AND8480/D

CrM Buck LED Driver Evaluation Board

Prepared by: Fabien Franc
ON Semiconductor

ON Semiconductor®

http://onsemi.com

APPLICATION NOTE

Introduction

This document describes the CrM Buck LED driver evaluation board. This board provides a step−down converter for driving up to 6 strings of LEDs at 240 mA from an unregulated high−voltage supply up to 250 V. Each channel is regulated using the ON Semiconductor CAT4201 step−down LED driver. The solution provides a very high overall efficiency around 95%, minimizing the heat dissipation and is ideal for powering a large number of LEDs, such as those found in LCD TV backlight applications. Mismatch between LED string forward voltages does not impact the overall efficiency as each string has an independent buck converter.

Board Description

The step−down conversion is achieved by a reverse Critical conduction Mode (CrM) switching regulator (CAT4201) using a high−voltage cascode MOSFET to support supply voltages up to 250 V. The switching frequency automatically adjusts itself depending on the supply voltage and the LED load configuration.

The board requires a regulated low voltage supply V_{CC} (12 V) to bias the CAT4201 LED drivers (VBAT pin). Figure 1 shows a simplified block diagram of the CrM buck evaluation board with the power supply. For an introduction to the CAT4201 LED driver operation, please refer to pages 4, 5, and to the CAT4201 datasheet. Figures 2 and 3 show pictures of the actual board.

The evaluation boards are set−up for driving LED strings at a constant average current of 240 mA or 120 mA depending on the board configuration. This note describes the 240 mA board. Ideally, the LED string forward voltage (V_{LED}) is close to half of the supply voltage (V_{IN}). For example, a 100 V LED string voltage and a 200 V supply. Figure 2 shows the recommended operating condition for a range of supply and output voltages.

In order to support high supply voltages, each CAT4201 has an external cascode transistors connected between the SW pin and the LED cathode. The LED current is set−up independently on each channel by external resistors. On the CrM buck 240 mA board, the LED current is set to 240 mA on all channels. The board schematic is shown in Figure 3.

A PWM logic input (active high) allows to turn on all 6 channels together. The PWM can be used to control the brightness of the LEDs by using a PWM signal where the duty cycle sets the brightness. A frequency of 100 Hz is recommended to get the best dimming resolution.

