Application Report
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Using TLC5940 With Higher LED Supply Voltages and Series LEDs

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ABSTRACT

This application report describes how to accommodate higher LED supply voltages and increase the number of series LEDs that the TLC5940 can drive.

1 Introduction

The TLC5940 drives 16 LED channels with each channel able to drive a number of series LEDs. The number of series LEDs the TLC5940 can drive is dictated by the available LED supply voltage, and the voltage rating of the OUTx pins. However, in applications where higher LED supply voltages are necessary, such as when driving many series LEDs, a MOSFET placed in series with the OUTx pin and series LED(s) can be used to widen the range of applications where the TLC5940 can be used. Figure 1 shows a typical circuit describing the inserted series MOSFET.

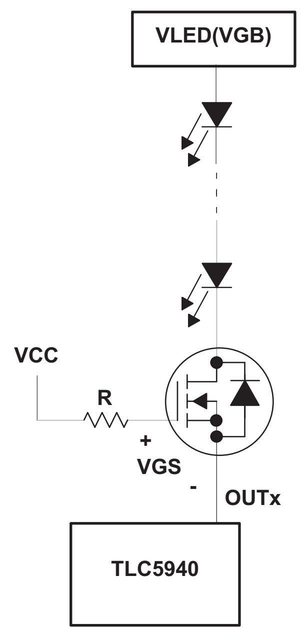

Figure 1. Typical TLC5940 OUTx Circuitry With Series N-Channel MOSFET

2 Application

With a MOSFET in this configuration, the number of series LEDs and the maximum allowable LED supply voltage depends on the voltage rating of the series n-channel MOSFET. The MOSFET isolates the LED cathode from the 17-V rated OUTx pin and limits the maximum voltage on the OUTx pin to the voltage just below the voltage applied to the gate of the MOSFET, which is V_{CC} in this example. This worst case occurs when the LED channel is off. During turnoff, the parasitic board capacitances cause the voltage at

OUTx to float up just high enough so that V_{CC} minus OUTx is less than the MOSFET's turnon threshold, $V_{GS(th)}$, which turns the MOSFET off. To restate, under these conditions, the voltage on the OUTx pin is less than V_{CC}, but greater than $V_{CC} – V_{GS(th)}$. When the LEDs are on and the OUTx channel sinks current, the TLC5940 pulls the OUTx pin low, such that V_{GS} is slightly larger than $V_{CC}–V_{GS(th)}$ by the amount necessary for the MOSFET to pass the current satisfying OUTx. In either case, with LED(s) on or off, the OUTx pin always has a voltage less than V_{CC}. The voltage on the MOSFET drain equals the LED drive voltage (VLED) minus the forward voltage drop across the LEDs (Vf) for the given current and temperature. Figure 2, Figure 3, and Figure 4 illustrate this.

Figure 2 shows the drain-to-source voltage across the MOSFET, Vds, which is measured at the cathode of the LED and at the OUTx pin (blue and green trace, respectively). Without the series MOSFET, the OUTx pin voltage would be equal to the LED's cathode voltage, the blue trace. With a 5-V LED supply voltage, there is no danger to the TLC5940, and the series MOSFET is not required. The voltage difference between the pink and blue traces depicts the forward voltage drop across one LED, which varies when LED current changes.

Figure 2. One LED With 5-V LED Supply Voltage, LED Current (Yellow), V_GB (Pink), Voltage on MOSFET's Drain (Blue), and Voltage on MOSFET's Source, or on OUTx Pin (Green).

Figure 3 shows a similar plot of traces as in Figure 2 but with a 25-V LED supply voltage. Again, the figure shows the MOSFET Vds, voltage difference between the cathode of the LED and OUTx pin (blue and green trace, respectively), this time protecting the TLC5940. Without the series MOSFET, the OUTx pin voltage would be equal to the LED's cathode voltage, the blue trace, and would violate the absolute maximum ratings for the device.

