Zero-Drift, Rail-to-Rail I/O CMOS Operational Amplifiers

Features

- **Low Offset Voltage: ±1uV (TYP)**
- **Input Offset Drift: ±0.005uV/°C**
- **High Gain Bandwidth Product: 1.6MHz**
- **Rail-to-Rail Input and Output**
- **High Gain, CMRR, PSRR:130dB**
- **High Slew Rate: 0.7V/us**
- **Low Noise: 1.3uVp-p (0.01Hz~10Hz)**
- **Low Power Consumption: 180uA /op amp**
- **Overload Recovery Time:2us**
- **Low Supply Voltage: +2.5 V to +5.5 V**
- **No External Capacitors Required**
- **Extended Temperature: -40°C to +125°C**

Applications

- **Temperature Sensors**
- **Medical/Industrial Instrumentation**
- **Pressure Sensors**
- **Battery-Powered Instrumentation**
- **Active Filtering**
- **Weight Scale Sensor**
- **Strain Gage Amplifiers**
- **Power Converter/Inverter**

Description

The RS8538, RS8539 series of CMOS operational amplifiers use auto-zero techniques to simultaneously provide very low offset voltage (5uV max) and near-zero drift over time and temperature. This family of amplifiers has ultralow noise, offset and power.

This miniature, high-precision operational amplifiers offer high input impedance and rail-to-rail input and rail-to-rail output swing. With high gain-bandwidth product of 1.6MHz and slew rate of 0.7V/us.
Single or dual supplies as low as +2.5V (±1.25V) and up to +5.5V (±2.75V) may be used.

The RS8538/RS8539 are specified for the extended industrial and automotive temperature range (-40°C to 125°C). The RS8538 single amplifier is available in 5-lead SOT23, 8-lead MSOP and 8-lead SOIC packages, The RS8539 dual amplifier is available in 8-lead SOIC and 8-lead MSOP narrow surface mount packages.

Device Information (1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
RS8538	SOT23-5	2.90mm×1.60mm
	SOIC-8 (SOP8)	4.90mm×3.90mm
	MSOP-8	3.00mm×3.00mm
RS8539	SOIC-8 (SOP8)	4.90mm×3.90mm
	MSOP-8	3.00mm×3.00mm

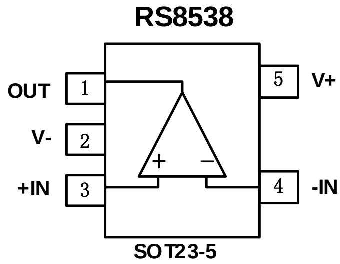
(1) For all available packages, see the orderable addendum at the end of the data sheet.

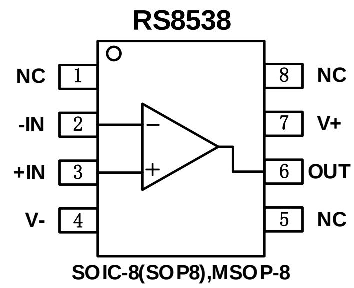
Revision History

Note: Page numbers for previous revisions may different from page numbers in the current version.

Version	Change Date	Change Item
C.1	2022/05/17	1. Update Package Qty on Page 2@RevB.3 2. Added TAPE AND REEL INFORMATION 3. Added APPLICATION NOTE

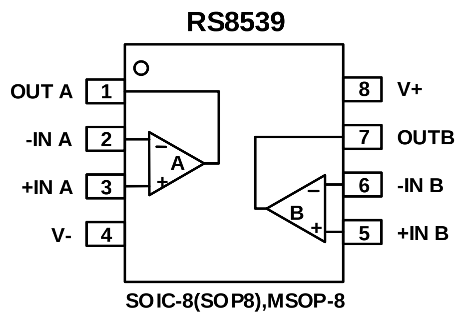
Pin Configuration and Functions (Top View)





Pin Description

NAME	PIN		I/O	DESCRIPTION
	RS8531	RS8531		
	SOT23-5	SOIC-8 (SOP8)/ MSOP8		
-IN	4	2	I	Negative (inverting) input
+IN	3	3	I	Positive (noninverting) input
NC	-	1,5,8	-	No internal connection (can be left floating)
OUT	1	6	O	Output
V-	2	4	-	Negative (lowest) power supply
V+	5	7	-	Positive (highest) power supply



Pin Description

NAME	PIN	I/O	DESCRIPTION
	SOIC-8 (SOP8)/ MSOP8		
-INA	2	I	Inverting input, channel A
+INA	3	I	Noninverting input, channel A
-INB	6	I	Inverting input, channel B
+INB	5	I	Noninverting input, channel B
OUTA	1	O	Output, channel A
OUTB	7	O	Output, channel B
V-	4	-	Negative (lowest) power supply
V+	8	-	Positive (highest) power supply

SPECIFICATIONS

Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Voltage	Supply, Vs=(V+) - (V-)		7	V
	Signal input pin (2)	(V-)-0.5	(V+) +0.5	
	Signal output pin (3)	(V-)-0.5	(V+) +0.5	
Current	Signal input pin (2)	-10	10	mA
	Signal output pin (3)	-55	55	mA
	Output short-circuit (4)	Continuous		
Temperature	Operating range, T_A	-40	125	°C
	Junction, T_J	-40	150	
	Storage, T_{stg}	-65	150	

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.
(2) Input terminals are diode-clamped to the power-supply rails. Input signals that can swing more than 0.5V beyond the supply rails should be current-limited to 10mA or less.
(3) Output terminals are diode-clamped to the power-supply rails. Output signals that can swing more than 0.5V beyond the supply rails should be current-limited to ±55mA or less.
(4) Short-circuit to ground, one amplifier per package.

ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM)	±5000	V
		Machine Model (MM)	±400	

Recommended Operating Conditions

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

		MIN	NOM	MAX	UNIT
Supply voltage，Vs= (V+) - (V-)	Single-supply	2.5		5.5	V
	Dual-supply	±1.25		±2.75	

Thermal Information: RS8538

THERMAL METRIC		RS8538			UNIT
		5PINS	8PINS		
		SOT23-5	SOIC-8	MSOP8	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	273.8	116	165	°C/W
$R_{\theta JC (top)}$	Junction-to-case (top) thermal resistance	126.8	60	53	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	85.9	56	87	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	10.9	12.8	4.9	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	84.9	98.3	85	°C/W
$R_{\theta JC (bot)}$	Junction-to-case (bottom) thermal resistance	N/A	N/A	N/A	°C/W

Thermal Information: RS8539

THERMAL METRIC		RS8539 8PINS SOIC-8	RS8539 8PINS MSOP8	UNIT
$R_{θJA}$	Junction-to-ambient thermal resistance	116	165	°C/W
$R_{θJC (top)}$	Junction-to-case (top) thermal resistance	60	53	°C/W
$R_{θJB}$	Junction-to-board thermal resistance	56	87	°C/W
$Ψ_{JT}$	Junction-to-top characterization parameter	12.8	4.9	°C/W
$Ψ_{JB}$	Junction-to-board characterization parameter	98.3	85	°C/W
$R_{θJC (bot)}$	Junction-to-case (bottom) thermal resistance	N/A	N/A	°C/W

PACKAGE/ORDERING INFORMATION

Orderable Device	Package Type	Pin	Channel	Op Temp(°C)	Device Marking[(1)]	Package Qty
RS8538XF	SOT23-5	5	1	-40°C ~125°C	8538	Tape and Reel,3000
RS8538XK	SOIC-8 (SOP8)	8	1	-40°C ~125°C	RS8538	Tape and Reel,4000
RS8538XM	MSOP-8	8	1	-40°C ~125°C	RS8538	Tape and Reel,4000
RS8539XK	SOIC-8 (SOP8)	8	2	-40°C ~125°C	RS8539	Tape and Reel,4000
RS8539XM	MSOP-8	8	2	-40°C ~125°C	RS8539	Tape and Reel,4000

NOTE:

(1) There may be additional marking, which relates to the lot trace code information (data code and vendor code), the logo or the environmental category on the device.

ELECTRICAL CHARACTERISTICS

Boldface limits apply over the specified temperature range, T_A = -40°C to +125°C.
(At T_A = +25°C, Vs=5V, R_L = 10kΩ connected to V_S/2, and V_{OUT} = V_S/2, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITION	RS8538, RS8539			UNIT
			MIN	TYP	MAX	
OFFSET VOLTAGE						
Input Offset Voltage	V_{OS}	V_{CM}= V_S/2	-5	±1	5	uV
Input Offset Voltage Average Drift	Vos Tc			±0.005	±0.05	uV/°C
Power-Supply Rejection Ratio	PSRR	V_S= +2.5V to +5.5V, V_{CM}= 0	110	130		dB
Channel Separation, dc				0.1		uV/V
INPUT BIAS CURRENT						
Input Bias Current	IB	V_{CM} = V_S/2		±50		pA
Input Offset Current	I_{OS}			±10		pA
NOISE PERFORMANCE						
Input Voltage Noise	e_np-p	f= 0.01Hz to 10Hz		1.3		uVpp
Input Voltage Noise	e_np-p	f= 0.01Hz to 1Hz		0.4		uVpp
Input Voltage Noise Density	e_n	f= 1KHz		60		$nV/\sqrt{Hz}$
Input Current Noise Density	i_n	f= 10Hz		8		$fA/\sqrt{Hz}$
INPUT VOLTAGE RANGE						
Common-Mode Voltage Range	V_{CM}		(V-) -0.1		(V+) +0.1	V
Common-Mode Rejection Ratio	CMRR	(V-) -0.1V < V_{CM} < (V+)+ 0.1V	110	130		dB
INPUT CAPACITANCE						
Differential				1		pF
Common-Mode				5		pF
Open-Loop Gain						
Open-Loop Voltage Gain	A_{OL}	R_L= 10KΩ, V_O= 0.3V to 4.7V, T_A= -40°C to 125°C	110	130		dB
DYNAMIC PERFORMANCE						
Slew Rate	SR	G= +1		0.7		V/us
Gain-Bandwidth Product	GBW			1.6		MHz
Overload Recovery Time	t_{OR}			2		us
OUTPUT CHARACTERISTICS						
Output Voltage High	V_{OH}	R_L=100 KΩ to GND	4.99	4.998		V
		R_L=10 KΩ to GND	4.95	4.98		
Output Voltage Low	V_{OL}	R_L=100 KΩ to V+		1	10	mV
		R_L=10 KΩ to V+		10	30	
Short-Circuit Current	I_{SC}			40		mA
POWER SUPPLY						
Operating Voltage Range	V_S		2.5		5.5	V
Quiescent Current/ Amplifier	IQ			180	260	uA

TYPICAL CHARACTERISTICS

At T_A = +25°C, Vs = 5V, R_L = 10kΩ connected to V_S/2, V_{OUT} = V_S/2, unless otherwise noted.

