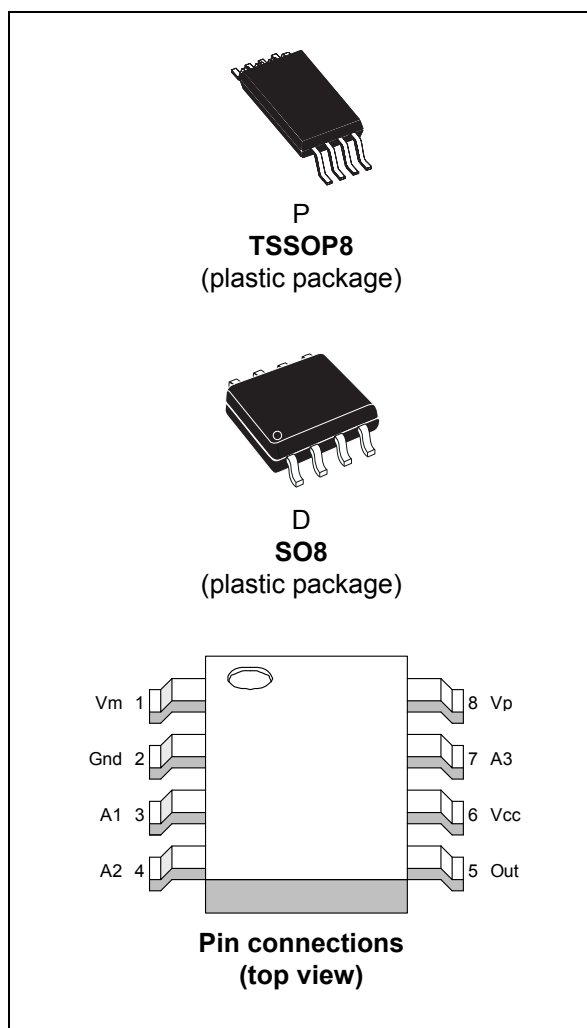


High-side current sense amplifier plus signal conditioning amplifier

Datasheet - production data



- Output amplifier for tailor-made signal conditioning
- -40 °C to 125 °C operating temperature range
- 4 kV ESD protection

Applications

- Battery chargers
- Automotive current monitoring
- Notebook computers
- DC motor control
- Photo-voltaic systems
- Precision current sources
- Uninterruptible power supplies
- High-end power supplies

Description

The TSC102 measures a small differential voltage on a high-side shunt resistor and translates it into a ground-referenced output voltage.

The device's wide input common-mode voltage range, low quiescent current and tiny TSSOP8 packaging enable use in a wide variety of applications (also available in SO8 package).

The input common-mode and power supply voltages are independent. The common-mode voltage can range from 2.8 to 30 V in operating conditions.

The TSC102 is rugged against abnormal conditions on the input pins: Vp and Vm can withstand up to 60 V in case of voltage spikes, as little as -16 V in case of reversed battery, and up to 4 kV in case of electrostatic discharge.

In addition to the current sensing amplifier, the TSC102 offers a fully accessible amplifier for output signal conditioning. The device's overall current consumption is lower than 420 μ A.

Features

- Independent supply and input common-mode voltages
- Wide common-mode operating range: 2.8 to 30 V
- Wide common-mode surviving range: -16 to 60 V (reversed battery and load-dump conditions)
- Low current consumption: I_{CC} max = 420 μ A

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1 Application schematic and pin description

The TSC102 high-side current sense amplifier features a 2.8 V to 30 V input common-mode range that is independent of the supply voltage. The main advantage of this feature is that it allows high-side current sensing at voltages much greater than the supply voltage (V_{CC}).

Figure 1. Application schematics

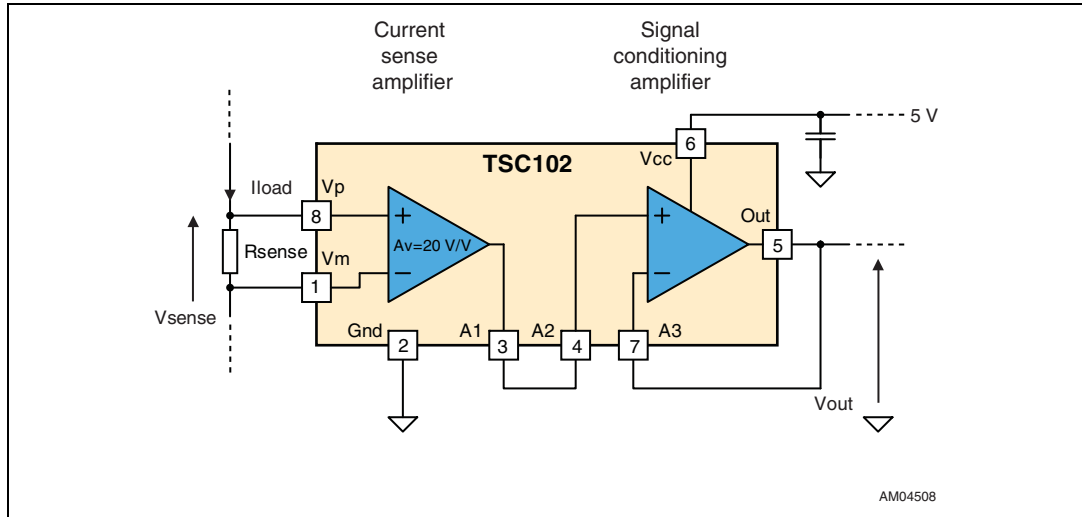


Table 1 describes the function of each pin. Their position is shown in the illustration on the cover page and in Figure 1 above.

Table 1. Pin description

| Symbol | Type | Function |
|----------|---------------|---|
| Out | Analog output | Out voltage is proportional to the magnitude of the sense voltage $V_p - V_m$ |
| Gnd | Power supply | Ground line |
| V_{CC} | | 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 | | Connection for the external sense resistor. The measured current exits the shunt on the V_m side |
| A1 | | Connection to current sensing amplifier output |
| A2 | | Connection to signal conditioning amplifier non-inverting input |
| A3 | | Connection to signal conditioning amplifier inverting input |

2 Absolute maximum ratings and operating conditions

Table 2. Absolute maximum ratings

| Symbol | Parameter | Value | Unit |
|------------|---|------------|------|
| V_{id} | Input pins differential voltage ($V_p - V_m$) | ± 20 | V |
| V_i | Current sensing input pin voltages (V_p and V_m) ⁽¹⁾ | -16 to 60 | |
| V_1 | Voltage for pins A1, A2, A3, Out, V_{cc} ⁽¹⁾ | -0.3 to 7 | |
| T_{stg} | Storage temperature | -55 to 150 | °C |
| T_j | Maximum junction temperature | 150 | |
| R_{thja} | TSSOP8 thermal resistance junction to ambient | 120 | °C/W |
| | SO8 thermal resistance junction to ambient | 125 | |
| ESD | HBM: human body model for V_m and V_p pins ⁽²⁾ | 4 | kV |
| | HBM: human body model ⁽³⁾ | 2.5 | |
| | MM: machine model ⁽⁴⁾ | 200 | V |
| | CDM: charged device model ⁽⁵⁾ | 1.5 | kV |

1. These voltage values are measured with respect to the GND pin.
2. Human body model for V_m and V_p : a 100 pF capacitor is charged to the specified voltage, then discharged through a 1.5 kΩ resistor between the V_p or V_m pin and Gnd while the other pins are floating.
3. Human body model: a 100 pF capacitor is charged to the specified voltage, then discharged through a 1.5 kΩ resistor between two pins of the device. This is done for all couples of connected pin combinations while the other pins are floating.
4. Machine model: a 200 pF capacitor is charged to the specified voltage, then discharged directly between two pins of the device with no external series resistor (internal resistor < 5 Ω). This is done for all couples of connected pin combinations while the other pins are floating.
5. Charged device model: all pins plus package are charged together to the specified voltage and then discharged directly to ground.

