Application Report

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Analog Thermal Foldback With LED Drivers

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ABSTRACT

A challenge faced in Automotive Lighting applications today is protecting the Light Emitting Diodes (LED) from their operating junction temperature ratings and doing so with minimal system cost added. Automotive systems can provide some of the most rough temperature environments. In many applications, such as headlights, LEDs are exposed to high ambient temperatures which in turn increase the junction temperature of these LEDs. In addition to these ambient temperatures, there is also a high current running through the LEDs. This current introduces self-heating into the LEDs, which in effect increases this junction temperature further. Running the junction temperature of these LEDs to their operating temperature limits can have adverse effects such as: decreasing the lifetime of the LED, altering the wavelength and therefore affecting the color emitted by the LED or damaging the LED altogether. System designers must take care in monitoring the temperature environment as well as limiting the current drawn by the LEDs.

One way to protect the LEDs is by shutting down the system, but in these critical applications that is not a viable option due to safety reasons. A convenient way of protecting your LEDs and controlling these parameters is with thermal foldback. This is performed to reduce, or fold back, the current driving a string of LEDs, for example. At high temperatures, the LEDs begin to heat up due to environmental conditions and self heating. Thus, at a certain temperature threshold based on the LEDs safe operating area, the driving current must be reduced to cool down the LEDs and prevent thermal runaway. Traditionally, NTC thermistors are used with linear LED Drivers to achieve analog thermal foldback. However, due to the nonlinearity and therefore inaccuracy of NTC thermistors at high temperatures, the critical kneepoint and derating slope characteristics of the foldback curve can be hard to control. The TMP61-Q1 linear thermistor provides linearity and thus higher accuracy at high temperatures, allowing more precise control of both the kneepoint and derating curves.

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1 LED Driver and TMP61-Q1 Characteristics

LED Drivers are often used in lighting applications to control the current output to the LEDs. These devices are often used, rather than an MCU based solution, because they offer integrated features which can reduce the form factor of the design. Some of these features include: LED current modulation through PWM Dimming or Analog dimming, continuous LED status checking, and fault protection. For the analog dimming feature, many of these devices have the ability to interface with thermistors, such as the TMP61-Q1 linear thermistor. To implement analog dimming understand the analog foldback curve, review the characteristics of the TMP61-Q1 thermistor. As temperature increases the resistance of the device increases and changes linearly. This is shown in Figure 1. When used in a voltage divider circuit, the TMP61-Q1 provides an analog voltage that changes linearly with temperature.

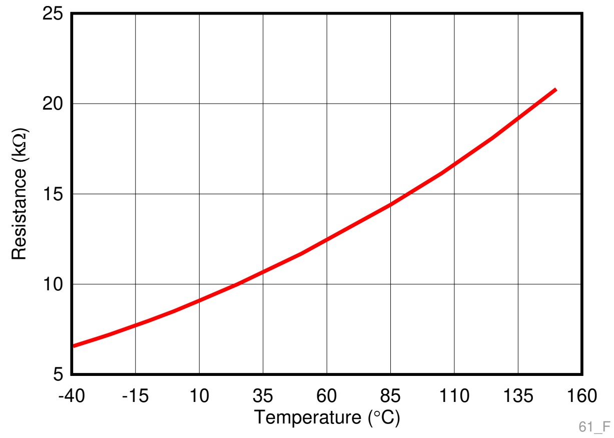

Figure 1. TMP61-Q1 Resistance Curve vs Temperature

TI's TPS92692-Q1 is a high accuracy peak current mode based controllers designed to support step-up/down LED driver topologies. The TPS92692-Q1 has an IADJ pin which can perform thermal foldback when interfaced with a temperature sensing circuit. The IADJ pin is connected to Vcc and has an internal reference to 2.42 V. This internal reference acts as a voltage clamp. The IADJ pin can then be modulated by an external voltage source from 140 mV to 2.42 V to implement the analog dimming.

The TMP61-Q1 linear thermistor voltage output increases with temperature when the output is in the lower position of the voltage divider and can provide a response used to fold back the current. Typically, the thermistor holds the current at a specified level until a high temperature is reached, known as the knee point, at which point the current must be rapidly reduced to continue operation.

Traditionally thermal foldback is done with NTC thermistors. LED Driver ICs, such as the TPS92692-Q1, are often designed for the negative temperature slope that NTC thermistors provide. To provide a negative slope with the TMP61-Q1, the thermistor must be placed on the top of the voltage divider. This is in contrast to the NTC which is placed on the bottom of the voltage divider. The separate circuits are shown in Figure 2 and Figure 3.

