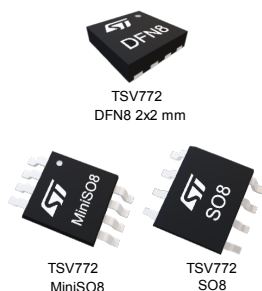


### High bandwidth (20 MHz) low offset (200 $\mu$ V) rail-to-rail 5 V Op Amp



#### Features

- Gain bandwidth product 20 MHz, unity gain stable
- Low input offset voltage: 50  $\mu$ V typ., 200  $\mu$ V max.
- Low input bias current: 2 pA typ.
- Low noise: 7 nV/ $\sqrt{\text{Hz}}$
- Slew rate: 13 V/ $\mu$ s
- Wide supply voltage range: 2.0 V to 5.5 V
- Rail-to-rail input and output
- 4 kV HBM ESD tolerance
- Input common-mode range includes low rail
- Extended temperature range: -40  $^{\circ}\text{C}$  to +125  $^{\circ}\text{C}$
- Automotive grade versions available
- Benefits:
  - Accuracy of measurement virtually unaffected by noise or input bias current
  - Signal conditioning for high frequencies

#### Application

- High bandwidth low-side and high-side current sensing
- Photodiode amplifiers
- A/D converters input buffers
- Power management in solar powered systems
- Automotive high bandwidth signal conditioning
- Active filters

#### Description

The **TSV772** is a dual 20 MHz-bandwidth unity-gain-stable amplifier. The rail-to-rail input stage and the slew rate of 13 V/ $\mu$ s make the **TSV772** ideal for low-side current measurement. The excellent accuracy provided by maximum input voltage of 200  $\mu$ V allows amplifying accurately small-amplitude input signal.

The **TSV772** can operate from a 2.0 V to 5.5 V single supply and is fully characterized for an output capacitor of 47 pF, for easy usage as an A/D converter input buffer.

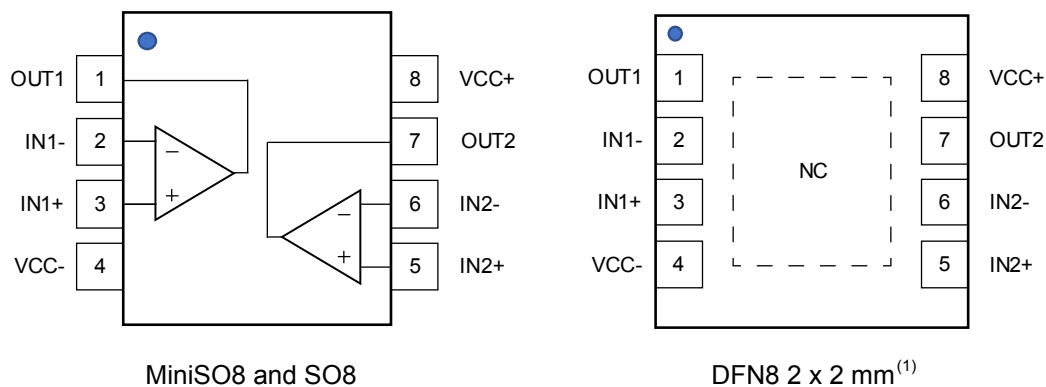
Maturity status link	Channel	Automotive	Package
TSV772	2		DFN8
	2		MiniSO8
	2		SO8
	2	•	MiniSO8
	2	•	SO8

Related products	
TSV7722	Low rail 22 MHz amplifier
TSV792	Rail-to-rail amplifier with higher GBW 50 MHz

## 1 Pin description

### 1.1 TSV772 dual operational amplifier

**Figure 1. Pin connections (top view)**



1. The exposed pad of the DFN8 2x2 can be connected to VCC- or left floating.

**Table 1. Pin description**

Pin n°	Pin name	Description
1	OUT1	Output channel 1
2	IN1-	Inverting input channel 1
3	IN1+	Non-inverting input channel 1
4	VCC-	Negative supply voltage
5	IN2+	Non-inverting input channel 2
6	IN2-	Inverting input channel 2
7	OUT2	Output channel 2
8	VCC+	Positive supply voltage

## 2 Absolute maximum ratings and operating conditions

**Table 2. Absolute maximum ratings**

Symbol	Parameter <sup>(1)</sup>	Value	Unit
$V_{CC}$	Supply voltage	-0.3 to 6.0	V
$V_{id}$	Input voltage differential ( $V_{IN+} - V_{IN-}$ )	$\pm V_{CC}$	V
$V_{IN}^{(2)}$	Input pins voltage	( $V_{CC-}$ ) - 0.3 V to $V_{CC+} + 0.3$	V
$I_{IN}$	Input current	$\pm 10$	mA
$T_{stg}$	Storage temperature	150	°C
$R_{th-j-a}^{(3)}$	Thermal resistance junction-to-ambient	-	°C / W
	DFN8 (2 mm x 2 mm)	76	
	MiniSO8	127	
	SO8	113	
$T_j$	Maximum junction temperature	150	°C
ESD	HBM: human body model <sup>(4)</sup>	4	kV
	CDM: charged device model <sup>(5)</sup>	1.5	kV

1. All voltage values are with respect to VCC- pin, unless otherwise specified.
2. The maximum input voltage value may be extended to the condition that the input current is limited to  $\pm 10$  mA.
3.  $R_{th-j-a}$  are typical values obtained with a PCB according to JEDEC 2s2p without vias.
4. Human Body Model: the test HBM is done in accordance with the standards ESDA-JS-001-2017 and Q100-002.
5. Charged device model: the test CDM is done in accordance with the standards ESDA-JS-002-2018 and Q100-011.

**Table 3. Operating conditions**

Symbol	Parameter	Value
$V_{CC}$	Supply voltage	2.0 to 5.5 V
$V_{icm}$	Common-mode input voltage range	$V_{CC-} - 0.2$ V to $V_{CC+} + 0.1$ V
$T_{oper}$	Operating free air temperature range	-40 °C to +125 °C

### 3 Electrical characteristics

**Table 4. Electrical characteristics at  $V_{CC} = 5.0\text{ V}$ ,  $V_{icm} = V_{OUT} = V_{CC} / 2$ ,  $T = 25\text{ °C}$ ,  $R_L = 10\text{ k}\Omega$  connected to  $V_{CC} / 2$  and  $C_L = 47\text{ pF}$  (unless otherwise specified)**

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
<b>DC performance</b>						
$V_{io}$	Input offset voltage	$T = 25\text{ °C}$			$\pm 200$	$\mu\text{V}$
		$-40\text{ °C} \leq T \leq 125\text{ °C}$			$\pm 700$	
$\Delta V_{io}/\Delta T$	Input offset voltage drift	$-40\text{ °C} \leq T \leq 125\text{ °C}$			$\pm 5$	$\mu\text{V}/\text{°C}$
$I_{ib}$	Input bias current	$T = 25\text{ °C}$		2		$\text{pA}$
		$-40\text{ °C} \leq T \leq 125\text{ °C}$		75		
$I_{io}$	Input offset current	$T = 25\text{ °C}$		1		$\text{pA}$
		$-40\text{ °C} \leq T \leq 125\text{ °C}$		20		
$A_{VD}$	Open loop gain	$V_{CC-} + 100\text{ mV} \leq V_{OUT} \leq V_{CC+} - 100\text{ mV}$ , $T = 25\text{ °C}$	110			$\text{dB}$
		$V_{CC-} + 100\text{ mV} \leq V_{OUT} \leq V_{CC+} - 100\text{ mV}$ , $-40\text{ °C} \leq T \leq 125\text{ °C}$	95			
		$R_L = 2\text{ k}\Omega$ , $V_{CC-} + 200\text{ mV} \leq V_{OUT} \leq V_{CC+} - 200\text{ mV}$ , $T = 25\text{ °C}$	105			
		$R_L = 2\text{ k}\Omega$ , $V_{CC-} + 200\text{ mV} \leq V_{OUT} \leq V_{CC+} - 200\text{ mV}$ , $40\text{ °C} \leq T \leq 125\text{ °C}$	90			
CMR1	Common-mode rejection ratio	$V_{CC-} - 0.1\text{ V} \leq V_{icm} \leq V_{CC+} - 1.8\text{ V}$ , $T = 25\text{ °C}$	98	120		$\text{dB}$
		$V_{CC-} - 0.1\text{ V} \leq V_{icm} \leq V_{CC+} - 1.8\text{ V}$ , $-40\text{ °C} \leq T \leq 125\text{ °C}$	90	110		
CMR2	$20 \cdot \log(\Delta V_{io}/\Delta V_{icm})$	$V_{CC-} - 0.1\text{ V} \leq V_{icm} \leq V_{CC+}$ , $T = 25\text{ °C}$	81	100		
		$V_{CC-} - 0.1\text{ V} \leq V_{icm} \leq V_{CC+}$ , $-40\text{ °C} \leq T \leq 125\text{ °C}$	76	92		
SVR	Supply voltage rejection ratio $20 \cdot \log(\Delta V_{io}/\Delta V_{CC})$	$2.0\text{ V} \leq V_{CC} \leq 5.5\text{ V}$ , $T = 25\text{ °C}$ , $V_{icm} = 0\text{ V}$	90	110		$\text{dB}$
		$2.0\text{ V} \leq V_{CC} \leq 5.5\text{ V}$ , $-40\text{ °C} \leq T \leq 125\text{ °C}$ , $V_{icm} = 0\text{ V}$	90	110		
$V_{OH}$	High level output voltage drop ( $V_{OH} = V_{CC+} - V_{OUT}$ )	$T = 25\text{ °C}$			10	$\text{mV}$
		$-40\text{ °C} \leq T \leq 125\text{ °C}$			20	
$V_{OL}$	Low level output voltage drop ( $V_{OL} = V_{OUT}$ )	$T = 25\text{ °C}$			10	
		$-40\text{ °C} \leq T \leq 125\text{ °C}$			20	
$I_{OUT}$	$I_{sink}$ ( $R_L$ connected to $V_{CC+}$ )	$T = 25\text{ °C}$	45	65		$\text{mA}$
		$-40\text{ °C} \leq T \leq 125\text{ °C}$	30			
	$I_{source}$ ( $R_L$ connected to $V_{CC-}$ )	$T = 25\text{ °C}$	45	65		
		$-40\text{ °C} \leq T \leq 125\text{ °C}$	30			

