

# TL431C, TL431AC, TL431I, TL431AI, TL431M, TL431Y ADJUSTABLE PRECISION SHUNT REGULATORS

SLVS005G – JULY 1978 – REVISED MARCH 1997

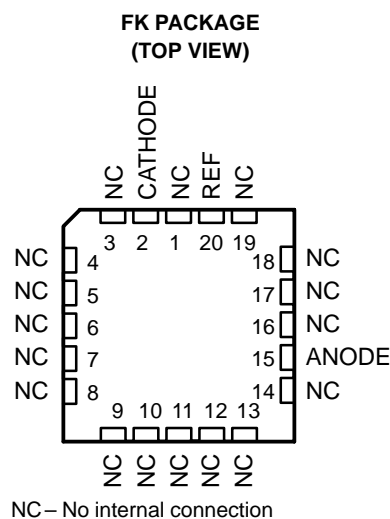
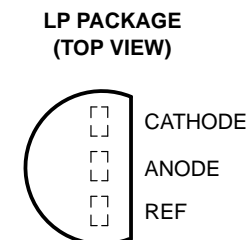
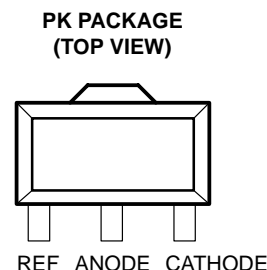
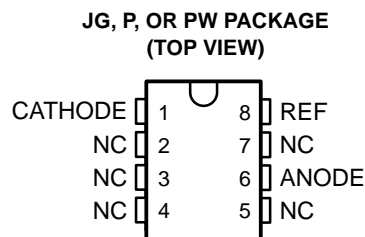
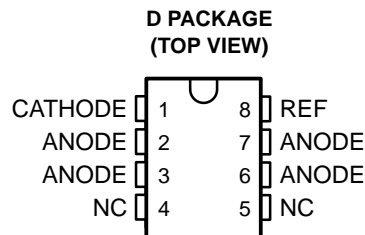
- Equivalent Full-Range Temperature Coefficient . . . 30 ppm/°C
- 0.2-Ω Typical Output Impedance
- Sink-Current Capability . . . 1 mA to 100 mA
- Low Output Noise
- Adjustable Output Voltage . . .  $V_{ref}$  to 36 V
- Available in a Wide Range of High-Density Packaging Options:
  - Small Outline (D)
  - TO-226AA (LP)
  - SOT-89 (PK)
  - TSSOP (PW)

## description

The TL431 and TL431A are 3-terminal adjustable shunt regulators with specified thermal stability over applicable automotive, commercial, and military temperature ranges. The output voltage can be set to any value between  $V_{ref}$  (approximately 2.5 V) and 36 V with two external resistors (see Figure 16). These devices have a typical output impedance of 0.2 Ω. Active output circuitry provides a very sharp turn-on characteristic, making these devices excellent replacements for zener diodes in many applications, such as on-board regulation, adjustable power supplies, and switching power supplies.

The TL431 is offered in a wide variety of high-density packaging options that includes an SOT-89-type package (suffix PK).

The TL431C and TL431AC are characterized for operation from 0°C to 70°C, and the TL431I and TL431AI are characterized for operation from -40°C to 85°C. The TL431M is characterized for operation over the full military temperature range of -55°C to 125°C.



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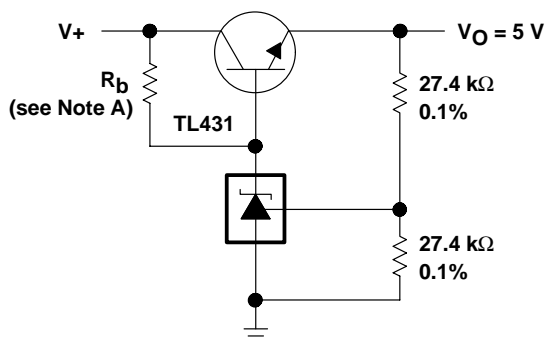
## AVAILABLE OPTIONS

T <sub>A</sub>	PACKAGED DEVICES							CHIP FORM (Y)
	SMALL OUTLINE (D)	CHIP CARRIER (FK)	CERAMIC DIP (JG)	TO-226AA (LP)	PLASTIC DIP (P)	SOT-89 (PK)	SHRINK SMALL OUTLINE (PW)	
0°C to 70°C	TL431CD TL431ACD			TL431CLP TL431ACL	TL431CP TL431ACP	TL431CPK	TL431CPW	TL431Y
-40°C to 85°C	TL431ID TL431AID			TL431ILP TL431AILP	TL431IP TL431AIP	TL431IPK		
-55°C to 125°C		TL431MFK	TL431MJG					

The D and LP packages are available taped and reeled. Add R suffix to device type (e.g., TL431CDR). The PK package is only available taped and reeled (no R suffix required). Chip forms are tested at T<sub>A</sub> = 25°C.

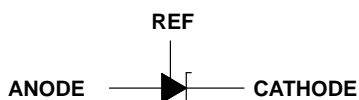
## application schematic

5-V Precision Regulator

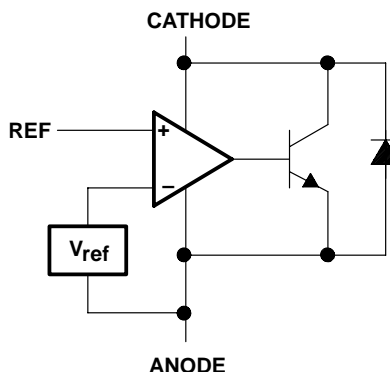


NOTE A: R<sub>b</sub> should provide cathode current ≥ 1-mA to the TL431.

