

# 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 (<100ppm/°C).
- ▲ 2.5V reference with 4% accuracy over the -60°C to +230°C temperature range.
- ▲ Fast turn-on response.
- ▲ Shut-down mode.
- ▲ Stable over a continuous range of load capacitors (100nF min).
- ▲ Monolithic design.
- ▲ Ruggedized SMT and thru-hole packages.
- ▲ Also available as bare die.

## APPLICATIONS

- ▲ Reliability-critical, Automotive, Aeronautics & Aerospace, Down-hole.
- ▲ 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 average temperature coefficient (TC) as low as 100ppm/°C. The output voltage may be set from 2.5V 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. Functionality features include shut-down mode and low dynamic output impedance.

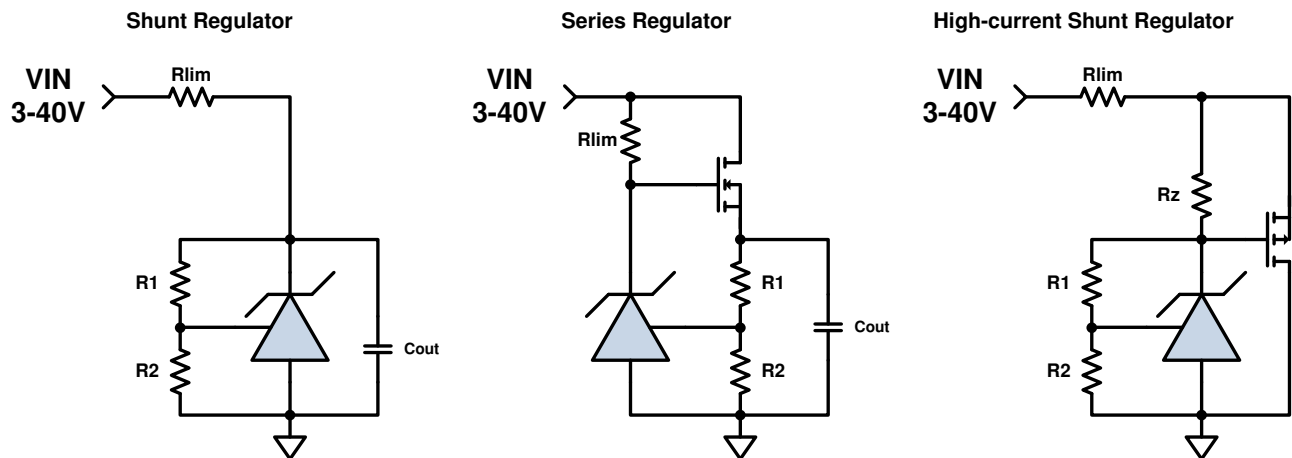
This part can be used as a high-reliability, high-temperature replacement of zener diodes in many applications such as on-board regulation, adjustable power supply and switching power supplies. The fact of operating as a zener diode makes the XTR431 convenient to be used as a positive or negative regulator.

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.

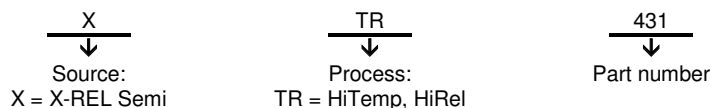
The XTR431 has been designed to reduce system cost and ease adoption by reducing the learning curve and providing smart and easy to use features.

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	Flat pack with exposed pad	8	XTR431
XTR431-D	-60°C to +230°C	Ceramic side braze DIP	8	XTR431

Other packages and packaging configurations possible upon request.

