

## High side current sense amplifier

Target Specification

### Features

- Independent supply and input common-mode voltages
- Wide common-mode operating range: 2.8 to 30V
- Wide common-mode surviving range: -0.3 to 60V (load-dump)
- Wide supply voltage range: 4 to 28V
- Low current consumption:  $I_{CC}$  max = 300 $\mu$ A
- Internally fixed gain: 20V/V, 50V/V or 100V/V
- Buffered output

### Applications

- Battery chargers
- Automotive current monitoring
- Notebook computers
- DC motor control
- Precision current sources

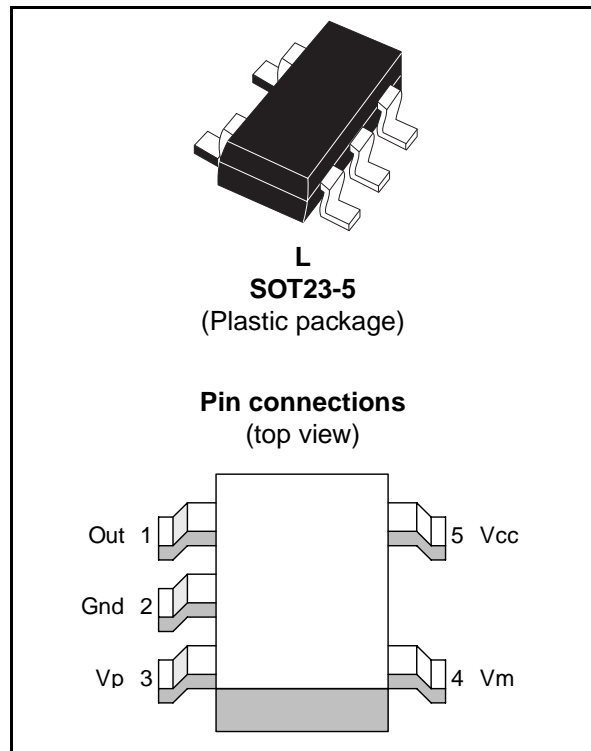
### Description

The TSC101 measures a small differential voltage on a high-side shunt resistor and translates it into a ground-referenced output voltage. The gain is internally fixed.

Wide input common-mode voltage range, low quiescent current, and tiny SOT23 packaging enable use in a wide variety of applications.

Input common-mode and power supply voltages are independent. Common-mode voltage can range from 2.8V to 30V in operating conditions and up to 60V in absolute maximum ratings.

Current consumption lower than 300 $\mu$ A and wide supply voltage range allow to connect the power supply to either side of the current measurement shunt with minimal error.



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# 1 Application schematic and pin description

The TSC101 high-side current-sense amplifier features a 2.8V to 30V input common-mode range that is independent of supply voltage. The main advantage of this feature is to allow high-side current sensing at voltages much greater than the supply voltage ( $V_{CC}$ ).