Table 3. Operating conditions

| Symbol | Parameter | Value | Unit |
|------------|--|------------|------|
| V_{CC} | DC supply voltage from T_{min} to T_{max} | 3.5 to 5.5 | V |
| T_{oper} | Operational temperature range (T_{min} to T_{max}) | -40 to 125 | °C |
| V_{icm} | Common-mode voltage range (V_m pin voltage) | 2.8 to 30 | V |

3 Electrical characteristics

Unless otherwise specified, the electrical characteristics given in the following tables have been measured under the following test conditions.

- $T_{amb} = 25\text{ °C}$, $V_{CC} = 5\text{ V}$, $V_{sense} = V_p - V_m = 50\text{ mV}$, $V_m = 12\text{ V}$.
- No load on Out pin.
- Signal conditioning amplifier used as a buffer (pin A3 connected to pin Out and pin A1 connected to pin A2).

Table 4. Supply

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
|-----------|----------------------|--|------|------|------|---------------|
| I_{CC} | Total supply current | $V_{sense} = 0\text{ V}$, pin A1 open, pin A2 shorted to Gnd $T_{min} < T_{amb} < T_{max}$ | - | 240 | 420 | μA |
| I_{CC1} | | $V_{sense} = 50\text{ mV}$, pin A1 connected to pin A2 $T_{min} < T_{amb} < T_{max}$ | | 420 | 700 | |

Table 5. Current sensing amplifier input stage

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
|--------------|---|---|------|---------|------------------------|-------------------------|
| DC CMR1 | DC common-mode rejection Variation of V_{a1} versus V_{icm} referred to input ⁽¹⁾ | $2.8\text{ V} < V_m < 30\text{ V}$ $-40\text{ °C} < T_{amb} < 150\text{ °C}$ | 90 | 100 | | dB |
| AC CMR1 | AC common-mode rejection Variation of V_{a1} versus V_{icm} referred to input (peak-to-peak voltage variation) | $2.8\text{ V} < V_m < 30\text{ V}$ 1 kHz sine wave | | 75 | | |
| | | $2.8\text{ V} < V_m < 30\text{ V}$ 10 kHz sine wave | | 60 | | |
| SVR1 | Supply voltage rejection Variation of V_{a1} versus V_{CC} ⁽²⁾ | $3.5\text{ V} < V_{CC} < 5.5\text{ V}$ $-40\text{ °C} < T_{amb} < 125\text{ °C}$ | 85 | 90 | | |
| V_{os} | Input offset voltage ⁽³⁾ | $T_{amb} = 25\text{ °C}$ $-40\text{ °C} < T_{amb} < 125\text{ °C}$ | | | ± 1.5 ± 2.3 | mV |
| dV_{os}/dT | Input offset drift versus T | $-40\text{ °C} < T_{amb} < 125\text{ °C}$ | | ± 3 | ± 8 | $\mu\text{V}/\text{°C}$ |
| I_{lk} | Input leakage current | $V_{CC} = 0\text{ V}$ $T_{min} < T_{amb} < T_{max}$ | | | 1 | μA |
| I_{ib} | Input bias current | $V_{sense} = 0\text{ V}$ $T_{min} < T_{amb} < T_{max}$ | | 5 | 7 | |

1. See [Section 6: Parameter definitions](#) for the definition of CMR

2. See [Section 6](#) for the definition of SVR

3. See [Section 6](#) for the definition of V_{os}

Table 6. Current sensing amplifier output stage

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
|-------------------------------|--|--|------|------|----------------------|--------|
| A_v | Gain (variation of V_{a1} versus V_{sense}) | | | 20 | | V/V |
| V_{oh1} | A1 node high-level saturation voltage $V_{oh1} = V_{cc} - V_{a1}$ | $V_{sense} = 1\text{ V}$ $I_{a1} = 1\text{ mA}$ $-40\text{ °C} < T_{amb} < 125\text{ °C}$ | | 85 | 185 | mV |
| V_{ol1} | A1 node low-level saturation voltage | $V_{sense} = -1\text{ V}$ $I_{a1} = 1\text{ mA}$ $-40\text{ °C} < T_{amb} < 125\text{ °C}$ | | 75 | 165 | |
| I_{sc1} | Short-circuit current | A1 connected to V_{CC} or Gnd | 10 | 30 | | mA |
| $\Delta V_{a1}/\Delta T$ | Output voltage drift versus $T^{(1)}$ | $T_{min} < T_{amb} < T_{max}$ | | | ± 400 | ppm/°C |
| $\Delta V_{a1}/\Delta I_{a1}$ | Output stage load regulation | $-5\text{ mA} < I_{a1} < +5\text{ mA}$ I_{a1} sink or source current | | 0.4 | ± 2 | mV/mA |
| ΔV_{a1} | Total output voltage accuracy ⁽²⁾ | $V_{sense} = 50\text{ mV}$ $T_{amb} = 25\text{ °C}$ $T_{min} < T_{amb} < T_{max}$ | | | ± 2.5 ± 4 | % |
| ΔV_{a1} | Total output voltage accuracy ⁽²⁾ | $V_{sense} = 100\text{ mV}$ $T_{amb} = 25\text{ °C}$ $T_{min} < T_{amb} < T_{max}$ | | | ± 2.5 ± 4 | |
| ΔV_{a1} | Total output voltage accuracy ⁽²⁾ | $V_{sense} = 20\text{ mV}$ $T_{amb} = 25\text{ °C}$ $T_{min} < T_{amb} < T_{max}$ | | | ± 8 ± 10 | |
| ΔV_{a1} | Total output voltage accuracy ⁽²⁾ | $V_{sense} = 10\text{ mV}$ $T_{amb} = 25\text{ °C}$ $T_{min} < T_{amb} < T_{max}$ | | | ± 13 ± 16 | |

1. See [Section 6: Parameter definitions](#) for the definition of output voltage drift versus temperature.
2. Output voltage accuracy is the difference with the expected theoretical output voltage $V_{a1-th} = A_v * V_{sense}$. See [Section 6](#) for a more detailed definition.

Table 7. Current sensing amplifier frequency response

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
|--------|-------------------------------------|--|------|------|------|------------------|
| t_s | V_{a1} settling to 1% final value | $V_{sense} = 10\text{ mV to }100\text{ mV}$, $C_{load} = 47\text{ pF}$ | - | 7 | - | μs |
| SR | Slew rate | $V_{sense} = 10\text{ mV to }100\text{ mV}$ | 0.2 | 0.4 | - | V/ μs |
| BW | 3 dB bandwidth | $C_{load} = 47\text{ pF}$ | - | 800 | - | kHz |

Table 8. Current sensing amplifier noise

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
|--------|--------------------------------|--------------------|------|------|------|------------------------|
| e_N | Equivalent input noise voltage | $f = 1\text{ kHz}$ | - | 50 | - | nV/ $\sqrt{\text{Hz}}$ |

