

TL431, A, B Series, NCV431A, B

Programmable Precision References

The TL431, A, B integrated circuits are three-terminal programmable shunt regulator diodes. These monolithic IC voltage references operate as a low temperature coefficient zener which is programmable from V_{ref} to 36 V with two external resistors. These devices exhibit a wide operating current range of 1.0 mA to 100 mA with a typical dynamic impedance of 0.22 Ω . The characteristics of these references make them excellent replacements for zener diodes in many applications such as digital voltmeters, power supplies, and op amp circuitry. The 2.5 V reference makes it convenient to obtain a stable reference from 5.0 V logic supplies, and since the TL431, A, B operates as a shunt regulator, it can be used as either a positive or negative voltage reference.

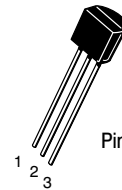
Features

- Programmable Output Voltage to 36 V
- Voltage Reference Tolerance: $\pm 0.4\%$, Typ @ 25°C (TL431B)
- Low Dynamic Output Impedance, 0.22 Ω Typical
- Sink Current Capability of 1.0 mA to 100 mA
- Equivalent Full-Range Temperature Coefficient of 50 ppm/°C Typical
- Temperature Compensated for Operation over Full Rated Operating Temperature Range
- Low Output Noise Voltage
- Pb-Free Packages are Available



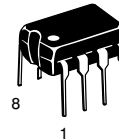
ON Semiconductor®

<http://onsemi.com>



**TO-92 (TO-226)
LP SUFFIX
CASE 29**

Pin 1. Reference
2. Anode
3. Cathode



**PDIP-8
P SUFFIX
CASE 626**



**Micro8™
DM SUFFIX
CASE 846A**



**SOIC-8
D SUFFIX
CASE 751**



This is an internally modified SOIC-8 package. Pins 2, 3, 6 and 7 are electrically common to the die attach flag. This internal lead frame modification increases power dissipation capability when appropriately mounted on a printed circuit board. This modified package conforms to all external dimensions of the standard SOIC-8 package.

ORDERING INFORMATION

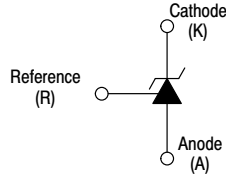
See detailed ordering and shipping information in the package dimensions section on page 13 of this data sheet.

DEVICE MARKING INFORMATION

See general marking information in the device marking section on page 16 of this data sheet.

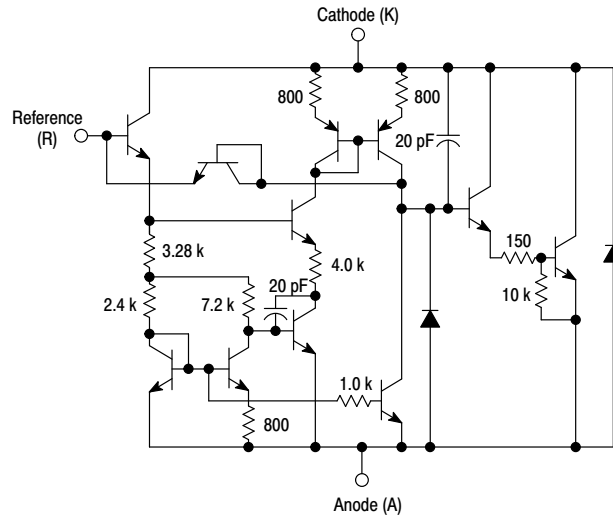
TL431, A, B Series, NCV431A, B

Symbol



Representative Schematic Diagram

Component values are nominal



Representative Block Diagram



This device contains 12 active transistors.

MAXIMUM RATINGS (Full operating ambient temperature range applies, unless otherwise noted.)

