

# **Designing Overcurrent Protection for the TPL7407L Peripheral Driver**

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## **ABSTRACT**

Microcontroller units (MCUs) are generally limited with lower drive on the I/Os. Most of the applications requiring MCU boards to drive high-current loads need discrete implementation and additional components, which use a lot of board space. This board space is called a peripheral driver section. The TPL7407L device is an integrated peripheral driver with seven channel drivers inside. The TPL7407L device is a higher performance version of popular ULN2003 drivers. The TPL7407L device does not have overcurrent protection. For markets such as industrial and automotive, short and overcurrent protection features are imperative for a device. This application report shows some examples of designing with the TPL7407L device for high-current applications, including the overcurrent protection for the circuit without the use of external current sense.

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## 1 Designing a Typical Application

Figure 1 shows a typical LED-drive application with one channel connected.

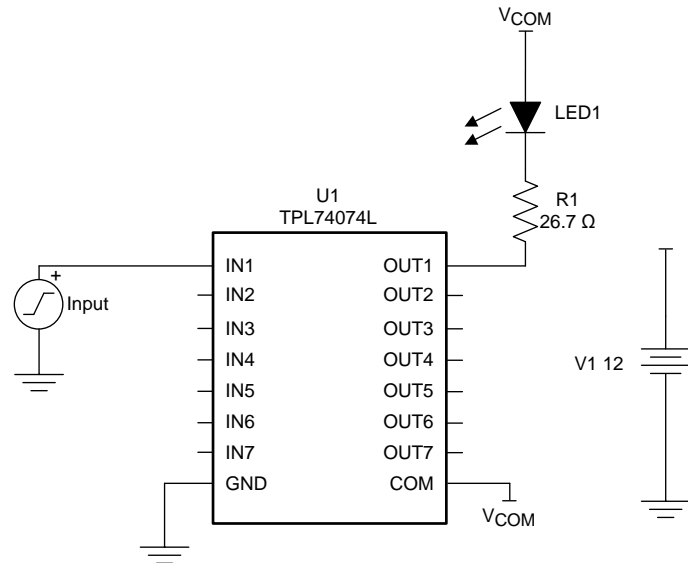


Figure 1. LED Driving Using TPL7407L

For the LED drive application, the following values are assumed:

- Current through the LED,  $I_{LED} = 100 \text{ mA}$  (high-brightness LED)
- $V_{COM} = 12 \text{ V}$

To design with the TPL7407L device, use Equation 1 to calculate the series resistance.

$$R1 + R_{FET} = \frac{(V_{COM} - V_F)}{I_{LED}} = \frac{(12 - 3)}{0.1} = 90 \Omega$$

where

- $R_{FET}$  is the channel FET resistance of the TPL7407L device. (1)

See the TPL7407L data sheet for the specified FET resistance ([SLRS066](#)).

The maximum voltage drop at 100 mA is 320 mV, which implies that the maximum  $R_{FET}$  value is equal to  $V / I = 3.2 \Omega$ . Use the standard value of 86.8  $\Omega$  for R1:  $R1 = 90 - 3.2 \Omega = 86.8 \Omega$ .

Assuming that all channels are driving LEDs each with a current of 100 mA, use Equation 2 to calculate the total power dissipation on the package.

$$P_{D(\text{tot})} \text{ TPL7407L} = I_{LED}^2 R_{FET} \times 7 = 0.1^2 \times 3.2 \times 7 = 0.224 \text{ W} \quad (2)$$

Use Equation 3 to calculate the temperature rise for the device ( $\Delta T$ ).

$$\Delta T = R_{\theta JA} \times P_D = 91.9 \times 0.224 = 20^\circ\text{C} \quad (3)$$

$R_{\theta JA}$  describes the rate of increase in device temperature as the device dissipates power. See the TPL7407L data sheet for the specified thermal information ([SLRS066](#)). For the previous example, the SOIC package was used with a junction-to-ambient thermal resistance ( $R_{\theta JA}$ ) of 91.9°C/W.

Assuming an ambient temperature of 80°C, the junction temperature of the device would be 100°C, which is less than the maximum junction temperature of about 150°C allowed for the device.

