# TL431LI-Q1 / TL432LI-Q1 Programmable Shunt Regulator With Optimized Reference Current

## 1 Features

- Qualified for automotive applications
- AEC-Q100 qualified with the following results:
  - Device temperature grade 1: –40°C to +125°C ambient operating temperature
  - Device temperature grade 0: –40°C to +150°C ambient operating temperature
- Reference voltage tolerance at 25°C
  - 0.5% (B grade)
  - 1% (A grade)
- Minimum typical output voltage: 2.495 V
- Adjustable output voltage: $V_{ref}$ to 36 V
- 27 mV maximum temperature drift for grade 1
- 34 mV maximum temperature drift for grade 0
- 0.3-Ω typical output impedance
- Sink-current capability
  - $I_{min}$ = 0.6 mA (max)
  - $I_{KA}$ = 15 mA (max)
- Reference input current $I_{REF}$: 0.4 µA (max)
- Deviation of reference input current over temperature, $I_{I(dev)}$: 0.3 µA (max)

## 2 Applications

- Inverter and motor control
- DC/DC converter
- LED lighting
- On-board charger (OBC)
- Infotainment and cluster
- Engine management actuator
- Transmission
- Power steering
- Powertrain exhaust sensor
- Alternator starter

## 3 Description

The TL431LI-Q1 is a three-terminal adjustable shunt regulator, with specified thermal stability over applicable automotive, commercial, and military temperature ranges. The output voltage can be set to any value between $V_{ref}$ (approximately 2.495 V) and 36 V with two external resistors. The device has a typical output impedance of 0.3 Ω. Its active output circuitry provides a very sharp turn-on characteristic, making it an excellent replacement for Zener diodes in many applications, such as onboard regulation, adjustable power supplies, and switching power supplies. This device is a pin-to-pin alternative to the industry standard TL431-Q1 with optimized $I_{ref}$ and $I_{Idev}$ performance. The lower $I_{ref}$ and $I_{Idev}$ values of the TL431LI-Q1 enable designers to achieve higher system accuracy and lower leakage current. The TL432LI-Q1 has exactly the same functionality and electrical specifications as the TL431LI-Q1, but has a different pinout for the DBZ package.

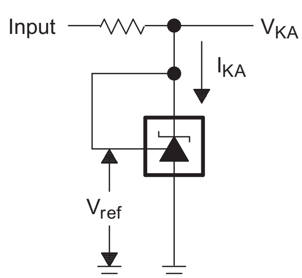
The TL431LI-Q1 is offered in two grades, with initial tolerances (at 25°C) of 0.5% and 1%, for the B and A grade, respectively. The TL431LI-Q1 is also available in two temperature grades: grade 1 (denoted by a 'Q' in the part number), and grade 0 (denoted by a 'E' in the part number), which represent maximum ambient operating temperatures of 125°C and 150°C respectively. The TL43xLI-Q1 is characterized for operation from –40°C to 125°C for grade 1, and –40°C to 150°C for grade 0, and its low output drift versus temperature ensures good stability over the entire temperature range.

**Device Information(1)**

| PART NUMBER | PACKAGE (PIN) | BODY SIZE (NOM) |
|---|---|---|
| TL43xLI-Q1 | SOT-23 (3) | 2.90 mm x 1.30 mm |

(1) For all available packages, see the orderable addendum at the end of the data sheet.

**Simplified Schematic**



## Table of Contents



## 4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

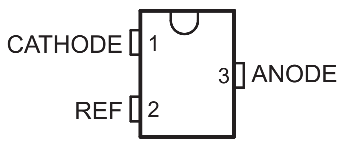
| Changes from Original (May 2019) to Revision A | Page |
|---|---|
| • Changed device status from Advance Information to Production Data | 1 |

## 5 Device Comparison Table

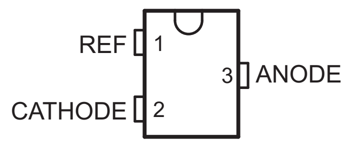
| DEVICE PINOUT | INITIAL ACCURACY | OPERATING FREE-AIR TEMPERATURE ($T_A$) |
|---|---|---|
| TL431LI-Q1<br>TL432LI-Q1 | A: 1% B: 0.5% | Q: -40°C to 125°C<br>E: -40°C to 150°C |

## 6 Pin Configuration and Functions

**TL431LI-Q1 DBZ Package**
**3-Pin SOT-23**
**Top View**




**TL432LI-Q1 DBZ Package**
**3-Pin SOT-23**
**Top View**




### Pin Functions

| NAME | PIN NUMBER | | TYPE | DESCRIPTION |
|---|---|---|---|---|
| | TL431LI-Q1 | TL432LI-Q1 | | |
| | DBZ | DBZ | | |
| ANODE | 3 | 3 | O | Common pin, normally connected to ground |
| CATHODE | 1 | 2 | I/O | Shunt current/Voltage input |
| REF | 2 | 1 | I | Threshold relative to common anode |

# 7 Specifications

## 7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[1]

| | | MIN | MAX | UNIT |
|---|---|---|---|---|
| $V_{KA}$ | Cathode Voltage[2] | | 37 | V |
| $I_{KA}$ | Continuos Cathode Current Range | –10 | 18 | mA |
| $I_{I(ref)}$ | Reference Input Current | –5 | 10 | mA |
| $T_J$ | Operating Junction Temperature Range | –40 | 150 | C |
| $T_{stg}$ | Storage Temperature Range | –65 | 150 | C |

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltage values are with respect to ANODE, unless otherwise noted.

## 7.2 ESD Ratings

| | | | VALUE | UNIT |
|---|---|---|---|---|
| $V_{(ESD)}$ | Electrostatic discharge | Human body model (HBM), per AEC Q100-002[1] | ±4000 | V |
| | | Charged-device model (CDM), per AEC Q100-011 | ±1000 | |

(1) AEC Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specification

## 7.3 Recommended Operating Conditions

| | | | MIN | MAX | UNIT |
|---|---|---|---|---|---|
| $V_{KA}$ | Cathode Voltage | | $V_{REF}$ | 36 | V |
| $I_{KA}$ | Continuous Cathode Current Range | | 0.6 | 15 | mA |
| $T_A$ | Operating Free-Air Temperature[1] | TL43xLIxQ | –40 | 125 | C |
| | | TL43xLIxE | –40 | 150 | C |

(1) Maximum power dissipation is a function of $T_{J(max)}$, $\theta_{JA}$, and $T_A$. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_{J(max)} – T_A)/\theta_{JA}$. Operating at the absolute maximum $T_J$ can affect reliability. Please see the *Semiconductor and IC Package Thermal Metrics Application Report* for more information.

## 7.4 Thermal Information

| THERMAL METRIC[1] | | TL43xLI | UNIT |
|---|---|---|---|
| | | DBZ | |
| | | 3 PINS | |
| $R_{\theta JA}$ | Junction-to-ambient thermal resistance | 371.7 | C/W |
| $R_{\theta JC(top)}$ | Junction-to-case (top) thermal resistance | 145.9 | C/W |
| $R_{\theta JB}$ | Junction-to-boardthermal resistance | 104.7 | C/W |
| $\psi_{JT}$ | Junction-to-top characterization resistance | 23.9 | C/W |
| $\psi_{JB}$ | Junction-to-board characterization resistance | 102.9 | C/W |

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics Application Report*.

## 7.5 Electrical Characteristics

over recommended operating conditions, $T_A$ = 25°C (unless otherwise noted)

| PARAMETER | | TEST CIRCUIT | TEST CONDITIONS | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|---|
| $V_{ref}$ | Reference Voltage | See Figure 14 | $V_{KA} = V_{ref}$, $I_{KA}$ = 1 mA | TL43xLIAx devices | 2470 | 2495 | 2520 | mV |
| | | | | TL43xLIBx devices | 2483 | 2495 | 2507 | mV |
| $V_{I(dev)}$ | Deviation of reference input voltage over full temperature range [1] | See Figure 14 | $V_{KA} = V_{ref}$, $I_{KA}$ = 1 mA | TL43xLIxQ devices | | 10 | 27 | mV |
| | | | | TL43xLIxE devices | | 14 | 34 | mV |
| $\Delta V_{ref}$ / $\Delta V_{KA}$ | Ratio of change in reference voltage to the change in cathode voltage | See Figure 15 | $I_{KA}$ = 1 mA | $\Delta V_{KA}$ = 10 V - $V_{ref}$ | | –1.4 | –2.7 | mV/V |
| | | | | $\Delta V_{KA}$ = 36 V - 10 V | | –1 | –2 | mV/V |
| $I_{ref}$ | Reference Input Current | See Figure 15 | $I_{KA}$ = 1 mA, R1 = 10kΩ, R2 = ∞ | | | 0.2 | 0.4 | µA |
| $I_{I(dev)}$ | Deviation of reference input current over full temperature range [1] | See Figure 15 | $I_{KA}$ = 1 mA, R1 = 10kΩ, R2 = ∞ | | | 0.1 | 0.3 | µA |
| $I_{min}$ | Minimum cathode current for regulation | See Figure 14 | $V_{KA} = V_{ref}$ | | | | 0.6 | mA |
| $I_{off}$ | Off-state cathode current | See Figure 16 | $V_{KA}$ = 36 V, $V_{ref}$ = 0 | | | 0.1 | 1 | µA |
| $\|Z_{KA}\|$ | Dynamic Impedance [2] | See Figure 14 | $V_{KA} = V_{ref}$, $I_{KA}$ = 1 mA to 15 mA | | | 0.3 | 0.75 | Ω |

(1) The deviation parameters $V_{I(dev)}$ and $I_{I(dev)}$ are defined as the differences between the maximum and minimum values obtained over the rated temperature range. For more details on $V_{I(dev)}$ and how it relates to the average temperature coefficient, see the *Temperature Coefficient* section.

(2) The dynamic impedance is defined by $|Z_{KA}| = \Delta V_{KA}/\Delta I_{KA}$. For more details on $|Z_{KA}|$ and how it relates to $V_{KA}$, see the *Temperature Coefficient* section.

## 7.6 Typical Characteristics

Data at high and low temperatures are applicable only within the recommended operating free-air temperature ranges of the various devices.