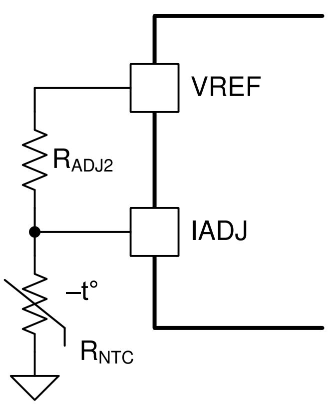

Figure 2. TPS92692-Q1 Functional Diagram NTC Thermistor Schematic

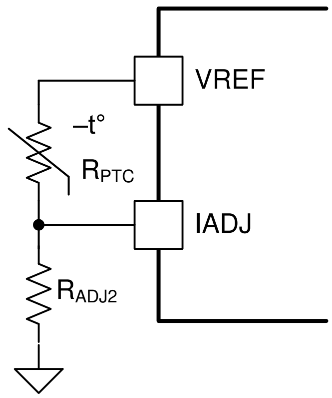

Figure 3. TPS92692-Q1 Functional Diagram PTC Schematic

The following sections will cover thermal foldback application examples using the TMP61-Q1 thermistor.

2 Thermal Foldback Application Examples

2.1 Voltage Divider with TMP61-Q1 Thermistor

Let's take a look at the following example to provide an output current response to the LEDs as shown in Figure 4:

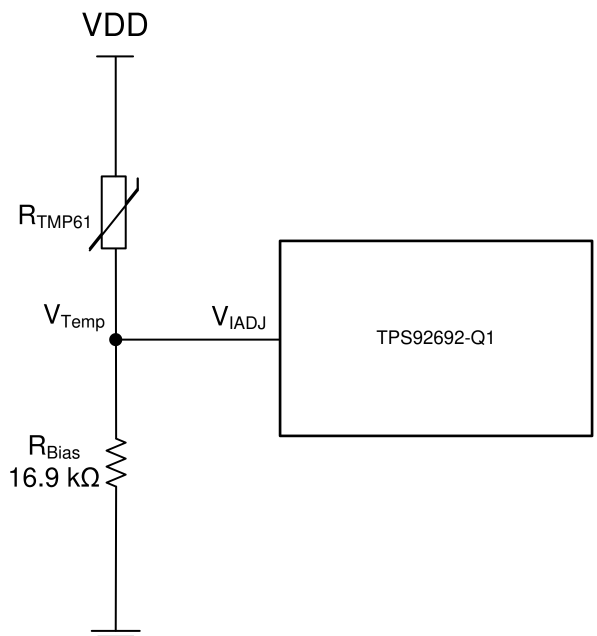

Figure 4. Voltage Divider With TMP61-Q1

The resistive circuit divider method produces an output voltage (Vtemp) scaled according to the bias voltage (VDD). Equation 1 describes the output voltage (Vtemp) based on the variable resistance of the TMP61-Q1 thermistor and bias resistor. The value of the Radj resistor when used with the TMP61-Q1 thermistor will determine at which temperature the foldback occurs. The TMP61-Q1 thermistor is expected to have a resistance of about 17.1kΩ at 115°C as well as 5-V VDD and the targeted 2.42-V Vtemp. With those values, the proper bias resistor value comes out to about 16 kΩ, but adjustments were made in the simulation for a more accurate kneepoint. In this example, we used a 16.9-kΩ resistor to achieve an analog foldback at 115 °C.

$$V_{TEMP} = V_{BIAS} \times \left(\frac{R_{BIAS}}{R_{TMP61} + R_{BIAS}}\right) \tag{1}$$