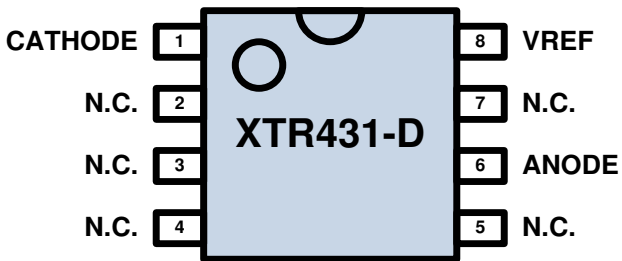
## ABSOLUTE MAXIMUM RATINGS

Voltage on CATHODE to ANODE	-1.5 to 40V
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

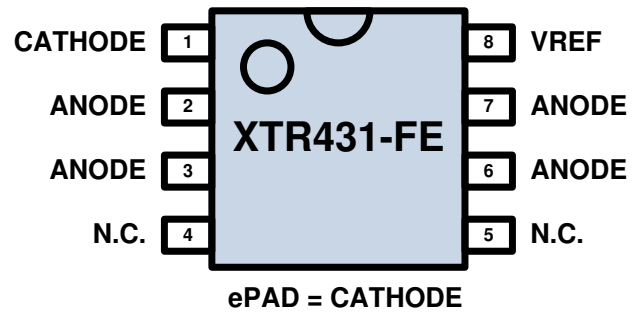
**Caution:** Stresses beyond those listed in “ABSOLUTE MAXIMUM RATINGS” may cause permanent damage to the device. These are stress ratings only and functionality of the device at these or any other condition beyond those indicated in the operational sections of the specifications is not implied. Exposure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

## PACKAGING

Ceramic side braze DIP8

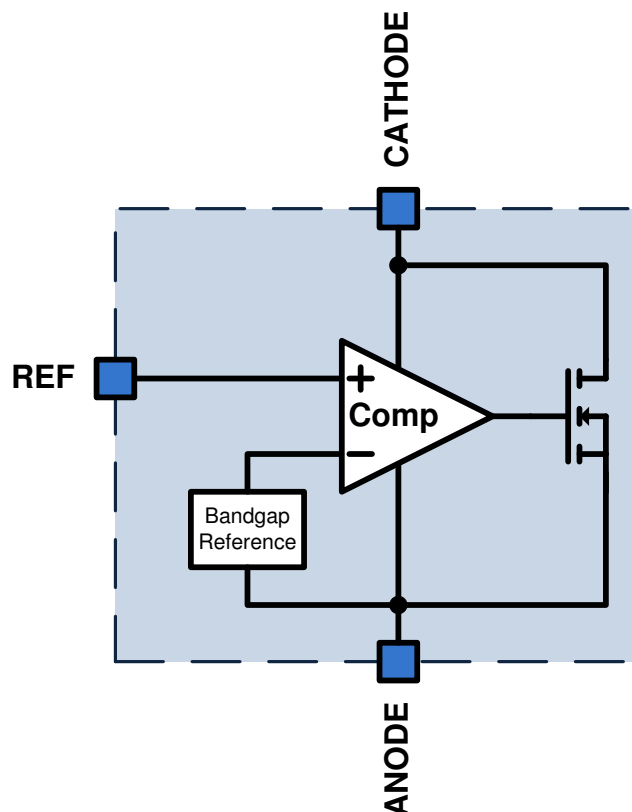


8-lead gull-wing flat pack with ePAD



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

## BLOCK DIAGRAM



**PIN DESCRIPTION**

XTR431-D		
Pin Number	Name	Description
1	CATHODE	Cathode terminal of equivalent zener diode. It is mandatory to connect this pin.
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.

**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.

**THERMAL CHARACTERISTICS**

Parameter	Condition	Min	Typ	Max	Units
<b>XTR431-D (DIP8)</b>					
Thermal Resistance: J-C $R_{Th, J-C}$			20		°C/W
Thermal Resistance: J-A $R_{Th, J-A}$			TBD		°C/W
<b>XTR431-FE (DFP8)</b>					
Thermal Resistance: J-C $R_{Th, J-C}$			15		°C/W
Thermal Resistance: J-A $R_{Th, J-A}$			TBD		°C/W

