D2410, JULY 1978–REVISED AUGUST 1991

- **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)**

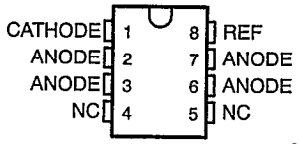
description

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 may 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 like on-board regulation, adjustable power supplies, and switching power supplies.

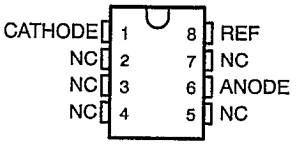
The TL431 is offered in a wide variety of high-density packaging options that includes an SOT-89-type package (suffix PK).

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.

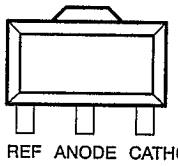
D PACKAGE
(TOP VIEW)



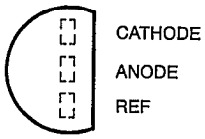
JG AND P PACKAGE
(TOP VIEW)



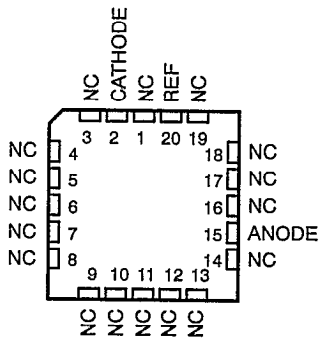
PK PACKAGE
(TOP VIEW)



LP PACKAGE
(TOP VIEW)



FK PACKAGE
(TOP VIEW)



NC–No internal connection

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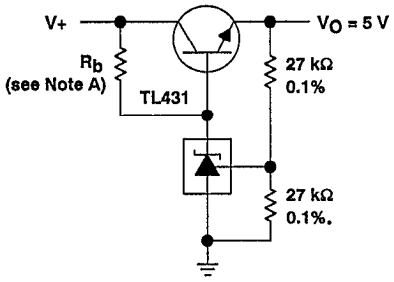
AVAILABLE OPTIONS

T_A	PACKAGE					
	SMALL OUTLINE (D)	CHIP CARRIER (FX)	CERAMIC DIP (JG)	TO-226AA (LP)	PLASTIC DIP (P)	SOT-89 (PK)
0°C to 70°C	TL431CD TL431ACD			TL431CLP TL431ACLP	TL431CP TL431ACP	TL431CPK TL431ACPK
−40°C to 85°C	TL431ID TL431AID			TL431ILP TL431AILP	TL431IP TL431AIP	TL431IPK TL431AIPK
−55°C to 125°C		TL431MFK	TL431MJG			

D and LP packages are available taped and reeled. Add "R" suffix to device type (e.g., TL431CDR). PK package is only available taped and reeled. No "R" suffix required.

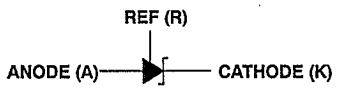
application schematic

Efficient 5-V Precision Regulator

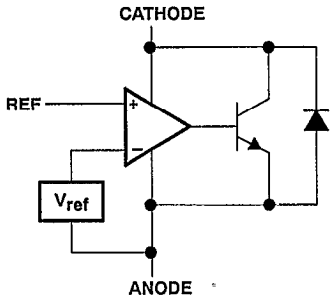


NOTE A: R_b should provide ≥ 1 mA cathode current to the TL431.

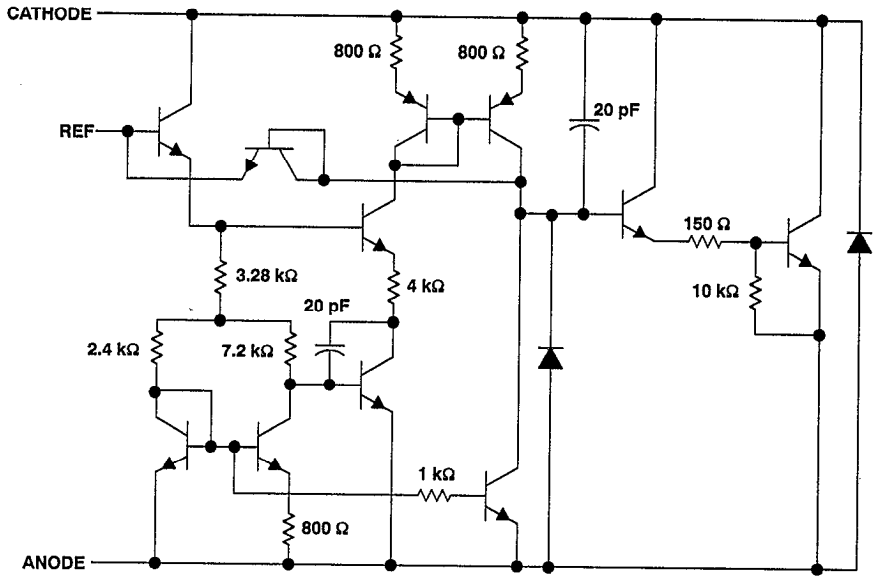
symbol



functional block diagram



equivalent schematic



All component values are nominal.

