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

D2410, JULY 1978—REVISED AUGUST 1988

T-58-11-23

- Equivalent Full-Range Temperature Coefficient . . . 30 ppm/°C
- Temperature Compensated for Operation Over Full Rated Operating Temperature Range
- Adjustable Output Voltage
- Fast Turn-On Response
- Sink Current Capability . . . 1 mA to 100 mA
- Low (0.2 Ω Typ) Dynamic Output Impedance
- Low Output Noise

description

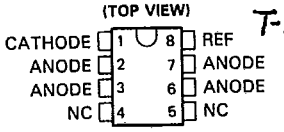
The TL431 and TL431A are three-terminal adjustable shunt regulators with specified thermal stability over applicable industrial and commercial temperature ranges. The output voltage may be set to any value between V_{ref} (approximately 2.5 V) and 36 V with two external resistors (see Figure 16). These 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.

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

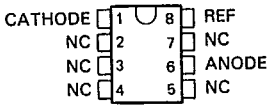
NOTICE

SEE ORDER OF DATA FOR ERRATA INFORMATION

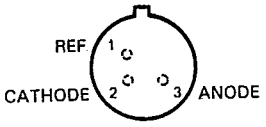
TL431I, TL431AI, TL431C, TL431AC . . . D PACKAGE
(TOP VIEW)



TL431M . . . JG PACKAGE
(TOP VIEW)

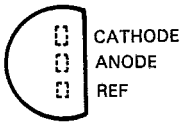


TL431M . . . LD PACKAGE
(TOP VIEW)

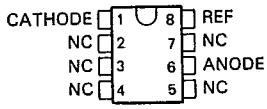


THE ANODE IS IN ELECTRICAL CONTACT WITH THE CASE.

TL431I, TL431AI, TL431C, TL431AC . . . LP PACKAGE
(TOP VIEW)

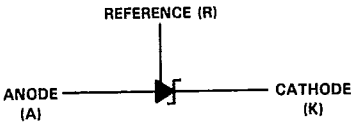


TL431I, TL431AI, TL431C, TL431AC . . . P PACKAGE
(TOP VIEW)



NC—No internal connection

symbol



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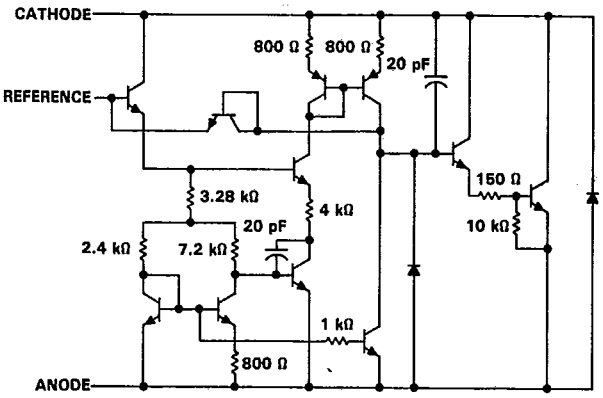
TL431M, TL431I, TL431AI, TL431C, TL431AC
ADJUSTABLE PRECISION SHUNT REGULATORS

T-58-11-23

schematic



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: TL431C, TL431AC ..... 0°C to 70°C
TL431I, TL431AI ..... −40°C to 85°C
TL431M ..... −55°C to 125°C
Storage temperature range ..... −65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds: LD or JG package ..... 300°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds: D, LP, or P package ..... 260°C

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

DISSIPATION RATING TABLE 1—FREE-AIR TEMPERATURE

PACKAGE	$T_A \le 25°C$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25°C$	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ POWER RATING	$T_A = 125°C$ POWER RATING
D	825 mW	6.6 mW/°C	528 mW	429 mW	
JG	1050 mW	8.4 mW/°C	672 mW	546 mW	210 mW
LD	275 mW	2.2 mW/°C	176 mW	143 mW	55 mW
LP	775 mW	6.2 mW/°C	496 mW	403 mW	
P	1000 mW	8.0 mW/°C	640 mW	520 mW	

