

## Output rail-to-rail micropower operational amplifiers

Datasheet – production data

### Features

- Rail-to-rail output voltage swing
- Micropower consumption (20  $\mu$ A)
- Single supply operation (2.7 to 10 V)
- Low offset (2 mV max. for TS93xB)
- CMOS inputs
- Ultra low input bias current (1 pA)
- ESD protection (2 kV)
- Latch-up immunity (class A)
- Available in SO-8, SO-14, SOT23-5, and TSSOP-14 package
- Automotive grade

### Applications

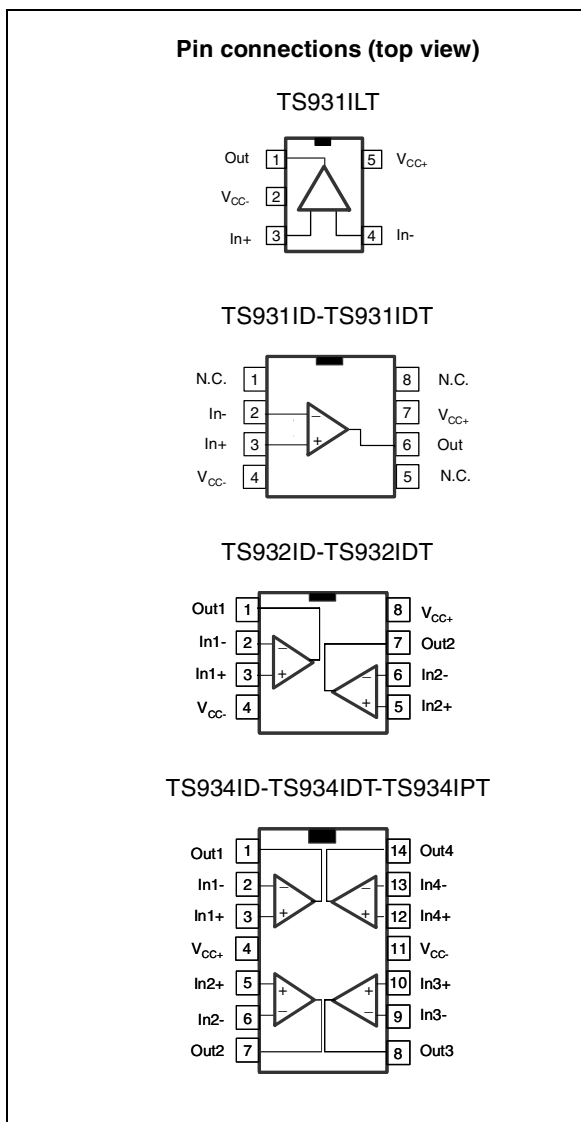
- Battery powered systems
- Portable communication systems
- Alarms, smoke detectors
- Instrumentation and sensing
- PH meters
- Digital scales
- Automotive

### Description

The TS93x (single, dual and quad) series are operational amplifiers that can operate with voltages as low as 2.7 V and reach a 2.9 V<sub>pp</sub> output swing with R<sub>L</sub> = 100 k $\Omega$  when supplied at 3 V.

Offering a typical consumption of only 20  $\mu$ A, these devices are particularly well suited to battery powered applications.

The amplifiers space saving 5-pin SOT23-5 package with outer dimensions of 2.8 mm x 2.9 mm make them very easy to implement on a board design.



**Table 1. Device summary**

Reference	Part number
TS93x	TS931, TS932, TS934
TS93xA	TS931A, TS932A, TS934A
TS93xB	TS931B, TS932B, TS934B

# 1 Absolute maximum ratings and operating conditions

**Table 2. Absolute maximum ratings**

Symbol	Parameter	Value	Unit
$V_{CC}$	Supply voltage <sup>(1)</sup>	12	V
$V_{id}$	Differential input voltage <sup>(2)</sup>	$\pm V_{CC}$	V
$V_{in}$	Input voltage range <sup>(3)</sup>	$V_{CC-} -0.3$ to $V_{CC+} +0.3$	V
$I_{in}$	Input current range <sup>(4)</sup>	10	mA
$T_{std}$	Storage temperature range	-65 to +150	°C
$T_j$	Maximum junction temperature	150	°C
$R_{thja}$	Thermal resistance junction-to-ambient <sup>(5)</sup>		°C/W
	– SOT23-5	250	
	– SO8	125	
	– SO14	103	
	– TSSOP14	100	
ESD	HBM: human body model <sup>(6)</sup>	2	kV
	MM: machine model <sup>(7)</sup>	200	V
	CDM: charged device model <sup>(8)</sup>	2	kV
	Latch-up immunity	200	mA
	Soldering temperature (10 sec.), leaded version	250	°C

- All voltages values, except differential voltage are with respect to network terminal.
- Differential voltages are non-inverting input terminal with respect to the inverting input terminal.
- The magnitude of input and output voltages must never exceed  $V_{CC+} +0.3$  V.
- Input current must be limited by a resistor in series with the inputs.
- Short-circuits can cause excessive heating and destructive dissipation.
- Human body model: 100 pF discharged through a 1.5 k $\Omega$  resistor into pin of device.
- Machine model ESD: a 200 pF capacitor is charged to the specified voltage, then discharged directly into the IC with no external series resistor (internal resistor < 5  $\Omega$ ), into pin-to-pin of device.
- Charged device model: all pins and the package are charged together to the specified voltage and then discharged directly to ground through only one pin. This is done for all pins.

**Table 3. Operating conditions**

Symbol	Parameter	Value	Unit
$V_{CC}$	Supply voltage	2.7 to 10	V
$V_{icm}$	Common mode input voltage range	$V_{CC-} -0.2$ to $V_{CC+} -1.5$	V
$T_{oper}$	Operating free air temperature range	-40 to +105	°C

## 2 Electrical characteristics

[Table 4](#) and [Table 5](#) give the electrical characteristics at each  $V_{CC}$  value.

