# TSH300

## Ultra Low-Noise High-Speed Operational Amplifier

- Structure: VFA
- 200 MHz bandwidth
- Input noise: 0.65 nV/√Hz
- Stable for gains > 5
- Slew rate: 230 V/μs
- Specified on 100Ω load
- Tested on 5 V power supply
- Single or dual supply operation
- Minimum and maximum limits are tested in full production

## Description

The TSH300 is a voltage feedback amplifier featuring ultra-low input voltage and current noise. This feature, associated with a large bandwidth, large slew rate and a good linearity, makes the TSH300 a good choice for high-speed data acquisition systems where sensitivity and signal integrity are the main priorities.

The TSH300 is a single operator available in SO8 and the tiny SOT23-5L plastic package, saving board space as well as providing excellent thermal performances.

## Applications

- High speed data acquisition systems
- Probe equipment
- Communication & video test equipment
- Medical instrumentation
- ADC drivers

## Pin Connections (top view)
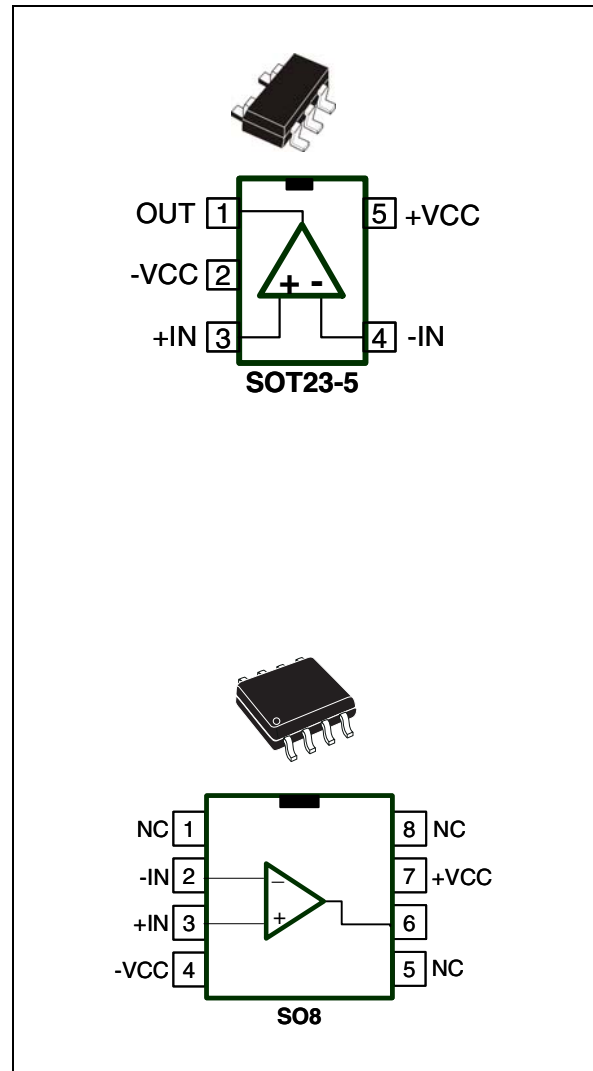


## Order Codes

| Part Number | Temperature Range | Package | Packing | Marking |
|---|---|---|---|---|
| TSH300ILT | -40°C to +85°C | SOT23-5L | Tape & Reel | K308 |
| TSH300ID | | SO-8 | Tube | TSH300I |
| TSH300IDT | | SO-8 | Tape & Reel | TSH300I |

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1/18

# 1 Absolute Maximum Ratings

**Table 1.** **Key parameters and their absolute maximum ratings**

| Symbol | Parameter | Value | Unit |
|---|---|---|---|
| $V_{CC}$ | Supply Voltage [1] | 6 | V |
| $V_{id}$ | Differential Input Voltage[2] | +/-0.5 | V |
| $V_{in}$ | Input Voltage Range[3] | +/-2.5 | V |
| $T_{oper}$ | Operating Free Air Temperature Range | -40 to +85 | °C |
| $T_{stg}$ | Storage Temperature | -65 to +150 | °C |
| $T_j$ | Maximum Junction Temperature | 150 | °C |
| $R_{thja}$ | Thermal Resistance Junction to Ambient<br>SOT23-5L<br>SO8 | 250<br>150 | °C/W |
| $R_{thjc}$ | Thermal Resistance Junction to Case<br>SOT23-5L<br>SO8 | 80<br>28 | °C/W |
| $P_{max}$ | Maximum Power Dissipation[4] ( @Ta=25°C) for Tj=150°C<br>SOT23-5L<br>SO8 | 500<br>830 | mW |
| | HBM: Human Body Model [5] (all packages) | 1 | kV |
| ESD | MM: Machine Model [6] (all packages) | 150 | V |
| | CDM: Charged Device Model (SO8) | 1.5 | kV |
| | Latch-up Immunity | 200 | mA |

1. All voltage values are measured with respect to the ground pin.
2. Differential voltage is between the non-inverting input terminal and the inverting input terminal.
3. The magnitude of input and output voltage must never exceed $V_{CC}$ +0.3V.
4. Short-circuits can cause excessive heating. Destructive dissipation can result from short circuits on amplifiers.
5. Human body model, 100pF discharged through a 1.5kΩ resistor into $P_{min}$ of device.
6. This is a minimum value. Machine model ESD, a 200pF cap is charged to the specified voltage, then discharged directly into the IC with no external series resistor (internal resistor < 5Ω), into pin to pin of device.

**Table 2.** **Operating conditions**

| Symbol | Parameter | Value | Unit |
|---|---|---|---|
| $V_{CC}$ | Supply Voltage [1] | 4.5 to 5.5 | V |
| $V_{icm}$ | Common Mode Input Voltage | -1.5 to +1.6 | V |

1. Tested in full production at 5V (±2.5V) supply voltage.

# 2    Electrical Characteristics

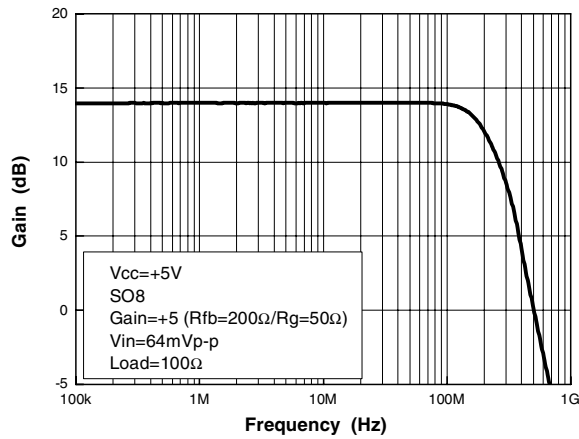**Table 3.**    **Electrical characteristics for $V_{CC}$ = ±2.5V, $T_{amb}$ = 25°C (unless otherwise specified)**

| Symbol | Parameter | Test Condition | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|
| **DC performance** | | | | | | |
| $V_{io}$ | **Input Offset Voltage** Offset Voltage between both inputs | $T_{amb}$ | -1.8 | 0.5 | 1.8 | mV |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | 0.5 | | |
| $\Delta V_{io}$ | $V_{io}$ drift vs. Temperature | $T_{min.} < T_{amb} < T_{max.}$ | | -3.8 | | µV/°C |
| $I_{ib+}$ | **Non Inverting Input Bias Current** DC current necessary to bias the input + | $T_{amb}$ | | 30 | 46 | µA |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | 33 | | |
| $I_{ib-}$ | **Inverting Input Bias Current** DC current necessary to bias the input - | $T_{amb}$ | -46 | -30 | | µA |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | -34 | | |
| CMR | **Common Mode Rejection Ratio** 20 log $(\Delta V_{ic}/\Delta V_{io})$ | $\Delta V_{ic}$ = ±1V | 60 | 88 | | dB |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | 83 | | |
| SVR | **Supply Voltage Rejection Ratio** 20 log $(\Delta V_{cc}/\Delta V_{io})$ | $\Delta V_{cc}$= 3.5V to 5V | 70 | 77 | | dB |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | 74 | | |
| PSRR | **Power Supply Rejection Ratio** 20 log $(\Delta V_{cc}/\Delta V_{out})$ | Gain = +5, $\Delta V_{cc}$=±100mV at 1kHz | | 76 | | dB |
| $I_{CC}$ | **Positive Supply Current** DC consumption with no input signal | No load | | 15 | 19.5 | mA |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | 15.3 | | |
| **Dynamic performance and output characteristics** | | | | | | |
| $A_{VD}$ | **Open Loop Gain** Output Voltage/Input Voltage Gain in open loop of a VFA. | $R_L$ = 100Ω, $V_{out}$ = ±1V | 65 | 67 | | dB |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | 66 | | dB |
| Bw | **Bandwidth** Frequency where the gain is 3dB below the DC gain | Small Signal $V_{out}$=20mVp-p $R_L$ = 100Ω Gain = +5 Gain = +20 | 30 | 200 43 | | MHz |
| | **Gain Flatness @ 0.1dB** Band of frequency where the gain variation does not exceed 0.1dB | Small Signal $V_{out}$=20mVp-p Gain = +5 | | 160 | | |
| SR | **Slew Rate** Maximum output speed of sweep in large signal | $V_{out}$ = 2Vp-p, Gain = +20, $R_L$ = 100Ω | 160 | 230 | | V/µs |
| $V_{OH}$ | **High Level Output Voltage** | $R_L$ = 100Ω | 1.39 | 1.45 | | V |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | 1.46 | | |
| $V_{OL}$ | **Low Level Output Voltage** | $R_L$ = 100Ω | | -1.45 | -1.39 | V |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | -1.46 | | |
| $I_{out}$ | **$I_{sink}$** Short-circuit output current entering op-amp. | Output to GND | 44 | 77 | | mA |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | 78 | | |
| | **$I_{source}$** Output current coming out of the op-amp. | Output to GND | | -82 | -44 | |
| | | $T_{min.} < T_{amb} < T_{max.}$ | | -78 | | |

