

## VS431E / CD431E Voltage References

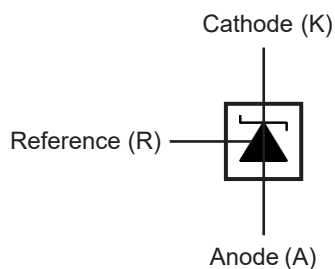
### 1 Introduction

The VS431E / CD431E is a three terminal adjustable precision Zener shunt regulator with guaranteed thermal stability over a full operation range. It has sharp turn-on characteristics, low temperature coefficient and low output impedance, and the output voltage can be set to any value between  $V_{REF}$  and maximum cathode voltage by selecting two external resistors acting as voltage divider networks, which makes them ideal substitutes for Zener diodes in applications such as switching power supplies, chargers and other adjustable regulators.

### 2 Available Packages

| PART NUMBER | PACKAGE   |
|-------------|-----------|
| VS431E      | SOT-23    |
|             | SOT-89-3L |
|             | TO-92     |
| CD431E      | SOT-23    |

**Note:** The CD431E is a version of the VS431E's SOT-23 package with different pin arrangement sequences.



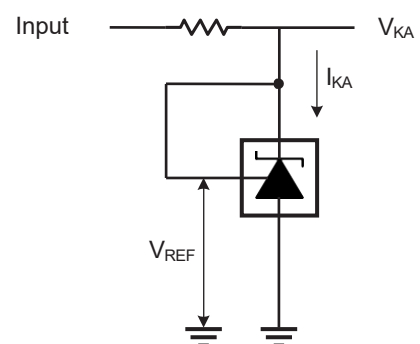
Symbol

### 3 Features

- Adjustable Output Voltage:  $V_{REF}$  to 36 V
- Reference Voltage Tolerance at 25°C:  
Available in  $\pm 0.4\%$  or  $\pm 0.8\%$  Grade
- Sink-current Capability: 1 ~ 100mA
- Excellent Temperature Performance:  
Op  $T_A$ : -40 ~ 125°C  
Low Drift: 10mV (Typ.)  
Excellent Temperature Coefficient:  
50 ppm/°C
- Low Dynamic Output Resistance:  
0.15Ω (Typ.)
- Fast Turn-on Response
- Low Output Noise
- High Stability under Capacitive Load

### 4 Applications

- Adjustable Voltage and Current Referencing
- Comparator with Integrated Reference
- Secondary Side Regulation in Flyback SMPSs
- Voltage Monitoring
- Zener Replacement



Simplified Schematic

## 5 Orderable Information

**Note:**

**ECO PLAN:** For the RoHS and Green certification standards of this product, please refer to the official report provided by JSVS.

**MSL:** Moisture Sensitivity Level. Determined according to JEDEC industry standard classification.

**SORT:** Specifically defined as follows:

Active: Recommended for new products;

Customized: Products manufactured to meet the specific needs of customers;

Preview: The device has been released and has not been fully mass produced. The sample may or may not be available;

NoRD: It is not recommended to use the device for new design. The device is only produced for the needs of existing customers;

Obsolete: The device has been discontinued.

## 7 Specifications

### 7.1 Absolute Maximum Ratings

(T<sub>A</sub> = 25°C, unless otherwise specified)<sup>(1)</sup>

| CHARACTERISTIC                     | SYMBOL             | VALUE      | UNIT |
|------------------------------------|--------------------|------------|------|
| Cathode voltage <sup>(2)</sup>     | V <sub>KA</sub>    | 40         | V    |
| Cathode current range (continuous) | I <sub>KA</sub>    | -100 ~ 150 | mA   |
| Reference input current range      | I <sub>REF</sub>   | -0.05 ~ 10 | mA   |
| Maximum junction temperature       | T <sub>J Max</sub> | 150        | °C   |
| Storage temperature                | T <sub>stg</sub>   | -65 ~ 150  | °C   |

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum rated conditions for extended periods may affect device reliability.

(2) All voltages are with respect to network Anode terminal.

