

具有经优化的基准电流的 TL431LI-Q1/TL432LI-Q1 可编程并联稳压器

1 特性

- 符合汽车类应用要求
- 具有符合 AEC-Q100 标准的下列特性：
 - 器件温度等级 1: -40°C 至 $+125^{\circ}\text{C}$ 的环境工作温度范围
 - 器件温度等级 0: -40°C 至 $+150^{\circ}\text{C}$ 的环境工作温度范围
- 25°C 下的基准电压容差
 - 0.5% (B 级)
 - 1% (A 级)
- 最低输出电压典型值: 2.495V
- 可调输出电压: V_{ref} 至 36V
- 等级 1 最大温漂 27mV
- 等级 0 最大温漂 34mV
- 输出阻抗典型值 0.3Ω
- 灌电流能力
 - $I_{\text{min}} = 0.6\text{mA}$ (最大值)
 - $I_{\text{KA}} = 15\text{mA}$ (最大值)
- 基准输入电流 I_{REF} : $0.4\mu\text{A}$ (最大值)
- 整个温度范围内的基准输入电流偏差 $I_{\text{I(dev)}}$: $0.3\mu\text{A}$ (最大值)

2 应用

- 逆变器和电机控制
- 直流/直流转换器
- LED 照明
- 车载充电器 (OBC)
- 信息娱乐系统和仪表组
- 引擎管理传动器
- 变速器
- 动力转向
- 动力总成排气传感器
- 交流发电机起动机

3 说明

TL431LI-Q1 是一款可调节三端并联稳压器，在适用的汽车级、商用级和军用级温度范围内具有额定的热稳定性。可以通过两个外部电阻器将输出电压设置为 V_{ref} (约为 2.495V) 和 36V 之间的任意值。该器件的输出阻抗典型值为 0.3Ω ，其有源输出电路可提供快速导通特性，从而可在板载稳压、可调节电源和开关电源等多种应用中完美地替代齐纳二极管。这款器件是业界通用 TL431-Q1 的引脚对引脚替代品，具有经优化的 I_{ref} 和 I_{Idev} 性能。TL431LI-Q1 的较低 I_{ref} 和 I_{Idev} 值可帮助设计人员提高系统精度和降低泄漏电流。TL432LI-Q1 具有与 TL431LI-Q1 完全相同的功能和电气规格，但是具有不同的 DBZ 封装引脚排布。

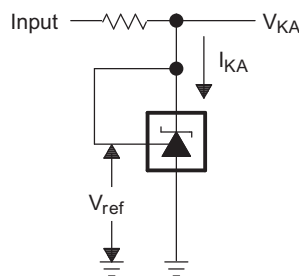
TL431LI-Q1 具有 A、B 两个等级，初始容差（在 25°C 下）分别为 1% 和 0.5%。TL431LI-Q1 还具有两个温度等级，即等级 1（在器件型号中用“Q”表示）和等级 0（在器件型号中用“E”表示），最大环境温度分别为 125°C 和 150°C 。TL43xLI-Q1 等级 1 的额定工作温度范围为 -40°C 至 125°C ，等级 0 为 -40°C 至 150°C ；其低输出温漂可确保在整个温度范围内保持良好稳定性。

器件信息⁽¹⁾

器件型号	封装 (引脚)	封装尺寸 (标称值)
TL43xLI-Q1	SOT-23 (3)	2.90mm x 1.30mm

(1) 如需了解所有可用封装，请参阅数据表末尾的可订购产品附录。

简化原理图



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4 修订历史记录

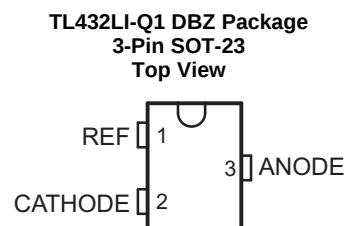
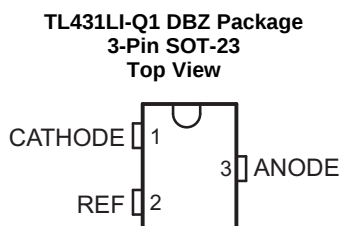
注：之前版本的页码可能与当前版本有所不同。

Changes from Original (May 2019) to Revision A	Page
• 将器件状态从“预告信息”更改为“生产数据”	1

5 Device Comparison Table

DEVICE PINOUT	INITIAL ACCURACY	OPERATING FREE-AIR TEMPERATURE (T _A)
TL431LI-Q1 TL432LI-Q1	A: 1% B: 0.5%	Q: -40°C to 125°C E: -40°C to 150°C

6 Pin Configuration and Functions



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}	Continuous 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
		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
		TL43xLIxE	–40	150

- (1) Maximum power dissipation is a function of $T_{J(max)}$, θ_{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-board thermal resistance	104.7	C/W
Ψ_{JT}	Junction-to-top characterization resistance	23.9	C/W
Ψ_{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, $T_A = 25^\circ\text{C}$ (unless otherwise noted)

PARAMETER	TEST CIRCUIT	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{ref}	Reference Voltage	See 图 14	$V_{KA} = V_{\text{ref}}, I_{KA} = 1 \text{ mA}$			
		TL43xLlAx devices	2470	2495	2520	mV
		TL43xLlBx devices	2483	2495	2507	mV
$V_{I(\text{dev})}$	Deviation of reference input voltage over full temperature range ⁽¹⁾	See 图 14	$V_{KA} = V_{\text{ref}}, I_{KA} = 1 \text{ mA}$			
		TL43xLlQ devices		10	27	mV
		TL43xLlEx devices		14	34	mV
$\Delta V_{\text{ref}} / \Delta V_{KA}$	Ratio of change in reference voltage to the change in cathode voltage	See 图 15	$I_{KA} = 1 \text{ mA}$			
		$\Delta V_{KA} = 10 \text{ V} - V_{\text{ref}}$		–1.4	–2.7	mV/V
		$\Delta V_{KA} = 36 \text{ V} - 10 \text{ V}$		–1	–2	mV/V
I_{ref}	Reference Input Current	See 图 15	$I_{KA} = 1 \text{ mA}, R1 = 10\text{k}\Omega, R2 = \infty$			
				0.2	0.4	μA
$I_{I(\text{dev})}$	Deviation of reference input current over full temperature range ⁽¹⁾	See 图 15	$I_{KA} = 1 \text{ mA}, R1 = 10\text{k}\Omega, R2 = \infty$			
				0.1	0.3	μA
I_{min}	Minimum cathode current for regulation	See 图 14	$V_{KA} = V_{\text{ref}}$			
					0.6	mA
I_{off}	Off-state cathode current	See 图 16	$V_{KA} = 36 \text{ V}, V_{\text{ref}} = 0$			
				0.1	1	μA
$ Z_{KA} $	Dynamic Impedance ⁽²⁾	See 图 14	$V_{KA} = V_{\text{ref}}, I_{KA} = 1 \text{ mA to } 15 \text{ mA}$			
				0.3	0.75	Ω

- (1) The deviation parameters $V_{I(\text{dev})}$ and $I_{I(\text{dev})}$ are defined as the differences between the maximum and minimum values obtained over the rated temperature range. For more details on $V_{I(\text{dev})}$ 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.

