

COT Drivers Control LED Ripple Current

National Semiconductor
Application Note 1853
Chris Richardson
September 23, 2008



The constant on-time (COT) control method used by the LM3402 and LM3404 constant-current buck regulators provides a balance between control over switching frequency and fast transient response. Normally this "quasi-hysteretic" control senses the input voltage and adjusts the on-time t_{ON} of the power MOSFET as needed to keep f_{SW} constant. Investigating a little more deeply reveals that t_{ON} is in fact proportional to the current flowing into the R_{ON} pin. The addition of a single, general purpose PNP transistor forces t_{ON} to be proportional to $(V_{IN} - V_O)$ and provides two benefits that are particularly useful to LED drivers: improved tolerance of the average LED current, I_F , and constant LED ripple current, ΔI_F .

Benefits of Constant Ripple

The luminous flux and dominant wavelength (or color temperature for white LEDs) of LED light are controlled by average current. The constant-ripple LED driver in *Figure 1* is much better at controlling average LED current over changes in both input voltage and changes in output voltage because it fixes the valley of the inductor current and also fixes the current ripple.

Controlling LED ripple current implies control over peak LED current, which in turn affects the luminous flux of an LED. All

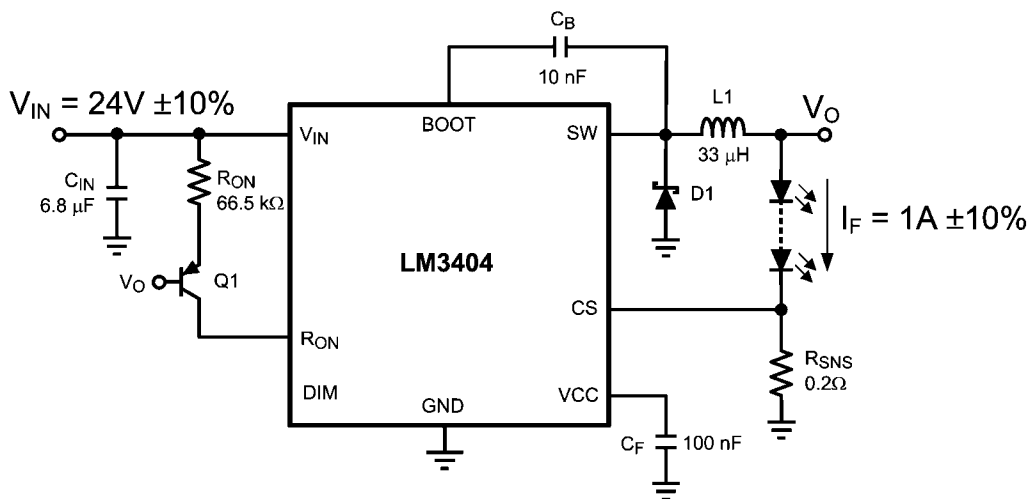
LEDs have a relationship between their luminous flux and forward current, I_F , that is linear up to a point. Beyond that point, increasing I_F causes more heat than light. High ripple current forces the LED to spend half of the time at a high peak current, putting it in the lower lm/W region of the flux curve. This reduces the light output when compared to a purely DC drive current even though the average forward current remains the same.

Close inspection of LED datasheets also reveals that the absolute maximum ratings for peak current are close to or often equal to the ratings for average current. High current density in the LED junction lowers lumen maintenance, providing yet another incentive for keeping the ripple current under control.

Circuit Performance

The circuit of *Figure 1* uses the PNP-based constant ripple concept to take an input voltage of $24VDC \pm 10\%$ and drive 1A through as many LEDs in series as the maximum output voltage will allow. For a circuit with 'n' LEDs of forward voltage V_F in series, the output voltage is:

$$V_O = 0.2 + n \times V_F$$



30064501

FIGURE 1. Constant Ripple LED Driver Using the LM3404 Buck Regulator

The maximum voltage that can be achieved is then:

$$V_{O-MAX} = V_{IN-MIN} \times (1 - f_{SW} \times 300 \text{ ns})$$

In the above equation, the 300 ns term reflects the minimum off-time of the LM3402 and LM3404 buck regulators.

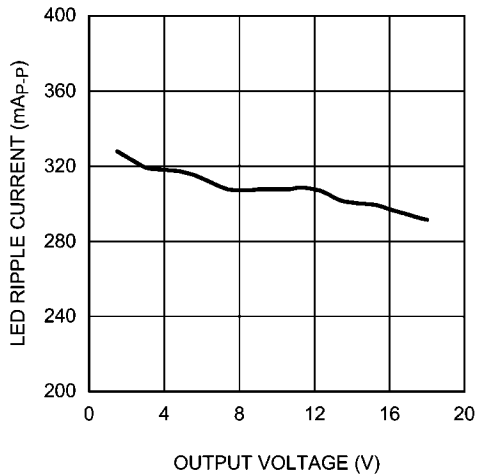
Making a "Universal" Current Source

Figure 2 and *Figure 3* show the dependence of ripple current and switching frequency against output voltage. This change

in output voltage is effectively a change in the number of series-connected LEDs that the circuit drives.