$$R_{BIAS} = \frac{V_{TEMP} R_{TMP61}}{V_{DD} - V_{TEMP}} \tag{2}$$

$$V_{IADJ} = V_{TEMP} \tag{3}$$

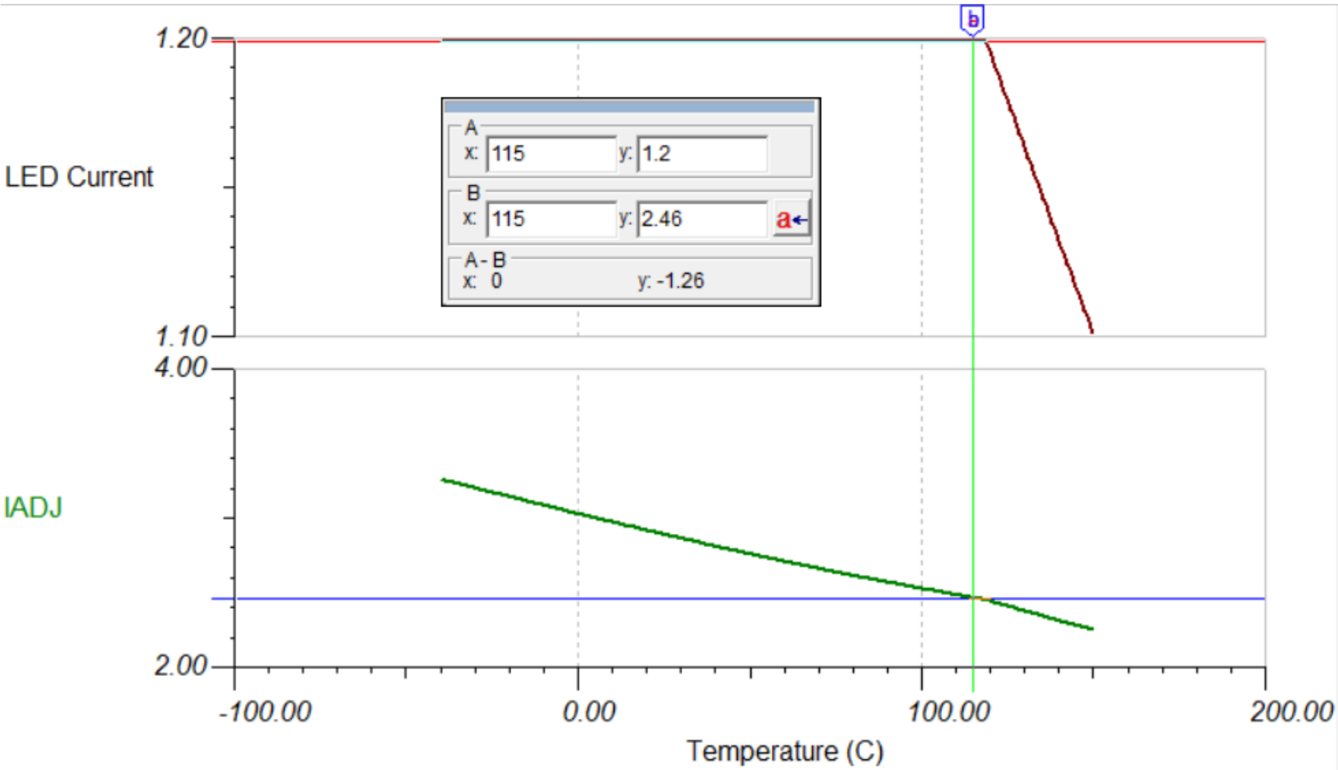

Figure 5. LED Output Current vs Temperature

From the simulation shown in Figure 5, the voltage divider output is above the 2.42-V threshold and crosses at 115 °C. This enables the LED Driver to output a constant 1.2 A. The output current needed depends on the application, but for a headlights application, for example, the output could be required to be in the 1A range. When the temperature reaches 115 °C, the current derating begins. The current varies from 1.2 A at 115 °C to 1.1 A at 150 °C. One limitation to this design is that the LED Derating curve is limited by the dynamic range of the TMP61-Q1thermistor resistance response. The voltage with TMP61-Q1 thermistor approach allows for the easiest way to achieve an analog thermal foldback.

2.2 Voltage Divider With TMP61-Q1 Thermistor and Op Amp

A next step of complexity for the thermal foldback is to have the flexibility to control the derating response. The addition of an op amp into the system provides a low cost solution to achieve this. Use this example for a response shown in Figure 5 where the output current to derate from 100% output to 80% of the output over the 115 °C to 130 °C temperature range.