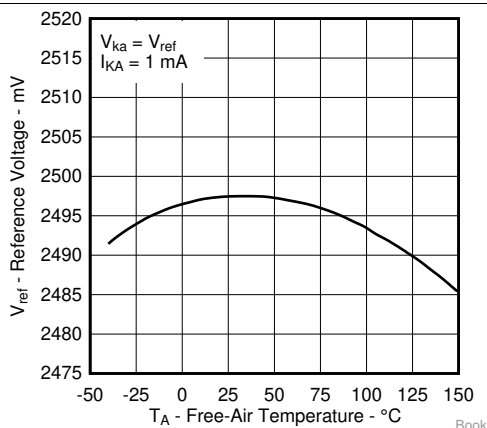


图 1. Reference Voltage versus Free-Air Temperature

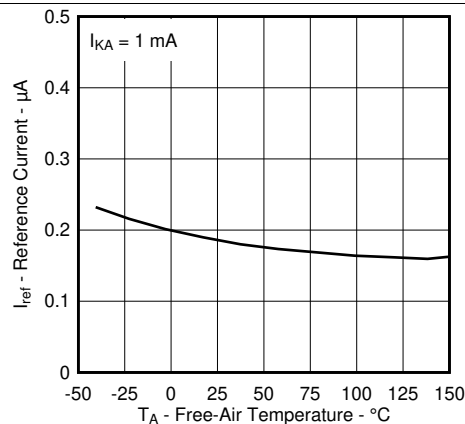


图 2. Reference Current versus Free-Air Temperature

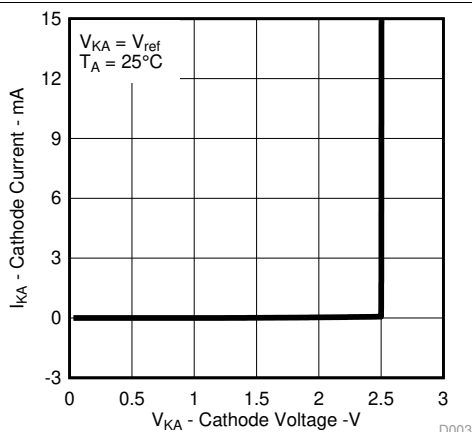


图 3. Cathode Current versus Cathode Voltage

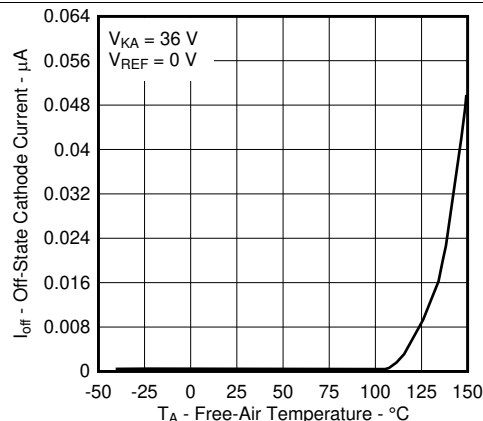


图 4. Off-State Cathode Current versus Free-Air Temperature

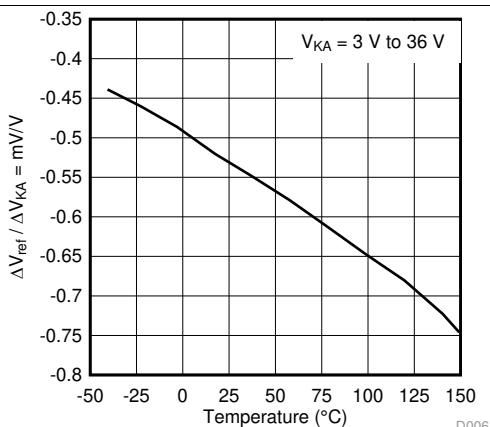


图 5. Ratio of Delta Reference Voltage to Delta Cathode Voltage versus Free-Air Temperature

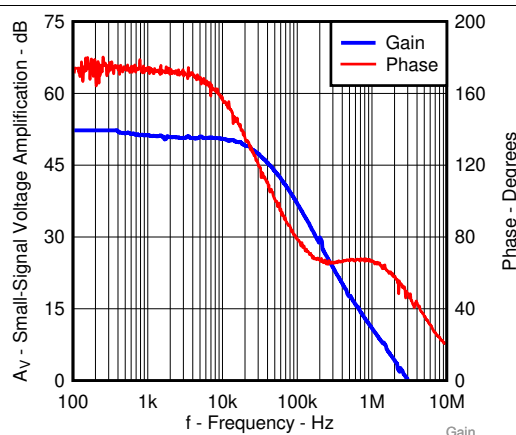


图 6. Small-Signal Voltage Amplification versus Frequency

Typical Characteristics (接下页)