### 7.2 Recommended Operating Conditions

| PARAMETER                     | SYMBOL          | MIN.             | NOM. | MAX. | UNIT |
|-------------------------------|-----------------|------------------|------|------|------|
| Cathode voltage               | V <sub>KA</sub> | V <sub>REF</sub> | -    | 36   | V    |
| Cathode current               | I <sub>KA</sub> | 1.0              | -    | 100  | mA   |
| Operating ambient temperature | T <sub>A</sub>  | -40              | -    | 125  | °C   |

### 7.3 ESD Ratings

| ESD RATINGS                            |                  | SYMBOL               | VALUE | UNIT |
|----------------------------------------|------------------|----------------------|-------|------|
| Electrostatic discharge <sup>(3)</sup> | Human body model | V <sub>ESD-HBM</sub> | 5000  | V    |

(3) ESD testing is conducted in accordance with the relevant specifications formulated by the Joint Electronic Equipment Engineering Commission (JEDEC). The human body model (HBM) electrostatic discharge test is based on the JESD22-A114D test standard, using a 100pF capacitor and discharging to each pin of the device through a resistance of 1.5kΩ.

## 7 Specifications

### 7.4 Thermal Information

| THERMAL METRIC <sup>(4)</sup>                                | SYMBOL          | VS431E / CD431E |           |       | UNIT |
|--------------------------------------------------------------|-----------------|-----------------|-----------|-------|------|
|                                                              |                 | SOT-23          | SOT-89-3L | TO-92 |      |
| Junction-to-ambient thermal resistance                       | $R_{\theta JA}$ | 356.4           | 198.4     | 181.9 | °C/W |
| Junction-to-case thermal resistance                          | $R_{\theta JC}$ | 133.5           | 52.5      | 46.2  | °C/W |
| Reference maximum power dissipation for continuous operation | $P_{D Ref}$     | 0.35            | 0.63      | 0.68  | W    |

(4) Thermal metric is measured in still air with  $T_A = 25^\circ\text{C}$  and installed on a 1 in<sup>2</sup> FR-4 board covered with 2 ounces of copper.

### 7.5 Electrical Characteristics

**VS431E / CD431E ( $T_A = 25^\circ\text{C}$ , unless otherwise specified)**

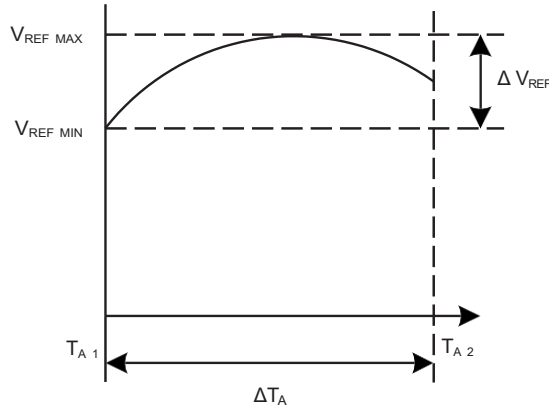
| CHARACTERISTIC                                                            | SYMBOL                           | TEST CONDITIONS |                                                                                                         |                                           | MIN.  | TYP. <sup>(5)</sup> | MAX.  | UNIT          |
|---------------------------------------------------------------------------|----------------------------------|-----------------|---------------------------------------------------------------------------------------------------------|-------------------------------------------|-------|---------------------|-------|---------------|
| Reference voltage                                                         | $V_{REF}$                        | Figure. 1       | $V_{KA} = V_{REF}$ ,<br>$I_{KA} = 10\text{mA}$                                                          | $\pm 0.4\%$ grade                         | 2.490 | 2.500               | 2.510 | V             |
|                                                                           |                                  |                 |                                                                                                         | $\pm 0.8\%$ grade                         | 2.480 |                     | 2.520 |               |
| Deviation of reference voltage over full temperature range <sup>(6)</sup> | $\Delta V_{REF}$                 | Figure. 1       | $V_{KA} = V_{REF}$ ,<br>$I_{KA} = 10\text{mA}$                                                          | $T_A = 0$ to $70^\circ\text{C}$           | -     | 2                   | 8     | mV            |
|                                                                           |                                  |                 |                                                                                                         | $T_A = -40$ to $85^\circ\text{C}$         | -     | 7                   | 20    |               |
|                                                                           |                                  |                 |                                                                                                         | $T_A = -40$ to $125^\circ\text{C}$        | -     | 10                  | 30    |               |
| Ratio of change in reference voltage to the change in cathode voltage     | $\Delta V_{REF} / \Delta V_{KA}$ | Figure. 2       | $I_{KA} = 10\text{mA}$                                                                                  | $\Delta V_{KA} = 10\text{V}$ to $V_{REF}$ | -     | -1.0                | -2.7  | mV / V        |
|                                                                           |                                  |                 |                                                                                                         | $\Delta V_{KA} = 36$ to $10\text{V}$      | -     | -0.5                | -2.0  |               |
| Reference current                                                         | $I_{REF}$                        | Figure. 2       | $I_{KA} = 10\text{mA}$ , $R_1 = 10\text{k}\Omega$ , $R_2 = \infty$                                      |                                           | -     | 0.7                 | 4.0   | $\mu\text{A}$ |
| Deviation of reference current over full temperature range <sup>(7)</sup> | $\Delta I_{REF}$                 | Figure. 2       | $I_{KA} = 10\text{mA}$ , $R_1 = 10\text{k}\Omega$ , $R_2 = \infty$ , $T_A = -40$ to $125^\circ\text{C}$ |                                           | -     | 0.4                 | 1.2   | $\mu\text{A}$ |
| Minimum cathode current for regulation                                    | $I_{KA MIN}$                     | Figure. 1       | $V_{KA} = V_{REF}$                                                                                      |                                           | -     | 0.3                 | 1.0   | mA            |
| Off-state cathode current                                                 | $I_{KA OFF}$                     | Figure. 3       | $V_{KA} = 36\text{V}$ , $V_{REF} = 0\text{V}$                                                           |                                           | -     | 0.01                | 1.00  | $\mu\text{A}$ |
| Dynamic impedance <sup>(8)</sup>                                          | $Z_{KA}$                         | Figure. 1       | $V_{KA} = V_{REF}$ , $I_{KA} = 1$ to $100\text{mA}$ ,<br>$f \leq 1.0\text{kHz}$                         |                                           | -     | 0.17                | 0.50  | $\Omega$      |

