Application Note DC-020

DC/DC CONVERTER

Power Design Considerations for LED Applications

In recent years, LEDs have been improved through technological advances in material and manufacturing processes. Today LEDs possess high efficiency, long life, vivid colors and are used in a variety of industries including the automotive, computer, telecom, military and consumer goods. New LEDs such as Luxeon's Lumileds (www.lumileds.com) need up to 350mA DC and up to 550mA peak pulse current for proper operation. As long as they are designed to operate within their maximum current and temperature limits, LEDs will provide 100 times longer life than any incandescent bulb and use less energy as well.

Figure 1 shows a schematic diagram to drive an LED bank to supply white backlight to an LCD monitor using Luxeon's LXHL-MGDA DCC Backlighting Emitter Assembly[1]. The assembly has 2 strings of red LEDs (5 LEDs per string), 2 strings of blue LEDs (3 LEDs per string) and 2 strings of green LEDs (9 LEDs per string). A quad operational amplifier is used to design the three electronic loads and the fourth OPAM is used for the temperature sensor. From Luxeon's LXHL-MGDA data sheet[1], the maximum forward voltage drop for the green LED string is given as 30.8V typical and 33.1V maximum. Assuming 1V is required by the electronic load and all six LED strings are powered from a single power source, we would need 34.1V @ 2.17A (or 74W) for DC operation and 105.7W maximum for pulsed operation when all the LEDs are switched on/off.

In Figure 1, the 34.1V is generated by an 80W step-up converter (a model from Beta Dyne's SR80 series) that offers 96% efficiency. The forward voltage drop for the red LED strings is 15.9V max and for the blue is 10.8V max, therefore the electronic load for the red LED strings must dissipate (34.1-15.9)*0.77A = 14W and the blue LED strings (34.1-10.8)*0.7A = 16.3W, or 41% of the available power is wasted by the electronic load.

Better power efficiency can be achieved if two step-up converters are used for the green LED strings to provide the 34.1V and one converter to provide the 16.9V for the red LED strings. For the blue LED strings, the input voltage of 12V can be used if it is well regulated.