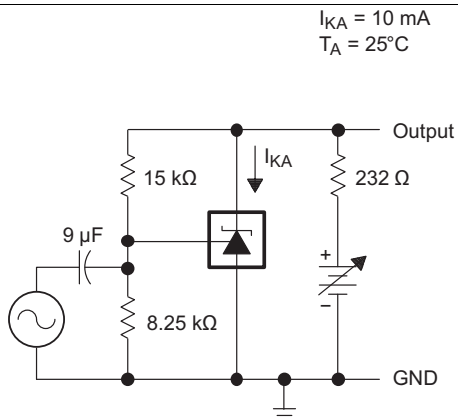


图 7. Test Circuit for Voltage Amplification

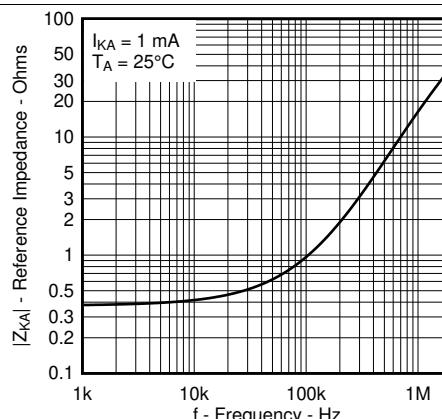


图 8. Reference Impedance versus Frequency

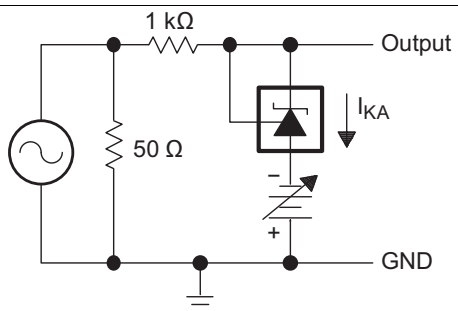


图 9. Test Circuit for Reference Impedance

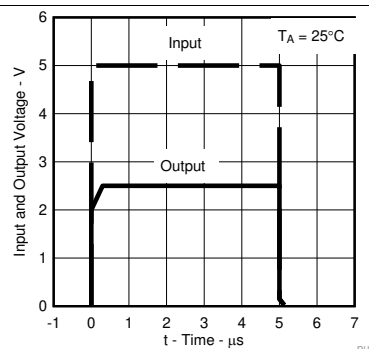


图 10. Pulse Response

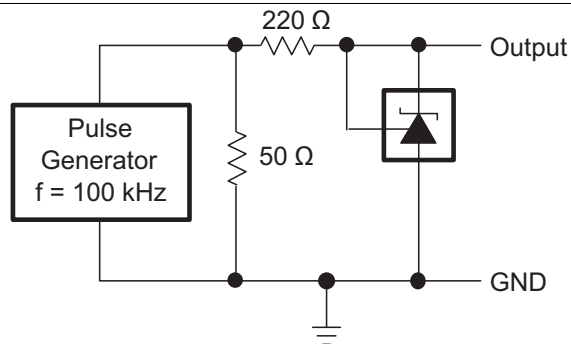
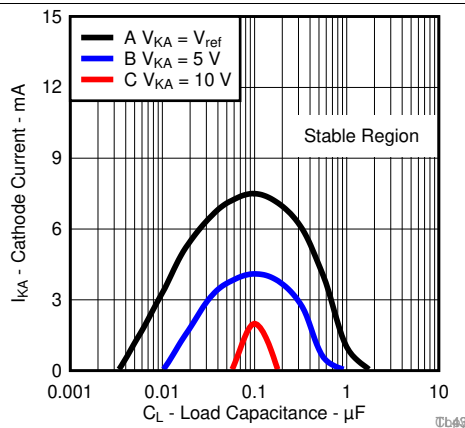


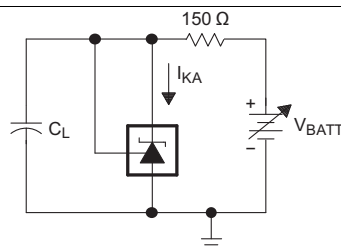
图 11. Test Circuit for Pulse Response



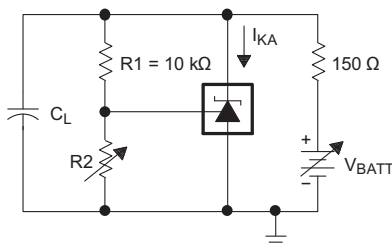
The areas under the curves represent conditions that may cause the device to oscillate. For curves B and C, R_2 and V_+ are adjusted to establish the initial V_{KA} and I_{KA} conditions, with $C_L = 0$. V_{BATT} and C_L then are adjusted to determine the ranges of stability.

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

Typical Characteristics (接下页)



TEST CIRCUIT FOR CURVE A



TEST CIRCUIT FOR CURVES B, C, AND D

图 13. Test Circuits for Stability Boundary Conditions

8 Parameter Measurement Information

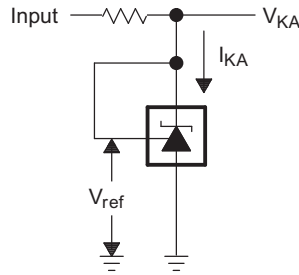


图 14. Test Circuit for $V_{KA} = V_{ref}$

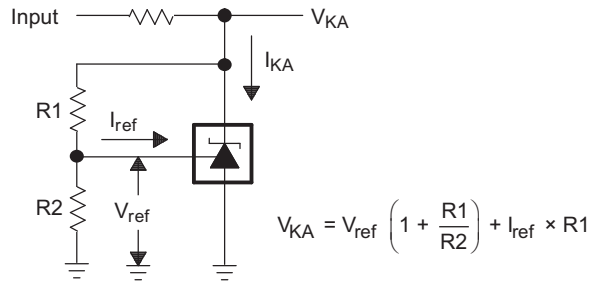


图 15. Test Circuit for $V_{KA} > V_{ref}$

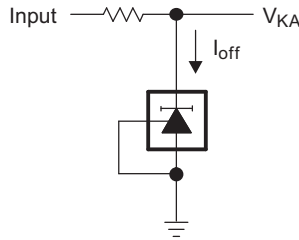


图 16. Test Circuit for I_{off}

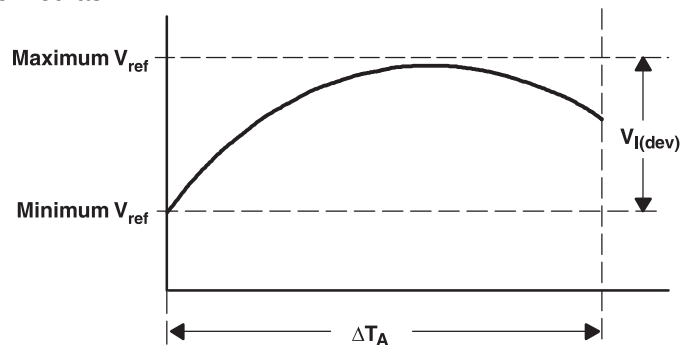
8.1 Temperature Coefficient

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, α_{Vref} , is defined as:

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

where:

ΔT_A is the rated operating temperature range of the device.



α_{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 图 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} . 图 17 shows the effect of the dynamic impedance on the V_{KA} .

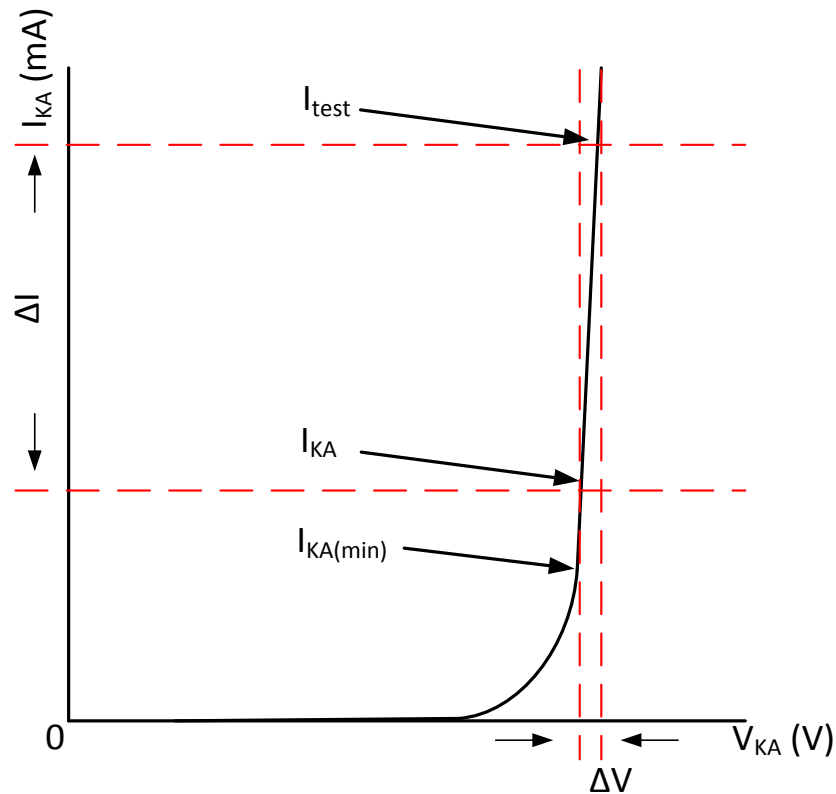


图 17. Dynamic Impedance

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, $>0.6\text{mA}$ ($I_{\min}(\text{max})$) 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