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
I <sub>CC</sub>	Supply current (per channel, R <sub>L</sub> > 1 MΩ)	T = 25 °C		1.9	2.1	mA
		-40 °C ≤ T ≤ 125 °C			2.1	
AC performance						
GBP	Gain bandwidth product		17	20		MHz
SR	Slew rate	A <sub>V</sub> = 1 V/V, 10% to 90% <sup>(1)</sup>	11	13		V/μs
t <sub>s</sub>	Settling time	R <sub>L</sub> = 4.7 kΩ, A <sub>V</sub> = -1 V/V, to 0.1%, V <sub>in</sub> = 1 Vp-p		300		ns
		R <sub>L</sub> = 4.7 kΩ, A <sub>V</sub> = -1 V/V, to 0.01%, V <sub>in</sub> = 1 Vp-p <sup>(2)</sup>		470		
t <sub>rec</sub>	Overload recovery time	V <sub>OUT</sub> 100 mV from rail, A <sub>V</sub> = +1		235		ns
CR	Cross talk	V <sub>OUT</sub> = 4 Vpp, A <sub>V</sub> = +101, f = 1 kHz		120		dB
Φ <sub>m</sub>	Phase margin			50		degrees
GM	Gain margin			9		dB
C <sub>in</sub>	Differential input capacitance			6.5		pF
	Common-mode input capacitance			2.5		
e <sub>n</sub>	Input voltage noise density	f = 1 kHz		13		nV/√Hz
		f = 10 kHz		7		
en p-p	Input noise voltage	0.1 Hz ≤ f ≤ 10 Hz		7		μVpp

1. Slew rate value is the average of rising and falling values.
2. Settling time at 0.01% is guaranteed by design.

**Table 5. Electrical characteristics at  $V_{CC+} = 3.3\text{ V}$ ,  $V_{icm} = V_{OUT} = V_{CC} / 2$ ,  $T = 25\text{ }^{\circ}\text{C}$ ,  $R_L = 10\text{ k}\Omega$  connected to  $V_{CC} / 2$  and  $C_L = 47\text{ pF}$  (unless otherwise specified)**

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
DC performance						
V <sub>io</sub>	Input offset voltage	T = 25 °C			±200	μV
		-40 °C ≤ T ≤ 125 °C			±700	
ΔV <sub>io</sub> /ΔT	Input offset voltage drift	-40 °C ≤ T ≤ 125 °C			±5	μV/°C
I <sub>ib</sub>	Input bias current	T = 25 °C		1.8		pA
		-40 °C ≤ T ≤ 125 °C		60		
I <sub>io</sub>	Input offset current	T = 25 °C		1		pA
		-40 °C ≤ T ≤ 125 °C		20		
A <sub>VD</sub>	Open loop gain	V <sub>CC-</sub> +100 mV ≤ V <sub>OUT</sub> ≤ V <sub>CC+</sub> -100 mV, T = 25 °C	105			dB
		V <sub>CC-</sub> +100 mV ≤ V <sub>OUT</sub> ≤ V <sub>CC+</sub> -100 mV, -40 °C ≤ T ≤ 125 °C	90			
		R <sub>L</sub> = 2 kΩ, V <sub>CC-</sub> + 200 mV ≤ V <sub>OUT</sub> ≤ V <sub>CC+</sub> -200 mV, T = 25 °C	100			
		R <sub>L</sub> = 2 kΩ, V <sub>CC-</sub> + 200 mV ≤ V <sub>OUT</sub> ≤ V <sub>CC+</sub> -200 mV, -40 °C ≤ T ≤ 125 °C	85			
CMR1	Common-mode rejection ratio 20.log(ΔV <sub>io</sub> /ΔV <sub>icm</sub> )	V <sub>CC-</sub> -0.1 V ≤ V <sub>icm</sub> ≤ V <sub>CC+</sub> -1.8 V, T = 25 °C	93	115		dB
		V <sub>CC-</sub> -0.1 V ≤ V <sub>icm</sub> ≤ V <sub>CC+</sub> -1.8 V, -40 °C ≤ T ≤ 125 °C	85	108		
CMR2		V <sub>CC-</sub> -0.1 V ≤ V <sub>icm</sub> ≤ V <sub>CC+</sub> , T = 25 °C	77	98		
		V <sub>CC-</sub> -0.1 V ≤ V <sub>icm</sub> ≤ V <sub>CC+</sub> , -40 °C ≤ T ≤ 125 °C	70	90		
V <sub>OH</sub>	High level output voltage drop (V <sub>OH</sub> = V <sub>CC+</sub> - V <sub>OUT</sub> )	T = 25 °C			10	mV
		-40 °C ≤ T ≤ 125 °C			20	
V <sub>OL</sub>	Low level output voltage drop (V <sub>OL</sub> = V <sub>OUT</sub> )	T = 25 °C			10	
		-40 °C ≤ T ≤ 125 °C			20	
I <sub>OUT</sub>	I <sub>sink</sub> (R <sub>L</sub> connected to V <sub>CC+</sub> )	T = 25 °C	45	60		mA
		-40 °C ≤ T ≤ 125 °C	30			
	I <sub>source</sub> (R <sub>L</sub> connected to V <sub>CC-</sub> )	T = 25 °C	45	65		
		-40 °C ≤ T ≤ 125 °C	30			
I <sub>CC</sub>	Supply current (per channel, R <sub>L</sub> > 1 MΩ)	T = 25 °C		1.8	2.0	mA
		-40 °C ≤ T ≤ 125 °C			2.0	
AC performance						
GBP	Gain bandwidth product		17	20		MHz
SR	Slew rate	A <sub>V</sub> = 1 V/V, 10% to 90% <sup>(1)</sup>	11	13		V/μs
t <sub>s</sub>	Settling time	R <sub>L</sub> = 4.7 kΩ, A <sub>V</sub> = -1 V/V, to 0.1%, V <sub>in</sub> = 1 Vp-p		310		ns
		R <sub>L</sub> = 4.7 kΩ, A <sub>V</sub> = -1 V/V, to 0.01%, V <sub>in</sub> = 1 Vp-p <sup>(2)</sup>		480		
t <sub>rec</sub>	Overload recovery time	V <sub>OUT</sub> 100 mV from rail, A <sub>V</sub> = +1		260		ns

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$\Phi_m$	Phase margin			48		degrees
GM	Gain margin			9		dB
$C_{in}$	Differential input capacitance			6.5		pF
	Common-mode input capacitance			2.5		
en	Input voltage noise density	f = 1 kHz		13		nV/ $\sqrt{\text{Hz}}$
		f = 10 kHz		7		
en p-p	Input noise voltage	0.1 Hz $\leq$ f $\leq$ 10 Hz		7		$\mu\text{V}_{pp}$

1. Slew rate value is the average of rising and falling values.
2. Settling time at 0.01% is guaranteed by design.

**Table 6. Electrical characteristics at  $V_{CC+} = 2.0\text{ V}$ ,  $V_{icm} = V_{OUT} = V_{CC}/2$ ,  $T = 25\text{ }^{\circ}\text{C}$ ,  $R_L = 10\text{ k}\Omega$  connected to  $V_{CC}/2$  and  $C_L = 47\text{ pF}$  (unless otherwise specified)**

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
DC Performance						
V <sub>io</sub>	Input offset voltage (V <sub>icm</sub> = 0 V)	T = 25 °C			±200	μV
		-40 °C ≤ T ≤ 125 °C			±700	
ΔV <sub>io</sub> /ΔT	Input offset voltage drift	-40 °C ≤ T ≤ 125 °C			±5	μV/°C
I <sub>ib</sub>	Input bias current	T = 25 °C		1		pA
		-40 °C ≤ T ≤ 125 °C		40		
I <sub>io</sub>	Input offset current	T = 25 °C		1		pA
		-40 °C ≤ T ≤ 125 °C		15		
A <sub>VD</sub>	Open loop gain	V <sub>CC-</sub> +100 mV ≤ V <sub>OUT</sub> ≤ V <sub>CC+</sub> -100 mV, T = 25 °C	95			dB
		V <sub>CC-</sub> +100 mV ≤ V <sub>OUT</sub> ≤ V <sub>CC+</sub> -100 mV, -40 °C ≤ T ≤ 125 °C	80			
		R <sub>L</sub> = 2 kΩ, V <sub>CC-</sub> + 200 mV ≤ V <sub>OUT</sub> ≤ V <sub>CC+</sub> -200 mV, T = 25 °C	90			
		R <sub>L</sub> = 2 kΩ, V <sub>CC-</sub> + 200 mV ≤ V <sub>OUT</sub> ≤ V <sub>CC+</sub> -200 mV, 40 °C ≤ T ≤125 °C	80			
CMR	Common-mode rejection ratio 20.log(ΔV <sub>io</sub> /ΔV <sub>icm</sub> )	V <sub>CC-</sub> -0.1 V ≤ V <sub>icm</sub> ≤ V <sub>CC+</sub> , T = 25 °C	73	94		dB
		V <sub>CC-</sub> -0.1 V ≤ V <sub>icm</sub> ≤ V <sub>CC+</sub> , -40 °C ≤ T ≤ 125 °C	67	86		
V <sub>OH</sub>	High level output voltage drop (V <sub>OH</sub> = V <sub>CC+</sub> - V <sub>OUT</sub> )	T = 25 °C			10	mV
		-40 °C ≤ T ≤ 125 °C			20	
V <sub>OL</sub>	Low level output voltage drop (V <sub>OL</sub> = V <sub>OUT</sub> )	T = 25 °C			10	
		-40 °C ≤ T ≤ 125 °C			20	
I <sub>OUT</sub>	I <sub>sink</sub> (R <sub>L</sub> connected to V <sub>CC+</sub> )	T = 25 °C	45	60		mA
		-40 °C ≤ T ≤ 125 °C	30			
	I <sub>source</sub> (R <sub>L</sub> connected to V <sub>CC-</sub> )	T = 25 °C	45	65		
		-40 °C ≤ T ≤ 125 °C	30			
I <sub>CC</sub>	Supply current (per channel, R <sub>L</sub> > 1 MΩ, V <sub>icm</sub> = 0 V)	T = 25 °C		1.7	1.9	mA
		-40 °C ≤ T ≤ 125 °C			1.9	
AC performance						
GBP	Gain bandwidth product		17	20		MHz
SR	Slew rate	A <sub>V</sub> = 1 V/V, 10% to 90% <sup>(1)</sup>	9	11		V/μs
t <sub>s</sub>	Settling time	R <sub>L</sub> = 4.7 kΩ, A <sub>V</sub> = -1 V/V, to 0.1%, V <sub>in</sub> = 1 Vp-p		450		ns
		R <sub>L</sub> = 4.7 kΩ, A <sub>V</sub> = -1 V/V, to 0.01%, V <sub>in</sub> = 1 Vp-p <sup>(2)</sup>		570		
t <sub>rec</sub>	Overload recovery time	V <sub>OUT</sub> 50 mV from initial value, A <sub>V</sub> = +1		300		ns
Φ <sub>m</sub>	Phase margin			47		degrees
GM	Gain margin			8		dB
C <sub>in</sub>	Differential input capacitance			6.5		pF



