminate hand winding) and move more of the driver manufacturing to SMT assembly processes.

Further research is needed to develop consistency, improve reliability, and to reduce cost of wide bandgap power devices. One of the advantages of GaN power electronics is that it is able to draw on the considerable existing knowledge and manufacturing base established by GaN-based LED lighting. Because of this, it would be coming full circle for LED lighting to in turn benefit from the incorporation of GaN into LED drivers. Indeed, because they share the same materials platform, a long-term opportunity could be integration of GaN power electronics with InGaN/GaN LEDs. Such monolithic integration brings challenges: potential incompatibilities in some of their epitaxial growth and fabrication processes, as well as an inability to bin and match electronic and optoelectronic characteristics after separate fabrication. But such monumental integration also brings opportunities: the pixelated light source discussed above might be most elegantly realized with GaN-based display drivers integrated underneath pixelated LED light sources.

Additional power supply developments include increased integration of drivers and driver functionality at the LED board and component level (e.g., high voltage multi-junction LEDs) can help reduce overall luminaire size and provide more installation flexibility. This requires compact driver schemes and simultaneous consideration of power supply component, circuit, and LED design and fabrication processes. Additionally, innovative circuit topologies, such as a multiplexing based circuit topology, can address the performance of multi-channel drivers with the potential of providing higher efficiency at dimmed operation, no flicker (no pulse width modulation), lower component count, and lower power supply volume.

Driver Reliability

Typically, the driver is one of the first component of a luminaire to fail. Predominantly, this is because LEDs are so intrinsically reliable that drivers are the resulting weakest link. Driver reliability in some cases is not even as robust as it was for earlier generations of traditional lighting, such as a copper-wound ballast system used for HID lighting in industrial spaces. This is because power surges and other electrical events that cause abnormalities in power quality can damage LED lighting components more so than traditional lighting systems. While this is not a problem unique to lighting, as more fragile components are introduced into the SSL system, protecting LED luminaires from poor power quality becomes more important. Current surge protection systems are built around larger events, meaning that several smaller events or transitions can get through surge protection systems, and these load transitions cause field failures when the power quality is poor.

Driver reliability is an area that presents a significant opportunity for improvement, including fundamental reliability limitations of many of the subcomponents of the driver, such as electrolytic and film capacitors, and to do so in a manner consistent with the ongoing trend to higher performance shown previously in Figure. Another goal would be to develop a greater degree of power conditioning, especially as fragile components are introduced into the SSL system due to the need for improved performance, particularly those involved in multi-functionality. Currently, most current surge protection systems are designed to block larger events, but not smaller events, which can accumulate over time and eventually cause damage to downstream components.

A closely related challenge is to develop predictive driver reliability models and metrics. Current metrics, such as mean time between failures (MTBF) for individual components, are considered inadequate. Therefore, developing additional metrics to define failure, and ways to predict them, would be beneficial to the SSL industry. Metrics to describe performance features such as driver efficiency, maximum temperature rise over ambient, and how these change over time are also desirable. Coupled with such models and metrics would be standard highly accelerated reliability testing protocols that can return results quickly, within a matter of weeks.

Further research is needed to improve driver temperature performance, surge rating, reliability, and cost. Solid-state component integration into the driver should be explored as a more robust alternative since solid-state drivers can simplify the part count and reduce failures. It would also improve the surge rating and reduce the driver size. Moving GaN or SiC-based power electronics has the potential to improve the efficiency and reliability, though today these solid-state components are still very costly and further research is required in the electronics industry to improve the defect count and reduce cost. Establishing the reliability for GaN and SiC components and the impact on driver reliability is an important opportunity.

Enhanced Functionality of Drivers

Enhanced lighting functionality will be a vital feature for future deployment of connected lighting systems with advanced capabilities and can enable programmable control of that functionality. Real-time control of light placement is an important enhanced functionality. For example, optical beam shaping through digitally controllable liquid-crystal lenses could enable significant improvement in the use efficiency of light by tailoring, in real-time, the lighting field of view to the user field of view. In another example, pixelated beams from micro-LED arrays could enable not only similar improvements in use efficiency of light, but can also deliver high-precision dynamic beam shaping and color projection (see -3.23) or provide other information to the user. Taken to its logical limit, these pixelated light sources would start to create lighting-display fusion by, which would require drivers with video-display-like driver capability.

Finally, by implementing connectivity, lighting fixtures may well become the most ubiquitous grid-connected endpoint in the Internet of Things (IoT), with opportunity for many desirable new functionalities to be embedded into the fixture. In the short term, separate drivers may be used for these new functionalities. However, in the long term, there may be opportunity for integrated drivers that drive both the LED as well as these new components. One new functionality is communication via Li-Fi, with its need for high-speed modulation, interoperability, and end-to-end security requirements. Another new potential functionality is sensors for monitoring all aspects of the environment including sound, light, temperature, chemicals, motion, human presence, perhaps even LIDAR-based 3-D mapping. The complexity of these offerings becomes enormous as each has its own requirements for interoperability and end-to-end security.

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