## 7 Specifications

### 7.5 Electrical Characteristics (continued)

(5) Typical numbers are at 25°C and represent the most likely norm.

(6) The deviation parameters  $\Delta V_{REF}$  and  $\Delta I_{REF}$  are defined as the differences between the maximum and minimum values obtained over the rated temperature range.



$$\Delta V_{REF} = V_{REF\ MAX} - V_{REF\ MIN}$$

$$\Delta T_A = T_{A2} - T_{A1}$$

The average full-range temperature coefficient of the reference input voltage  $\alpha V_{REF}$  is defined as:

$$\alpha V_{REF} \left( \frac{\%}{^\circ C} \right) = \frac{[V_{REF}(at\ 25^\circ C)] \times 10^6 - [V_{REF}(at\ T_{A1})] \times 10^6}{T_{A1} - 25} = \frac{[V_{REF}(at\ 25^\circ C)] \times 10^6 - [V_{REF}(at\ T_{A2})] \times 10^6}{T_{A2} - 25}$$

$\alpha V_{REF}$  is positive or negative, depending on whether  $V_{REF\ MIN}$  or  $V_{REF\ MAX}$  respectively, occurs at the lower temperature.

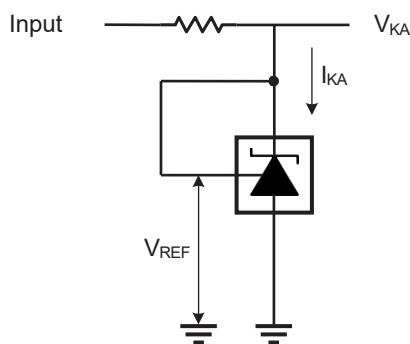
(7) The dynamic impedance is defined as:

$$|Z| = \frac{\Delta V_{KA}}{\Delta I_{KA}}$$

When the device is operating with two external resistors (see test figure. 2), the total dynamic impedance of the circuit is given by:

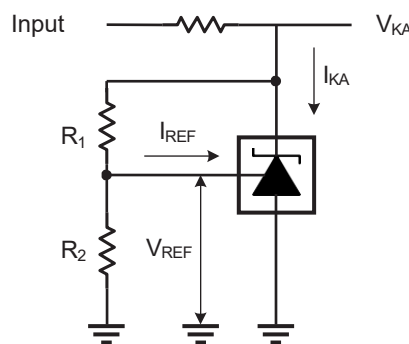
$$|Z'| = \frac{\Delta V}{\Delta I} \approx |Z| \times \left( 1 + \frac{R_1}{R_2} \right)$$

