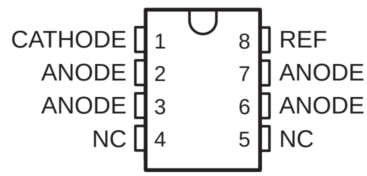
- **Equivalent Full-Range Temperature Coefficient . . . 30 ppm/°C**
- **0.2-Ω Typical Output Impedance**
- **Sink-Current Capability . . . 1 mA to 100 mA**
- **Low Output Noise**
- **Adjustable Output Voltage . . . V_{ref} to 36 V**
- **Available in a Wide Range of High-Density Packages**

description

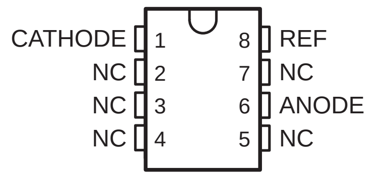
The TL431 and TL431A are three-terminal adjustable shunt regulators with specified thermal stability over applicable automotive, commercial, and military temperature ranges. The output voltage can be set to any value between V_{ref} (approximately 2.5 V) and 36 V, with two external resistors (see Figure 17). 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 onboard regulation, adjustable power supplies, and switching power supplies.

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.

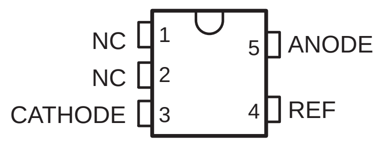
D PACKAGE
(TOP VIEW)



P OR PW PACKAGE
(TOP VIEW)

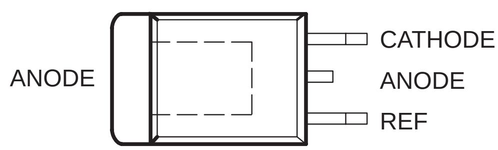


DBV PACKAGE
(TOP VIEW)

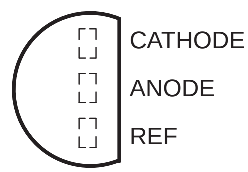


NC – No internal connection

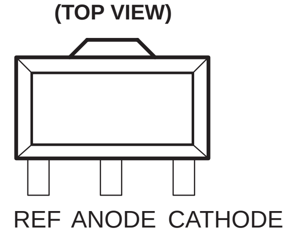
KTP PACKAGE
(TOP VIEW)



LP PACKAGE
(TOP VIEW)



PK PACKAGE
(TOP VIEW)

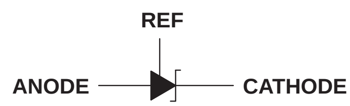


AVAILABLE OPTIONS

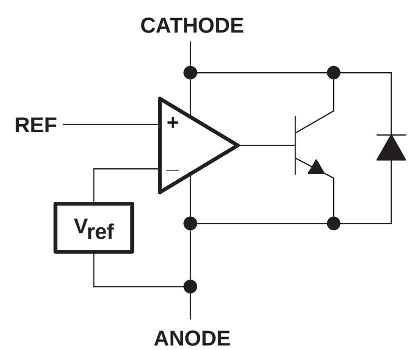
T_A	PACKAGED DEVICES						
	SMALL-OUTLINE (D)	SOT-23 (DBV)	PLASTIC FLANGE MOUNT (KTP)	TO-226AA (LP)	PLASTIC DIP (P)	PLASTIC SHRINK SMALL-OUTLINE (PW)	SOT-89 (PK)
0°C to 70°C	TL431CD TL431ACD	TL431CDBVR	TL431CKTPR	TL431CLP TL431ACLP	TL431CP TL431ACP	TL431CPWR TL431ACPWR	TL431CPKR
–40°C to 85°C	TL431ID TL431AID			TL431ILP TL431AILP	TL431IP TL431AIP		TL431IPKR

The D, LP, and PW packages are available taped and reeled. The DBV, KTP, and PK packages are only available taped and reeled. Add the suffix R to device type (e.g., TL431CDR).

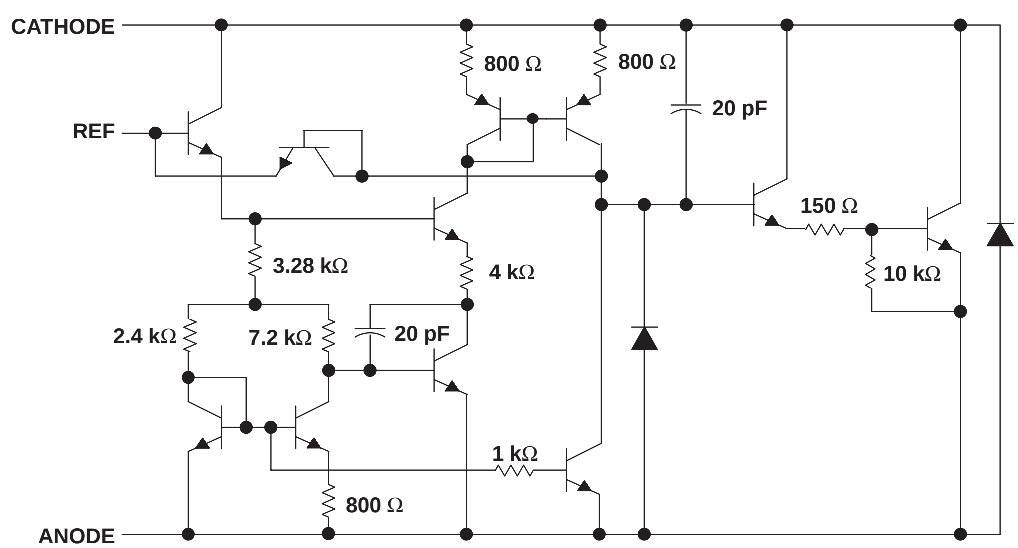
symbol



functional block diagram



equivalent schematic†



† All component values are nominal.