Rating	Symbol	Value	Unit
Cathode to Anode Voltage	V_{KA}	37	V
Cathode Current Range, Continuous	I_K	-100 to +150	mA
Reference Input Current Range, Continuous	I_{ref}	-0.05 to +10	mA
Operating Junction Temperature	T_J	150	°C
Operating Ambient Temperature Range TL431I, TL431AI, TL431BI TL431C, TL431AC, TL431BC NCV431AI, NCV431B, TL431BV	T_A	-40 to +85 0 to +70 -40 to +125	°C
Storage Temperature Range	T_{stg}	-65 to +150	°C
Total Power Dissipation @ $T_A = 25^\circ\text{C}$ Derate above 25°C Ambient Temperature D, LP Suffix Plastic Package P Suffix Plastic Package DM Suffix Plastic Package	P_D	0.70 1.10 0.52	W
Total Power Dissipation @ $T_C = 25^\circ\text{C}$ Derate above 25°C Case Temperature D, LP Suffix Plastic Package P Suffix Plastic Package	P_D	1.5 3.0	W
ESD Rating	HBM MM	>2000 >200	V

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

RECOMMENDED OPERATING CONDITIONS

Condition	Symbol	Min	Max	Unit
Cathode to Anode Voltage	V_{KA}	V_{ref}	36	V
Cathode Current	I_K	1.0	100	mA

THERMAL CHARACTERISTICS

Characteristic	Symbol	D, LP Suffix Package	P Suffix Package	DM Suffix Package	Unit
Thermal Resistance, Junction-to-Ambient	$R_{\theta JA}$	178	114	240	°C/W
Thermal Resistance, Junction-to-Case	$R_{\theta JC}$	83	41	-	°C/W

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ELECTRICAL CHARACTERISTICS ($T_A = 25^\circ\text{C}$, unless otherwise noted.)

Characteristic	Symbol
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ELECTRICAL CHARACTERISTICS ($T_A = 25^\circ\text{C}$, unless otherwise noted.)

Characteristic	Symbol	TL431AI / NCV431AI	TL431AC	TL431BI / TL431BV NCV431BV	Unit
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TL431, A, B Series, NCV431A, B



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}



Figure 4. Cathode Current versus Cathode Voltage



Figure 5. Cathode Current versus Cathode Voltage

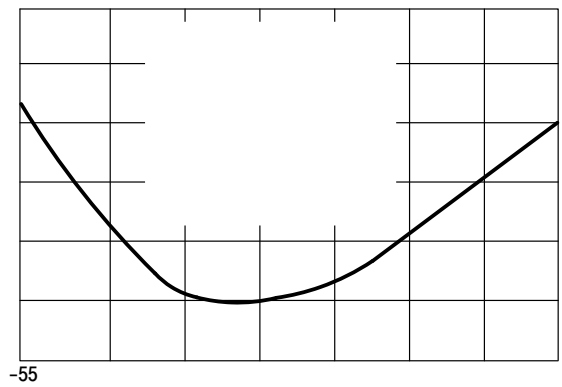
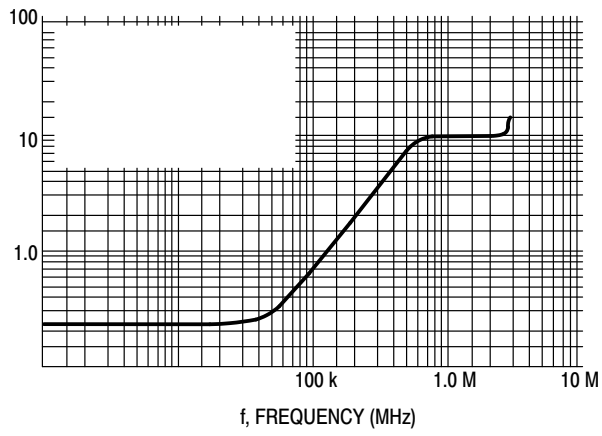


Figure 6. Reference Input Voltage versus Ambient Temperature



Figure 7. Reference Input Current versus Ambient Temperature

TL431, A, B Series, NCV431A, B



NOISE VOLTAGE ($\mu\text{V}/\sqrt{\text{Hz}}$)

