TL1431 Precision Programmable Reference

1 Features

• 0.4% Initial Voltage Tolerance
• 0.2-Ω Typical Output Impedance
• Fast Turnon (500 ns)
• Sink Current Capability (1 mA to 100 mA)
• Low Reference Current (REF)
• Adjustable Output Voltage (V\text{\(I\text{(ref)}\)} 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 TL1431 device is a precision programmable reference with specified thermal stability over automotive, commercial, and military temperature ranges. The output voltage can be set to any value between V\text{\(I\text{(ref)}\)} (approximately 2.5 V) and 36 V with two external resistors (see Figure 25). This device has a typical output impedance of 0.2 Ω. Active output circuitry provides a sharp turnon characteristic, making the device an excellent replacement for Zener diodes and other types of references in applications such as onboard regulation, adjustable power supplies, and switching power supplies.

The TL1431C is characterized for operation over the commercial temperature range of 0°C to 70°C. The TL1431Q is characterized for operation over the full automotive temperature range of –40°C to 125°C. The TL1431M is characterized for operation over the full military temperature range of –55°C to 125°C.

Device Information\(^{(1)}\)

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>PACKAGE</th>
<th>BODY SIZE (NOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL1431D</td>
<td>SOIC (8)</td>
<td>3.90 mm × 4.90 mm</td>
</tr>
<tr>
<td>TL1431PW</td>
<td>TSSOP (8)</td>
<td>4.40 mm × 3.00 mm</td>
</tr>
<tr>
<td>TL1431LP</td>
<td>TO-92 (3)</td>
<td>4.83 mm × 3.68 mm</td>
</tr>
<tr>
<td>TL1431MJG</td>
<td>CDIP (8)</td>
<td>9.58 mm x 6.67 mm</td>
</tr>
<tr>
<td>TL1431MFK</td>
<td>LCCC (20)</td>
<td>8.89 mm x 8.89 mm</td>
</tr>
</tbody>
</table>

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

Simplified Schematic

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4 Revision History

Changes from Revision M (April 2012) to Revision N  
Page

• Added Device Information table, ESD Ratings table, Feature Description section, Device Functional Modes, Application and Implementation section, Power Supply Recommendations section, Layout section, Device and Documentation Support section, and Mechanical, Packaging, and Orderable Information section .............................................................. 1

• Deleted ORDERING INFORMATION table; see POA at the end of the data sheet ................................................................................................. 1

• Changed $R_{\theta JA}$ for D, LP and PW package from: 97 °C/W to 114.7 °C/W (D), 140 °C/W to 157 °C/W (LP) and 149 °C/W to 172.4 °C/W (PW) in the Thermal Information table .............................................................. 4

• Changed $R_{\theta JC(bot)}$ for FK and JG package from: 5.61 °C/W to 9.5 °C/W (FK) and 14.5 °C/W to 9.5 °C/W (JG) in the Thermal Information table ............................................................................................................... 4

Changes from Revision L (October 2007) to Revision M  
Page

• Added Ammo option to the LP package in the ORDERING INFORMATION table ........................................................................................................ 2

Submit Documentation Feedback
5 Pin Configuration and Functions

D Package
9-Pin SOIC
Top View

CATHODE 1 8 REF
ANODE 2 7 ANODE
ANODE 3 6 ANODE
NC 4 5 NC

LP Package
3-Pin TO-92
Top View

CATHODE
ANODE
REF

CATHODE
ANODE
REF

JG or PW Package
8-Pin CDIP or TSSOP
Top View

CATHODE 1 8 REF
NC 2 7 NC
NC 3 6 ANODE
NC 4 5 NC

FK Package
20-Pin LCCC
Top View

Pin Functions

<table>
<thead>
<tr>
<th>NAME</th>
<th>SOIC</th>
<th>CDIP, TSSOP</th>
<th>TO-92</th>
<th>LCCC</th>
<th>I/O</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANODE</td>
<td>2, 3, 6, 7</td>
<td>6</td>
<td>2</td>
<td>15</td>
<td>O</td>
<td>Common pin, normally connected to ground</td>
</tr>
<tr>
<td>CATHODE</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>I/O</td>
<td>Shunt current/voltage input</td>
</tr>
<tr>
<td>REF</td>
<td>8</td>
<td>8</td>
<td>3</td>
<td>20</td>
<td>I</td>
<td>Threshold relative to common ground</td>
</tr>
<tr>
<td>NC</td>
<td>4, 5</td>
<td>2, 3, 4, 5, 7</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>No internal connection</td>
</tr>
</tbody>
</table>
6 Specifications

