

## Output rail-to-rail micropower operational amplifiers

### Features

- Rail-to-rail output voltage swing
- Micropower consumption (1.2  $\mu$ 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

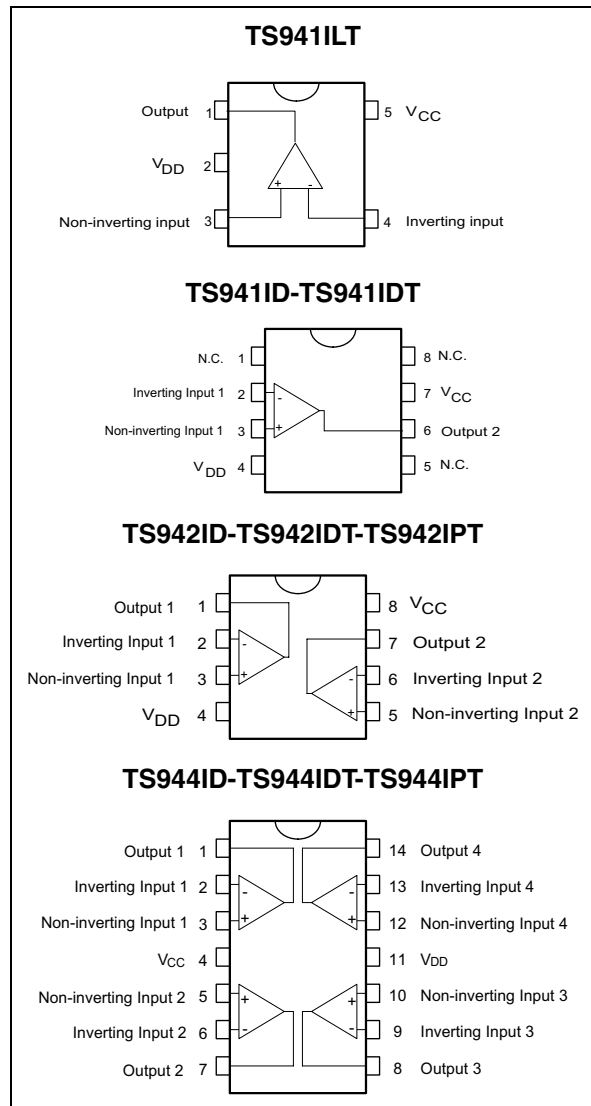
- Battery-powered systems (alarm)
- Portable communication systems (paggers)
- Smoke/gas/fire detectors
- Instrumentation and sensing
- PH meter

### Description

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

They exhibit excellent consumption -1.2  $\mu$ A, while featuring 10 kHz gain bandwidth product, 1.5 mA output capability and output rail-to-rail operation - 2.85 V typical at 3 V with  $R_L=10$  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 typical input bias current and constant supply current over supply voltage enhance the devices' performance near the end of the battery charge or battery life.



**Table 1. Device summary**

Reference	Selection on offset voltage
TS94x	TS941, TS942, TS944
TS94xA	TS941A, TS942A, TS944A
TS94xB	TS941B, TS942B, TS944B

# 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>	$V_{DD}-0.3$ 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
	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
	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  $V_{CC} + 0.3$  V.
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 k $\Omega$  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  $\Omega$ ). 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 3. 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 4.**  $V_{CC} = +2.5\text{ V}$ ,  $V_{DD} = 0\text{ V}$ ,  $R_L$  connected to  $V_{CC}/2$ ,  $T_{amb} = 25^\circ\text{ C}$   
(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		$\mu\text{V}/^\circ\text{C}$
$I_{io}$	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 $V_O = 2\text{ V}_{pp}$ , $R_L = 1\text{ M}\Omega$		100		dB
$V_{OH}$	High level output voltage $V_{ID} = 100\text{ mV}$ , $R_L = 1\text{ M}\Omega$ $R_L = 10\text{ k}\Omega$	2.45 2.3	2.49 2.4		V
$V_{OL}$	Low level output voltage $V_{ID} = -100\text{ mV}$ , $R_L = 1\text{ M}\Omega$ $R_L = 10\text{ k}\Omega$		1 100	5 200	mV
$I_o$	Output source current $V_{ID} = 100\text{ mV}$ , $V_O = V_{DD}$ Output sink current $V_{ID} = -100\text{ mV}$ , $V_O = V_{CC}$	350 280	650 500		$\mu\text{A}$
$I_{CC}$	Supply current (per amplifier), $A_{VCL} = 1$ , no load		1.2	1.8	$\mu\text{A}$
GBP	Gain bandwidth product, $R_L = 1\text{ M}\Omega$ , $C_L = 50\text{ pF}$		10		kHz
SR	Slew rate, $R_L = 1\text{ M}\Omega$ , $C_L = 50\text{ pF}$	3	4.5		V/ms
$\phi_m$	Phase margin, $C_L = 50\text{ pF}$		65		Degrees

