

# HIGH-TEMPERATURE PROGRAMMABLE SHUNT REGULATOR

## FEATURES

- ▲ Adjustable output voltage from 2.5V to 40V.
- ▲ Operational beyond the -60°C to +230°C temperature range.
- ▲ Low dynamic output impedance.
- ▲ Sink current capability 500µA to 50mA
- ▲ Low temperature coefficient ( $\Delta V_{REF}=35\text{mV typ}$ ).
- ▲ 2.55V reference with 6% accuracy.
- ▲ Fast turn-on response.
- ▲ Shut-down mode.
- ▲ Stable over a continuous range of load capacitors (27nF min).
- ▲ Monolithic design.
- ▲ Ruggedized SMT and thru-hole packages.
- ▲ Also available as bare die.

## APPLICATIONS

- ▲ Reliability-critical, Automotive, Aeronautics & Aerospace, Down-hole.
- ▲ Shunt regulators, voltage clamping, voltage references, voltage regulators, switching regulators, feedback networks, voltage monitors, current sources.

## DESCRIPTION

XTR431 is a high-reliability, high-temperature version of the well known "431" shunt voltage regulator. It operates as a 3-terminal shunt regulator with an total drift of the reference voltage as low as 35mV (typical). The output voltage may be set from 2.55V to 40V by selecting the value of two external resistors implementing a divider network.

The XTR431 is able to reliably operate over a wide range of currents from 500µA to 50mA and load capacitors from 27nF and up. Functionality features include shut-down mode and low dynamic output impedance.

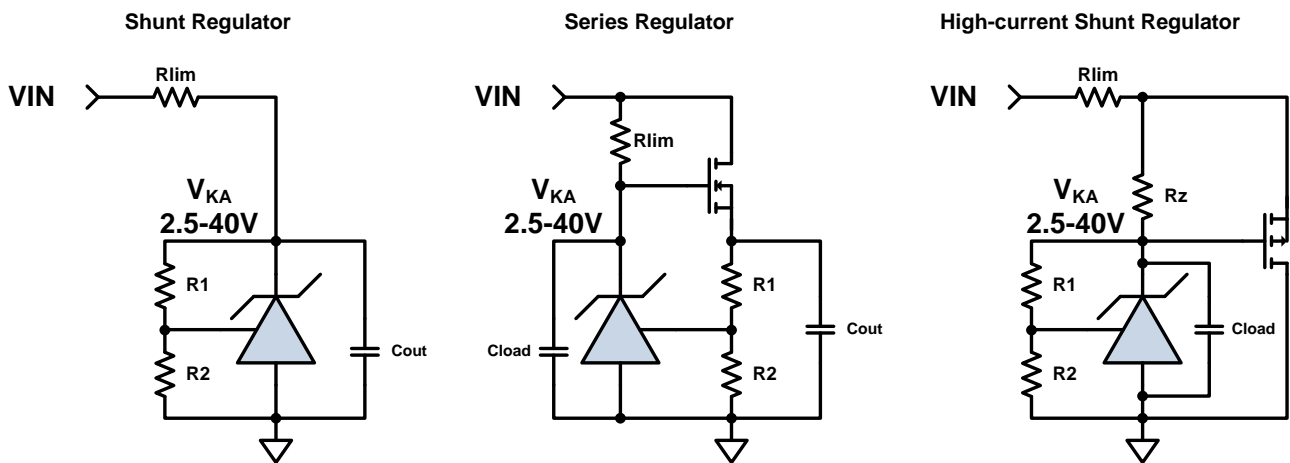
This part can be used as a high-reliability, high-temperature replacement of zener diodes in many applications such as on-board regulation, adjustable power supply and switching power supplies. The fact of operating as a zener diode makes the XTR431 convenient to be used as a positive or negative regulator.

Special design techniques were used allowing the XTR431 parts to offer a precise, robust and reliable operation in critical applications. Full functionality is guaranteed from -60°C to +230°C, though operation well below and above this temperature range is achieved.

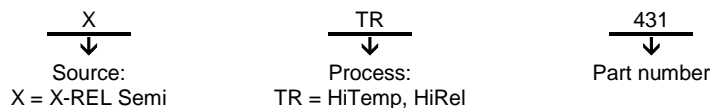
The XTR431 has been designed to reduce system cost and ease adoption by reducing the learning curve and providing smart and easy to use features.

XTR431 is available in ruggedized SMT and thru-hole packages. Parts are also available as bare dies.

## PRODUCT HIGHLIGHT



## ORDERING INFORMATION



Product Reference	Temperature Range	Package	Pin Count	Marking
XTR431-BD	-60°C to +230°C	Bare die		XTR431
XTR431-TD	-60°C to +230°C	Tested bare die		XTR431
XTR431-FE	-60°C to +230°C	Gull-wing flat pack with ePad	8	XTR431
XTR431-D	-60°C to +230°C	Ceramic side brazed DIP	8	XTR431
XTR431-T	-60°C to +230°C	TO-39 metal can	3	XTR431

Other packages and packaging configurations possible upon request. For some packages or packaging configurations, MOQ may apply. Contact X-REL for plastic packaged parts.