## symbol



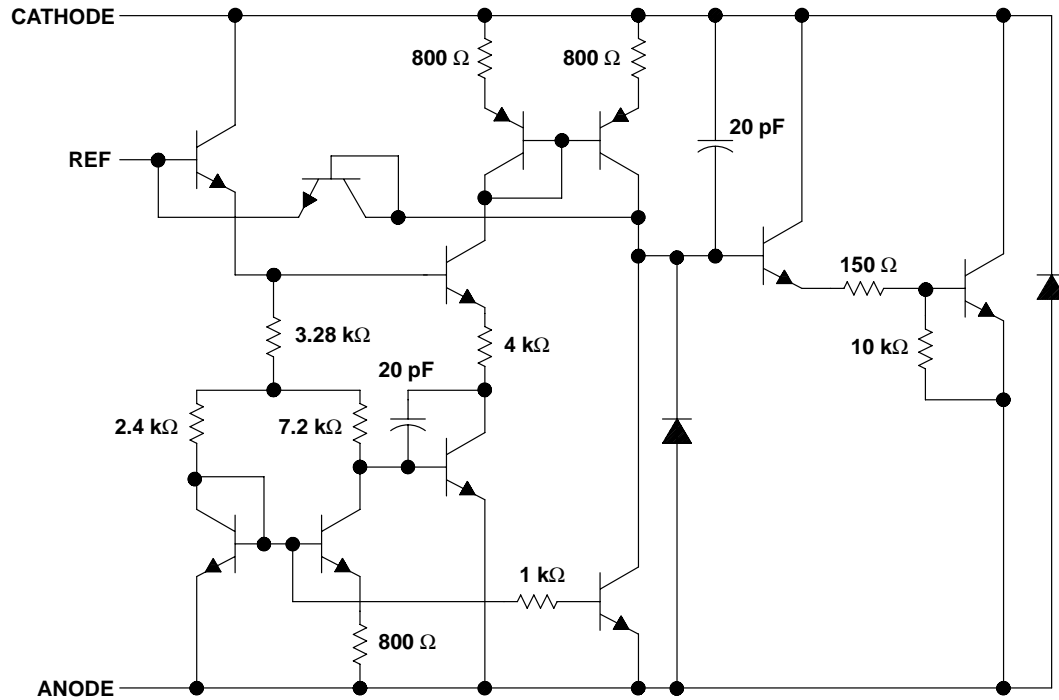
## functional block diagram



# TL431C, TL431AC, TL431I, TL431AI, TL431M, TL431Y ADJUSTABLE PRECISION SHUNT REGULATORS

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## equivalent schematic



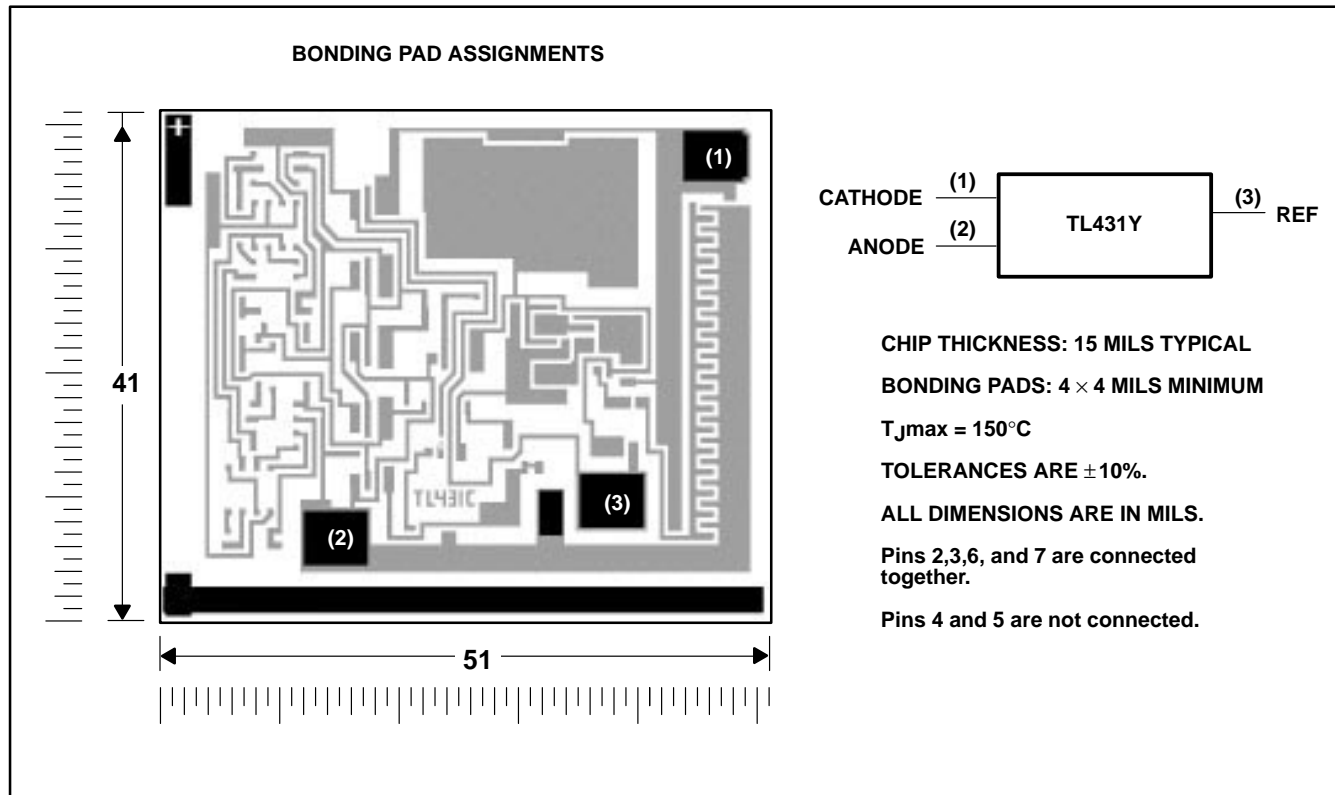
NOTE A: All component values are nominal.

# TL431C, TL431AC, TL431I, TL431AI, TL431M, TL431Y ADJUSTABLE PRECISION SHUNT REGULATORS

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## TL431Y chip information

This chip, when properly assembled, displays characteristics similar to those of the TL431C. Thermal compression or ultrasonic bonding may be used on the doped aluminum bonding pads. The chip may be mounted with conductive epoxy or a gold-silicon preform.



# TL431C, TL431AC, TL431I, TL431AI, TL431M, TL431Y ADJUSTABLE PRECISION SHUNT REGULATORS

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## absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Cathode voltage, $V_{KA}$ (see Note 1) .....	37 V
Continuous cathode current range, $I_{KA}$ .....	–100 mA to 150 mA
Reference input current range .....	–50 $\mu$ A to 10 mA
Continuous total power dissipation .....	See Dissipation Rating Tables 1 and 2
Operating free-air temperature range, $T_A$ : C-suffix .....	0°C to 70°C
I-suffix .....	–40°C to 85°C
M-suffix .....	–55°C to 125°C
Storage temperature range, $T_{stg}$ .....	–65°C to 150°C
Case temperature for 60 seconds: FK package .....	260°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds: D, P, or PW package .....	260°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds: JG, LP, or PK package .....	300°C

† 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.

NOTE 1: Voltage values are with respect to the anode terminal unless otherwise noted.

**DISSIPATION RATING TABLE 1 – FREE-AIR TEMPERATURE**

PACKAGE	$T_A = 25^\circ\text{C}$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25^\circ\text{C}$	$T_A = 70^\circ\text{C}$ POWER RATING	$T_A = 85^\circ\text{C}$ POWER RATING	$T_A = 125^\circ\text{C}$ POWER RATING
D	725 mW	5.8 mW/°C	464 mW	377 mW	—
FK	1375 mW	11.0 mW/°C	880 mW	715 mW	275 mW
JG	1050 mW	8.4 mW/°C	672 mW	546 mW	210 mW
LP	775 mW	6.2 mW/°C	496 mW	403 mW	—
P	1000 mW	8.0 mW/°C	640 mW	520 mW	—
PK	500 mW	4.0 mW/°C	320 mW	260 mW	—
PW	525 mW	4.2 mW/°C	336 mW	—	—

**DISSIPATION RATING TABLE 2 – CASE TEMPERATURE**

PACKAGE	$T_C = 25^\circ\text{C}$ POWER RATING	DERATING FACTOR ABOVE $T_C = 25^\circ\text{C}$	$T_C = 70^\circ\text{C}$ POWER RATING	$T_C = 85^\circ\text{C}$ POWER RATING
PK	3125 mW	25 mW/°C	2000 mW	1625 mW

## recommended operating conditions

	MIN	MAX	UNIT
Cathode voltage, $V_{KA}$	$V_{ref}$	36	V
Cathode current, $I_{KA}$	1	100	mA



electrical characteristics over recommended operating conditions, T<sub>A</sub> = 25°C (unless otherwise noted)