**Table 4. Electrical characteristics at  $V_{CC+} = +3\text{ V}$ ,  $V_{CC-} = 0\text{ V}$ ,  $T_{\text{amb}} = 25\text{ °C}$  (unless otherwise specified)**

Symbol	Parameter	Min.	Typ.	Max.	Unit
$V_{io}$	Input offset voltage TS931/2/4 TS931/2/4A TS931/2/4B			10 5 2	mV
	$T_{\text{min}} < T_{\text{op}} < T_{\text{max}}$ TS931/2/4 TS931/2/4A TS931/2/4B			15 10 6	
$\Delta V_{io}$	Input offset voltage drift		3		$\mu\text{V}/\text{°C}$
$I_{io}$	Input offset current <sup>(1)</sup> $T_{\text{min}} < T_{\text{op}} < T_{\text{max}}$		1	100 200	pA
$I_{ib}$	Input bias current <sup>(1)</sup> $T_{\text{min}} < T_{\text{op}} < T_{\text{max}}$		1	150 300	pA
CMR	Common mode rejection ratio, $0 \leq V_{\text{icm}} \leq V_{\text{CC+}} - 1.7$ $T_{\text{min}} < T_{\text{op}} < T_{\text{max}}$	55 55	85 85		dB
SVR	Supply voltage rejection ratio <sup>(2)</sup> $T_{\text{min}} < T_{\text{op}} < T_{\text{max}}$	55 55	85 85		dB
$A_{\text{vd}}$	Large signal voltage gain $V_{\text{O}} = 2\text{ Vpp}$ , $R_{\text{L}} = 1\text{ M}\Omega$ $R_{\text{L}} = 100\text{ k}\Omega$		120 106		dB
$V_{\text{OH}}$	High level output voltage, $V_{\text{ID}} = 100\text{ mV}$ , $R_{\text{L}} = 100\text{ k}\Omega$ $T_{\text{min}} < T_{\text{op}} < T_{\text{max}}$	2.95 2.95	2.99		V
$V_{\text{OL}}$	Low level output voltage, $V_{\text{ID}} = -100\text{ mV}$ , $R_{\text{L}} = 100\text{ k}\Omega$ $T_{\text{min}} < T_{\text{op}} < T_{\text{max}}$		10	50 50	mV
$I_{\text{o}}$	Output source current $V_{\text{ID}} = 100\text{ mV}$ , $V_{\text{O}} = V_{\text{CC-}}$		1.5		mA
	Output sink current $V_{\text{ID}} = -100\text{ mV}$ , $V_{\text{O}} = V_{\text{CC+}}$		1.5		
$I_{\text{CC}}$	Supply current (per amplifier), $A_{\text{VCL}} = 1$ , no load $T_{\text{min}} < T_{\text{op}} < T_{\text{max}}$		20	31 33	$\mu\text{A}$
GBP	Gain bandwidth product $R_{\text{L}} = 100\text{ k}\Omega$ , $C_{\text{L}} = 50\text{ pF}$		100		kHz
SR	Slew rate $R_{\text{L}} = 100\text{ k}\Omega$ , $C_{\text{L}} = 50\text{ pF}$		50		V/ms

**Table 4. Electrical characteristics at  $V_{CC+} = +3\text{ V}$ ,  $V_{CC-} = 0\text{ V}$ ,  $T_{amb} = 25\text{ }^{\circ}\text{C}$  (unless otherwise specified) (continued)**

Symbol	Parameter	Min.	Typ.	Max.	Unit
$\phi_m$	Phase margin $C_L = 50\text{ pF}$		65		Degrees
en	Input voltage noise		75		nV/ $\sqrt{\text{Hz}}$

1. Maximum values including unavoidable inaccuracies of the industrial test.
2.  $V_{CC}$  has a 0.2 V variation.

**Table 5. Electrical characteristics at  $V_{CC+} = +5\text{ V}$ ,  $V_{CC-} = 0\text{ V}$ ,  $T_{amb} = 25\text{ }^{\circ}\text{C}$  (unless otherwise specified)**

Symbol	Parameter	Min.	Typ.	Max.	Unit
$V_{io}$	Input offset voltage TS931/2/4 TS931/2/4A TS931/2/4B			10 5 2	mV
	$T_{min} < T_{op} < T_{max}$ TS931/2/4 TS931/2/4A TS931/2/4B			15 10 6	
$\Delta V_{io}$	Input offset voltage drift		3		$\mu\text{V}/^{\circ}\text{C}$
$I_{io}$	Input offset current <sup>(1)</sup> $T_{min} < T_{op} < T_{max}$		1	100 200	pA
$I_{ib}$	Input bias current <sup>(1)</sup> $T_{min} < T_{op} < T_{max}$		1	150 300	pA
CMR	Common mode rejection ratio, $0 \leq V_{icm} \leq V_{CC+} - 1.7$ $T_{min} < T_{op} < T_{max}$	55 55	85 85		dB
SVR	Supply voltage rejection ratio <sup>(2)</sup> $T_{min} < T_{op} < T_{max}$	55 55	85 85		dB
$A_{vd}$	Large signal voltage gain $V_O = 4\text{ Vpp}$ , $R_L = 1\text{ M}\Omega$ $R_L = 100\text{ k}\Omega$		120 112		dB
$V_{OH}$	High level output voltage, $V_{ID} = 100\text{ mV}$ , $R_L = 100\text{ k}\Omega$ $T_{min} < T_{op} < T_{max}$	4.95 4.95	4.99		V
$V_{OL}$	Low level output voltage, $V_{ID} = -100\text{ mV}$ , $R_L = 100\text{ k}\Omega$ $T_{min} < T_{op} < T_{max}$		10	50 50	mV
$I_o$	Output source current $V_{ID} = 100\text{ mV}$ , $V_O = V_{DD}$		5		mA
	Output sink current $V_{ID} = -100\text{ mV}$ , $V_O = V_{CC}$		5		
$I_{CC}$	Supply current (per amplifier), $A_{VCL} = 1$ , no load $T_{min} < T_{op} < T_{max}$		20	33 35	$\mu\text{A}$