**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),  $-60^\circ\text{C}<T_j<230^\circ\text{C}$ .

Parameter	Condition	Min	Typ	Max	Units
<b>VREF Input</b>					
Reference Voltage $V_{REF}$	Cathode connected to $V_{REF}$ , $I_{KA}=1\text{mA}$ , $T_j=85^\circ\text{C}$	2.32	2.52	2.72	V
Drift with Temperature <sup>1</sup> $\Delta V_{REF}/\Delta T$	$I_{KA}=1\text{mA}$ , $T_j=-60^\circ\text{C}$ to $230^\circ\text{C}$ $V_{KA}=2.5\text{V}$ (Cathode connected to $V_{REF}$ ) $V_{KA}=10\text{V}$ $V_{KA}=40\text{V}$		66	120	mV
Sensitivity on Cathode Voltage $\Delta V_{REF}/\Delta V_{KA}$	$I_{KA}=1\text{mA}$ , $T_j=85^\circ\text{C}$ $V_{KA}=2.5\text{V}$ $V_{KA}=10\text{V}$ $V_{KA}=40\text{V}$		-8 -3 -0.9		mV/V
Reference Input Current $I_{VREF}$	$T_j=230^\circ\text{C}$ (Worst case) $V_{KA}=2.5\text{V}$ $V_{KA}=10\text{V}$ $V_{KA}=40\text{V}$		26 32 142	50 70 250	nA
<b>Cathode (Static Characteristics)</b>					
Minimum Cathode Current $I_{KA\_Min}$	$T_j=230^\circ\text{C}$ (Worst case) $V_{KA}=2.5\text{V}$ $V_{KA}=10\text{V}$ $V_{KA}=40\text{V}$		190 380 420	250 500 550	$\mu\text{A}$
Maximum Cathode Current $I_{KA\_Max}$	$T_j=230^\circ\text{C}$ (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
Stand-by Cathode Current $I_{KA\_StdBy}$	$V_{VREF}=0\text{V}$ , $V_{KA}=40\text{V}$ $T_j=-60^\circ\text{C}$ $T_j=85^\circ\text{C}$ $T_j=230^\circ\text{C}$		42 55 66	65 80 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 $50\text{mA}$ $T_j=-60^\circ\text{C}$ to $230^\circ\text{C}$		22	50	nF
<b>Cathode (Dynamic Characteristics)</b>					
Output Impedance $Z_{KA}=\delta V_{KA}/\delta I_K$	$I_C=1\text{mA}$ , $f_s\leq 500\text{Hz}$ $T_j=-60^\circ\text{C}$ $T_j=100^\circ\text{C}$ $T_j=230^\circ\text{C}$		1.0 1.8 4.0		$\Omega$
	$I_C=10\text{mA}$ , $f_s\leq 500\text{Hz}$ $T_j=-60^\circ\text{C}$ $T_j=100^\circ\text{C}$ $T_j=230^\circ\text{C}$		0.25 0.4 0.75		$\Omega$
	$I_C=10\text{mA}$ , $f_s\leq 500\text{Hz}$ $T_j=-60^\circ\text{C}$ $T_j=100^\circ\text{C}$ $T_j=230^\circ\text{C}$		0.15 0.25 0.55		$\Omega$
Transconductance $G_m=\delta I_K/\delta V_{VREF}$	$I_C=1\text{mA}$ , $V_{KA}=3.3\text{V}$ $T_j=-60^\circ\text{C}$ $T_j=100^\circ\text{C}$ $T_j=230^\circ\text{C}$		1.0 0.7 0.3		A/V
	$I_C=30\text{mA}$ , $V_{KA}=3.3\text{V}$ $T_j=-60^\circ\text{C}$ $T_j=100^\circ\text{C}$ $T_j=230^\circ\text{C}$		4.8 3 1.4		A/V
	$I_C=1\text{mA}$ , $V_{KA}\geq 5\text{V}$ $T_j=-60^\circ\text{C}$ $T_j=100^\circ\text{C}$ $T_j=230^\circ\text{C}$		1.2 0.9 0.4		A/V
	$I_C=30\text{mA}$ , $V_{KA}\geq 5\text{V}$ $T_j=-60^\circ\text{C}$ $T_j=100^\circ\text{C}$ $T_j=230^\circ\text{C}$		7.8 6.2 3.4		A/V

<sup>1</sup> Defined as the difference between the max and the min value of  $V_{REF}$  over the full operational temperature range.

