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Methods of controlling multiple LED strings with C2000™ microcontrollers (MCUs)

Introduction

As more applications continue to integrate LED technology, developers find themselves facing the challenge of driving greater numbers of LEDs while lowering system cost and increasing power efficiency. For systems requiring multiple strings of LEDs, TI provides two example solutions illustrating differing power stage topology designs and digital control methods. This whitepaper explores the different LED driver topologies and digital control methods available for driving multiple LED strings efficiently to reduce system cost, lower operating expenses, increase color accuracy, and improve overall reliability.

As LED technology continues to evolve, the improved power efficiency and cost savings made possible has led to an increase in the number of ways LEDs are being used. At the same time, systems are using a greater variety of LEDs, each of which needs to be driven differently to achieve optimal performance, efficiency, and color accuracy. Automotive systems, for example, use LEDs for a variety of functions – including headlights, high beams, fog lights, cornering lights, etc. – each requiring a different type of LED and/or different number of LEDs.

Developers can drive multiple LED strings using different power stage topologies and control methods. Each topology and control method offers its own advantages, depending upon the application. Demonstrating implementations of two common LED lighting design implementations, TI offers two LED lighting developer's kits based on its real-time control C2000 Piccolo™ architecture – the DC/DC LED Lighting Developer's Kit and Multi-DC/DC Color LED Developer's Kit. Combined with TI's industry-leading development software and tools, engineers can use these kits to accelerate the development of a wide range of lighting applications.

Power Stage Topologies and Control Methods

There are several common power stage design topologies and digital control methods used in the LED lighting industry today. Each design implementation and control method offers its unique advantages and considerations. TI showcases two of these power stage design topologies and two accompanying control methods with its C2000 LED lighting developer's kits. Figure 1 shows the power topology for a single, shared power stage as used in the DC/DC LED Lighting Developer's Kit. This topology utilizes a Piccolo MCU to control a single, flexible SEPIC DC/DC power stage and eight separate LED dimming stages for control of same type and same length LED strings. SEPIC is a dynamic topology which can run off a high voltage (up to 48 V) and step up or step down the drive voltage appropriately. With this control topology, developers can precisely and independently control luminosity and color temperature of same-type/same-length LED strings.

Alternatively, Figure 2 shows a multiple power stage topology for LED strings of variable length and LED types as used in the Multi-DC/DC Color LED Lighting Developer's Kit. This topology uses a single Piccolo MCU to control two SEPIC DC/DC power stages and six boost DC/DC power stages appropriate for driving color LEDs. With this versatile topology, developers can support up to eight LED strings of variable length and type. For example, a single Piccolo digital LED controller can drive up to eight LED strings, including a system of two white LED strings plus 2 sets of RGB strings (i.e., each RGB set is comprised of a red, green, and blue LED string).

The two topologies require a different approach to driving LED strings. When only a single power stage is available to drive multiple strings, the LED "on" voltage bias is varied through the power stage to achieve the desired LED color hue and efficiency (see Figure 3a). Dimming of individual strings (see Figure 3b) is achieved by toggling the LED current off and on with variable duty cycles using pulse width modulation (PWM). Alternatively, when each string has its own independent power stage, the LED is driven using average current mode control. With this approach, current flows continuously through each LED in a string. Instead of directly varying the voltage, the current in each power stage is varied. (see Figure 4). Dimming is achieved by lowering and raising the average current flowing through the LEDs. Color mixing is controlled by independently adjusting the individual current levels for separate red, green, and blue LED strings. The overall output of these LEDs then creates the desired color level. Precise color control is maintained while varying brightness by dimming the three RGB strings simultaneously and in conjunction with each other.

