

High bandwidth (20 MHz for gain  $\geq 4$ ) micro-power (820  $\mu$ A) rail-to-rail 5 V op amps

TSV991



TSV992



TSV994



## Features

- Low input offset voltage: 1.5 mV max. (A grade)
- Rail-to-rail input and output
- Wide bandwidth 20 MHz
- Stable for gain  $\geq 4$  or  $\leq -3$
- Low power consumption: 820  $\mu$ A typ.
- High output current: 35 mA
- Operating from 2.5 V to 5.5 V
- Low input bias current, 1 pA typ.
- ESD internal protection  $\geq 5$  kV

## Applications

- Battery-powered applications
- Portable devices
- Signal conditioning and active filtering
- Medical instrumentation
- Automotive applications

### Maturity status link

TSV991, TSV992, TSV994, TSV991A, TSV992A, TSV994A

### Related products

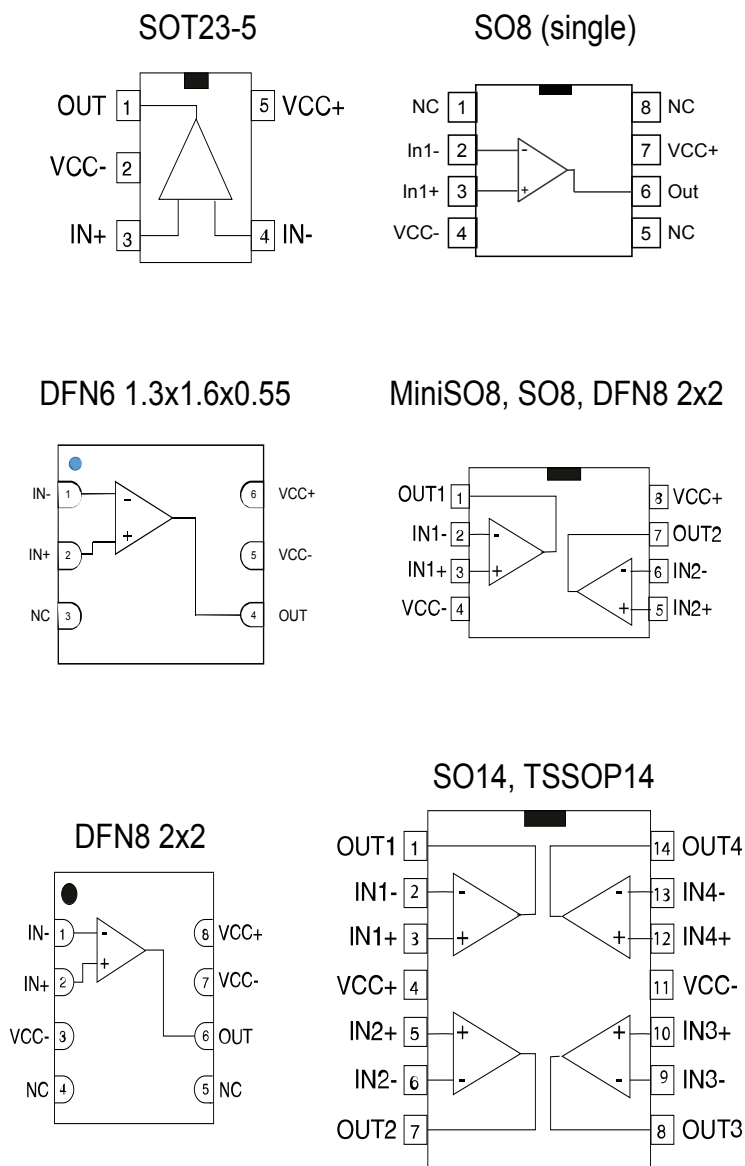
|                                                       |                                         |
|-------------------------------------------------------|-----------------------------------------|
| See TSV771, TSV772                                    | For 20 MHz unity-gain stable amplifiers |
| See TSV911, TSV912, TSV914, TSV911A, TSV912A, TSV914A | For 8 MHz unity-gain stable amplifiers  |

## Description

The TSV99x and TSV99xA family of single, dual, and quad operational amplifiers offers low voltage operation and rail-to-rail input and output. These devices feature an excellent speed/power consumption ratio, offering a 20 MHz gain-bandwidth, stable for gains above 4 (100 pF capacitive load), while consuming only 1.1 mA maximum at 5 V. They also feature an ultra-low input bias current. These characteristics make the TSV99x family ideal for sensor interfaces, battery-supplied and portable applications, as well as active filtering. These characteristics make the TSV99x, TSV99xA family ideal for sensor interfaces, battery-supplied and portable applications, as well as active filtering.

# 1 Package pin connections

Figure 1. Pin connection (top view)



## 2 Absolute maximum ratings and operating conditions

**Table 1. Absolute maximum ratings (AMR)**

| Symbol            | Parameter                                                            |                                          | Value                                                  | Unit |
|-------------------|----------------------------------------------------------------------|------------------------------------------|--------------------------------------------------------|------|
| V <sub>CC</sub>   | Supply voltage <sup>(1)</sup>                                        |                                          | 6                                                      | V    |
| V <sub>id</sub>   | Differential input voltage <sup>(2)</sup>                            |                                          | ±V <sub>CC</sub>                                       |      |
| V <sub>in</sub>   | Input voltage <sup>(3)</sup>                                         |                                          | (V <sub>CC-</sub> ) - 0.2 to (V <sub>CC+</sub> ) + 0.2 |      |
| I <sub>in</sub>   | Input current <sup>(4)</sup>                                         |                                          | 10                                                     | mA   |
| T <sub>stg</sub>  | Storage temperature                                                  |                                          | -65 to 150                                             | °C   |
| T <sub>j</sub>    | Maximum junction temperature                                         |                                          | 150                                                    |      |
| R <sub>thja</sub> | Thermal resistance junction to ambient <sup>(5)</sup> <sup>(6)</sup> | DFN8 2x2                                 | 57                                                     | °C/W |
|                   |                                                                      | DFN6<br>1.3x1.6x0.55                     | 230                                                    |      |
|                   |                                                                      | SOT23-5                                  | 250                                                    |      |
|                   |                                                                      | SO8                                      | 125                                                    |      |
|                   |                                                                      | MiniSO8                                  | 190                                                    |      |
|                   |                                                                      | SO14                                     | 103                                                    |      |
|                   |                                                                      | TSSOP14                                  | 100                                                    |      |
| R <sub>thjc</sub> | Thermal resistance junction to case                                  | SOT23-5                                  | 81                                                     |      |
|                   |                                                                      | SO8                                      | 40                                                     |      |
|                   |                                                                      | MiniSO8                                  | 39                                                     |      |
|                   |                                                                      | SO14                                     | 31                                                     |      |
|                   |                                                                      | TSSOP14                                  | 32                                                     |      |
| ESD               | HBM: human body model <sup>(7)</sup>                                 |                                          | 5                                                      | kV   |
|                   | MM: machine model <sup>(8)</sup>                                     |                                          | 400                                                    | V    |
|                   | CDM: charged device model <sup>(9)</sup>                             | SOT23-5,<br>SO8,<br>MiniSO8,<br>DFN8 2x2 | 1500                                                   |      |
|                   |                                                                      | DFN6<br>1.3x1.6x0.55                     | 1500                                                   |      |
|                   |                                                                      | TSSOP14                                  | 750                                                    |      |
|                   |                                                                      | SO14                                     | 500                                                    |      |
| Latch-up immunity |                                                                      |                                          | 200                                                    | mA   |

1. Value is with respect to the  $V_{CC-}$  pin.

2. Differential voltages are the non-inverting input terminal with respect to the inverting input terminal.

3.  $V_{CC} - V_{IN}$  must not exceed 6 V.

4. Input current must be limited by a resistor in series with the inputs.

5. Short-circuits can cause excessive heating and destructive dissipation.

6.  $R_{th}$  are typical values.

7. Human body model: 100 pF discharged through a 1.5 k $\Omega$  resistor between two pins of the device, done for all couples of pin combinations with other pins floating.

8. Machine model: 200 pF charged to the specified voltage, then discharged directly between two pins of the device with no external series resistor (internal resistor < 5  $\Omega$ ), done for all couples of pin combinations with other pins floating.

9. Charged device model: all pins plus packages are charged together to the specified voltage and then discharged directly to the ground.

**Table 2. Operating conditions**

| Symbol    | Parameter                            | Value                                  | Unit |
|-----------|--------------------------------------|----------------------------------------|------|
| $V_{CC}$  | Supply voltage                       | 2.5 to 5.5                             | V    |
| $V_{icm}$ | Common mode input voltage range      | $(V_{CC-}) - 0.1$ to $(V_{CC+}) + 0.1$ |      |
| $T_{op}$  | Operating free air temperature range | -40 to 125                             | °C   |

### 3 Electrical characteristics

**Note:** In the electrical characteristic tables below, all parameter limits at temperatures other than 25 °C are guaranteed by correlation.