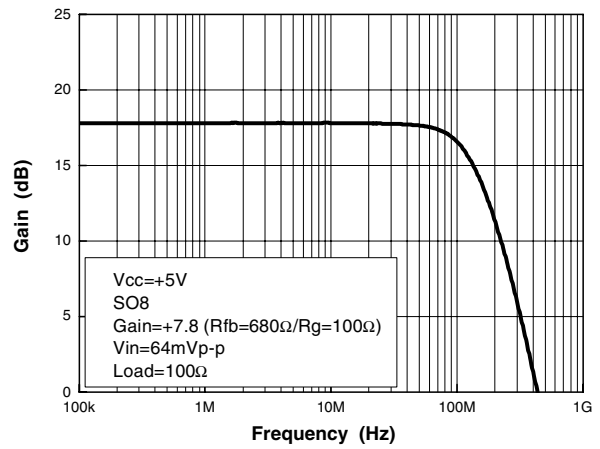**Table 3.** **Electrical characteristics for $V_{CC}$ = ±2.5V, $T_{amb}$ = 25°C (unless otherwise specified)**

| Symbol | Parameter | Test Condition | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|
| | **Noise and distortion** | | | | | |
| eN | **Equivalent Input Noise Voltage**<br>see application note on page 13 | F = 100kHz | | 0.65 | 0.77[1] | nV/√Hz |
| iN | **Equivalent Input Noise Current (+)**<br>see application note on page 13 | F = 100kHz | | 3.3 | 5.5[1] | pA/√Hz |
| SFDR | **Spurious Free Dynamic Range**<br>The highest harmonic of the output spectrum when injecting a filtered sine wave | $V_{out}$ = 2Vp-p, Gain = +5,<br>$R_L$ = 100Ω, F = 10MHz | | 55 | | dBc |

1. This parameter is guaranteed by design and evaluated using corner lots. This value is not tested in full production.

**Figure 1. Frequency response G=+5, SO8**



Vcc=+5V
SO8
Gain=+5 (Rfb=200Ω/Rg=50Ω)
Vin=64mVp-p
Load=100Ω

**Figure 2. Frequency response G=+7.8, SO8**



Vcc=+5V
SO8
Gain=+7.8 (Rfb=680Ω/Rg=100Ω)
Vin=64mVp-p
Load=100Ω

**Figure 3. Frequency response G=+10.2, SO8**



Vcc=+5V
SO8
Gain=+10.1 (Rfb=910Ω/Rg=100Ω)
Vin=64mVp-p
Load=100Ω
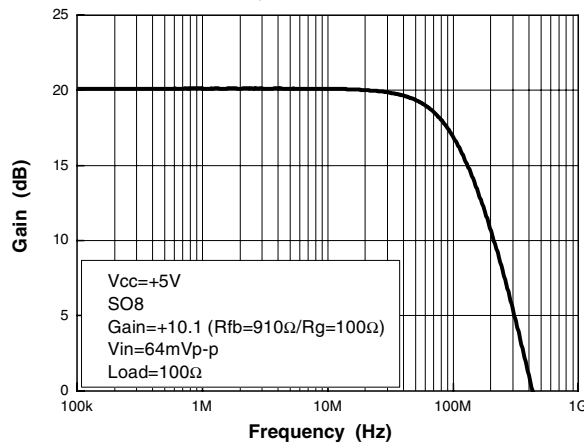
**Figure 4. Frequency response G=+19.9, SO8**



Vcc=+5V
SO8
Gain=+19.9 (Rfb=510Ω/Rg=27Ω)
Vin=64mVp-p
Load=100Ω
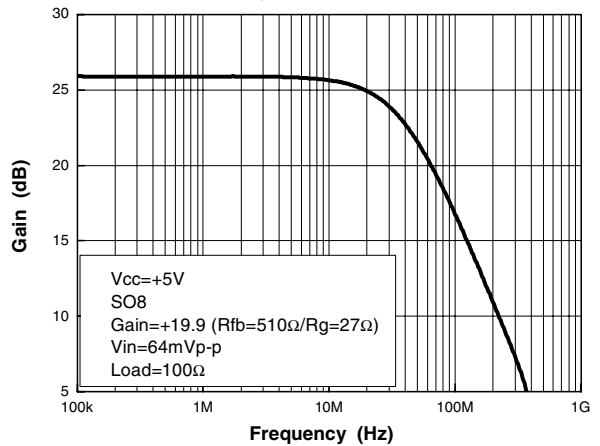
**Figure 5. Frequency response G=-5, SO8**



Vcc=+5V
SO8
Gain= -5 (Rfb=270Ω//1pF, Rg=43Ω)
Vin=64mVp-p
Load=100Ω
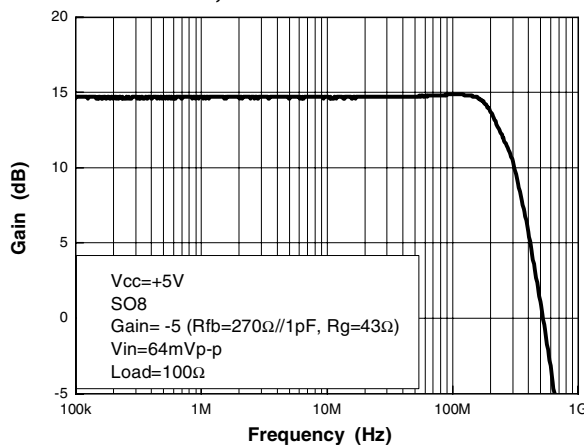
**Figure 6. Frequency response G=-7.8, SO8**



Vcc=+5V
SO8
Gain= -7.8 (Rfb=390Ω//1pF, Rg=43Ω)
Vin=64mVp-p
Load=100Ω
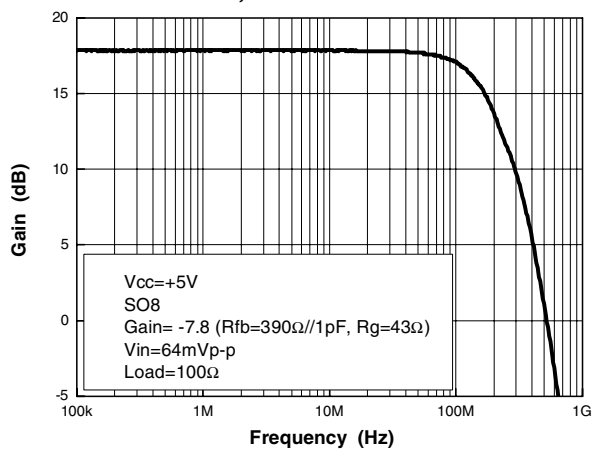
**Figure 7.    Frequency response G=-10.2, SO8**