**TYPICAL PERFORMANCE**

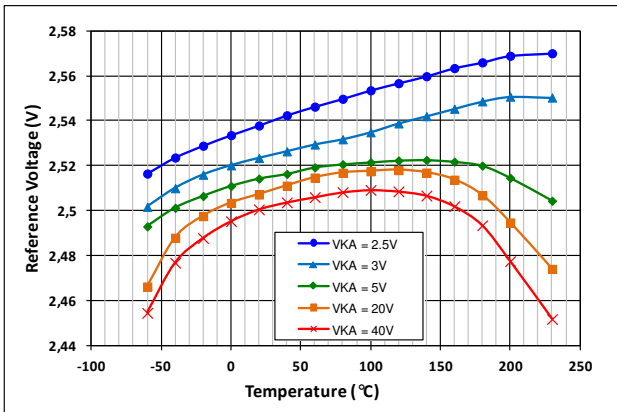


Figure 1. Reference voltage ( $V_{REF}$ ) vs. case temperature for several  $V_{KA}$ .  $I_{KA}=1mA$ .

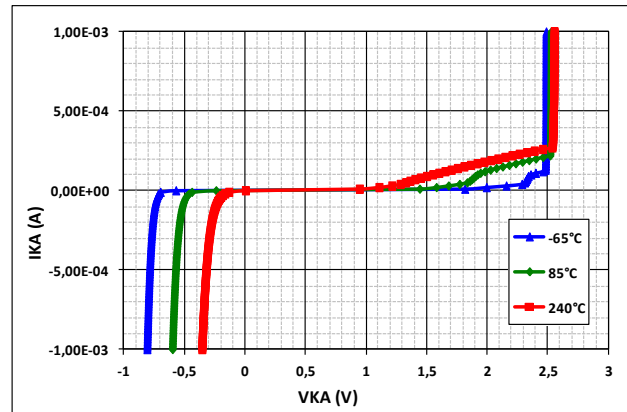


Figure 2. Cathode current vs. cathode voltage for several case temperatures. Limits show minimum needed and maximum guaranteed currents. Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ).

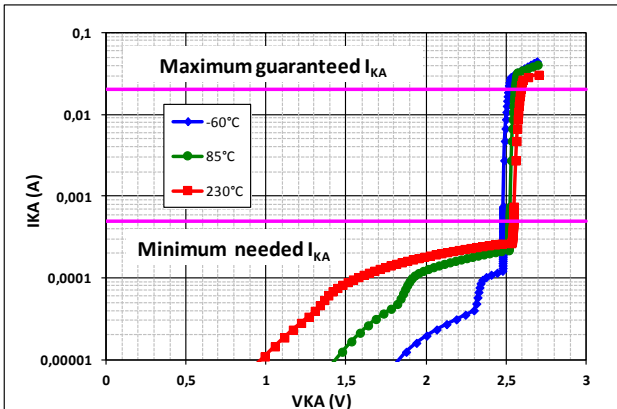


Figure 3. Cathode current vs. cathode voltage for several case temperatures. Limits show minimum needed and maximum guaranteed currents. Cathode connected to  $V_{REF}$  ( $V_{KA}=2.5V$ ).

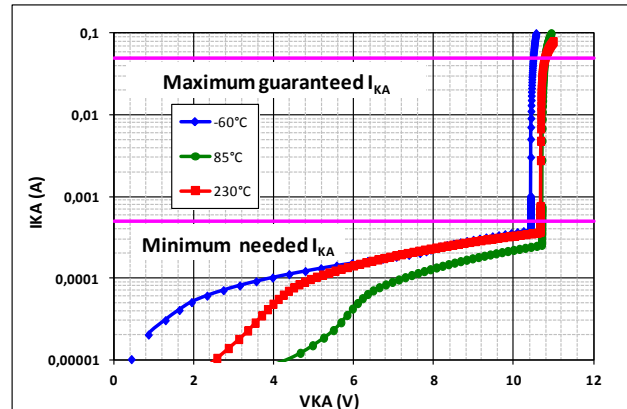


Figure 4. Cathode current vs. cathode voltage for several case temperatures. Limits show minimum needed and maximum guaranteed currents.  $R_1=33k\Omega$ ,  $R_2=10k\Omega$  ( $V_{KA}=10.75V$ ).

