

## Output rail-to-rail micropower operational amplifiers

### Features

- Rail-to-rail output voltage swing
- Micropower consumption (1.2  $\mu\text{A}$ )
- Single supply operation (2.5 V to 10 V)
- CMOS inputs
- Ultra low input bias current (1 pA)
- ESD protection (2 kV)
- Latch-up immunity (class A)
- Available in SOT23-5 micropackage

### Applications

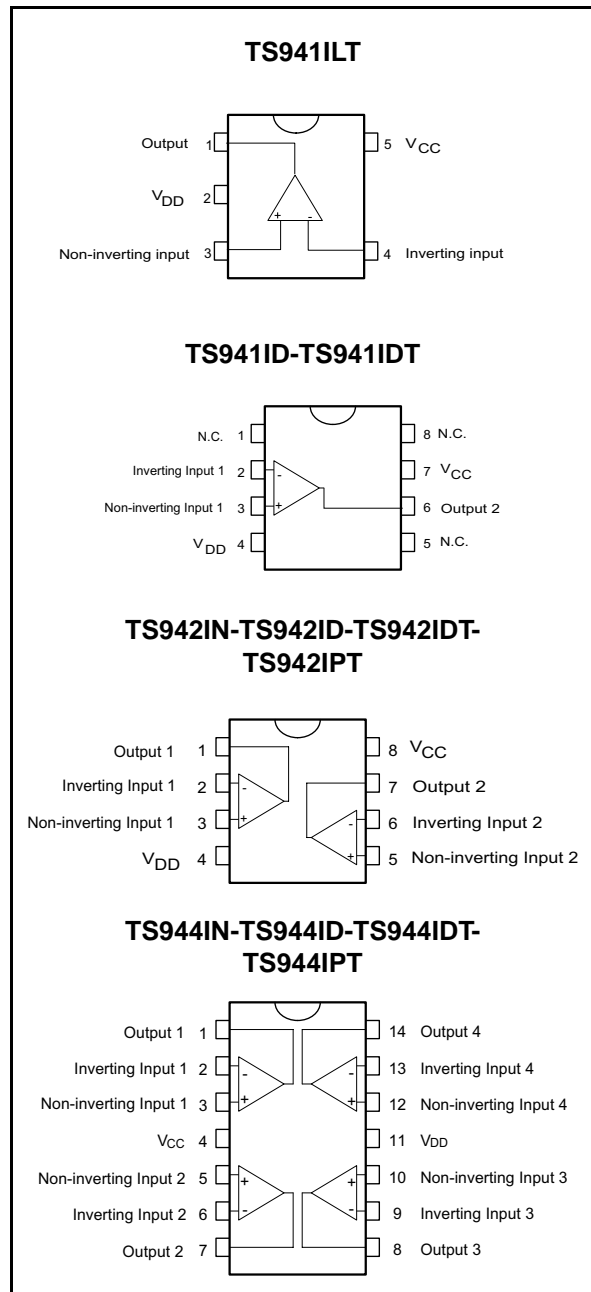
- Battery-powered systems (alarm)
- Portable communication systems (paggers)
- Smoke/gas/fire detectors
- Instrumentation and sensing
- PH meter

### Description

The TS94x (single, dual and quad) series are operational amplifiers characterized for 2.5 V to 10 V operation over  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  temperature range.

They exhibit excellent consumption -1.2  $\mu\text{A}$ , while featuring 10 kHz gain bandwidth product, 1.5 mA output capability and output rail-to-rail operation - 2.85 V typ @ 3 V with  $R_L=10\text{ k}\Omega$

The TS94x op-amps are ideal for battery-powered systems, where very low supply current and output rail-to-rail are required. Their very low - 1 pA typ input bias current and constant supply current over supply voltage enhance TS94x's performance near the end of the battery charge or battery life.



# 1 Absolute maximum ratings and operating conditions

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

Symbol	Parameter	Value	Unit
$V_{CC}$	Supply voltage <sup>(1)</sup>	12	V
$V_{id}$	Differential input voltage <sup>(2)</sup>	±12	V
$V_{in}$	Input voltage range <sup>(3)</sup>	$V_{DD}-0.3$ to $V_{CC}+0.3$	V
$T_{stg}$	Storage temperature range	-65 to +150	°C
$T_j$	Maximum junction temperature	150	°C
$R_{thja}$	Thermal resistance junction to ambient <sup>(4)</sup>		
	SOT23-5	250	°C/W
	DIP8	85	
	DIP14	66	
	SO-8	125	
	SO-14	103	
	TSSOP8	120	
TSSOP14	100		
$R_{thjc}$	Thermal resistance junction to case <sup>(4)</sup>		
	SOT23-5	81	°C/W
	DIP8	41	
	DIP14	33	
	SO-8	40	
	SO-14	31	
	TSSOP8	37	
TSSOP14	32		
ESD	HBM: human body model <sup>(5)</sup>	2	kV
	MM: machine model <sup>(6)</sup> (TS941, TS942)	200	V
	CDM: charged device model <sup>(7)</sup>		
	TS941 - TS944IDT	1.5	kV
	TS942 - TS944IPT	1	
	Latch-up immunity	200	mA
	Lead temperature (soldering, 10sec)	250	°C

1. All voltage values, except differential voltage are with respect to network terminal.
2. Differential voltages are the non-inverting input terminal with respect to the inverting input terminal.
3. The magnitude of input and output voltages must never exceed  $V_{CC} + 0.3V$ .
4. Short-circuits can cause excessive heating and destructive dissipation.  $R_{th}$  are typical values.
5. 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.
6. 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.
7. Charged device model: all pins and the package are charged together to the specified voltage and then discharged directly to the ground through only one pin. This is done for all pins.