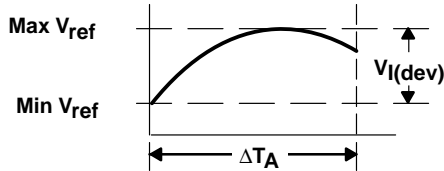
PARAMETER	TEST CIRCUIT	TEST CONDITIONS	TL431C			TL431I			TL431M			UNIT			
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX				
V <sub>ref</sub>	Reference voltage	1	V <sub>KA</sub> = V <sub>ref</sub> , I <sub>KA</sub> = 10 mA			2440	2495	2550	2440	2495	2550	2400	2495	2600	mV
V <sub>I(dev)</sub>	Deviation of reference voltage over full temperature range †	1	V <sub>KA</sub> = V <sub>ref</sub> , I <sub>KA</sub> = 10 mA, T <sub>A</sub> = Full range †				4	25		5	50		22		mV
$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	Ratio of change in reference voltage to the change in cathode voltage	2	I <sub>KA</sub> = 10 mA	$\Delta V_{KA} = 10\text{ V} - V_{ref}$		-1.4	-2.7		-1.4	-2.7		-1.4	-3		$\frac{\text{mV}}{\text{V}}$
				$\Delta V_{KA} = 36\text{ V} - 10\text{ V}$		-1	-2		-1	-2		-1	-2.3		
I <sub>ref</sub>	Reference current	2	I <sub>KA</sub> = 10 mA, R1 = 10 kΩ, R2 = ∞			2	4		2	4		2	8*		μA
I <sub>I(dev)</sub>	Deviation of reference current over full temperature range †	2	I <sub>KA</sub> = 10 mA, R1 = 10 kΩ, R2 = ∞, T <sub>A</sub> = Full range †			0.4	1.2		0.8	2.5		1			μA
I <sub>min</sub>	Minimum cathode current for regulation	1	V <sub>KA</sub> = V <sub>ref</sub>			0.4	1		0.4	1		0.4	1.5		mA
I <sub>off</sub>	Off-state cathode current	3	V <sub>KA</sub> = 36 V, V <sub>ref</sub> = 0			0.1	1		0.1	1		0.1	3		μA
z <sub>KA</sub>	Dynamic impedance §	1	I <sub>KA</sub> = 1 mA to 100 mA, V <sub>KA</sub> = V <sub>ref</sub> , f ≤ 1 kHz			0.2	0.5		0.2	0.5		0.2	0.9*		Ω

\* On products compliant to MIL-STD-883, Class B, this parameter is not production tested.

† Full temperature range is 0°C to 70°C for the TL431C, -40°C to 85°C for the TL431I, and -55°C to 125°C for the TL431M.

‡ The deviation parameters V<sub>ref(dev)</sub> and I<sub>ref(dev)</sub> 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 voltage, α<sub>Vref</sub>, is defined as:

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



where ΔT<sub>A</sub> is the rated operating free-air temperature range of the device.

α<sub>Vref</sub> can be positive or negative depending on whether minimum V<sub>ref</sub> or maximum V<sub>ref</sub>, respectively, occurs at the lower temperature.

Example: Max V<sub>ref</sub> = 2496 mV at 30°C, Min V<sub>ref</sub> = 2492 mV at 0°C, V<sub>ref</sub> = 2495 mV at 25°C, ΔT<sub>A</sub> = 70°C for TL431C

$$|\alpha_{Vref}| = \frac{\left( \frac{4\text{ mV}}{2495\text{ mV}} \right) \times 10^6}{70^\circ\text{C}} \approx 23\text{ ppm}/^\circ\text{C}$$

Because minimum V<sub>ref</sub> occurs at the lower temperature, the coefficient is positive.

§ The dynamic impedance is defined as:  $|z_{KA}| = \frac{\Delta V_{KA}}{\Delta I_{KA}}$

When the device is operating with two external resistors (see Figure 2), the total dynamic impedance of the circuit is given by:  $|z'| = \frac{\Delta V}{\Delta I} \approx |z_{KA}| \left( 1 + \frac{R1}{R2} \right)$

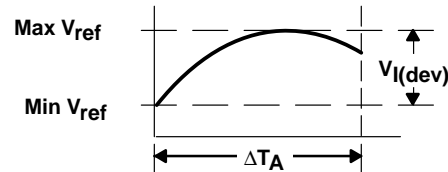
electrical characteristics over recommended operating conditions,  $T_A = 25^\circ\text{C}$  (unless otherwise noted)

PARAMETER	TEST CIRCUIT	TEST CONDITIONS	TL431AC			TL431AI			UNIT			
			MIN	TYP	MAX	MIN	TYP	MAX				
$V_{\text{ref}}$	Reference voltage	1	$V_{\text{KA}} = V_{\text{ref}}, I_{\text{KA}} = 10 \text{ mA}$			2470	2495	2520	2470	2495	2520	mV
$V_{\text{I(dev)}}$	Deviation of reference voltage over full temperature range ‡	1	$V_{\text{KA}} = V_{\text{ref}}, I_{\text{KA}} = 10 \text{ mA}, T_A = \text{Full range}^\dagger$				4	25		5	50	mV
$\frac{\Delta V_{\text{ref}}}{\Delta V_{\text{KA}}}$	Ratio of change in reference voltage to the change in cathode voltage	2	$I_{\text{KA}} = 10 \text{ mA}$	$\frac{\Delta V_{\text{KA}} = 10 \text{ V} - V_{\text{ref}}}{\Delta V_{\text{KA}} = 36 \text{ V} - 10 \text{ V}}$		-1.4	-2.7		-1.4	-2.7		$\frac{\text{mV}}{\text{V}}$
$I_{\text{ref}}$	Reference current	2	$I_{\text{KA}} = 10 \text{ mA}, R1 = 10 \text{ k}\Omega, R2 = \infty$				2	4		2	4	$\mu\text{A}$
$I_{\text{I(dev)}}$	Deviation of reference current over full temperature range ‡	2	$I_{\text{KA}} = 10 \text{ mA}, R1 = 10 \text{ k}\Omega, R2 = \infty, T_A = \text{Full range}^\dagger$				0.8	1.2		0.8	2.5	$\mu\text{A}$
$I_{\text{min}}$	Minimum cathode current for regulation	1	$V_{\text{KA}} = V_{\text{ref}}$				0.4	0.6		0.4	0.7	mA
$I_{\text{off}}$	Off-state cathode current	3	$V_{\text{KA}} = 36 \text{ V}, V_{\text{ref}} = 0$				0.1	0.5		0.1	0.5	$\mu\text{A}$
$ z_{\text{KA}} $	Dynamic impedance §	1	$V_{\text{KA}} = V_{\text{ref}}, I_{\text{KA}} = 1 \text{ mA to } 100 \text{ mA}, f \leq 1 \text{ kHz}$				0.2	0.5		0.2	0.5	$\Omega$

† Full temperature range is  $0^\circ\text{C}$  to  $70^\circ\text{C}$  for the TL431AC and  $-40^\circ\text{C}$  to  $85^\circ\text{C}$  for the TL431AI.

‡ The deviation parameters  $V_{\text{ref(dev)}}$  and  $I_{\text{ref(dev)}}$  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,  $\alpha_{V_{\text{ref}}}$ , is defined as:

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



where  $\Delta T_A$  is the rated 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: Max  $V_{\text{ref}} = 2496 \text{ mV}$  at  $30^\circ\text{C}$ , Min  $V_{\text{ref}} = 2492 \text{ mV}$  at  $0^\circ\text{C}$ ,  $V_{\text{ref}} = 2495 \text{ mV}$  at  $25^\circ\text{C}$ ,  $\Delta T_A = 70^\circ\text{C}$  for TL431AC

$$|\alpha_{V_{\text{ref}}}| = \frac{\left( \frac{4 \text{ mV}}{2495 \text{ mV}} \right) \times 10^6}{70^\circ\text{C}} \approx 23 \text{ ppm}/^\circ\text{C}$$

Because minimum  $V_{\text{ref}}$  occurs at the lower temperature, the coefficient is positive.