## ABSOLUTE MAXIMUM RATINGS

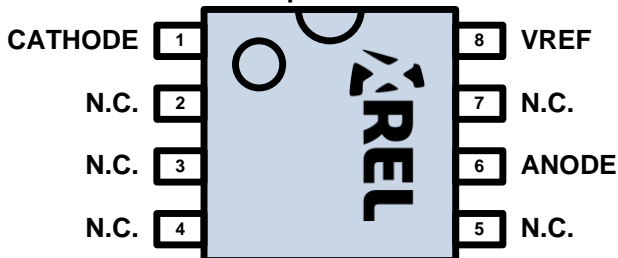
Voltage on CATHODE to ANODE	-1.5 to 45V
Voltage on VREF to ANODE	-0.5 to 6.0V
Storage Temperature Range	-70°C to +230°C
Operating Junction Temperature Range	-70°C to +300°C
ESD Classification	1kV HBM MIL-STD-883

**Caution:** Stresses beyond those listed in “ABSOLUTE MAXIMUM RATINGS” may cause permanent damage to the device. These are stress ratings only and functionality of the device at these or any other condition beyond those indicated in the operational sections of the specifications is not implied. Exposure to “ABSOLUTE MAXIMUM RATINGS” conditions for extended periods may permanently affect device reliability.

## PACKAGING

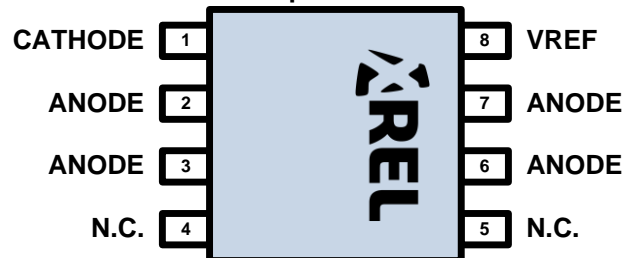
**Ceramic Side Brazed DIP14**  
**XTR431-D**

Top view



**CDFP8 with ePad**  
**XTR431-FE**

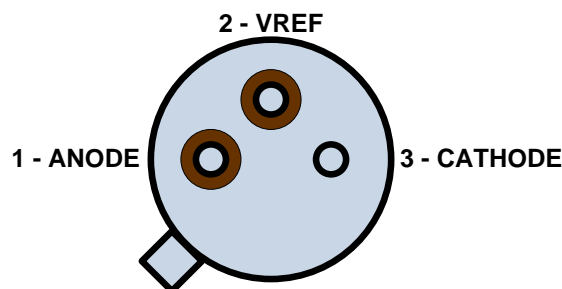
Top view



ePAD on bottom of package connected to CATHODE. Pin #1 shall be used as main CATHODE connection. ePAD can be left floating on the PCB.

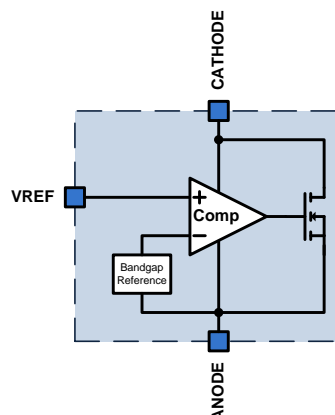
**TO-39**  
**XTR431-T**

Bottom view



Package case connected to CATHODE. Pin #3 shall be used as main CATHODE connection.

## BLOCK DIAGRAM



**PIN DESCRIPTION**

XTR431-D		
Pin Number	Name	Description
1	CATHODE	Cathode terminal of equivalent zener diode.
2	N.C.	No internal connection.
3	N.C.	No internal connection.
4	N.C.	No internal connection.
5	N.C.	No internal connection.
6	ANODE	Anode terminal of equivalent zener diode.
7	N.C.	No internal connection.
8	VREF	Feedback of error amplifier.

XTR431-FE		
Pin Number	Name	Description
1	CATHODE	Cathode terminal of equivalent zener diode. It is mandatory to connect this pin.
2	ANODE	Anode terminal of equivalent zener diode.
3	ANODE	Anode terminal of equivalent zener diode.
4	N.C.	No internal connection.
5	N.C.	No internal connection.
6	ANODE	Anode terminal of equivalent zener diode.
7	ANODE	Anode terminal of equivalent zener diode.
8	VREF	Feedback of error amplifier.
ePAD	CATHODE	The ePAD can be connected to CATHODE on PCB or left floating, but it cannot be used as main CATHODE connection.

XTR431-T		
Pin Number	Name	Description
1	ANODE	ANODE terminal of equivalent zener diode.
2	VREF	Feedback of error amplifier.
3	CATHODE	Anode terminal of equivalent zener diode. It is mandatory to connect this pin.
Case	CATHODE	The case can be connected to CATHODE on PCB or left floating, but it is not recommended to use it as main CATHODE connection.