**Table 3. Electrical characteristics at  $V_{CC+} = 2.5\text{ V}$ ,  $V_{CC-} = 0\text{ V}$ ,  $V_{icm} = V_{CC}/2$ , with  $R_L$  connected to  $V_{CC}/2$ , full temperature range (unless otherwise specified)**

| Symbol                   | Parameter                                                               | Conditions                                                                                                                                                     | Min. | Typ. | Max. | Unit                    |
|--------------------------|-------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------|------|-------------------------|
| <b>DC performance</b>    |                                                                         |                                                                                                                                                                |      |      |      |                         |
| $V_{io}$                 | Offset voltage, TSV99x                                                  | $T_{op} = 25\text{ °C}$                                                                                                                                        |      | 0.1  | 4.5  | mV                      |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                   |      |      | 7.5  |                         |
|                          | Offset voltage, TSV99xA                                                 | $T_{op} = 25\text{ °C}$                                                                                                                                        |      |      | 1.5  |                         |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                   |      |      | 3    |                         |
| $\Delta V_{io}/\Delta T$ | Input offset voltage drift                                              |                                                                                                                                                                |      | 2    |      | $\mu\text{V}/\text{°C}$ |
| $I_{io}$                 | Input offset current, $V_{out} = V_{CC}/2$<br>(1)                       | $T_{op} = 25\text{ °C}$                                                                                                                                        |      | 1    | 10   | pA                      |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                   |      |      | 100  |                         |
| $I_{ib}$                 | Input bias current, $V_{out} = V_{CC}/2$<br>(1)                         | $T_{op} = 25\text{ °C}$                                                                                                                                        |      | 1    | 10   |                         |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                   |      |      | 100  |                         |
| CMR                      | Common mode rejection ratio,<br>$20 \log (\Delta V_{ic}/\Delta V_{io})$ | $0\text{ V to } 2.5\text{ V}$ , $V_{out} = 1.25\text{ V}$ , $T_{op} = 25\text{ °C}$                                                                            | 58   | 75   |      | dB                      |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                   | 53   |      |      |                         |
| $A_{vd}$                 | Large signal voltage gain                                               | $R_L = 10\text{ k}\Omega$ , $V_{out} = 0.5\text{ V to } 2\text{ V}$ ,<br>$T_{op} = 25\text{ °C}$                                                               | 80   | 89   |      |                         |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                   | 75   |      |      |                         |
| $V_{CC} - V_{OH}$        | High-level output voltage                                               | $R_L = 10\text{ k}\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                       |      | 15   | 40   | mV                      |
|                          |                                                                         | $R_L = 600\text{ }\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                       |      | 45   | 150  |                         |
| $V_{OL}$                 | Low-level output voltage                                                | $R_L = 10\text{ k}\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                       |      | 15   | 40   |                         |
|                          |                                                                         | $R_L = 600\text{ }\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                       |      | 45   | 150  |                         |
| $I_{out}$                | $I_{sink}$                                                              | $V_o = 2.5\text{ V}$ , $T_{op} = 25\text{ °C}$                                                                                                                 | 18   | 32   |      | mA                      |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                   | 16   |      |      |                         |
|                          | $I_{source}$                                                            | $V_o = 0\text{ V}$ , $T_{op} = 25\text{ °C}$                                                                                                                   | 18   | 35   |      |                         |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                   | 16   |      |      |                         |
| $I_{CC}$                 | Supply current (per channel)                                            | No load, $V_{out} = V_{CC}/2$ , $T_{min} < T_{op} < T_{max}$                                                                                                   |      | 0.78 | 1.1  |                         |
| <b>AC performance</b>    |                                                                         |                                                                                                                                                                |      |      |      |                         |
| GBP                      | Gain bandwidth product                                                  | $R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $f = 100\text{ kHz}$ ,<br>$T_{op} = 25\text{ °C}$                                                           |      | 20   |      | MHz                     |
| Gain                     | Minimum gain for stability                                              | Phase margin = 45°, $R_f = 10\text{ k}\Omega$ ,<br>$R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $T_{op} = 25\text{ °C}$ ,<br>positive gain configuration |      | 4    |      | V/V                     |
| Gain                     | Minimum gain for stability                                              | Phase margin = 45°, $R_f = 10\text{ k}\Omega$ ,<br>$R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $T_{op} = 25\text{ °C}$ ,<br>negative gain configuration |      | -3   |      | V/V                     |
| SR                       | Slew rate                                                               | $R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $T_{op} = 25\text{ °C}$                                                                                     |      | 10   |      | V/ $\mu\text{s}$        |



| Symbol | Parameter                      | Conditions                                                                                                                                                                           | Min. | Typ.   | Max. | Unit                         |
|--------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|--------|------|------------------------------|
| $e_n$  | Equivalent input noise voltage | $f = 10 \text{ kHz}$ , $T_{op} = 25 \text{ }^{\circ}\text{C}$                                                                                                                        |      | 21     |      | $\text{nV}/\sqrt{\text{Hz}}$ |
| THD+N  | Total harmonic distortion      | $G = -3$ , $f = 1 \text{ kHz}$ , $R_L = 2 \text{ k}\Omega$ , $Bw = 22 \text{ kHz}$ , $V_{icm} = V_{CC}/2$ , $V_{out} = 2 \text{ V}_{pp}$ ,<br>$T_{op} = 25 \text{ }^{\circ}\text{C}$ |      | 0.0025 |      | %                            |

1. Guaranteed by design.

**Table 4. Electrical characteristics at  $V_{CC+} = 3.3\text{ V}$ ,  $V_{CC-} = 0\text{ V}$ ,  $V_{icm} = V_{CC}/2$ , with  $R_L$  connected to  $V_{CC}/2$ , full temperature range (unless otherwise specified)**

| Symbol                   | Parameter                                                               | Conditions                                                                                                                                                                             | Min. | Typ.   | Max. | Unit                           |
|--------------------------|-------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|--------|------|--------------------------------|
| <b>DC performance</b>    |                                                                         |                                                                                                                                                                                        |      |        |      |                                |
| $V_{io}$                 | Offset voltage, TSV99x                                                  | $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                                                  |      | 0.1    | 4.5  | mV                             |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           |      |        | 7.5  |                                |
|                          | Offset voltage, TSV99xA                                                 | $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                                                  |      |        | 1.5  |                                |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           |      |        | 3    |                                |
| $\Delta V_{io}/\Delta T$ | Input offset voltage drift                                              |                                                                                                                                                                                        |      | 2      |      | $\mu\text{V}/^{\circ}\text{C}$ |
| $I_{io}$                 | Input offset current, $V_{out} = V_{CC}/2$<br>(1)                       | $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                                                  |      | 1      | 10   | pA                             |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           |      |        | 100  |                                |
| $I_{ib}$                 | Input bias current, $V_{out} = V_{CC}/2$<br>(1)                         | $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                                                  |      | 1      | 10   |                                |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           |      |        | 100  |                                |
| CMR                      | Common mode rejection ratio,<br>$20 \log (\Delta V_{ic}/\Delta V_{io})$ | $0\text{ V to } 3.3\text{ V}$ , $V_{out} = 1.65\text{ V}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                      | 60   | 78     |      | dB                             |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           | 55   |        |      |                                |
| $A_{vd}$                 | Large signal voltage gain                                               | $R_L = 10\text{ k}\Omega$ , $V_{out} = 0.5\text{ V to } 2.8\text{ V}$ ,<br>$T_{op} = 25\text{ }^{\circ}\text{C}$                                                                       | 80   | 89     |      |                                |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           | 75   |        |      |                                |
| $V_{CC} - V_{OH}$        | High-level output voltage                                               | $R_L = 10\text{ k}\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                                               |      | 15     | 40   | mV                             |
|                          |                                                                         | $R_L = 600\text{ }\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                                               |      | 45     | 150  |                                |
| $V_{OL}$                 | Low-level output voltage                                                | $R_L = 10\text{ k}\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                                               |      | 15     | 40   |                                |
|                          |                                                                         | $R_L = 600\text{ }\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                                               |      | 45     | 150  |                                |
| $I_{out}$                | $I_{sink}$                                                              | $V_o = 3.3\text{ V}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                           | 18   | 32     |      | mA                             |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           | 16   |        |      |                                |
|                          | $I_{source}$                                                            | $V_o = 0\text{ V}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                             | 18   | 35     |      |                                |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           | 16   |        |      |                                |
| $I_{CC}$                 | Supply current (per channel)                                            | No load, $V_{out} = V_{CC}/2$ , $T_{min} < T_{op} < T_{max}$                                                                                                                           |      | 0.8    | 1.1  |                                |
| <b>AC performance</b>    |                                                                         |                                                                                                                                                                                        |      |        |      |                                |
| GBP                      | Gain bandwidth product                                                  | $R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $f = 100\text{ kHz}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                        |      | 20     |      | MHz                            |
| Gain                     | Minimum gain for stability                                              | Phase margin = $45^{\circ}$ , $R_f = 10\text{ k}\Omega$ ,<br>$R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$ ,<br>positive gain configuration |      | 4      |      | V/V                            |
|                          |                                                                         | Phase margin = $45^{\circ}$ , $R_f = 10\text{ k}\Omega$ ,<br>$R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$ ,<br>negative gain configuration |      | -3     |      |                                |
| SR                       | Slew rate                                                               | $R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $f = 100\text{ kHz}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                        |      | 10     |      | V/ $\mu\text{s}$               |
| $e_n$                    | Equivalent input noise voltage                                          | $f = 10\text{ kHz}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                            |      | 21     |      | nV/ $\sqrt{\text{Hz}}$         |
| THD+N                    | Total harmonic distortion                                               | $G = -3$ , $f = 1\text{ kHz}$ , $R_L = 2\text{ k}\Omega$ , $B_w = 22\text{ kHz}$ , $V_{icm} = V_{CC}/2$ , $V_{out} = 2.8\text{ V}_{pp}$ ,<br>$T_{op} = 25\text{ }^{\circ}\text{C}$     |      | 0.0018 |      | %                              |