§ The dynamic impedance is defined as:  $|z_{\text{KA}}| = \frac{\Delta V_{\text{KA}}}{\Delta I_{\text{KA}}}$

When the device is operating with two external resistors (see Figure 2), the total dynamic impedance of the circuit is given by:  $|z'| = \frac{\Delta V}{\Delta I} \approx |z_{\text{KA}}| \left( 1 + \frac{R1}{R2} \right)$

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electrical characteristics over recommended operating conditions,  $T_A = 25^\circ\text{C}$  (unless otherwise noted)

PARAMETER	TEST CIRCUIT	TEST CONDITIONS	TL431Y			UNIT
			MIN	TYP	MAX	
$V_{ref}$ Reference voltage	1	$V_{KA} = V_{ref}$ , $I_{KA} = 10\text{ mA}$	2495			mV
$\frac{\Delta V_{ref}}{\Delta V_{KA}}$ Ratio of change in reference voltage to the change in cathode voltage	2	$I_{KA} = 10\text{ mA}$	$\Delta V_{KA} = 10\text{ V} - V_{ref}$		-1.4	$\frac{mV}{V}$
			$\Delta V_{KA} = 36\text{ V} - 10\text{ V}$		-1	
$I_{ref}$ Reference input current	2	$I_{KA} = 10\text{ mA}$ , $R_1 = 10\text{ k}\Omega$ , $R_2 = \infty$	2			$\mu\text{A}$
$I_{min}$ Minimum cathode current for regulation	1	$V_{KA} = V_{ref}$	0.4			mA
$I_{off}$ Off-state cathode current	3	$V_{KA} = 36\text{ V}$ , $V_{ref} = 0$	0.1			$\mu\text{A}$
$ z_{KA} $ Dynamic impedance†	1	$V_{KA} = V_{ref}$ , $I_{KA} = 1\text{ mA to }100\text{ mA}$ , $f \leq 1\text{ kHz}$	0.2			$\Omega$

† The dynamic impedance is defined as:  $|z_{ka}| = \frac{\Delta V_{KA}}{\Delta I_{KA}}$

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

$$|z'| = \frac{\Delta V}{\Delta I} \approx |z_{KA}| \left( 1 + \frac{R_1}{R_2} \right)$$

## PARAMETER MEASUREMENT INFORMATION

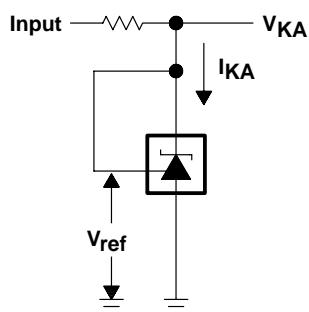


Figure 1. Test Circuit for  $V_{KA} = V_{ref}$

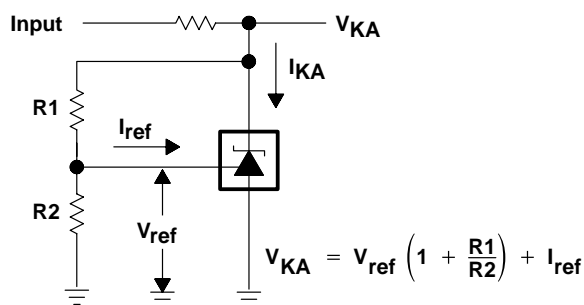


Figure 2. Test Circuit for  $V_{KA} > V_{ref}$

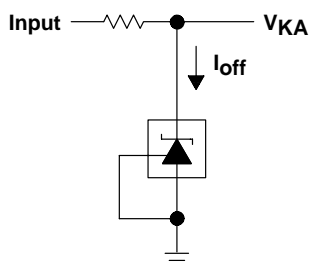


Figure 3. Test Circuit for  $I_{off}$



# TL431C, TL431AC, TL431I, TL431AI, TL431M, TL431Y ADJUSTABLE PRECISION SHUNT REGULATORS

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## TYPICAL CHARACTERISTICS

Table of Graphs

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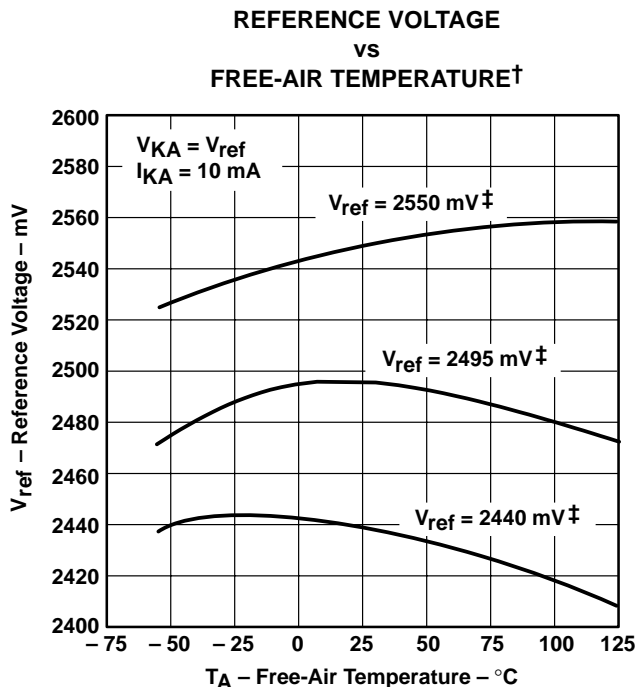
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## TYPICAL CHARACTERISTICS



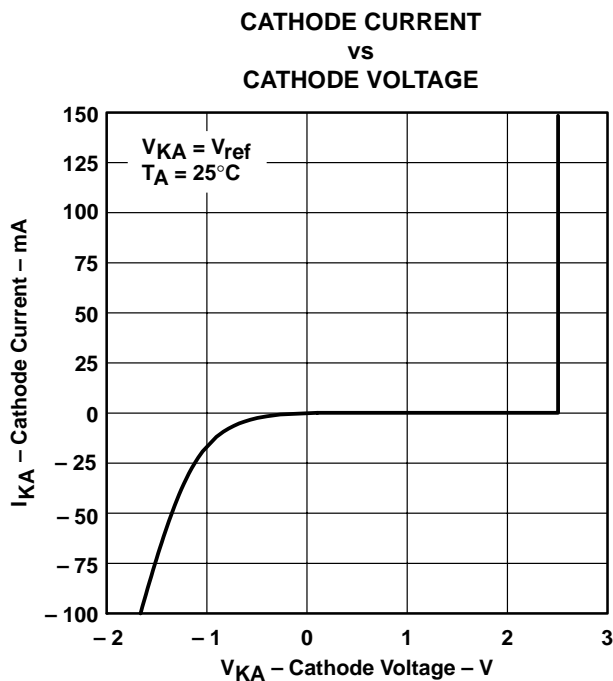
† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

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

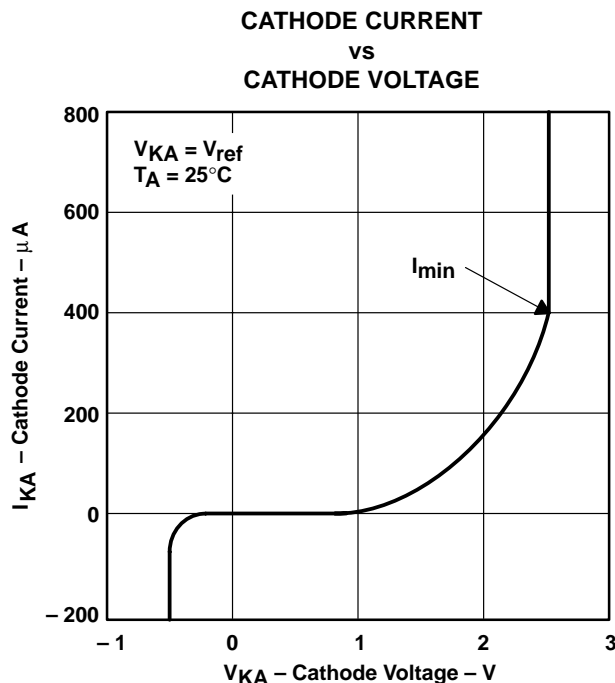
† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

