# Diagnose LEDs by monitoring the switch-mode duty cycle

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Engineers often monitor the forward voltage, $V_F$, of HB LEDs (high-brightness light-emitting diodes) to assess the LEDs' health. Big changes in forward voltage 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 forward voltages can reach 40V or more, and, if you do not reference that voltage to ground, it requires a differential measurement. In addition to the challenges of high voltage and differential measurement, HB LEDs are often dimmed using PWM (pulse-width modulation). If so, you can't measure forward voltage during the low portion of the PWM duty cycle when the LEDs are unlit and the forward voltage is not present. For a hysteretic buck-LED driver driving three LEDs in series (**Figure 1**), you must measure the anode and cathode voltages of the string when the Dim pin is high.

To avoid the need for a differential high-voltage measurement, you can take the indirect approach of measuring the duty cycle at the driver pin, DRV. For this LED driver, a first-order estimate of forward voltage for

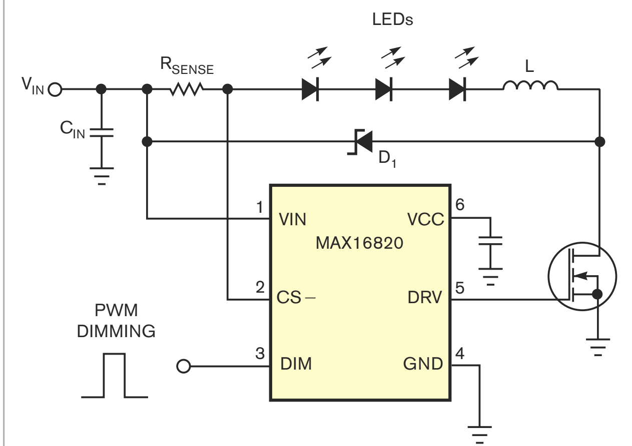


Figure 1 For a hysteretic buck-LED driver driving three LEDs in series, you must measure the anode and cathode voltages of the string when the Dim pin is high.

the LED string is $V_F = D \times V_{IN}$, where D is an internal duty cycle that the IC's switch-mode section produces; do not confuse this duty cycle with that at the Dim pin. You reference the driver signal to ground and limit it to the power-supply voltage, $V_{CC}$, at 5V. That condition allows the use of low-voltage ADCs or comparators, which the LED driver's $V_{CC}$ output, a maximum of 10 mA, can power.

**Figure 2** shows how to detect a short-circuited LED with the aid of a comparator. Filter $R_1C_1$ converts the ac PWM signal at the driver to a dc voltage, $V_D$, proportional to $D \times V_{CC}$. You should sample $V_D$ when its value is greater than perhaps 90% of its steady-state value; this sampling requires a period of at least $2.3R_1C_1$. Because the comparator's LE (latch enable) latches the output when LE is low, LE should assert not earlier than $2.3R_1C_1$ after the Dim pin goes high. $R_2$, $C_2$, and $D_2$ ensure that LE deasserts immediately after the Dim pin goes low. The value of $R_2C_2$ is higher than that of $R_1C_1$, so the comparator enables when the input signal reaches at least 90% of its steady-state value. $D_2$ immediately discharges $C_2$ after the Dim pin goes low, which latches the output as soon as the LEDs turn off.

Because the reference voltage is lower than $D \times V_{IN}$, the comparator output is normally low. If an LED fails shorted, its forward voltage drops and causes the duty cycle at the driver to drop. $V_D$ then drops below the reference, causing the comparator's output to go high, indicating a shorted LED. Because the output latches when the Dim pin goes low, the error signal remains asserted even when the LEDs are off. **Figure 3** shows the filtered Dim pin and driver signals for normal operation versus a shorted-LED condition.