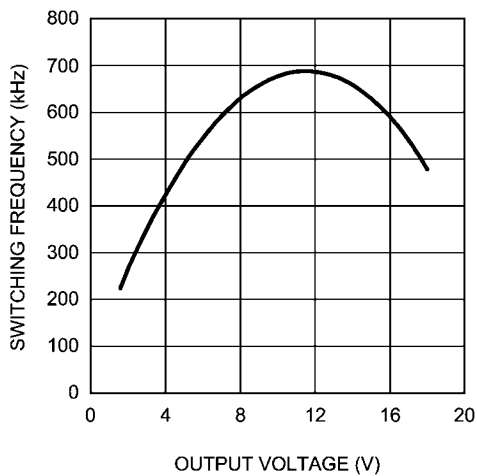
One circuit with both average current and ripple current controlled independently of V_O can now power anything from a single infrared LED (V_{F-TYP} of $\sim 1.8V$) to as many as five white LEDs in series, yielding a V_O of $\sim 18V$. Such a circuit would be ideal for an LED-driving power-supply module. Many of the existing, commercial AC-input 'brick' modules for driving LEDs are specified to provide a constant current of 'x' mA at a voltage up to 'y' volts. Depending on the need for galvanic

isolation and/or power factor correction, the LM3402 or LM3404 buck regulator could be paired with an existing AC-DC regulator to provide the 24V, resulting in a high-quality universal current source.



30064502

FIGURE 2. Ripple Current vs. Output Voltage



30064503

FIGURE 3. Switching Frequency vs. Output Voltage

Design Procedure

Designing for constant ripple in a COT converter requires a change in the selection of the on-time setting resistor R_{ON} :

1. Start with the typical input voltage, V_{IN-TYP} , and an output voltage that is at the center between the minimum and maximum expected value, V_{O-CTR} . Use the maximum permissible switching frequency, f_{SW-MAX} , and the

desired peak-to-peak inductor ripple current, ΔI_L . The required inductance is then:

$$L = \frac{(V_{IN-TYP} - V_{O-CTR}) \times V_{O-CTR}}{V_{IN-TYP} \times f_{SW-MAX} \times \Delta I_L}$$

2. Select the closest standard inductor value to L and call it L_{STD} . R_{ON} can then be calculated with the following expression:

$$R_{ON} = \frac{\Delta I_L \times L_{STD}}{1.34 \times 10^{-10}}$$

3. Use the closest 1% resistor value for R_{ON} .
4. Design for the remaining components (input capacitor, Schottky diode, etc.) remains the same, and is outlined in the LM3402 and LM3404 datasheets.

Switching Frequency Changes

When using the LM3402 and LM3404 buck regulators in the constant-ripple configuration, the switching frequency will change with V_{IN} and V_O . Careful attention to PCB layout and proper filtering must be employed with all switching converters, and particular care is needed for systems where f_{SW} changes. The following steps can be used to predict the switching frequency:

1. Calculate the on-time at the minimum and maximum values of V_{IN} and V_O using the actual 1% resistor value of R_{ON} and the following equation:

$$t_{ON} = \frac{0.134 \times R_{ON}}{V_{IN} - V_O + 0.6}$$

2. The switching frequency can then be determined using t_{ON} and the following expression:

$$f_{SW} = \frac{V_O}{V_{IN} \times t_{ON}}$$

Conclusion

A pure DC LED drive current would be ideal for LEDs, but in practice the majority of LED lighting is powered from the AC mains and includes at least one switching regulator between the wall and the LEDs. Even battery or solar-powered systems are likely to employ a switching regulator in the interest of power efficiency. Therefore, some amount of ripple current will be present in almost every LED driver design. Allowing higher ripple current reduces the size and cost of the drive circuit, but comes at the expense of light output and reliability. Armed with the ability to control both LED ripple current and switching frequency, the LED lighting designer can make his/her own trade-offs between solution size, cost, and quality based on the needs of the application.

BOM

ID	Part Number	Type	Size	Parameters	Qty	Vendor
U1	LM3404	LED Driver	SO-8	42V, 1.2A	1	NSC
Q1	CMPT3906	PNP	SOT23-6	40 V _{CE} , 10 mA	1	Central Semi
L1	VL10040T-330M2R1	Inductor	10 x 10 x 4.0 mm	33 μ H, 2.1A, 80 Ω	1	TDK
D1	CMSH2-40M	Schottky Diode	SMA	40V, 2A	1	Central Semi
C _F	VJ0603Y104KXXAT	Capacitor	0603	100 nF, 10%	1	Vishay
C _B	VJ0603Y103KXXAT	Capacitor	0603	10 nF, 10%	1	Vishay
C _{IN}	C4532X7R1H685M	Capacitor	1812	6.8 μ F, 50V	1	TDK
R _{SNS}	ERJ8RQFR20V	Resistor	1206	0.2 Ω , 1%	1	Panasonic
R _{ON}	CRCW06035762F	Resistor	0603	57.6 k Ω , 1%	1	Vishay