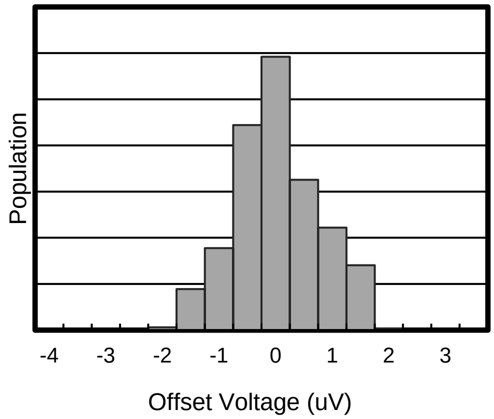


Figure 1. Offset Voltage Production Distribution

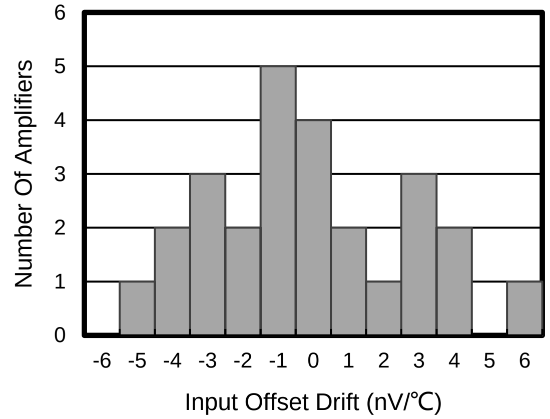


Figure 2. Offset Voltage Drift Production Distribution

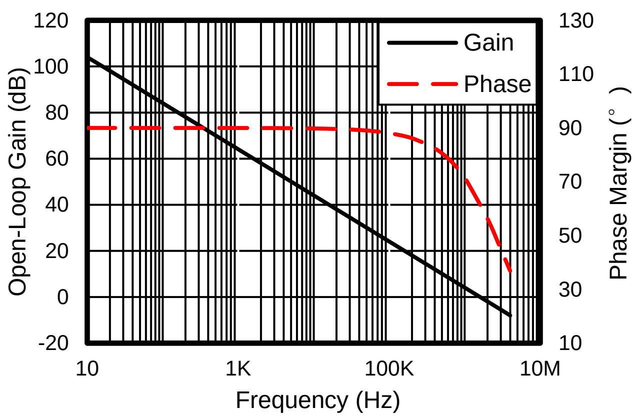


Figure 3. Open-Loop Gain and Phase vs Frequency

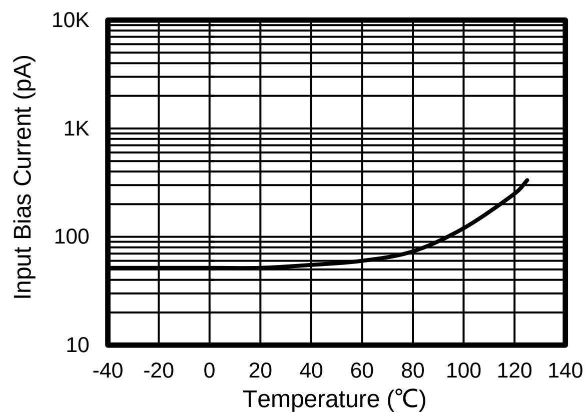


Figure 4. Input Bias Current vs Temperature

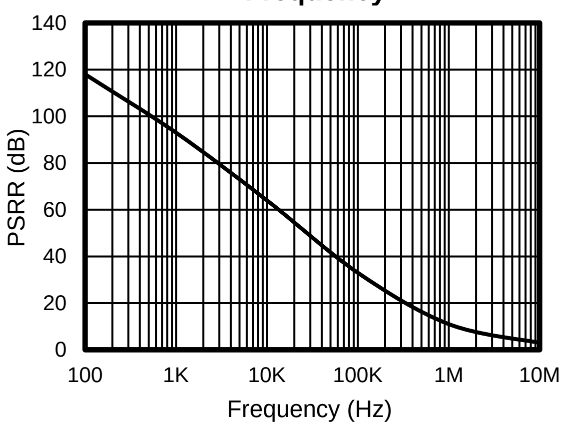


Figure 5. Power-Supply Rejection Ratio vs Frequency

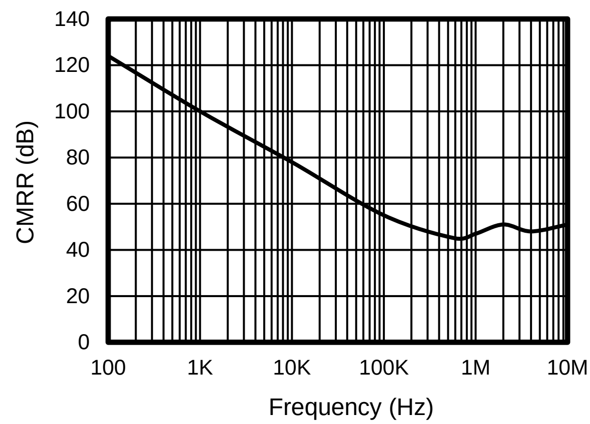


Figure 6. Common-Mode Rejection Ratio vs Frequency

TYPICAL CHARACTERISTICS

At T_A = +25°C, Vs = 5V, R_L = 10kΩ connected to $V_S/2$, V_{OUT} = $V_S/2$, unless otherwise noted.