**Figure 1. Application schematic**

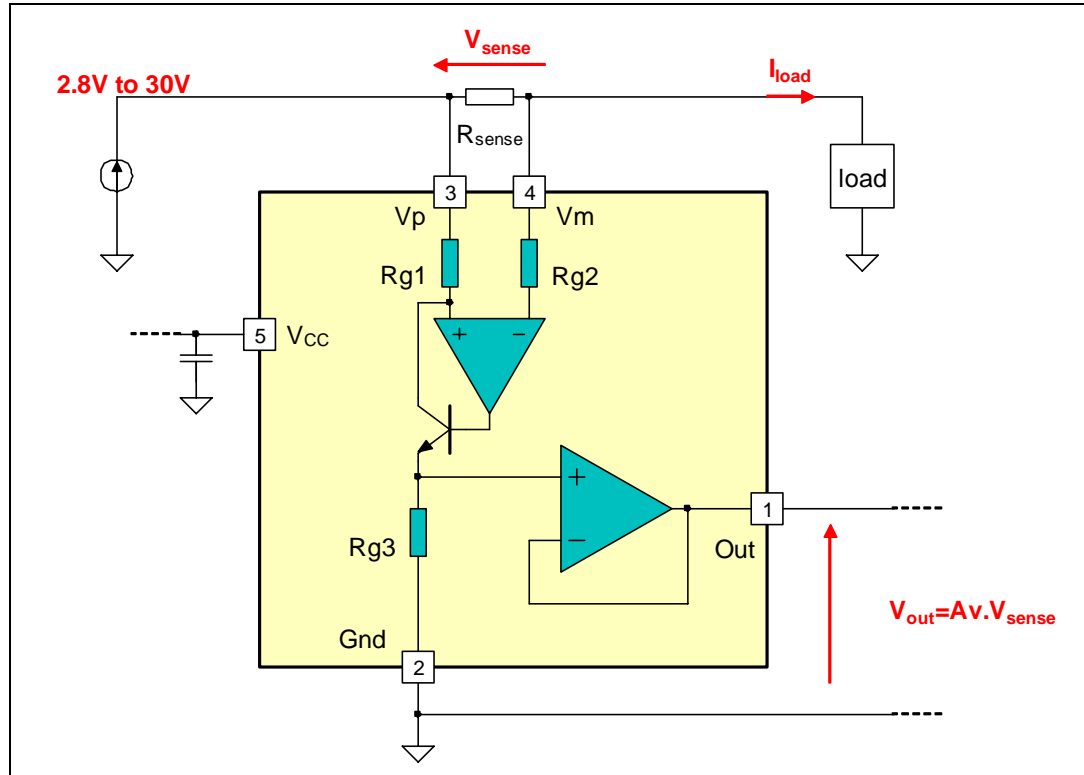


Table 1 below describes the function of each pin. Their position is shown in the illustration on the cover page and in Figure 1 above.

**Table 1. Pin description**

Symbol	Type	Function
Out	Analog output	The OUT voltage is proportional to the magnitude of the sense voltage $V_p - V_m$ .
Gnd	Power supply	Ground line.
$V_{CC}$	Power supply	Positive power supply line.
$V_p$	Analog input	Connection for the external sense resistor. The measured current enters the shunt on the $V_p$ side.
$V_m$	Analog input	Connection for the external sense resistor. The measured current exits the shunt on the $V_m$ side.

## 2 Absolute maximum ratings and operating conditions

**Table 2. Absolute maximum ratings**

Symbol	Parameter	Value	Unit
$V_{id}$	Input pins differential voltage ( $V_p - V_m$ )	$\pm 60$	V
$V_i$	Input pin voltages ( $V_p, V_m$ ) <sup>(1)</sup>	-0.3 to 60	V
$V_{CC}$	DC supply voltage <sup>(1)</sup>	-0.3 to 30	V
$V_{out}$	DC output pin voltage <sup>(1)</sup>	-0.3 to 28	V
$T_{stg}$	Storage temperature	-55 to 150	°C
$T_j$	Maximum junction temperature	150	°C
ESD <sup>(2)</sup>	Human body model (HBM)	2	kV
	Machine model (MM)	200	V

1. Voltage values are measured with respect to the GND pin.
2. ESD test for each couple of pins.

**Table 3. Operating conditions**

Symbol	Parameter	Value	Unit
$V_{CC}$	DC supply voltage from $T_{min}$ to $T_{max}$	4.0 to 28	V
$T_{oper}$	Operational temperature range ( $T_{min}$ to $T_{max}$ )	-40 to 125	°C
$R_{thja}$	SOT23-5 thermal resistance junction to ambient	250	°C/W

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### 3 Electrical characteristics

The electrical characteristics given in the following tables are measured under the following test conditions unless otherwise specified:

$$T_{amb}=25^{\circ}\text{C}, V_{CC}=12\text{V}, V_{sense}=V_p-V_m=50\text{mV}, V_m=12\text{V}, \text{no load on Out}$$

**Table 4. Supply**

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$I_{CC}$	Total supply current	$V_{sense} = 0$ $T_{min} < T_{amb} < T_{max}$			300	$\mu\text{A}$

