500nA, Rail-to-Rail I/O CMOS Operational Amplifier

FEATURES

- **Low Power Consumption: 500nA**
- **Low Offset Voltage: 3.0mV (MAX)**
- **High PSRR: 85dB (TYP)**
- **Rail-to-Rail Input and Output**
- **Wide Supply Voltage: 1.7V to 5.5V**
- **Gain Bandwidth Product: 10kHz**
- **High Gain: 110dB (TYP)**
- **Unity Gain Stable**

APPLICATIONS

- **Signal Conditioning**
- **Current Sensor Amplifier**
- **Battery-Powered Applications**
- **Portable Devices**
- **Weight Scale Sensor**
- **Medical/Industrial Instrumentation**
- **Power Converter/Inverter**

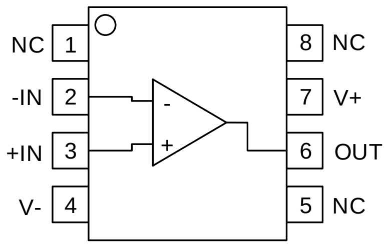
PRODUCT DESCRIPTION

The TS2X02 family of products are high precision, ultra-low power CMOS operational amplifiers. These devices support rail-to-rail input and output operation, also the input and common mode range extends beyond the supply rails.

The TS2X02 family of operational amplifiers are unity gain stable and they have 10kHz gain-bandwidth product with 4.5V/ms slew rate. The input offset voltage is maximum 3.0mV. These devices are calibrated to specified at the full temperature range of −40°C to +125°C and operate with a single or dual power supply ranged from 1.7V to 5.5V.

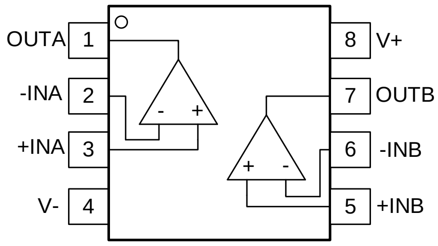
PIN ASSIGNMENTS

TS2102



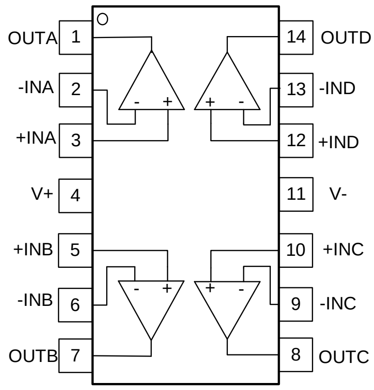
SOP8

TS2202



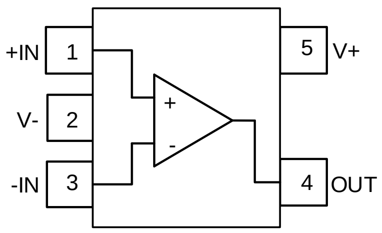
SOP8, MSOP8, TSSOP8

TS2402



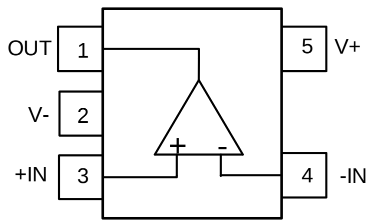
SOP14, TSSOP14

TS2102



SOT-23-5L

TS2102



SOT-23-5L

ORDERING INFORMATION

Model	Part Number	Eco Plan	Package	AMP	Container, Pack Qty
TS2102	TS2102SOT235LR	RoHS	SOT-23-5L	1	Reel, 3000
TS2102	TS2102SOP8R	RoHS	SOP8	1	Reel, 2500
TS2202	TS2202SOP8R	RoHS	SOP8	2	Reel, 2500
TS2202	TS2202MSOP8R	RoHS	MSOP8	2	Reel, 3000
TS2202	TS2202TSSOP8R	RoHS	TSSOP8	2	Reel, 4000
TS2402	TS2402SOP14R	RoHS	SOP14	4	Reel, 2500
TS2402	TS2402TSSOP14R	RoHS	TSSOP14	4	Reel, 3000

ABSOLUTE MAXIMUM RATINGS

Over operating free-air temperature range (unless otherwise noted) (1)

Parameter	Min	Max	Unit
Supply Voltage V_S = (V+) - (V-)		7	V
Signal Input Terminal Voltage	(V-) - 0.5	(V+) + 0.5	V
Junction Temperature		150	°C
Storage Temperature Range	-65	150	°C
Lead Temperature (Soldering, 10s)		260	°C
ESD HBM		±3000	V
ESD MM		±300	V
ESC CDM		±1000	V

(1) Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

RECOMMENDED OPERATING CONDITIONS

Parameter	Min	Max	Unit
Supply Voltage V_S = (V+) - (V-)	1.7	5.5	V
Common-Mode Input voltage	(V-) - 0.2	(V+) + 0.2	V
Operating Temperature Range	-40	125	°C

ESD CAUTION

ESD (electrostatic discharge) sensitive device.

Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjects to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

ELECTRICAL CHARACTERISTICS: V_S = +1.7V to +5.5V

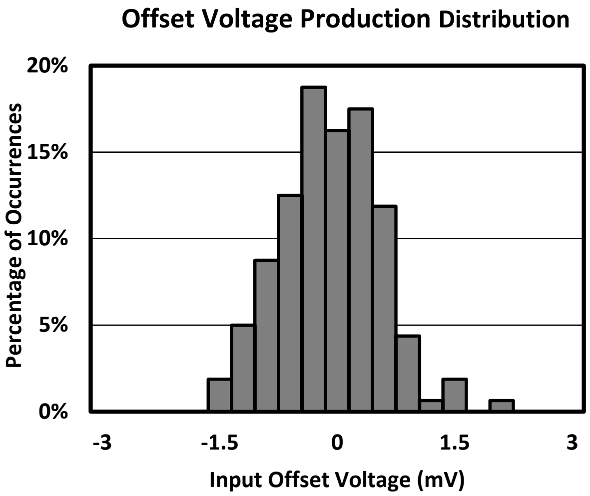
Boldface limits apply over the specified temperature range, **T_A = −40°C to +125°C.**

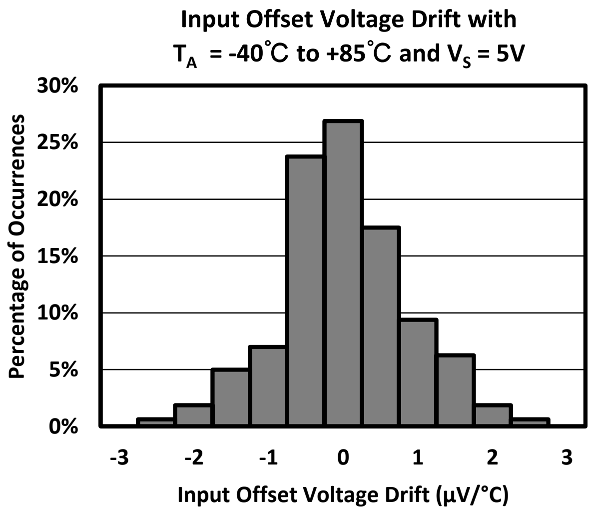
At T_A = +25°C, R_L = 1MΩ connected to V_S / 2, and V_{OUT} = V_S / 2 (unless otherwise noted)