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

**Table 5.**  $V_{CC} = +3\text{ V}$ ,  $V_{DD} = 0\text{ V}$ ,  $R_L$  connected to  $V_{CC}/2$ ,  $T_{amb} = 25^\circ\text{ C}$   
(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		$\mu\text{V}/^\circ\text{C}$
$I_{io}$	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 $V_O = 2 V_{pp}$ , $R_L = 1\text{ M}\Omega$		100		dB
$V_{OH}$	High level output voltage $V_{ID} = 100\text{ mV}$ , $R_L = 1\text{ M}\Omega$ $R_L = 10\text{ k}\Omega$	2.9 2.8	2.99 2.85		V
$V_{OL}$	Low level output voltage $V_{ID} = -100\text{ mV}$ , $R_L = 1\text{ M}\Omega$ $R_L = 10\text{ k}\Omega$		1 100	5 200	mV
$I_o$	Output source current $V_{ID} = 100\text{ mV}$ , $V_O = V_{DD}$ Output sink current $V_{ID} = -100\text{ mV}$ , $V_O = V_{CC}$	680 650	1500 1300		$\mu\text{A}$
$I_{CC}$	Supply current (per amplifier), $A_{VCL} = 1$ , no load		1.2	1.8	$\mu\text{A}$
GBP	Gain bandwidth product, $R_L = 1\text{ M}\Omega$ , $C_L = 50\text{ pF}$		10		kHz
SR	Slew rate, $R_L = 1\text{ M}\Omega$ , $C_L = 50\text{ pF}$	3	4.5		V/ms
$\phi_m$	Phase margin, $C_L = 50\text{ pF}$		65		Degrees

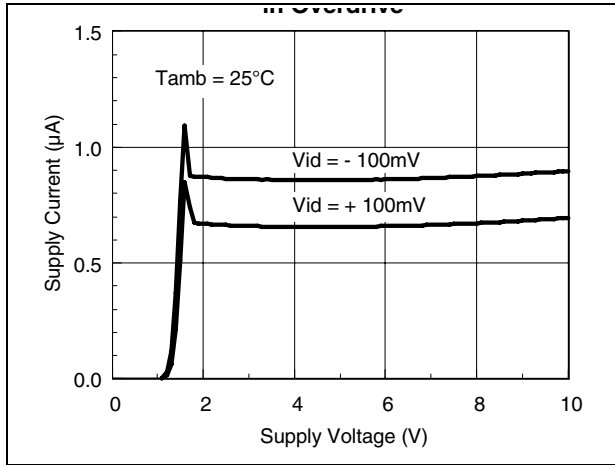
1. All electrical values are guaranteed with correlation measurements at 2.5 V and 5 V.
2. Maximum values include unavoidable inaccuracies of the industrial tests.

**Table 6.**  $V_{CC} = +5\text{ V}$ ,  $V_{DD} = 0\text{ V}$ ,  $R_L$  connected to  $V_{CC}/2$ ,  $T_{amb} = 25^\circ\text{ C}$   
(unless otherwise specified)

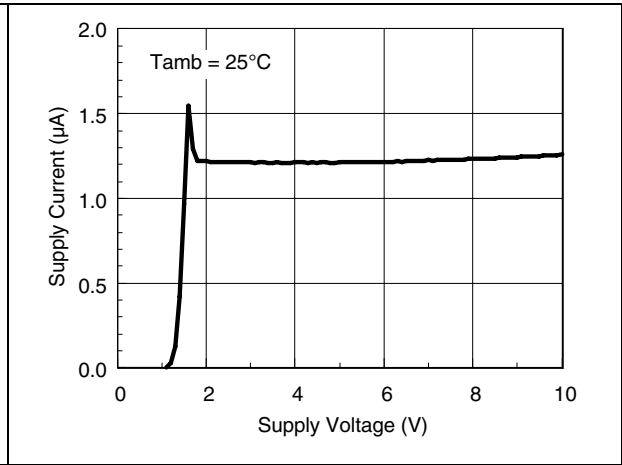
Symbol	Parameter	Min.	Typ.	Max.	Unit
$V_{io}$	Input offset voltage TS941/2/4 TS941/2/4A TS941/2/4B			10 5 2	mV
$\Delta V_{io}$	Input offset voltage drift		7		$\mu\text{V}/^\circ\text{C}$
$I_{io}$	Input offset current <sup>(1)</sup>		1	100	pA
$I_{ib}$	Input bias current <sup>(1)</sup>		1	150	pA
CMR	Common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