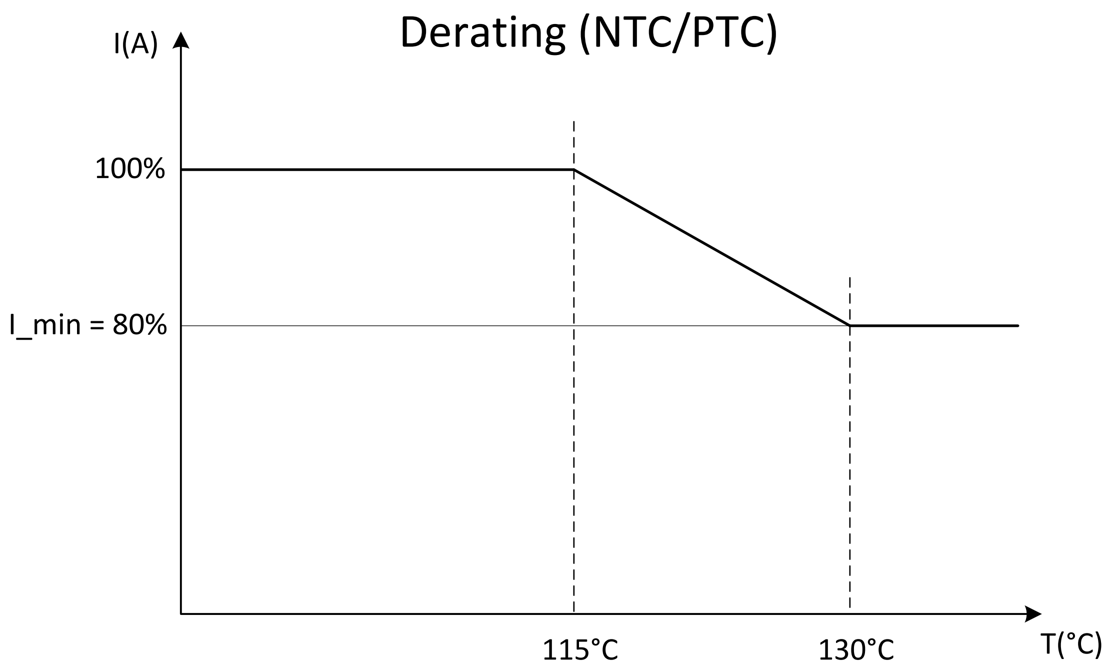

Figure 6. Output Current Profile

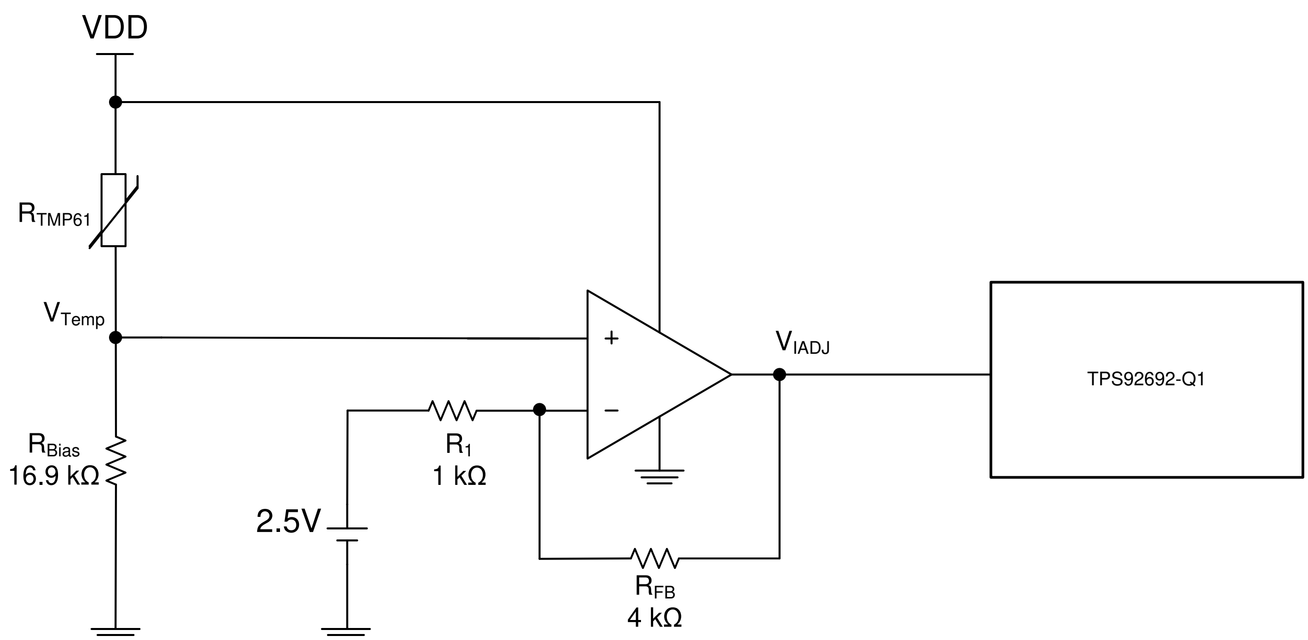

Figure 7. Voltage Divider With TMP61-Q1 Thermistor and Op Amp

The rate at which the foldback occurs depends on the feedback network, RFB and R1, which varies the gain of the op amp, A, as shown in Equation 5. The foldback behavior controls the voltage and temperature sensitivity of the circuit. The device feeds this voltage output into a LED driver circuit that adjusts output current accordingly. VIADJ is the final output voltage used for thermal foldback and is calculated in Equation 6 where VREF is equal to 2.5V. Figure 6 describes the output voltage curve in this example which requires a knee point at 115 °C