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

Cathode voltage (see Note 1) ..... 37 V
Continuous cathode current range ..... −100 mA to 150 mA
Reference input current range ..... −50 μA to 10 mA
Continuous 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 ..... −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 or P package ..... 260°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds: JG, LP or PK package ..... 300°C

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

DISSIPATION RATING TABLE 1 – FREE-AIR TEMPERATURE

PACKAGE	DERATING FACTOR ABOVE T_A = 25°C	T_A = 25°C POWER RATING	T_A = 70°C POWER RATING	T_A = 85°C POWER RATING	T_A = 125°C POWER RATING
D	5.8 mW/°C	725 mW	464 mW	429 mW	
FK	11 mW/°C	1375 mW	880 mW	715 mW	275 mW
JG	8.4 mW/°C	1050 mW	672 mW	546 mW	210 mW
LP	6.2 mW/°C	775 mW	496 mW	403 mW	
P	8.0 mW/°C	1000 mW	640 mW	520 mW	
PK	4.0 mW/°C	500 mW	320 mW	266 mW	

DISSIPATION RATING TABLE 2 – CASE TEMPERATURE

PACKAGE	DERATING FACTOR ABOVE T_C = 25°C	T_C = 25°C POWER RATING	T_C = 70°C POWER RATING	T_C = 85°C POWER RATING
PK	25 mW/°C	3125 mW	2000 mW	2625 mW

recommended operating conditions

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

electrical characteristics at 25°C free-air temperature (unless otherwise noted)

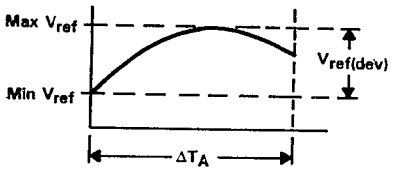
PARAMETER		TEST CIRCUIT	TEST CONDITIONS		TL431M			TL431I			TL431C			UNIT
					MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
V_{ref}	Reference input voltage	1	$V_{KA} = V_{ref}$, I_K = 10 mA		2400	2495	2600	2440	2495	2550	2440	2495	2550	mV
$V_{ref(dev)}$	Deviation of reference input voltage over full temperature range‡	1	$V_{KA} = V_{ref}$, I_K = 10 mA, T_A = full range†			22			5	30		4	17	mV
$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	Ratio of change in reference input voltage to the change in cathode voltage	2	I_K = 10 mA	ΔV_{KA} = 10 V − V_{ref}		−1.4	−3		−1.4	−2.7		−1.4	−2.7	$\frac{mV}{V}$
				ΔV_{KA} = 36 V − 10 V		−1	−2.3		−1	−2		−1	−2	
I_{ref}	Reference input current	2	I_K = 10 mA, R1 = 10 kΩ, R2 = ∞			2	8*		2	4		2	4	μA
$I_{ref(dev)}$	Deviation of reference input current over full temperature range‡	2	I_K = 10 mA, R1 = 10 kΩ, R2 = ∞, T_A = full range†			1			0.8	2.5		0.4	1.2	μA
I_{min}	Minimum cathode current for regulation	1	$V_{KA} = V_{ref}$			0.4	1.5		0.4	1		0.4	1	mA
I_{off}	Off-state cathode current	3	V_{KA} = 36 V, V_{ref} = 0			0.1	3		0.1	1		0.1	1	μA
$\lvert z_{ka} \rvert$	Dynamic impedance§	1	$V_{KA} = V_{ref}$, I_K = 1 mA to 100 mA, f ≤ 1 kHz			0.2	0.9*		0.2	0.5		0.2	0.5	Ω

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

† Full temperature range is −55°C to 125°C for the TL431M, −40°C to 85°C for the TL431I and TL431AI, and 0°C to 70°C for the TL431C and TL431AC.