### 7.6 Test Figures and Typical Characteristics



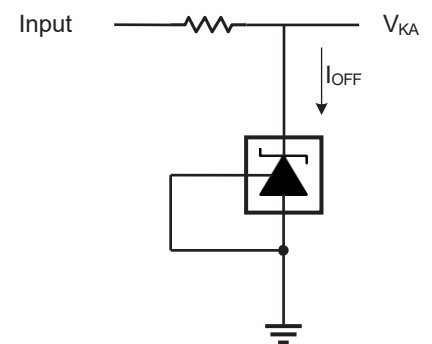
**Test Figure. 1**

For  $V_{KA} = V_{REF}$



**Test Figure. 2**

For  $V_{KA} > V_{REF}$

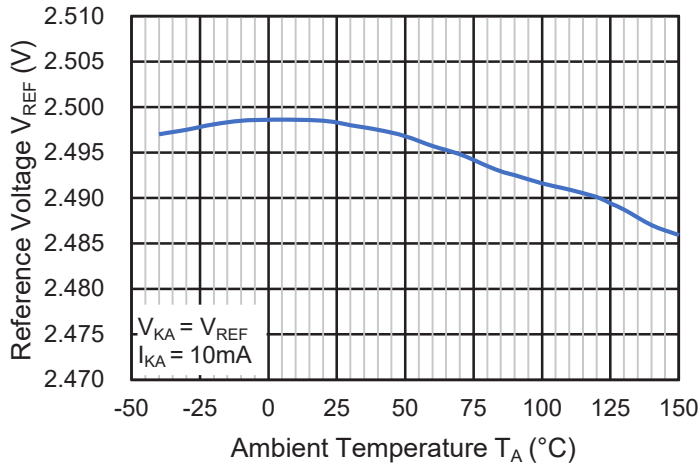
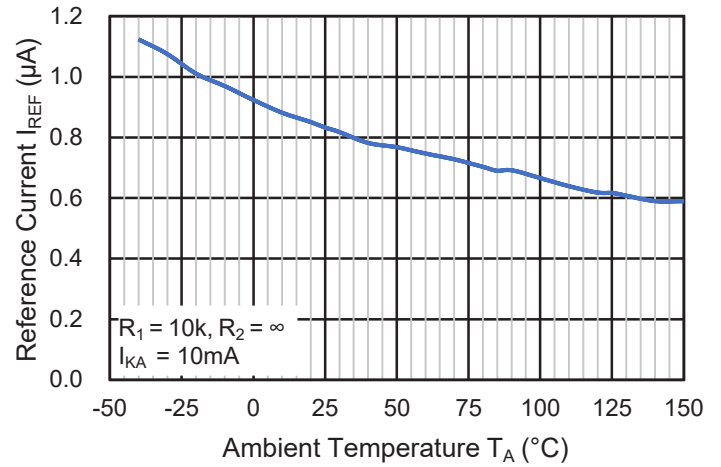
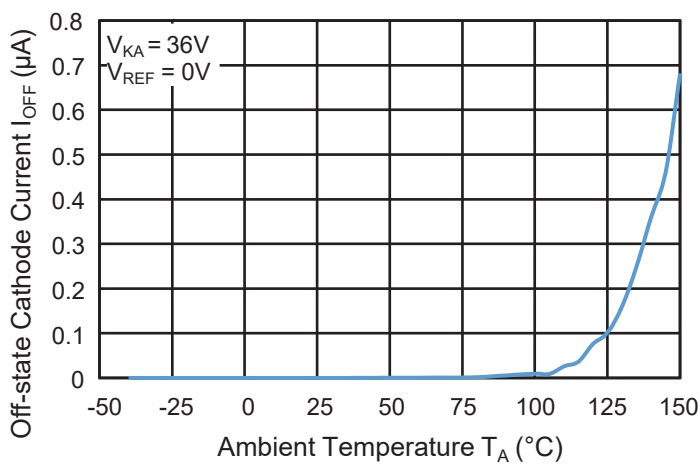
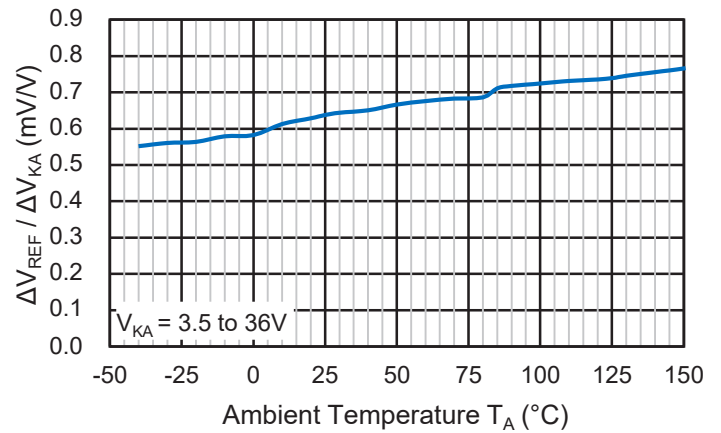
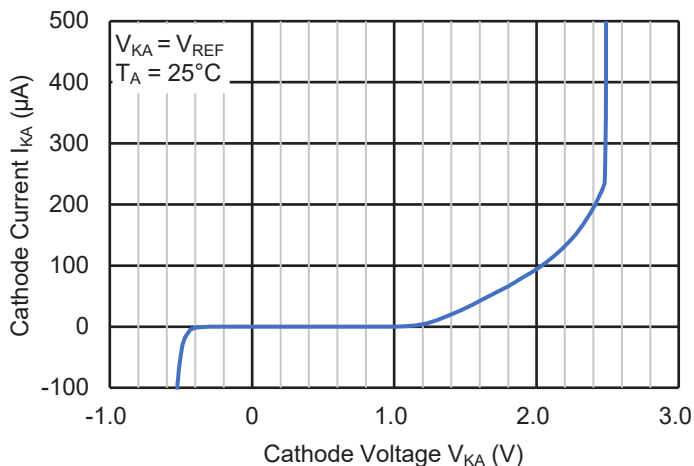
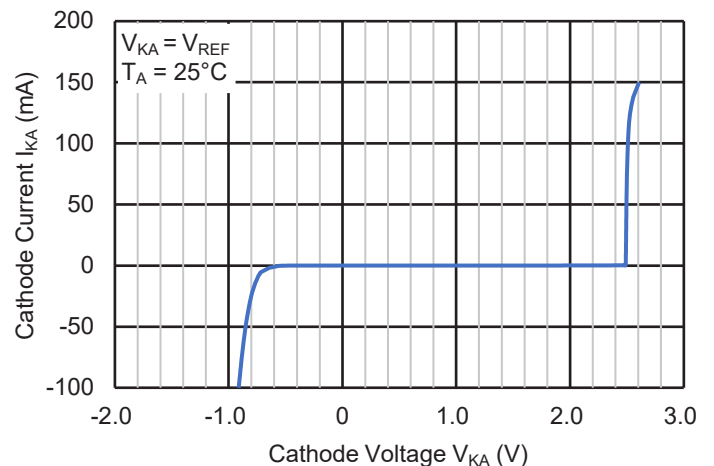