DISSIPATION RATING TABLE 2—CASE TEMPERATURE

PACKAGE	$T_C \le 25°C$ POWER RATING	DERATING FACTOR ABOVE $T_C = 25°C$	$T_C = 125°C$ POWER RATING
LD	1550 mW	12.4 mW/°C	310 mW

recommended operating conditions

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

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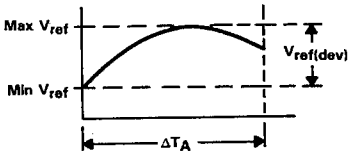
electrical characteristics at 25°C free-air temperature (unless otherwise noted)

PARAMETER		TEST CIRCUIT	TEST CONDITIONS		TL431M MIN	TL431M TYP	TL431M MAX	TL431I MIN	TL431I TYP	TL431I MAX	TL431C MIN	TL431C TYP	TL431C MAX	UNIT
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	$\Delta V_{KA} = 10\ V - V_{ref}$		−1.4	−3		−1.4	−2.7		−1.4	−2.7	mV/V
				$\Delta V_{KA} = 36\ V - 10\ V$		−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

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

‡ 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:

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



where ΔT_A is the rated 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 (see Figure 8).

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

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

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

§ The dynamic impedance is defined as:

$$|z_{ka}| = \frac{\Delta V_{KA}}{\Delta I_K}$$

When the device is operated 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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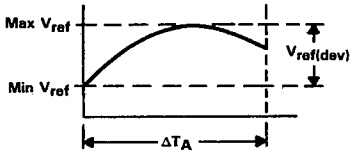
electrical characteristics at 25°C free-air temperature (unless otherwise noted)

PARAMETER		TEST CIRCUIT	TEST CONDITIONS		TL431AI MIN	TL431AI TYP	TL431AI MAX	TL431AC MIN	TL431AC TYP	TL431AC MAX	UNIT
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	$\Delta V_{KA} = 10\ V - V_{ref}$		−1.4	−2.7		−1.4	−2.7	mV/V
				$\Delta K_{VA} = 36\ V - 10\ V$		−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 −40°C to 85°C for TL431AI and 0°C to 70°C for 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, αV_{ref}, is defined as:

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



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.

§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:

$$|z'| = \frac{\Delta V}{\Delta I}, \text{ which is approximately equal to } |z_{ka}| \left(1 + \frac{R1}{R2}\right)$$

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PARAMETER MEASUREMENT INFORMATION

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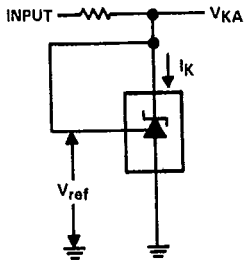