**Table 5. Electrical characteristics at  $V_{CC+} = +5\text{ V}$ ,  $V_{CC-} = 0\text{ V}$ ,  $T_{amb} = 25\text{ °C}$   
(unless otherwise specified) (continued)**

Symbol	Parameter	Min.	Typ.	Max.	Unit
GBP	Gain bandwidth product $R_L = 100\text{ K}\Omega$ , $C_L = 50\text{ pF}$		100		kHz
SR	Slew rate $R_L = 100\text{ K}\Omega$ , $C_L = 50\text{ pF}$		50		V/ms
$\phi_m$	Phase margin $C_L = 50\text{ pF}$		65		Degrees
en	Input voltage noise		76		nV/ $\sqrt{\text{Hz}}$

1. Maximum values including unavoidable inaccuracies of the industrial test.
2.  $V_{CC}$  has a 0.2 V variation.

Figure 1. Input offset voltage vs. temperature

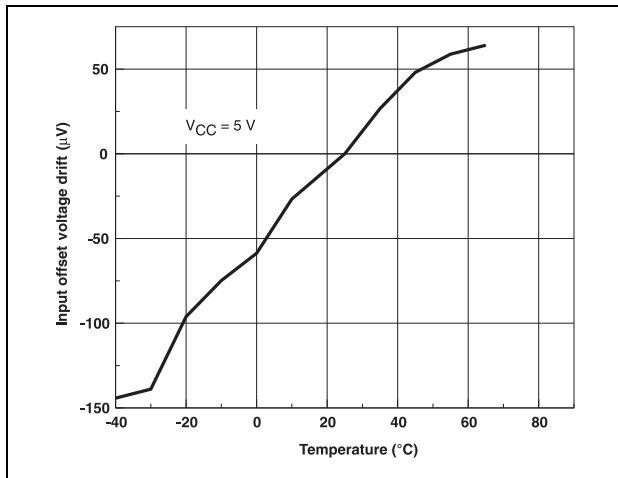


Figure 2. Supply current vs. supply voltage, in open loop configuration

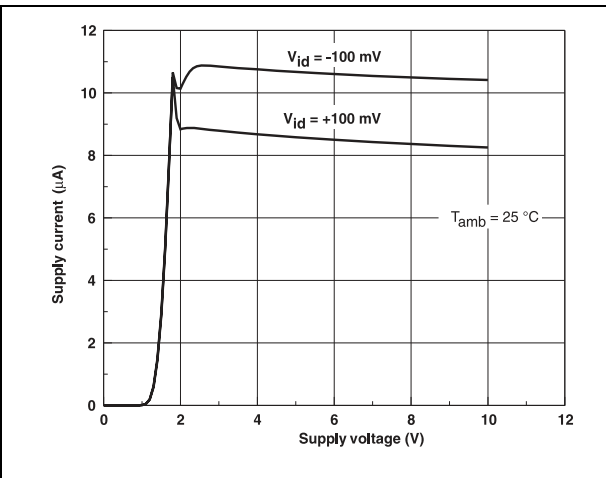


Figure 3. Supply current vs. supply voltage in follower configuration,  $V_{icm} = V_{CC}/2$