TL431, A, B Series, NCV431A, B



Figure 14. Pulse Response



Figure 15. Stability Boundary Conditions



Figure 16. Test Circuit For Curve A of Stability Boundary Conditions

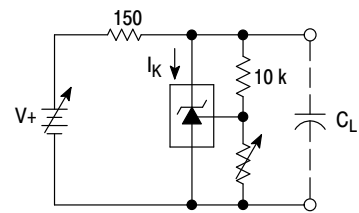


Figure 17. Test Circuit For Curves B, C, and D of Stability Boundary Conditions

TYPICAL APPLICATIONS



Figure 18. Shunt Regulator

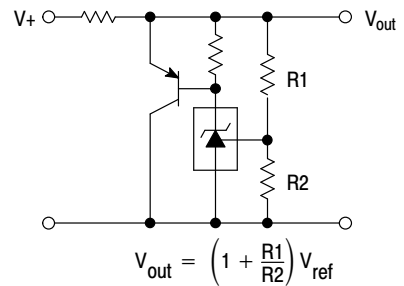


Figure 19. High Current Shunt Regulator

TL431, A, B Series, NCV431A, B



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

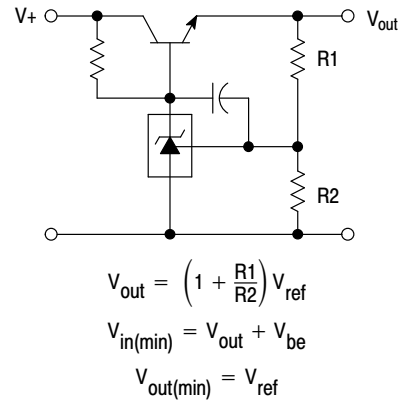


Figure 21. Series Pass Regulator



Figure 22. Constant Current Source

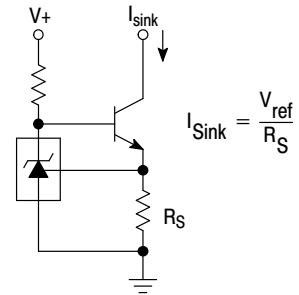


Figure 23. Constant Current Sink

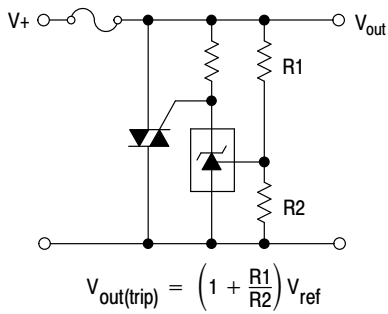


Figure 24. TRIAC Crowbar

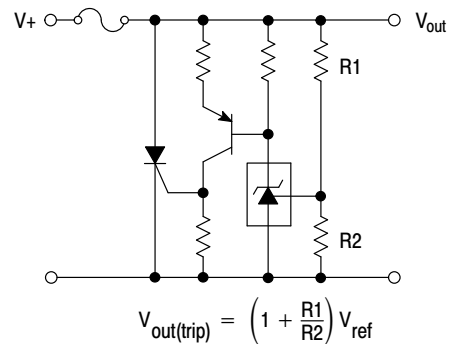


Figure 25. SRC Crowbar

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

$$\text{Upper Limit} = \left(1 + \frac{R3}{R4}\right) V_{ref}$$

Figure 26. Voltage Monitor

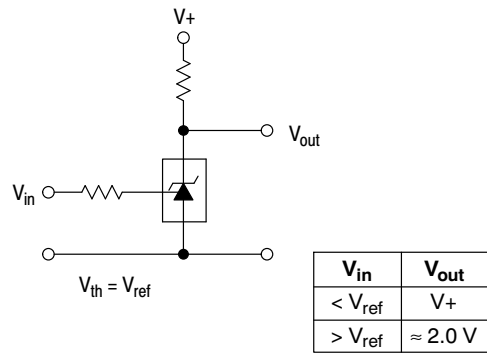


Figure 27. Single-Supply Comparator with Temperature-Compensated Threshold



Figure 28. Linear Ohmmeter



Figure 29. Simple 400 mW Phono Amplifier

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Figure 30. High Efficiency Step-Down Switching Converter

Test	Conditions	Results
Line Regulation	$V_{in} = 10 \text{ V to } 20 \text{ V}, I_o = 1.0 \text{ A}$	53 mV (1.1%)
Load Regulation	$V_{in} = 15 \text{ V}, I_o = 0 \text{ A to } 1.0 \text{ A}$	25 mV (0.5%)
Output Ripple	$V_{in} = 10 \text{ V}, I_o = 1.0 \text{ A}$	50 mVpp P.A.R.D.
Output Ripple	$V_{in} = 20 \text{ V}, I_o = 1.0 \text{ A}$	100 mVpp P.A.R.D.
Efficiency	$V_{in} = 15 \text{ V}, I_o = 1.0 \text{ A}$	82%

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APPLICATIONS INFORMATION

The TL431 is a programmable precision reference which is used in a variety of ways. It serves as a reference voltage in circuits where a non-standard reference voltage is needed. Other uses include feedback control for driving an optocoupler in power supplies, voltage monitor, constant current source, constant current sink and series pass regulator. In each of these applications, it is critical to maintain stability of the device at various operating currents and load capacitances. In some cases the circuit designer can estimate the stabilization capacitance from the stability boundary conditions curve provided in Figure 15. However, these typical curves only provide stability information at specific cathode voltages and at a specific load condition. Additional information is needed to determine the capacitance needed to optimize phase margin or allow for process variation.