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 μA to 10 mA
Package thermal impedance, θ_{JA} (see Notes 2 and 3): D package . . . . 97°C/W
DBV package . . . . 206°C/W
KTP package . . . . 28°C/W
LP package . . . . 156°C/W
P package . . . . 85°C/W
PK package . . . . 52°C/W
PW package . . . . 149°C/W
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds . . . . 260°C
Storage temperature range, T_{stg} . . . . –65°C to 150°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.

NOTES: 1. Voltage values are with respect to the anode terminal unless otherwise noted.
2. 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 of 150°C can affect reliability.
3. The package thermal impedance is calculated in accordance with JESD 51-7.

recommended operating conditions

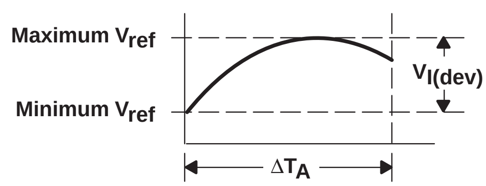
		MIN	MAX	UNIT
Cathode voltage, V_{KA}		V_{ref}	36	V
Cathode current, I_{KA}		1	100	mA
Operating free-air temperature range, T_A	TL431C, TL431AC	0	70	°C
	TL431I, TL431AI	–40	85	

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

PARAMETER		TEST CIRCUIT	TEST CONDITIONS		TL431C MIN	TL431C TYP	TL431C MAX	UNIT
V_{ref}	Reference voltage	2	$V_{KA} = V_{ref}$, I_{KA} = 10 mA		2440	2495	2550	mV
$V_{I(dev)}$	Deviation of reference voltage over full temperature range (see Figure 1)	2	$V_{KA} = V_{ref}$, I_{KA} = 10 mA, T_A = 0°C to 70°C			4	25	mV
$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	Ratio of change in reference voltage to the change in cathode voltage	3	I_{KA} = 10 mA	ΔV_{KA} = 10 V – V_{ref}		–1.4	–2.7	$\frac{mV}{V}$
				ΔV_{KA} = 36 V – 10 V		–1	–2	
I_{ref}	Reference current	3	I_{KA} = 10 mA, R1 = 10 kΩ, R2 = ∞			2	4	µA
$I_{I(dev)}$	Deviation of reference current over full temperature range (see Figure 1)	3	I_{KA} = 10 mA, R1 = 10 kΩ, R2 = ∞, T_A = 0°C to 70°C			0.4	1.2	µA
I_{min}	Minimum cathode current for regulation	2	$V_{KA} = V_{ref}$			0.4	1	mA
I_{off}	Off-state cathode current	4	V_{KA} = 36 V, V_{ref} = 0			0.1	1	µA
$\lvert z_{KA} \rvert$	Dynamic impedance (see Figure 1)	1	I_{KA} = 1 mA to 100 mA, $V_{KA} = V_{ref}$, f ≤ 1 kHz			0.2	0.5	Ω

The deviation parameters $V_{ref(dev)}$ and $I_{ref(dev)}$ are defined as the differences between the maximum and minimum values obtained over the recommended temperature range. The average full-range temperature coefficient of the reference voltage, α_{Vref}, is defined as:

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



where:
ΔT_A is the recommended operating free-air temperature range of the device.

α_{Vref} can be positive or negative, depending on whether minimum V_{ref} or maximum V_{ref}, respectively, occurs at the lower temperature.

Example: maximum V_{ref} = 2496 mV at 30°C, minimum V_{ref} = 2492 mV at 0°C, V_{ref} = 2495 mV at 25°C, ΔT_A = 70°C for TL431C

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

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

Calculating Dynamic Impedance

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

When the device is operating with two external resistors (see Figure 3), the total dynamic impedance of the circuit is given by:

$$|z'| = \frac{\Delta V}{\Delta I} \approx \left|z_{KA}\right| \left(1 + \frac{R1}{R2}\right)$$

Figure 1. Calculating Deviation Parameters and Dynamic Impedance

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

PARAMETER		TEST CIRCUIT	TEST CONDITIONS		TL431I			UNIT
					MIN	TYP	MAX	
V_{ref}	Reference voltage	2	$V_{KA} = V_{ref}$, I_{KA} = 10 mA		2440	2495	2550	mV
$V_{I(dev)}$	Deviation of reference voltage over full temperature range (see Figure 1)	2	$V_{KA} = V_{ref}$, I_{KA} = 10 mA, T_A = –40°C to 85°C			5	50	mV
$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	Ratio of change in reference voltage to the change in cathode voltage	3	I_{KA} = 10 mA	ΔV_{KA} = 10 V – V_{ref}		–1.4	–2.7	mV/V
				ΔV_{KA} = 36 V – 10 V		–1	–2	
I_{ref}	Reference current	3	I_{KA} = 10 mA, R1 = 10 kΩ, R2 = ∞			2	4	µA
$I_{I(dev)}$	Deviation of reference current over full temperature range (see Figure 1)	3	I_{KA} = 10 mA, R1 = 10 kΩ, R2 = ∞, T_A = –40°C to 85°C			0.8	2.5	µA
I_{min}	Minimum cathode current for regulation	2	$V_{KA} = V_{ref}$			0.4	1	mA
I_{off}	Off-state cathode current	4	V_{KA} = 36 V, V_{ref} = 0			0.1	1	µA
$\lvert z_{KA} \rvert$	Dynamic impedance (see Figure 1)	2	I_{KA} = 1 mA to 100 mA, $V_{KA} = V_{ref}$, f ≤ 1 kHz			0.2	0.5	Ω

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

PARAMETER		TEST CIRCUIT	TEST CONDITIONS		TL431AC			UNIT
					MIN	TYP	MAX	
V_{ref}	Reference voltage	2	$V_{KA} = V_{ref}$, I_{KA} = 10 mA		2470	2495	2520	mV
$V_{I(dev)}$	Deviation of reference voltage over full temperature range (see Figure 1)	2	$V_{KA} = V_{ref}$, I_{KA} = 10 mA, T_A = 0°C to 70°C			4	25	mV
$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	Ratio of change in reference voltage to the change in cathode voltage	3	I_{KA} = 10 mA	ΔV_{KA} = 10 V – V_{ref}		–1.4	–2.7	mV/V
				ΔV_{KA} = 36 V – 10 V		–1	–2	
I_{ref}	Reference current	3	I_{KA} = 10 mA, R1 = 10 kΩ, R2 = ∞			2	4	µA
$I_{I(dev)}$	Deviation of reference current over full temperature range (see Figure 1)	3	I_{KA} = 10 mA, R1 = 10 kΩ, R2 = ∞, T_A = 0°C to 70°C			0.8	1.2	µA
I_{min}	Minimum cathode current for regulation	2	$V_{KA} = V_{ref}$			0.4	0.6	mA
I_{off}	Off-state cathode current	4	V_{KA} = 36 V, V_{ref} = 0			0.1	0.5	µA
$\lvert z_{KA} \rvert$	Dynamic impedance (see Figure 1)	1	I_{KA} = 1 mA to 100 mA, $V_{KA} = V_{ref}$, f ≤ 1 kHz			0.2	0.5	Ω

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

PARAMETER		TEST CIRCUIT	TEST CONDITIONS		TL431AI			UNIT
					MIN	TYP	MAX	
V_{ref}	Reference voltage	2	$V_{KA} = V_{ref}$,	I_{KA} = 10 mA	2470	2495	2520	mV
$V_{I(dev)}$	Deviation of reference voltage over full temperature range (see Figure 1)	2	$V_{KA} = V_{ref}$, I_{KA} = 10 mA, T_A = –40°C to 85°C			5	50	mV
$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	Ratio of change in reference voltage to the change in cathode voltage	3	I_{KA} = 10 mA	ΔV_{KA} = 10 V – V_{ref}		–1.4	–2.7	$\frac{mV}{V}$
				ΔV_{KA} = 36 V – 10 V		–1	–2	
I_{ref}	Reference current	3	I_{KA} = 10 mA, R1 = 10 kΩ, R2 = ∞			2	4	μA
$I_{I(dev)}$	Deviation of reference current over full temperature range (see Figure 1)	3	I_{KA} = 10 mA, R1 = 10 kΩ, R2 = ∞, T_A = –40°C to 85°C			0.8	2.5	μA
I_{min}	Minimum cathode current for regulation	2	$V_{KA} = V_{ref}$			0.4	0.7	mA
I_{off}	Off-state cathode current	4	V_{KA} = 36 V,	V_{ref} = 0		0.1	0.5	μA
$\|z_{KA}\|$	Dynamic impedance (see Figure 1)	2	I_{KA} = 1 mA to 100 mA, $V_{KA} = V_{ref}$, f ≤ 1 kHz			0.2	0.5	Ω

PARAMETER MEASUREMENT INFORMATION

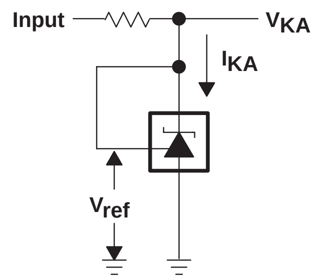


Figure 2. Test Circuit for $V_{KA} = V_{ref}$

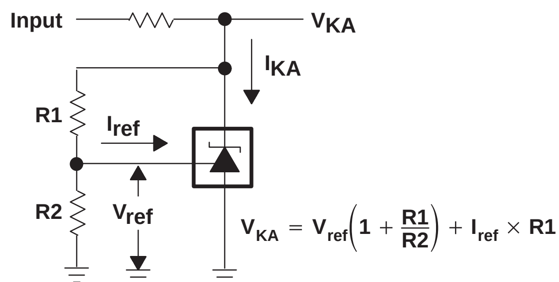


Figure 3. Test Circuit for $V_{KA} > V_{ref}$

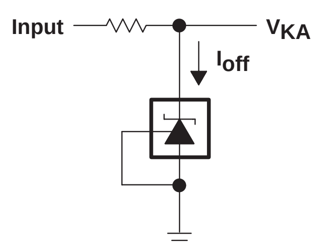


Figure 4. Test Circuit for I_{off}

TYPICAL CHARACTERISTICS

Table 1. Graphs

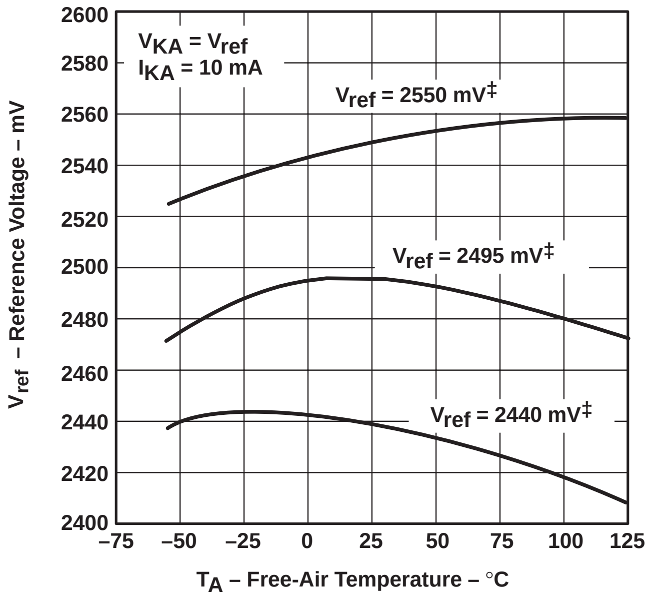
	FIGURE
Reference input voltage vs Free-air temperature	5
Reference input current vs Free-air temperature	6
Cathode current vs Cathode voltage	7, 8
Off-state cathode current vs Free-air temperature	9
Ratio of delta reference voltage to change in cathode voltage vs Free-air temperature	10
Equivalent input noise voltage vs Frequency	11
Equivalent input noise voltage over a 10-second period	12
Small-signal voltage amplification vs Frequency	13
Reference impedance vs Frequency	14
Pulse response	15
Stability boundary conditions	16

Table 2. Application Circuits

	FIGURE
Shunt regulator	17
Single-supply comparator with temperature-compensated threshold	18
Precision high-current series regulator	19
Output control of a three-terminal fixed regulator	20
High-current shunt regulator	21
Crowbar circuit	22
Precision 5-V 1.5-A regulator	23
Efficient 5-V precision regulator	24
PWM converter with reference	25
Voltage monitor	26
Delay timer	27
Precision current limiter	28
Precision constant-current sink	29

TYPICAL CHARACTERISTICS†

REFERENCE VOLTAGE vs FREE-AIR TEMPERATURE



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

Figure 5

REFERENCE CURRENT vs FREE-AIR TEMPERATURE

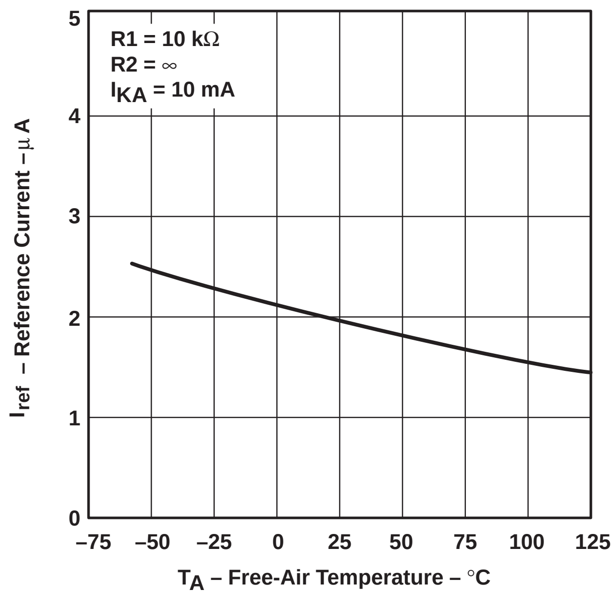


Figure 6

CATHODE CURRENT vs CATHODE VOLTAGE

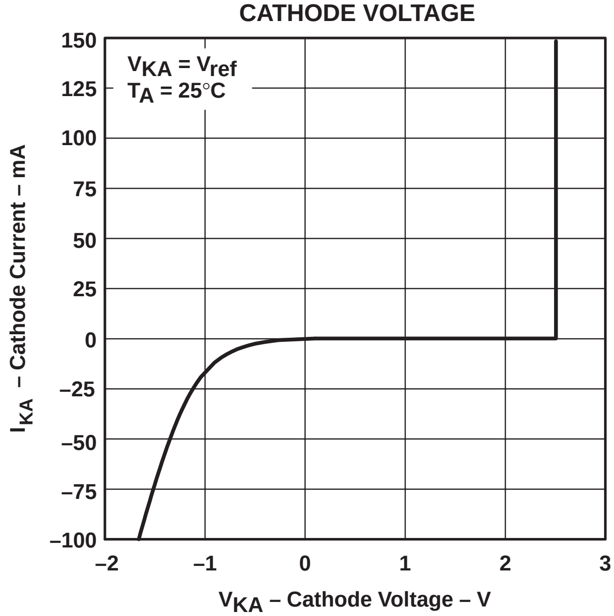


Figure 7

CATHODE CURRENT vs CATHODE VOLTAGE

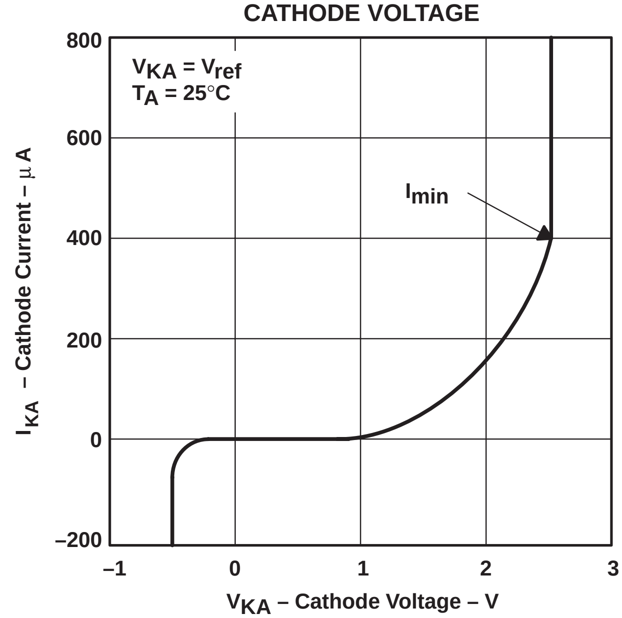


Figure 8

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

TYPICAL CHARACTERISTICS†

OFF-STATE CATHODE CURRENT
vs
FREE-AIR TEMPERATURE

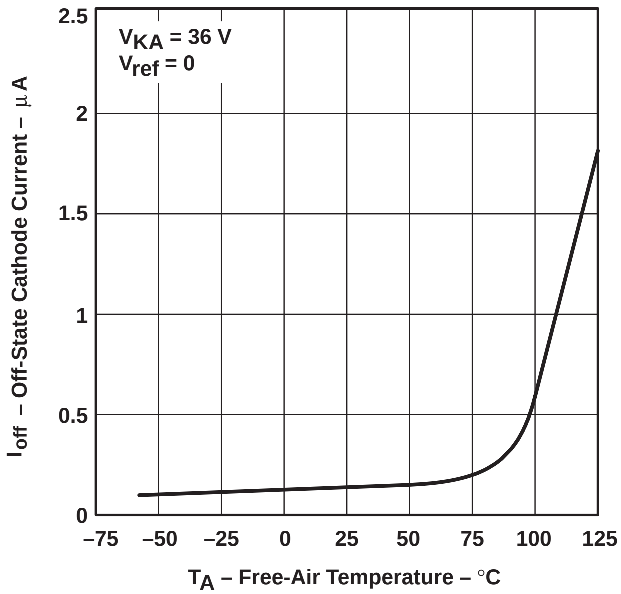


Figure 9

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

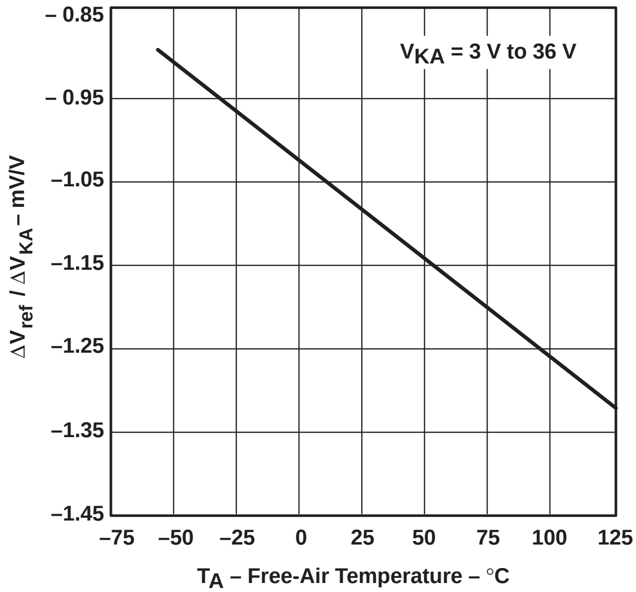


Figure 10

EQUIVALENT INPUT NOISE VOLTAGE
vs
FREQUENCY

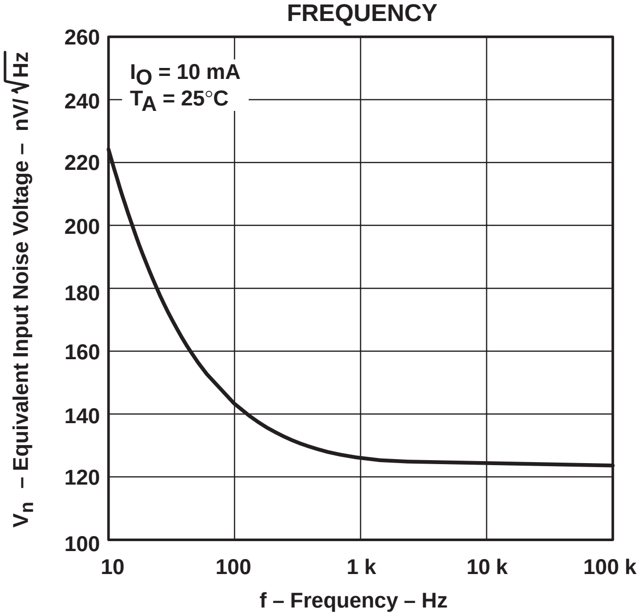
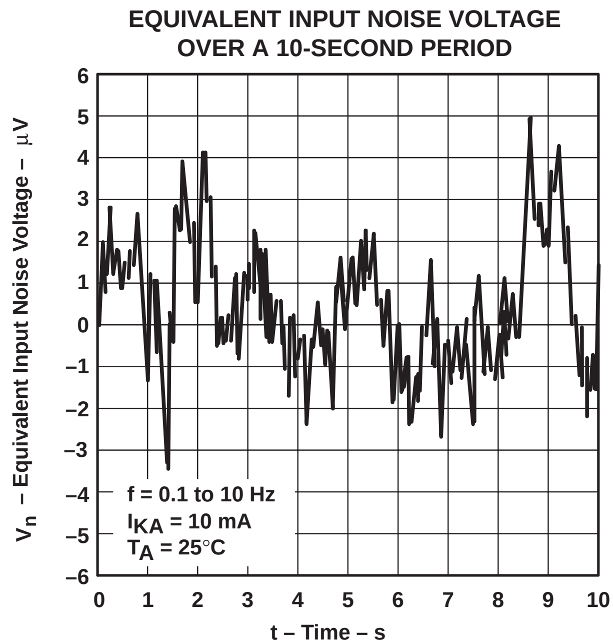


Figure 11

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

TYPICAL CHARACTERISTICS



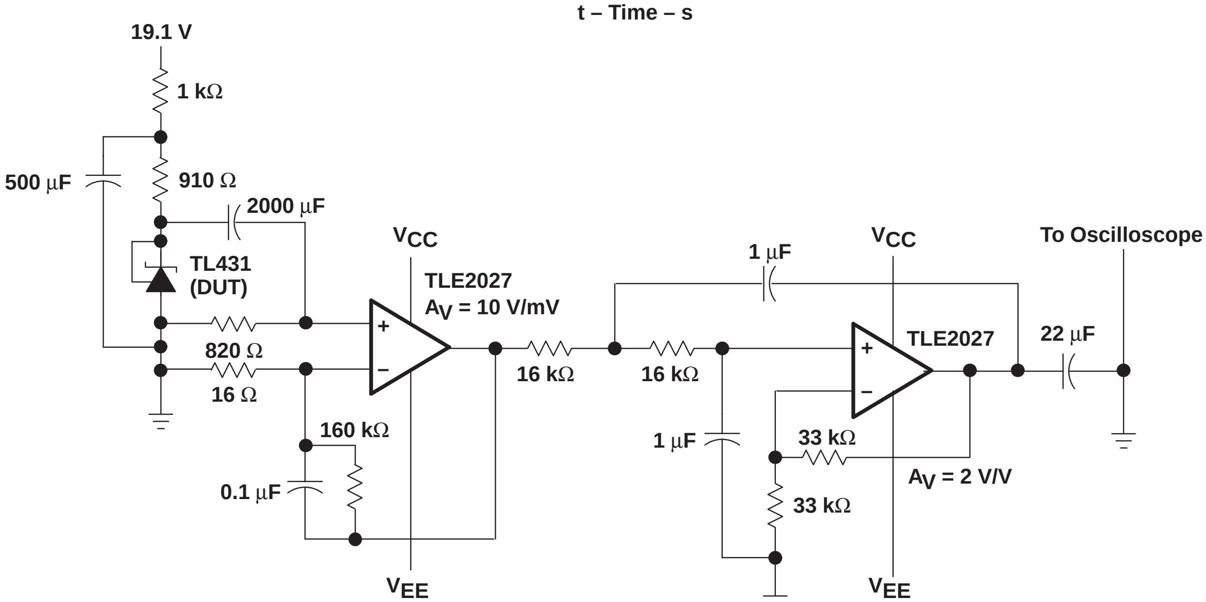
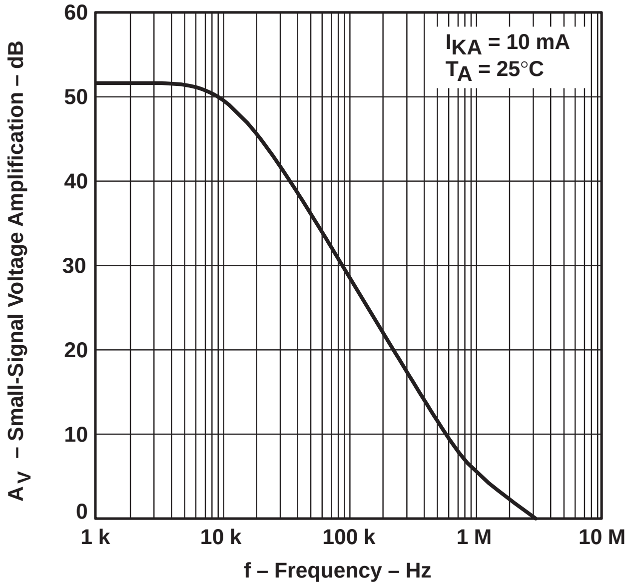
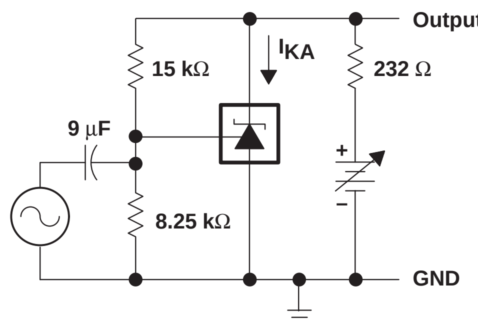


Figure 12. Test Circuit for Equivalent Input Noise Voltage

TYPICAL CHARACTERISTICS

SMALL-SIGNAL VOLTAGE AMPLIFICATION vs FREQUENCY

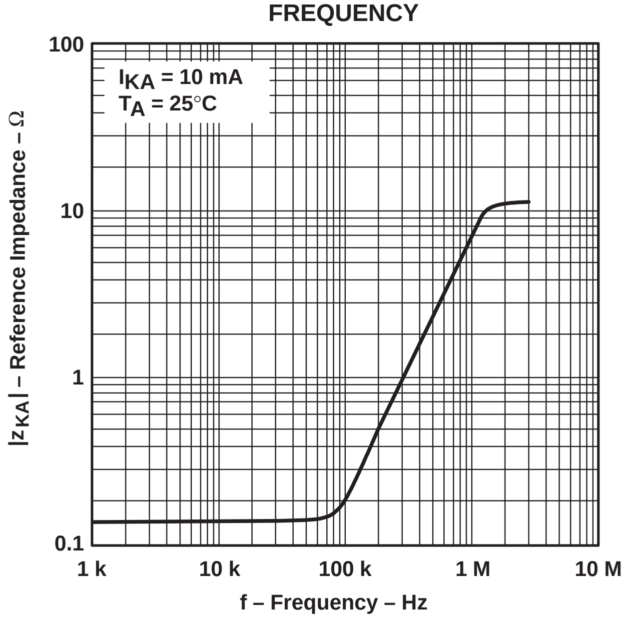


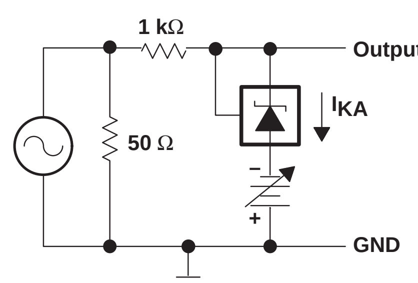


TEST CIRCUIT FOR VOLTAGE AMPLIFICATION

Figure 13

REFERENCE IMPEDANCE vs FREQUENCY



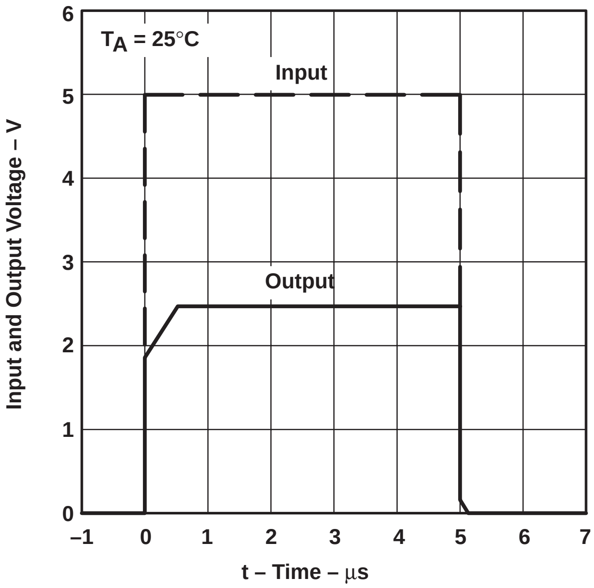


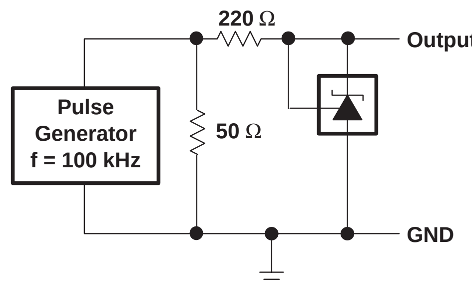
TEST CIRCUIT FOR REFERENCE IMPEDANCE

Figure 14

TYPICAL CHARACTERISTICS

PULSE RESPONSE

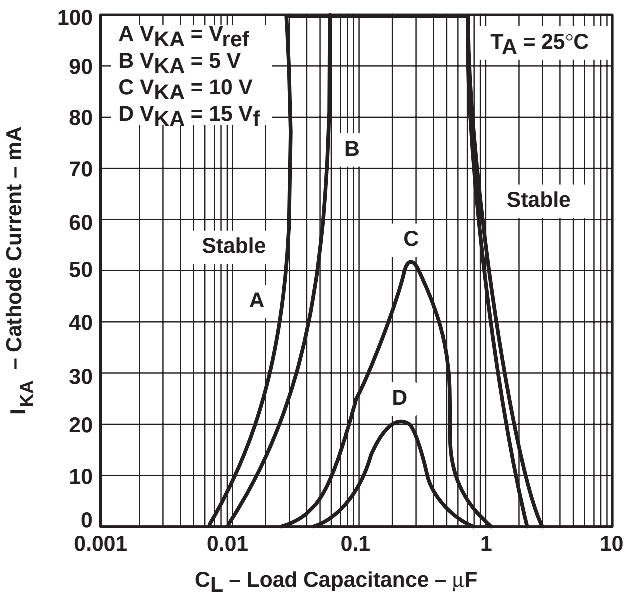




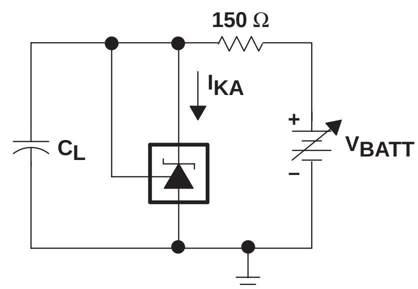
TEST CIRCUIT FOR PULSE RESPONSE

Figure 15

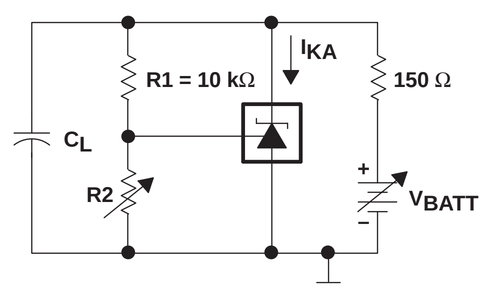
STABILITY BOUNDARY CONDITIONS†



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



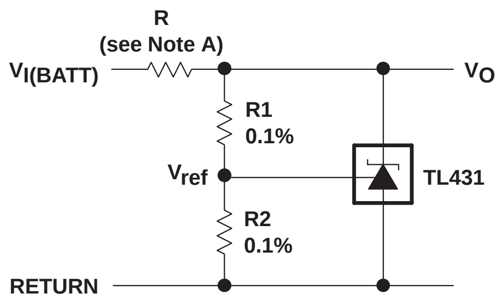
TEST CIRCUIT FOR CURVE A



TEST CIRCUIT FOR CURVES B, C, AND D

Figure 16

APPLICATION INFORMATION



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

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

Figure 17. Shunt Regulator

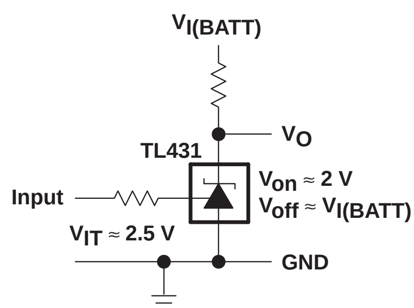
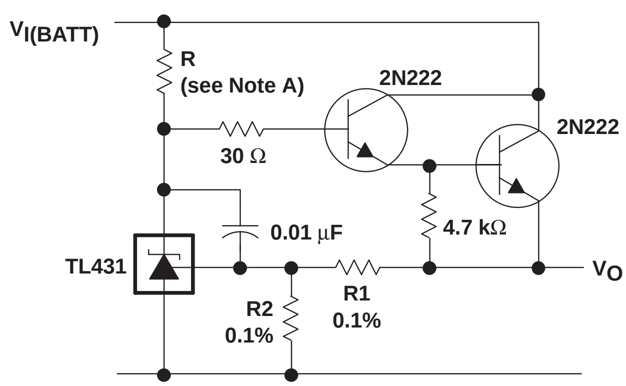


Figure 18. Single-Supply Comparator With Temperature-Compensated Threshold

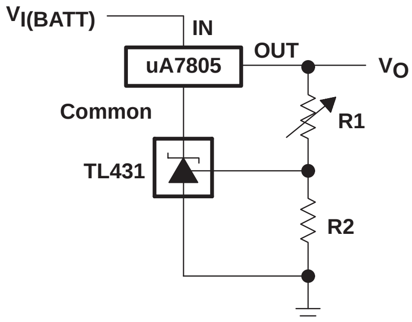


$$V_O = \left(1 + \frac{R1}{R2}\right)V_{ref}$$

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

Figure 19. Precision High-Current Series Regulator

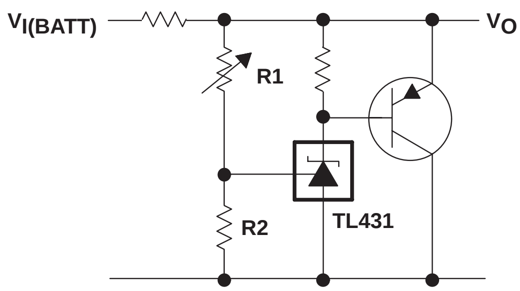
APPLICATION INFORMATION



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

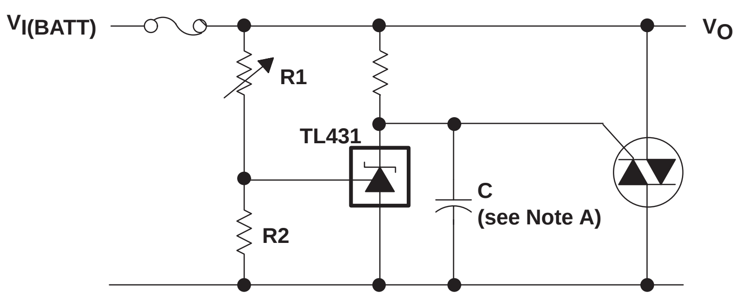
$$\text{Minimum } V_O = V_{ref} + 5\ V$$

Figure 20. Output Control of a Three-Terminal Fixed Regulator



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

Figure 21. High-Current Shunt Regulator



NOTE A: Refer to the stability boundary conditions in Figure 16 to determine allowable values for C.

Figure 22. Crowbar Circuit

APPLICATION INFORMATION

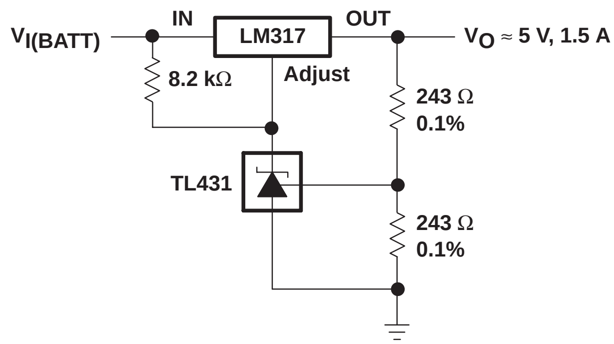
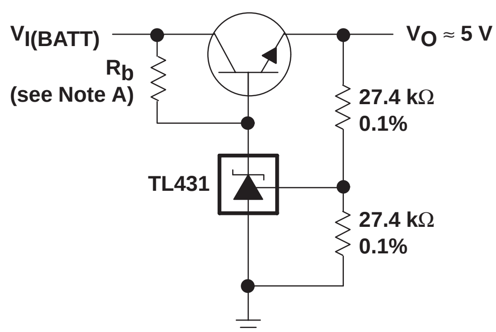


Figure 23. Precision 5-V 1.5-A Regulator



NOTE A: R_b should provide cathode current ≥1 mA to the TL431.

Figure 24. Efficient 5-V Precision Regulator

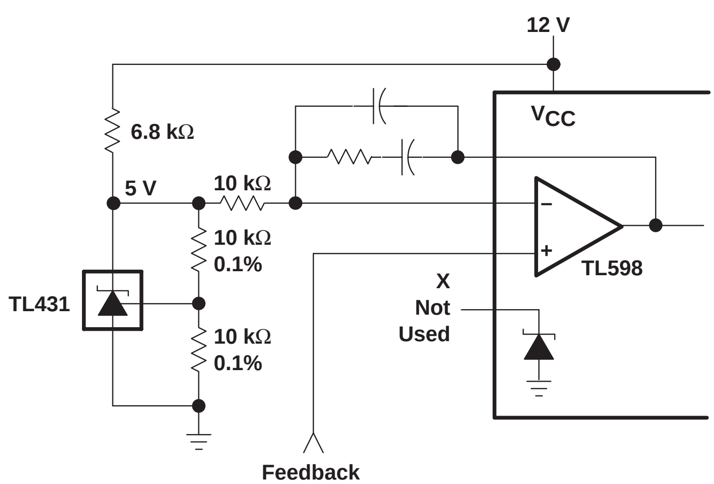
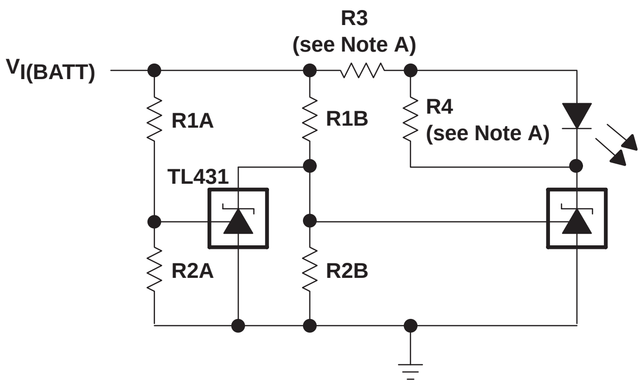


Figure 25. PWM Converter With Reference

APPLICATION INFORMATION



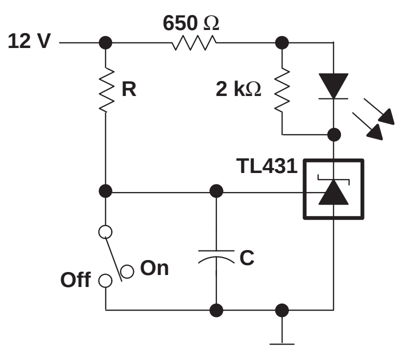
$$\text{Low Limit} = \left(1 + \frac{R1B}{R2B}\right)V_{ref}$$

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

LED on When Low Limit < $V_{I(BATT)}$ < High Limit

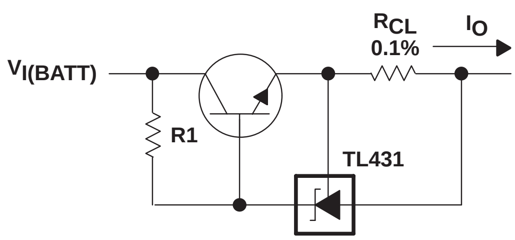
NOTE A: R3 and R4 are selected to provide the desired LED intensity and cathode current ≥1 mA to the TL431 at the available $V_{I(BATT)}$.

Figure 26. Voltage Monitor



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

Figure 27. Delay Timer



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

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

Figure 28. Precision Current Limiter

APPLICATION INFORMATION

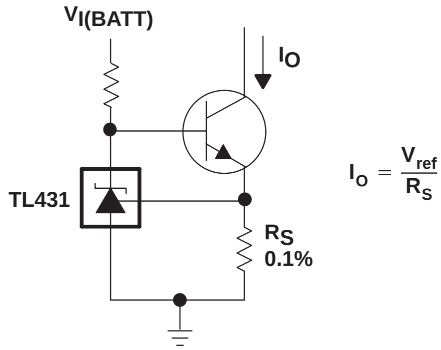


Figure 29. Precision Constant-Current Sink

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