Battery-Powered Constant Current LED Drivers

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INTRODUCTION

This document aims to help engineers design different low-power applications, and to provide insight on which LED driver to chose in order to meet specific requirements. Typical application examples that make best use of the highlights of the chips are also provided.

BOOST CONVERTER ESSENTIALS - LED DRIVERS OPERATION FUNDAMENTALS

LED drivers can be implemented with several switching topologies, including Buck, Boost and SEPIC. This application note describes Boost LED drivers, with a few particularities: lower feedback voltage and no soft-start.

The Boost topology is commonly used in today's battery-powered devices, as it requires the minimum number of components in order to develop a DC-DC power converter that provides a stable output voltage from a lower input source ($V_{IN} < V_{OUT}$). Figure 1 shows an idealized version of a non-synchronous boost converter.

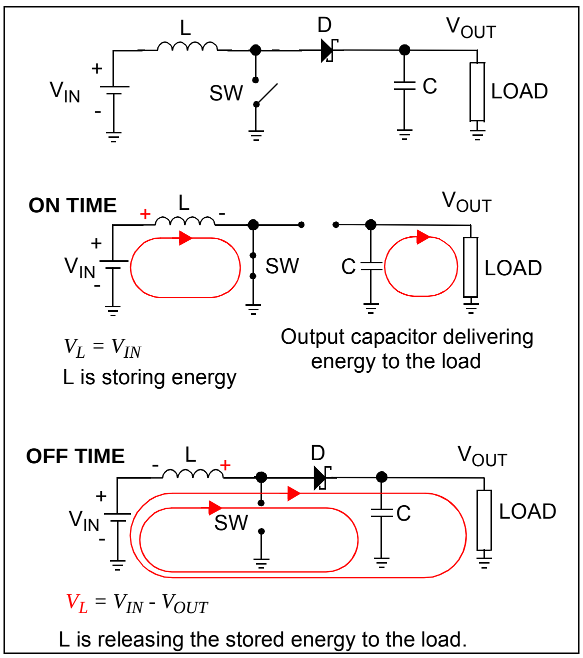

FIGURE 1: Boost Converter Topology.

The basic operation of the boost converter can be summarized by looking at the two current paths created by the state of the switch.

- When the switch is turned ON (ON TIME circuit in Figure 1), a DC voltage equal to V_{IN} is applied to the inductor, resulting in a positive linear ramp of the inductor current (simplified model). During this time, the diode D is reverse-biased and the energy to the load is provided by the output capacitor.
- When the switch is turned OFF (OFF TIME circuit in Figure 1), the polarity across the inductor will reverse in order to sustain the current flow towards the load. The voltage across L will be $V_{IN} – V_{OUT}$ (where $V_{OUT} > V_{IN}$), resulting in a negative linear ramp of the inductor current (simplified model). With the switch opened, there is no path from the right side of the inductor to the negative power supply terminal. During this time, the rectifying diode is forward-biased and the energy is delivered to the output capacitor and load.

A boost converter operates in Continuous Inductor Current Mode (Figure 2) if the current through the inductor never falls to zero during the commutation cycle. If the inductor current reaches zero, the boost converter operates in Discontinuous Inductor Current Mode (Figure 3).

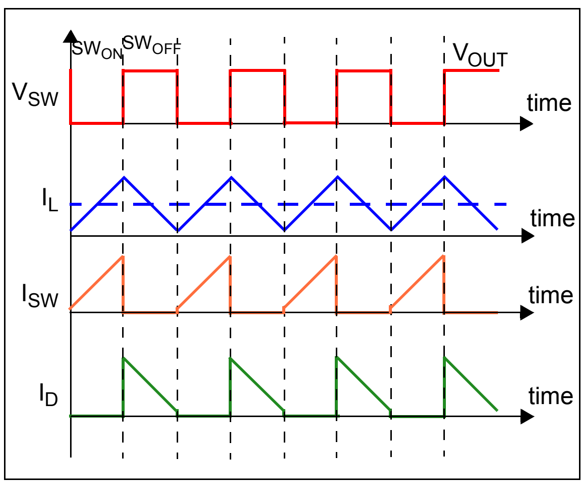

FIGURE 2: Boost Converter – Continuous Conduction Mode Waveforms.

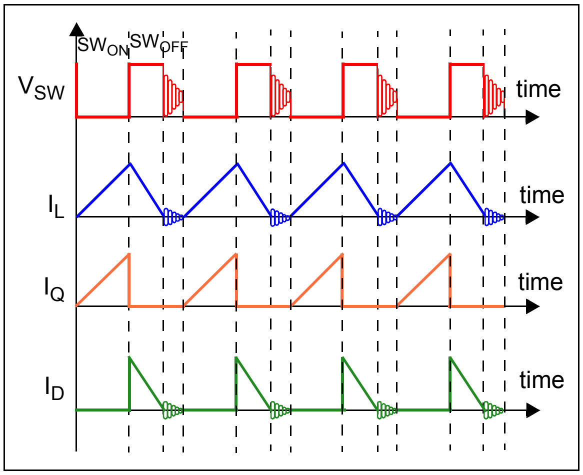

FIGURE 3: Boost Converter – Discontinuous Conduction Mode Waveforms.

Boost Converter Power Stage Design

In order to build an efficient and competitive power supply that can meet the requirements of the industry standards, engineers have to include in the design process the calculation of the external components based on the input parameters and load requirements of the actual application. In order to do this, there are a few steps that have to be covered.

The system parameters and components relevant for the design are listed in Tables 1 to 4.

