TB060

Drive High Intensity White LEDs Efficiently Using the PIC16C781

Author: Ward Brown
Microchip Technology Inc.

INTRODUCTION

High intensity white LED's are rapidly gaining popularity because of their high light output for relatively low input current. Applications include small flashlights, backlighting, night visibility strobes for pedestrians and bikers, just to mention a few. This Technical Brief discusses how to design a high efficiency LED driver with minimum components using the PIC16C781.

Theory Of Operation

The circuit, shown in Figure 1, is essentially a Boost mode switching regulator with current feedback. Output voltage is determined by the inherent forward bias voltages of the LEDs. Output current is determined by the peak charge current of L1. This configuration differs slightly from the normal Boost mode configuration in that the load circuit is comprised of only the white LEDs in parallel with the power inductor, L1, instead of in series with the supply voltage and the power inductor. Each power cycle consists of a charge phase, when energy is stored in L1, and a discharge phase, when the stored energy is delivered to the LEDs. The charge/discharge cycle time is equal to the inverse of the Programmable Switch Mode Controller (PSMC) frequency.

During the charge phase Q1 is turned on, allowing current to flow through L1. Current rises linearly in L1, in accordance with Equation 1. Current in L1 is sensed by the voltage across R6. When the voltage across R6, amplified by the Op Amp, reaches the intended intensity threshold voltage (determined by the DAC output) Comparator 1 output will go low. When Comparator 1 goes low, the PSMC output is immediately terminated, removing the drive to Q1. The PSMC is configured for Pulse Width Modulation (PWM), which means that the output will remain low until the start of the next charge/discharge cycle. The PSMC is also configured for a maximum duty cycle, so the inductor charge time is limited even if the inductor current does not reach the intensity threshold.

During the discharge phase, the current in L1 is initially identical to the current when the charge phase terminated. The stored energy in L1 causes the voltage across L1 to reverse and rise to the combined forward-bias voltages of D1 through D4 at the initial L1 discharge current level. Current in L1 falls approximately linearly, in accordance with Equation 2, until the voltage across L1 falls below the combined forward junction breakdown voltages of D1 through D4, at which time current in L1 ceases to flow and the residual charge of L1 rings with the parasitic capacitance of the surrounding circuitry for the duration of the PSMC cycle time, or until the charge in L1 is dissipated, whichever occurs first.

High efficiency is achieved since no power-hungry current limiting resistor is required to protect the LEDs. Current limiting is inherent in the current Feedback mode of the switching regulator.