Vcc=+5V
SO8
Gain= -10.2 (Rfb=510Ω//1pF, Rg=43Ω)
Vin=64mVp-p
Load=100Ω
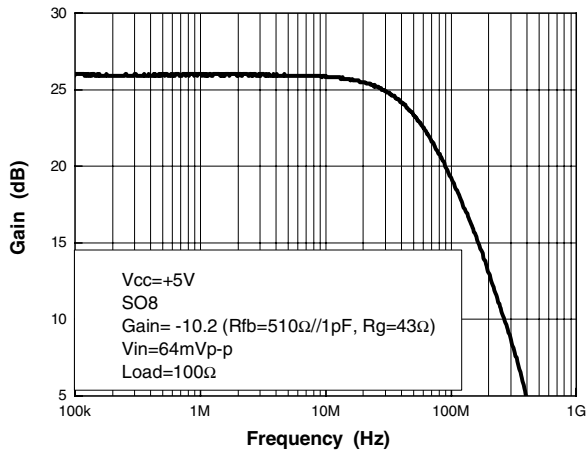
**Figure 8.    Frequency response G=-19.9, SO8**



Vcc=+5V
SO8
Gain= -20 (Rfb=1kΩ//1pF, Rg=47Ω)
Vin=64mVp-p
Load=100Ω
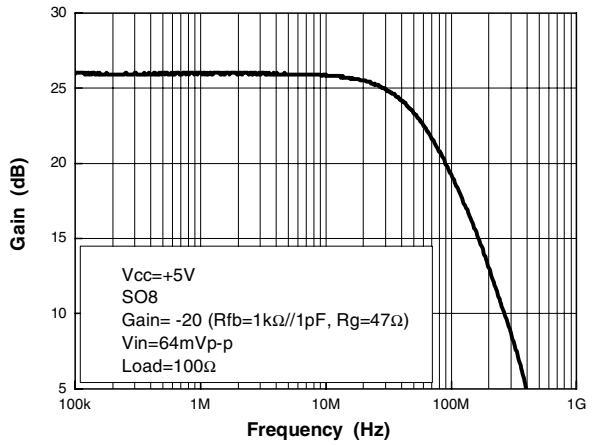
**Figure 9.    Frequency response G=+5, SOT23-5L**



Vcc=+5V
SOT23-5
Gain=+5 (Rfb=200Ω/Rg=50Ω)
Vin=64mVp-p
Load=100Ω
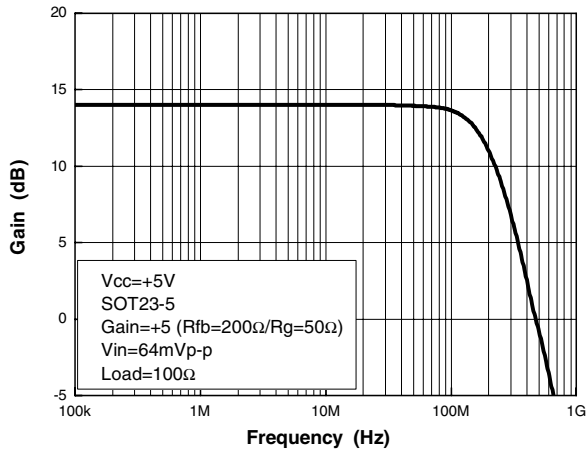
**Figure 10.   Frequency response G=+7.8, SOT23-5L**



Vcc=+5V
SOT23-5
Gain=+7.8 (Rfb=680Ω/Rg=100Ω)
Vin=64mVp-p
Load=100Ω
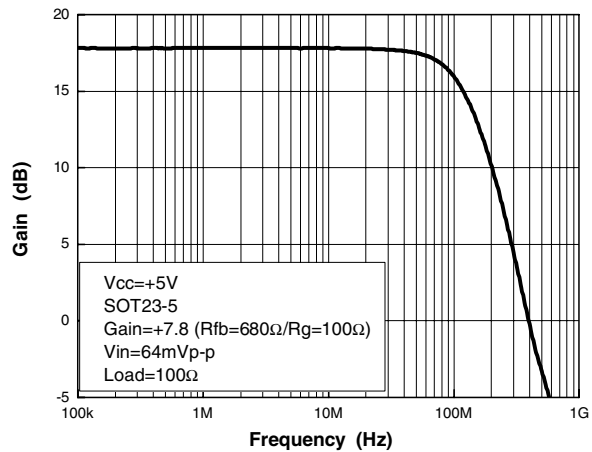
**Figure 11.   Frequency response G=+10.1, SOT23-5L**



Vcc=+5V
SOT23-5
Gain=+10.1 (Rfb=910Ω/Rg=100Ω)
Vin=64mVp-p
Load=100Ω
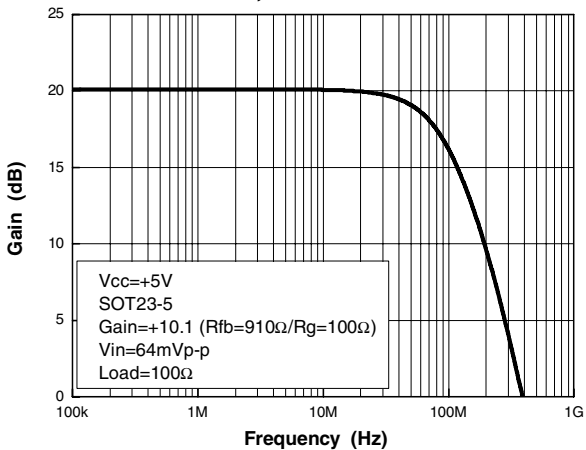
**Figure 12.   Frequency response G=+19.9, SOT23-5L**



Vcc=+5V
SOT23-5
Gain=+19.9 (Rfb=510Ω/Rg=27Ω)
Vin=64mVp-p
Load=100Ω
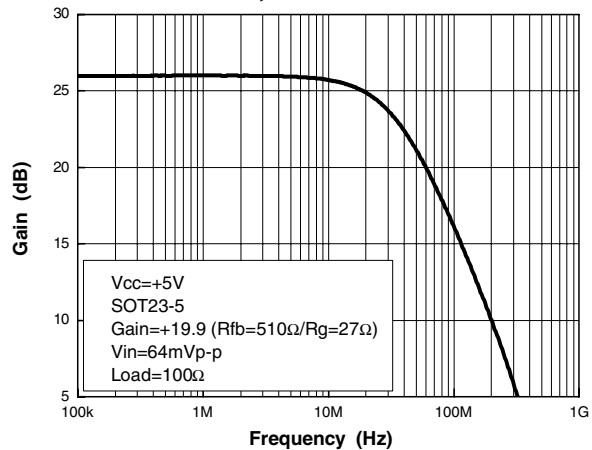
**Figure 13.  Gain flatness, G=+5, SO8**



Vcc=+5V
SO8
Gain=+5 (Rfb=200Ω/Rg=50Ω)
Vin=64mVp-p
Load=100Ω
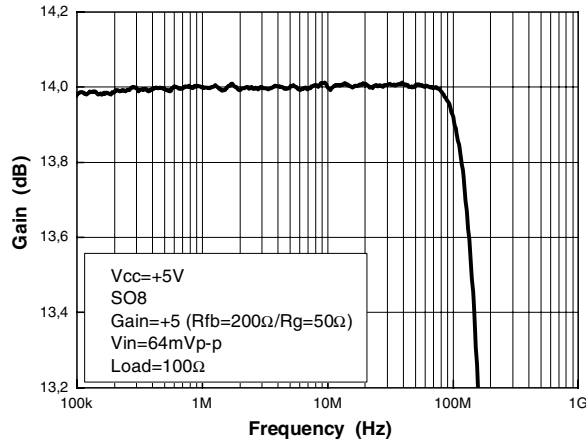
**Figure 14.  Gain flatness, G=+7.8, SO8**



Vcc=+5V
SO8
Gain=+7.8 (Rfb=680Ω/Rg=100Ω)
Vin=64mVp-p
Load=100Ω
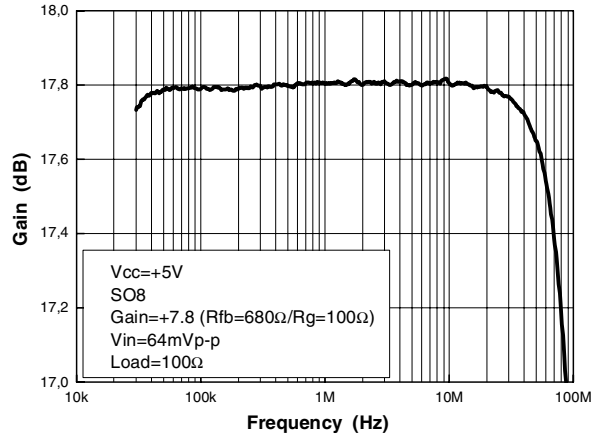
**Figure 15.  Gain flatness, G=+10.2, SO8**