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

<table>
<thead>
<tr>
<th></th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode voltage, (V_{KA})(^{(2)})</td>
<td></td>
<td>37</td>
<td>V</td>
</tr>
<tr>
<td>Continuous cathode current, (I_{KA})</td>
<td>-100</td>
<td>150</td>
<td>mA</td>
</tr>
<tr>
<td>Reference input current, (I_{\text{ref}})</td>
<td>-0.05</td>
<td>10</td>
<td>mA</td>
</tr>
<tr>
<td>Lead temperature, 1.6 mm (1/16 in) from case for 10 s</td>
<td>260</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>Junction temperature, (T_J)</td>
<td>150</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature, (T_{\text{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, and functional operation of the device at these or any other conditions beyond those indicated under recommended operating conditions is not implied. 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.

6.2 ESD Ratings – TL1431C, TL1431Q

<table>
<thead>
<tr>
<th>(V_{\text{ESD}})</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrostatic discharge</td>
<td>Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(^{(1)})</td>
<td>±2000</td>
</tr>
<tr>
<td></td>
<td>Charged-device model (CDM), per JEDEC specification JESD22-C101(^{(2)})</td>
<td>±1000</td>
</tr>
</tbody>
</table>

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

<table>
<thead>
<tr>
<th></th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{KA}) Cathode voltage</td>
<td>0</td>
<td>70</td>
<td>V</td>
</tr>
<tr>
<td>(I_{KA}) Cathode current</td>
<td>1</td>
<td>100</td>
<td>mA</td>
</tr>
<tr>
<td>(T_A) Operating free-air temperature</td>
<td>TL1431C</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>TL1431Q</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>TL1431M</td>
<td></td>
<td>°C</td>
</tr>
</tbody>
</table>

6.4 Thermal Information

<table>
<thead>
<tr>
<th>THERMAL METRIC(^{(1)})</th>
<th>TL1431</th>
<th>TL1431M(^{(2)})</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_{\text{JA}}) Junction-to-ambient thermal resistance</td>
<td>157</td>
<td>114.7</td>
<td>172.4</td>
</tr>
<tr>
<td>(R_{\text{JC(top)}}) Junction-to-case (top) thermal resistance</td>
<td>80.7</td>
<td>59</td>
<td>55.2</td>
</tr>
<tr>
<td>(R_{\text{JB}}) Junction-to-board thermal resistance</td>
<td>—</td>
<td>55.4</td>
<td>100.8</td>
</tr>
<tr>
<td>(\psi_{\text{JT}}) Junction-to-top characterization parameter</td>
<td>24.6</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>(\psi_{\text{JB}}) Junction-to-board characterization parameter</td>
<td>136.4</td>
<td>54.8</td>
<td>99</td>
</tr>
<tr>
<td>(R_{\text{JC(bot)}}) Junction-to-case (bottom) thermal resistance</td>
<td>—</td>
<td>—</td>
<td>21</td>
</tr>
</tbody>
</table>

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

(2) \(R_{\text{JC}}\) based on MIL-STD-883, and \(R_{\text{JB}}\) based on JESD51.
6.5 Electrical Characteristics – TL1431C

