1 Features

- Qualified for automotive applications
- AEC-Q100 test guidance with the following:
  - Device temperature grade 1: –40°C to 125°C ambient operating temperature range
- Reference voltage tolerance at 25°C:
  - 1% (A Grade)
  - 0.5% (B Grade)
- Typical temperature drift:
  - 14 mV (Q Temp)
- Low output noise
- 0.2-Ω Typical output impedance
- Sink-current capability: 1 mA to 100 mA
- Adjustable output voltage: $V_{\text{REF}}$ to 36 V

2 Applications

- Adjustable voltage and current referencing
- Secondary side regulation in flyback SMPSs
- Zener replacement
- Voltage monitoring
- Comparator with integrated reference

3 Description

The TL431LI-Q1 / TL432LI-Q1 are pin-to-pin alternatives to TL431-Q1 / TL432-Q1. TL43xLI-Q1 offers better stability, lower temperature drift ($V_{I\text{dev}}$), and lower reference current ($I_{\text{ref}}$) for improved system accuracy.

The TL431-Q1 is a three-pin adjustable shunt regulator with specified thermal stability over applicable automotive temperature ranges. The output voltage can be set to any value from $V_{\text{REF}}$ (approximately 2.5 V) to 36 V, with two external resistors (see Figure 28). This device has a typical output impedance of 0.2 Ω. Active output circuitry provides a sharp turnon characteristic, making this device an excellent replacement for Zener diodes in many applications, such as onboard regulation, adjustable power supplies, and switching power supplies.

The TL432-Q1 has exactly the same functionality and electrical specifications as the TL431-Q1 device, but has a different pinout for the DBZ package.

### Device Information

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>PACKAGE</th>
<th>BODY SIZE (NOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL431A-Q1</td>
<td>SOT-23 (5)</td>
<td>2.90 mm x 1.60 mm</td>
</tr>
<tr>
<td>TL43x-Q1</td>
<td>SOT-23 (3)</td>
<td>2.92 mm x 1.30 mm</td>
</tr>
</tbody>
</table>

(1) For all available packages, see the orderable addendum at the end of the data sheet.
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4 Revision History
NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision F (July 2019) to Revision G

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Added RoC Cathode Current for TL431Ax-Q1 and TL431xB-Q1.</td>
</tr>
</tbody>
</table>

Changes from Revision E (November 2016) to Revision F

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The TL431LI-Q1 / TL432LI-Q1 are pin-to-pin alternatives to TL431-Q1 / TL432-Q1. TL43xLI-Q1 offers better stability, lower temperature drift (VI(dev)), and lower reference current (Iref) for improved system accuracy.</td>
</tr>
<tr>
<td>Merged the TL431-Q1 with the TL432-Q1 data sheet.</td>
</tr>
</tbody>
</table>

Changes from Revision D (March 2013) to Revision E

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Added Applications section, Device Information table, Pin Configuration and Functions section, Specifications section, ESD Ratings table, Detailed Description section, Application and Implementation section, Power Supply Recommendations section, Layout section, Device and Documentation Support section, and Mechanical, Packaging, and Orderable Information section</td>
</tr>
<tr>
<td>Deleted Ordering Information table; see Package Option Addendum at the end of the data sheet</td>
</tr>
<tr>
<td>Added Thermal Information table</td>
</tr>
<tr>
<td>Changed $R_{θJA}$ values for 5-pin DBV (SOT-23) From: 206 To: 215 and for 3-pin DBZ (SOT-23) From: 206 To: 334.7</td>
</tr>
</tbody>
</table>
5 Pin Configuration and Functions

(1) Pin 2 is connected internally to ANODE (die substrate) and must be left floating or connected to ANODE.