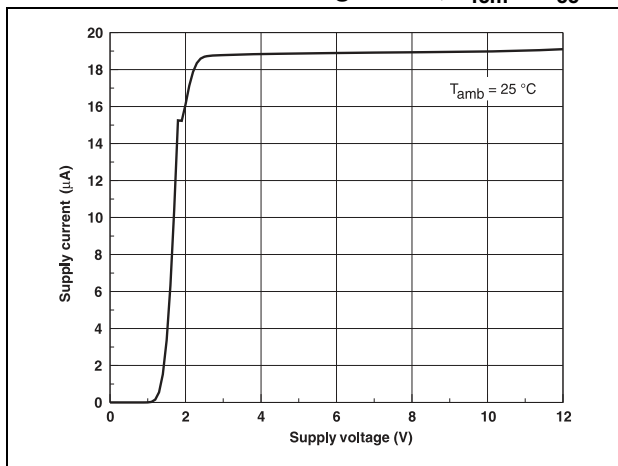


Figure 4. Supply current vs. temperature

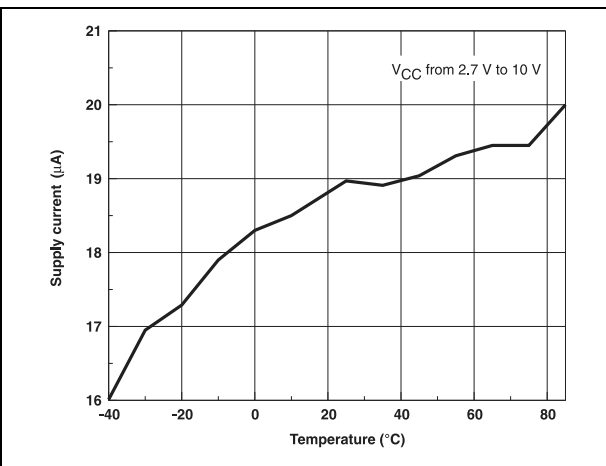


Figure 5. Output short-circuit current vs. temperature

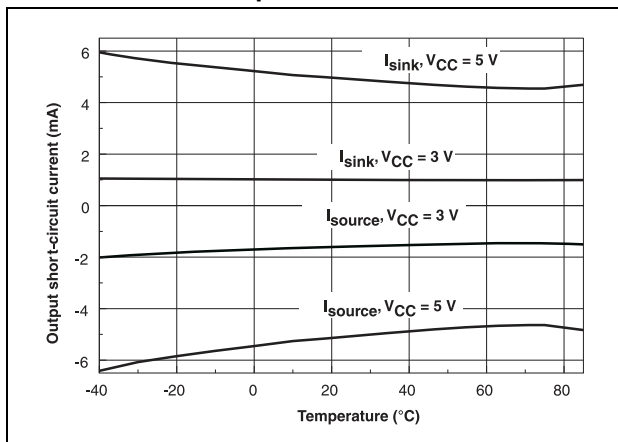
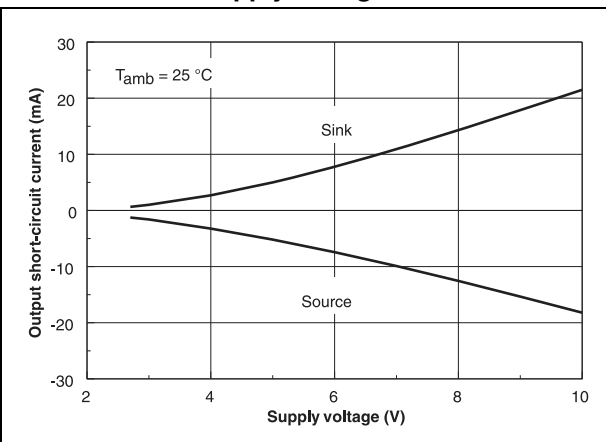
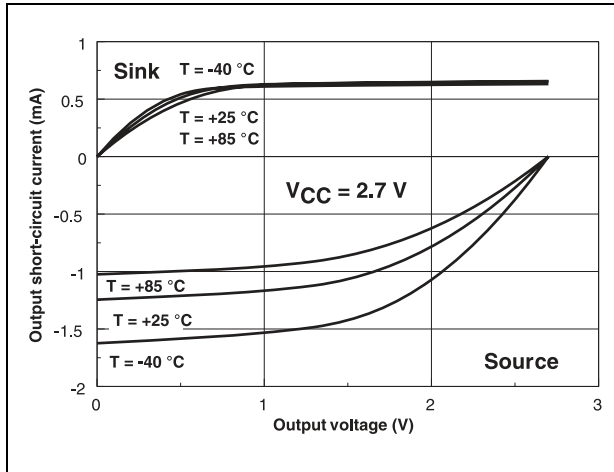


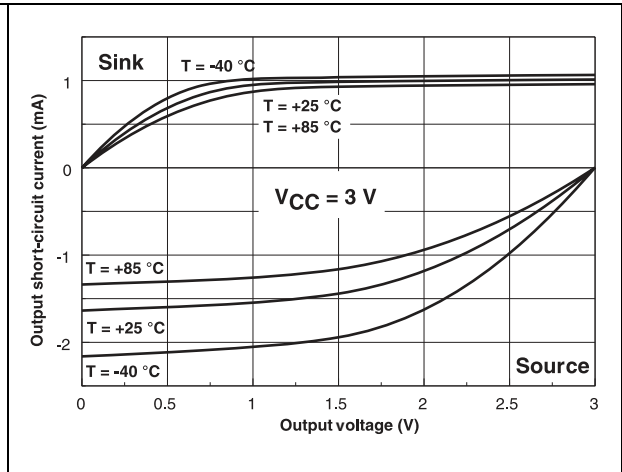
Figure 6. Output short-circuit current vs. supply voltage



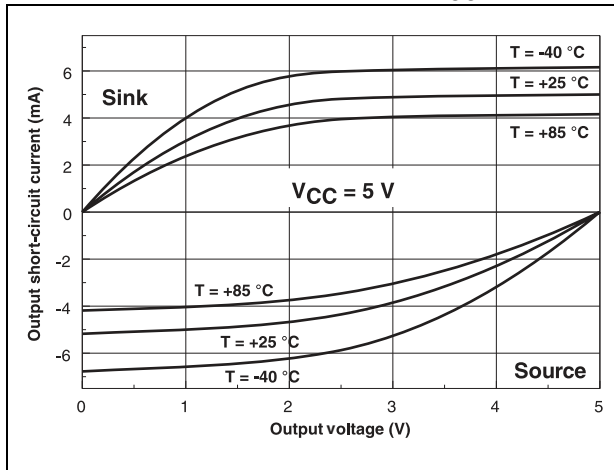
**Figure 7. Output short-circuit current vs. output voltage at  $V_{CC+} = 2.7\text{ V}$**



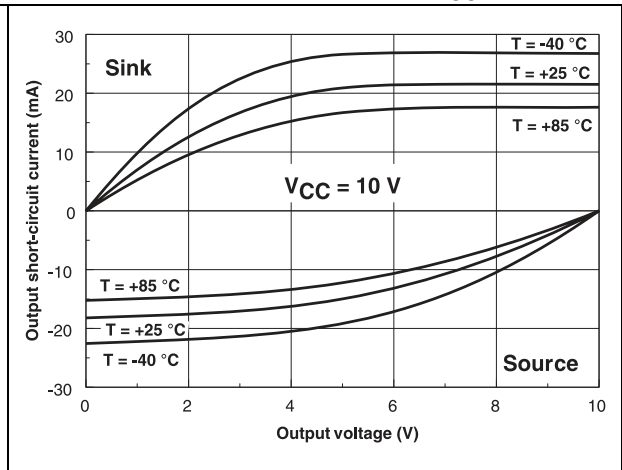
**Figure 8. Output short-circuit current vs. output voltage at  $V_{CC+} = 3\text{ V}$**



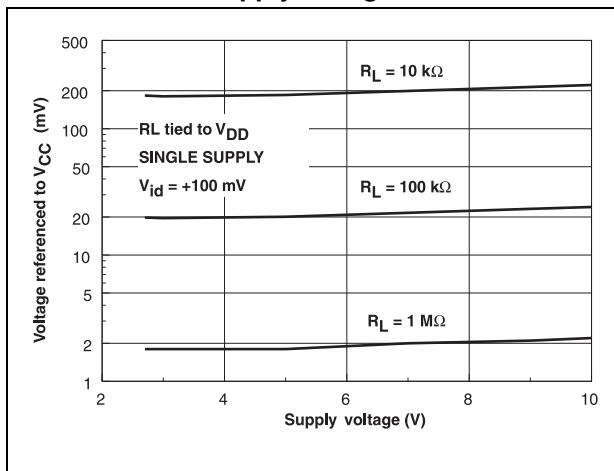
**Figure 9. Output short-circuit current vs. output voltage at  $V_{CC+} = 5\text{ V}$**