TABLE 1: SYSTEM PARAMETERS

Parameter	Symbol	Unit
Typical Input Voltage	V_{IN}	V
Minimum Input Voltage	V_{INmin}	V
Maximum Input Voltage	V_{INmax}	V
Output Voltage	V_{OUT}	V
Output Current	I_{OUT}	A

TABLE 2: SYSTEM COMPONENTS

Component	Designator	Unit
Inductor	L	µH
Output Capacitor	C_{OUT}	µF
Output Capacitor ESR	$C_{OUT,ESR}$	Ω
Input Capacitor	C_{IN}	µF
Rectifying Diode	V_D	V

TABLE 3: PARAMETERS RELEVANT TO SYSTEM BEHAVIOR

Parameter	Designator	Unit
Duty Cycle	D	%
Equivalent Output Voltage	V_{OUT}	V
Equivalent Input Current	I_{IN}	A
Maximum Duty Cycle	D_{MAX}	%
Inductor Ripple Current	I_{Lp-p}	A
Inductor Peak Current	I_{PEAK}	A
Output Voltage Ripple	V_{OUTp-p}	mV
Output Current	I_{OUT}	mA
Estimated Efficiency	η	%

TABLE 4: CONVERTER PARAMETERS

Parameter	Designator	Unit
Switching Frequency	f_{SW}	kHz
NMOS Switch ON Resistance	R_{DS-ON}	Ω
Feedback Voltage	V_{FB}	V

Equations 1 to 6 apply only for Continuous Conduction mode.

EQUATION 1: CALCULATING THE INPUT CURRENT

$$I_{IN} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times \eta_{est}}$$

EQUATION 2: CALCULATING THE DUTY CYCLE

$$D = \frac{V_{OUT} - V_{IN} \times \eta}{V_{OUT}}$$

Note 1: For minimum duty cycle, replace V_{IN} with V_{INmax} in the above formula.

2: For maximum duty cycle, replace V_{IN} with V_{INmin} in the above formula.

EQUATION 3: INDUCTOR RIPPLE CURRENT

$$I_{Lp-p} = \frac{(V_{IN} - I_{IN} \times R_{DS-ON}) \times D}{f_{SW} \times L}$$

EQUATION 4: INDUCTOR PEAK CURRENT

$$I_{PEAK} = \frac{I_{Lp-p}}{2} + \frac{I_{OUT}}{1-D}$$

EQUATION 5: OUTPUT VOLTAGE RIPPLE

$$V_{OUTp-p} = \frac{V_{OUT} - V_{IN}}{V_{OUT} \times F_S} \times \frac{I_{OUT}}{C_{OUT}}$$

Note 1: Output voltage ripple due to capacitor's ESR is neglected (ceramic capacitors have low ESR).

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RECTIFIER DIODE SELECTION

- Schottky diodes should be used (to reduce losses).
- The Schottky diode must have a current rating higher than the inductor peak current limit.
- The reverse voltage rating has to be higher than the maximum output voltage of the converter.
- The rectifier diode should withstand the power dissipation:

EQUATION 6: RECTIFIER DIODE SELECTION

$$P_D = I_F \times V_F$$

Where:

I_F = Average forward current of the rectifier diode (maximum output current)

V_F = Diode forward voltage corresponding to forward current

OVERVIEW OF THE BATTERY-POWERED LED DRIVERS

Low feedback voltage is what differentiates LED drivers from typical boost converters. This has the benefit of allowing more serially connected LEDs and lower dissipation on the bottom (current set) resistor.

Considering the typical LED drivers are battery-powered, correct use of batteries becomes essential.

Figure 4 shows the typical discharge curve of two cells used to power an LED driver. The power-down and restart events are determined by the Undervoltage Lockout (UVLO) thresholds.

Below its Functional End Point (FEP), the battery quickly discharges and is no longer able to supply the board. The UVLO feature is implemented to avoid such an event.

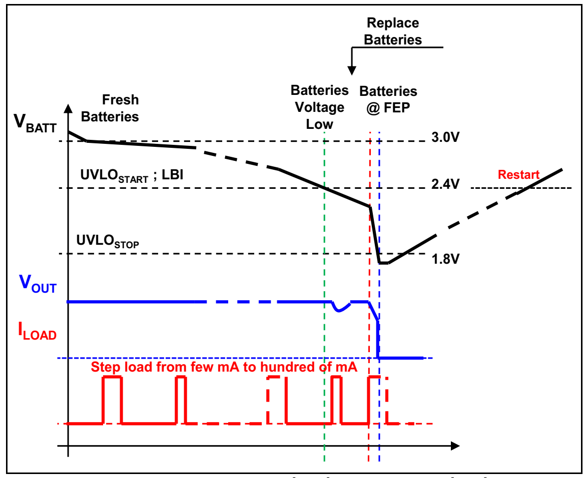

***FIGURE 4:** Typical Battery Discharge Cycle vs. Driver Output.*

Table 5 provides a head-to-head comparison between Microchip Technology Incorporated LED drivers and their highlights.

TABLE 5: MICROCHIP LED DRIVERS COMPARISON

Device	Key Definitions	No. of cells(1)	No. of LEDs	Maximum output voltage	Protection Features
MCP1643	One-cell high-efficiency LED driver V_{FB} = 120 mV Low Start-up and Shutdown Voltage	1 - 2	1/parallel config.	5V	Overvoltage Clamp @ 5V
MCP1664	Two-cells operation or one-cell Li-Ion, Low Reference, V_{FB} = 300 mV, High Current Output 2.4V Start-up, 1.8V Shutdown, Low I_Q	2 - 3	3 - 10	32V	Open Load Protection, UVLO, 1.8A Input Peak Current
MCP1662	Two-cells operation or one Li-Ion, 5V USB, Low Reference, V_{FB} = 300 mV, Low Shutdown I_Q, 2.4V start-up, 1.8V Shutdown	2 - 3	3 - 10	32V	Open Load Protection, UVLO, 1.2A Input Peak Current

Note 1: One cell is considered alkaline or NiMH/NiCd. Alternately, MCP1662/4 can be supplied from a single Li-Ion battery.

