VS431D / CD431D Voltage References

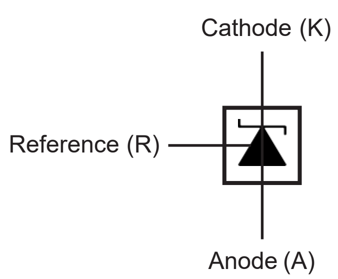
1 Introduction

The VS431D / CD431D 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
VS431D	SOT-23
	SOT-89-3L
	TO-92
CD431D	SOT-23

Note: CD431D is a version of VS431D's SOT-23 package with different pin arrangement sequences.



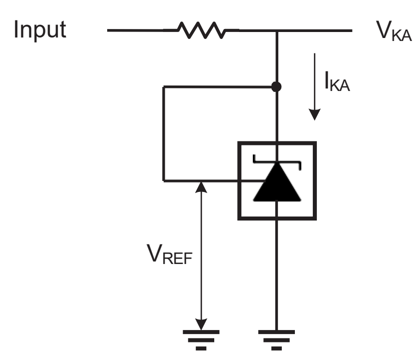
Symbol

3 Features

- Adjustable Output Voltage: V_{REF} to 36 V
- Reference Voltage Tolerance at 25°C: Available in ±0.4% or ±0.8%
- Sink-current Capability: 1 ~ 100mA
- Operation Ambient Temperature: -40 ~ 125°C
- Low Temperature Drift: 4.5mV (Typ.)
- Excellent Temperature Coefficient: 20 ppm/°C over the full temperature
- 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
- Secondary Side Regulation in Flyback SMPSs
- Zener Replacement
- Voltage Monitoring
- Comparator with Integrated Reference



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_A = 25°C, unless otherwise specified)[1]

CHARACTERISTIC	SYMBOL	VALUE	UNIT
Cathode voltage[2]	V_{KA}	40	V
Cathode current range (continuous)	I_{KA}	-100 ~ 150	mA
Reference input current range	I_{REF}	-0.05 ~ 10	mA
Maximum junction temperature	$T_{J\ Max}$	150	°C
Storage temperature	T_{stg}	-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_{KA}	V_{REF}	-	36	V
Cathode current	I_{KA}	1.0	-	100	mA
Operating ambient temperature	T_A	-40	-	125	°C

7.3 ESD Ratings

ESD RATINGS		SYMBOL	VALUE	UNIT
Electrostatic discharge[3]	Human body model	$V_{ESD-HBM}$	2000	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 JESD22-114D 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(4)	SYMBOL	VS431D / CD431D			UNIT
		SOT-23	SOT-89-3L	TO-92	
Junction-to-ambient thermal resistance	$R_{\Theta JA}$	416.7	208.3	198.4	°C/W
Junction-to-case thermal resistance	$R_{\Theta JC}$	139.4	56.5	49.6	°C/W
Reference maximum power dissipation for continuous operation	$P_{D\ Ref}$	0.30	0.60	0.63	W

(4) Thermal metric is measured in still air with T_A = 25°C and installed on a 1 in2 FR-4 board covered with 2 ounces of copper.

7.5 Electrical Characteristics

VS431D / CD431D (T_A = 25°C, unless otherwise specified)