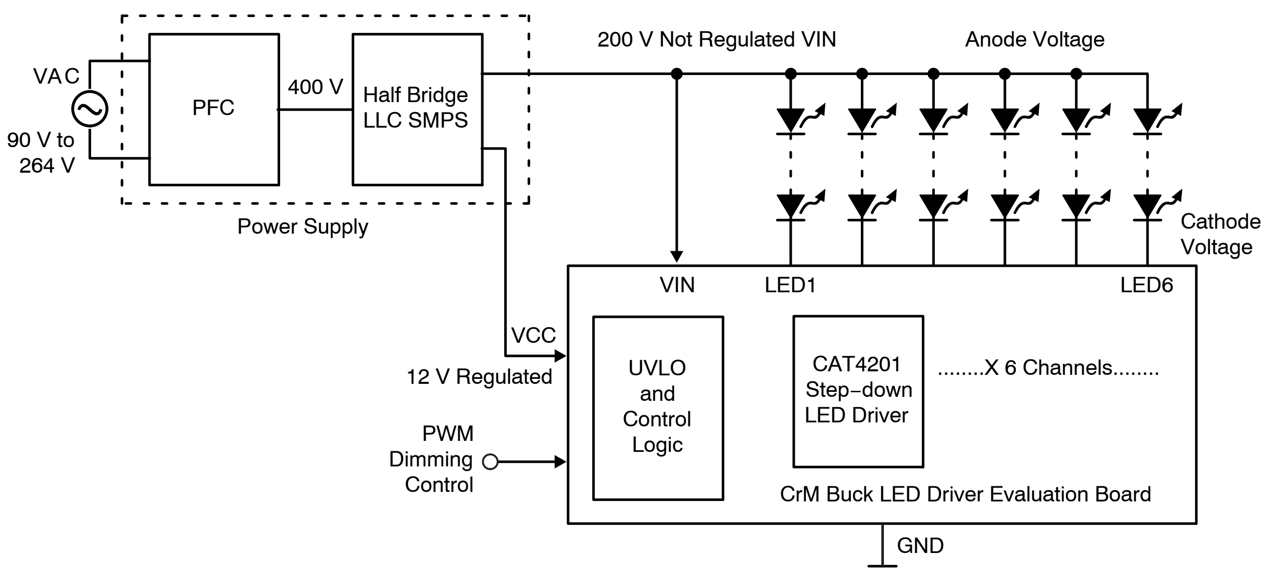

Figure 1. CrM Buck LED Driver Block Diagram

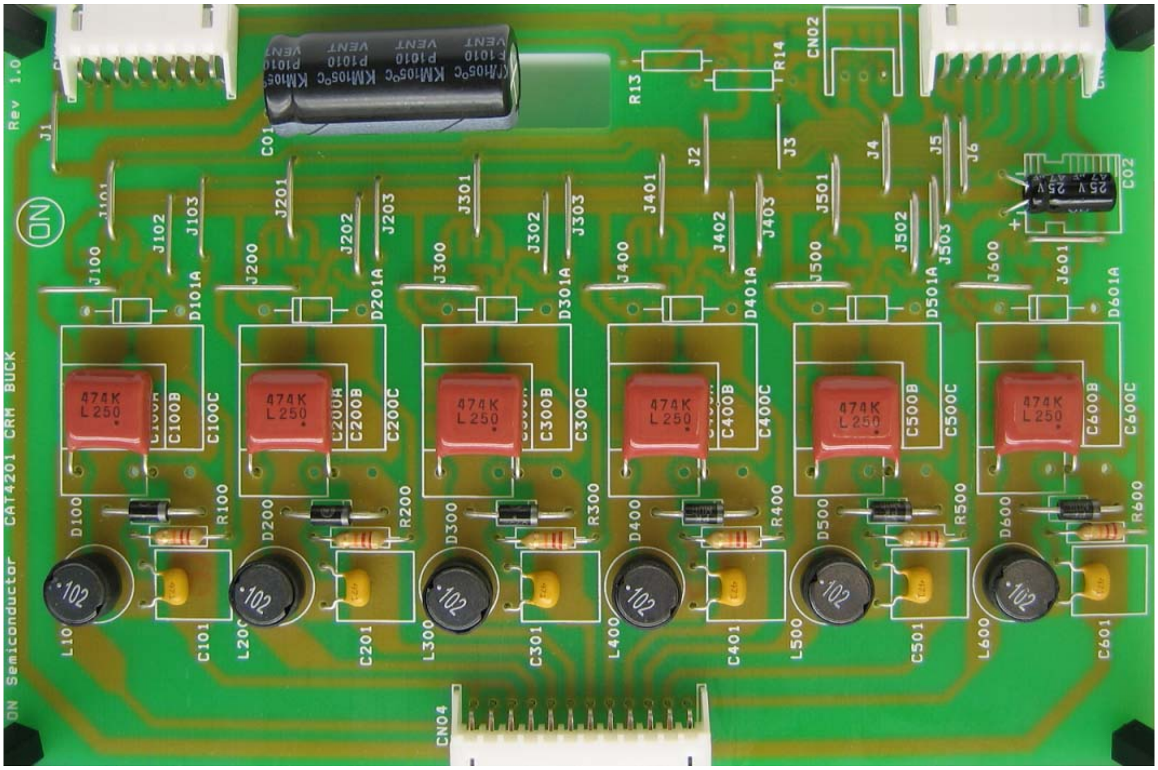

Figure 2. CrM Buck LED Driver Board (Top Side)

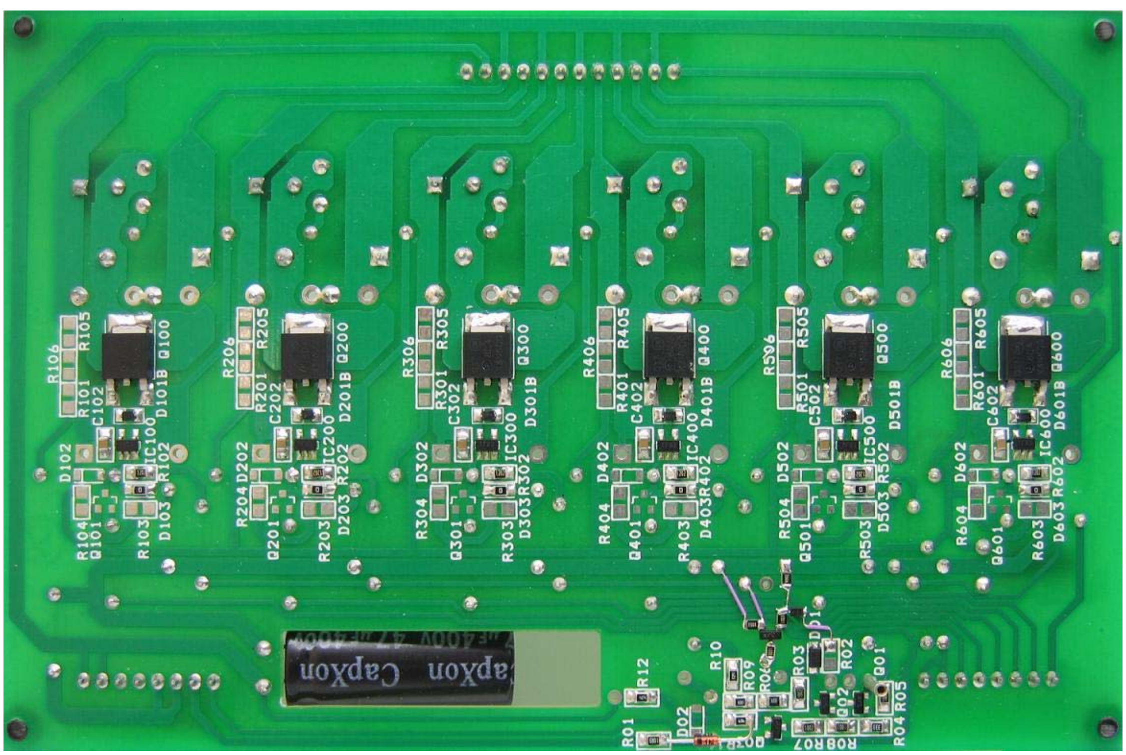

Figure 3. CrM Buck LED Driver Board (Bottom Side)

Detailed Operation

Operating Voltage Range

The graph below shows the recommended operating region for a range of V_{LED} string voltage and supply voltage V_{IN} defined by the equation:

$$1.3 \times V_{LED} < V_{IN} < 2.5 \times V_{LED}$$

For example, with V_{LED} = 100 V, the recommended V_{IN} range is between 130 V minimum and 250 V maximum.