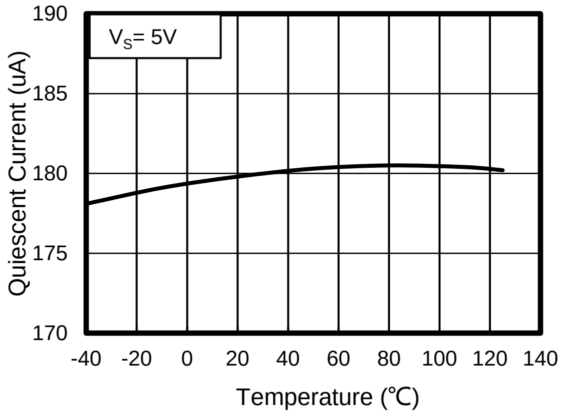


Figure 7. Quiescent Current vs Temperature

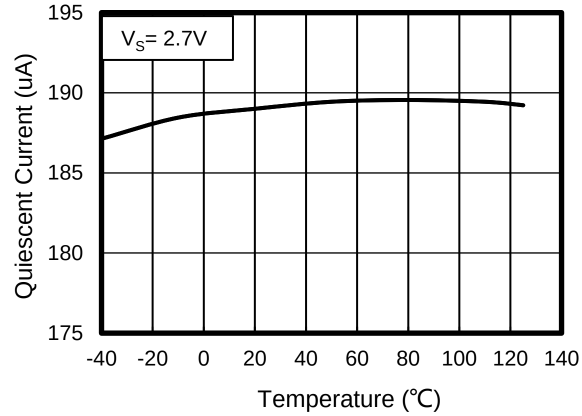


Figure 8. Quiescent Current vs Temperature

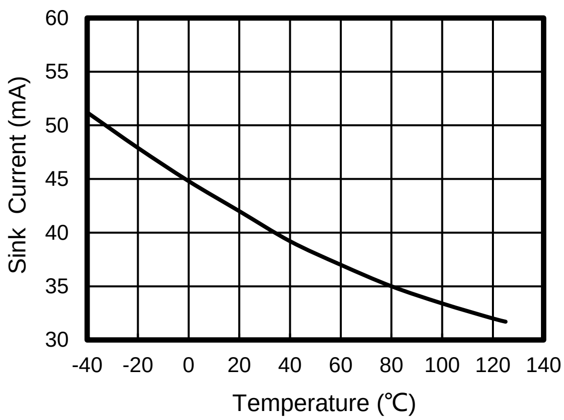


Figure 9. Sink Current vs Temperature

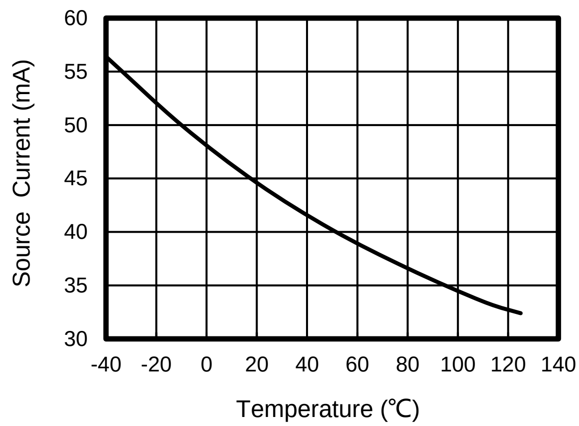


Figure 10. Source Current vs Temperature

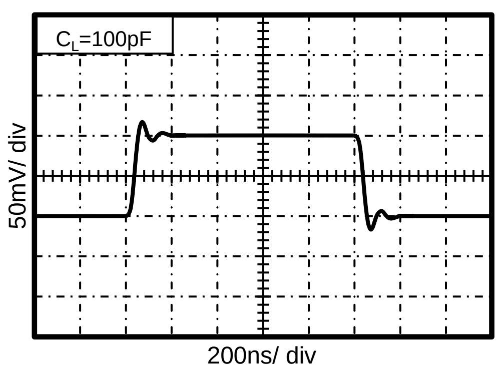


Figure 11. Small-Signal Step Response

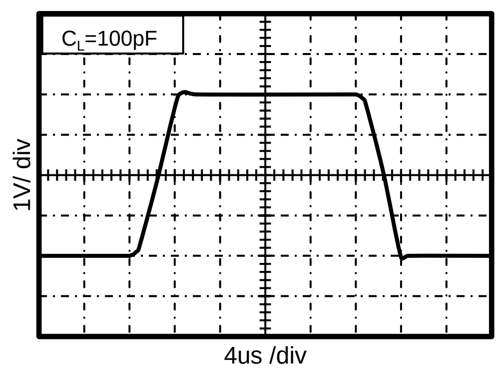


Figure 12. Large-Signal Step Response

TYPICAL CHARACTERISTICS

At T_A = +25°C, Vs = 5V, R_L = 10kΩ connected to Vs/2, V_{OUT} = Vs/2, unless otherwise noted.