**THERMAL CHARACTERISTICS**

Parameter	Condition	Min	Typ	Max	Units
<b>XTR431-D (DIP8)</b>					
Thermal Resistance: J-C $R_{Th\_J-C}$			25		°C/W
Thermal Resistance: J-A $R_{Th\_J-A}$			100		°C/W
<b>XTR431-FE (DFP8 with exposed pad)</b>					
Thermal Resistance: J-C $R_{Th\_J-C}$	Measured on ePAD.		7		°C/W
Thermal Resistance: J-A $R_{Th\_J-A}$	ePAD thermally connected to 3cm <sup>2</sup> PCB copper		70		°C/W
<b>XTR431-T (TO-39)</b>					
Thermal Resistance: J-C $R_{Th\_J-C}$			20		°C/W
Thermal Resistance: J-A $R_{Th\_J-A}$			200		°C/W

**RECOMMENDED OPERATING CONDITIONS**

Parameter	Min	Typ	Max	Units
Cathode-Anode Voltage $V_{KA}$	2.5		40	V
Feedback Input Voltage $V_{VREF}$	-0.3		5.5	V
Cathode Current $I_{KA}$	0.5		50 <sup>1</sup>	mA
Junction Temperature <sup>2</sup> $T_j$	-60		230	°C

<sup>1</sup> Depending on cathode voltage, min-max cathode current range can be limited.

<sup>2</sup> Operation beyond the specified temperature range is achieved.

**ELECTRICAL SPECIFICATIONS**

Unless otherwise stated, specification applies for  $I_{KA}=10\text{mA}$ ,  $V_A=0\text{V}$ ,  $R_2=100\text{k}\Omega$  (VREF-ANODE),  $-60^\circ\text{C}<T_C<230^\circ\text{C}$ .

Parameter	Condition	Min	Typ	Max	Units
<b>VREF Input</b>					
Reference Voltage $V_{REF}$	Cathode connected to $V_{REF}$ , $I_{KA}=1\text{mA}$ , $T_C=85^\circ\text{C}$	2.40	2.55	2.70	V
Deviation of Reference Voltage with Temperature <sup>1</sup> $\Delta V_{REF}$	$I_{KA}=1\text{mA}$ , $T_C=-60^\circ\text{C}$ to $230^\circ\text{C}$ $V_{KA}=2.5\text{V}$ (Cathode connected to $V_{REF}$ )		35	90	mV
Sensitivity on Cathode Voltage <sup>1</sup> $\Delta V_{REF}/\Delta V_{KA}$	$I_{KA}=5\text{mA}$ , $T_C=85^\circ\text{C}$ $V_{KA}=3.3\text{V}$ to $10\text{V}$ $V_{KA}=10\text{V}$ to $40\text{V}$		3.8 0.05		mV/V
Reference Input Current $I_{VREF}$	$V_{KA}=2.5\text{V}$ , $T_C=230^\circ\text{C}$ (Worst case)		20	60	nA
<b>Cathode (Static Characteristics)</b>					
Minimum Cathode Current for Regulation $I_{KA\_min}$	$T_C=230^\circ\text{C}$ (Worst case) $V_{KA}=2.5\text{V}$ $V_{KA}=10\text{V}$ $V_{KA}=40\text{V}$		250 360 420	400 450 550	$\mu\text{A}$
Maximum Cathode Current $I_{KA\_Max}$	$T_C=230^\circ\text{C}$ (Worst case) $V_{KA}=2.5\text{V}$ $V_{KA}=3.3\text{V}$ $V_{KA}>10\text{V}$	20 40 50	30 50 60		mA
Off-state Cathode Current $I_{off}$	$V_{VREF}=0\text{V}$ , worst case temperature condition $V_{KA}=40\text{V}$ $V_{KA}=3.3\text{V}$ $V_{KA}=10\text{V}$ $V_{KA}=40\text{V}$		4.5 16 65	8.0 25 90	$\mu\text{A}$
Minimum Load Capacitance $C_{LOAD\_min}$	$V_{KA}=2.5\text{V}$ to $40\text{V}$ , $I_{KA}=500\mu\text{A}$ to $50\text{mA}$ $T_C=-60^\circ\text{C}$ to $230^\circ\text{C}$		27	50	nF
<b>Cathode (Dynamic Characteristics)</b>					
Output Impedance $Z_{KA}=\delta V_{KA}/\delta I_K$	$V_{KA}=2.5\text{V}$ , $I_{KA}=10\text{mA}$ , $f\leq 8\text{kHz}$ $T_C=-60^\circ\text{C}$ $T_C=100^\circ\text{C}$ $T_C=230^\circ\text{C}$		1.61 1.50 1.87	2.1 2.0 2.5	$\Omega$

<sup>1</sup>  $\Delta V_{REF}$  is defined as  $|V_{REF\_Max} - V_{REF\_min}|$  within the indicated range of temperature, input voltage or load current.

**TYPICAL PERFORMANCE**

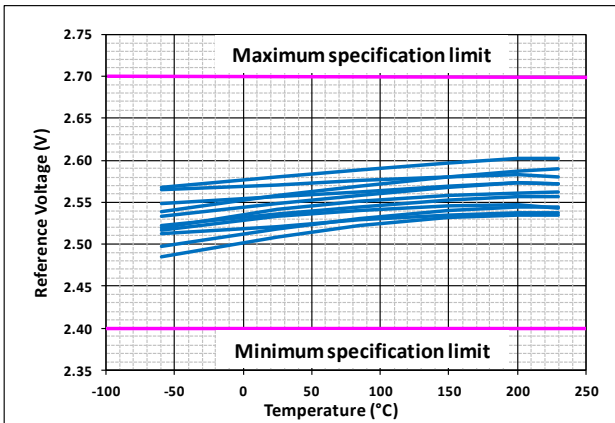


Figure 1. Reference voltage ( $V_{REF}$ ) vs. case temperature.  $I_{KA}=1mA$ . Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ). Values for 11 typical parts.