**Table 5. Input**

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{icm}$	Common mode voltage range	$T_{min} < T_{amb} < T_{max}$	2.8		30	V
DC CMR	DC common mode rejection Variation of $V_{out}$ versus $V_{icm}$ referred to input <sup>(1)</sup>	$2.8\text{V} < V_{icm} < 30\text{V}$ $T_{min} < T_{amb} < T_{max}$	90	105		dB
AC CMR	AC common mode rejection Variation of $V_{out}$ versus $V_{icm}$ referred to input (peak-to-peak voltage variation)	$2.8\text{V} < V_{icm} < 30\text{V}$ 1kHz sine wave		95		dB
		$2.8\text{V} < V_{icm} < 30\text{V}$ 10kHz sine wave		80		dB
SVR	Supply voltage rejection Variation of $V_{out}$ versus $V_{CC}$ <sup>(2)</sup>	$4.0\text{V} < V_{CC} < 28\text{V}$ $V_{sense}=30\text{mV}$ $T_{min} < T_{amb} < T_{max}$	90	105		dB
$V_{os}$	Input offset voltage <sup>(3)</sup>	$T_{amb}=25^{\circ}\text{C}$ $T_{min} < T_{amb} < T_{max}$		$\pm 0.2$ $\pm 0.9$	$\pm 1.5$ $\pm 2.3$	mV
$dV_{os}/dT$	Input offset drift vs. T	$T_{min} < T_{amb} < T_{max}$	0		4.5	$\mu\text{V}/^{\circ}\text{C}$
$I_{lk}$	Input leakage current	$V_{CC}=0\text{V}$ $T_{min} < T_{amb} < T_{max}$			1	$\mu\text{A}$
$I_{ib}$	Input bias current	$V_{sense}=0\text{V}$ $T_{min} < T_{amb} < T_{max}$		5.5	8	$\mu\text{A}$

1. See [Section 4: Parameter definitions on page 8](#) for the definition of CMR.

2. See [Section 4: Parameter definitions on page 8](#) for the definition of SVR.

3. See [Section 4: Parameter definitions on page 8](#) for the definition of  $V_{os}$ .

**Table 6. Output**

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$A_v$	Gain	TSC101A TSC101B TSC101C		20 50 100		V/V
$\Delta A_v$	Gain accuracy	$T_{amb}=25^{\circ}C$ $T_{min} < T_{amb} < T_{max}$			$\pm 3$ $\pm 5$	%
$\Delta V_{out}/\Delta T$	Output voltage drift vs. $T^{(1)}$	$T_{min} < T_{amb} < T_{max}$	-600	-300	0	$\mu V/^{\circ}C$
$\Delta V_{out}/\Delta I_{out}$	Output stage load regulation	$-10mA < I_{out} < 10mA$ $I_{out}$ sink or source current		2	tbd	mV/mA
$\Delta V_{out}$	Total output voltage accuracy <sup>(2)</sup>	$V_{sense}=10mV$ $T_{amb}=25^{\circ}C$ $T_{min} < T_{amb} < T_{max}$			tbd tbd	%
$\Delta V_{out}$	Total output voltage accuracy	$V_{sense}=20mV$ $T_{amb}=25^{\circ}C$ $T_{min} < T_{amb} < T_{max}$			tbd tbd	%
$\Delta V_{out}$	Total output voltage accuracy	$V_{sense}=50mV$ $T_{amb}=25^{\circ}C$ $T_{min} < T_{amb} < T_{max}$			tbd tbd	%
$\Delta V_{out}$	Total output voltage accuracy	$V_{sense}=100mV$ $T_{amb}=25^{\circ}C$ $T_{min} < T_{amb} < T_{max}$			tbd tbd	%
$I_{sc}$	Short-circuit current	OUT connected to $V_{CC}$ or GND	15	40		mA
$V_{OH}$	Output stage high-state saturation voltage $V_{OH}=V_{CC}-V_{out}$	$V_{sense}=1V$ $I_{out}=1mA$		0.8	1	V
$V_{OL}$	Output stage low-state saturation voltage	$V_{sense}=-1V$ $I_{out}=1mA$		50	100	mV

1. See [Section 4: Parameter definitions on page 8](#) for the definition of output voltage drift versus temperature.
2. Output voltage accuracy is the difference with the expected theoretical output voltage  $V_{out-th}=A_v \cdot V_{sense}$ . See [Section 4: Parameter definitions on page 8](#) for a more detailed definition.