at specified free-air temperature and $I_{KA} =$ 10 mA (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>$V_{I(ref)}$</td>
<td>Reference input voltage</td>
<td>$V_{KA} = V_{I(ref)}$ (see Figure 13)</td>
<td>$T_A = 25°C$</td>
<td>2490</td>
<td>2500</td>
</tr>
<tr>
<td>$V_{I(dev)}$</td>
<td>Deviation of reference input voltage over full temperature range(^{(1)})</td>
<td>$V_{KA} = V_{I(ref)}, T_A = 0°C$ to $70°C$ (see Figure 13)</td>
<td>4</td>
<td>20</td>
<td>mV</td>
</tr>
<tr>
<td>$\frac{\Delta V_{I}}{\Delta T_A}$ Ratio of change in reference input voltage to the change in cathode voltage</td>
<td>$\Delta V_{KA} = 3$ V to $36$ V, $T_A = 0°C$ to $70°C$ (see Figure 14)</td>
<td>$T_A = 0°C$ to $70°C$</td>
<td>-1.1</td>
<td>-2</td>
<td>mV/V</td>
</tr>
<tr>
<td>$I_{I(ref)}$</td>
<td>Reference input current</td>
<td>$R_1 = 10$ kΩ, $R_2 = \infty$ (see Figure 14)</td>
<td>$T_A = 25°C$</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>$I_{I(dev)}$</td>
<td>Deviation of reference input current over full temperature range(^{(1)})</td>
<td>$R_1 = 10$ kΩ, $R_2 = \infty$, $T_A = 0°C$ to $70°C$ (see Figure 14)</td>
<td>0.2</td>
<td>1.2</td>
<td>µA</td>
</tr>
<tr>
<td>$I_{min}$</td>
<td>Minimum cathode current for regulation</td>
<td>$V_{KA} = V_{I(ref)}$, $T_A = 25°C$ (see Figure 13)</td>
<td>0.45</td>
<td>1</td>
<td>mA</td>
</tr>
<tr>
<td>$I_{off}$</td>
<td>Off-state cathode current</td>
<td>$V_{KA} = 36$ V, $V_{I(ref)} = 0$ (see Figure 15)</td>
<td>$T_A = 25°C$</td>
<td>0.18</td>
<td>0.5</td>
</tr>
<tr>
<td>$</td>
<td>z_{KA}</td>
<td>$ Output impedance(^{(2)})</td>
<td>$V_{KA} = V_{I(ref)}$, $f \leq 1$ kHz, $I_{KA} = 1$ mA to $100$ mA, $T_A = 25°C$ (see Figure 13)</td>
<td>0.2</td>
<td>0.4</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 rated temperature range. The average full-range temperature coefficient of the reference input voltage $\alpha_{V_{I(ref)}}$ is defined as:

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

where:

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

$\alpha_{V_{I(ref)}}$ is positive or negative, depending on whether minimum $V_{I(ref)}$ or maximum $V_{I(ref)}$, respectively, occurs at the lower temperature.

\(^{(2)}\) The output impedance is defined as:

$$|z_{KA}| = \frac{\Delta V_{KA}}{\Delta T_A}$$

When the device is operating with two external resistors (see Figure 2), the total dynamic impedance of the circuit is given by:

$$|z'| = \frac{\Delta V}{\Delta T}$$

which is approximately equal to $|z_{KA}| \left( 1 + \frac{R_1}{R_2} \right)$.
6.6 Electrical Characteristics – TL1431Q

at specified free-air temperature and $I_{KA} = 10$ mA (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>$V_{I(ref)}$ Reference input voltage</td>
<td>$V_{KA} = V_{I(ref)}$ (see Figure 13)</td>
<td>2490</td>
<td>2500</td>
<td>2510</td>
<td>mV</td>
</tr>
<tr>
<td>$V_{I(dev)}$ Deviation of reference input voltage over full temperature range $^{(1)}$</td>
<td>$V_{KA} = V_{I(ref)}, T_A = -40^\circ$ C to 125$^\circ$ C (see Figure 13)</td>
<td>17</td>
<td>55</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>$\Delta V_{I(ref)}$ Ratio of change in reference input voltage to the change in cathode voltage</td>
<td>$\Delta V_{KA} = 3$ V to 36 V, $T_A = -40^\circ$ C to 125$^\circ$ C (see Figure 14)</td>
<td>-1.1</td>
<td>-2</td>
<td></td>
<td>mV/V</td>
</tr>
<tr>
<td>$I_{I(ref)}$ Reference input current</td>
<td>$R_1 = 10 \text{k}\Omega, R_2 = \infty$ (see Figure 14)</td>
<td>1.5</td>
<td>2.5</td>
<td></td>
<td>$\mu A$</td>
</tr>
<tr>
<td>$I_{I(dev)}$ Deviation of reference input current over full temperature range $^{(1)}$</td>
<td>$R_1 = 10 \text{k}\Omega, R_2 = \infty, T_A = -40^\circ$ C to 125$^\circ$ C (see Figure 14)</td>
<td>0.5</td>
<td>2</td>
<td></td>
<td>$\mu A$</td>
</tr>
<tr>
<td>$I_{I(min)}$ Minimum cathode current for regulation</td>
<td>$V_{KA} = V_{I(ref)}, T_A = 25^\circ$ C (see Figure 13)</td>
<td>0.45</td>
<td>1</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>$I_{I(off)}$ Off-state cathode current</td>
<td>$V_{KA} = 36$ V, $V_{I(ref)} = 0$ (see Figure 15)</td>
<td>0.18</td>
<td>0.5</td>
<td></td>
<td>$\mu A$</td>
</tr>
<tr>
<td>$</td>
<td>z</td>
<td>_{KA}$ Output impedance $^{(2)}$</td>
<td>$V_{KA} = V_{I(ref)}, f \leq 1$ kHz, $I_{KA} = 1$ mA to 100 mA, $T_A = 25^\circ$ C (see Figure 13)</td>
<td>0.2</td>
<td>0.4</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 rated temperature range. The average full-range temperature coefficient of the reference input voltage $\alpha_{V_{I(ref)}}$ is defined as:

$$\alpha_{V_{I(ref)}} = \frac{\Delta V_{I(ref)}}{V_{I(ref)} \Delta T_A} \times 10^6$$

where:

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

$\alpha_{V_{I(ref)}}$ is positive or negative, depending on whether minimum $V_{I(ref)}$ or maximum $V_{I(ref)}$, respectively, occurs at the lower temperature.

$^{(2)}$ The output impedance is defined as:

$$|z_{KA}| = \frac{\Delta V}{\Delta I_{KA}}$$

When the device is operating with two external resistors (see Figure 2), the total dynamic impedance of the circuit is given by:

$$|z| = \frac{\Delta V}{\Delta I}, \text{ which is approximately equal to } |z|_{KA} \left(1 + \frac{R_1}{R_2}\right).$$
### 6.7 Electrical Characteristics – TL1431M

at specified free-air temperature and $I_{KA} = 10$ mA (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>$V_{I(ref)}$ Reference input voltage</td>
<td>$V_{KA} = V_{I(ref)}$ (see Figure 13)</td>
<td>2475</td>
<td>2500</td>
<td>2540</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td>$T_A = 25^\circ$C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$T_A = -55^\circ$ to 125$^\circ$C</td>
<td>2460</td>
<td>2550</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{I(dev)}$ Deviation of reference input voltage over full temperature range $^{(1)}$</td>
<td>$V_{KA} = V_{I(ref)}, T_A = -55^\circ$ to 125$^\circ$C (see Figure 13)</td>
<td>17</td>
<td>55</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>$\Delta V_{I(ref)}$ Ratio of change in reference input voltage to the change in cathode voltage</td>
<td>$\Delta V_{KA} = 3$ V to 36 V, $T_A = -55^\circ$ to 125$^\circ$C (see Figure 14)</td>
<td>-1.1</td>
<td>-2</td>
<td></td>
<td>mV/V</td>
</tr>
<tr>
<td>$I_{I(ref)}$ Reference input current</td>
<td>$R_1 = 10$ k$\Omega$, $R_2 = \infty$ (see Figure 14)</td>
<td>1.5</td>
<td>2.5</td>
<td></td>
<td>$\mu$A</td>
</tr>
<tr>
<td></td>
<td>$T_A = 25^\circ$C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$T_A = -55^\circ$ to 125$^\circ$C</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{I(dev)}$ Deviation of reference input current over full temperature range $^{(1)}$</td>
<td>$R_1 = 10$ k$\Omega$, $R_2 = \infty$, $T_A = -55^\circ$ to 125$^\circ$C (see Figure 14)</td>
<td>0.5</td>
<td>3</td>
<td></td>
<td>$\mu$A</td>
</tr>
<tr>
<td>$I_{\text{min}}$ Minimum cathode current for regulation</td>
<td>$V_{KA} = V_{I(ref)}, T_A = 25^\circ$C (see Figure 13)</td>
<td>0.45</td>
<td>1</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>$I_{\text{off}}$ Off-state cathode current</td>
<td>$V_{KA} = 36$ V, $V_{I(ref)} = 0$ (see Figure 15)</td>
<td>0.18</td>
<td>0.5</td>
<td></td>
<td>$\mu$A</td>
</tr>
<tr>
<td></td>
<td>$T_A = 25^\circ$C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$T_A = -55^\circ$ to 125$^\circ$C</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>z_{KA}</td>
<td>$ Output impedance $^{(3)}$</td>
<td>$V_{KA} = V_{I(ref)}$, $f \leq 1$ kHz, $I_{KA} = 1$ mA to 100 mA, $T_A = 25^\circ$C (see Figure 13)</td>
<td>0.2</td>
<td>0.4</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 rated temperature range. The average full-range temperature coefficient of the reference input voltage $\alpha_{V_{I(ref)}}$ is defined as:

$$\alpha_{V_{I(ref)}} \left( \frac{\text{ppm}}{\circ \text{C}} \right) = \frac{\left( V_{I(dev)} \text{ at } 25^\circ \text{C} \right) - V_{I(ref)}}{V_{I(ref)}} \times 10^6$$

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

$^{(2)}$ On products compliant to MIL-PRF-38535, this parameter is not production tested.