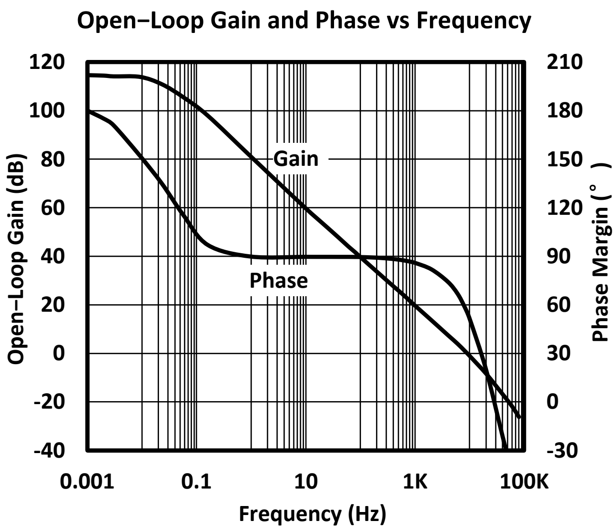
Parameter		Operating Conditions		Min	Typ	Max	Unit
V_S	Power Supply Voltage			1.7		5.5	V
I_S	Supply Current (Per Amplifer)	V_S = 5V, V_{CM} = 2.5V			0.5	1.0	μA
PSRR	Power Supply Rejection Ratio	V_S = 1.7V to 5.5V, V_{CM} = 0V		73 **70**	85		dB **dB**
Input Characteristics							
V_{OS}	Input Offset Voltage	V_S = 5V, V_{CM} = 2.5V			0.5	3.0	mV
$\Delta V_{OS}/\Delta T_A$	**Average Drift**	V_S = 5V, V_{CM} = 2.5V			**0.5**		**μV/°C**
I_B	Input Bias Current	V_S = 5V, V_{CM} = 2.5V			1		pA
I_{OS}	Input Offset Current	V_S = 5V, V_{CM} = 2.5V			1		pA
CMRR	Common-Mode Rejection Ratio	V_S = 5.5V	(V-) – 0.2V < V_{CM} < (V+) - 1.5V	74 **72**	88		dB **dB**
			(V-) – 0.2V < V_{CM} < (V+) + 0.2V	60 **58**	74		dB **dB**
AOL	Open-Loop Gain	V_S = 5V, R_L = 1MΩ (V-) + 25mV < Vout < (V+) - 25mV		95 **90**	110		dB **dB**
		V_S = 5V, R_L = 50kΩ (V-) - 100mV < Vout < (V+) - 100mV		95 **90**	105		dB **dB**
Output Characteristics							
V_{OUT}	Output Voltage Swing from Rail	R_L = 1MΩ				25 **25**	mV **mV**
		R_L = 50kΩ				100 **100**	mV **mV**
I_{OUT}	Output Current	V_O = 0V,short V- or V+			22		mA
R_{OUT}	Open-Loop Output Impedance	f = 1kHz, I_O = 0			TBD		Ω
Dynamic Performance							
GBW	Gain Bandwidth Product				10		kHz
SR	Slew Rate	V_S = 5V, Vo = $4V_{PP}$			4.5		V/ms
Noise Performance							
V_{noise}	Input Voltage Noise	f = 0.1Hz to 10Hz			5		μVpp
e_n	Input Voltage Noise Density	f = 1kHz			200		$nV/\sqrt{Hz}$
i_n	Input Current Noise Density	f = 1kHz			1		$fA/\sqrt{Hz}$
Temperature Range							
θ_{JA}	Thermal Resistance						
	SOT-23-5L				200		°C/W
	MSOP10, SOP8				150		°C/W
	SOP14, TSSOP14				100		°C/W

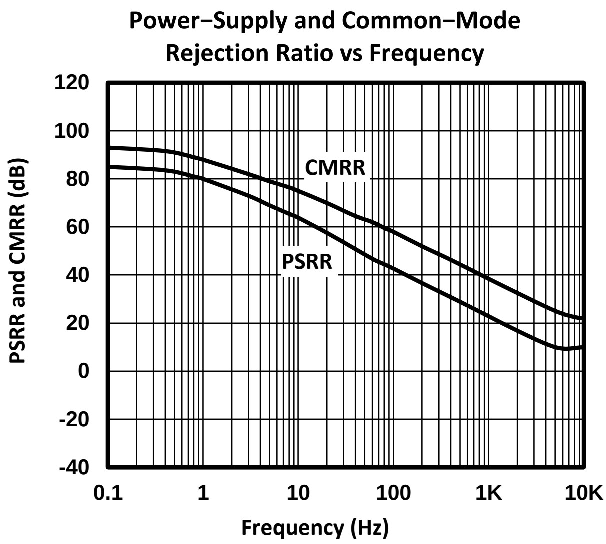
TYPICAL CHARACTERISTICS

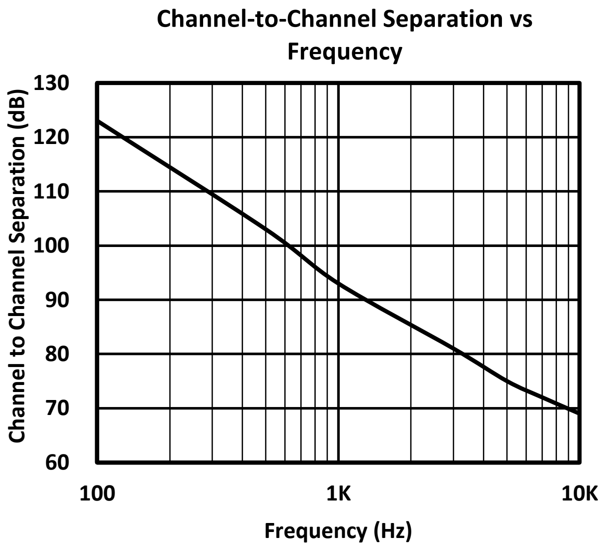
At T_A = +25°C, R_L = 1MΩ, and C_L = 60pF connected to V_S / 2, and V_{OUT} = V_S / 2 (unless otherwise noted)