Vcc=+5V
SO8
Gain=+10.1 (Rfb=910Ω/Rg=100Ω)
Vin=64mVp-p
Load=100Ω
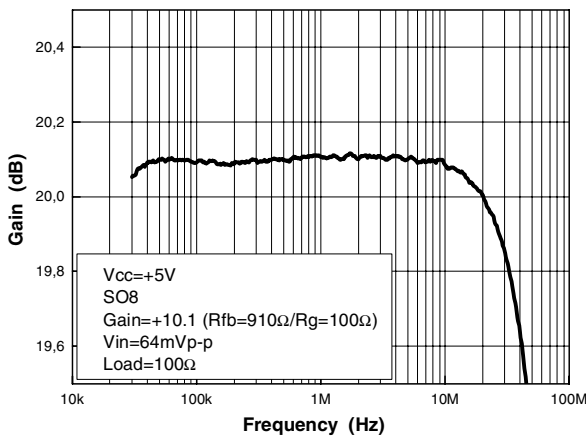
**Figure 16.  Gain flatness, G=+19.9, SO8**



Vcc=+5V
SO8
Gain=+19.9 (Rfb=510Ω/Rg=27Ω)
Vin=64mVp-p
Load=100Ω
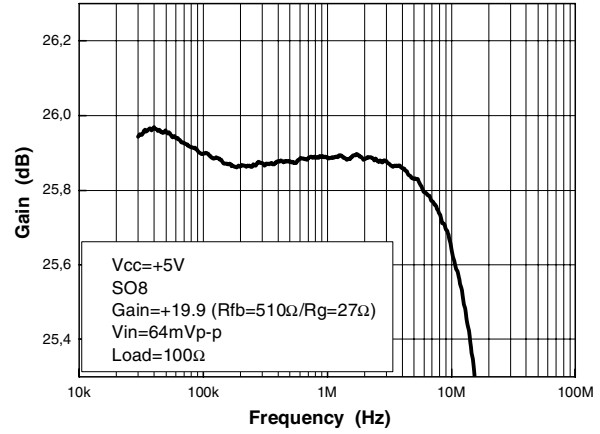
**Figure 17.  Gain flatness, G=+5, SOT23-5L**



Vcc=+5V
SOT23-5
Gain=+5 (Rfb=200Ω/Rg=50Ω)
Vin=64mVp-p
Load=100Ω
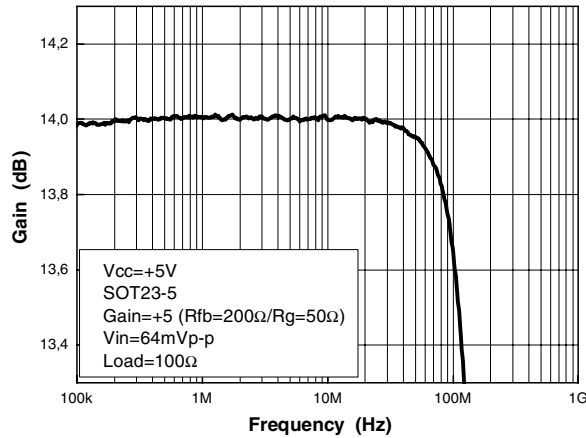
**Figure 18.  Gain flatness, G=+7.8, SOT23-5L**



Vcc=+5V
SOT23-5
Gain=+7.8 (Rfb=680Ω/Rg=100Ω)
Vin=64mVp-p
Load=100Ω
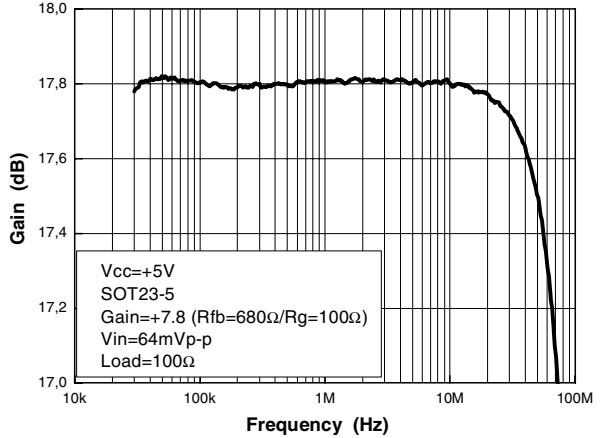
**Figure 19. Gain flatness, G=+10.1, SOT23-5L**



Vcc=+5V
SOT23-5
Gain=+10.1 (Rfb=910Ω/Rg=100Ω)
Vin=64mVp-p
Load=100Ω
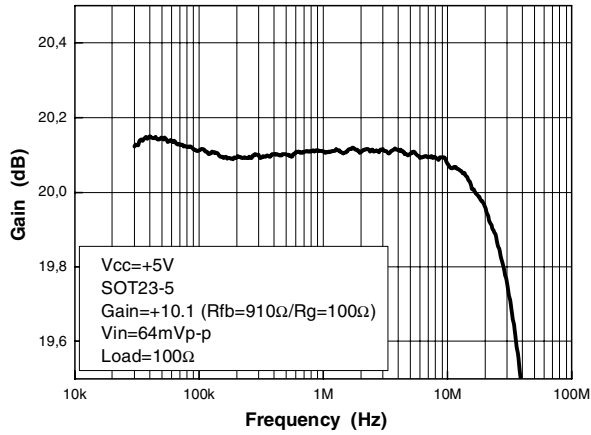
**Figure 20. Gain flatness, G=+19.9, SOT23-5L**



Vcc=+5V
SOT23-5
Gain=+19.9 (Rfb=510Ω/Rg=27Ω)
Vin=64mVp-p
Load=100Ω
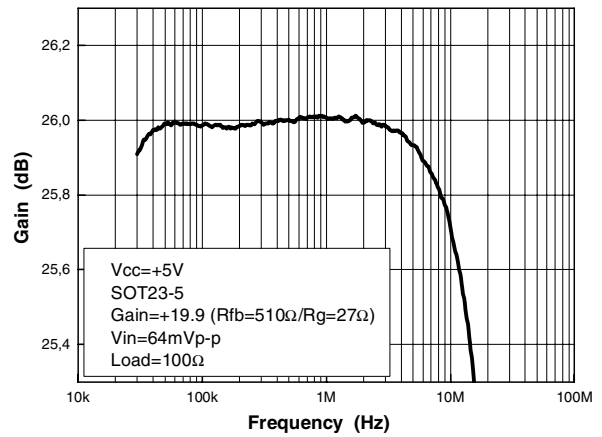
**Figure 21. Input voltage noise**



Gain=26dB
Rg=27Ω
Rfb=510Ω
non-inverting input in short-circuit
Vcc=+5V
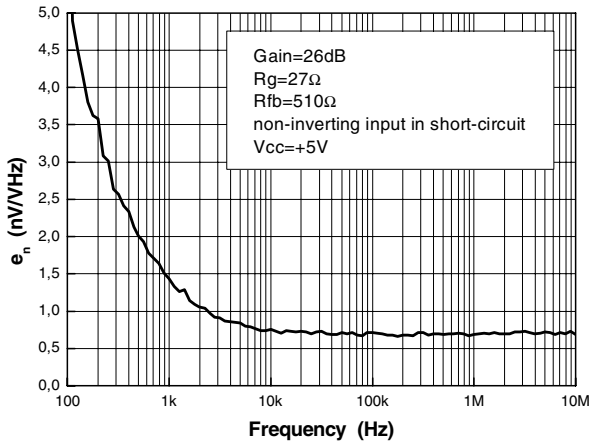
**Figure 22. Input voltage noise (corner lot)**



Max.
Typ.
Gain=26dB
Rg=27Ω
Rfb=510Ω
non-inverting input in short-circuit
Vcc=+5V
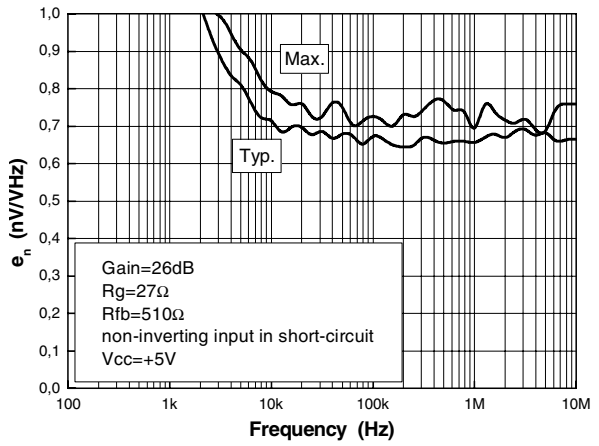
**Figure 23. Input current noise**