Table 7. Frequency response

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
ts	Output settling to 1% final value	$V_{\text{sense}}=10\text{mV to }100\text{mV}$ , $C_{\text{load}}=47\text{pF}$				
		TSC101A		3		$\mu\text{s}$
		TSC101B		6		$\mu\text{s}$
		TSC101C		10		$\mu\text{s}$
SR	Slew rate	$V_{\text{sense}}=10\text{mV to }100\text{mV}$	0.55	0.9		$\text{V}/\mu\text{s}$
BW	3dB bandwidth	$C_{\text{load}}=47\text{pF}$ $V_{\text{icm}}=12\text{V}$ $V_{\text{sense}}=100\text{mV}$				
		TSC101A		650		$\text{kHz}$
		TSC101B		710		$\text{kHz}$
		TSC101C		540		$\text{kHz}$

Table 8. Noise

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
	Total output voltage noise			50		$\text{nV}/\sqrt{\text{Hz}}$

## 4 Parameter definitions

### Common mode rejection ratio (CMR)

The common-mode rejection ratio (CMR) measures the ability of the current-sensing amplifier to reject any DC voltage applied on both inputs  $V_p$  and  $V_m$ . The CMR is referred back to the input so that its effect can be compared with the applied differential signal. The CMR is defined by the formula:

$$\text{CMR} = -20 \cdot \log \frac{\Delta V_{\text{out}}}{\Delta V_{\text{icm}} \cdot A_v}$$

### Supply voltage rejection ratio (SVR)

The supply-voltage rejection ratio (SVR) measures the ability of the current-sensing amplifier to reject any variation of the supply voltage  $V_{CC}$ . The SVR is referred back to the input so that its effect can be compared with the applied differential signal. The SVR is defined by the formula:

$$\text{SVR} = -20 \cdot \log \frac{\Delta V_{\text{out}}}{\Delta V_{CC} \cdot A_v}$$



## Gain ( $A_v$ ) and input offset voltage ( $V_{os}$ )

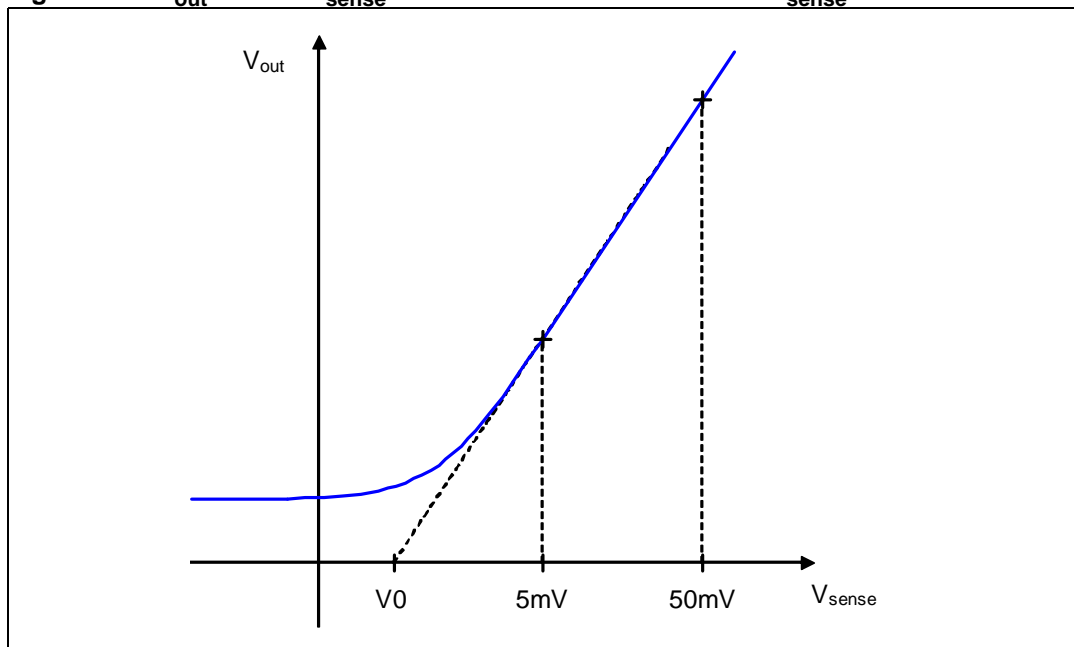
The input offset voltage is defined as the intersection between the linear regression of  $V_{out}$  vs.  $V_{sense}$  curve with the X-axis (see [Figure 2](#)). If  $V_{out1}$  is the output voltage with  $V_{sense}=V_{sense1}=50\text{mV}$  and  $V_{out2}$  is the output voltage with  $V_{sense}=V_{sense2}=5\text{mV}$ , then  $V_{os}$  can be calculated with the following formula:

$$V_{os} = V_{sense1} - \left( \frac{V_{sense1} - V_{sense2}}{V_{out1} - V_{out2}} \cdot V_{out1} \right)$$