Driving Multiple LED Strings

There are many design considerations which go into making the decision whether to use a shared power stage or multiple independent power stages. LED output is determined by the voltage and current applied to the string of LEDs, and several factors affect the optimal drive level required for a particular string of LEDs:

LED type: Each type of LED (such as a 350mA or 1A LED) has its own brightness/voltage curve which the developer needs to take into account to accurately manage brightness. LEDs made from different manufacturers may also have a different curve even if the current rating is the same.

String length: Two strings with a different number of LEDs, even if the LEDs are of the same type and from the same bin, have different drive requirements.

LED color: For applications utilizing red, green, and blue LED triplets to mix colors, each different color LED has its own optimal operating voltage.

LED variation: the manufacturing process can lead to variations between LEDs. LEDs which are close in output can be purchased at a premium (i.e. binning). Alternatively, the operating voltage of a string can be dynamically adjusted to compensate for these variations.

In general, applications that use only a single type of LED, such as city or industrial lighting applications, may be well served by a single power stage topology, given that the number and type of LEDs is constant. A single power stage topology can also be an excellent way to consolidate analog components when many

strings of LEDs are in use. For example, a single controller, as used in TI's Piccolo LED kits, can efficiently manage eight separate strings of the same LED type.

Many applications, on the other hand, might benefit from a topology with multiple independent DC/DC supplies, each driving a separate LED string. When the LED strings in a system differ, in length or LED type, for example, working from a single power stage requires that the drive voltage be adjusted to match each string specification. Dropping this voltage for a particular string could decrease the power efficiency of the other strings or lead to suboptimal color control.

Furthermore, using separate and independent DC/DC stages for each LED string could be useful when precise operating values are required of each LED string, whether these values be brightness, color tone, or other measure. Supplying a separate voltage to each string through individual DC/DC stages can provide developers further control over the operating efficiency and light output accuracy of each LED string. With this design topology, each DC/DC stage drives LED strings of different types and lengths, providing great flexibility in an LED lighting design.

Accurate Color Mixing

The value of color accuracy varies from application to application. Accuracy for ambient lighting in a car may not be important if the driver can adjust the color based on preference. However, accuracy is very important if lighting needs to reflect a specific color. Accuracy can also be important, even when only white LEDs are in use. Xenon headlights, for example, can be too yellow or purple. Not only are such inaccuracies undesirable (i.e., purple headlights distract other drivers), they can negatively impact product life.

The decision whether to use a single or multiple power stage topology can also be affected by maintenance and risk considerations. For example, a simple lighting application replacing fluorescent bulbs in ballasts uses light modules that are all identical. Using a single power stage may help keep maintenance costs down; since the power stage circuitry will be located in the main controller, each light module is comprised primarily of the casing and LEDs. However, a single power stage is also a single point of failure for the many light modules connected to it. Alternatively, a system requiring high reliability, then, may rely upon a multiple power stage topology, as a failure is likely to disable only a single lighting module. However, this redundancy also increases light module replacement costs since power stage circuitry is part of the light module.

Simplifying Power Stage Design

Power stage design is a relatively straightforward process using TI reference designs and software tools. TI provides reference designs which developers can modify to optimize the power stage for the particular LED type and number of LEDs used in a string. Developers can create a fine-tuned power stage by supplying the brightness/voltage curve of the LEDs in use and having the controller sense the current and voltage levels using a high-precision ADC to further tune parameters. Furthermore, tools from the Mathworks, PSIM from Powersim, and Embedded Controls Developer from VisSim, all support the Piccolo architecture and ease power stage design.

In addition to TI's industry-leading Code Composer Studio™ integrated development environment, developers have access to controlSUITE™ software, a comprehensive collection of production-worthy control software. Offering an extensive range of functions, controlSUITE software provides example projects which provide much of the base code required for complete lighting applications, including closed loop control of DC/DC power and LED driver stages. For developers new to LED design, the example projects substantially lower the LED learning curve.