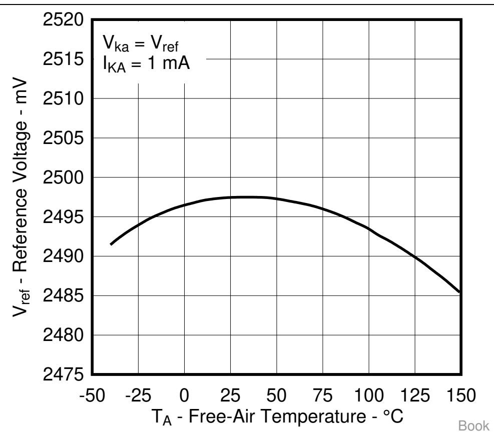



**Figure 1. Reference Voltage versus Free-Air Temperature**

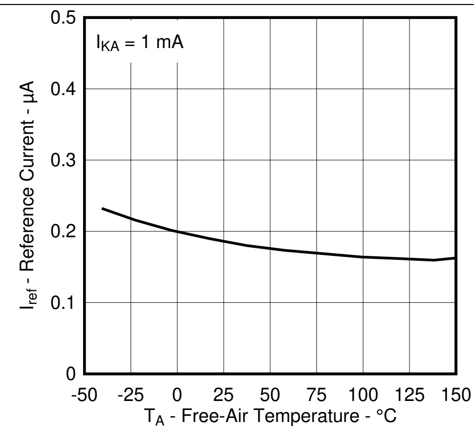



**Figure 2. Reference Current versus Free-Air Temperature**

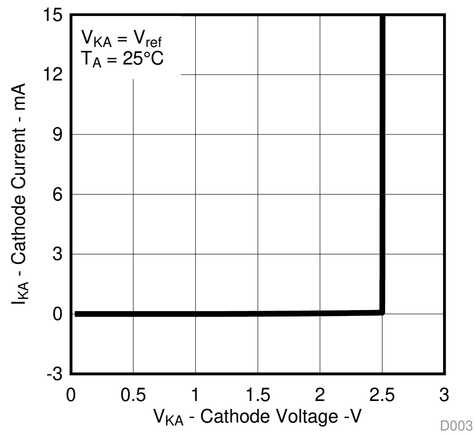



**Figure 3. Cathode Current versus Cathode Voltage**

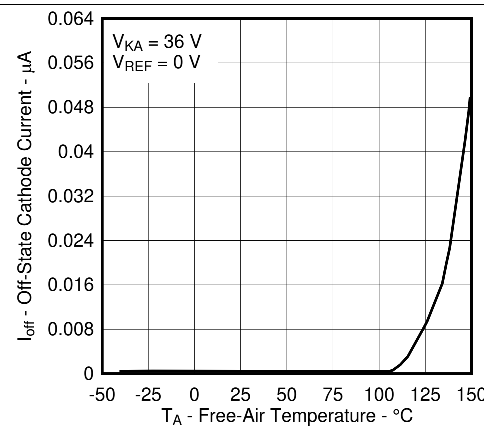



**Figure 4. Off-State Cathode Current versus Free-Air Temperature**

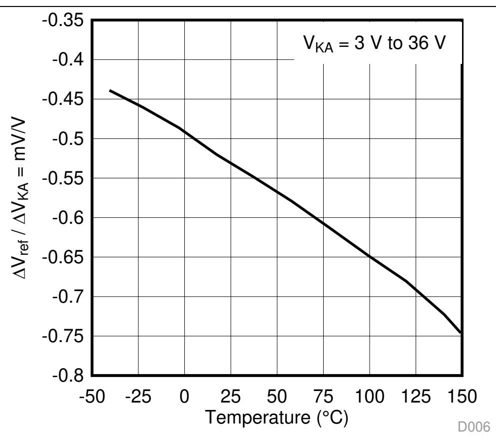



**Figure 5. Ratio of Delta Reference Voltage to Delta Cathode Voltage versus Free-Air Temperature**

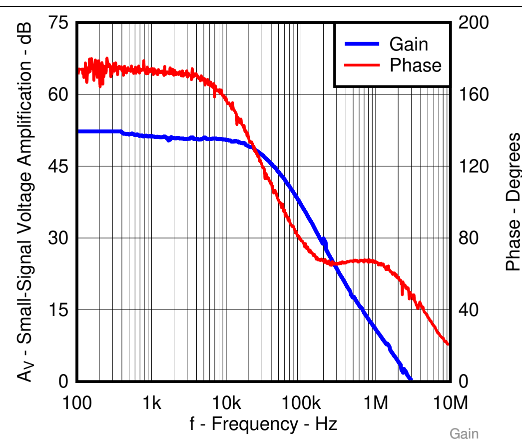



**Figure 6. Small-Signal Voltage Amplification versus Frequency**

## Typical Characteristics (continued)

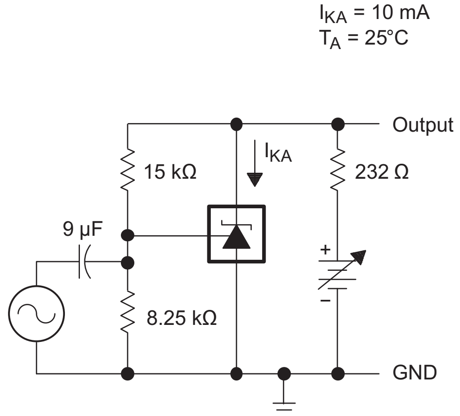



**Figure 7. Test Circuit for Voltage Amplification**

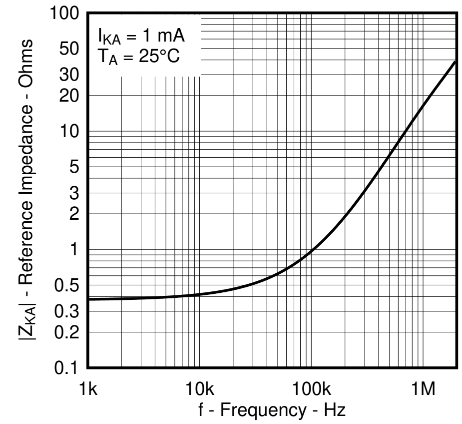



**Figure 8. Reference Impedance versus Frequency**

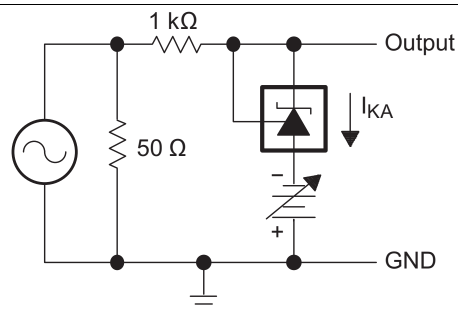



**Figure 9. Test Circuit for Reference Impedance**

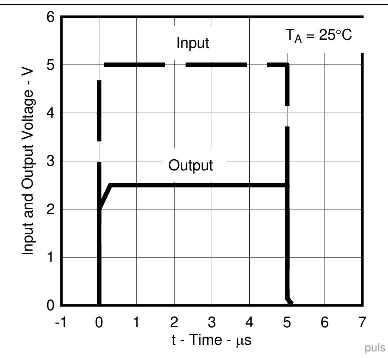



**Figure 10. Pulse Response**

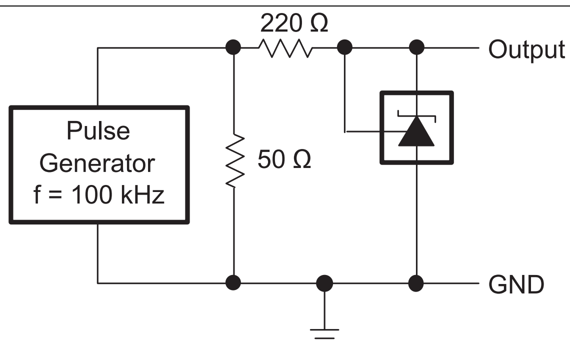
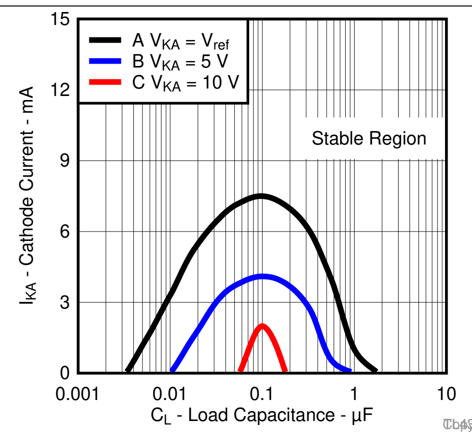



**Figure 11. Test Circuit for Pulse Response**




The areas under the curves represent conditions that may cause the device to oscillate. For curves B and C, R2 and V+ are adjusted to establish the initial $V_{KA}$ and $I_{KA}$ conditions, with $C_L$ = 0. $V_{BATT}$ and $C_L$ then are adjusted to determine the ranges of stability.

**Figure 12. Stability Boundary Conditions for All TL431LI-Q1, TL432LI-Q1 Devices**

## Typical Characteristics (continued)

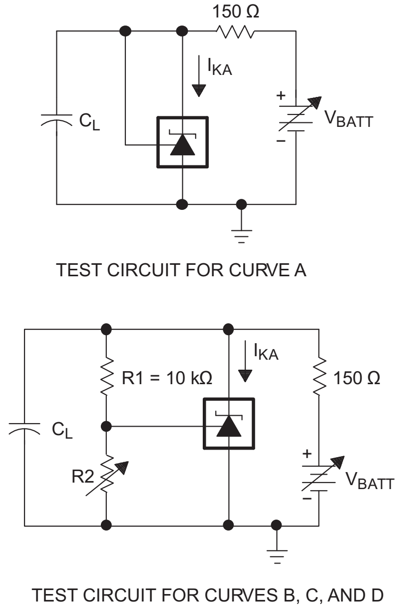



**Figure 13. Test Circuits for Stability Boundary Conditions**

# 8 Parameter Measurement Information

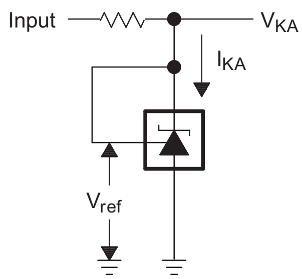



Figure 14. Test Circuit for $V_{KA} = V_{ref}$

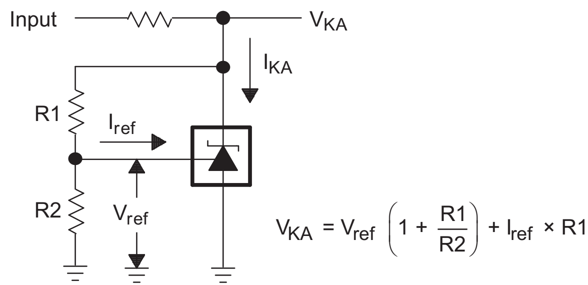



Figure 15. Test Circuit for $V_{KA} > V_{ref}$

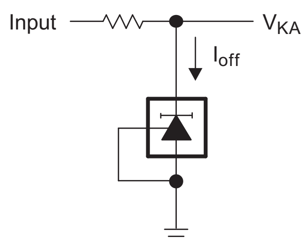


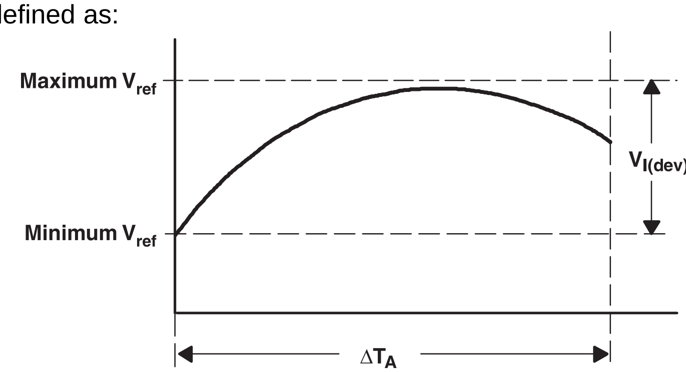

Figure 16. Test Circuit for $I_{off}$

## 8.1 Temperature Coefficient

The deviation of the reference voltage, $V_{ref}$, over the full temperature range is known as $V_{I(dev)}$. The parameter of $V_{I(dev)}$ can be used to find the temperature coefficient of the device. The average full-range temperature coefficient of the reference input voltage, $\alpha_{Vref}$, is defined as:

$$\left|\alpha_{Vref}\right| \left(\frac{ppm}{°C}\right) = \frac{\left(\frac{V_{I(dev)}}{V_{ref\ at\ 25°C}}\right) \times 10^6}{\Delta T_A}$$

where:
$\Delta T_A$ is the rated operating temperature range of the device.




