Meeting the Power Management Challenges of Automotive Lighting

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Abstract

The proliferation of LED modules in automobiles places new requirements on system hardware including reduced component size to fit additional electronics in the same space, improved energy efficiency to perform within the same or lower thermal budget, connected and flexible architectures supporting multiple configurations, and accurate control to preserve LED light characteristics. This white paper reviews the challenges for automotive LED electronic components and presents a few examples of how effective power management can help.

Introduction

LEDs are taking the automotive industry by storm due to significant advantages over traditional technologies and their diverse range of automotive applications (Figure 1).

Front-light modules tend to need higher power (more than 100W), utilizing high-efficiency, switching-based drivers. Rear lights and other exterior lights need lower power, sometimes low enough to allow the use of simple linear drivers. The superior clarity of white light in LED headlights improves driver reaction time. Adaptive front-lighting systems (AFS), enabled by LED matrixes, produce fast, complex light pattern changes that improve visibility for drivers in poor light conditions. At night, in response to the beams of an incoming car, AFS can automatically adjust the light pattern, preventing oncoming drivers from being blinded by harsh lighting.

The superior clarity of white light in LED headlights improves driver reaction time

The LED illumination rise-time is twice as fast as incandescent sources, allowing LED-based brake lights to illuminate more quickly providing advanced warning to drivers and increasing road safety. Finally, LEDs consume less power than their incandescent counterparts leading to substantial advantages in fuel consumption. LED controllers play an important role in preserving and enhancing the inherent LED qualities of clarity, speed, and efficiency.

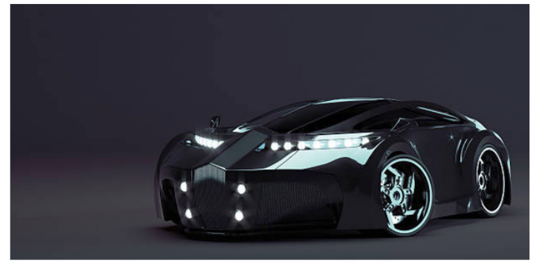

Figure 1. LED-lighted modern car.

Powering the LEDs

LEDs have many automotive applications and are used in diverse configurations from a single LED to a string or matrix of LEDs. High-brightness (HB) LEDs require constant current for optimal performance. The current correlates with junction temperature and hence color. Accordingly, HB LEDs must be driven with current, not voltage. The power source can range from a 12V car battery up to a 60V boost converter to accommodate a long LED string. Vehicles that employ start/stop technology experience large battery voltage dips when the engine starts, causing the battery voltage to droop well below the typical 12V, sometimes even 6V or lower.

The Challenges

The proliferation of LED modules in automobiles places new requirements on system hardware including: reduced component size to fit additional electronics in the same space, improved energy efficiency to perform within the same or lower thermal budget, supporting connected and flexible architectures that enable multiple configurations, as well as accurate control to preserve LED light characteristics.

In the following sections, we will address the challenges for the following applications:

1. High-power front-end lights
2. Low/mid-power front-end lights
3. Infrared (IR) cameras for driver monitoring systems (DMS)
4. Rear lights and other exterior lights

The Solutions

High-Power Front-End Lights

High-power LEDs are becoming very popular in automotive front lighting design (Figure 2) thanks to superior lighting characteristics and efficiency. The electronics that support LEDs must in turn be fast, efficient, and accurate for controlling light intensity, direction, and focus. They must support a wide input voltage range and must operate outside the car radio's AM frequency band to avoid electromagnetic interference (EMI). They must also support complex light patterns required in LED matrixes for AFS.

Figure 2. LED-powered car headlight.

Dimming is a ubiquitous function in many automotive applications and an important safety feature for LED headlights. The human eye can barely detect light dimming from 100% to 50%. Dimming must go down to 1% or less to be clearly discernable. With this in mind, it is not surprising that dimming is specified by a ratio of 1000:1 or higher. Given that the human eye, under proper conditions, can sense a single photon, there is practically no limit to this function.

Since current must be kept constant to preserve color, the best dimming strategy for LEDs is PWM (pulse-width modulation), where the light intensity is modulated by time-slicing the current rather than by changing the amplitude. The PWM frequency must be kept above 200Hz to prevent the LED from flickering.