The Advantages of Digital LED Control

TI's Piccolo MCU architecture is ideal for LED applications. In addition to offering flexible LED drive control, Piccolo MCUs have the capacity to implement advanced features that are becoming increasingly important in many lighting applications:

Temperature sensing: Integrated ADCs allow the Piccolo MCU to easily monitor LED operating temperature. As temperature increases, LED efficiency drops. In addition, for color mixing applications, temperature also affects LED color. With temperature sensing, the digital controller can either dynamically compensate for changing temperature by adjusting the LED drive algorithm or by activating other system components such as a fan.

Green operation: Systems can use a variety of sensing techniques to implement more complex control algorithms to optimize power utilization. For example, a system could dynamically adjust LED drive levels based on the available ambient light. Lower power consumption also reduces heat dissipation to result in lower operating costs and higher long-term reliability.

System coordination and communications: Intelligent lighting control is essential for many LED-based systems ranging from flashing decorative lights to activating a vehicle's cornering headlights to high-end stage lighting. Developers can implement a variety of generic and application-specific communications channels, including CAN, DMX, and power line communications (PLC). Combined with digital control of LEDs, a communications interface opens lighting systems to remote management and an extensive range of advanced usage models.

Programmability: A programmable architecture enables developers to continue to introduce new features to existing architectures without requiring time-intensive and costly redesign of system hardware. Programmability also enables simple field upgradeability when a communications interface is available so that systems can be updated without requiring a physical visit from a technician.

Color correction: The output of LEDs varies over temperature and time. To provide long-term accurate color mixing, Piccolo-based lighting systems can be programmed to compensate for temperature variation and to adjust the operating voltage to compensate for degradation from aging components.

High reliability: Developers can introduce features such as fault detection and alarm notification to both improve reliability and reduce maintenance expenses.

Integrated functionality: Piccolo digital LED controllers reduce system size and complexity by integrating a variety of on-chip peripherals required for a wide range of applications. For example, high-resolution ADCs support accurate current and voltage sensing for motor and power control applications.

Adaptability: Piccolo digital LED controllers provide sufficient performance headroom to accommodate changing market conditions, shifting customer requirements, and evolving standards, thus future-proofing designs and protecting design investment. TI also offers an expanding range of microcontrollers to meet the needs of emerging applications so manufacturers can exploit new opportunities quickly and cost-effectively.