**Test Figure. 3**

For  $I_{OFF}$

## 7 Specifications

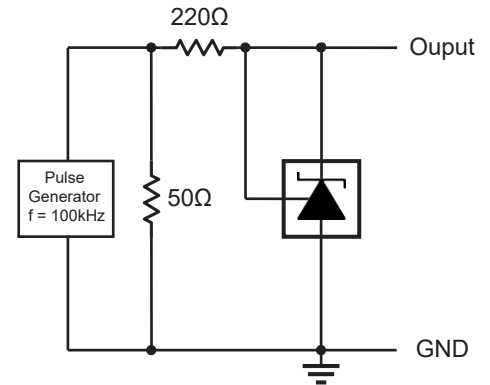
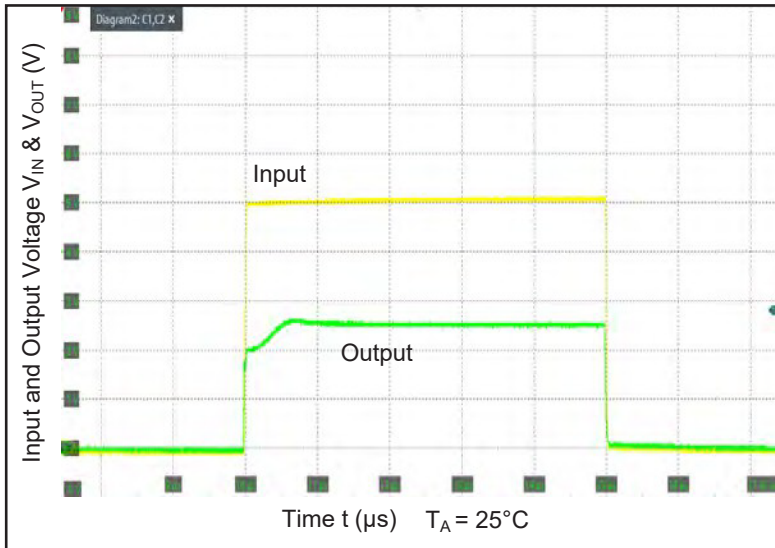
### 7.6 Test Figures and Typical Characteristics (continued)