The power dissipation for the TPL7407 device in the previous design example can be compared with the performance of the ULN2003 device. The  $V_{CE}$  value for the output node of the ULN2003 device is 0.9 V. Use Equation 4 to calculate the power dissipation.

$$P_{D(\text{tot})} \text{ ULN2003} = V_{CE(\text{sat})} \times I_{LED} \times 7 = 0.9 \times 0.1 \times 7 = 0.63 \text{ W} \quad (4)$$

As is evident Equation 2 and Equation 3, the ULN2003 power dissipation is 2.8 times more than that of the TPL7407L device. For the ULN2003 device, the delta increase in temperature is about 45.9°C which yields an IC junction temperature of approximately 125.9°C, which is about 25.9°C more than the TPL7407 device.

## 2 How to Calculate the Maximum Current Draw from TPL7407L

Some applications may require that more current is driven from the device. The output-current drive capability can be increased by shorting multiple outputs together.

Assuming all the outputs are short for the device, use Equation 1, Equation 2, and Equation 3 to calculate the maximum current from the device. Figure 2(a) shows an example.

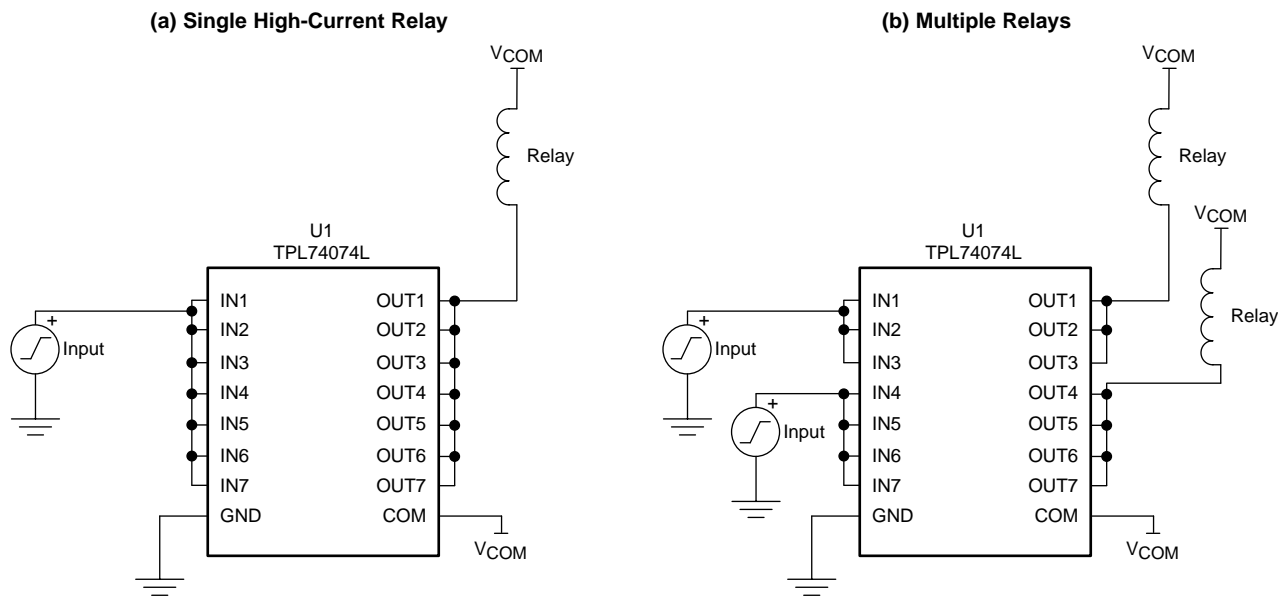


Figure 2. Relay Drive Example

The maximum allowed junction temperature for the TPL7407L device is 150°C. Suppose a stable ambient temperature for the system is about 40°C. The total temperature rise is given by 150°C – 40°C = 110°C. Use Equation 5 to calculate the maximum temperature dissipation for the SOIC package.

$$110 = 91.9 \times P_D \quad (5)$$

$$P_D = \frac{110}{91.1} = 1.2 \text{ W} \quad (6)$$

Assuming all the channels are shorted together at the output, the effective on-resistance for the FETs of the device is  $R_{FET} / 7$ .

$$P_{D(\text{tot})} = \frac{I_O^2 \times R_{FET}}{7} \Rightarrow 1.2 \text{ W} = \frac{I_{\text{max}}^2 \times 3.2}{7}$$

where

- $I_{\text{max}}$  for the TPL7407L device with all output channels shorted = 1.62 A at 40°C ambient. (7)

### 3 Overcurrent Protection for the Channels

**CAUTION**

To avoid device malfunction or damage, protect the device from an over current condition by either limiting the current from the source or by adding overcurrent protection.