<table>
<thead>
<tr>
<th>PIN</th>
<th>I/O</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANODE</td>
<td>O</td>
<td>Common pin, normally connected to ground.</td>
</tr>
<tr>
<td>CATHODE</td>
<td>I/O</td>
<td>Shunt current or voltage input</td>
</tr>
<tr>
<td>NC</td>
<td>No connection&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>REF</td>
<td></td>
<td>Threshold relative to common anode</td>
</tr>
</tbody>
</table>

(1) Pin 2 of the 5-pin DBV (SOT-23) package is connected internally to ANODE (die substrate) and must be left floating or connected to ANODE.
6 Specifications

6.1 Absolute Maximum Ratings
over operating free-air temperature range (unless otherwise noted)(1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode voltage(2)</td>
<td></td>
<td>37</td>
<td>V</td>
</tr>
<tr>
<td>Continuous cathode current</td>
<td>–100</td>
<td>150</td>
<td>mA</td>
</tr>
<tr>
<td>Reference input current Low</td>
<td>–50</td>
<td>10</td>
<td>µA</td>
</tr>
<tr>
<td>Reference input current High</td>
<td></td>
<td>10</td>
<td>mA</td>
</tr>
<tr>
<td>Operating junction temperature, TJ</td>
<td></td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature, T_{stg}</td>
<td>–65</td>
<td>150</td>
<td>°C</td>
</tr>
</tbody>
</table>

(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) Voltage values are with respect to the ANODE pin, unless otherwise noted.

6.2 ESD Ratings

<table>
<thead>
<tr>
<th>ESD Model</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human-body model (HBM), per AEC Q100-002(1)</td>
<td>±2500</td>
<td>V</td>
</tr>
<tr>
<td>Charged-device model (CDM), per AEC Q100-011</td>
<td>±1000</td>
<td>V</td>
</tr>
<tr>
<td>Machine model (MM)</td>
<td>±200</td>
<td></td>
</tr>
</tbody>
</table>

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

6.3 Recommended Operating Conditions
over operating free-air temperature range (unless otherwise noted)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{KA}</td>
<td>Cathode voltage</td>
<td>V_{REF}</td>
<td>36</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>I_{KA}</td>
<td>Cathode current</td>
<td>TL431x-Q1</td>
<td>100</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TL431xA-Q1</td>
<td>100</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TL431xB-Q1</td>
<td>100</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>T_{A}</td>
<td>Operating free-air temperature</td>
<td>–40</td>
<td>125</td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

6.4 Thermal Information

<table>
<thead>
<tr>
<th>THERMAL METRIC(1)</th>
<th>TL43x-Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DBV (SOT-23)</td>
</tr>
<tr>
<td>R_{J/A}</td>
<td>215</td>
</tr>
<tr>
<td>R_{J/C(top)}</td>
<td>135.2</td>
</tr>
<tr>
<td>R_{J/B}</td>
<td>43</td>
</tr>
<tr>
<td>ψ_{J/T}</td>
<td>19.6</td>
</tr>
<tr>
<td>ψ_{J/B}</td>
<td>42.1</td>
</tr>
</tbody>
</table>

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

6.5 Electrical Characteristics: TL43x-Q1
over recommended operating conditions, T_{A} = 25°C (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{REF}</td>
<td>Reference voltage</td>
<td>V_{REF}, I_{REF} = 10 mA, see Figure 20</td>
<td>2440</td>
<td>2495</td>
<td>2550</td>
</tr>
<tr>
<td>V_{I(DEV)}</td>
<td>Deviation of reference voltage over full temperature (1)</td>
<td>V_{REF}, I_{REF} = 10 mA, T_{A} = –40°C to 125°C, see Figure 20</td>
<td>14</td>
<td>34</td>
<td></td>
</tr>
</tbody>
</table>

