Control Individual LEDs in Matrix Headlights with Integrated 8-Switch Flicker-Free Driver

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LEDs combine design flexibility with practical, robust circuitry, enabling automotive designers to produce striking headlights designs matched by exceptionally long life and performance. Automobile designers are increasingly incorporating LEDs in lighting because they can be arranged in distinctive eye-catching designs—helping distinguish new models from old, or high end from economy.

There is no question that automobile LED lighting has arrived, but it has not yet reached its full potential. Future models will feature more LED lights, including new shapes and colors, and more control over the individual LEDs. Simple strings of LEDs will give way to matrices of LEDs that can be individually dimmed via computer control, enabling unlimited real-time pattern control and animation. The future has arrived: Linear Technology’s LT®3965 matrix LED driver makes it easy to take the next step in automotive lighting design.

I²C CONTROL OF EIGHT POWER SWITCHES WITH A SINGLE IC

A basic LED headlight design operates with uniform LED current, and thus, uniform brightness. But this leaves much of the LEDs’ potential on the table. Matrix headlights take advantage of the innate abilities of LEDs by enabling control of the brightness of individual LEDs within LED strings.

It is not difficult, in theory, to address the individual LEDs in a matrix via computer-controlled power switches, allowing individual LEDs to be turned on or off, or PWM dimmed,

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When combined with a suitable constant-current LED driver, the matrix dimmer LED driver allows the individual LEDs to be computer-controlled in headlights, daytime running lights, brake and tail lights, side-bending lights, and other trim lighting.

The LT3965 is a versatile LED controller that can be used to control LED matrices in many ways, including:

- The LT3965 can control multiple LEDs per channel, or channels can be combined to efficiently control a single LED at higher current.
- The LT3965 can control multiple LED strings, 16 LEDs at 500mA with two LT3965s

When combined with a suitable constant-current LED driver, the matrix dimmer LED driver allows the individual LEDs to be computer-controlled in headlights, daytime running lights, brake and tail lights, side-bending lights, dashboard display and other trim lighting. The LT3965’s built-in automatic fault detection protects individual LEDs in case of a failure and reports failures to the microcontroller.

The 60V LT3965 includes eight integrated 330mΩ power switches, which can be connected to one or more LEDs. The power switches act as shunt devices by turning off or PWM dimming the LEDs on a particular channel. The switches create eight individually controlled brightness channels (up to 256:1 dimming ratio) and eight fault-proof segments of an LED string.

The LT3965 can handle a string current of 500mA when all eight power switches are on at the same time (all LEDs off). The switches can be connected in parallel and run at 1A through four channels of LEDs as shown later in this article. Regardless of the number of LEDs or current, the LED string must be driven by a properly designed converter that has the bandwidth to handle the fast transients of the matrix dimmer. Some reference designs are included in this article.
Demonstration circuit DC2218 features a complete matrix LED dimmer system with LT3797 boost-then-dual-buck mode LED drivers and two LT3965 matrix dimmers that drive 16 LEDs at 500mA from a car battery. The board operates a matrix headlight with an attached I²C microcontroller via DC2026, the Linduino One demo circuit.

for EMI) and the resulting 170Hz PWM dimming frequency of the LT3965, generated from the same 350kHz clock, is above the visible range. With the system properly synchronized, the LT3797 and LT3965 matrix headlight operates flicker-free.

The LT3797 buck mode converters are optimized for extremely fast transients with little or no output capacitor and properly compensated control loops. These >30kHz bandwidth converters tolerate fast LED transients as the LEDs are turned on and off and PWM dimmed at will. A filter capacitor placed on the LED sense resistor replaces a pole in the control system that is lost when the output capacitor is reduced or removed for the fast transient performance of the matrix dimmer.
A charge pump from the switch node is used to power the LT3965 V_{IN} pin more than 7V above the LED* voltage to enable the top channel NMOS to be fully enhanced when driven. The low $R_{DS(ON)}$ NMOS switches in the LT3965 enable high power operation without the IC getting hot, even when all eight shunt switches are on, turning the entire LED string off. In this case, the LT3797 LED driver survives the virtual output short created by all eight shunt switches without any issues, and is ready to quickly regulate 500mA through the next LED that is turned on.