FIGURE 1. TEST CIRCUIT FOR $V_{KA} = V_{ref}$

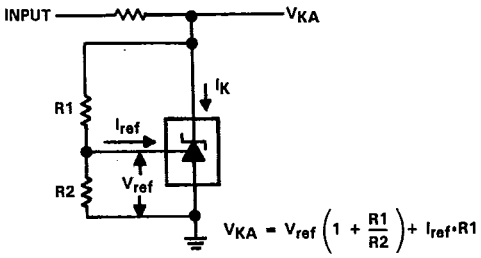

FIGURE 2. TEST CIRCUIT FOR $V_{KA} > V_{ref}$

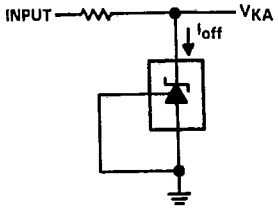

FIGURE 3. TEST CIRCUIT FOR I_{off}

TYPICAL CHARACTERISTICS

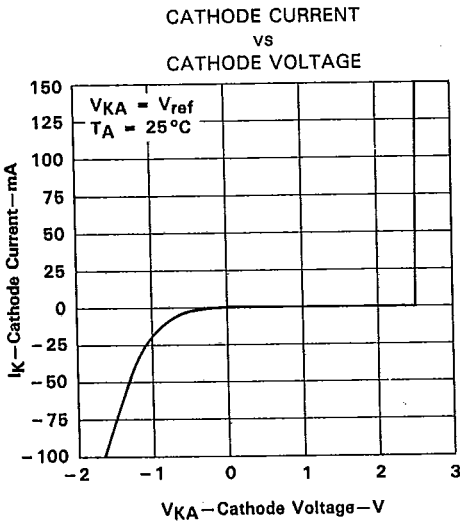

FIGURE 4

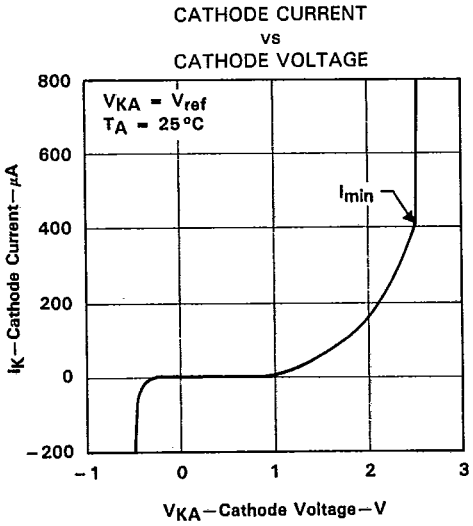

FIGURE 5

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TYPICAL CHARACTERISTICS

OFF-STATE CATHODE CURRENT
vs
FREE-AIR TEMPERATURE†

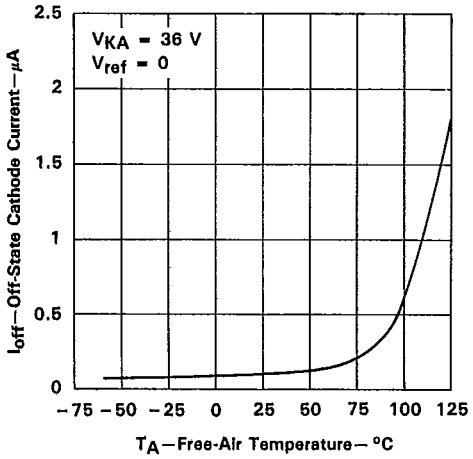


FIGURE 6

NOISE VOLTAGE
vs
FREQUENCY

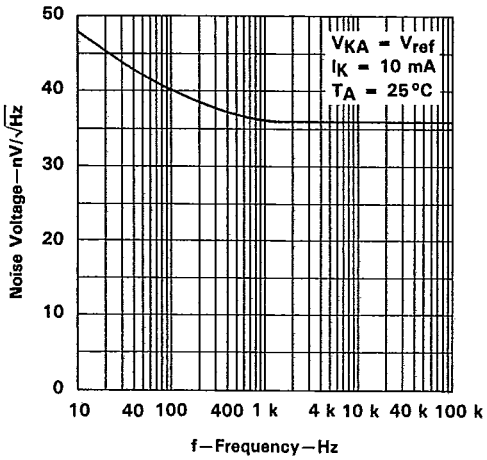


FIGURE 7

REFERENCE INPUT VOLTAGE
vs
FREE-AIR TEMPERATURE†

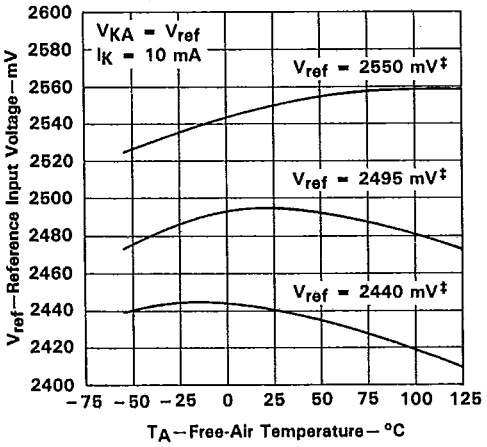