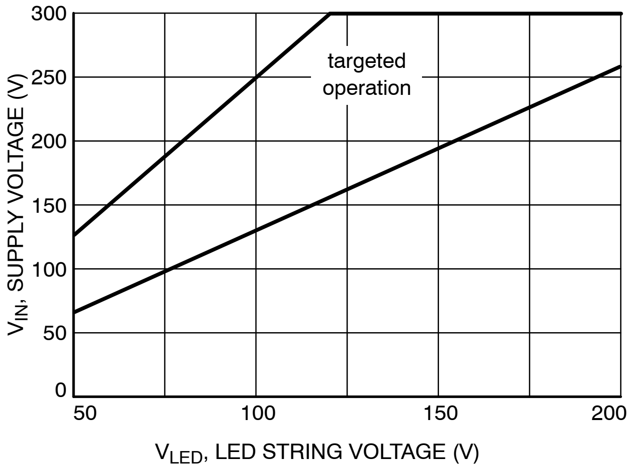

Figure 4. Region of Operation

UVLO Set-up

NOTE: The board is configured for operating V_{IN} voltage of 150 V minimum. It will not turn on for a supply below 150 V.

The high voltage power supply (V_{IN}) should be always greater than the LED forward voltage (V_{LED}) to guarantee proper regulation of the LED current. An undervoltage lockout (UVLO) protection logic is included on the board to shutdown all LED drivers when V_{IN} drops below a defined threshold (V_{UVLO}). Figure 14 shows the control logic and UVLO circuitry. The following formula shows how to calculate the UVLO threshold voltage.

$$V_{UVLO} = V_{IN(min)}$$
$$= V_{CC} \times \left(1 + \frac{(R_{12} + R_{11})}{(R_9 + R_{10})}\right)$$
$$= 12\ V \times \left(1 + \frac{(620\ k\Omega + 470\ k)}{(47\ k\Omega + 47\ k\Omega)}\right)$$
$$= 12\ V \times 12.6 = 150\ V$$

It is recommended to have V_{UVLO} greater than the V_{LEDmax} + 10 V. The UVLO threshold can be changed, if needed, by replacing resistor R_{11} or R_{12}.

The board is configured for 12 V supply V_{CC}, if a different supply (must be below 15 V), some of the above resistors must be changed accordingly.

There is also an undervoltage protection on the supply V_{CC}. If V_{CC} drops below a threshold of about 7.6 V, the CAT4201 CTRL signal is pulled low and all CAT4201 drivers are disabled.

LED Brightness Setting

The LED current is set to 240 mA in each channel by the 12 kΩ resistors (Rx02) connected between each CAT4201 RSET pin and ground. For setting the LED current to another value, please refer to the CAT4201 datasheet to find out the desired resistor values.

The LEDs can be dimmed dynamically by applying a 100 Hz PWM signal to the PWM input. Figure 5 shows the PWM waveform and the LED current.

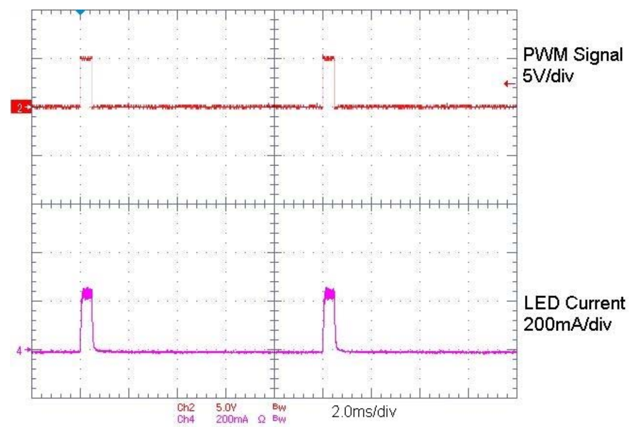

Figure 5. PWM Waveform with 5% Duty Cycle

NOTE: The PWM input voltage should not exceed 5 V maximum. The PWM logic high level should be 2.5 V or higher.

Figure 6 shows the variation of the LED current versus the PWM duty cycle.

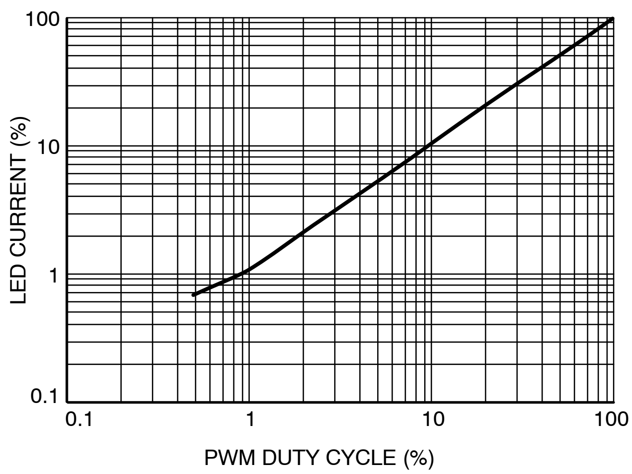

Figure 6. LED Current vs. PWM Duty Cycle

LED Current Ripple

The LED current ripple depends on several parameters including the LED current, the CAT4201 switching frequency and the size of the output capacitors Cx00A on each channel. A 0.47 μF capacitor is recommended for 240 mA LED current. For smaller LED current values, the value of the output capacitors can be reduced. For 120 mA LED current, a 0.22 μF capacitors can be used.

