

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.

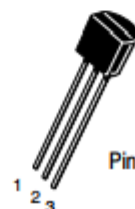
Features

- 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
- These are Pb-Free and Halide-Free Devices



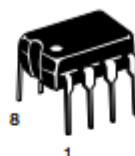
ON Semiconductor®

<http://onsemi.com>



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

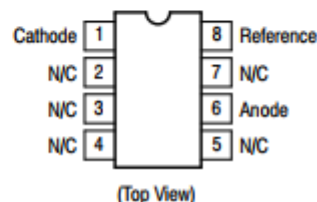
Pin 1. Reference
2. Anode
3. Cathode



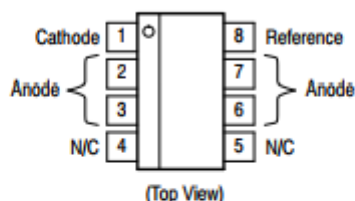
PDIP-8
P SUFFIX
CASE 626



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.

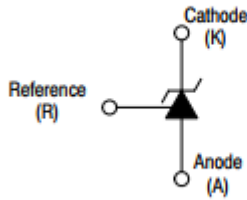
ORDERING INFORMATION

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

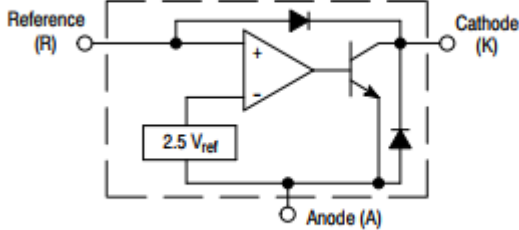
DEVICE MARKING INFORMATION

See general marking information in the device marking section on page 14 of this data sheet.

Symbol

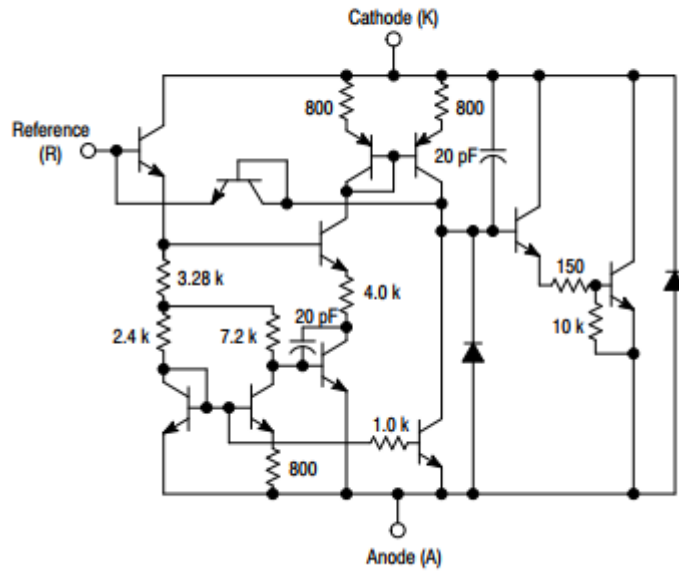


Representative Block Diagram



Representative Schematic Diagram

Component values are nominal



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

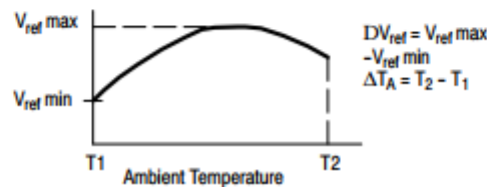
THERMAL CHARACTERISTICS

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

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

Characteristic	Symbol	TL431I			TL431C			Unit
		Min	Typ	Max	Min	Typ	Max	
Reference Input Voltage (Figure 1) $V_{KA} = V_{ref}$, $I_K = 10\text{ mA}$ $T_A = 25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 1)	V_{ref}	2.44 2.41	2.495 -	2.55 2.58	2.44 2.423	2.495 -	2.55 2.567	V
Reference Input Voltage Deviation Over Temperature Range (Figure 1, Notes 1, 2) $V_{KA} = V_{ref}$, $I_K = 10\text{ mA}$	ΔV_{ref}	-	7.0	30	-	3.0	17	mV
Ratio of Change in Reference Input Voltage to Change in Cathode to Anode Voltage $I_K = 10\text{ mA}$ (Figure 2), $\Delta V_{KA} = 10\text{ V to } V_{ref}$ $\Delta V_{KA} = 36\text{ V to } 10\text{ V}$	$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	- -	-1.4 -1.0	-2.7 -2.0	- -	-1.4 -1.0	-2.7 -2.0	mV/V
Reference Input Current (Figure 2) $I_K = 10\text{ mA}$, $R1 = 10\text{ k}$, $R2 = \infty$ $T_A = 25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 1)	I_{ref}	- -	1.8 -	4.0 6.5	- -	1.8 -	4.0 5.2	μA
Reference Input Current Deviation Over Temperature Range (Figure 2, Note 1, 4) $I_K = 10\text{ mA}$, $R1 = 10\text{ k}$, $R2 = \infty$	ΔI_{ref}	-	0.8	2.5	-	0.4	1.2	μA
Minimum Cathode Current For Regulation $V_{KA} = V_{ref}$ (Figure 1)	I_{min}	-	0.5	1.0	-	0.5	1.0	mA
Off-State Cathode Current (Figure 3) $V_{KA} = 36\text{ V}$, $V_{ref} = 0\text{ V}$	I_{off}	-	20	1000	-	20	1000	nA
Dynamic Impedance (Figure 1, Note 3) $V_{KA} = V_{ref}$, $\Delta I_K = 1.0\text{ mA to } 100\text{ mA}$ $f \leq 1.0\text{ kHz}$	$ Z_{KA} $	-	0.22	0.5	-	0.22	0.5	Ω