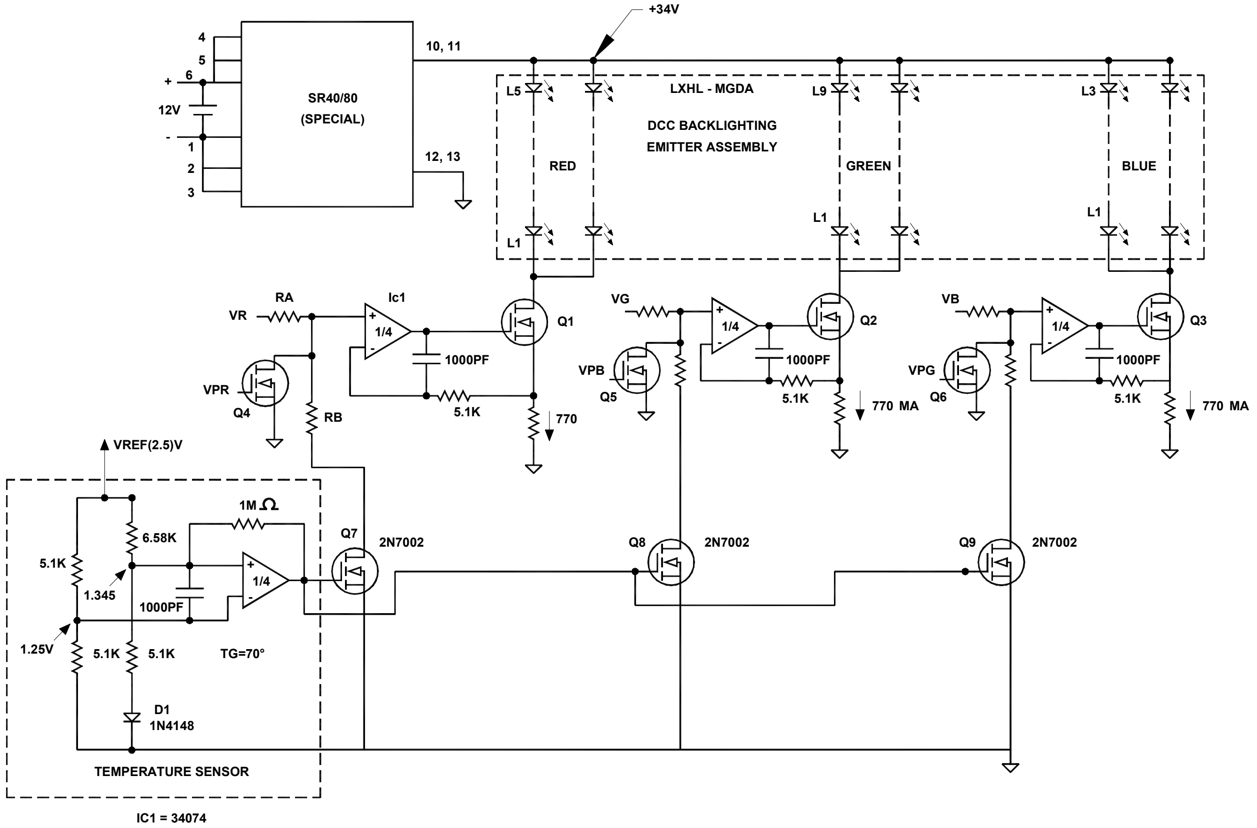

FIGURE 1. Backlight control circuit with single supply, electronic loads and temperature sensors

ELECTRONIC LOAD FOR LEDS

In applications where dimming is required, electronic loads can be used to achieve fast current switching and precise current control. In Figure 2, a dual OPAM is used to provide all the necessary control and protection for the LED. The current through the LED strings is set by the input voltage VA to the positive input to A1 and is given by: IE = VA/RE.

Amplifier or comparator A2 with Q2 is used only for LED protection when VDC is disconnected while VA is set higher than zero volts or when VDC has a longer turn on delay than V_{CC}. For a better understanding of the overcurrent condition of any electronic load, let's assume VA is set to 1V, RE is 1Ω and DC VDC supply is momentarily disconnected. In order to maintain zero volts between its + and – inputs, the output of A1 will saturate to $+V_{CC}$ driving the gate of Q1 to this high potential. For a V_{CC} voltage of 15V, the maximum possible current through Q1 will be approximately $(V_{CC}-V_{DS})/RE$.

Depending on the response time of A1 and the input capacitance of Q1 when VDC is applied to the LED string, a catastrophic high current through the LEDs will be allowed through. To eliminate this problem, A1 monitors VDC and when VDC is not present A2 turns on Q2, thus V_{DS}=VA and Q1 effectively is turned off.

The 5.1K resistor connected between the negative input of A1 and RE in Figure 2 provides high source impedance for Q2. The drain of Q2 can be connected to V_{CC} through a series resistor if zero volts is required at the gate of Q1 when VDC is disconnected. If the power dissipation of Q1 is kept below 0.5W, an SOT-23 or SOT-89 packaged MOSFET can be used.

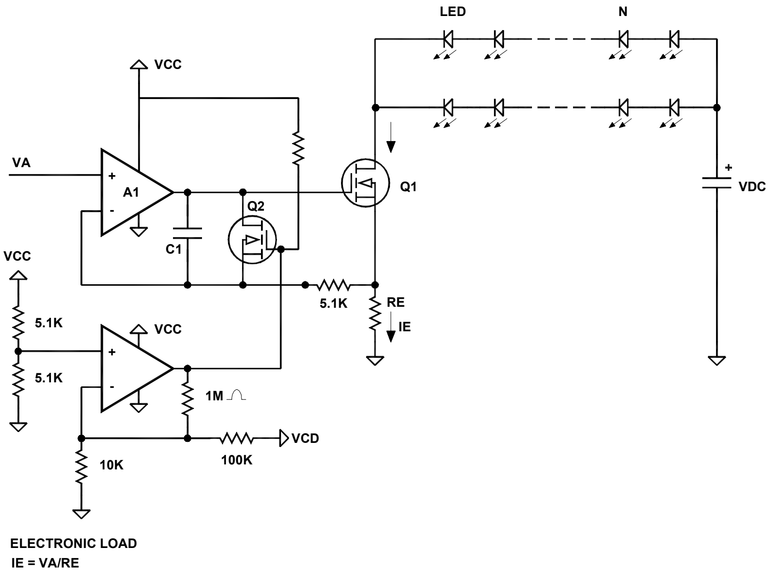

FIGURE 2. Electronic load

THERMAL PROTECTION FOR THE LED

Referring back to Figure 1, D1 is used as a temperature sensor that must be installed on the LED assembly substrate. The LEDs—like any diode—has negative TC approximately 2.1mV/°C. By offsetting the inputs of the comparator by the required amount in mV, we can make A4 to switch at 70°C ±2°C. The forward voltage of D1 @ 25°C is assumed to be 0.45V and the current through it is approximately 175µA. For a ΔT=45°C, the negative input of A4 is set as: 45*0.0021 = 94.5mV higher than the positive input 1.25+0.0945 = 1.3445.