Notes

For more National Semiconductor product information and proven design tools, visit the following Web sites at:

Products		Design Support	
Amplifiers	www.national.com/amplifiers	WEBENCH	www.national.com/webench
Audio	www.national.com/audio	Analog University	www.national.com/AU
Clock Conditioners	www.national.com/timing	App Notes	www.national.com/appnotes
Data Converters	www.national.com/adc	Distributors	www.national.com/contacts
Displays	www.national.com/displays	Green Compliance	www.national.com/quality/green
Ethernet	www.national.com/ethernet	Packaging	www.national.com/packaging
Interface	www.national.com/interface	Quality and Reliability	www.national.com/quality
LVDS	www.national.com/lvds	Reference Designs	www.national.com/refdesigns
Power Management	www.national.com/power	Feedback	www.national.com/feedback
Switching Regulators	www.national.com/switchers		
LDOs	www.national.com/lido		
LED Lighting	www.national.com/led		
PowerWise	www.national.com/powerwise		
Serial Digital Interface (SDI)	www.national.com/sdi		
Temperature Sensors	www.national.com/tempsensors		
Wireless (PLL/VCO)	www.national.com/wireless		

THE CONTENTS OF THIS DOCUMENT ARE PROVIDED IN CONNECTION WITH NATIONAL SEMICONDUCTOR CORPORATION ("NATIONAL") PRODUCTS. NATIONAL MAKES NO REPRESENTATIONS OR WARRANTIES WITH RESPECT TO THE ACCURACY OR COMPLETENESS OF THE CONTENTS OF THIS PUBLICATION AND RESERVES THE RIGHT TO MAKE CHANGES TO SPECIFICATIONS AND PRODUCT DESCRIPTIONS AT ANY TIME WITHOUT NOTICE. NO LICENSE, WHETHER EXPRESS, IMPLIED, ARISING BY ESTOPPEL OR OTHERWISE, TO ANY INTELLECTUAL PROPERTY RIGHTS IS GRANTED BY THIS DOCUMENT.

TESTING AND OTHER QUALITY CONTROLS ARE USED TO THE EXTENT NATIONAL DEEMS NECESSARY TO SUPPORT NATIONAL'S PRODUCT WARRANTY. EXCEPT WHERE MANDATED BY GOVERNMENT REQUIREMENTS, TESTING OF ALL PARAMETERS OF EACH PRODUCT IS NOT NECESSARILY PERFORMED. NATIONAL ASSUMES NO LIABILITY FOR APPLICATIONS ASSISTANCE OR BUYER PRODUCT DESIGN. BUYERS ARE RESPONSIBLE FOR THEIR PRODUCTS AND APPLICATIONS USING NATIONAL COMPONENTS. PRIOR TO USING OR DISTRIBUTING ANY PRODUCTS THAT INCLUDE NATIONAL COMPONENTS, BUYERS SHOULD PROVIDE ADEQUATE DESIGN, TESTING AND OPERATING SAFEGUARDS.

EXCEPT AS PROVIDED IN NATIONAL'S TERMS AND CONDITIONS OF SALE FOR SUCH PRODUCTS, NATIONAL ASSUMES NO LIABILITY WHATSOEVER, AND NATIONAL DISCLAIMS ANY EXPRESS OR IMPLIED WARRANTY RELATING TO THE SALE AND/OR USE OF NATIONAL PRODUCTS INCLUDING LIABILITY OR WARRANTIES RELATING TO FITNESS FOR A PARTICULAR PURPOSE, MERCHANTABILITY, OR INFRINGEMENT OF ANY PATENT, COPYRIGHT OR OTHER INTELLECTUAL PROPERTY RIGHT.

LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS PRIOR WRITTEN APPROVAL OF THE CHIEF EXECUTIVE OFFICER AND GENERAL COUNSEL OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

Life support devices or systems are devices which (a) are intended for surgical implant into the body, or (b) support or sustain life and whose failure to perform when properly used in accordance with instructions for use provided in the labeling can be reasonably expected to result in a significant injury to the user. A critical component is any component in a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system or to affect its safety or effectiveness.

National Semiconductor and the National Semiconductor logo are registered trademarks of National Semiconductor Corporation. All other brand or product names may be trademarks or registered trademarks of their respective holders.

Copyright© 2008 National Semiconductor Corporation

For the most current product information visit us at www.national.com



National Semiconductor Americas Technical Support Center
Email: support@nsc.com
Tel: 1-800-272-9959

National Semiconductor Europe Technical Support Center
Email: europe.support@nsc.com
German Tel: +49 (0) 180 5010 771
English Tel: +44 (0) 870 850 4288

National Semiconductor Asia Pacific Technical Support Center
Email: ap.support@nsc.com

National Semiconductor Japan Technical Support Center
Email: jpn.feedback@nsc.com