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DN05034/D

Enhanced PWM LED Dimming

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DESIGN NOTE

Circuit Description

The NCL30051LEDGEVB LED driver evaluation board provides PWM dimming capability via gating the resonant half bridge converter on and off at the PWM rate. Effective minimum duty factor is about 10% being limited by biasing considerations.

Some applications require wider range PWM dimming often extending to 1% or below. This design note presents a method to achieve PWM dimming from 100% down to less than 1% using an enhanced power control circuit. A series FET switch is introduced in the driver output to interrupt the LED current in response to the PWM control signal. This method allows the converter to maintain proper bias conditions needed to support dimming over an extremely wide dimming range.

The feedback control utilizes the sample and hold feature in the evaluation board to maintain consistent drive conditions for the LED load while dimming. Additional control circuits monitor LED current and automatically limit power during start up or transient conditions. A latch-off feature is included to avoid stress induced during shorted load conditions.

Table 1. DEVICE DETAILS

Device	Application	Input Voltage	Output Power	Topology	Isolation
NCL30051 + NCS1002	LED Dimming	90−305 Vac	50 W	CrM PFC + Resonant Half Bridge	Isolated

Table 2. OTHER SPECIFICATIONS

	LED Output
Output Current	1 A
Ripple	N/A
Nominal Voltage	50 V
Max Voltage	54 V

PFC (Yes/No)	Yes
Typical Efficiency	87%
Inrush Limiting/Fuse	Thermistor + Fuse
Cooling Method/Supply Orientation	Convection/Any
Signal Level Control	Low Voltage PWM

Present Solution

The PWM dimming control of the evaluation board activates a sample and hold circuit to maintain the regulation point when the LED current is off. The PWM signal is routed to the primary side of the converter through an opto coupler. The resonant half bridge driver is switched off when the PWM dimming signal is issued. LED current decays to zero as the output capacitors discharge.

When the PWM dimming signal commands the LED current to resume, the half bridge controller always begins operation by turning on the lower half bridge switch first. This allows the charge pump for the upper switch to properly bias.

When switching resumes, the operating point voltage of the half bridge capacitors C6 and C7 is shifted as the transformer charges output capacitors C18 and C19 along with current flowing to the LEDs. The operating point at C6 and C7 is restored after a few half bridge cycles. This effect results in some current overshoot in the LEDs.

Figure 1 shows typical PWM dimming for the NCL30051LEDGEVB evaluation board. The PWM control signal is shown in the top green trace. The middle purple trace is C6 and C7 half bridge capacitor voltage, and the lower trace is the LED current in blue. Note the short duration overshoot in LED current.

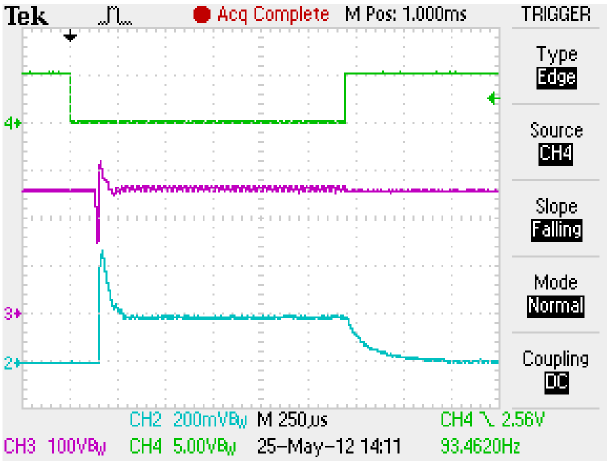

Figure 1. NCL30051 PWM Dimming

Enhanced Solution

In the schematic of Figure 2, FET Q102 is inserted in series with the cathode lead of the LED load forming a load switch. The gate of the FET is biased on with a simple op amp constant current source which utilizes the existing current sense resistor R22 of the evaluation board. The operating current is set higher than the peak of the normal ripple current seen by the LEDs. This ensures that under normal operation, the FET load switch is fully conducting which minimizes power loss.

Diode D102 couples the gate of Q102 load switch to transistor Q6 on the evaluation board. When the PWM signal activates Q6, the sample and hold FET Q5 is activated and the FET load switch Q102 is turned off halting the current to the LEDs.

The PWM control signal restores current flow to the LEDs and turns off the sample and hold. The on/off cycle repeats at the PWM control frequency.