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MCP1643 ONE-CELL LED DRIVER

The MCP1643 is a compact, high-efficiency, fixed frequency, synchronous step-up converter optimized to drive one LED with constant current, that operates from one and two-cell alkaline and NiMH/NiCd batteries.

The device can also drive two red/green/yellow series-connection LEDs.

The internal feedback voltage is set to 120 mV for low power dissipation when sensing and regulating LED current. A single resistor sets the constant current output that drives the LED load.

The device features an output overvoltage protection that limits the output voltage to 5.0V typical, in case the LED fails or output load is disconnected.

The LED can either be turned OFF or turned ON using the enable input. A True Output Load Disconnect mode provides input-to-output isolation during Shutdown (EN = GND) by removing the normal boost regulator diode path from input to output. Shutdown state consumes 1.2 µA from input at room temperature.

For dimming applications, the LED can be turned ON and OFF with a variable duty cycle pulse-width modulation (PWM) signal applied to the EN pin.

The device also features thermal shutdown at +150°C, with +25°C hysteresis. Two package options are available: 8-lead MSOP and 8-lead 2 x 3 mm DFN.

Typical Application Circuits

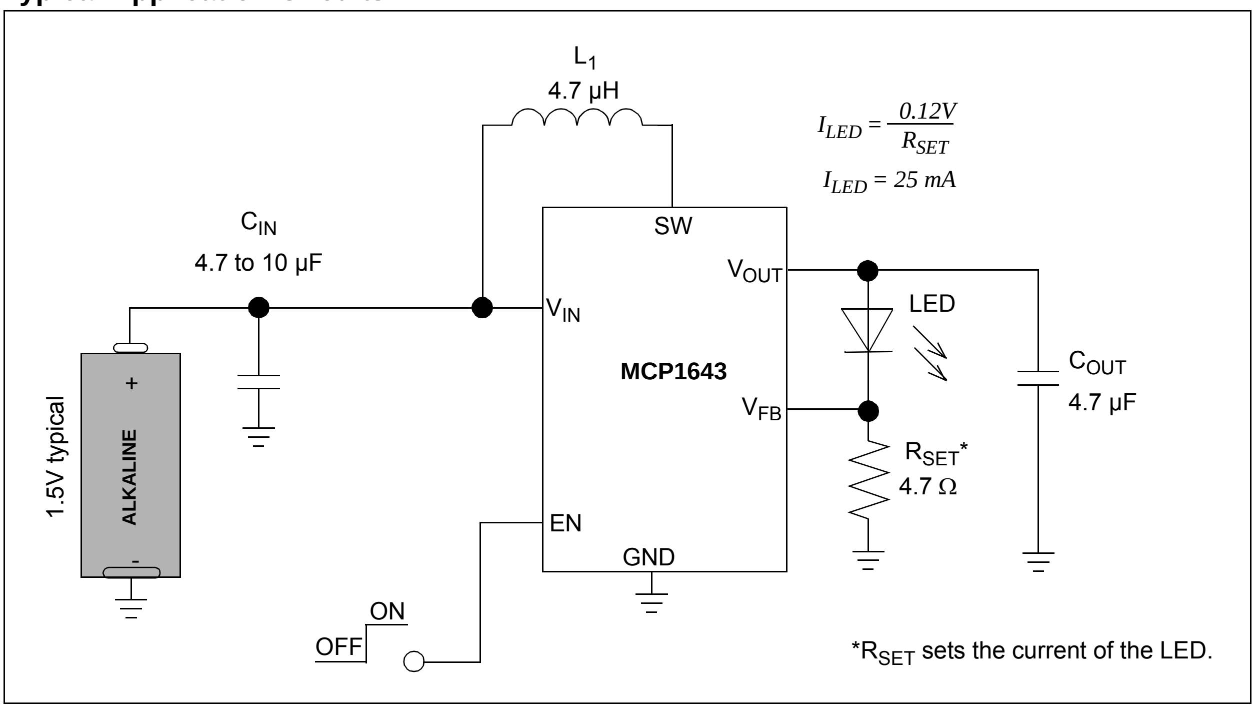

FIGURE 5: One LED Powered from One Cell.

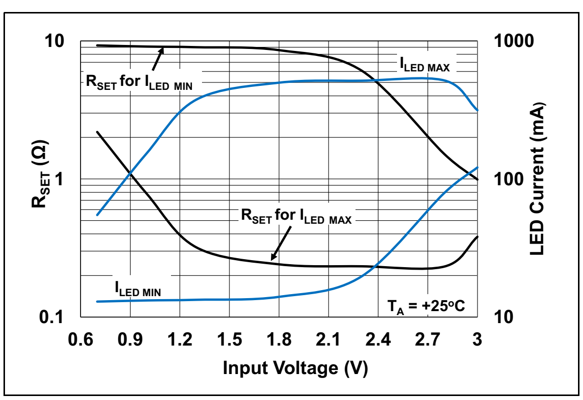

FIGURE 6: LED Current vs. Input Voltage.