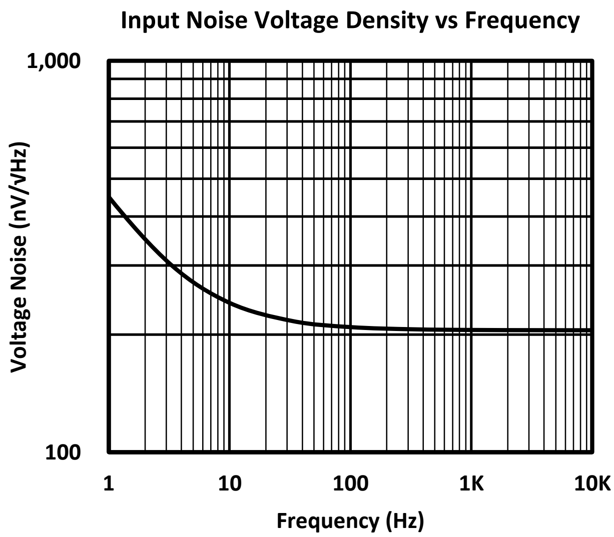








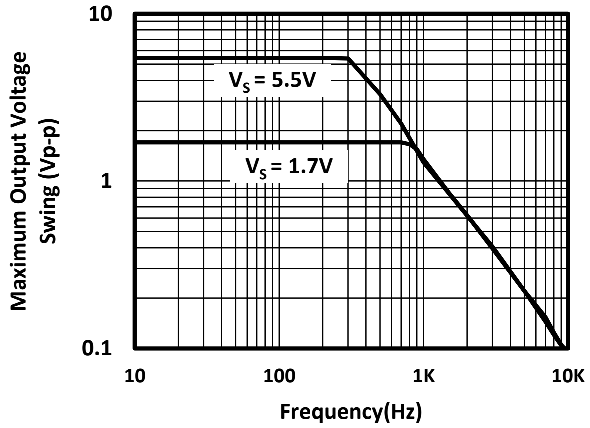




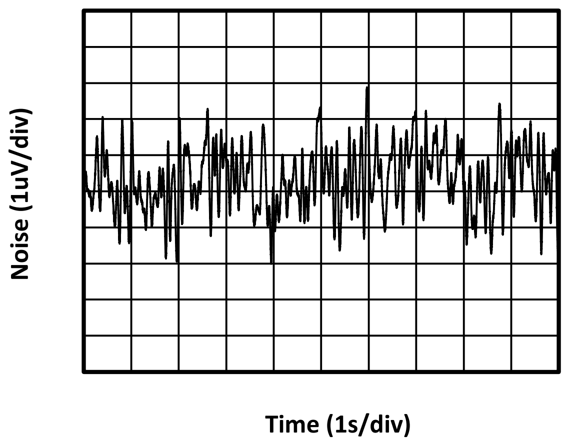
TYPICAL CHARACTERISTICS (CONTINUE)

At T_A = +25°C, R_L = 1MΩ, and C_L = 60pF connected to V_S / 2, and V_{OUT} = V_S / 2 (unless otherwise noted)

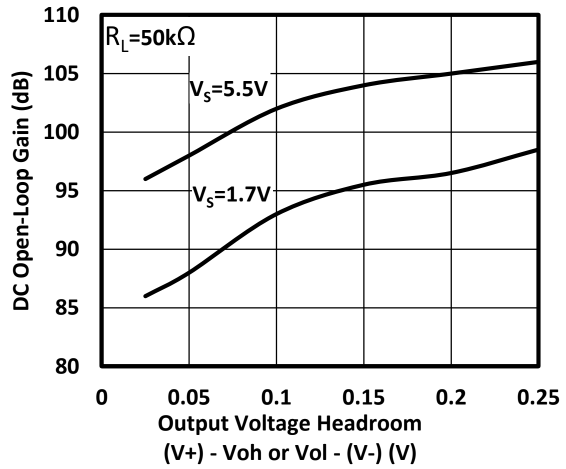
Maximum Output Voltage Swing vs Frequency



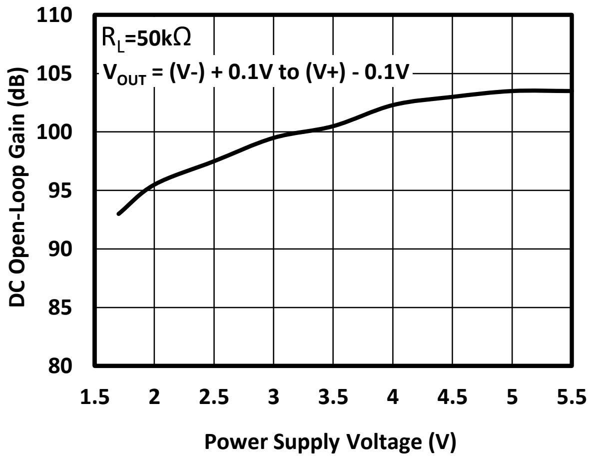
0.1Hz-10Hz Noise



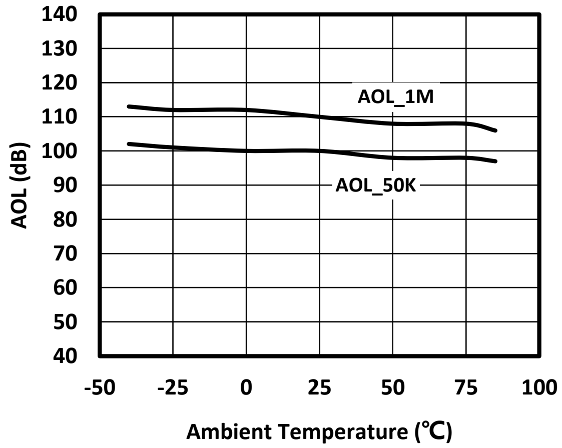
DC Open-Loop Gain vs Output Voltage Headroom



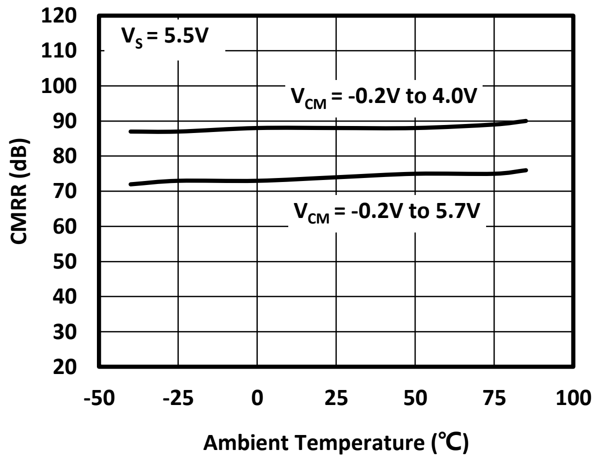
DC Open-Loop Gain vs Power Supply Voltage



Open–loop Gain Rejection Ration vs Ambient Temperature



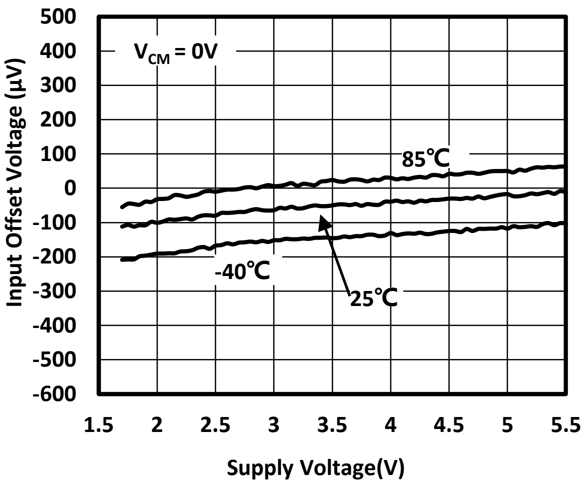
Common-mode Rejection Ration vs Ambient Temperature



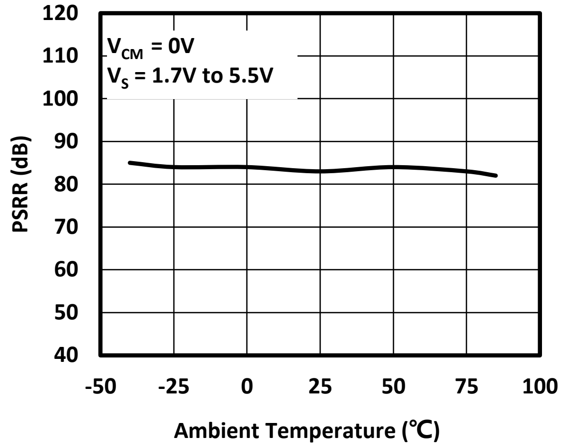
TYPICAL CHARACTERISTICS (CONTINUE)