(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 recommended temperature range.
## Electrical Characteristics: TL43x-Q1 (continued)

over recommended operating conditions, $T_A = 25^\circ C$ (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta V_{\text{REF}}/\Delta V_{\text{KA}}$</td>
<td>$I_{\text{KA}} = 10 \text{ mA}$, see Figure 21</td>
<td>$\Delta V_{\text{KA}} = 10 \text{ V} - V_{\text{REF}}$</td>
<td>$-1.4$</td>
<td>$-2.7$</td>
<td>mV/V</td>
</tr>
<tr>
<td>$I_{\text{REF}}$</td>
<td>$I_{\text{KA}} = 10 \text{ mA}$, $R_1 = 10 \text{ k}\Omega$, $R_2 = \infty$, see Figure 21</td>
<td></td>
<td>$2$</td>
<td>$4$</td>
<td>µA</td>
</tr>
<tr>
<td>$I_{(\text{DEV})}$</td>
<td>$I_{\text{KA}} = 10 \text{ mA}$, $R_1 = 10 \text{ k}\Omega$, $R_2 = \infty$, $T_A = -40^\circ C$ to $125^\circ C$, see Figure 20</td>
<td></td>
<td>$0.8$</td>
<td>$2.5$</td>
<td>µA</td>
</tr>
<tr>
<td>$I_{\text{MIN}}$</td>
<td>$V_{\text{KA}} = V_{\text{REF}}$, see Figure 20</td>
<td></td>
<td>$0.4$</td>
<td>$1$</td>
<td>mA</td>
</tr>
<tr>
<td>$I_{\text{OFF}}$</td>
<td>Off-state cathode current</td>
<td></td>
<td>$0.1$</td>
<td>$1$</td>
<td>µA</td>
</tr>
<tr>
<td>$</td>
<td>Z_{\text{KA}}</td>
<td>$</td>
<td>Dynamic impedance$^{(1)}$</td>
<td>$I_{\text{KA}} = 1 \text{ mA}$ to 100 mA, $V_{\text{KA}} = V_{\text{REF}}$, $f \leq 1 \text{ kHz}$, see Figure 20</td>
<td></td>
</tr>
</tbody>
</table>

$^{(1)}$ The deviation parameters ($V_{(\text{DEV})}$ and $I_{(\text{DEV})}$) are defined as the differences between the maximum and minimum values obtained over the recommended temperature range.

## 6.6 Electrical Characteristics: TL43xA-Q1

over recommended operating conditions, $T_A = 25^\circ C$ (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{REF}}$</td>
<td>$V_{\text{KA}} = V_{\text{REF}}$, $I_{\text{KA}} = 10 \text{ mA}$, see Figure 20</td>
<td></td>
<td>$2470$</td>
<td>$2495$</td>
<td>$2520$</td>
</tr>
<tr>
<td>$V_{(\text{DEV})}$</td>
<td>Deviation of reference voltage over full temperature$^{(1)}$</td>
<td>$V_{\text{KA}} = V_{\text{REF}}$, $I_{\text{KA}} = 10 \text{ mA}$, $T_A = -40^\circ C$ to $125^\circ C$, see Figure 20</td>
<td></td>
<td>$14$</td>
<td>$34$</td>
</tr>
<tr>
<td>$\Delta V_{\text{REF}}/\Delta V_{\text{KA}}$</td>
<td>Ratio of change in reference voltage to the change in cathode voltage</td>
<td>$I_{\text{KA}} = 10 \text{ mA}$, see Figure 21</td>
<td>$\Delta V_{\text{KA}} = 10 \text{ V} - V_{\text{REF}}$</td>
<td>$-1.4$</td>
<td>$-2.7$</td>
</tr>
<tr>
<td>$I_{\text{REF}}$</td>
<td>$I_{\text{KA}} = 10 \text{ mA}$, $R_1 = 10 \text{ k}\Omega$, $R_2 = \infty$, see Figure 21</td>
<td></td>
<td></td>
<td>$2$</td>
<td>$4$</td>
</tr>
<tr>
<td>$I_{(\text{DEV})}$</td>
<td>Deviation of reference current over full temperature$^{(1)}$</td>
<td>$I_{\text{KA}} = 10 \text{ mA}$, $R_1 = 10 \text{ k}\Omega$, $R_2 = \infty$, $T_A = 36 \text{ V}$, $V_{\text{REF}} = 0$, see Figure 22</td>
<td></td>
<td>$0.1$</td>
<td>$0.5$</td>
</tr>
<tr>
<td>$I_{\text{MIN}}$</td>
<td>Minimum cathode current for regulation</td>
<td>$V_{\text{KA}} = V_{\text{REF}}$, see Figure 20</td>
<td></td>
<td>$0.2$</td>
<td>$0.5$</td>
</tr>
<tr>
<td>$I_{\text{OFF}}$</td>
<td>Off-state cathode current</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>Z_{\text{KA}}</td>
<td>$</td>
<td>Dynamic impedance$^{(1)}$</td>
<td>$I_{\text{KA}} = 1 \text{ mA}$ to 100 mA, $V_{\text{KA}} = V_{\text{REF}}$, $f \leq 1 \text{ kHz}$, see Figure 20</td>
<td></td>
</tr>
</tbody>
</table>