Op amp U101B forms the constant current source by sampling the voltage across R22 and comparing to a divided reference voltage. This circuit is critical under output overload conditions. The constant current function limits LED current and ensures that adequate secondary bias voltage is available to maintain feedback control. The resonant half bridge converter remains operational which supplies power to the secondary side. Opto coupler U2 and surrounding components are not required and can be removed.

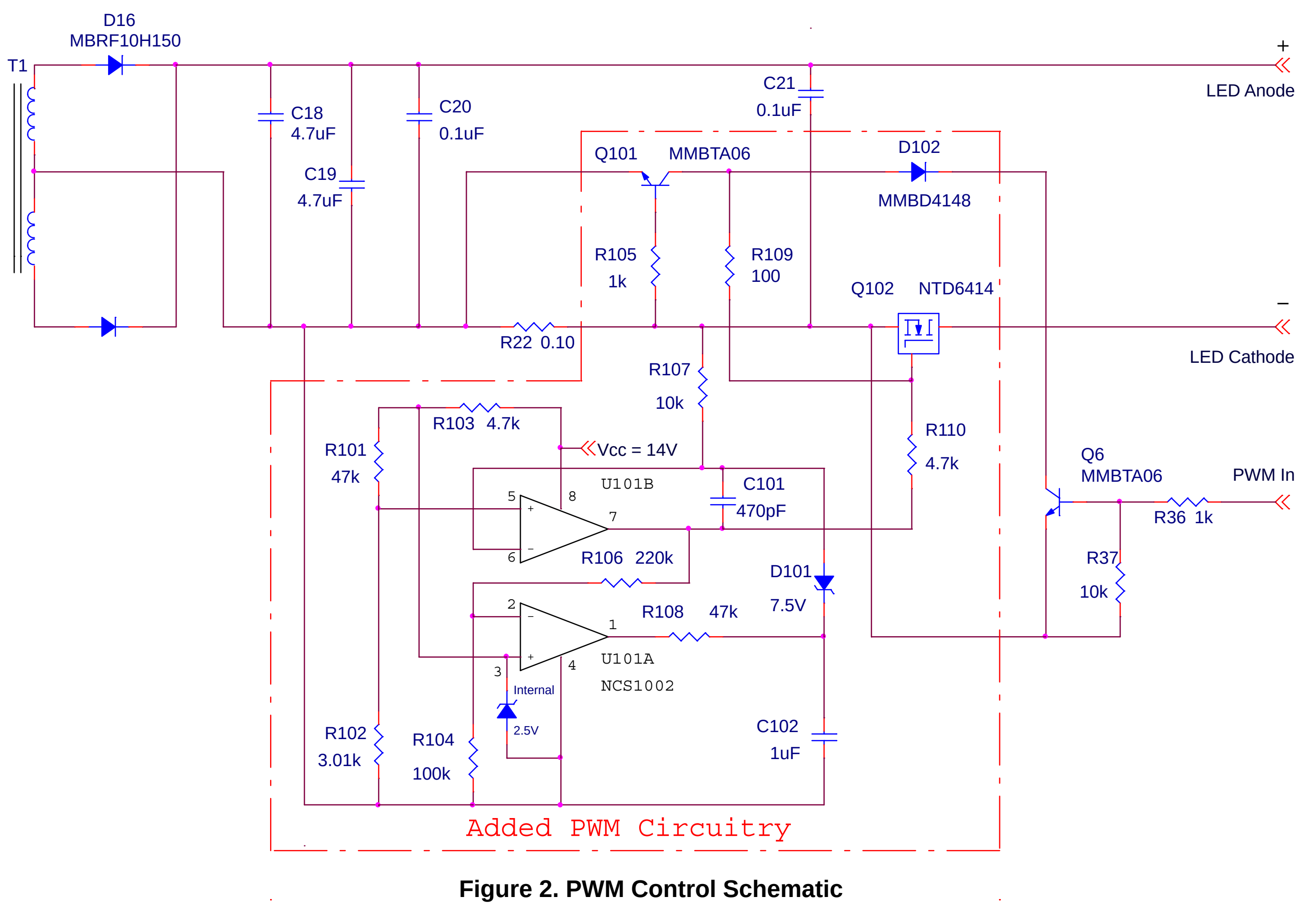

Figure 2. PWM Control Schematic

As an example, if the output was shorted and the FET switch not in place, there would not be any voltage in the secondary available to control the power supply. Note that under a short circuit condition, Q102 load switch is operating in a linear region dissipating significant power. Op amp U101A monitors the state of Q102 and starts an RC timer (R108 and C102) when the Q102 is operating in the linear mode.

After a delay, the U101A shuts down the current source through D101 and latches it off. This prevents overheating Q102. The ac input power must be recycled to restore operation.