1. Guaranteed by design.

**Table 5. Electrical characteristics at  $V_{CC+} = 5\text{ V}$ ,  $V_{CC-} = 0\text{ V}$ ,  $V_{icm} = V_{CC}/2$ , with  $R_L$  connected to  $V_{CC}/2$ , full temperature range (unless otherwise specified)**

| Symbol                   | Parameter                                                               | Conditions                                                                                                                                                                             | Min. | Typ. | Max. | Unit                           |
|--------------------------|-------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------|------|--------------------------------|
| <b>DC performance</b>    |                                                                         |                                                                                                                                                                                        |      |      |      |                                |
| $V_{io}$                 | Offset voltage, TSV99x                                                  | $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                                                  |      | 0.1  | 4.5  | mV                             |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           |      |      | 7.5  |                                |
|                          | Offset voltage, TSV99xA                                                 | $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                                                  |      |      | 1.5  |                                |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           |      |      | 3    |                                |
| $\Delta V_{io}/\Delta T$ | Input offset voltage drift                                              |                                                                                                                                                                                        |      | 2    |      | $\mu\text{V}/^{\circ}\text{C}$ |
| $I_{io}$                 | Input offset current, $V_{out} = V_{CC}/2$<br>(1)                       | $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                                                  |      | 1    | 10   | pA                             |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           |      |      | 100  |                                |
| $I_{ib}$                 | Input bias current, $V_{out} = V_{CC}/2$<br>(1)                         | $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                                                  |      | 1    | 10   |                                |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           |      |      | 100  |                                |
| CMR                      | Common mode rejection ratio,<br>$20 \log (\Delta V_{ic}/\Delta V_{io})$ | 0 V to 5 V, $V_{out} = 2.5\text{ V}$ ,<br>$T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                        | 62   | 82   |      | dB                             |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           | 57   |      |      |                                |
| SVR                      | Supply voltage rejection ratio, $20 \log (\Delta V_{cc}/\Delta V_{io})$ | $V_{CC} = 2.5\text{ V to } 5\text{ V}$                                                                                                                                                 | 70   | 86   |      |                                |
| $A_{vd}$                 | Large signal voltage gain                                               | $R_L = 10\text{ k}\Omega$ , $V_{out} = 0.5\text{ V to } 4.5\text{ V}$ ,<br>$T_{op} = 25\text{ }^{\circ}\text{C}$                                                                       | 80   | 91   |      |                                |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           | 75   |      |      |                                |
| $V_{CC} - V_{OH}$        | High-level output voltage                                               | $R_L = 10\text{ k}\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                                               |      | 15   | 40   | mV                             |
|                          |                                                                         | $R_L = 600\text{ }\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                                               |      | 45   | 150  |                                |
| $V_{OL}$                 | Low-level output voltage                                                | $R_L = 10\text{ k}\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                                               |      | 15   | 40   |                                |
|                          |                                                                         | $R_L = 600\text{ }\Omega$ , $T_{min} < T_{op} < T_{max}$                                                                                                                               |      | 45   | 150  |                                |
| $I_{out}$                | $I_{sink}$                                                              | $V_o = 5\text{ V}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                             | 18   | 32   |      | mA                             |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           | 16   |      |      |                                |
|                          | $I_{source}$                                                            | $V_o = 0\text{ V}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                             | 18   | 35   |      |                                |
|                          |                                                                         | $T_{min} < T_{op} < T_{max}$                                                                                                                                                           | 16   |      |      |                                |
| $I_{CC}$                 | Supply current (per channel)                                            | No load, $V_{out} = 2.5\text{ V}$ , $T_{min} < T_{op} < T_{max}$                                                                                                                       |      | 0.82 | 1.1  |                                |
| <b>AC performance</b>    |                                                                         |                                                                                                                                                                                        |      |      |      |                                |
| GBP                      | Gain bandwidth product                                                  | $R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $f = 100\text{ kHz}$ ,<br>$T_{op} = 25\text{ }^{\circ}\text{C}$                                                                     |      | 20   |      | MHz                            |
| Gain                     | Minimum gain for stability                                              | Phase margin = $45^{\circ}$ , $R_f = 10\text{ k}\Omega$ ,<br>$R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$ ,<br>positive gain configuration |      | 4    |      | V/V                            |
|                          |                                                                         | Phase margin = $45^{\circ}$ , $R_f = 10\text{ k}\Omega$ ,<br>$R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$ ,<br>negative gain configuration |      | -3   |      |                                |
| SR                       | Slew rate                                                               | $R_L = 2\text{ k}\Omega$ , $C_L = 100\text{ pF}$ , $f = 100\text{ kHz}$ ,<br>$T_{op} = 25\text{ }^{\circ}\text{C}$                                                                     |      | 10   |      | V/ $\mu\text{s}$               |
| $e_n$                    | Equivalent input noise voltage                                          | $f = 10\text{ kHz}$ , $T_{op} = 25\text{ }^{\circ}\text{C}$                                                                                                                            |      | 21   |      | nV/ $\sqrt{\text{Hz}}$         |

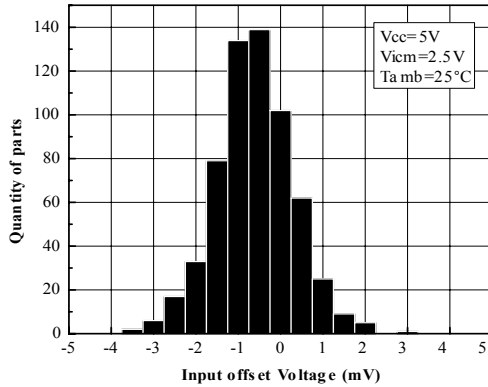
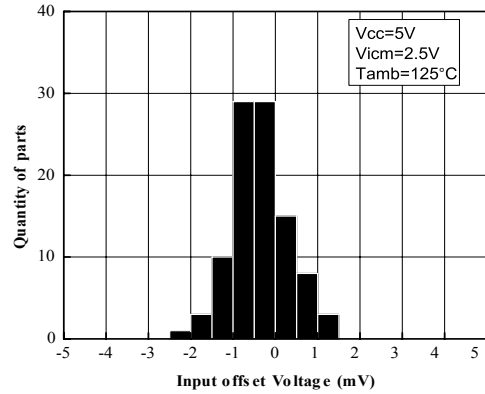
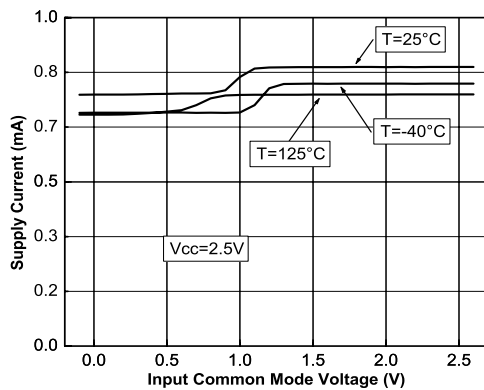
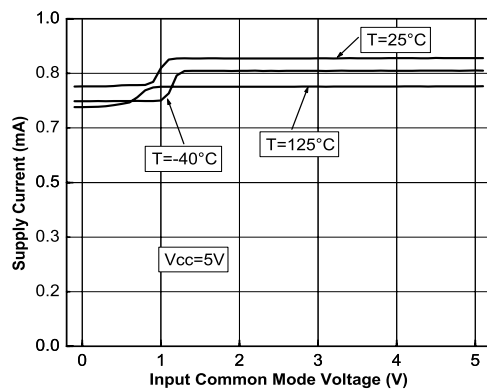
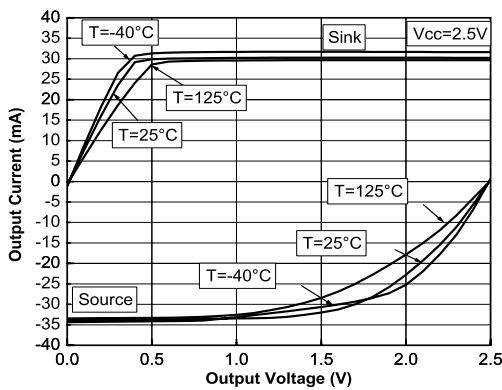
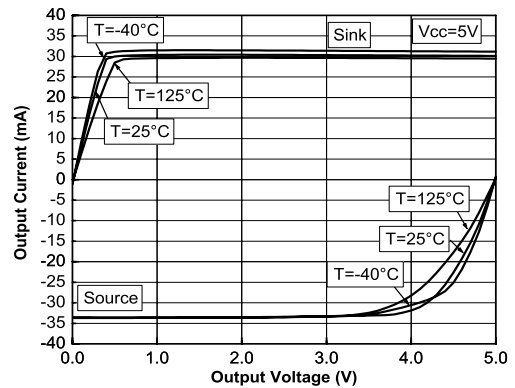