- $T_{low} = -40^\circ\text{C}$ for TL431AIP, TL431AILP, TL431IP, TL431ILP, TL431BID, TL431BIP, TL431BILP, TL431AIDM, TL431IDM, TL431BIDM;
 $= 0^\circ\text{C}$ for TL431ACP, TL431ACLP, TL431CP, TL431CLP, TL431CD, TL431ACD, TL431BCD, TL431BCP, TL431BCLP, TL431CDM, TL431ACDM, TL431BCDM
 $T_{high} = +85^\circ\text{C}$ for TL431AIP, TL431AILP, TL431IP, TL431ILP, TL431BID, TL431BIP, TL431BILP, TL431IDM, TL431AIDM, TL431BIDM
 $= +70^\circ\text{C}$ for TL431ACP, TL431ACLP, TL431CP, TL431ACD, TL431BCD, TL431BCP, TL431BCLP, TL431CDM, TL431ACDM, TL431BCDM
- The deviation parameter ΔV_{ref} is defined as the difference between the maximum and minimum values obtained over the full operating ambient temperature range that applies.



The average temperature coefficient of the reference input voltage, αV_{ref} is defined as:

$$V_{ref} \frac{\text{ppm}}{^\circ\text{C}} = \frac{\left(\frac{\Delta V_{ref}}{V_{ref} @ 25^\circ\text{C}} \right) \times 10^6}{\Delta T_A} = \frac{\Delta V_{ref} \times 10^6}{\Delta T_A (V_{ref} @ 25^\circ\text{C})}$$

αV_{ref} can be positive or negative depending on whether V_{ref} Min or V_{ref} Max occurs at the lower ambient temperature. (Refer to Figure 6.)

Example : $\Delta V_{ref} = 8.0\text{ mV}$ and slope is positive,

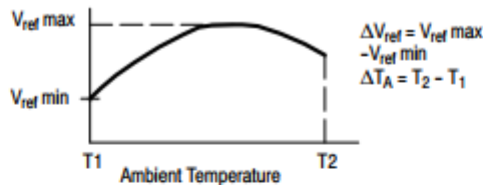
$$V_{ref} @ 25^\circ\text{C} = 2.495\text{ V}, \Delta T_A = 70^\circ\text{C} \quad \alpha V_{ref} = \frac{0.008 \times 10^6}{70 (2.495)} = 45.8\text{ ppm}/^\circ\text{C}$$

- The dynamic impedance Z_{KA} is defined as: $|Z_{KA}| = \frac{\Delta V_{KA}}{\Delta I_K}$. When the device is programmed with two external resistors, R1 and R2, (refer to Figure 2) the total dynamic impedance of the circuit is defined as: $|Z_{KA}'| \approx |Z_{KA}| \left(1 + \frac{R1}{R2} \right)$

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

Characteristic	Symbol	TL431AI / NCV431AI			TL431AC			TL431BC / TL431BI / TL431BV / NCV431BV			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Reference Input Voltage (Figure 1) $V_{KA} = V_{ref}$, $I_K = 10\text{ mA}$ $T_A = 25^\circ\text{C}$ $T_A = T_{low}$ to T_{high}	V_{ref}	2.47 2.44	2.495 -	2.52 2.55	2.47 2.453	2.495 -	2.52 2.537	2.485 2.475	2.495 2.495	2.505 2.515	V
Reference Input Voltage Deviation Over Temperature Range (Figure 1, Notes 4, 5) $V_{KA} = V_{ref}$, $I_K = 10\text{ mA}$	ΔV_{ref}	-	7.0	30	-	3.0	17	-	3.0	17	mV
Ratio of Change in Reference Input Voltage to Change in Cathode to Anode Voltage $I_K = 10\text{ mA}$ (Figure 2), $\Delta V_{KA} = 10\text{ V}$ to V_{ref} $\Delta V_{KA} = 36\text{ V}$ to 10 V	$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	-	-1.4 -1.0	-2.7 -2.0	-	-1.4 -1.0	-2.7 -2.0	-	-1.4 -1.0	-2.7 -2.0	mV/V
Reference Input Current (Figure 2) $I_K = 10\text{ mA}$, $R1 = 10\text{ k}$, $R2 = \infty$ $T_A = 25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 4)	I_{ref}	-	1.8 -	4.0 6.5	-	1.8 -	4.0 5.2	-	1.1 -	2.0 4.0	μA
Reference Input Current Deviation Over Temperature Range (Figure 2, Note 4) $I_K = 10\text{ mA}$, $R1 = 10\text{ k}$, $R2 = \infty$	ΔI_{ref}	-	0.8	2.5	-	0.4	1.2	-	0.8	2.5	μA
Minimum Cathode Current For Regulation $V_{KA} = V_{ref}$ (Figure 1)	I_{min}	-	0.5	1.0	-	0.5	1.0	-	0.5	1.0	mA
Off-State Cathode Current (Figure 3) $V_{KA} = 36\text{ V}$, $V_{ref} = 0\text{ V}$	I_{off}	-	20	1000	-	20	1000	-	0.23	500	nA
Dynamic Impedance (Figure 1, Note 6) $V_{KA} = V_{ref}$, $\Delta I_K = 1.0\text{ mA}$ to 100 mA $f \leq 1.0\text{ kHz}$	$ Z_{KA} $	-	0.22	0.5	-	0.22	0.5	-	0.14	0.3	Ω