**Table 2. Operating conditions**

Symbol	Parameter	Value	Unit
$V_{CC}$	Supply voltage	2.5 to 10	V
$V_{icm}$	Common mode input voltage range	$V_{DD} - 0.2$ to $V_{CC} - 1.3$	V
$T_{oper}$	Operating free air temperature range	-40 to + 85	°C

## 2 Electrical characteristics

**Table 3.**  $V_{CC} = +2.5V$ ,  $V_{DD} = 0V$ ,  $R_L$  connected to  $V_{CC}/2$ ,  $T_{amb} = 25^\circ C$  (unless otherwise specified)

Symbol	Parameter	Min.	Typ.	Max.	Unit
$V_{io}$	Input offset voltage TS941/2/4 TS941/2/4A TS941/2/4B			10 5 2	mV
$\Delta V_{io}$	Input offset voltage drift		7		$\mu V/^\circ C$
$I_{io}$	Input offset current <sup>(1)</sup>		1	100	pA
$I_{ib}$	Input bias current <sup>(1)</sup>		1	150	pA
CMR	Common mode rejection ratio	60	85		dB
SVR	Supply voltage rejection ratio	50	78		dB
$A_{vd}$	Large signal voltage gain $V_O = 2V_{pp}$ , $R_L = 1M\Omega$		100		dB
$V_{OH}$	High level output voltage $V_{ID} = 100mV$ , $R_L = 1M\Omega$ $R_L = 10k\Omega$	2.45 2.3	2.49 2.4		V
$V_{OL}$	Low level output voltage $V_{ID} = -100mV$ , $R_L = 1M\Omega$ $R_L = 10k\Omega$		1 100	5 200	mV
$I_o$	Output source current $V_{ID} = 100mV$ , $V_O = V_{DD}$ Output sink current $V_{ID} = -100mV$ , $V_O = V_{CC}$	350 280	650 500		$\mu A$
$I_{CC}$	Supply current (per amplifier), $A_{VCL} = 1$ , no load		1.2	1.8	$\mu A$
GBP	Gain bandwidth product, $R_L = 1M\Omega$ , $C_L = 50pF$		10		kHz
SR	Slew rate, $R_L = 1M\Omega$ , $C_L = 50pF$	3	4.5		V/ms
$\phi_m$	Phase margin, $C_L = 50pF$		65		Degrees

1. Maximum values include unavoidable inaccuracies of the industrial tests.

**Table 4.**  $V_{CC} = +3V$ ,  $V_{DD} = 0V$ ,  $R_L$  connected to  $V_{CC}/2$ ,  $T_{amb} = 25^{\circ}C$  (unless otherwise specified) <sup>(1)</sup>

Symbol	Parameter	Min.	Typ.	Max.	Unit
$V_{io}$	Input offset voltage TS941/2/4 TS941/2/4A TS941/2/4B			10 5 2	mV
$\Delta V_{io}$	Input offset voltage drift		7		$\mu V/^{\circ}C$
$I_{io}$	Input offset current <sup>(2)</sup>		1	100	pA
$I_{ib}$	Input bias current <sup>(2)</sup>		1	150	pA
CMR	Common mode rejection ratio	60	85		dB
SVR	Supply voltage rejection ratio	50	85		dB
$A_{vd}$	Large signal voltage gain $V_O = 2V_{pp}$ , $R_L = 1M\Omega$		100		dB
$V_{OH}$	High level output voltage $V_{ID} = 100mV$ , $R_L = 1M\Omega$ $R_L = 10k\Omega$	2.9 2.8	2.99 2.85		V
$V_{OL}$	Low level output voltage $V_{ID} = -100mV$ , $R_L = 1M\Omega$ $R_L = 10k\Omega$		1 100	5 200	mV
$I_o$	Output source current $V_{ID} = 100mV$ , $V_O = V_{DD}$ Output sink current $V_{ID} = -100mV$ , $V_O = V_{CC}$	680 650	1500 1300		$\mu A$
$I_{CC}$	Supply current (per amplifier), $A_{VCL} = 1$ , no load		1.2	1.8	$\mu A$
GBP	Gain bandwidth product, $R_L = 1M\Omega$ , $C_L = 50pF$		10		kHz
SR	Slew rate, $R_L = 1M\Omega$ , $C_L = 50pF$	3	4.5		V/ms
$\phi_m$	Phase margin, $C_L = 50pF$		65		Degrees

1. All electrical values are guaranteed with correlation measurements at 2.5 V and 5 V.

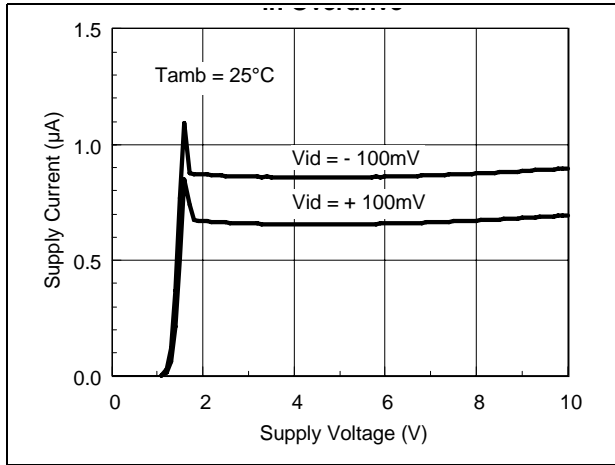
2. Maximum values include unavoidable inaccuracies of the industrial tests.