FIGURE 8

REFERENCE INPUT CURRENT
vs
FREE-AIR TEMPERATURE†

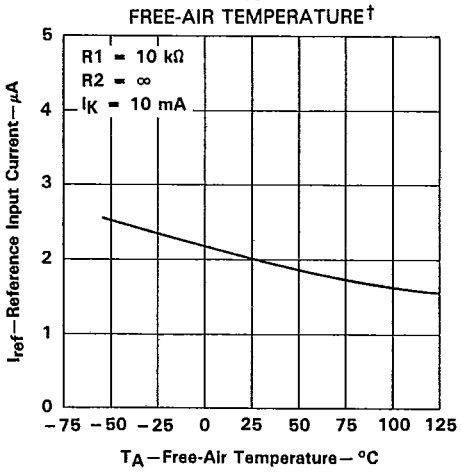


FIGURE 9

†For TL431I, TL431AI, TL431C, and TL431AC, the data applies only for the portions of the curves that lie within their recommended operating temperature ranges.
‡Data is for devices having the indicated value of V_{ref} at I_K = 10 mA, T_A = 25°C.

TYPICAL CHARACTERISTICS

CHANGE IN REFERENCE INPUT VOLTAGE
vs
CATHODE VOLTAGE

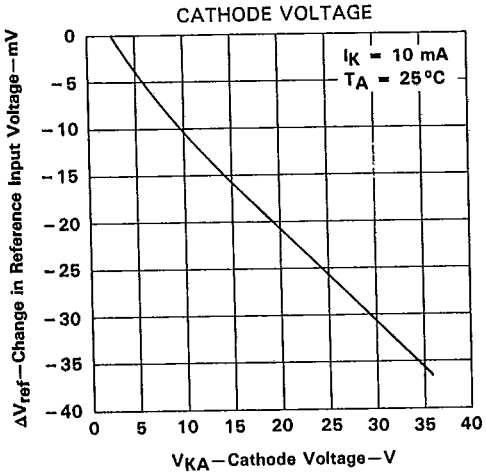


FIGURE 10

DYNAMIC IMPEDANCE
vs
FREE-AIR TEMPERATURE†

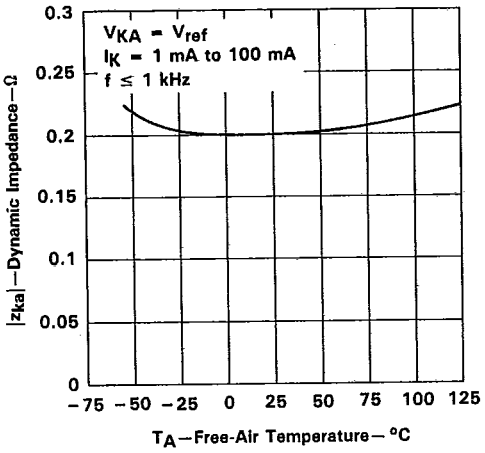
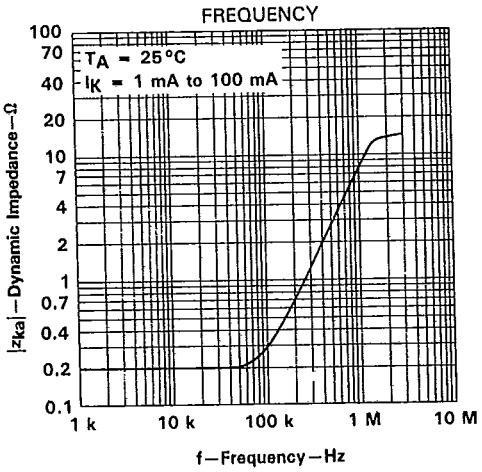
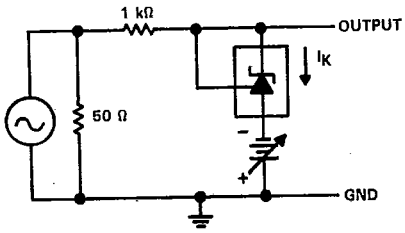