4. $T_{low} = -40^\circ\text{C}$ for TL431AIP, TL431AILP, TL431IP, TL431ILP, TL431BID, TL431BIP, TL431BILP, TL431BV, TL431AIDM, TL431IDM, TL431BIDM, NCV431AIDMR2G, NCV431AIDR2G, NCV431BVDR2G
 $= 0^\circ\text{C}$ for TL431ACP, TL431ACLP, TL431CP, TL431CLP, TL431CD, TL431ACD, TL431BCD, TL431BCP, TL431BCLP, TL431CDM, TL431ACDM, TL431BCDM
 $T_{high} = +85^\circ\text{C}$ for TL431AIP, TL431AILP, TL431IP, TL431ILP, TL431BID, TL431BIP, TL431BILP, TL431IDM, TL431AIDM, TL431BIDM
 $= +70^\circ\text{C}$ for TL431ACP, TL431ACLP, TL431CP, TL431ACD, TL431BCD, TL431BCP, TL431BCLP, TL431CDM, TL431ACDM, TL431BCDM
 $= +125^\circ\text{C}$ TL431BV, NCV431AIDMR2G, NCV431AIDR2G, NCV431BVDR2G, NCV431BVDR2G
5. The deviation parameter ΔV_{ref} is defined as the difference between the maximum and minimum values obtained over the full operating ambient temperature range that applies.



The average temperature coefficient of the reference input voltage, αV_{ref} is defined as:

$$V_{ref} \frac{\text{ppm}}{^\circ\text{C}} = \frac{\left(\frac{\Delta V_{ref}}{V_{ref} @ 25^\circ\text{C}} \right) \times 10^6}{\Delta T_A} = \frac{\Delta V_{ref} \times 10^6}{\Delta T_A (V_{ref} @ 25^\circ\text{C})}$$

αV_{ref} can be positive or negative depending on whether $V_{ref\ Min}$ or $V_{ref\ Max}$ occurs at the lower ambient temperature. (Refer to Figure 6.)

Example : $\Delta V_{ref} = 8.0\text{ mV}$ and slope is positive,
 $V_{ref} @ 25^\circ\text{C} = 2.495\text{ V}$, $\Delta T_A = 70^\circ\text{C}$

$$\alpha V_{ref} = \frac{0.008 \times 10^6}{70 (2.495)} = 45.8\text{ ppm}/^\circ\text{C}$$

6. The dynamic impedance Z_{KA} is defined as $|Z_{KA}| = \frac{\Delta V_{KA}}{\Delta I_K}$ When the device is programmed with two external resistors, $R1$ and $R2$, (refer to Figure 2) the total dynamic impedance of the circuit is defined as: $|Z_{KA}'| \approx |Z_{KA}| \left(1 + \frac{R1}{R2} \right)$
7. NCV431AIDMR2G, NCV431AIDR2G, NCV431BVDR2G, NCV431BVDR2G $T_{low} = -40^\circ\text{C}$, $T_{high} = +125^\circ\text{C}$. Guaranteed by design. NCV prefix is for automotive and other applications requiring unique site and control change requirements.