The voltage rating of the output capacitors Cx00A should be equal to or greater than the maximum supply voltage (V_{IN}) in order to handle the open LED conditions. For example, for V_{IN} supply voltages up to 250 V, use 250 V rated capacitors.

Figure 7 shows the LED current variation in the six different channels; the 0% is referenced to the average of all channles.

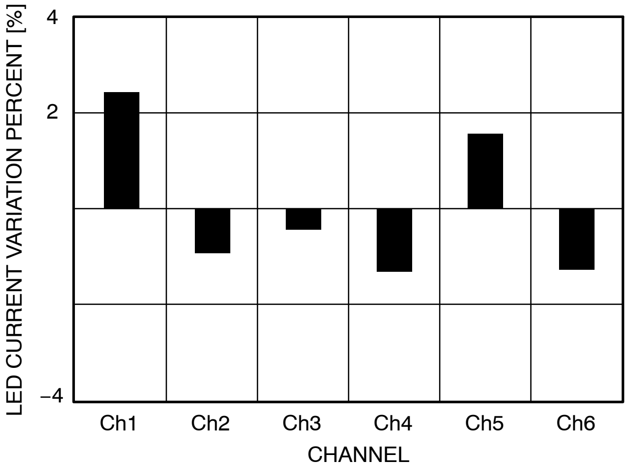

Figure 7. Channel Matching

Performance

Figure 8 shows the efficiency versus the total LED voltage and for various VIN supply voltages. For example, at V_{IN} = 200 V, V_{LED} = 100 V, the efficiency is about 95%. Since the efficiency is high, there is very little heat dissipated in the components on the board.

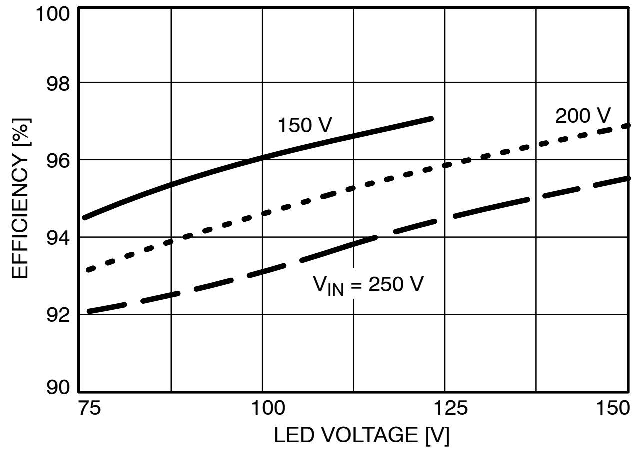

Figure 8. Efficiency vs. V_{IN} & V_{LED}

Figure 9 shows the LED Current regulation versus V_{LED}. The LED current regulation is best when the supply V_{IN} is equal to twice V_{LED}.

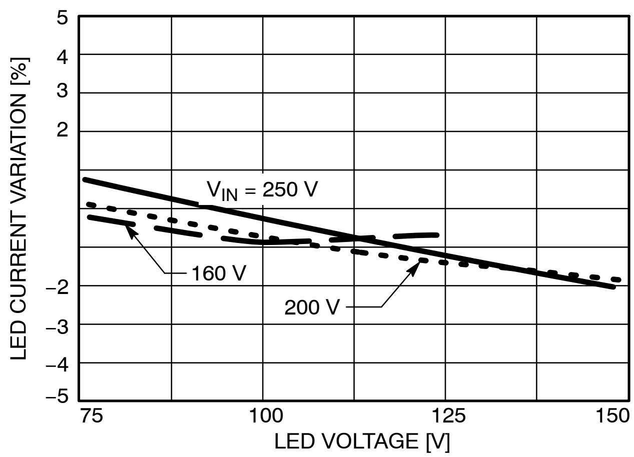

Figure 9. LED Current Line Regulation

CAT4201 LED Driver Operation

Each LED string is controlled by a CAT4201 step−down LED driver which operates in Critical conduction mode (CRM) or Zero current switching (ZCS) mode where the inductor current swings between zero and twice the average LED current.

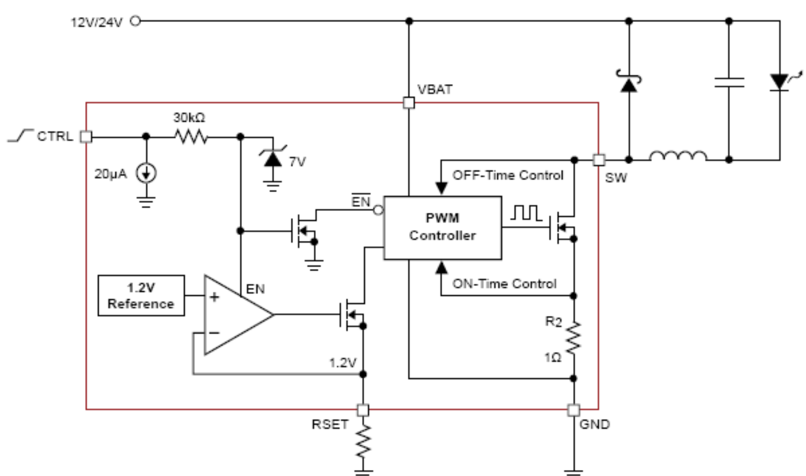

Figure 10. Simplified CAT4201 Block Diagram

The external RSET resistor sets the average LED current.