Gain=26dB
Rg=27Ω
Rfb=510Ω
1000Ω to GND on non-inverting input
Vcc=+5V
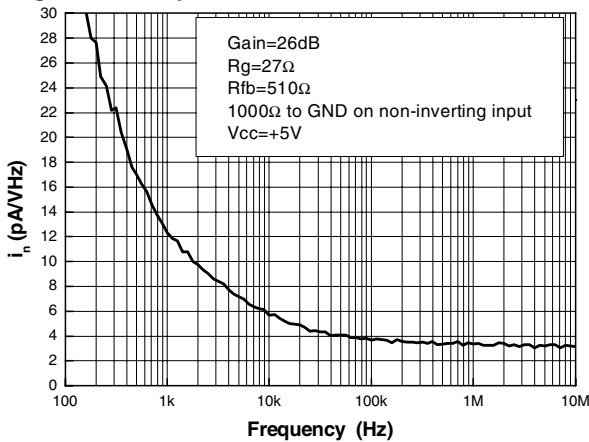
**Figure 24. Input current noise (corner lot)**



Max.
Typ.
Gain=26dB
Rg=27Ω
Rfb=510Ω
1000Ω to GND on non-inverting input
Vcc=+5V
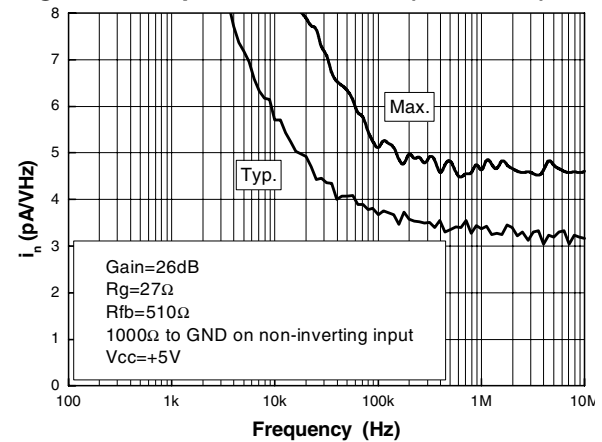
**Figure 25. Distortion vs. V$_{out}$, SO8**
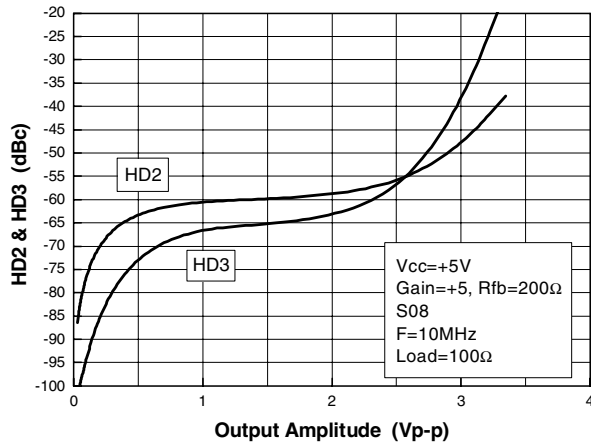


**Figure 26. Distortion vs. V$_{out}$, SOT23-5L**
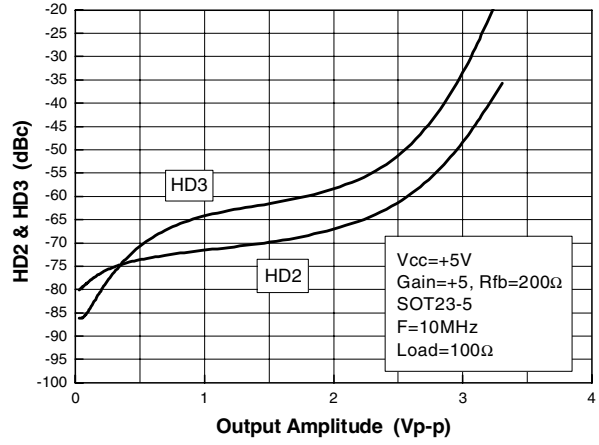


**Figure 27. Slew-rate**
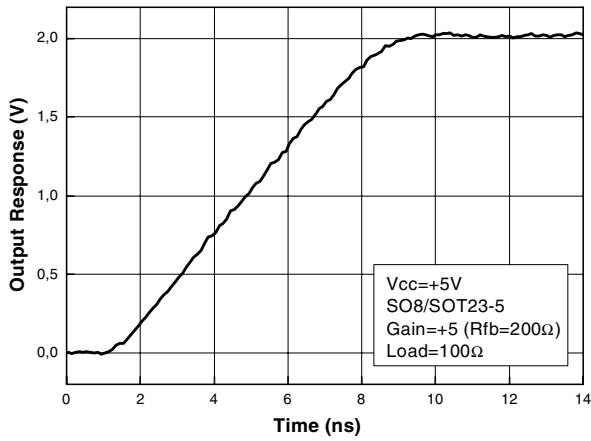


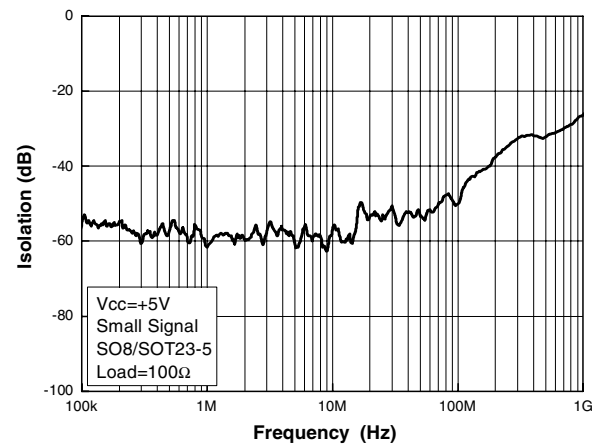**Figure 28. Reverse isolation vs. frequency**



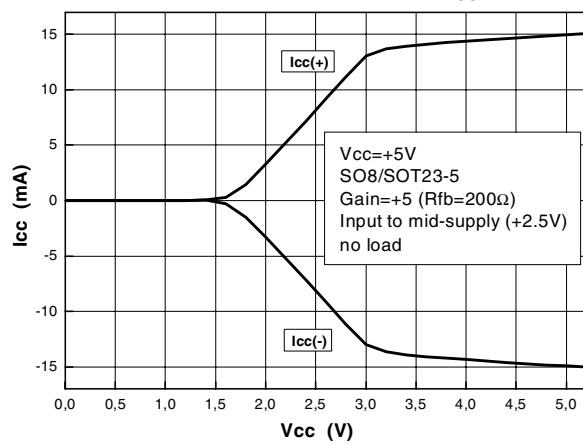**Figure 29. Quiescent current vs. V$_{cc}$**



**Figure 30. V$_{out\ max}$ vs. V$_{cc}$**

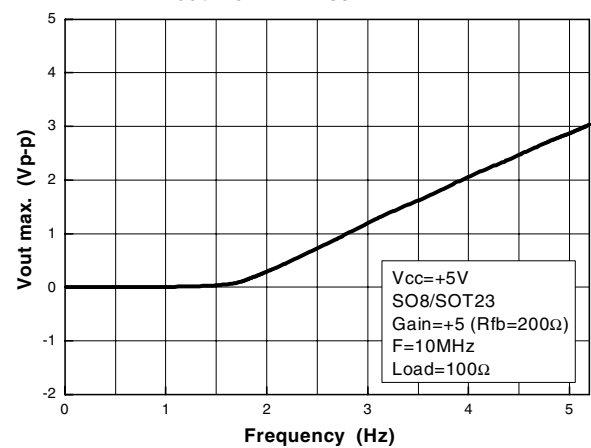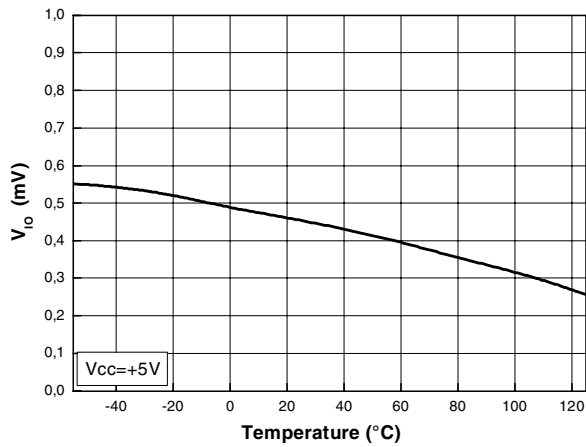**Figure 31. V$_{io}$ vs. temperature**