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

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



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

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

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

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

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

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

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

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

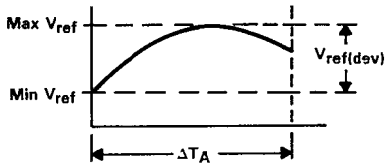
electrical characteristics at 25 °C free-air temperature (unless otherwise noted)

PARAMETER		TEST CIRCUIT	TEST CONDITIONS		TL431AI			TL431AC			UNIT
					MIN	TYP	MAX	MIN	TYP	MAX	
V_{ref}	Reference input voltage	1	$V_{KA} = V_{ref}$, I_K = 10 mA		2470	2495	2520	2470	2495	2520	mV
$V_{ref(dev)}$	Deviation of reference input voltage over full temperature range‡	1	$V_{KA} = V_{ref}$, I_K = 10 mA, T_A = full range†			5	25		4	15	mV
$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	Ratio of change in reference input voltage to the change in cathode voltage	2	I_K = 10 mA	ΔV_{KA} = 10 V − V_{ref}		−1.4	−2.7		−1.4	−2.7	$\frac{mV}{V}$
				ΔK_{VA} = 36 V − 10 V		−1	−2		−1	−2	
I_{ref}	Reference input current	2	I_K = 10 mA, R1 = 10 kΩ, R2 = ∞			2	4		2	4	μA
$I_{ref(dev)}$	Deviation of reference input current over full temperature range‡	2	I_K = 10 mA, R1 = 10 kΩ, R2 = ∞, T_A = full range†			0.8	2.5		0.8	1.2	μA
I_{min}	Minimum cathode current for regulation	1	$V_{KA} = V_{ref}$			0.4	0.7		0.4	0.6	mA
I_{off}	Off-state cathode current	3	V_{KA} = 36 V, V_{ref} = 0			0.1	0.5		0.1	0.5	μA
$\lvert z_{ka} \rvert$	Dynamic impedance§	1	$V_{KA} = V_{ref}$, I_K = 1 mA to 100 mA, f ≤ 1 kHz			0.2	0.5		0.2	0.5	Ω

†Full temperature range is 0 °C to 70 °C for TL431AC and −40 °C to 85 °C for TL431AI .

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

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



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

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

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

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

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

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

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

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

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PARAMETER MEASUREMENT INFORMATION

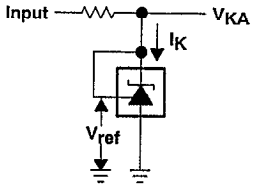

Figure 1. Test Circuit for $V_{KA} = V_{ref}$

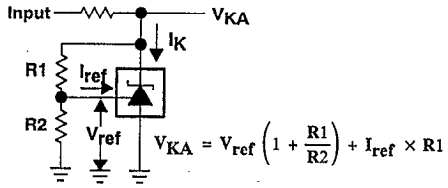

Figure 2. Test Circuit for $V_{KA} > V_{ref}$

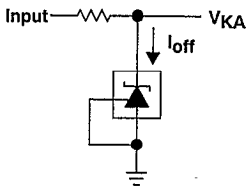

Figure 3. Test Circuit for I_{off}

TYPICAL CHARACTERISTICS

table of graphs

			FIGURE
V_{ref}	Reference voltage	vs Temperature	4
I_{ref}	Reference current	vs Temperature	5
I_K	Cathode current	vs Cathode voltage	6 and 7
I_{off}	Off-State cathode current	vs Temperature	8
ΔV_{ref}	Change in reference voltage to change in cathode voltage	vs Temperature	9
V_n	Noise voltage	vs Frequency over a 10-second time-period	10 and 11
A_V	Voltage amplification	vs Frequency	12
$\|\|z_{ka}\|\|$	Reference impedance	vs Frequency	13
	Pulse response		14
	Stability boundary conditions		15

table of application circuits

APPLICATION	FIGURE
Precision shunt regulator	16
Single-supply comparator with temperature-compensated threshold	17
Precision high-current series regulator	18
Output control of a 3-terminal fixed regulator	19
High-current shunt regulator	20
Crowbar circuit	21
Precision 5-V, 1.5-A regulator	22
Efficient 5-V, precision regulator	23
PWM downconverter with reference	24
Voltage monitor	25
Delay timer	26
Precision current limiter	27
Precision constant-current sink	28