| Symbol | Parameter                 | Conditions                                                                                                                        | Min. | Typ.   | Max. | Unit |
|--------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------|------|--------|------|------|
| THD+N  | Total harmonic distortion | $G = -3$ , $f = 1$ kHz, $R_L = 2$ k $\Omega$ , $Bw = 22$ kHz, $V_{icm} = V_{CC}/2$ , $V_{out} = 4.4 V_{pp}$ ,<br>$T_{op} = 25$ °C |      | 0.0014 |      | %    |

1. Guaranteed by design.

## 4 Electrical characteristic curves

**Figure 2. Input offset voltage distribution at  $T = 25^{\circ}\text{C}$** 

**Figure 3. Input offset voltage distribution at  $T = 125^{\circ}\text{C}$** 

**Figure 4. Supply current vs. input common-mode voltage at  $V_{CC} = 2.5\text{ V}$** 

**Figure 5. Supply current vs. input common-mode voltage at  $V_{CC} = 5\text{ V}$** 

**Figure 6. Output current vs. output voltage at  $V_{CC} = 2.5\text{ V}$** 

**Figure 7. Output current vs. output voltage at  $V_{CC} = 5\text{ V}$** 


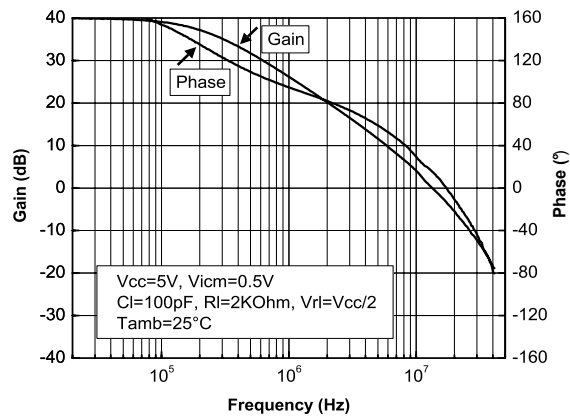
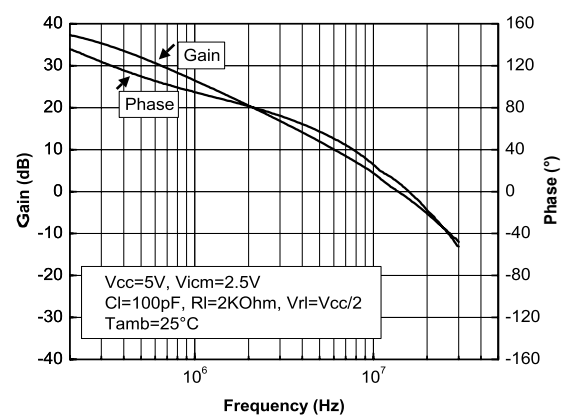
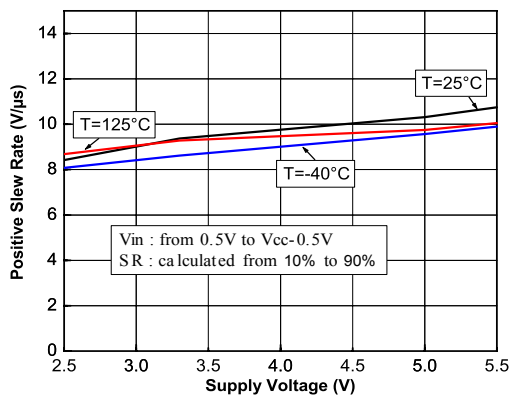
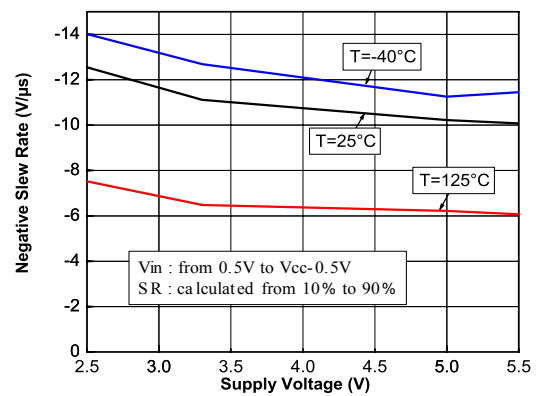
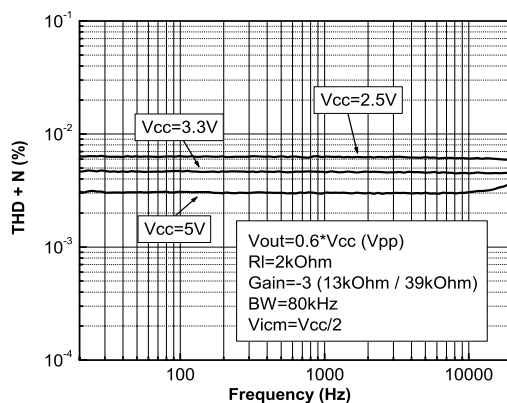
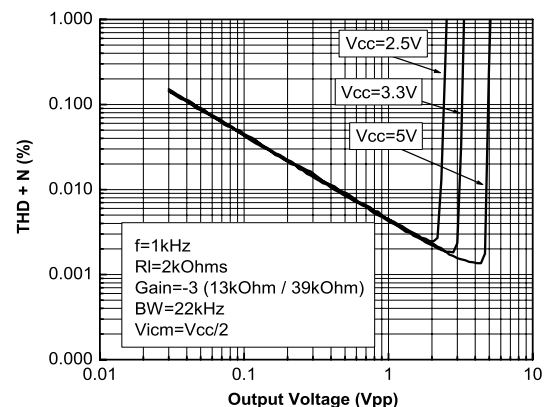
**Figure 8. Voltage gain and phase vs. frequency at  $V_{CC} = 5$  V and  $V_{icm} = 0.5$  V**

**Figure 9. Voltage gain and phase vs. frequency at  $V_{CC} = 5$  V and  $V_{icm} = 2.5$  V**

**Figure 10. Positive slew rate**

**Figure 11. Negative slew rate**

**Figure 12. Distortion + noise vs. frequency**

**Figure 13. Distortion + noise vs. output voltage**


Figure 14. Noise vs. frequency

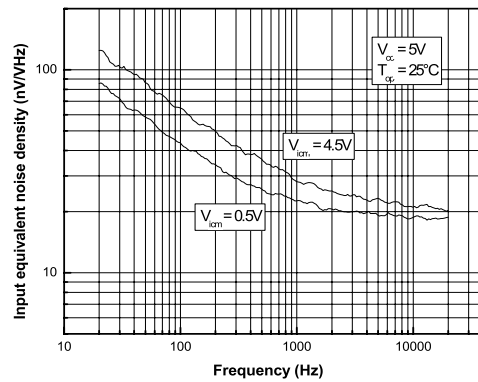
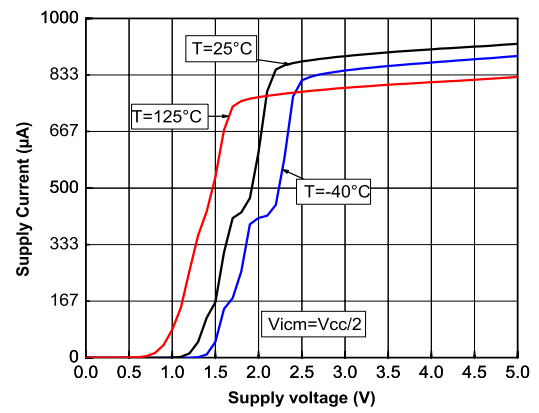