**Figure 4**

**Figure 5**



**Figure 6**

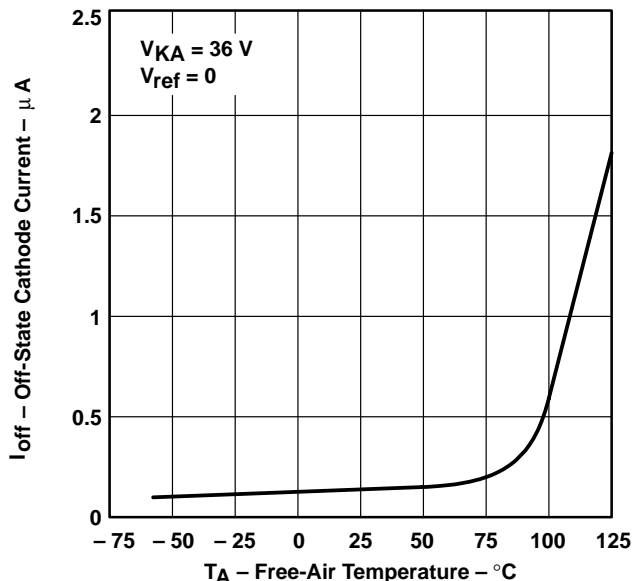


**Figure 7**



TYPICAL CHARACTERISTICS

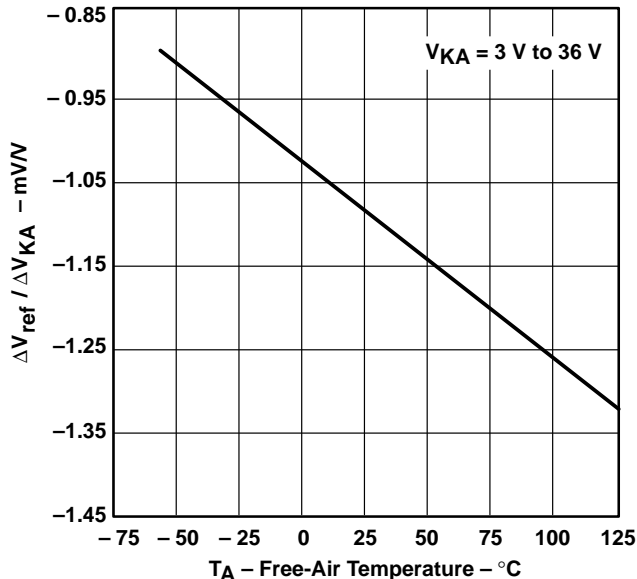
OFF-STATE CATHODE CURRENT  
 vs  
 FREE-AIR TEMPERATURE†



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

Figure 8

RATIO OF DELTA REFERENCE VOLTAGE TO  
 DELTA CATHODE VOLTAGE  
 vs  
 FREE-AIR TEMPERATURE†



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

Figure 9

EQUIVALENT-INPUT NOISE VOLTAGE  
 vs  
 FREQUENCY

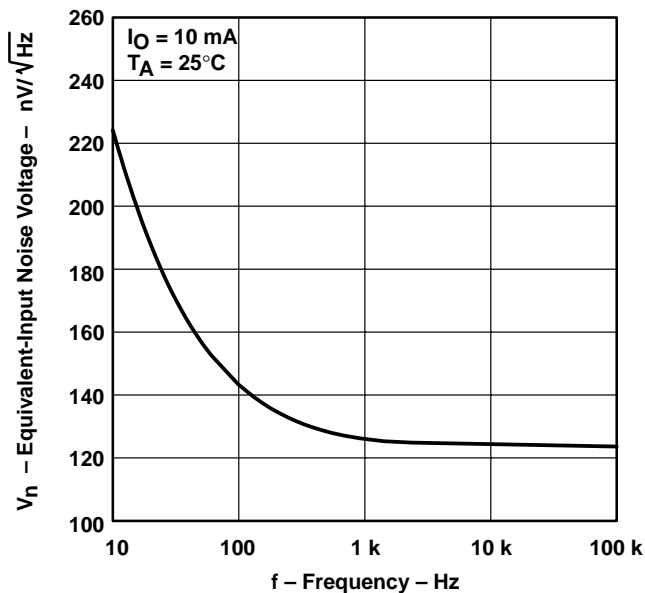


Figure 10

# TL431C, TL431AC, TL431I, TL431AI, TL431M, TL431Y ADJUSTABLE PRECISION SHUNT REGULATORS

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## TYPICAL CHARACTERISTICS

### EQUIVALENT-INPUT NOISE VOLTAGE OVER A 10-SECOND PERIOD

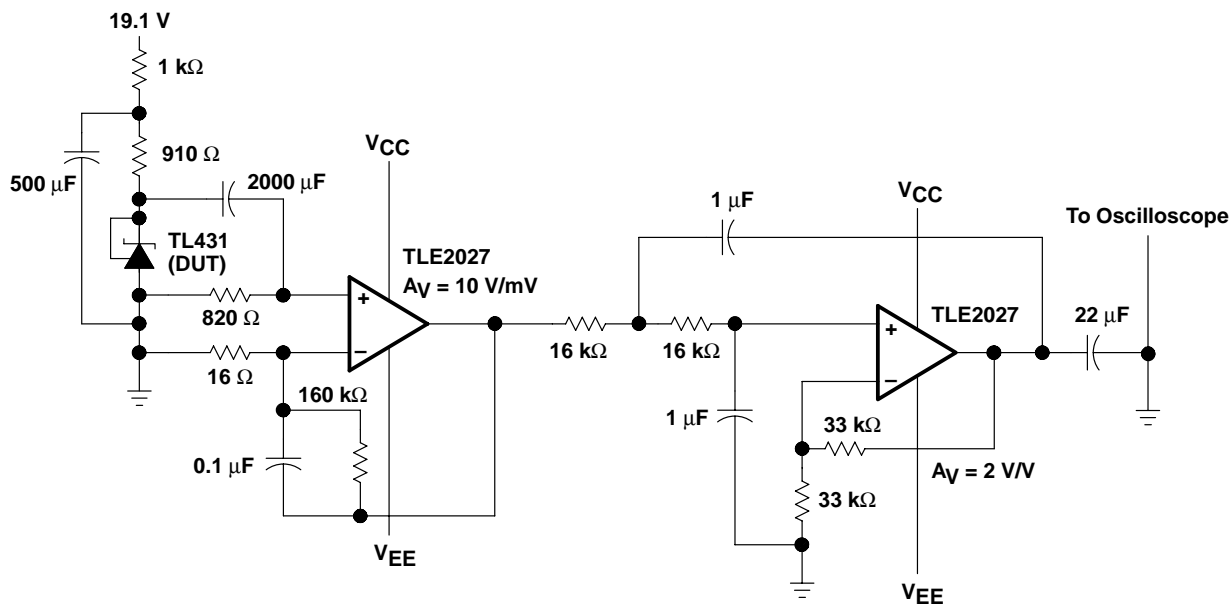
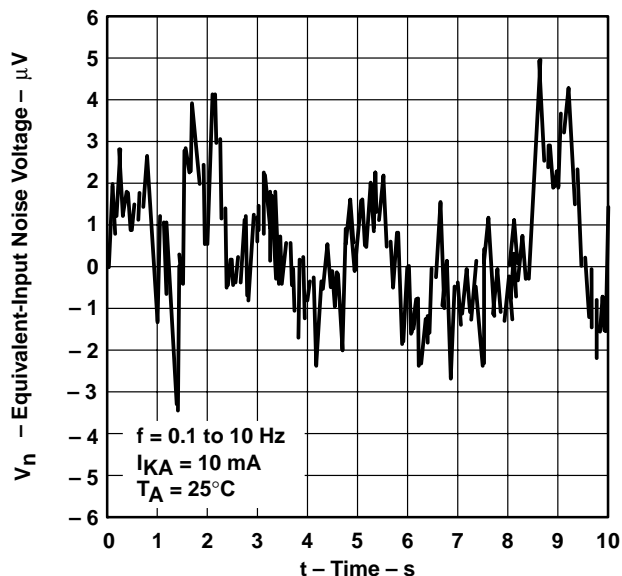


