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TEXAS INSTRUMENTS

Intelligent LED lighting control with the ultra-low-power MSP430F51x2 microcontrollers

Introduction

Lighting accounts for about 2,200 tera-watt hours (TWh) per year — almost one-fifth of total worldwide energy consumption. This number will grow by 80% unless the world adopts more energy efficient technologies and policies [according to the International Energy Agency per **Pike Research** Executive summary].

Technologies available today — specifically LEDs and digital lighting control — can easily make this transition possible while simultaneously improving customer satisfaction with lighting systems.

The trend toward more power-efficient portable products is particularly important. Today, portable lighting systems, such as flashlights, are powered by single-use batteries that are subject to strict environmental disposal regulations. Applications using LEDs will require an efficient digital power stage to maximize battery life, which can mitigate environmental concerns. In addition, incorporating capacitive touch technology to support dimming enhances user experience that differentiates and adds value to a product.

This paper illustrates an example of an efficient digital power stage topology design for portable applications requiring multiple LED strings (white or RGB) while utilizing capacitive touch for dimming with Texas Instruments' (TI) ultra-low-power microcontrollers.

LED use will significantly reduce the power consumption, operating expense and decrease environmental issues associated with battery-powered portable products. From a design engineer's perspective, however, LEDs are not simple devices. They have a wide range of operating characteristics that depend on fabrication technology, temperature and packaging. If not properly designed, they can be subject to burnout and radically diminished product lifetimes. Designs tend to be application specific, which means that LEDs are available in an exceptionally wide range of power ratings, sizes, configurations, shades of white and RGB colors. Additionally, designing an efficient and flexible power stage topology to control today's LEDs and support extra features, such as capacitive touch, are challenges that developers must face. By utilizing programmable architectures, like TI's ultra-low-power MSP430™ microcontrollers, developers can solve design issues by offering more flexibility and technology headroom for the next generation of LED-based portable products.

Digital control

In a digitally-controlled power supply, the microcontroller controls the power stage directly by generating the PWM signals to drive the power stage while sampling its output with analog-to-digital converters (ADCs). Because PWM signals are generated by software running on the microcontroller, the designer has a great deal of flexibility to control a wide range of functionality.

Introducing digital power control into a portable LED system requires a new topology where designers must take into account maximum battery usage and complexity of the overal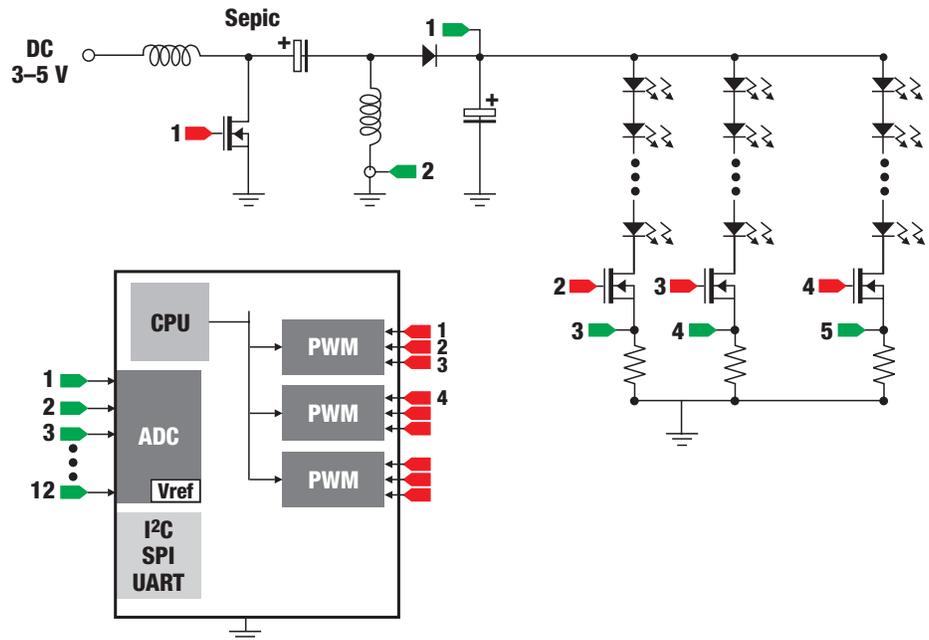l design. Figure 1, on the following page, shows a buck-boost converter (in this example a SEPIC converter) is connected in series with multiple LED strings with a MOSFET connected in series with each string. The on-time of each string's MOSFET controls the average current through any of the LED strings. Since LED brightness is roughly proportional to the LED current, the duty cycle of each string's MOSFET controls the brightness in the string.