BJT Q101 forms a very fast acting current limiter in case the LED output is shorted while at full operating voltage. This transistor quickly limits the current by controlling Q102 through R109 until U101B can respond and provide constant current control.

Performance Characteristics

Figure 3 shows PWM dimming performance with similar timing to that shown in Figure 1. Note there is virtually no current overshoot.

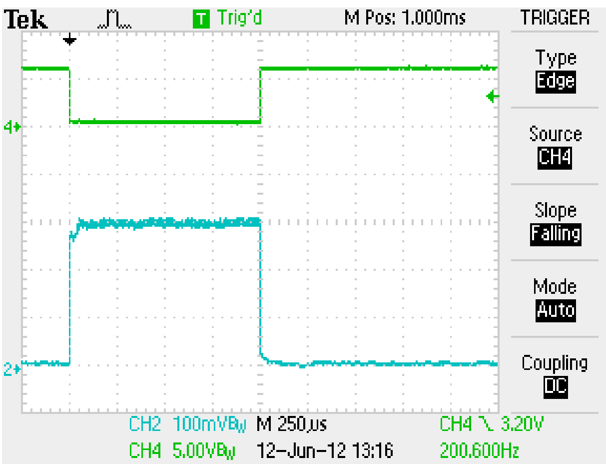

Figure 3. Enhanced PWM Response

Dimming with 5% duty factor at 200 Hz rate is shown in Figure 4. The PWM control signal is the green trace on top and the LED current is the lower trace at 333 mA div.

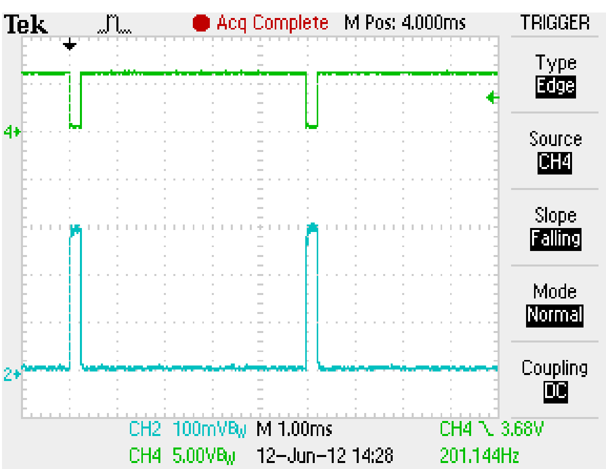

Figure 4. 5% Dimming at 200 Hz

Figure 5 shows an expanded view of the above.

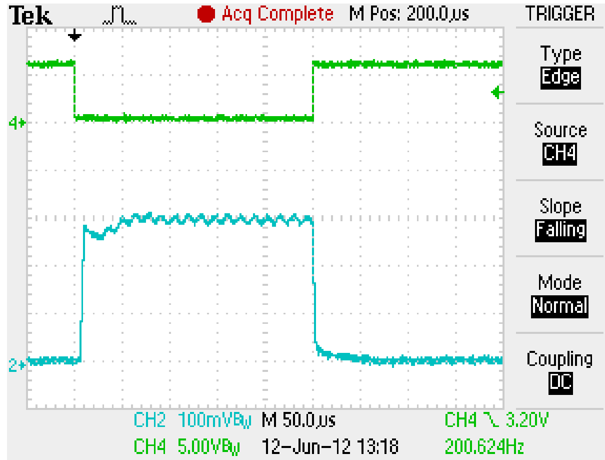

Figure 5. Expanded View of 5% PWM Dimming

Figure 6 below shows 1% PWM dimming.

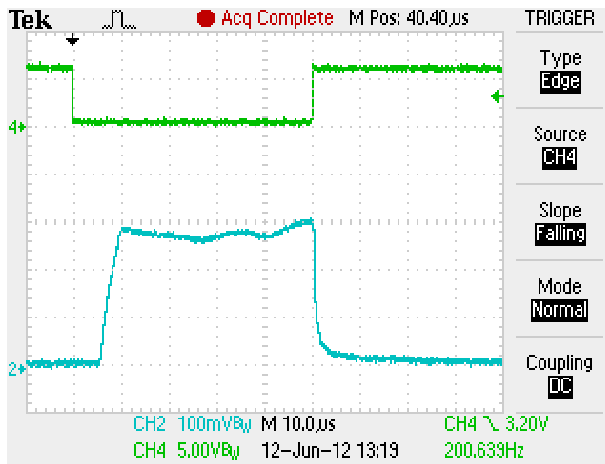

Figure 6. 1% PWM Dimming

This dimming approach works well for very wide duty factors as well. Figure 7 shows the PWM control signal in green on the top trace and the LED current below that in blue. This is 99% dimming at 200 Hz rate. Note the ripple in the LED current is pass-through of the 120 Hz ripple due to required low bandwidth of the PFC control loop. This solution utilizes low value non-electrolytic capacitors as the main secondary filter.