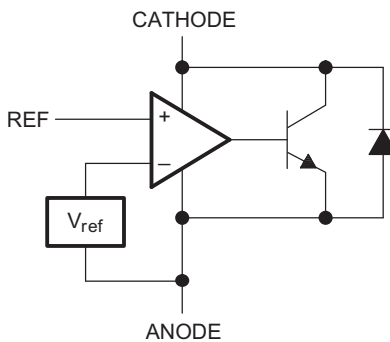


图 18. Equivalent Schematic

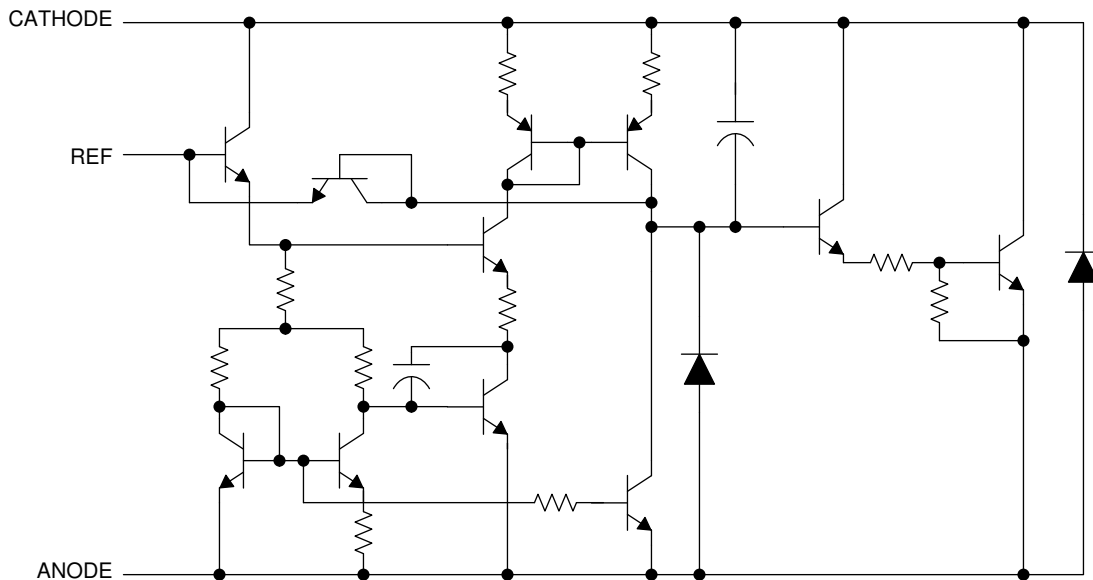


图 19. Detailed Schematic

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 $I_{REF} \geq 0.4$ μ A (see the [Specifications](#)). This is because the reference pin is driven into an npn, which needs base current in order to 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 (I_{KA}) 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

注

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

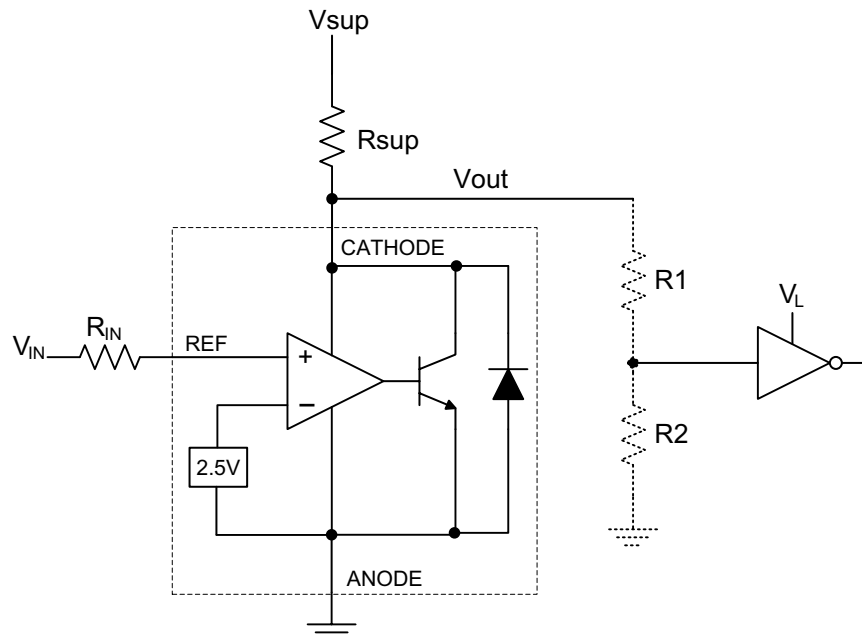


图 20. Comparator Application Schematic

Typical Applications (接下页)

10.2.2 Design Requirements

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

表 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 (I_K)	5 mA
Output Voltage Level	$\sim 2\text{ V} - V_{SUP}$
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 图 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 图 21 where the $R_{SUP} = 10\text{ k}\Omega$ ($I_{KA} = 500\text{ }\mu\text{A}$) situation responds much slower than $R_{SUP} = 1\text{ k}\Omega$ ($I_{KA} = 5\text{ mA}$). 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 $2.495\text{ V} \pm (0.5\% \text{ or } 1.0\%)$, 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 V_{in} to the ref pin, TI recommends to use an input resistor <10 kΩ to provide I_{ref} .

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 图 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 图 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