While this design uses a SEPIC converter for efficiency, it does provide a number of challenges. First, the design requires expensive matching LEDs in order to ensure there is no perceived difference between each string's color qualities. Second, it restricts the LED strings

to the same length. Third, as the number of strings increase, more timers are needed for PWM generation, which can limit a designer if capacitive touch for dimming becomes a requirement. And fourth, this topology does not provide flexibility and wastes battery life. Clearly, as the next section illustrates, there must be a more battery-efficient way to design a power stage topology for portable LED-based systems that can also support capacitive touch for dimming in a single ultra-low-power microcontroller.

Figure 1. A buck-boost converter (SEPIC) is connected in series with multiple LED strings with a MOSFET connected in series with each string.

Driving LED strings in portable applications

The low-power consumption of the MSP430F51x2 microcontroller along with its superior high-resolution Timer_D modules capable of generating pulse-width-modulated (PWM) signals to drive a variety of DC/DC power topologies, makes it an excellent choice for battery-powered LED applications. Compared to other 8-, 16- and even 32-bit microcontrollers, which usually have timers operating in the 10s of MHz range, MSP430F51x2 Timer_D modules have a maximum operating frequency of 256 MHz, which provide more flexibility and performance. Since choosing the right DC/DC power topology is the major consideration, the MSP430F51x2 microcontroller has the necessary features to address this need.

One design path to an efficient DC/DC power supply for LED strings is to break it into two stages. Stage one would consist of a buck/boost converter – typically a SEPIC convertor – to set and maintain the optimum operating voltage for the second stage. On the second stage, a boost DC/DC converter drives the LED strings (white or RBG).

The primary advantage of this approach is that it maximizes the power efficiency of the battery. Digital control also provides a large degree of design flexibility if system design requirements change. The SEPIC

stage in Figure 1, for example, could be omitted to meet budget restrictions without requiring an extensive circuit redesign.

For white LED strings, the likelihood is that the power supply will drive a single LED string, although multiple white strings would be driven independently for products with multiple luminaires. In the single-string case, microcontroller resources can be used to achieve capacitive touch buttons and sliders for dimming control. One Timer_D module can be used to drive the white LED string and the other Timer_D module can be allocated for capacitive touch. Timer_A can be used to drive the SEPIC buck/boost converter. Figure 2 illustrates this configuration.
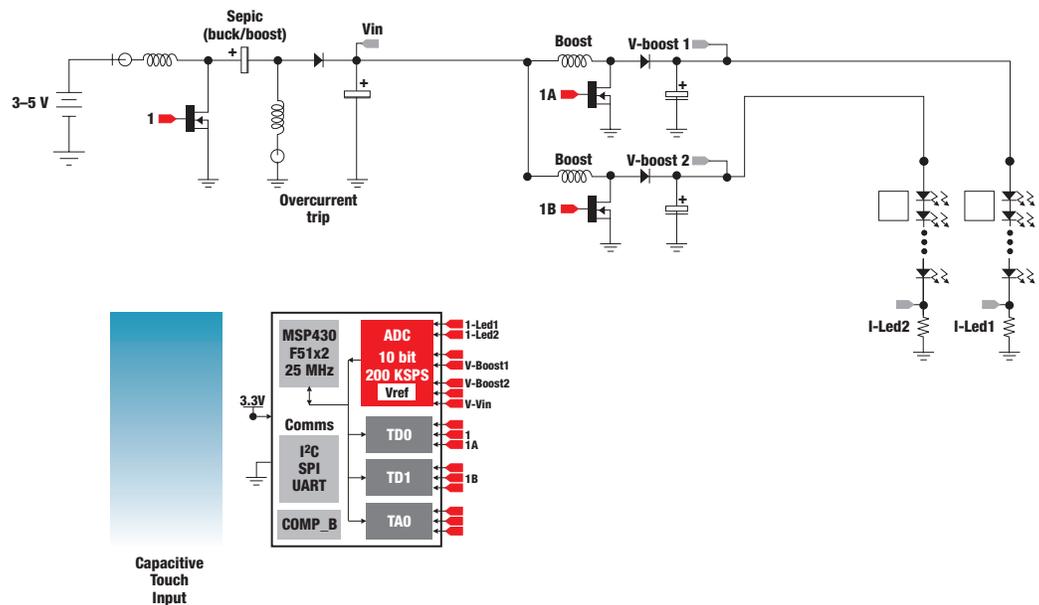
Figure 2. MSP430F51x2 device driving the power stage topology for white LED string and support for dimming through capacitive touch.