Table 9. Signal conditioning amplifier

| Symbol | Parameter | Test conditions | Min. | Typ. | Max. | Unit |
|---------------------------------|---|---|----------|----------|------------------------|--------------------------------|
| V_{icm} | Common-mode voltage range | $T_{min} < T_{amb} < T_{max}$ | 0 | | V_{CC} | |
| V_{IO} | Input offset voltage | $V_{a2} = 1\text{ V}$ $T_{amb} = 25\text{ }^{\circ}\text{C}$ $-40\text{ }^{\circ}\text{C} < T_{amb} < 150\text{ }^{\circ}\text{C}$ | | | ± 3.5 ± 4.5 | mV |
| ΔV_{IO} | Input offset voltage drift | $T_{min} < T_{amb} < T_{max}$ | | 5 | | $\mu\text{V}/^{\circ}\text{C}$ |
| I_{ib} | Input bias current | $V_{a2} = V_{a3} = V_{CC}/2$ | | 10 | | pA |
| V_{oh2} | Output high-level saturation voltage ($V_{oh2} = V_{CC} - V_{out}$) | $V_{a2} = 1\text{ V}$ $V_{a3} = 0\text{ V}$ $I_{out} = 1\text{ mA}$ $-40\text{ }^{\circ}\text{C} < T_{amb} < 125\text{ }^{\circ}\text{C}$ | | 85 | 185 | mV |
| V_{ol2} | Output low-level saturation voltage | $V_{a2} = 0\text{ V}$ $V_{a3} = 1\text{ V}$ $I_{out} = 1\text{ mA}$ $-40\text{ }^{\circ}\text{C} < T_{amb} < 125\text{ }^{\circ}\text{C}$ | | 75 | 165 | |
| I_{sc2} | Short-circuit current | Out connected to V_{CC} or Gnd | 12 | 30 | | mA |
| $\Delta V_{out}/\Delta I_{out}$ | Output stage load regulation | $-10\text{ mA} < I_{out} < +10\text{ mA}$ $V_{a2} = 1\text{ V}$ I_{out} sink or source current | | | 300 | $\mu\text{V}/\text{mA}$ |
| CMR2 | DC common-mode rejection Variation of V_{IO} versus V_{icm} | $T_{min} < T_{amb} < T_{max}$ $0\text{ V} < V_{a2} < 3\text{ V}$ $0\text{ V} < V_{a2} < 5\text{ V}$ | 70 60 | 95 80 | | dB |
| SVR2 | Supply voltage rejection Variation of V_{IO} versus V_{CC} | $3.5\text{ V} < V_{CC} < 5.5\text{ V}$ $V_{a2} = 1\text{ V}$ $-40\text{ }^{\circ}\text{C} < T_{amb} < 125\text{ }^{\circ}\text{C}$ | 85 | 105 | | |
| GBP | Gain bandwidth product | $R_L = 10\text{ k}\Omega$, $C_{load} = 100\text{ pF}$, $f = 100\text{ kHz}$ | | 1 | | MHz |
| PM | Phase margin | $R_L = 10\text{ k}\Omega$, $C_{load} = 100\text{ pF}$ | | 65 | | deg |
| SR | Slew rate | $R_L = 10\text{ k}\Omega$, $C_{load} = 100\text{ pF}$ $V_{a2} = 0.5\text{ V}$ to 4.5 V A3 connected to OUT (follower configuration) Slew rate measured from 10% to 90% of V_{out} step | 0.2 | 0.4 | | V/ μs |

4 Electrical characteristics curves: current sense amplifier

Unless otherwise specified, the test conditions for the following curves are:

- $T_{amb} = 25\text{ }^{\circ}\text{C}$, $V_{CC} = 5\text{ V}$, $V_{sense} = V_p - V_m = 50\text{ mV}$, $V_m = 12\text{ V}$.
- no load on Out pin.
- signal conditioning amplifier used as a buffer (pin A3 connected to pin Out and pin A1 connected to pin A2).

Figure 2. Output voltage vs. Vsense

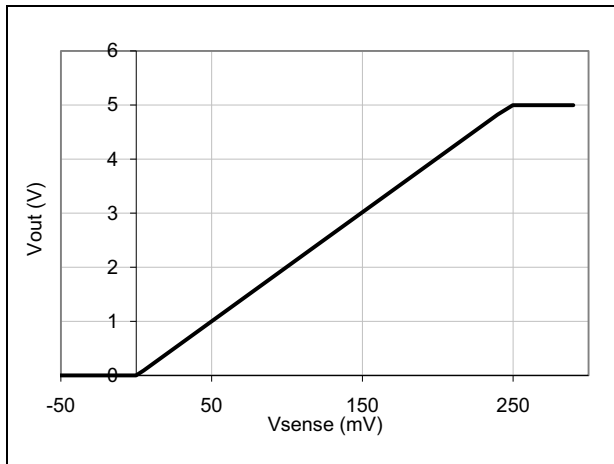


Figure 3. A1 pin voltage accuracy vs. Vsense

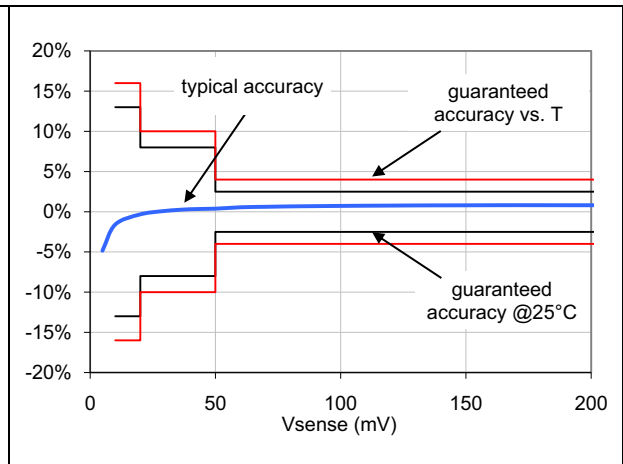


Figure 4. Supply current vs. supply voltage

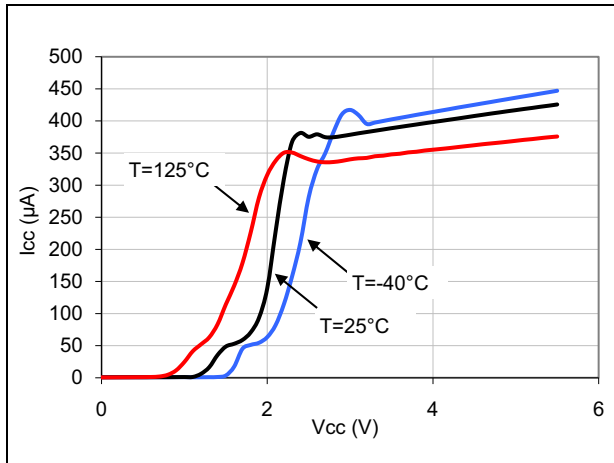


Figure 5. Supply current vs. Vsense

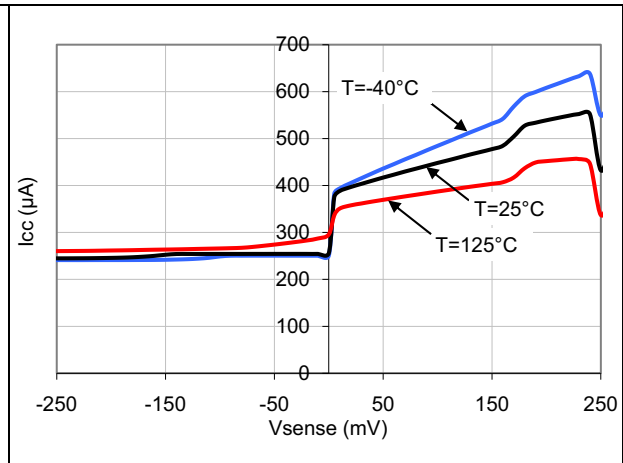


Figure 6. Vp pin input bias current vs. Vsense

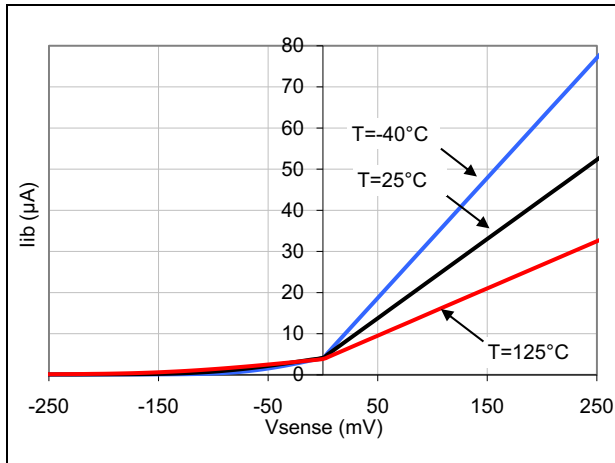


Figure 7. Vm pin input bias current vs. Vsense

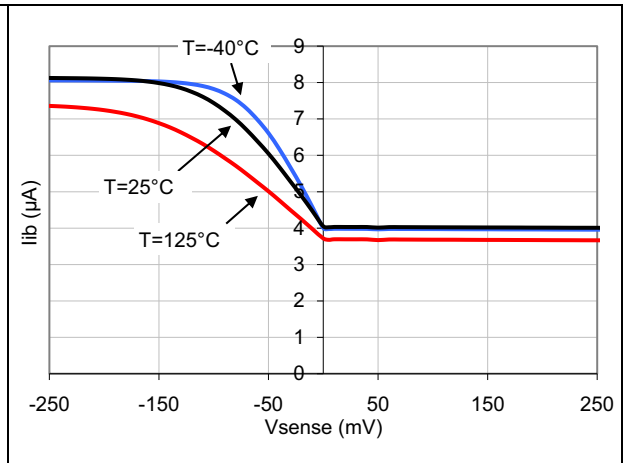


Figure 8. Output stage low-state saturation voltage versus output current (Vsense = -1 V)