A simplified model of the TL431 is shown in Figure 31. When tested for stability boundaries, the load resistance is 150 Ω. The model reference input consists of an input transistor and a dc emitter resistance connected to the device anode. A dependent current source, G_m, develops a current whose amplitude is determined by the difference between the 1.78 V internal reference voltage source and the input transistor emitter voltage. A portion of G_m flows through compensation capacitance, C_{P2}. The voltage across C_{P2} drives the output dependent current source, G_o, which is connected across the device cathode and anode.

Model component values are:

$$V_{\text{ref}} = 1.78 \text{ V}$$

$$G_m = 0.3 + 2.7 \exp(-I_C/26 \text{ mA})$$

where I_C is the device cathode current and G_m is in mhos

$$G_o = 1.25 (V_{\text{cp}2}) \mu\text{mhos.}$$

Resistor and capacitor typical values are shown on the model. Process tolerances are ±20% for resistors, ±10% for capacitors, and ±40% for transconductances.

An examination of the device model reveals the location of circuit poles and zeroes:

$$P_1 = \frac{1}{2\pi R_{GM} C_{P1}} = \frac{1}{2\pi * 1.0 \text{ M} * 20 \text{ pF}} = 7.96 \text{ kHz}$$

$$P_2 = \frac{1}{2\pi R_{P2} C_{P2}} = \frac{1}{2\pi * 10 \text{ M} * 0.265 \text{ pF}} = 60 \text{ kHz}$$

$$Z_1 = \frac{1}{2\pi R_{Z1} C_{P1}} = \frac{1}{2\pi * 15.9 \text{ k} * 20 \text{ pF}} = 500 \text{ kHz}$$

In addition, there is an external circuit pole defined by the load:

$$P_L = \frac{1}{2\pi R_L C_L}$$

Also, the transfer dc voltage gain of the TL431 is:

$$G = G_M R_{GM} G_o R_L$$

Example 1:

I_C = 10 mA, R_L = 230 Ω, C_L = 0. Define the transfer gain.

The DC gain is:

$$G = G_M R_{GM} G_o R_L = (2.138)(1.0 \text{ M})(1.25 \mu)(230) = 615 = 56 \text{ dB}$$

$$\text{Loop gain} = G \frac{8.25 \text{ k}}{8.25 \text{ k} + 15 \text{ k}} = 218 = 47 \text{ dB}$$

The resulting transfer function Bode plot is shown in Figure 32. The asymptotic plot may be expressed as the following equation:

$$A_v = 615 \frac{\left(1 + \frac{jf}{500 \text{ kHz}}\right)}{\left(1 + \frac{jf}{8.0 \text{ kHz}}\right)\left(1 + \frac{jf}{60 \text{ kHz}}\right)}$$

The Bode plot shows a unity gain crossover frequency of approximately 600 kHz. The phase margin, calculated from the equation, would be 55.9 degrees. This model matches the Open-Loop Bode Plot of Figure 12. The total loop would have a unity gain frequency of about 300 kHz with a phase margin of about 44 degrees.