**Figure 32. I$_{bias}$ vs. temperature**
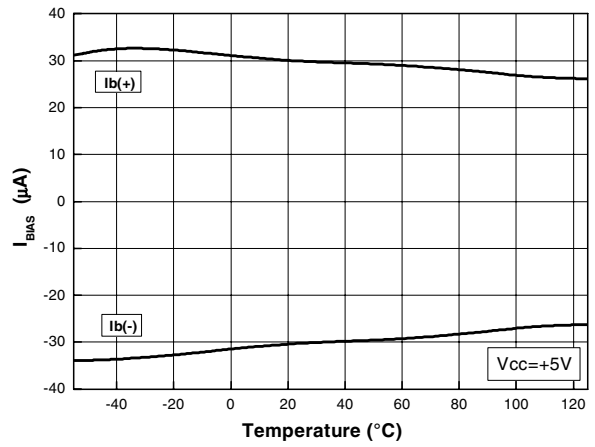


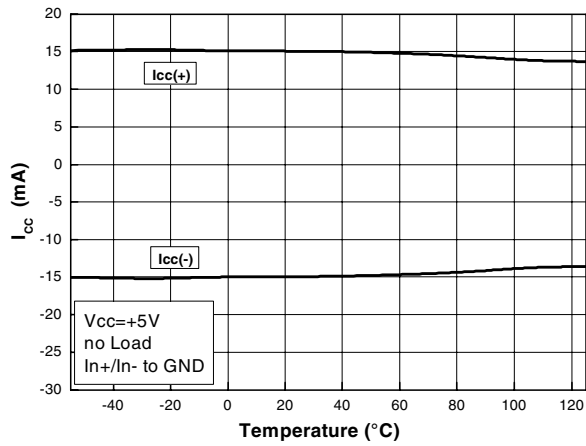**Figure 33. Supply current vs. temperature**



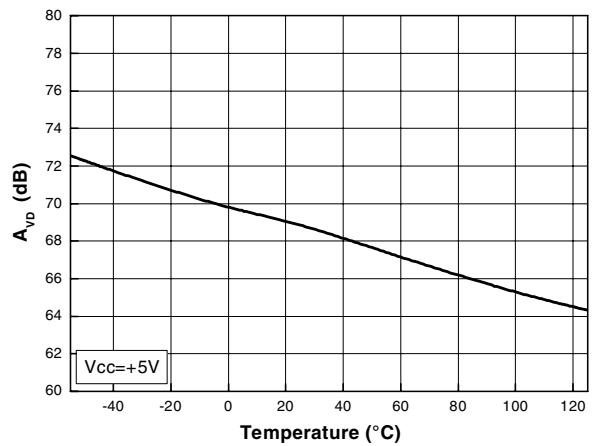**Figure 34. AVD vs. temperature**



**Figure 35. Output rails vs. temperature**
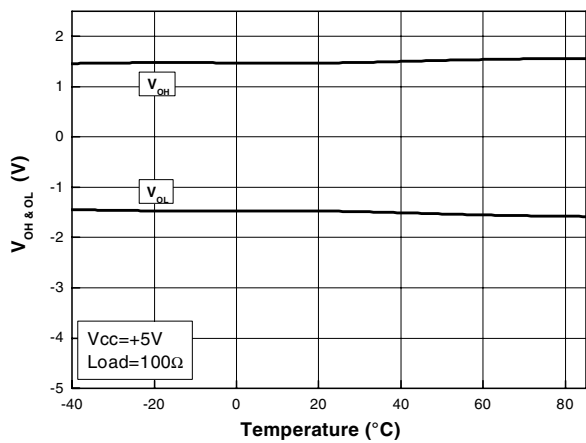


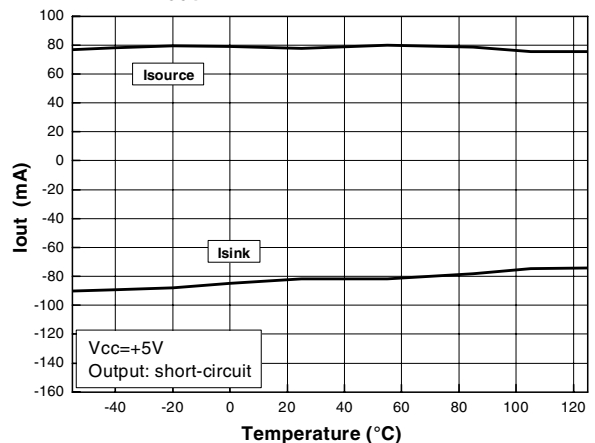**Figure 36. I$_{out}$ vs. temperature**

**Figure 37.    CMR vs. temperature**
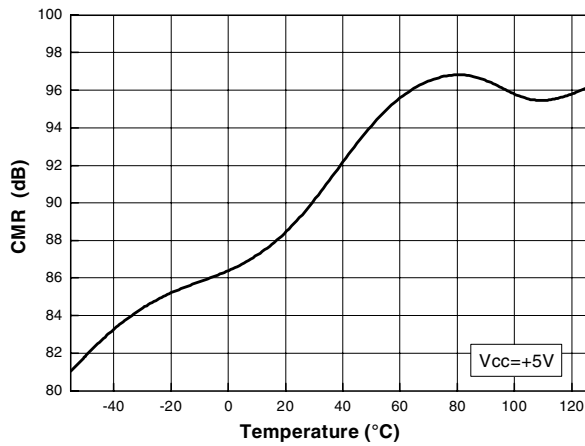


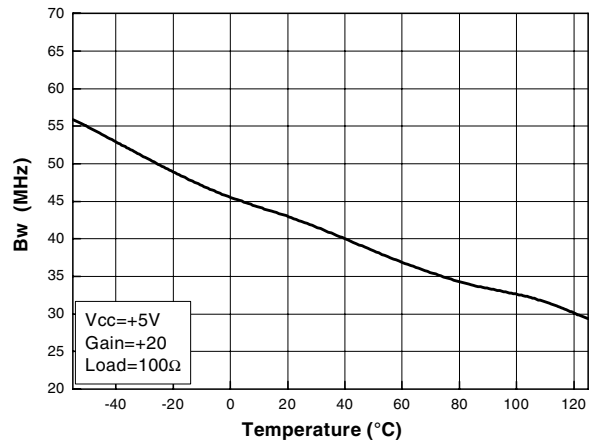**Figure 38.    Bandwidth vs. temperature**



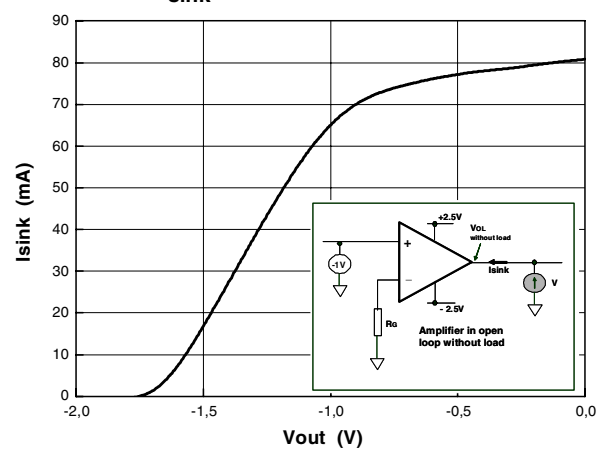**Figure 39.    Slew-rate vs. temperature**
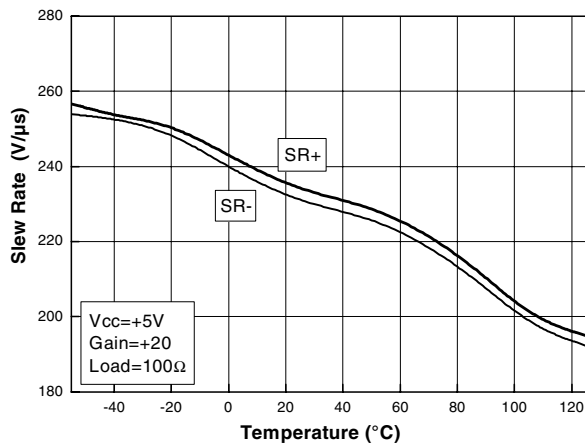