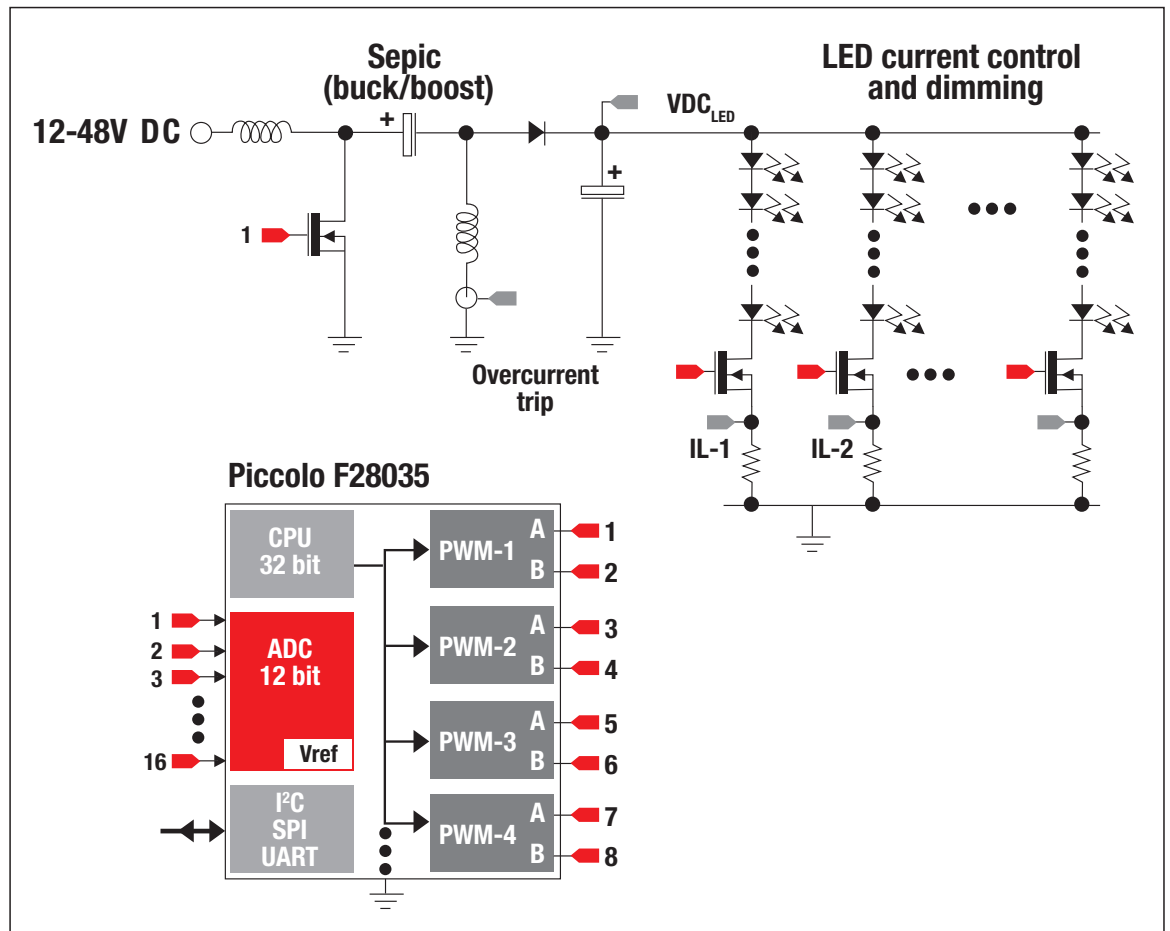
Single and multiple power stage topologies provide an effective approach for efficiently driving multiple LED strings. With its DC/DC LED Lighting Developer's Kit and Multi-DC/DC Color LED Developer's Kit, TI offers developers the option of implementing either a single or a multiple power stage topology, while demonstrating various methodologies for LED lighting control. Either approach can be used for most lighting systems, but each has its advantages, depending upon the particular application. Each Piccolo F2802x series microcontroller can control up to eight individual LED strings and, depending upon the power stage design used, drive virtually any number of LEDs per string.

Both kits come with a self-contained GUI-based control application which allows developers to experiment with LED brightness and color control and explore the many versatile capabilities of the Piccolo MCU (see Table 1). Developers can quickly evaluate the different power topologies and control methods, jumpstarting development using the most appropriate method.