Figure 11. Test Circuit For Equivalent-Input Noise Voltage

TYPICAL CHARACTERISTICS

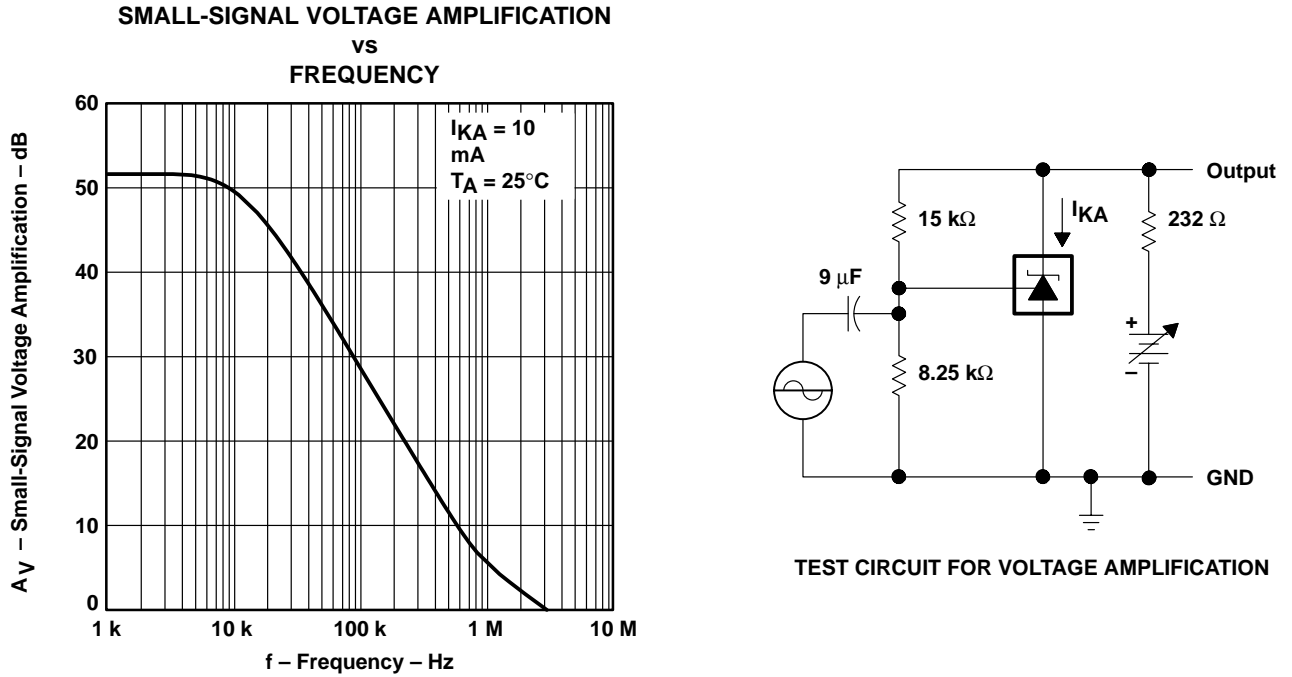


Figure 12

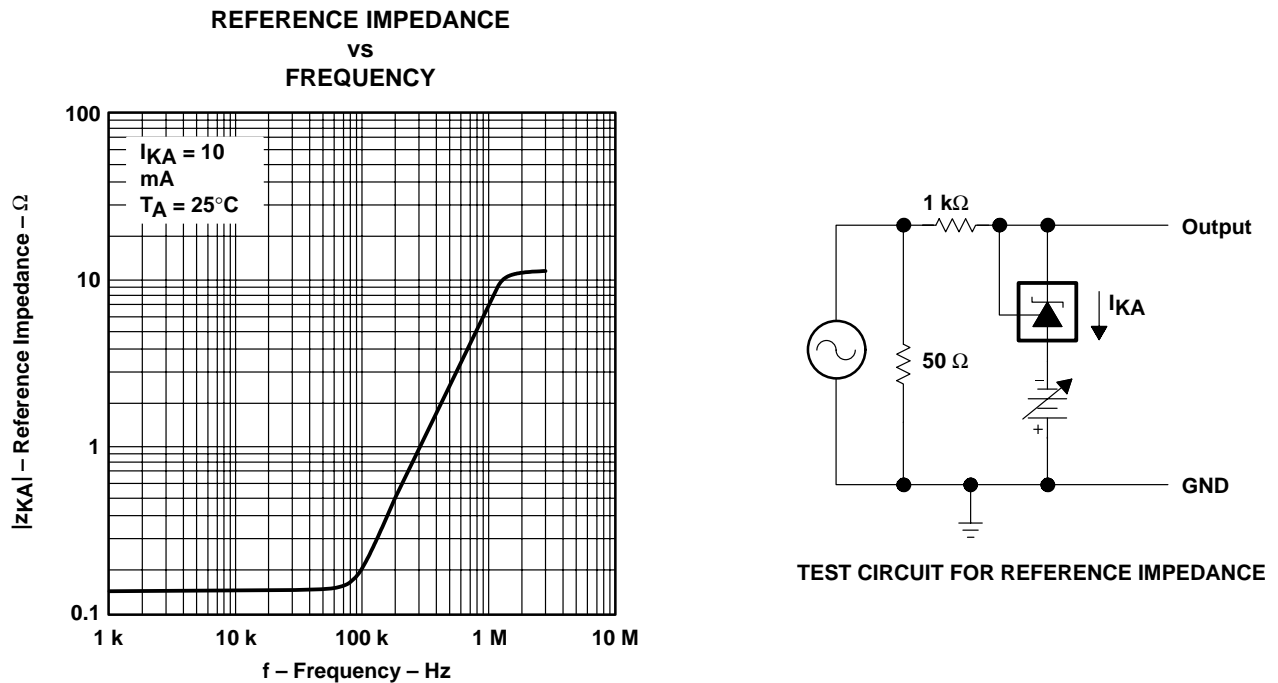


Figure 13

# TL431C, TL431AC, TL431I, TL431AI, TL431M, TL431Y ADJUSTABLE PRECISION SHUNT REGULATORS

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## TYPICAL CHARACTERISTICS

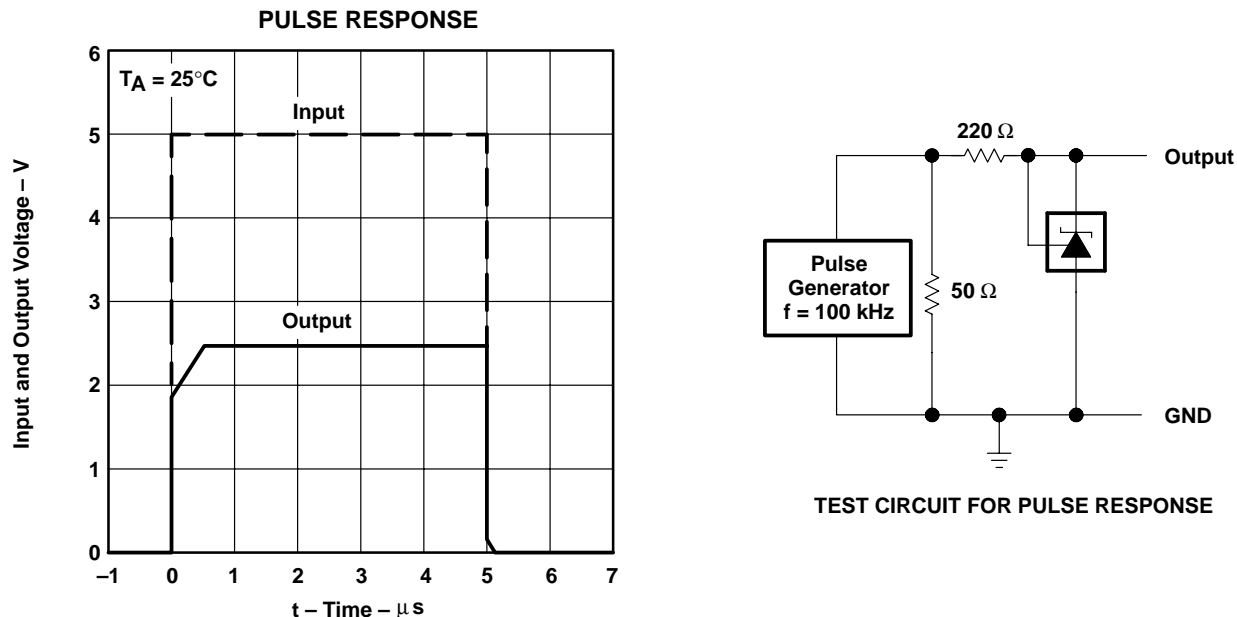
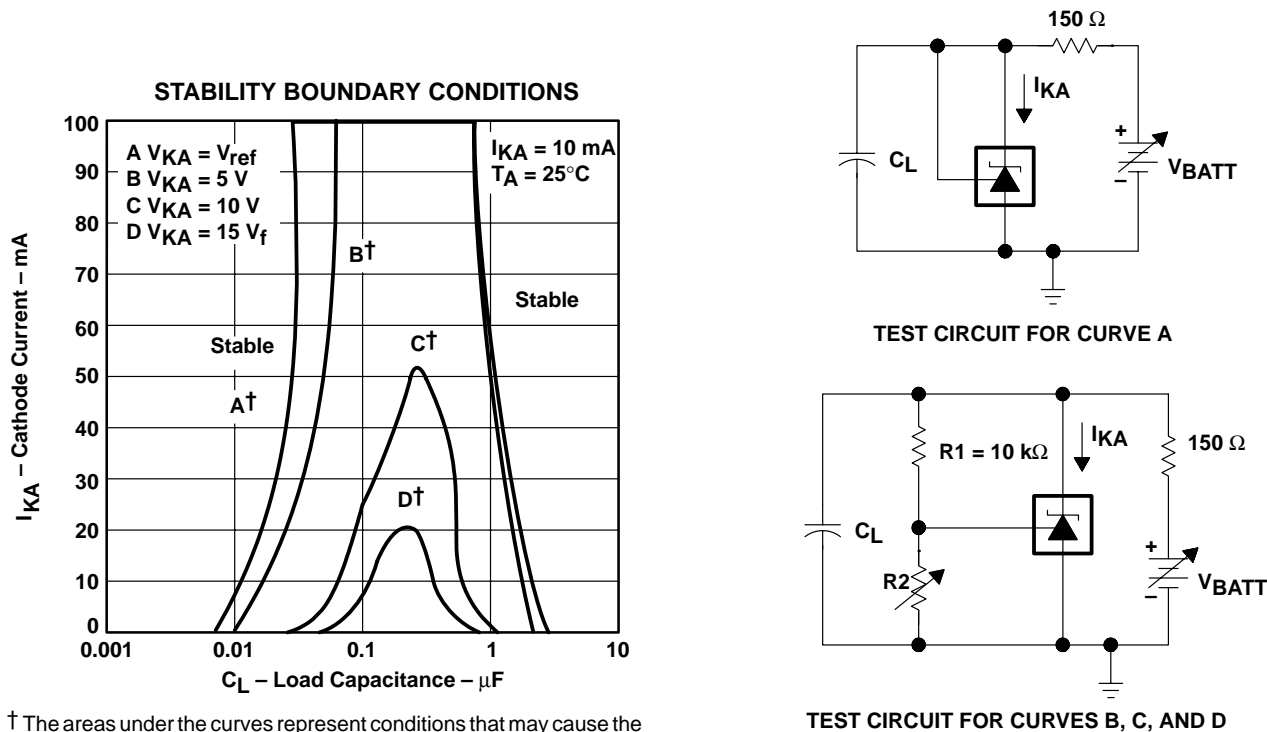


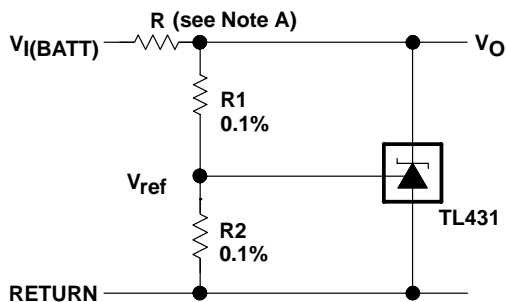
Figure 14



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