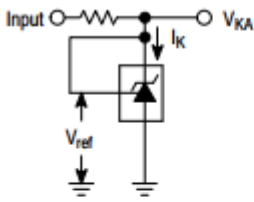


Figure 1. Test Circuit for $V_{KA} = V_{ref}$

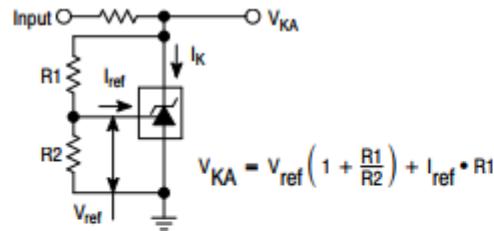


Figure 2. Test Circuit for $V_{KA} > V_{ref}$

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

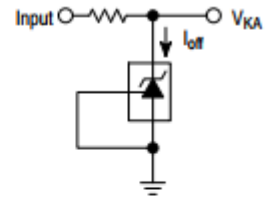


Figure 3. Test Circuit for I_{off}

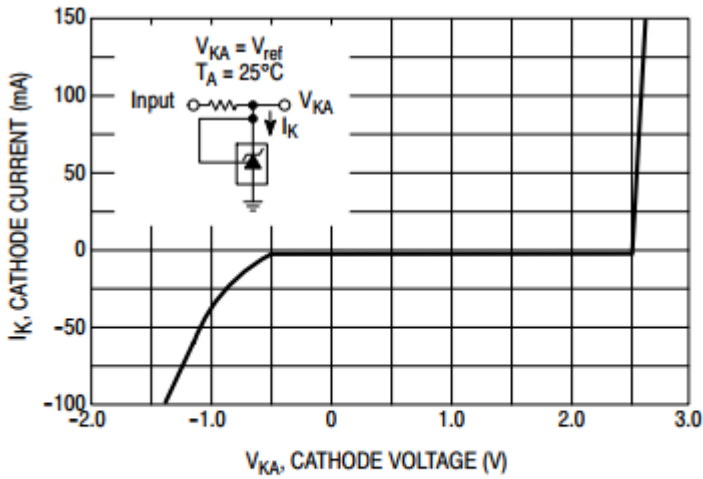


Figure 4. Cathode Current versus Cathode Voltage

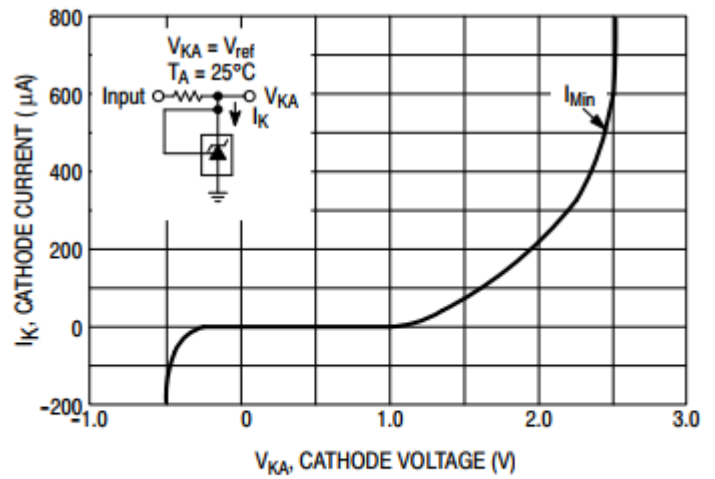


Figure 5. Cathode Current versus Cathode Voltage

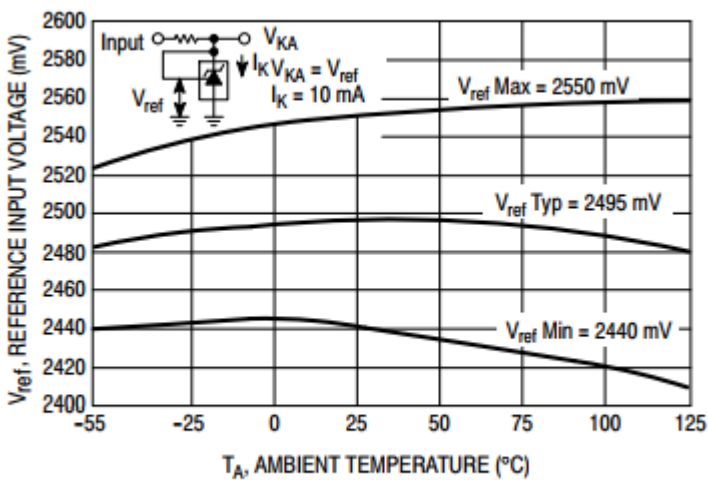


Figure 6. Reference Input Voltage versus Ambient Temperature

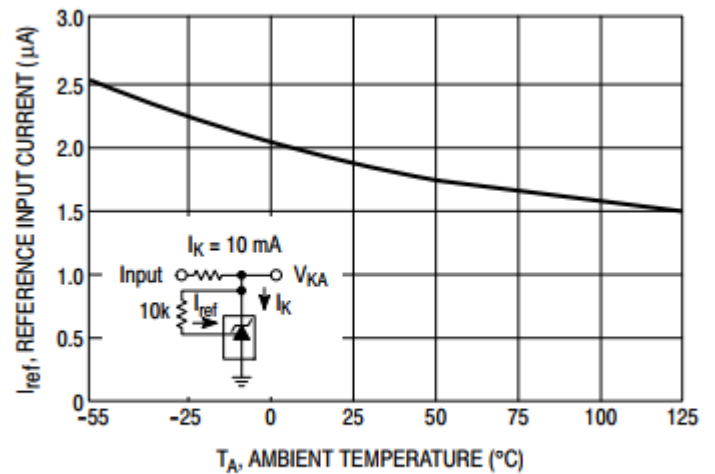


Figure 7. Reference Input Current versus Ambient Temperature

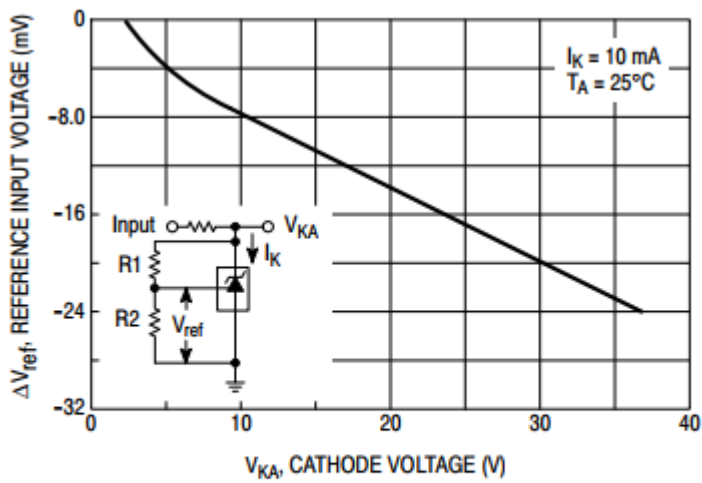


Figure 8. Change in Reference Input Voltage versus Cathode Voltage

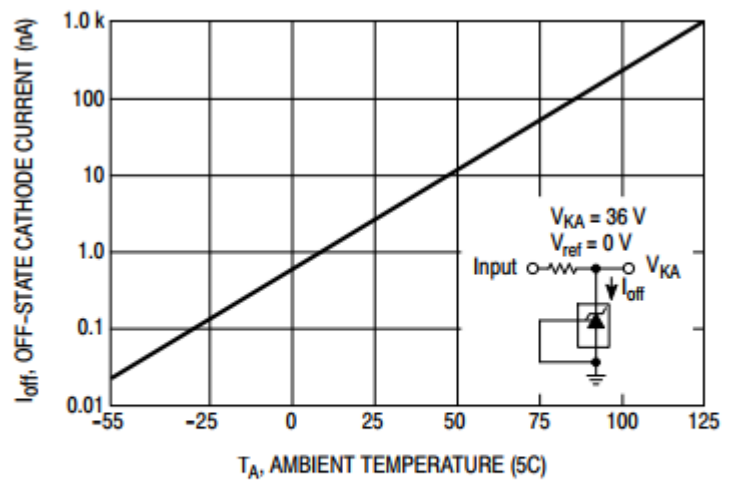


Figure 9. Off-State Cathode Current versus Ambient Temperature