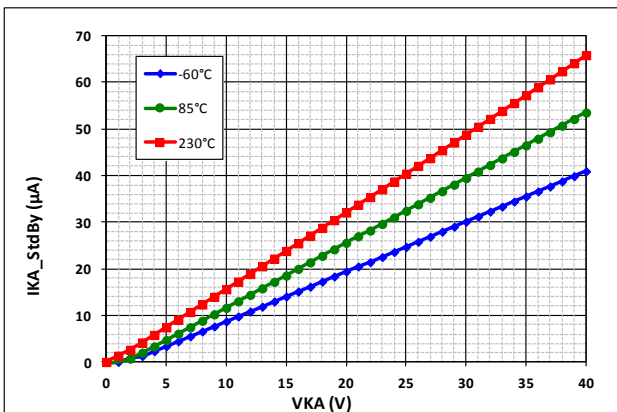


Figure 5. Stand-by cathode current ( $I_{KA\_StdBy}$ ) vs. cathode voltage for different case temperatures.

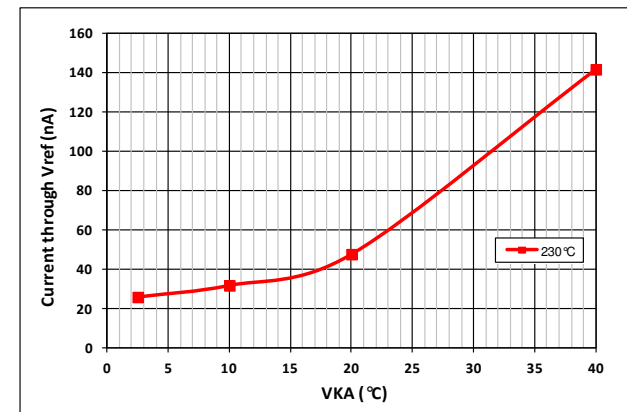
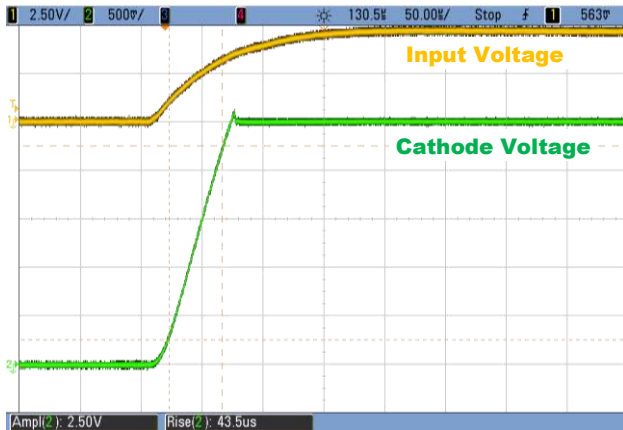
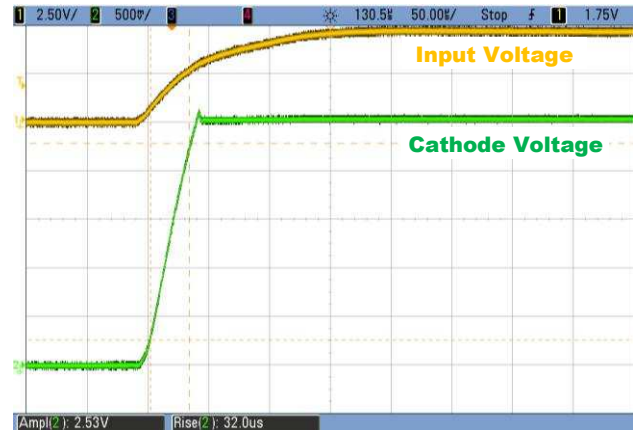