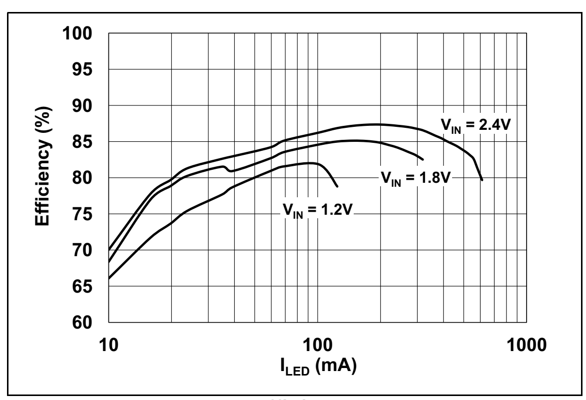

FIGURE 7: Efficiency vs. LED Current.

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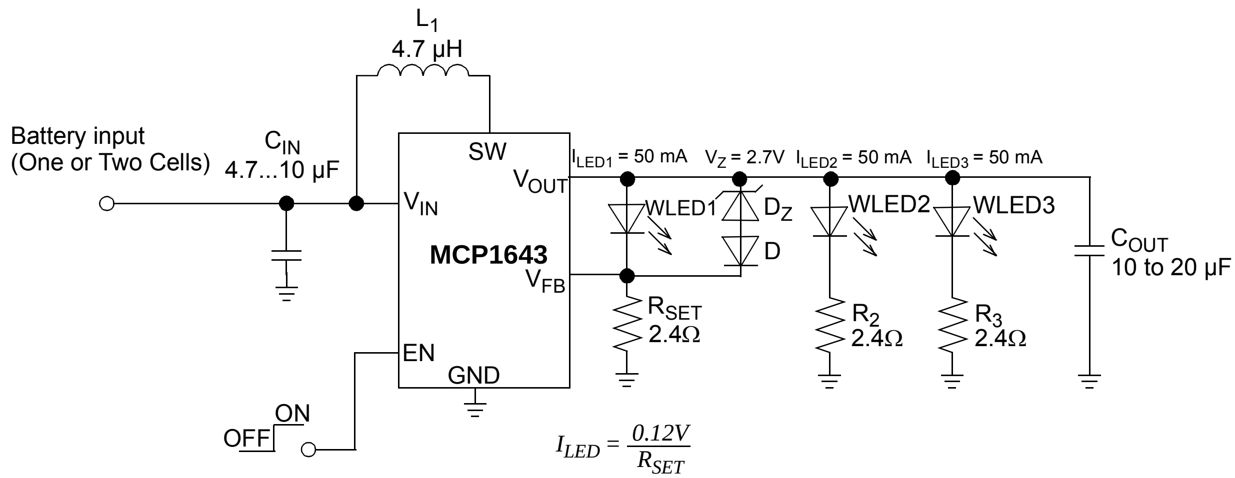

Note: D_Z and D group protects the WLED2 and WLED3 from excessive voltage and current if the WLED1 fails. The MCP1643's input quiescent current in Shutdown (EN = GND) is typically 1.2 µA. High load currents require additional output capacitance.

FIGURE 8: *Three White LEDs Application Powered from One or Two Cells.*

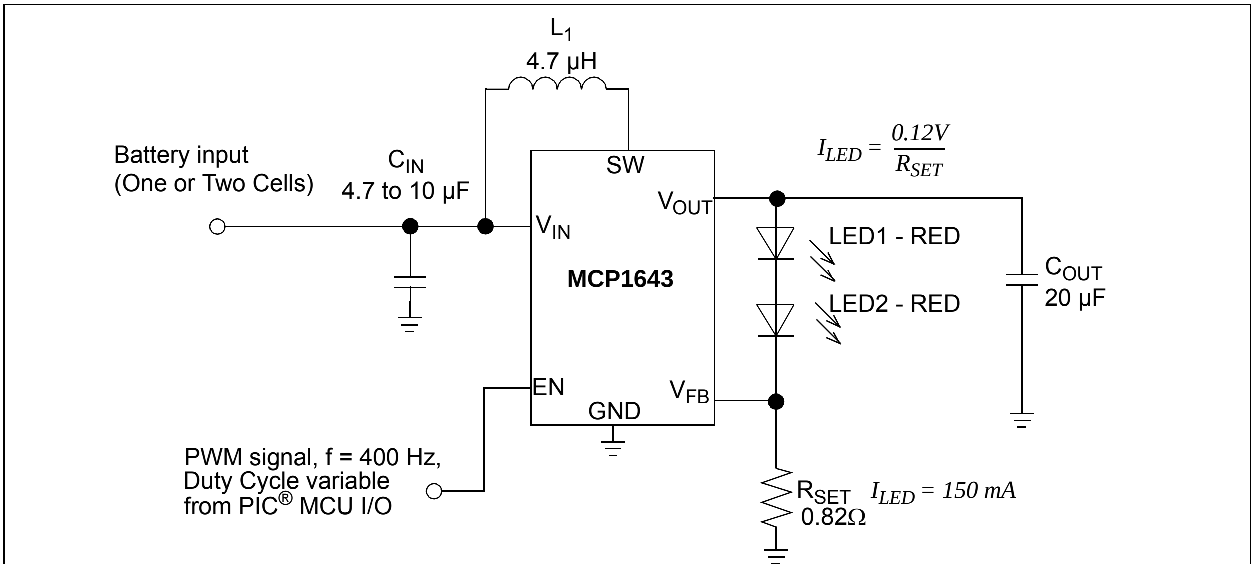

FIGURE 9: *150 mA Two Power RED LEDs Driver with PWM Dimming Control from PIC® MCU.*

The MCP1643 Synchronous Boost LED Constant Current Regulator Evaluation Board (ADM00435) features one LED powered from a single cell. The design allows the user to set the LED current to the following: 25 mA/50 mA/75 mA/100 mA.