Demonstration circuit DC2218 (Figure 1) features the system shown in Figure 3 and operates a matrix headlight with an attached I²C microcontroller via DC2026, the Linduino™ One demo circuit. DC2218, operated as a large Linduino shield, has up to 400kHz serial code that
The LT3965 I2C 8-switch matrix dimmer, LED driver eases the control of large or small LED matrices (up to 512 LEDs). Its highly integrated design minimizes component count, and built-in fault detection protects individual LEDs in case of a failure and reports failures to the microcontroller.

Figure 3. LT3965 matrix LED dimmer system with LT3797 boost-then-dual-buck mode LED drivers and two LT3965 matrix dimmers that drive 16 LEDs at 500mA from a car battery. I2C serial communications control the brightness of individual LEDs and check for LED and channel faults.
generates different headlight patterns and interfaces with Linear Technology’s graphical user interface (Figure 4).

Within the GUI shown in Figure 4, LED brightness and fault protection functions can be examined with ALL CHANNEL MODE and SINGLE CHANNEL MODE commands, as well as FAULT CHECK read and write commands to check for open and short LEDs. Flicker-free operation, fault protection and transient operation can be examined with this demonstration circuit system. DC2218 can be plugged directly into a 12V DC source and it can be controlled by a personal computer running the GUI or reprogrammed from a simple USB connection.

1A MATRIX LED DRIVER USING PARALLEL CHANNELS
The LT3965 can be used to drive matrices of 1A LED channels. It is easy to connect the power switches of the LT3965 in parallel so that two power switches split 1A of LED current and each LT3965 controls four 1A channels. One way to use parallel power switches for higher current is to run each of the anti-phase parallel switches for only 50% of the PWM period. By alternating and running 1A through a single NMOS power switch for half the time, the effective heating is about equal to running 500mA through the same NMOS all of the time.

Figure 5 shows a 1A matrix headlight system using eight LEDs driven by two LT3965s and another boost-then-dual-buck mode LT3797. When PWM dimming, the LT3797 uses a unique 1/8-cycle phasing of the eight switches, as shown in Figure 6. In this 1A matrix system, LT3797 channels are combined in parallel pairs, so
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Turning a high number of LEDs on or off presents a significant current load step to the DC/DC converter. The converters presented here handle these transients with grace, with a small output capacitor and high bandwidth. An ACM write transitioning a high number of LEDs produces no visible flicker or significant transient on the LED current.

More than one LED per channel

The LT3965 can support one to four LEDs per channel. Although it can be advantageous to individually control every single LED for fault protection or high resolution patterns, it is not always necessary. Using more than one LED per channel reduces the number of matrix dimmers in a system and is enough to accomplish the patterns or dimming required for some designs. Segments of headlights, signal lights and tail lights can have up to four LEDs with the same brightness. Emergency LED lights can have sets of three and four LEDs that blink and wave with the same pattern.

Each LT3965 controls the brightness of four 1A LEDs that are driven by two 1A buck mode LT3797 channels (from the LT3797-boosted 20V channel). This high power, robust system can be expanded to power more LEDs with more LT3965s or higher current LEDs with more channels in parallel. It is possible to drive two LEDs per channel at 1A and drive up the power of this flexible headlight system.

Figure 6. 1/8 PWM flicker-free phasing of the eight LT3965 power switches limits transients during PWM dimming brightness control.
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including open and short registers for fault diagnostics. The LT3965 asserts an ALERT flag when there is a new fault. The micro can respond to the fault by determining which LT3965 reported the fault, as well as the type and channel of fault. In the case that multiple LT3965 ICs are reporting faults, the LT3965s can sequence fault reporting to the master to prevent overlap errors. This makes the alert response system reliable and conclusive. A complete list of the registers and command set is given in the LT3965 data sheet.