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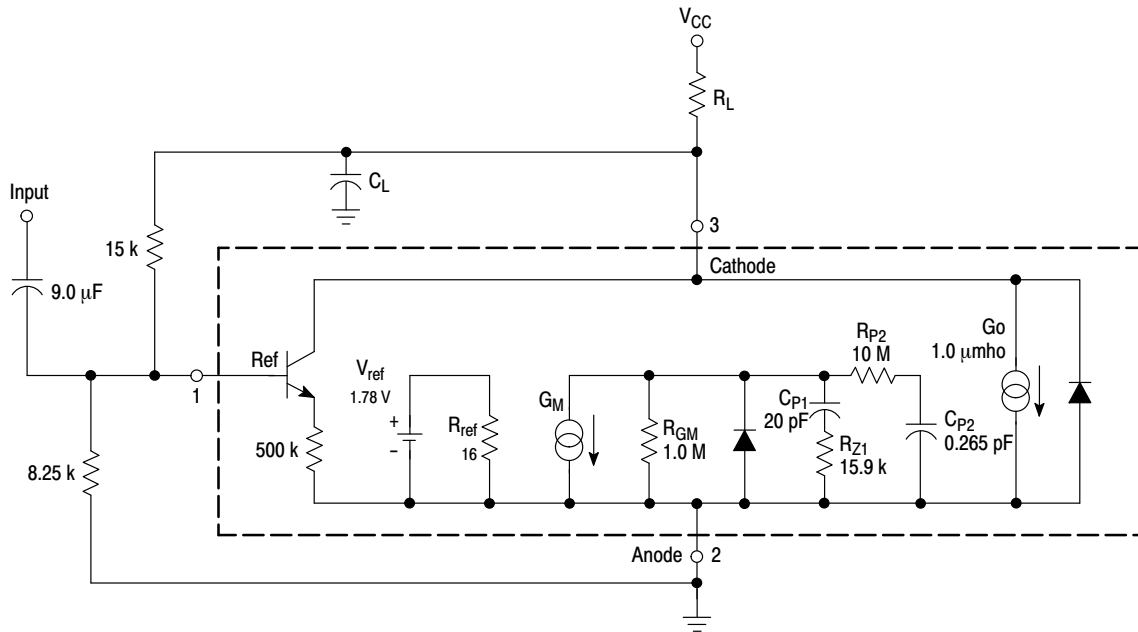


Figure 31. Simplified TL431 Device Model



Figure 32. Example 1 Circuit Open Loop Gain Plot

Example 2.

$I_C = 7.5 \text{ mA}$, $R_L = 2.2 \text{ k}\Omega$, $C_L = 0.01 \text{ }\mu\text{F}$. Cathode tied to reference input pin. An examination of the data sheet stability boundary curve (Figure 15) shows that this value of load capacitance and cathode current is on the boundary. Define the transfer gain.

The DC gain is:

$$G = G_M R_{GM} G_O R_L =$$

$$(2.323)(1.0 \text{ M})(1.25 \text{ }\mu)(2200) = 6389 = 76 \text{ dB}$$

The resulting open loop Bode plot is shown in Figure 33. The asymptotic plot may be expressed as the following equation:

$$A_v = 615 \frac{\left(1 + \frac{jf}{500 \text{ kHz}}\right)}{\left(1 + \frac{jf}{8.0 \text{ kHz}}\right)\left(1 + \frac{jf}{60 \text{ kHz}}\right)\left(1 + \frac{jf}{7.2 \text{ kHz}}\right)}$$

Note that the transfer function now has an extra pole formed by the load capacitance and load resistance.

Note that the crossover frequency in this case is about 250 kHz, having a phase margin of about -46 degrees. Therefore, instability of this circuit is likely.



Figure 33. Example 2 Circuit Open Loop Gain Plot

With three poles, this system is unstable. The only hope for stabilizing this circuit is to add a zero. However, that can only be done by adding a series resistance to the output capacitance, which will reduce its effectiveness as a noise filter. Therefore, practically, in reference voltage applications, the best solution appears to be to use a smaller value of capacitance in low noise applications or a very large value to provide noise filtering and a dominant pole rolloff of the system.