FIGURE 11

DYNAMIC IMPEDANCE
vs
FREQUENCY





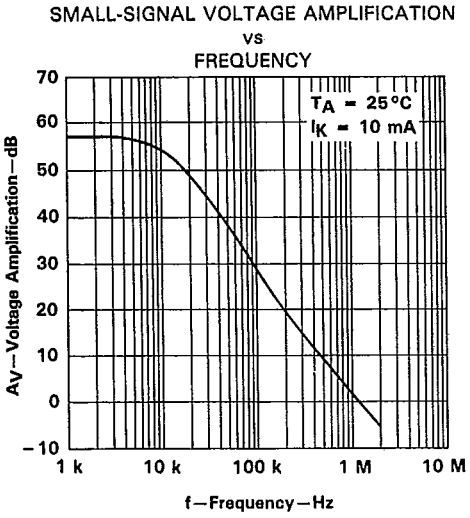
TEST CIRCUIT FOR DYNAMIC IMPEDANCE

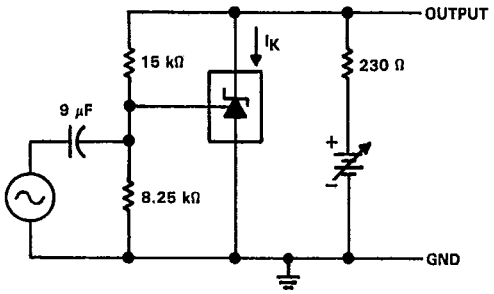
FIGURE 12

†For TL431I, TL431AI, TL431C, and TL431AC, the data applies only for the portions of the curves that lie within their recommended operating temperature ranges.