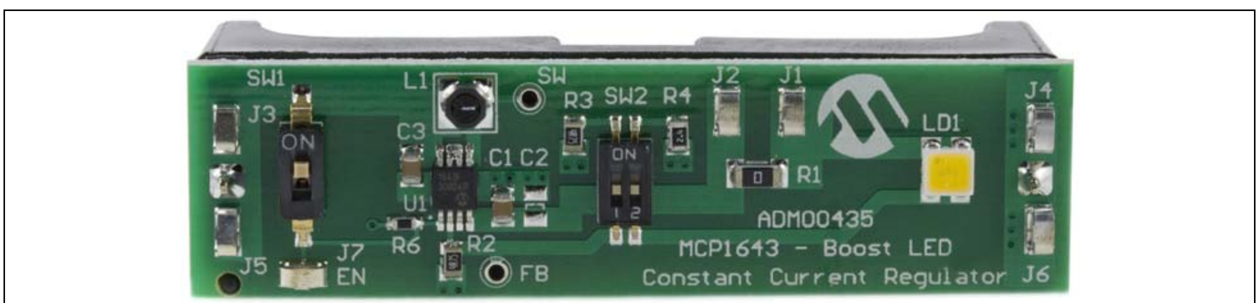

FIGURE 10: *MCP1643 Synchronous Boost LED Constant Current Regulator Evaluation Board.*

MCP1662/4 TWO-CELL LED DRIVER

The MCP1662/4 is a compact, space-efficient, fixed-frequency, non-synchronous step-up converter optimized to drive multiple strings of LEDs with constant current powered from two and three-cell alkaline or NiMH/NiCd batteries, as well as from one-cell Li-Ion or Li-Polymer batteries.

The internal feedback voltage is set to 300 mV for low-power dissipation when sensing and regulating the LED current. A single resistor sets the LED current.

The device features an Undervoltage Lockout (UVLO) which avoids start-up with low inputs or discharged batteries for two-cell powered applications.

The MCP1662/4 features an Open Load Protection (OLP) that turns off the operation in situations when the LED string is accidentally disconnected or the feedback pin is short-circuited to GND. Once the feedback voltage drops below 50 mV, the device stops switching and the output voltage will be equal to the input voltage (minus a diode voltage drop). This feature prevents damage to the device and LEDs in case of an accidental event.

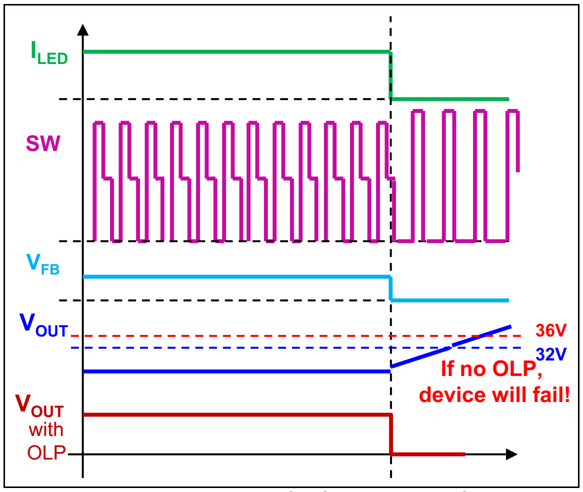

FIGURE 11: *Typical Open Load Event Waveforms.*

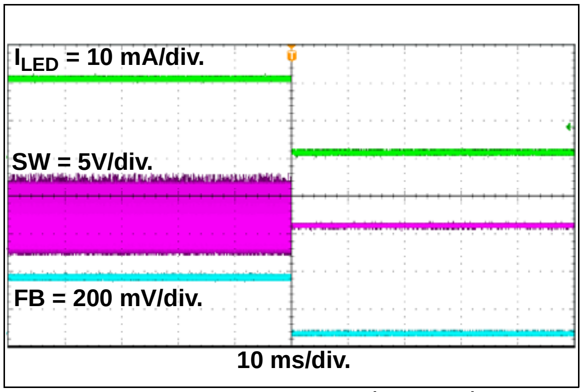

FIGURE 12: *Open Load Protection Waveforms.*

The maximum number of LEDs that can be placed in series and be driven is dependent on the maximum LED forward voltage (V_{Fmax}) and LED current set by the R_{SET} resistor. The voltage at the output of the MCP1662/4 plus a margin should be below 36V. Consider that the V_{Fmax} has some variation over the operating temperature range and that the LED data sheet must be reviewed. A maximum of 10 white LEDs in series connection can be driven safely.

For applications which require driving more series LEDs, a 10 µH inductor is recommended. Table 6 provides the recommended values.