At T_A = +25°C, R_L = 1MΩ, and C_L = 60pF connected to V_S / 2, and V_{OUT} = V_S / 2 (unless otherwise noted)

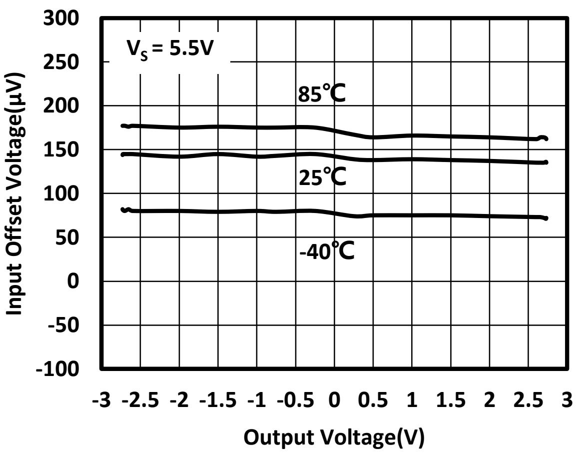
Input Offset Voltage vs Supply Voltage



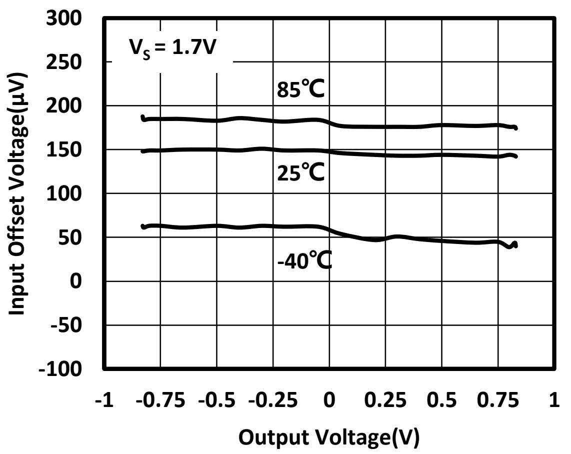
Power Supply Rejection Ratio vs Ambient Temperature



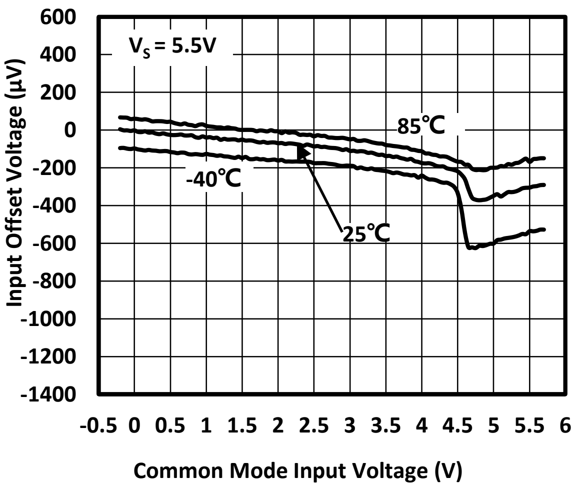
Input Offset Voltage vs Output Voltage



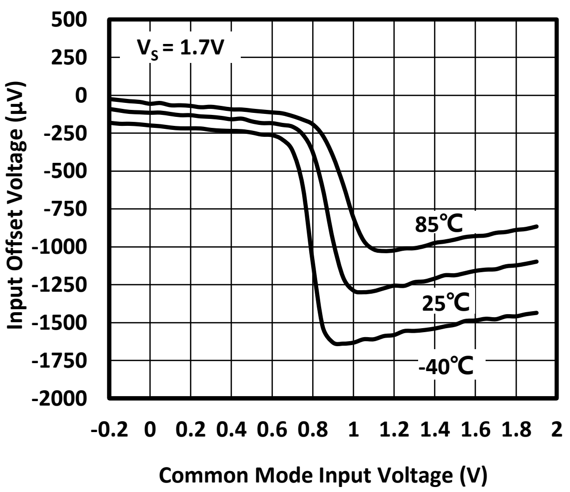
Input Offset Voltage vs Output Voltage



Input Offset Voltage vs Common-Mode Input Voltage



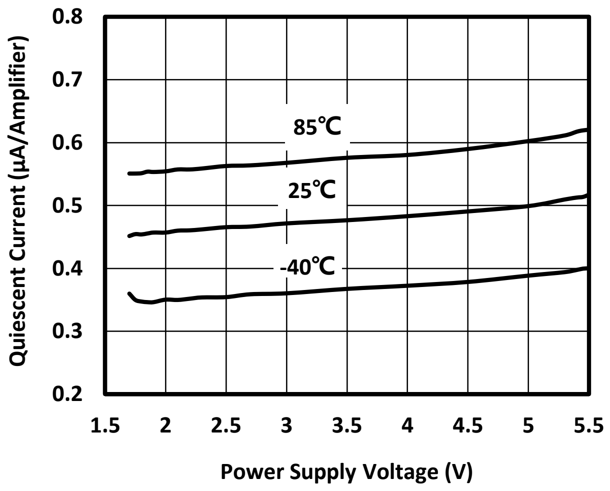
Input Offset Voltage vs Common-Mode Input Voltage



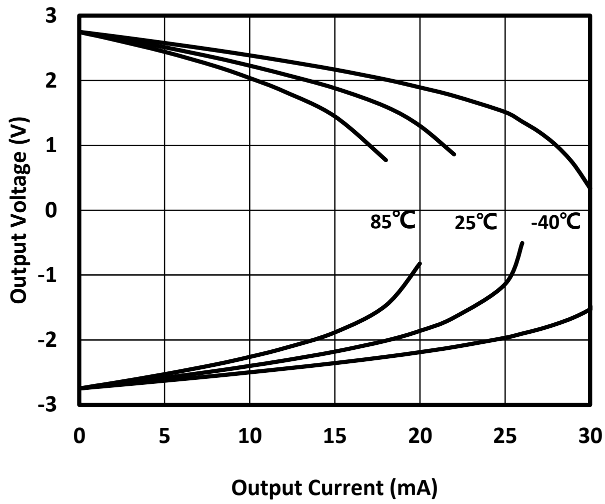
TYPICAL CHARACTERISTICS (CONTINUE)

At T_A = +25°C, R_L = 1MΩ, and C_L = 60pF connected to V_S / 2, and V_{OUT} = V_S / 2 (unless otherwise noted)

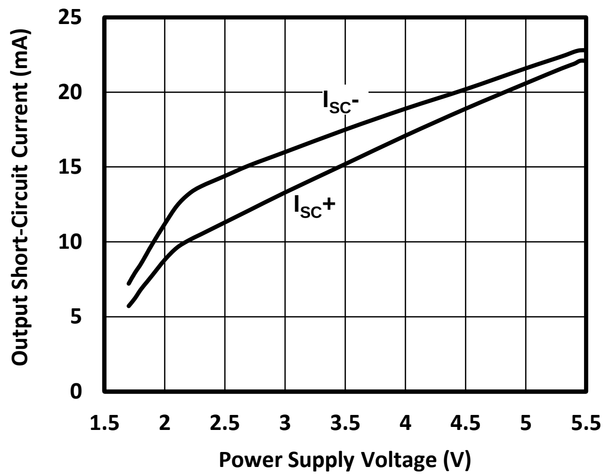
Quiescent Current vs Power Supply Voltage