2 Data Sheets

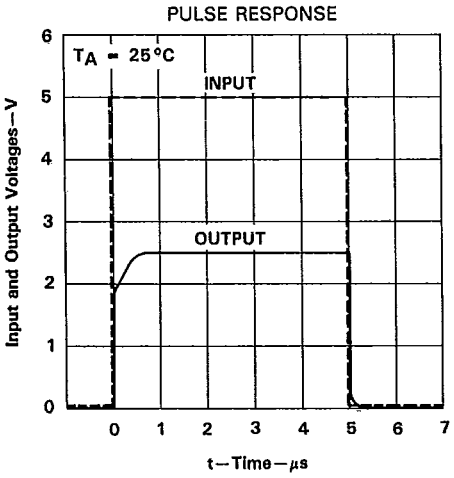
TYPICAL CHARACTERISTICS

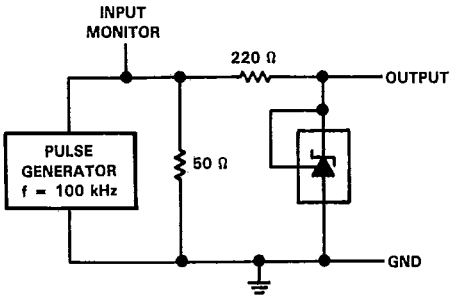




TEST CIRCUIT FOR VOLTAGE AMPLIFICATION

FIGURE 13



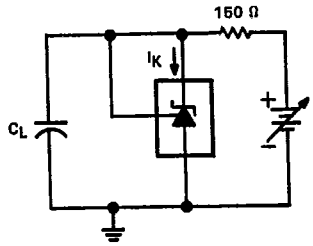


TEST CIRCUIT FOR PULSE RESPONSE

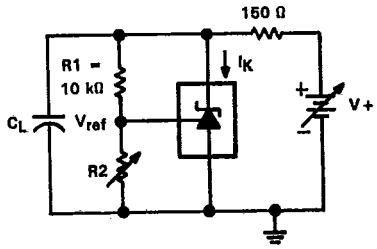
FIGURE 14

TYPICAL CHARACTERISTICS

T-58-11-23

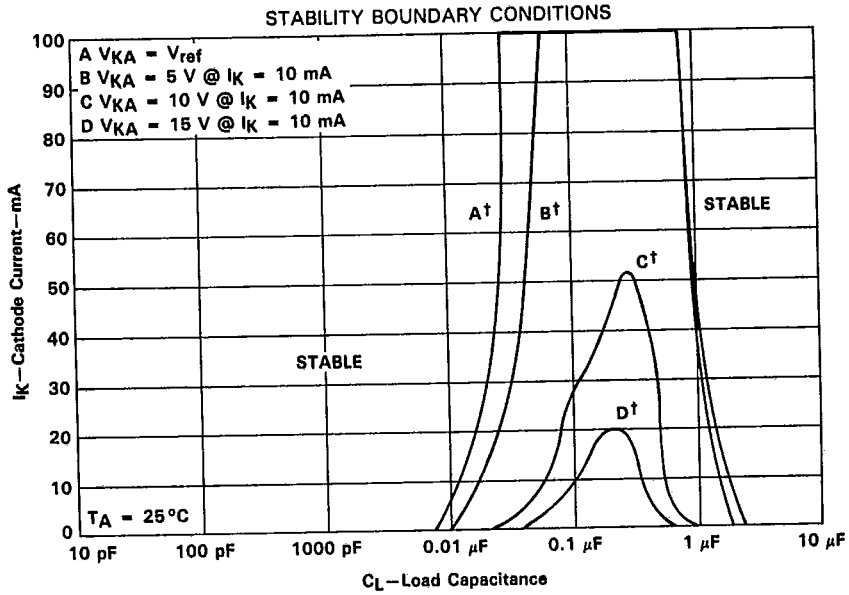


TEST CIRCUIT FOR CURVE A BELOW



TEST CIRCUIT FOR CURVES B, C, AND D BELOW

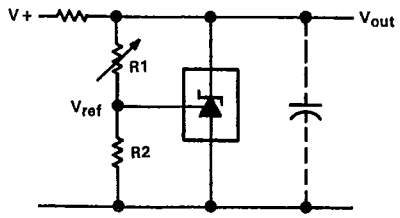
STABILITY BOUNDARY CONDITIONS



† 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_K conditions with C_L = 0. V+ and C_L were then adjusted to determine the ranges of stability.

FIGURE 15

TYPICAL APPLICATIONS



$$V_{out} \approx \left(1 + \frac{R1}{R2}\right) V_{ref}$$

FIGURE 16. SHUNT REGULATOR

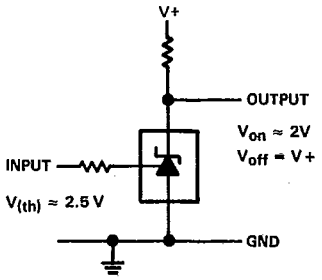
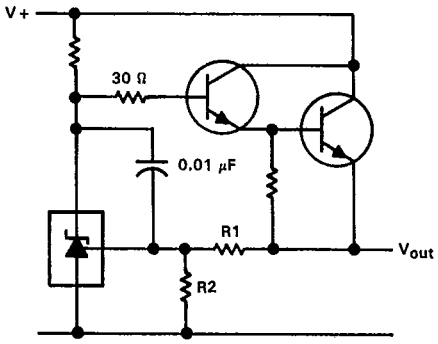
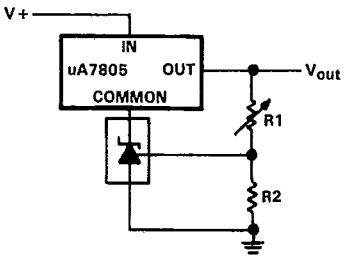