$^{(3)}$ The output impedance is defined as:

$|z_{KA}| = \frac{\Delta V_{KA}}{\Delta I_{KA}}$.

When the device is operating with two external resistors (see Figure 2), the total dynamic impedance of the circuit is given by:

$|z'| = \frac{\Delta V}{\Delta T} \cdot \frac{1}{R_1 + \frac{R_2 + R_1}{1}}$.
6.8 Typical Characteristics

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

Table 1. Table Of Graphs

<table>
<thead>
<tr>
<th>GRAPH</th>
<th>FIGURE</th>
</tr>
</thead>
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<td>Reference voltage vs Free-air temperature</td>
<td>Figure 1</td>
</tr>
<tr>
<td>Reference current vs Free-air temperature</td>
<td>Figure 2</td>
</tr>
<tr>
<td>Cathode current vs Cathode voltage</td>
<td>Figure 3, Figure 4</td>
</tr>
<tr>
<td>Off-state cathode current vs Free-air temperature</td>
<td>Figure 5</td>
</tr>
<tr>
<td>Ratio of delta reference voltage to delta cathode voltage vs Free-air temperature</td>
<td>Figure 6</td>
</tr>
<tr>
<td>Equivalent input-noise voltage vs Frequency</td>
<td>Figure 7</td>
</tr>
<tr>
<td>Equivalent input-noise voltage over a 10-second period</td>
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</tr>
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<td>Small-signal voltage amplification vs Frequency</td>
<td>Figure 9</td>
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<tr>
<td>Reference impedance vs Frequency</td>
<td>Figure 10</td>
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<td>Pulse response</td>
<td>Figure 11</td>
</tr>
<tr>
<td>Stability boundary conditions</td>
<td>Figure 12</td>
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</table>
- Off-State Cathode Current vs Free-Air Temperature

- Ratio Of Delta Reference Voltage To Delta Cathode Voltage vs Free-Air Temperature

- Equivalent Input-Noise Voltage vs Frequency

- Equivalent Input-Noise Voltage Over A 10-S Period

- Small-Signal Voltage Amplification vs Frequency

- Reference Impedance vs Frequency
7 Parameter Measurement Information

Figure 11. Pulse Response

Figure 12. Stability Boundary Conditions

The areas under the curves represent conditions that may cause the device to oscillate. For curves B, C, and D, 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 13. Test Circuit For V_(KA) = V_ref

Figure 14. Test Circuit For V_(KA) > V_ref

V_KA = V_(ref) \left( 1 + \frac{R1}{R2} \right) + I_(ref) \times R1

Figure 15. Test Circuit For I_off

Figure 16. Test Circuit For 0.1-Hz To 10-Hz Equivalent Input-Noise Voltage
Parameter Measurement Information (continued)

Figure 17. Test Circuit For Voltage Amplification

Pulse Generator
f = 100 kHz

Figure 18. Test Circuit For Reference Impedance

Test Circuit for Curve A

Test Circuit for Curves B, C, and D

Figure 19. Test Circuit For Pulse Response

Figure 20. Test Circuits For Curves A Through D
8 Detailed Description

8.1 Overview
The TL1431 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. TL1431 is used in conjunction with its key components to behave as a single voltage reference, error amplifier, voltage clamp, or comparator with integrated reference. TL1431 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, telecom, and computing. In order for this device to behave as a shunt regulator or error amplifier, >1 mA (Imin(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 0.4% and 1%. The TL1431C devices are characterized for operation from 0°C to 70°C, the TL1431Q devices are characterized for operation from –40°C to 125°C, and the TL1431M devices are characterized for operation from –55°C to 125°C.

8.2 Functional Block Diagram

Figure 21. Equivalent Schematic
8.3 Feature Description

TL1431 consists of an internal reference and amplifier that outputs a sink current base 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 22. A Darlington pair is used in order for this device to be able to sink a maximum current of 100 mA. When operated with enough voltage headroom (≥ 2.5 V) and cathode current (I_{KA}), TL1431 forces the reference pin to 2.5 V. However, the reference pin can not be left floating, as it needs I_{REF} ≥ 5 µA (see Electrical Characteristics – TL1431M). This is because the reference pin is driven into an npn, which needs base current to operate properly. When feedback is applied from the cathode and reference pins, TL1431 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 needed in the above feedback situation must be applied to this device in open loop, servo, or error amplifying implementations in order for it to be in the proper linear region giving TL1431 enough gain. Unlike many linear regulators, TL1431 is internally compensated to be stable without an output capacitor between the cathode and anode. However, if desired an output capacitor 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 TL1431 is not being fed back to the reference or input pin in any form, this device is operating in open loop. With proper cathode current \( I_{KA} \) applied to this device, TL1431 has the characteristics shown in Figure 22. With such high gain in this configuration, TL1431 is typically used as a comparator. With the reference integrated makes TL1431 the preferred choice when users are trying to monitor a certain level of a single signal.