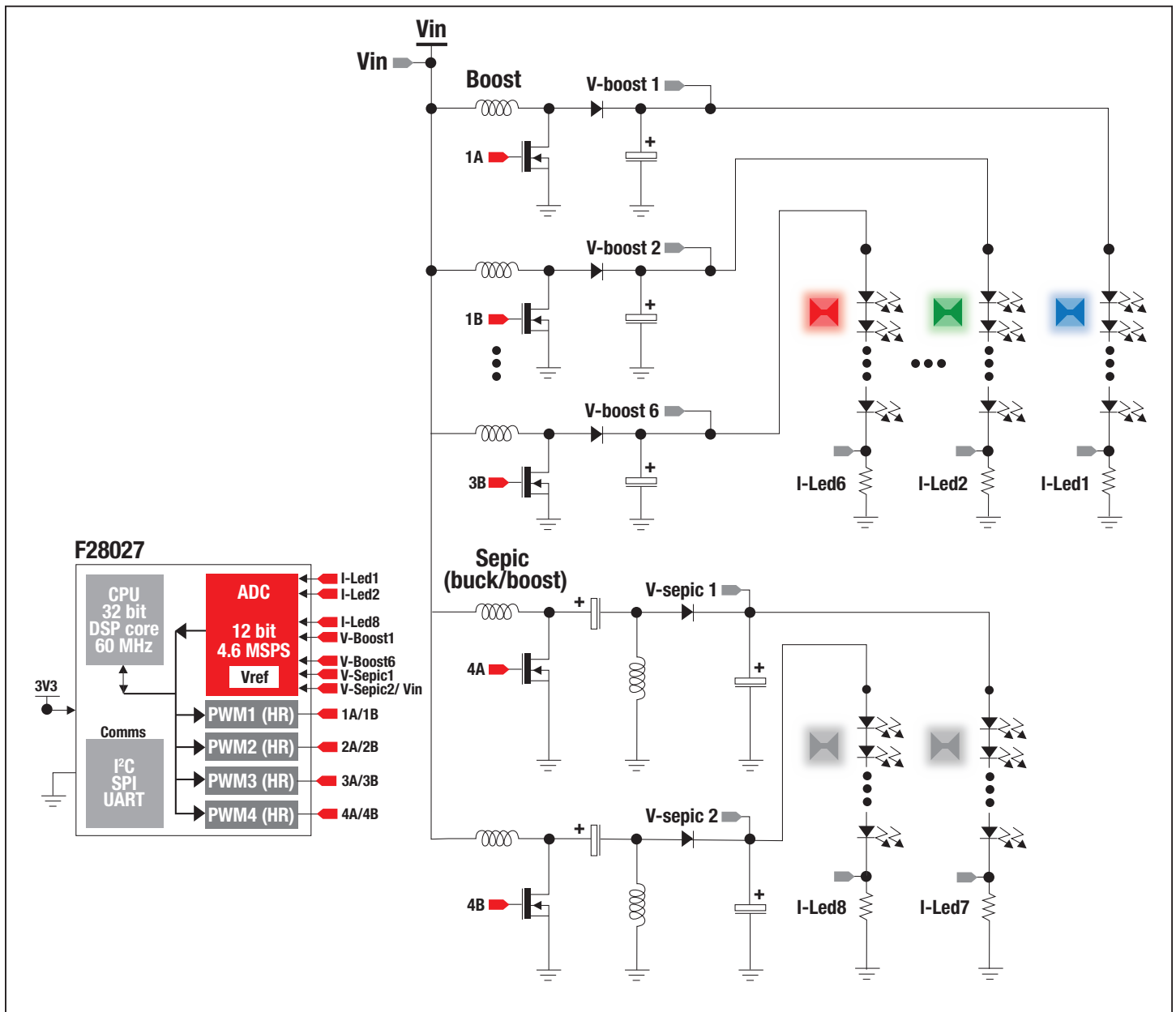
TI digital LED controllers provide the highest flexibility and adaptability to changing application requirements. TI also offers an extensive range of analog components backed by years of system-level expertise, comprehensive development tools, and extensive application software to provide developers with a complete LED lighting solution. Using Piccolo MCUs, developers can design systems that balance product price, size, complexity, power efficiency, accuracy, reliability, maintainability, and performance to create the optimal system.