Reference Voltage vs.  $T_A$ 

Reference Current vs.  $T_A$ 

Off-state Cathode Current vs.  $T_A$ 

Ratio of Delta Reference Voltage to Delta Cathode Voltage vs.  $T_A$ 

Cathode Current vs.  $V_{KA}$ 

Cathode Current vs.  $V_{KA}$ 


## 7 Specifications

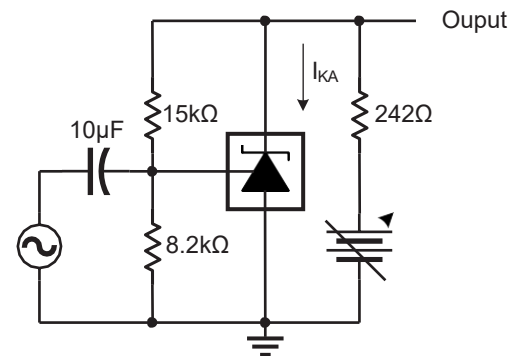
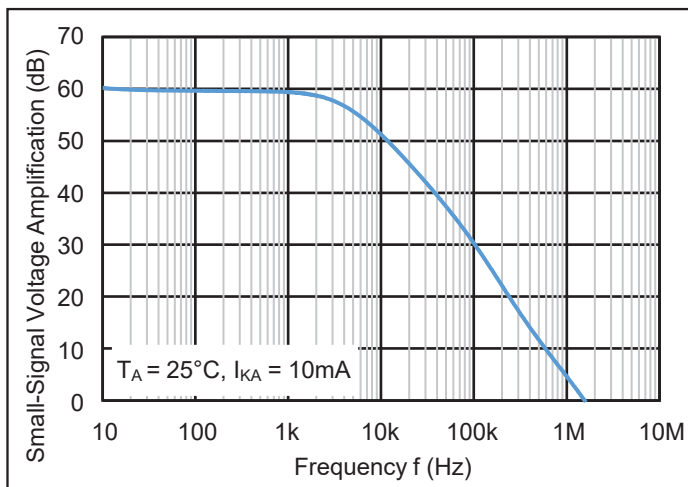
### 7.6 Test Figures and Typical Characteristics (continued)

#### Pulse Response



Test Figure. 4

#### Small Signal Voltage Gain

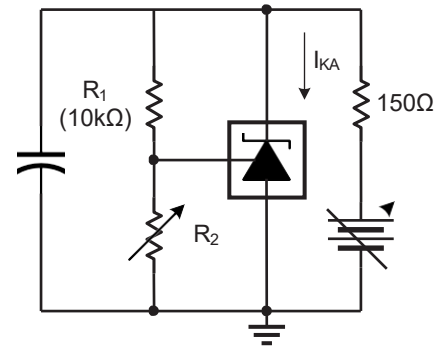
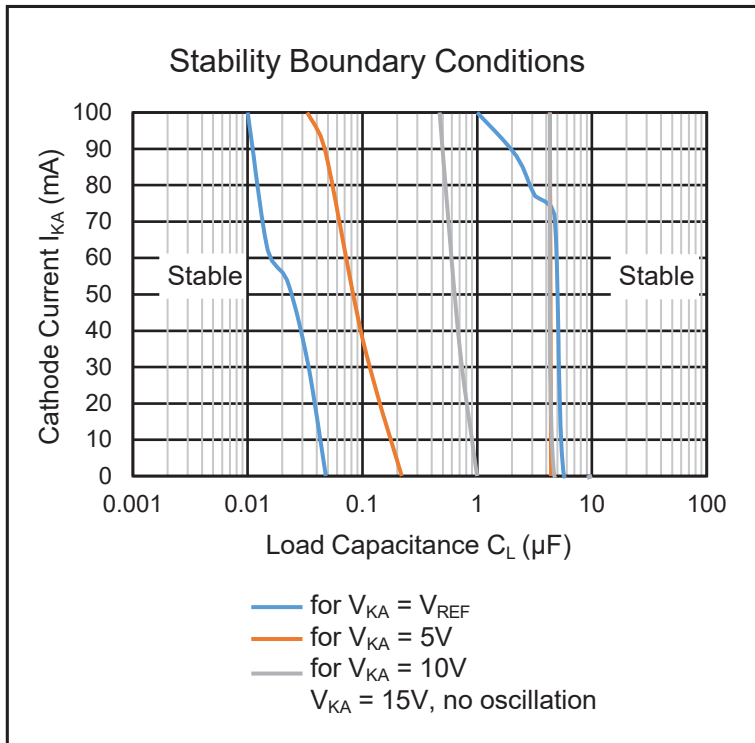