$\alpha_{Vref}$ is positive or negative, depending on whether minimum $V_{ref}$ or maximum $V_{ref}$, respectively, occurs at the lower temperature. The full-range temperature coefficient is an average and therefore any subsection of the rated operating temperature range can yield a value that is greater or less than the average. For more details on temperature coefficient, refer to the *Voltage Reference Selection Basics White Paper*.

## 8.2 Dynamic Impedance

The dynamic impedance is defined as $|Z_{KA}| = \frac{\Delta V_{KA}}{\Delta I_{KA}}$. When the device is operating with two external resistors (see Figure 15), the total dynamic impedance of the circuit is given by $|z'| = \frac{\Delta V}{\Delta I}$, which is approximately equal to $|Z_{KA}|\left(1+\frac{R1}{R2}\right)$.

The $V_{KA}$ of the TL431LI-Q1 can be affected by the dynamic impedance. The TL431LI-Q1 test current $I_{test}$ for $V_{KA}$ is specified in the *Electrical Characteristics*. Any deviation from $I_{test}$ can cause deviation on the output $V_{KA}$. Figure 17 shows the effect of the dynamic impedance on the $V_{KA}$.

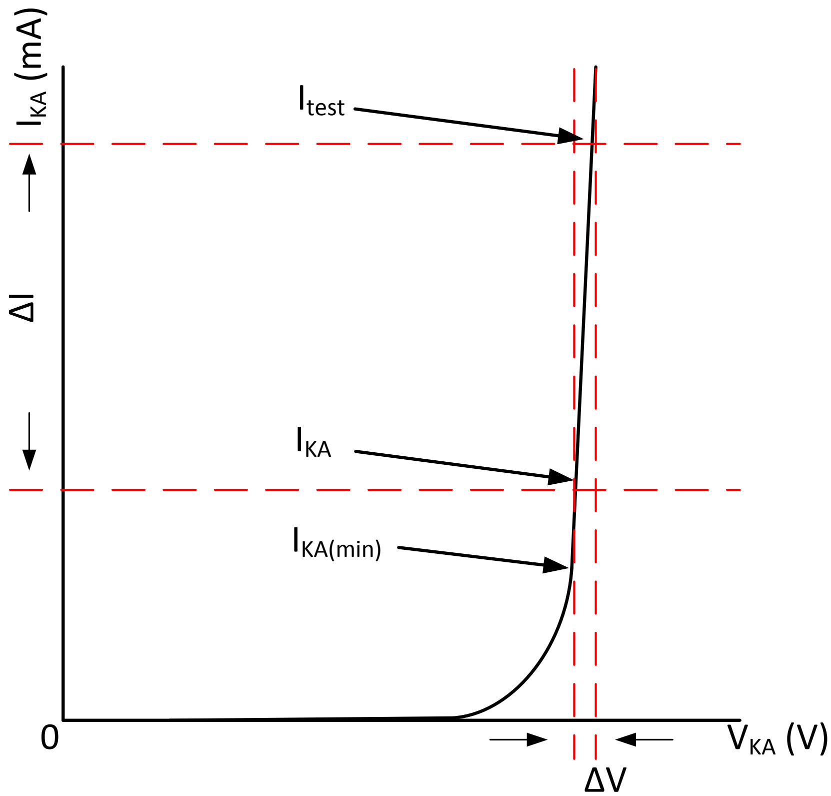



**Figure 17. Dynamic Impedance**

# 9 Detailed Description

## 9.1 Overview

This standard device has proven ubiquity and versatility across a wide range of applications, ranging from power to signal path. This is due to its key components containing an accurate voltage reference and op amp, which are very fundamental analog building blocks. TL43xLI-Q1 is used in conjunction with its key components to behave as a single voltage reference, error amplifier, voltage clamp or comparator with integrated reference.

TL43xLI-Q1 can be operated and adjusted to cathode voltages from 2.495 V to 36 V, making this part optimal for a wide range of end equipments in industrial, auto, telecom and computing. In order for this device to behave as a shunt regulator or error amplifier, >0.6mA ($I_{min}$(max)) must be supplied in to the cathode pin. Under this condition, feedback can be applied from the Cathode and Ref pins to create a replica of the internal reference voltage.

Various reference voltage options can be purchased with initial tolerances (at 25°C) of 0.5% (denoted by B), and 1% (denoted by A). TL431LI-Q1 and TL432LI-Q1 are both functionally the same, but have different pinout options.

## 9.2 Functional Block Diagram

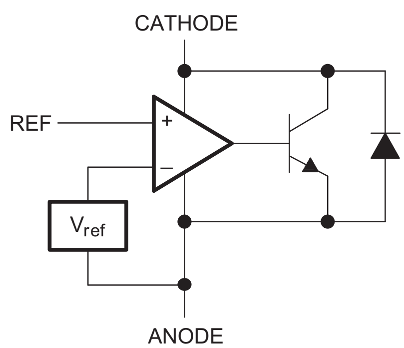



**Figure 18. Equivalent Schematic**

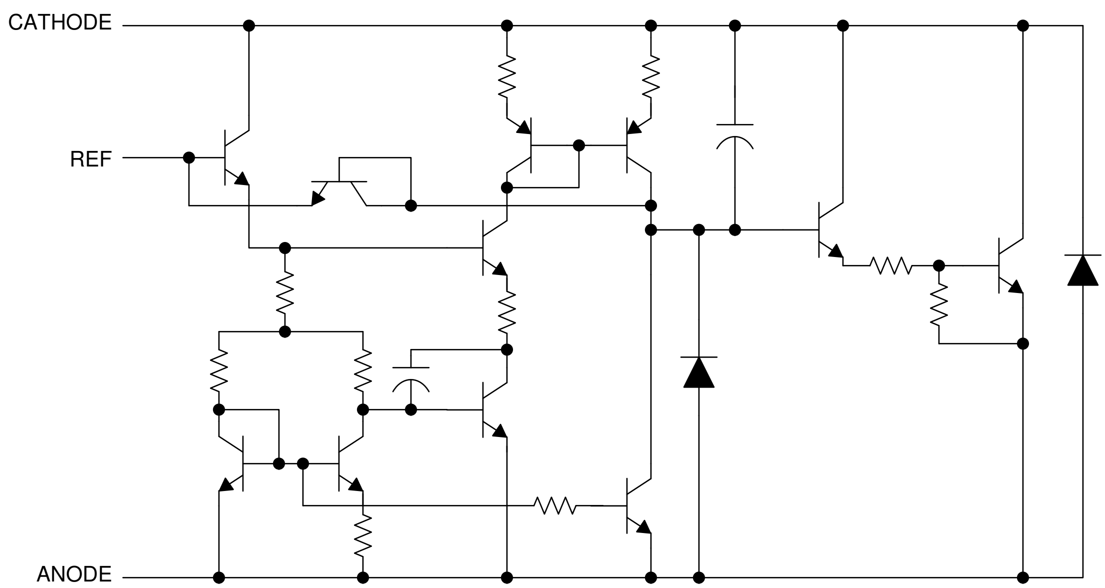



**Figure 19. Detailed Schematic**

## 9.3 Feature Description

TL43xLI-Q1 consists of an internal reference and amplifier that outputs a sink current based on the difference between the reference pin and the virtual internal pin. The sink current is produced by the internal Darlington pair, shown in Figure 19. A Darlington pair is used for this device to be able to sink a maximum current of 15 mA.

When operated with enough voltage headroom (≥ 2.495 V) and cathode current ($I_{KA}$), TL43xLI-Q1 forces the reference pin to 2.495 V. However, the reference pin can not be left floating, as it needs $I_{REF}$ ≥ 0.4 µA (see the *Specifications*). This is because the reference pin is driven into an npn, which needs base current in order operate properly.

When feedback is applied from the Cathode and Reference pins, TL43xLI-Q1 behaves as a Zener diode (refer to Figure 23 for a circuit example), regulating to a constant voltage dependent on current being supplied into the cathode. This is due to the internal amplifier and reference entering the proper operating regions. The same amount of current needed in the above feedback situation must be applied to this device in open loop, servo, or error amplifying implementations for it to be in the proper linear region giving TL43xLI-Q1 enough gain.

Unlike many linear regulators, TL43xLI-Q1 is internally compensated to be stable without an output capacitor between the cathode and anode. However, if it is desired to use an output capacitor, Figure 12 can be used as a guide to assist in choosing the correct capacitor to maintain stability.

## 9.4 Device Functional Modes

### 9.4.1 Open Loop (Comparator)

When the cathode/output voltage or current of TL43xLI-Q1 is not being fed back to the reference/input pin in any form, this device is operating in open loop. With proper cathode current (Ika) applied to this device, TL43xLI-Q1 has the characteristics shown in Figure 18. With such high gain in this configuration, TL43xLI-Q1 is typically used as a comparator. Since the reference is integrated, TL43xLI-Q1 is the preferred choice when users are trying to monitor a certain level of a single signal. Refer to the *Using the TL431 as a Voltage Comparator Application Report* for more details on open loop comparator applications on the TL431LI-Q1.

