Automotive LED Lighting With Adjustable Shunt References

Automotive suppliers are developing innovative ways to further enhance the user experience within vehicles. For instance, the external rear lights have various functions such as sequential illuminating turn signal indicators, dynamic braking lights, and multiple design elements for aesthetics - all possible with the adoption of LED lighting. There are various methods to implement how these LEDs are powered, one discrete method is by using a simple voltage reference. This method could yield design advantages such as ease in design efforts and reduction in solution cost.

The TL431-Q1 is an automotive grade adjustable shunt voltage reference. The three-terminal device has a 2.5 V internal bandgap voltage reference with a feedback pin to adjust the voltage reference from 2.5 V to 36 V. In addition, the feedback pin can be utilized to create a constant-current topology which can be used for automotive LEDs applications.

LEDs require proper current drive for illumination. A constant current source is one way to achieve correct current regulation, as shown in Figure 1. The current source circuit uses a bipolar junction transistor (BJT) and sense resistor. The base current of the transistor is being controlled by the TL431-Q1 such that the transistor is conducting to produce a 2.5 V current sense voltage at R_s. The current sense voltage is fed back to the feedback pin of the TL431-Q1 for a negative feedback control loop. In case of any transients, the TL431-Q1 can regulate properly to provide the constant current required.

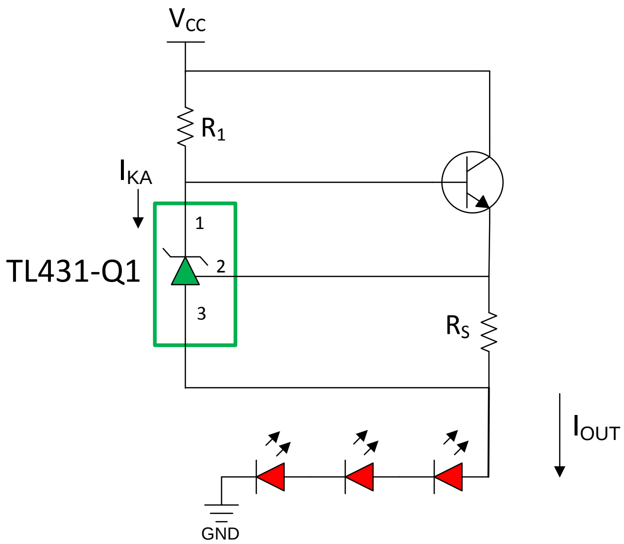

Figure 1. Constant Current Source Circuit

$$R_1 = \frac{V_{CC}}{\frac{I_{OUT}}{h_{FE}} + I_{KA}} \qquad I_{OUT} = \frac{V_{REF}}{R_S} + I_{KA} \tag{1}$$

where

- R_1 = Input bias resistor (Ω)
- R_S = Current sense resistor(Ω)
- I_{OUT} = Output current source (A)
- I_{KA} = Cathode current (A)
- V_{REF} = Internal feedback reference (V)
- V_{CC} = Input supply voltage (V)
- h_{FE} = Transistor DC current gain (1)

Equation 1 shows, the cathode current of the TL431-Q1, I_{KA}, contributes to the overall current source. The TL431-Q1 will require at most 1 mA of cathode current to function. If the required constant current is low, the varying I_{KA} across devices can affect the accuracy of the current source.

One solution to omit the cathode current is to use a constant current sink circuit instead of a sourcing circuit, as shown in Figure 2. The circuit is designed to sink the proper current for proper lighting of the LEDs. The relationship between the transistor, sense resistor, and TL431-Q1 are the same as the circuit shown in . Equation 2 shows, the current sink circuit does not need to take the cathode current into consideration when selecting the current sink.