8.4.2 Closed Loop

When the cathode or output voltage or current of TL1431 is being fed back to the reference or input pin in any form, this device is operating in closed loop. The majority of applications involving TL1431 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.
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 the TL1431 device has many applications and setups, there are many situations that this datasheet cannot characterize in detail. The linked application notes help the designer make the best choices when using this part. Understanding Stability Boundary Conditions Charts in TL431, TL432 Data Sheet (SLVA482) provides a deeper understanding of this devices 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 (SLVA445) assists designers in setting the shunt voltage to achieve optimum accuracy for this device.

9.2 Typical Application

Figure 23. Comparator Application Schematic

9.2.1 Design Requirements
For this design example, use the parameters listed in Table 2 as the input parameters.

Table 2. Design Parameters

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
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<tbody>
<tr>
<td>Reference initial accuracy</td>
<td>0.4%</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>48 V</td>
</tr>
<tr>
<td>Cathode current (I_K)</td>
<td>50 µA</td>
</tr>
<tr>
<td>Output voltage level</td>
<td>2.5 V to 36 V</td>
</tr>
<tr>
<td>Load capacitance</td>
<td>1 nF</td>
</tr>
<tr>
<td>Feedback resistor values and accuracy (R1 and R2)</td>
<td>10 kΩ</td>
</tr>
</tbody>
</table>

9.2.2 Detailed Design Procedure
When using TL1431 as a shunt regulator, determine the following:
• Input voltage range
• Temperature range
• Total accuracy
• Cathode current
9.2.2.1 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 accurately determined by taking in to account the cathode current with Equation 1.

\[ V_o = \left(1 + \frac{R1}{R2}\right) \times V_{REF} - I_{REF} \times R1 \]  

(1)

For this equation to be valid, TL1431 must be fully biased so that it has enough open loop gain to mitigate any gain error. This can be done by meeting the Imin specification denoted in Electrical Characteristics – TL1431M.

9.2.2.2 Total Accuracy

When programming the output above unity gain (\(V_{KA}=V_{REF}\)), TL1431 is susceptible to other errors that may 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.

9.2.2.3 Stability

Though TL1431 is stable with no capacitive load, the device that receives the shunt regulator’s output voltage could present a capacitive load that is within the TL1431 region of stability, shown in Figure 12. Also, designers may 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.

9.2.2.4 Start-up Time

As shown in Figure 24, TL1431 has a fast response up to approximately 2 V and then slowly charges to its programmed value. This is due to the compensation capacitance the TL1431 has to meet its stability criteria. Despite the secondary delay, TL1431 still has a fast response suitable for many clamp applications.

9.2.3 Application Curve

![Figure 24. TL1431 Start-up Response](Image)
9.3 System Examples

Table 3 lists example circuits of the TL1431.

Table 3. Table Of Example Circuits

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>FIGURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shunt regulator</td>
<td>Figure 25</td>
</tr>
<tr>
<td>Single-supply comparator with temperature-compensated threshold</td>
<td>Figure 26</td>
</tr>
<tr>
<td>Precision high-current series regulator</td>
<td>Figure 27</td>
</tr>
<tr>
<td>Output control of a three-terminal fixed regulator</td>
<td>Figure 28</td>
</tr>
<tr>
<td>Higher-current shunt regulator</td>
<td>Figure 29</td>
</tr>
<tr>
<td>Crowbar</td>
<td>Figure 30</td>
</tr>
<tr>
<td>Precision 5-V, 1.5-A, 0.5% regulator</td>
<td>Figure 31</td>
</tr>
<tr>
<td>5-V precision regulator</td>
<td>Figure 32</td>
</tr>
<tr>
<td>PWM converter with 0.5% reference</td>
<td>Figure 33</td>
</tr>
<tr>
<td>Voltage monitor</td>
<td>Figure 34</td>
</tr>
<tr>
<td>Delay timer</td>
<td>Figure 35</td>
</tr>
<tr>
<td>Precision current limiter</td>
<td>Figure 36</td>
</tr>
<tr>
<td>Precision constant-current sink</td>
<td>Figure 37</td>
</tr>
</tbody>
</table>

R must provide cathode current $\geq 1$ mA to the TL1431 at minimum $V_{BATT}$.