The amplification gain  $A_v$  is defined as the ratio between output voltage and input differential voltage:

$$A_v = \frac{V_{out}}{V_{sense}}$$

**Figure 2.**  $V_{out}$  versus  $V_{sense}$  characteristics: detail for low  $V_{sense}$  values



### Output voltage drift versus temperature

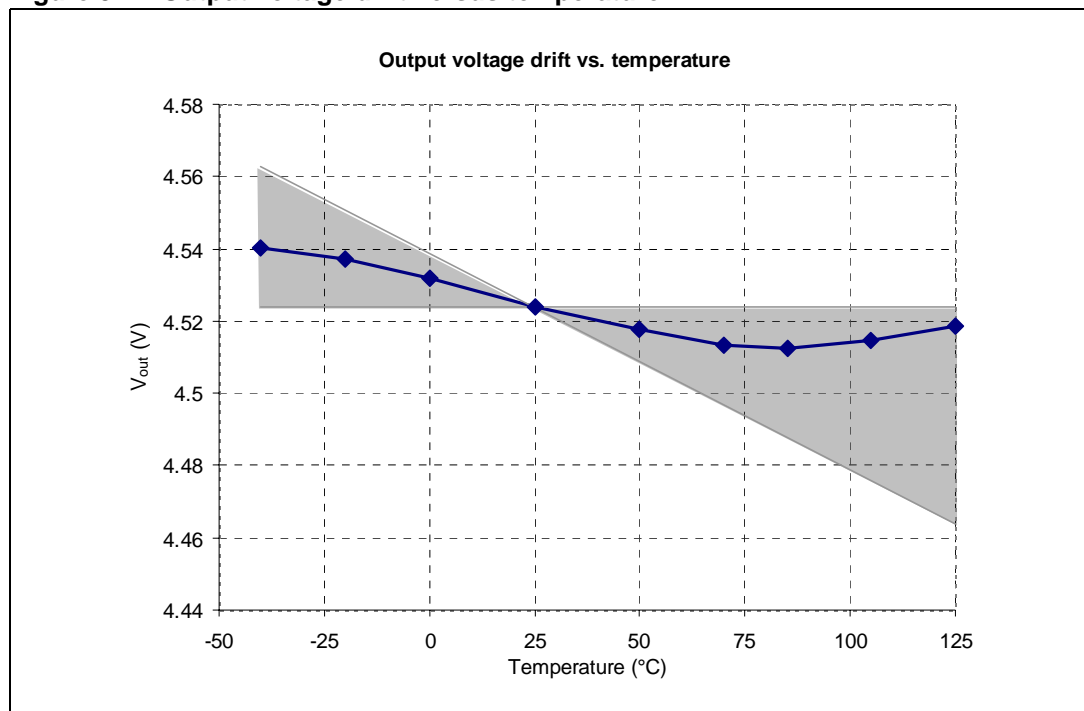
The output voltage drift versus temperature is defined as the maximum variation of  $V_{out}$  with respect to its value at 25°C, over the temperature range. It is calculated as follows:

$$\frac{\Delta V_{out}}{\Delta T} = \max \frac{V_{out}(T_{amb}) - V_{out}(25^\circ C)}{T_{amb} - 25^\circ C}$$

with  $T_{min} < T_{amb} < T_{max}$ .

Figure 3 provides a graphical definition of output voltage drift versus temperature. On this chart,  $V_{out}$  is always comprised in the grey area defined by the maximum and minimum variation of  $V_{out}$  vs.  $T$ , and  $T=25^\circ C$  is considered to be the reference.