$^{(1)}$ The deviation parameters ($V_{(\text{DEV})}$ and $I_{(\text{DEV})}$) are defined as the differences between the maximum and minimum values obtained over the recommended temperature range.

## 6.7 Electrical Characteristics: TL43xB-Q1

over recommended operating conditions, $T_A = 25^\circ C$ (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{REF}}$</td>
<td>$V_{\text{KA}} = V_{\text{REF}}$, $I_{\text{KA}} = 10 \text{ mA}$, see Figure 20</td>
<td></td>
<td>$2483$</td>
<td>$2495$</td>
<td>$2507$</td>
</tr>
<tr>
<td>$V_{(\text{DEV})}$</td>
<td>Deviation of reference voltage over full temperature$^{(1)}$</td>
<td>$V_{\text{KA}} = V_{\text{REF}}$, $I_{\text{KA}} = 10 \text{ mA}$, $T_A = -40^\circ C$ to $125^\circ C$, see Figure 20</td>
<td></td>
<td>$14$</td>
<td>$34$</td>
</tr>
<tr>
<td>$\Delta V_{\text{REF}}/\Delta V_{\text{KA}}$</td>
<td>Ratio of change in reference voltage to the change in cathode voltage</td>
<td>$I_{\text{KA}} = 10 \text{ mA}$, see Figure 21</td>
<td>$\Delta V_{\text{KA}} = 10 \text{ V} - V_{\text{REF}}$</td>
<td>$-1.4$</td>
<td>$-2.7$</td>
</tr>
<tr>
<td>$I_{\text{REF}}$</td>
<td>$I_{\text{KA}} = 10 \text{ mA}$, $R_1 = 10 \text{ k}\Omega$, $R_2 = \infty$, see Figure 21</td>
<td></td>
<td></td>
<td>$2$</td>
<td>$4$</td>
</tr>
<tr>
<td>$I_{(\text{DEV})}$</td>
<td>Deviation of reference current over full temperature$^{(1)}$</td>
<td>$I_{\text{KA}} = 10 \text{ mA}$, $R_1 = 10 \text{ k}\Omega$, $R_2 = \infty$, $T_A = 36 \text{ V}$, $V_{\text{REF}} = 0$, see Figure 22</td>
<td></td>
<td>$0.1$</td>
<td>$0.5$</td>
</tr>
<tr>
<td>$I_{\text{MIN}}$</td>
<td>Minimum cathode current for regulation</td>
<td>$V_{\text{KA}} = V_{\text{REF}}$, see Figure 20</td>
<td></td>
<td>$0.4$</td>
<td>$0.7$</td>
</tr>
<tr>
<td>$I_{\text{OFF}}$</td>
<td>Off-state cathode current</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>Z_{\text{KA}}</td>
<td>$</td>
<td>Dynamic impedance$^{(1)}$</td>
<td>$I_{\text{KA}} = 1 \text{ mA}$ to 100 mA, $V_{\text{KA}} = V_{\text{REF}}$, $f \leq 1 \text{ kHz}$, see Figure 20</td>
<td></td>
</tr>
</tbody>
</table>