TEXAS INSTRUMENTS
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TYPICAL CHARACTERISTICS†

REFERENCE INPUT VOLTAGE
vs
FREE-AIR TEMPERATURE †

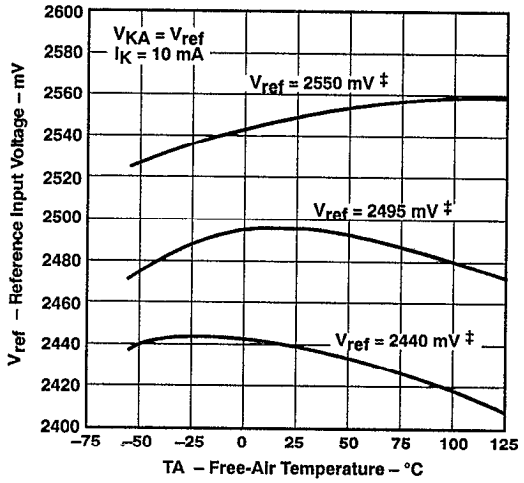


Figure 4

REFERENCE INPUT CURRENT
vs
FREE-AIR TEMPERATURE †

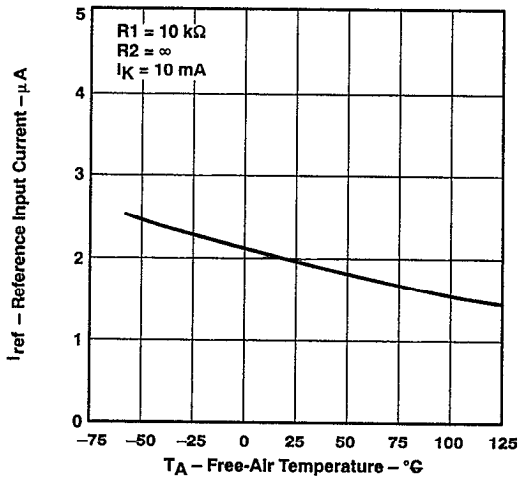


Figure 5

CATHODE CURRENT
vs
CATHODE VOLTAGE

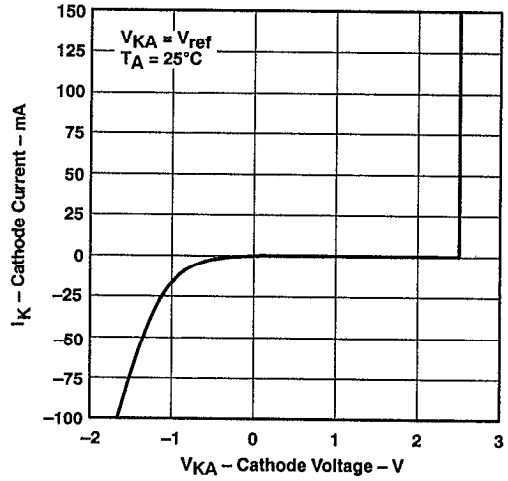


Figure 6

CATHODE CURRENT
vs
CATHODE VOLTAGE

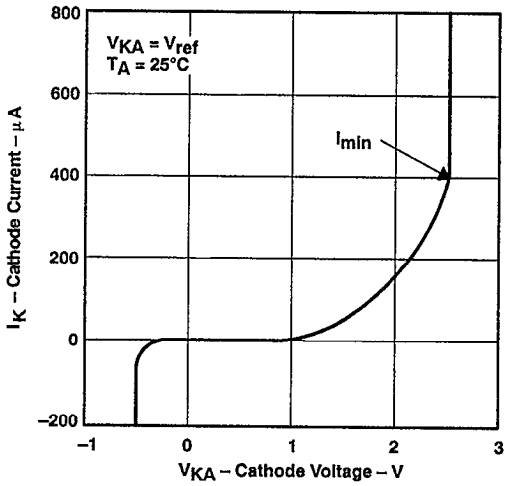


Figure 7

† 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_K = 10 mA, T_A = 25°C.