Figure 15

APPLICATION INFORMATION



$$V_O = \left(1 + \frac{R_1}{R_2}\right) V_{ref}$$

NOTE A: R should provide cathode current  $\geq 1$  mA to the TL431 at minimum  $V_{I(BATT)}$ .

Figure 16. Shunt Regulator

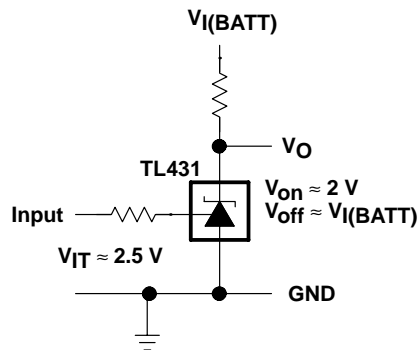
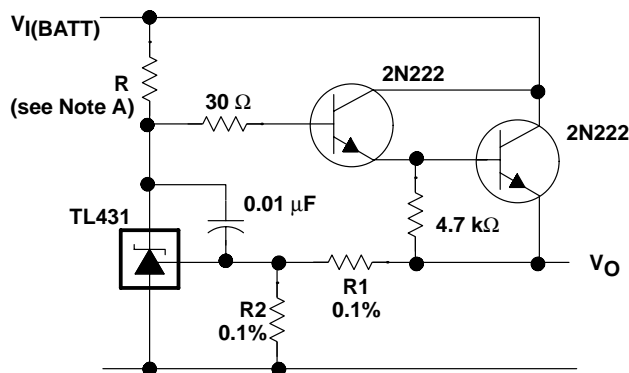


Figure 17. Single-Supply Comparator With Temperature-Compensated Threshold



$$V_O = \left(1 + \frac{R_1}{R_2}\right) V_{ref}$$

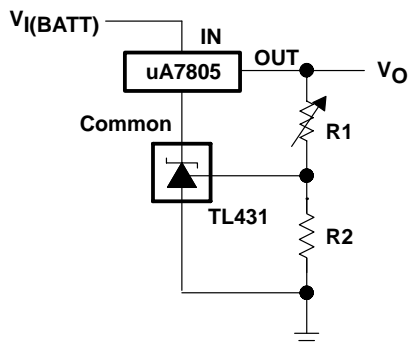
NOTE A: R should provide cathode current  $\geq 1$ -mA to the TL431 at minimum  $V_{I(BATT)}$ .