Figure 11 shows the switching waveform of the CAT4201 SW pin and the current flowing in the inductor.

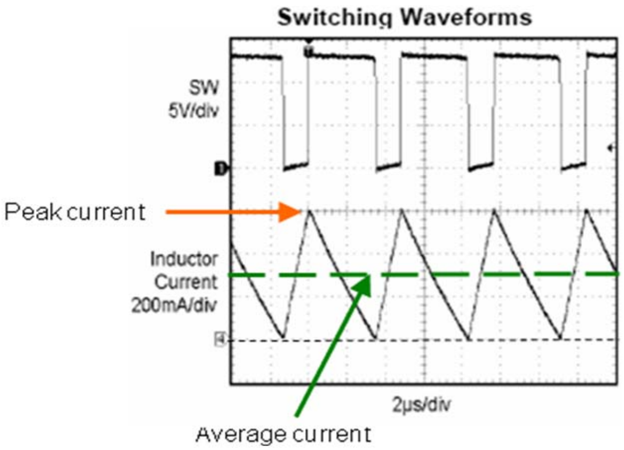

Figure 11. SW Pin and Inductor Current Waveform

In the case of the CrM buck application, long strings of LEDs require a high−voltage supply. Due to the limitation on the CAT4201 SW pin voltage rating (maximum 40 V), there is a need to add high−voltage cascode transistors (Qx00) between the inductor and the CAT4201 SW pin. The board is populated with 500 V N−channel transistors NDD03N50ZT4G from ON Semiconductor.

Figure 12 shows the power up of the circuit with the steady−state current ripple.

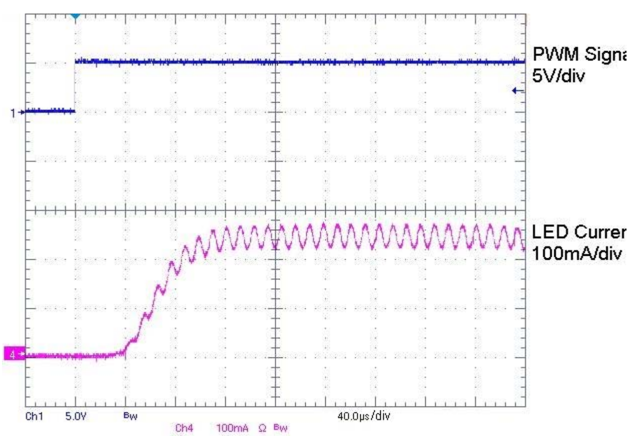

Figure 12. Power−Up Waveforms

Switching Frequency

For critical conduction mode, the switching frequency of the LED driver is dictated by the input voltage V_{IN}, forward LED voltage drop V_{LED}, output current I_{LED}, and the inductor (Lx00). This relationship can be closely modeled by the following equation, with about 14% to account for non−idealities and loss in the various components.

$$\text{Frequency} = 0.86 \times \left(\frac{V_{LED} - \frac{V_{LED}^2}{V_{IN}}}{2 \times I_{LED} \times L} \right)$$

For duty cycle calculations use the following equation.

$$\text{Duty Cycle} = 1 - \left(\frac{V_{LED}}{V_{IN}} \right)$$

In a typical 240 mA current setting and a 100 V string of LEDs using the 1mH inductor and a 200 V supply, the frequency should be about 90 kHz at a duty cycle of 62.5%. We recommended the 1.0 mH inductor from Wurth Elektronik part number 744732102. Switching frequencies higher than 20 kHz are recommended to guarantee the best regulation. A more detailed illustration of the switching frequency is modeled by Figure 13.

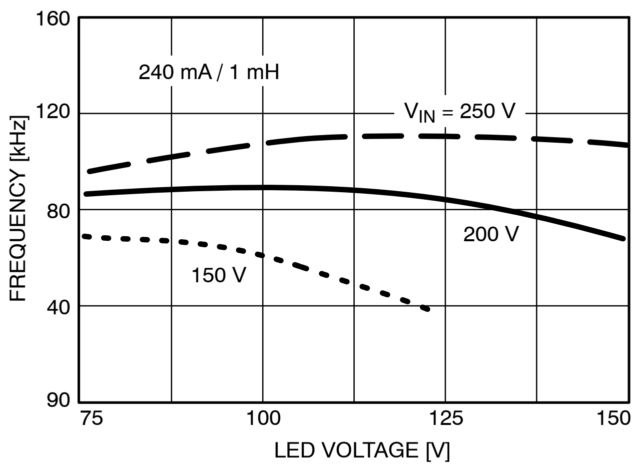

Figure 13. Frequency vs. Input Voltage

Open and Short LED Faults

The CrM Buck board can handle both open−LED and shorted−LED fault conditions. Since each of the 6 strings are independent from other strings, these fault conditions do not cause any significant loss of efficiency or extra heat dissipation and do not require external circuitry for protection.