**Figure 10. Output short-circuit current vs. output voltage at  $V_{CC+} = 10\text{ V}$**



**Figure 11. High level output voltage drop vs. supply voltage**



**Figure 12. Low level output voltage drop vs. supply voltage**

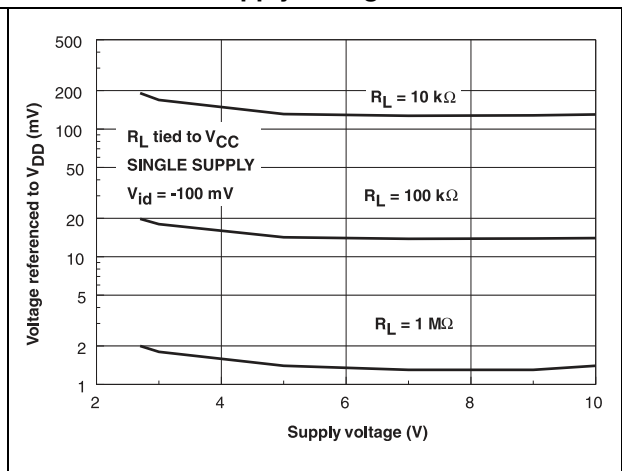


Figure 13. Voltage gain and phase vs. frequency for  $C_L = 50$  pF

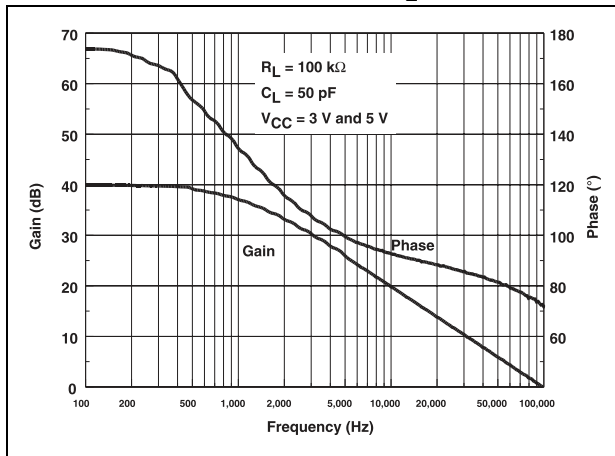


Figure 14. Voltage gain and phase vs. frequency for  $C_L = 100$  pF

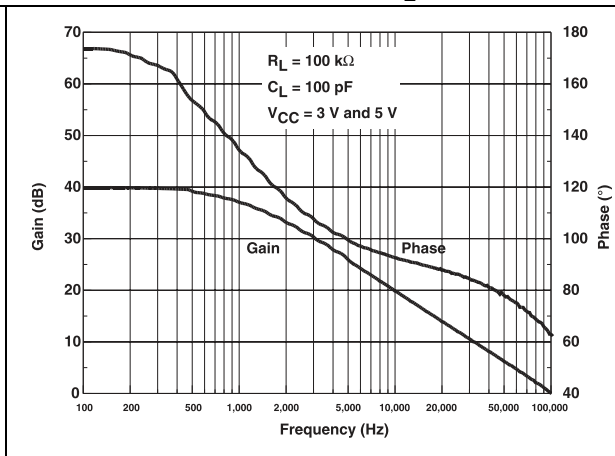


Figure 15. Distortion vs. frequency

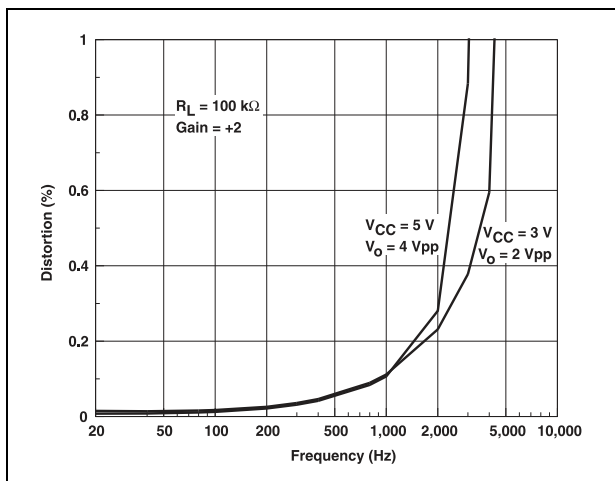


Figure 16. Equivalent input noise voltage vs. frequency

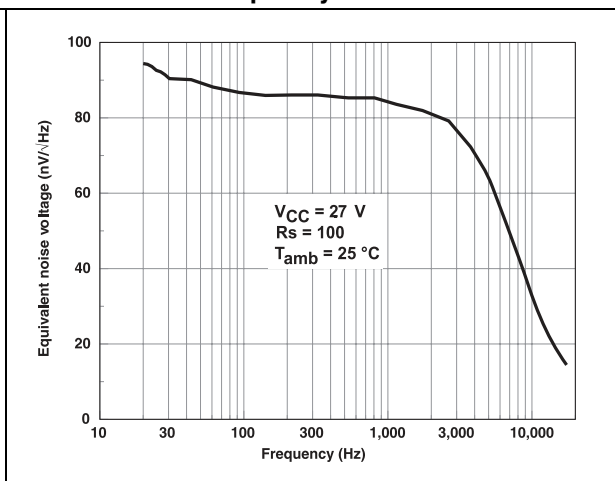