TL431, A, B Series, NCV431A, B

ORDERING INFORMATION

Device	Operating Temperature Range	Package Code	Shipping Information†	Tolerance
TL431ACD	0°C to 70°C	SOIC-8	98 Units / Rail	1.0%
TL431ACDG		SOIC-8 (Pb-Free)		
TL431BCD		SOIC-8		
TL431BCDG		SOIC-8 (Pb-Free)		
TL431CD		SOIC-8		
TL431CDG		SOIC-8 (Pb-Free)		
TL431ACDR2		SOIC-8	2500 Units / Tape & Reel	1.0%
TL431ACDR2G		SOIC-8 (Pb-Free)		
TL431BCDR2		SOIC-8		
TL431BCDR2G		SOIC-8 (Pb-Free)		
TL431CDR2		SOIC-8		
TL431CDR2G		SOIC-8 (Pb-Free)		
TL431ACDMR2		Micro8	4000 Units / Tape & Reel	1.0%
TL431ACDMR2G		Micro8 (Pb-Free)		
TL431BCDMR2		Micro8		
TL431BCDMR2G		Micro8 (Pb-Free)		
TL431CDMR2		Micro8		
TL431CDMR2G		Micro8 (Pb-Free)		
TL431ACP		PDIP-8	50 Units / Rail	1.0%
TL431ACPG		PDIP-8 (Pb-Free)		
TL431BCP		PDIP-8		
TL431BCPG		PDIP-8 (Pb-Free)		
TL431CP		PDIP-8		
TL431CPG		PDIP-8 (Pb-Free)		
TL431ACLP		TO-92 (TO-226)	2000 Units / Bag	1.0%
TL431ACLPG		TO-92 (TO-226) (Pb-Free)		
TL431BCLP		TO-92 (TO-226)		
TL431BCLPG		TO-92 (TO-226) (Pb-Free)		
TL431CLP	TO-92 (TO-226)			
TL431CLPG	TO-92 (TO-226) (Pb-Free)			
TL431ACLPRAG	TO-92 (TO-226)	2000 Units / Tape & Reel	1.0%	
TL431ACLPRAG	TO-92 (TO-226) (Pb-Free)			

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

TL431, A, B Series, NCV431A, B

ORDERING INFORMATION

Device	Operating Temperature Range	Package Code	Shipping Information†	Tolerance
TL431BCLPRA	0°C to 70°C	TO-92 (TO-226)	2000 Units / Tape & Reel	0.4%
TL431BCLPRAG		TO-92 (TO-226) (Pb-Free)		
TL431CLPRA		TO-92 (TO-226)		
TL431CLPRAG		TO-92 (TO-226) (Pb-Free)		2.2%
TL431ACLPRE		TO-92 (TO-226)		
TL431ACLPRAG		TO-92 (TO-226) (Pb-Free)		1.0%
TL431BCLPRE		TO-92 (TO-226)		0.4%
TL431BCLPRAG		TO-92 (TO-226) (Pb-Free)		0.4%
TL431ACLPRP		TO-92 (TO-226)	2000 / Tape & Ammo Box	1.0%
TL431ACLPRPG		TO-92 (TO-226) (Pb-Free)		
TL431BCLPRM		TO-92 (TO-226)	2000 Units / Fan-Fold	0.4%
TL431BCLPRMG		TO-92 (TO-226) (Pb-Free)		
TL431CLPRP		TO-92 (TO-226)		
TL431CLPRPG		TO-92 (TO-226) (Pb-Free)		2.2%
TL431AID	-40°C to 85°C	SOIC-8	98 Units / Rail	1.0%
TL431AIDG		SOIC-8 (Pb-Free)		1.0%
TL431BID		SOIC-8		
TL431BIDG		SOIC-8 (Pb-Free)		0.4%
TL431ID		SOIC-8		
TL431IDG		SOIC-8 (Pb-Free)		2.2%
TL431AIDR2		SOIC-8	2500 Units / Tape & Reel	1.0%
TL431AIDR2G		SOIC-8 (Pb-Free)		
TL431BIDR2		SOIC-8		
TL431BIDR2G		SOIC-8 (Pb-Free)		0.4%
TL431IDR2		SOIC-8		
TL431IDR2G		SOIC-8 (Pb-Free)		2.2%
TL431AIDMR2		Micro8	4000 Units / Tape & Reel	1.0%
TL431AIDMR2G		Micro8 (Pb-Free)		1.0%
TL431BIDMR2		Micro8		
TL431BIDMR2G		Micro8 (Pb-Free)		0.4%
TL431IDMR2		Micro8		
TL431IDMR2G		Micro8 (Pb-Free)		2.2%