Table 1: LED Lighting Developer's Kits: Key Features and Benefits

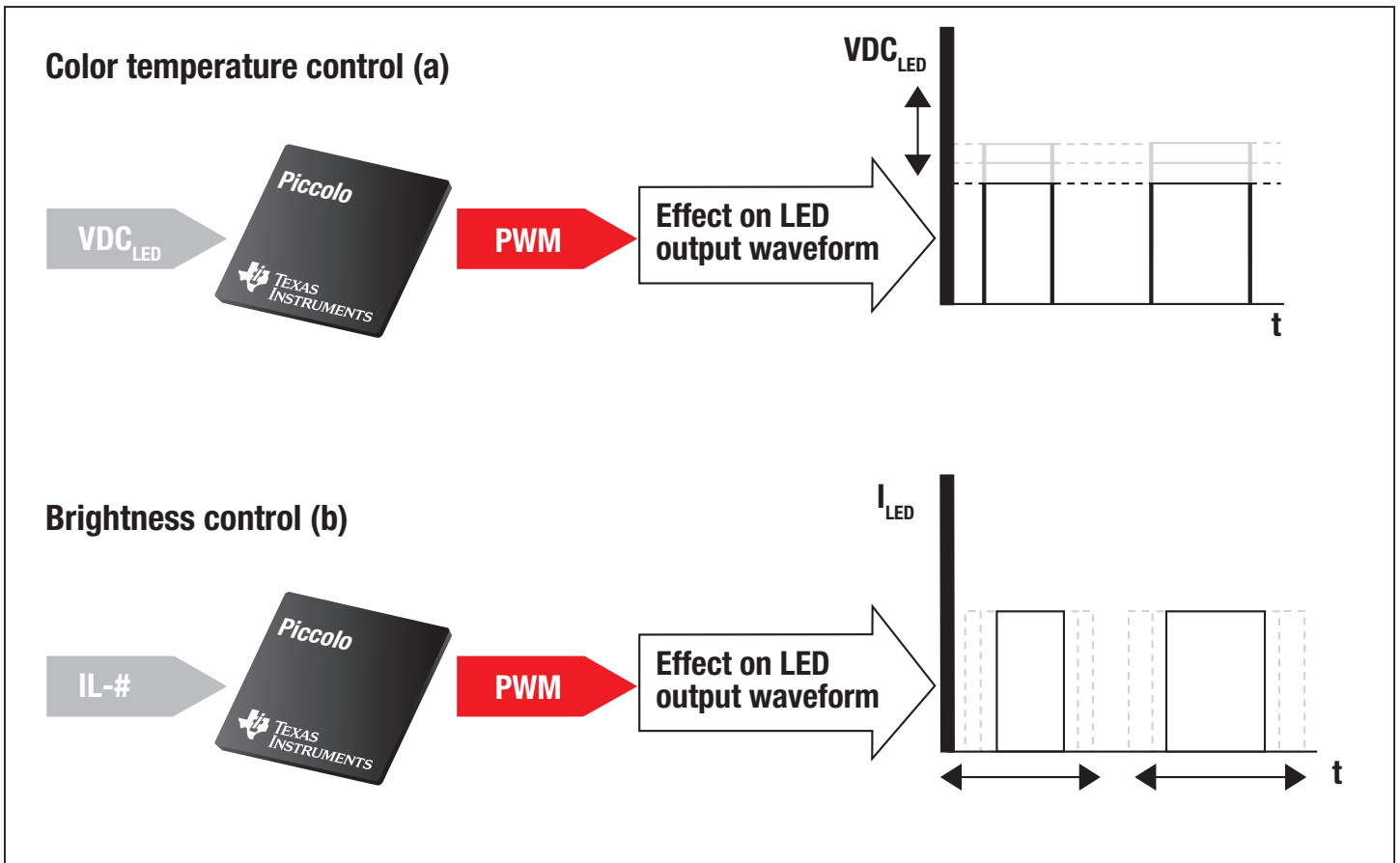
Feature	DC/DC LED Kit (TMDSDCDCLEDKIT)	Multi-DC/DC Color LED Kit (TMDSRGBLEDKIT)
Digital LED Controller	Piccolo F28035 (60 MHz, 32-bit performance, 14 PWM channels, 12-bit 4.6Msps ADC, 128 KB Flash)	Piccolo F28027 (60 MHz, 32-bit performance, 8 PWM channels, 13-channel 12-bit ADC, 64 KB Flash)
Power Topology	Single SEPIC DC/DC stage	Six Boost DC/DC stages Two SEPIC DC/DC stages
Number of Strings	Up to 8 strings of same length and same type LEDs	Up to 8 LED strings of variable lengths and LED types
Control Scheme	PWM dimming	Average current-mode control
Input/Output Voltage	12-48 V DC / 15-36 V DC	36 V DC (max) / 50 V DC (max)
Color Tone/Brightness Control	Luminosity of same-type/same-length LED strings is controlled. Color temperature of each string stays constant while dimming.	Luminosity of individual strings is controlled. Independent voltage rails allow multiple types and colors of LEDs to be controlled.