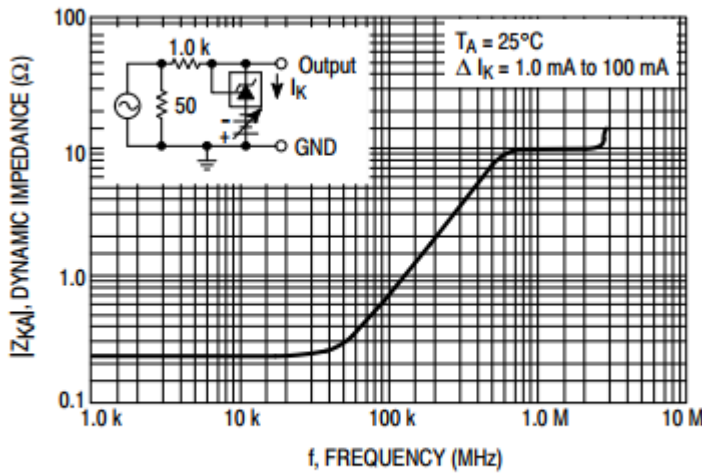


Figure 10. Dynamic Impedance versus Frequency

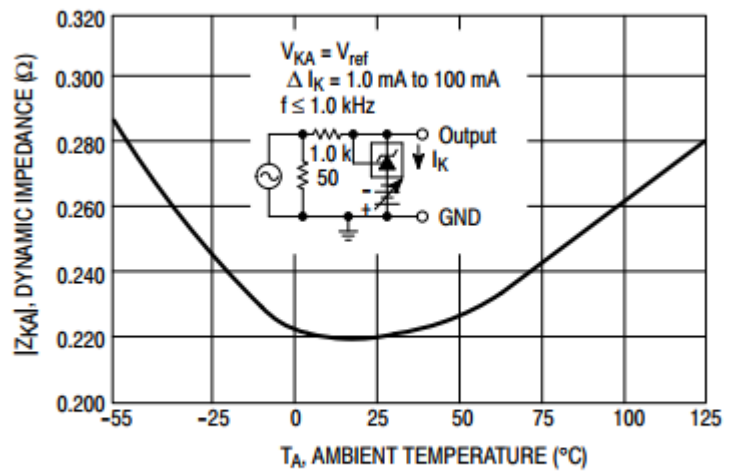


Figure 11. Dynamic Impedance versus Ambient Temperature

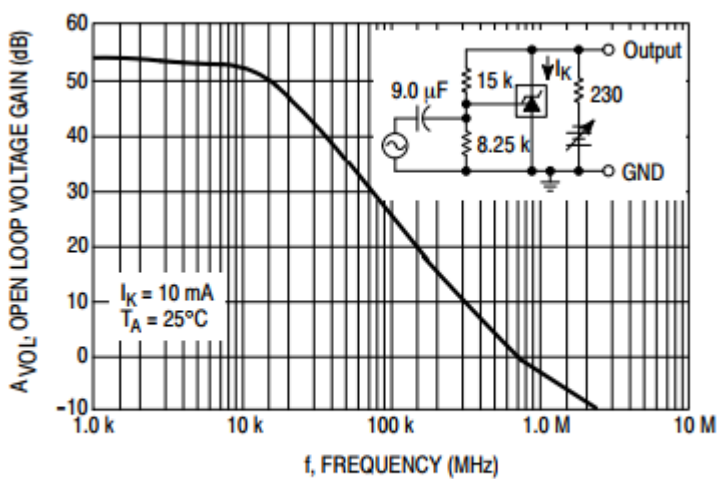


Figure 12. Open-Loop Voltage Gain versus Frequency

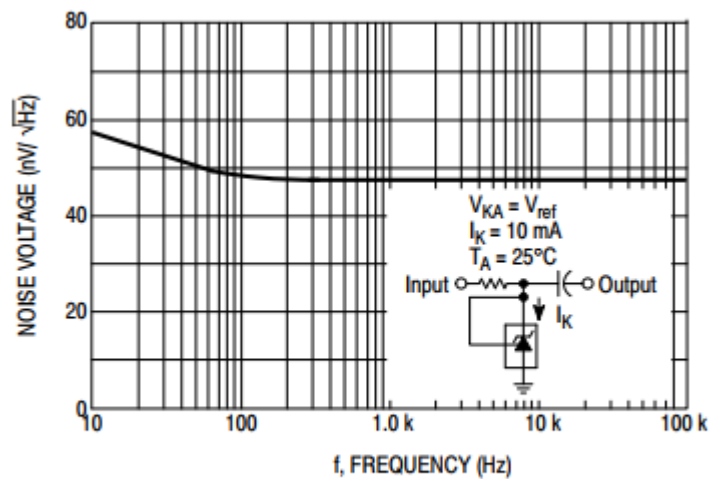


Figure 13. Spectral Noise Density

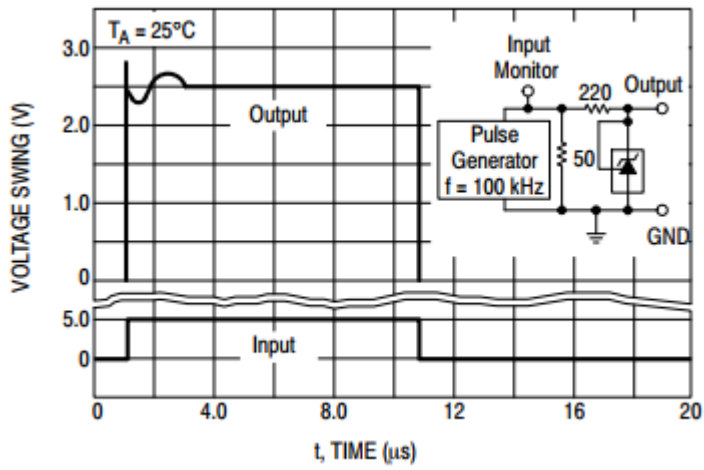


Figure 14. Pulse Response

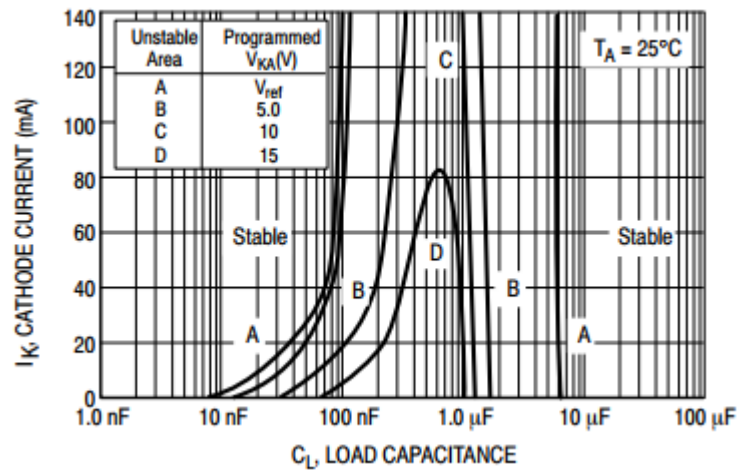


Figure 15. Stability Boundary Conditions

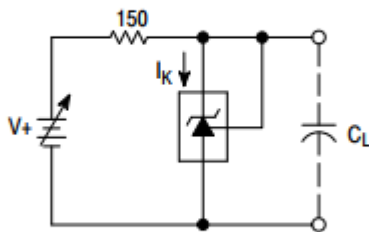


Figure 16. Test Circuit For Curve A of Stability Boundary Conditions

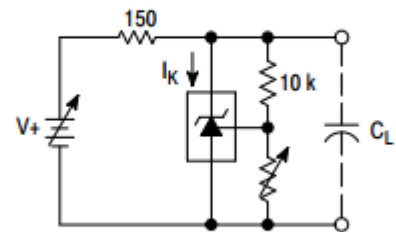


Figure 17. Test Circuit For Curves B, C, and D of Stability Boundary Conditions

TYPICAL APPLICATIONS

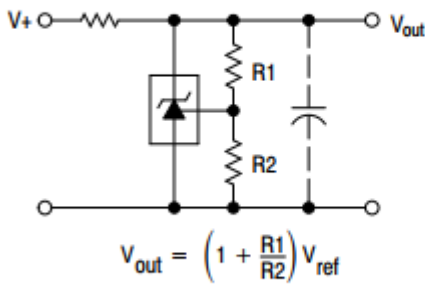


Figure 18. Shunt Regulator

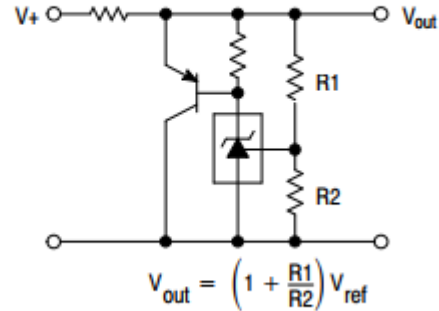


Figure 19. High Current Shunt Regulator

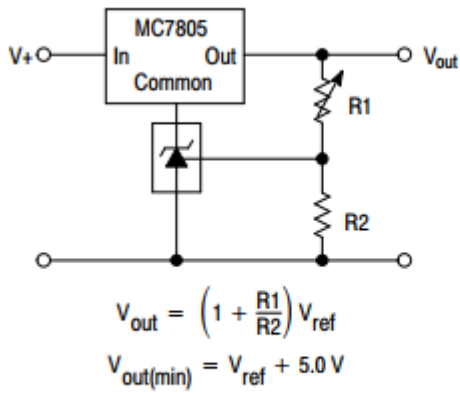


