

VS431L Voltage References

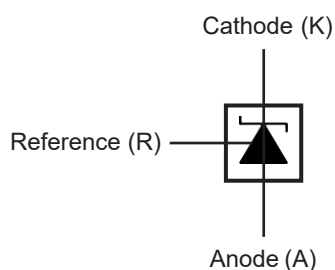
1 Introduction

The VS431L is three-terminal adjustable shunt regulators, with specified thermal stability over applicable automotive, commercial, and industrial temperature ranges. The output voltage can be set to any value between V_{REF} (approximately 2.5V) and 36V, with two external resistors. These devices have a typical output impedance of 0.05Ω. Active output circuitry provides a very sharp turn-on characteristic, making these devices excellent replacements for Zener diodes in many applications, such as onboard regulation, adjustable power supplies, and switching power supplies.

The VS431L has >20x improvement cathode current range over its VS431 predecessor. It also is stable with a wider range of load capacitance types and values. The VS431L is offered in two grades, with initial tolerances (at 25°C) of 0.4%, 0.8%, for the A and B grade, respectively. In addition, low output drift vs temperature ensures consistent voltage regulation over the entire temperature range.

2 Available Packages

PART NUMBER	PACKAGE
VS431L	SOT-23
	SOT-89-3L
	TO-92



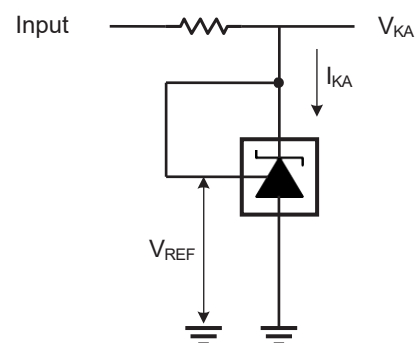
Symbol

3 Features

- Adjustable Output Voltage: V_{REF} to 36 V
- Very-Low Operating Current:
 $I_{KA(min)} = 35\mu A$ (Max)
 $I_{REF} = 300nA$ (Max)
- Reference Voltage Tolerances at 25°C:
Available in $\pm 0.4\%$ or $\pm 0.8\%$
- Internally Compensated for Stability:
Stable With No Capacitive Load
- Low Dynamic Output Resistance:
0.05Ω (Typ.)
- Extended Cathode Current Range:
35μA to 100mA
- Low output noise
- Wide temperature range -40 to 125°C

4 Applications

- Secondary Side Regulation in Flyback SMPSs
- Industrial, Computing, Consumer, and Portables
- Adjustable Voltage and Current Referencing
- Power Management
- Power Isolation
- 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

($T_A = 25^{\circ}\text{C}$, unless otherwise specified)⁽¹⁾

CHARACTERISTIC	SYMBOL	VALUE	UNIT
Cathode voltage ⁽²⁾	V_{KA}	40	V
Cathode current range (continuous)	I_{KA}	-100 ~ +100	mA
Reference input current range	I_{REF}	10	mA
Maximum junction temperature	$T_{J\text{ Max}}$	150	$^{\circ}\text{C}$
Storage temperature	T_{stg}	-65 ~ 150	$^{\circ}\text{C}$

(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}	0.035	-	100	mA
Operating ambient temperature	T_A	-40	-	125	$^{\circ}\text{C}$

7.3 ESD Ratings

ESD RATINGS		SYMBOL	VALUE	UNIT
Electrostatic discharge ⁽³⁾	Human body model	$V_{\text{ESD-HBM}}$	6000	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 1.5k Ω .

7 Specifications

7.4 Thermal Information

THERMAL METRIC ⁽⁴⁾	SYMBOL	VS431L			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 in² FR-4 board covered with 2 ounces of copper.

7.5 Electrical Characteristics

VS431L ($T_A = 25^\circ\text{C}$, unless otherwise specified)

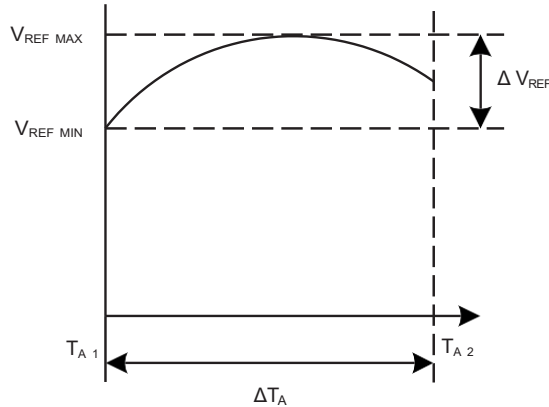
CHARACTERISTIC	SYMBOL	TEST CONDITIONS			MIN.	TYP. ⁽⁵⁾	MAX.	UNIT
Reference voltage	V_{REF}	Figure. 1	$V_{KA} = V_{REF}$, $I_{KA} = 10\text{mA}$	$\pm 0.4\%$ grade	2.490	2.500	2.510	V
				$\pm 0.8\%$ grade	2.480		2.520	
Deviation of reference voltage over full temperature range ⁽⁶⁾	ΔV_{REF}	Figure. 1	$V_{KA} = V_{REF}$, $I_{KA} = 10\text{mA}$	$T_A = 0$ to 70°C	-	5	-	mV
				$T_A = -40$ to 85°C	-	10	-	
				$T_A = -40$ to 125°C	-	20	-	
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 10V	-	-0.4	-2.0	
Reference current	I_{REF}	Figure. 2	$I_{KA} = 10\text{mA}$, $R_1 = 10\text{k}\Omega$, $R_2 = \infty$		-	0.03	0.3	μA
Deviation of reference current over full temperature range ⁽⁷⁾	ΔI_{REF}	Figure. 2	$I_{KA} = 10\text{mA}$, $R_1 = 10\text{k}\Omega$, $R_2 = \infty$, $T_A = -40$ to 125°C		-	0.03	0.1	μA
Minimum cathode current for regulation	$I_{KA MIN}$	Figure. 1	$V_{KA} = V_{REF}$		-	20	35	μA
Off-state cathode current	$I_{KA OFF}$	Figure. 3	$V_{KA} = 36\text{V}$, $V_{REF} = 0\text{V}$		-	0.05	1.00	μA
Dynamic impedance ⁽⁸⁾	Z_{KA}	Figure. 1	$V_{KA} = V_{REF}$, $I_{KA} = 1$ to 100mA , $f \leq 1.0\text{kHz}$		-	0.05	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:

$$\alpha V_{REF} (\frac{\%}{^{\circ}C}) = \frac{[V_{REF}(at\ 25^{\circ}C)] \times 10^6}{[V_{REF}(at\ 25^{\circ}C)] \times 10^6} = \frac{[V_{REF}(at\ 25^{\circ}C)] \times 10^6}{[V_{REF}(at\ 25^{\circ}C)] \times 10^6}$$

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

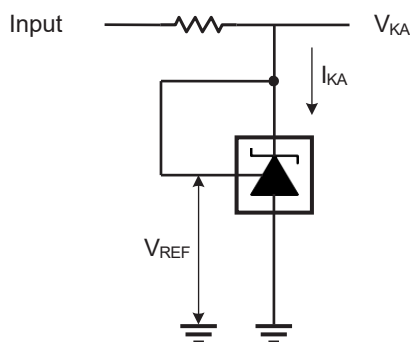
(7) The dynamic impedance is defined as:

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

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

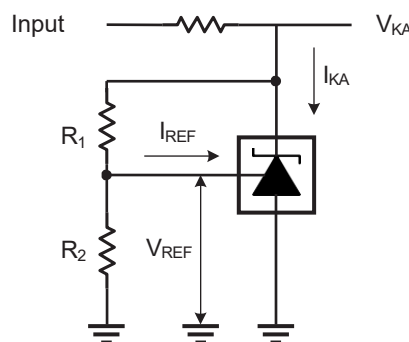
$$|Z'| = \frac{\Delta V}{\Delta I} \approx |Z| \times (1 + \frac{R_1}{R_2})$$

7.6 Test Figures and Typical Characteristics



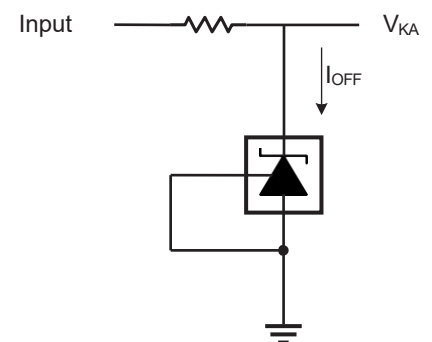
Test Figure. 1

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



Test Figure. 2

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



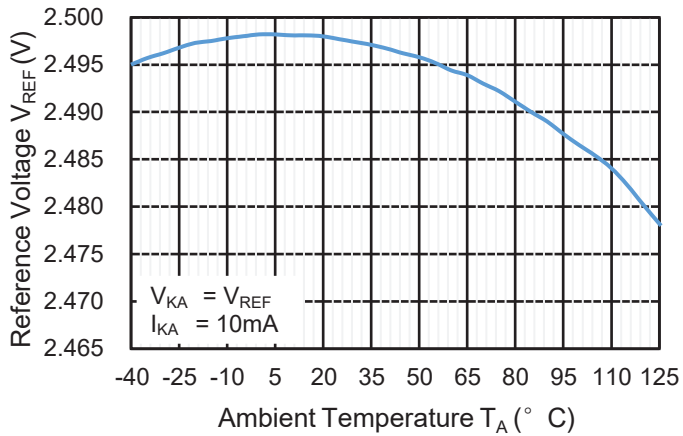
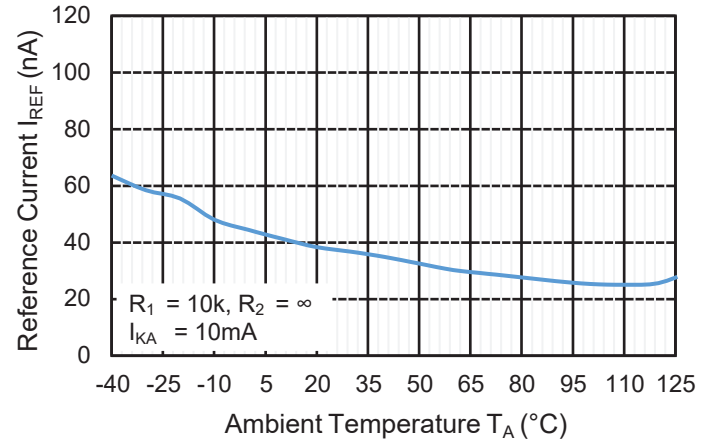
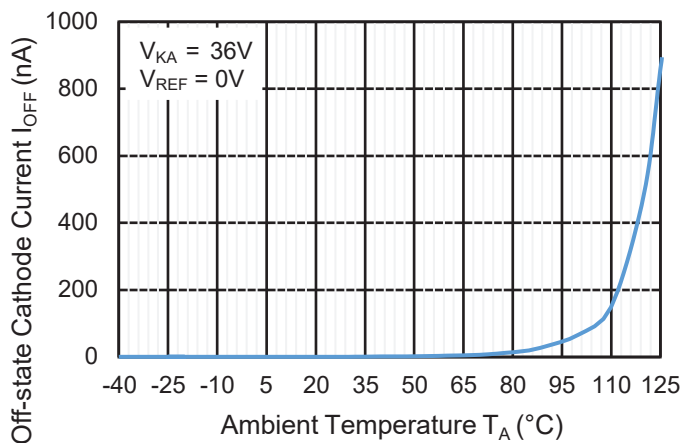
Test Figure. 3

For I_{OFF}

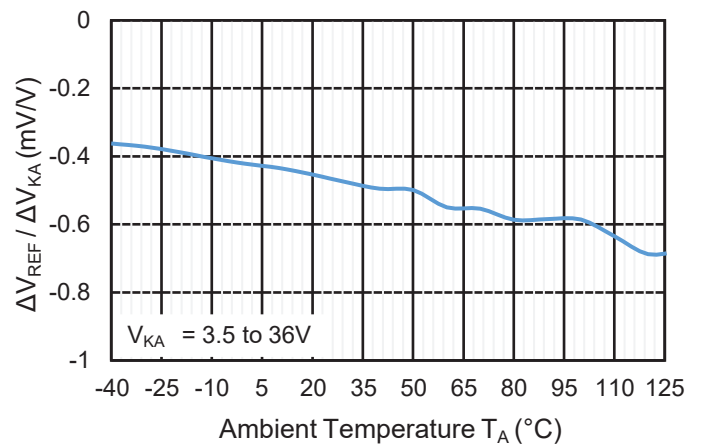
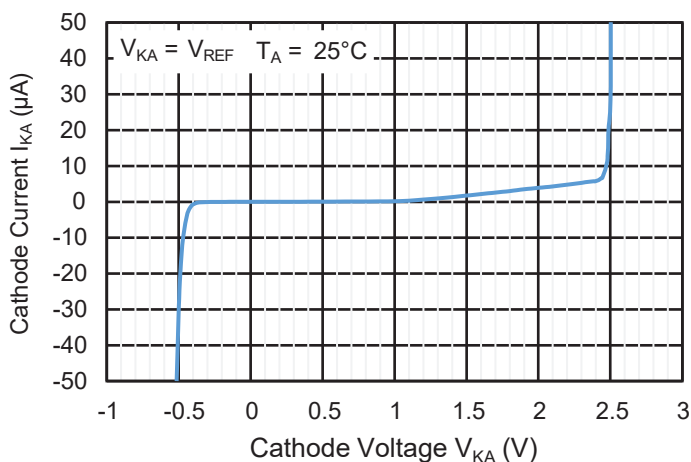
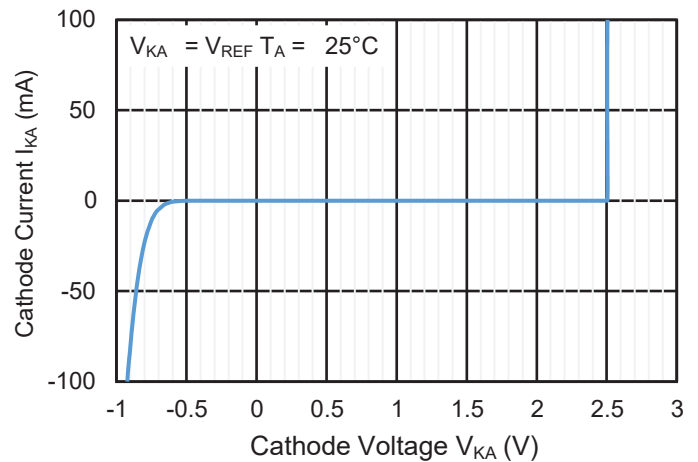
$$V_{KA} = V_{REF} \times (1 + \frac{R_1}{R_2}) + I_{REF} \times R_1$$

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


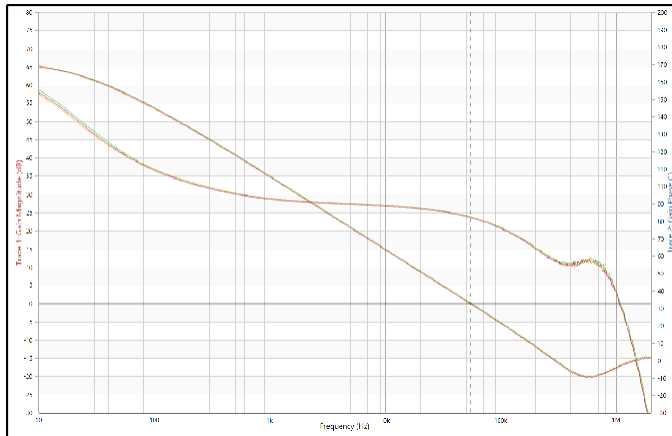
Ratio of Delta Reference Voltage to Delta Cathode Voltage


Cathode Current vs. V_{KA}

Cathode Current vs. V_{KA}


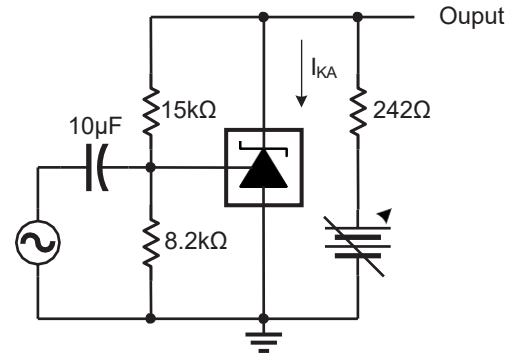
7 Specifications

7.6 Test Figures and Typical Characteristics (continued)

Small Signal Voltage Gain



$T_A = 25^\circ\text{C}$, $I_{KA} = 10\text{mA}$



Test Figure. 4

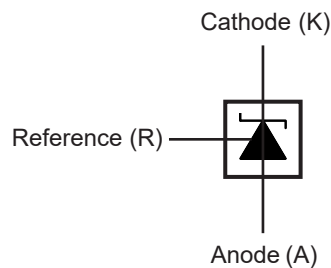
8 Detailed Description

8.1 Description

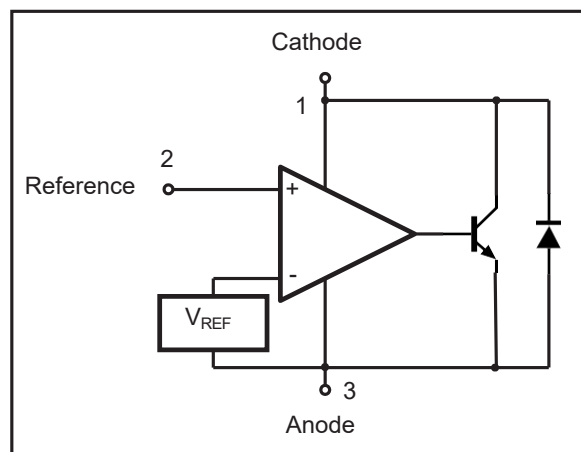
The VS431L is an adjustable precision shunt voltage regulator. Its internal circuit module contains a precise voltage reference source and operational amplifier, which can support operation and adjustment within the cathode voltage range of V_{REF} to 36V, and has good temperature stability within the entire operating temperature range.

The VS431L can be used with peripheral components as a single voltage reference, error amplifier, voltage clamp or comparator with integrated reference. The VS431L 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 VS431L 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 VS431L is shown in Test Figure 1.

External Components

The only external component requirement of the VS431L 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 VS431L 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 VS431L 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 VS431L, 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 VS431L 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 VS431L will have the characteristics shown in the *Representative Schematic Diagram*. This circuit configuration has very high gain, so this circuit configuration of the VS431L is usually used as a comparator. When users try to monitor a certain level of a single signal, the integrated reference makes the VS431L the first choice.

Closed Loop

When the cathode / output voltage or current of the VS431L 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 VS431L 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:

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

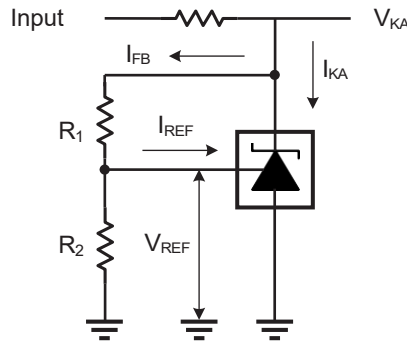


Figure 9-1. Common Anode Shunt Regulating Circuit

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 0.03 μA . The $\Delta V_{REF} / \Delta V_{KA}$ at different rates: it is -1.0mV/V from V_{REF} to 10V then -0.4mV/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

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

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:

$$R_1 = \frac{V_{KA} - V_{REF}}{I}$$

$$R_2 = \frac{V_{KA}}{I}$$

Note that R_2 has less current than R_1 .

Boundary Stability Condition

As a shunt regulator, the VS431L is designed with wide bandwidth and can ensure stability without external frequency compensation, which makes the VS431L 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 VS431L 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 VS431L is used as a reference voltage generator (Test Figure. 6). The curve includes the stability of four series of V_{KA} voltage conditions: $V_{KA} = V_{REF}$, $V_{KA} = 2.5V$, $V_{KA} = 5V$, 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 VS431L 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.