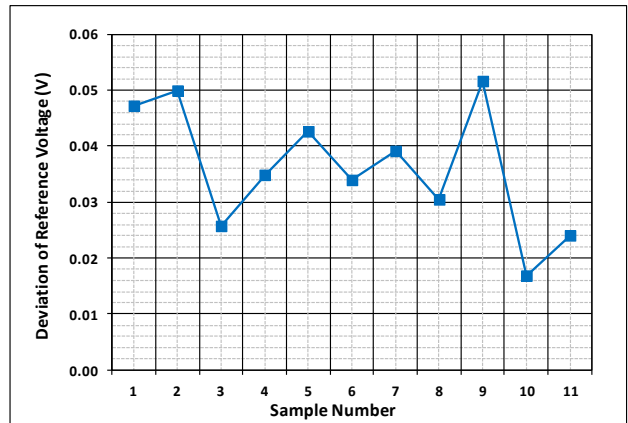


Figure 2. Deviation of reference voltage ( $\Delta V_{REF}$ ) over the  $-60^{\circ}C$  to  $+230^{\circ}C$  temperature range.  $I_{KA}=1mA$ . Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ). Values for 11 typical parts.

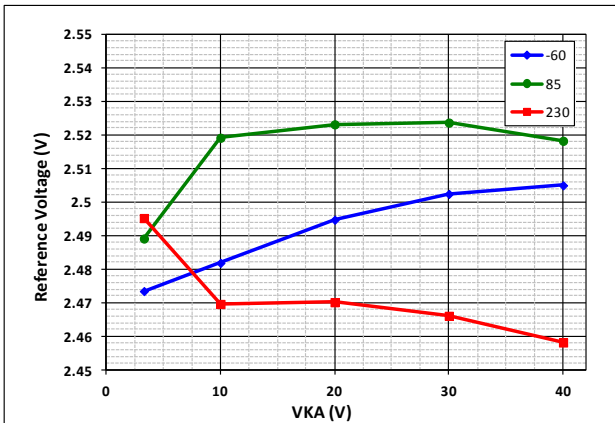


Figure 3. Reference voltage sensitivity on cathode voltage ( $V_{REF}$ ) vs. cathode voltage ( $V_{KA}$ ) for several case temperatures.  $V_{KA}$  from 3.3V to 40V.  $I_{KA}=1mA$ .

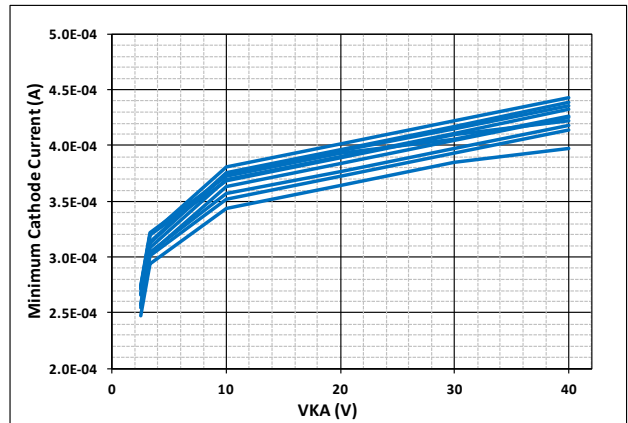


Figure 4. Minimum cathode current for regulation ( $I_{KA,min}$ ) vs. cathode voltage ( $V_{KA}$ ).  $T_C=230^{\circ}C$  (worst case). Values for 10 typical parts.

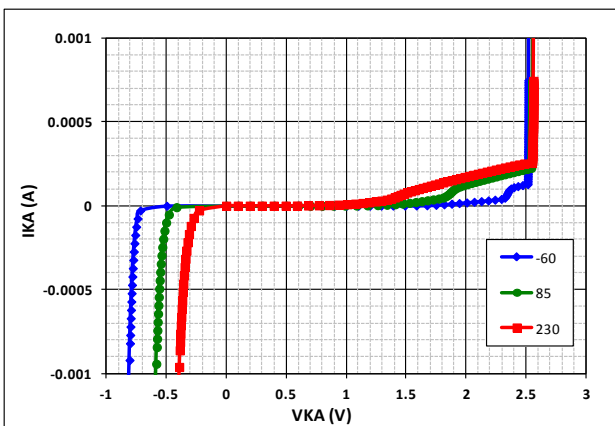


Figure 5. Cathode current vs. cathode voltage for several case temperatures. Limits show minimum needed and maximum guaranteed currents. Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ).