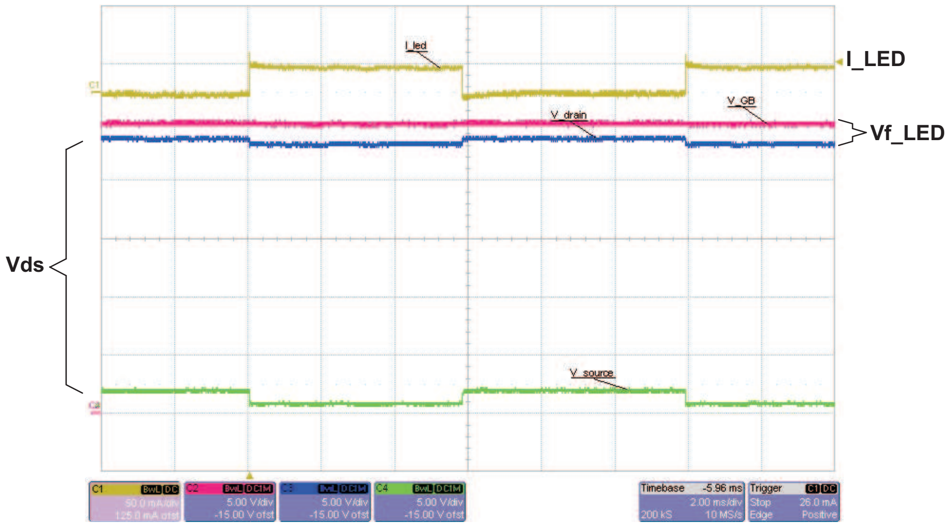

Figure 3. One LED With 25-V LED Supply Voltage, LED Current (Yellow), V_GB (Pink), Voltage on MOSFET's Drain (Blue), and Voltage on MOSFET's Source, or on the OUTX Pin (Green).

Figure 4 shows similar traces as those in Figure 2 and Figure 3 but now with 24 series red LEDs driven by a 50-V LED supply voltage. When the driver is off and no current is flowing, the voltage across the LEDs is 29 V. Even though the driver is off, the LEDs have a forward voltage drop due to leakage currents that flow through them. The voltage on the OUTx pin is 2 V, which is greater than V_{CC} – $V_{GS(th)}$, or greater than 3.3 V – 1.5 V = 1.8 V. This also means that V_{GS}, which is V_{CC} – VOUTx = 3.3 V – 2 V = 1.3 V, is less than $V_{GS(th)}$ = 1.5 V. The MOSFET's drain-to-source voltage is VLED – Vf – VOUTx = 50 V – 29 V – 2 V = 19 V. When the driver is on, VOUTx drops so that the MOSFET's VI curve satisfies the condition to allow 20 mA of drain current. The voltage across the LEDs is now 39 V. The voltage on the OUTx pin is V_{CC} – $V_{GS@Idrain=Isink}$, or 3.3 V – 2.3 V = 1 V. The MOSFET's drain-to-source voltage is VLED – Vf – VOUTx = 50 V – 39 V – 1 V = 10 V. The conditions in Figure 2, Figure 3 , and Figure 4, show that the voltage on OUTx depends on the LED supply voltage and $V_{GS(th)}$, yet never goes above V_{CC}. See Table 1 for clarification.

Table 1. Summary of Voltages When LEDs Are On and Off

V_{CC} = 3.3 V, $V_{GS(th)}$ = 1.5 V	LEDs Off	LEDs On
I_LED	0 mA	25 mA
V_GB (LED supply)	50 V	50 V
V_drain	21 V	11 V
V_f_LED (LED forward voltage)	29 V	39 V
V_source=V_outx	2 V	1 V
V_gs	1.3 V (<V_GS(th))	2.3 V (>V_GS(th))
V_ds (drain-to-source voltage)	19 V	10 V

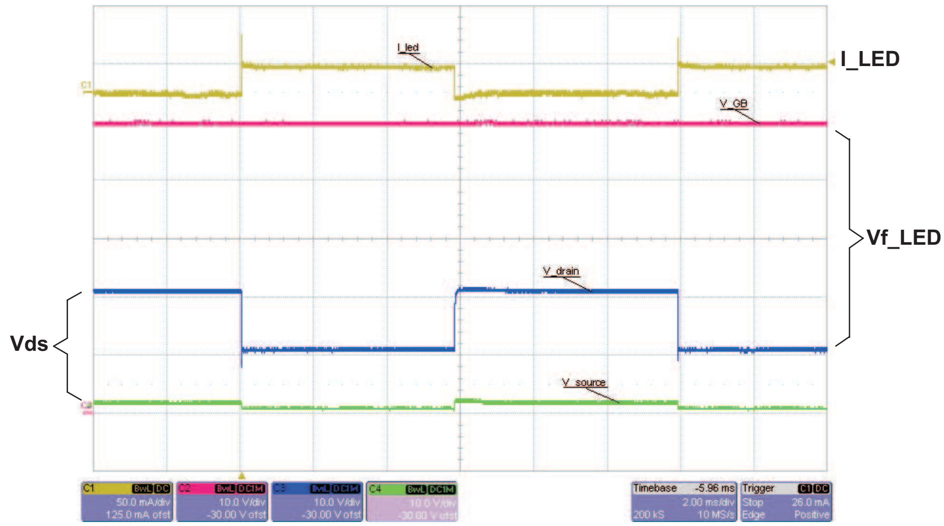

Figure 4. 24 LEDs With 50-V LED Supply Voltage, LED Current (Yellow), V_GB (Pink), Voltage on MOSFET's Drain (Blue), and Voltage on MOSFET's Source, or on OUTX Pin (Green).