Figure 25. Shunt Regulator

Figure 26. Single-Supply Comparator With Temperature-Compensated Threshold
V \text{(BATT)} = 5 \text{ V}

\begin{align*}
R_b & \geq 1 \text{ mA} \\
\text{Copyright © 2016, Texas Instruments Incorporated}
\end{align*}

Figure 27. Precision High-Current Series Regulator

\begin{align*}
V_O &= \left(1 + \frac{R_1}{R_2}\right) V_{\text{ref}} \\
\text{Copyright © 2016, Texas Instruments Incorporated}
\end{align*}

Figure 28. Output Control Of A Three-Terminal Fixed Regulator

\begin{align*}
V_{\text{trip}} &= \left(1 + \frac{R_1}{R_2}\right) V_{\text{ref}} \\
\text{Copyright © 2016, Texas Instruments Incorporated}
\end{align*}

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

Figure 29. Higher-Current Shunt Regulator

\begin{align*}
\text{Copyright © 2016, Texas Instruments Incorporated}
\end{align*}

Figure 30. Crowbar

\begin{align*}
\text{Copyright © 2016, Texas Instruments Incorporated}
\end{align*}

Figure 31. Precision 5-V, 1.5-A, 0.5% Regulator

\begin{align*}
\text{Copyright © 2016, Texas Instruments Incorporated}
\end{align*}

Figure 32. 5-V Precision Regulator

\begin{align*}
\text{Copyright © 2016, Texas Instruments Incorporated}
\end{align*}
Figure 33. PWM Converter With 0.5% Reference

Delay = $R \times C \times \left(\frac{12 V}{(12 V) - V_{I(\text{ref})}}\right)$

Copyright © 2016, Texas Instruments Incorporated

Figure 35. Delay Timer

Figure 34. Voltage Monitor

Figure 36. Precision Current Limiter

Figure 37. Precision Constant-Current Sink
10 Power Supply Recommendations

When using TL1431 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, ensure the supply voltage is current limited. Also, be sure to limit the current being driven into the Ref pin, as not to exceed it's 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 part as possible. Current-carrying traces need to have widths appropriate for the amount of current they are carrying; in the case of the TL1431, these currents are low.

11.2 Layout Example

![Figure 38. PW Package Layout Example](image-url)
12 Device and Documentation Support

12.1 Documentation Support

12.1.1 Related Documentation

For related documentation see the following:

- *Understanding Stability Boundary Conditions Charts in TL431, TL432 Data Sheet* (SLVA482)
- *Setting the Shunt Voltage on an Adjustable Shunt Regulator* (SLVA445)

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.

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<tr>
<td>TL1431M</td>
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</tr>
</tbody>
</table>

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

The following links connect to TI community resources. Linked contents are 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.

**TI E2E™ Online Community** *TI’s Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI’s Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

12.5 Trademarks

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

12.6 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

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>Pins</th>
<th>Package Qty</th>
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<th>Lead/Ball Finish</th>
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<th>Op Temp (°C)</th>
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<td>9962001QPA TL1431M</td>
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<td>SOIC</td>
<td>D</td>
<td>8</td>
<td>75</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU NIPDAU</td>
<td>Level-1-260C-UNLIM</td>
<td>-40 to 125</td>
<td>1431Q</td>
<td></td>
</tr>
<tr>
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<td>ACTIVE</td>
<td>SOIC</td>
<td>D</td>
<td>8</td>
<td>75</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU NIPDAU</td>
<td>Level-1-260C-UNLIM</td>
<td>-40 to 125</td>
<td>1431Q</td>
<td></td>
</tr>
<tr>
<td>TL1431QDR</td>
<td>ACTIVE</td>
<td>SOIC</td>
<td>D</td>
<td>8</td>
<td>2500</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
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<td>Level-1-260C-UNLIM</td>
<td>-40 to 125</td>
<td>1431Q</td>
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<td>D</td>
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<td>2500</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU NIPDAU</td>
<td>Level-1-260C-UNLIM</td>
<td>-40 to 125</td>
<td>1431Q</td>
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<tr>
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<td>ACTIVE</td>
<td>TSSOP</td>
<td>PW</td>
<td>8</td>
<td>2000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU NIPDAU</td>
<td>Level-1-260C-UNLIM</td>
<td>-40 to 125</td>
<td>1431Q</td>
<td></td>
</tr>
</tbody>
</table>