At approximately 70°C, the output of A4 goes high turning on Q7 through Q9 thus lowering the current through the electronic load by forming a voltage divider with RA and RB for each electronic load. The same circuit can be used with the NTC provided on the LED assembly by replacing D1 with the onboard NTC, which may require adjustment on the resistor values in the temperature sensor.

When the voltage required to set the current at each electronic load is generated by a CPU, a master temperature monitor can be used to lower the voltage VR, VB, VG as required. In Figure 1A, the power required for the different color LEDs is provided by two different step-up converters. The SR20[2] is set for an output of 34V and the SRA40 is set for 16V for the red and blue LED strings. NOTE: Do not connect any power dissipation components close to the LED assembly.

The electronic load is designed with a dual N channel MOSFET IRF7303 20V V_{DSS} while the dual electronic load for the green string IRF7103Q is used with 50V V_{DSS}. For over current protection in the dual electronic load Q2 is driven high when the base current of Q3 drops to zero. When a dim control is required, the block diagram given in Figure 3 can be used to provide independent current control and to generate the required duty cycle for light intensity control.

Referring to Figure 5, for independent current control for each color of LED, three SPI-compatible digital-to-analog (D/A) converters are used, allowing the converters to be placed anywhere on the PCB while reducing the number of data and control lines. The maximum output voltage of each D/A converter must be equal to or less than the maximum current through the LEDs. The dimming function is provided through an FGD4000 function generator[3] set for 1,000Hz and triangle DAC out function.