With PWM dimming, the limit to the minimum LED "on/off" time is the time it takes to ramp up/down the current in the switching regulator inductor. This may add up to tens of microseconds of response time, which is too slow for LED headlight cluster applications that require fast, complex dimming patterns. Dimming in this case can only be performed by individually switching on/off each LED in a string by means of dedicated MOSFET switches (SW1-K in Figure 3). The challenge for the current control loop is to be fast enough to quickly recover from the output voltage transient due to switching in and out of the diodes.

To be most effective, the LED controller must accommodate a wide input voltage range and have a fast-transient response as discussed earlier. A high, well-controlled switching frequency, outside the

Dimming is a ubiquitous function in many automotive applications and an important safety feature for LED headlights

AM frequency band, is required to reduce radio frequency interference and meet EMI standards. Finally, high efficiency reduces heat generation, improving the LED light system's reliability.

Sophisticated headlight systems utilize a boost converter as a front-end to manage both the variabilities of the input voltage (dump or cold-crank) and the EMI emissions. The boost converter delivers a well-regulated and sufficiently high output voltage (Figure 3). Dedicated buck converters, working from this stable input supply, can then handle the complexities of controlling the lamp's intensity and position by allowing each buck converter to control a single function, such as high beam, low beam, fog, daytime running lights (DRL), position, etc. Individual diodes are switched in and out by the switch matrix manager, allowing pixel-level adaptive lighting.

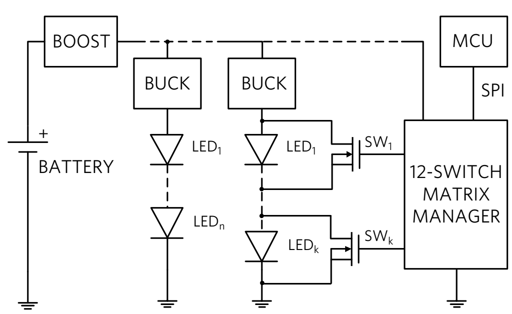

Figure 3. Advanced LED lighting system.

In this application, each buck converter's main control loop sets the current in its LED string, with two secondary loops that implement the overvoltage and overcurrent protection.

An ideal solution should meet the requirements of a wide input voltage range, fast transient response, high and well-controlled switching frequency, all while enabling high efficiency with synchronous rectification. The MAX20078 LED buck controller enables such a solution.

The MAX20096 synchronous, all n-channel, buck LED controller with SPI, integrates two channels in a single IC, reducing the solution footprint and the BOM.

The 12-matrix switch manager can be implemented by the MAX20092. The IC features a serial peripheral interface (SPI) for serial communication. The MAX20092 is a slave device that uses the SPI to communicate with an external microcontroller (µC), which is the master device. Each of the 12 switches can be independently programmed to bypass the LEDs across each of the switches in the string.

The boost converter in Figure 3 is implemented with the MAX16990/MAX16992, 36V, 2.5MHz automotive boost/SEPIC controllers.

Low/Mid-Power Front-End Lights

In low/mid-power headlight systems, headlight functions like high beam and low beam are performed by simpler, single-function controller ICs.

A low/mid-power headlight system architecture that can accommodate a series of LEDs uses a boost converter. In the boost controller IC of Figure 4, one of the three feedback loops (CURRENT LOOP) ensures tight control of the output current.

Individual diodes are switched in and out by the switch matrix manager, allowing pixel-level adaptive lighting

The other two feedback loops perform overvoltage protection (OVP LOOP) and overcurrent protection (OCP LOOP) for a string of 12 diodes, which creates 42V across the string (3.5V per LED).

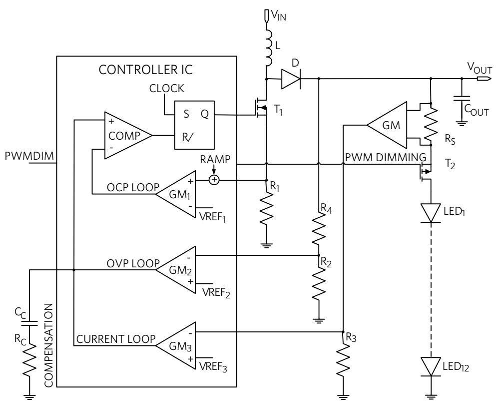

Figure 4. Typical boost LED control system.