$^{(1)}$ The deviation parameters ($V_{(\text{DEV})}$ and $I_{(\text{DEV})}$) are defined as the differences between the maximum and minimum values obtained over the recommended temperature range.
6.8 Typical Characteristics

Data is for devices having the indicated value of \( V_{\text{REF}} \) at \( I_{\text{KA}} = 10 \, \text{mA}, \) \( T_A = 25^\circ\text{C}. \)

**Figure 1. Reference Voltage vs Free-air Temperature**

**Figure 2. Reference Current vs Free-air Temperature**

**Figure 3. Cathode Current vs Cathode Voltage**

**Figure 4. Cathode Current vs Cathode Voltage**

**Figure 5. OFF-State Cathode Current vs Free-air Temperature**

**Figure 6. Ratio of Delta Reference Voltage to Delta Cathode Voltage vs Free-air Temperature**
Typical Characteristics (continued)

Figure 7. Equivalent Input Noise Voltage vs Frequency

Figure 8. Equivalent Input Noise Voltage Over a 10-s Period

Figure 9. Small-Signal Voltage Amplification vs Frequency

Figure 10. Reference Impedance vs Frequency

Figure 11. Pulse Response

Figure 12. Stability Boundary Conditions for All TL43x Devices (Except for SOT23-3, SC-70, and Q-TEMP Devices)

The areas under the curves represent conditions that may cause the device to oscillate. For curves B, C, and D, R2 and \( V_{\text{REF}} \) were adjusted to establish the initial \( V_{\text{KA}} \) and \( I_{\text{KA}} \) conditions with \( C_L = 0 \). \( V_{\text{BATT}} \) and \( C_L \) then were adjusted to determine the ranges of stability (see Figure 18 and Figure 19 for test circuits).
Typical Characteristics (continued)

The areas under the curves represent conditions that may cause the device to oscillate. For curves B, C, and D, R2 and \( V_{REF} \) were adjusted to establish the initial \( V_{KA} \) and \( I_{KA} \) conditions with \( C_L = 0 \). \( V_{BATT} \) and \( C_L \) then were adjusted to determine the ranges of stability (see Figure 18 and Figure 19 for test circuits).

Figure 13. Stability Boundary Conditions for All TL43x, SOT-23, SC-70, and Q-TEMP Devices
7 Parameter Measurement Information

Figure 14. Test Circuit for Equivalent Input Noise Voltage

Figure 15. Test Circuit for Voltage Amplification

Figure 16. Test Circuit for Reference Impedance

Figure 17. Test Circuit for Pulse Response

Figure 18. Test Circuit for Curve A
Figure 19. Test Circuit for Curves B, C, and D

Figure 20. Test Circuit for \(V_{KA} = V_{REF}\)

Figure 21. Test Circuit for \(V_{KA} > V_{REF}\)

Figure 22. Test Circuit for \(I_{OFF}\)
8 Detailed Description

8.1 Overview

This 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 fundamental analog building blocks. The TL43x-Q1 can be used as a single voltage reference, error amplifier, voltage clamp, or comparator with integrated reference.

The TL43x-Q1 can be operated and adjusted to cathode voltages from 2.5 V to 36 V, making this part optimum for a wide range of end equipments in industrial, auto, telecommunications, and computing. For this device to behave as a shunt regulator or error amplifier, at least 1 mA ($I_{\text{MIN/\text{MAX}}}$) must be supplied 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% and 1%. These reference options are denoted by B (0.5%) or A (1%) in the part number (TL431x-Q1).