TABLE 6: EXTERNAL COMPONENTS

No.of LEDs	Recommended Inductance	C_{IN} V_{IN} < 2.5V	C_{IN} V_{IN} > 2.5V
up to 4	4.7 µH	20 - 30 µF	4.7 - 10 µF
5 - 10	10 µH	20 - 30 µF	4.7 - 10 µF

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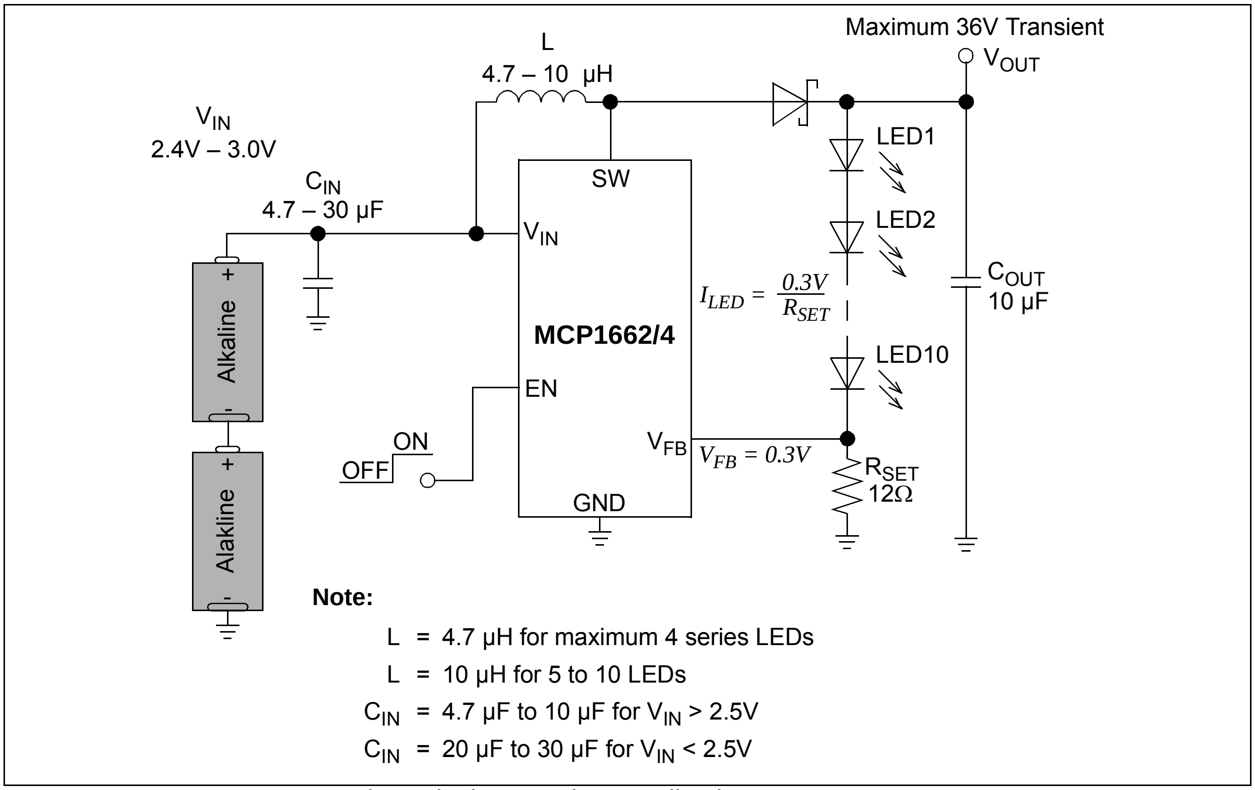

FIGURE 13: *MCP1662/4 Typical LED Driver Application.*

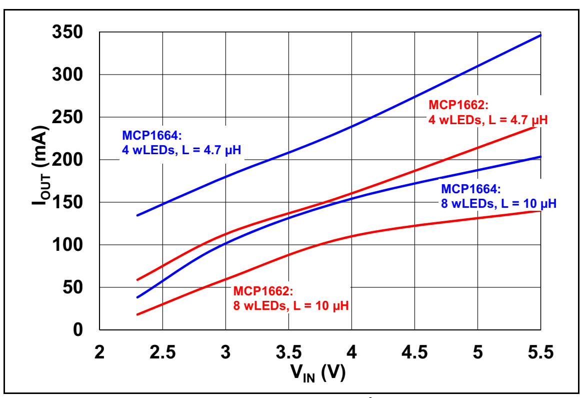

FIGURE 14: *MCP1662/4 Output Current vs. Input Voltage.*

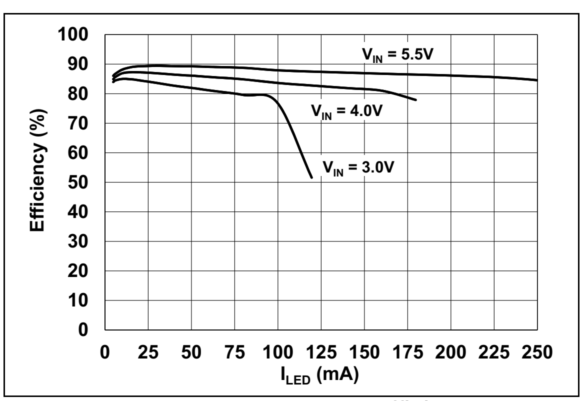

FIGURE 15: *MCP1662 Efficiency vs. Output Current.*

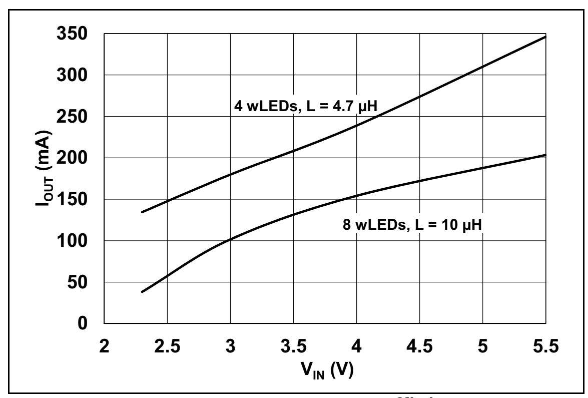

FIGURE 16: *MCP1664 Efficiency vs. Output Current.*

The MCP1662 Evaluation Board (ADM00555) features a string of LEDs driven from two cells (fitted on the backside) or an external source (maximum 5.5V). On-board switches select between three output currents: 30 mA, 60 mA or 90 mA.