### 9.4.2 Closed Loop

When the cathode/output voltage or current of TL43xLI-Q1 is being fed back to the reference/input pin in any form, this device is operating in closed loop. The majority of applications involving TL43xLI-Q1 use it in this manner to regulate a fixed voltage or current. The feedback enables this device to behave as an error amplifier, computing a portion of the output voltage and adjusting it to maintain the desired regulation. This is done by relating the output voltage back to the reference pin in a manner to make it equal to the internal reference voltage, which can be accomplished through resistive or direct feedback.

# 10 Applications and Implementation

**NOTE**

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

## 10.1 Application Information

As this device has many applications and setups, there are many situations that this data sheet can not characterize in detail. The linked application notes help the designer make the best choices when using this part.

*Designing with the Improved TL431LI Application Note* provides a deeper understanding of this accuracy of the device in a flyback optocoupler application. *Setting the Shunt Voltage on an Adjustable Shunt Regulator Application Note* assists designers in setting the shunt voltage to achieve optimum accuracy for this device.

## 10.2 Typical Applications

### 10.2.1 Comparator With Integrated Reference

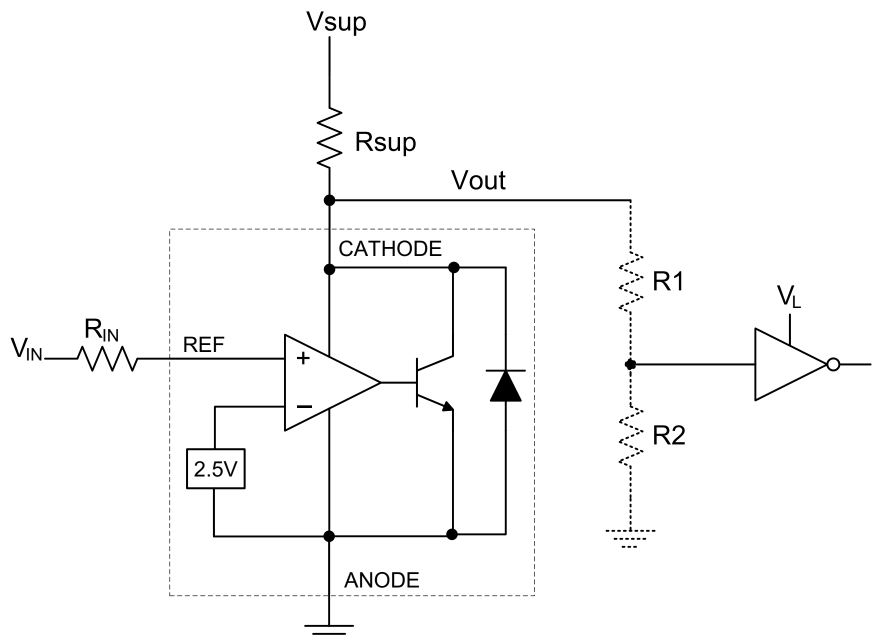



**Figure 20. Comparator Application Schematic**

## Typical Applications (continued)

### 10.2.2 Design Requirements

For this design example, use the parameters listed in Table 1 as the input parameters.

**Table 1. Design Parameters**

| DESIGN PARAMETER | EXAMPLE VALUE |
|---|---|
| Input Voltage Range | 0 V to 5 V |
| Input Resistance | 10 kΩ |
| Supply Voltage | 24 V |
| Cathode Current (Ik) | 5 mA |
| Output Voltage Level | ~2 V – $V_{SUP}$ |
| Logic Input Thresholds $V_{IH}/V_{IL}$ | $V_L$ |

### 10.2.3 Detailed Design Procedure

When using TL43xLI-Q1 as a comparator with reference, determine the following:

- Input voltage range
- Reference voltage accuracy
- Output logic input high and low level thresholds
- Current source resistance

#### *10.2.3.1 Basic Operation*

In the configuration shown in Figure 20, TL43xLI-Q1 behaves as a comparator, comparing the $V_{REF}$ pin voltage to the internal virtual reference voltage. When provided a proper cathode current ($I_K$), TL43xLI-Q1 has enough open loop gain to provide a quick response. This can be seen in Figure 21 where the $R_{SUP}$ = 10 kΩ ($I_{KA}$ = 500 µA) situation responds much slower than $R_{SUP}$ = 1 kΩ ($I_{KA}$ = 5 mA). With the TL43xLI-Q1 max operating current ($I_{MIN}$) being 1 mA, operation below that can result in low gain, leading to a slow response.

##### 10.2.3.1.1 Overdrive

Slow or inaccurate responses can also occur when the reference pin is not provided enough overdrive voltage. This is the amount of voltage that is higher than the internal virtual reference. The internal virtual reference voltage is within the range of 2.495 V ±(0.5% or 1.0%), depending on which version is being used. The more overdrive voltage provided, the faster the TL43xLI-Q1 responds.

For applications where TL43xLI-Q1 is being used as a comparator, it is best to set the trip point to greater than the positive expected error (that is +1.0% for the A version). For fast response, setting the trip point to >10% of the internal $V_{REF}$ suffices.

For minimal voltage drop or difference from Vin to the ref pin, TI recommends to use an input resistor <10 kΩ to provide Iref.

#### *10.2.3.2 Output Voltage and Logic Input Level*

For TL43xLI-Q1 to properly be used as a comparator, the logic output must be readable by the receiving logic device. This is accomplished by knowing the input high and low level threshold voltage levels, typically denoted by $V_{IH}$ and $V_{IL}$.

As seen in Figure 21, the output low level voltage of the TL43xLI in open-loop/comparator mode is approximately 2 V, which is typically sufficient for 5 V supplied logic. However, this does not work for 3.3 V and 1.8 V supplied logic. To accommodate this, a resistive divider can be tied to the output to attenuate the output voltage to a voltage legible to the receiving low voltage logic device.

The output high voltage of the TL43xLI is equal to $V_{SUP}$ due to TL43xLI-Q1 being open-collector. If $V_{SUP}$ is much higher than the maximum input voltage tolerance of the maximum logic, the output must be attenuated to accommodate the reliability of the outgoing logic.

When using a resistive divider on the output, make sure the sum of the resistive divider (R1 and R2 in Figure 20) is much greater than $R_{SUP}$ to not interfere with the ability of the TL43xLI to pull close to $V_{SUP}$ when turning off.

##### 10.2.3.2.1 Input Resistance

TL43xLI-Q1 requires an input resistance in this application to source the reference current ($I_{REF}$) needed from this device to be in the proper operating regions while turning on. The actual voltage seen at the ref pin is $V_{REF} = V_{IN} - I_{REF}R_{IN}$. Because $I_{REF}$ can be as high as 0.4 µA, it is recommended to use a resistance small enough that mitigates the error that $I_{REF}$ creates from $V_{IN}$.

### 10.2.4 Application Curves

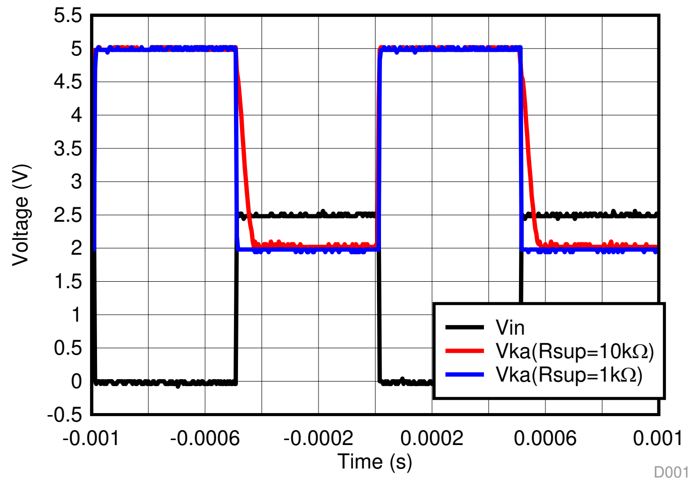



**Figure 21. Output Response With Various Cathode Currents**

### 10.2.5 Precision LED Lighting Current Sink Regulator

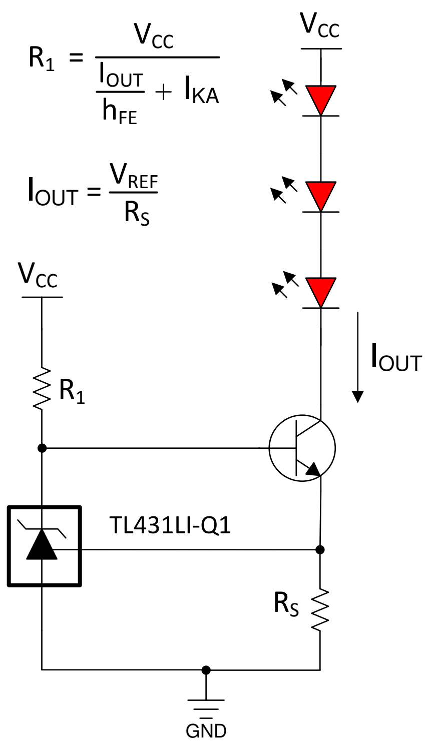



**Figure 22. LED Lighting Current Sink Regulator**

#### *10.2.5.1 Design Requirements*

For this design example, use the parameters listed in Table 1 as the input parameters.

**Table 2. Design Parameters**

| DESIGN PARAMETER | EXAMPLE VALUE |
|---|---|
| Supply Voltage ($V_{I(BATT)}$) | 5 V |
| Sink Current ($I_O$) | 100mA |
| Cathode Current (Ik) | 5 mA |

#### *10.2.5.2 Detailed Design Procedure*

When using the TL43xLI-Q1 as a constant current sink, determine the following:

- Output current range
- Output current accuracy
- Power consumption for TL43xLI-Q1

##### 10.2.5.2.1 Basic Operation

In the configuration shown, TL43xLI-Q1 acts as a control component within a feedback loop of the constant current sink. Working with an external passing component such as a BJT, TL43xLI-Q1 provides precision current sink with accuracy set by itself and the sense resistor $R_S$. The LEDs are lit based on the desired current sink and regulated for accurate brightness and color.

#### *10.2.5.2.1.1 Output Current Range and Accuracy*

The output current range of the circuit is determined by the equation shown in the configuration. Keep in mind that the $V_{REF}$ equals to 2.495 V. When choosing the sense resistor $R_S$, it needs to generate 2.495 V for the TL43xLI-Q1 when $I_O$ reaches the target current. If the overhead voltage of 2.495 V is not acceptable, consider lower voltage reference devices such as the TLV43x-Q1 or TLVH43x-Q1.

The output current accuracy is determined by both the accuracy of TL43xLI-Q1 chosen, as well as the accuracy of the sense resistor $R_S$. The internal virtual reference voltage of TL43xLI-Q1 is within the range of 2.495 V ±(0.5% or 1.0%), depending on which version is being used. Another consideration for the output current accuracy is the temperature coefficient of the TL43xLI-Q1 and $R_S$. Refer to the *Electrical Characteristics* of these parameters.