**Table 5.**  $V_{CC} = +5V$ ,  $V_{DD} = 0V$ ,  $R_L$  connected to  $V_{CC}/2$ ,  $T_{amb} = 25^\circ C$  (unless otherwise specified)

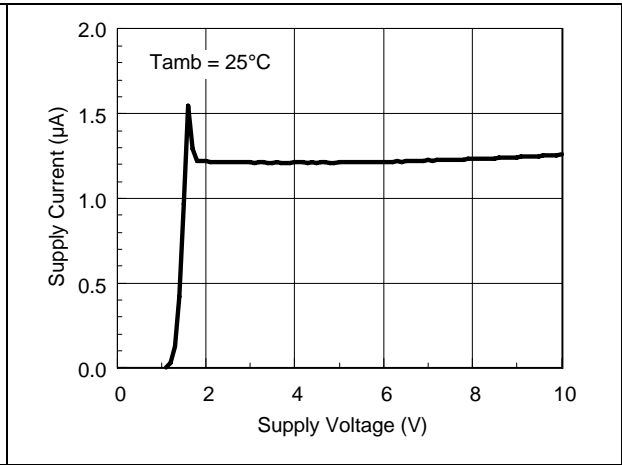
Symbol	Parameter	Min.	Typ.	Max.	Unit
$V_{io}$	Input offset voltage TS941/2/4 TS941/2/4A TS941/2/4B			10 5 2	mV
$\Delta V_{io}$	Input offset voltage drift		7		$\mu V/^\circ C$
$I_{io}$	Input offset current <sup>(1)</sup>		1	100	pA
$I_{ib}$	Input bias current <sup>(1)</sup>		1	150	pA
CMR	Common mode rejection ratio	60	85		dB
SVR	Supply voltage rejection ratio	50	85		dB
$A_{vd}$	Large signal voltage gain $V_O = 2V_{pp}$ , $R_L = 1M\Omega$		100		dB
$V_{OH}$	High level output voltage $V_{ID} = 100mV$ , $R_L = 1M\Omega$ $R_L = 10k\Omega$	4.9 4.8	4.99 4.85		V
$V_{OL}$	Low level output voltage $V_{ID} = -100mV$ , $R_L = 1M\Omega$ $R_L = 10k\Omega$		1 100	5 150	mV
$I_o$	Output source current $V_{ID} = 100mV$ , $V_O = V_{DD}$ Output sink current $V_{ID} = -100mV$ , $V_O = V_{CC}$	3 3.7	4.5 5		mA
$I_{CC}$	Supply current (per amplifier), $A_{VCL} = 1$ , no load		1.2	1.85	$\mu A$
GBP	Gain bandwidth product, $R_L = 1M\Omega$ , $C_L = 50pF$		10		kHz
SR	Slew rate, $R_L = 1M\Omega$ , $C_L = 50pF$	3	4.5		V/ms
$\phi_m$	Phase margin, $C_L = 50pF$		65		Degrees

1. Maximum values include unavoidable inaccuracies of the industrial tests.

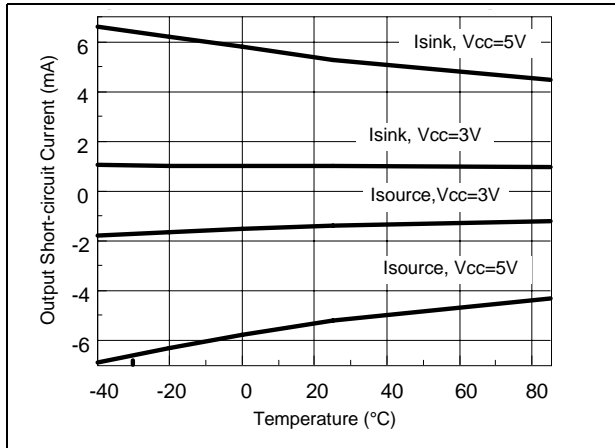
**Figure 1. Supply current per amplifier vs. supply voltage in overdrive**



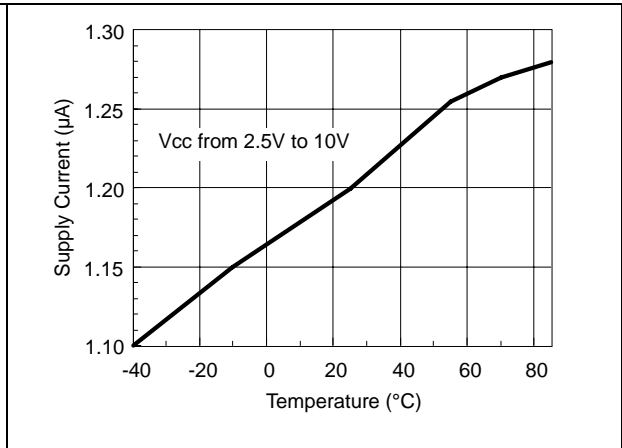
**Figure 2. Supply current per amplifier vs. supply voltage**



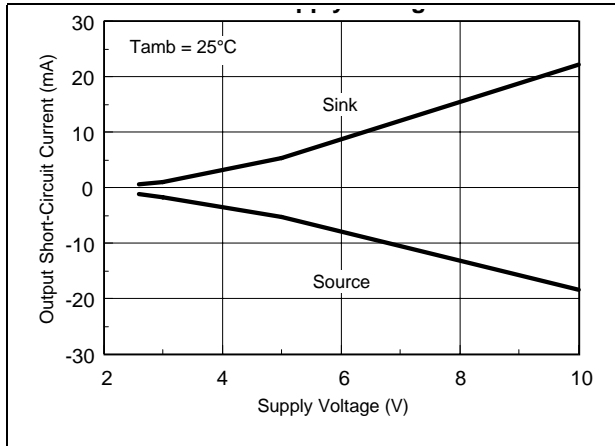
**Figure 3. Output short-circuit current vs. temperature**



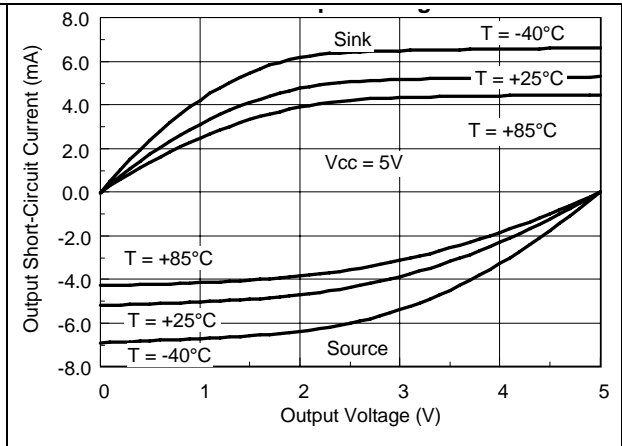
**Figure 4. Supply current per amplifier vs. temperature**



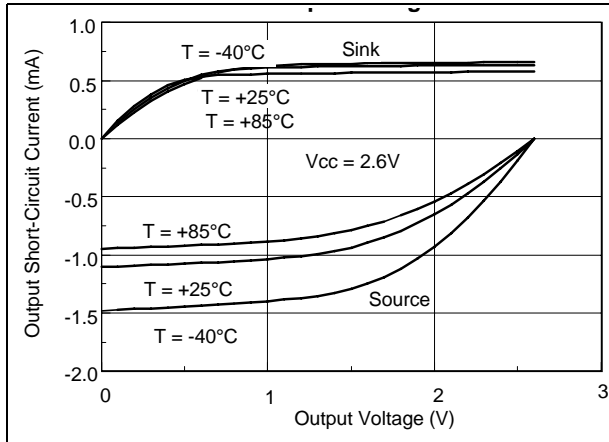
**Figure 5. Output short-circuit current vs. supply voltage**



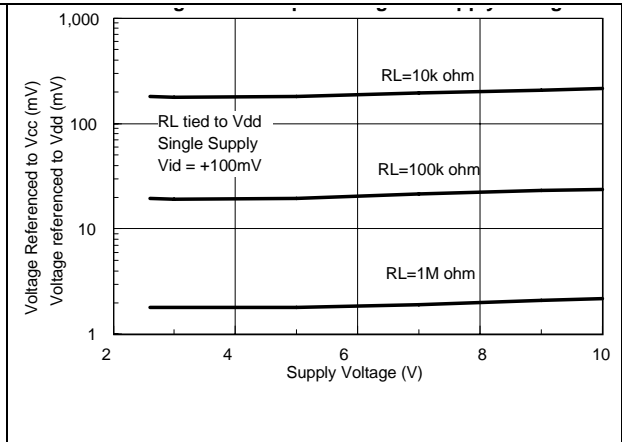
**Figure 6. Output short-circuit current vs. output voltage**



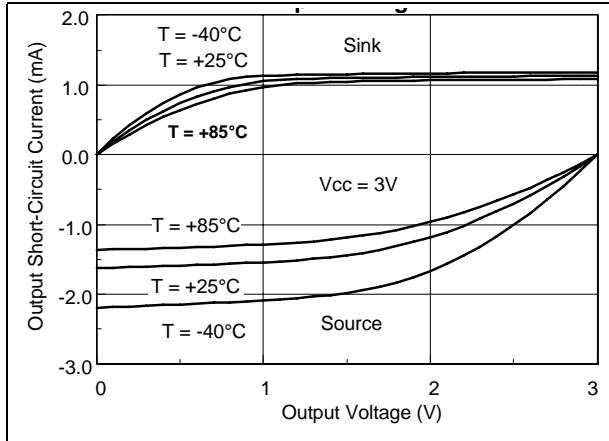
**Figure 7. Output short-circuit current vs. output voltage**



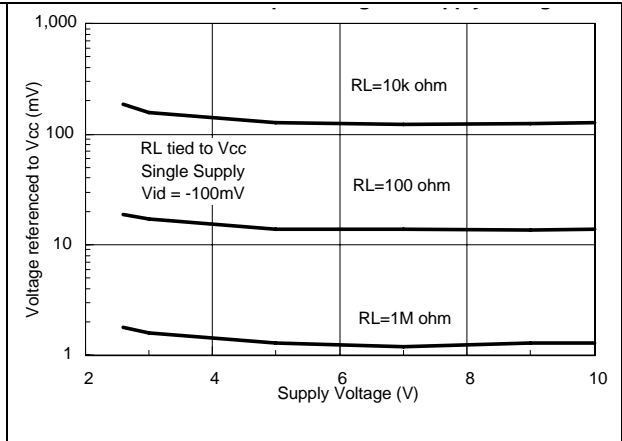
**Figure 8. High level output voltage vs. supply voltage**



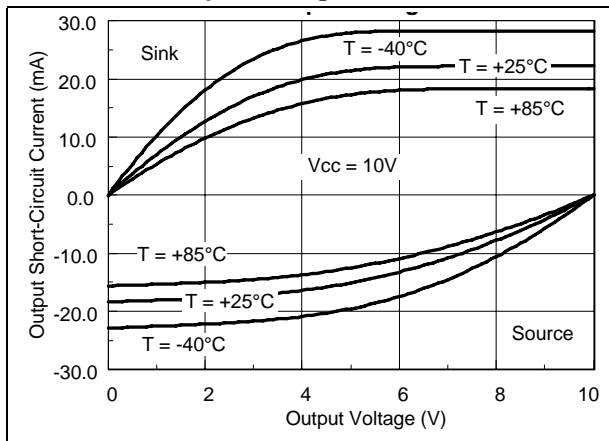
**Figure 9. Output short-circuit current vs. output voltage**



**Figure 10. Low level output voltage vs. supply voltage**



**Figure 11. Output short-circuit current vs. output voltage**



**Figure 12. Gain and phase vs. frequency**

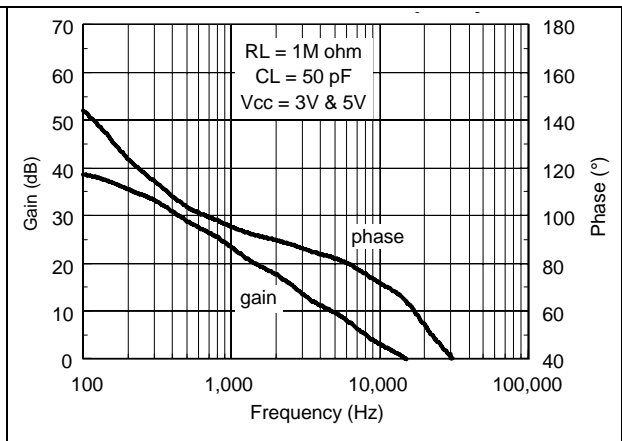




Figure 13. Small signal transient response

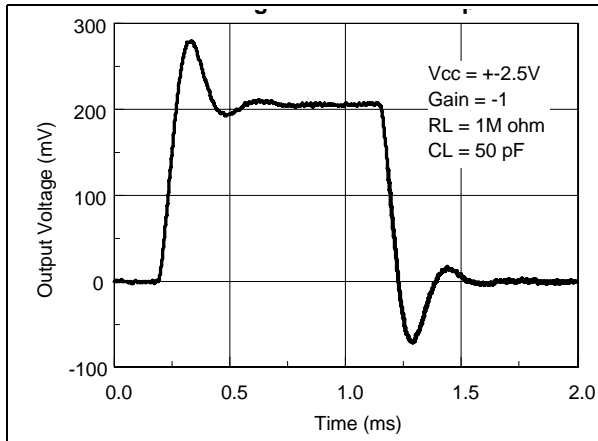


Figure 14. Gain and phase versus frequency

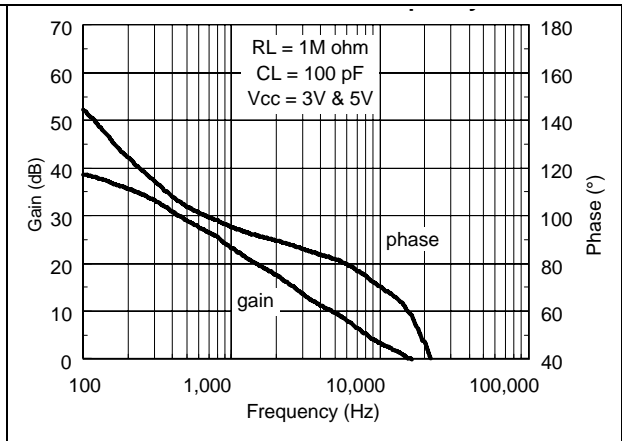


Figure 15. Slew rate positive and negative vs. temperature

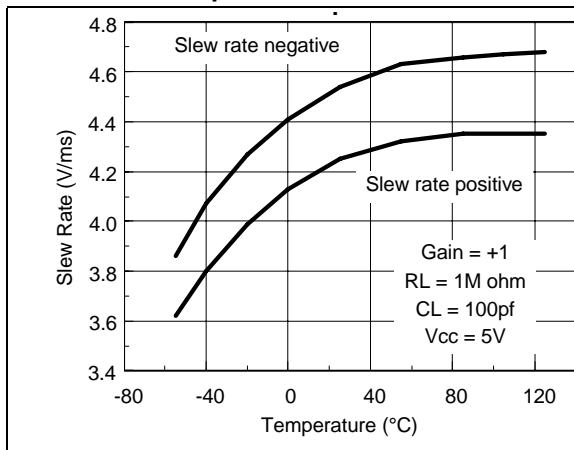
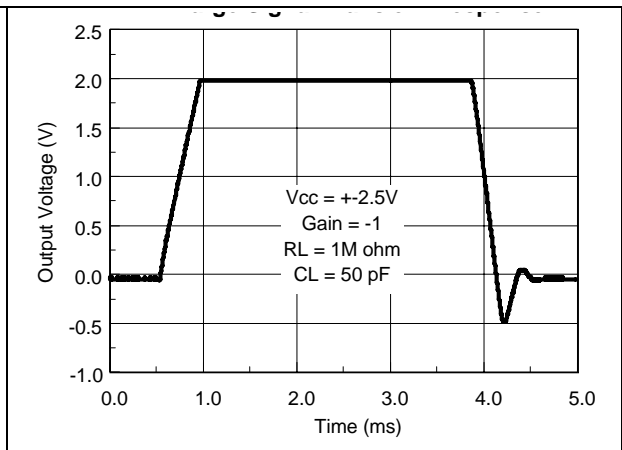


Figure 16. Large signal transient response



### 3 Package information

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

#### 3.1 SOT23-5 package information

Figure 17. SOT23-5 package mechanical drawing

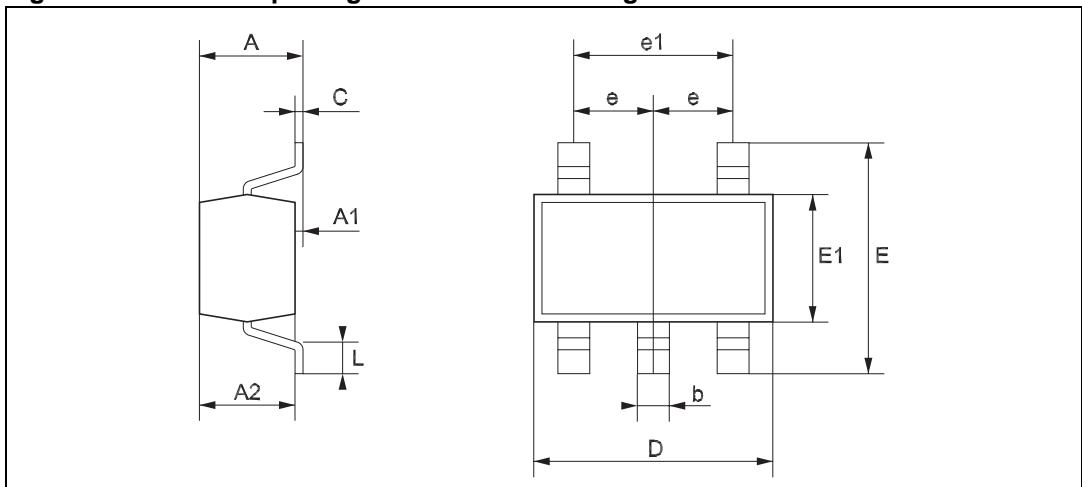


Table 6. SOT23-5 package mechanical data

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

### 3.2 DIP8 package information

Figure 18. DIP8 package mechanical drawing

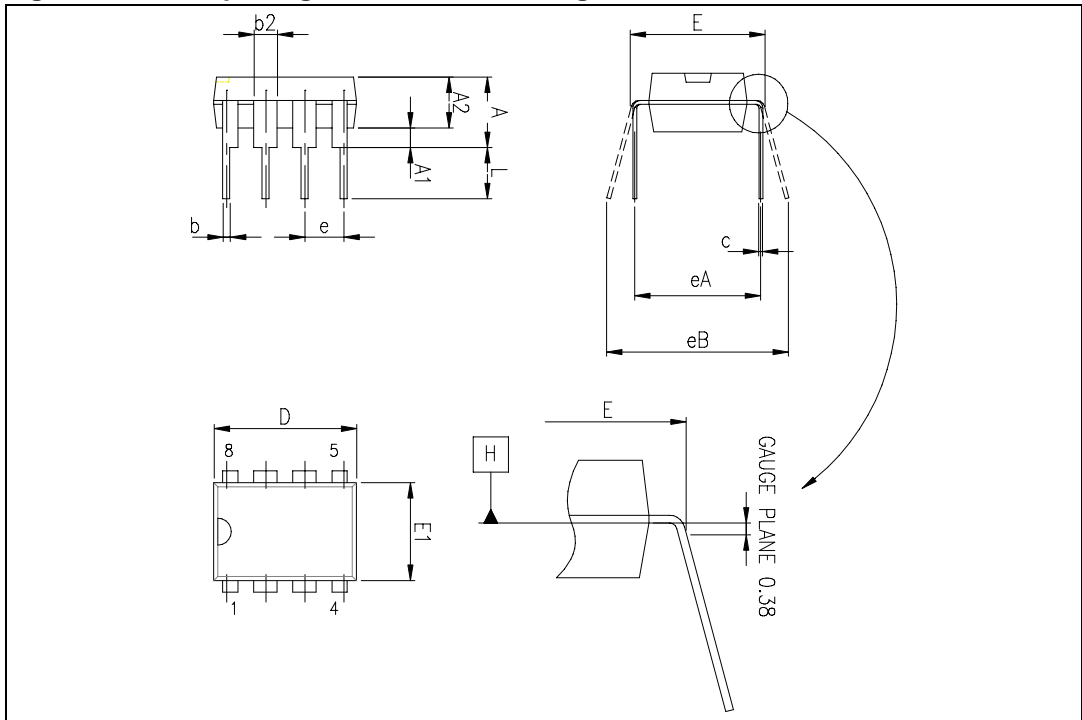


Table 7. DIP8 package mechanical data

Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			5.33			0.210
A1	0.38			0.015		
A2	2.92	3.30	4.95	0.115	0.130	0.195
b	0.36	0.46	0.56	0.014	0.018	0.022
b2	1.14	1.52	1.78	0.045	0.060	0.070
c	0.20	0.25	0.36	0.008	0.010	0.014
D	9.02	9.27	10.16	0.355	0.365	0.400
E	7.62	7.87	8.26	0.300	0.310	0.325
E1	6.10	6.35	7.11	0.240	0.250	0.280
e		2.54			0.100	
eA		7.62			0.300	
eB			10.92			0.430
L	2.92	3.30	3.81	0.115	0.130	0.150

### 3.3 SO-8 package information

Figure 19. SO-8 package mechanical drawing

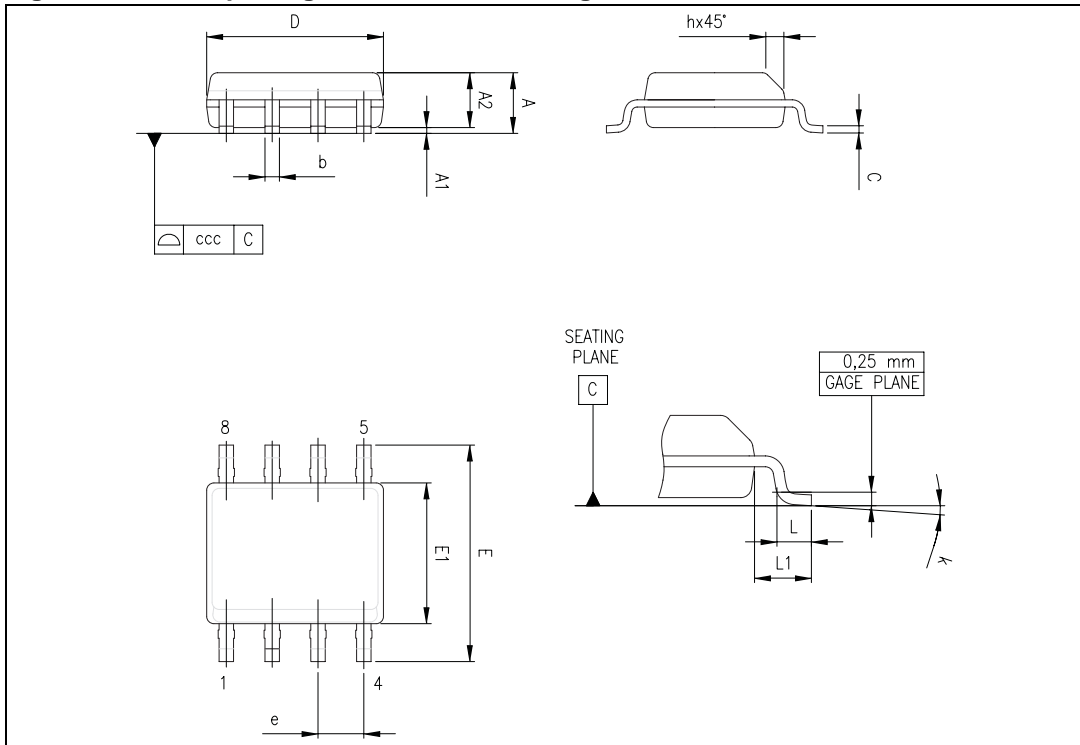


Table 8. SO-8 package mechanical data

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
k	1°		8°	1°		8°
ccc			0.10			0.004

### 3.4 TSSOP8 package information

Figure 20. TSSOP8 package mechanical drawing

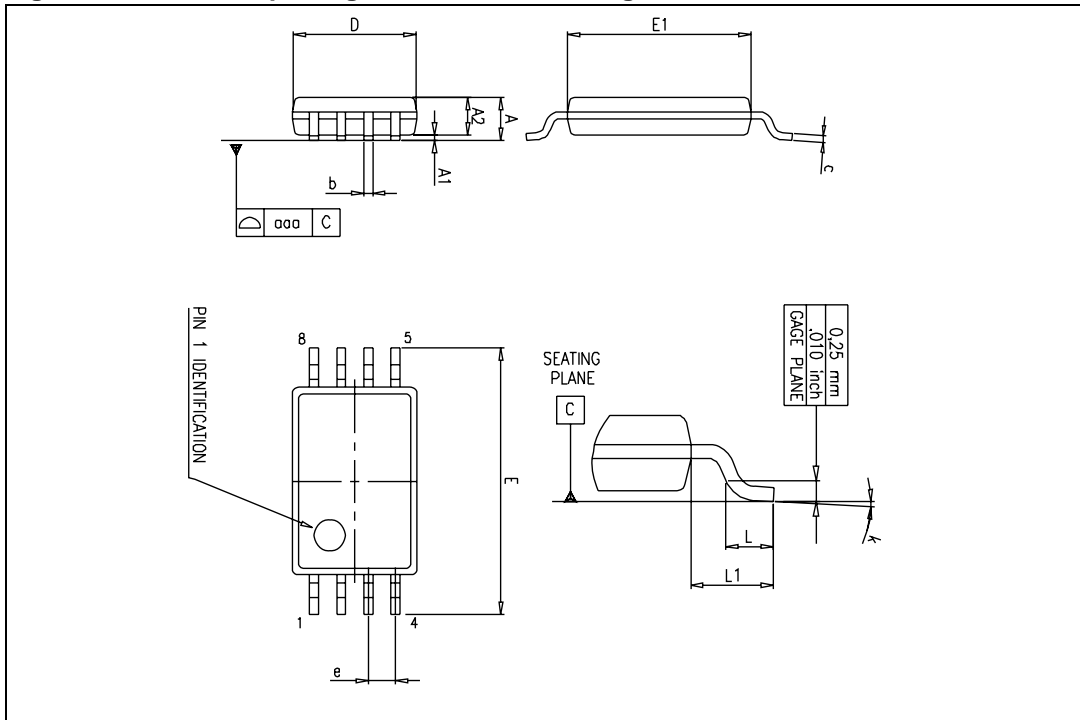


Table 9. TSSOP8 package mechanical data

Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.2			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		0.1			0.004	

### 3.5 DIP14 package information

Figure 21. DIP14 package mechanical drawing

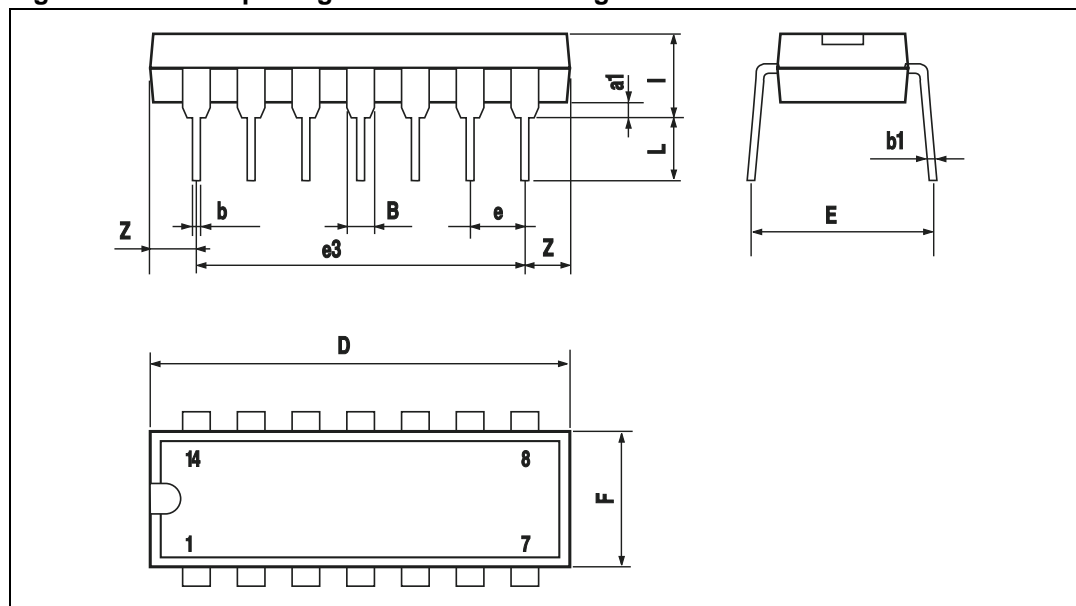


Table 10. DIP14 package mechanical data

Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
a1	0.51			0.020		
B	1.39		1.65	0.055		0.065
b		0.5			0.020	
b1		0.25			0.010	
D			20			0.787
E		8.5			0.335	
e		2.54			0.100	
e3		15.24			0.600	
F			7.1			0.280
I			5.1			0.201
L		3.3			0.130	
Z	1.27		2.54	0.050		0.100

### 3.6 SO-14 package information

Figure 22. SO-14 package mechanical drawing

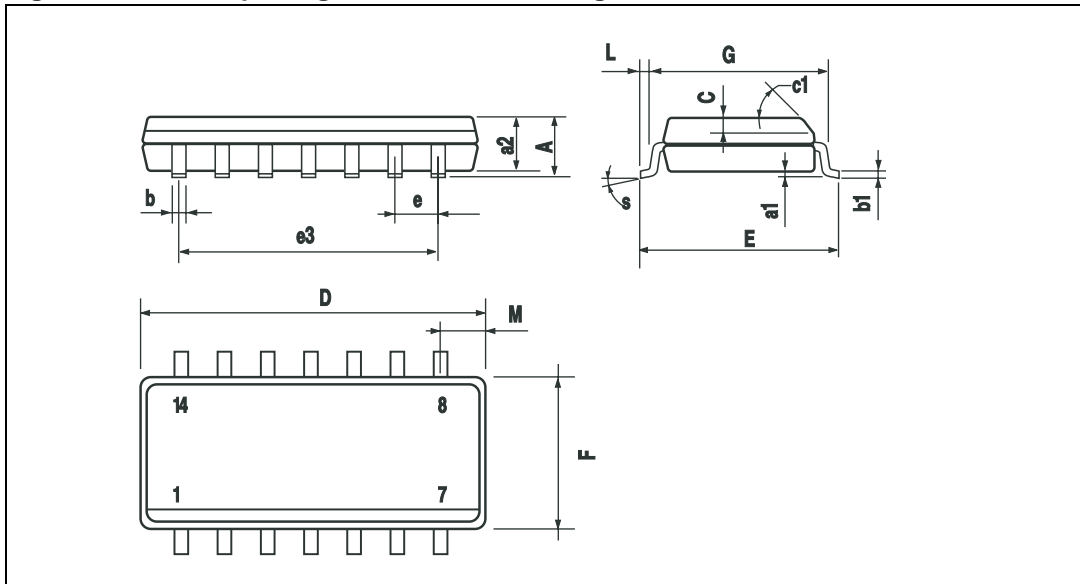


Table 11. SO-14 package mechanical data

Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.75			0.068
a1	0.1		0.2	0.003		0.007
a2			1.65			0.064
b	0.35		0.46	0.013		0.018
b1	0.19		0.25	0.007		0.010
C		0.5			0.019	
c1	45° (typ.)					
D	8.55		8.75	0.336		0.344
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		7.62			0.300	
F	3.8		4.0	0.149		0.157
G	4.6		5.3	0.181		0.208
L	0.5		1.27	0.019		0.050
M			0.68			0.026
S	8° (max.)					

### 3.7 TSSOP14 package information

Figure 23. TSSOP14 package mechanical drawing

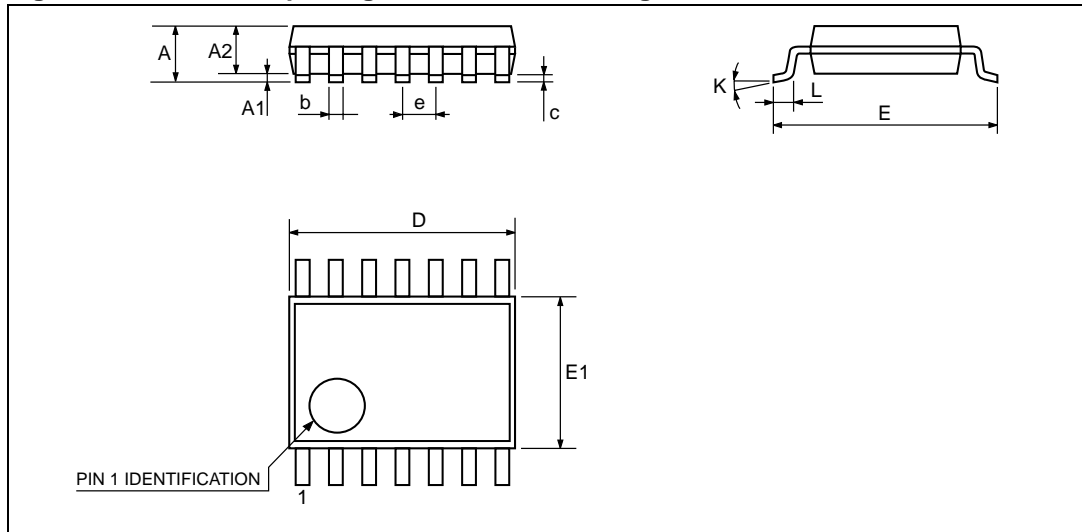


Figure 24. TSSOP14 package mechanical data

Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.2			0.047
A1	0.05		0.15	0.002	0.004	0.006
A2	0.8	1	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	4.9	5	5.1	0.193	0.197	0.201
E	6.2	6.4	6.6	0.244	0.252	0.260
E1	4.3	4.4	4.48	0.169	0.173	0.176
e		0.65 BSC			0.0256 BSC	
K	0°		8°	0°		8°
L1	0.45	0.60	0.75	0.018	0.024	0.030



## 4 Ordering information

Table 12. Order codes

Order code	Temperature range	Package	Packaging	Marking
TS941ID TS941IDT	-40°C to +85°C	SO-8	Tube or Tape & reel	TS941ID TS941IDT
TS941AID TS941AIDT				TS941AID
TS941BID TS941BIDT				TS941BID
TS941ILT		SOT23-5L	Tape & reel	K201
TS941AILT				K202
TS941BILT				K203
TS942IN		DIP-8	Tube	TS942IN
TS942AIN				TS942AIN
TS942BIN				TS942BIN
TS942ID TS942IDT		SO-8	Tube or Tape & reel	TS942ID TS942IDT
TS942AID TS942AIDT				TS942AID
TS942BID TS942BIDT				TS942BID
TS942IPT		TSSOP8	Tape & reel	TS942
TS942AIPT				942AI
TS942BIPT				942BI
TS944IN		DIP14	Tube	TS944IN
TS944AIN				TS944AIN
TS944BIN				TS944BIN
TS944ID TS944IDT		SO-14	Tube or Tape & reel	TS944ID TS944IDT
TS944AID TS944AIDT				TS944AID TS944AIDT
TS944BID TS944BIDT				TS944BID TS944BIDT
TS944IPT		TSSOP14	Tape & reel	TS944IPT
TS944AIPT				TS944AI
TS944BIPT				TS944BI

## 5 Revision history

**Table 13. Document revision history**

Date	Revision	Changes
01-Dec-2001	1	Initial release.
01-Dec-2004	2	Modifications on AMR table (explanation of $V_{id}$ and $V_{in}$ limits).
13-Mar-2008	3	CDM values added for TS944 in SO and TSSOP packages. Document reformatted.
09-Apr-2008	4	Corrected error in power consumption on cover page (1.2 $\mu$ A, not 1.2mA).

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