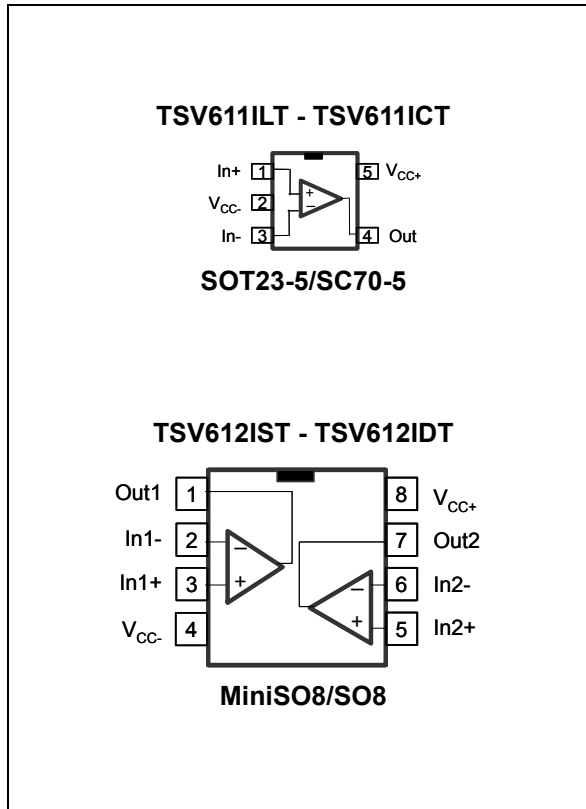


## Rail-to-rail input/output 10 $\mu$ A, 120 kHz CMOS operational amplifiers

Datasheet - production data



### Applications

- Battery-powered applications
- Smoke detectors
- Proximity sensors
- Portable devices
- Signal conditioning
- Active filtering
- Medical instrumentation

### Description

The TSV61x family of single and dual operational amplifiers offers low voltage, low power operation, and rail-to-rail input and output.

The devices also feature an ultra-low input bias current as well as a low input offset voltage.

The TSV61x have a gain bandwidth product of 120 kHz while consuming only 10  $\mu$ A at 5 V.

These features make the TSV61x family ideal for sensor interfaces, battery supplied and portable applications, as well as active filtering.

### Features

- Rail-to-rail input and output
- Low power consumption: 10  $\mu$ A typ at 5 V
- Low supply voltage: 1.5 to 5.5 V
- Gain bandwidth product: 120 kHz typ
- Unity gain stable
- Low input offset voltage: 800  $\mu$ V max (A version)
- Low input bias current: 1 pA typ
- Temperature range: -40 to 85  $^{\circ}$ C

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# 1 Absolute maximum ratings and operating conditions

**Table 1. Absolute maximum ratings**

Symbol	Parameter	Value	Unit
$V_{CC}$	Supply voltage <sup>(1)</sup>	6	V
$V_{id}$	Differential input voltage <sup>(2)</sup>	$\pm V_{CC}$	
$V_{in}$	Input voltage <sup>(3)</sup>	$(V_{CC-}) - 0.2$ to $(V_{CC+}) + 0.2$	
$T_{stg}$	Storage temperature	-65 to 150	°C
$R_{thja}$	Thermal resistance junction to ambient <sup>(4)</sup> <sup>(5)</sup>		°C/W
	SC70-5	205	
	SOT23-5	250	
	MiniSO8	190	
	SO8	125	
$T_j$	Maximum junction temperature	150	°C
ESD	HBM: human body model <sup>(6)</sup>	4	kV
	MM: machine model <sup>(7)</sup>	200	V
	CDM: charged device model <sup>(8)</sup>	1.5	kV
	Latch-up immunity	200	mA

- All voltage values, except differential voltage are with respect to network ground terminal.
- Differential voltages are the non-inverting input terminal with respect to the inverting input terminal.
- $V_{CC}$ - $V_{in}$  must not exceed 6 V.
- Short-circuits can cause excessive heating and destructive dissipation.
- $R_{th}$  are typical values.
- 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.
- Machine model: a 200 pF cap is 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.
- Charged device model: all pins plus package are charged together to the specified voltage and then discharged directly to ground.