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

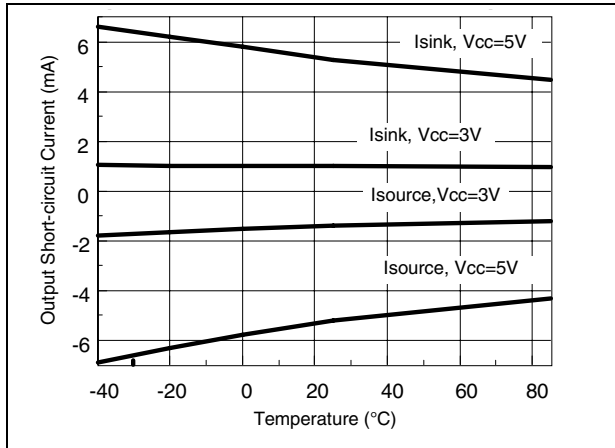
**Figure 1. Supply current per amplifier vs. supply voltage in overdrive**



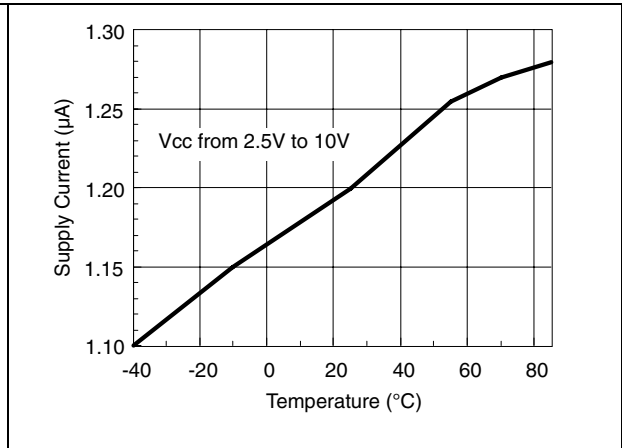
**Figure 2. Supply current per amplifier vs. supply voltage**



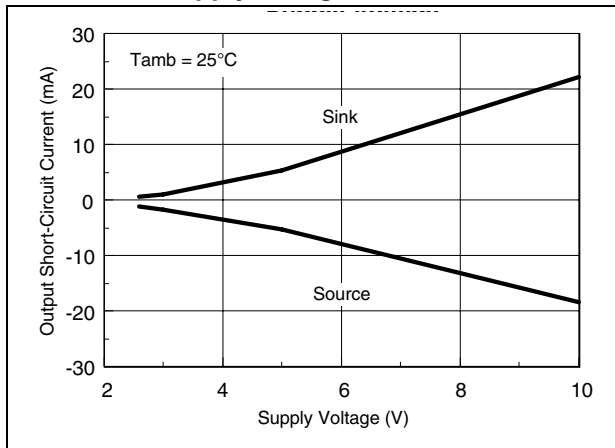
**Figure 3. Output short-circuit current vs. temperature**



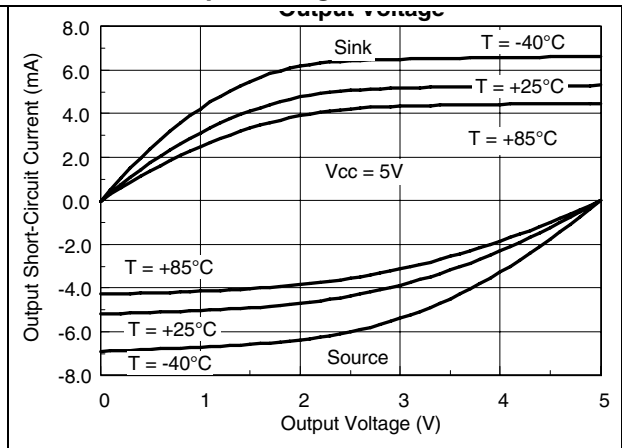
**Figure 4. Supply current per amplifier vs. temperature**