Figure 18. Precision High-Current Series Regulator

# TL431C, TL431AC, TL431I, TL431AI, TL431M, TL431Y ADJUSTABLE PRECISION SHUNT REGULATORS

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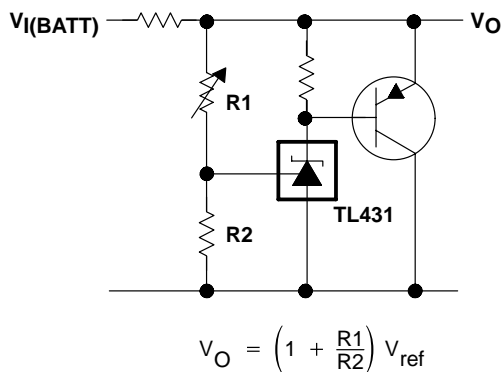
## APPLICATION INFORMATION



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

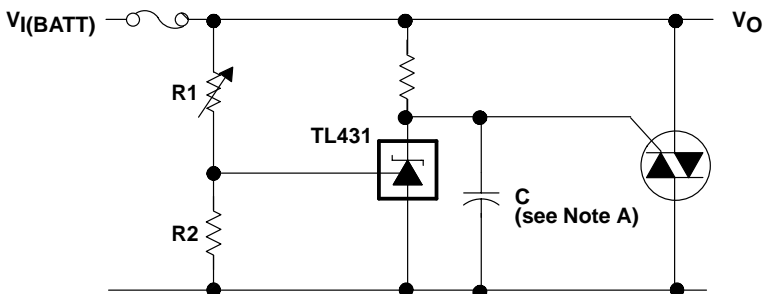
$$\text{Min } V_O = V_{ref} + 5 \text{ V}$$

Figure 19. Output Control of a 3-Terminal Fixed Regulator



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

Figure 20. High-Current Shunt Regulator



NOTE A: Refer to the stability boundary conditions in Figure 15 to determine allowable values for C.

Figure 21. Crowbar Circuit



APPLICATION INFORMATION

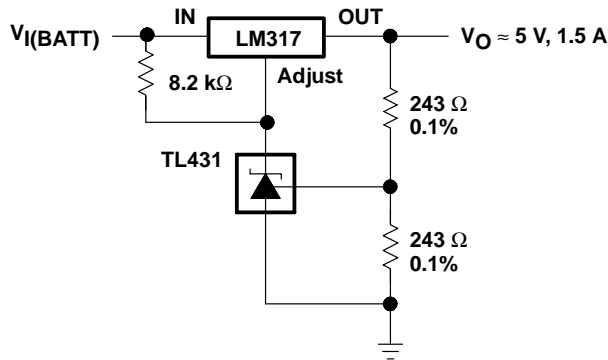
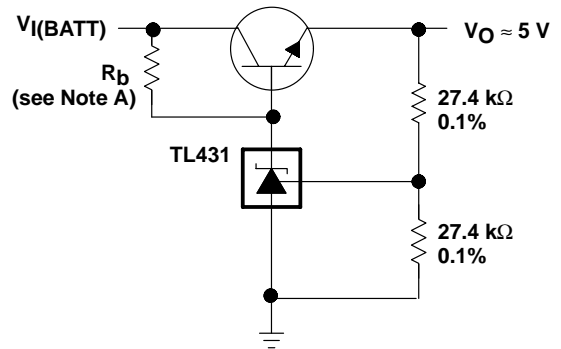


Figure 22. Precision 5-V, 1.5-A Regulator



NOTE A:  $R_b$  should provide cathode current  $\geq 1$ -mA to the TL431.

Figure 23. Efficient 5-V Precision Regulator

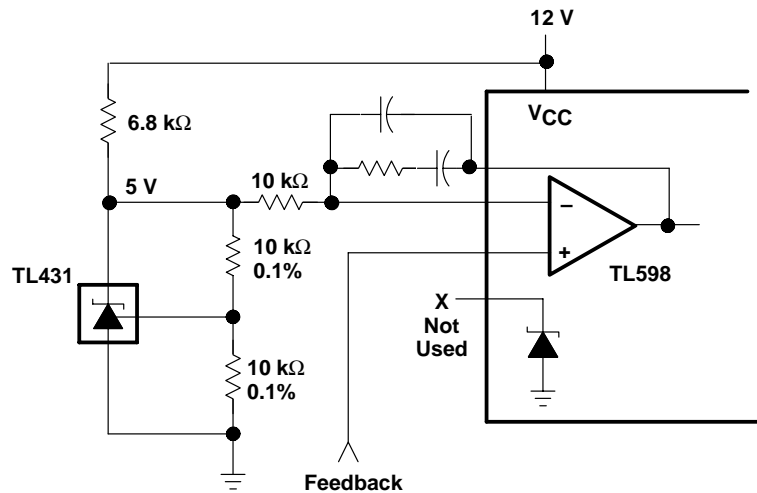
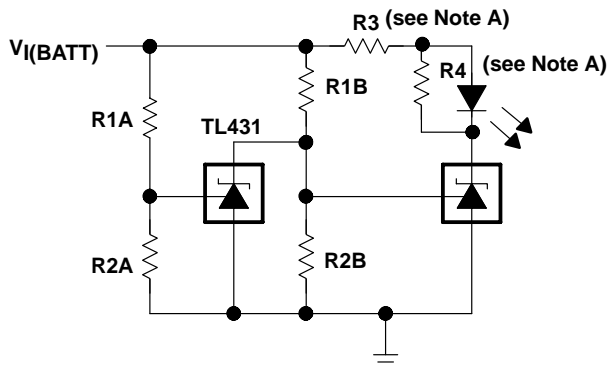


Figure 24. PWM Converter With Reference

# TL431C, TL431AC, TL431I, TL431AI, TL431M, TL431Y ADJUSTABLE PRECISION SHUNT REGULATORS

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## APPLICATION INFORMATION



$$\text{Low Limit} = \left(1 + \frac{R1B}{R2B}\right) V_{ref}$$

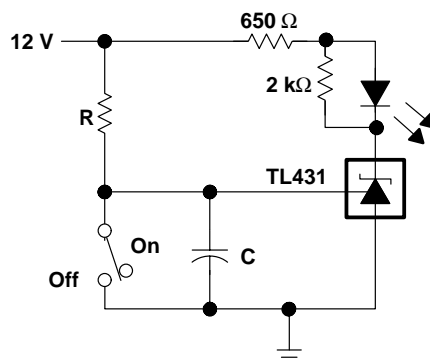
$$\text{High Limit} = \left(1 + \frac{R1A}{R2A}\right) V_{ref}$$

LED on when

$$\text{Low Limit} < V_{I(BATT)} < \text{High Limit}$$

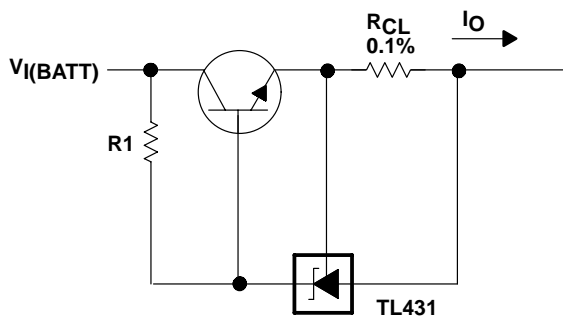
NOTE A: R3 and R4 are selected to provide the desired LED intensity and cathode current  $\geq 1$  mA to the TL431 at the available  $V_{I(BATT)}$ .

Figure 25. Voltage Monitor



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

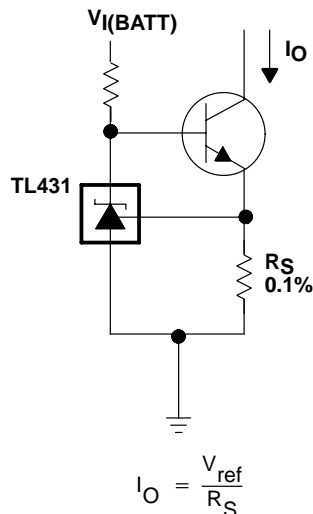
Figure 26. Delay Timer



$$I_{out} = \frac{V_{ref}}{R_{CL}} + I_{KA}$$

$$R1 = \frac{V_{I(BATT)}}{\frac{I_O}{h_{FE}} + I_{KA}}$$

Figure 27. Precision Current Limiter



$$I_O = \frac{V_{ref}}{R_S}$$

Figure 28. Precision Constant-Current Sink

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