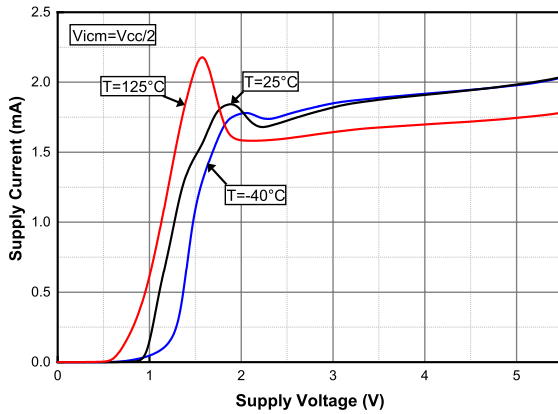
Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
$C_{in}$	Common-mode input capacitance			2.5		pF
$e_n$	Input voltage noise density	$f = 1 \text{ kHz}$		30		$\text{nV}/\sqrt{\text{Hz}}$
		$f = 10 \text{ kHz}$		14		
$e_n \text{ p-p}$	Input noise voltage	$0.1 \text{ Hz} \leq f \leq 10 \text{ Hz}$		10		$\mu\text{Vpp}$

1. Slew rate value is the average of rising and falling values.
2. Settling time at 0.01% is guaranteed by design.

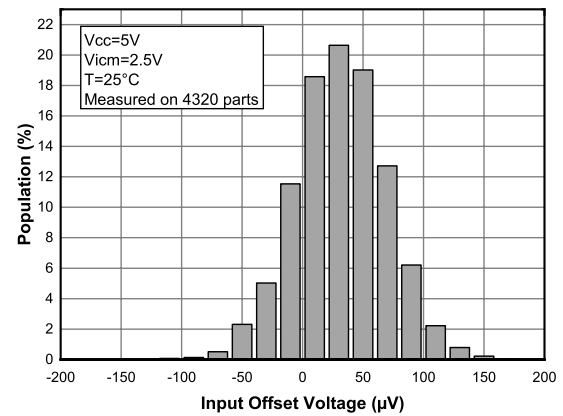
## 4 Typical performance characteristics

$R_L = 10\text{ k}\Omega$  connected to  $V_{CC} / 2$  and  $C_L = 47\text{ pF}$ , unless otherwise specified.

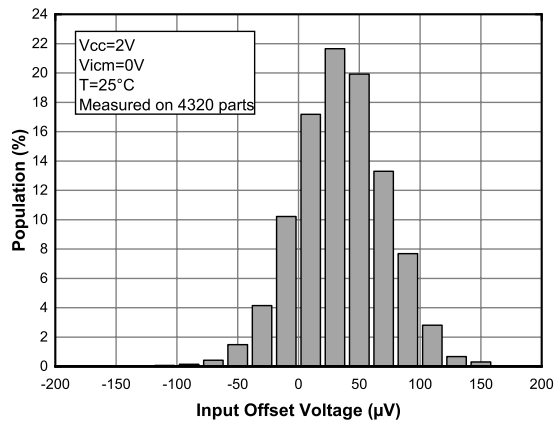
**Figure 2. Supply current vs. supply voltage**



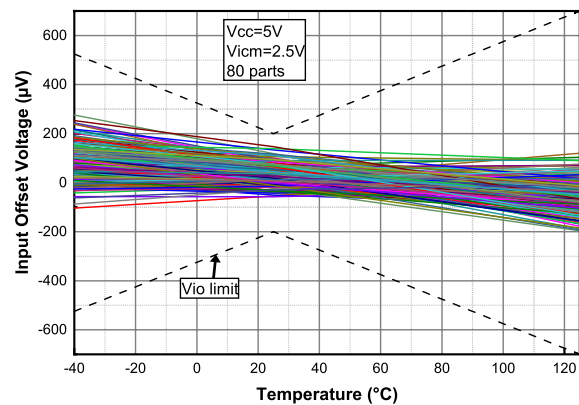
**Figure 3. Input offset voltage distribution at  $V_{CC} = 5\text{ V}$**



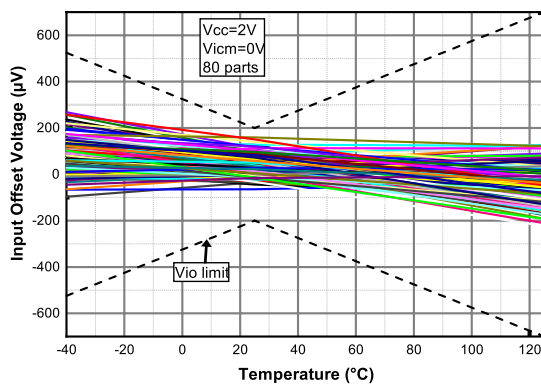
**Figure 4. Input offset voltage distribution at  $V_{CC} = 2\text{ V}$**



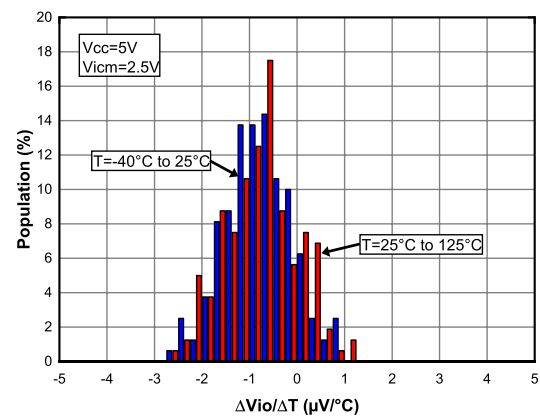
**Figure 5. Input offset voltage vs. temperature at  $V_{CC} = 5\text{ V}$**

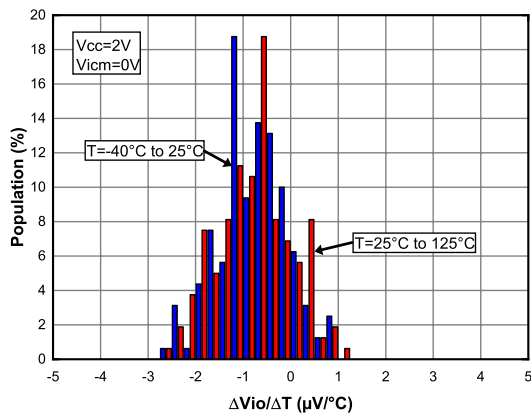
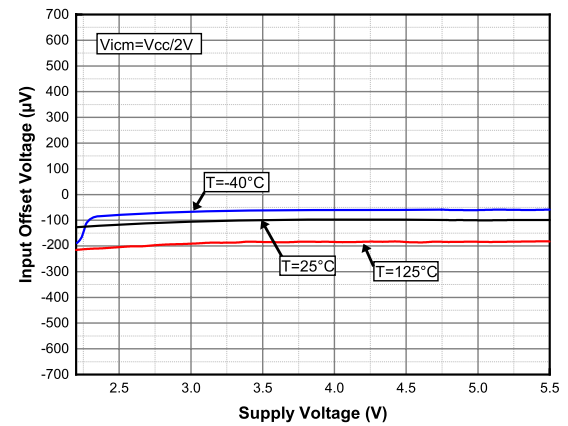
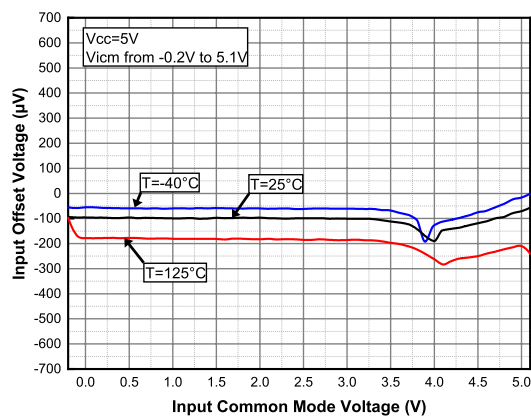
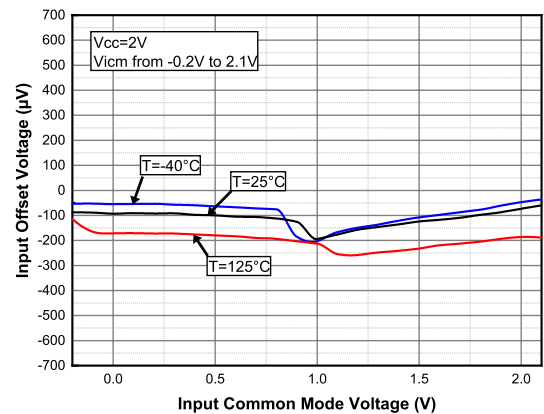
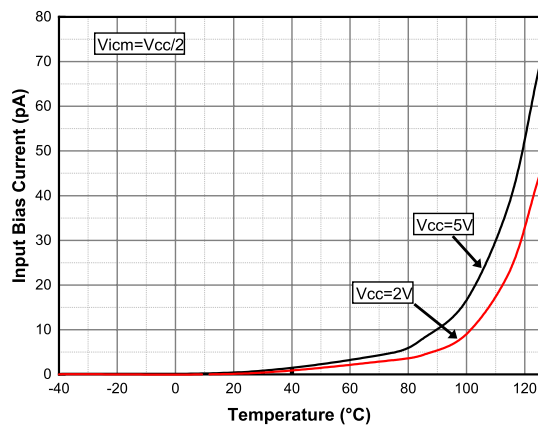
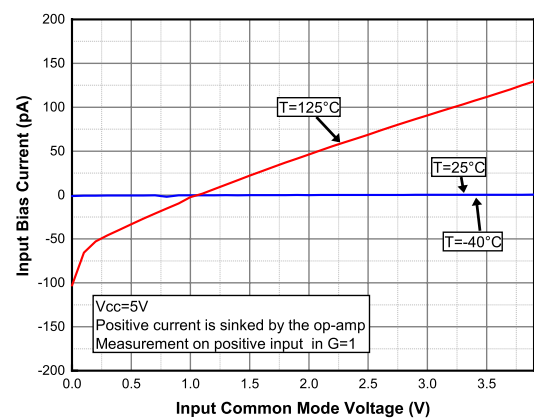