**Table 2. Operating conditions**

Symbol	Parameter	Value	Unit
$V_{CC}$	Supply voltage	1.5 to 5.5	V
$V_{icm}$	Common mode input voltage range	$(V_{CC-}) - 0.1$ to $(V_{CC+}) + 0.1$	
$T_{oper}$	Operating free air temperature range	-40 to 85	°C

## 2 Electrical characteristics

**Table 3. Electrical characteristics at  $V_{CC+} = 1.8\text{ V}$  with  $V_{CC-} = 0\text{ V}$ ,  $V_{icm} = V_{CC}/2$ ,  $T_{amb} = 25\text{ °C}$ , and  $R_L$  connected to  $V_{CC}/2$  (unless otherwise specified)**

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
<b>DC performance</b>						
$V_{io}$	Offset voltage	TSV61x			4	mV
		TSV61xA			0.8	
		$T_{min.} < T_{op} < T_{max.}$ TSV61x			5	
		$T_{min.} < T_{op} < T_{max.}$ TSV61xA			2	
$\Delta V_{io}/\Delta T$	Input offset voltage drift			2		$\mu\text{V}/\text{°C}$
$I_{io}$	Input offset current ( $V_{out} = V_{CC}/2$ )			1	$10^{(1)}$	pA
		$T_{min.} < T_{op} < T_{max.}$		1	100	
$I_{ib}$	Input bias current ( $V_{out} = V_{CC}/2$ )			1	$10^{(1)}$	pA
		$T_{min.} < T_{op} < T_{max.}$		1	100	
CMR	Common mode rejection ratio $20 \log(\Delta V_{ic}/\Delta V_{io})$	$0\text{ V to }1.8\text{ V}$ , $V_{out} = 0.9\text{ V}$	55	71		dB
		$T_{min.} < T_{op} < T_{max.}$	53			
$A_{vd}$	Large signal voltage gain	$R_L = 10\text{ k}\Omega$ , $V_{out} = 0.5\text{ V to }1.3\text{ V}$	78	83		dB
		$T_{min.} < T_{op} < T_{max.}$	74			
$V_{OH}$	High level output voltage ( $V_{OH} = V_{CC} - V_{out}$ )	$R_L = 10\text{ k}\Omega$ $T_{min.} < T_{op} < T_{max.}$		4	35 50	mV
$V_{OL}$	Low level output voltage	$R_L = 10\text{ k}\Omega$ $T_{min.} < T_{op} < T_{max.}$		7	35 50	
$I_{out}$	Isink	$V_o = 1.8\text{ V}$ $T_{min.} < T_{op} < T_{max.}$	9 9	13		mA
	Isource	$V_o = 0\text{ V}$ $T_{min.} < T_{op} < T_{max.}$	8 8	10		
$I_{CC}$	Supply current (per operator)	No load, $V_{out} = V_{CC}/2$	6.5	9	12	$\mu\text{A}$
		$T_{min.} < T_{op} < T_{max.}$	6		12.5	
<b>AC performance</b>						
GBP	Gain bandwidth product			100		kHz
$\phi_m$	Phase margin	$R_L = 10\text{ k}\Omega$ , $C_L = 20\text{ pF}$		60		Degrees
$G_m$	Gain margin			9.5		dB
SR	Slew rate	$R_L = 10\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , $V_{out} = 0.5\text{ V to }1.3\text{ V}$		0.03		$\text{V}/\mu\text{s}$

**Table 3. Electrical characteristics at  $V_{CC+} = 1.8\text{ V}$  with  $V_{CC-} = 0\text{ V}$ ,  $V_{icm} = V_{CC}/2$ ,  $T_{amb} = 25\text{ °C}$ , and  $R_L$  connected to  $V_{CC}/2$  (unless otherwise specified) (continued)**

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$e_n$	Equivalent input noise voltage	$f = 1\text{ kHz}$		110		$\frac{nV}{\sqrt{Hz}}$
THD+N	Total harmonic distortion + noise	$F_{in} = 1\text{ kHz}$ , $A_v = 1$ , $V_{out} = 1\text{ V}_{pp}$ , $R_L = 100\text{ k}\Omega$ , $BW = 22\text{ kHz}$		0.07		%