Figure 3. Output voltage drift versus temperature



## Output voltage accuracy

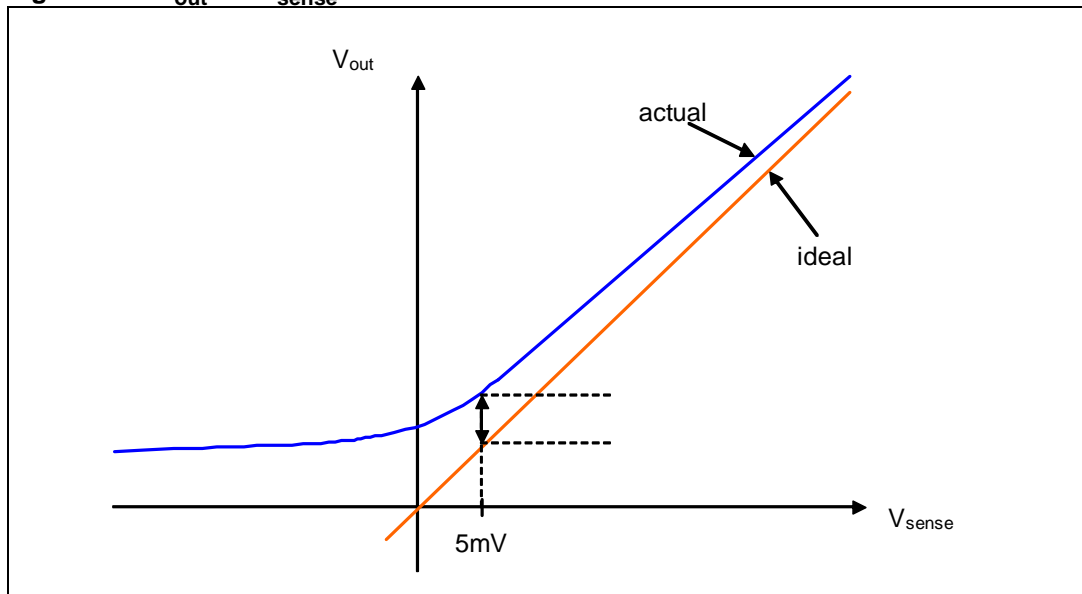
The output voltage accuracy is the difference between the actual output voltage and the theoretical output voltage. Ideally, the current sensing output voltage should be equal to the input differential voltage multiplied by the theoretical gain, as in the following formula:

$$V_{\text{out-th}} = A_v \cdot V_{\text{sense}}$$

The actual value is very slightly different, mainly due to the effects of:

- the input offset voltage  $V_{\text{OS}}$ ,
- non-linearity,
- $V_{\text{OL}}$  and  $V_{\text{OH}}$  voltage saturation (see [Figure 5 on page 12](#))

**Figure 4.  $V_{\text{out}}$  vs.  $V_{\text{sense}}$  theoretical and actual characteristics**



The output voltage accuracy, expressed in percentage, can be calculated with the following formula:

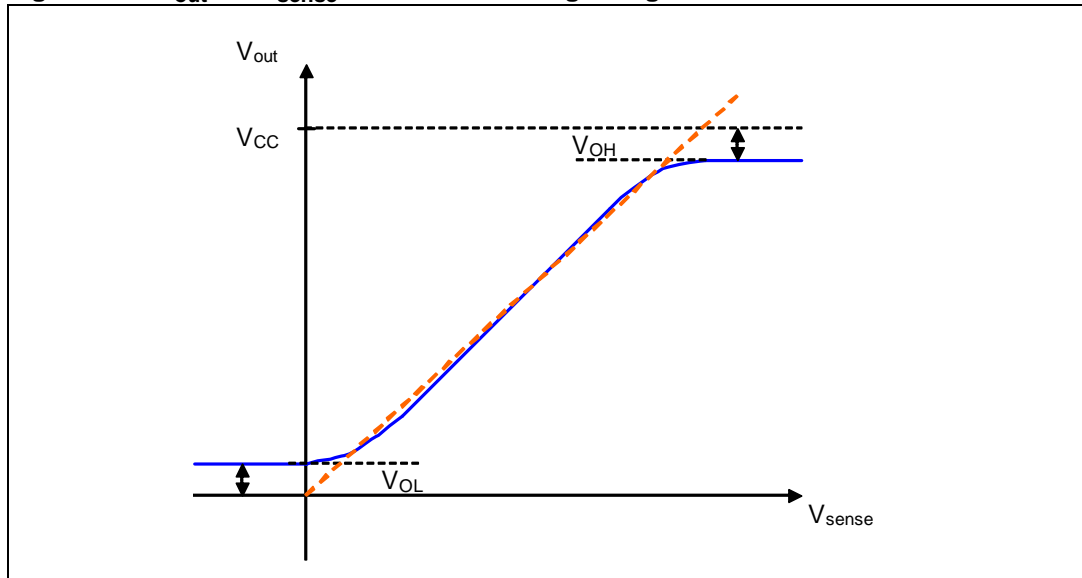
$$\Delta V_{\text{out}} = \frac{\text{abs}(V_{\text{out}} - (A_v \cdot V_{\text{sense}}))}{A_v \cdot V_{\text{sense}}}$$