Figure 2, Figure 3, and Figure 4 show that the MOSFET drain-to-source voltage changes in relation to the voltage necessary to keep the OUTx pin below V_{CC}. The MOSFET drain-to-source voltage also changes in direct relation with the voltage necessary to keep the corresponding LED current equal to the sinking current. Because of this buffering effect of the MOSFET, the OUTx pins are protected from being damaged. This allows for higher LED supply voltages and allows for more series LEDs. The figures also show that the number of LEDs a TLC5940 OUTx channel can drive, or the maximum LED supply voltage limit, is determined by MOSFET ratings.

Another consideration, which is not clearly evident in the figures, is the speed of the MOSFET. During testing, it was observed that a fast MOSFET can cause oscillations. Adding a series 100-Ω gate resistor slowed the MOSFET's response and eliminated oscillations.

3 Alternate Solution

An alternate solution to the MOSFET used in the previous circuit is to use a NPN transistor and a base resistor. Typically, this alternate solution is more cost-effective, but with the trade-off of lower LED current accuracy. The lower accuracy is a result of the regulated current being the transistor base current in addition to the LED current. The base resistor should be sized small enough to allow the maximum LED current to pass from collector to emitter, but large enough to minimize base current, and to effectively provide LED overcurrent protection. The base resistor can be sized using the following guidelines.

$$\frac{\left(V_{CC} - V_{BE}\right)\beta}{I_{LED\_OC}} < R < \frac{\left(V_{CC} - V_{BE}\right)\beta}{I_{LED\_max}}$$

where I_{LED_max} is the maximum LED current and I_{LED_OC} is the LED overcurrent limit, recommended to be set 20% to 30% greater than I_{LED_max}.

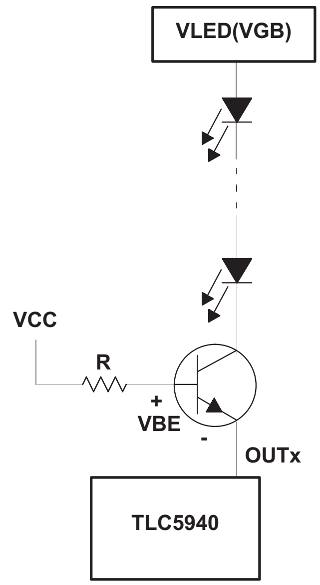

Figure 5. Typical TLC5940 OUTx Circuitry With Series NPN Transistor

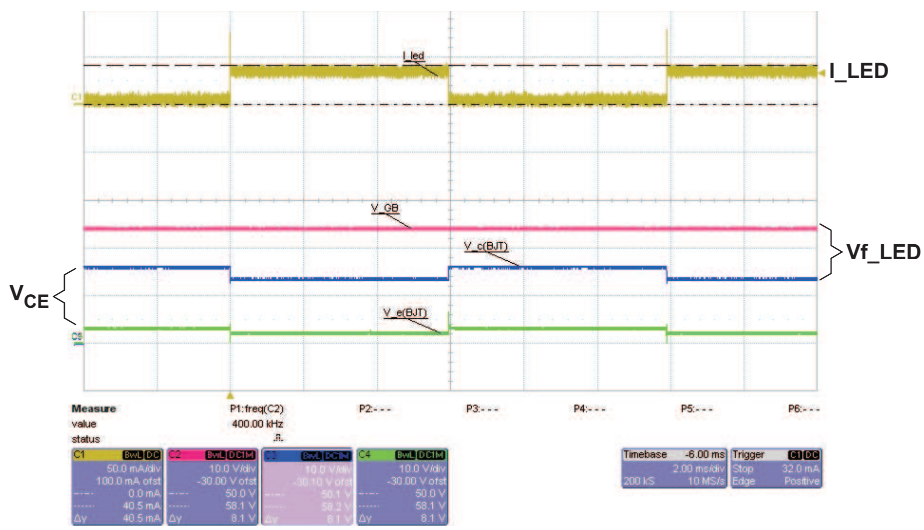

Figure 6. Six LEDs With 24-V LED Supply Voltage, LED Current (Yellow), V_GB (Pink), Voltage on BJT's Collector (Blue), and Voltage on BJT's Emitter, or on the OUTX Pin (Green).

Similar to the MOSFET solution, Figure 6 shows that the number of LEDs a TLC5940 OUTx channel can drive, or the maximum LED supply voltage limit, is determined by NPN transistor ratings.

4 Conclusion

With one N-channel MOSFET, or one NPN transistor plus one base resistor, placed in series with the OUTx pin of the TLC5940 and series LED(s), the TLC5940 can be used with higher LED supply voltages and to drive more series LEDs.

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