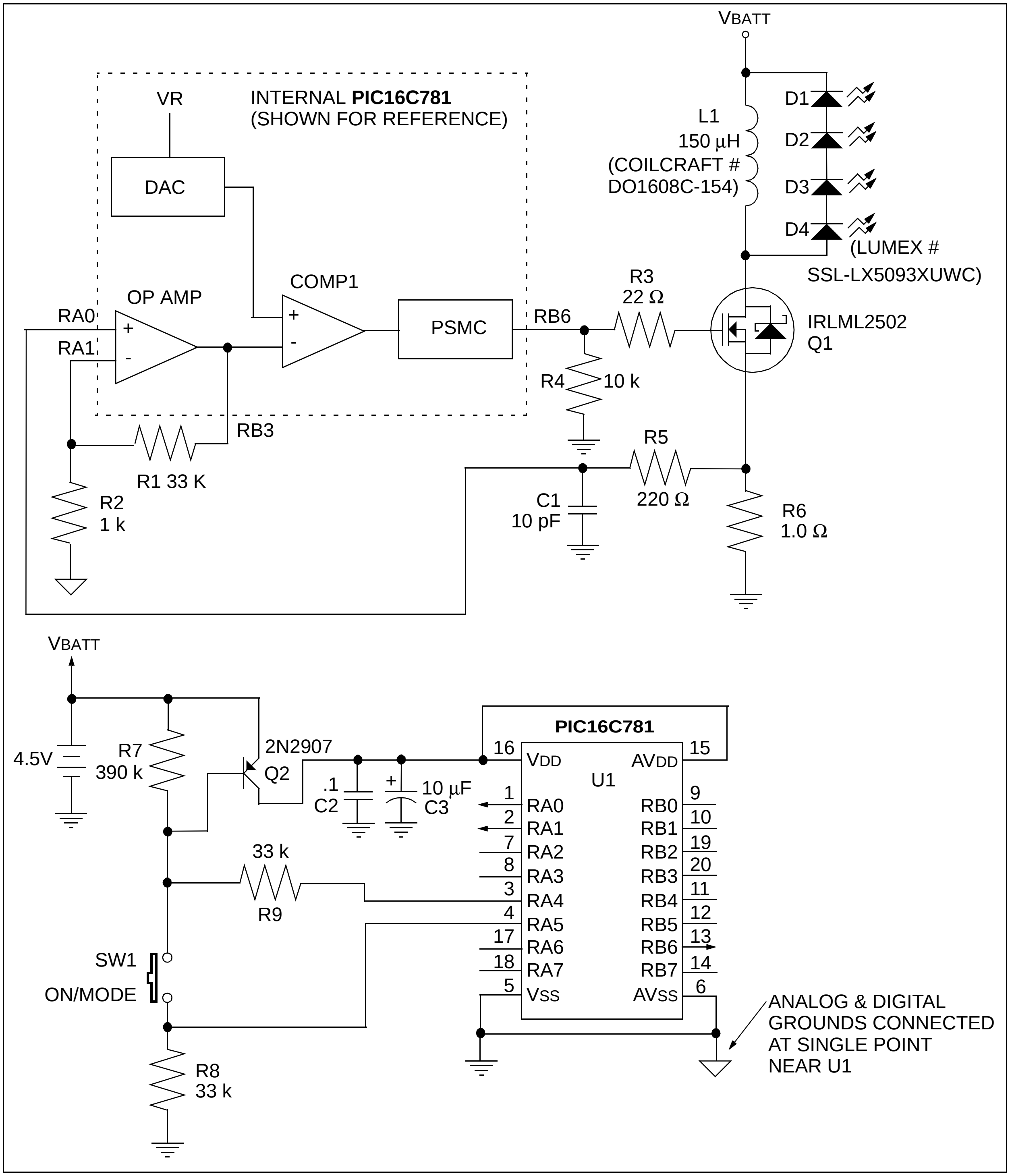
The control loop is designed to be discontinuous for reasons of EMI and stability. 'Discontinuous' means that the stored energy in L1 is completely dissipated during the discharge phase. In other words, the current in L1 falls to zero in every cycle.

Switch SW1 controls power and mode changes. Pin RA4 of U1 is an open drain output. When power is off, the output drive of RA4 is also off, so the base current of Q2 is zero and Q2 is off. When SW1 is closed, Q2 is biased on by current flow from the emitter to base of Q2 through R8. Power initialization of U1 includes driving the output of RA4 low. With RA4 low, Q1 is held on by current through R9. When Q2 is biased on, the voltage at the base of Q2 is VBATT - 0.7V. Subsequent SW1 closings pulse RA5 high with the base voltage of Q2. The U1 program recognizes the RA5 pulses as mode changes. Modes include:

- Constant on
- 50% duty cycle flashing
- 25% duty cycle flashing
- Power off
- Dim/Bright (button held for longer than 0.5 seconds)

The Power Off mode waits for SW1 to be released then enters an infinite loop, driving the open drain output of RA4 high. With RA4 high, current stops flowing through the emitter base junction of Q2 biasing Q2 off, thereby removing power from U1. When the voltage at the U1 VDD and AVDD pins falls below the brown-out threshold voltage, U1 enters Brown-out Reset keeping RA4 in the RESET high impedance state.

FIGURE 1: CIRCUIT DESIGN



Circuit Design

The inductor is determined from the applied voltage (V_S), the desired peak current (i), and the time to reach the peak (t) (see Equation 1).

EQUATION 1

$$L = \frac{V_S \Delta t}{\Delta i}$$

Since the initial time and current are both zero, Δt and Δi in Equation 1 reduce to t and i. The applied voltage is three AAA alkaline cells which, at a nominal 1.5 volts each, amount to 4.5 volts. At this writing, the PIC16C781 minimum voltage is 4.0 volts which requires three cells. The maximum PSMC frequency will be used to minimize the inductor size. The PIC16C781 internal oscillator operates at a nominal 4 MHz. At that clock rate, the maximum PSMC frequency is 250 kHz. At 250 kHz a single PSMC cycle is 4 microseconds. If we use the 75% maximum duty cycle limit of the PSMC, the maximum charge time will be 3 microseconds allowing a minimum 1 microsecond for discharge. The LEDs are rated for 30 milliamps continuous current, or 100 milliamps peak current at a 10% duty cycle. For maximum intensity, we want the peak current to limit at 100 milliamps. Maximum inductor discharge current is equal to the peak inductor charge current, which occurs at the end of the charge phase and beginning of the discharge phase. This means that the inductor must charge to 100 milliamps in 3 microseconds with an applied voltage of 4.5 volts. Substituting these values in Equation 1 results in an inductor value of 135 micro Henrys. The closest standard value from Coilcraft is 150 micro Henrys, which will result in a peak current of 90 milliamps.