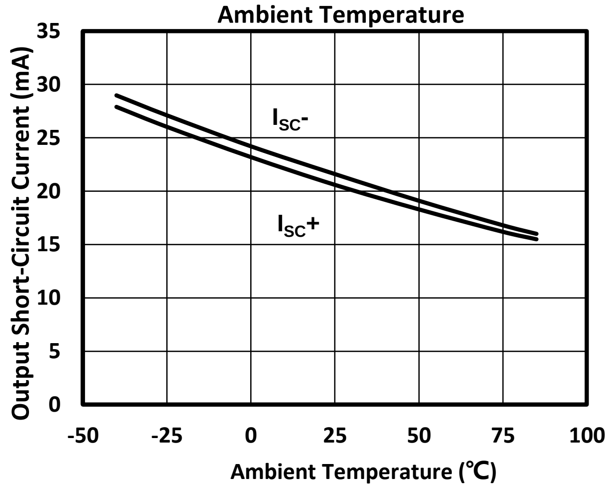
Output Voltage Swing vs Output Current



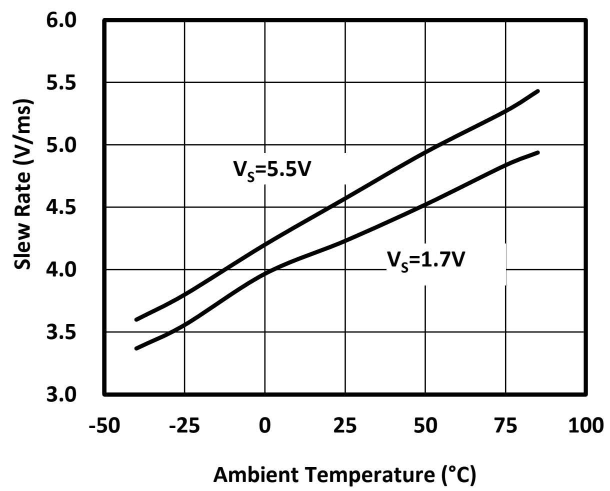
Output Short-Circuit Current vs Power Supply Voltage



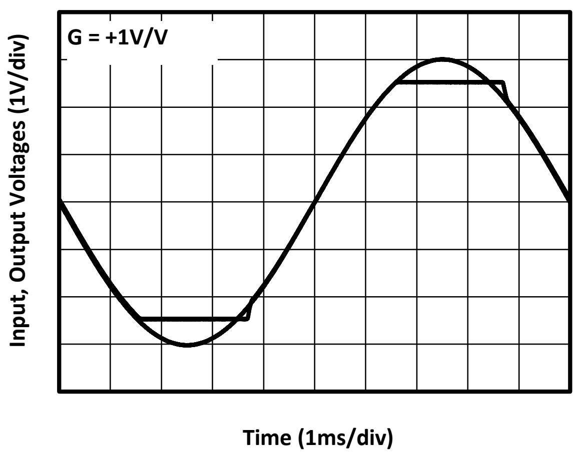
Output Short-Circuit Current vs Ambient Temperature



Slew Rate vs Ambient Temperature



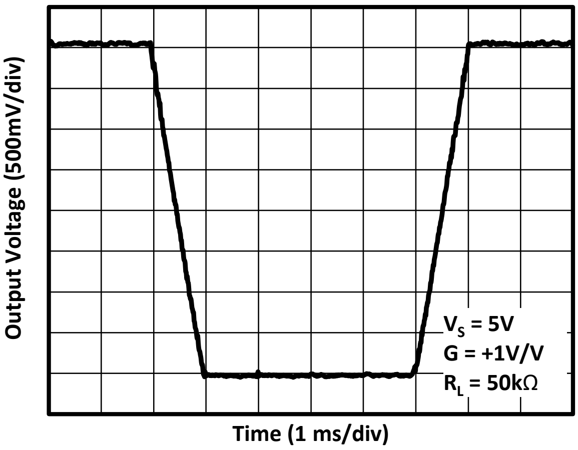
The TS2202 Familyshows no Phase Reversal



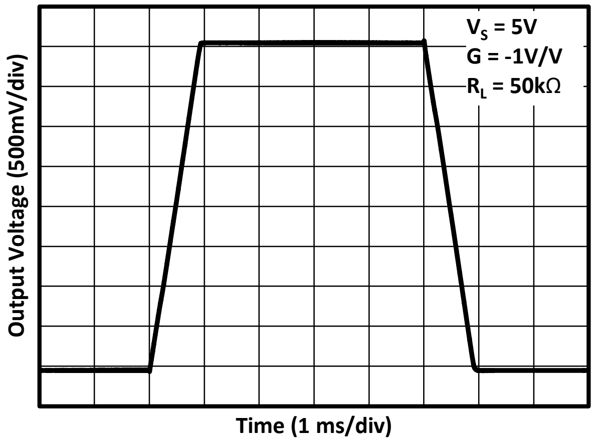
TYPICAL CHARACTERISTICS (CONTINUE)

At T_A = +25°C, R_L = 1MΩ, and C_L = 60pF connected to V_S / 2, and V_{OUT} = V_S / 2 (unless otherwise noted)

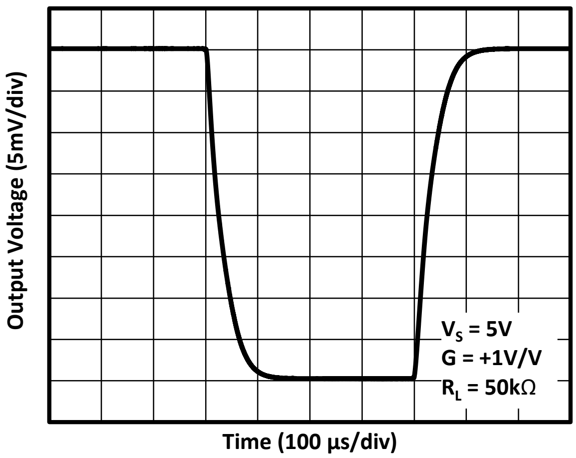
Large Signal Non-inverting Pulse Response.



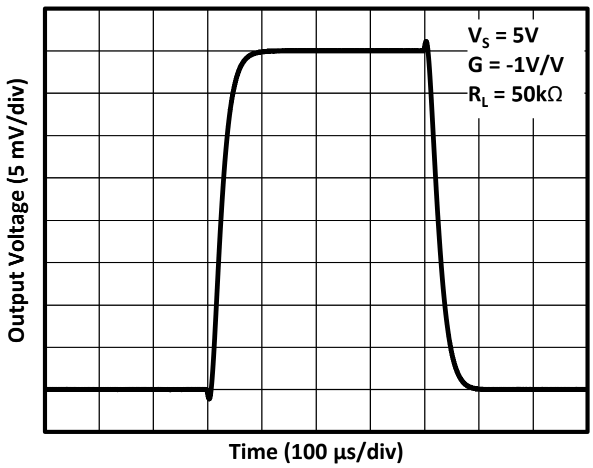
Large Signal Inverting Pulse Response.



Small Signal Non-inverting Pulse Response.



Small Signal Inverting Pulse Response.



TYPICAL APPLICATION NOTES

The TS2X02 family of products are high precision, ultra-low power CMOS operational amplifiers. These devices support rail-to-rail input and output operation, also the input and common mode range extends beyond the supply rails.