To achieve the response in Figure 5, resistor RFB was chosen to be 4k and R3 to be 1k. Having a 16.9-kΩ resistor for R1 lets us achieve the same starting point for the foldback at 115 °C.

$$V_{TEMP} = V_{BIAS} \times \left(\frac{R_{BIAS}}{R_{TMP61} + R_{BIAS}}\right) \quad (4)$$

$$A = \left(\frac{R_{FB}}{R_1}\right) + 1 \quad (5)$$

$$V_{IADJ} = V_{TEMP} \times A + V_{REF} \times \left(\frac{-R_{FB}}{R_1}\right) \quad (6)$$

The current in Figure 8 and Figure 9 derates from 1.2 A at 115 °C to 970 mA at 130 °C.

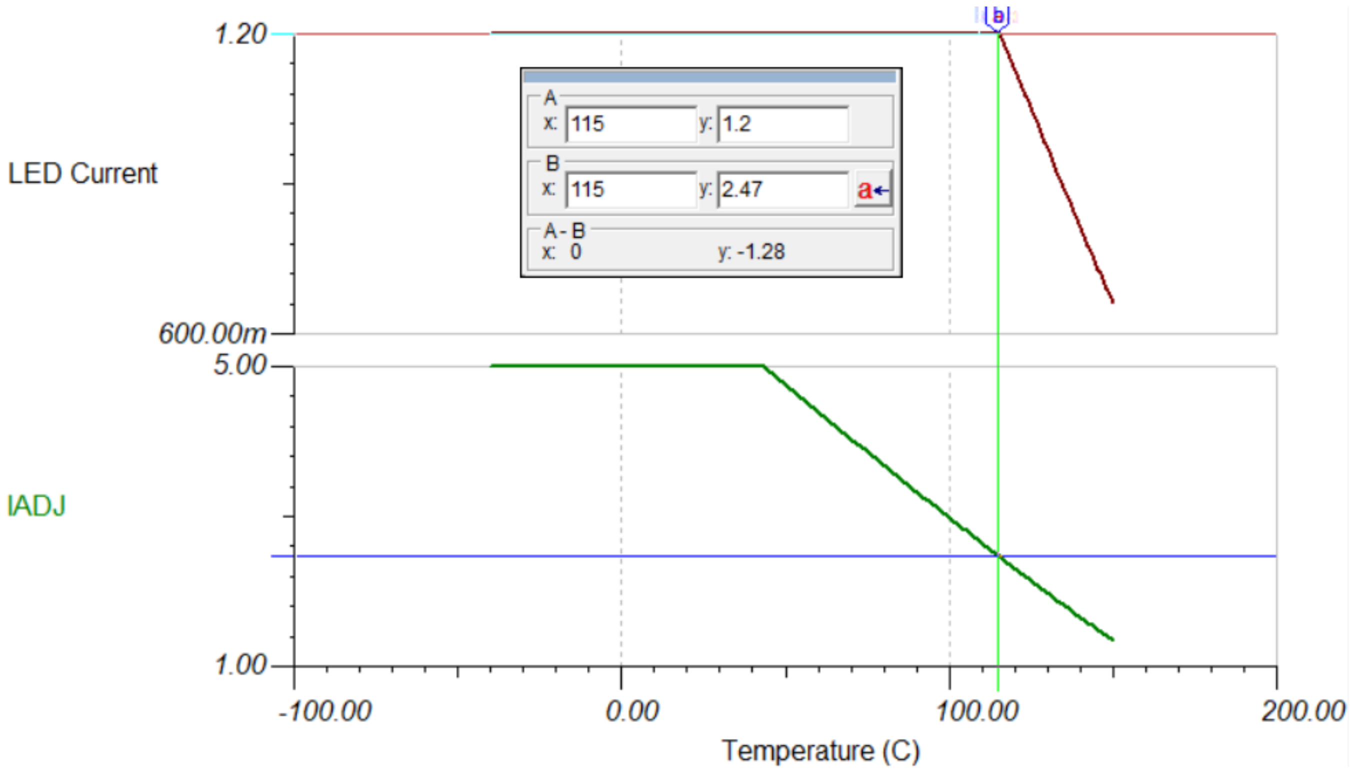

Figure 8. 115 °C Output Current Curve

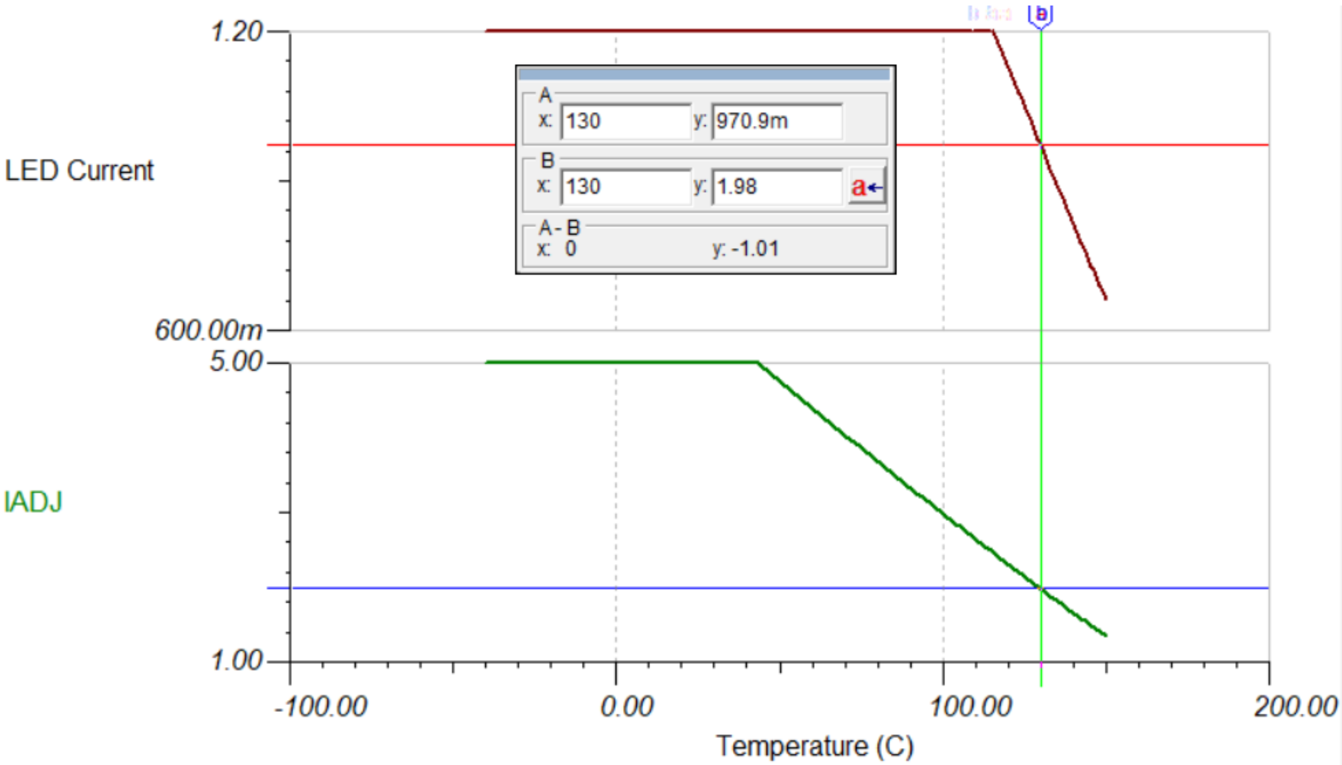

Figure 9. 130 °C Output Current Curve

The voltage divider with the TMP61-Q1 thermistor and op amp circuit allows for control of the kneepoint and derating response. This circuit provides configurability of the analog thermal foldback curve simply by adjusting the resistor values. The linearity of the TMP61-Q1 thermistor ensures a reliable solution for accurate output current profiles.

2.3 Voltage Divider With TMP61-Q1 Thermistor, Op Amp, and Binning Resistors

The previous solutions are good ways to provide simple thermal foldback, however there is another method that allows for flexibility of both the kneepoint and the LED derating response. This circuit also includes binning resistors which can be selected for various output LED current settings.

Figure 10 shows the temperature knee point where the foldback begins. This is set by the reference voltage (2.5 V) at the positive input, and the feedback resistors set the response of the foldback curve. The foldback knee point may be chosen based on the output of the voltage divider and the corresponding temperature from Equation 5 (100 °C, for example).