In case an LED string becomes disconnected, the associated CAT4201 LED driver stops switching and the LED cathode is pulled to Ground. The voltage across the corresponding capacitor Cx00A is equal to the full V_{IN}. Therefore each capacitor should be rated to V_{IN}. There is no fault detection and no need for protection. The CAT4201 resumes normal operation as soon as the LED string is reconnected.

In case some of the LEDs within a string become shorted, the LED forward voltage is reduced and the switching frequency will adjust itself and increase, but the average LED current remains unchanged. The board can handle a large number of shorted LEDs. It is not recommended to operate with less than 4 LEDs per string as the LED current may increase.

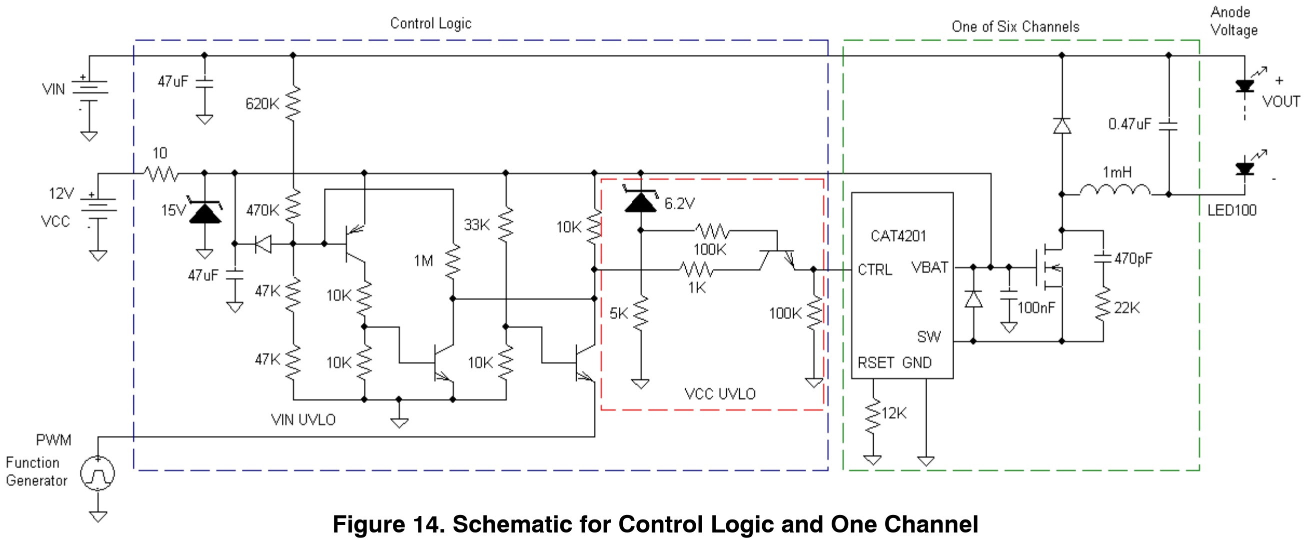

Figure 14. Schematic for Control Logic and One Channel

Test Procedure

Warning: Due to the high−voltage present on the board, power supply and LED load; the set−up should be handled with care.

The following steps are needed for the installation of the board together with the two power supplies and the load. In this procedure, we will limit the usage to a single channel load. Any populated channel can be tested individually. The load should be an LED string, or an equivalent resistive load, with a voltage drop of about 50 V to 60 V when biased with a 240 mA current. This test procedure is designed for channel 1 and can be replicated for the other channels. Figure 15 shows the correct test setup.