TYPICAL CHARACTERISTICS†

OFF-STATE CATHODE CURRENT
vs
FREE-AIR TEMPERATURE †

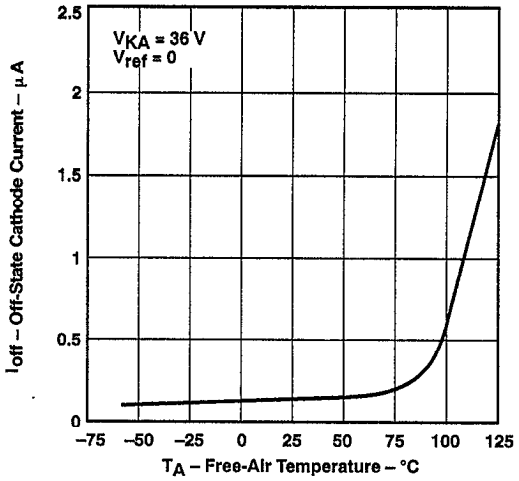


Figure 8

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

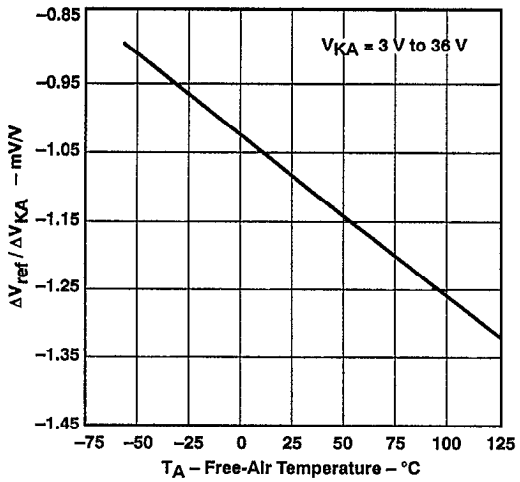


Figure 9

EQUIVALENT INPUT NOISE VOLTAGE
vs
FREQUENCY

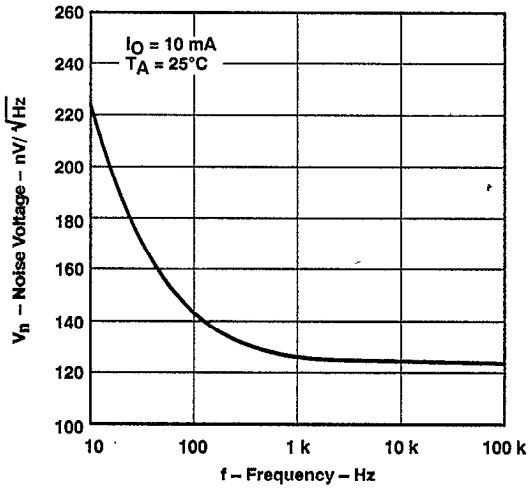
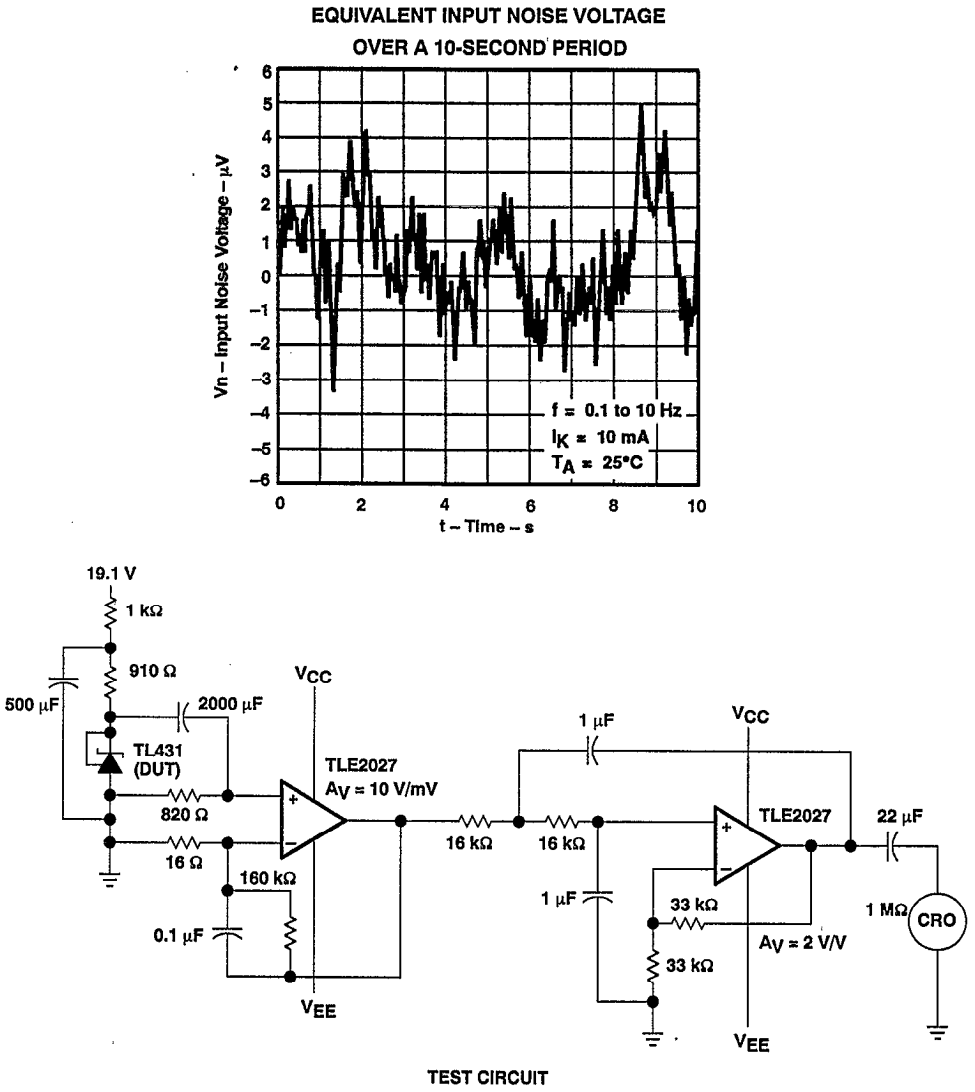