Figure 17. Distortion vs. output voltage

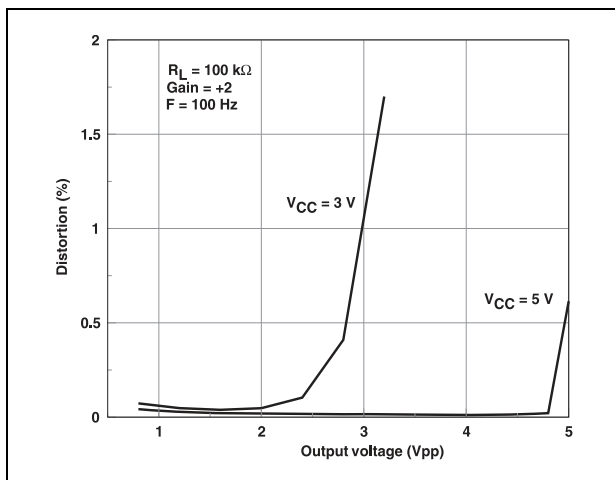


Figure 18. Supply voltage rejection vs. frequency

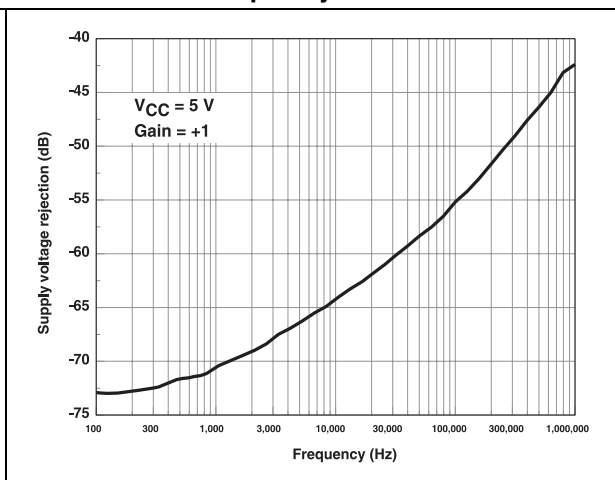




Figure 19. Slew rate vs. time for small input voltage signal

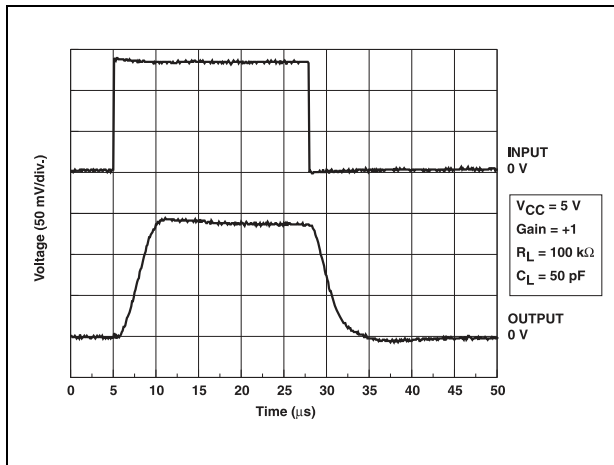
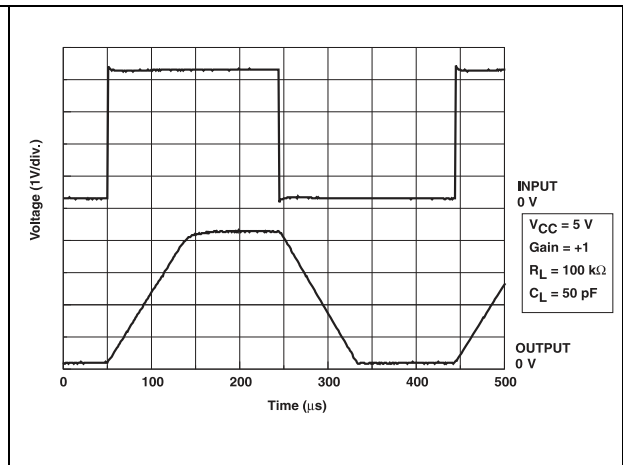


Figure 20. Slew rate vs. time for large input voltage signal



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

### 3.1 SO-8 package information

Figure 21. SO-8 package outline

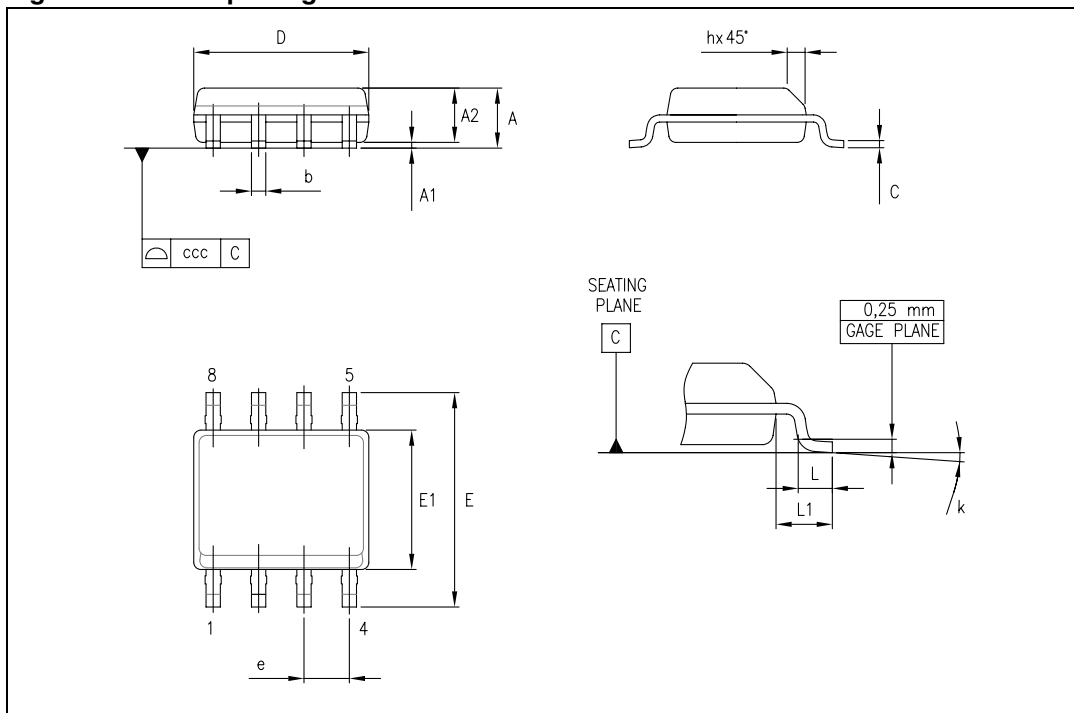


Table 6. SO-8 package mechanical data

Symbol	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	1°		8°	1°		8°
ccc			0.10			0.004