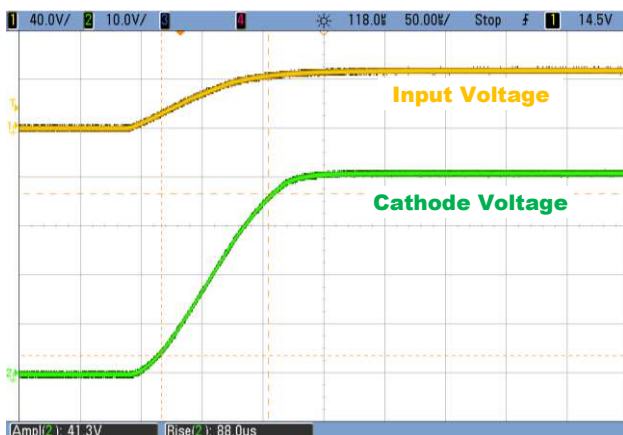
Figure 6. Reference input current ( $I_{VREF}$ ) vs. cathode voltage for  $T_c=230^\circ C$  (worst case).



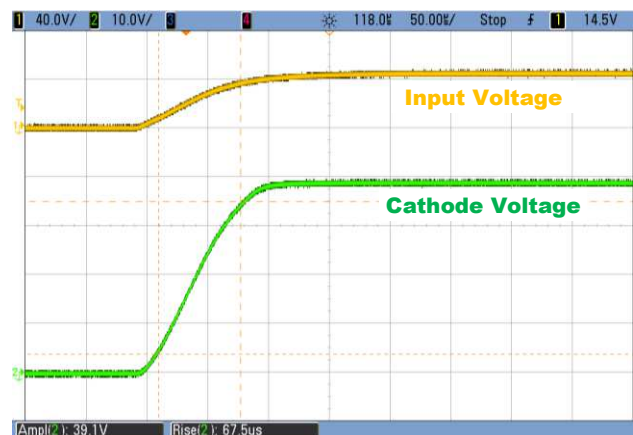
**Figure 7. Start-up at  $T_c = -60^\circ\text{C}$ .  $V_{KA} = V_{REF}$ ,  $I_{KA} = 10\text{mA}$ ,  $C_{LOAD} = 100\text{nF}$ .**



**Figure 8. Start-up at  $T_c = 230^\circ\text{C}$ .  $V_{KA} = V_{REF}$ ,  $I_{KA} = 10\text{mA}$ ,  $C_{LOAD} = 100\text{nF}$ .**



**Figure 9. Start-up at  $T_c = -60^\circ\text{C}$ .  $V_{KA} = 40\text{V}$ ,  $I_{KA} = 30\text{mA}$ ,  $C_{LOAD} = 100\text{nF}$ .**



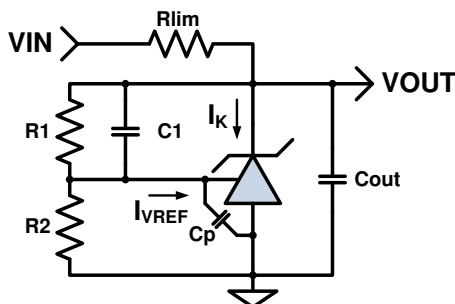
**Figure 10. Start-up at  $T_c = 230^\circ\text{C}$ .  $V_{KA} = 40\text{V}$ ,  $I_{KA} = 30\text{mA}$ ,  $C_{LOAD} = 100\text{nF}$ .**

## THEORY OF OPERATION

### Introduction

The XTR431 is a full CMOS shunt voltage regulator able to operate from  $-60^\circ\text{C}$  to  $+230^\circ\text{C}$ , 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 primarily observed on the minimum operating voltage, stability behavior and in the start-up timing characteristics.

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

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

### General Considerations

#### Thermal considerations

The XTR431 has no internal thermal shutdown feature, allowing it to operate even above the  $-60^\circ\text{C}$  to  $+230^\circ\text{C}$  range. The user must ensure that the junction temperature will not exceed the temperature Absolute Maximum Ratings for long periods and remain within the recommended temperature range whenever possible. Functionality can be achieved up to nearly  $250^\circ\text{C}$  at the expenses of reducing product lifetime.

Notice that above  $200^\circ\text{C}$  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 turns 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.

