Figure 1. Physical Photos of AT8541

FEATURES

- Input Offset Voltage: ±7μV (TYP)
- Input Offset Drift: ±0.08μV/°C
- Low Quiescent Current: 40μA/Amp
- Gain Bandwidth: 350kHz
- Rail to Rail Input and Output
- Low Noise: 0.9μV_{P-P} (0.1Hz to 10Hz)
- Slew Rate: 0.16V/μs
- Supply Voltage Range: 2V to 5.5V
- Extended Temperature: −40°C to +125°C
- Micro SIZE PACKAGES: SOT23-5

APPLICATIONS

- Battery Powered Instruments
- Medical Instruments
- Handheld Test Equipment
- Temperature Measurements
- Transducers
- Electronic Scales

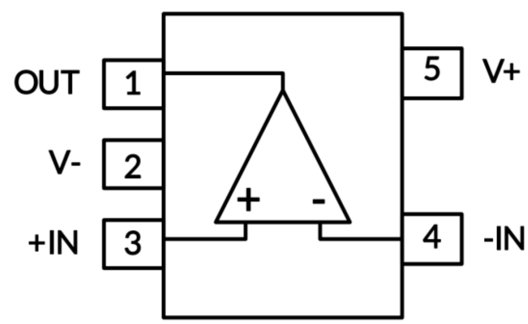
DESCRIPTION

The AT8541 CMOS operational amplifiers employ auto-calibration techniques to deliver exceptionally low offset voltage (7μV TYP) while maintaining near-zero drift across varying time and temperature conditions. This amplifier boasts ultralow levels of noise, offset, and power consumption.

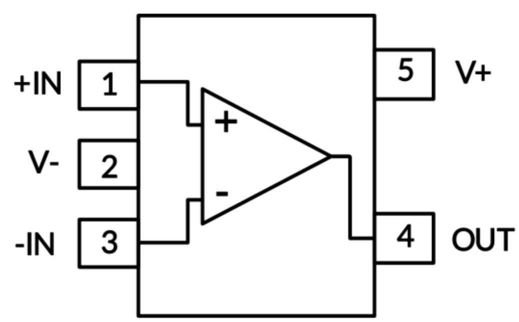
This miniature, high-precision operational amplifiers feature high input impedance and support rail-to-rail input and output swing. They boast a gain-bandwidth product of 350KHz and a slew rate of 0.16V/μs. Suitable for single or dual supplies, they can operate with voltages as low as +2V (±1V) and as high as +5.5V (±2.75V).

The AT8541 is specified for the extended industrial and automotive temperature range (−40°C to 125°C). The AT8541 single amplifier is available in 5-lead SOT23-5 and SOT353(SC70-5) packages.

PIN CONFIGURATIONS



SOT23-5



SOT353 (SC70-5)

PIN DESCRIPTION

Table 1: Pin Function (SOT23-5)

Pin #	Symbol	Description
1	OUT	Analog Output
3	+IN	Noninverting Input
4	−IN	Inverting Input
5	V+	Positive Power Supply
2	V−	Negative Power Supply

Table 2: Pin Function (SOT353 or SC70-5)

Pin #	Symbol	Description
4	OUT	Analog Output
1	+IN	Noninverting Input
3	−IN	Inverting Input
5	V+	Positive Power Supply
2	V−	Negative Power Supply

ABSOLUTE MAXIMUM RATINGS

Table 3. Absolute Maximum Ratings

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

Parameter	Rating
Voltage	
Supply Voltage, V+ to V−	7.0V
Input Pin (2)	(V−) −0.3 to (V+) + 0.3V
Output Pin (3)	(V−) −0.3 to (V+) + 0.3V
Current	
Input Pin (2)	−10mA to 10mA
Output Pin (3)	−10mA to 10mA
Output Short-circuit (4)	Continuous
Temperature	
Storage Temperature	−65°C to +150°C
Operating Temperature	−40°C to +125°C
Junction Temperature (6)	−40°C to +150°C
Package Thermal Resistance (5)	
SOT23-5	200°C/W
SOT353(SC-70)	380°C/W
ESD Susceptibility	
Human-body model (HBM)	±4000V
Charge device model (CDM)	±1000V
Machine Model (MM)	±300V

(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 0.3V 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 0.3V beyond the supply rails should be current-limited to ±10mA or less.