In addition to current and voltage control, the IC must be equipped with all the features previously described (dimming, spread spectrum, etc.). High-side current sensing (via the resistors R_3 and R_S) is required to protect the LED system in case of shorts from the output to the ground or battery input.

Ideally, an LED controller should have a flexible architecture that supports multiple configurations that implement different features. We have discussed the boost configuration, but we should also consider the buck-boost configuration. A buck-boost mode configuration is necessary if the diode string is short, for example two or three LEDs (7V or 10.5V), against a battery voltage that can vary from less than 6V (cold crank) up to 16V. If the concern is input-to-output isolation, then a SEPIC (discontinuous output current) or a Chuck (continuous output current) converter may be the right solution. A single controller that supports many architectures has clear advantages of economies of scale and ease of reuse.

As an example, the MAX20090 is a very flexible controller for driving LEDs, allowing boost, high-side buck, SEPIC mode, or buck-boost mode configurations.

IR Camera for Driver Monitoring Systems (DMS)

Infrared (IR) cameras, utilizing an IR-LED diode in combination with a CMOS sensor, help recognize hazardous microsleep that affects motorists. The advantage of using infrared is its invisibility to the human eye and its ability to operate day and night. Image analysis processes information to determine if the driver is fatigued or distracted. With a typical forward voltage of 2.8V and a forward current of 1A, the electronics that drives the LED is directly connected to the battery.

As an example, the MAX20050 buck LED driver is an ideal solution (Figure 5). The fully synchronous, 2A step-down converter integrates two low $R_{DS(ON)}$ 0.14Ω (typ) MOSFETs, assuring high efficiencies up to 95%. With its 4.5V to 65V input supply range, the MAX20050 can easily withstand battery load dump, making it ideal as a front-end buck converter in DMS applications.

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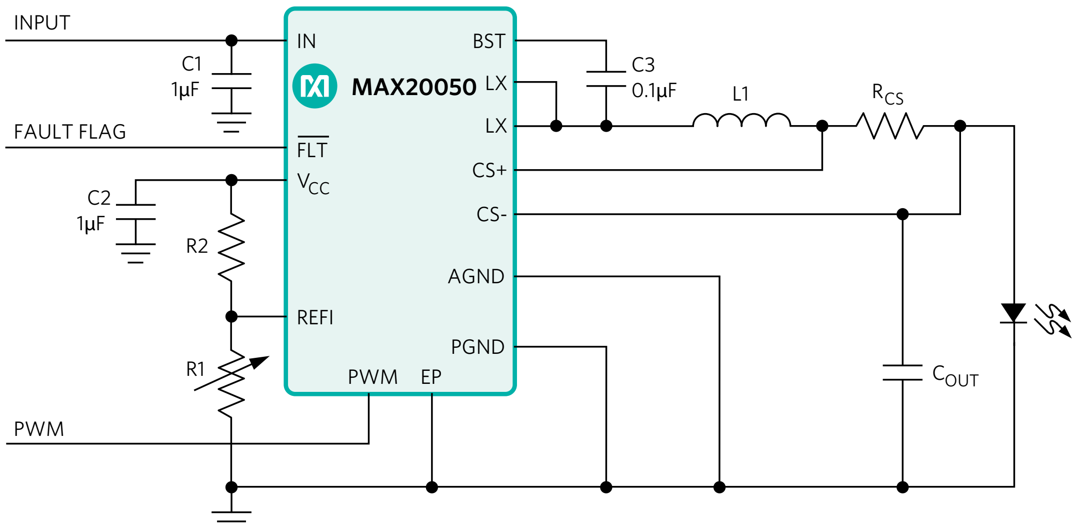

Figure 5. IR-LED driver solution.

For higher power, the MAX20078 synchronous buck LED controller can be utilized. For higher voltage applications, the MAX20090 high voltage HB LED controller is an excellent choice.

Rear Lights and Other Exterior Lights

Rear lights and other exterior lights like stop lights, door-handle lights, etc., require less power and are handled by simple single-function ICs. Here, the MAX20090 can be utilized as a boost LED controller or for long strings that require voltages above the minimum battery voltage or as a front-end boost voltage regulator. The MAX20050 buck converter can drive short strings of diodes connected directly to the battery. Alternatively, it can drive long strings of diodes with the help of a front-end boost converter.

