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APPLICATION NOTE 4479

Diagnose LEDs by Monitoring the Switch-Mode Duty Cycle

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Abstract: A change in the forward voltage (V_F) for a string of series-connected, high-brightness LEDs (HB LEDs) can indicate deterioration or complete failure of one or more of the LEDs. Accordingly, this circuit assesses the LED's health by monitoring V_F.

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The forward voltage (V_F) of high-brightness LEDs (HB LEDs) is often monitored to assess the health of the LED. Big changes in V_F can indicate deterioration or even a complete failure of one or more LEDs connected in series.

For several LEDs in series, the sum of their V_F voltages can go to 40V or more, and if not referenced to ground, that V_F sum requires a differential measurement. As a third challenge (in addition to high voltage and differential measurement), HBLEDs are often dimmed using pulse-width modulation (PWM). If so, you can't measure V_F during the low portion of the PWM duty cycle, when the LEDs are not illuminated and V_F is not present. For a hysteretic buck LED driver (MAX16820) driving three LEDs in series (Figure 1), you must measure the anode and cathode voltages of the string when DIM is high.

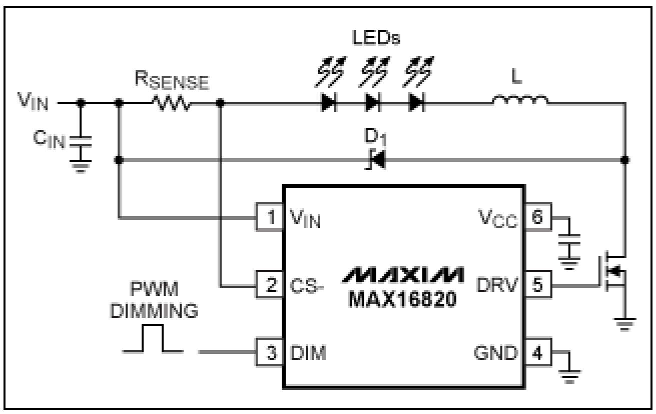

Figure 1. Standard driver circuit for HB LEDs.

To avoid the need for a differential high-voltage measurement, you can take the indirect approach of measuring the duty cycle at the DRV pin. For this particular LED driver, a first-order estimate of forward voltage for the LED string is $V_F = D \times V_{IN}$, where D represents an internal duty cycle produced in the IC's switchmode section (not to be confused with the duty cycle at DIM). The DRV signal is referenced to ground and limited to V_{CC} (5V). That condition allows the use of low voltage ADCs or comparators, which in turn can be powered by the LED driver's V_{CC} output (10mA maximum).

Figure 2 shows how to detect a short-circuited LED with the aid of a comparator (MAX9141). Filter R_1C_1 converts the AC PWM signal at DRV to a DC voltage (V_D) proportional to $D \times V_{CC}$. V_D should be sampled when its value is greater than (perhaps) 90% of its steady-state value, which requires a period of at least $2.3R_1C_1$. Because the comparator's Latch Enable (LE) latches the output when LE is low, LE should assert not earlier than $2.3R_1C_1$ after DIM goes high. R_2C_2 in combination with D_2 ensures that LE de-asserts immediately after DIM goes low. The R_2C_2 value is higher than R_1C_1, so the comparator enables when the input signal reaches at least 90% of its steady-state value. D_2 discharges C_2 immediately after DIM goes low, which latches the output as soon as the LEDs go off.

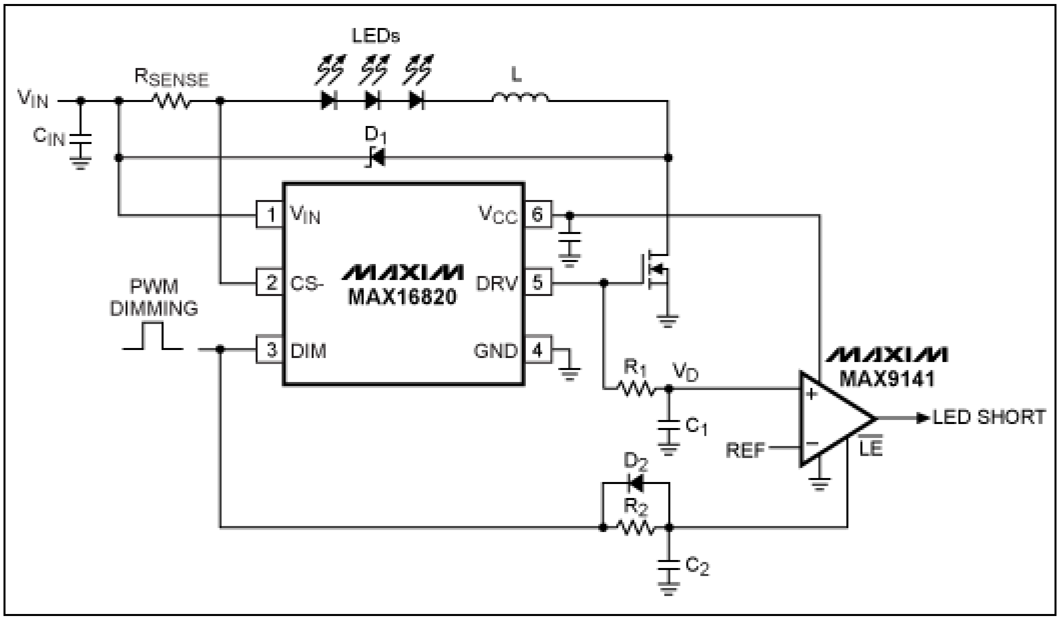

Figure 2. Adding this comparator circuit to the Figure 1 circuit provides detection of shorted LEDs.