Using overcurrent protection is imperative for the peripheral drivers in some applications if the load is not controllable and short circuits could occur.

One of the advantages of the TPL7407L device over the industry-popular Darlington-pair peripheral drivers is that because of the internal NMOSFETs, implementing overcurrent protection is easy and cost effective. The following section describes two ways to implement overcurrent protection.

#### 3.1 Using Multiple, Cost-Effective BJTs

The protection can be implemented using external, minimum discrete components (such as bipolar-junction transistors [BJTs]) as shown in Figure 3.

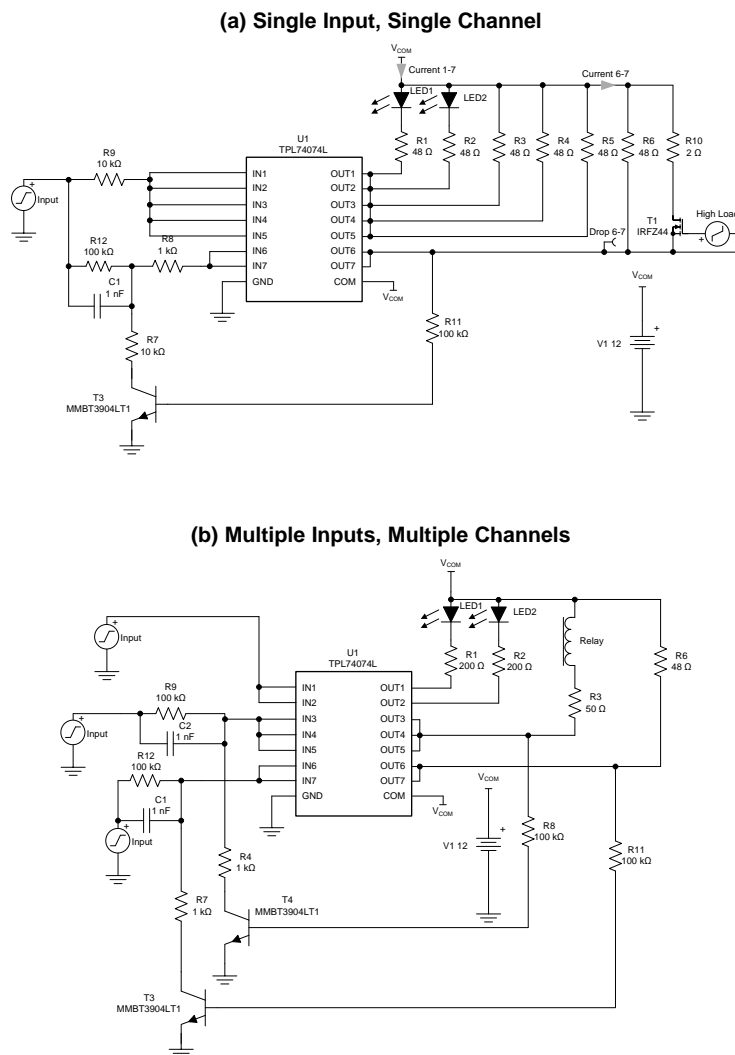


Figure 3. Overcurrent Protection Using a BJT

The circuits in [Figure 3](#) use the  $V_{BE}$  (base emitter voltage) of transistor T3 and T4 as a reference to turn off the respective input of the device if an overcurrent condition occurs at the output. Because the driver is no longer a Darlington pair but a MOSFET device, the drop across the resistance of the FETs can be measured to protect the device. BJT T3 in [Figure 3\(a\)](#) and T3 and T4 in [Figure 3\(b\)](#) both turn on when the drop across the driving FET increases and crosses the  $V_{BE}$  voltage to turn off the corresponding inputs. The T1 transistor in [Figure 3\(a\)](#) is used to simulate a high-load condition only and does not appear in the actual application circuit as shown in [Figure 3\(b\)](#). Use [Equation 8](#) when BJT will turn on to calculate the overcurrent through the channel.

$$V_{BE} = I_{OC} \times \left( \frac{R_{FET}}{N} \right)$$

where

- $V_{BE}$  is the base emitter voltage of the BJT.
  - $I_{OC}$  is the overcurrent.
  - $R_{FET}$  is the typical on-resistance.
  - $N$  is the number of channels shorted together.
- (8)