#### 10.2.5.2.2 Power Consumption

For TL43xLI-Q1 to properly be used as a control component in this circuit, the minimum operating current needs to be reached. This is accomplished by setting the external biasing resistor in series with the TL43xLI-Q1.

For TL43xLI, the minimum operating current is 0.6 mA and with margin consideration, most of the designs set this current to be higher than 0.6 mA. To achieve lower power consumption, consider devices such as the ATL43x-Q1 and ATL43xLI-Q1.

### 10.2.6 Shunt Regulator/Reference

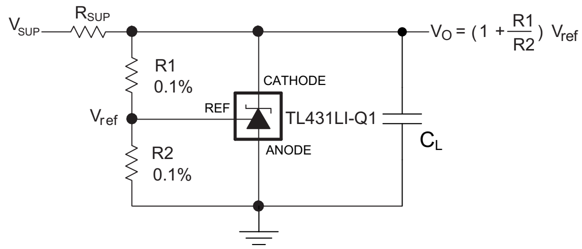



**Figure 23. Shunt Regulator Schematic**

#### *10.2.6.1 Design Requirements*

For this design example, use the parameters listed in Table 1 as the input parameters.

**Table 3. Design Parameters**

| DESIGN PARAMETER | EXAMPLE VALUE |
|---|---|
| Reference Initial Accuracy | 1.0% |
| Supply Voltage | 24 V |
| Cathode Current (Ik) | 5 mA |
| Output Voltage Level | 2.495 V–36 V |
| Load Capacitance | 2 µF |
| Feedback Resistor Values and Accuracy (R1 and R2) | 10 kΩ |

#### *10.2.6.2 Detailed Design Procedure*

When using TL43xLI-Q1 as a shunt regulator, determine the following:

- Input voltage range
- Temperature range
- Total accuracy
- Cathode current
- Reference initial accuracy
- Output capacitance

##### 10.2.6.2.1 Programming Output/Cathode Voltage

To program the cathode voltage to a regulated voltage, a resistive bridge must be shunted between the cathode and anode pins with the mid point tied to the reference pin. This can be seen in Figure 23, with R1 and R2 being the resistive bridge. The cathode/output voltage in the shunt regulator configuration can be approximated by the equation shown in Figure 23. The cathode voltage can be more accurate determined by taking in to account the cathode current:

$$Vo=(1+R1/R2)V_{REF}-I_{REF}R1 \quad (1)$$

For this equation to be valid, TL43xLI-Q1 must be fully biased so that it has enough open loop gain to mitigate any gain error. This can be done by meeting the $I_{min}$ spec denoted in the *Specifications*.

#### 10.2.6.2.2 Total Accuracy

When programming the output above unity gain ($V_{KA}$=$V_{REF}$), TL43xLI-Q1 is susceptible to other errors that can effect the overall accuracy beyond $V_{REF}$. These errors include:

- R1 and R2 accuracies
- $V_{I(dev)}$: Change in reference voltage over temperature
- $\Delta V_{REF}$ / $\Delta V_{KA}$: Change in reference voltage to the change in cathode voltage
- $|z_{KA}|$ - Dynamic impedance, causing a change in cathode voltage with cathode current

Worst case cathode voltage can be determined taking all of the variables in to account. The *Setting the Shunt Voltage on an Adjustable Shunt Regulator Application Note* assists designers in setting the shunt voltage to achieve optimum accuracy for this device.

#### 10.2.6.2.3 Stability

Though TL43xLI-Q1 is stable with no capacitive load, the device that receives the output voltage of the shunt regulator can presents a capacitive load that is within the TL43xLI-Q1 region of stability, shown in Figure 12. Also, designers can use capacitive loads to improve the transient response or for power supply decoupling. When using additional capacitance between Cathode and Anode, refer to Figure 12. Also, the *Understanding Stability Boundary Conditions Charts in TL431, TL432 Data Sheet Application Note* provides a deeper understanding of this devices stability characteristics and aids the user in making the right choices when choosing a load capacitor.

#### 10.2.6.2.4 Start-up Time

As shown in Figure 24, TL43xLI-Q1 has a fast response up to approximately 2 V and then slowly charges to the programmed value. This is due to the compensation capacitance (shown in Figure 19) the TL43xLI-Q1 has to meet the stability criteria. Despite the secondary delay, TL43xLI-Q1 still has a fast response suitable for many clamp applications.

### *10.2.6.3 Application Curves*

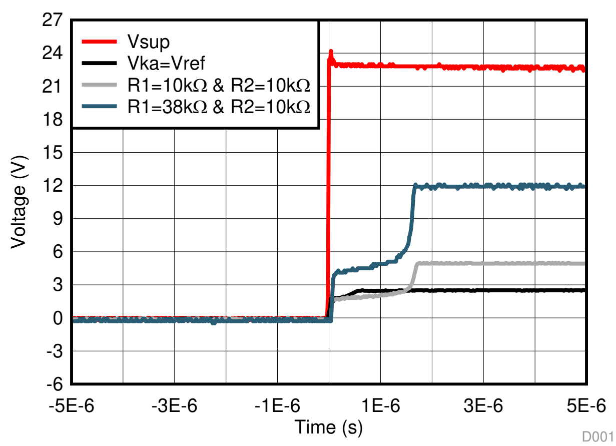



**Figure 24. TL43xLI-Q1 Start-Up Response**

### 10.2.7 Isolated Flyback with Optocoupler

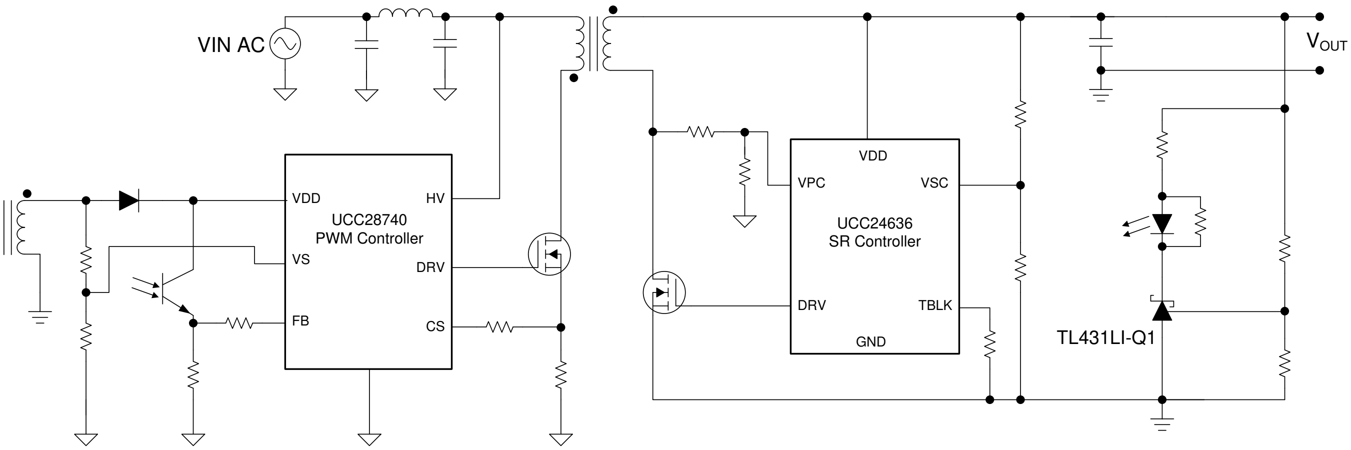



**Figure 25. Isolated Flyback with Optocoupler**

#### *10.2.7.1 Design Requirements*

The TL431LI-Q1 is used in the feedback network on the secondary side in an isolated flyback with optocoupler design. Figure 25 shows the simplified flyback converter with the TL431LI-Q1. For this design example, use the parameters in Table 4 as the input parameters. In this example, a simplified design procedure will be discussed. The compensation network for the feedback network is beyond the scope of this section. Details on compensation network can be found in the *Compensation Design with TL431 for UCC28600 Application Report*.

**Table 4. Design Parameters**

| DESIGN PARAMETER | EXAMPLE VALUE |
|---|---|
| Voltage Output | 15 V |
| Secondary Side Feedback Loop Accuracy | < 3% |

#### *10.2.7.2 Detailed Design Procedure*

The goal of this design is to design a high accuracy feedback network to meet 3% $V_{OUT}$ accuracy requirements over the full temperature range. To meet the design requirements, the total secondary side feedback loop error has to be below 3%. To meet these requirements, it is necessary to take full advantage of the improved temperature drift, $I_{ref(min)}$, and $I_{I(dev)}$ of the TL431LI-Q1.

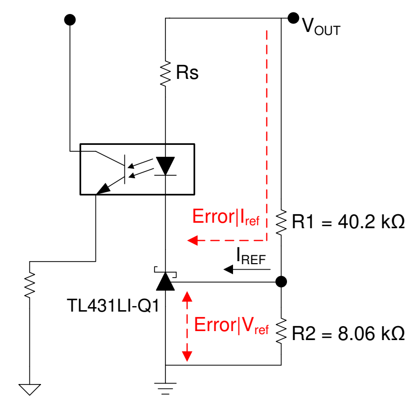



**Figure 26. Feedback Quiescent Current**

#### 10.2.7.2.1 TL431 Feedback Loop Error Calculation

Figure 26 shows the simplified version of the feedback network. The accuracy of the output voltage is dependent on the regulation voltage accuracy of the TL431LI-Q1. A simplified $V_{OUT}$ can be seen in Equation 2, but this equation does not include errors that deviates the output.

$$V_{OUT} = V_{ref} \times (1 + \frac{R1}{R2}) + R1 \times (I_{ref})$$
$$V_{OUT} = (2.495\,V) \times (1 + \frac{40.2\,k\Omega}{8.06\,k\Omega}) + 40.2\,k\Omega \times (0.4\,\mu A)$$
$$V_{OUT} = 14.955\,V \tag{2}$$

The primary sources of error are the $Error|_{Vref}$ and $Error|_{Iref}$. The $Error|_{Vref}$ primarily consists of the errors that affect the internal bandgap voltage reference of the TL431LI-Q1. This consists of errors from the initial accuracy, temperature drift, ratio of change in reference voltage to the change in cathode voltage, and dynamic impedance. The benefit of the TL431LI-Q1 is its low temperature drift, $V_{I(dev)}$, which allows the $V_{ref}$ to be more accurate across the full temperature range compared to typical TL431LI-Q1 devices. Equation 3 shows a simplified worst case $V_{ref}$ with initial accuracy and temperature drift.