1. Guaranteed by design.

**Table 4. Electrical characteristics at  $V_{CC+} = 3.3\text{ V}$ ,  $V_{CC-} = 0\text{ V}$ ,  $V_{icm} = V_{CC}/2$ ,  $T_{amb} = 25\text{ }^{\circ}\text{C}$ ,  $R_L$  connected to  $V_{CC}/2$  (unless otherwise specified)**

Symbol	Parameter		Min.	Typ.	Max.	Unit
<b>DC performance</b>						
$V_{io}$	Offset voltage	TSV61x			4	mV
		TSV61xA			0.8	
		$T_{min} < T_{op} < T_{max}$ TSV61x			5	
		$T_{min} < T_{op} < T_{max}$ TSV61xA			2	
$\Delta V_{io}/\Delta T$	Input offset voltage drift			2		$\mu\text{V}/^{\circ}\text{C}$
$I_{io}$	Input offset current			1	$10^{(1)}$	pA
		$T_{min.} < T_{op} < T_{max.}$		1	100	
$I_{ib}$	Input bias current			1	$10^{(1)}$	pA
		$T_{min.} < T_{op} < T_{max.}$		1	100	
CMR	Common mode rejection ratio $20 \log (\Delta V_{ic}/\Delta V_{io})$	0 V to 3.3 V, $V_{out} = 1.75\text{ V}$	61	76		dB
		$T_{min.} < T_{op} < T_{max.}$	58			
$A_{vd}$	Large signal voltage gain	$R_L = 10\text{ k}\Omega$ , $V_{out} = 0.5\text{ V}$ to $2.8\text{ V}$	85	92		dB
		$T_{min.} < T_{op} < T_{max.}$	83			
$V_{OH}$	High level output voltage ( $V_{OH} = V_{CC} - V_{out}$ )	$R_L = 10\text{ k}\Omega$ $T_{min.} < T_{op} < T_{max.}$		5	35 50	mV
$V_{OL}$	Low level output voltage	$R_L = 10\text{ k}\Omega$ $T_{min.} < T_{op} < T_{max.}$		10	35 50	
$I_{out}$	Isink	$V_o = V_{CC}$ $T_{min.} < T_{op} < T_{max.}$	37 35	44		mA
	Isource	$V_o = 0\text{ V}$ $T_{min.} < T_{op} < T_{max.}$	32 30	38		
$I_{CC}$	Supply current (per operator)	No load, $V_{out} = V_{CC}/2$	6.5	9.5	12.5	$\mu\text{A}$
		$T_{min.} < T_{op} < T_{max.}$	6		13	
<b>AC performance</b>						
GBP	Gain bandwidth product			110		kHz
$\phi_m$	Phase margin	$R_L = 10\text{ k}\Omega$ , $C_L = 20\text{ pF}$		60		Degrees
$G_m$	Gain margin			9.5		dB
SR	Slew rate	$R_L = 10\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , $V_{out} = 0.5\text{ V}$ to $2.8\text{ V}$		0.035		$\text{V}/\mu\text{s}$
$e_n$	Equivalent input noise voltage	$f = 1\text{ kHz}$		110		$\frac{\text{nV}}{\sqrt{\text{Hz}}}$