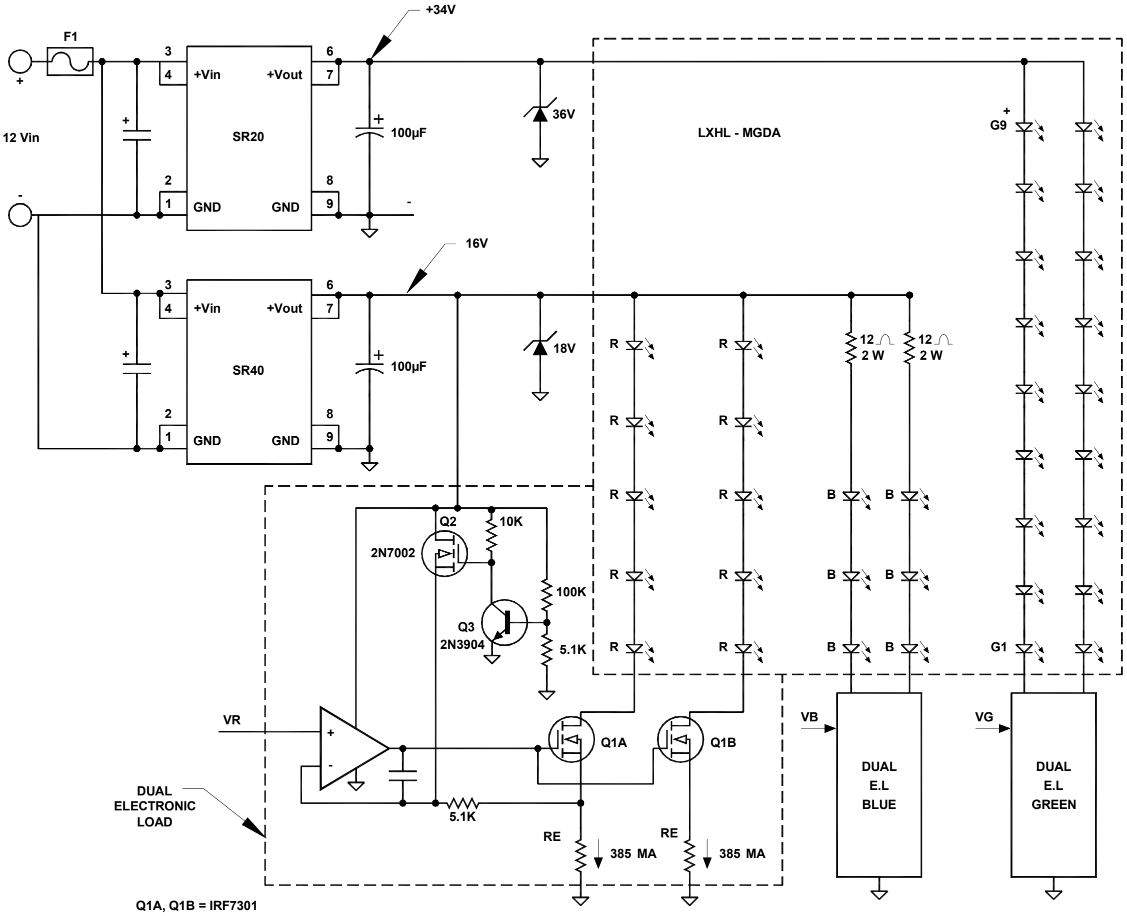

FIGURE 3. Power and control circuit for backlight emitter assembly with dual supply and dual electronic load

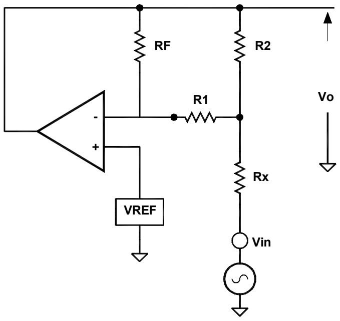

FIGURE 4. SRAD20 output adjust network

$$V_O = \frac{V_{REF}(R_2(R_1+RF) + R_X(R_1+R_2+RF)) - R_2{*}RF{*}V_{IN}}{R_1{*}R_2 + R_X(R_1+R_2+RF)}$$

The output of each D/A converter is connected at the negative input of a quad open collector voltage comparator while the positive input of each comparator is connected through a 5.1KΩ resistor to the output of the function generator. The output of each comparator drives the gate of the MOSFET connected between the positive input of the electronic load amplifier and ground (see Figure 1 Q4, Q5, and Q6 for red, green, and blue LEDs respectively).

For direct current (DC) operation—constant current through the LEDs—the output of the function generator DAC out is set for zero or a few negative millivolts (mV), thus disabling all three comparators CR, CB, CG. When dimming is required the DAC out of the function generator is set for the required duty cycle. To minimize the power dissipation in the electronic loads, the maximum current through the red LED string is set for 550mA, and 500mA for the green and blue LED strings. Assuming 500mV is the full scale output voltage for each color, the current sense resistor (RE) in the electronic load is calculated by:

$$RE_R = 500/550 = 0.909$$

$$RE_B = RE_G = 500/500 = 1W$$

Therefore, the output voltage range of each D/A converter is 0 to 0.5V and the output of the function generator can vary from –2.5V to +2.5V, which allows from 0% to 100% duty cycle under software control.

Depending on the design and budget of the project, more or less hardware can be used. For low power applications, e.g. cell phones, handheld devices, and flashlights, a single step-up converter such as Intersil EL7513, National Semiconductor LM4970, and Micrel MIC2292, can be used.

When a DC/DC converter or a step-up converter is used to power multiple LEDs with much higher current limit than the maximum LED current, the circuit in Figure 6 can be used to provide current limit. Referring to Figure 6, the output of an adjustable step-up switching regulator (SRAD20 with V_O = 0Vdc to 200Vdc)[4] is used to provide 20Vdc for an LED bank on the right. The output current of the converter is monitored by a high-side current sense amplifier MAX4173H[5], which has an output voltage V_X Pin 6 given by: V_X = GAIN * RS * I_O.

The gain of MAX4173H is 100 and IL is set for 1 amp. The output impedance of MAX4173H is 12KΩ and is connected in series with the input resistor R_X (36.5KΩ) to the SRAD20. With R_2 open and IL = 0A (zero amps), the output voltage at Pin 5 is given by:

$$V_O = (1 + \frac{RF}{R_1+R_X+12})^2 = (1 + \frac{511}{4.99+36.5+12})^2 = 21.1V$$

At IL = 1A, V_X = 100 * 0.005 * 1 = 0.5V. And V_O is given by:

$$V_O = (1 + \frac{RF}{R_1+R_X})^2 - \frac{RF*V_X}{R_1+R_X} = 26.6 - 6.16 = 20.44V$$

The current sense amplifier has a maximum V_{CC} of 28V, which sets the zener voltage D_2 to 26V and D_1 zener to 24V. The over voltage zener D_1 can be replaced with R_2 in order to reduce the gain of the SRAD20.