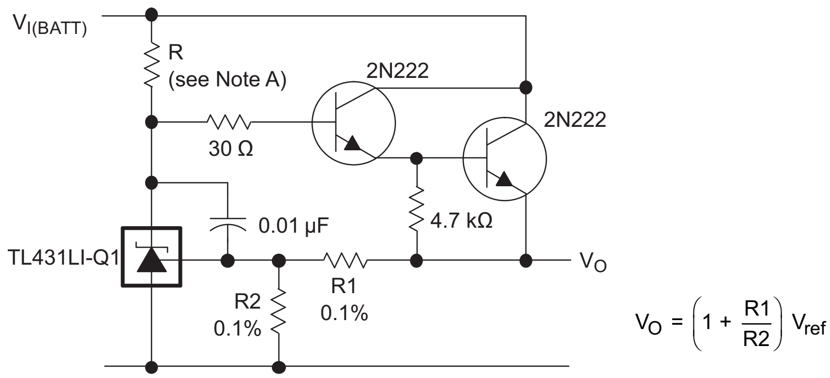
$$V_{ref}(Error|_{Vref}) = V_{ref} \times (1 + \text{Initial Accuracy}) + V_{I(dev)} + ...$$
$$V_{ref}(Error|_{Vref}) = 2.495\,V \times (1 + 0.5\%) + 17\,mV + ...$$
$$V_{ref}(Error|_{Vref}) \approx 2.524\,V \tag{3}$$

The $Error|_{Iref}$ in Figure 26 is dependent on the $I_{ref}$ and $I_{I(dev)}$ along with R1. The TL431LI-Q1 has improved $I_{ref}$ and $I_{I(dev)}$ which allows the values of the resistor R1 to be increased to save power. Typically optocoupler feedback design requires the $I_{ref}$ to be taken into account when doing $V_{OUT}$ calculations but the error comes from the deviation from the maximum to typical value of $I_{ref}$. In addition to this, the $I_{I(dev)}$ is the temperature deviation on the $I_{ref}$ current which affects the overall reference current into the TL431LI-Q1. Equation 4 shows the $V_{OUT}$ of the TL431LI-Q1 for Figure 26, which includes the improved $I_{ref}$ and $I_{I(dev)}$. The $V_{OUT}$ equation assumes that the resistors R1 and R2 have a 0.5% accuracy tolerance.

$$V_{OUT}(Error|_{Iref}) = V_{ref}(Error|_{Vref}) \times (1 + \frac{R1}{R2}) + R1 \times (I_{ref} + I_{I(dev)})$$
$$V_{OUT}(Error|_{Iref}) = (2.495\,V \times (1 + 0.5\%) + 0.017\,V) \times (1 + \frac{40.2\,k\Omega \times (1 + 0.5\%)}{8.06\,k\Omega \times (1 - 0.5\%)})$$
$$+ 40.2\,k\Omega \times (1 + 0.5\%) \times (0.4\,\mu A + 0.3\,\mu A)$$
$$V_{OUT} = 15.270\,V \tag{4}$$

Comparing the calculated $V_{OUT}$ without and without error, the expected worst case max error is 2.1% which meets the 3% error target.

## 10.3 System Examples




R should provide cathode current ≥0.6 mA to the TL431LI-Q1 at minimum $V_{(BATT)}$.

**Figure 27. Precision High-Current Series Regulator**

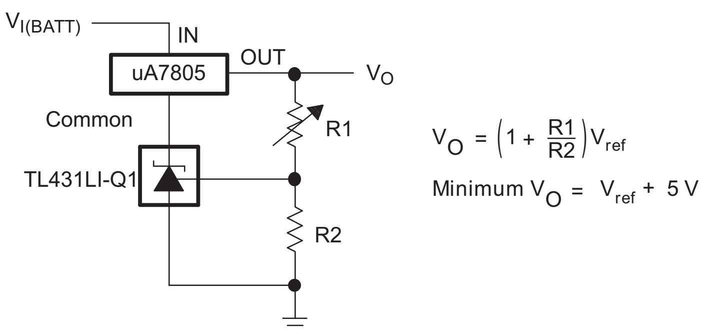



**Figure 28. Output Control of a Three-Terminal Fixed Regulator**

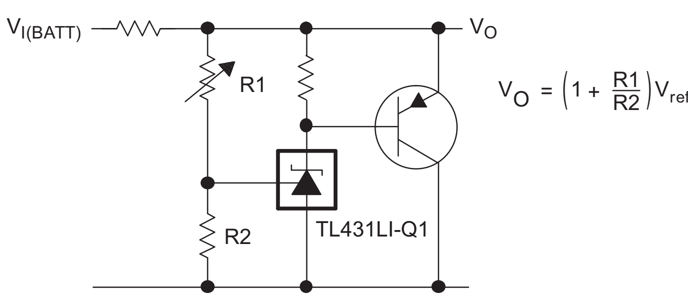
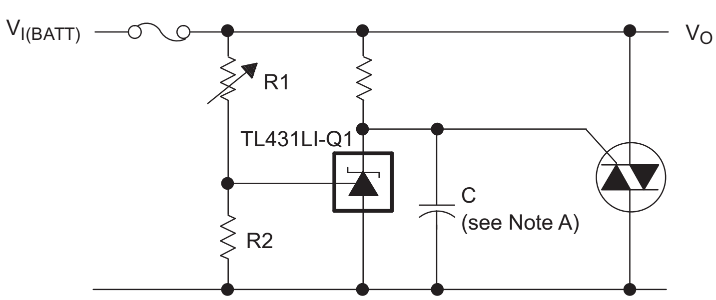



**Figure 29. High-Current Shunt Regulator**




Refer to the stability boundary conditions in Figure 12 to determine allowable values for C.

**Figure 30. Crowbar Circuit**

## System Examples (continued)

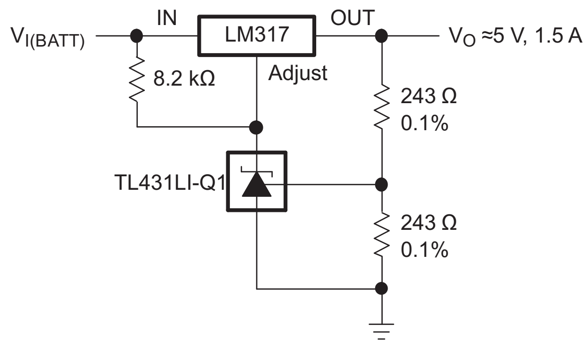
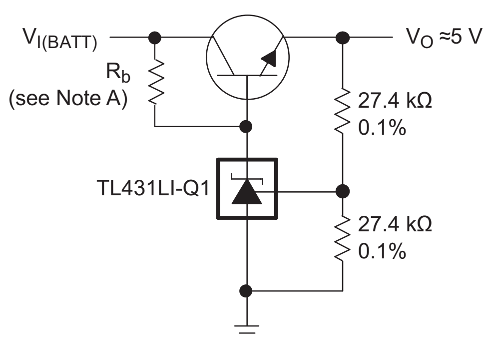



**Figure 31. Precision 5-V, 1.5-A Regulator**




$R_b$ should provide cathode current ≥0.6 mA to the TL431LI-Q1.

**Figure 32. Efficient 5-V Low-Dropout (LDO) Regulator Configuration**

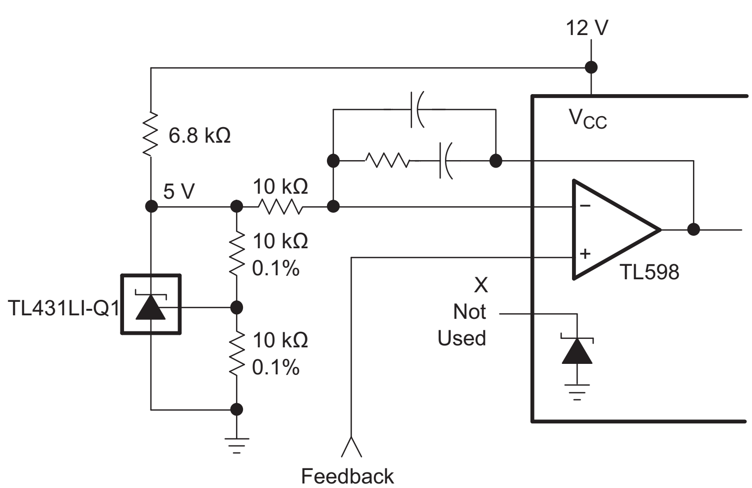
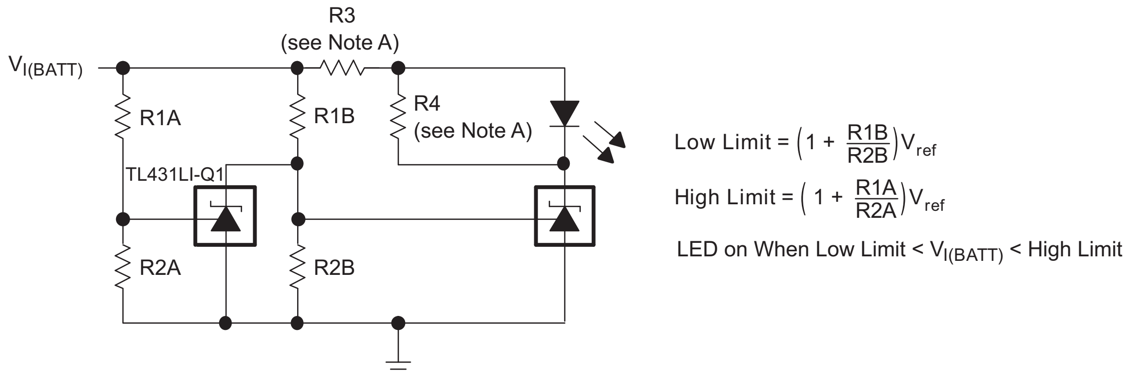



**Figure 33. PWM Converter With Reference**

## System Examples (continued)




Select R3 and R4 to provide the desired LED intensity and cathode current ≥0.6 mA to the TL431LI-Q1 at the available $V_{I(BATT)}$.