- **Supply Bypass**

Power-supply pins should have a local bypass capacitor. A capacitance value of at least 10 nF and the capacitance should be as close to the power supply pin as possible.

- **Capacitive Loads**

The TS2X02 families can directly drive 100pF in unity-gain without oscillation. The unity-gain follower (buffer) is the most sensitive configuration to capacitive loading. Direct capacitive loading reduces the phase margin of amplifiers and this result in ringing or even oscillation. Applications that require greater capacitive driving capability should use an isolation resistor between the output and the capacitive load like the circuit in Figure1. The isolation resistor R_{ISO} and the load capacitor CL form a zero to increase stability. The bigger the R_{ISO} resistor value, the more stable V_{OUT} will be. Note that this method results in a loss of gain accuracy because R_{ISO} forms a voltage divider with the R_{LOAD}.

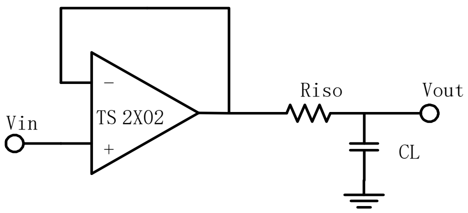


Figure 1. Indirectly Driving Heavy Capacitive Load

An improved circuit is shown in Figure 2. It provides DC accuracy as well as AC stability. Rf provides the DC accuracy by connecting the inverting signal with the output. Cf and R_{ISO} serve to counteract the loss of phase margin by feeding the high frequency component of the output signal back to the amplifier's inverting input, thereby preserving phase margin in the overall feedback loop.

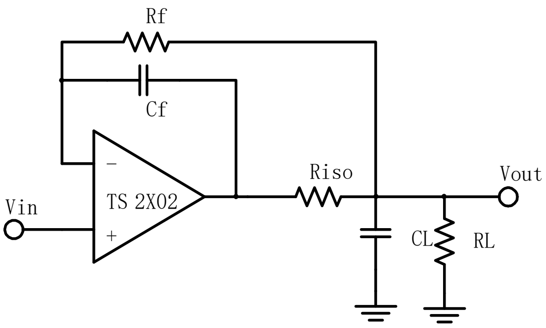


Figure 2. Indirectly Driving Heavy Capacitive Load with DC Accuracy

- **Unused Op Amps**

For the multi-channel version, the unused channels need to be connected to a follower circuit and the input connected to a determined level (as shown in Figure 3, R1 and R2 can be 0 ohms). Or connect its in-phase and inverting input terminals to two power pins respectively. Unused channel input pins cannot be suspended.

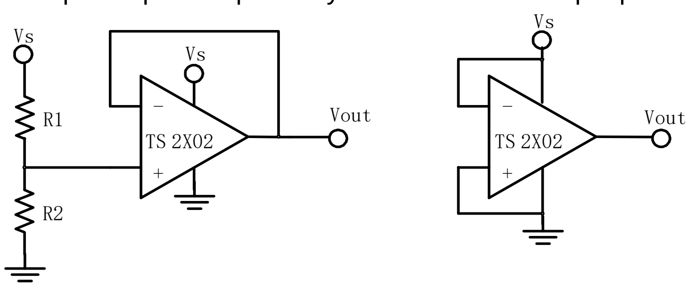


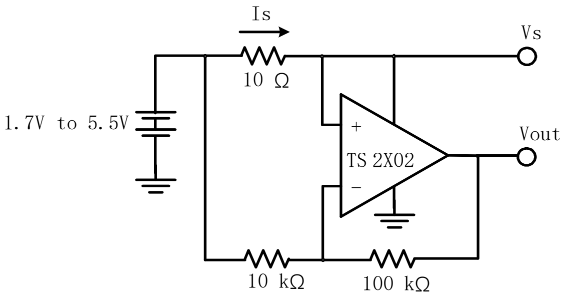
Figure 3. Unused Op Amps

TYPICAL APPLICATION NOTES (CONTINUE)

- **Battery Current Sensing**

The TS2X02 op amps' Common Mode Input Range, which goes 0.3V beyond both supply rails, supports their use in high-side and low-side battery current sensing applications. The very low quiescent current (0.6 µA, typical) helps prolong battery life, and the rail-to-rail output supports detection low currents.

Figure 4 shows a high-side battery current sensor circuit. The 10Ω resistor is sized to minimize power losses. The battery current through the 10Ω resistor causes its top terminal to be more negative than the bottom terminal. This keeps the Common mode input voltage of the op amp below V_S, which is within its allowed range. The output of the op amp will also be below V_S, which is within its Maximum Output Voltage Swing specification.

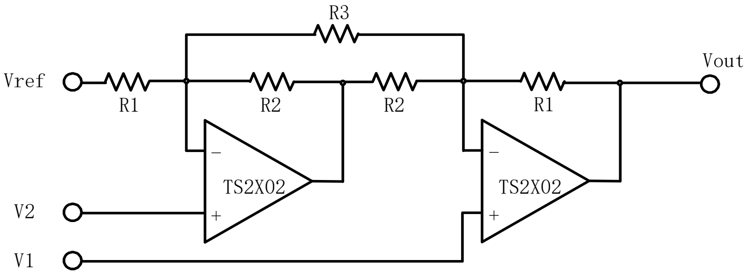


$$I_S = \frac{V_S - V_{OUT}}{(10V/V) * (10\Omega)}$$

Figure 4. High-Side Battery Current Sensor

- **Instrumentation Amplifier**

The TS2X02 op amp is well suited for conditioning sensor signals in battery-powered applications. Figure 5 shows a two op amp instrumentation amplifier, using the TS2X02, that works well for applications requiring rejection of Common mode noise at higher gains. The reference voltage (V_{REF}) is supplied by a low impedance source. In single supply applications, V_{REF} is typically $V_S/2$.

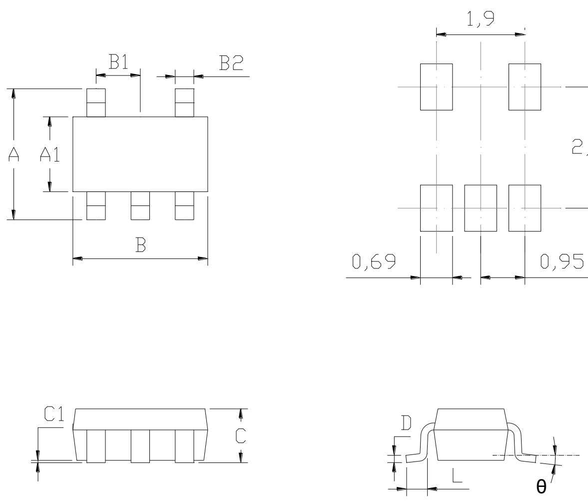


$$V_{OUT} = (V1 - V2) * \left(1 + \frac{R1}{R2} + \frac{2 * R1}{R3}\right) + V_{REF}$$