Figure 15. Supply current vs. supply voltage



## 5 Application information

### 5.1 Driving resistive and capacitive loads

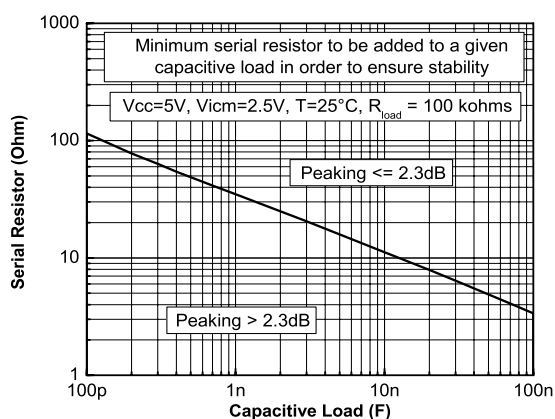
These products are low-voltage, low-power operational amplifiers optimized to drive rather large resistive loads above 2 k $\Omega$ .

The TSV99x products are not unity gain stable. To ensure proper stability they must be used in a gain configuration, with a minimum gain of -3 or 4.

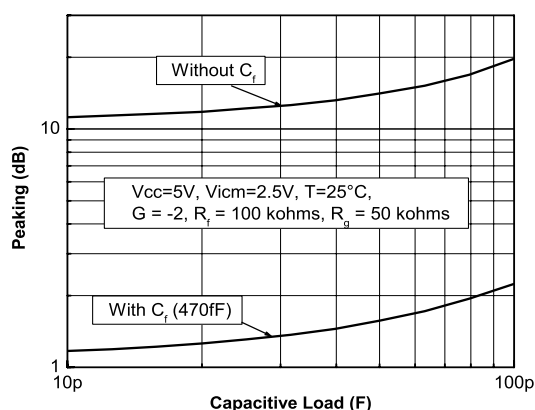
However, they can be used in a "follower" configuration by adding a small, in-series resistor at the output, which drastically improves the stability of the device (Figure 16 shows the recommended in-series resistor values). Once the in-series resistor value has been selected, the stability of the circuit should be tested on the bench and simulated with the simulation model.

Another way to improve stability and reduce peaking is to add a capacitor in parallel with the feedback resistor. As shown in Figure 17, the feedback capacitor drastically reduces the peaking versus capacitive load (inverting gain configuration, gain = -2).

**Figure 16. In-series resistor vs. capacitive load when TSV99x is used in follower configuration**



**Figure 17. Peaking versus capacitive load, with or without feedback capacitor in inverting gain configuration**



### 5.2 PCB layouts

For correct operation, it is advised to add 10 nF decoupling capacitors as close as possible to the power supply pins.

### 5.3 Macromodel

An accurate macromodel of the TSV99x is available on STMicroelectronics' web site at [www.st.com](http://www.st.com). This model is a trade-off between accuracy and complexity (that is, time simulation) of the TSV99x operational amplifiers. It emulates the nominal performance of a typical device within the specified operating conditions mentioned in the datasheet. It helps to validate a design approach and to select the right operational amplifier, however, it does not replace on-board measurements.



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## 6 Package information

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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](http://www.st.com). ECOPACK is an ST trademark.

## 6.1 SOT23-5 package information

Figure 18. SOT23-5 package outline

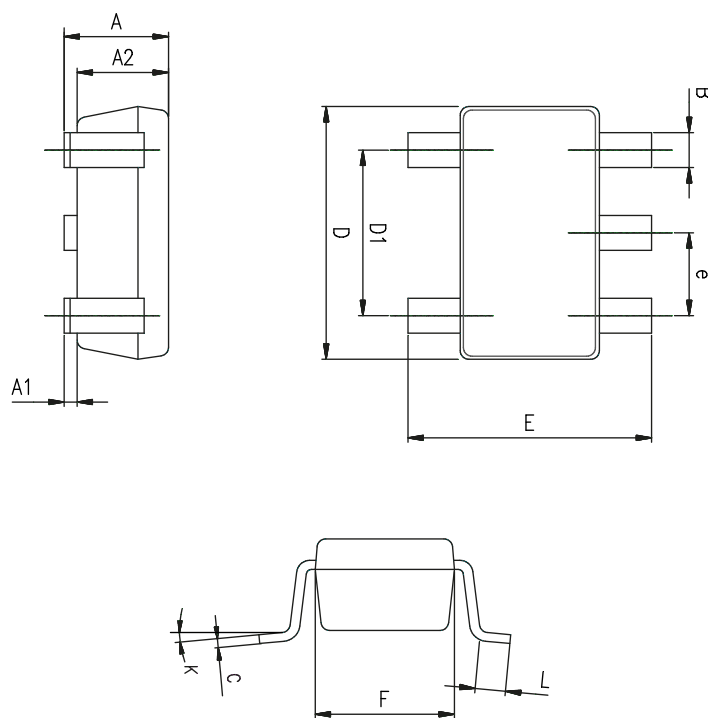


Table 6. SOT23-5 mechanical data

| Ref. | Dimensions  |      |            |           |       |            |
|------|-------------|------|------------|-----------|-------|------------|
|      | Millimeters |      |            | Inches    |       |            |
|      | Min.        | Typ. | Max.       | Min.      | Typ.  | Max.       |
| A    | 0.90        | 1.20 | 1.45       | 0.035     | 0.047 | 0.057      |
| A1   |             |      | 0.15       |           |       | 0.006      |
| A2   | 0.90        | 1.05 | 1.30       | 0.035     | 0.041 | 0.051      |
| B    | 0.35        | 0.40 | 0.50       | 0.014     | 0.016 | 0.020      |
| C    | 0.09        | 0.15 | 0.20       | 0.004     | 0.006 | 0.008      |
| D    | 2.80        | 2.90 | 3.00       | 0.110     | 0.114 | 0.118      |
| D1   |             | 1.90 |            |           | 0.075 |            |
| e    |             | 0.95 |            |           | 0.037 |            |
| E    | 2.60        | 2.80 | 3.00       | 0.102     | 0.110 | 0.118      |
| F    | 1.50        | 1.60 | 1.75       | 0.059     | 0.063 | 0.069      |
| L    | 0.10        | 0.35 | 0.60       | 0.004     | 0.014 | 0.024      |
| K    | 0 degrees   |      | 10 degrees | 0 degrees |       | 10 degrees |

## 6.2 DFN8 2 x 2 package information

Figure 19. DFN8 2 x 2 package outline

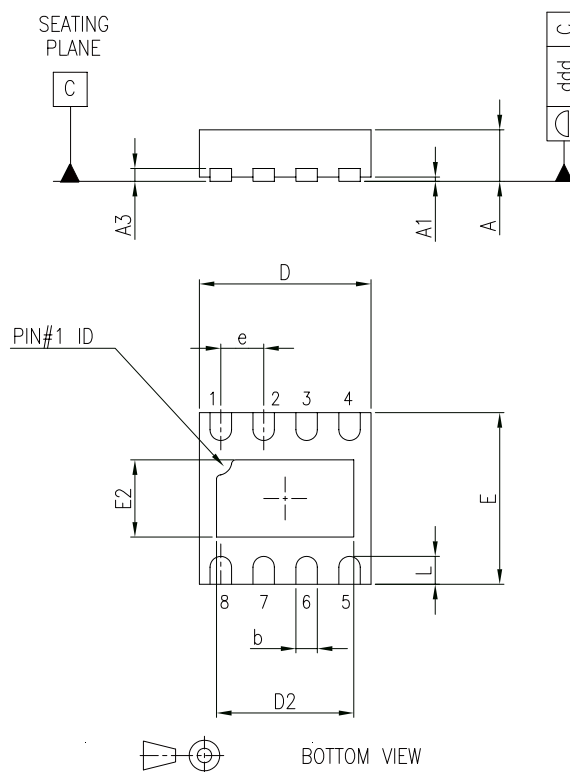
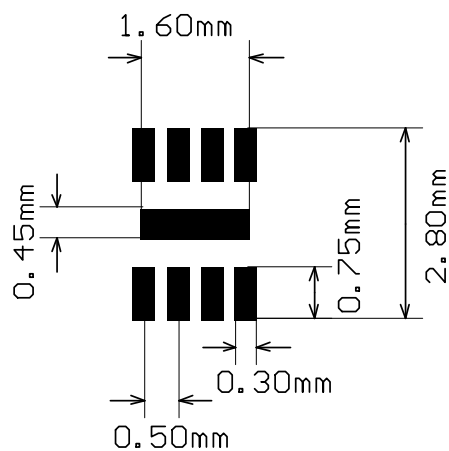