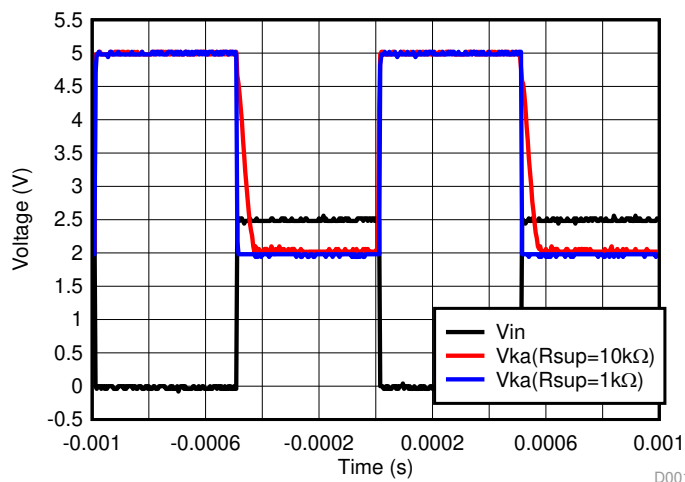


图 21. Output Response With Various Cathode Currents

10.2.5 Precision LED Lighting Current Sink Regulator

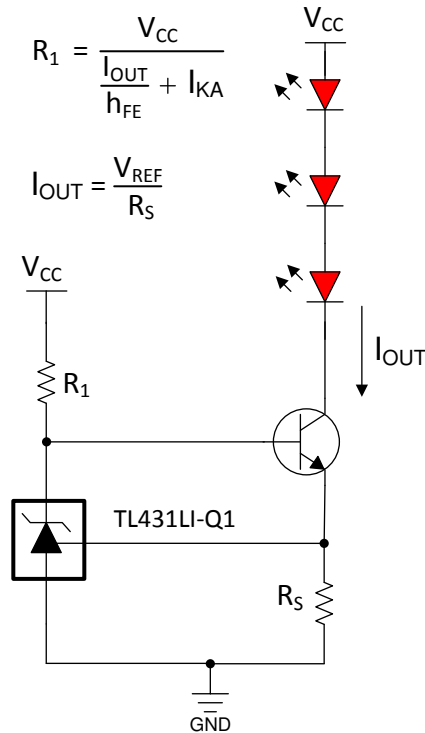


图 22. LED Lighting Current Sink Regulator

10.2.5.1 Design Requirements

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

表 2. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Supply Voltage ($V_{I(BATT)}$)	5 V
Sink Current (I_O)	100mA
Cathode Current (I_K)	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 $\pm$ (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

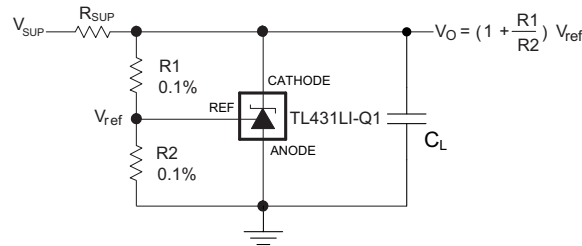


图 23. Shunt Regulator Schematic

10.2.6.1 Design Requirements

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

表 3. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Reference Initial Accuracy	1.0%
Supply Voltage	24 V
Cathode Current (I _k)	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 图 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 图 23. The cathode voltage can be more accurately determined by taking in to account the cathode current:

$$V_O = (1 + R_1/R_2)V_{REF} - I_{REF}R_1 \quad (1)$$

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

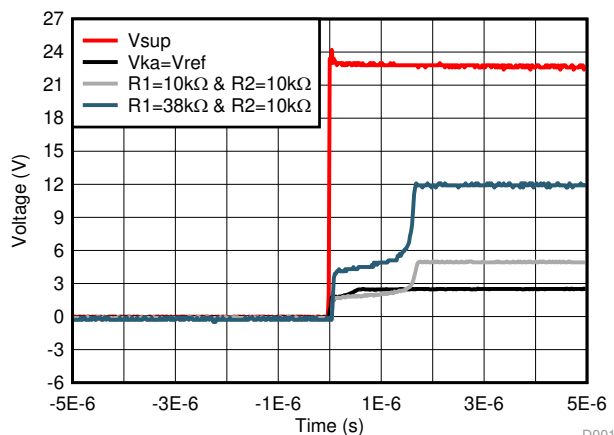


图 24. TL43xLI-Q1 Start-Up Response

10.2.7 Isolated Flyback with Optocoupler

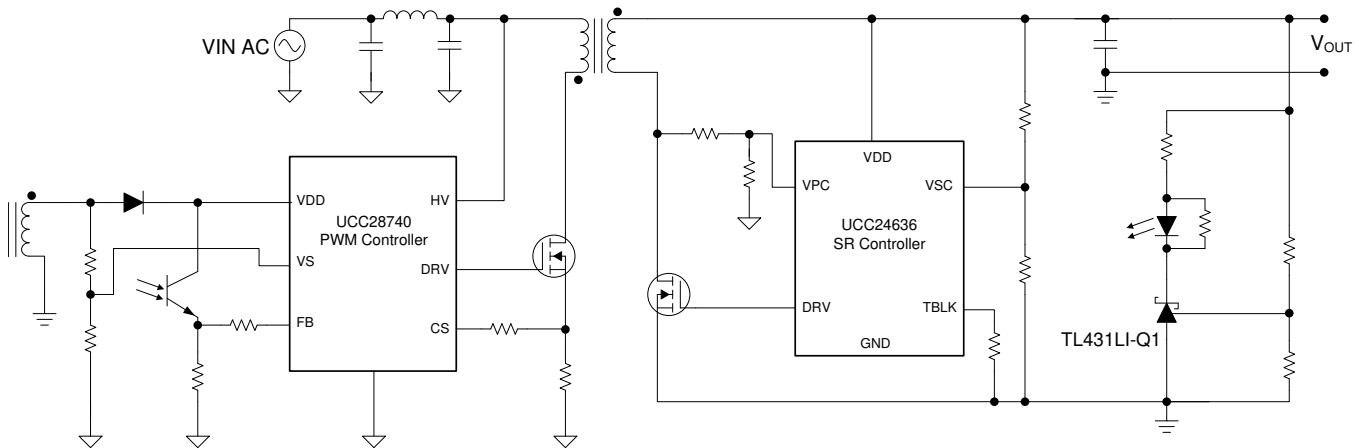


图 25. Isolated Flyback with Optocoupler

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. 图 25 shows the simplified flyback converter with the TL431LI-Q1. For this design example, use the parameters in 表 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](#).

表 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.

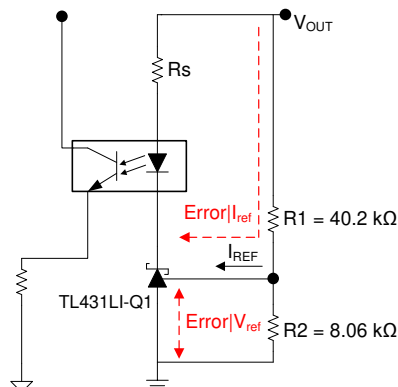


图 26. Feedback Quiescent Current

10.2.7.2.1 TL431 Feedback Loop Error Calculation

图 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 公式 2, but this equation does not include errors that deviates the output.

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

$$V_{OUT} = (2.495 \text{ V}) \times \left(1 + \frac{40.2 \text{ k}\Omega}{8.06 \text{ k}\Omega}\right) + 40.2 \text{ k}\Omega \times (0.4 \mu\text{A})$$

$$V_{OUT} = 14.955 \text{ V} \quad (2)$$

The primary sources of error are the $\text{Error}|_{V_{ref}}$ and $\text{Error}|_{I_{ref}}$. The $\text{Error}|_{V_{ref}}$ 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. 公式 3 shows a simplified worst case V_{ref} with initial accuracy and temperature drift.

$$V_{ref}(\text{Error}|_{V_{ref}}) = V_{ref} \times (1 + \text{Initial Accuracy}) + V_{I(dev)} + \dots$$

$$V_{ref}(\text{Error}|_{V_{ref}}) = 2.495 \text{ V} \times (1 + 0.5\%) + 17 \text{ mV} + \dots$$

$$V_{ref}(\text{Error}|_{V_{ref}}) \approx 2.524 \text{ V} \quad (3)$$

The $\text{Error}|_{I_{ref}}$ in 图 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. 公式 4 shows the V_{OUT} of the TL431LI-Q1 for 图 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.