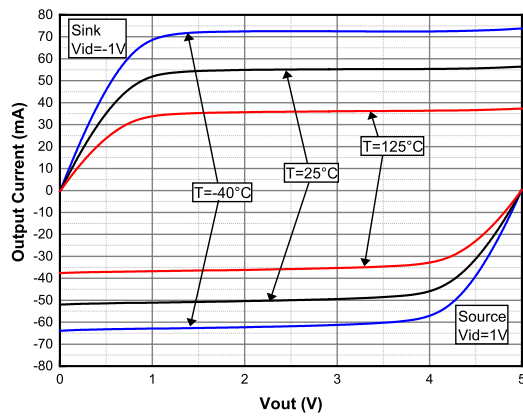
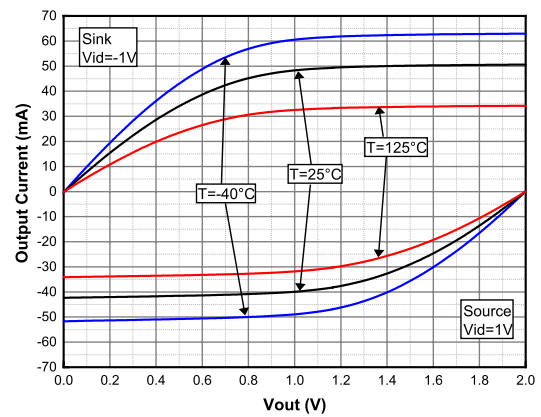
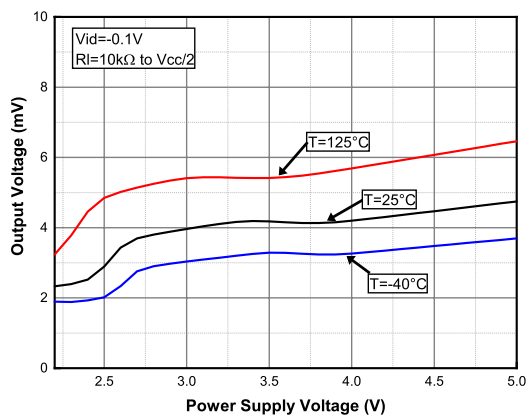
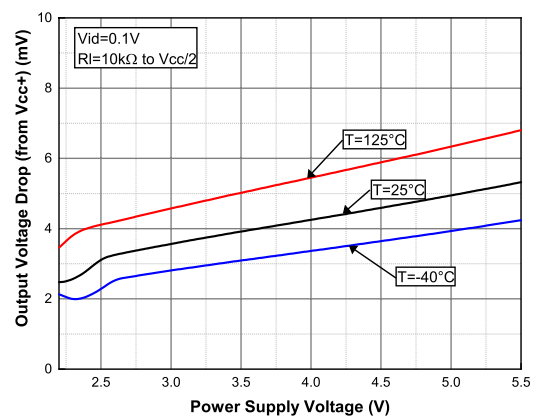
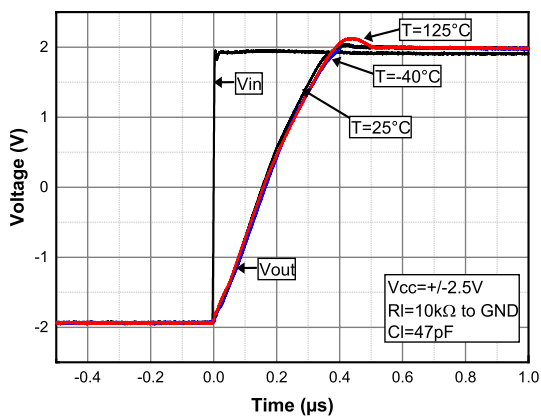
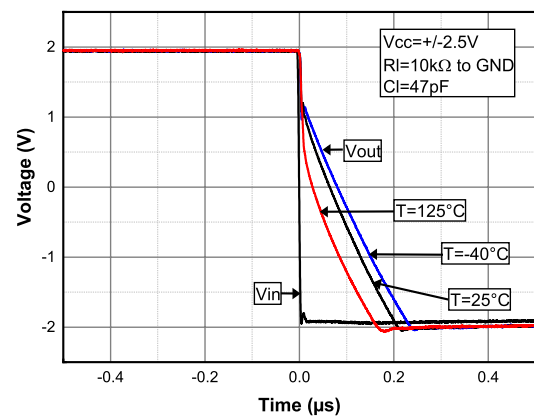
**Figure 6. Input offset voltage vs. temperature at  $V_{CC} = 2\text{ V}$**

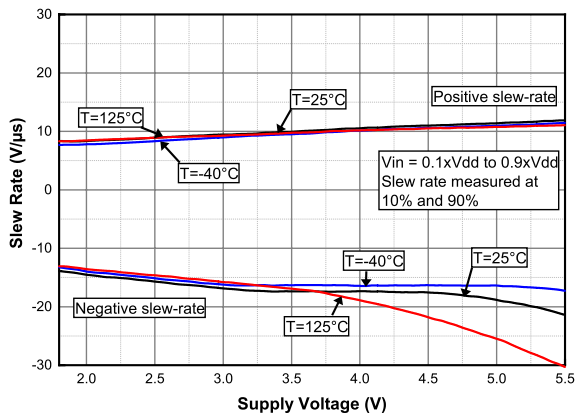
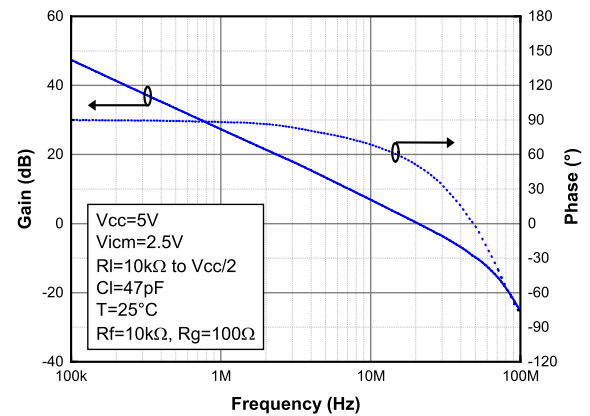
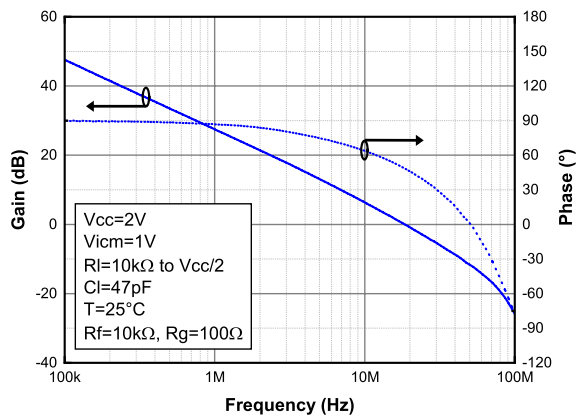
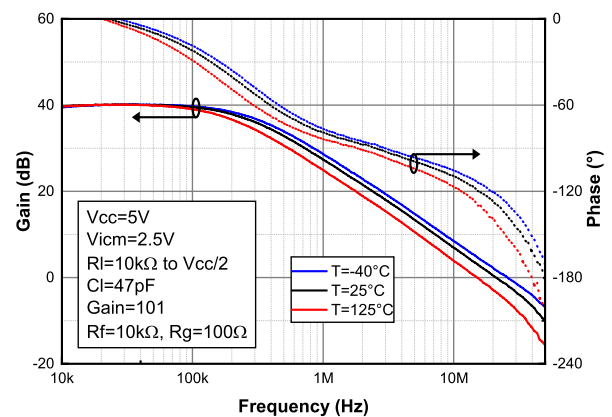
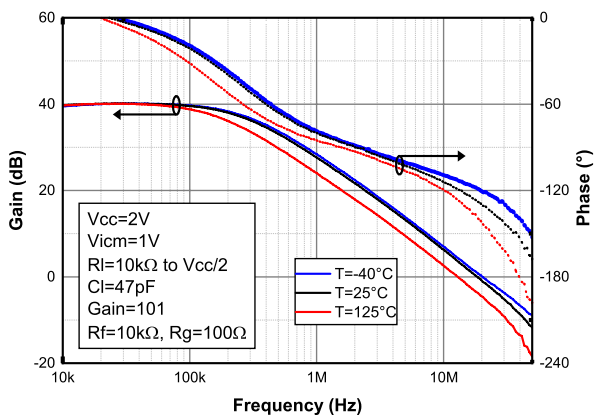
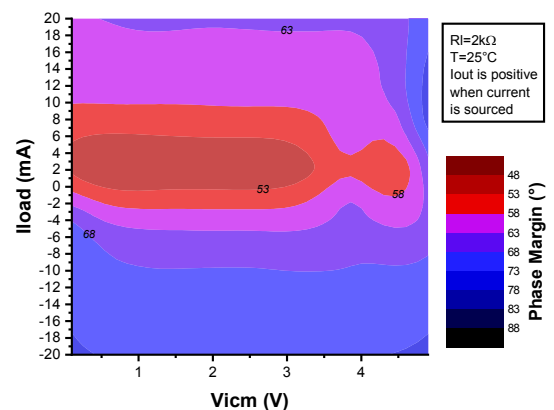