(4). Short-circuit to ground, one amplifier per package.

(5). The package thermal impedance is calculated in accordance with JESD-51.

(6). The maximum power dissipation is a function of $T_{J(MAX)}$, $R_{\theta JA}$, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)} - T_A)/R_{\theta JA}$. All numbers apply for packages soldered directly onto a PCB.

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 subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

ELECTRICAL CHARACTERISTICS

Boldface limits apply over the specified temperature range, Full [9] = −40°C to +125°C.

(At T_A = +25°C, V_S =5V, R_L = 10kΩ connected to V_S/2, and V_{OUT} = V_S/2, V_{CM} = V_S/2, unless otherwise noted.) [1]

Table 4.

Parameter	Symbol	Test Conditions	Min. [2]	Typ. [3]	Max. [2]	Unit
POWER SUPPLY						
Operating Voltage Range	V_S		2		5.5	V
Quiescent Current/Amplifier	I_Q			40	60	μA
Power Supply Rejection Ratio	PSRR	V_S = 2V to 5.5V	95	110		dB
INPUT						
Input Offset Voltage	V_{OS}	V_{CM} = 2V, V_{CM} = V_S/2	−30	±3	30	μV
		V_{CM} = 5V, V_{CM} = V_S/2	−30	±7	30	μV
Input Offset Voltage Average Drift	V_{OS}/T_C			±0.08		μV/°C
Input Bias Current [4][5]	I_B	V_{CM} = V_S/2		±330		pA
Input Offset Current	I_{OS} [5]	V_{CM} = V_S/2		±100		pA
Common-Mode Voltage Range	V_{CM}		(V−)−0.1		(V+)+0.1	V
Common-Mode Rejection Ratio	CMRR	(V−) − 0.1< V_{CM}<(V+) + 0.1	105	120		dB
Differential [5]				2.5		pF
Common-Mode [5]				5		pF
OUTPUT						
Open-Loop Voltage Gain	A_{OL}	R_L = 50kΩ, V_O = 0.3V ~ 4.7V	105	130		dB
Output Voltage Low from Rail	V_{OL}	R_L = 100kΩ to GND		1		mV
		R_L = 10kΩ to GND		10	20	
Output Voltage Low from Rail	V_{OH}	R_L = 100kΩ to V+		1		
		R_L = 10kΩ to V+		10	20	
Output Short-Circuit Current [6][7]	I_{SC}		±20	±30		mA
FREQUENCY RESPONSE						
Slew Rate [8]	SR	G = +1		0.16		V/μs
Gain Bandwidth Product	GBP			350		kHz
Overload Recovery Time	t_{OR}	V_{IN} × Gain ≥ V_S		3		μs
NOISE PERFORMANCE						
Voltage Noise	e_n p-p	f = 0.1Hz to 10Hz		0.9		μVp-p
Voltage Noise [5]	e_n p-p	f = 0.01Hz to 1Hz		0.25		μVp-p
Voltage Noise Density [5]	e_n	f = 1kHz		45		nV/√Hz

NOTE:

(1). Electrical table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device.

(2). Limits are 100% production tested at 25°C. Limits over the operating temperature range are ensured through correlations using statistical quality control (SQC) method.

(3). Typical values represent the most likely parametric norm as determined at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration.

(4). Positive current corresponds to current flowing into the device.

(5). This parameter is ensured by design and/or characterization and is not tested in production.

(6). The maximum power dissipation is a function of $T_{J(MAX)}$, $R_{\theta JA}$, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)} - T_A) / R_{\theta JA}$. All numbers apply for packages soldered directly onto a PCB.

(7). Short circuit test is a momentary test.

(8). Number specified is the slower of positive and negative slew rates.

(9). Specified by characterization only.

TYPICAL CHARACTERISTICS

NOTE: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only.