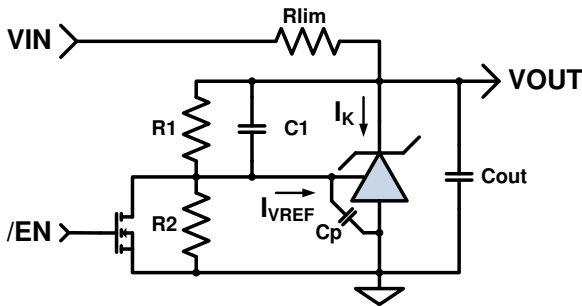
### Stability conditions

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  $I_K \leq 1\text{mA}$  and temperatures above  $25^\circ\text{C}$  or as high as some micro farads for cathode currents close to the maximum allowed and very low temperature.

### Functional Features & Operation

#### Disable feature

Whenever VREF voltage is pulled down (/EN in the image below is high) below its internal 2.5V reference, the cathode current  $I_K$  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), VREF will go up depending on  $R_1$ ,  $R_2$ ,  $C_P$  and  $C_1$  values. VREF will then go to its steady state value of 2.5V once the cathode current settles again. As shown previously, a delay of few tens of  $\mu s$  must be considered once the VREF voltage passes the 2.5V limit until the cathode current goes up. During this delay time, it must be guaranteed that VREF does not exceed 5.5V. 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  $R_1$  and  $R_2$  fixed, the previous relation gives a minimum recommended  $C_1$  value when the Enable functionality is used.

#### Start-up delay and transient behavior

In the previous section, the maximum slope allowed on the VREF terminal was determined. A similar analysis can be carried out to determine the maximum variation ratio on the cathode terminal.

For the start-up analysis, it is supposed that a shunt regulator is implemented leaving the voltage on VREF to be determined by  $V_{KA}$ , the resistive divider  $R_1$ - $R_2$  and capacitors  $C_1$  and  $C_P$ .

As a rule-of-thumb, in order to avoid a start-up overshoot larger than 10% on  $V_{KA}$  and assuming that  $C_1$  is large enough (see here after), capacitor  $C_{out}$  must be selected so that:

- Mode 3.3V:  $dV_{KA}/dt < 30mV/\mu s$
- Mode 5V :  $dV_{KA}/dt < 100mV/\mu s$
- Modes >5V :  $dV_{KA}/dt < 200mV/\mu s$