1. Guaranteed by design.

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

Symbol	Parameter		Min.	Typ.	Max.	Unit
<b>DC performance</b>						
$V_{io}$	Offset voltage	TSV61x			4	mV
		TSV61xA			0.8	
		$T_{min} < T_{op} < T_{max}$ TSV61x			5	
		$T_{min} < T_{op} < T_{max}$ TSV61xA			2	
$\Delta V_{io}/\Delta T$	Input offset voltage drift			2		$\mu\text{V}/^{\circ}\text{C}$
$I_{io}$	Input offset current			1	10 <sup>(1)</sup>	pA
		$T_{min} < T_{op} < T_{max}$ .		1	100	
$I_{ib}$	Input bias current			1	10 <sup>(1)</sup>	pA
		$T_{min} < T_{op} < T_{max}$ .		1	100	
CMR	Common mode rejection ratio $20 \log (\Delta V_{ic}/\Delta V_{io})$	0 V to 5 V, $V_{out} = 2.5\text{ V}$	64	80		dB
		$T_{min} < T_{op} < T_{max}$ .	63			
SVR	Supply voltage rejection ratio $20 \log (\Delta V_{cc}/\Delta V_{io})$	$V_{cc} = 1.8\text{ to }5\text{ V}$	76	93		dB
		$T_{min} < T_{op} < T_{max}$ .	74			
$A_{vd}$	Large signal voltage gain	$R_L = 10\text{ k}\Omega$ , $V_{out} = 0.5\text{ V to }4.5\text{ V}$	88	93		dB
		$T_{min} < T_{op} < T_{max}$	85			
$V_{OH}$	High level output voltage ( $V_{OH} = V_{CC} - V_{out}$ )	$R_L = 10\text{ k}\Omega$ $T_{min} < T_{op} < T_{max}$ .		7	35 50	mV
$V_{OL}$	Low level output voltage	$R_L = 10\text{ k}\Omega$ $T_{min} < T_{op} < T_{max}$ .		16	35 50	
$I_{out}$	Isink	$V_o = V_{CC}$ $T_{min} < T_{op} < T_{max}$ .	52 42	57		mA
	Isource	$V_o = 0\text{ V}$ $T_{min} < T_{op} < T_{max}$ .	58 49	63		
$I_{CC}$	Supply current (per operator)	No load, $V_{out} = V_{CC}/2$	7.5	10.5	14	$\mu\text{A}$
		$T_{min} < T_{op} < T_{max}$ .	7		15	
<b>AC performance</b>						
GBP	Gain bandwidth product			120		kHz
$\phi_m$	Phase margin	$R_L = 10\text{ k}\Omega$ , $C_L = 20\text{ pF}$		62		Degrees
$G_m$	Gain margin			10		dB
SR	Slew rate	$R_L = 10\text{ k}\Omega$ , $C_L = 20\text{ pF}$ , $V_{out} = 0.5\text{V to }4.5\text{V}$		0.04		V/ $\mu\text{s}$

**Table 5. Electrical characteristics at  $V_{CC+} = 5\text{ V}$ ,  $V_{CC-} = 0\text{ V}$ ,  $V_{icm} = V_{CC}/2$ ,  $T_{amb} = 25\text{ °C}$ ,  $R_L$  connected to  $V_{CC}/2$  (unless otherwise specified) (continued)**

Symbol	Parameter		Min.	Typ.	Max.	Unit
$e_n$	Equivalent input noise voltage	$f = 1\text{ kHz}$		105		$\frac{nV}{\sqrt{Hz}}$
THD+N	Total harmonic distortion + noise	$F_{in} = 1\text{ kHz}$ , $A_v = 1$ , $V_{out} = 1\text{ V}_{pp}$ , $R_L = 100\text{ k}\Omega$ , $BW = 22\text{ kHz}$		0.02		%

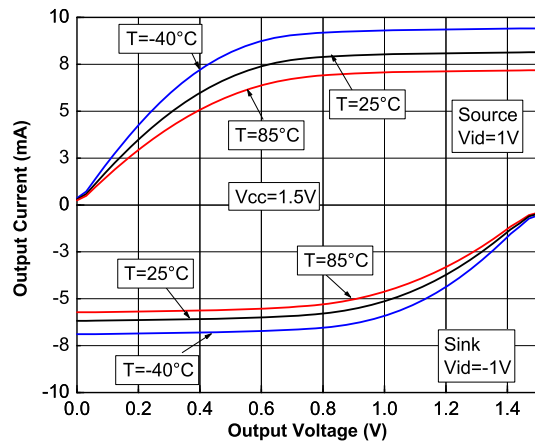
1. Guaranteed by design.