Figure 20. Output Control for a Three-Terminal Fixed Regulator

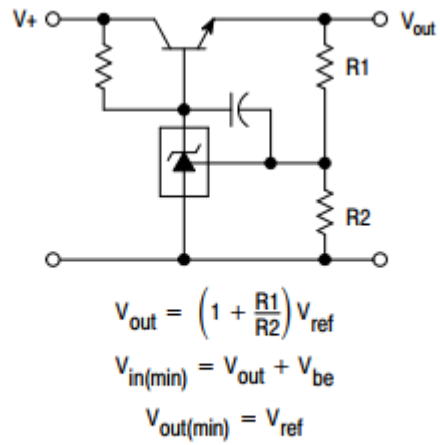


Figure 21. Series Pass Regulator

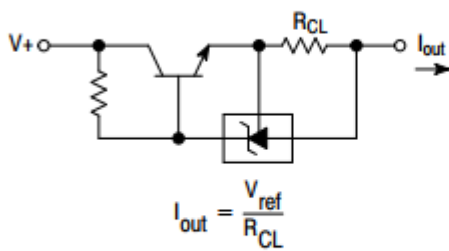


Figure 22. Constant Current Source

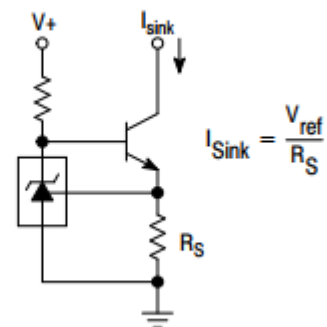


Figure 23. Constant Current Sink

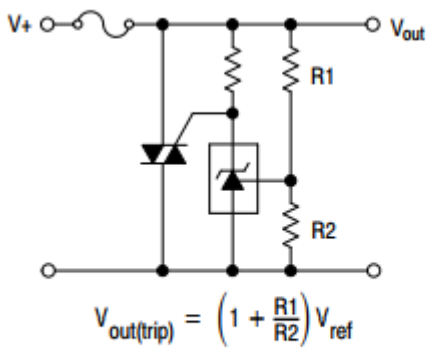


Figure 24. TRIAC Crowbar

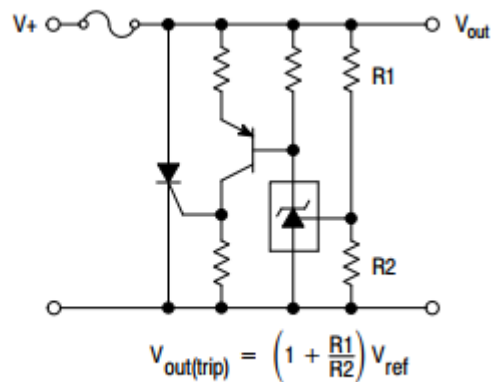
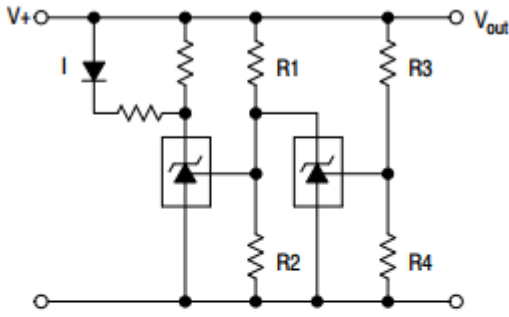


Figure 25. SRC Crowbar

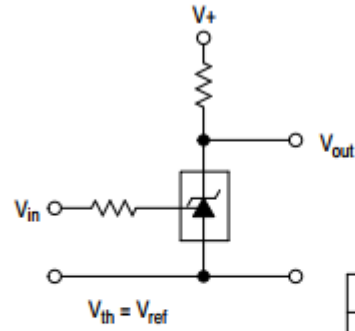


L.E.D. indicator is 'on' when V_+ is between the upper and lower limits.

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

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

Figure 26. Voltage Monitor



V_{in}	V_{out}
$< V_{ref}$	V_+
$> V_{ref}$	$\approx 2.0\text{ V}$

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

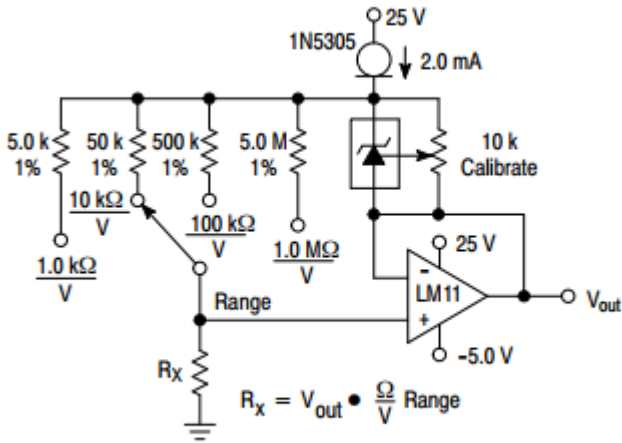


Figure 28. Linear Ohmmeter