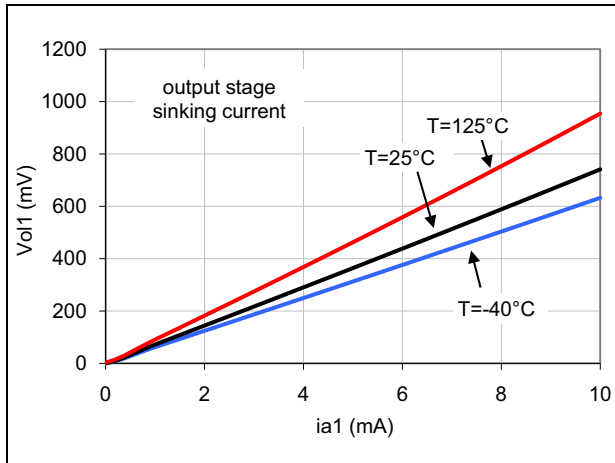


Figure 9. Output stage high-state saturation voltage versus output current (Vsense = +1 V)

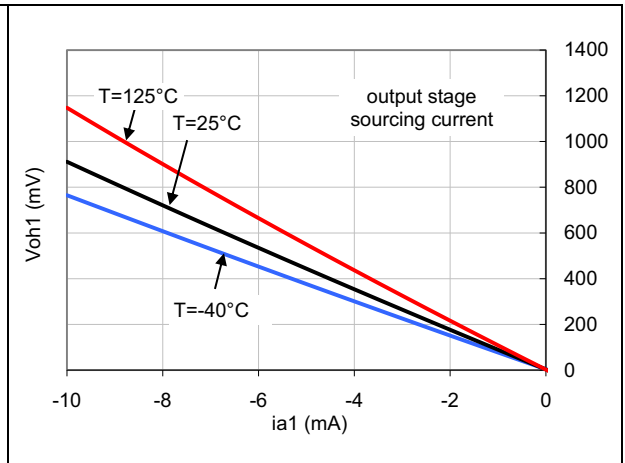


Figure 10. Output stage load regulation

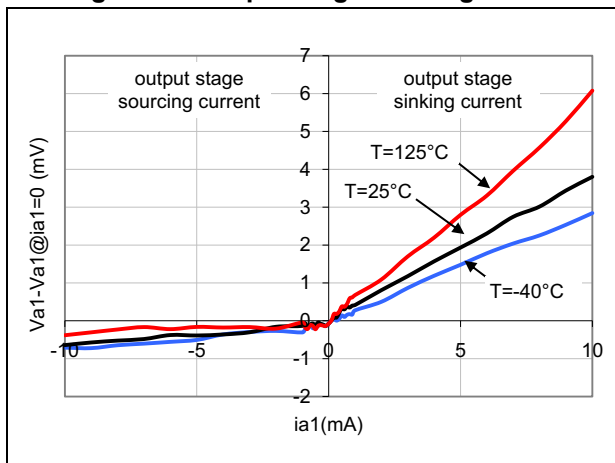


Figure 11. Step response

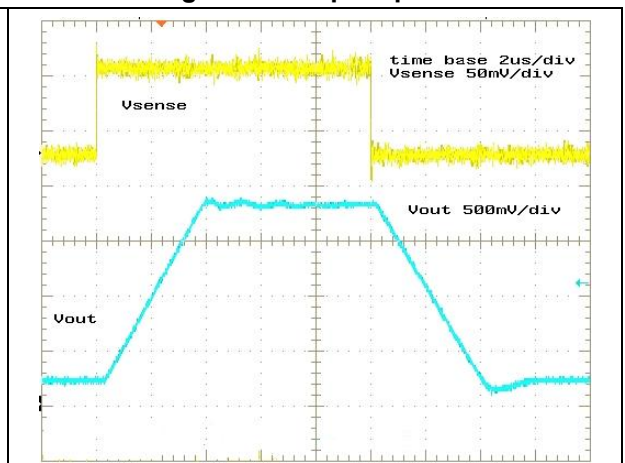


Figure 12. Bode diagram

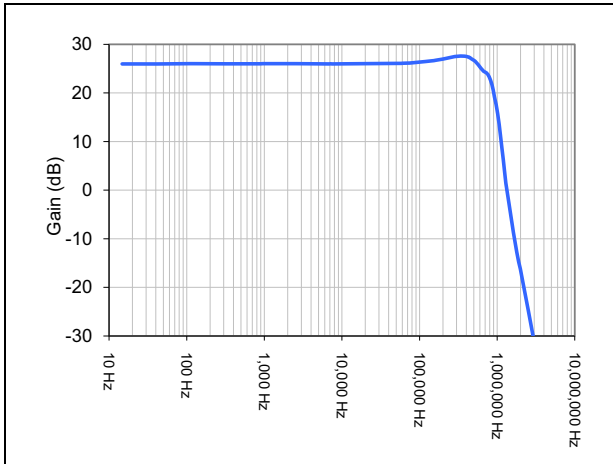
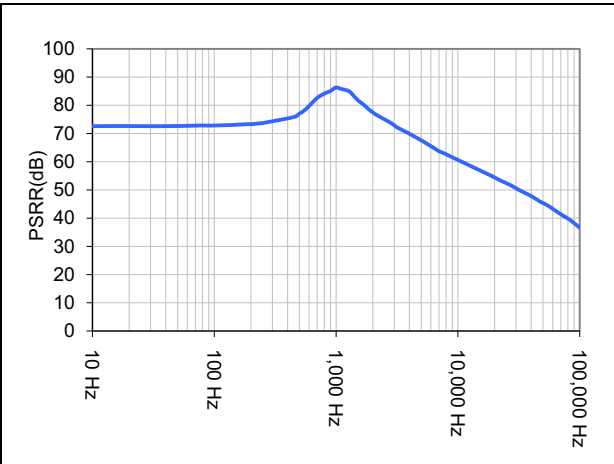


Figure 13. Power supply rejection ratio



5 Electrical characteristics curves: signal conditioning amplifier

Unless otherwise specified, the test conditions for the following curves are:

- $T_{amb} = 25\text{ }^{\circ}\text{C}$, $V_{CC} = 5\text{ V}$
- no load on Out.
- signal conditioning amplifier tested as standalone amplifier.

Figure 14. Input offset voltage versus input common-mode voltage

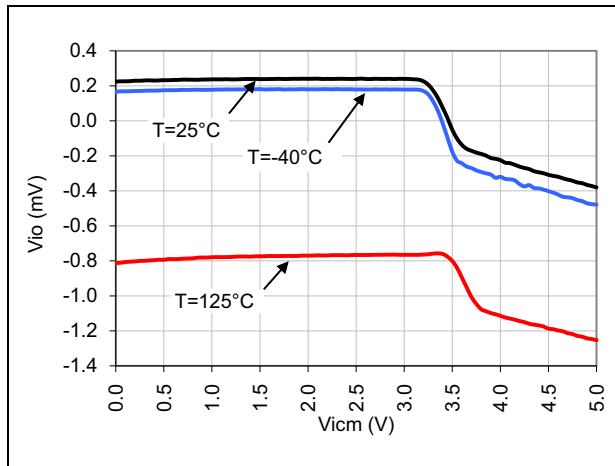


Figure 15. Input offset voltage versus supply voltage (Vicm = Vcc/2)