Test Figure. 5

## 7 Specifications

### 7.6 Test Figures and Typical Characteristics (continued)

Stability Boundary Conditions vs. Load Capacitance



Test Figure. 6

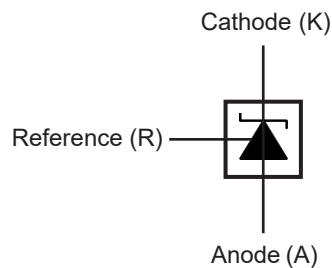
## 8 Detailed Description

### 8.1 Description

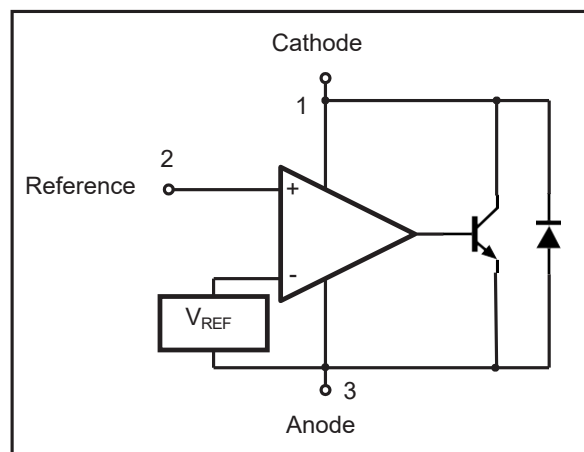
The VS431E / CD431E is an adjustable precision shunt voltage regulator. Its internal circuit module contains a precise voltage reference source and operational amplifier, which can support operation and adjustment within the cathode voltage range of  $V_{REF}$  to 36V, and has good temperature stability within the entire operating temperature range.

The VS431E / CD431E can be used with peripheral components as a single voltage reference, error amplifier, voltage clamp or comparator with integrated reference. The VS431E / CD431E has two reference voltage output tolerance levels to choose from:  $\pm 0.4\%$  and  $\pm 0.8\%$ , and supports SOT-23 packaging to meet the requirements of small size equipment.

### 8.2 Representative Schematic Diagram



**Symbol**



**Block Diagram**

## 8 Detailed Description

### 8.3 Feature Description

#### Basic Operation

The VS431E / CD431E is an adjustable precision shunt voltage regulator. With sufficient cathode voltage input  $V_{KA}$  and cathode current  $I_{KA}$ , the voltage between the Reference and Anode of the device will be maintained at  $V_{REF}$ . The simplest function realization circuit of the VS431E / CD431E is shown in Test Figure 1.

#### External Components

The only external component requirement of the VS431E / CD431E is the resistor between the cathode and the input voltage to set the input current. In the absence of output capacitor between cathode and anode, the VS431E / CD431E can still conduct internal compensation to maintain output stability, which is different from many linear regulators. Therefore, the external capacitor can be used for input or output, but it is not necessary. If the output capacitor is needed, the correct capacitor should be selected to maintain stability.

#### Sink Current

The internal part of the VS431E / CD431E is composed of a reference voltage source and an amplifier. The Reference pin and internal virtual pin of the amplifier will output a sink current, which is generated by the Darlington pair in the internal circuit of the amplifier. The conditions for sink current must be met, otherwise the device cannot operate normally. For the requirements of sink current  $I_{KA\ MIN}$ , see *Electrical Characteristics*.

#### Reference Pin

During normal operation of the VS431E / CD431E, there will be a small current  $I_{REF}$  flowing into the Reference. The Reference cannot be floated because the Reference is driven to the base of the internal triode, which requires the base current to work properly.

#### Open Loop

When the cathode / output voltage or current of the VS431E / CD431E is not fed back to the Reference / input pin in any form, the device operates in an open loop. If appropriate cathode current  $I_{KA}$  is applied to the device, the VS431E / CD431E will have the characteristics shown in the *Representative Schematic Diagram*. This circuit configuration has very high gain, so this circuit configuration of the VS431E / CD431E is usually used as a comparator. When users try to monitor a certain level of a single signal, the integrated reference makes the VS431E / CD431E the first choice.