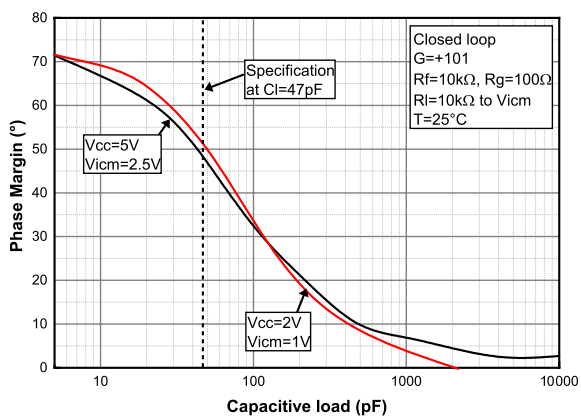
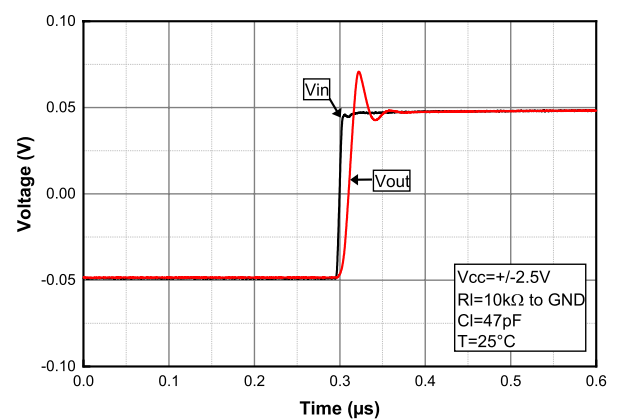
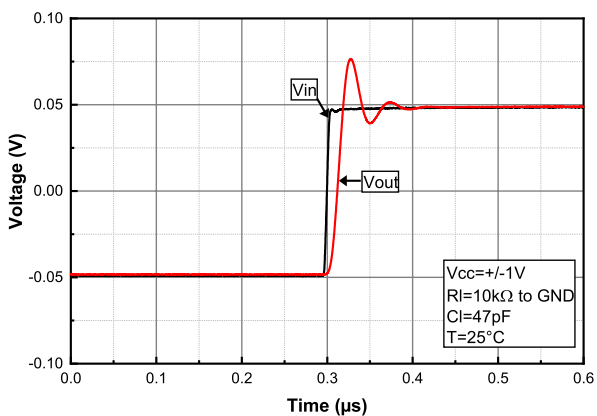
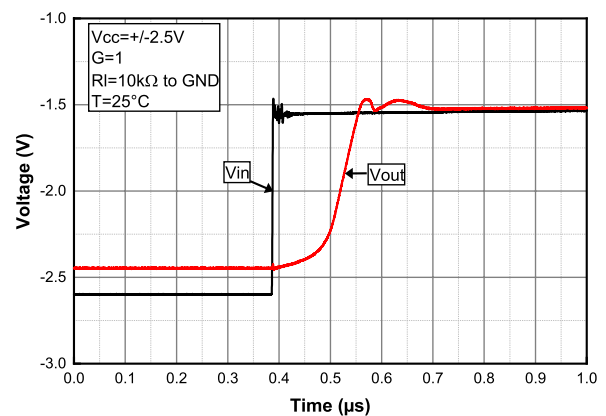
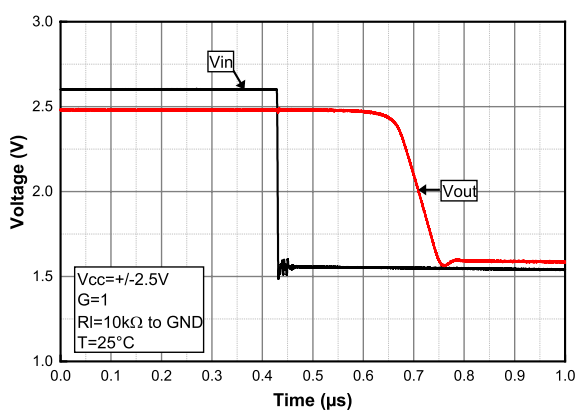
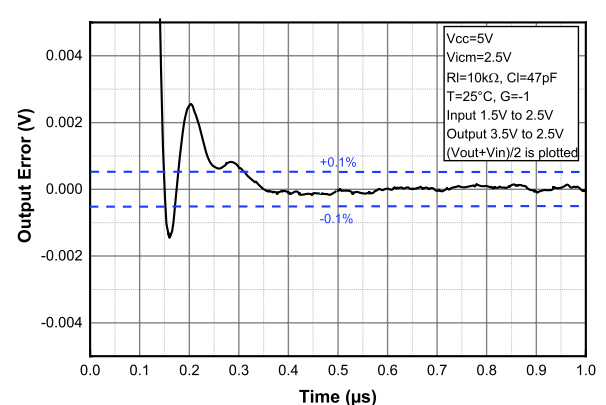
**Figure 7. Input offset voltage thermal drift distribution at  $V_{CC} = 5\text{ V}$**

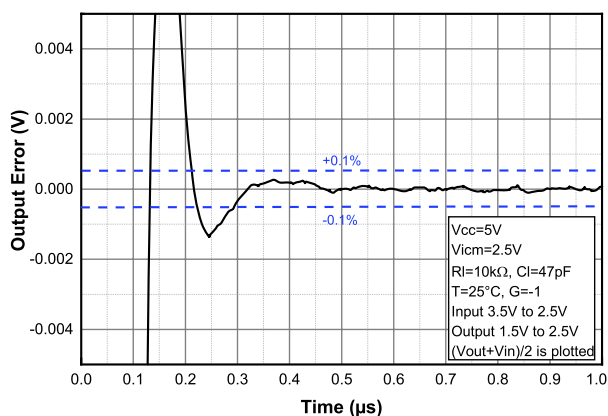
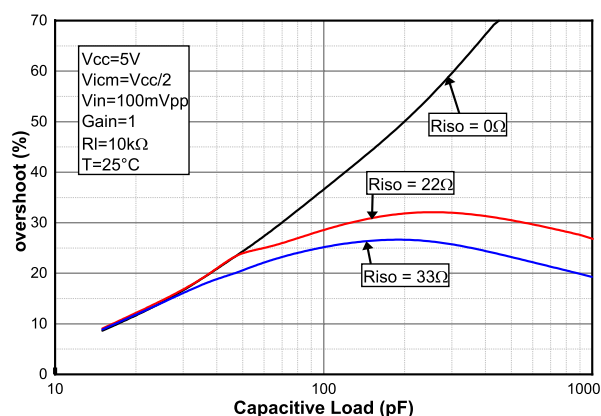
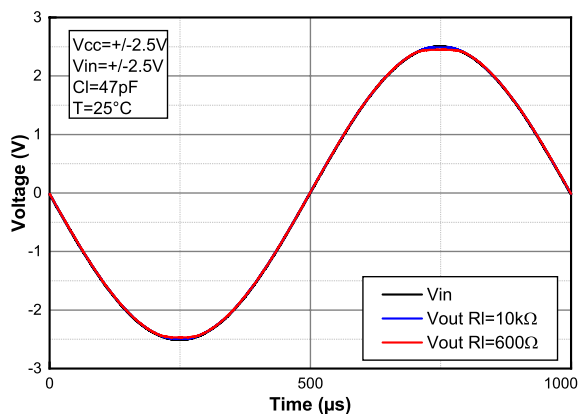
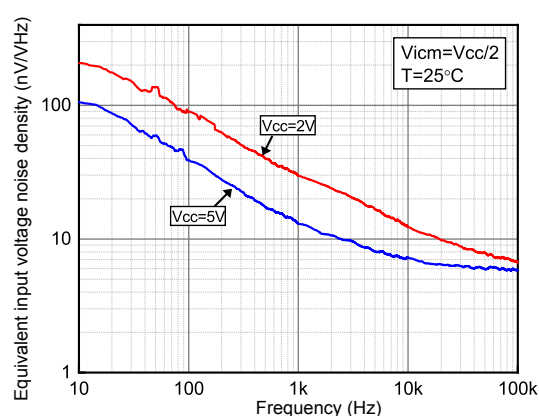
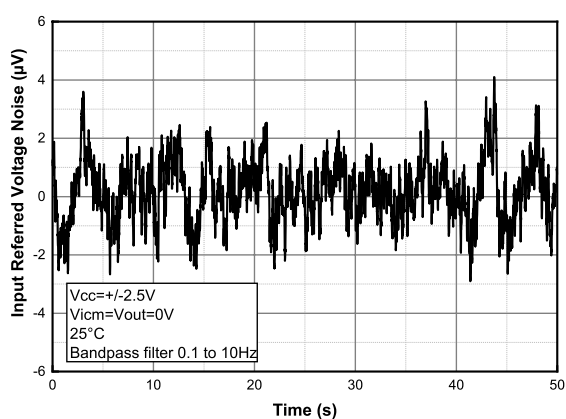
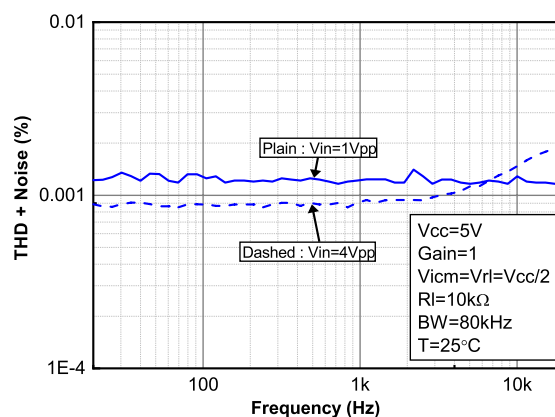