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

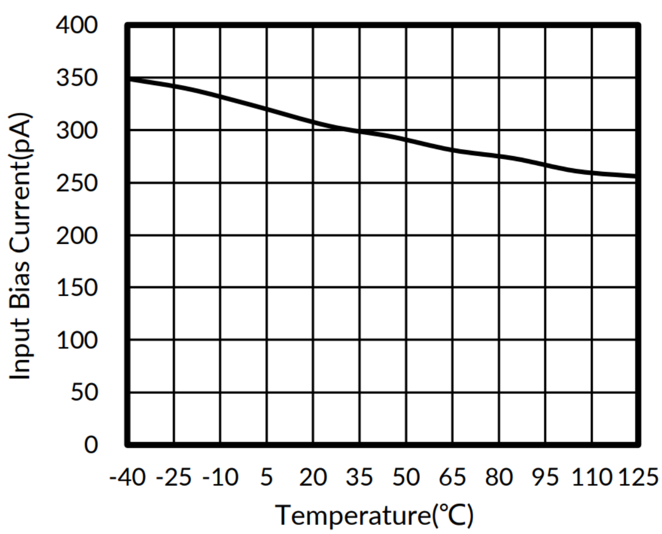


Figure 2. Input Bias Current vs. Temperature

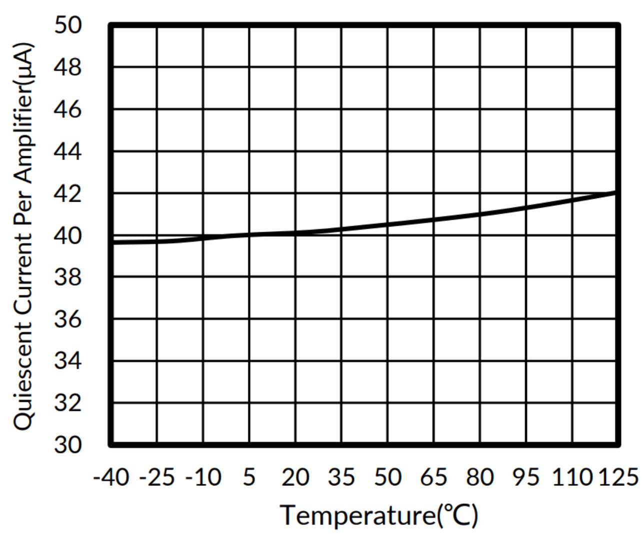


Figure 3. Quiescent Current vs. Temperature

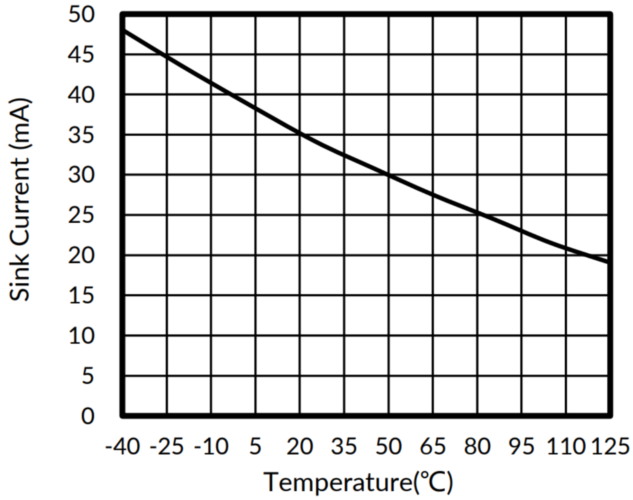


Figure 4. Sink Current vs Temperature

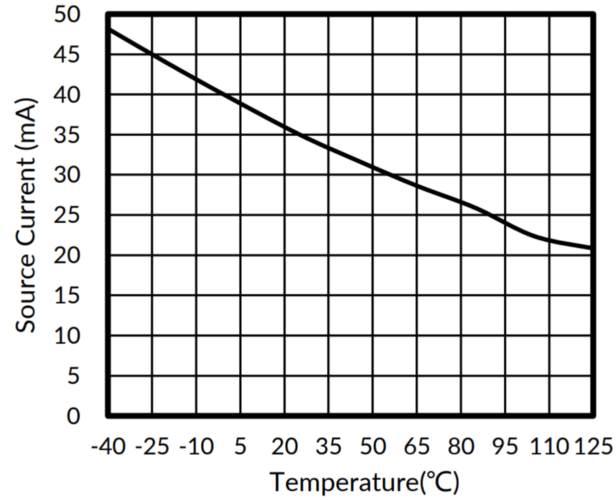