Table 7. DFN8 2 x 2 mechanical data

| Ref. | Dimensions  |      |       |        |       |       |
|------|-------------|------|-------|--------|-------|-------|
|      | Millimeters |      |       | Inches |       |       |
|      | Min.        | Typ. | Max.  | Min.   | Typ.  | Max.  |
| A    | 0.51        | 0.55 | 0.60  | 0.020  | 0.022 | 0.024 |
| A1   |             |      | 0.05  |        |       | 0.002 |
| A3   |             | 0.15 |       |        | 0.006 |       |
| b    | 0.18        | 0.25 | 0.30  | 0.007  | 0.010 | 0.012 |
| D    | 1.85        | 2.00 | 2.15  | 0.073  | 0.079 | 0.085 |
| D2   | 1.45        | 1.60 | 1.70  | 0.057  | 0.063 | 0.067 |
| E    | 1.85        | 2.00 | 2.15  | 0.073  | 0.079 | 0.085 |
| E2   | 0.75        | 0.90 | 1.00  | 0.030  | 0.035 | 0.039 |
| e    |             | 0.50 |       |        | 0.020 |       |
| L    |             |      | 0.425 |        |       | 0.017 |
| ddd  |             |      | 0.08  |        |       | 0.003 |



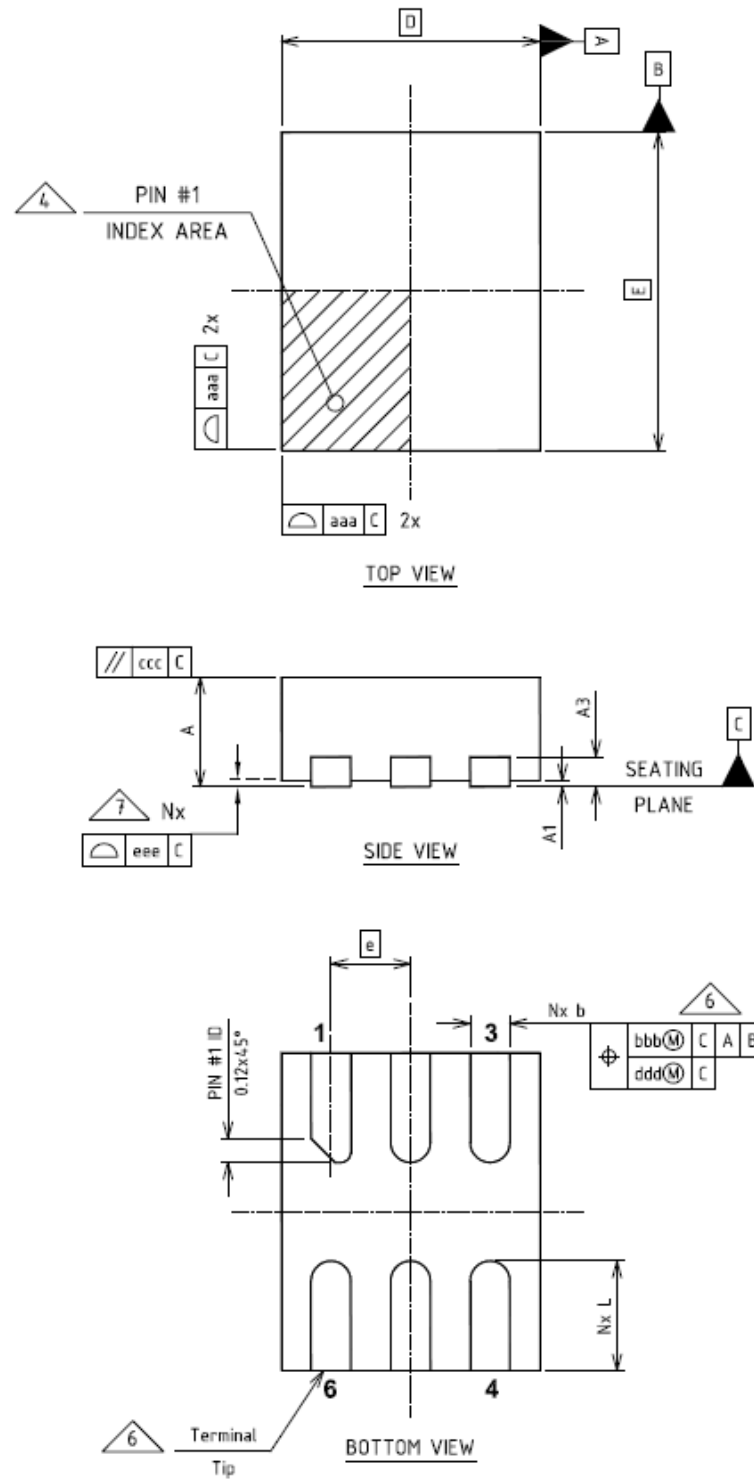
Figure 20. DFN8 2 x 2 recommended footprint



**Note:** The exposed pad of the DFN8 2x2 package is not internally connected. It can be set to  $V_{CC^-}$  or left floating.

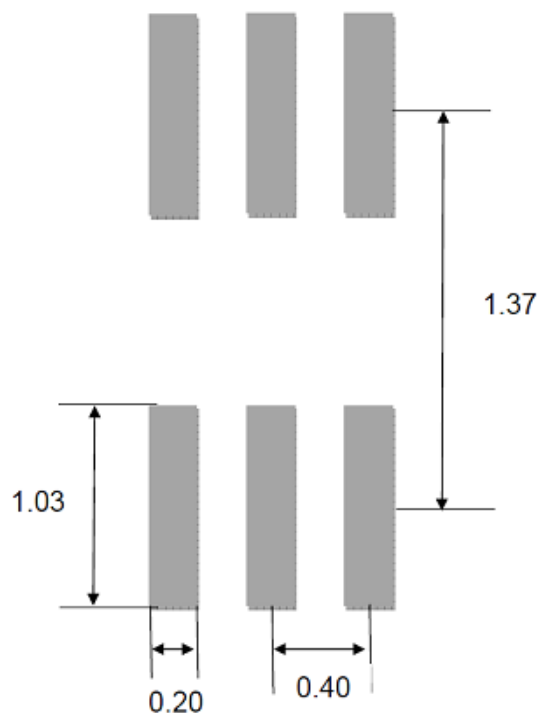
### 6.3 DFN6 1.3 x 1.6 x 0.55 package information

Figure 21. DFN6 1.3 x 1.6 x 0.55 package outline



**Table 8. DFN6 1.3 x 1.6 x 0.55 mechanical data**

| Ref. | Dimensions  |       |       |        |       |       |
|------|-------------|-------|-------|--------|-------|-------|
|      | Millimeters |       |       | Inches |       |       |
|      | Min.        | Typ.  | Max.  | Min.   | Typ.  | Max.  |
| A    | 0.50        | 0.55  | 0.60  | 0.020  | 0.022 | 0.024 |
| A1   | 0.00        | 0.02  | 0.05  | 0.000  | 0.001 | 0.002 |
| A3   |             | 0.15  |       |        | 0.006 |       |
| B    | 0.15        | 0.20  | 0.25  | 0.006  | 0.008 | 0.010 |
| D    |             | 1.30  |       |        | 0.051 |       |
| E    |             | 1.60  |       |        | 0.063 |       |
| e    |             | 0.40  |       |        | 0.016 |       |
| L    | 0.453       | 0.553 | 0.653 | 0.018  | 0.022 | 0.026 |
| N    |             | 6     |       |        | 0.236 |       |
| aaa  |             | 0.05  |       |        | 0.002 |       |
| bbb  |             | 0.07  |       |        | 0.003 |       |
| ccc  |             | 0.10  |       |        | 0.004 |       |
| ddd  |             | 0.05  |       |        | 0.002 |       |
| eee  |             | 0.08  |       |        | 0.003 |       |