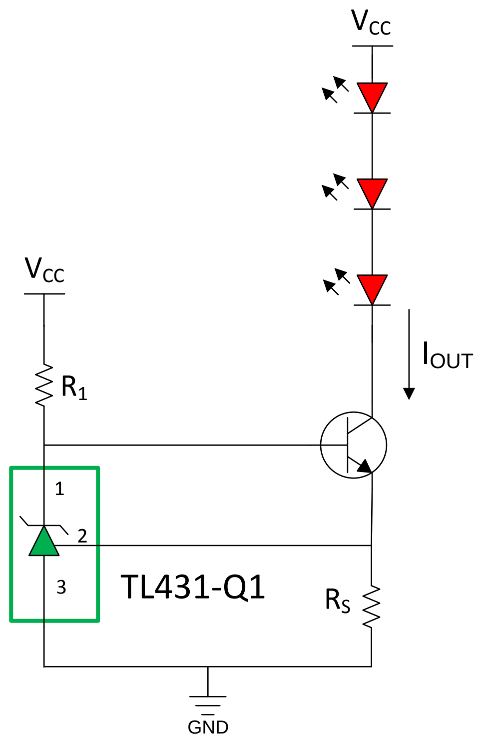

Figure 2. Constant Current Sink Circuit

$$R_1 = \frac{V_{CC}}{\frac{I_{OUT}}{h_{FE}} + I_{KA}} \qquad I_{OUT} = \frac{V_{REF}}{R_S} \tag{2}$$

where

- I_{OUT} = Output current sink
- Others = Same as before

In some applications, multiple LED strings are required. In both circuit topologies, parallel LED strings can be implemented using one TL431-Q1 as long as the strings of LEDs require the same current. Figure 3 shows a constant-current sink with three parallel LED strings. The cathode is connecting to the base of each transistor. One of the sense resistors is fed back to the feedback pin of the TL431-Q1 as a sense voltage for regulation. One thing to note is the current of other strings may vary due varying transistor characteristics and resistor accuracy.

The accuracy of the current depends on the TL431-Q1 grade, current sense resistor, and transistor. R_1 must be a properly sized to provide minimum cathode current to the TL431-Q1 for regulation and enough base current to conduct the transistor. Current sense resistors accuracy varies and can be chosen depending on the application. For the transistor, the DC current gain, h_{FE}, will be the main characteristic for inaccuracy. The manufacture's datasheet will provide minimum and maximum values.

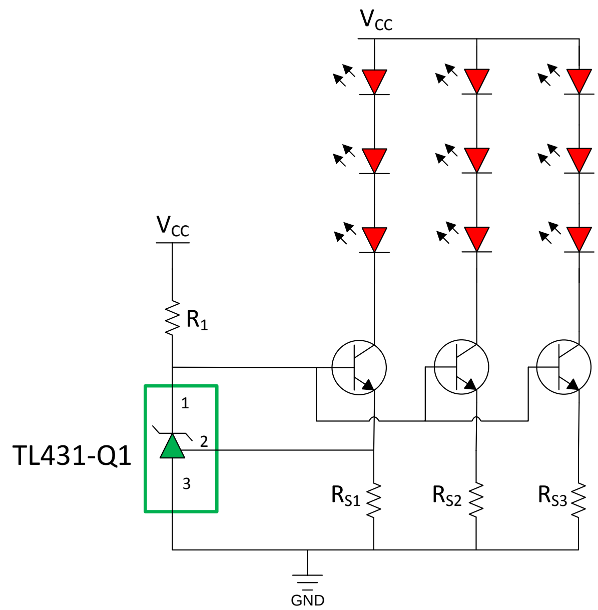

Figure 3. Current Sink With Parallel LED Strings

Alternate Device Recommendations

If the TL431-Q1 cathode current becomes an issue for high side current sourcing, consider using an alternate device featured in Table 1. The devices are all adjustable shunt references with $I_{KA(MIN)}$ less than 100 µA. The devices also have an internal bandgap reference of 1.24 V compared to the 2.5 V of the TL431-Q1. Ensure that the sense resistors are designed properly.

Table 1. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
LM4041-N-Q1	Minimum I_{KA}; Temperature coefficient	Cathode current rating
TLV431-Q1	Minimum I_{KA}	Initial accuracy; Cathode current rating; Temperature coefficient
TLVH431-Q1	Minimum I_{KA}	Initial accuracy; Cathode current rating; Temperature coefficient

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