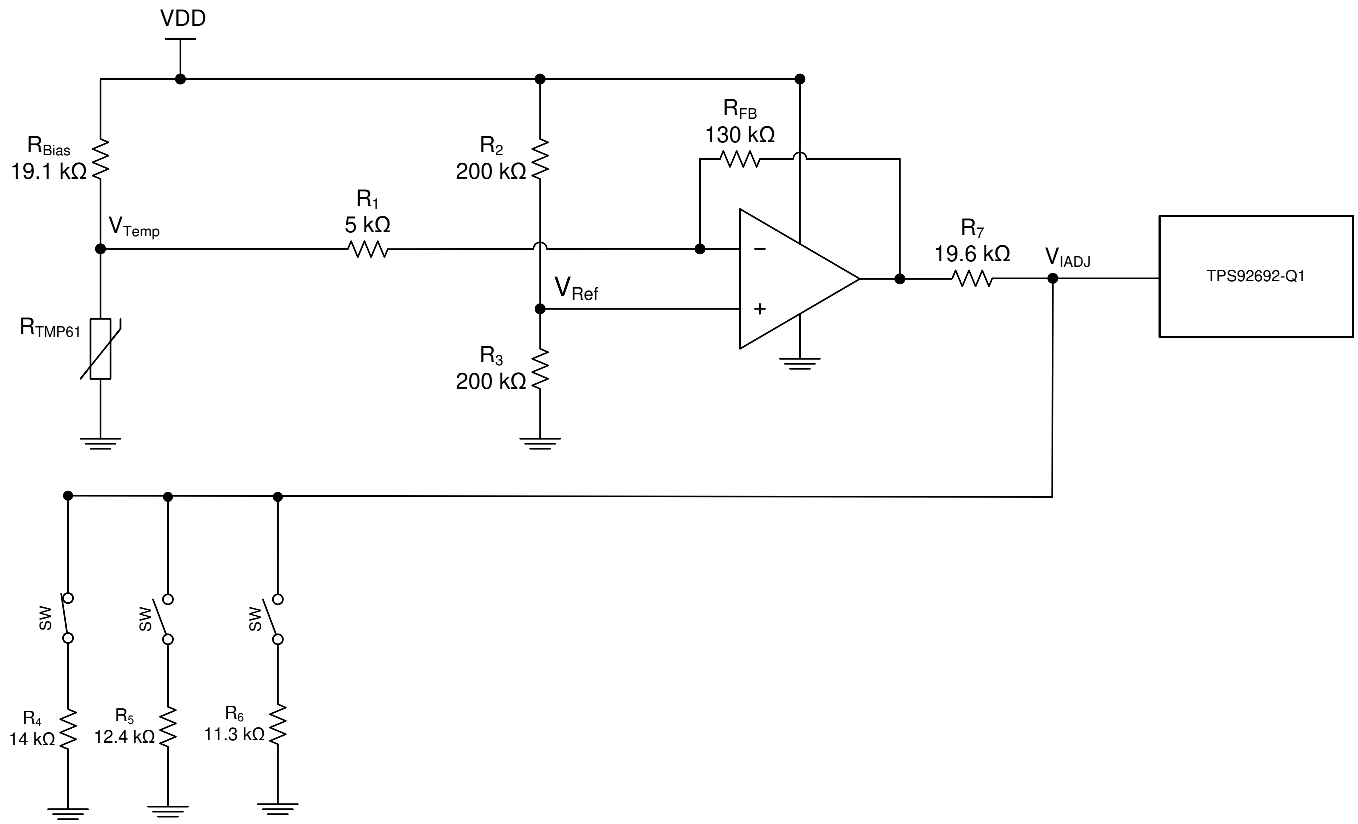

Figure 10. Voltage Divider With TMP61-Q1 Thermistor, Op Amp, and Binning Resistors

The op amp remains high as long as the voltage output is below VREF. When the temperature goes above 100 °C, the output falls to the 0-V rail of the op amp. The rate at which the foldback occurs depends on the feedback network, RFB and R1 , which varies the gain of the op amp, A, as shown in Equation 8. The foldback behavior controls the voltage and temperature sensitivity of the circuit. The device feeds this voltage output into a LED driver circuit that adjusts output current accordingly. VIADJ is the final output voltage used for thermal foldback and is calculated in Equation 9. Figure 11 describes the output voltage curve in this example, which sets the knee point at 100 °C.

$$V_{TEMP} = V_{BIAS} \times \left(\frac{R_{BIAS}}{R_{TMP61} + R_{BIAS}}\right) \tag{7}$$

$$A = \left(\frac{R_{FB}}{R_1}\right) \tag{8}$$

$$V_{IADJ} = V_{TEMP} \times (-A) + (1 + A) \times (V_{REF}) \tag{9}$$

In Figure 11, the LED Current derating is set at 100 °C with a LED current output of 1.2 A due to binning resistor R14.