8.2 Functional Block Diagram

![Equivalent Schematic](image1)

**Figure 23.** Equivalent Schematic

![Detailed Schematic](image2)

All component values are nominal.

**Figure 24.** Detailed Schematic
8.3 Feature Description

The TL43x-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 24. A Darlington pair is used to allow this device to sink a maximum current of 100 mA.

When operated with enough voltage headroom (at least 2.5 V) and cathode current (I_{KA}), the TL43x-Q1 forces the reference pin to 2.5 V. However, the reference pin can not be left floating, as I_{REF} must be at least 4 µA (see Specifications). This is because the reference pin is driven into an NPN, which requires base current to operate properly.

When feedback is applied from the CATHODE and REF pins, the TL43x-Q1 behaves as a Zener diode, 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 required 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 the device enough gain.

Unlike many linear regulators, the TL43x-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 24 can be used as a guide to assist in choosing the correct capacitor to maintain stability.

8.4 Device Functional Modes

8.4.1 Open Loop (Comparator)

When the cathode or output voltage or current of the TL43x-Q1 is not being fed back to the reference or input pin in any form, the device operates in open loop. With proper cathode current (I_{KA}) applied to this device, the TL43x-Q1 has the characteristics shown in Figure 24. With such high gain in this configuration, the device is typically used as a comparator. The integrated reference makes TL43x the preferred choice when trying to monitor a certain level of a single signal for applications such as undervoltage and overvoltage detection.

When designing with open loop mode, it is important to ensure that the I_{REF} not violate 10mA. For design recommendations and considerations for open loop mode look into Using the TL431 for Undervoltage and Overvoltage Detection.

8.4.2 Closed Loop

When the cathode or output voltage or current of the TL43x-Q1 is being fed back to the reference or input pin in any form, the device operates in closed loop. The majority of applications involving the TL43x-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.

Figure 25. Logic Symbol
9 Application 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.

9.1 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 make the best choices when using this part.

Understanding Stability Boundary Conditions Charts in TL431, TL432 Data Sheet provides a deeper understanding of this device's stability characteristics and aid the user in making the right choices when choosing a load capacitor. Setting the Shunt Voltage on an Adjustable Shunt Regulator assists designers in setting the shunt voltage to achieve optimum accuracy for this device.

9.2 Typical Applications

9.2.1 Comparator Application

Figure 26. Comparator Application Schematic
Typical Applications (continued)

9.2.1.1 Design Requirements

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

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
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<tr>
<td>Input voltage</td>
<td>0 V to 5 V</td>
</tr>
<tr>
<td>Input resistance</td>
<td>10 kΩ</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>24 V</td>
</tr>
<tr>
<td>Cathode current, $I_K$</td>
<td>5 mA</td>
</tr>
<tr>
<td>Output voltage level</td>
<td>Approximately 2 V to $V_{SUP}$</td>
</tr>
<tr>
<td>Logic input thresholds, $V_{IH}$ / $V_{IL}$</td>
<td>$V_L$</td>
</tr>
</tbody>
</table>

9.2.1.2 Detailed Design Procedure

When using the TL43x-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

9.2.1.2.1 Basic Operation

In the configuration shown in Figure 26 the TL43x-Q1 behaves as a comparator, comparing the REF pin voltage to the internal virtual reference voltage. When provided a proper cathode current ($I_K$), the TL43x-Q1 has enough open loop gain to provide a quick response. This is shown in Figure 27, where the $R_{SUP} = 10$ kΩ ($I_K = 500$ µA) situation responds much slower than $R_{SUP} = 1$ kΩ ($I_K = 5$ mA). With the TL43x-Q1's maximum operating current ($I_{MIN}$) being 1 mA, operation below that could result in low gain, leading to a slow response.

9.2.1.2.2 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 2.5 V ± (0.5%, 1%, or 1.5%) depending on which version is being used. The more overdrive voltage provided, the faster the TL43x-Q1 responds.