Figure 5. Two Op Amp Instrumentation Amplifier

MECHANICAL DIMENSIONS

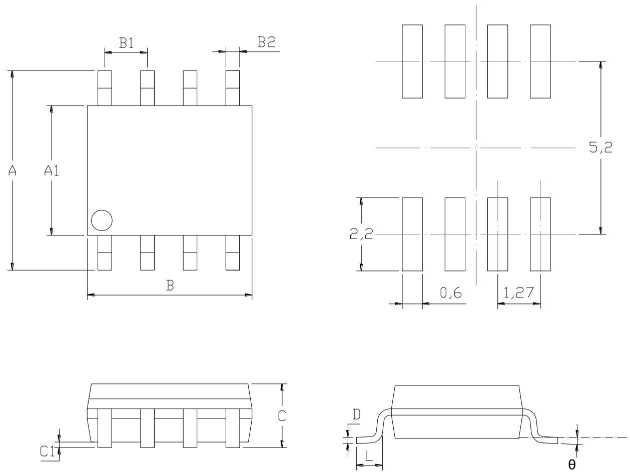
SOT-23-5L PACKAGE MECHANICAL DRAWING



SOT-23-5L PACKAGE MECHANICAL DATA

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	2.65	2.95	0.104	0.116
A1	1.50	1.70	0.059	0.067
B	2.82	3.02	0.111	0.119
B1	0.95		0.0374	
B2	0.30	0.50	0.012	0.020
C		1.25		0.049
C1	0.00	0.10	0.000	0.004
L	0.30	0.60	0.012	0.024
D	0.10	0.20	0.004	0.008
θ	0º	8º	0º	8º

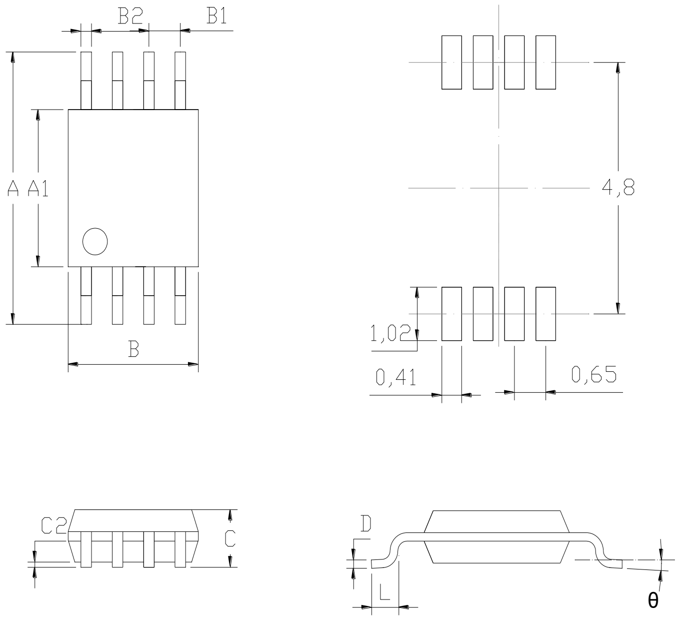
SOP8 PACKAGE MECHANICAL DRAWING



SOP8 PACKAGE MECHANICAL DATA

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	5.80	6.20	0.228	0.244
A1	3.80	4.00	0.150	0.157
B	4.70	5.10	0.185	0.201
B1	1.27		0.050	
B2	0.33	0.51	0.013	0.020
C		1.75		0.069
C1	0.10	0.25	0.004	0.010
L	0.40	1.27	0.016	0.050
D	0.17	0.25	0.007	0.010
θ	0º	8º	0º	8º

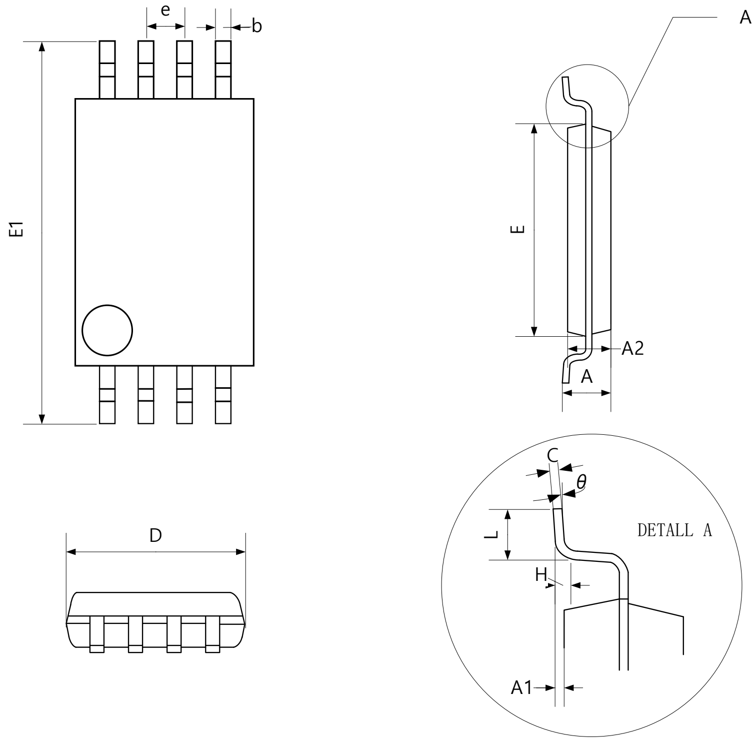
MSOP8 PACKAGE MECHANICAL DRAWING



MSOP8 PACKAGE MECHANICAL SPECIFICATIONS

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	4.750	5.050	0.187	0.199
A1	2.900	3.100	0.114	0.122
B	2.900	3.100	0.114	0.122
B1	0.650		0.026	
B2	0.250	0.380	0.010	0.015
C	0.820	1.100	0.032	0.043
C2	0.020	0.150	0.001	0.006
L	0.400	0.800	0.016	0.031
D	0.090	0.230	0.004	0.009
θ	0º	6 º	0º	6 º

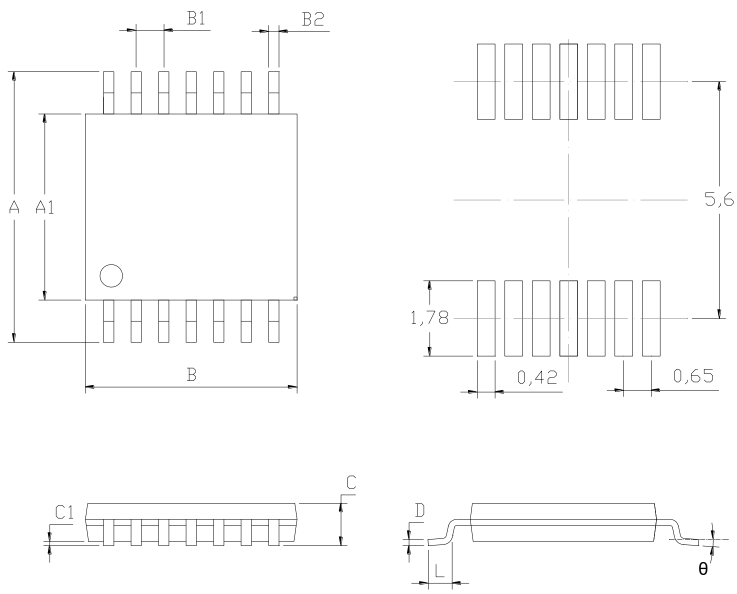
TSSOP8 PACKAGE MECHANICAL DRAWING



TSSOP8 PACKAGE MECHANICAL DATA

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
D	2.900	3.100	0.114	0.122
E	4.300	4.500	0.169	0.177
b	0.190	0.300	0.007	0.012
c	0.090	0.200	0.004	0.008
E1	6.250	6.550	0.246	0.258
A		1.200		0.047
A2	0.800	1.000	0.031	0.039
A1	0.050	0.150	0.002	0.006
e	0.65(BSC)		0.026(BSC)	
L	0.500	0.007	0.020	0.028
H	0.25(TYP)		0.01(TYP)	
θ	1º	7º	1º	7º