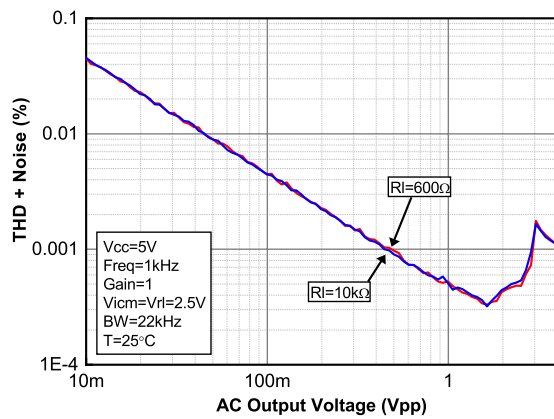
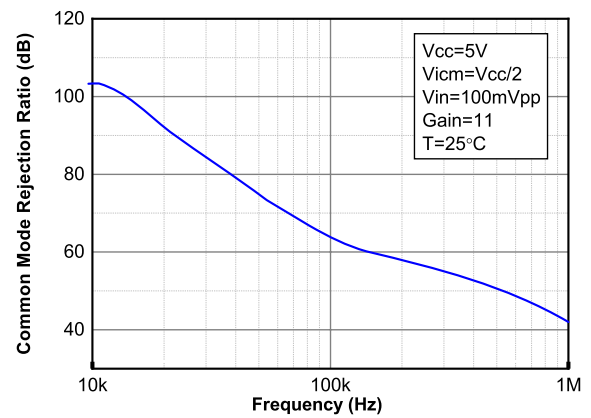
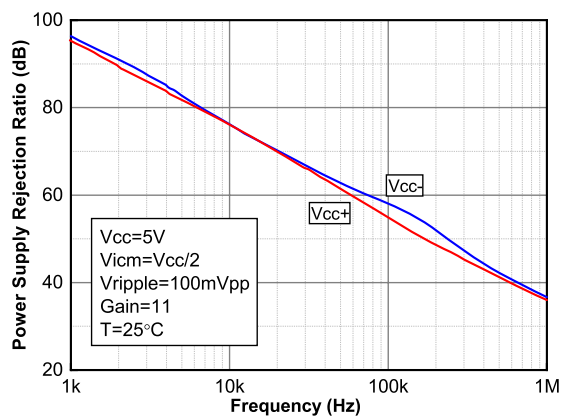
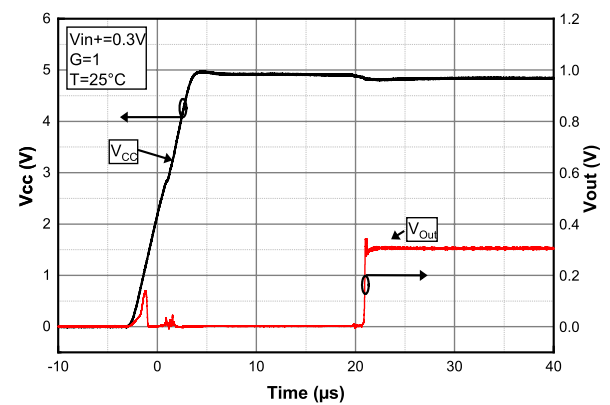
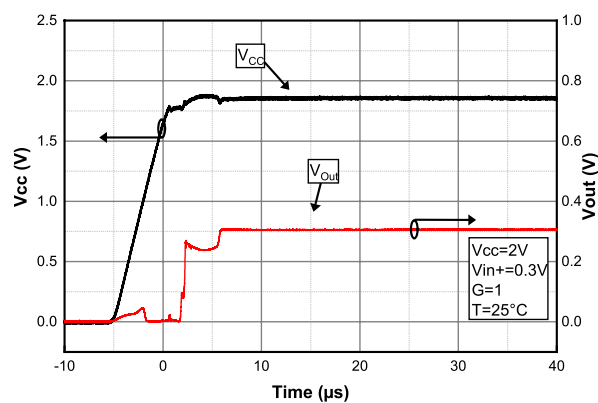
**Figure 8. Input offset voltage thermal drift distribution at  $V_{CC} = 2\text{ V}$** 

**Figure 9. Input offset voltage vs. supply voltage**

**Figure 10. Input offset voltage vs. common-mode voltage at  $V_{CC} = 5\text{ V}$** 

**Figure 11. Input offset voltage vs. common-mode voltage at  $V_{CC} = 2\text{ V}$** 

**Figure 12. Input bias current vs. temperature**

**Figure 13. Input bias current vs. common-mode voltage at  $V_{CC} = 5\text{ V}$** 


**Figure 14. Output current vs. output voltage at  $V_{CC} = 5\text{ V}$** 

**Figure 15. Output current versus output voltage at  $V_{CC} = 2\text{ V}$** 

**Figure 16. Output saturation voltage ( $V_{OL}$ ) vs. supply voltage**

**Figure 17. Output saturation voltage ( $V_{OH}$ ) vs. supply voltage**

**Figure 18. Positive slew rate at  $V_{CC} = 5\text{ V}$** 

**Figure 19. Negative slew rate at  $V_{CC} = 5\text{ V}$** 


**Figure 20. Slew rate vs.  $V_{CC}$** 

**Figure 21. Open loop bode diagram at  $V_{CC} = 5\text{ V}$** 

**Figure 22. Open loop bode diagram at  $V_{CC} = 2\text{ V}$** 

**Figure 23. Closed loop bode diagram at  $V_{CC} = 5\text{ V}$** 

**Figure 24. Closed loop bode diagram at  $V_{CC} = 2\text{ V}$** 

**Figure 25. Phase margin vs. common-mode voltage and load current at  $V_{CC} = 5\text{ V}$** 


**Figure 26. Phase margin vs. capacitive load**

**Figure 27. Small step response at  $V_{CC} = 5\text{ V}$** 

**Figure 28. Small step response at  $V_{CC} = 2\text{ V}$** 

**Figure 29. Desaturation from low rail at  $V_{CC} = 5\text{ V}$** 

**Figure 30. Desaturation from high rail at  $V_{CC} = 5\text{ V}$** 

**Figure 31. Settling time output high to low at  $V_{CC} = 5\text{ V}$** 


**Figure 32. Settling time output low to high at  $V_{CC} = 5\text{ V}$** 

**Figure 33. Small step overshoot vs. load capacitance**

**Figure 34. Linearity vs. load resistance at  $V_{CC} = 5\text{ V}$** 

**Figure 35. Noise vs. frequency**

**Figure 36. Noise vs. time at  $V_{CC} = 5\text{ V}$** 

**Figure 37. THD+N vs. frequency**


**Figure 38. THD+N vs. output voltage**

**Figure 39. CMRR vs. frequency at  $V_{CC} = 5V$** 

**Figure 40. PSRR vs. frequency at  $V_{CC} = 5V$** 

**Figure 41. Turn-on time at  $V_{CC} = 5V$** 

**Figure 42. Turn-on time at  $V_{CC} = 2V$** 




## 5 Application information

### 5.1 Operating voltages

The TSV772 device can operate from 2.0 to 5.5 V. The parameters are fully specified at 2.0 V, 3.3 V and 5 V power supplies. However, the parameters are very stable over the full  $V_{CC}$  range and several characterization curves show the TSV772 device characteristics over the full operating range. Additionally, the main specifications are guaranteed in extended temperature range from -40 to 125 °C.

The TSV772 device is rail-to-rail input and output and features two input transistor pairs, allowing the op amp to operate over all the common mode range, from  $V_{CC-} - 0.2$  V, to  $V_{CC+} + 0.1$  V. The input pair transition typically occurs at  $V_{CC+} - 1$  V, as seen in Figure 10. Input offset voltage vs. common-mode voltage at  $V_{CC} = 5$  V and Figure 11. Input offset voltage vs. common-mode voltage at  $V_{CC} = 2$  V. The precision and dynamic performances are particularly optimized on the low pair, from  $V_{CC-} - 0.1$  V to  $V_{CC+} - 1.8$  V, and operating in this  $V_{icm}$  range is advised for the best performance whenever possible. Besides, operating near the pair transition should be avoided when precision is a concern, as CMRR can be lower in these conditions.

### 5.2 Input offset voltage drift over the temperature

The input voltage drift variation over the temperature is defined as the offset variation related to the offset value measured at 25 °C. The operational amplifier is one of the main circuits of the signal conditioning chain, and the amplifier input offset ( $V_{io}$ ) is a major contributor to the chain accuracy. The signal chain accuracy at 25 °C can be compensated during the production at the application level. The maximum input voltage drift over the temperature enables the system designer to anticipate the effect of temperature variations.

The maximum input voltage drift overtemperature is computed using the following equation:

$$\frac{\Delta V_{io}}{\Delta T} = \max \left| \frac{V_{io}(T) - V_{io}(25^{\circ}\text{C})}{T - 25^{\circ}\text{C}} \right| \quad (1)$$

Where  $T = -40$  °C and 125 °C.

The datasheet maximum value is guaranteed by a measurement on a representative sample size ensuring a  $C_{pk}$  (process capability index) greater than 1.3. The absolute worst case value between -40 °C and 125 °C is reported in the datasheet.

### 5.3 Unused channel

When one of the two channels of the TSV772 is not used, it must be properly connected in order to avoid internal oscillations that can negatively impact the signal integrity on the other channel, as well as the current consumption. Two different configurations can be used:

Gain or buffer configuration: the channel can be set in gain, the input can be set to any voltage within the  $V_{icm}$  operating range.

Comparator configuration: the channel can be set to a comparator configuration (without negative feedback). In this case, positive and negative inputs can be set to any value provided these values are significantly different (100 mV or more, to avoid oscillation between positive and negative state and within operating range) and the differential input is lower than the maximum specified in the operating range.

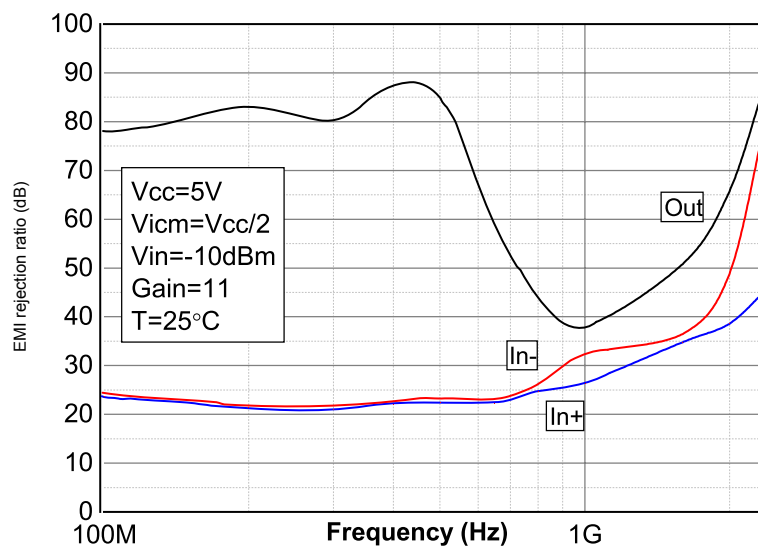
## 5.4 EMI rejection

The electromagnetic interference (EMI) rejection ratio, or EMIRR, describes the EMI immunity of operational amplifiers. An adverse effect that is common to many op amps is a change in the offset voltage as a result of RF signal rectification. EMIRR is defined in Eq. (2):

$$EMIRR = 20 \cdot \log\left(\frac{V_{in\ pp}}{\Delta V_{io}}\right) \quad (2)$$

The TSV772 has been specially designed to minimize susceptibility to EMIRR and shows a low sensitivity. As can be seen in Figure 43. EMIRR on In+, In- and Out pins, EMI rejection ratio has been measured on both inputs and output, from 400 MHz to 2.4 GHz.