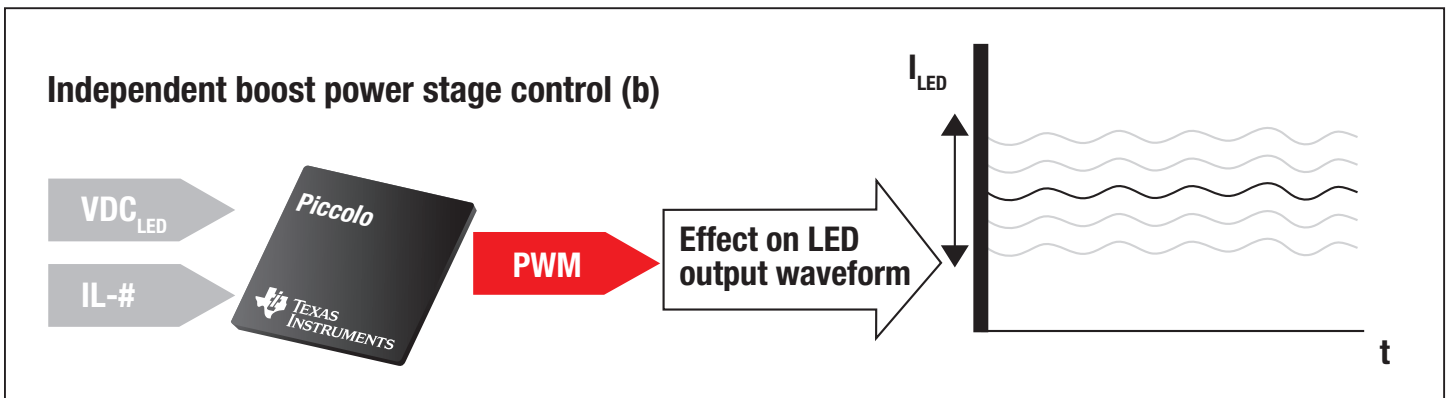
▲ **Fig. 1** – Using a SEPIC DC/DC power stage to buck or boost the voltage rail appropriately, the Piccolo F28035 MCU can drive up to eight LED strings of the same length and type. A single power stage topology is well-suited for applications such as industrial lighting where consistent output is required.



▲ **Fig. 2** – The Piccolo F28027 MCU can drive up to eight LED strings of variable length and different LED types. By utilizing a separate power stage for each LED string, the F28027 can independently control the color tone and brightness for each LED string. The use of a multiple power stage topology provides the most control and flexibility for applications that require color mixing and/or a variety of lighting options.



▲ **Fig. 3** – When driving multiple LED strings with a single power stage topology, (a) the LED “on” voltage bias is varied through the power stage to achieve the desired LED color hue and efficiency. Dimming of individual strings (b) is achieved by toggling the LED current off and on with a variable duty cycle using pulse width modulation (PWM).



▲ **Fig. 4** – When driving multiple LED strings each with its own independent power stage, average current mode control is used. Instead of varying the voltage, current varied using pulse width modulation (PWM) flows continuously through each LED in a string. Dimming is achieved by lowering and raising the average current flowing through the LEDs. Different color levels are created by independently adjusting the individual current levels for the separate red, green, and blue LED strings. Precise color control is maintained while varying brightness by dimming the three RGB strings simultaneous and in conjunction with each other.

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