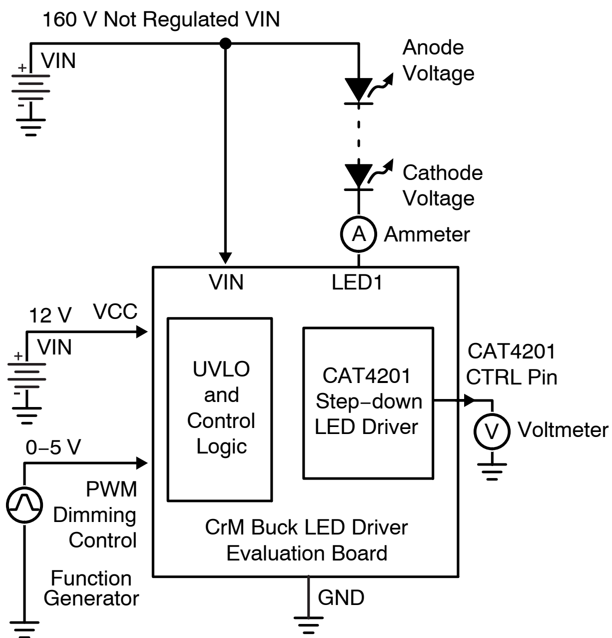

Figure 15. Test Set−up

- Connect the 12 V DC external supply to the board connector CN01 P2 (V_{CC}). Connect the external supply Ground to connector CN01 P3 (GND).
- Connect a high−voltage supply ground to the connector CN01 P4 (GND). Connect the high−voltage supply to the connector CN01 P7 and P8 (VIN or V−Power). Set the high−voltage power supply current limit to 500 mA, (see Note 1).
- Connect the PWM input to the connector CN02 P1. The PWM input should never exceed 5 V.
- Before powering−up the board, an LED load (or equivalent resistive load) should be connected to one of the six LED channels on connector CN04. The connector CN04 includes 6 LED cathode pins and 6 anode voltage pins connected together.
- Connect the connector CN04 P2 (LED1 channel 1) to either an LED string cathode, or to a resistive load. Connect the connector CN04 P1 (VIN) to either an LED string anode, or to the other side of a resistive load.
- Connect the PWM input to GND (disabled).
- Turn on the 12 V supply (V_{CC}).
- Turn on the high−voltage supply (V_{IN}) to 130 V to test the under−voltage lockout (UVLO) function.
- Set the PWM input to 5 V (enabled).
- Make sure the LEDs do *not* turn on, and the CAT4201 CTRL pin (pin 1) voltage is under 0.5 V or logic low (disabled).
- Connect the PWM input to GND (disabled).
- Set the high−voltage supply (V_{IN}) to 160 V (above the UVLO threshold).
- Set the PWM input to 5 V (logic high).
- Measure the CAT4201 CTRL pin voltage (IC100 pin 1), the pin voltage should be around 5.2 V, well above the 3 V threshold to be in logic high (enabled).
- Measure the current in the LED string (or resistive load) with an ammeter, the average current should be around 240 mA (120 mA for 120 mA board).
- Using a function generator, set the PWM signal to have a 300 Hz frequency, a 0 V to 5 V amplitude swing, and a 50% duty cycle pulse train. Measure the average current through the load which should be around half or 120 mA.
- Connect the PWM input to GND (disabled).
- Turn off all power sources starting with the high−voltage supply (VIN).
- When testing with a board setup for 120 mA maximum LED current, the currents for 100% and 50% duty cycle PWM should be around 120 mA and 60 mA respectively.

1. If several LED channels are turned on, the high−voltage power supply current limit must be increased to the number of channels x 2 x 240 mA (for 240 mA board).