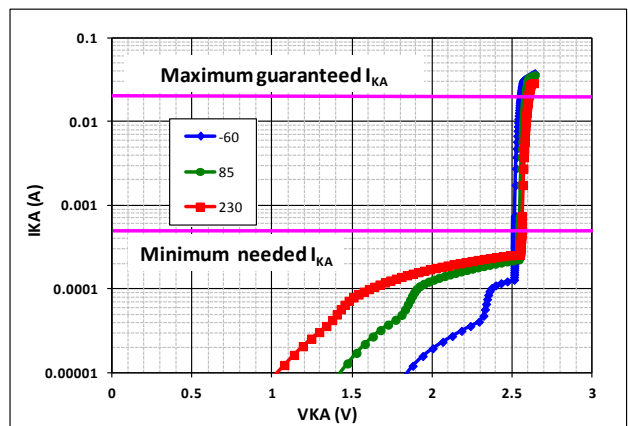


Figure 6. Cathode current vs. cathode voltage for several case temperatures. Limits show minimum needed and maximum guaranteed currents. Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ).

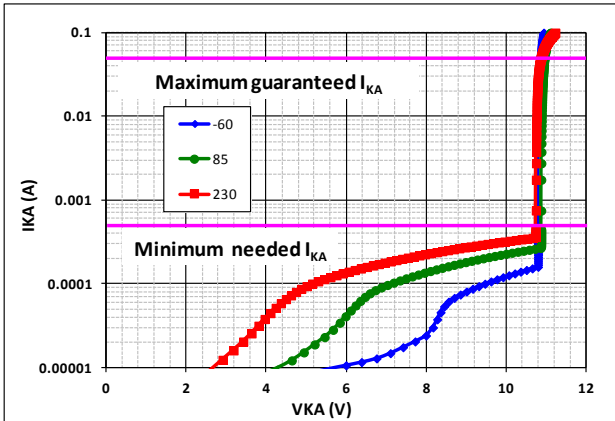


Figure 7. Cathode current vs. cathode voltage for several case temperatures. Limits show minimum needed and maximum guaranteed currents.  $R_1=33k\Omega$ ,  $R_2=10k\Omega$  ( $V_{KA}=10.75V$ ).

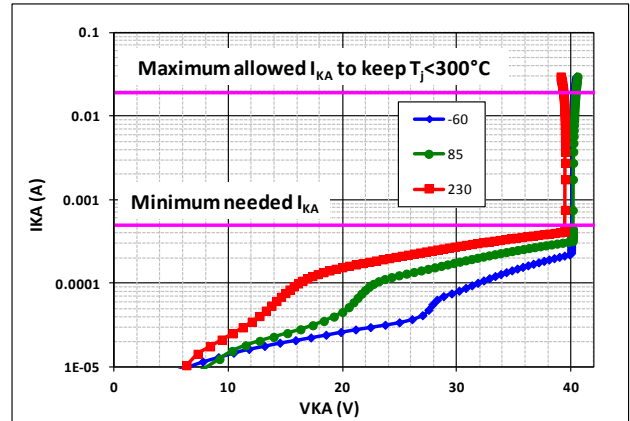


Figure 8. Cathode current vs. cathode voltage for several case temperatures. Limits show minimum needed and maximum guaranteed currents.  $R_1=150k\Omega$ ,  $R_2=10k\Omega$  ( $V_{KA}=40V$ ).

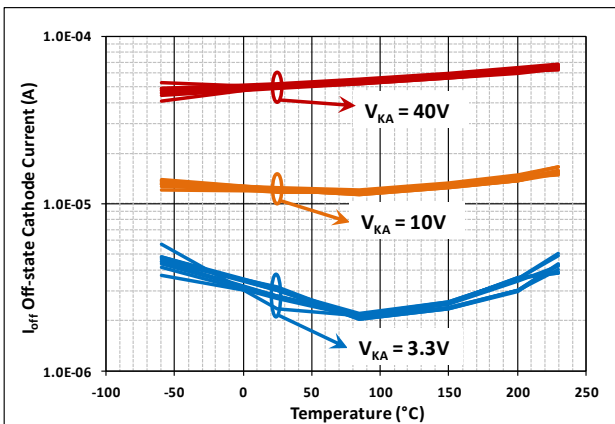


Figure 9. Off-state cathode current ( $I_{off}$ ) vs. case temperature for different cathode voltages. Values for 10 typical parts.

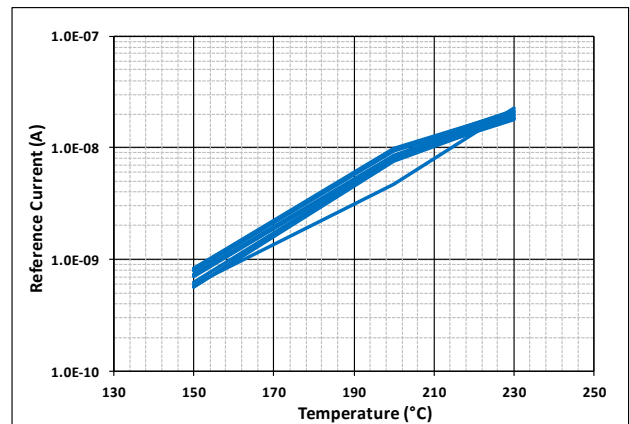


Figure 10. Reference input current ( $I_{REF}$ ) vs. case temperature for several cathode voltages. Values for 10 typical parts.

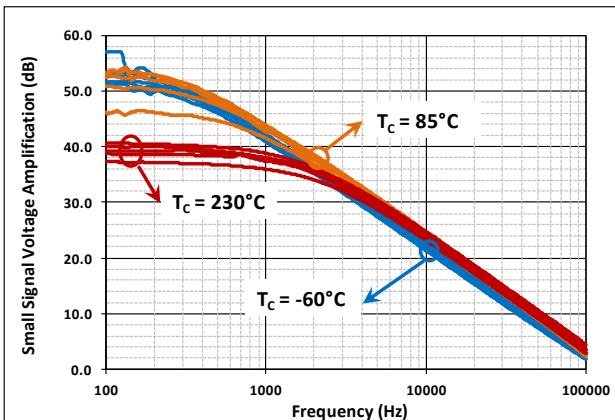


Figure 11. Small-signal voltage amplification ( $A_v$ ) vs. frequency for several case temperatures.  $I_{KA}=10mA$ . Values for 5 typical parts.

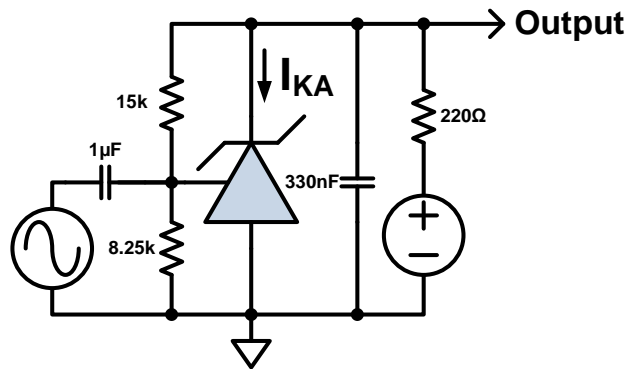


Figure 12. Test circuit for voltage amplification ( $A_v$ ).

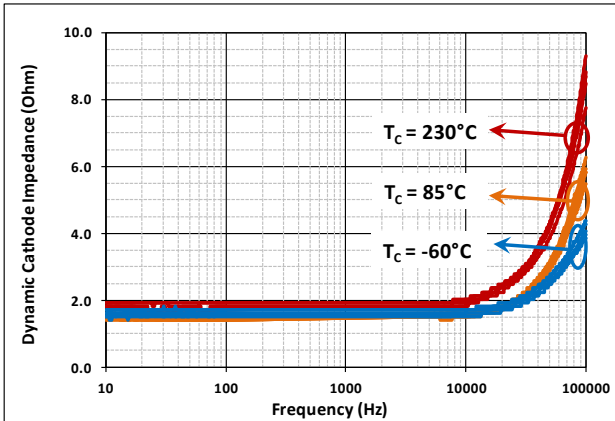


Figure 13. Dynamic cathode-anode impedance ( $Z_{KA}$ ) vs. frequency for several case temperatures. Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ),  $I_{KA}=10mA$ . Values for 5 typical parts.

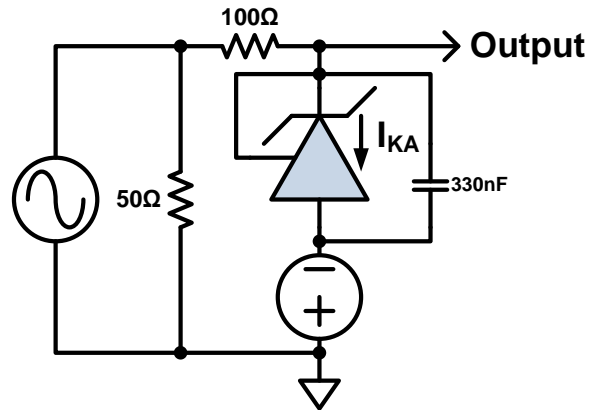


Figure 14. Test circuit for dynamic cathode-anode impedance ( $Z_{KA}$ ).

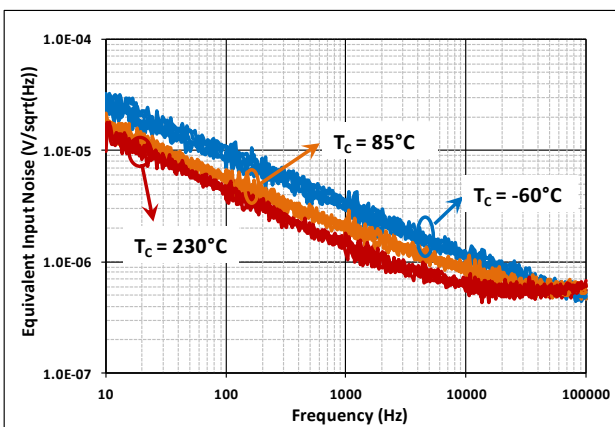


Figure 15. Equivalent input noise ( $V_n$ ) vs. frequency for several case temperatures. Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ),  $I_{KA}=10mA$ . Values for 5 typical parts.