When R_2 is used, the output of the SRAD20 is given by (see also Figure 4):

$$V_O = \frac{V_{REF}(R_2(R_1+RF) + R_X(R_1+R_2+RF)) - R_2*RF*V_{IN}}{R_1*R_2 + R_X(R_1+R_2+RF)}$$

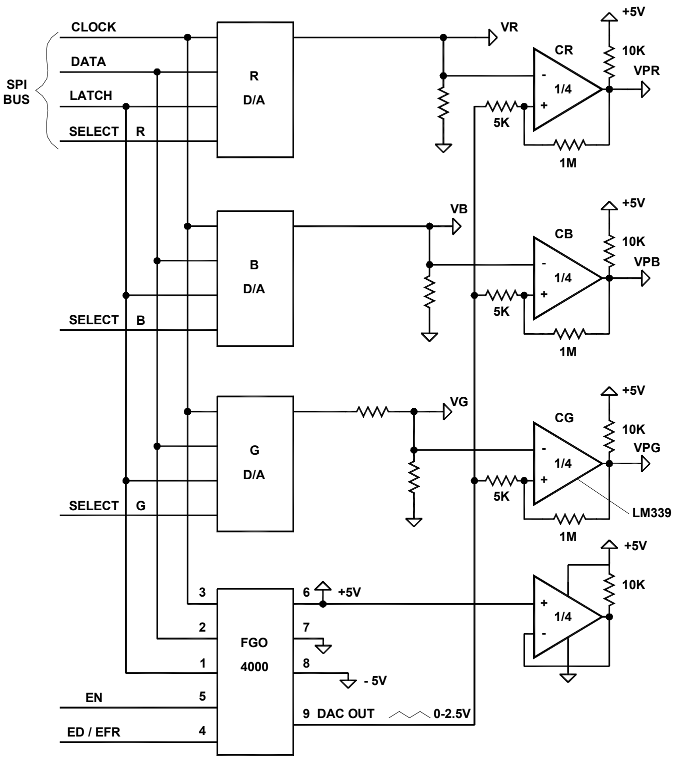

FIGURE 5. LED backlight control diagram

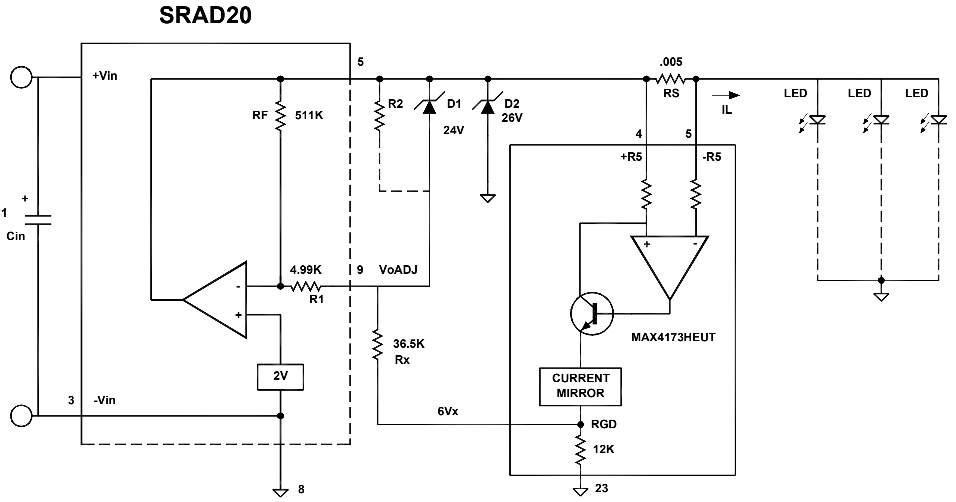

FIGURE 6. Adjustable switching regulator with current limiter

$$V_x = GRS\ IL = 100*0.005*1$$

REFERENCES

[1] Luxeon LXHL-MGDA DCC Backlighting Emitter Assembly (http://www.luxeonstar.com/item.php?id=440)
Luxeon LXHL-MGDA data sheet (http://www.lumileds.com/pdfs/protected/DS48.PDF)
Luxeon Application Brief AB27 (http://www.lumileds.com/pdfs/AB27.PDF)
[2] SR20 20W Switching Regulator (http://www.beta-dyne.com/products/sr2040.html)
[3] FGD4000 Function Generator (http://www.beta-dyne.com/products/fgd40.html)
[4] SRAD20 20W Adjustable Switching Regulator (http://www.beta-dyne.com/products/srad20.html)
[5] Maxim Integrated Products MAX4173H Low-Cost, SOT23, Voltage-Output, High-Side Current-Sense Amplifier (http://www.maxim-ic.com/quick_view2.cfm/qv_pk/1971)