Because Ref is lower than D × V_{IN}, the comparator output is normally low. If an LED fails shorted, its forward voltage drops and causes the duty cycle at DRV to drop. V_D then drops below Ref, causing the comparator output to go high, indicating a shorted LED. Because the output latches when DIM goes low, the error signal remains asserted even when the LEDs are off. Figure 3 shows the filtered DIM and DRV signals for normal operation vs. a shorted-LED condition.

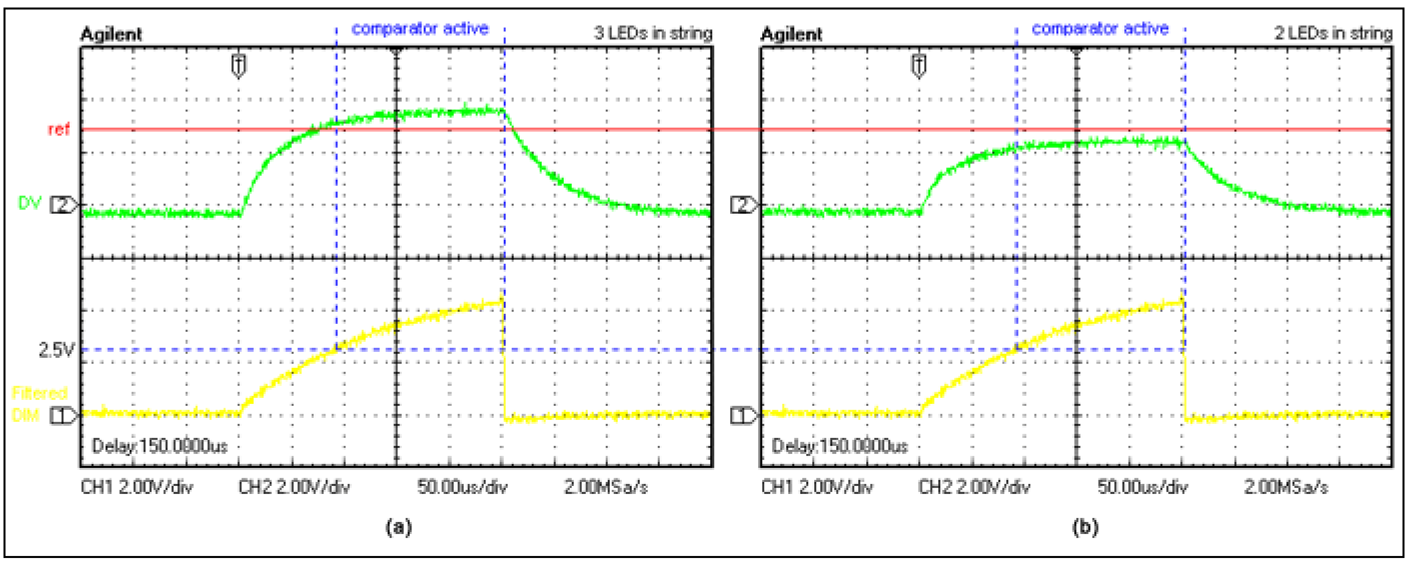

Figure 3. For the Figure 2 circuit with three LEDs in series and a 200Hz DIM signal with 5% duty cycle, these graphs show the filtered DRV signal V_D (green) and filtered DIM signal (yellow) obtained with normal operation (a), and one LED shorted (b).

For a system with V_{IN} = 12V and three LEDs in series, where $V_F \approx$ 3V per LED (Figure 3a), the filtered DRV signal (green graph) stabilizes at approximately D × V_{CC} = (9V/12V)5V = 3.75V. The comparator latches when the filtered DIM signal (yellow graph) goes lower than 2.5V, so the comparator begins interpreting the filtered DRV signal after approximately 100µs. Clearly, V_D is higher than the threshold Ref (red line) when the comparator is active.

After one of the LEDs shorts out (Figure 3b), V_D stabilizes at approximately (6V/12V)5V = 2.5V, and does not exceed the threshold anymore. That condition causes the comparator output to go high, indicating that one of the LEDs has become a short circuit.

The choice of filter constants R_1C_1 and R_2C_2 depends on several parameters. The cut-off frequency should be low enough to properly filter the DRV signal, yet small enough to allow the filtered signal to stabilize near the steady-state value achievable within the shortest dimming pulse.

This circuit can easily be adjusted to detect open-circuit LEDs. When an LED breaks and stops conducting current, the DRV duty cycle goes to 100% (when DIM is high). If you then swap the comparator-input connections and put Ref slightly below V_{CC}, the comparator output goes high in response to an open LED.

Related Parts

MAX16820	2MHz High-Brightness LED Drivers with High-Side Current Sense and 5000:1 Dimming	-- Free Samples
MAX9141	40ns, Low-Power, 3V/5V, Rail-to-Rail Single-Supply Comparators	-- Free Samples

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