**Figure 22. DFN6 1.3 x 1.6 x 0.55 recommended footprint**


## 6.4 MiniSO8 package information

Figure 23. MiniSO8 package outline

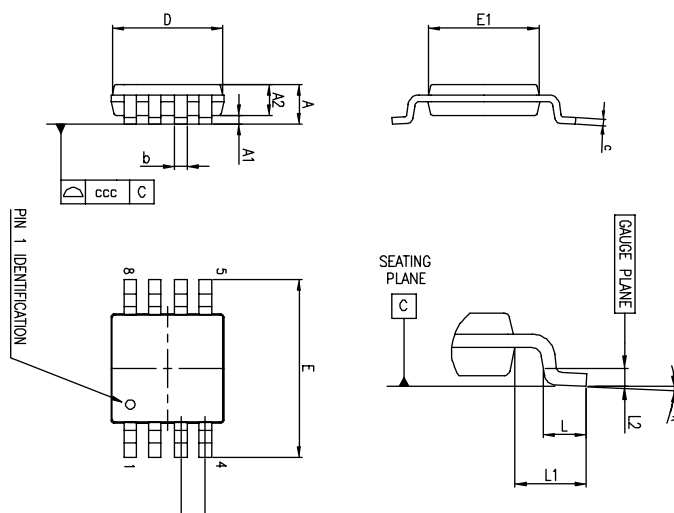


Table 9. MiniSO8 package mechanical data

| Ref. | Dimensions  |      |      |        |       |        |
|------|-------------|------|------|--------|-------|--------|
|      | Millimeters |      |      | Inches |       |        |
|      | Min.        | Typ. | Max. | Min.   | Typ.  | Max.   |
| A    |             |      | 1.1  |        |       | 0.043  |
| A1   | 0           |      | 0.15 | 0      |       | 0.0006 |
| A2   | 0.75        | 0.85 | 0.95 | 0.030  | 0.033 | 0.037  |
| b    | 0.22        |      | 0.40 | 0.009  |       | 0.016  |
| c    | 0.08        |      | 0.23 | 0.003  |       | 0.009  |
| D    | 2.80        | 3.00 | 3.20 | 0.11   | 0.118 | 0.126  |
| E    | 4.65        | 4.90 | 5.15 | 0.183  | 0.193 | 0.203  |
| E1   | 2.80        | 3.00 | 3.10 | 0.11   | 0.118 | 0.122  |
| e    |             | 0.65 |      |        | 0.026 |        |
| L    | 0.40        | 0.60 | 0.80 | 0.016  | 0.024 | 0.031  |
| L1   |             | 0.95 |      |        | 0.037 |        |
| L2   |             | 0.25 |      |        | 0.010 |        |
| k    | 0°          |      | 8°   | 0°     |       | 8°     |
| ccc  |             |      | 0.10 |        |       | 0.004  |

## 6.5 SO8 package information

Figure 24. SO8 package outline

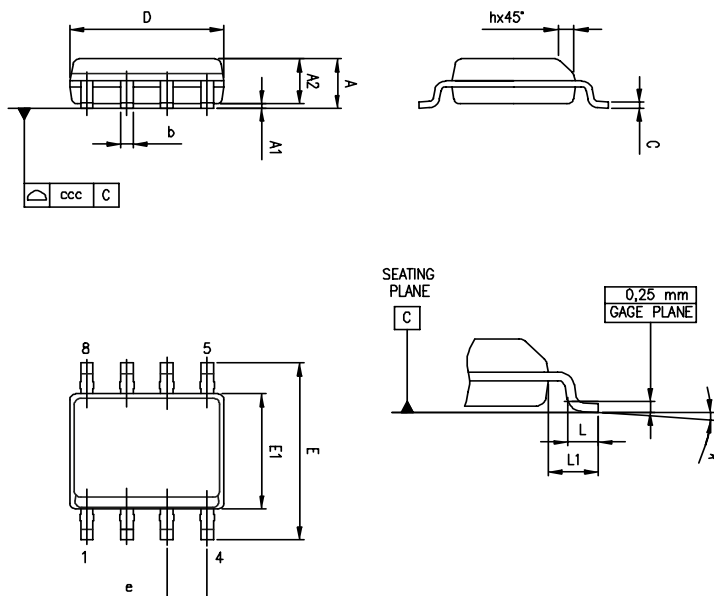
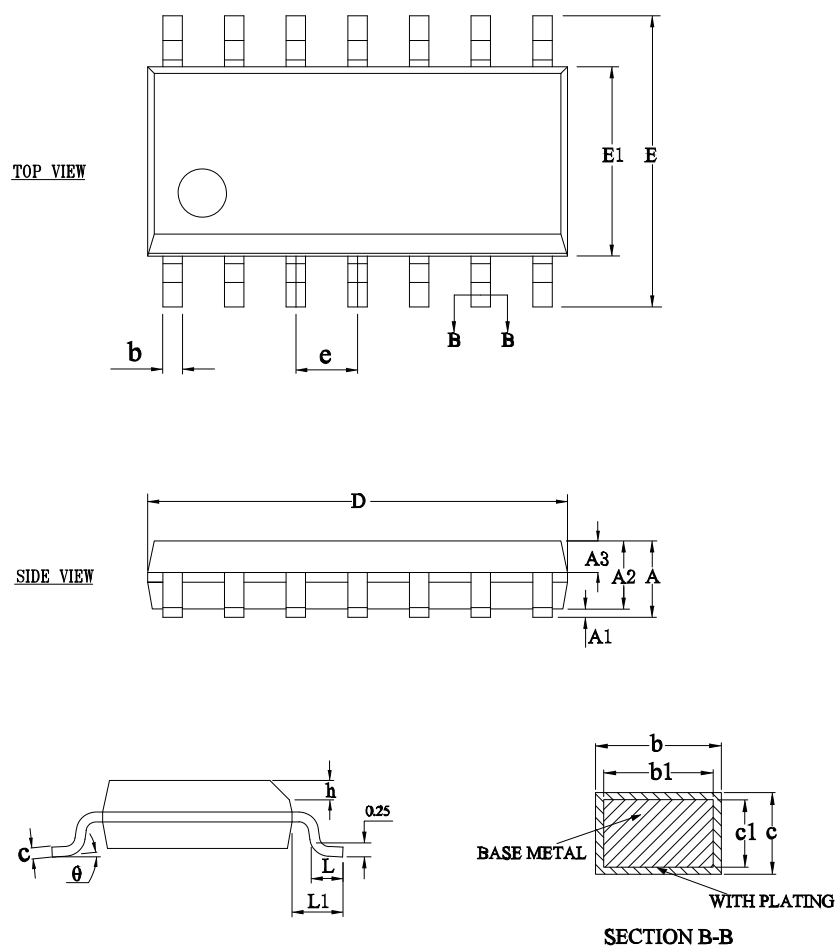


Table 10. SO8 package mechanical data

| 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°   | 0°     |       | 8°    |
| ccc  |             |      | 0.10 |        |       | 0.004 |

## 6.6 SO-14 package information

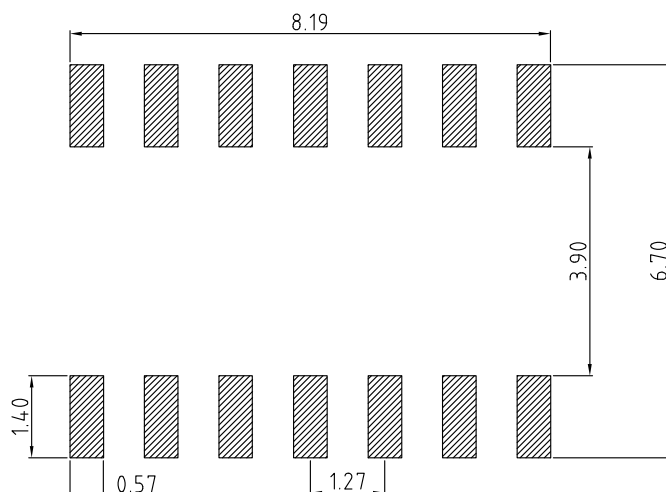
Figure 25. SO-14 package outline



### Table 11. SO-14 package mechanical data

| Dim. | Dimensions  |      |       |           |        |        |
|------|-------------|------|-------|-----------|--------|--------|
|      | Millimeters |      |       | Inches    |        |        |
|      | Min.        | Typ. | Max.  | Min.      | Typ.   | Max.   |
| A    |             |      | 1.75  |           |        | 0.069  |
| A1   | 0.10        |      | 0.225 | 0.004     |        | 0.009  |
| A2   | 1.30        | 1.40 | 1.50  | 0.051     | 0.055  | 0.059  |
| A3   | 0.60        | 0.65 | 0.70  | 0.024     | 0.026  | 0.028  |
| b    | 0.39        |      | 0.47  | 0.015     |        | 0.019  |
| b1   | 0.38        | 0.41 | 0.44  | 0.015     | 0.016  | 0.017  |
| c    | 0.20        |      | 0.24  | 0.008     |        | 0.009  |
| c1   | 0.19        | 0.20 | 0.21  | 0.0075    | 0.0079 | 0.0083 |
| D    | 8.55        | 8.65 | 8.75  | 0.337     | 0.341  | 0.344  |
| 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 BSC    |      |       | 0.050 BSC |        |        |
| h    | 0.25        |      | 0.50  | 0.010     |        | 0.020  |
| L    | 0.50        |      | 0.80  | 0.020     |        | 0.031  |
| L1   | 1.05 REF    |      |       | 0.041 REF |        |        |
| θ    | 8° (max)    |      |       |           |        |        |