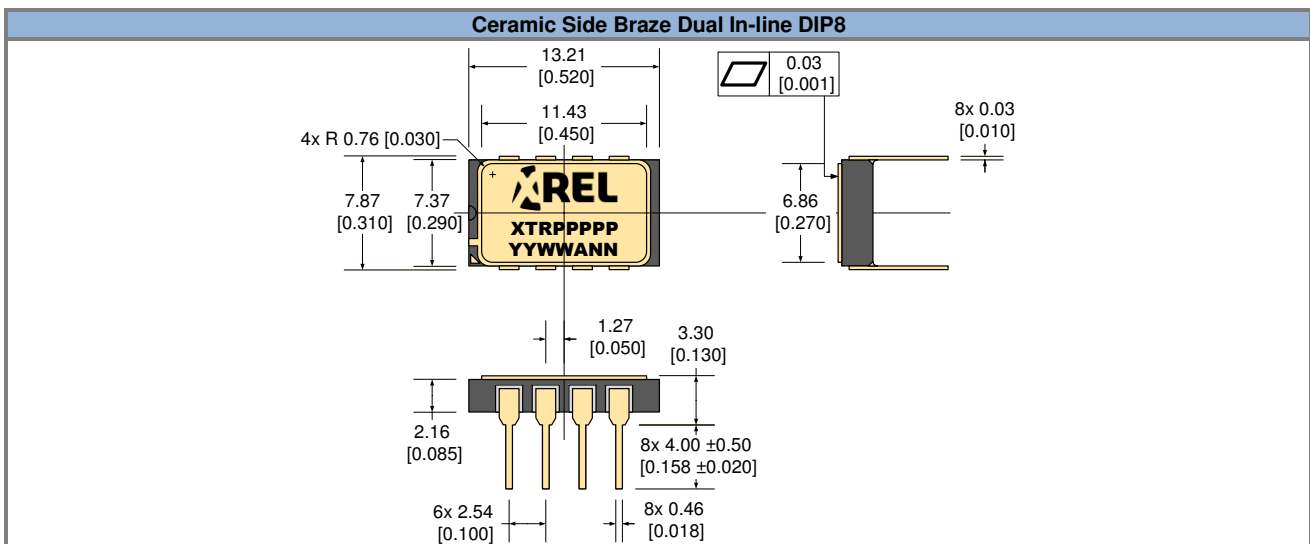
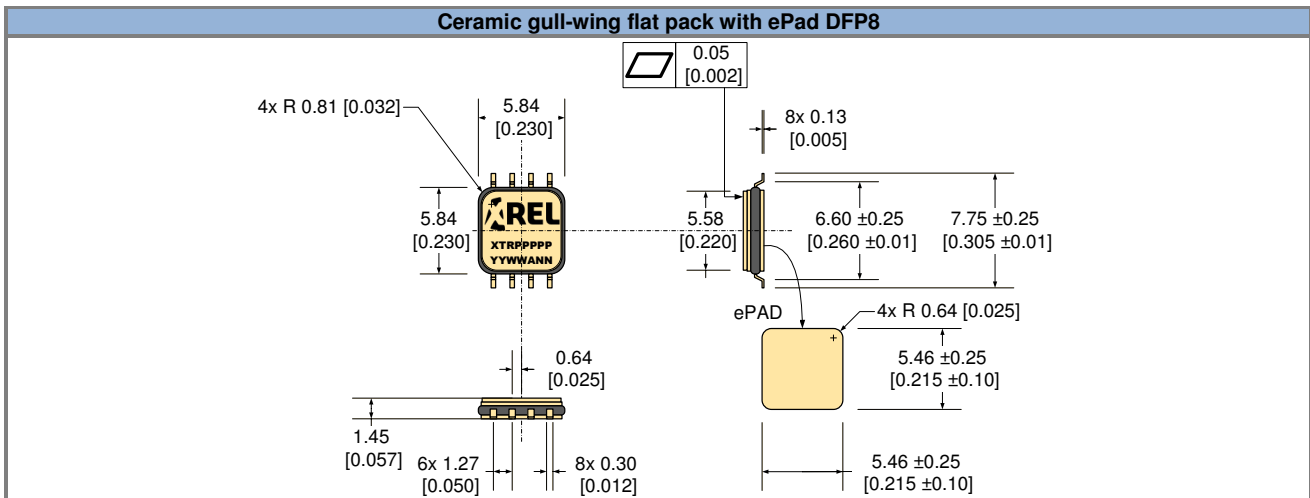
If  $C_1$  does not exist or is too small, then the previous slope limits should be reduced roughly by a factor of five. If  $C_1$  is used, it should preferably be larger than  $[10^{-4} / \min(R_1, R_2)]$ .

#### Stability

Considering a clean and neat PCB layout when implementing the standard shunt regulator, capacitor  $C_P$  can roughly be estimated at 10pF. Together with  $R_1$ , this parasitic capacitance makes a low pass filter from the cathode to VREF. If the associated parasitic pole appear within the transition frequency of the XTR431 VREF-Cathode transfer function, the closed loop could become unstable. In practice, the transition frequency ( $f_T$ ) of the XTR431 is inversely proportional to the load capacitance  $C_{out}$ . This  $f_T$  increases with the cathode current and with lower temperature. At a 30mA cathode current and  $-60^\circ C$ , using a 100nF load capacitance, the  $f_T$  is at 1MHz. Considering a 5V shunt regulator (i.e.  $R_1=R_2$ ), the closed loop transition frequency  $f_{T(CL)}$  is 500kHz (with a  $45^\circ$  phase margin). The absolute value of  $R_1$  must be such that  $R_1 \cdot C_P < 1/(2\pi f_{T(CL)})$  in order to keep a good phase margin. This means  $R_1 < 30k\Omega$ . In practice, higher values can be used if capacitor  $C_1$  is used between the cathode and VREF nodes. Using  $C_1 \gg C_P$ , the above constraints disappear, so that  $R_1$  could be increased, thus lowering power consumption, and parasitic capacitance  $C_P$  can be relaxed without stability issues.

**PACKAGE OUTLINES**

Dimensions shown in mm [inches].



**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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