

## 6.5MHz, Rail-to-Rail I/O CMOS Operational Amplifier

### Features

- **Low Offset Voltage:** 1mV (typ)
- **High Gain:** 105dB (typ)
- **High Gain Bandwidth Product:** 6.5MHz
- **Rail-to-rail Input/Output**
- **Low  $I_B$ :** 5pA (typ)
- **Low supply voltage:** +2.7 V to +5.5 V
- **Low Power Consumption:** 580 $\mu$ A at 5 V (per amplifier)
- **Extended Temperature :** -40°C to +125°C

### Applications

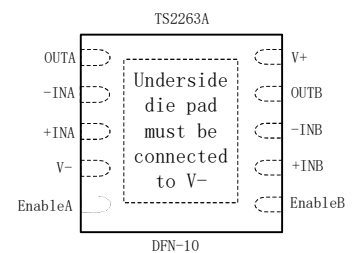
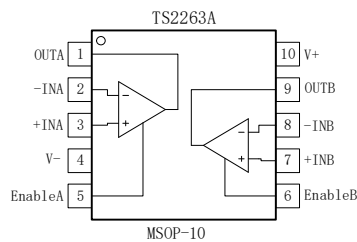
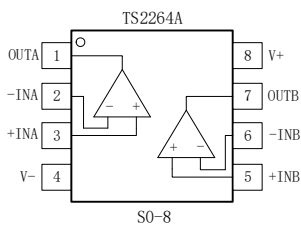
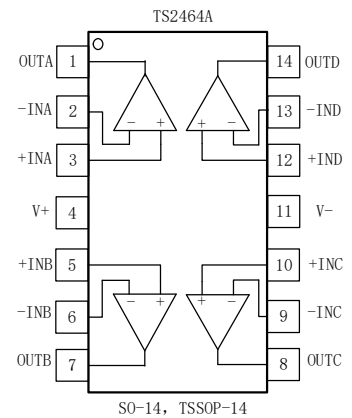
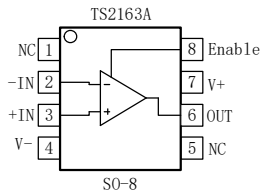
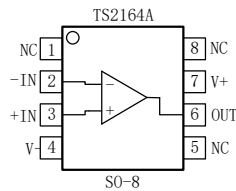
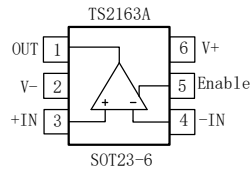
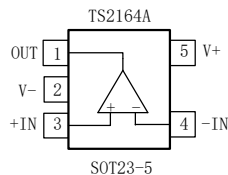
- **Signal Conditioning**
- **Current Sensor Amplifier**
- **Battery-Powered Applications**
- **Portable Devices**
- **Active Filtering**
- **Weight Scale Sensor**
- **Medical/Industrial Instrumentation**
- **Power Converter/Inverter**

### Product Description

The TS2163A/TS2164A families of products are low noise, low voltage and low power operational amplifiers with high gain-bandwidth product of 6.5MHz and slew rate of 5V/ $\mu$ s. The maximum input offset voltage is only 3.5mV and the input common mode range extends beyond the supply rails.

TS2163A/TS2164A families of operational amplifiers are specified at the full temperature range of -40°C to +125°C under single or dual power supplies of 2.7V to 5.5V, however these products will operate under an extended supply range from 2.7V to 5.5V at a reduced temperatures range.

The TS2163A and TS2263A have a power-down feature that reduces the supply current to 1 $\mu$ A.



## ORDERING INFORMATION

Model	Part Number	Eco Plan	Package	AMP	Shutdown	Container, Pack Qty
TS2164A	TS2164ASOT235R	Rohs	SOT23-5	1	NO	Reel,3000
TS2164A	TS2164ASO8R	Rohs	SO-8	1	NO	Reel,2500
TS2163A	TS2163ASOT236R	Rohs	SOT23-6	1	YES	Reel,3000
TS2163A	TS2163ASO8R	Rohs	SO-8	1	YES	Reel,2500
TS2263A	TS2263AMSOP10R	Rohs	MSOP-10	2	YES	Reel,4000
TS2264A	TS2264ASO8R	Rohs	SO-8	2	NO	Reel,2500
TS2264A	TS2264AMSO8R	Rohs	MSOP-8	2	NO	Reel,4000
TS2264A	TS2264ATSSO8R	Rohs	TSSOP-8	2	NO	Reel,4000
TS2464A	TS2464ASO14R	Rohs	SO-14	4	NO	Reel,2500
TS2464A	TS2464ATSSOP14R	Rohs	TSSOP-14	4	NO	Reel,3000
TS2263A	TS2263ADFN10R	Rohs	DFN-10	2	YES	Reel,2500

## ABSOLUTE MAXIMUM RATINGS

Parameter	Min	Max	Unit
Supply Voltage		7	V
Signal Input Terminal voltage	(V-)-0.5	(V+)+0.5	V
Operating Temperature	-50	150	°C
Junction Temperature		150	°C
Storage Temperature Range	-65	150	°C
Lead Temperature (Soldering, 10s)		260	°C
ESD HBM		±3000	V
ESD MM		±400	V
ESC CDM		±1000	V

## 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:  $V_S = +2.7V$  to  $+5.5V$**

**Boldface** limits apply over the specified temperature range,  $T_A = -40^\circ C$  to  $+125^\circ C$ .

At  $T_A = +25^\circ C$ ,  $R_L = 10k\Omega$  connected to  $V_S/2$ , and  $V_{OUT} = V_S/2$ , unless otherwise noted.

Symbol	Parameter	Operating Conditions	Min	Typ	Max	Unit
$V_S$	Power Supply Voltage		<b>2.7</b>		<b>5.5</b>	V
$V_{IN +/-}$	Input Voltage Range		(V-)-0.2		(V+) +0.2	V
$I_S$	Supply Current(per amplifier)	$I_O=0$		580	750	$\mu A$
PSRR	Power Supply Rejection Ratio	$V_S = 2.7$ to $V_S = 5.5V$ , $V_{CM} < (V+) - 2V$		25	125	$\mu V/V$
<b>Input Characteristics</b>						
$V_{OS}$	Input Offset Voltage	$V_S = 5.5V$		1	3.5	mV
$dV_{OS}/dT$	Average Drift			<b>3</b>		$\mu V/^\circ C$
$I_B$	Input Bias Current			5		pA
$I_{OS}$	Input Offset Current			5		pA
CMRR	Common Mode Rejection Ratio $T_A = -40^\circ C$ to $+125^\circ C$	$(V-)-0.2V < V_{CM} < (V+)-2V$	76	88		dB
		<b><math>(V-)-0.2V &lt; V_{CM} &lt; (V+)-2V</math></b>	<b>68</b>	<b>72</b>		<b>dB</b>
		$V_S = 5.5V, (V-) - 0.2V < V_{CM} < (V+) + 0.2V$	64			dB
		<b><math>V_S = 5.5V, (V-) - 0.2V &lt; V_{CM} &lt; (V+) + 0.2V</math></b>	<b>58</b>			<b>dB</b>
AOL	Open-Loop Gain $T_A = -40^\circ C$ to $+125^\circ C$	$V_S = 5V, R_L = 5K\Omega$	95	104		dB
		$(V-) + 0.125V < V_{out} < (V+) - 0.125V$	<b>85</b>			<b>dB</b>
		$V_S = 5V, R_L = 100k\Omega$	96	105		dB
		$(V-) - 25mV < V_{out} < (V+) - 25mV$	<b>85</b>			<b>dB</b>
<b>Output Characteristics</b>						
$V_{OUT}$	Output Voltage Swing from Rail $T_A = -40^\circ C$ to $+125^\circ C$	$R_L = 100K\Omega$ <b><math>R_L = 100K\Omega</math></b>		18	25	mV
$I_{OUT}$	Output Voltage Swing from Rail $T_A = -40^\circ C$ to $+125^\circ C$	$R_L = 5K\Omega$ <b><math>R_L = 5K\Omega</math></b>		100	125	mV
$R_{OUT}$	Output Current Open-Loop Output Impedance	$f = 1MHz, I_O = 0$		See typical characteristics		$\Omega$
				40		
<b>Dynamic Performance</b>						
GBW	Gain Bandwidth Product			6.5		MHz
$t_s$	Settling Time to 0.1%	$V_{OUT} = 2V$ step; $G = +1$		1		$\mu s$
	Settling Time to 0.01%	$V_{OUT} = 2V$ step; $G = +1$		1.5		$\mu s$
	Overload recovery time	$V_{in} * Gain > V_S$		0.2		$\mu s$
SR	Slew Rate	$G = +1$		5		V/ $\mu s$
THD	Total Harmonic Distortion+ Noise	$V_S = 5V, V_o = 3V_{pp}$ , $G = +1, f = 1kHz$		TBD		%

**ELECTRICAL CHARACTERISTICS:  $V_S = +2.7V$  to  $+5.5V$**

**Boldface** limits apply over the specified temperature range,  $T_A = -40^{\circ}C$  to  $+125^{\circ}C$ .

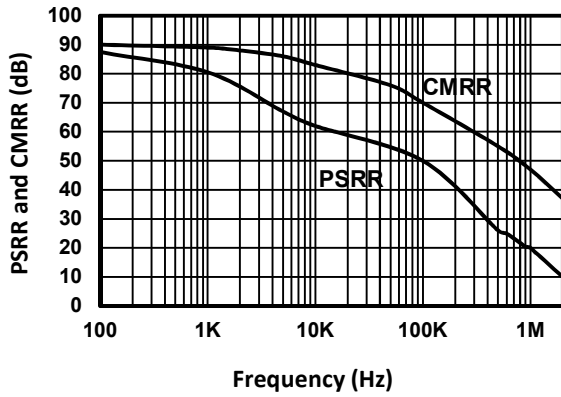
At  $T_A = +25^{\circ}C$ ,  $R_L = 10k\Omega$  connected to  $V_S/2$ , and  $V_{OUT} = V_S/2$ , unless otherwise noted.

Symbol	Parameter	Operating Conditions	Min	Type	Max	Unit
<b>Noise Performance</b>						
$V_{noise}$	Input Voltage Noise	$f=0.1Hz$ to $10Hz$		5		$\mu V_{pp}$
$e_n$	Input Voltage Noise Density	$f=10kHz$		15		$nV/\sqrt{Hz}$
$i_n$	Input Current Noise Density	$f=10kHz$		4		$fA/\sqrt{Hz}$
<b>Temperature Range</b>						
$\theta_{JA}$	Specified Range		-40		+125	$^{\circ}C$
	Operating Range		-50		+150	$^{\circ}C$
	Storage Range		-65		+150	$^{\circ}C$
	Thermal Resistance SOT23-5,SOT23-6,SOT23-8			200		$^{\circ}C/W$
	MSOP-10,SO-8			150		$^{\circ}C/W$
	SO-14, TSSOP-14 DFN-10			100 56		$^{\circ}C/W$ $^{\circ}C/W$

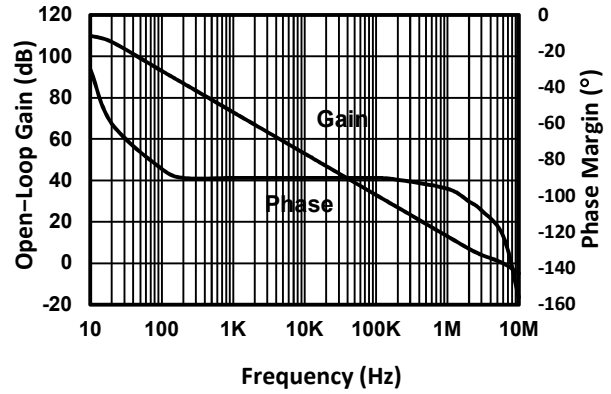
**TYPICAL CHARACTERISTICS**

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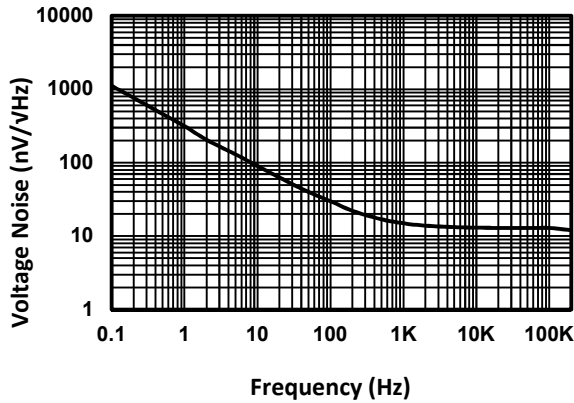
**POWER-SUPPLY AND COMMON-MODE REJECTION RATIO vs FREQUENCY**



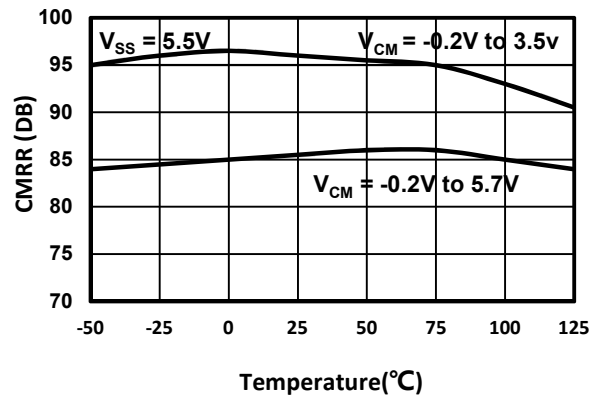
**OPEN-LOOP GAIN AND PHASE vs FREQUENCY**



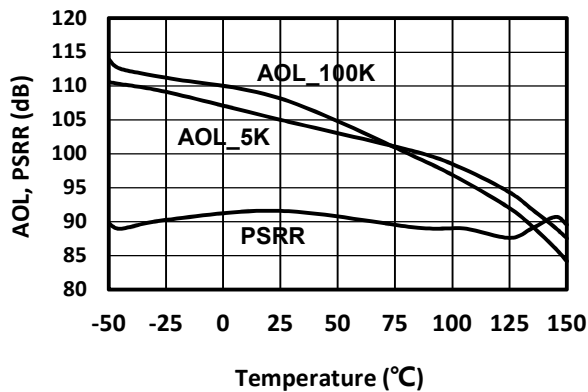
**INPUT VOLTAGE NOISE SPECTRAL DENSITY vs FREQUENCY**



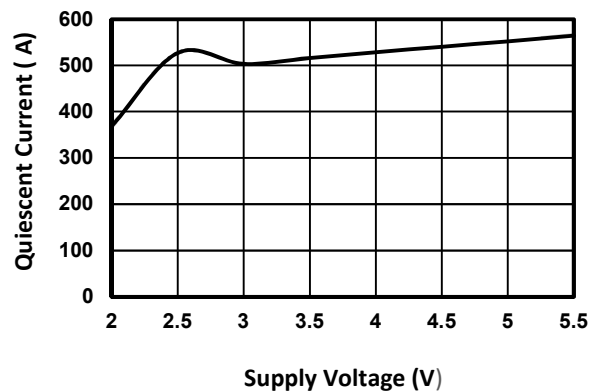
**COMMON-MODE REJECTION RATION vs TEMPERATURE**



**OPEN-LOOP GAIN AND POWER-SUPPLY REJECTION RATIO vs TEMPERATURE**



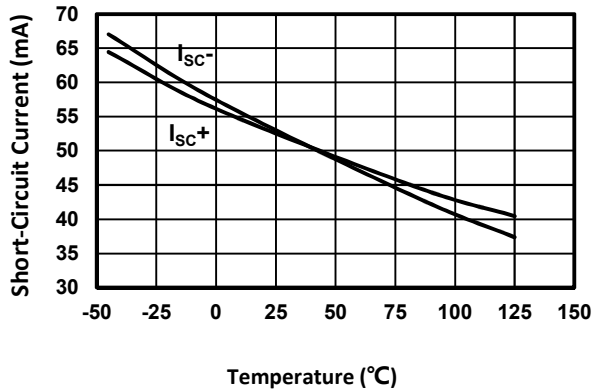
**QUIESCENT CURRENT vs SUPPLY VOLTAGE**



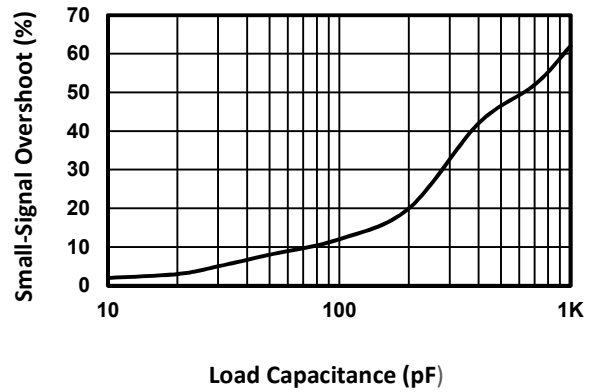
**TYPICAL CHARACTERISTICS**

At  $T_A = +25^\circ\text{C}$ ,  $R_L = 10\text{k}\Omega$  connected to  $V_S/2$ , and  $V_{OUT} = V_S/2$ , unless otherwise noted.

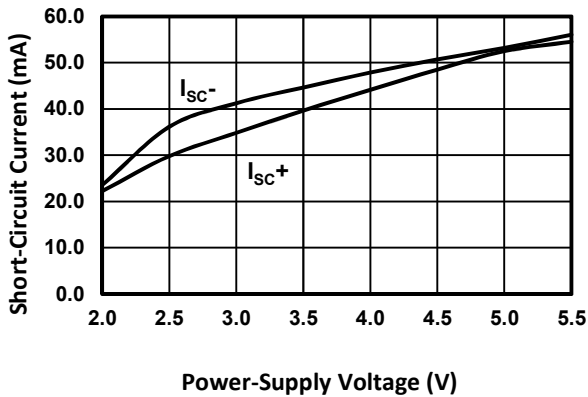
**SHORT-CIRCUIT CURRENT vs TEMPERATURE**



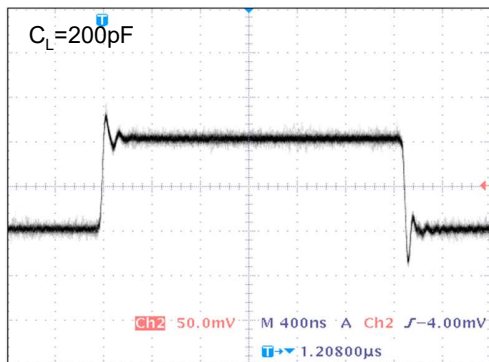
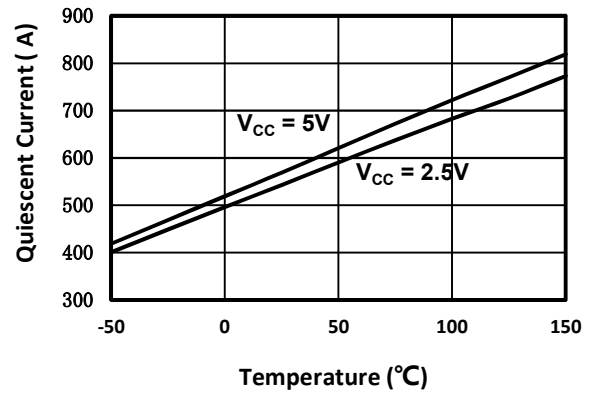
**SMALL-SIGNAL OVERSHOOT vs LOAD CAPACITANCE**



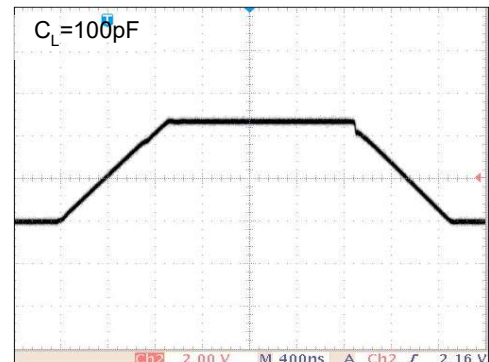
**CONTINUOUS SHORT-CIRCUIT CURRENT vs POWER-SUPPLY VOLTAGE**



**QUIESCIENT CURRENT vs TEMPERATURE**



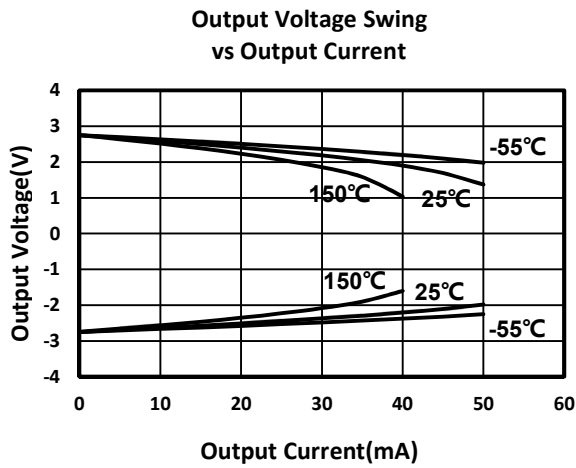
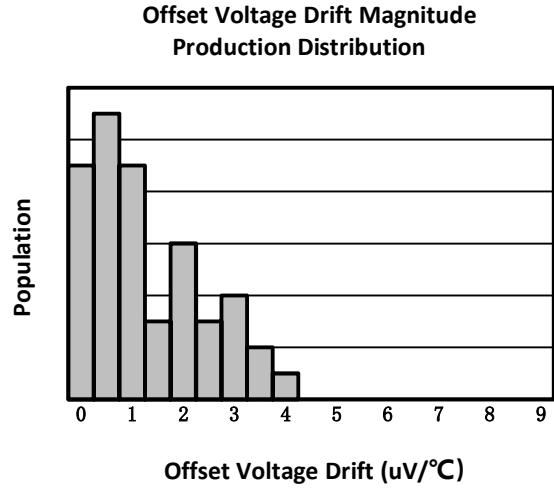
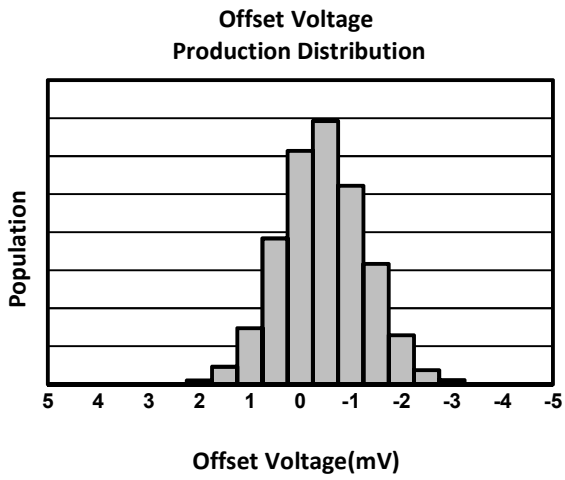
**Small-Signal Step Response**



**Large-Signal Step Response**

**TYPICAL CHARACTERISTICS**

At  $T_A = +25^\circ\text{C}$ ,  $R_L = 10\text{k}\Omega$  connected to  $V_S/2$ , and  $V_{OUT} = V_S/2$ , unless otherwise noted.



## APPLICATION NOTES

The TS2163A and TS2164A families of op amps are suitable for a wide range of general-purpose applications. They provide Rail-to-rail input and output. Excellent ac performance makes them well-suited for audio and sensor applications. The input common-mode voltage range includes both rails, allowing the TS2163A and TS2164A families op amps to be used in bipolar and unipolar application. Rail-to-rail input and output swing significantly increases dynamic range, especially in low-supply applications. Power-supply pins should be bypassed with 0.1 $\mu$ F ceramic capacitors.

## POWER SUPPLY

The TS2163A and TS2164A families operate from a single +2.5V to +5.5V supply or dual  $\pm$ 1.25V to  $\pm$ 2.75V supplies. For single supply operation, bypass the power supply +VS with a 0.1 $\mu$ F capacitor which should be placed close to the +VS pin. For dual-supply operation, both the +VS and the -VS supplies should be bypassed to ground with separate 0.1 $\mu$ F ceramic capacitors. 2.2 $\mu$ F tantalum capacitor can be added for better performance.

The TS2163A and TS2164A families are ideal for battery-powered instrumentation and handheld devices because it can operate at the end of discharge voltage of most popular batteries.

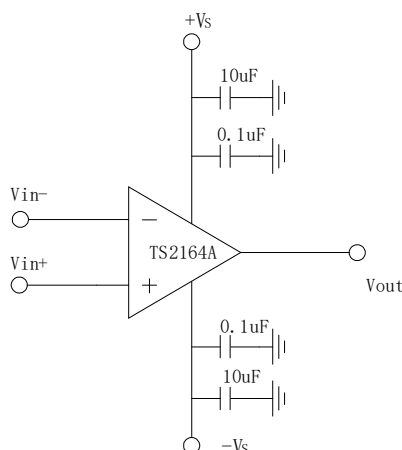


Figure1. Amplifier with Bypass Capacitors

## DRIVING CAPACITIVE LOADS

The TS2163A and TS2164A families can directly drive 1000pF 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 Figure2. The isolation resistor  $R_{ISO}$  and the load capacitor  $C_L$  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  $R_{LOAD}$ .

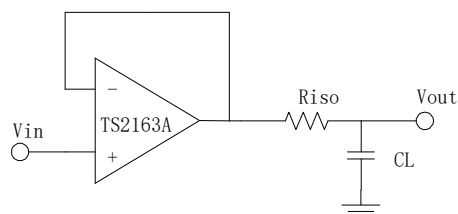


Figure 2. Indirectly Driving Heavy Capacitive Load

An improved circuit is shown in Figure 3. It provides DC accuracy as well as AC stability.  $R_f$  provides the DC accuracy by connecting the inverting signal with the output.  $C_f$  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.

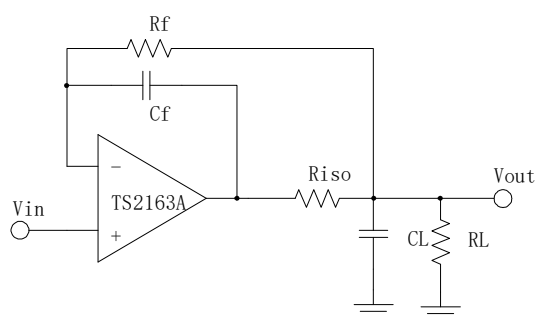


Figure 3. Indirectly Driving Heavy Capacitive Load with DC Accuracy

For non-buffer configuration, there are two other ways to increase the phase margin: (a) by increasing the amplifier's gain or (b) by placing a capacitor in parallel with the feedback resistor to counteract the parasitic capacitance associated with inverting node.



## TYPICAL APPLICATIONS

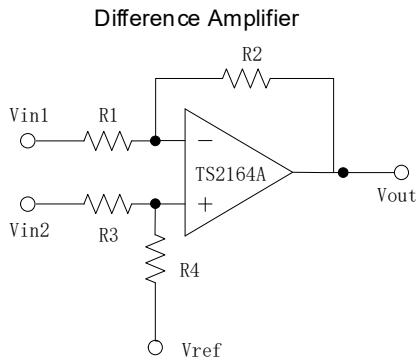


Figure 4. Differential Amplifier

The circuit shown in Figure 4 performs the difference function. If the resistor ratios are equal ( $R4/R3 = R2/R1$ ) then  $V_{out} = (V_{in2} - V_{in1}) \times R2/R1 + V_{ref}$ .

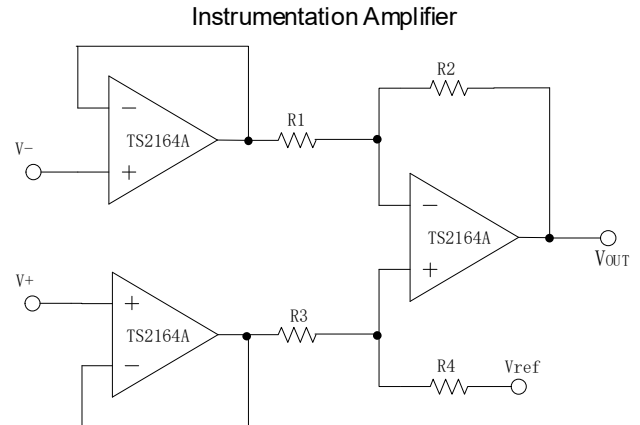


Figure 6. Instrumentation Amplifier

The circuit in Figure 6 performs the same function as that in Figure 4 but with the high input impedance.

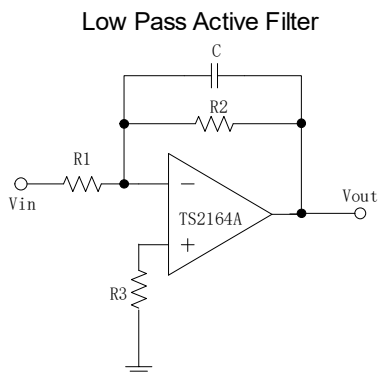
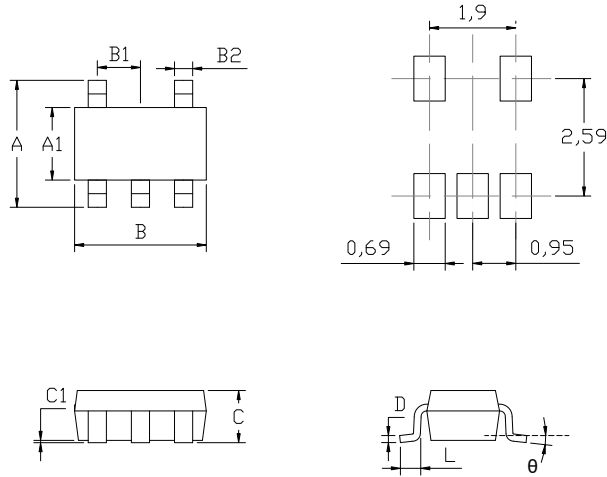


Figure 5. Low Pass Active Filter

The low pass filter shown in Figure 5 has a DC gain of  $(-R2 / R1)$  and the  $-3\text{dB}$  corner frequency is  $1/2\pi R2C$ . Make sure the filter within the bandwidth of the amplifier. The Large values of feedback resistors can couple with parasitic capacitance and cause undesired effects such as ringing or oscillation in high-speed amplifiers. Keep resistors value as low as possible and consistent with output loading consideration.

## MECHANICAL DIMENSIONS

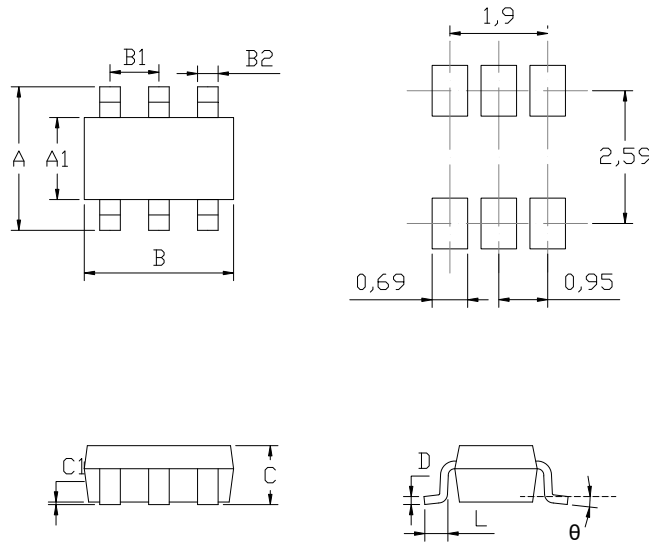
### SOT23-5 PACKAGE MECHANICAL DRAWING



### SOT23-5 PACKAGE MECHANICAL DATA

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	2.6	3	0.1024	0.1181
A1	1.45	1.75	0.0571	0.0689
B	2.75	3.05	0.1083	0.1201
B1	0.95		0.0374	
B2	0.3	0.5	0.0118	0.0197
C		1.45MAX		0.0571MAX
C1	0	0.15	0.0000	0.0059
L	0.3	0.5	0.0118	0.0197
D	0.08	0.22	0.0031	0.0087
θ	0°	8°	0°	8°

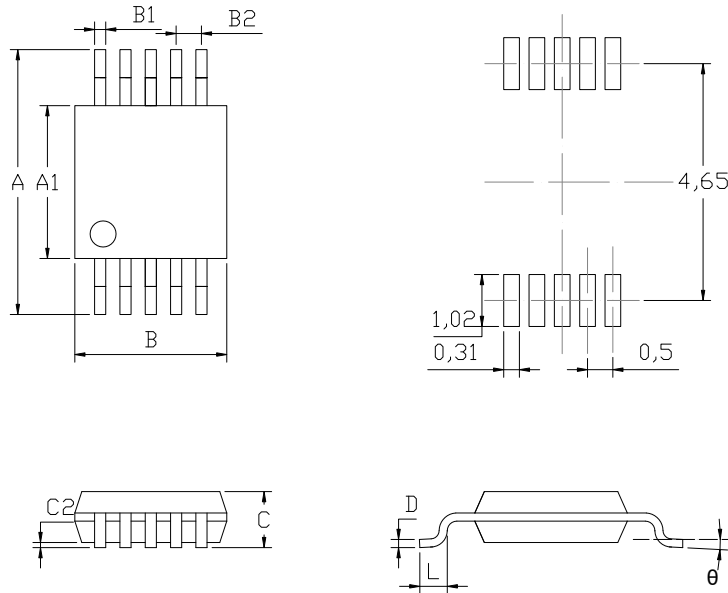
**SOT23-6 PACKAGE MECHANICAL DRAWING**



**SOT23-6 PACKAGE MECHANICAL DATA**

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	2.6	3	0.1024	0.1181
A1	1.45	1.75	0.0571	0.0689
B	2.75	3.05	0.1083	0.1201
B1	0.95		0.0374	
B2	0.3	0.5	0.0118	0.0197
C		1.45MAX		0.0571 MAX
C1	0	0.15	0.0000	0.0059
L	0.3	0.5	0.0118	0.0197
D	0.08	0.22	0.0031	0.0087
θ	0°	8°	0°	8°

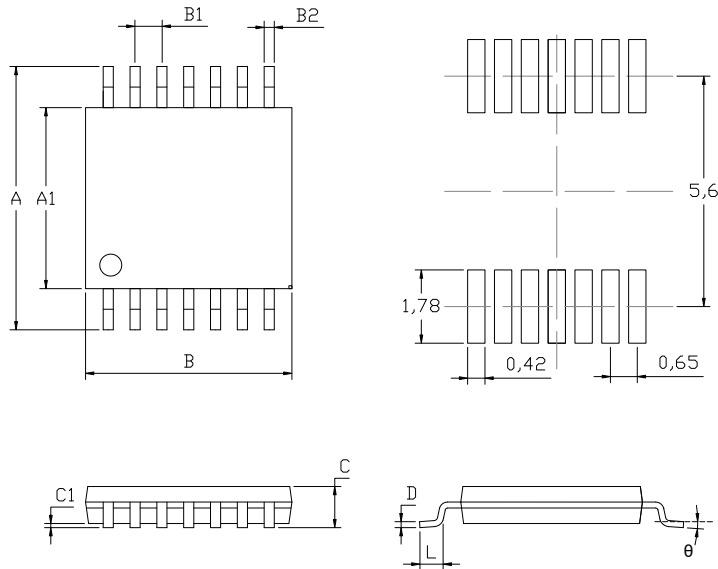
**MSOP-10 PACKAGE MECHANICAL DRAWING**



**MSOP-10 PACKAGE MECHANICAL DATA**

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	4.75	5.05	0.1870	0.1988
A1	2.9	3.1	0.1142	0.1220
B	2.9	3.1	0.1142	0.1220
B1	0.50		0.0197	
B2	0.17	0.27	0.0067	0.0106
C		1.10MAX		0.0433
C1	0.05	0.15	0.0020	0.0059
L	0.4	0.7	0.0157	0.0276
D	0.13	0.23	0.0051	0.0091
θ	0°	8°	0°	8°

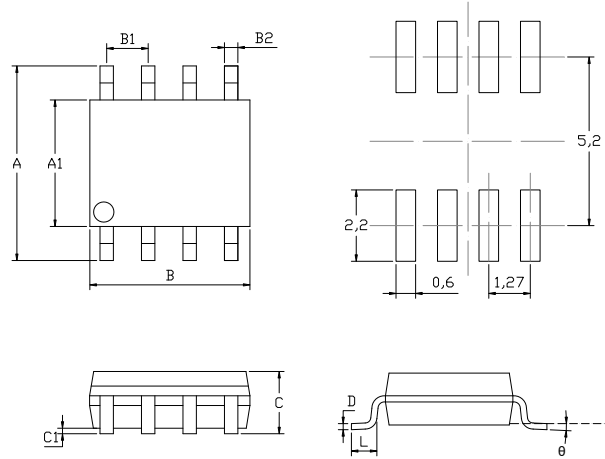
**TSSOP-14 PACKAGE MECHANICAL DRAWING**



**TSSOP-14 PACKAGE MECHANICAL DATA**

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	6.2	6.6	0.2441	0.2598
A1	4.3	4.5	0.1693	0.1772
B	4.9	5.1	0.1929	0.2008
B1	0.65		0.0256	
B2	0.19	0.3	0.0075	0.0118
C		1.20MAX		0.0472MAX
C1	0.05	0.15	0.0020	0.0059
L	0.5	0.75	0.0197	0.0295
D	0.1	0.2	0.0039	0.0079
theta	0°	8°	0°	8°

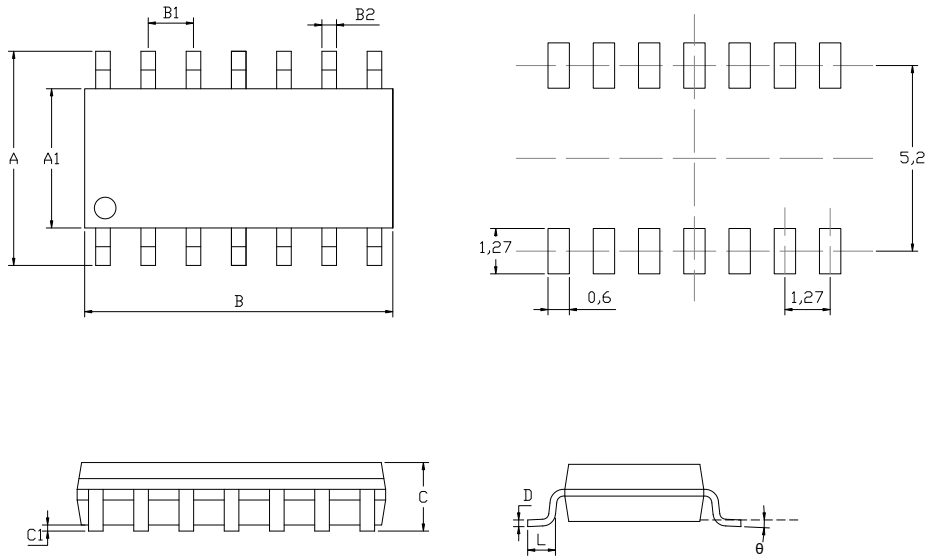
**SO-8 PACKAGE MECHANICAL DRAWING**



**SO-8 PACKAGE MECHANICAL DATA**

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	5.8	6.2	0.2283	0.2441
A1	3.8	4	0.1496	0.1575
B	4.8	5	0.1890	0.1969
B1	1.27		0.0500	
B2	0.31	0.51	0.0122	0.0201
C		1.75MAX		0.0689MAX
C1	0.1	0.25	0.0039	0.0098
L	0.4	1.27	0.0157	0.0500
D	0.13	0.25	0.0051	0.0098
θ	0°	8°	0°	8°

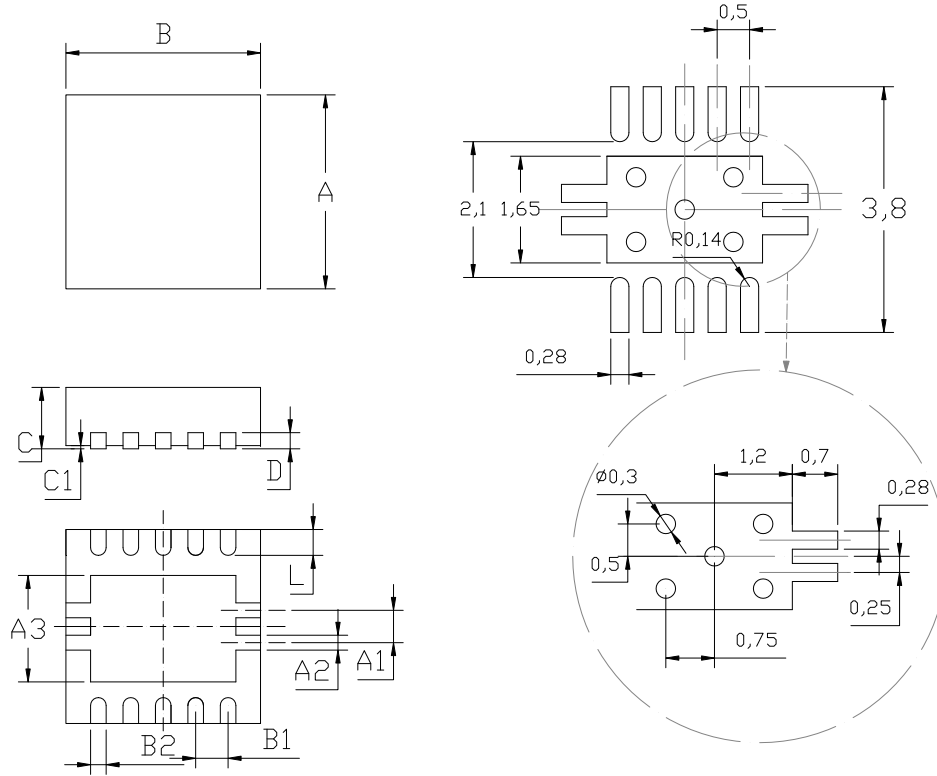
**SO-14 PACKAGE MECHANICAL DRAWING**



**SO-14 PACKAGE MECHANICAL DATA**

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	6.2	5.8	0.2441	0.2283
A1	3.8	4	0.1496	0.1575
B	8.55	8.75	0.3366	0.3445
B1	1.27		0.0500	
B2	0.31	0.51	0.0122	0.0201
C		1.75MAX		0.0689
C1	0.1	0.25	0.0039	0.0098
L	0.4	1.27	0.0157	0.0500
D	0.13	0.25	0.0051	0.0098
θ	0°	8°	0°	8°

**DFN-10 PACKAGE MECHANICAL DRAWING**



**DFN-10 PACKAGE MECHANICAL DATA**

symbol	dimensions			
	millimeters		inches	
	min	max	min	max
A	2.9	3.1	0.1142	0.1220
A1	0.5		0.0197	
A2	0.23		0.0091	
A3	1.55	1.75	0.0610	0.0689
B	2.9	3.1	0.1142	0.1220
B1	0.5		0.0197	
B2	0.18	0.3	0.0071	0.0118
C	0.8	1	0.0315	0.0394
C1	0	0.05	0.0000	0.0020
L	0.3	0.5	0.0118	0.0197
D	0.2		0.0079	



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