$$V_{OUT}(\text{Error}|_{I_{ref}}) = V_{ref}(\text{Error}|_{V_{ref}}) \times \left(1 + \frac{R1}{R2}\right) + R1 \times (I_{ref} + I_{I(dev)})$$

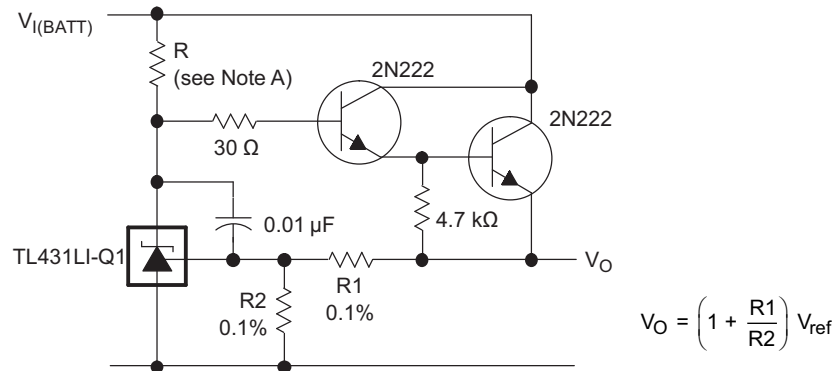
$$V_{OUT}(\text{Error}|_{I_{ref}}) = (2.495 \text{ V} \times (1 + 0.5\%) + 0.017 \text{ V}) \times \left(1 + \frac{40.2 \text{ k}\Omega \times (1 + 0.5\%)}{8.06 \text{ k}\Omega \times (1 - 0.5\%)}\right)$$

$$+ 40.2 \text{ k}\Omega \times (1 + 0.5\%) \times (0.4 \mu\text{A} + 0.3 \mu\text{A})$$

$$V_{OUT} = 15.270 \text{ V} \quad (4)$$

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 $V_{I(BATT)}$.

图 27. Precision High-Current Series Regulator

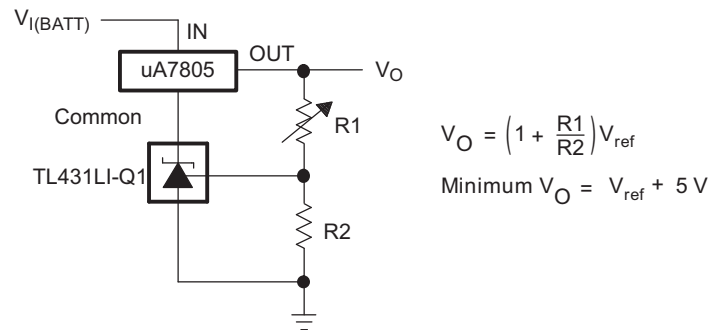


图 28. Output Control of a Three-Terminal Fixed Regulator

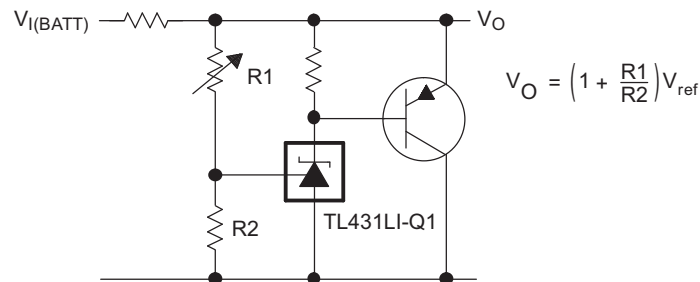
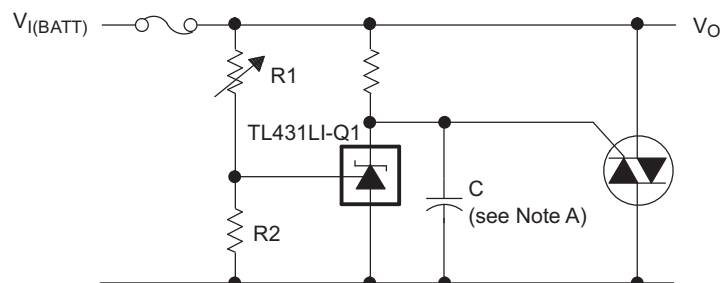


图 29. High-Current Shunt Regulator



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

图 30. Crowbar Circuit

System Examples (接下页)

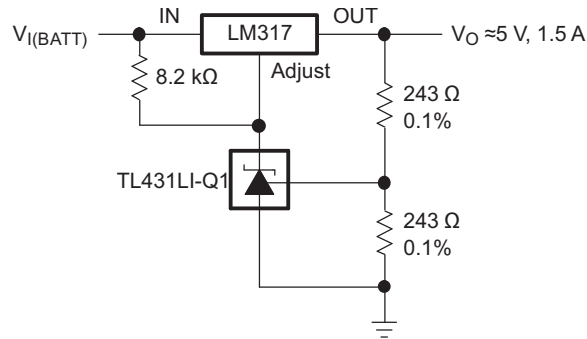
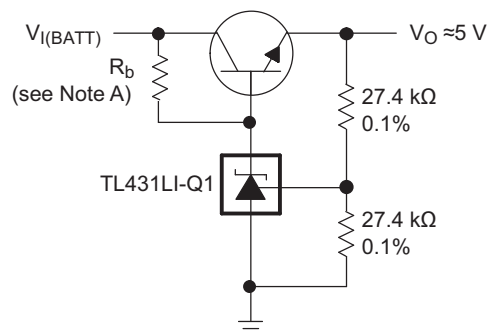


图 31. Precision 5-V, 1.5-A Regulator



R_b should provide cathode current $\geq 0.6\text{ mA}$ to the TL431LI-Q1.

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

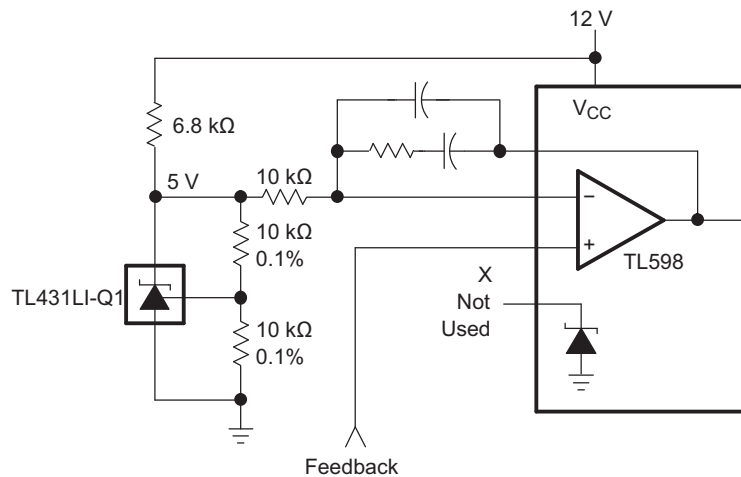
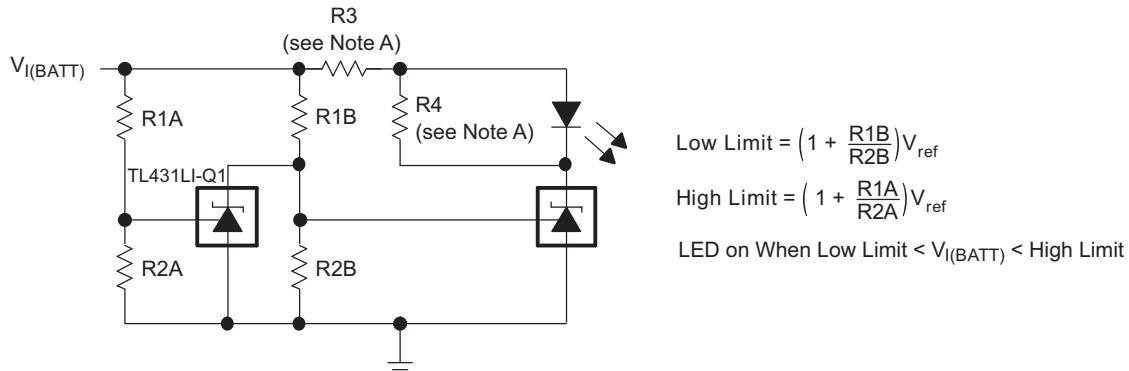