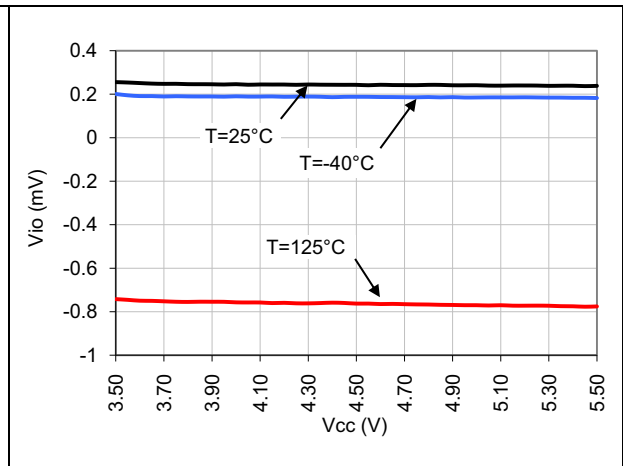


Figure 16. Output current versus output voltage

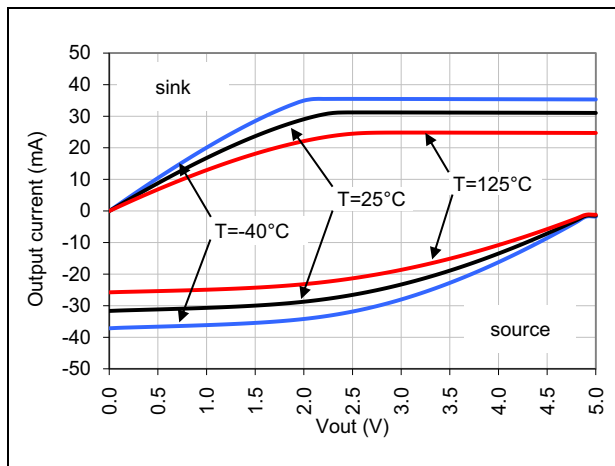
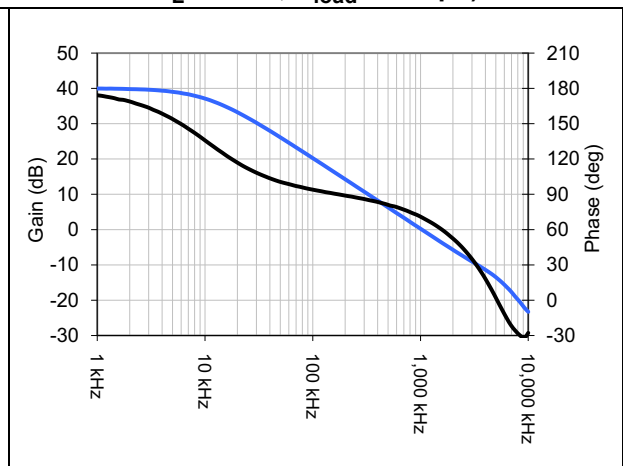


Figure 17. Bode diagram (Vout = Vcc/2, R_L = 10 kΩ, C_{load} = 100 pF)



6 Parameter definitions

6.1 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:

$$\text{CMR} = -20 \cdot \log \frac{\Delta V_{a1}}{\Delta V_{icm} \cdot A_v}$$

6.2 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:

$$\text{SVR} = -20 \cdot \log \frac{\Delta V_{a1}}{\Delta V_{cc} \cdot A_v}$$

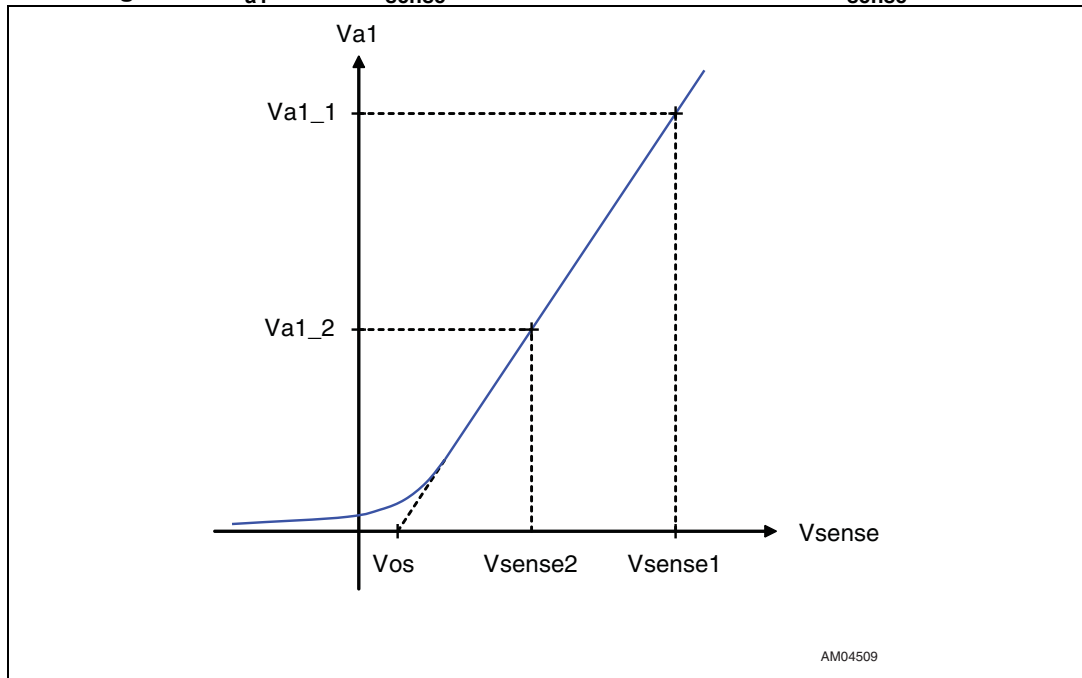
6.3 Gain (A_v) and input offset voltage (V_{os})

The input offset voltage is defined as the intersection between the linear regression of the V_{a1} versus V_{sense} curve with the X-axis (see [Figure 18](#)). If V_{a11} is the output voltage with $V_{sense} = V_{sense1} = 50$ mV and V_{a12} is the output voltage with $V_{sense} = V_{sense2} = 5$ mV, then V_{os} can be calculated with the formula:

$$V_{os} = V_{sense1} - \left(\frac{V_{sense1} - V_{sense2}}{V_{a11} - V_{a12}} \cdot V_{out1} \right)$$

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

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

Figure 18. V_{a1} versus V_{sense} characteristics: detail for low V_{sense} values

6.4 Output voltage drift versus temperature

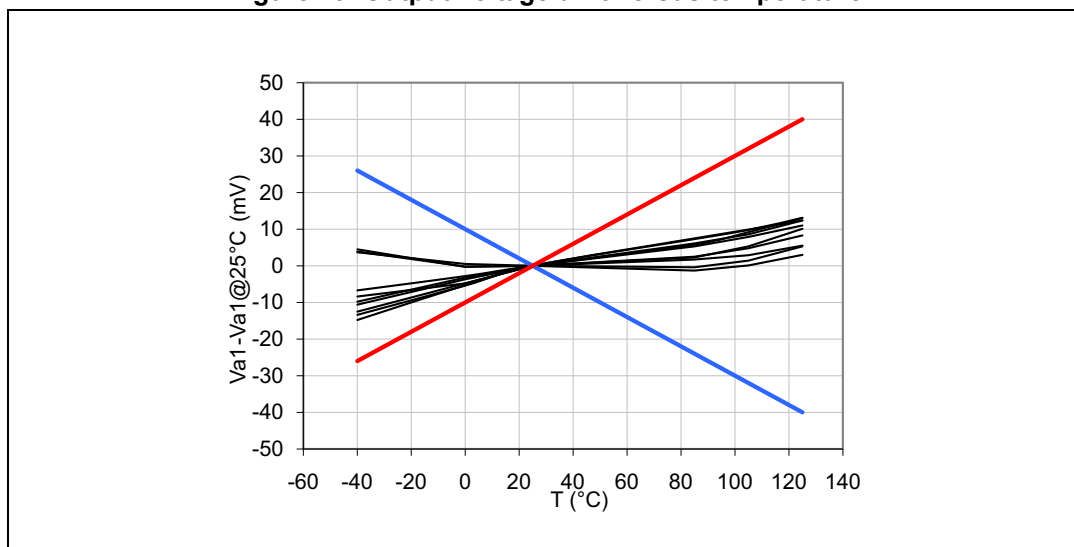
The output voltage drift versus temperature is defined as the maximum variation of V_{a1} with respect to its value at 25 °C, over the temperature range. It is calculated as follows:

$$\frac{\Delta V_{a1}}{\Delta T} = \max \frac{V_{a1}(T_{amb}) - V_{a1}(25^\circ \text{C})}{T_{amb} - 25^\circ \text{C}}$$

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

[Figure 19](#) provides a graphical definition of the output voltage drift versus temperature. On this chart, V_{a1} is always within the area defined by the maximum and minimum variation of V_{a1} versus T , and $T = 25^\circ \text{C}$ is considered to be the reference.