RGB LEDs   The design complication that arises with RGB LEDs is that to accurately implement color mixing; each of the three colors – red, green and blue – requires its own PWM signal. The MSP430F51x2 microcontroller's two Timer_D modules are well suited for this purpose. Typically, a period of between 50 and 300 KHz is needed to control the voltage boost for each RBG string. Timer_D has the advantage of providing superior PWM resolution because it can generate up to a 64-MHz clock with only an 8-MHz clock as input. This high switching frequency can easily accommodate a PWM period of 100 KHz with 640 steps, which is quite a stretch for most 8- and 16-bit microcontrollers. The ability to support such a high switching frequency also lowers total system cost because less expensive inductors and capacitors can be used in the design (see Figure 3 on the following page). In this configuration, Timer_D modules can drive the RGB LEDs and the SEPIC stage while Timer_A resources can be used to implement a capacitive touch slider or button.
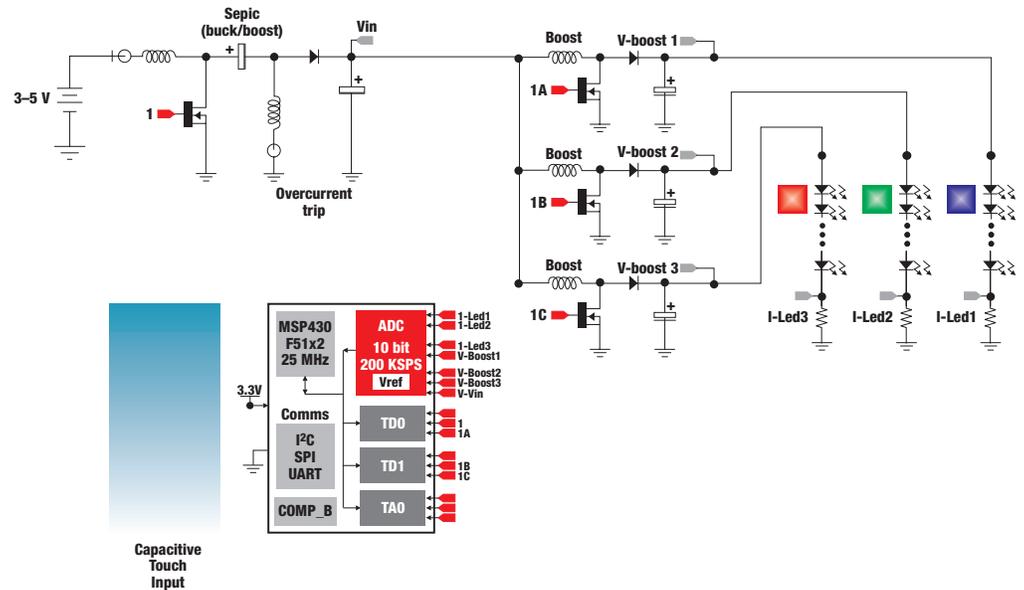
Figure 3. MSP430F51x2 device driving the power stage topology for RGB LED string and support for dimming through capacitive touch.

Capacitive touch

When dimming using capacitive touch technology is required, the need for an advanced microcontroller functionality increases significantly. Essentially, touch-sensitive sensors can be created by constructing an open capacitive structure that allows the electric field to leak away from the material. The disruption of this electric field by conductive foreign objects can be measured and compared against a known base capacitance for the sensor. As a conductive object enters the electric field, the result is an increase in capacitance. Touch events can be detected by comparing the effect of the increase in capacitance against the baseline capacitance where no object is present. The sensitivity of a sensor is based on the sensor design as well as the material and thickness of the PCB.
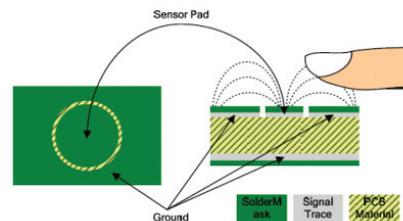
Figure 4. Open capacitor acting as a sensor.