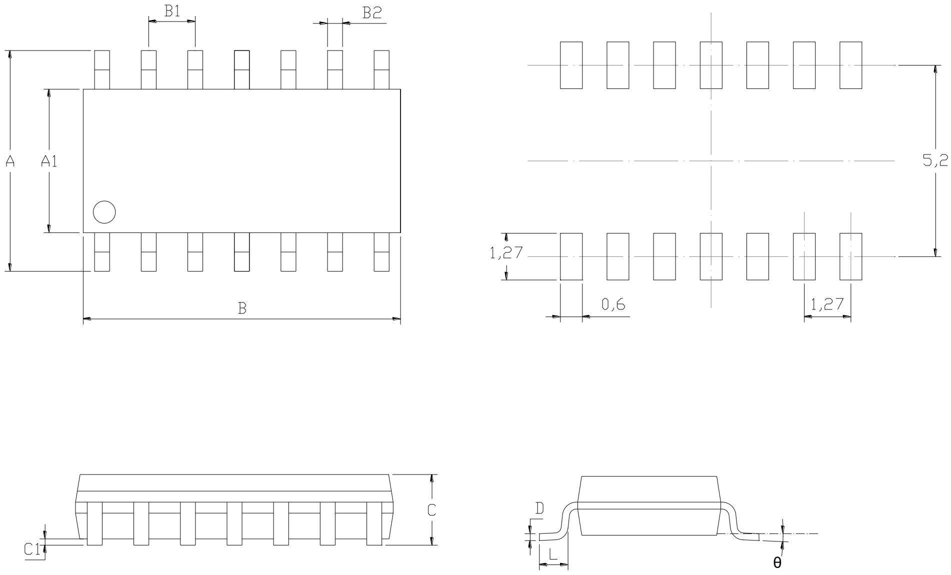
TSSOP14 PACKAGE MECHANICAL DRAWING



TSSOP14 PACKAGE MECHANICAL DATA

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	6.25	6.55	0.246	0.258
A1	4.30	4.50	0.169	0.177
B	4.90	5.10	0.193	0.201
B1	0.65		0.026	
B2	0.19	0.30	0.007	0.012
C		1.20		0.047
C1	0.05	0.15	0.002	0.006
L	0.5	0.7	0.020	0.028
D	0.09	0.20	0.004	0.008
θ	1º	7º	1º	7º

SOP14 PACKAGE MECHANICAL DRAWING

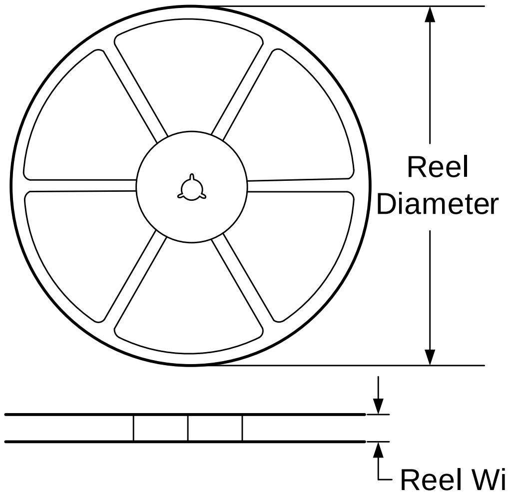


SOP14 PACKAGE MECHANICAL DATA

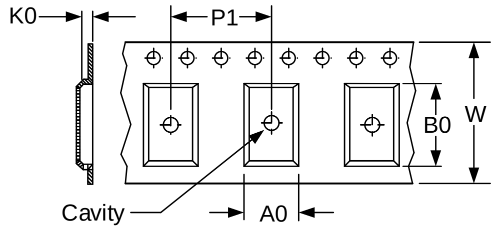
symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	5.80	6.20	0.228	0.244
A1	3.80	4.00	0.150	0.157
B	8.45	8.85	0.333	0.348
B1	1.27		0.050	
B2	0.31	0.51	0.012	0.020
C		1.75		0.069
C1	0.10	0.25	0.004	0.010
L	0.40	1.27	0.016	0.050
D	0.10	0.25	0.004	0. 010
θ	0º	8º	0º	8º

TAPE AND REEL INFORMATION

REEL DIMENSIONS

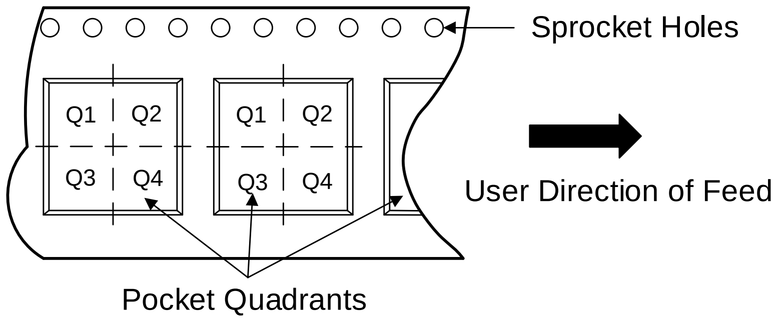


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component width thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



Device	Package Type	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TS2102SOT235LR	SOT-23-5L	5	3000	180.0	9.0	3.2	3.3	1.4	4.0	8.0	Q3
TS2102SOP8R	SOP8	8	2500	330.0	12.4	6.4	5.4	2.1	8.0	12.0	Q1
TS2202SOP8R	SOP8	8	2500	330.0	12.4	6.4	5.4	2.1	8.0	12.0	Q1
TS2202MSOP8R	MSOP8	8	3000	330.0	12.4	5.2	3.3	1.5	8.0	12.0	Q1
TS2202TSSOP8R	TSSOP8	8	4000	330.0	12.4	6.4	5.4	2.1	8.0	12.0	Q1
TS2402SOP14R	SOP14	14	2500	330.0	12.4	6.5	9.0	2.1	8.0	16.0	Q1
TS2402TSSOP14R	TSSOP14	14	3000	330.0	12.4	6.8	5.4	1.2	8.0	12.0	Q1

REVISION HIETORY

NOTE: Page numbers for previous revisions may be different from that of the current version.

2020/7/24— REV KY1.0.4 TO REV KY1.0.5

Updated MECHANICAL DIMENSIONS ……………………………………………………………………………10

Updated TAPE AND REEL INFORMATION …………………………………………………………………14

2021/4/19— REV KY1.0.5 TO REV KY1.1.5

Updated CMRR ……………………………………………………………………………………….………………2

2021/07/13 — REV KY1.1.5 to REV KY1.2.5

Updated TSSOP14 SPQ…………………………………………………………………………………………...2,15

2023/03/15 — REV KY1.2.5 to REV KY1.3.5

Upgrade the chip version and update most of the main parameters……………………………………...All pages

Add APPLOCATION NOTES……………………………………. …. …. …. …. …. …. …. …. …. …. …. ….…...9

2021/04/10 — REV KY1.3.5 to REV KY1.4.5

add SOT23-5……………………………………………………………………………………………………...2

CONTACT INFORMATION

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