图 33. PWM Converter With Reference

System Examples (接下页)



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

图 34. Voltage Monitor

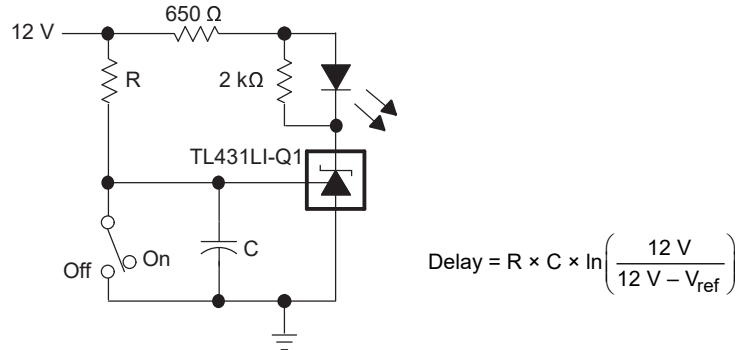


图 35. Delay Timer

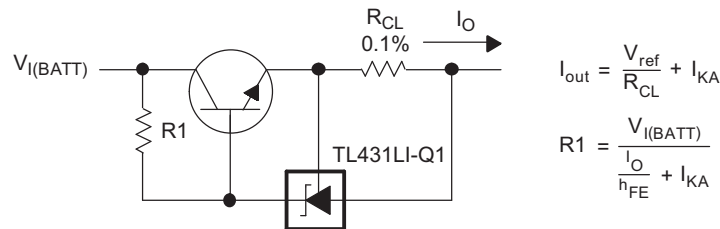


图 36. Precision Current Limiter

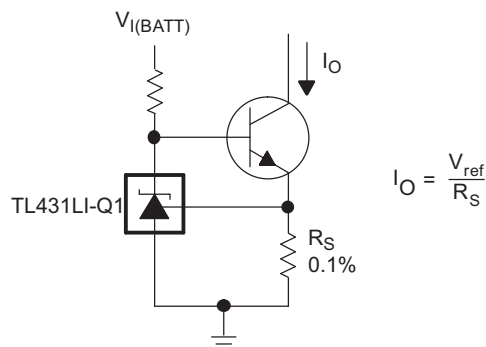


图 37. Precision Constant-Current Sink

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

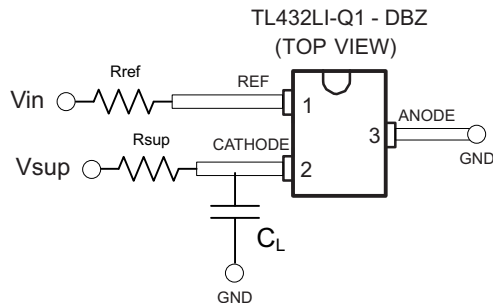


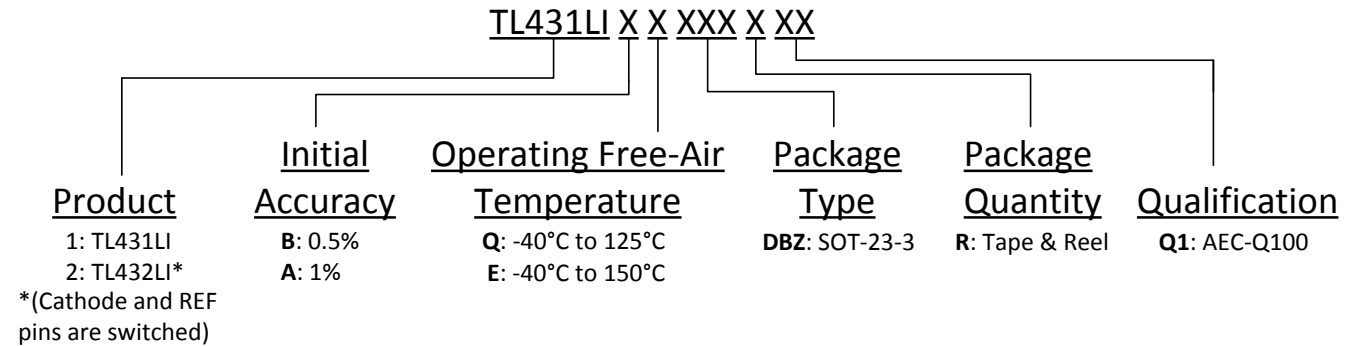
图 38. DBZ Layout Example

13 器件和文档支持

13.1 器件支持

13.1.1 器件命名规则

TI 通过分配后缀和前缀来区分 TL43xLI-Q1 系列的所有组合。更多详细信息和可以订购的组合请参见“封装选项附录”。



13.2 文档支持

13.2.1 相关文档

请参阅如下相关文档：

- 德州仪器 (TI), 《了解 TL431/TL432 数据表中的稳定性边界条件图》
- 德州仪器 (TI), 《在可调节并联稳压器上设置并联电压》
- 德州仪器 (TI), 《使用改进的 TL431LI 进行设计》

13.3 相关链接

下表列出了快速访问链接。类别包括技术文档、支持和社区资源、工具和软件，以及立即订购快速访问。

表 5. 相关链接

器件	产品文件夹	立即订购	技术文档	工具与软件	支持和社区
TL431LI-Q1	单击此处	单击此处	单击此处	单击此处	单击此处
TL432LI-Q1	单击此处	单击此处	单击此处	单击此处	单击此处

13.4 接收文档更新通知

要接收文档更新通知，请导航至 ti.com 上的器件产品文件夹。单击右上角的通知我进行注册，即可每周接收产品信息更改摘要。有关更改的详细信息，请查看任何已修订文档中包含的修订历史记录。

13.5 支持资源

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.

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ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

13.8 Glossary

[SLYZ022](#) — *TI Glossary*.