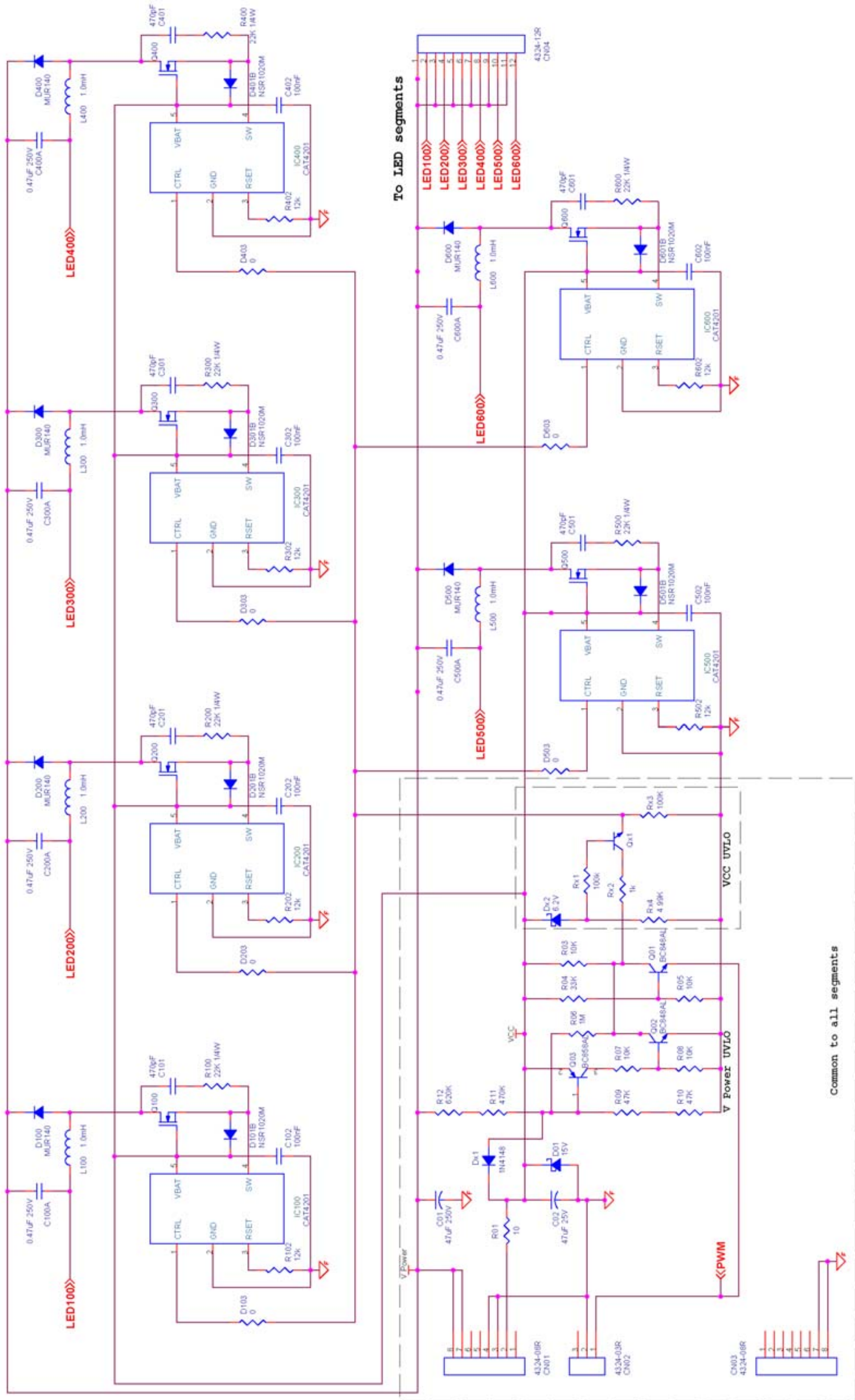

Figure 16. CrM Buck Board 240 mA Schematic

BOARD LIST OF COMPONENTS

Table 1. CrM BUCK BOARD LIST OF COMPONENTS CONFIGURED FOR 240 mA LED CURRENT

Name	Manufacturer	Description	Part Number	Units
IC100, IC200, IC300, IC400, IC500, IC600	ON Semiconductor	CAT4201 Buck LED Driver	CAT4201TD	6
C01	RUBYCON	Electrolytic Cap, 47 μF, 450 V	450BXA47MEFG18X31.5	1
C02	RUBYCON	Electrolytic Cap, 47 μF, 25 V	25ZL47M5X11	1
C100A, C200A, C300A, C400A, C500A, C600A	Panasonic	Metal Polyester capacitor, 0.47 μF, 250 V	ECQ−E2474KB	6
C101, C201, C301, C401, C501, C601	Kemet	Ceramic capacitor, 470 pF, 1 kV	C322C471JDG5TA	6
C102, C202, C302, C402, C502, C602	Kemet	Ceramic capacitor, 0.1 μF, 25 V, 0805	C0805F104K3RACTU	6
CN01		8−pin connector	4324−08R	1
CN02		3−pin connector	4324−03R	1
CN04		12−pin connector	4324−12R	1
D01	ON Semiconductor	15 V zener diode, 500 mW, SOD−123	MMSZ15	1
Dx1	NXP	High Speed Switching Diode	1N4148	1
Dx2	ON Semiconductor	6.2 V zener diode, 200 mW, SOD−323	MM3Z6V2	1
D100, D200, D300, D400, D500, D600	ON Semiconductor	1 A, 400 V Ultrafast Rectifier	MUR140	6
D101B, D201B, D301B, D401B, D501B, D601B	ON Semiconductor	40 V, 0.3 A Schottky Diode, SOD−323	NSR0340H	6
D103, D203, D303, D403. D503, D603	Yageo	0 Ω resistor, 1/8 W, 0805	RC0805JR−070RL	6
L100, L200, L300, L400, L500, L600	Würth Elektronik	1 mH inductor, 0.6 A, ±10%	744732102	6
Q01, Q02, Qx1	ON Semiconductor	NPN transistor, SOT23	BC848AL	3
Q03	ON Semiconductor	PNP transistor, SOT23	BC858AL	1
Q100, Q200, Q300, Q400, Q500, Q600	ON Semiconductor	N−Channel 500 V, 2.3 A, DPAK	NDD03N50ZT4G	6
R01	Yageo	10 Ω resistor, 1%, 0805	RC0805FR−0710RL	1
R03, R05, R07, R08	Yageo	10 kΩ resistor, 1%, 1/8 W, 0805	RC0805FR−0710KL	4
R102, R202, R302, R402, R502, R602	Yageo	12 kΩ resistor, 1%, 1/8 W, 0805	RC0805FR−0712KL	6
R04	Yageo	33 kΩ resistor, 1%, 1/8 W, 0805	RC0805FR−0733KL	1
R06	Yageo	1 MΩ resistor, 1%, 1/8 W, 0805	RC0805FR−071ML	1
R09, R10	Yageo	47 kΩ resistor, 1%, 1/8 W, 0805	RC0805FR−0747KL	2
R11	Yageo	470 kΩ resistor, 1% 1/8 W, 0805	RC0805FR−07470KL	1
R12	Yageo	620 kΩ resistor, 1%, 1/8 W, 0805	RC0805FR−07620KL	1
R100, R200, R300, R400, R500, R600	Yageo	22 kΩ resistor, 1%, 1/8 W, 0805	RC0805FR−0722KL	6
Rx1, Rx3	Yageo	100 kΩ resistor, 1% 1/8 W, 0805	RC0805FR−07100KL	2
Rx2	Yageo	1 kΩ resistor, 1%, 1/8 W, 0805	RC0805FR−071KL	1
Rx4	Yageo	4.99 kΩ resistor, 1%, 1/8 W, 0805	RC0805FR−074K99L	1

Listed below are only the components that differ from the 240 mA board configuration.

Table 2. CrM BUCK BOARD LIST OF COMPONENTS CONFIGURED FOR 120 mA LED CURRENT

Name	Manufacturer	Description	Part Number	Units
C100A, C200A, C300A, C400A, C500A, C600A	Panasonic	Metal Polyester capacitor, 0.22 μF, 250 V	ECQ−E2224KF	6
D101B, D201B, D301B, D401B, D501B, D601B	ON Semiconductor	100 V Switching Diode, SOD−123	MMSD4148	6
L100, L200, L300, L400, L500, L600	Würth Elektronik	1.0 mH inductor, 0.6 A, ±10% or 1.5 mH inductor, 0.3 A, ±10%	744732102 or 744732152	6
R102, R202, R302, R402, R502, R602	Yageo	24 kΩ resistor, 1%, 1/8 W, 0805	RC0805FR−0724KL	6

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
P.O. Box 5163, Denver, Colorado 80217 USA
Phone: 303−675−2175 or 800−344−3860 Toll Free USA/Canada
Fax: 303−675−2176 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81−3−5773−3850

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative