

## Features

- Small Voltage Offset:  $\pm 0.5$  mV
- Wide Common-Mode Voltage:  $-0.1$  V to 70 V
- Wide CMRR through Common Voltage: 100 dB
- Supply Voltage: 3.0 V to 18 V
- Accuracy and Zero-Drift Performance
  - $\pm 0.5\%$  Gain Error (Max,  $-40^{\circ}\text{C} \sim 125^{\circ}\text{C}$ )
  - $0.6\mu\text{V}/^{\circ}\text{C}$  Offset Drift (Max,  $-40^{\circ}\text{C} \sim 125^{\circ}\text{C}$ )
  - $5\text{ppm}/^{\circ}\text{C}$  Gain Drift (Max,  $-40^{\circ}\text{C} \sim 125^{\circ}\text{C}$ )
- Three Gain Options for Voltage Output
  - TPA2296T: 20 V/V, 50 V/V, 100 V/V,
- Qualified for Automotive Applications with AEC-Q100 Reliability Test:
  - TPA2296T-S5TR-S

## Applications

- Current Sensing (High-Side/Low-Side)
- Battery Chargers & Power Management
- Automotive & Industrial Control
- Base Stations & Telecom Equipment

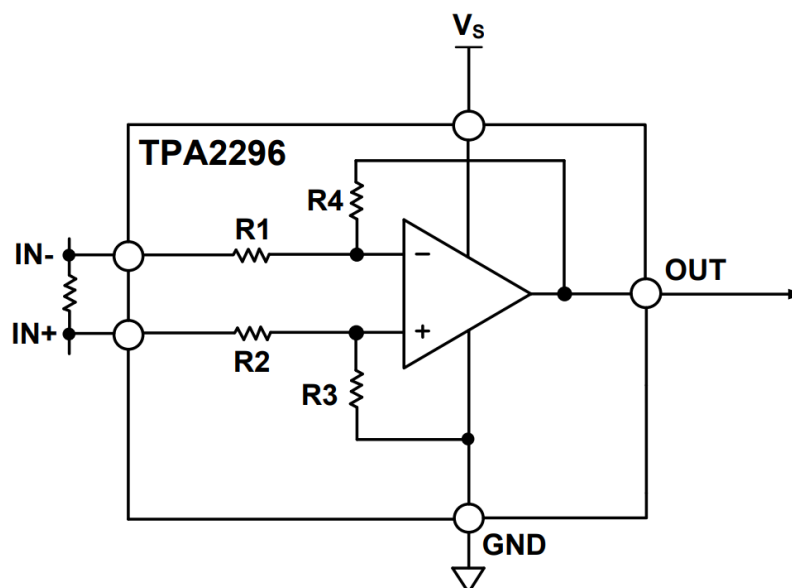
## Description

The TPA2296 family is high-voltage, high-side current sense amplifier with voltage output. The TPA2296 can sense drops across shunts at common-mode voltages from  $-0.1$  V up to 70 V. The TPA2296 is available with three output voltage scales: 20 V/V, 50 V/V, and 100 V/V, with up to 0.5-MHz bandwidth.

The TPA2296 operates from a single 3.0-V to 18-V supply and offers breakthrough performance throughout the  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  temperature range. It features a zero-drift core, which leads to an offset drift of  $0.6\mu\text{V}/^{\circ}\text{C}$  throughout the operating temperature range and the common-mode voltage range.

The TPA2296 is offered in 6-pin and 5-pin SOT23 packages.

## Functional Block Diagram



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## Revision History

Date	Revision	Notes
2020-08-17	Rev.A.0	Released version
2020-10-17	Rev.A.1	Added Vos test condition
2021-10-16	Rev.A.2	Updated figure of step response
2022-05-01	Rev.A.3	Updated order information and package outline dimensions
2023-11-23	Rev.A.4	Updated part number status: TPA2296F-S6TR-S
2024-04-17	Rev.A.5	The following updates are all about the new datasheet formats or typo, the actual product remains unchanged. Updated to new format of datasheet. Updated tape and reel information. Added part number: TPA2296T-S5TR-S.

Pin Configuration and Functions

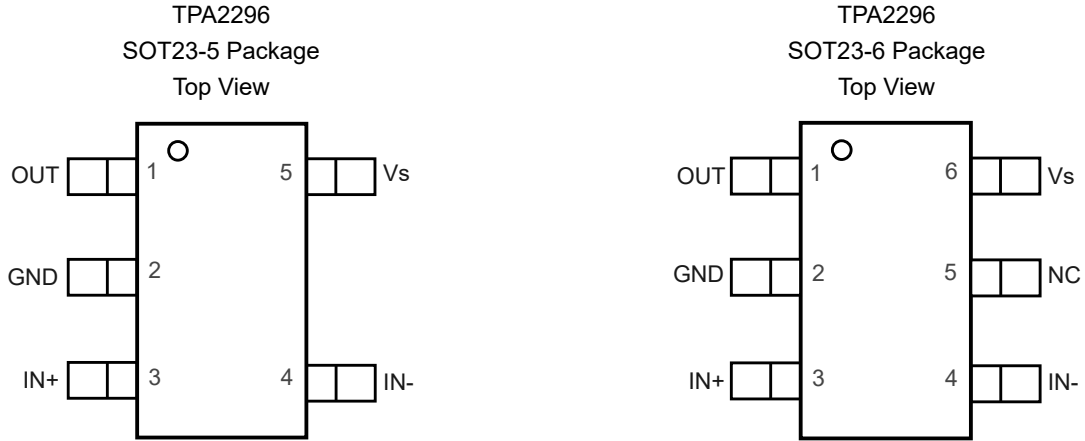


Table 1. Pin Functions: TPA2296

Pin		Name	Description
SOT23-5	SOT23-6		
4	4	IN-	Negative Input
2	2	GND	Ground
1	1	OUT	Output
5	6	Vs	Power supply
3	3	IN+	Positive Input.
	5	NC	No Connect

## High-Voltage, High-Side Current Sense Amplifier

### Specifications

#### Absolute Maximum Ratings <sup>(1)</sup>

Parameter	Min	Max	Unit
Supply Voltage		40	V
Input Common Voltage (Continuous)	-0.3	75	V
Input Common Voltage (Survival)	-0.3	80	V
Input Current: IN+, IN- <sup>(2)</sup>	-10	10	mA
Operating Temperature Range	-40	125	°C
Maximum Working Junction Temperature		150	°C
Storage Temperature Range	-65	150	°C

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

(2) The inputs are protected by ESD protection diodes to the power supply.

#### ESD, Electrostatic Discharge Protection

Symbol	Parameter	Condition	Minimum Level	Unit
HBM	Human Body Model ESD	ANSI/ESDA/JEDEC JS-001	2	kV
CDM	Charged Device Model ESD	ANSI/ESDA/JEDEC JS-002	1.5	kV

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

#### Thermal Information

Package Type	$\theta_{JA}$	$\theta_{JC}$	Unit
SOT23-6	250	81	°C/W
SOT23-5	250	81	°C/W

**High-Voltage, High-Side Current Sense Amplifier**
**Electrical Characteristics**

The specifications are at  $T_A = 25^\circ\text{C}$ ,  $V_{\text{SENSE}} = V_{\text{IN+}} - V_{\text{IN-}} = 1\text{mV}$ ,  $V_S = 12\text{V}$ ,  $V_{\text{IN+}} = 70\text{V}$ , unless otherwise noted

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
<b>Input</b>						
$V_{\text{OS}}$	Input Offset Voltage	$-40^\circ\text{C}$ to $125^\circ\text{C}$ , $V_{\text{IN-}} = 0\text{V}$	-500	$\pm 50$	500	$\mu\text{V}$
$V_{\text{OS TC}}^{(1)}$	Input Offset Voltage Drift	$-40^\circ\text{C}$ to $125^\circ\text{C}$			0.6	$\mu\text{V}/^\circ\text{C}$
$V_{\text{CM}}$	Common-mode Input Range	$-40^\circ\text{C}$ to $125^\circ\text{C}$	-0.1		70	V
CMRR	Common Mode Rejection Ratio	$-40^\circ\text{C}$ to $125^\circ\text{C}$ , $-0.3\text{V} < V_{\text{IN+}} < 70\text{V}$ , $G = 20\text{V/V}$	90	110		dB
		$-40^\circ\text{C}$ to $125^\circ\text{C}$ , $-0.3\text{V} < V_{\text{IN+}} < 70\text{V}$ , $G = 50\text{V/V}$	95	115		dB
		$-40^\circ\text{C}$ to $125^\circ\text{C}$ , $-0.3\text{V} < V_{\text{IN+}} < 70\text{V}$ , $G = 100\text{V/V}$	100	120		dB
$I_B$	Input Bias Current	$-40^\circ\text{C}$ to $125^\circ\text{C}$ , TPA2296F-S6TR-S, TPA2296T-S5TR-S			250	$\mu\text{A}$
		$-40^\circ\text{C}$ to $125^\circ\text{C}$ , All other part number			210	$\mu\text{A}$
PSRR	Power Supply Rejection Ratio	$-40^\circ\text{C}$ to $125^\circ\text{C}$		110		dB
<b>NOISE , Referred to Input)</b>						
$e_n$	Input Voltage Noise Density	$f = 1\text{kHz}$		55		$\text{nV}/\sqrt{\text{Hz}}$
<b>Output</b>						
G	Gain	TPA2296T, $-40^\circ\text{C}$ to $125^\circ\text{C}$	19.9	20	20.1	V/V
		TPA2296F, $-40^\circ\text{C}$ to $125^\circ\text{C}$	49.75	50	50.25	V/V
		TPA2296H, $-40^\circ\text{C}$ to $125^\circ\text{C}$	99.5	100	100.5	V/V
GE	Gain Error	$-40^\circ\text{C}$ to $125^\circ\text{C}$	-0.5	$\pm 0.1$	0.5	%
GE TC	Gain Error Vs Temperature	$-40^\circ\text{C}$ to $125^\circ\text{C}$		3	5	$\text{ppm}/^\circ\text{C}$
$C_{\text{LOAD}}$	Maxim Capacitive load	No Oscillation		0.5		nF
$V_{\text{OH}}$	Output Swing from Supply Rail	$-40^\circ\text{C}$ to $125^\circ\text{C}$ , Source 1.2 mA		0.15	0.31	V
$V_{\text{OL}}$	Output Swing from GND	$-40^\circ\text{C}$ to $125^\circ\text{C}$		0.01	0.02	V
<b>Frequency Response</b>						
BW	Bandwidth	TPA2296T, $G = 20$		400		kHz
		TPA2296F, $G = 50$		300		kHz
		TPA2296H, $G = 100$		200		kHz
SR	Slew Rate	$V_{\text{SENSE}} = V_{\text{IN+}} - V_{\text{IN-}} = 500\text{mV}$		20		$\text{V}/\mu\text{s}$
<b>Power Supply</b>						
$V_S$	Supply Voltage		3.0		18	V
$I_Q$	Quiescent Current	$-40^\circ\text{C}$ to $125^\circ\text{C}$		600	1000	$\mu\text{A}$
<b>Temperature Range</b>						

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**High-Voltage, High-Side Current Sense Amplifier**

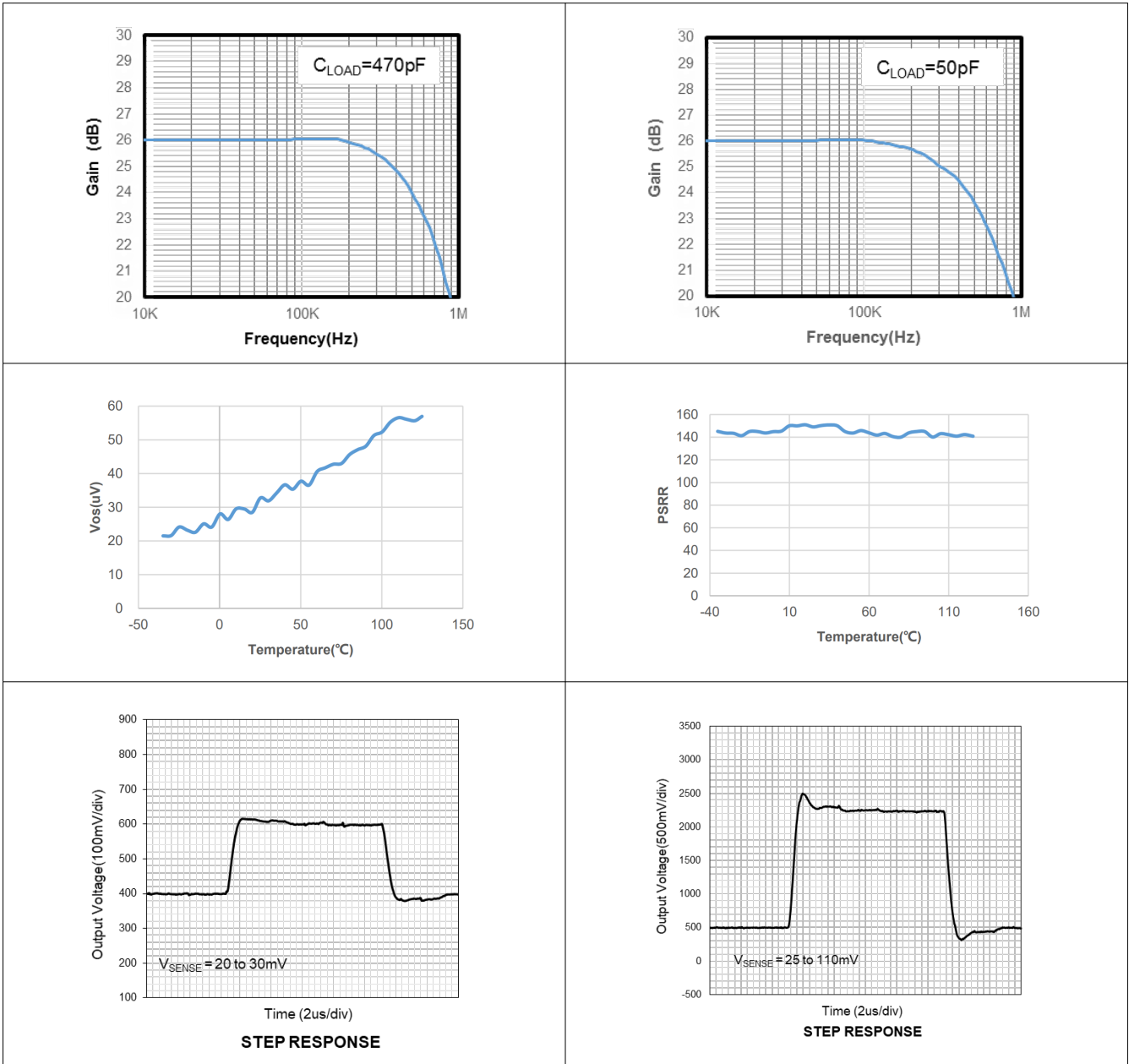
Symbol	Parameter	Conditions	Min	Typ	Max	Unit
	Specified Range		-40		125	°C

- (1) Maxim specification is calculated with limited sample quantity in the laboratory.  
(2) RTI = referred to input.

# High-Voltage, High-Side Current Sense Amplifier

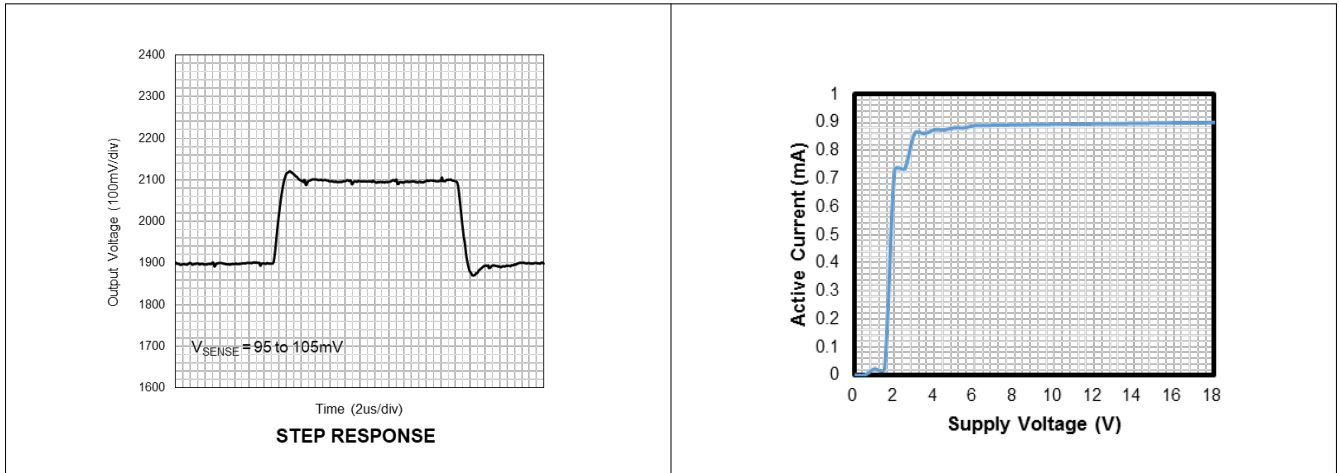
## Typical Performance Characteristics

All test conditions:  $T_A = 25^\circ\text{C}$ ,  $V_{\text{SENSE}} = V_{\text{IN}+} - V_{\text{IN}-} = 1\text{ mV}$ ,  $V_s = 12\text{ V}$ ,  $V_{\text{IN}+} = 24\text{ V}$ , unless otherwise noted.





## Typical Performance Characteristics (continued)



## Detailed Description

### Overview

The TPA2296 family is high-voltage, high-side current sense amplifier with voltage output. The TPA2296 can sense drops across shunts at common-mode voltages from  $-0.1\text{ V}$  up to  $70\text{ V}$ . The TPA2296 is available with three output voltage scales:  $20\text{ V/V}$ ,  $50\text{ V/V}$ , and  $100\text{ V/V}$ , with up to  $0.5\text{ MHz}$  bandwidth.

## Application and Implementation

### Note

Information in the following application sections is not part of the 3PEAK's component specification and 3PEAK does not warrant its accuracy or completeness. 3PEAK's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

## Application Information

### Selecting $R_{\text{sense}}$

The zero-drift offset performance of the TPA2296 offers several benefits. Most often, the primary advantage of the low offset characteristic enables lower full-scale drops across the  $R_{\text{sense}}$ . For example, non-zero-drift current sense monitors typically require a full-scale range of 100 mV. The TPA2296 family gives equivalent accuracy at a full-scale range on the order of 10 mV. This accuracy reduces  $R_{\text{sense}}$  dissipation by an order of magnitude with many additional benefits.

Alternatively, some applications must measure current over a wide dynamic range that can take advantage of the low offset on the low end of the measurement. Most often, these applications can use the lower gains of the TPA2296 to accommodate larger  $R_{\text{sense}}$  drops on the upper end of the scale.

### Recommended Component Values

Ideally, the maximum load current develops the full-scale sense voltage across the current-sense resistor. Choose the gain needed to match the maximum output voltage required for the application:

$$V_{\text{out}} = V_{\text{sense}} \times A_V \quad (1)$$

Where  $V_{\text{sense}}$  is the full-scale sense voltage, and  $A_V$  is the gain of the TPA2296.

In applications of monitoring a high current, ensure that  $R_{\text{sense}}$  can dissipate its own  $I^2R$  power loss. If the resistor's power dissipation exceeds the nominal value, its value may drift, or it may fail altogether. The TPA2296 senses a wide variety of currents with different sense-resistor values.

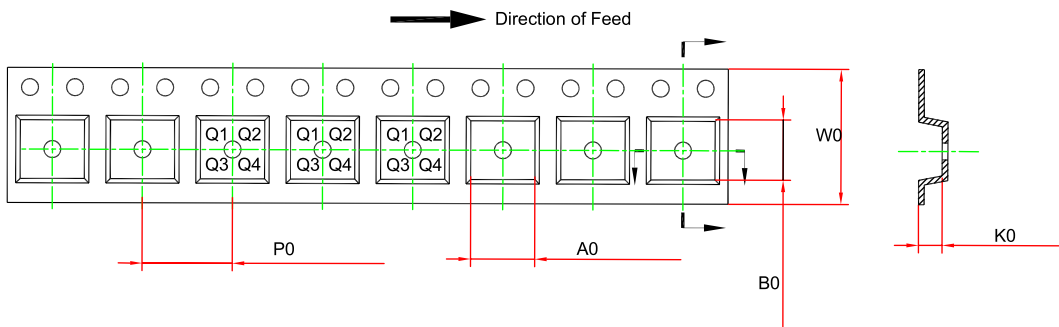
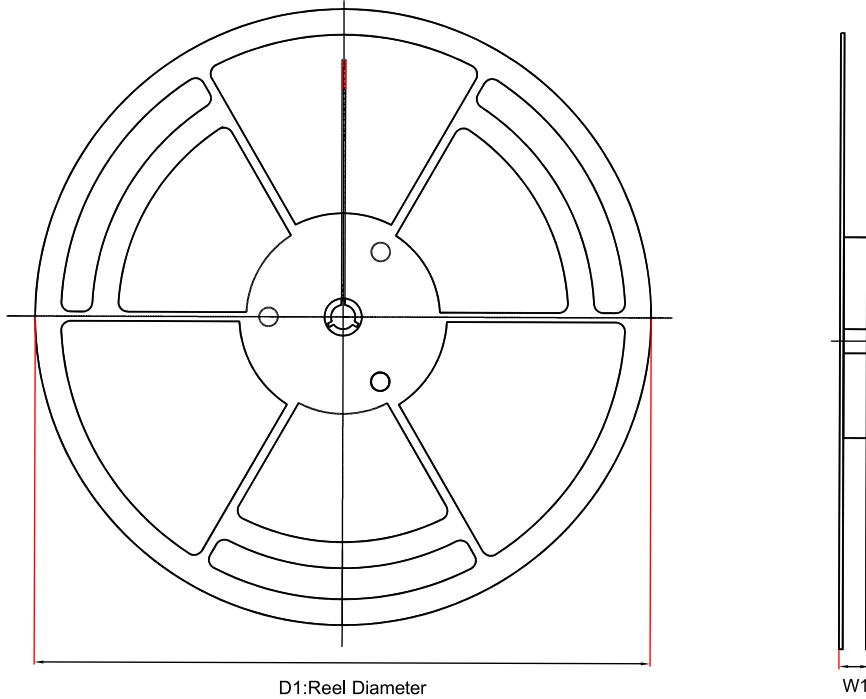
### Power Supply Recommendation

The input circuitry of the TPA2296 can accurately measure beyond its power-supply voltage,  $V_s$ . For example, the  $V_s$  power supply can be 5 V, whereas the load power-supply voltage can be as high as 70 V. However, the output voltage range of the OUT pin is limited by the voltages on the power-supply pin.

### Layout: Kelvin Connection

A typical routing of Kelvin-sensed traces to the inputs of the TPA2296 is needed in the PCB Layout. The Kelvin-sense traces should be as close as possible to the current-sense resistor's solder contact pads. Any additional high-current carrying impedance can cause significant measurement errors because the current resistor has a very low value.

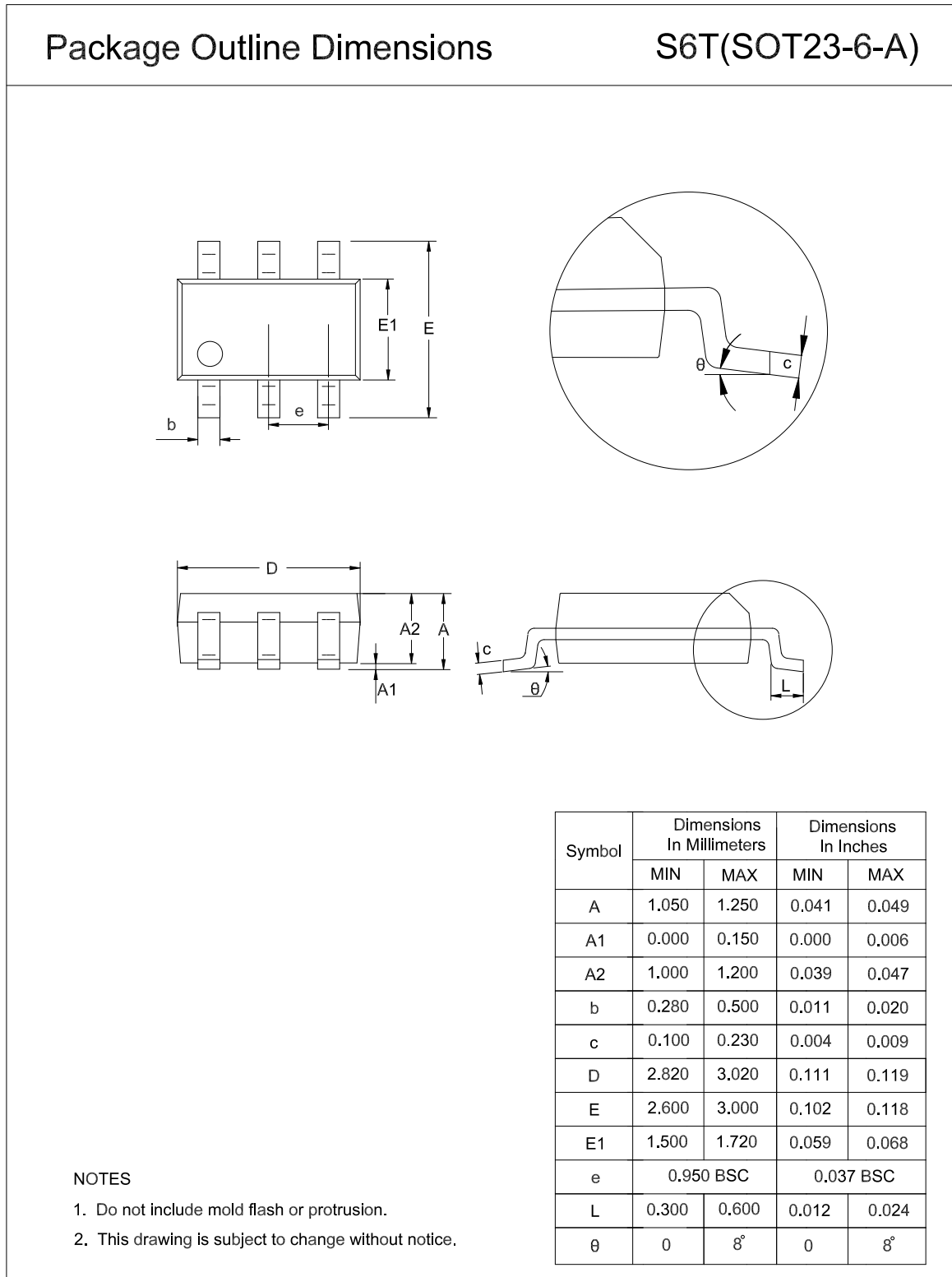
Tape and Reel Information



Order Number	Package	D1 (mm)	W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	W0 (mm)	Pin1 Quadrant
TPA2296T-S5TR	SOT23-5	180.0	12.0	3.3	3.25	1.4	4.0	8.0	Q3
TPA2296T-S5TR-S	SOT23-5	180.0	12.0	3.3	3.25	1.4	4.0	8.0	Q3
TPA2296F-S6TR-S	SOT23-6	180.0	12.0	3.3	3.2	1.4	4.0	8.0	Q3
TPA2296H-S5TR-S	SOT23-5	180.0	12.0	3.3	3.25	1.4	4.0	8.0	Q3
TPA2296H-S6TR-S	SOT23-6	180.0	12.0	3.3	3.2	1.4	4.0	8.0	Q3

Package Outline Dimensions

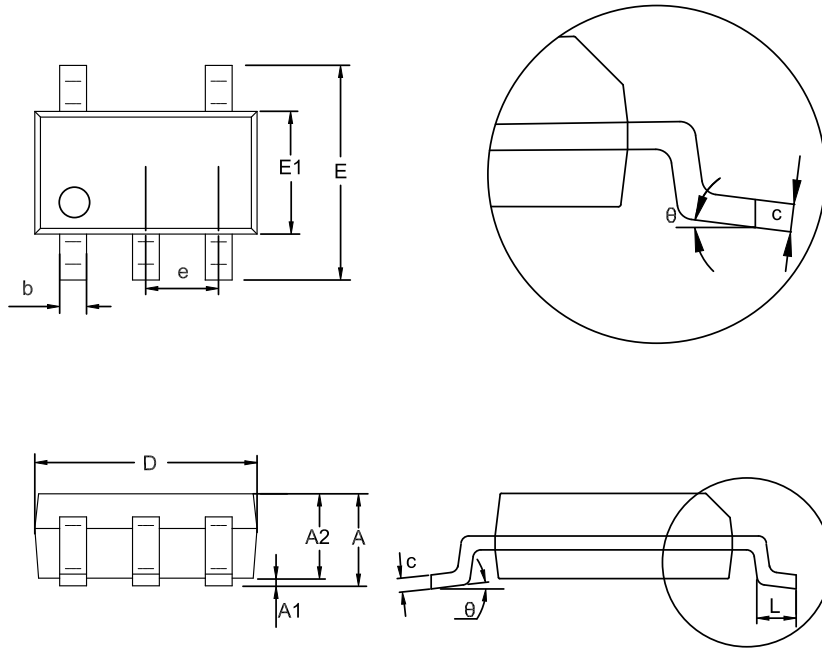
SOT23-6



SOT23-5

Package Outline Dimensions

S5T(SOT23-5-A)



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	1.050	1.250	0.041	0.049
A1	0.000	0.150	0.000	0.006
A2	1.000	1.200	0.039	0.047
b	0.280	0.500	0.011	0.020
c	0.100	0.230	0.004	0.009
D	2.820	3.020	0.111	0.119
E	2.600	3.000	0.102	0.118
E1	1.500	1.720	0.059	0.068
e	0.950 BSC		0.037 BSC	
L	0.300	0.600	0.012	0.024
theta	0	8°	0	8°

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

## Order Information

Order Number	Gain	Package	Marking	MSL	Transport Media, Quantity	Eco Plan
TPA2296T-S5TR	20	SOT23-5	A6T	3	Tape and Reel, 3,000	Green
TPA2296T-S5TR-S <sup>(1)</sup>	20	SOT23-5	A6T	3	Tape and Reel, 3,000	Green
TPA2296F-S6TR-S	50	SOT23-6	C6F	3	Tape and Reel, 3,000	Green
TPA2296H-S5TR-S	100	SOT23-5	A6H	3	Tape and Reel, 3,000	Green
TPA2296H-S6TR-S	100	SOT23-6	C6H	3	Tape and Reel, 3,000	Green

(1) Qualified for automotive applications with aec-q100 reliability test.

(2) **Green:** 3PEAK defines "Green" to mean RoHS compatible and free of halogen substances.

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