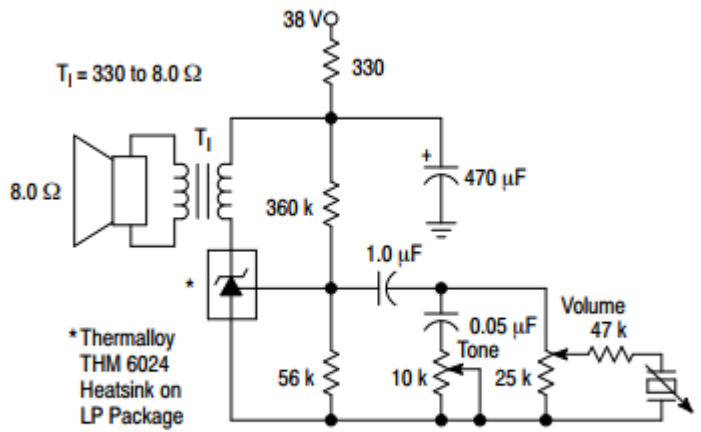


Figure 29. Simple 400 mW Phono Amplifier

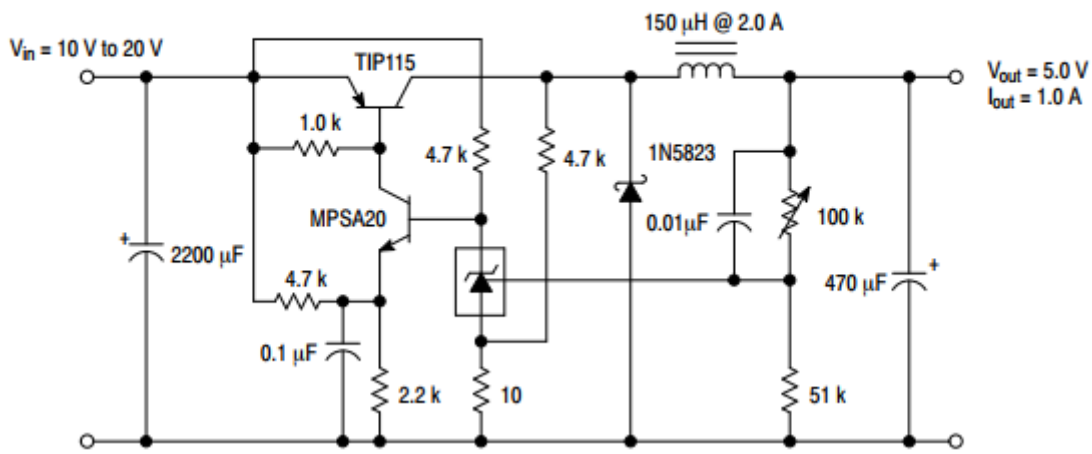


Figure 30. High Efficiency Step-Down Switching Converter

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%

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:

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

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

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

$$G_o = 1.25 (V_{cp2}) \mu\text{mhos.}$$

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

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

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

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

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

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:

$I_C = 10 \text{ mA}$, $R_L = 230 \Omega$, $C_L = 0$. 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.