**Figure 40.    I$_{sink}$**



**Figure 41.    SVR vs. temperature**
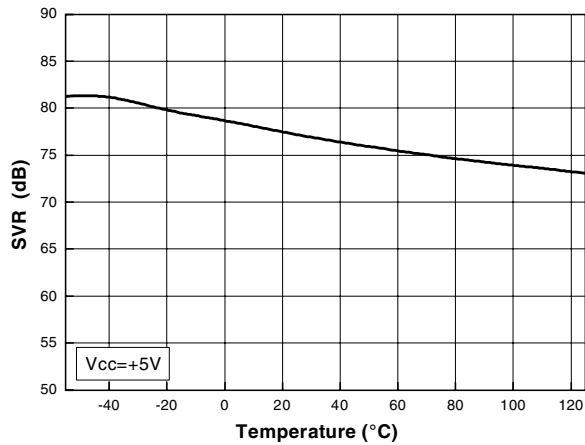


**Figure 42.    I$_{source}$**
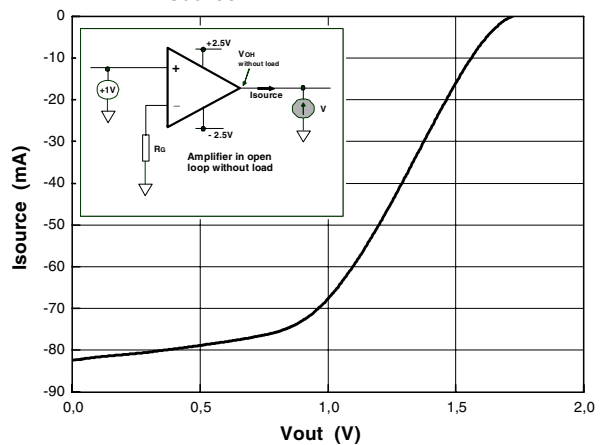
# 3 Power Supply Considerations

Correct power supply bypassing is very important for optimizing performance in high-frequency ranges. Bypass capacitors should be placed as close as possible to the IC pins to improve high-frequency bypassing. A capacitor greater than 1µF is necessary to minimize the distortion. For better quality bypassing, a capacitor of 10nF can be added using the same implementation conditions. Bypass capacitors must be incorporated for both the negative and the positive supply.

**Figure 43. Circuit for power supply bypassing**
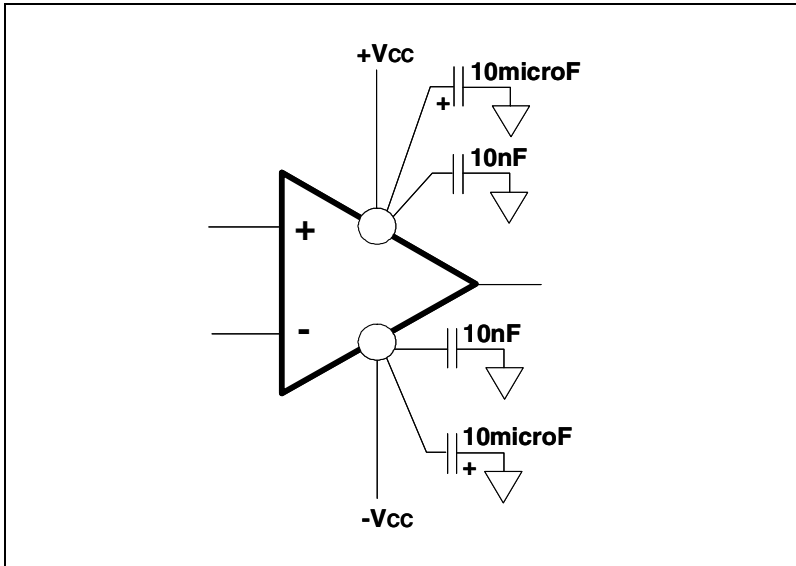
# 4 Evaluation Boards

An evaluation board kit optimized for high-speed operational amplifiers is available (order code: KITHSEVAL/STDL). The kit includes the following evaluation boards, as well as a CD-ROM containing datasheets, articles, application notes and a user manual:

● SOT23_SINGLE_HF BOARD: Board for the evaluation of a single high-speed op-amp in SOT23-5L package.

● SO8_SINGLE_HF: Board for the evaluation of a single high-speed op-amp in SO8 package.

● SO8_DUAL_HF: Board for the evaluation of a dual high-speed op-amp in SO8 package.

● SO8_S_MULTI: Board for the evaluation of a single high-speed op-amp in SO8 package in inverting and non-inverting configuration, dual and single supply.

● SO14_TRIPLE: Board for the evaluation of a triple high-speed op-amp in SO14 package with video application considerations.

Board material description:

● 2 layers

● FR4 ($\varepsilon$r=4.6)

● epoxy 1.6mm

● copper thickness: 35µm

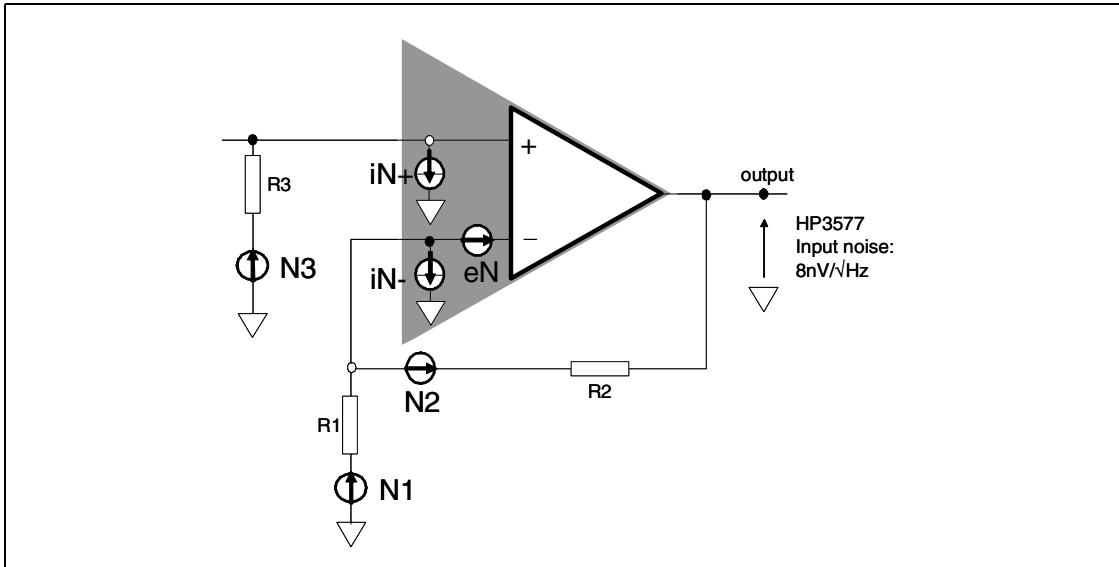**Figure 44. Evaluation kit for high-speed op-amps**

# 5 Noise Measurements

The noise model is shown in *Figure 45*, where:

- eN: input voltage noise of the amplifier
- iNn: negative input current noise of the amplifier
- iNp: positive input current noise of the amplifier

**Figure 45. Noise model**



The thermal noise of a resistance R is:

$$\sqrt{4kTR\Delta F}$$

where ΔF is the specified bandwidth.

On a 1Hz bandwidth the thermal noise is reduced to

$$\sqrt{4kTR}$$

where k is the Boltzmann's constant, equal to 1,374.10-23J/°K. T is the temperature (°K).

The output noise eNo is calculated using the Superposition Theorem. However eNo is not the simple sum of all noise sources, but rather the square root of the sum of the square of each noise source, as shown in Equation 1:

$$eNo = \sqrt{V1^2 + V2^2 + V3^2 + V4^2 + V5^2 + V6^2} \quad \text{(Equation 1)}$$

$$eNo^2 = eN^2 \times g^2 + iNn^2 \times R2^2 + iNp^2 \times R3^2 \times g^2 + \left(\frac{R2}{R1}\right)^2 \times 4kTR1 + 4kTR2 + g^2 \times 4kTR3 \quad \text{(Equation 2)}$$

The input noise of the instrumentation must be extracted from the measured noise value. The real output noise value of the driver is:

$$eNo = \sqrt{(Measured)^2 - (instrumentation)^2} \qquad \text{(Equation 3)}$$

The input noise is called the Equivalent Input Noise as it is not directly measured but is evaluated from the measurement of the output divided by the closed loop gain (eNo/g).