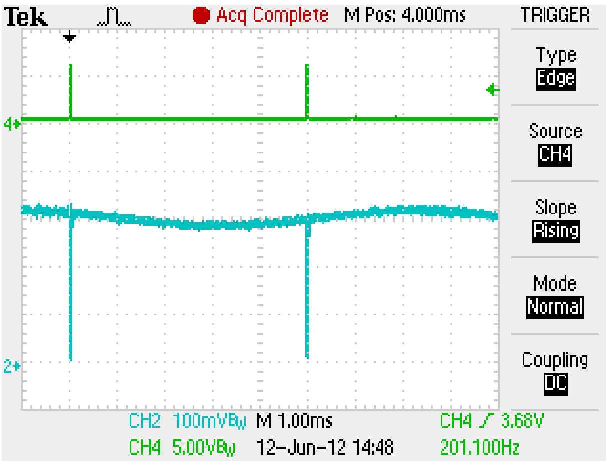

Figure 7. 99% Dimming at 200 Hz

Figure 8 below is an expanded view of the 99% dimming shown in the figure above.

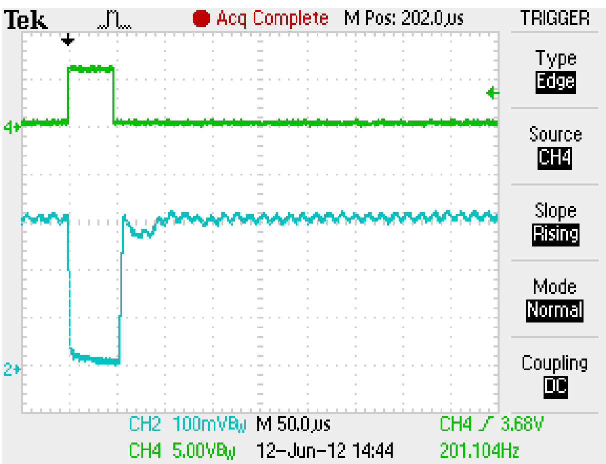

Figure 8. Expanded View of 99% Dimming

The examples above depict dimming with a 200 Hz frequency. Higher frequencies yield similar results and this circuit is suitable up to 500 Hz operation.

Overload operation

The PWM control circuit must maintain proper operation during overload conditions as described earlier. Figure 9 shows the NCL30051LEDGEVB evaluation board with the modified PWM control at initial start up with a short placed on the output. The current scale is 667 mA/division. Peak current is about 1.67 A. The RC timer function shuts the LED current off after about 64 msec.

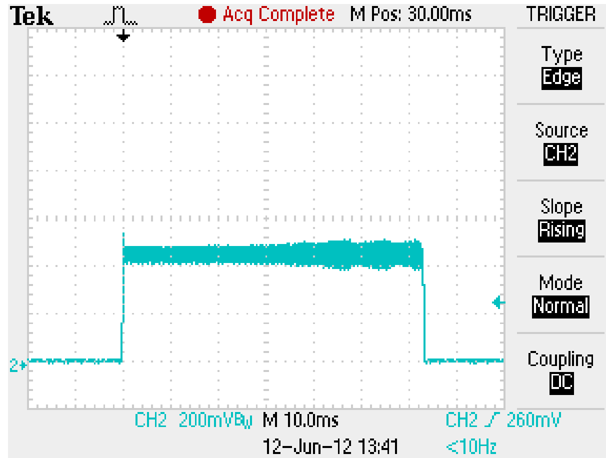

Figure 9. Start Up into Short Circuit

Shorting the output of any power supply while it is operating can generate high surge currents as the filter capacitors rapidly discharge. The PWM control circuit includes provisions to control the current stress and then turn the output current off after a delay.

Figure 10 below shows the output current profile with the converter driving a 50 V load at 1 A and then a short is applied across the output. The current is shut off after about 45 msec.