FIGURE 17. SINGLE-SUPPLY COMPARATOR WITH TEMPERATURE-COMPENSATED THRESHOLD



$$V_{out} \approx \left(1 + \frac{R1}{R2}\right) V_{ref}$$

FIGURE 18. SERIES REGULATOR



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

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

FIGURE 19. OUTPUT CONTROL OF A THREE-TERMINAL FIXED REGULATOR

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TYPICAL APPLICATIONS

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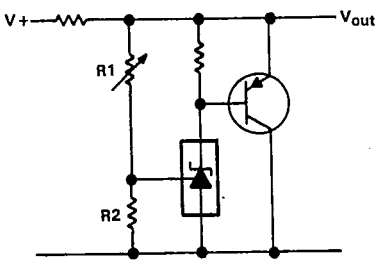
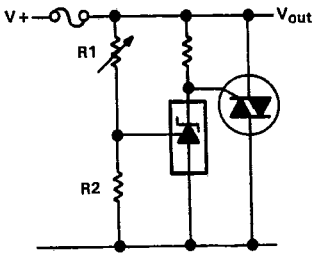


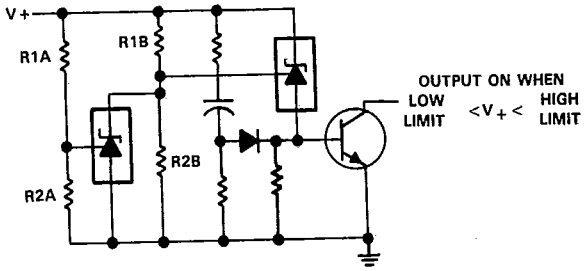
$$V_{out} = \left(1 + \frac{R1}{R2}\right)V_{ref}$$

FIGURE 20. HIGHER-CURRENT SHUNT REGULATOR



$$V_{limit} \approx \left(1 + \frac{R1}{R2}\right)V_{ref}$$

FIGURE 21. CROW BAR

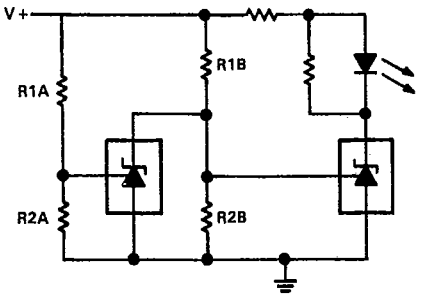


$$\text{Low limit} \approx V_{ref}\left(1 + \frac{R1B}{R2B}\right) + V_{BE}$$

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

FIGURE 22. OVER-VOLTAGE/UNDER-VOLTAGE PROTECTION CIRCUIT

TYPICAL APPLICATIONS

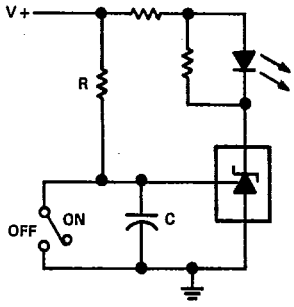


$$\text{Low limit} \approx V_{ref}\left(1 + \frac{R1B}{R2B}\right)$$

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

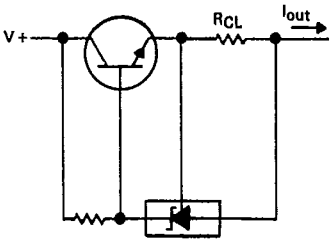
LED ON WHEN LOW LIMIT <V+< HIGH LIMIT

FIGURE 23. VOLTAGE MONITOR



$$\text{Delay} = R \cdot C \cdot \ln \frac{V+}{(V+) - V_{ref}}$$

FIGURE 24. DELAY TIMER



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

FIGURE 25. CURRENT LIMITER OR CURRENT SOURCE

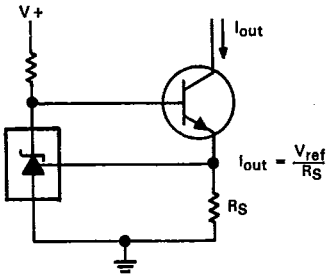


FIGURE 26. CONSTANT-CURRENT SINK

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