For applications where the TL43x-Q1 is being used as a comparator, it is best to set the trip point to greater than the positive expected error (for example: +1% for the A version). For fast response, setting the trip point to at least 10% of the internal $V_{REF}$ should suffice.

For minimal drop or difference from $V_{INREF}$ to the REF pin, TI recommends using an input resistor <10 kΩ to provide $I_{REF}$

9.2.1.2.3 Output Voltage and Logic Input Level

For the TL43x-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 26, the TL43x-Q1's output low level voltage in open-loop or comparator mode is approximately 2 V, which is typically sufficient for 5-V supplied logic. However, would 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 TL43x-Q1's output high voltage is equal to $V_{SUP}$ due to the TL43x-Q1 being open-collector. If $V_{SUP}$ is much higher than the receiving logic's maximum input voltage tolerance, the output must be attenuated to accommodate the outgoing logic's reliability.

When using a resistive divider on the output, ensure the sum of the resistive divider (R1 and R2 in Figure 24) is much greater than $R_{SUP}$ to not interfere with the TL43x-Q1's ability to pull close to $V_{SUP}$ when turning off.
9.2.1.2.4 Input Resistance

In this application, the TL43x-Q1 requires an input resistance in addition to the reference current (I_{REF}) to ensure the device is in the proper operating regions while turning on. The actual voltage seen at the REF pin is \( V_{\text{REF}} = V_{\text{IN}} - I_{\text{REF}} \times R_{\text{IN}} \). Because \( I_{\text{REF}} \) can be as high as 4 µA, TI recommends using a resistance small enough to mitigate the error that \( I_{\text{REF}} \) creates from \( V_{\text{IN}} \).

9.2.1.2.5 Deviation Parameters and Calculating Dynamic Impedance

The deviation parameters, \( V_{\text{I(DEV)}} \) and \( I_{\text{I(DEV)}} \), are defined as the differences between the maximum and minimum values obtained over the recommended temperature range. The average full-range temperature coefficient of the reference voltage (\( \alpha_{V_{\text{ref}}} \)) is defined in Equation 1.

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

where

- \( \Delta T_A \) is the recommended operating free-air temperature range of the device

\( \alpha_{V_{\text{ref}}} \) can be positive or negative, depending on whether minimum \( V_{\text{REF}} \) or maximum \( V_{\text{REF}} \), respectively, occurs at the lower temperature.

Example:

Maximum \( V_{\text{REF}} \) = 2496 mV at 30°C, minimum \( V_{\text{REF}} \) = 2492 mV at 0°C, \( V_{\text{REF}} \) = 2495 mV at 25°C, \( \Delta T_A = 70°C \)
for TL43x.

\[
\left| \alpha_{V_{\text{ref}}} \right| = \left( \frac{4 \text{ mV}}{70°C} \right) \times 10^6 \approx 23 \text{ ppm/°C}
\]

Because minimum \( V_{\text{REF}} \) occurs at the lower temperature, the coefficient is positive.

The dynamic impedance is defined as \( |Z_{\text{KA}}| = \Delta V_{\text{KA}} / \Delta I_{\text{KA}} \).

When the device is operating with two external resistors, see Figure 21, the total dynamic impedance of the circuit is given by Equation 3.

\[
|Z| \approx \left| Z_{\text{KA}} \right| \left( 1 + \frac{R1}{R2} \right)
\]

9.2.1.3 Application Curve

Figure 27. Output Response With Various Cathode Currents
9.2.2 Other Application Circuits

Figure 28 to Figure 40 show application circuit examples using the TL431-Q1 device. Customers must fully validate and test any circuit before implementing a design based on an example in this section. Unless otherwise noted, the design procedures in Comparator Application are applicable.