For noise-sensitive applications, a linear LED driver can be utilized. The MAX16823 three-channel LED driver (Figure 6) operates from a 5.5V to 40V input voltage range and delivers up to 100mA per channel to one or more strings of HB LEDs. Each channel's current is programmable using an external current-sense resistor in series with the LEDs. Three DIM inputs allow a wide range of independent pulsed dimming in addition to providing the on and off control of the outputs. Wave-shaping circuitry reduces EMI while providing fast turn-on and turn-off times.

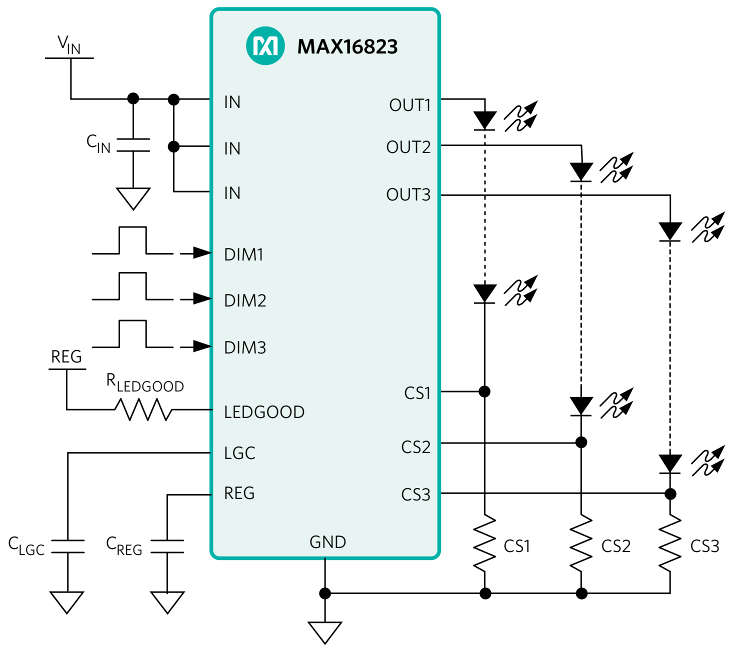

Figure 6. Linear driver for low noise.

Summary

Table 1 is a summary of automotive LED driver applications and proposed product solutions.

Table 1. Automotive LED Drivers

Application	Function	Product
High-Power Front-End Lights	36V, 2.5MHz Automotive Boost/SEPIC Controllers	MAX16990/ MAX16992
	Synchronous High-Power Buck LED Controller	MAX20078
	Synchronous High-Power Dual-Buck LED Controller	MAX20096/ MAX20097
Low/ Mid-Power Front-End Lights	12-Switch Matrix Manager for LED Lighting	MAX20092
	High-Voltage High-Brightness Boost LED Controller	MAX20090
	2A Synchronous Buck LED Drivers with Integrated MOSFETs	MAX20050/ MAX20051/ MAX20052/ MAX20053
IR Camera for DMS	2A Synchronous-Buck LED Drivers with Integrated MOSFETs	MAX20050/ MAX20051/ MAX20052/ MAX20053
	Synchronous High-Power Buck LED Controller	MAX20078
	High-Voltage High-Brightness Boost LED Controller	MAX20090
Rear Lights and Other	High-Voltage High-Brightness Boost LED Controller	MAX20090
	2A Synchronous Buck LED Drivers with Integrated MOSFETs	MAX20050/ MAX20051/ MAX20052/ MAX20053
	High-Voltage, 3-Channel Linear High-Brightness LED Driver with Open LED Detection	MAX16823

Conclusion

The proliferation of LED modules in automobiles places new requirements on system hardware including: reduced component size to fit additional electronics in the same space, improved energy efficiency to perform within the same or lower thermal budget, connected and flexible architectures supporting multiple configurations, and accurate control preserving the LED light characteristics.

In this paper, we addressed the challenges encountered when designing high-power and low/mid-power front-end lights, IR cameras used in DMS, as well as rear and exterior lights. In each case, an optimal power management solution was presented based on the application at hand.

Related Resources

Web Pages

Automotive Lighting

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Achieve Superior Automotive Exterior Lighting with a High-Power Buck LED Controller

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