The user can use the device to parallel the appropriate number of channels. Use [Equation 9](#) to calculate the maximum overcurrent ( $I_{OC}$ ).

$$I_{OC} = V_{BE} \times \left( \frac{N}{R_{FET}} \right) = 0.7 \times \frac{2}{2.1} = 667 \text{ mA}$$

(9)

The overcurrent is based on the value of  $V_{BE}$  so it varies with the temperature. The value of  $R_{FET}$  according to data sheet varies from 2.1 to 3.25  $\Omega$ . The  $V_{BE}$  variation must also be considered when designing with this type of protection. For example, if the application operates with an ambient temperature of  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ , the  $V_{BE}$  variation should be considered to ensure that the protection does not trigger while in normal-mode operation. For the maximum current calculation, the minimum resistance of  $R_{FET}$  is considered in [Equation 9](#).

[Figure 4](#) shows the results based on TINA-TI™ simulation software. The explanation of the waveforms shown in the simulation for circuit shown in [Figure 3\(a\)](#) follows:

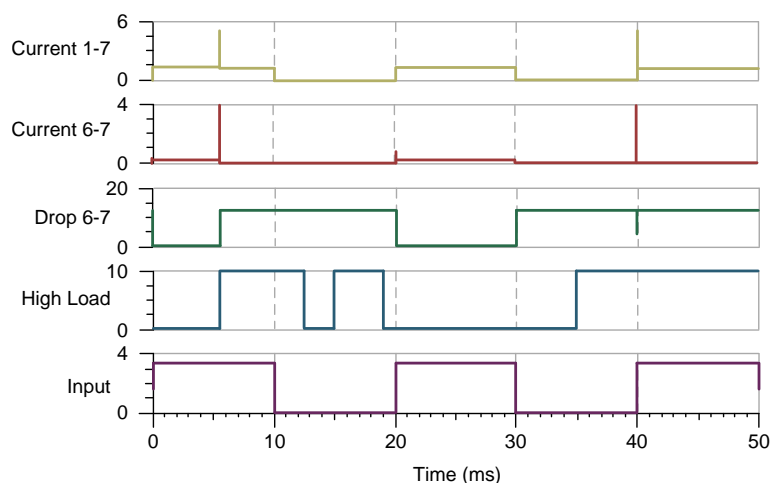
**Current 1-7** — is the measurement on all the currents through channels 1 through 7 of the device.

**Current 6-7** — is the current measured through channels 6 and 7.

**Drop 6-7** — is the input voltage for the T3 transistor to sense overcurrent condition.

**High Load** — is a dummy load which simulates the overcurrent for channels 6 and 7.

**Input** — is the signal for turning all the channels on simultaneously.



**Figure 4. TINA Simulation Results for Overcurrent Conditions**

Figure 4 shows, that during normal operation, currents 6-7 is in the nominal range of 240 mA, but when a simulated *high load* goes high, a spike occurs on currents 6-7. The circuit reacts in about 10 to 20  $\mu$ s which causes a current spike to occur. When the *high load* is active and an overcurrent is detected by T3, the input IN6 and IN7 are pulled low, resulting in a 0-A current through channels 6 and 7. This method does not allow flexibility when selecting the overcurrent value because it is dependent on the  $V_{BE}$  of the BJT and the internal resistance of the TPL7407 FETs.

### 3.2 Using Open-Drain Comparator (LM2903) and Reference (TLV431)

Figure 5 shows a more flexible and precise method of the short-circuit protection. This circuit overcomes the limitation of the previously mentioned circuits in terms of the flexibility and precision of the reference used for the implementation.

The LM2903 device, in combination with the TLV431 device, can be used to protect the most vulnerable output loads on the TPL7407L device in a precise manner.

The TLV431 reference voltage of 1.25 V is further divided with the resistance to achieve any reference voltage allowing user to program protection for any value of output current.

When the voltage across the internal OUT FET exceeds the reference voltage, the LM2903 device, which is an open-drain output, mimics the circuit mentioned in Section 3.1 by pulling the input to ground.