### 3.2 SO-14 package information

Figure 22. SO-14 package outline

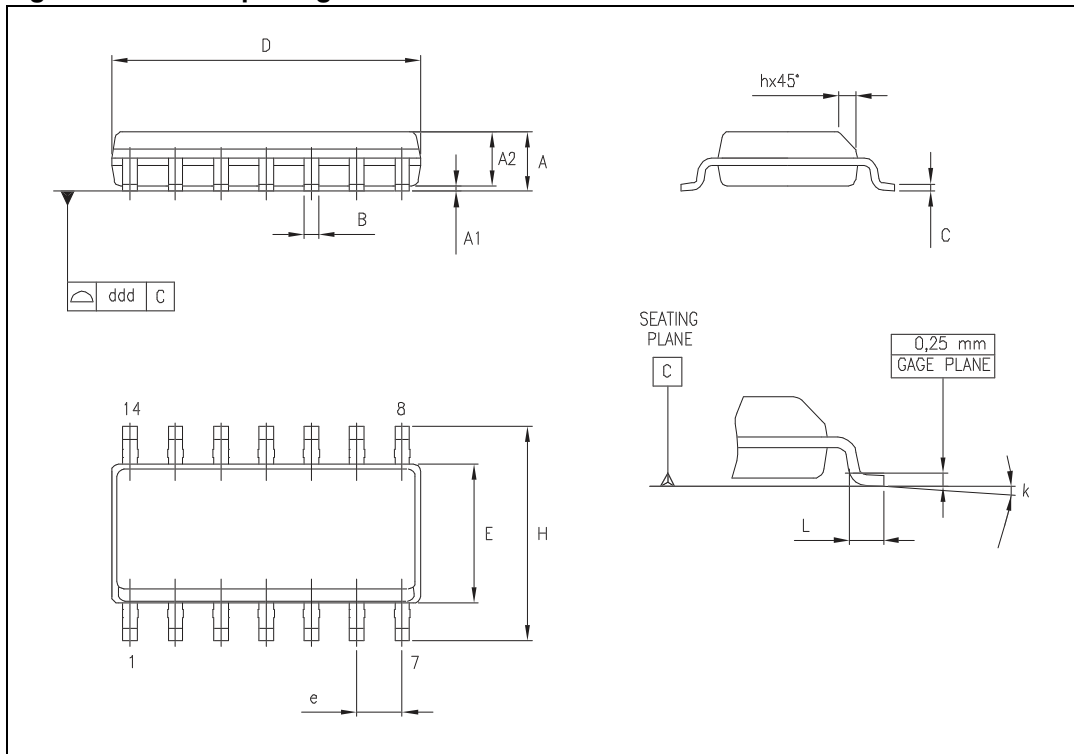


Table 7. SO-14 package mechanical data

Dimensions						
Symbol	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A	1.35		1.75	0.05		0.068
A1	0.10		0.25	0.004		0.009
A2	1.10		1.65	0.04		0.06
B	0.33		0.51	0.01		0.02
C	0.19		0.25	0.007		0.009
D	8.55		8.75	0.33		0.34
E	3.80		4.0	0.15		0.15
e		1.27			0.05	
H	5.80		6.20	0.22		0.24
h	0.25		0.50	0.009		0.02
L	0.40		1.27	0.015		0.05
k	8° (max.)					
ddd			0.10			0.004