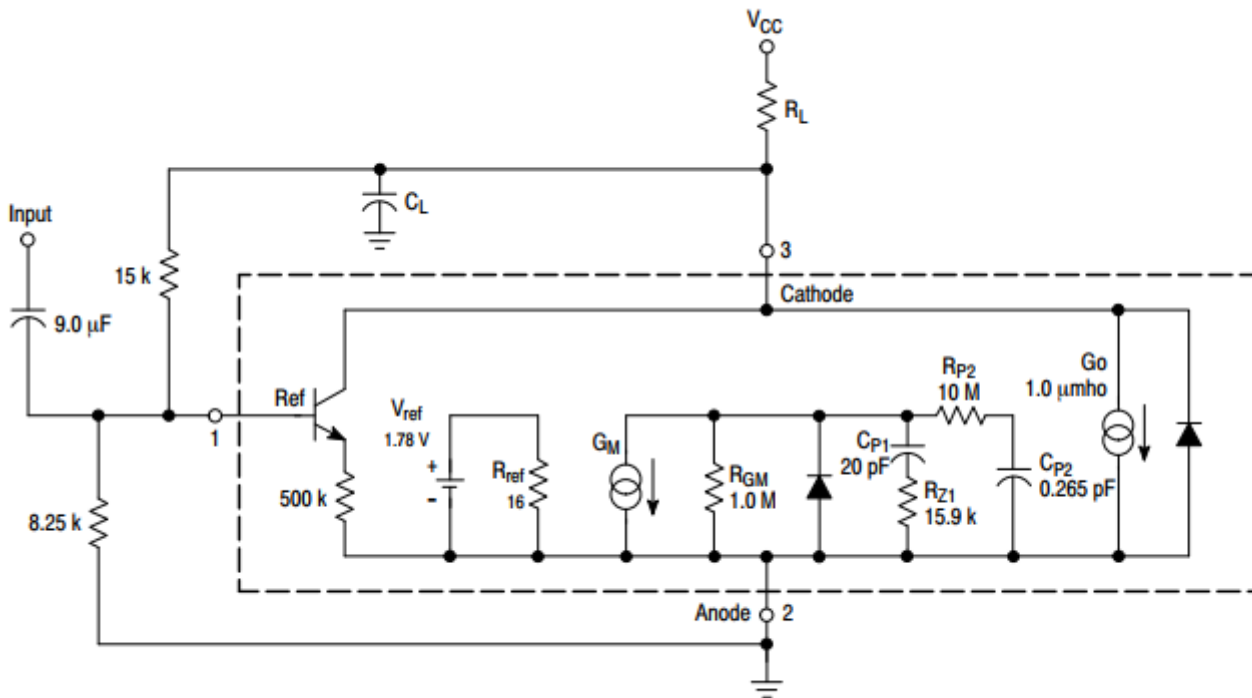


Figure 31. Simplified TL431 Device Model

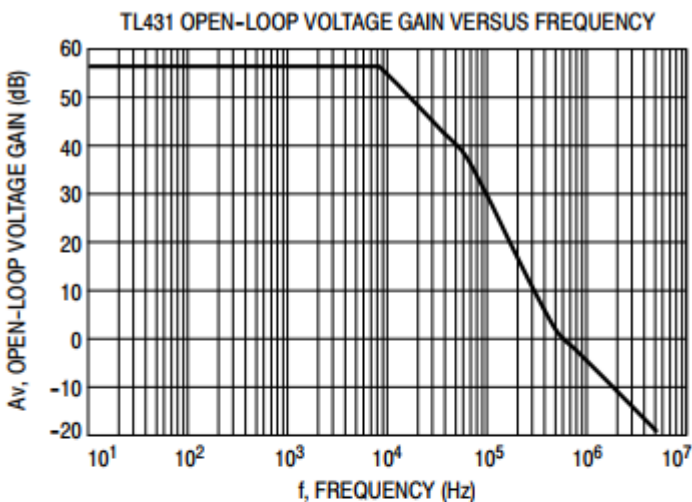


Figure 32. Example 1 Circuit Open Loop Gain Plot

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.

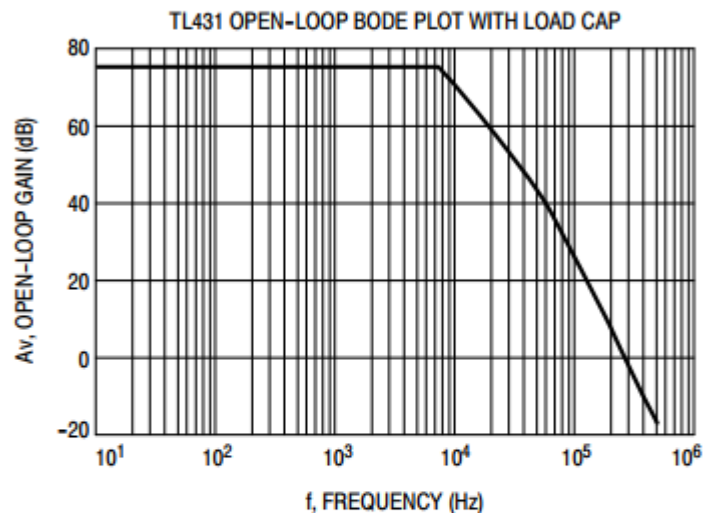


Figure 33. Example 2 Circuit Open Loop Gain Plot

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.