with  $A_v=20\text{V/V}$  for TSC101A,  $A_v=50\text{V/V}$  for TSC101B and  $A_v=100\text{V/V}$  for TSC101C.

## Output voltage range

The output voltage versus input differential voltage is linear in a range of output voltage limited by high-level and low-level saturation voltage.

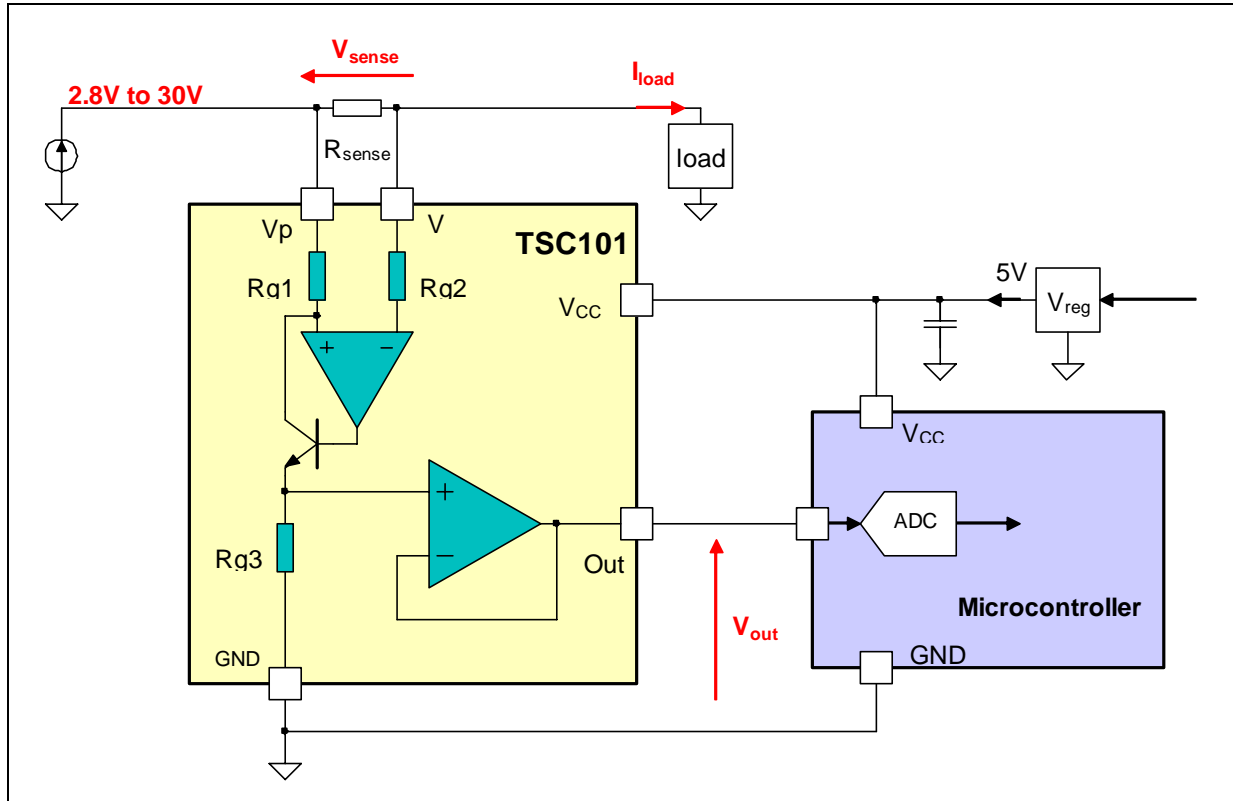
**Figure 5.**  $V_{out}$  vs.  $V_{sense}$  over the full voltage range



## 5 Application information

TSC101 can be used to measure current and to feed back the information to a micro controller, as shown in [Figure 6](#) below.