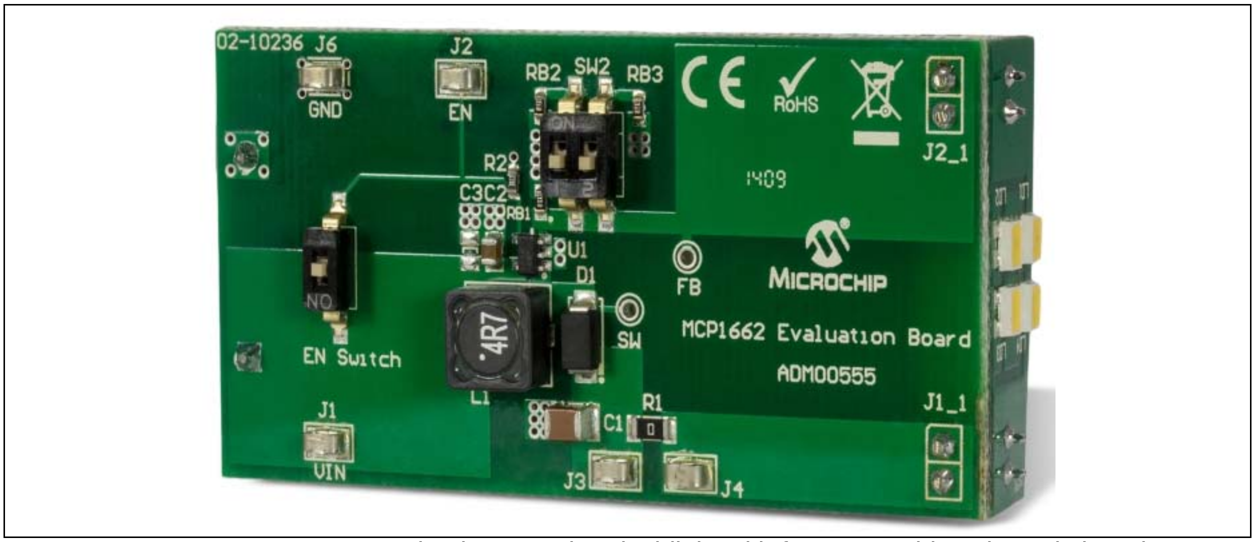

FIGURE 17: *MCP1662 Evaluation Board – Flashlight with four LEDs driven by switch to three current levels (30 mA, 60 mA, 90 mA).*

One of the main advantages of the LEDs is the possibility for dimming (Figure 18). An adjustable dimming block based on three op amps provides a simple, yet robust solution (see Figure 19).