Figure 10

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

TYPICAL CHARACTERISTICS

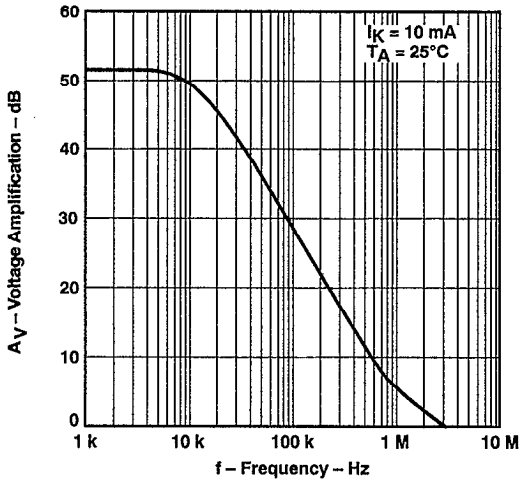


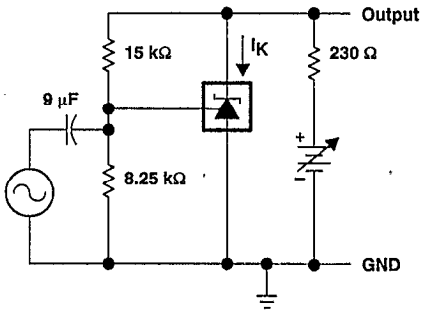
TEST CIRCUIT

Figure 11

TYPICAL CHARACTERISTICS

SMALL-SIGNAL VOLTAGE AMPLIFICATION
vs
FREQUENCY

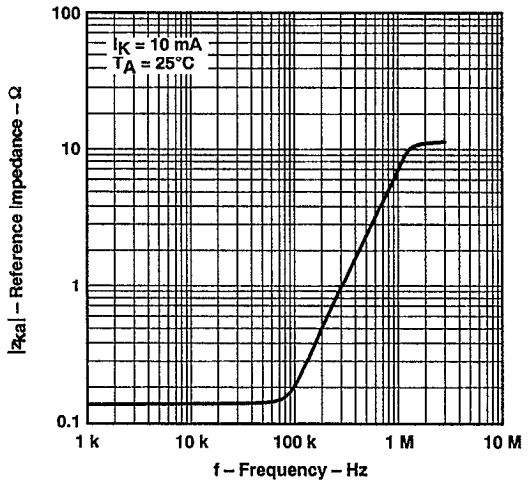


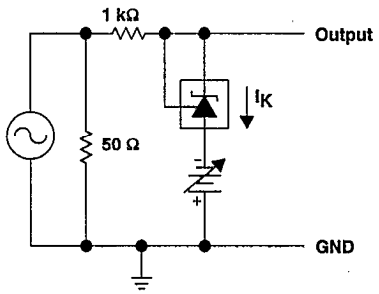


TEST CIRCUIT FOR VOLTAGE AMPLIFICATION

Figure 12

REFERENCE IMPEDANCE
vs
FREQUENCY





TEST CIRCUIT FOR REFERENCE IMPEDANCE

Figure 13

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TYPICAL CHARACTERISTICS