The MSP430F51x2 microcontroller can accommodate capacitive touch in a similar manner to the other MSP430 devices by using the integrated comparator. In addition, it also features the Timer_D high-resolution timer that captures pulse widths to a few nanoseconds that is used to achieve much higher sensitivities and faster scan times than other solutions.

Capacitive touch dimming

Because LEDs are current-controlled devices, dimming can be implemented by monitoring the current that flows through the shunt resistor (see Figure 2) and driving the boost DC/DC converter accordingly.

The data set necessary to implement accurate dimming can be found in an LED's forward current vs. luminous flux curve, which shows light output rising non-linearly as current rises.

Simply varying the LED's forward current is not the best approach because most LEDs change color when the forward current changes. A better solution is to take advantage of the LED's ability to turn on and off almost instantaneously. This characteristic allows the designer to reduce light intensity by pulsing the LED's current faster than the human eye can detect. In other words, precisely varying the time the LED is on (but keeping the forward current constant) can change the device's effective brightness. The average current in the LED and the corresponding light output changes but the LED's forward current remains constant.

Digital control makes pulsed-current dimming control fairly straightforward because the LED current is software-controlled via the PWM signals that control the power stage. A pulsed-current can be created by implementing a counter in software that turns the PWM off instantly when the required dimming point is reached. The counter would continue counting and turn the PWM back on to achieve the average light flux required for the desired dimming setting.

With MSP430F51x2 devices, developers can implement capacitive touch for dimming using either a slider or a wheel as the human interface device by downloading the capacitive touch sense library for the MSP portfolio (**www.ti.com/litv/zip/slac489**). The library takes advantage of the high-resolution timers available in MSP430F51x2 devices and speeds up development time.

Driving more intelligence in lighting applications with TI's MSP microcontrollers

While the hi-res Timer_D peripheral drives digital power stage topologies and offers capacitive touch support in portable LED intelligent lighting, TI's overall MSP product portfolio offers many low-power solutions for other intelligent lighting applications. For example, industrial and commercial buildings are rapidly deploying occupancy and ambient sensors to control an intelligent light source to either dim the room/office space or turn off the lights completely. Another would be hosting a lighting communication stack such as DALI (digital addressable lighting interface – **www.ti.com/litv/pdf/slaa422a**) to connect an intelligent light source to building energy-management systems. Wireless systems needing ultra-low-power microcontrollers for sensors as well as for lighting system commissioning are also up and coming applications. Collectively, and with TI's MSP microcontroller portfolio, the adoption and deployment of these intelligent lighting applications will go a long way in further reducing the worldwide energy consumption attributed to lighting.

Benefits of MSP430F51x2 microcontrollers in battery-powered LED intelligent lighting applications include:

- Two high-resolution Timer_D modules
  - Useful in generating high-resolution PWM for portable DC/DC power topology
  - Support fast scan rate without compromising sensitivity for capacitive touch
- Capacitive touch for dimming
- Accurate color matching through separate DC/DC power stages for each individual RGB string
- Adaptive luminous flux (brightness) control based on aging profile, external ambient light sensor and usage
- Support for a wide range of communication protocols such as UART, SPI, IrDA and I²C
- 25 MHz, 16-bit RISC architecture that provides better code density, performance and peripheral integration vs. 8-bit microcontrollers
- 5 × 5 mm 40-pin QFN package and bare die offering for ultra-thin portable products
- Ultra-low-power consumption and flexible operating modes
  - Active mode at 180 µA/MHz
  - Standby mode (LPM3 watchdog timer mode) at 1.1 µA
  - Off mode at 0.9 µA
  - Shutdown mode at 0.25 µA

MSP430 software & tools

MSP430F51x2, MSP430F51x1 40-Pin RSB Target Board → Part# MSP-TS430RSB40

MSP430 Capacitive Touch BoosterPack → Part# 430BOOST-SENSE1

MSP430 Capacitive Touch Sense Library

IMPORTANT NOTICE

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Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
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Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
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