### 3.3 TSSOP14 package information

Figure 23. TSSOP14 package outline

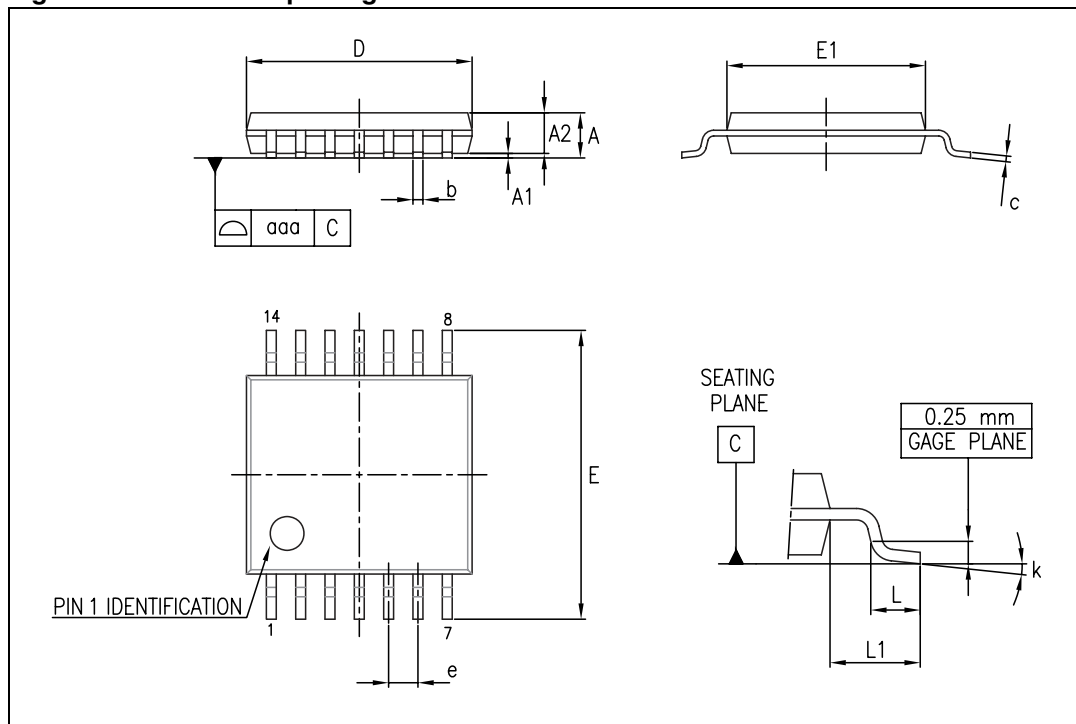


Table 8. TSSOP14 package mechanical data

Symbol	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.20			0.047
A1	0.05		0.15	0.002	0.004	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		0.0089
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	0.176
e		0.65			0.0256	
L	0.45	0.60	0.75	0.018	0.024	0.030
L1		1.00			0.039	
k	0°		8°	0°		8°
aaa			0.10			0.004

### 3.4 SOT23-5 package information

Figure 24. SOT23-5 package outline

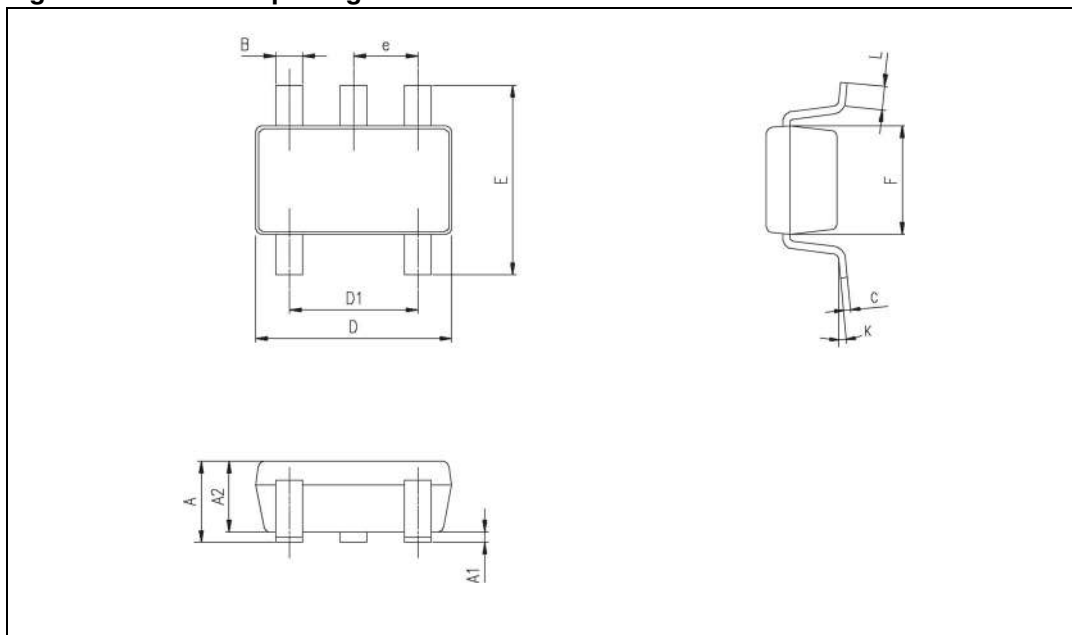


Table 9. SOT23-5 package mechanical data

Symbol	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	0.013	0.015	0.019
C	0.09	0.15	0.20	0.003	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	0.013	0.023
K	0 degrees		10 degrees			

## 4 Ordering information

**Table 10. Order codes**

Order code	Temperature range	Package	Packaging	Marking
TS931ID TS931IDT TS931AID TS931AIDT TS931BID TS931BIDT	-40 °C, +105 °C	SO-8	Tube Tape and reel Tube Tape and reel Tube Tape and reel	931I 931I 931AI 931AI 931BI 931BI
TS931ILT TS931AILT TS931BILT		SOT23-5L	Tape and reel	K205 K206 K207
TS932ID TS932IDT TS932AID TS932AIDT TS932BID TS932BIDT		SO-8	Tube Tape and reel Tube Tape and reel Tube Tape and reel	932I 932I 932AI 932AI 932BI 932BI
TS934ID TS934IDT TS934AID TS934AIDT TS934BIDT TS934BIDT		SO-14	Tube Tape and reel Tube Tape and reel Tube Tape and reel	934I 934I 934AI 934AI 934BI 934BI
TS934IPT TS934AIPT TS934BIPT		TSSOP-14 (thin shrink outline package)	Tape and reel	934I 934AI 934BI
TS934IYDT <sup>(1)</sup> TS934AIYDT <sup>(1)</sup>		SO-14 (automotive grade)	Tape and reel	934IY 934AIY

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

## 5 Revision history

**Table 11. Document revision history**

Date	Revision	Changes
01-Nov-2001	1	Initial release.
01-Dec-2004	2	Modified AMR values in <a href="#">Table 2</a> (explanation of Vid and Vi limits).
04-May-2009	3	Document reformatted. Removed DIP package information and order codes from <a href="#">Chapter 3</a> . Modified temperature range: extended to -40 to +105° C in <a href="#">Table 10: Order codes</a> . Added automotive grade products in <a href="#">Table 10</a> .
07-Sep-2009	4	Added root part numbers (TS93xA, TS93xB) and <a href="#">Table 1: Device summary</a> on cover page. Added parameters for full temperature range in <a href="#">Table 4</a> and in <a href="#">Table 5</a> .
07-Nov-2012	5	Updated <a href="#">Features</a> (added SO-8, SO-14, and TSSOP-14 package). Updated <a href="#">Table 2</a> (removed TSSOP8 package). Removed TS934IYD and TS934AIYD order codes from <a href="#">Table 10</a> , qualified status of TS934IYDT and TS934AIYDT order codes in <a href="#">Table 10</a> . Minor corrections throughout document.



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