Figure 19. Output voltage drift versus temperature



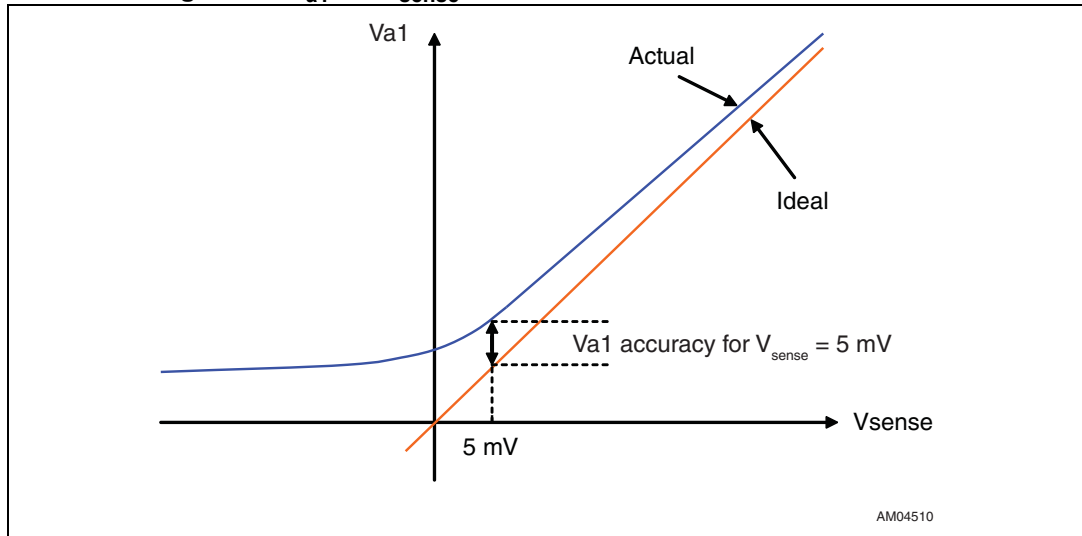
6.5 Output voltage accuracy

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.

$$V_{a1-th} = Av \cdot V_{sense}$$

The actual value is very slightly different, mainly due to the effects of the input offset voltage V_{OS} and the non-linearity.

Figure 20. V_{a1} vs. V_{sense} theoretical and actual characteristics



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

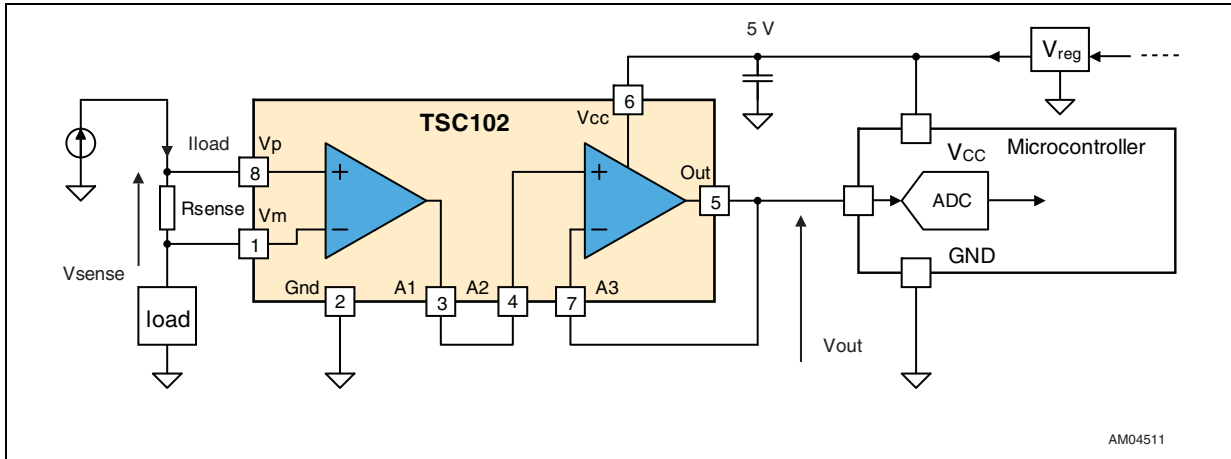
$$\Delta V_{a1} = \frac{\text{abs}(V_{a1} - (Av \cdot V_{sense}))}{Av \cdot V_{sense}}$$

with $Av = 20 \text{ V/V}$.

7 Application information

The TSC102 can be used to measure current and feed back the information to a microcontroller, as shown in [Figure 21](#).

Figure 21. Typical application schematic



This fully-accessible output amplifier offers wide schematic possibilities, as shown in the following examples.