**Figure 34. Voltage Monitor**

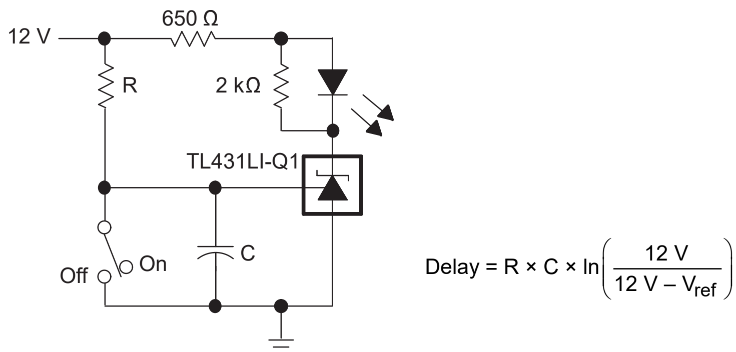



**Figure 35. Delay Timer**

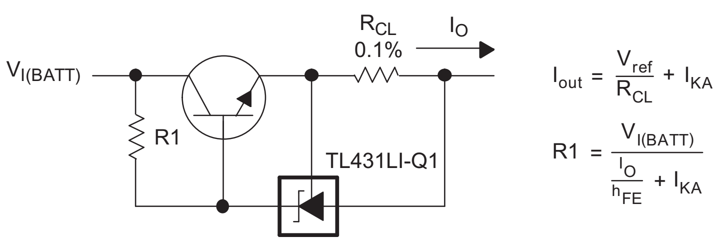



**Figure 36. Precision Current Limiter**

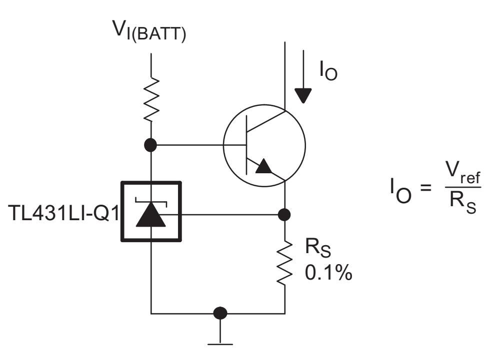



**Figure 37. Precision Constant-Current Sink**

## 11 Power Supply Recommendations

When using TL43xLI-Q1 as a Linear Regulator to supply a load, designers typically use a bypass capacitor on the output/cathode pin. When doing this, be sure that the capacitance is within the stability criteria shown in Figure 12.

To not exceed the maximum cathode current, be sure that the supply voltage is current limited. Also, be sure to limit the current being driven into the Ref pin, as not to exceed the absolute maximum rating.

For applications shunting high currents, pay attention to the cathode and anode trace lengths, adjusting the width of the traces to have the proper current density.

## 12 Layout

### 12.1 Layout Guidelines

Bypass capacitors must be placed as close to the part as possible. Current-carrying traces need to have widths appropriate for the amount of current they are carrying; in the case of the TL43xLI-Q1, these currents are low.

### 12.2 Layout Example

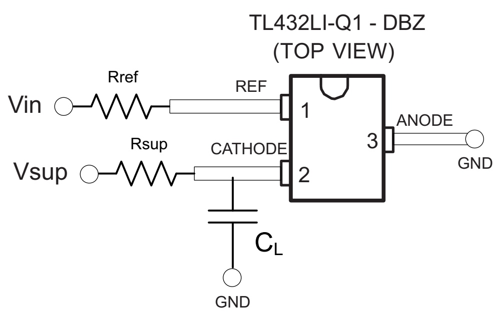


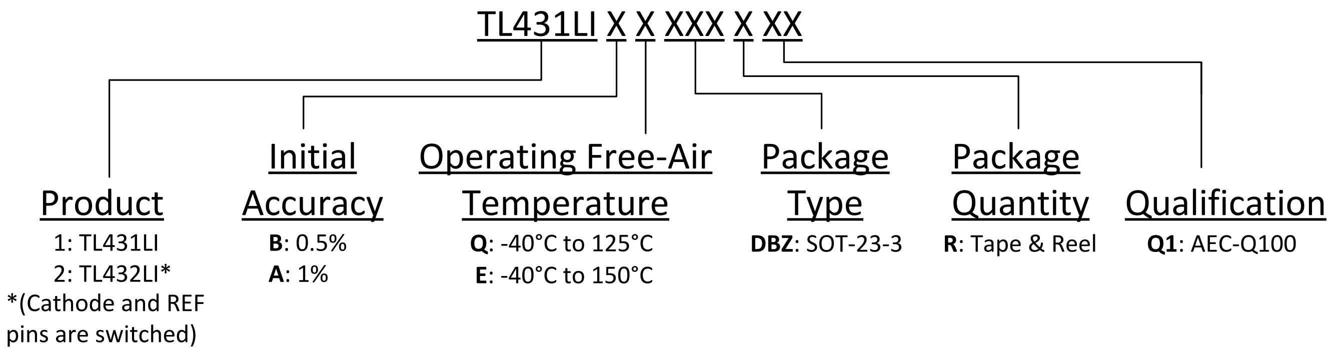

**Figure 38. DBZ Layout Example**

# 13 Device and Documentation Support

## 13.1 Device Support

### 13.1.1 Device Nomenclature

TI assigns suffixes and prefixes to differentiate all the combinations of the TL43xLI-Q1 family. More details and possible orderable combinations are located in the Package Option Addendum.




## 13.2 Documentation Support

### 13.2.1 Related Documentation

For related documentation see the following:

- Texas Instruments, *Understanding Stability Boundary Conditions Charts in TL431, TL432 Data Sheet*
- Texas Instruments, *Setting the Shunt Voltage on an Adjustable Shunt Regulator*
- Texas Instruments, *Designing With the Improved TL431LI*

## 13.3 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to order now.

**Table 5. Related Links**

| PARTS | PRODUCT FOLDER | ORDER NOW | TECHNICAL DOCUMENTS | TOOLS & SOFTWARE | SUPPORT & COMMUNITY |
|---|---|---|---|---|---|
| TL431LI-Q1 | Click here | Click here | Click here | Click here | Click here |
| TL432LI-Q1 | Click here | Click here | Click here | Click here | Click here |

## 13.4 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

## 13.5 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

## 13.6 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

## 13.7 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

## 13.8 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

# 14 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

## PACKAGING INFORMATION

| Orderable part number | Status (1) | Material type (2) | Package \| Pins | Package qty \| Carrier | RoHS (3) | Lead finish/ Ball material (4) | MSL rating/ Peak reflow (5) | Op temp (°C) | Part marking (6) |
|---|---|---|---|---|---|---|---|---|---|
| TL431LIAEDBZRQ1 | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 150 | 23CP |
| TL431LIAEDBZRQ1.B | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 150 | 23CP |
| TL431LIAQDBZRQ1 | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 22TP |
| TL431LIAQDBZRQ1.B | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 22TP |
| TL431LIBEDBZRQ1 | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 150 | 23DP |
| TL431LIBEDBZRQ1.B | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 150 | 23DP |
| TL431LIBQDBZRQ1 | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 22UP |
| TL431LIBQDBZRQ1.B | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 22UP |
| TL432LIAEDBZRQ1 | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 150 | 23EP |
| TL432LIAEDBZRQ1.B | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 150 | 23EP |
| TL432LIAQDBZRQ1 | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 22VP |
| TL432LIAQDBZRQ1.B | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 22VP |
| TL432LIBEDBZRQ1 | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 150 | 23FP |
| TL432LIBEDBZRQ1.B | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 150 | 23FP |
| TL432LIBQDBZRQ1 | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 22WP |
| TL432LIBQDBZRQ1.B | Active | Production | SOT-23 (DBZ) \| 3 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | 22WP |

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

**Important Information and Disclaimer:**The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

**OTHER QUALIFIED VERSIONS OF TL431LI-Q1, TL432LI-Q1 :**

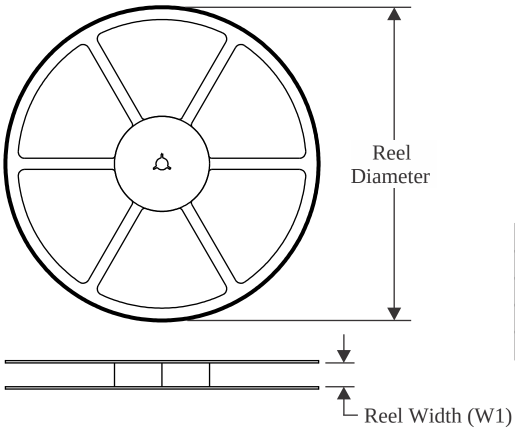
- Catalog : TL431LI, TL432LI

NOTE: Qualified Version Definitions:

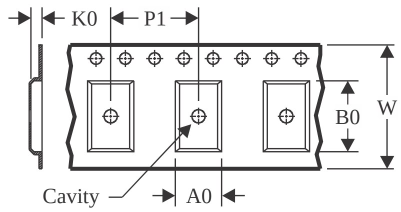
- Catalog - TI's standard catalog product

## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**

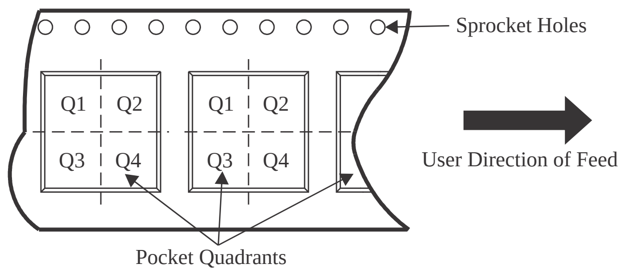



**TAPE DIMENSIONS**




| | |
|---|---|
| A0 | Dimension designed to accommodate the component width |
| B0 | Dimension designed to accommodate the component length |
| K0 | Dimension designed to accommodate the component thickness |
| W | Overall width of the carrier tape |
| P1 | Pitch between successive cavity centers |

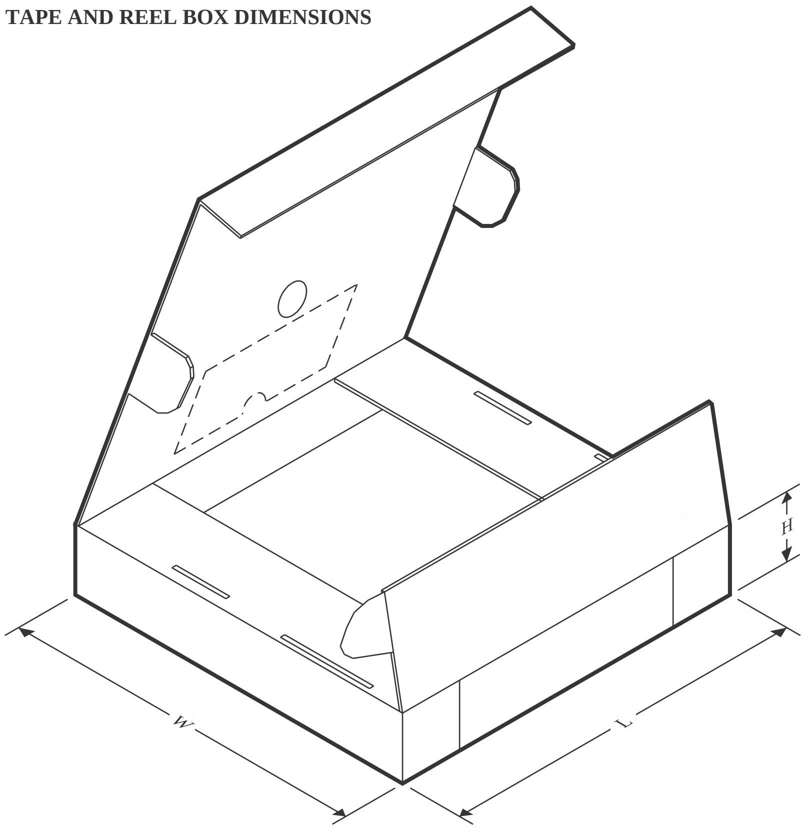
**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**