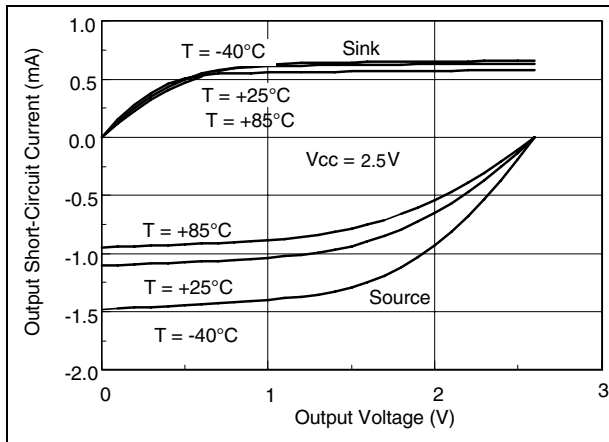
**Figure 5. Output short-circuit current vs. supply voltage**



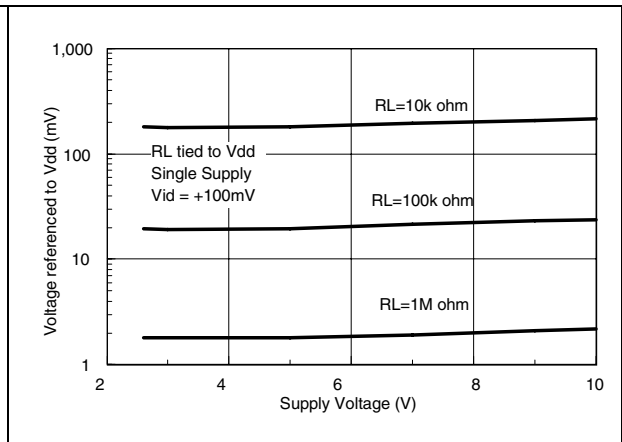
**Figure 6. Output short-circuit current vs. output voltage**



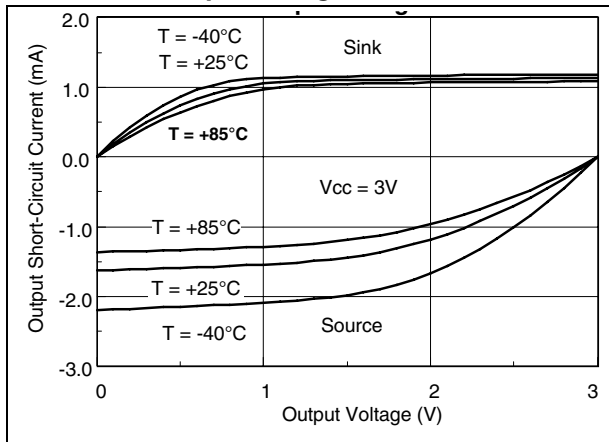
**Figure 7. Output short-circuit current vs. output voltage**



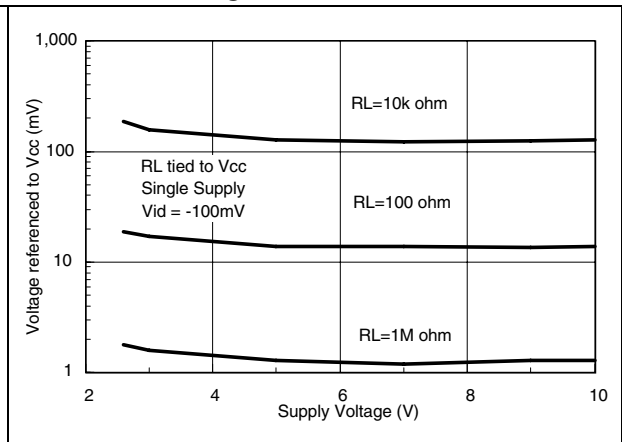
**Figure 8. High level output voltage vs. supply voltage**



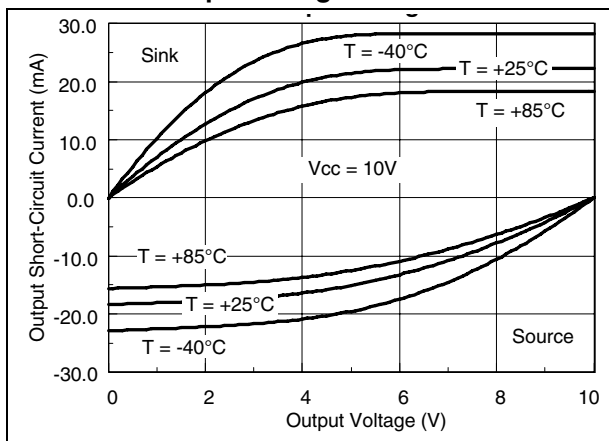
**Figure 9. Output short-circuit current vs. output voltage**