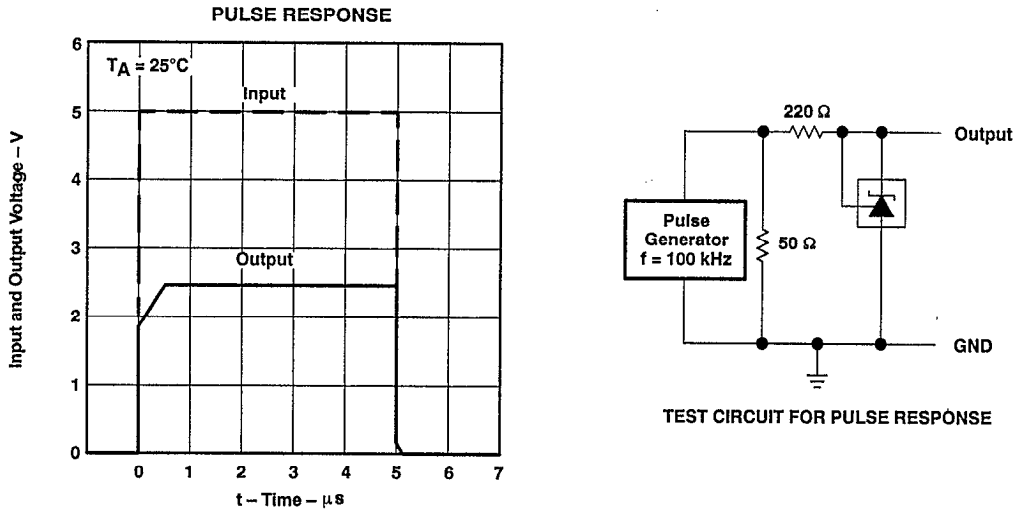


Figure 14

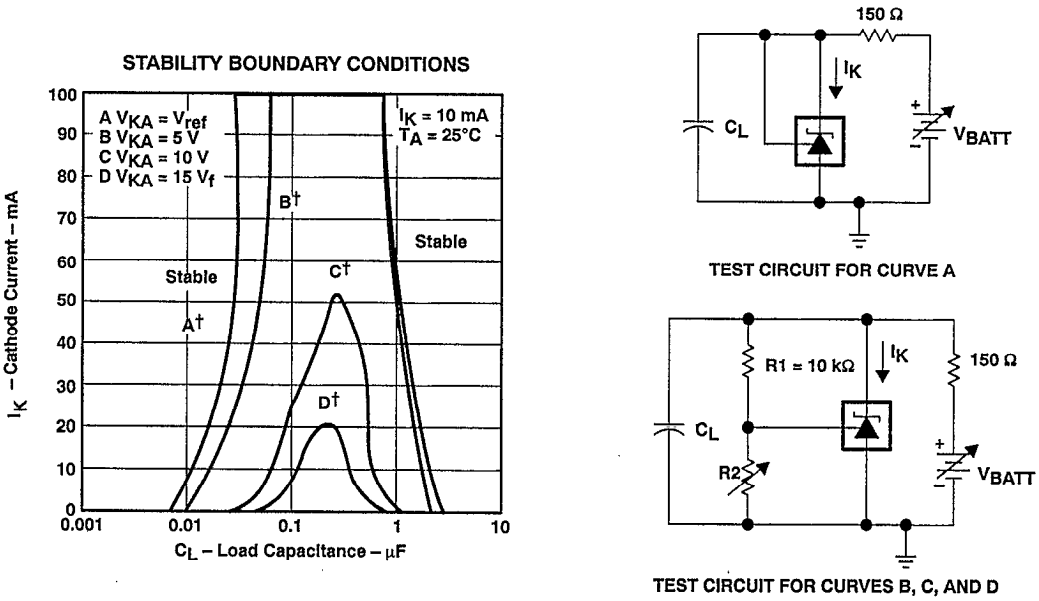
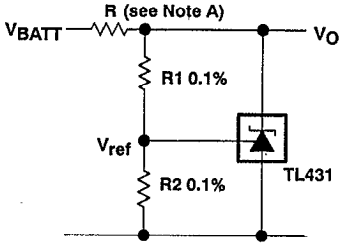


Figure 15

† 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_K conditions with C_L = 0. V_{BATT} and C_L were then adjusted to determine the ranges of stability.

APPLICATION INFORMATION



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

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

Figure 16. Shunt Regulator

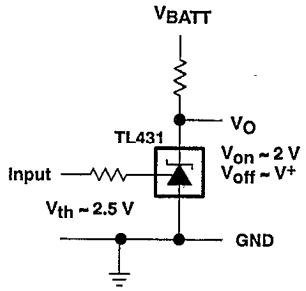
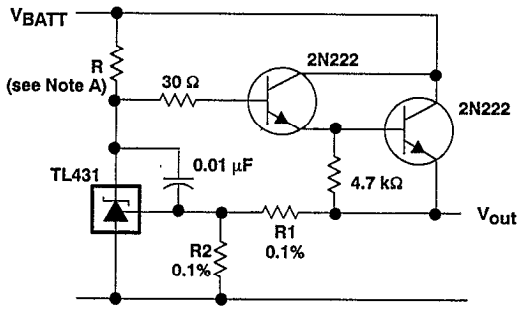