**Figure 1. Supply current vs. supply voltage at  $V_{icm} = V_{CC}/2$**



**Figure 2. Output current vs. output voltage at  $V_{CC} = 1.5V$**



**Figure 3. Output current vs. output voltage at  $V_{CC} = 5V$**



**Figure 4. Voltage gain and phase vs. frequency at  $V_{CC} = 1.5V$**



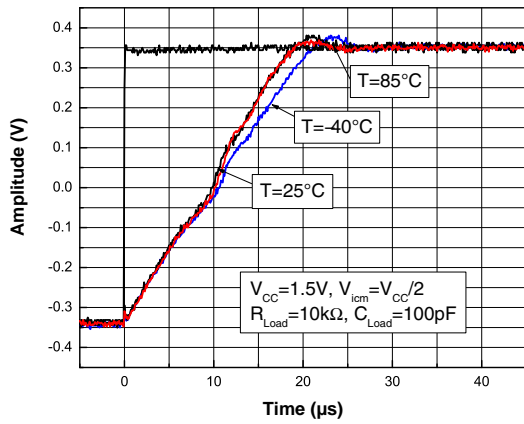
**Figure 5. Voltage gain and phase vs. frequency at  $V_{CC} = 5V$**



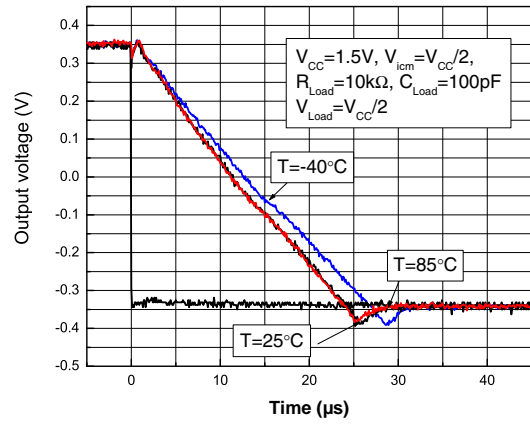
**Figure 6. Phase margin vs. output current**



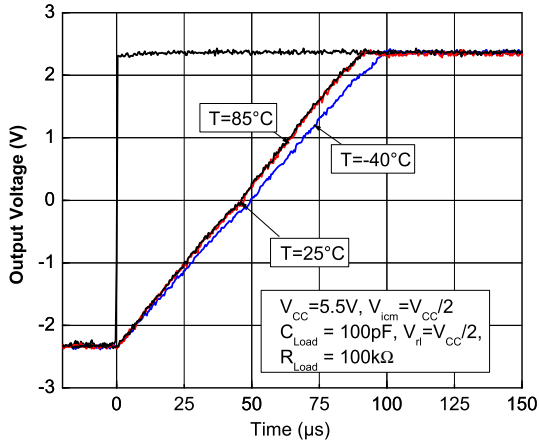
**Figure 7. Positive slew rate vs. time,  $V_{CC} = 1.5\text{ V}$ ,  $C_{Load} = 100\text{ pF}$ ,  $R_{Load} = 10\text{ k}\Omega$**



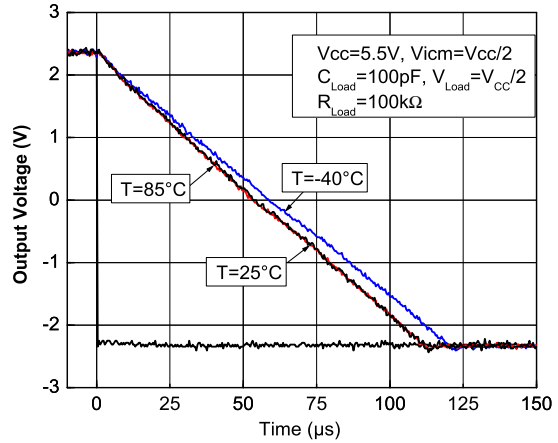
**Figure 8. Negative slew rate vs. time,  $V_{CC} = 1.5\text{ V}$ ,  $C_{Load} = 100\text{ pF}$ ,  $R_{Load} = 10\text{ k}\Omega$**