**Figure 26. SO-14 recommended footprint**



## 6.7 TSSOP-14 package information

Figure 27. TSSOP-14 package outline

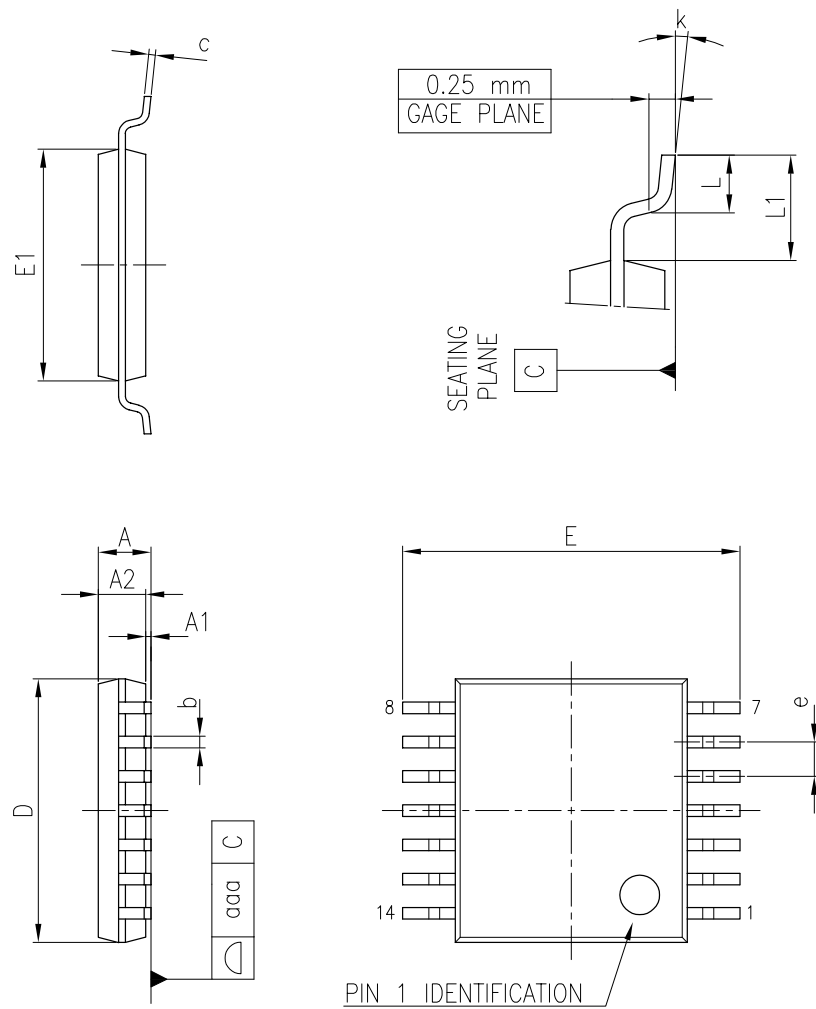
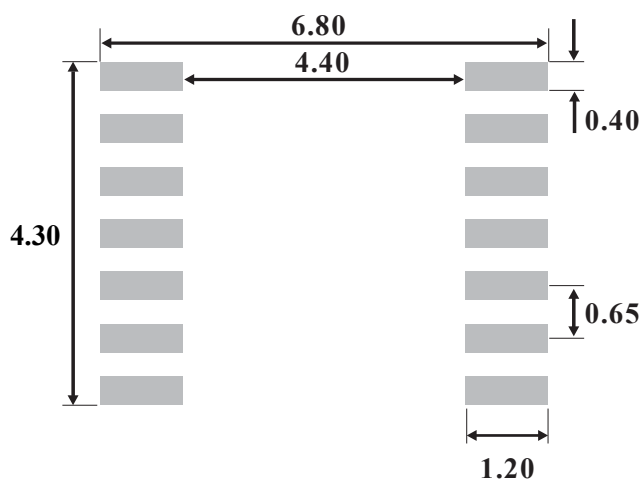




Table 12. TSSOP-14 package mechanical data

| Dim. | Dimension   |      |      |          |       |       |
|------|-------------|------|------|----------|-------|-------|
|      | 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    | 4.90        | 5.00 | 5.10 | 0.193    | 0.197 | 0.201 |
| 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 BSC    |      |      | 0.25 BSC |       |       |
| L    | 0.45        | 0.60 | 0.75 | 0.018    | 0.024 | 0.030 |
| L1   |             | 1.00 |      |          | 0.039 |       |
| k    | 8° (max)    |      |      |          |       |       |
| aaa  |             |      | 0.10 |          |       | 0.004 |

Figure 28. TSSOP-14 recommended footprint



## 7 Ordering information

**Table 13. Order code**

| Order code  | Temperature range                                   | Package           | Packing       | Marking |
|-------------|-----------------------------------------------------|-------------------|---------------|---------|
| TSV991ILT   | -40 °C to 125 °C                                    | SOT23-5           | Tape and reel | K130    |
| TSV991AILT  |                                                     |                   |               | K129    |
| TSV991IQ2T  |                                                     | DFN8 2x2          |               | K1F     |
| TSV991AIQ2T |                                                     |                   |               | K1E     |
| TSV991AIQ1T |                                                     | DFN6 1.3x1.6x0.55 |               | K5      |
| TSV992IST   |                                                     | MiniSO8           |               | K132    |
| TSV992AIST  |                                                     |                   |               | K135    |
| TSV992IDT   |                                                     | SO8               |               | V992I   |
| TSV992AIDT  |                                                     |                   |               | V992AI  |
| TSV992IQ2T  |                                                     | DFN8 2x2          |               | K38     |
| TSV994IPT   |                                                     | TSSOP14           |               | V994I   |
| TSV994AIPT  |                                                     |                   |               | V994AI  |
| TSV994IDT   |                                                     | SO14              |               | V994I   |
| TSV994AIDT  |                                                     |                   |               | V994AI  |
| TSV991IYLT  | -40 °C to 125 °C<br>automotive grade <sup>(1)</sup> | SOT23-5           | K149          |         |
| TSV991AIYLT |                                                     |                   | K150          |         |
| TSV991IYDT  |                                                     | SO8               | V991IY        |         |
| TSV991AIYDT |                                                     |                   | V991AY        |         |
| TSV992IYDT  |                                                     |                   | V992IY        |         |
| TSV992AIYDT |                                                     |                   | V992AY        |         |
| TSV992IYST  |                                                     | MiniSO8           | K149          |         |
| TSV992AIYST |                                                     |                   | K150          |         |
| TSV994IYDT  |                                                     | SO14              | V994IY        |         |
| TSV994AIYDT |                                                     |                   | V994AIY       |         |
| TSV994IYPT  |                                                     | TSSOP14           | V994IY        |         |
| TSV994AIYPT |                                                     |                   | V994AY        |         |

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

**Note:** In the table above, all packages except the SO14 are "moisture sensitivity level 1" as per JEDEC J-STD-020-C. SO14 is JEDEC level 3.

## Revision history

**Table 14. Document revision history**

| Date        | Revision | Changes                                                                                                                                                                                                                                                                                             |
|-------------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10-Mar-2014 | 10       | Table 13: "Order codes": added new commercial product TSV991AIQ2T; corrected "Marking" error for TSV991IQ2T from K1E to K1F.                                                                                                                                                                        |
| 12-Jun-2015 | 11       | Added DFN6 1.3 x 1.6 x 0.55 package for new order code TSV991AIQ1T.<br>Updated "L" dimension of Section 4: "DFN8 2 x 2 mm (NB) package information".<br>Updated min "k" value of Section 4.5: "SO8 package information".                                                                            |
| 27-Nov-2015 | 12       | Table 3, Table 4, and Table 5: modified that $R_L = 600\ \Omega$ (not 600 k $\Omega$ ) for the high-level and low-level output voltage parameters.<br>Section 5.2: updated name of package and titles of drawings and table; added note about exposed pad.<br>Section 5.3: updated name of package. |
| 03-Apr-2018 | 13       | Updated cover image and Table 13. Order code.                                                                                                                                                                                                                                                       |
| 19-Jun-2019 | 14       | Updated the related product table in cover page.                                                                                                                                                                                                                                                    |
| 14-Sep-2022 | 15       | Updated figure on the cover page.<br>Added TSV991IYDT and TSV991AIYDT new order codes in <a href="#">Table 13. Order code</a> .                                                                                                                                                                     |
| 14-Mar-2023 | 16       | Updated title, figure and related products on the cover page.<br>Added ESD value for DFN6 in <a href="#">Table 1</a> and new <a href="#">Section 1 Package pin connections</a> .                                                                                                                    |



## Contents

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