**Figure 6. Typical application schematic**



The current from the supply flows to the load through the  $R_{sense}$  resistor causing a voltage drop equal to  $V_{sense}$  across  $R_{sense}$ . The amplifier input currents are negligible, therefore its inverting input voltage is equal to  $V_m$ . The amplifier's open-loop gain forces its non-inverting input to the same voltage as the inverting input. As a consequence, the amplifier will adjust current flowing through  $R_{g1}$  so that the voltage drop across  $R_{g1}$  will exactly match  $V_{sense}$ .

Therefore, the drop across  $R_{g1}$  is:

$$V_{R_{g1}} = V_{sense} = R_{sense} \cdot I_{load}$$

If  $I_{R_{g1}}$  is the current flowing through  $R_{g1}$ , then  $I_{R_{g1}}$  is given by the formula:

$$I_{R_{g1}} = V_{sense} / R_{g1}$$

The  $I_{R_{g1}}$  current flows entirely into resistor  $R_{g3}$  (the input bias current of the buffer is negligible). Therefore, the voltage drop on the  $R_{g3}$  resistor can be calculated as follows:

$$V_{R_{g3}} = R_{g3} \cdot I_{R_{g1}} = (R_{g3} / R_{g1}) \cdot V_{sense}$$

Because the voltage across the  $R_{g3}$  resistor is buffered to the Out pin,  $V_{out}$  can be expressed as:

$$V_{out} = (R_{g3}/R_{g1}) \cdot V_{sense}$$

or

$$V_{out} = (R_{g3}/R_{g1}) \cdot R_{sense} \cdot I_{load}$$

The resistor ratio  $R_{g3}/R_{g1}$  is internally set to 20V/V for TSC101A, to 50V/V for TSC101B and to 100V/V for TSC101C.

Because they define the full scale output range of your application, the  $R_{sense}$  resistor and the  $R_{g3}/R_{g1}$  resistor ratio (equal to  $A_v$ ) are important parameters, and therefore must be selected carefully.

## 6 Package information

In order to meet environmental requirements, STMicroelectronics offers these devices in ECOPACK® packages. These packages have a lead-free second level interconnect. The category of second level interconnect is marked on the package and on the inner box label, in compliance with JEDEC Standard JESD97. The maximum ratings related to soldering conditions are also marked on the inner box label. ECOPACK is an STMicroelectronics trademark. ECOPACK specifications are available at: [www.st.com](http://www.st.com).

**Figure 7. SOT23-5 package**

Ref.	Dimensions					
	Millimeters			Mils		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A	0.90		1.45	35.4		57.1
A1	0.00		0.15	0.00		5.9
A2	0.90		1.30	35.4		51.2
b	0.35		0.50	13.7		19.7
C	0.09		0.20	3.5		7.8
D	2.80		3.00	110.2		118.1
E	2.60		3.00	102.3		118.1
E1	1.50		1.75	59.0		68.8
e		0.95			37.4	
e1		1.9			74.8	
L	0.35		0.55	13.7		21.6

The figure shows two views of the SOT23-5 package. The left view is a side profile showing dimensions A (total width), A1 (lead width), A2 (lead length), C (lead thickness), and L (lead height). The right view is a top-down view showing dimensions D (package width), E (package height), E1 (package height excluding leads), e (lead pitch), e1 (lead spacing), and b (lead width).

## 7 Ordering information

**Table 9. Order codes**

Part number	Temperature range	Package	Packaging	Marking	Gain
TSC101AILT	-40°C, +125°C	SOT23-5	Tape & reel	O104	20
TSC101BILT				O105	50
TSC101CILT				O106	100
TSC101AIYLT <sup>(1)</sup>	-40°C, +125°C automotive grade	SOT23-5	Tape & reel	O101	20
TSC101BIYLT <sup>(1)</sup>				O102	50
TSC101CIYLT <sup>(1)</sup>				O103	100

1. Qualified and characterized according to AEC Q100 and Q003 or equivalent, advanced screening according to AEC Q001 & Q 002 or equivalent.



## 8 Revision history

Date	Revision	Changes
5-Mar-2007	Rev 1	First release, preliminary data.

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