After simplification of the fourth and the fifth term of Equation 2 we obtain:

$$eNo^2 = eN^2 \times g^2 + iNn^2 \times R2^2 + iNp^2 \times R3^2 \times g^2 + g \times 4kTR2 + g^2 \times 4kTR3 \qquad \text{(Equation 4)}$$

### Measurement of the input voltage noise *eN*

If we assume a short-circuit on the non-inverting input (R3=0), from Equation 4 we can derive:

$$eNo = \sqrt{eN^2 \times g^2 + iNn^2 \times R2^2 + g \times 4kTR2} \qquad \text{(Equation 5)}$$

In order to easily extract the value of eN, the resistance R2 will be chosen to be as low as possible. In the other hand, the gain must be large enough:

R3=0, gain: g=100

### Measurement of the negative input current noise *iNn*

To measure the negative input current noise iNn, we set R3=0 and use Equation 5. This time the gain must be lower in order to decrease the thermal noise contribution:

R3=0, gain: g=10
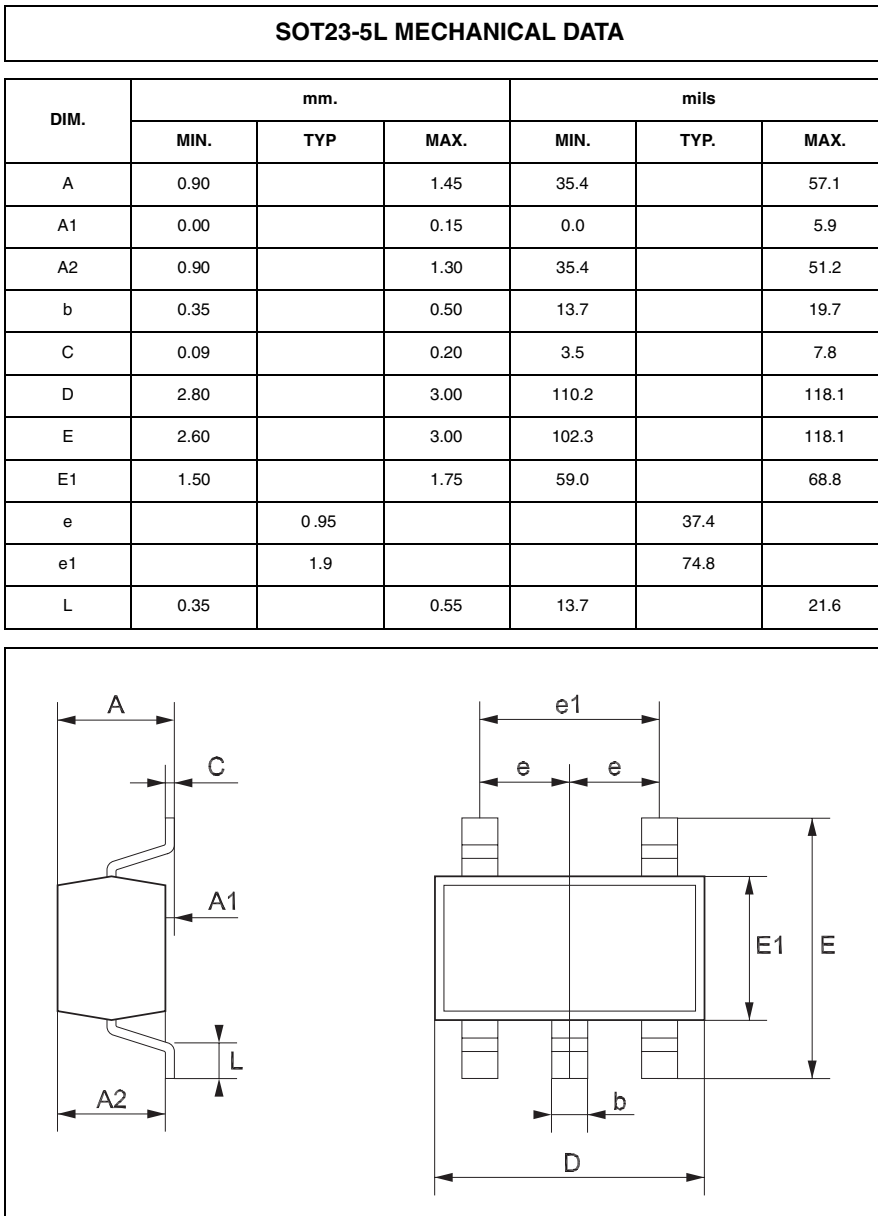
### Measurement of the positive input current noise *iNp*

To extract iNp from Equation 3, a resistance R3 is connected to the non-inverting input. The value of R3 must be chosen in order to keep its thermal noise contribution as low as possible against the iNp contribution:

R3=100$\Omega$,  gain: g=10

# 6 Package Mechanical Data

In order to meet environmental requirements, ST 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 ST trademark. ECOPACK specifications are available at: www.st.com.

## 6.1 SOT23-5L package

| DIM. | mm. | | | mils | | |
|------|------|------|------|------|------|------|
| | **MIN.** | **TYP** | **MAX.** | **MIN.** | **TYP.** | **MAX.** |
| A | 0.90 | | 1.45 | 35.4 | | 57.1 |
| A1 | 0.00 | | 0.15 | 0.0 | | 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 |

*SOT23-5L MECHANICAL DATA*

## 6.2 SO8 package

| DIM. | mm. | | | inch | | |
|------|-----|-----|------|------|------|------|
| | MIN. | TYP | MAX. | MIN. | TYP. | MAX. |
| A | 1.35 | | 1.75 | 0.053 | | 0.069 |
| A1 | 0.10 | | 0.25 | 0.04 | | 0.010 |
| A2 | 1.10 | | 1.65 | 0.043 | | 0.065 |
| B | 0.33 | | 0.51 | 0.013 | | 0.020 |
| C | 0.19 | | 0.25 | 0.007 | | 0.010 |
| D | 4.80 | | 5.00 | 0.189 | | 0.197 |
| E | 3.80 | | 4.00 | 0.150 | | 0.157 |
| e | | 1.27 | | | 0.050 | |
| H | 5.80 | | 6.20 | 0.228 | | 0.244 |
| h | 0.25 | | 0.50 | 0.010 | | 0.020 |
| L | 0.40 | | 1.27 | 0.016 | | 0.050 |
| k | $8°$ (max.) | | | | | |
| ddd | | | 0.1 | | | 0.04 |

**SO-8 MECHANICAL DATA**



0016023/C
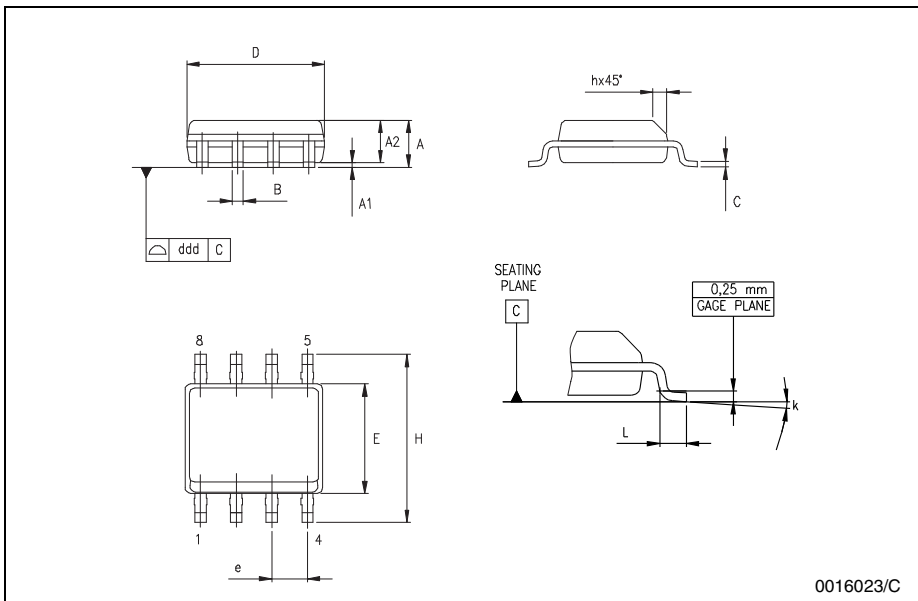
# 7 Revision History

| Date | Revision | Description of Changes |
|------|----------|------------------------|
| Sept. 2005 | 1 | Release of mature product datasheet |
| Sept. 2005 | 2 | Update to ESD information in *Table 1 on page 2*. |