Figure 22. Gain higher than 20

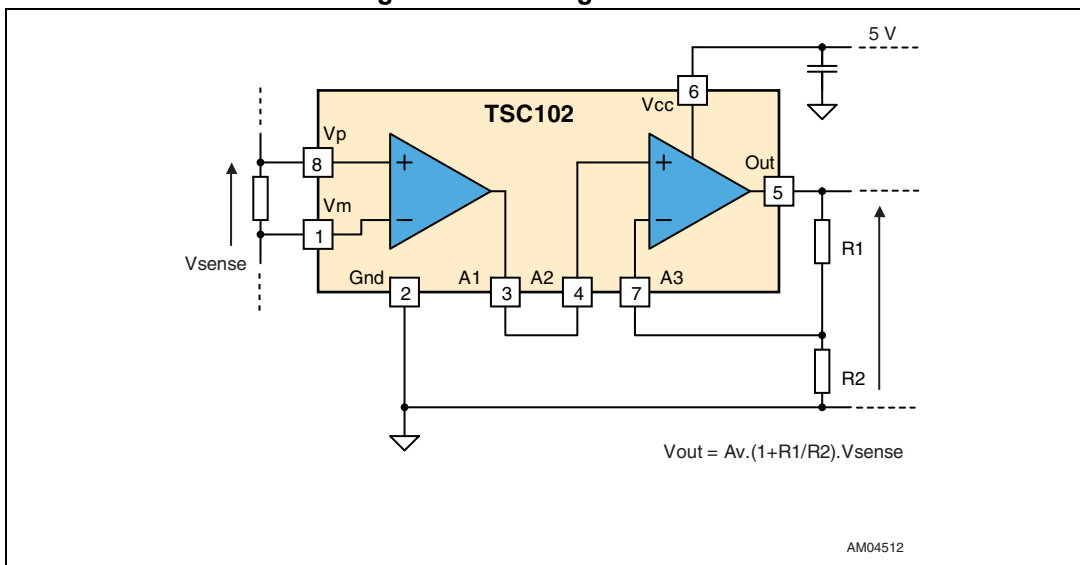


Figure 23. Gain lower than 20

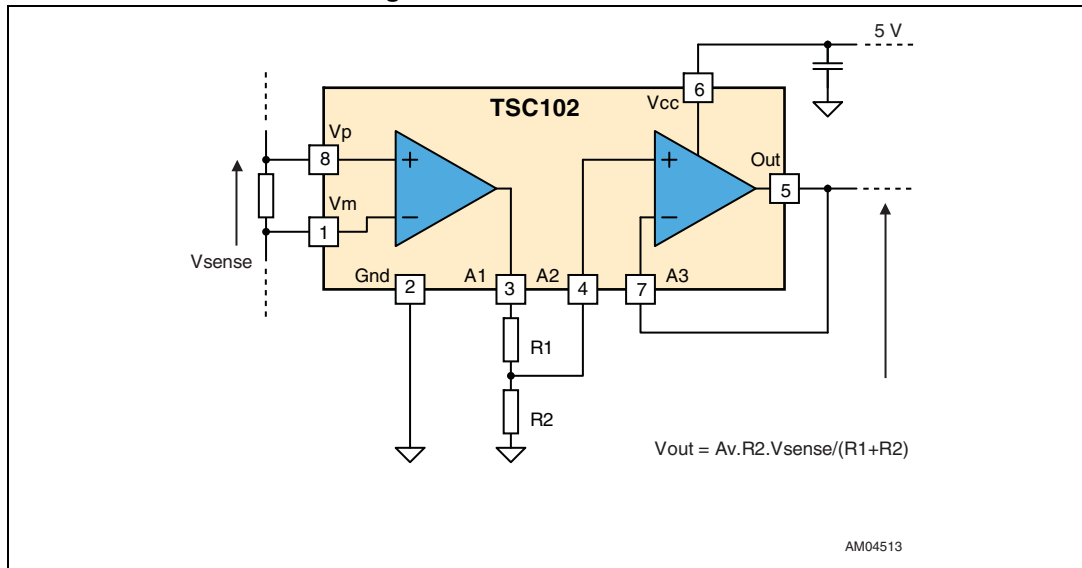


Figure 24. Overcurrent protection

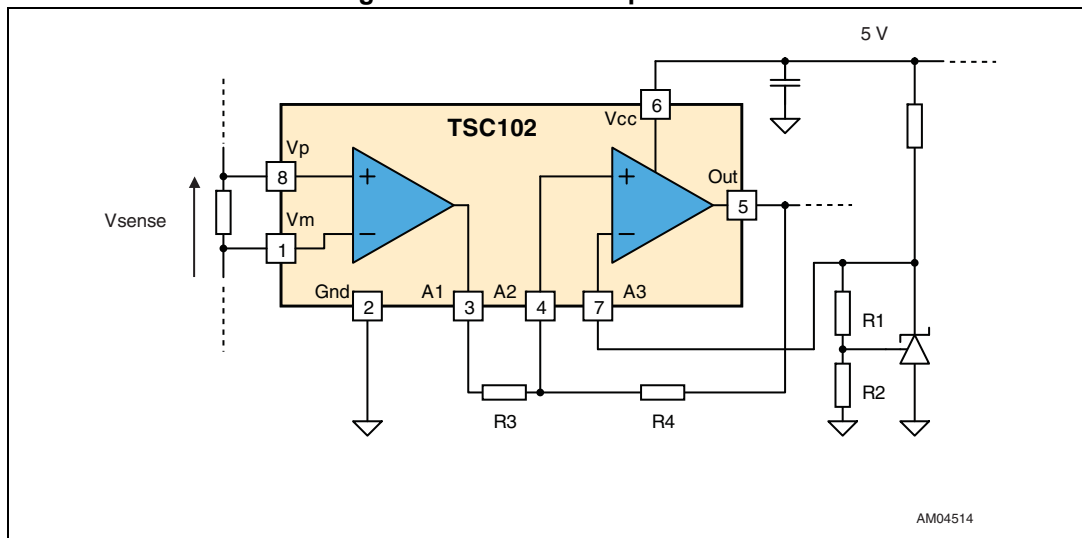
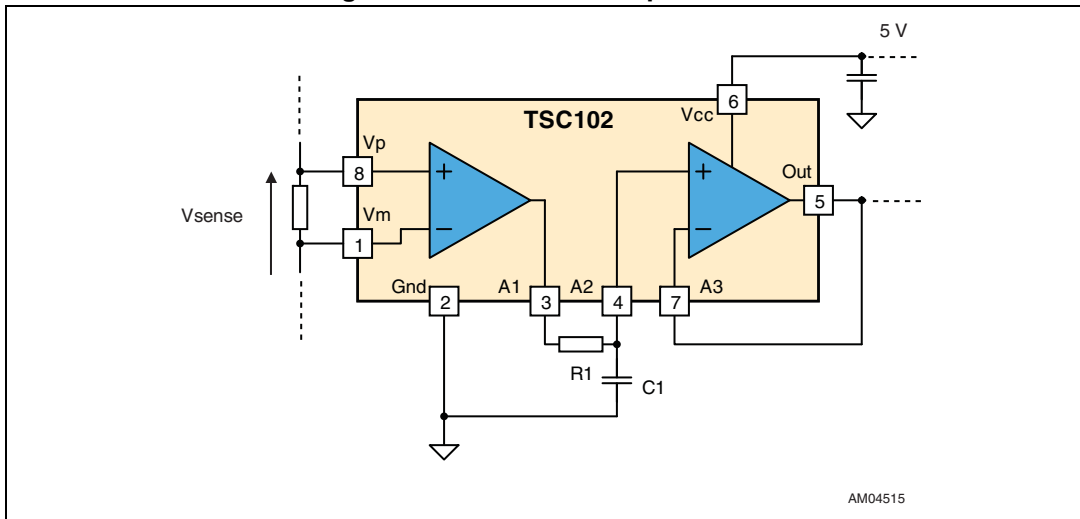
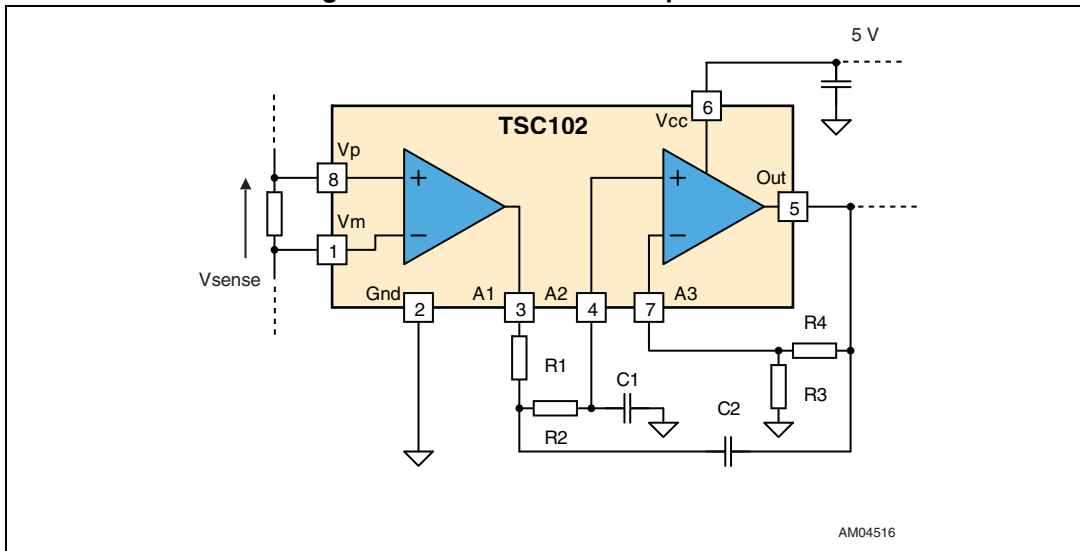


Figure 25. First-order low-pass filter



AM04515

Figure 26. Second-order low-pass filter



AM04516

8 Package information

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK[®] packages, depending on their level of environmental compliance. ECOPACK[®] specifications, grade definitions and product status are available at: www.st.com. ECOPACK[®] is an ST trademark.