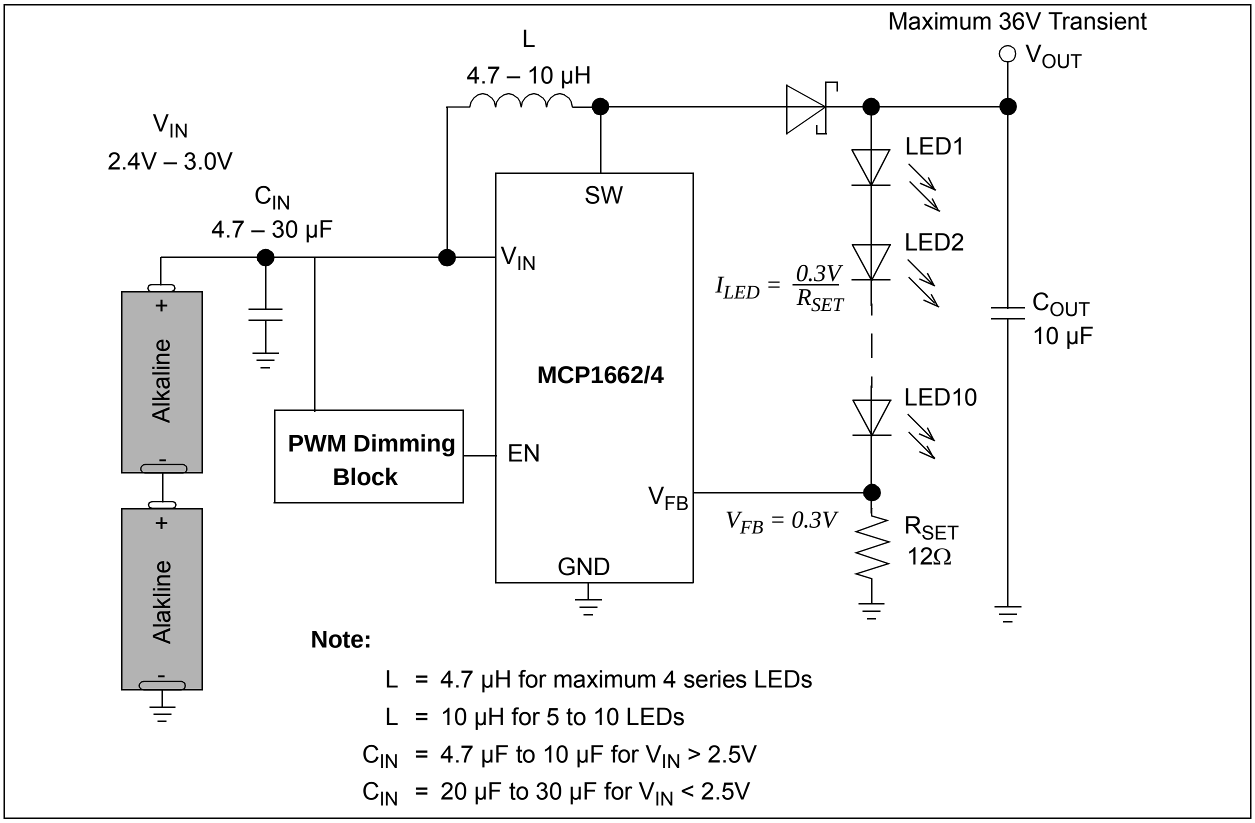

FIGURE 18: *MCP1662/4 Application with PWM Dimming.*

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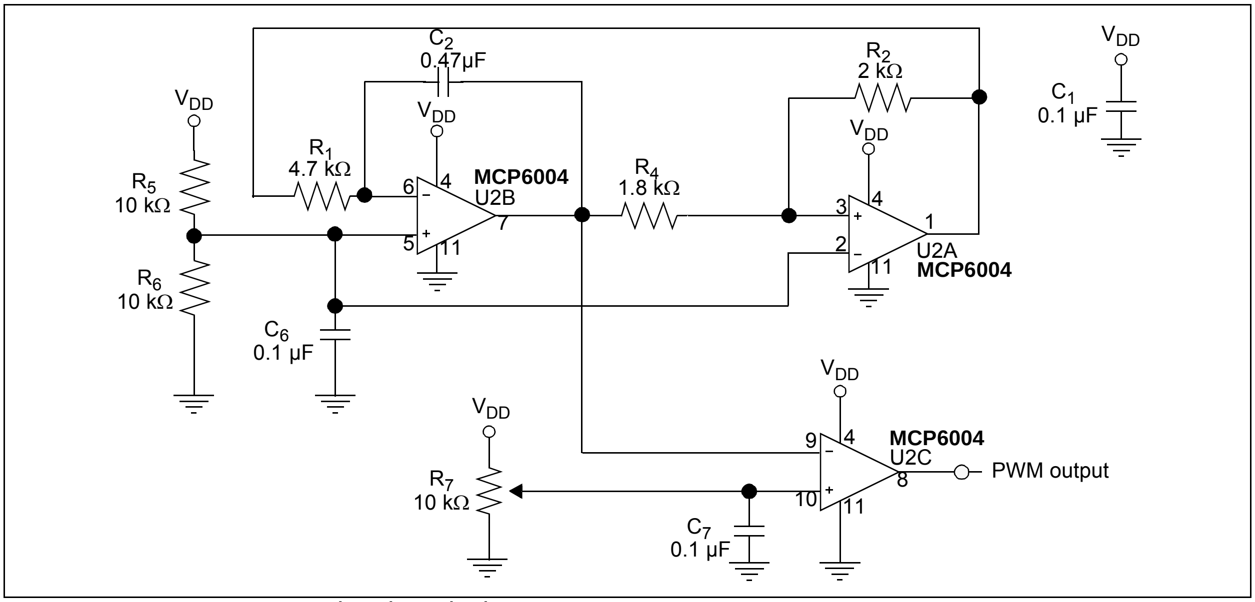

FIGURE 19: PWM Dimming Block.

The circuit consists of a triangular wave generator:

- U2B is functioning as an integrator
- U2A is functioning as a comparator with hysteresis
- U2C is functioning as a simple comparator with adjustable threshold.

The U2B non-inverting input is biased at $V_{DD}/2$. A virtual connection between the inverting and non-inverting inputs allows a constant current through R_1 equal to $I = V_{DD}/(2 \times R_1)$, which charges the capacitor C_2. Thus, the U2A integrator output increases linearly with time.

When capacitor C_2 reaches 95% V_{DD}, the comparator output changes to its maximum output voltage V_{DD}. At that point, the output voltage of the integrator decreases linearly.

When capacitor C_2 reaches 5% V_{DD}, the comparator output voltage changes to zero and the cycle repeats. Thus, the integrator output is a triangular wave that swings between 5% and 95% V_{DD}.

U2C compares the triangular wave against the DC level given by the R_7 variable resistor. Its output is a square wave, with a duty cycle that varies from 0% to 100%.

The frequency of the PWM signal in determined by R_1, C_2, R_2 and R_4:

EQUATION 7: PWM SIGNAL FREQUENCY

$$f = \frac{R_2}{4 \times R_1 \times R_4 \times C_2}$$

LED Driver with PWM Dimming Frequency Evaluation Board

The implementation described in the previous section has been integrated into the MCP1664 LED Driver Evaluation Board (ADM00641). This board features an LED string powered from an external source (maximum 5.5V). Three output currents can be set via on-board switches: 90 mA, 180 mA and 270 mA. Additionally, the LEDs can be dimmed, through PWM, from a potentiometer.

FIGURE 20: MCP1664 LED Driver Evaluation Board.

BOOST LED DRIVERS EVALUATION BOARDS

Board Name	Part Number
MCP1643 Synchronous Boost LED Constant Current Regulator Evaluation Board	ADM00435
MCP1662 Evaluation Board	ADM00555
MCP1664 LED Driver Evaluation Board	ADM00641

CONCLUSION

The MCP1662/4 and MCP1643 target battery-powered applications that require low standby quiescent current and high efficiency. Due to the features integrated in the device, the run time of battery-powered applications with long idle periods is extended while still providing an efficient power transfer with high current values at the output. Special protection features, such as OLP and UVLO, ensure stable operation and battery protection.

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