Discharge time is a variation of Equation 1. The initial voltage is the combined forward bias voltage of the 4 LEDs at 90 milliamps (V_D). This was measured and determined to be 3.89 volts per LED, or 15.56 volts for all four in series. The sign of V_D is negative since the voltage source is the inductor. The change in discharge current (Δi) is -90 milliamps, since it is going from the initial 90 milliamp current to zero. Rearranging the terms of Equation 1 to solve for time results in Equation 2.

EQUATION 2

$$\Delta t = \frac{L \Delta i}{V_D}$$

Again, Δt and Δi reduce to t and i since it is assumed that the current goes to zero. Solving Equation 2 for t reveals that the discharge time is 971 nanoseconds, which is about 97% of the available time. This confirms discontinuous operation.

Dimming is controlled by limiting the peak current. Peak current is limited by terminating the charge time early. This is accomplished by sensing the current, via the voltage across R6 and terminating the charge phase at the instant the desired peak current occurs. The maximum DAC output with the internal voltage reference selected is about 3.05 volts. The Op Amp gain (G) should be such that the Op Amp output is 3.05 volts at the maximum inductor current. At 90 milliamps, the voltage across R6 is 0.09 volts. So 0.09 * G = 3.05 or G = 3.05/0.09. We need a gain of 33.9. The gain of the Op Amp configuration shown in Figure 1 is G = (1+ R1/R2). Assuming that R2 is 1 k, R1 is determined to be 32.9 k. The closest standard value is 33 k.

With power off, transistor Q2 is biased off by R7. The leakage into RA4 can be 1 microamp. To keep the emitter-base voltage of Q2 below 0.5 volts, R7 must be no greater than 0.5/1e-6, or 800 k Ohms. We'll let R7 be 390 k Ohms for a margin of error factor of about 2. At power on, transistor Q2 is initially biased on by emitter-base current through R8. Q2 supplies current to U1 and associated U1 output drives. Power current for the LEDs comes directly from the battery. The minimum DC current gain (h_{FE}) of Q2 is 100. Assuming a maximum U1 supply current of 5 milliamps, the emitter-base current of Q2 needs to be 1/100th of that, or 50 microamps. V_{BATT} is assumed to be 4.5 volts. The base of a forward biased Q2 is about 0.7 volts below V_{BATT}, or 3.8 volts. R8 computes to be 3.8/(50e-6+1.8e-6), or 73.4 k Ohms. Again, allowing for a margin of error factor of 2 we'll use 33 k Ohms for R8 and R9.

When U1 is reset, and before the U1 output pins have been configured by the initialization code, all U1 port pins are configured as high impedance inputs. In this state it is possible for the gate of Q1 to float high, thereby biasing Q1 on. To avoid this condition, R4 provides a relatively low impedance to ground for the MOSFET gate keeping Q1 biased off until the PSMC output becomes active. R3 limits the transient current into the gate of Q1, slowing the slew rate to help control EMI emissions.

SUMMARY

The integrated peripherals of the PIC16C781 enhance the capability and significantly reduce the part count for this application. Besides the LEDs and microcontroller, only one active device is required. Dimming and several modes of operation are possible with only a single momentary switch. The open drain output of RA4 makes it possible to add a second low cost active device in lieu of a second switch for power control. The autonomous nature of the PSMC control loop means that the code is minimal. With 11 remaining I/O pins there is plenty of reserve capability to expand the role of the microcontroller for additional tasks.

Source and object code accompany this application and are available for free download from the Microchip web site www.microchip.com.