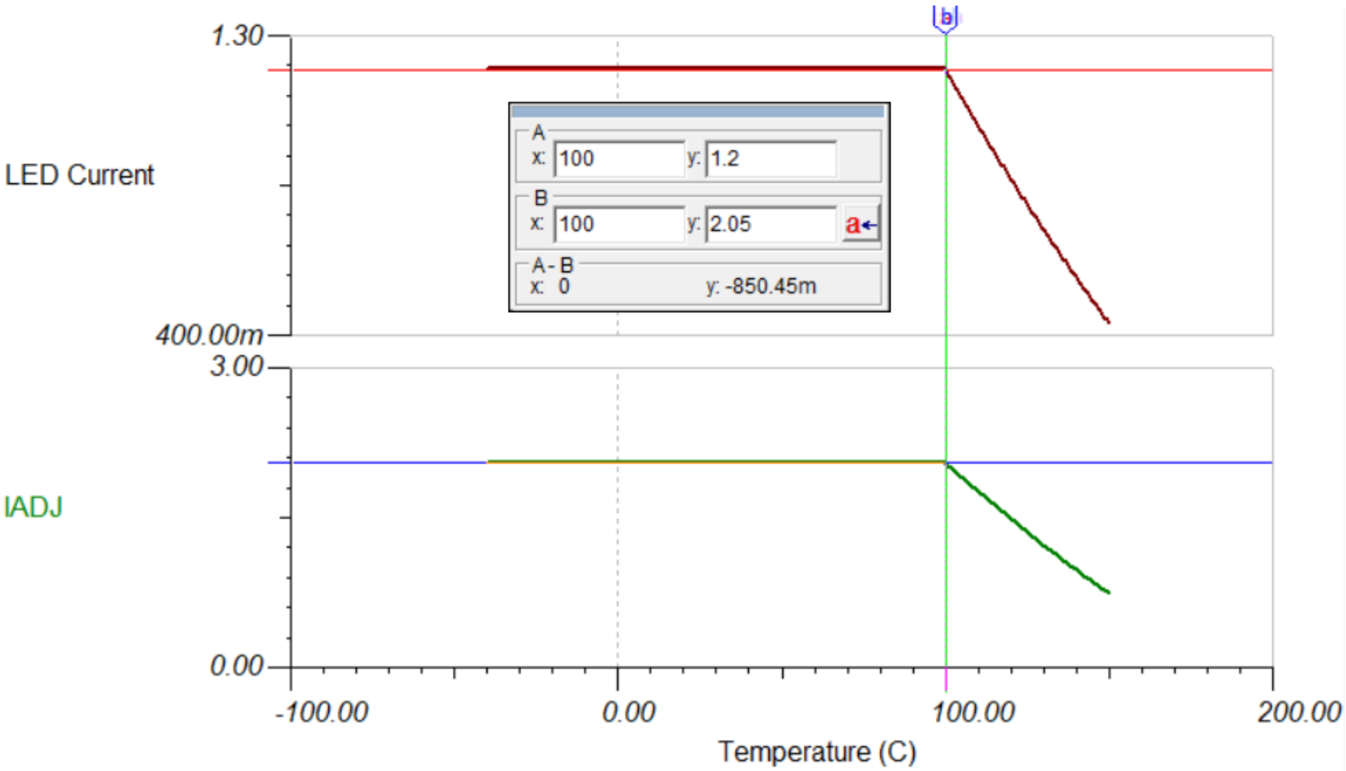

Figure 11. 100 °C Current Output Curve

The voltage divider with TMP61-Q1 thermistor, op amp, and binning resistors circuit gives designers complete control over LED protection in the system. An added benefit of this circuit is that it can be used in multiple systems due to the binning resistors which can address the varying outputs needed for LED strings across applications.

3 Summary

In conclusion, although NTC thermistors are traditionally used to perform thermal foldback with LED Drivers, designers can use the TMP61-Q1 linear thermistor with a linear LED Driver such as the TPS92692-Q1 and provide a simple yet effective way or protecting LEDs from thermal damage in critical Automotive Lighting applications. With addition of an op amp, more functionality can be added to these circuits with minimum addition to system cost. By leveraging the linear thermistors, designers can achieve better accuracy and response time, enabling a more efficient and reliable system.