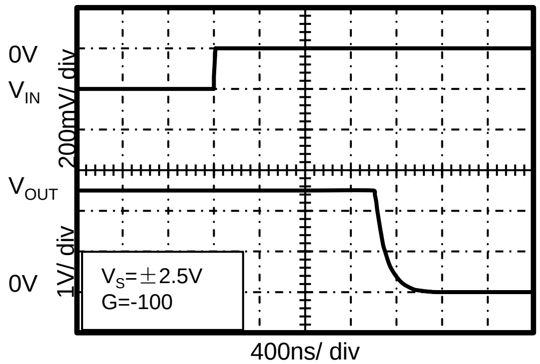


Figure 13. Positive Overvoltage Recovery

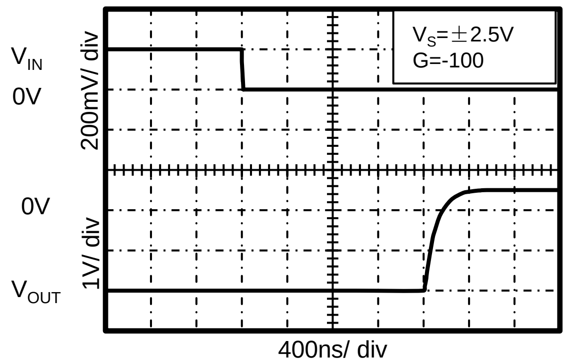


Figure 14. Negative Overvoltage Recovery

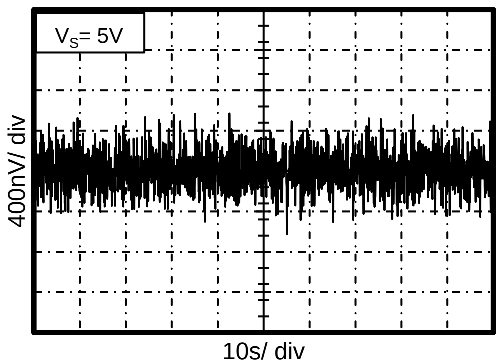


Figure 15. 0.01Hz to 10Hz Noise

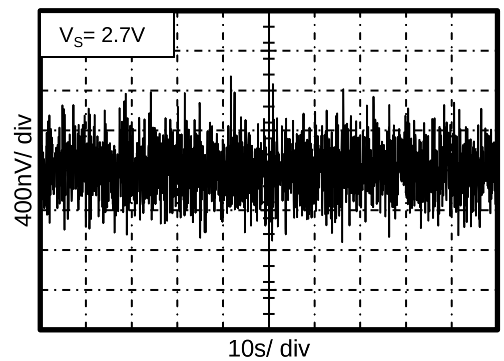


Figure 16. 0.01Hz to 10Hz Noise

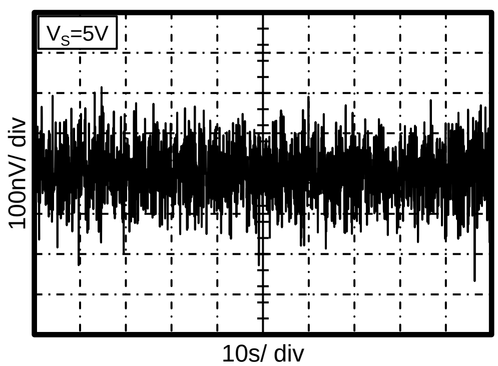


Figure 17. 0.01Hz to 1Hz Noise

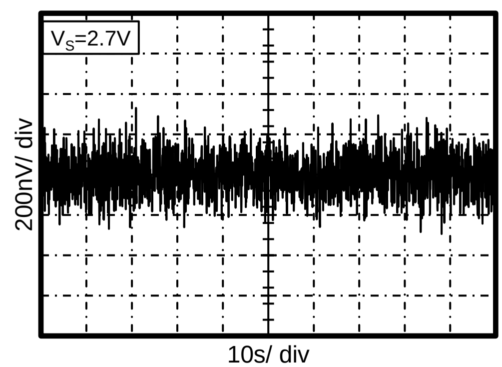


Figure 18. 0.01Hz to 1Hz Noise

Detailed Description

Overview

The RS8538, RS8539 series op amps are unity-gain stable and free from unexpected output phase reversal. They use auto-zeroing techniques to provide low offset voltage and very low drift over time and temperature.

Good layout practice mandates use of a 0.1µF capacitor placed closely across the supply pins.

For lowest offset voltage and precision performance, circuit layout and mechanical conditions should be optimized. Avoid temperature gradients that create thermoelectric (Seebeck) effects in thermocouple junctions formed from connecting dissimilar conductors. These thermally-generated potentials can be made to cancel by assuring that they are equal on both input terminals.

- Use low thermoelectric-coefficient connections (avoid dissimilar metals).
- Thermally isolate components from power supplies or other heat-sources.
- Shield op amp and input circuitry from air currents, such as cooling fans.

Following these guidelines will reduce the likelihood of junctions being at different temperatures, which can cause thermoelectric voltages of 0.1µV/°C or higher, depending on materials used.

OPERATING VOLTAGE

The RS8538, RS8539 series op amps operate over a power-supply range of +2.5V to +5.5V (±1.25V to ±2.75V). Supply voltages higher than 7V (absolute maximum) can permanently damage the amplifier. Parameters that vary over supply voltage or temperature are shown in the Typical Characteristics section of this data sheet.

APPLICATION NOTE

Typical Applications

Bidirectional Current-Sensing

This single-supply, low-side, bidirectional current-sensing solution detects load currents from -1A to 1A. The single-ended output spans from 110mV to 3.19V. This design uses the RS8538, RS8539 because of its low offset voltage and rail-to-rail input and output. One of the amplifiers is configured as a difference amplifier and the other provides the reference voltage.

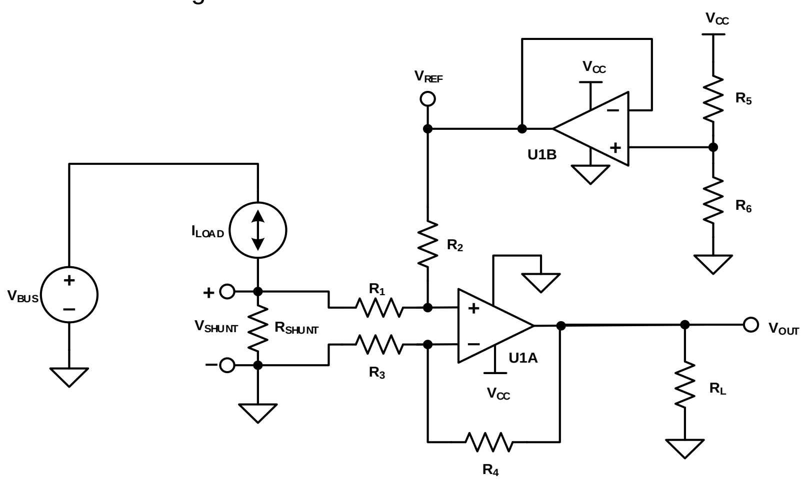


Figure 19. Bidirectional Current-Sensing Schematic

Design Requirements

This solution has the following requirements:

• Supply voltage: 3.3V
• Input: -1 A to 1 A
• Output: 1.65V ±1.54V (110mV to 3.19V)

Detailed Design Procedure

The load current, I_{LOAD}, flows through the shunt resistor (R_{SHUNT}) to develop the shunt voltage, V_{SHUNT}. The shunt voltage is then amplified by the difference amplifier, which consists of U1A and R_1 through R_4. The gain of the difference amplifier is set by the ratio of R_4 to R_3. To minimize errors, set $R_2 = R_4$ and $R_1 = R_3$. The reference voltage, V_{REF}, is supplied by buffering a resistor divider using U1B. The transfer function is given by Equation 1.

$V_{OUT}=V_{SHUNT}\times Gain_{Diff\_Amp}+V_{REF}$

Where

$V_{SHUNT}=I_{LOAD}\times R_{SHUNT}$

$$Gain_{Diff\_Amp}=\frac{R_4}{R_3}$$

$$V_{REF}=V_{CC}\times\left(\frac{R_6}{R_5+R_6}\right) \quad (1)$$

There are two types of errors in this design: offset and gain. Gain errors are introduced by the tolerance of the shunt resistor and the ratios of R_4 to R_3 and, similarly, R_2 to R_1. Offset errors are introduced by the voltage divider (R_5 and R_6) and how closely the ratio of R_4/R_3 matches R_2/R_1. The latter value impacts the CMRR of the difference amplifier, which ultimately translates to an offset error. Because this is a low-side measurement, the value of V_{SHUNT} is the ground potential for the system load. Therefore, it is important to place a maximum value on V_{SHUNT}. In this design, the maximum value for V_{SHUNT} is set to 100 mV. Equation 2 calculates the maximum value of the shunt resistor given a maximum shunt voltage of 100 mV and maximum load current of 1 A.

$$R_{SHUNT(Max)}=\frac{V_{SHUNT(Max)}}{I_{LOAD(Max)}}=\frac{100\ mV}{1\ A}=100\ m\Omega \quad (2)$$

The tolerance of R_{SHUNT} is directly proportional to cost. For this design, a shunt resistor with a tolerance of 0.5% was selected. If greater accuracy is required, select a 0.1% resistor or better.

The load current is bidirectional; therefore, the shunt voltage range is –100 mV to 100 mV. This voltage is divided down by R_1 and R_2 before reaching the operational amplifier, U1A. Take care to ensure that the voltage present at the noninverting node of U1A is within the common-mode range of the device. Therefore, it is important to use an operational amplifier, such as the RS8538, and RS8539 that has a common-mode range that extends below the negative supply voltage. Finally, to minimize offset error, note that the RS8538, RS8539 has a typical offset voltage of ±3µV (±20µV maximum). Given a symmetric load current of -1A to 1A, the voltage divider resistors (R_5 and R_6) must be equal. To be consistent with the shunt resistor, a tolerance of 0.5% was selected. To minimize power consumption, 10kΩ resistors were used. To set the gain of the difference amplifier, the common-mode range and output swing of the RS8538, and RS8539 must be considered. Equation 3 and Equation 4 depict the typical common-mode range and maximum output swing, respectively of the RS8538, and RS8539 given a 3.3V supply.

$$-100mV < V_{CM} < 3.4V \quad (3)$$

$$100mV < V_{OUT} < 3.2V \quad (4)$$

The gain of the difference amplifier can now be calculated as shown in Equation 5.

$$Gain_{Diff\_Amp} = \frac{V_{OUT\_Max} - V_{OUT\_Min}}{R_{SHUNT} \times (I_{MAX} - I_{MIN})} = \frac{3.2\ V - 100\ mV}{100\ m\Omega \times [1\ A - (-1A)]} = 15.5\ \frac{V}{V} \quad (5)$$

The resistor value selected for R_1 and R_3 was 1kΩ. 15.4kΩ was selected for R_2 and R_4 because it is the nearest standard value. Therefore, the ideal gain of the difference amplifier is 15.4 V/V.

The gain error of the circuit primarily depends on R_1 through R_4. As a result of this dependence, 0.1% resistors were selected. This configuration reduces the likelihood that the design requires a two-point calibration. A simple one-point calibration, if desired, removes the offset errors introduced by the 0.5% resistors.

Application Curve

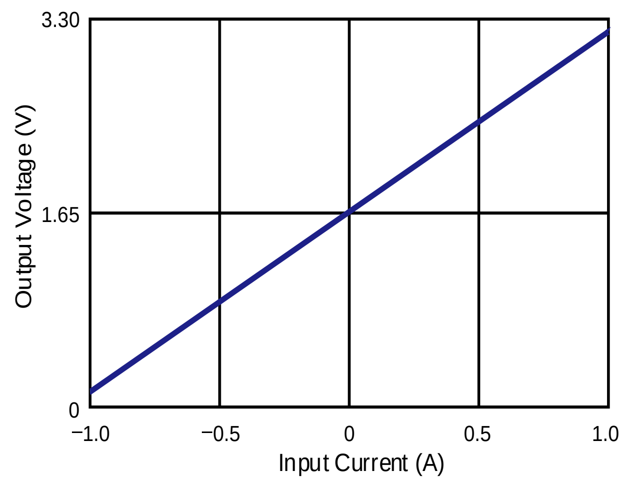


Figure 20. Bidirectional Current-Sensing Circuit Performance: Output Voltage vs Input Current

LAYOUT

LAYOUT GUIDELINES

Attention to good layout practices is always recommended. Keep traces short. When possible, use a PCB ground plane with surface-mount components placed as close to the device pins as possible. Place a 0.1µF capacitor closely across the supply pins. These guidelines should be applied throughout the analog circuit to improve performance and provide benefits such as reducing the EMI (electromagnetic-interference) susceptibility.

Layout Example

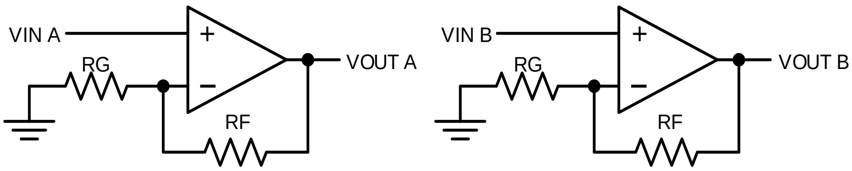


Figure 21. Schematic Representation

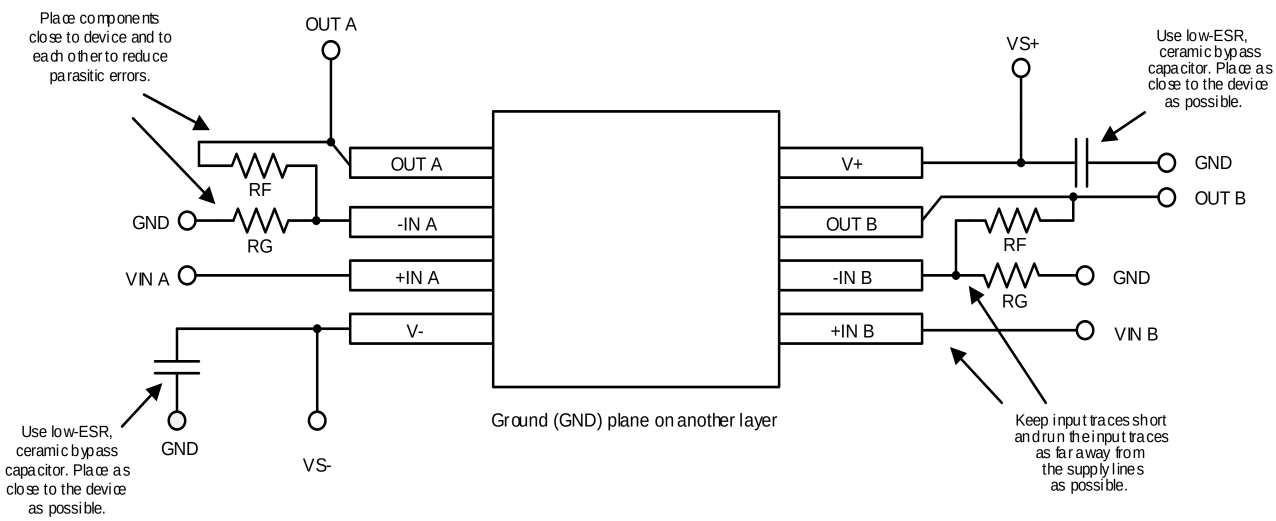
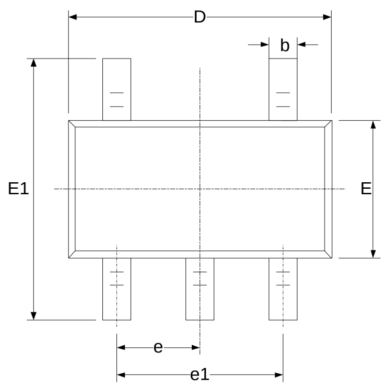
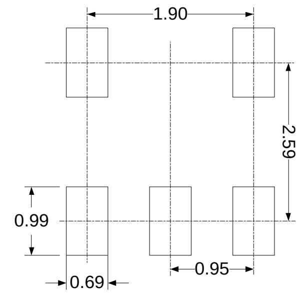


Figure 22. Layout Example

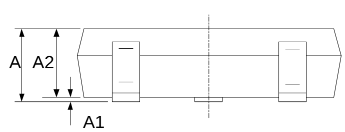
PACKAGE OUTLINE DIMENSIONS

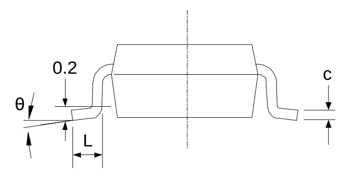
SOT23-5





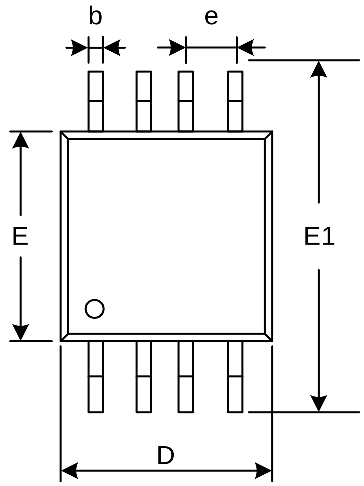
RECOMMENDED LAND PATTERN (Unit: mm)

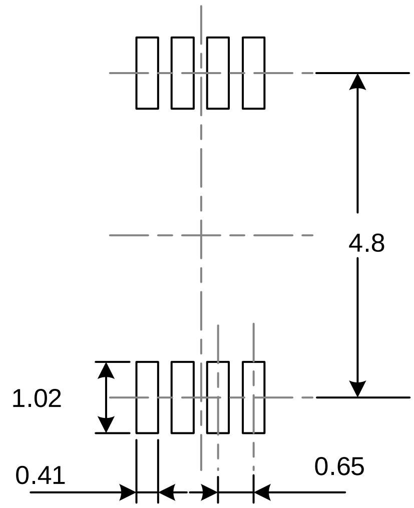




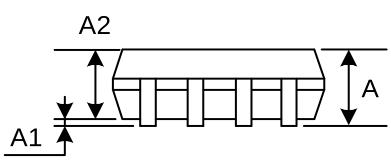
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	1.050	1.250	0.041	0.049
A1	0.000	0.100	0.000	0.004
A2	1.050	1.150	0.041	0.045
b	0.300	0.500	0.012	0.020
c	0.100	0.200	0.004	0.008
D	2.820	3.020	0.111	0.119
E	1.500	1.700	0.059	0.067
E1	2.650	2.950	0.104	0.116
e	0.950(BSC)		0.037(BSC)	
e1	1.800	2.000	0.071	0.079
L	0.300	0.600	0.012	0.024
θ	0°	8°	0°	8°

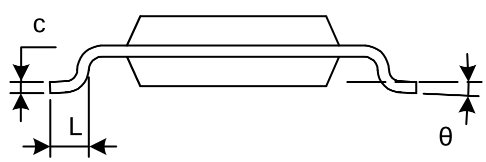
MSOP-8





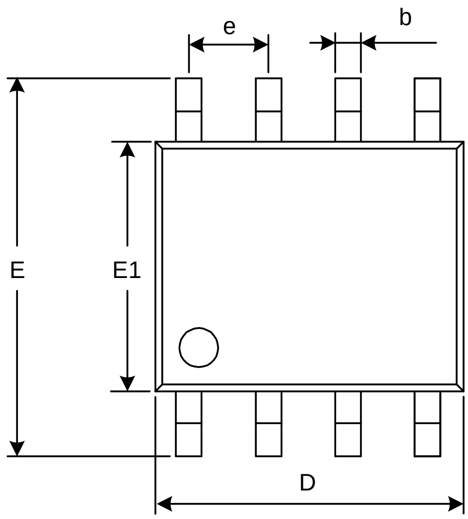
RECOMMENDED LAND PATTERN (Unit: mm)

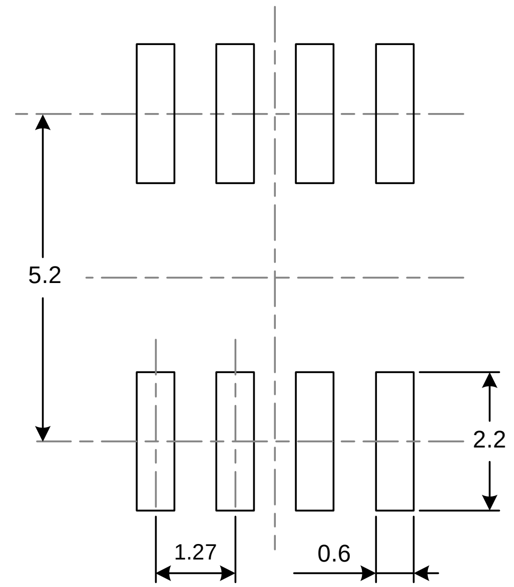




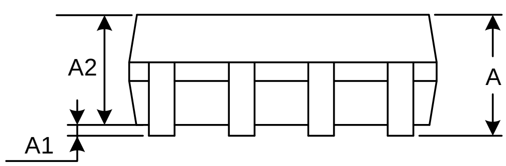
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.820	1.100	0.032	0.043
A1	0.020	0.150	0.001	0.006
A2	0.750	0.950	0.030	0.037
b	0.250	0.380	0.010	0.015
c	0.090	0.230	0.004	0.009
D	2.900	3.100	0.114	0.122
e	0.650(BSC)		0.026(BSC)	
E	2.900	3.100	0.114	0.122
E1	4.750	5.050	0.187	0.199
L	0.400	0.800	0.016	0.031
θ	0°	6°	0°	6°

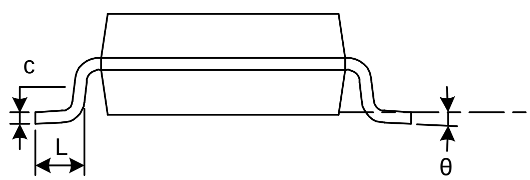
SOIC-8 (SOP8)





RECOMMENDED LAND PATTERN (Unit: mm)



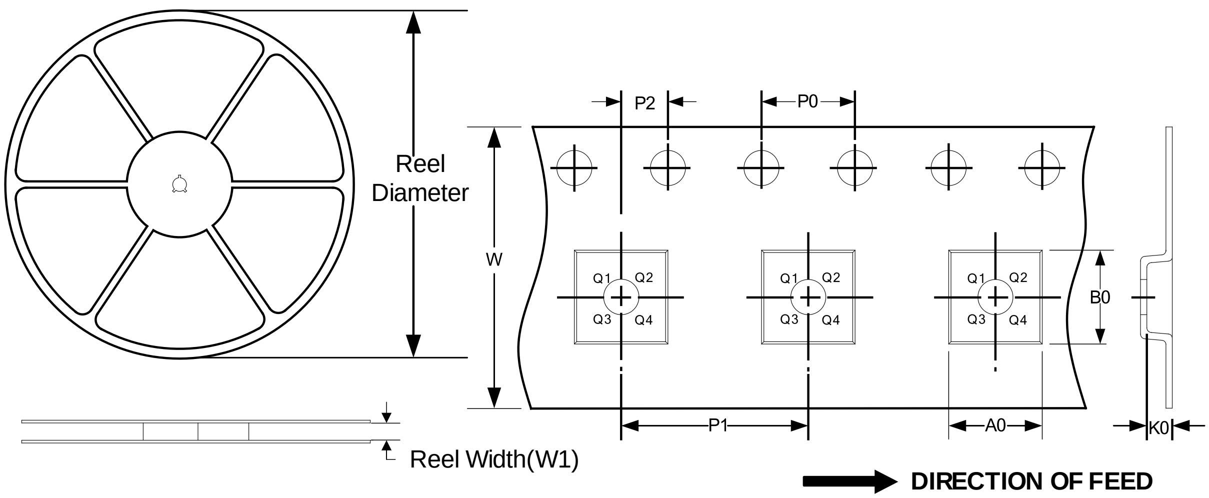


Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	1.350	1.750	0.053	0.069
A1	0.100	0.250	0.004	0.010
A2	1.350	1.550	0.053	0.061
b	0.330	0.510	0.013	0.020
c	0.170	0.250	0.007	0.010
D	4.800	5.000	0.189	0.197
e	1.270(BSC)		0.050(BSC)	
E	5.800	6.200	0.228	0.244
E1	3.800	4.000	0.150	0.157
L	0.400	1.270	0.016	0.050
θ	0°	8°	0°	8°

TAPE AND REEL INFORMATION

REEL DIMENSIONS

TAPE DIMENSION



NOTE: The picture is only for reference. Please make the object as the standard.

KEY PARAMETER LIST OF TAPE AND REEL

Package Type	Reel Diameter	Reel Width (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	P1 (mm)	P2 (mm)	W (mm)	Pin1 Quadrant
SOT23-5	7’’	9.5	3.20	3.20	1.40	4.0	4.0	2.0	8.0	Q3
MSOP8	13’’	12.4	5.20	3.30	1.50	4.0	8.0	2.0	12.0	Q1
SOIC-8 (SOP8)	13’’	12.4	6.40	5.40	2.10	4.0	8.0	2.0	12.0	Q1