*All dimensions are nominal

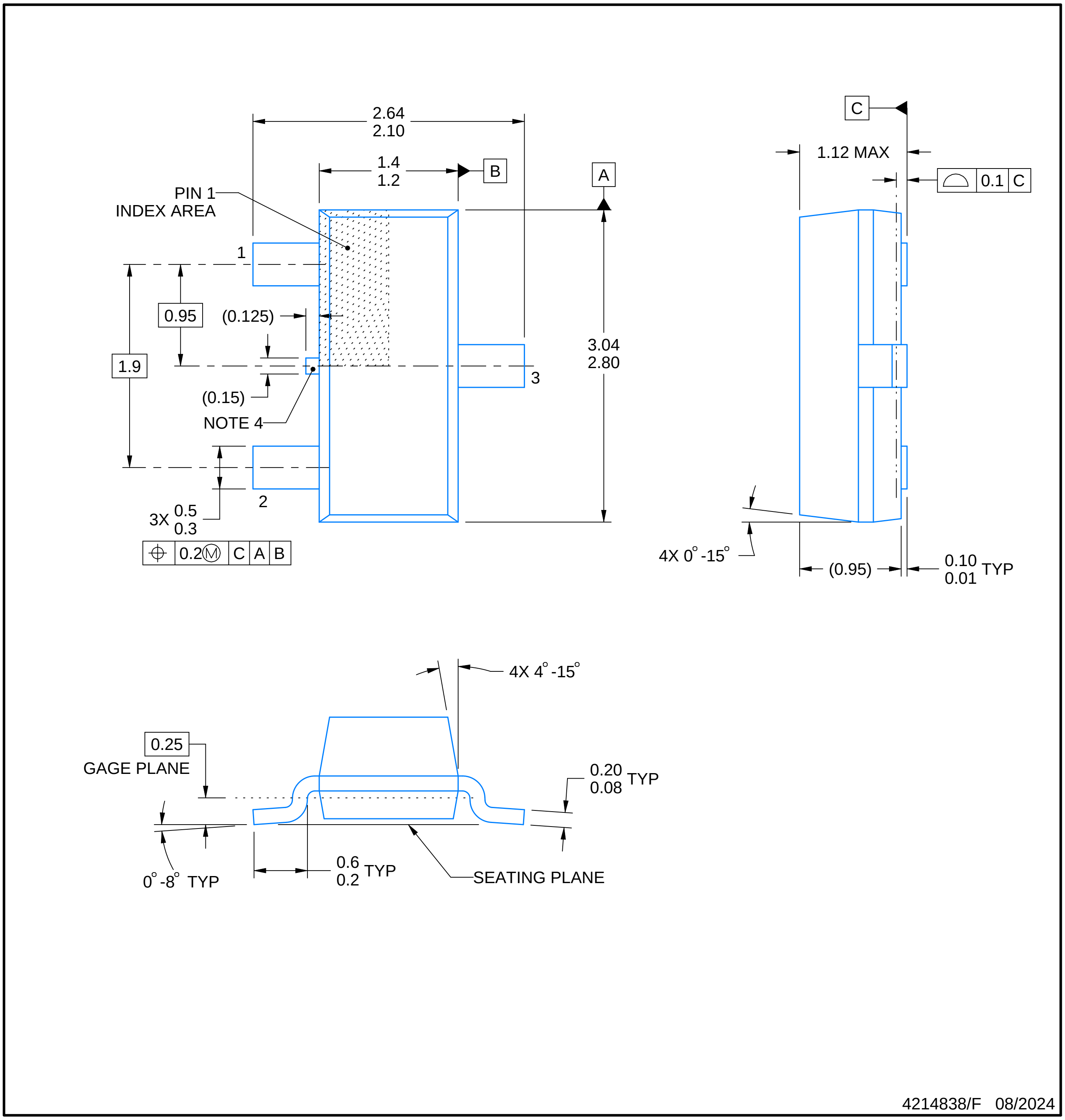
| Device | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TL431LIAEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 178.0 | 9.0 | 3.15 | 2.77 | 1.22 | 4.0 | 8.0 | Q3 |
| TL431LIAQDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 178.0 | 9.0 | 3.15 | 2.77 | 1.22 | 4.0 | 8.0 | Q3 |
| TL431LIBEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 178.0 | 9.0 | 3.15 | 2.77 | 1.22 | 4.0 | 8.0 | Q3 |
| TL431LIBQDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 178.0 | 9.0 | 3.15 | 2.77 | 1.22 | 4.0 | 8.0 | Q3 |
| TL432LIAEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 178.0 | 9.0 | 3.15 | 2.77 | 1.22 | 4.0 | 8.0 | Q3 |
| TL432LIAEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 180.0 | 8.4 | 2.9 | 3.35 | 1.35 | 4.0 | 8.0 | Q3 |
| TL432LIAQDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 178.0 | 9.0 | 3.15 | 2.77 | 1.22 | 4.0 | 8.0 | Q3 |
| TL432LIBEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 180.0 | 8.4 | 2.9 | 3.35 | 1.35 | 4.0 | 8.0 | Q3 |
| TL432LIBEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 178.0 | 9.0 | 3.15 | 2.77 | 1.22 | 4.0 | 8.0 | Q3 |
| TL432LIBQDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 178.0 | 9.0 | 3.15 | 2.77 | 1.22 | 4.0 | 8.0 | Q3 |

TAPE AND REEL BOX DIMENSIONS



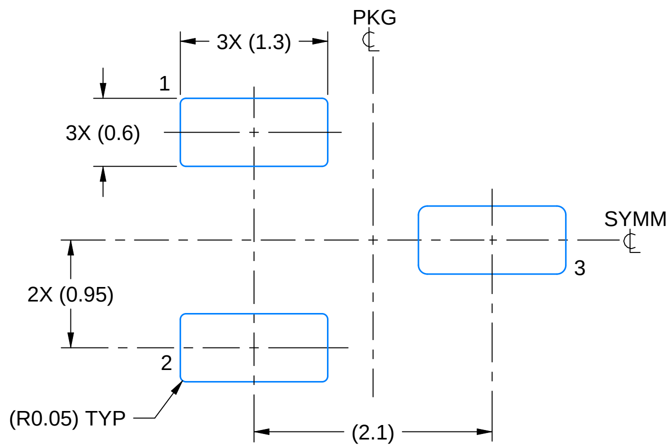

*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| TL431LIAEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 180.0 | 180.0 | 18.0 |
| TL431LIAQDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 180.0 | 180.0 | 18.0 |
| TL431LIBEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 180.0 | 180.0 | 18.0 |
| TL431LIBQDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 180.0 | 180.0 | 18.0 |
| TL432LIAEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 180.0 | 180.0 | 18.0 |
| TL432LIAEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 210.0 | 185.0 | 35.0 |
| TL432LIAQDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 180.0 | 180.0 | 18.0 |
| TL432LIBEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 210.0 | 185.0 | 35.0 |
| TL432LIBEDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 180.0 | 180.0 | 18.0 |
| TL432LIBQDBZRQ1 | SOT-23 | DBZ | 3 | 3000 | 180.0 | 180.0 | 18.0 |

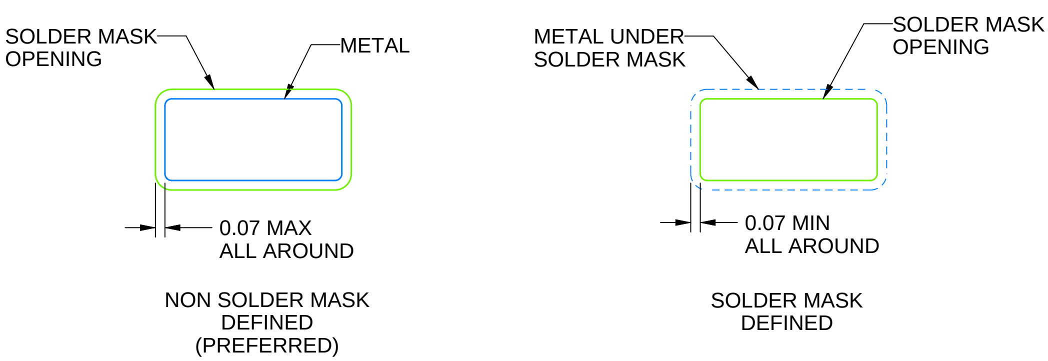



NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC registration TO-236, except minimum foot length.
4. Support pin may differ or may not be present.
5. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25mm per side




LAND PATTERN EXAMPLE
SCALE:15X




SOLDER MASK DETAILS

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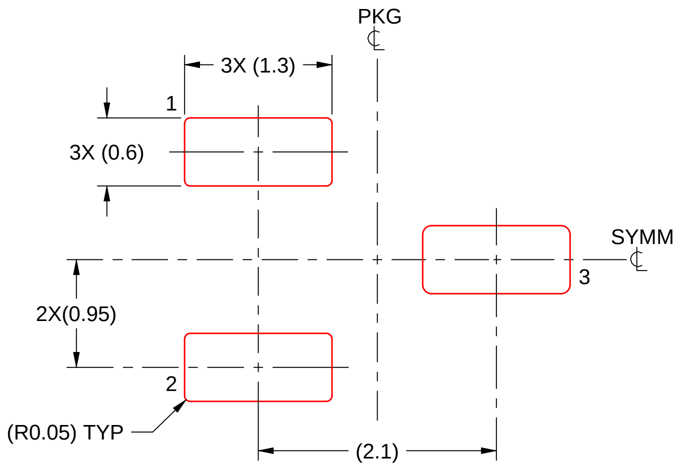
NOTES: (continued)

5. Publication IPC-7351 may have alternate designs.
6. Solder mask tolerances between and around signal pads can vary based on board fabrication site.




SOLDER PASTE EXAMPLE
BASED ON 0.125 THICK STENCIL
SCALE:15X

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NOTES: (continued)

7. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
8. Board assembly site may have different recommendations for stencil design.