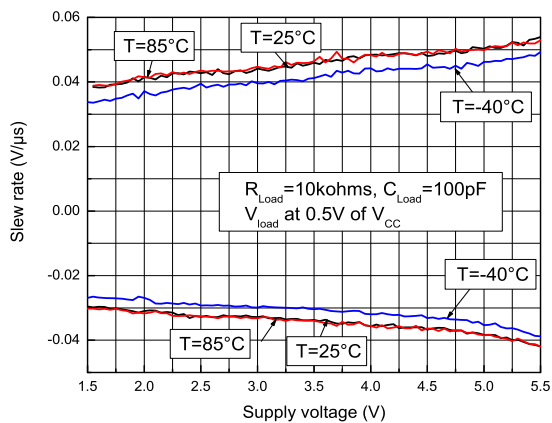
**Figure 9. Positive slew rate vs. time,  $V_{CC} = 5.5\text{ V}$ ,  $C_{Load} = 100\text{ pF}$ ,  $R_{Load} = 100\text{ k}\Omega$**



**Figure 10. Negative slew rate vs. time,  $V_{CC} = 5.5\text{ V}$ ,  $C_{Load} = 100\text{ pF}$ ,  $R_{Load} = 100\text{ k}\Omega$**



**Figure 11. Slew rate vs. supply voltage**



**Figure 12. Noise vs. frequency at  $V_{CC} = 5\text{ V}$**

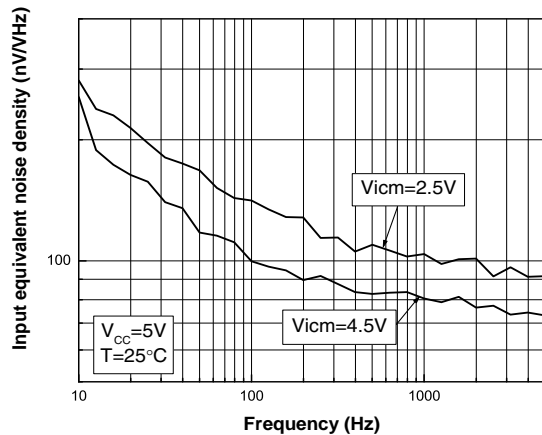


Figure 13. Distortion + noise vs. frequency



Figure 14. Distortion + noise vs. output voltage



Figure 15. Voltage gain and phase vs. frequency at  $V_{CC} = 1.8 V$  (based on simulation results)

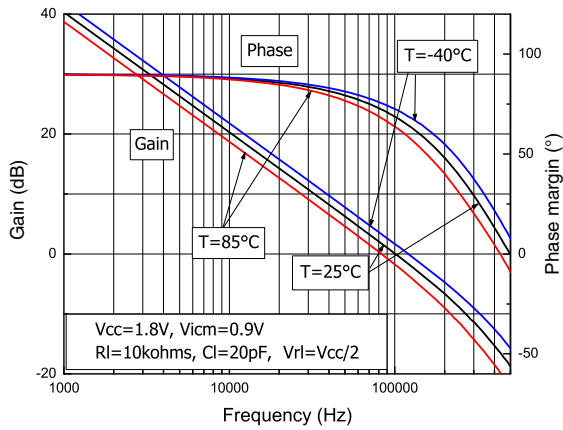


Figure 16. Voltage gain and phase vs. frequency at  $V_{CC} = 5 V$  (based on simulation results)