Use Equation 10 to calculate the overcurrent protection for implementation in Figure 5.

$$I_{OC} = \frac{V_{ref} \times R10}{(R5 + R10)} \times \frac{N}{R_{FET}}$$

where

- $I_{OC}$  is the overcurrent
  - $V_{ref}$  is the voltage reference which is 1.25 V for the TLV431
  - N is the number of channels parallel
  - $R_{FET}$  is the on resistance for internal FETs
- (10)

For Figure 5, outputs 3, 4, and 5 are shorted together and therefore the overcurrent can be calculated using Equation 10 as shown in Equation 11.

$$I_{OC} = \frac{1.25 \times 100}{(100 + 100)} \times \frac{3}{2.1} = 892 \text{ mA}$$
(11)

Depending on the selected reference source, such as the TLV431 device, the output overcurrent variations are minimal in this case when compared to the BJT implementations previously discussed.

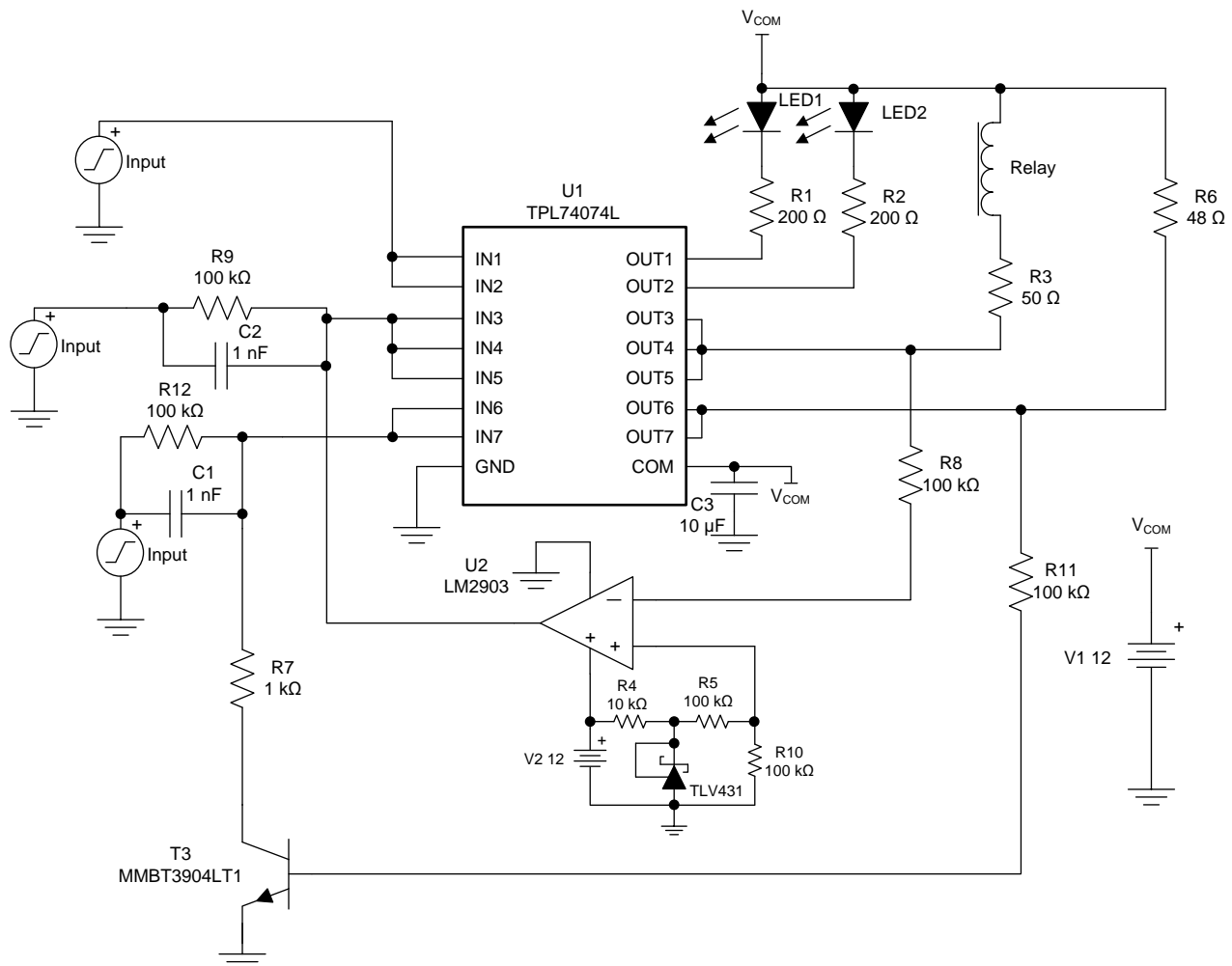


Figure 5. Overcurrent Protection Using LM2903 and TLV431

### 3.3 Self-Protecting TPL7407L

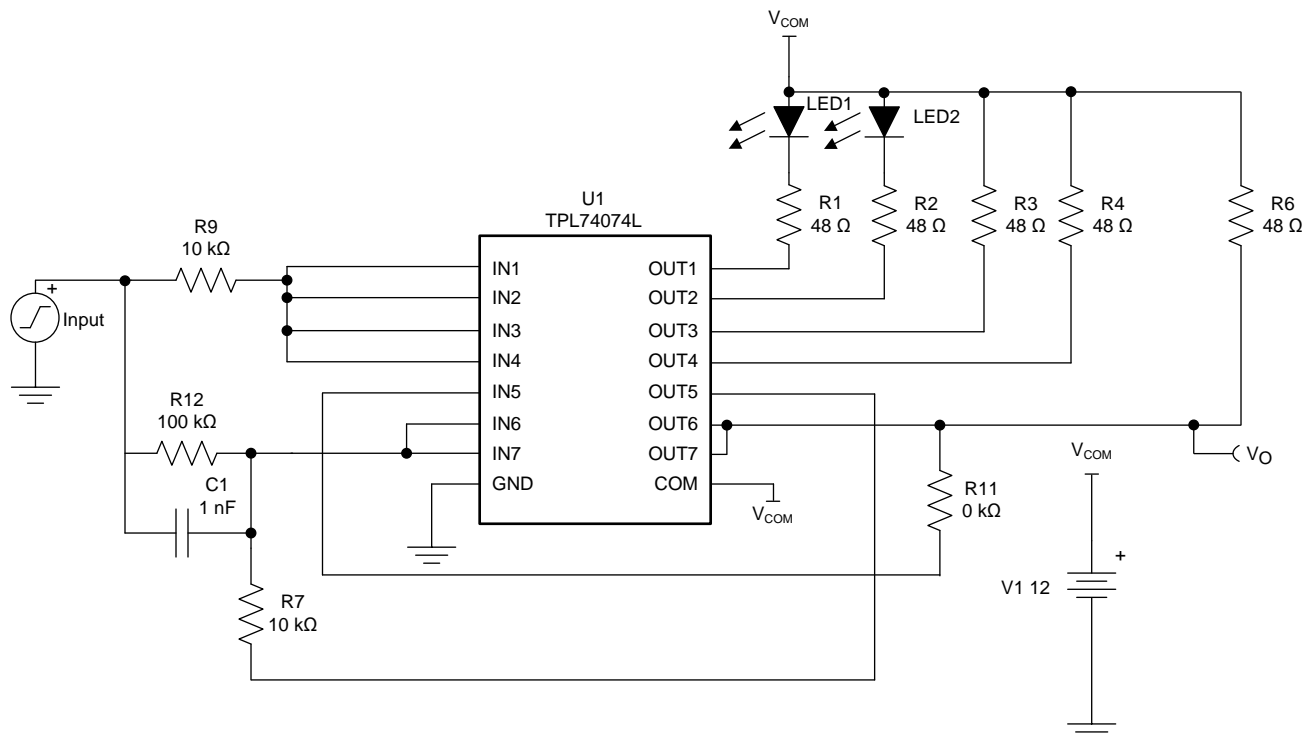
The TPL7407L device has input nodes with a high input-level ( $V_{IH}$ ) threshold of about 1.5 V. This option can be used if only short-circuit protection is required. Consider using Equation 12 to calculate the peak current through each OUT pin ( $I_{OC}$ ).

$$I_{OC} = V_{IH} \times \left( \frac{N}{R_{FET}} \right) = 1.5 \times \frac{1}{2.1}$$

where

- $I_{OC} = 714 \text{ mA}$  (12)

Figure 6 shows the method to implement self-protection, where channel 5 is used similar to external BJT and pulls down the IN6 and IN7 pins to protect the output channels 6 and 7.



**Figure 6. Without any External Active Component Internal Channel used for Protection**

#### 4 Conclusion

To drive high-current applications, consider the thermal characteristics of the package used.

To protect the device from an overcurrent and short-circuit event, carefully selecting the most appropriate and affordable option based on the tradeoff for cost and performance is recommended.

For cost-constrained applications, use the self-protection option or use a bipolar-junction transistor. For applications requiring precise control of overcurrent and short-circuit protections, using the LM2903 device in conjunction with a precision reference such as the TLV431 device is recommended.



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