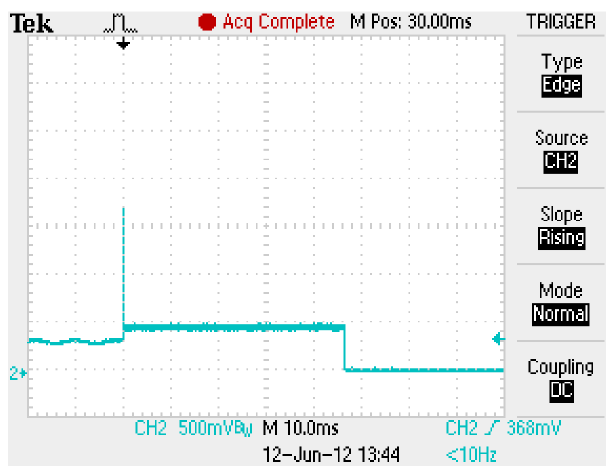

Figure 10. Output Current

The data below shows performance of the NCL30051LEDGEVB evaluation board in its original configuration with a 14 LED load and no PWM dimming.

Vin:	115 V ac
Iin:	0.45 A rms
Pin:	51.13 W
PF:	0.99
THDi:	9.8%
Iout:	975 mA
Vout:	46.1 V
Output Power:	44.9 W
Efficiency:	87.9 %

The performance of the NCL30051LEDGEVB evaluation board is not significantly impacted by the added PWM control circuitry. The data below shows performance with a 14 LED load and no PWM dimming.

Vin:	115 V ac
Iin:	0.46 A rms
Pin:	51.86 W
PF:	0.99
THDi:	9.7%
Iout:	975 mA
Vout:	46.3 V
Output Power:	45.1 W
Efficiency:	87.0 %

A bill of materials for the modifications to the NCL30051LEDGEVB evaluation board and the additional components required as shown in the schematic of Figure 2 is included at the end of this document.

Conclusion

This design note illustrates how to improve the secondary side control circuitry to allow dimming to very narrow duty ratios. It has been demonstrated and tested by adding a small amount of additional circuitry and interfacing it to the NCL30051LEDGEVB evaluation board. This can enhance PWM dimming performance providing a wider operating range and more precise current waveform.

References

[1] NCL30051/D Data Sheet

[2] Evaluation Board Documents

Table 3. BILL OF MATERIALS

Designator	Qty	Description	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed
COMPONENT CHANGES ON NCL30051LEDGEVB EVALUATION BOARD						
R39	1	2.7 kΩ 0.25 W 1%	1206		Delete Part	
R40	1	1.2 kΩ 0.25 W 1%	1206		Delete Part	
R42	1	5.1 kΩ 0.25 W 1%	1206		Delete Part	
Q7	1	NPN	SOT−23		Delete Part	
U2	1	Opto Coupler	SMT		Delete Part	
R37, R41	2	10 kΩ 0.25 W 1%	1206		Delete Part	
R36	1	1 kΩ 0.25 W 1%	1206	Panasonic	ERJ−8ENF1001V	Yes
COMPONENTS FOR ENHANCED PWM DIMMING CONTROL						
R101, R108	2	47 kΩ 0.1 W 1%	0603	Panasonic	ERJ−3EKF4702V	Yes
R102	1	3.01 kΩ 0.1 W 1%	0603	Panasonic	ERJ−3EKF3011V	Yes
R103, R110	2	4.7 kΩ 0.1 W 1%	0603	Panasonic	ERJ−3EKF4701V	Yes
R104	1	100 kΩ 0.1 W 1%	0603	Panasonic	ERJ−3EKF1003V	Yes
R105	1	1 kΩ 0.1 W 1%	0603	Panasonic	ERJ−3EKF1001V	Yes
R106	1	220 kΩ 0.1 W 1%	0603	Panasonic	ERJ−3EKF2203V	Yes
R107	1	10 kΩ 0.1 W 1%	0603	Panasonic	ERJ−3EKF1002V	Yes
R109	1	100 Ω 0.1 W 1%	0603	Panasonic	ERJ−3EKF1000V	Yes
U101	1	Dual Op Amp/Ref	SOIC−8	ON Semiconductor	NCS1002	No
Q101	1	NPN	SOT−23	ON Semiconductor	MMBTA06	No
Q102	1	N−FET	DPAK	ON Semiconductor	NTD6414	No
D101	1	7.5 V Zener	SOD 123	ON Semiconductor	MMSZ7V5	No
D102	1	Diode	SOD 123	ON Semiconductor	MMBD4148	No
C101	1	470 pF 50 V	0603	TDK	C1608X7R1H471K	Yes
C102	1	1 μF 25 V	0603	TDK	C1608Y5V1E105Z	Yes

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