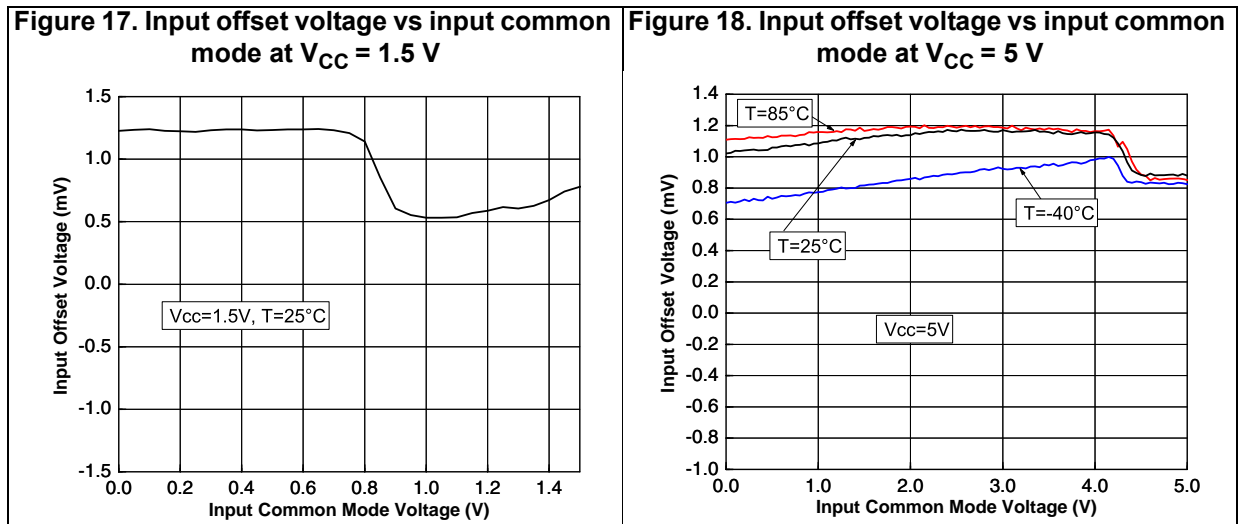
### 3 Application information

#### 3.1 Operating voltages

The TSV61x can operate from 1.5 to 5.5 V. The parameters are fully specified for 1.8, 3.3, and 5 V power supplies. However, the parameters are very stable in the full  $V_{CC}$  range and several characterization curves show the TSV61x characteristics at 1.5 V. Additionally, the main specifications are guaranteed in extended temperature ranges from -40 °C to 85 °C.

#### 3.2 Rail-to-rail input

The TSV61x are built with two complementary PMOS and NMOS input differential pairs. The devices have a rail-to-rail input, and the input common mode range is extended from  $(V_{CC-}) - 0.1$  V to  $(V_{CC+}) + 0.1$  V. The transition between the two pairs appears at  $(V_{CC+}) - 0.7$  V. In the transition region, the performance of CMRR, PSRR,  $V_{IO}$  and THD is slightly degraded (as shown in [Figure 17](#) and [Figure 18](#) for  $V_{IO}$  vs.  $V_{ICM}$ ).



The device is guaranteed without phase reversal.

#### 3.3 Rail-to-rail output

The operational amplifiers' output levels can go close to the rails: less than 35 mV above GND rail and less than 35 mV below  $V_{CC}$  rail when connected to 10 kΩ load to  $V_{CC}/2$ .

### 3.4 Driving resistive and capacitive loads

These products are micro-power, low-voltage operational amplifiers optimized to drive rather large resistive loads, above 10 k $\Omega$ . For lower resistive loads, the THD level may significantly increase.

In a follower configuration, these operational amplifiers can drive capacitive loads up to 100 pF with no oscillations. When driving larger capacitive loads, adding an in-series resistor at the output can improve the stability of the devices (see [Figure 19](#) for recommended in-series resistor values). Once the in-series resistor value has been selected, the stability of the circuit should be tested on bench and simulated with the simulation model.

**Figure 19. In-series resistor vs. capacitive load**



### 3.5 PCB layouts

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

### 3.6 Macromodel

An accurate macromodel of the TSV61x 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 TSV61x operational amplifiers. It emulates the nominal performances of a typical device within the specified operating conditions mentioned in the datasheet. It also helps to validate a design approach and to select the right operational amplifier, *but it does not replace on-board measurements*.