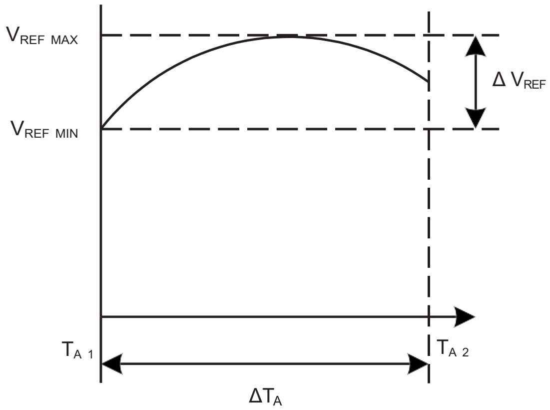
CHARACTERISTIC	SYMBOL	TEST CONDITIONS			MIN.	TYP.(5)	MAX.	UNIT
Reference voltage	V_{REF}	Figure. 1	$V_{KA} = V_{REF}$, I_{KA} = 10mA	0.4% grade	2.490	2.500	2.510	V
				0.8% grade	2.480	2.500	2.520	
Deviation of reference voltage over full temperature range(6)	ΔV_{REF}	Figure. 1	$V_{KA} = V_{REF}$, I_{KA} = 10mA	T_A = 0 to 70°C	-	4.5	8.0	mV
				T_A = -40 to 85°C	-	4.5	10	
				T_A = -40 to 125°C	-	4.5	16	
Ratio of change in reference voltage to the change in cathode voltage	$\Delta V_{REF} / \Delta V_{KA}$	Figure. 2	I_{KA} = 10mA	ΔV_{KA} = 10V to V_{REF}	-	-1.0	-2.7	mV / V
				ΔV_{KA} = 36 to 10V	-	-0.5	-2.0	
Reference current	I_{REF}	Figure. 2	I_{KA} = 10mA, R_1 = 10kΩ, R_2 = ∞		-	0.7	4.0	μA
Deviation of reference current over full temperature range(6)	ΔI_{REF}	Figure. 2	I_{KA} = 10mA, R_1 = 10kΩ, R_2 = ∞, T_A = -40 to 125°C		-	0.4	1.2	μA
Minimum cathode current for regulation	$I_{KA\ MIN}$	Figure. 1	$V_{KA} = V_{REF}$		-	0.4	1.0	mA
Off-state cathode current	$I_{KA\ OFF}$	Figure. 3	V_{KA} = 36V, V_{REF} = 0V		-	0.05	1	μA
Dynamic impedance(7)	Z_{KA}	Figure. 1	$V_{KA} = V_{REF}$, I_{KA} = 1 to 100mA, f ≤ 1.0kHz		-	0.15	0.50	Ω

7 Specifications

7.5 Electrical Characteristics (continued)

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

(6) The deviation parameters ΔV_{REF} and ΔI_{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 αV_{REF} is defined as:

$$|\alpha V_{REF}|\left(\frac{ppm}{°C}\right) = \frac{\left[\frac{\Delta V_{REF}}{V_{REF}(at\ 25°C)}\right] \times 10^6}{\Delta T_A} = \frac{\left[\frac{\Delta V_{REF}}{V_{REF}(at\ 25°C)}\right] \times 10^6}{\Delta T_A}$$

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

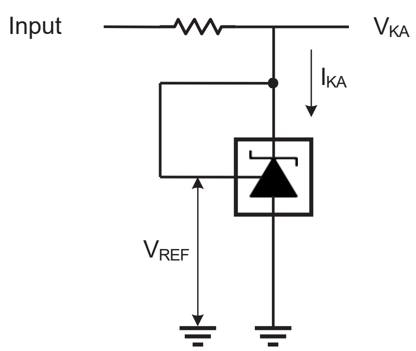
(7) The dynamic impedance is defined as:

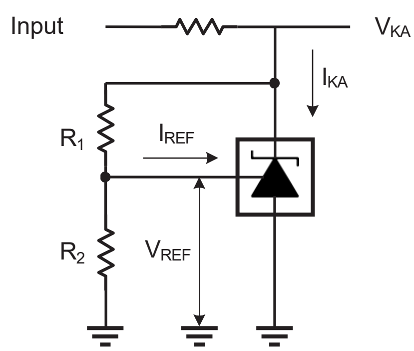
$$|Z_{KA}| = \frac{\Delta V_{KA}}{\Delta I_{KA}}$$

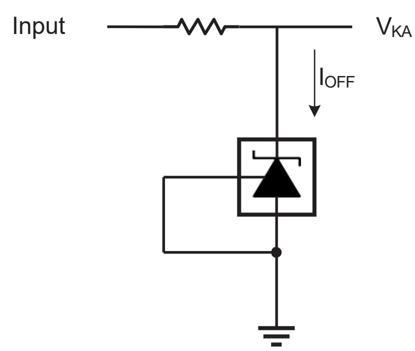
When the device is operating with two external resistors (see test figure. 2), the total dynamic impedance of the circuit is given by:

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

7.6 Test Figures and Typical Characteristics







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

Test Figure. 1

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

Test Figure. 2

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

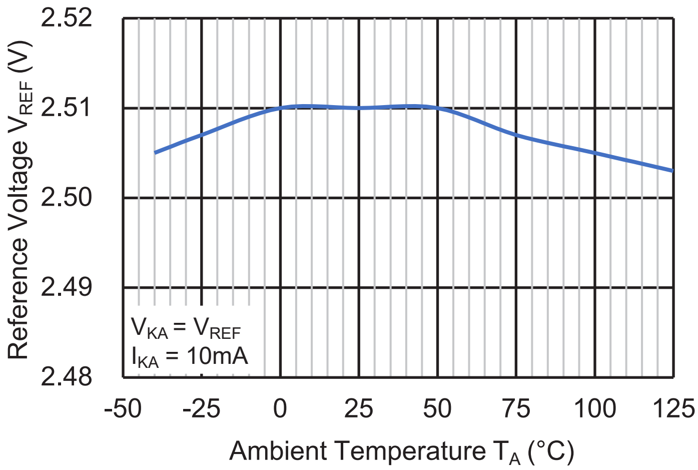
Test Figure. 3

For I_{OFF}

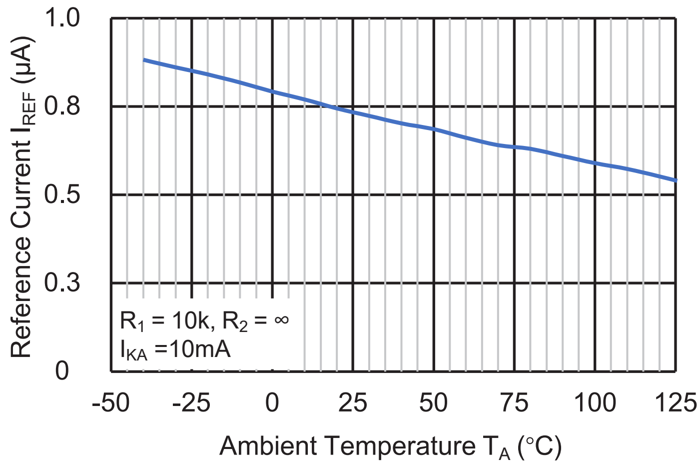
7 Specifications

7.6 Test Figures and Typical Characteristics (continued)

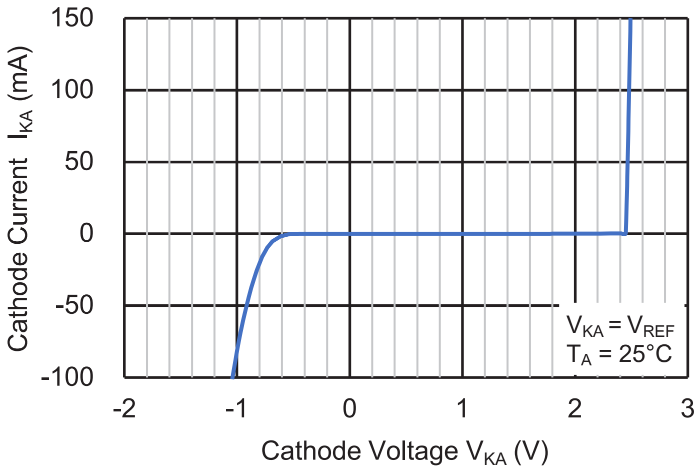
Reference Voltage



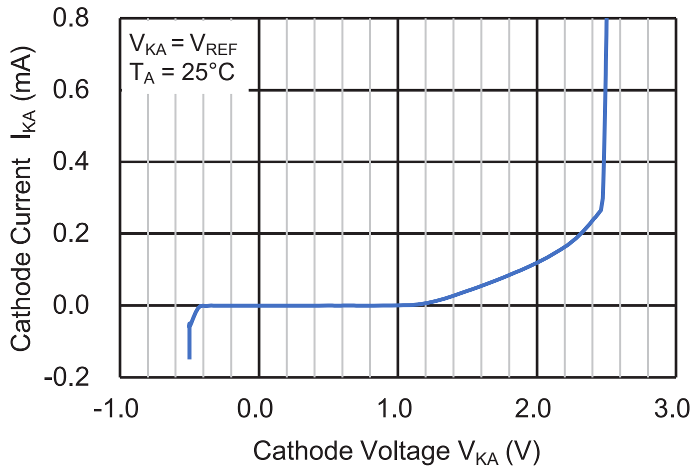
Reference Current



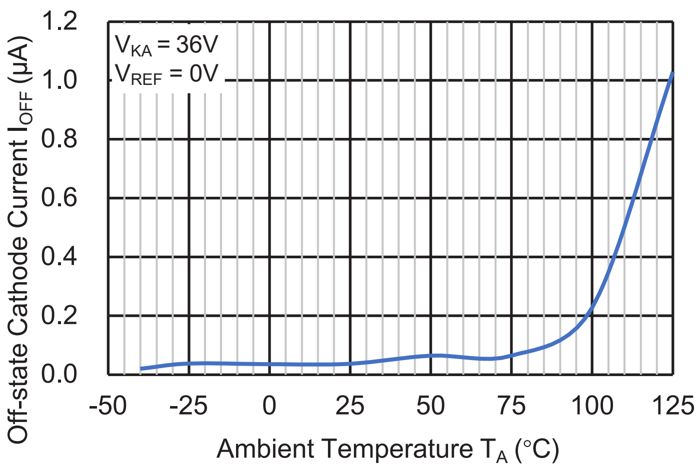
Cathode Current



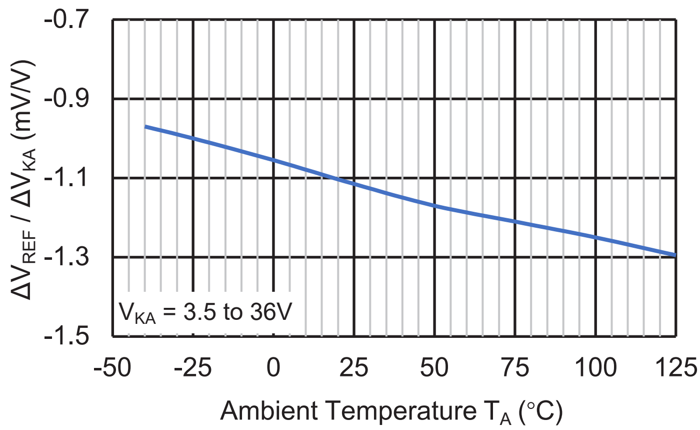
Cathode Current



Off-state Cathode Current



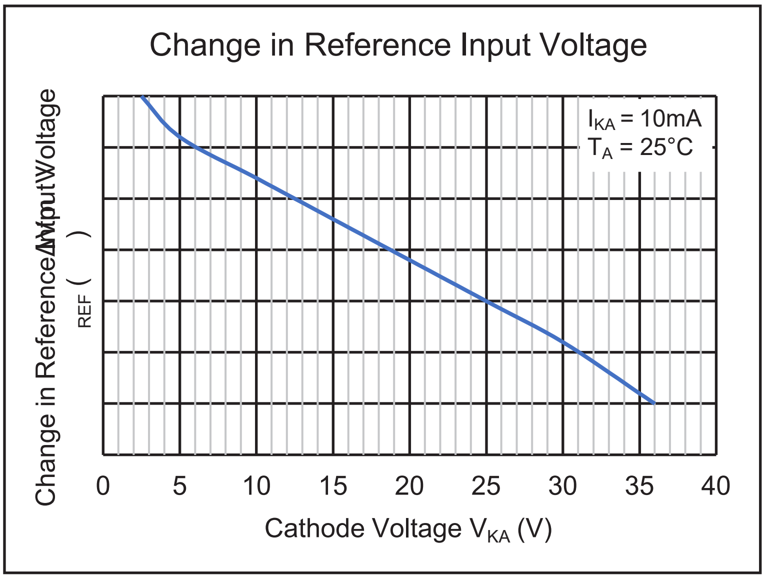
Ratio of Delta Reference Voltage to Delta Cathode Voltage

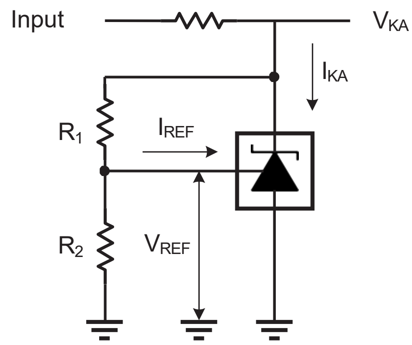


7 Specifications

7.6 Test Figures and Typical Characteristics (continued)

Change in Reference Input Voltage vs. Cathode Voltage

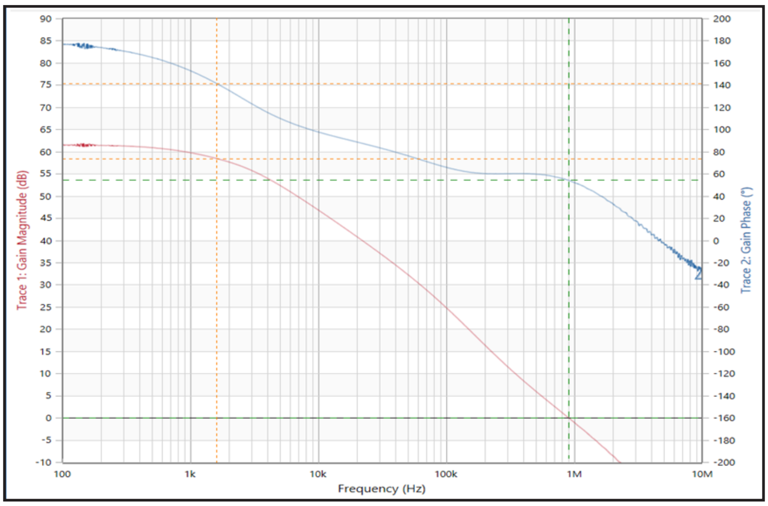




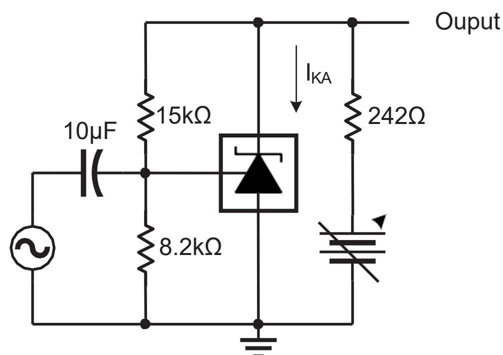
$$V_{KA} = V_{REF} \times (1 + \frac{R_1}{R_2}) + I_{REF} \times R_1$$

Test Figure. 2

Small Signal Voltage Gain vs. Frequency



T_A = 25°C, I_{KA} = 10mA

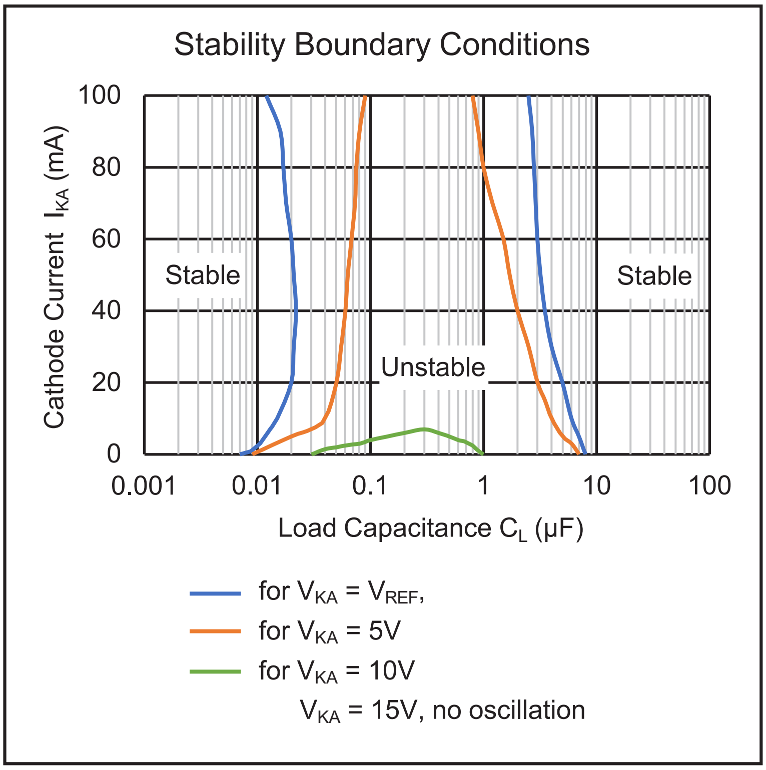


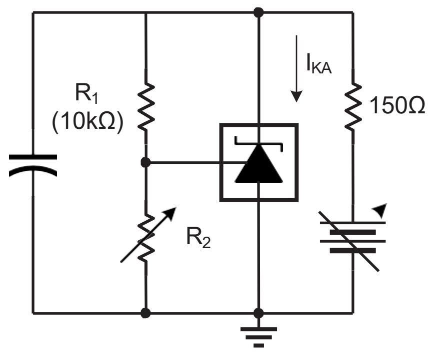
Test Figure. 4

7 Specifications

7.6 Test Figures and Typical Characteristics (continued)

Stability Boundary Conditions vs. Load Capacitance





Test Figure. 6

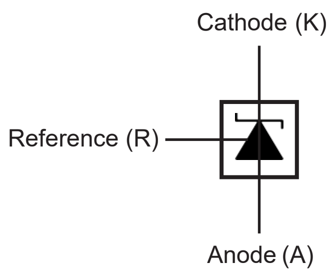
8 Detailed Description

8.1 Description

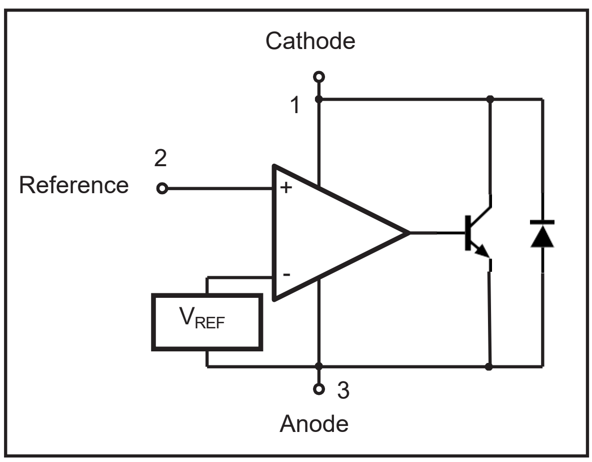
The VS431D / CD431D is an adjustable precision shunt voltage regulator. Its internal circuit module contains a precise voltage reference source and operational amplifier, which can support operation and adjustment within the cathode voltage range of V_{REF} to 36V, and has good temperature stability within the entire operating temperature range.

The VS431D / CD431D can be used with peripheral components as a single voltage reference, error amplifier, voltage clamp or comparator with integrated reference. The VS431D / CD431D has two reference voltage output tolerance levels to choose from: ± 0.4% and ± 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 VS431D / CD431D 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 VS431D / CD431D is shown in Test Figure 1.

External Components

The only external component requirement of the VS431D / CD431D 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 VS431D / CD431D 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 VS431D / CD431D 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 VS431D / CD431D, 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 VS431D / CD431D 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 VS431D / CD431D will have the characteristics shown in the *Representative Schematic Diagram*. This circuit configuration has very high gain, so this circuit configuration of the VS431D / CD431D is usually used as a comparator. When users try to monitor a certain level of a single signal, the integrated reference makes the VS431D / CD431D the first choice.

Closed Loop

When the cathode / output voltage or current of the VS431D / CD431D 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 VS431D / CD431D 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:

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

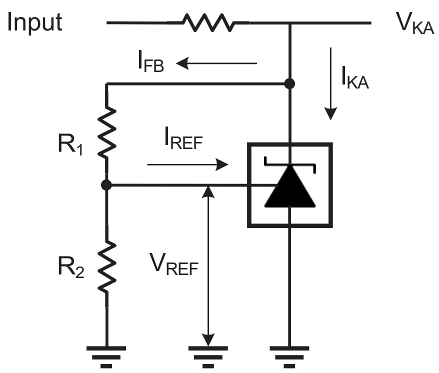


Figure 9-1. Common Anode Shunt Regulating Circuit

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:

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

3. Ratio of reference voltage change to cathode voltage change ΔV_{REF} / ΔV_{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}, ΔV_{REF} / ΔV_{KA} is affected by these parameters. When V_{KA} = V_{REF} and I_{KA} = 10mA, 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 0.7μA. The ΔV_{REF} / ΔV_{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 $V_{KA} \le 10$ V, then

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

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

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

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

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

9 Application Information and Implementation

9.1 Application Information (continued)

Setting the Shunt Voltage (continued)

After V_{REF} is obtained from the above two formulas, the resistance values of the two feedback resistors can be obtained, and the resistance values of R_1 and R_2 can be obtained from the following formula:

$$R_1 = \frac{V_{KA} - V_{REF}}{I_{R1}}$$

$$R_2 = \frac{V_{REF}}{I_{R1} - I_{REF}}$$

Note that R_2 has less current than R_1.

Boundary Stability Condition

As a shunt regulator, the VS431D / CD431D is designed with wide bandwidth and can ensure stability without external frequency compensation, which makes the VS431D / CD431D very suitable for application in control circuit and reference voltage generator without external capacitance.

In the application of reference voltage generator, adding an external capacitor between the cathode and anode (usually grounded) of the VS431D / CD431D may cause some problems in output stability. The external capacitor will produce an output pole and reduce the phase margin, which may destroy the stability of the output and make the output oscillate. Therefore, attention should be paid to the selection of external capacitance during circuit design. The capacitance value can be determined according to the *Stability Boundary Conditions* in the data sheet. The stability boundary conditions show the corresponding stability under different external capacitance and cathode current conditions when the VS431D / CD431D is used as a reference voltage generator (Test Figure. 6). The curve includes the stability of four series of V_{KA} voltage conditions: $V_{KA} = V_{REF}$, $V_{KA} = 5V$, $V_{KA} = 10V$, $V_{KA} = 15V$, other V_{KA} voltages can be interpolated between these four series visually. According to the intersection point of the stability curve under the condition of cathode current and V_{KA} voltage, the corresponding stability allowable external capacitance boundary value under this condition can be found. Using the capacitance in the internal range of the intersection (between two intersections) will cause device oscillation, while using the capacitance in the external range of the intersection (less than the relatively small intersection capacitance value, or greater than the relatively large intersection capacitance value) will not cause device oscillation.

However, the curve displayed in the *Stability Boundary Conditions* only represents the typical device characteristics with an application temperature of 25°C, which means that the actual boundary stability of a randomly selected the VS431D / CD431D sample may not be consistent with the curve shown, and the effect of temperature on stability must also be taken into account. Therefore, it is necessary to provide sufficient phase margin for all devices in circuit design to prevent transient oscillation or ringing. The recommended capacitance is less than 1/10 of the left boundary or more than 10 times of the right boundary.