#### Closed Loop

When the cathode / output voltage or current of the VS431E / CD431E is fed back to the Reference / input pin in any form, the device operates in a closed loop. Most applications involving 431 series use it to adjust fixed voltage or current in this way. Feedback enables the device to act as an error amplifier, calculate part of the output voltage and adjust it to maintain the desired adjustment. This is achieved by feedback the output voltage to the reference pin in the way that the output voltage is equal to the internal reference voltage, which can be achieved through resistance or direct feedback.

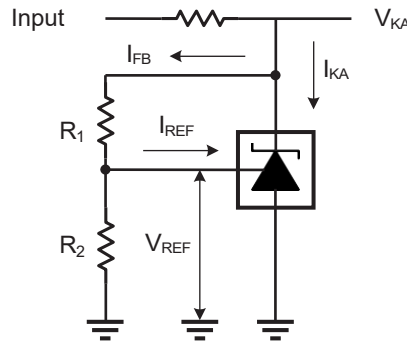
## 9 Application Information and Implementation

### 9.1 Application Information

#### Setting the Shunt Voltage

As an adjustable precision Zener parallel regulator, the VS431E / CD431E can set the shunt voltage  $V_{KA}$  to any value between the reference voltage  $V_{REF}$  and the maximum rated voltage by setting the resistance values of two feedback resistors  $R_1$  and  $R_2$ . In the ideal common anode shunt regulating circuit (as shown in Figure 9-1), the shunt voltage  $V_{KA}$  can be obtained from the following formula:

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



**Figure 9-1. Common Anode Shunt Regulating Circuit**

However, in the actual circuit design, the above formula cannot accurately reflect the relationship between  $V_{KA}$  and  $R_1$ ,  $R_2$ , because the following parameters of shunt regulator also affect the  $V_{KA}$ :

1. Dynamic impedance  $Z_{KA}$ . In any case, the  $Z_{KA}$  will offsets the  $V_{REF}$  in direct proportion to the cathode current, and the typical value of  $V_{REF}$  in the data table is only expressed as the typical value under the specific current.
2. Reference pin current  $I_{REF}$ . In the shunt regulating circuit of the common anode, when  $V_{KA}$  is greater than  $V_{REF}$ , the current flowing into the reference pin  $I_{REF}$  will cause the current flowing through  $R_1$  and  $R_2$  to be unequal, which will affect the effective DC feedback ratio. The  $V_{KA}$  formula in the data table usually includes this factor, as shown in the following formula:

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

3. Ratio of reference voltage change to cathode voltage change  $\Delta V_{REF} / \Delta V_{KA}$ . When  $V_{KA}$  is greater than  $V_{REF}$ ,  $V_{REF}$  will change to a certain extent when cathode voltage changes. Although this factor may have a significant impact on  $V_{REF}$ , it is often ignored by designers.

In the common anode parallel regulating circuit, the  $V_{REF}$  will be subject to  $R_1$ ,  $R_2$ ,  $Z_{KA}$ ,  $I_{REF}$ ,  $\Delta V_{REF} / \Delta V_{KA}$  is affected by these parameters. When  $V_{KA} = V_{REF}$  and  $I_{KA} = 10\text{mA}$ , the nominal  $V_{REF}$  is 2.500V, the nominal  $I_{KA}$  and  $V_{REF}$  is represented by  $I_{NOM}$  and  $V_{NOM}$  in the following text. The reference pin current  $I_{REF}$  is 0.7 $\mu\text{A}$ . The  $\Delta V_{REF} / \Delta V_{KA}$  at two different rates: it is -1.0mV/V from  $V_{REF}$  to 10V then -0.5mV/V above 10V. Therefore,  $V_{REF}$  should be determined by the following formula:

If  $V_{KA} \leq 10\text{ V}$ , then

$$V_{REF} = V_{NNNM} + (I_{KA} - I_{NNNM}) \times Z_{KA} + (V_{KA} - V_{NNNM}) \times (-1.0\text{ mV/V})$$

If  $V_{KA} > 10\text{ V}$ , then

$$V_{REF} = V_{NNNM} + (I_{KA} - I_{NNNM}) \times Z_{KA} + (10\text{V} - V_{NNNM}) \times (-1.0\text{ mV/V}) + (V_{KA} - 10\text{V}) \times (-0.5\text{ mV/V})$$

In the formula with  $V_{KA} > 10\text{V}$ , the calculation result of  $(10\text{V} - V_{NOM}) \times (-1.0\text{mV/V})$  is -7.5mV, then

$$V_{REF} = V_{NNNM} + (I_{KA} - I_{NNNM}) \times Z_{KA} - 7.5\text{mV} + (V_{KA} - 10\text{V}) \times (-0.5\text{mV/V})$$