Figure 17. Single-Supply Comparator With Temperature-Compensated Threshold



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

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

Figure 18. Precision High-Current Series Regulator

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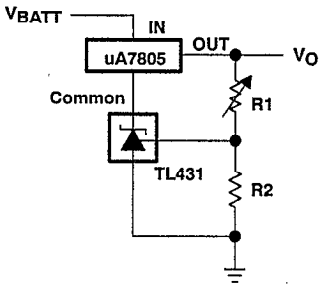
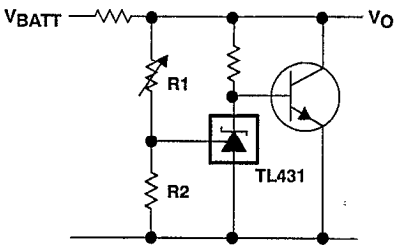


$$V = \left(1 + \frac{R1}{R2}\right) + V_{ref}$$

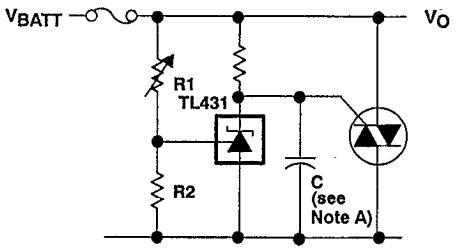
$$\text{Min } V = V_{ref} + 5\ V$$

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

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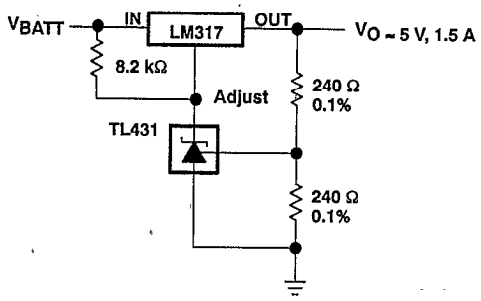
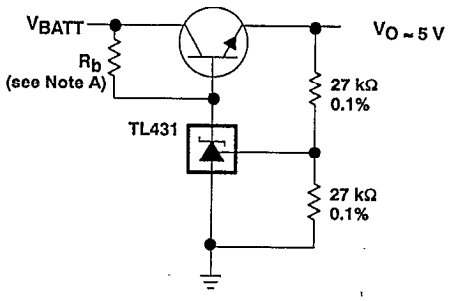


Figure 22. Precision 5-V, 1.5-A Regulator



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

Figure 23. Efficient 5-V Precision Regulator

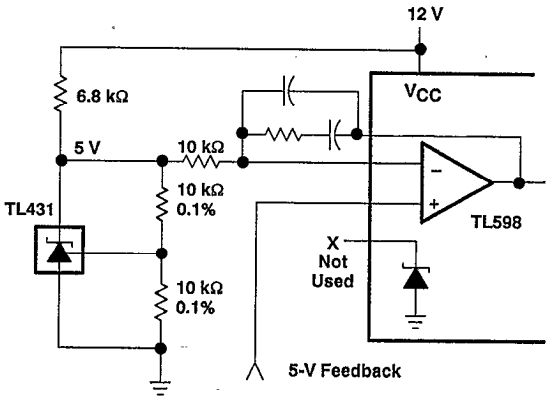


Figure 24. PWM Downconverter With Reference

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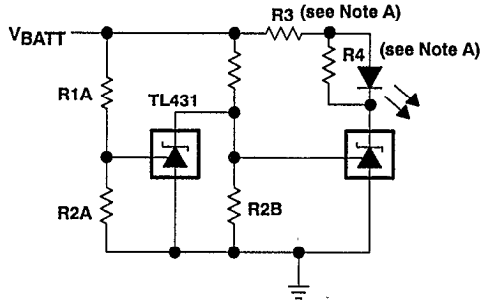


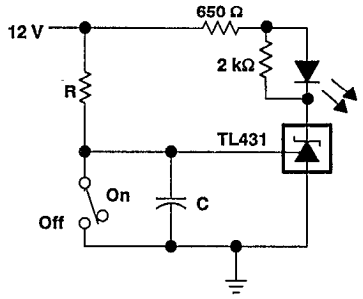
$$\text{Low Limit} = \left(1 + \frac{R1B}{R2B}\right) V_{ref}$$

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

LED On When
Low Limit < V_{BATT} < High Limit

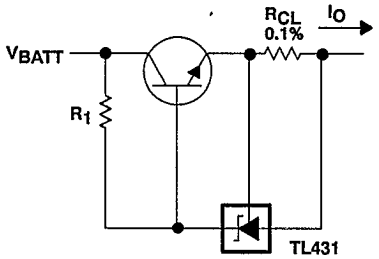
NOTE A: R3 and R4 are selected to provide the desired LED intensity and ≥ 1 mA cathode current to the TL431 at the available V+.

Figure 25. Voltage Monitor



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

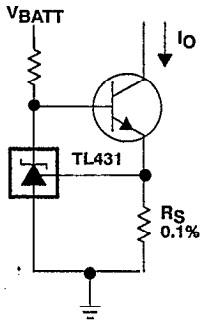
Figure 26. Delay Timer



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

$$R_1 = \frac{V+}{\frac{I_O}{h_{FE}} + I_K}$$

Figure 27. Precision Current Limiter



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

Figure 28. Precision Constant-Current Sink