(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) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(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/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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**OTHER QUALIFIED VERSIONS OF TL1431, TL1431M:**

- **Catalog:** TL1431
- **Automotive:** TL1431-Q1, TL1431-Q1
- **Enhanced Product:** TL1431-EP, TL1431-EP
- **Military:** TL1431M
- **Space:** TL1431-SP, TL1431-SP

**NOTE:** Qualified Version Definitions:

- **Catalog:** TI's standard catalog product
- **Automotive:** Q100 devices qualified for high-reliability automotive applications targeting zero defects
- **Enhanced Product:** Supports Defense, Aerospace and Medical Applications
- **Military:** QML certified for Military and Defense Applications
- **Space:** Radiation tolerant, ceramic packaging and qualified for use in Space-based application
TAPE AND REEL INFORMATION

**REEL DIMENSIONS**

**TAPE DIMENSIONS**

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Reel Diameter (mm)</th>
<th>Reel Width W1 (mm)</th>
<th>A0 (mm)</th>
<th>B0 (mm)</th>
<th>K0 (mm)</th>
<th>P1 (mm)</th>
<th>W (mm)</th>
<th>Pin 1 Quadrant</th>
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<tbody>
<tr>
<td>TL1431CDR</td>
<td>SOIC</td>
<td>D</td>
<td>8</td>
<td>2500</td>
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<td>2.1</td>
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<td>12.0</td>
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<td>12.0</td>
<td>Q1</td>
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<tr>
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<td>PW</td>
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<td>2000</td>
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<td>7.0</td>
<td>3.6</td>
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<td>8.0</td>
<td>12.0</td>
<td>Q1</td>
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<td>330.0</td>
<td>12.4</td>
<td>7.0</td>
<td>3.6</td>
<td>1.6</td>
<td>8.0</td>
<td>12.0</td>
<td>Q1</td>
</tr>
</tbody>
</table>

*All dimensions are nominal.*

- 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

---

Pack Materials-Page 1
## TAPE AND REEL BOX DIMENSIONS

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
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<td>D</td>
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<td>TSSOP</td>
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<td>2000</td>
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*All dimensions are nominal*
FK (S-CQCC-N**)
LEADLESS CERAMIC CHIP CARRIER

28 TERMINAL SHOWN

<table>
<thead>
<tr>
<th>NO. OF TERMINALS **</th>
<th>A</th>
<th>B</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>MIN</td>
<td>MAX</td>
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<tr>
<td>20</td>
<td>0.342 (8.69)</td>
<td>0.358 (9.09)</td>
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<tr>
<td>28</td>
<td>0.442 (11.23)</td>
<td>0.458 (11.63)</td>
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<tr>
<td>44</td>
<td>0.640 (16.26)</td>
<td>0.660 (16.76)</td>
</tr>
<tr>
<td>52</td>
<td>0.740 (18.78)</td>
<td>0.761 (19.32)</td>
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<tr>
<td>68</td>
<td>0.938 (23.81)</td>
<td>0.962 (24.43)</td>
</tr>
<tr>
<td>84</td>
<td>1.141 (28.99)</td>
<td>1.165 (29.59)</td>
</tr>
</tbody>
</table>

NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. This package can be hermetically sealed with a metal lid.
D. Falls within JEDEC MS-004
NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0.15) each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0.43) each side.
E. Reference JEDEC MS-012 variation AA.
NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC-7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.
NOTES:  
A. All linear dimensions are in inches (millimeters).  
B. This drawing is subject to change without notice.  
C. This package can be hermetically sealed with a ceramic lid using glass frit.  
D. Index point is provided on cap for terminal identification.  
E. Falls within MIL STD 1835 GDIP1-T8
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. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153, variation AA.
NOTES: (continued)

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

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

9. Board assembly site may have different recommendations for stencil design.
Images above are just a representation of the package family, actual package may vary. Refer to the product data sheet for package details.
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. Lead dimensions are not controlled within this area.
4. Reference JEDEC TO-226, variation AA.
5. Shipping method:
   a. Straight lead option available in bulk pack only.
   b. Formed lead option available in tape and reel or ammo pack.
   c. Specific products can be offered in limited combinations of shipping medium and lead options.
   d. Consult product folder for more information on available options.
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