**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**

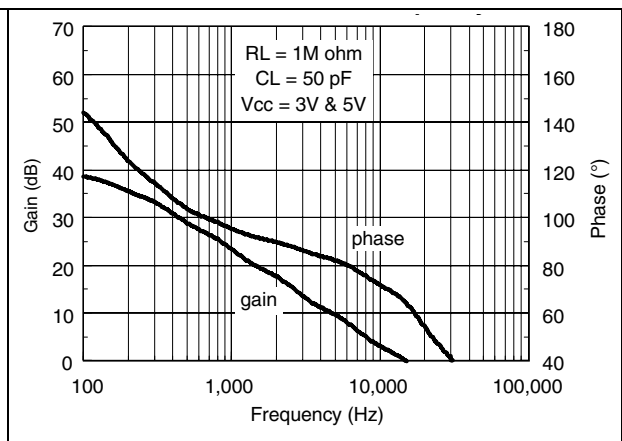




Figure 13. Small signal transient response

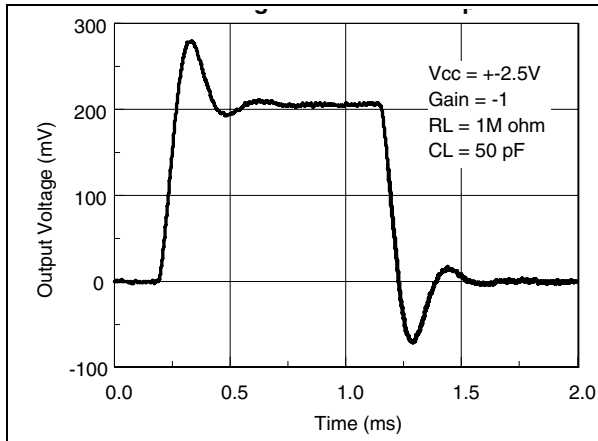


Figure 14. Gain and phase versus frequency

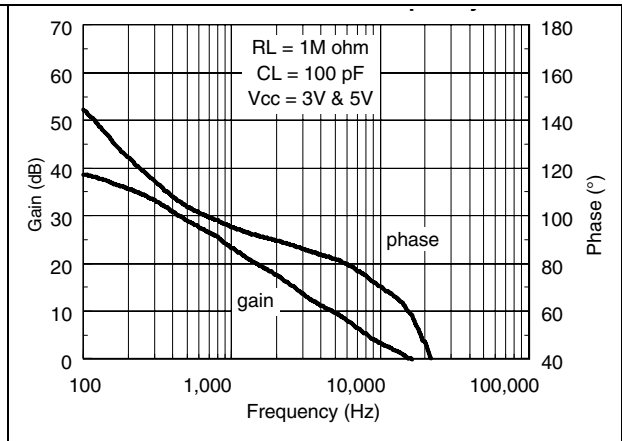


Figure 15. Slew rate positive and negative vs. temperature

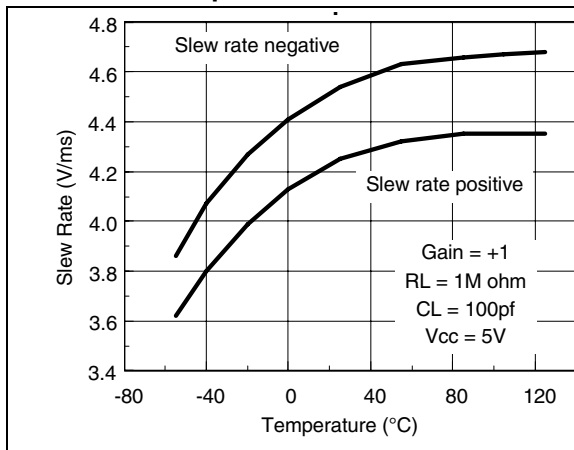
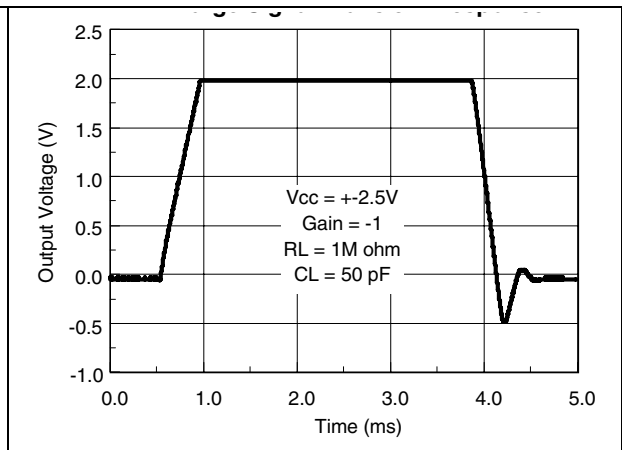