**Figure 43. EMIRR on In+, In- and Out pins**



EMIRR performances might be improved by adding small capacitances (in the pF range) on the inputs, power supply and output pins.

These capacitances help to minimize the impedance of these nodes at high frequencies.

## 5.5 Maximum power dissipation

The usable output load current drive is limited by the maximum power dissipation allowed by the device package. The absolute maximum junction temperature for the TSV772 is 150 °C. The junction temperature can be estimated as follows:

$$T_J = P_D \times \theta_{JA} + T_A \quad (3)$$

$T_J$  is the die junction temperature

$P_D$  is the power dissipated in the package

$\theta_{JA}$  is the junction-to-ambient thermal resistance of the package

$T_A$  is the ambient temperature

The power dissipated in the package  $P_D$  is the sum of the quiescent power dissipated and the power dissipated by the output stage transistor. It is calculated as follows:

$P_D = (V_{CC} \times I_{CC}) + (V_{CC} + -V_{OUT}) \times I_{Load}$  when the op amp is sourcing the current.

$P_D = (V_{CC} \times I_{CC}) + (V_{OUT} - V_{CC} -) \times I_{Load}$  when the op amp is sinking the current.

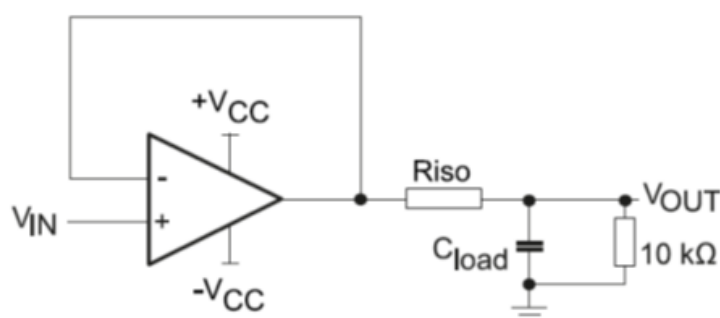
Do not exceed the 150 °C maximum junction temperature for the device. Exceeding the junction temperature limit can cause degradation in the parametric performance or even destroy the device.

## 5.6 Capacitive load and stability

Stability analysis must be performed for large capacitive loads over 47 pF; increasing the load capacitance to high values produces gain peaking in the frequency response, with overshoot and ringing in the step response.

Generally, unity gain configuration is the worst situation for stability and the ability to drive large capacitive loads. For additional capacitive load drive capability in unity-gain configuration, stability can be improved by inserting a small resistor  $R_{ISO}$  (10  $\Omega$  to 33  $\Omega$ ) in series with the output (see Figure 33. [Small step overshoot vs. load capacitance](#)). This resistor significantly reduces ringing while maintaining DC performance for purely capacitive loads. However, if there is a resistive load in parallel with the capacitive load, a voltage divider is created introducing a gain error at the output and slightly reducing the output swing. The error introduced is proportional to the ratio  $R_{ISO} / R_L$ .  $R_{ISO}$  modifies the maximum capacitive load acceptable from a stability point of view, as described in Figure 44. [Test configuration for  \$R\_{ISO}\$](#) :

Figure 44. Test configuration for  $R_{ISO}$

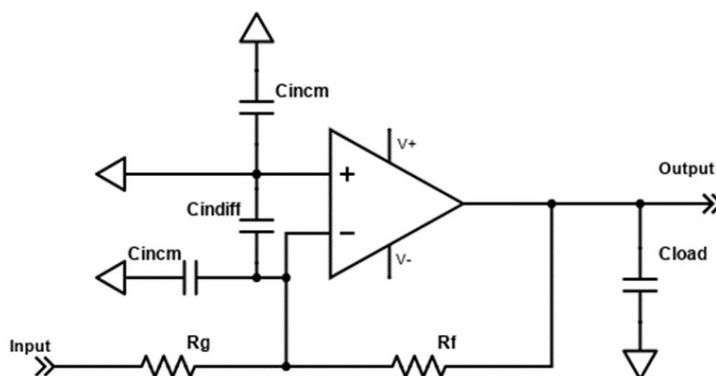


Please note that  $R_{ISO} = 33 \Omega$  is sufficient to make the TSV772 stable whatever the capacitive load.

## 5.7 Resistor values for high speed op amp design

Due to its high gain bandwidth product (GBP), this op amp is particularly sensitive to parasitic impedances. Board parasitics should be taken into account in any sensitive design. Indeed, excessive parasitic (both capacitive and inductive) in the op amp frequency range can alter performances and stability. These issues can often be mitigated by lowering the resistive impedances. More specifically, the RC network created by the schematic resistors ( $R_f$  and  $R_g$ ) and the parasitic capacitances of both the op amp (as documented in Table 1 to Table 5 and illustrated in Figure 45) and the PCB can generate a pole below or in the same order of magnitude than the closed-loop bandwidth of the circuit. In this case, the feedback circuit is not able to fully play its role at high frequency, and the application can be unstable. This issue can happen when the schematic gain is low (typically < 5), or the device is used in follower mode with a resistor in the feedback. In these cases, it is advised to use a low value feedback resistor ( $R_f$ ), typically 1 k $\Omega$ .

Figure 45. Inverting amplifier configuration with parasitic input capacitances

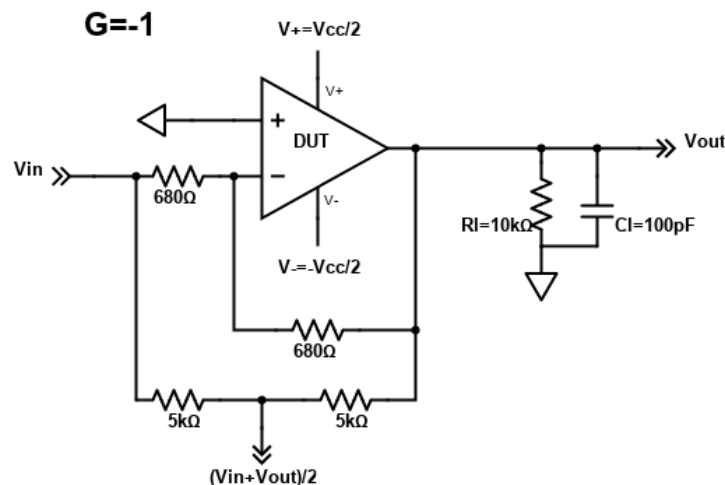


Also, some designs use an input resistor on the positive input, generally of the same value than the input resistance on the negative input. This resistor can be useful to balance the input currents on the positive and negative inputs, and reduce the impact of those input currents on precision. However, this is not useful on the TSV772 as the input currents are very low. Furthermore, this resistor can also interact with the input capacitances to generate a pole. The frequency of this pole should be kept higher than the closed-loop bandwidth frequency. The macromodel provided takes into account the circuit parasitic capacitors. Thus, a transient SPICE simulation (100 mV step) is an easy way to evaluate the stability of the application. However, this cannot replace a hardware evaluation of the application circuit.

## 5.8 Settling time

Settling time in an application can be defined as the amount of time between the input changes, and the output reaching its final value. It is usually defined with a given tolerance, so the output stability is reached when the output stays within the given range around the final value. In Figure 30 and Figure 31, the settling time is measured in an inverting configuration, using the so-called “false summing node” circuit.

**Figure 46. Settling time measurement configuration**



This circuit is used with a step input voltage from a positive or negative value, to 0 V. The measurement point being  $(V_{in} + V_{out}) / 2$ , and  $V_{out}$  being in an ideal circuit equal to  $V_{in}$ ; the measurement point gives half of the error on  $V_{out}$ , comparatively to  $V_{in}$ . This error is compared to the tolerance, 0.1% for this circuit, to deduce the settling time. This characteristic is particularly useful when driving an ADC. It is related to the slew rate, GBP and stability of the circuit. It also varies with the circuit gain, the circuit load, and the input voltage step value. However, computing the value of the settling time in a given configuration is not straightforward. The macromodel can give a good estimation, but prototyping can be needed for fine circuit optimization.

## 5.9 PCB layout recommendations

Particular attention must be paid to the layout of the PCB tracks connected to the amplifier, load, and power supply. The power and ground traces are critical as they must provide adequate energy and grounding for all circuits. The best practice is to use short and wide PCB traces to minimize voltage drops and parasitic inductance. In addition, to minimizing parasitic impedance over the entire surface, a multi-via technique that connects the bottom and top layer ground planes together in many locations is often used. The copper traces that connect the output pins to the load and supply pins should be as wide as possible to minimize trace resistance.

## 5.10 Decoupling capacitor

In order to ensure op amp full functionality, it is mandatory to place a decoupling capacitor of at least 22 nF as close as possible to the op amp supply pins. A good decoupling helps to reduce electromagnetic interference impact.

## 5.11 Macro model

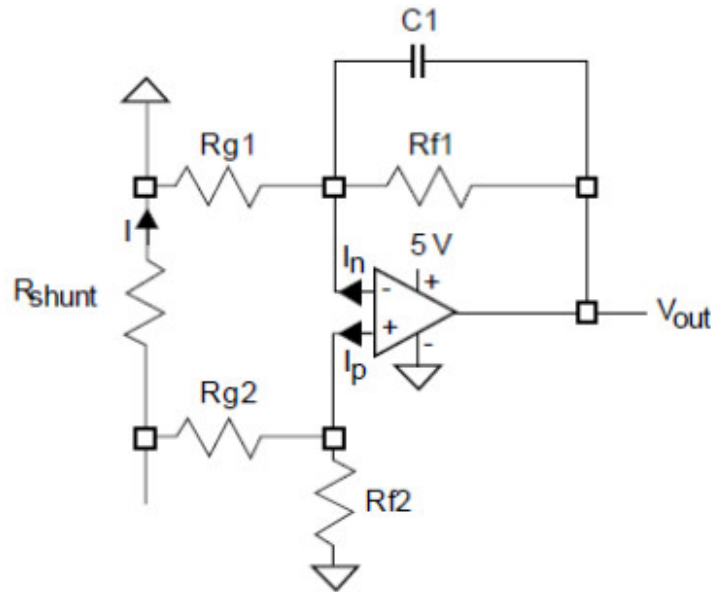
Accurate macromodels of the TSV772 device are available on the STMicroelectronics' website at: [www.st.com](http://www.st.com). These models are a trade-off between accuracy and complexity (that is, time simulation) of the TSV772 operational amplifier. They emulate the nominal performance of a typical device within the specified operating conditions mentioned in the datasheet. They also help to validate a design approach and to select the right operational amplifier, but they do not replace on-board measurements.