ACM write commands instantly turn all of the eight channels of a single LT3965 address on or off with just two I²C words—the channels transition on or off at the same time. Turning a high number of LEDs on or off presents a significant current voltage load step to the DC/DC converter. The converters presented here handle these transients with grace, with little or no output capacitor and high bandwidth.

As shown in Figure 8, an ACM write transitioning a high number of LEDs produces no visible flicker or significant transient on the LED current of other channels. The high bandwidth buck mode converter built around the LT3797 is the reason for such a small and controlled transient.

Single channel mode writes produce relatively small and fast single-LED transients. SCM writes are used to set the brightness of only one channel at a time to ON, OFF, or PWM dimming with or without fade. PWM dimming values between 1/256 and 255/256 are communicated in 3-word writes while ON and OFF can be communicated in shorter, 2-word commands. A fade bit on a single SCM write command enables the LT3965 to move between two PWM dimming levels with internally determined logarithmic fade and no additional I²C traffic. The open and short thresholds of each channel can be set between one and four LEDs with SCM write commands.

SHORT AND OPEN LED FAULT PROTECTION FOR EACH CHANNEL

Short- and open-circuit protection is an inherent benefit of the matrix dimmer. Each channel’s NMOS power switch can shunt out between one and four series LEDs. Traditional LED strings have protection against the entire string being open or shorted and only some ICs have output diagnostic flags to indicate these fault conditions. In contrast, the LT3965 protects against, and rides through, individual channel shorts and opens, keeping operational channels alive and running while recording and reporting the fault conditions.

When a fault occurs within a string, the LT3965 detects the fault and asserts its ALERT flag, indicating to the microcontroller that there is an issue to be addressed. If the fault is an open-circuit, the LT3965 automatically turns on its
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The LT3965 maintains registers of open and short faults for each channel and returns the data to the microcontroller during I^2C fault read commands. The command set includes reads that leave the status register unchanged and those that clear the fault registers, allowing user-programmable fault diagnostics. Registers can be read in the various modes allowed for writes, SCM, ACM, BCM:

- Single channel mode (SCM) reads return the open and short register bits for a single channel. SCM reads also check the open and short threshold register, the mode control, and the 8-bit PWM dimming value for that channel.
- All channel mode (ACM) reads return the open and short register bits for all channels of a given address without clearing the bits, as well as the ACM ON and OFF bits for all eight channels.
- In more complex systems with many LT3965 matrix dimmers sharing the same bus, a broadcast mode (BCM) read first requests which, if any, LT3965 address has asserted the fault flag.
- The ACM and SCM reads can be used to check and clear faults and to read all of the registers for a robust I^2C communications system.

**UP TO 16 ADDRESSABLE LT3965s ON THE SAME BUS**

Every LT3965 features four user-selectable address bits, enabling 16 unique bus addresses. Every ACM and SCM I^2C command is sent to the shared communications bus, but action is only taken by the addressed LT3965. BCM commands are followed by all ICs on the bus. The 4-bit address architecture allows a single microcontroller and a single I^2C 2-line communications bus to support up to $8 \times 16 = 128$ individually controllable channels. With the LT3965, for all but the most ambitious lighting displays, all individual LEDs in an automobile’s headlight, tail light and trim lights can be controlled by a single I^2C communications bus and a single microcontroller. Given that each channel can be connected to up to four LEDs, one relatively easy-to-implement system can support matrix dimming for up to 512 LEDs.

**CONCLUSION**

The LT3965 matrix LED dimmer controls eight LED-brightness channels on a single LED string, giving lighting designers unlimited access to sophisticated and striking automotive lighting designs. The I^2C communications interface allows a microprocessor to control the brightness of individual LEDs in the string. Fault protection in the I^2C interface ensures LED lighting system robustness. The channels of the matrix dimmer are versatile: each channel can control multiple LEDs; channels can be combined to support higher current LEDs; or high LED-count systems can be produced with up to 16 matrix dimmer ICs on the same communications bus. Take the next step in designing automotive headlights, tail lights, front, side, dash and trim lights—the future is now.