Figure 16. Large signal transient response



### 3 Package information

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

### 3.1 SOT23-5 package information

Figure 17. SOT23-5 package mechanical drawing

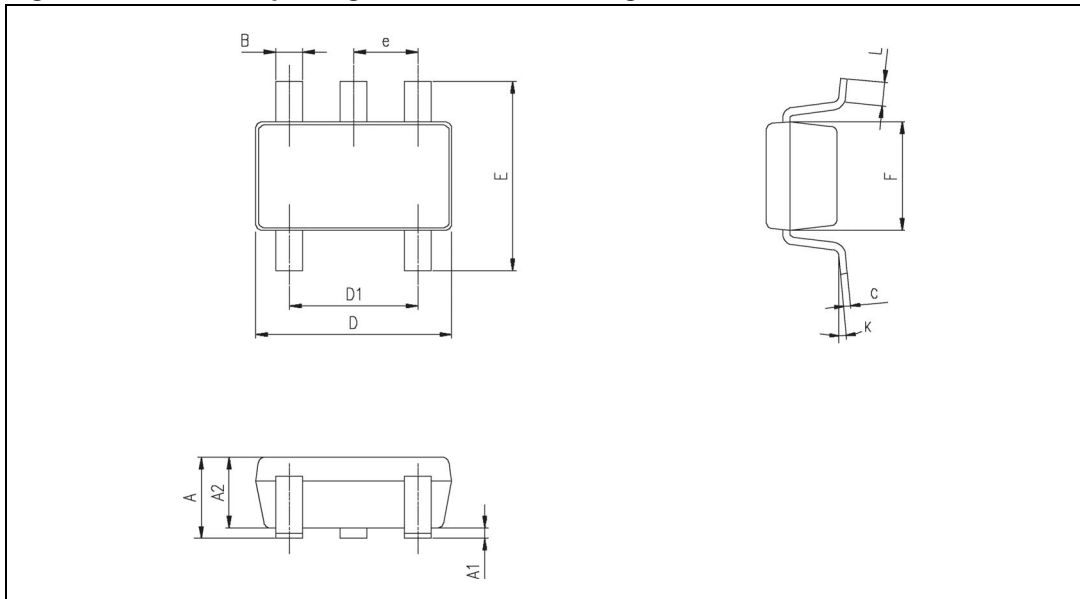


Table 7. SOT23-5 package mechanical data

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	0.013	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			

### 3.2 SO-8 package information

Figure 18. SO-8 package mechanical drawing

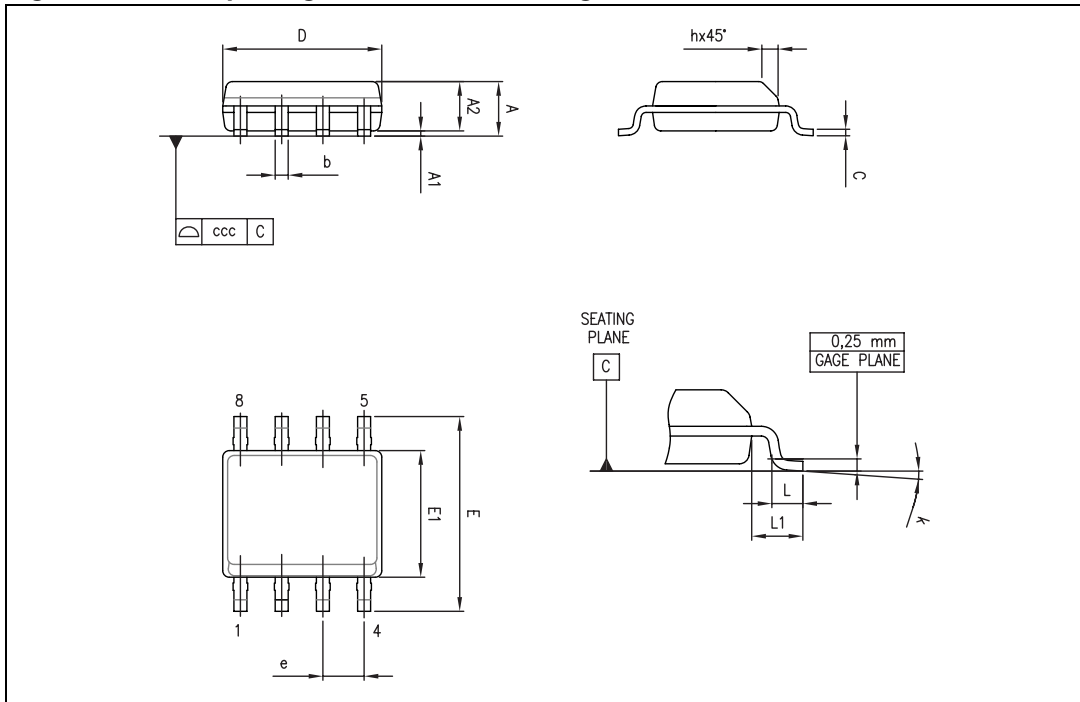


Table 8. SO-8 package mechanical data

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
L1		1.04			0.040	
k	0		8°	1°		8°
ccc			0.10			0.004

### 3.3 TSSOP8 package information

Figure 19. TSSOP8 package mechanical drawing

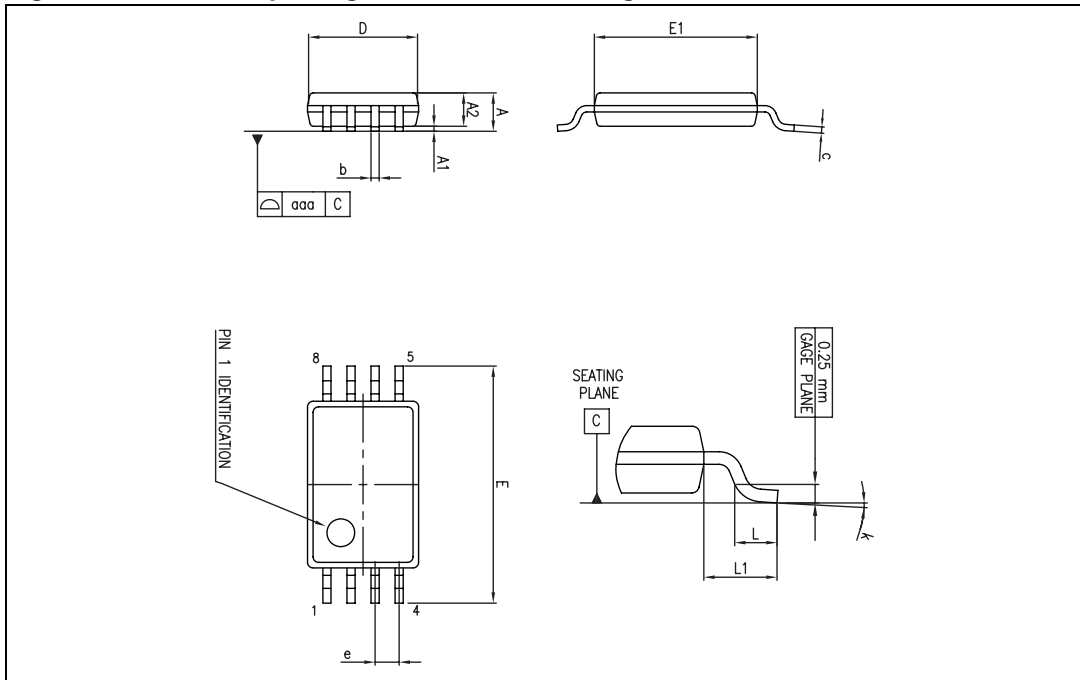


Table 9. TSSOP8 package mechanical data

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

### 3.4 SO-14 package information

Figure 20. SO-14 package mechanical drawing

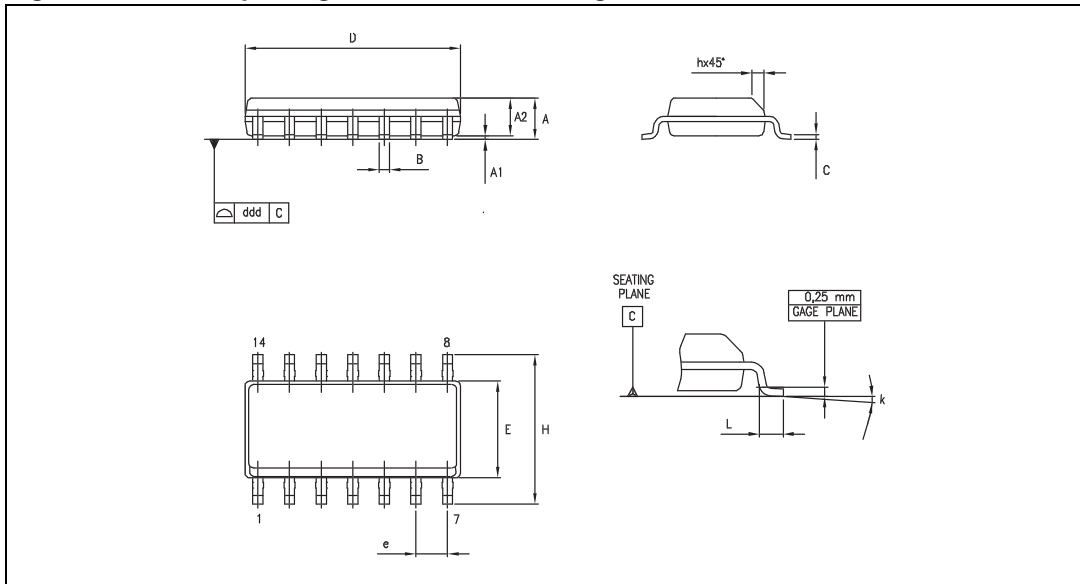


Table 10. SO-14 package mechanical data

Dimensions						
Ref.	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

### 3.5 TSSOP14 package information

Figure 21. TSSOP14 package mechanical drawing

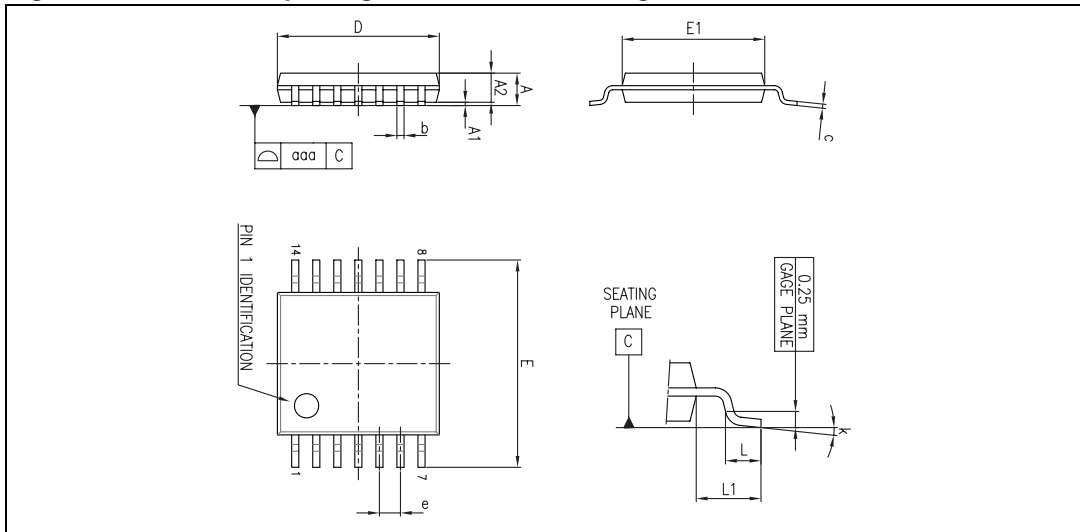


Table 11. TSSOP14 package mechanical data

Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.20			0.047
A1	0.05		0.15	0.002	0.004	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

## 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
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
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).
05-Mar-2009	5	Removed DIP package information and order codes in <a href="#">Chapter 3</a> and <a href="#">Chapter 4</a> . Updated all other package mechanical drawings and data in <a href="#">Chapter 3</a> .
06-Oct-2009	6	Added root part numbers (TS94xA, TS94xB) and <a href="#">Table 1: Device summary</a> on cover page.

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