## 4 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.

### 4.1 SOT23-5 package information

Figure 20. SOT23-5 package outline

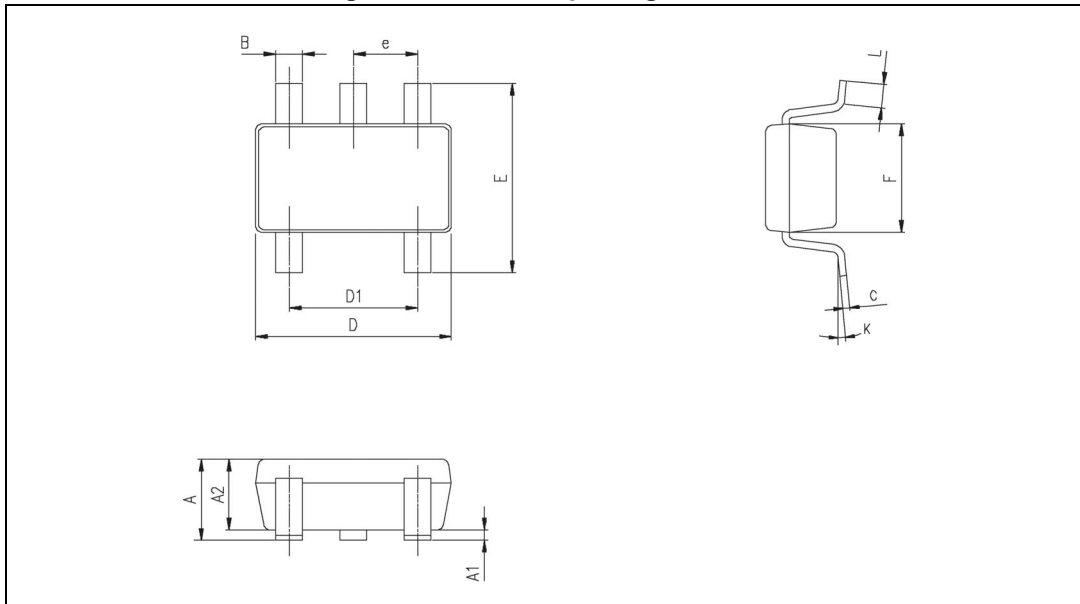


Table 6. SOT23-5 mechanical data

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	0.013	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			

### 4.2 SC70-5 (SOT323-5) package information

Figure 21. SC70-5 (SOT323-5) package outline



Table 7. SC70-5 (SOT323-5) mechanical data

Ref	Dimensions					
	Millimeters			Inches		
	Min	Typ	Max	Min	Typ	Max
A	0.80		1.10	0.315		0.043
A1			0.10			0.004
A2	0.80	0.90	1.00	0.315	0.035	0.039
b	0.15		0.30	0.006		0.012
c	0.10		0.22	0.004		0.009
D	1.80	2.00	2.20	0.071	0.079	0.087
E	1.80	2.10	2.40	0.071	0.083	0.094
E1	1.15	1.25	1.35	0.045	0.049	0.053
e		0.65			0.025	
e1		1.30			0.051	
L	0.26	0.36	0.46	0.010	0.014	0.018
<	0°		8°			



### 4.3 SO8 package information

Figure 22. SO8 package outline



Table 8. SO8 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	1°		8°	1°		8°
ccc			0.10			0.004

### 4.4 MiniSO8 package information

Figure 23. MiniSO8 package outline



Table 9. MiniSO8 mechanical data

Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.1			0.043
A1	0		0.15	0		0.006
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

## 5 Ordering information

Table 10. Order codes

Order code	Temperature range	Package	Packing	Marking
TSV611ILT	-40 °C to 85 °C	SOT23-5	Tape and reel	K12
TSV611AILT				K11
TSV611ICT		SC70-5		K12
TSV611AICT				K11
TSV612IDT		SO-8		V612I
TSV612AIDT				V612AI
TSV612IST		MiniSO-8		K113
TSV612AIST				K115

## 6 Revision history

**Table 11. Document revision history**

Date	Revision	Changes
28-May-2009	1	Initial release.
18-Jan-2010	2	Full datasheet for product now in production. Added Figure 1 to Figure 19.
11-May-2017	3	<i>Table 3, Table 4, and Table 5</i> : changed “ $DV_{io}$ to $\Delta V_{io}/\Delta T$ ”, updated $V_{OH}$ parameter information, changed min. values of $V_{OH}$ parameter to max. values. <i>Table 10: Order codes</i> : removed obsolete order codes TSV612ID and TSV612AID

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