Figure 28. Shunt Regulator

A. R must provide cathode current ≥1 mA to the TL431-Q1 at minimum \( V_{I(BATT)} \).

Figure 29. Single-Supply Comparator with Temperature-Compensated Threshold

Figure 30. Precision High-Current Series Regulator

Figure 31. Output Control of a Three-Terminal Fixed Regulator

Figure 32. High-Current Shunt Regulator

Figure 33. Crowbar Circuit

(1) See Figure 12 and Figure 13 to determine allowable values for \( C \).
(1) \( R_b \) must provide cathode current \( \geq 1 \) mA to the TL431-Q1.

A. R3 and R4 are selected to provide the desired LED intensity and cathode current \( \geq 1 \) mA to the TL431-Q1 at the available \( V_{I(BATT)} \).

![Figure 34. Precision 5-V, 1.5-A Regulator](image)

![Figure 35. Efficient 5-V Precision Regulator](image)

![Figure 36. PWM Converter with Reference](image)

![Figure 37. Voltage Monitor](image)

![Figure 38. Delay Timer](image)

![Figure 39. Precision Current Limiter](image)
10 Power Supply Recommendations

When using the TL43x-Q1 as a linear regulator to supply a load, designers typically use a bypass capacitor on the output or cathode pin. When doing this, be sure that the capacitance is within the stability criteria shown in Figure 12 and Figure 13.

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 its 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.

11 Layout

11.1 Layout Guidelines

Bypass capacitors must be placed as close to the device as possible. Current-carrying traces must have widths appropriate for the amount of current they are carrying; in the case of the TL43x-Q1, these currents are low.

11.2 Layout Example

Figure 41. DBZ Layout Example
12 Device and Documentation Support

12.1 Documentation Support

12.1.1 Related Documentation
For related documentation see the following:
- Automotive LED Lighting with Adjustable Shunt References
- Understanding Stability Boundary Conditions Charts in TL431, TL432 Data Sheet
- Setting the Shunt Voltage on an Adjustable Shunt Regulator

12.2 Related Links
The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

<table>
<thead>
<tr>
<th>PARTS</th>
<th>PRODUCT FOLDER</th>
<th>SAMPLE &amp; BUY</th>
<th>TECHNICAL DOCUMENTS</th>
<th>TOOLS &amp; SOFTWARE</th>
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12.3 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.

12.4 Community 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.

12.5 Trademarks
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All other trademarks are the property of their respective owners.

12.6 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.

12.7 Glossary
SLYZ022 — TI Glossary.
This glossary lists and explains terms, acronyms, and definitions.

13 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

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<th>Package Drawing</th>
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<th>Lead finish/Ball material (6)</th>
<th>MSL Peak Temp (3)</th>
<th>Op Temp (°C)</th>
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(1) The marketing status values are defined as follows:
- **ACTIVE**: Product device recommended for new designs.
- **LIFEBUY**: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
- **NRND**: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
- **PREVIEW**: Device has been announced but is not in production. Samples may or may not be available.
- **OBSOLETE**: TI has discontinued the production of the device.

(2) **RoHS**: TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
- **RoHS Exempt**: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
- **Green**: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) **MSL, Peak Temp.** - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) **Lead finish/Ball material**: Orderable Devices 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.
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OTHER QUALIFIED VERSIONS OF TL431-Q1, TL432-Q1:

• Catalog: TL431, TL432

NOTE: Qualified Version Definitions:

• Catalog - TI's standard catalog product
## TAPE AND REEL INFORMATION

### 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

### REEL DIMENSIONS

- Reel Diameter
- Reel Width (W1)

### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE

- **S1** S1
- **S2** S2
- **S3** S3
- **S4** S4

### PACKAGE MATERIALS INFORMATION

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*All dimensions are nominal.*
### TAPE AND REEL BOX DIMENSIONS

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*All dimensions are nominal*
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.
4. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25 mm per side.
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.
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.
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.
NOTES: (continued)

4. Publication IPC-7351 may have alternate designs.
5. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

7. Board assembly site may have different recommendations for stencil design.
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