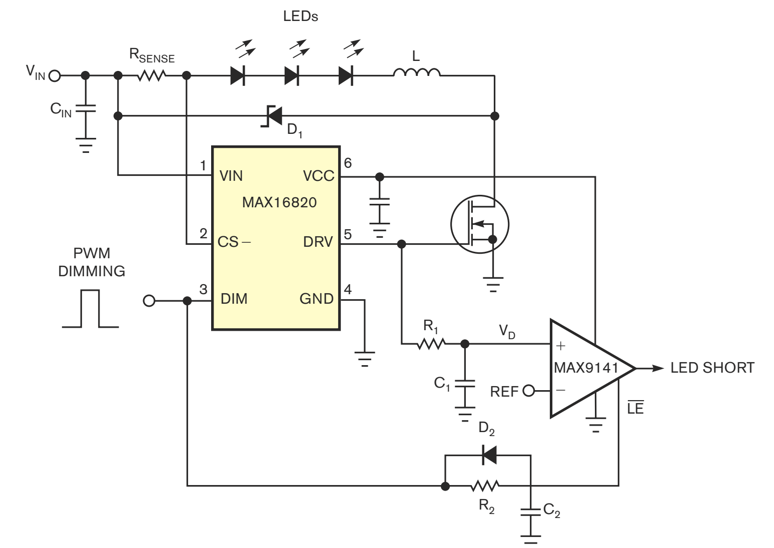


Figure 2 Adding this comparator circuit to the Figure 1 circuit provides detection of shorted LEDs.

For a system with an input voltage of 12V and three LEDs in series, in which the forward voltage is approximately 3V per LED (**Figure 3a**), the filtered driver signal (green) stabilizes at approximately $D \times V_{CC} = (9V/12V)5V = 3.75V$. The comparator latches when the filtered Dim signal (yellow) goes lower than 2.5V, so the comparator begins interpreting the filtered driver signal after approximately 100 µsec. Clearly, $V_D$ is higher than the threshold-reference voltage (red) 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 no longer exceeds the threshold. That condition causes the comparator's 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 cutoff frequency should be low enough to properly filter the driver signal yet small enough to allow the filtered signal to stabilize near the steady-state value achievable within the shortest dimming pulse. You can easily adjust this circuit to detect open-circuit LEDs. When an LED breaks and stops conducting current, the driver's duty cycle goes to 100% when the Dim pin is high. If you then swap the comparator-input connections and put the reference voltage slightly below $V_{CC}$, the comparator output goes high in response to an open LED. EDN

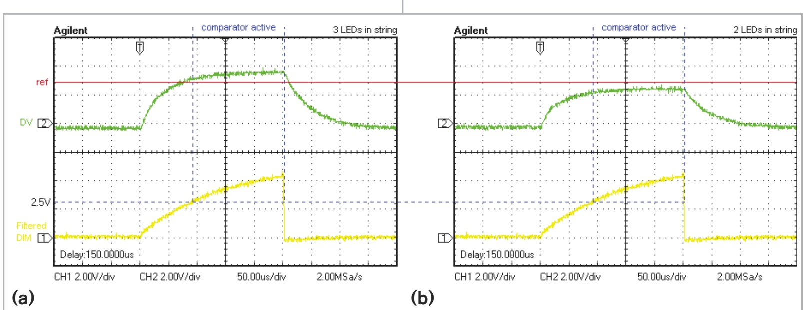


Figure 3 For a system with an input voltage of 12V and three LEDs in series, in which the forward voltage is approximately 3V per LED (a), the filtered driver signal (green) stabilizes at approximately $D \times V_{CC} = (9V/12V)5V = 3.75V$. The comparator latches when the filtered Dim signal (yellow) goes lower than 2.5V, so the comparator begins interpreting the filtered driver signal after approximately 100 µsec. Clearly, $V_D$ is higher than the threshold reference voltage (red) when the comparator is active. After one of the LEDs shorts out (b), $V_D$ stabilizes at approximately $(6V/12V)5V = 2.5V$ and no longer exceeds the threshold.