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

TL431, A, B Series, NCV431A, B

ORDERING INFORMATION

Device	Operating Temperature Range	Package Code	Shipping Information†	Tolerance
TL431AIP	-40°C to 85°C	PDIP-8	50 Units / Rail	1.0%
TL431AIPG		PDIP-8 (Pb-Free)		
TL431BIP		PDIP-8		
TL431BIPG		PDIP-8 (Pb-Free)		
TL431IP		PDIP-8		
TL431IPG		PDIP-8 (Pb-Free)		
TL431AILP		TO-92 (TO-226)	2000 Units / Bag	1.0%
TL431AILPG		TO-92 (TO-226)		
TL431BILP		TO-92 (TO-226)		
TL431BILPG		TO-92 (TO-226) (Pb-Free)		
TL431ILP		TO-92 (TO-226)		
TL431ILPG		TO-92 (TO-226) (Pb-Free)		
TL431AILPRA	-40°C to 85°C	TO-92 (TO-226)	2000 Units / Tape & Reel	1.0%
TL431AILPRAG		TO-92 (TO-226) (Pb-Free)		
TL431BILPRA		TO-92 (TO-226)		
TL431BILPRAG		TO-92 (TO-226) (Pb-Free)		
TL431ILPRA		TO-92 (TO-226)		
TL431ILPRAG		TO-92 (TO-226) (Pb-Free)		
TL431AILPRM		TO-92 (TO-226) (Pb-Free)	2000 / Tape & Ammo Box	1.0%
TL431AILPRMG		TO-92 (TO-226) (Pb-Free)		
TL431AILPRP		TO-92 (TO-226)		
TL431AILPRPG		TO-92 (TO-226) (Pb-Free)		
TL431ILPRP		TO-92 (TO-226)		
TL431ILPRPG		TO-92 (TO-226) (Pb-Free)		
TL431BVD	-40°C to 125°C	SOIC-8	98 Units / Rail	0.4%
TL431BV DG		SOIC-8 (Pb-Free)		
TL431BVDR2		SOIC-8	2500 Units / Tape & Reel	0.4%

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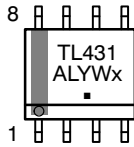
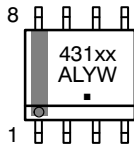
ORDERING INFORMATION

Device	Operating Temperature Range	Package Code	Shipping Information†	Tolerance
TL431BVP	-40°C to 125°C	PDIP-8	50 Units / Rail	0.4%
TL431BVPG		PDIP-8 (Pb-Free)		0.4%
NCV431AIDMR2		Micro8	4000 Units / Tape & Reel	1%
NCV431AIDMR2G		Micro8 (Pb-Free)		1%
NCV431AIDR2		SOIC-8	2500 Units / Tape & Reel	1%
NCV431AIDR2G		SOIC-8 (Pb-Free)		1%
NCV431BVDMR2G		Micro8 (Pb-Free)	4000 Units / Tape & Reel	0.4%

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

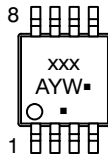
MARKING DIAGRAMS

**SOIC-8
D SUFFIX
CASE 751**

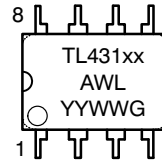


(Exception for the TL431CD and TL431ID only)

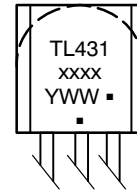
**Micro8
CASE 846A**



**PDIP-8
CASE 626**



**TO-92 (TO-226)
CASE 29**



xxxx = Specific Device Code
 A = Assembly Location
 Y, YY = Year
 WW, W = Work Week
 ■ or G = Pb-Free Package

(Note: Microdot may be in either location)

TL431, A, B Series, NCV431A, B

PACKAGE DIMENSIONS

TO-92 (TO-226)
CASE 29-11
ISSUE AM

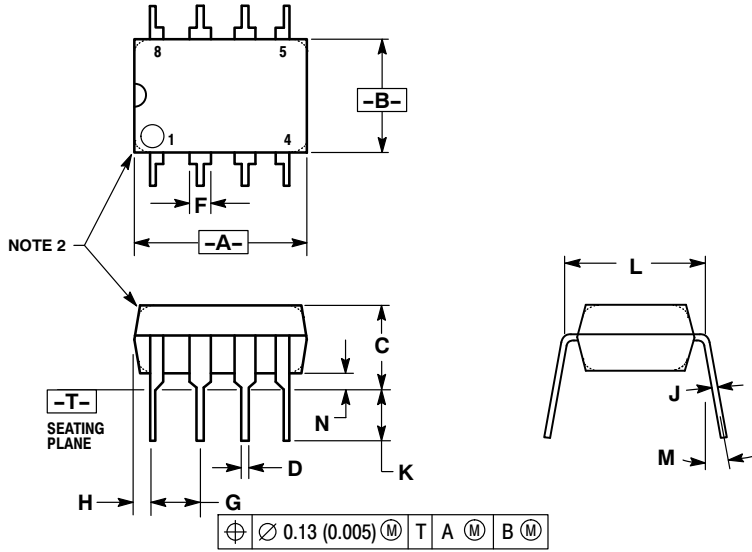
NOTES:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. CONTOUR OF PACKAGE BEYOND DIMENSION R IS UNCONTROLLED.
4. LEAD DIMENSION IS UNCONTROLLED IN P AND