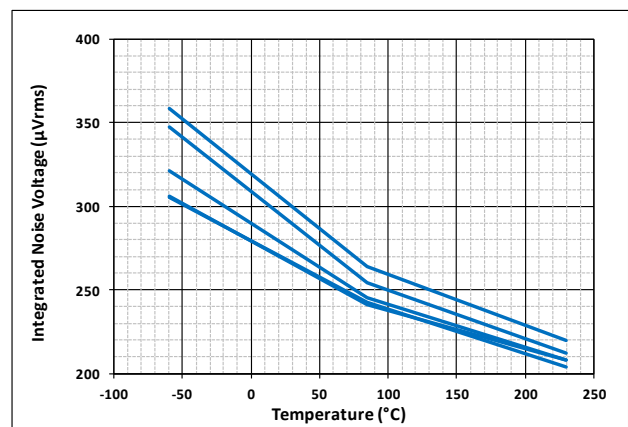


Figure 16. 10Hz-100kHz Integrated input noise ( $E_n$ ) vs. case temperatures. Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ),  $I_{KA}=10mA$ . Values for 5 typical parts.

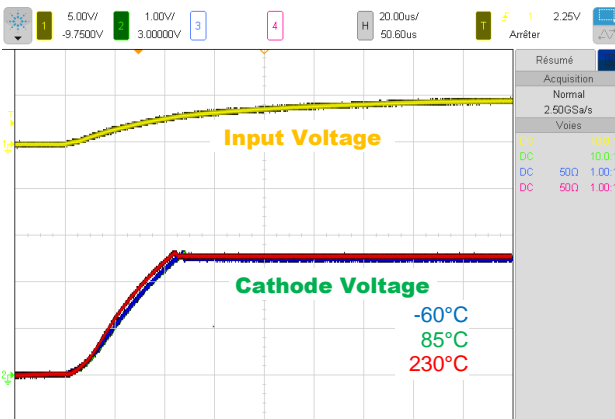


Figure 17. Start-up for three case temperatures (-60°C, 85°C and 230°C). Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ),  $I_{KA}=10mA$ ,  $C_{LOAD}=33nF$ .

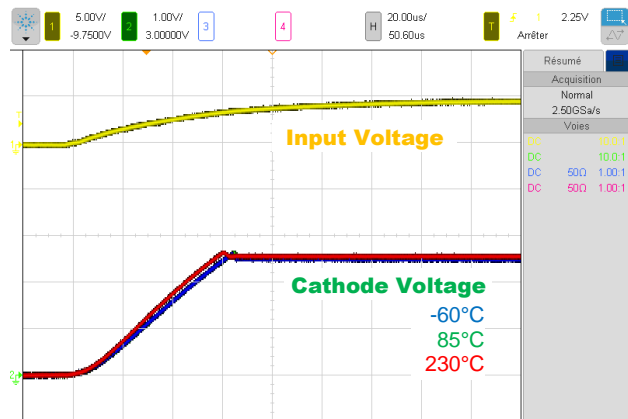


Figure 18. Start-up for three case temperatures (-60°C, 85°C and 230°C). Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ),  $I_{KA}=10mA$ ,  $C_{LOAD}=100nF$ .



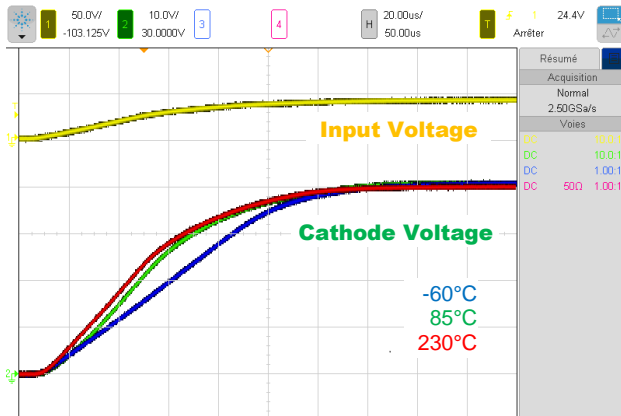


Figure 19. Start-up for three case temperatures (-60°C, 85°C and +230°C).  $V_{KA}=40V$ ,  $I_{KA}=10mA$ ,  $C_{LOAD}=33nF$ .

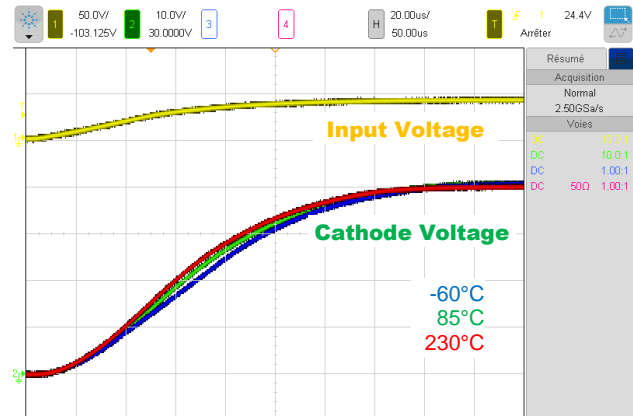


Figure 20. Start-up for three case temperatures (-60°C, 85°C and +230°C).  $V_{KA}=40V$ ,  $I_{KA}=10mA$ ,  $C_{LOAD}=100nF$ .