## 6 Typical applications

### 6.1 Low-side current sensing

Power management mechanisms are found in most electronic systems. Current sensing is useful for protecting applications. The low-side current sensing method consists of placing a sense resistor between the load and the circuit ground. The resulting voltage drop is amplified using the TSV772 (see Figure 47. Low-side current sensing schematic).

**Figure 47. Low-side current sensing schematic**



$V_{out}$  can be expressed as follows:

$$V_{Out} = R_{shunt} \cdot I \left( 1 - \frac{R_{g2}}{R_{g2} + R_{f2}} \right) \cdot \left( 1 + \frac{R_{f1}}{R_{g1}} \right) + I_p \cdot \frac{R_{g2} \cdot R_{f2}}{R_{g2} + R_{f2}} \cdot \left( 1 + \frac{R_{f1}}{R_{g1}} \right) - I_n \cdot R_{f1} - V_{io} \cdot \left( 1 + \frac{R_{f1}}{R_{g1}} \right) \quad (4)$$

Assuming that  $R_{f2} = R_{f1} = R_f$  and  $R_{g2} = R_{g1} = R_g$ , this equation can be simplified as follows:

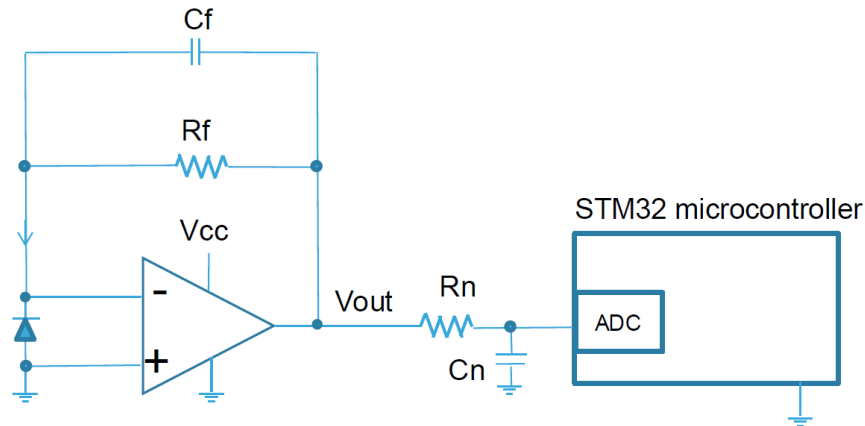
$$V_{Out} = R_{shunt} \cdot I \cdot \frac{R_f}{R_g} - V_{io} \cdot \left( 1 + \frac{R_f}{R_g} \right) + R_f \cdot I_{io} \quad (5)$$

The main advantage of using the TSV772 for a low-side current sensing relies on its low  $V_{io}$ , compared to general purpose operational amplifiers. For the same current and targeted accuracy, the shunt resistor can be chosen with a lower value, resulting in lower power dissipation, lower drop in the ground path, and lower cost. Particular attention must be paid to the matching and precision of  $R_{g1}$ ,  $R_{g2}$ ,  $R_{f1}$ , and  $R_{f2}$ , to maximize the accuracy of the measurement.

### 6.2 Photodiode transimpedance amplification

The TSV772, with high bandwidth and slew rate, is well suited for photodiode signal conditioning in a transimpedance amplifier circuit. This application is useful in high performance UV sensors, smoke detectors or particle sensors.

Figure 48. Photodiode transimpedance amplifier circuit



The transimpedance amplifier circuit converts the small photodiode output current in the nA range, into a voltage signal readable by an ADC following Eq. (6):

$$V_{out} = R_f \cdot I_{photodiode} \quad (6)$$

The feedback resistance is usually in the MΩ range, in order to get a large enough voltage output range. However, together with the diode parasitic capacitance, the op amp input capacitances and the PCB stray capacitance, this feedback network creates a pole that makes the circuit oscillate. Using a small (few pF) capacitor in parallel with the feedback resistor is mandatory to stabilize the circuit. The value of this capacitor can be tuned to optimize the application settling time with a SPICE simulation using the op amp macromodel, or by prototyping.

For more details on tuning this circuit, please read the application note AN4451.

## 7 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.

### 7.1 DFN8 2x2 package information

Figure 49. DFN8 2x2 package outline

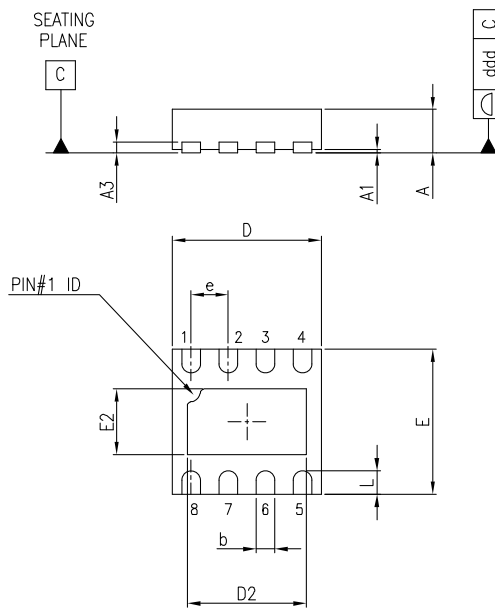
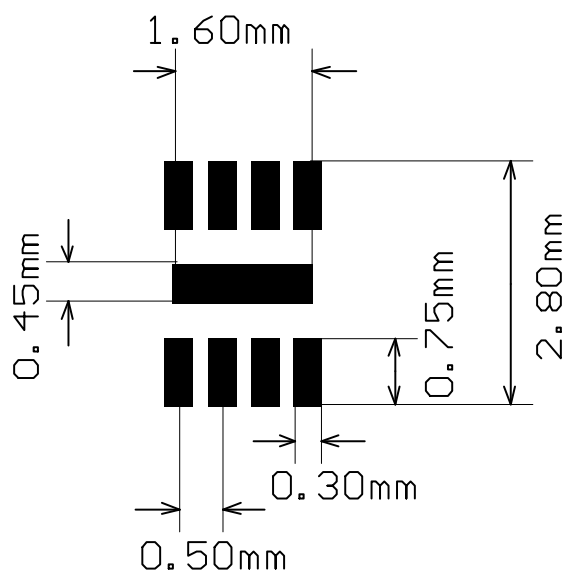


Table 7. DFN8 2x2 package mechanical data

Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A	0.51	0.55	0.60	0.020	0.022	0.024
A1			0.05			0.002
A3		0.15			0.006	
b	0.18	0.25	0.30	0.007	0.010	0.012
D	1.85	2.00	2.15	0.073	0.079	0.085
D2	1.45	1.60	1.70	0.057	0.063	0.067
E	1.85	2.00	2.15	0.073	0.079	0.085
E2	0.75	0.90	1.00	0.030	0.035	0.039
e		0.50			0.020	
L	0.225	0.325	0.425	0.009	0.013	0.017
ddd			0.08			0.003

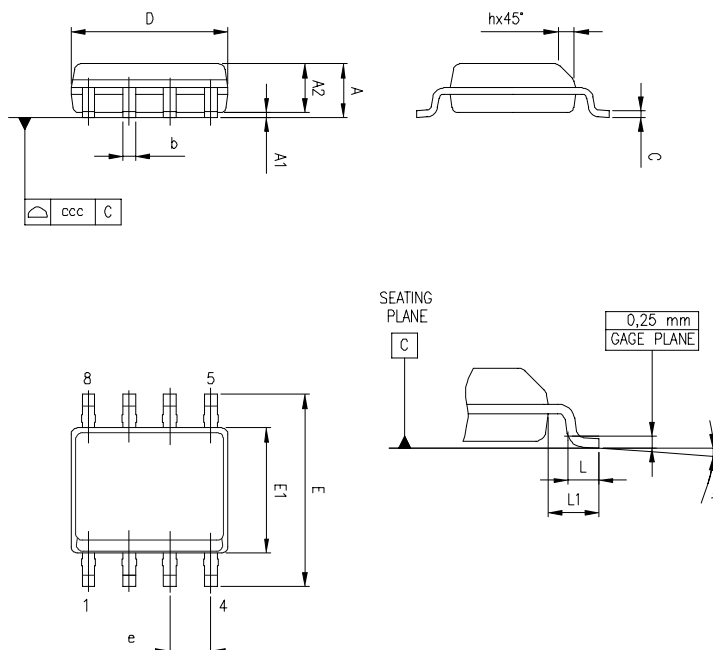


Figure 50. DFN8 2x2 recommended footprint



## 7.2 SO8 package information

**Figure 51. SO8 package outline**



**Table 8. SO-8 mechanical data**

Dim.	mm			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.75			0.069
A1	0.1		0.25	0.004		0.01
A2	1.25			0.049		
b	0.28		0.48	0.011		0.019
c	0.17		0.23	0.007		0.01
D	4.8	4.9	5	0.189	0.193	0.197
E	5.8	6	6.2	0.228	0.236	0.244
E1	3.8	3.9	4	0.15	0.154	0.157
e		1.27			0.05	
h	0.25		0.5	0.01		0.02
L	0.4		1.27	0.016		0.05
L1		1.04			0.04	
k	0		8 °	1 °		8 °
ccc			0.1			0.004

## 8 Ordering information

**Table 9. Order code**

Order code	Temperature range	Package	Marking
TSV772IQ2T	-40 to +125 °C	DFN8 2x2	K5R
TSV772IST		MiniSO8	K5R
TSV772IDT		SO8	TSV772I
TSV772IYST	-40 to +125 °C Automotive grade <sup>(1)</sup>	MiniSO8	K231
TSV772IYDT		SO8	TSV772Y

1. Qualification and characterization according to AEC Q100 and Q003 or equivalent, advanced screening according to AEC Q001 & Q 002 or equivalent are on-going.

## Revision history

**Table 10. Document revision history**

Date	Revision	Changes
12-Oct-2021	1	Initial release.
25-Nov-2021	2	Updated CDM value in <a href="#">Table 2</a> and <a href="#">Table 9</a> . Order code.

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