8.1 TSSOP8 package information

Figure 27. TSSOP8 package mechanical drawing

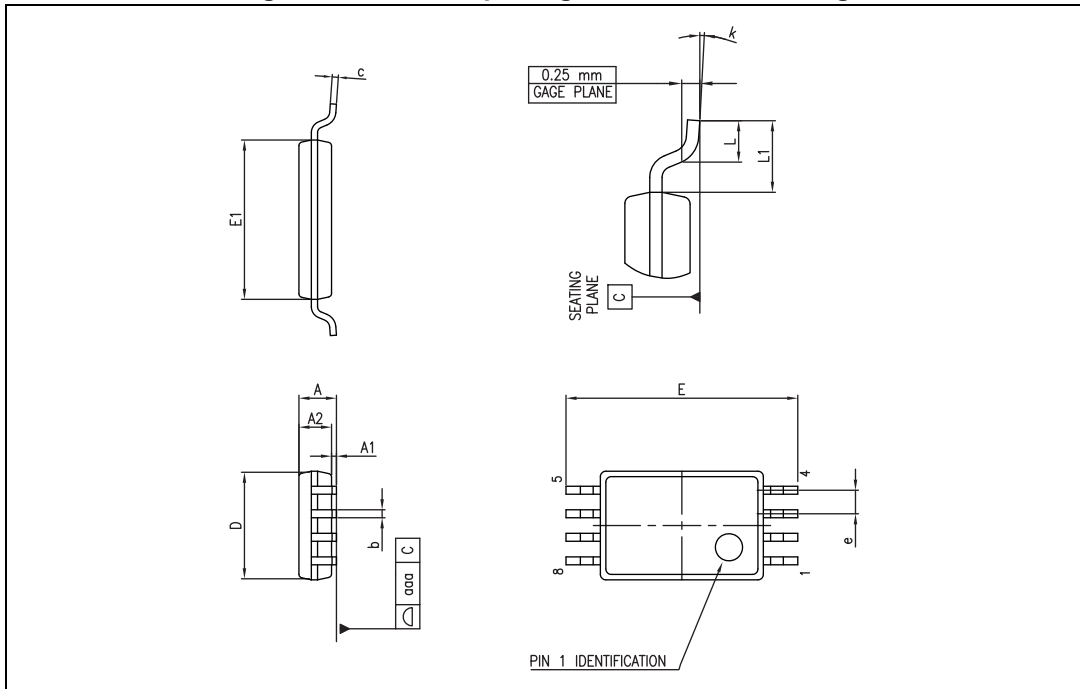


Table 10. TSSOP8 package mechanical data

| Ref. | Dimensions | | | | | |
|------|-------------|------|------|--------|--------|-------|
| | Millimeters | | | Inches | | |
| | Min. | Typ. | Max. | Min. | Typ. | Max. |
| A | | | 1.20 | | | 0.047 |
| A1 | 0.05 | | 0.15 | 0.002 | | 0.006 |
| A2 | 0.80 | 1.00 | 1.05 | 0.031 | 0.039 | 0.041 |
| b | 0.19 | | 0.30 | 0.007 | | 0.012 |
| c | 0.09 | | 0.20 | 0.004 | | 0.008 |
| D | 2.90 | 3.00 | 3.10 | 0.114 | 0.118 | 0.122 |
| E | 6.20 | 6.40 | 6.60 | 0.244 | 0.252 | 0.260 |
| E1 | 4.30 | 4.40 | 4.50 | 0.169 | 0.173 | 0.177 |
| e | | 0.65 | | | 0.0256 | |
| k | 0° | | 8° | 0° | | 8° |
| L | 0.45 | 0.60 | 0.75 | 0.018 | 0.024 | 0.030 |
| L1 | | 1 | | | 0.039 | |
| aaa | | | 0.10 | | | 0.004 |

8.2 SO8 package information

Figure 28. SO8 package mechanical drawing

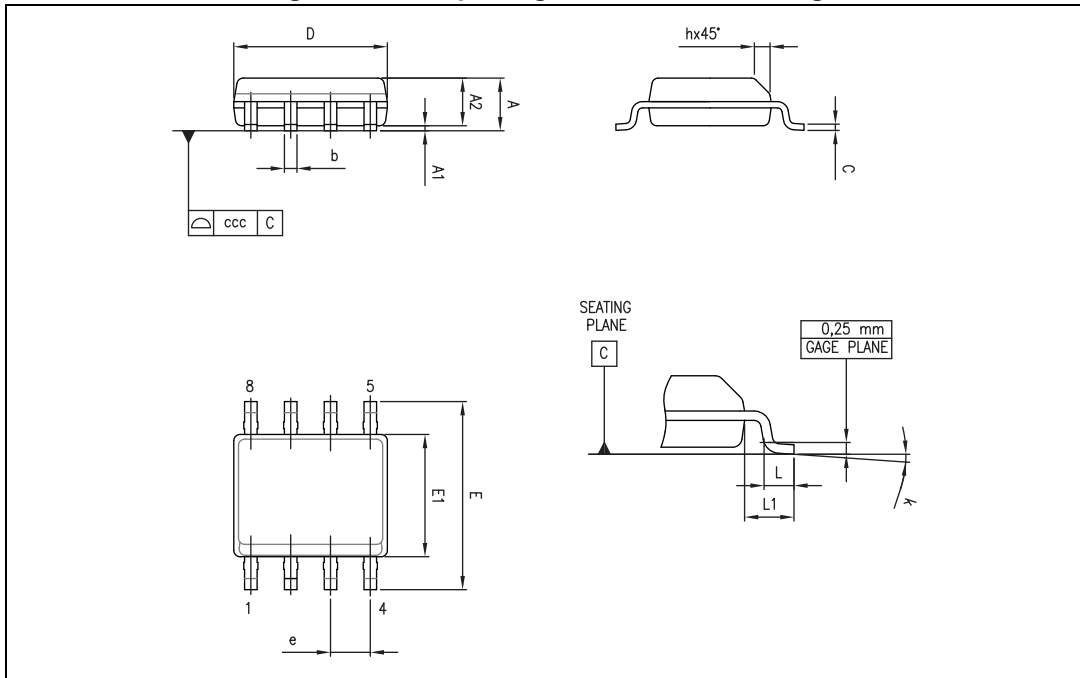


Table 11. SO8 package mechanical data

| Ref. | Dimensions | | | | | |
|------|-------------|------|------|--------|-------|-------|
| | Millimeters | | | Inches | | |
| | Min. | Typ. | Max. | Min. | Typ. | Max. |
| A | | | 1.75 | | | 0.069 |
| A1 | 0.10 | | 0.25 | 0.004 | | 0.010 |
| A2 | 1.25 | | | 0.049 | | |
| b | 0.28 | | 0.48 | 0.011 | | 0.019 |
| c | 0.17 | | 0.23 | 0.007 | | 0.010 |
| D | 4.80 | 4.90 | 5.00 | 0.189 | 0.193 | 0.197 |
| E | 5.80 | 6.00 | 6.20 | 0.228 | 0.236 | 0.244 |
| E1 | 3.80 | 3.90 | 4.00 | 0.150 | 0.154 | 0.157 |
| e | | 1.27 | | | 0.050 | |
| h | 0.25 | | 0.50 | 0.010 | | 0.020 |
| L | 0.40 | | 1.27 | 0.016 | | 0.050 |
| L1 | | 1.04 | | | 0.040 | |
| k | 0 | | 8° | 1° | | 8° |
| ccc | | | 0.10 | | | 0.004 |

9 Ordering information

Table 12. Order codes

| Part number | Temperature range | Package | Packing | Marking |
|-------------|-------------------------------------|-----------------------|---------------|----------|
| TSC102IPT | -40 °C, +125 °C | TSSOP8 | Tape and reel | 102I |
| TSC102IDT | | SO8 | | TSC102I |
| TSC102IYPT | -40 °C, +125 °C automotive grade | TSSOP8 ⁽¹⁾ | | 102Y |
| TSC102IYDT | | SO8 ⁽¹⁾ | | TSC102IY |

1. Qualification and characterization according to AEC Q100 and Q003 or equivalent, advanced screening according to AEC Q001 and Q 002 or equivalent.

10 Revision history

Table 13. Document revision history

| Date | Revision | Changes |
|-------------|----------|---|
| 09-Nov-2009 | 1 | Initial release. |
| 03-Mar-2011 | 2 | Added automotive grade qualification for SO8 package (note 2. under Table 12). |
| 31-Jan-2014 | 3 | Table 12 : Updated automotive-grade footnotes. |

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