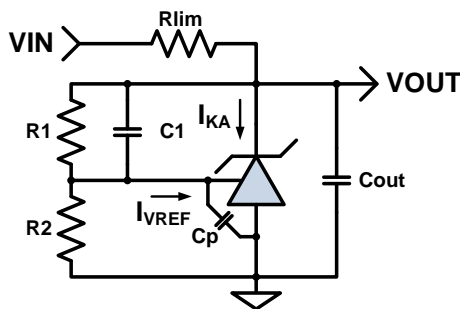
## THEORY OF OPERATION

### Introduction

The XTR431 is a SOI CMOS shunt voltage regulator able to operate from -60°C to +230°C, with voltages from 2.5V to 40V. As the XTR431 is built in a pure CMOS process, its internal structure is well different from those using BJTs in other commercial versions of the “431”. This fact is mainly observed on the minimum operating voltage, stability behavior, in the start-up timing characteristics, as well as in the small reference and leakage currents.

The following image shows the typical shunt regulator application with external components. Capacitor  $C_p$  represents the parasitic capacitance between  $V_{REF}$  and ANODE due to packaging and PCB routing. In cases where the parasitic capacitance  $C_p$  is above some tens of picofarads, a compensation capacitor  $C_1$  of some nanofarads may be needed.

Capacitor  $C_{out}$  connected between ANODE and CATHODE is always needed.



In this standard shunt regulator, the output voltage can be obtained from:

$$V_{KA} = V_{REF} \cdot \left(1 + \frac{R_1}{R_2}\right) + R_1 \cdot I_{VREF}$$

### General Considerations

#### Thermal considerations

The XTR431 has no internal thermal shutdown feature, allowing it to operate even above the -60°C to +230°C range. The user must ensure that the junction temperature will not exceed the temperature defined in the Absolute Maximum Ratings section for long periods and remain within the recommended temperature range whenever possible. Functionality can be demonstrated for temperatures well above 300°C (contact X-REL Semiconductor for further information).

Notice that above 200°C the  $V_{REF}$  input current increases, resulting in an increase of the  $V_{KA}$  voltage ( $V_{KA}$  increase is equal to  $R_1 \cdot I_{VREF}$ ). This further increases the dissipated power which in turn increases the junction temperature. The value of  $R_1$  should therefore not be too large when the circuit is expected to operate at high cathode voltage and current.

### Ground connection

The XTR431 anode pin should always be connected to the lower rail of the supply prior applying a cathode voltage. Accidental disconnecting of the anode under operation could damage the part.

### Stability conditions

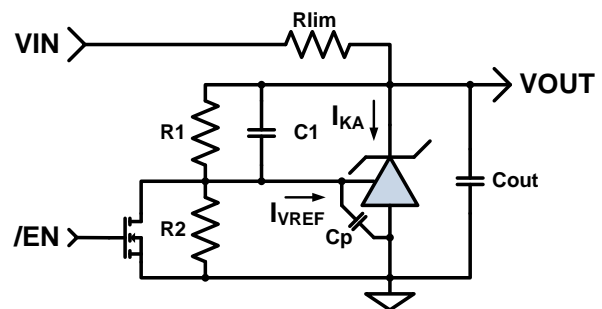
Conversely to BJT commercial versions of the “431”, the XTR431 presents a continuous range of possible load capacitors. This range has minimum values which vary with the output cathode voltage, cathode current and operating temperature. This minimum load capacitance can be as low as 10nF for  $I_{KA} \leq 1mA$  and temperatures above 25°C, though a minimum “one-fits-all” value of 27nF can be used for whatever cathode current and temperature condition.

If due to the layout of the substrate (ceramic or PCB) where the XTR431 is used, the parasitic capacitance ( $C_p$ ) between  $V_{REF}$  and ANODE is large (some tens of pF), an extra compensation capacitor  $C_1$  (1-10nF) may be needed.

### Functional Features & Operation

#### Disable feature

Whenever the  $V_{REF}$  terminal is pulled down below its internal 2.5V reference ( $/EN$  in the image below is high), the cathode current  $I_{KA}$  is quickly turned off. This means that, after this event,  $V_{KA}$  reaches the  $V_{IN}$  voltage.



When the circuit is enabled back again ( $/EN$  is low),  $V_{REF}$  will go up depending on  $R_1$ ,  $R_2$ ,  $C_p$  and  $C_1$  values.  $V_{REF}$  will then go to its steady state value of 2.5V once the cathode current settles again. A safe limit for  $dV_{ref}/dt$  is not to exceed  $0.2V/\mu s$ . Assuming that initially  $V_{KA}=V_{IN}$ ,

$$\frac{dV_{VREF}}{dt} \approx \frac{V_{IN}}{R_1 \cdot C_1} < 0.2[V/\mu s]$$

With  $R_1$  fixed, the previous relation gives a minimum recommended  $C_1$  value when the Enable functionality is used.





Part Marking Convention	
<b>Part Reference: XTRPPPPP</b>	
<b>XTR</b>	X-REL Semiconductor, high-temperature, high-reliability product (XTRM Series).
<b>PPPPP</b>	Part number (0-9, A-Z).
<b>Unique Lot Assembly Code: YYWWANN</b>	
<b>YY</b>	Two last digits of assembly year (e.g. 11 = 2011).
<b>WW</b>	Assembly week (01 to 52).
<b>A</b>	Assembly location code.
<b>NN</b>	Assembly lot code (01 to 99).

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