TL431, A, B Series, NCV431A, B

PACKAGE DIMENSIONS

PDIP-8
P SUFFIX
PLASTIC PACKAGE
CASE 626-05
ISSUE L



NOTES:

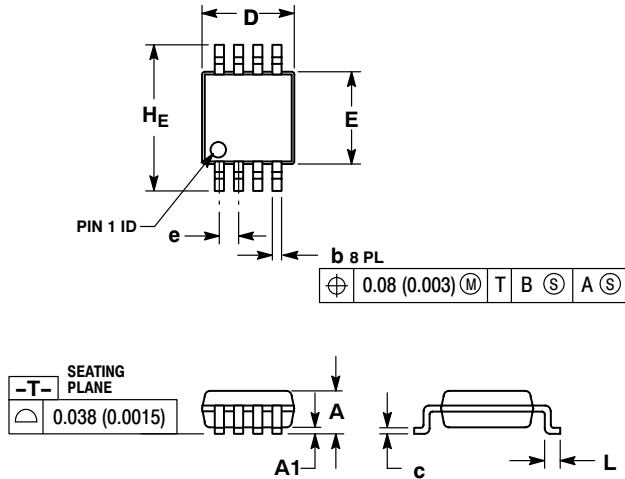
1. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
2. PACKAGE CONTOUR OPTIONAL (ROUND OR SQUARE CORNERS).
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	9.40	10.16	0.370	0.400
B	6.10	6.60	0.240	0.260
C	3.94	4.45	0.155	0.175
D	0.38	0.51	0.015	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
H	0.76	1.27	0.030	0.050
J	0.20	0.30	0.008	0.012
K	2.92	3.43	0.115	0.135
L	7.62 BSC		0.300 BSC	
M	---		10°	
N	0.76	1.01	0.030	0.040

TL431, A, B Series, NCV431A, B

PACKAGE DIMENSIONS

Micro8 DM SUFFIX PLASTIC PACKAGE CASE 846A-02 ISSUE G

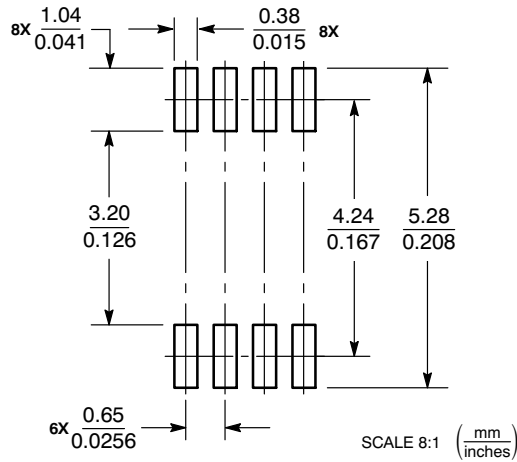


NOTES:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS. MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.15 (0.006) PER SIDE.
4. DIMENSION B DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION. INTERLEAD FLASH OR PROTRUSION SHALL NOT EXCEED 0.25 (0.010) PER SIDE.
5. 846A-01 OBSOLETE, NEW STANDARD 846A-02.

DIM	MILLIMETERS			INCHES		
	MIN	NOM	MAX	MIN	NOM	MAX
A	--	--	1.10	--	--	0.043
A1	0.05	0.08	0.15	0.002	0.003	0.006
b	0.25	0.33	0.40	0.010	0.013	0.016
c	0.13	0.18	0.23	0.005	0.007	0.009
D	2.90	3.00	3.10	0.114	0.118	0.122
E	2.90	3.00	3.10	0.114	0.118	0.122
e	0.65 BSC			0.026 BSC		
L	0.40	0.55	0.70	0.016	0.021	0.028
HE	4.75	4.90	5.05	0.187	0.193	0.199

SOLDERING FOOTPRINT*



*For additional information on our Pb-Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

TL431, A, B Series, NCV431A, B

PACKAGE DIMENSIONS

SOIC-8
D SUFFIX
PLASTIC PACKAGE
CASE 751-07
ISSUE AJ