MEMORY USAGE

Program memory ROM and RAM requirements for the PIC16C781 are as follows:

ROM
184 Words Used
840 Words Free

RAM
4 Bytes Used
124 Bytes Free

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WORLDWIDE SALES AND SERVICE

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200 Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: http://www.microchip.com

Rocky Mountain
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7966 Fax: 480-792-4338

Atlanta
500 Sugar Mill Road, Suite 200B
Atlanta, GA 30350
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2 Lan Drive, Suite 120
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Tel: 978-692-3848 Fax: 978-692-3821

Chicago
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Detroit
Tri-Atria Office Building
32255 Northwestern Highway, Suite 190
Farmington Hills, MI 48334
Tel: 248-538-2250 Fax: 248-538-2260

Kokomo
2767 S. Albright Road
Kokomo, Indiana 46902
Tel: 765-864-8360 Fax: 765-864-8387

Los Angeles
18201 Von Karman, Suite 1090
Irvine, CA 92612
Tel: 949-263-1888 Fax: 949-263-1338

New York
150 Motor Parkway, Suite 202
Hauppauge, NY 11788
Tel: 631-273-5305 Fax: 631-273-5335

San Jose
Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408-436-7950 Fax: 408-436-7955

Toronto
6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699 Fax: 905-673-6509

ASIA/PACIFIC

Australia
Microchip Technology Australia Pty Ltd
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

China - Beijing
Microchip Technology Consulting (Shanghai) Co., Ltd., Beijing Liaison Office
Unit 915
Bei Hai Wan Tai Bldg.
No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Chengdu
Microchip Technology Consulting (Shanghai) Co., Ltd., Chengdu Liaison Office
Rm. 2401, 24th Floor,
Ming Xing Financial Tower
No. 88 TIDU Street
Chengdu 610016, China
Tel: 86-28-86766200 Fax: 86-28-86766599

China - Fuzhou
Microchip Technology Consulting (Shanghai) Co., Ltd., Fuzhou Liaison Office
Unit 28F, World Trade Plaza
No. 71 Wusi Road
Fuzhou 350001, China
Tel: 86-591-7503506 Fax: 86-591-7503521

China - Shanghai
Microchip Technology Consulting (Shanghai) Co., Ltd.
Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xia Road
Shanghai, 200051
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

China - Shenzhen
Microchip Technology Consulting (Shanghai) Co., Ltd., Shenzhen Liaison Office
Rm. 1315, 13/F, Shenzhen Kerry Centre,
Renminnan Lu
Shenzhen 518001, China
Tel: 86-755-82350361 Fax: 86-755-82366086

China - Hong Kong SAR
Microchip Technology Hongkong Ltd.
Unit 901-6, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

India
Microchip Technology Inc.
India Liaison Office
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O'Shaugnessey Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan
Microchip Technology Japan K.K.
Benex S-1 6F
3-18-20, Shinyokohama
Kohoku-Ku, Yokohama-shi
Kanagawa, 222-0033, Japan
Tel: 81-45-471- 6166 Fax: 81-45-471-6122

Korea
Microchip Technology Korea
168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea 135-882
Tel: 82-2-554-7200 Fax: 82-2-558-5934

Singapore
Microchip Technology Singapore Pte Ltd.
200 Middle Road
#07-02 Prime Centre
Singapore, 188980
Tel: 65-6334-8870 Fax: 65-6334-8850

Taiwan
Microchip Technology (Barbados) Inc.,
Taiwan Branch
11F-3, No. 207
Tung Hua North Road
Taipei, 105, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE

Austria
Microchip Technology Austria GmbH
Durisolstrasse 2
A-4600 Wels
Austria
Tel: 43-7242-2244-399
Fax: 43-7242-2244-393

Denmark
Microchip Technology Nordic ApS
Regus Business Centre
Lautrup hoj 1-3
Ballerup DK-2750 Denmark
Tel: 45 4420 9895 Fax: 45 4420 9910

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Microchip Technology SARL
Parc d'Activite du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - ler Etage
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

Germany
Microchip Technology GmbH
Steinheilstrasse 10
D-85737 Ismaning, Germany
Tel: 49-89-627-144 0 Fax: 49-89-627-144-44

Italy
Microchip Technology SRL
Centro Direzionale Colleoni
Palazzo Taurus 1 V. Le Colleoni 1
20041 Agrate Brianza
Milan, Italy
Tel: 39-039-65791-1 Fax: 39-039-6899883

United Kingdom
Microchip Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44 118 921 5869 Fax: 44-118 921-5820

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