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

14 机械、封装和可订购信息

以下页面包含机械、封装和可订购信息。这些信息是指定器件的最新可用数据。数据如有变更，恕不另行通知，且不会对此文档进行修订。如需获取此数据表的浏览器版本，请查阅左侧的导航栏。

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TL431LIAEDBZRQ1	ACTIVE	SOT-23	DBZ	3	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 150	23CP	Samples
TL431LIAQDBZRQ1	ACTIVE	SOT-23	DBZ	3	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	22TP	Samples
TL431LIBEDBZRQ1	ACTIVE	SOT-23	DBZ	3	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 150	23DP	Samples
TL431LIBQDBZRQ1	ACTIVE	SOT-23	DBZ	3	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	22UP	Samples
TL432LIAEDBZRQ1	ACTIVE	SOT-23	DBZ	3	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 150	23EP	Samples
TL432LIAQDBZRQ1	ACTIVE	SOT-23	DBZ	3	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	22VP	Samples
TL432LIBEDBZRQ1	ACTIVE	SOT-23	DBZ	3	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 150	23FP	Samples
TL432LIBQDBZRQ1	ACTIVE	SOT-23	DBZ	3	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	22WP	Samples

(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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TAPE AND REEL INFORMATION


*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
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	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

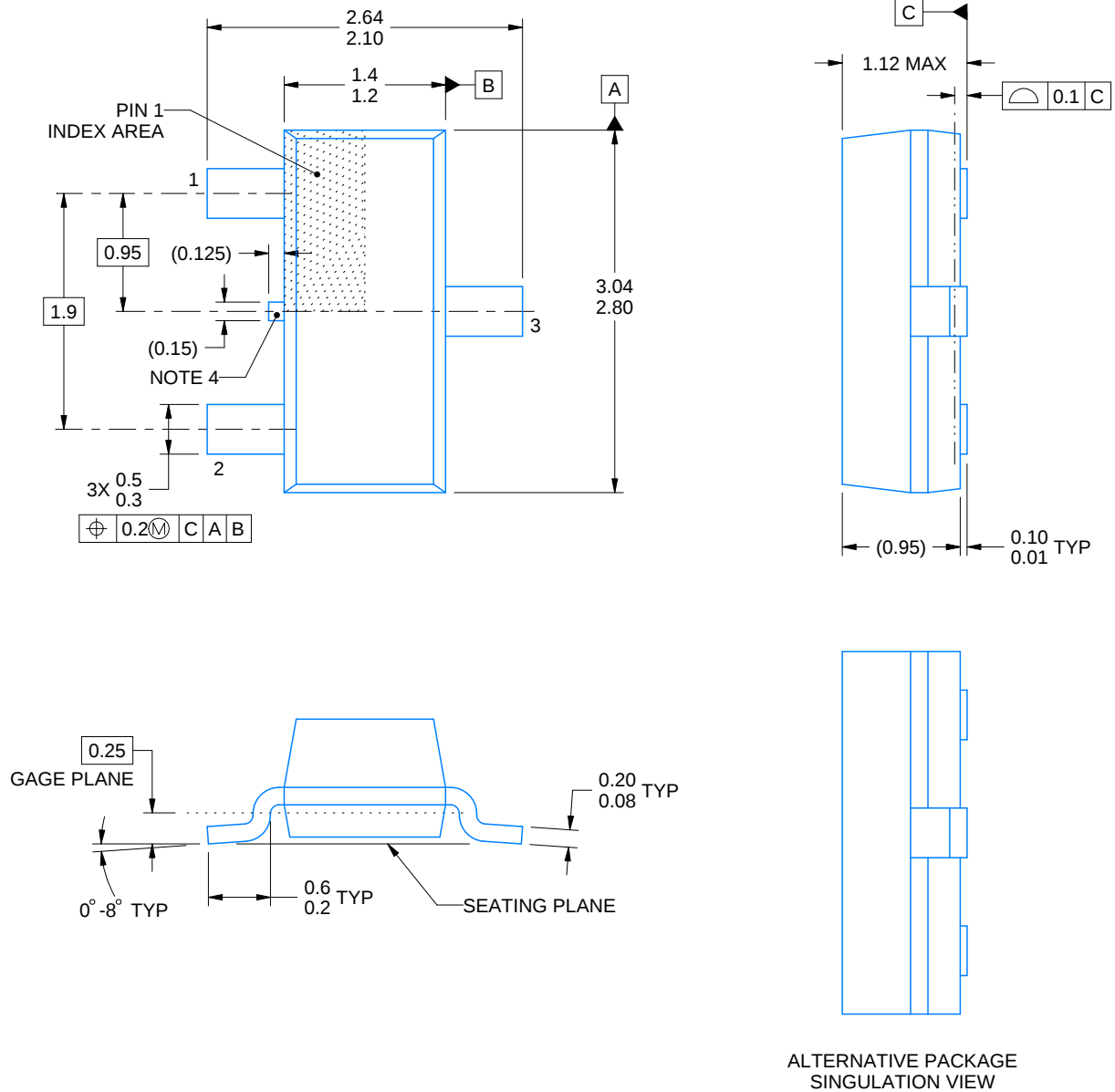
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TL431LIAEDBZRQ1	SOT-23	DBZ	3	3000	180.0	180.0	18.0
TL431LIAQDBZRQ1	SOT-23	DBZ	3	3000	180.0	180.0	18.0
TL431LIBEDBZRQ1	SOT-23	DBZ	3	3000	180.0	180.0	18.0
TL431LIBQDBZRQ1	SOT-23	DBZ	3	3000	180.0	180.0	18.0
TL432LIAEDBZRQ1	SOT-23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

DBZ0003A



PACKAGE OUTLINE
SOT-23 - 1.12 mm max height

SMALL OUTLINE TRANSISTOR



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NOTES:

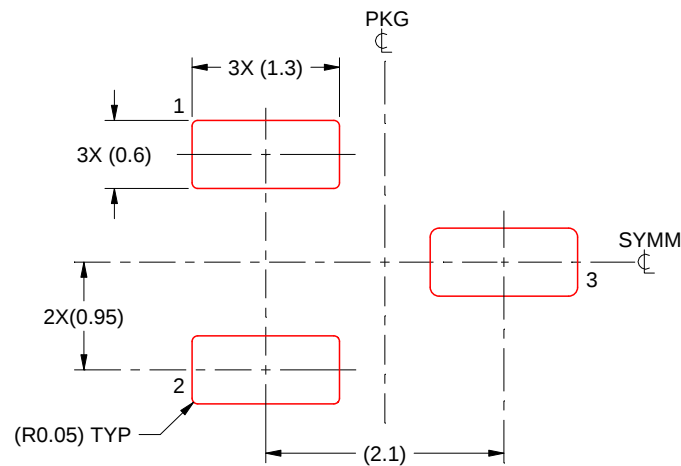
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC registration TO-236, except minimum foot length.
4. Support pin may differ or may not 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

EXAMPLE STENCIL DESIGN

DBZ0003A

SOT-23 - 1.12 mm max height

SMALL OUTLINE TRANSISTOR



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.

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