Figure 5. Source Current vs Temperature

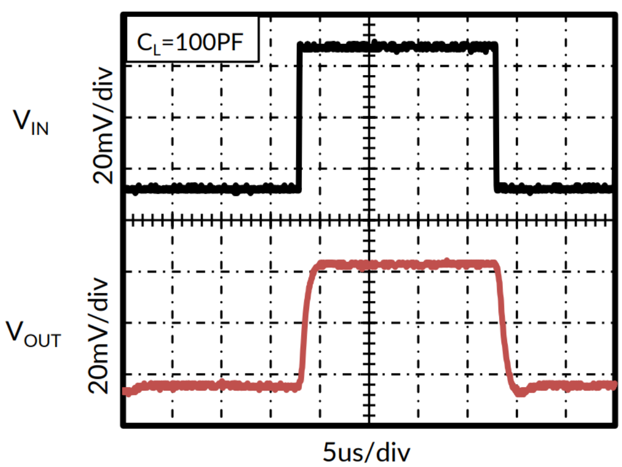


Figure 6. Small-Signal Step Response

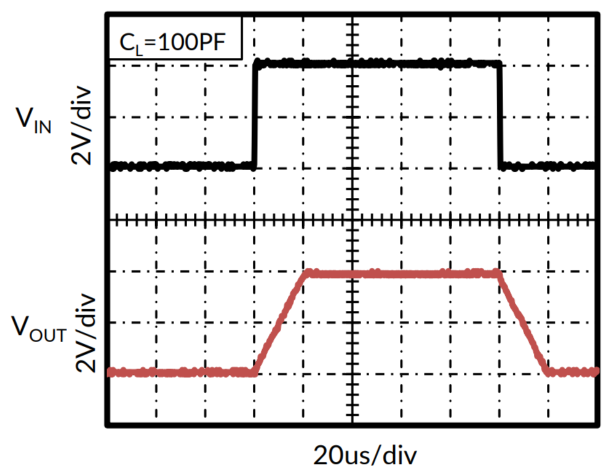


Figure 7. Large-Signal Step Response

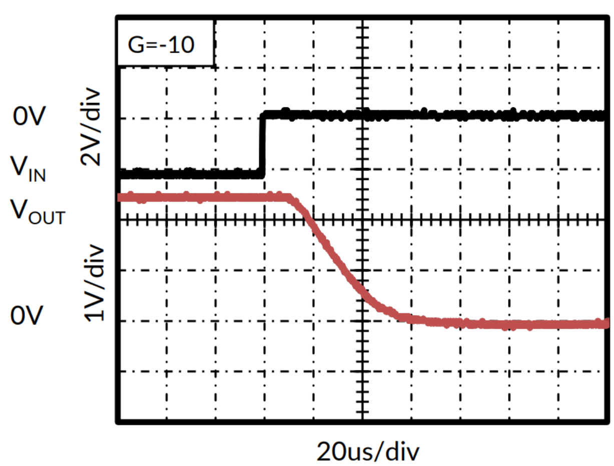


Figure 8. Positive Overvoltage Recovery

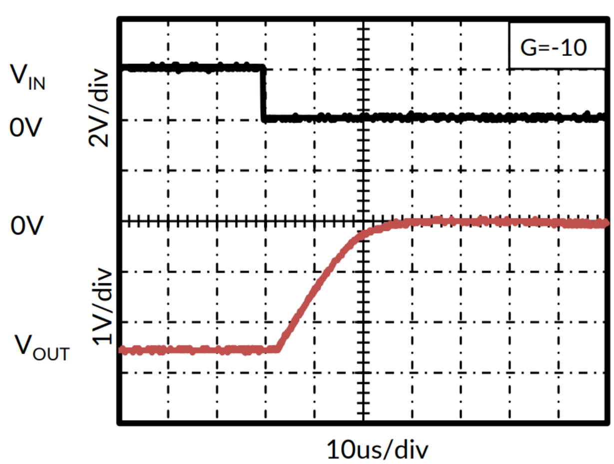


Figure 9. Negative Overvoltage Recovery

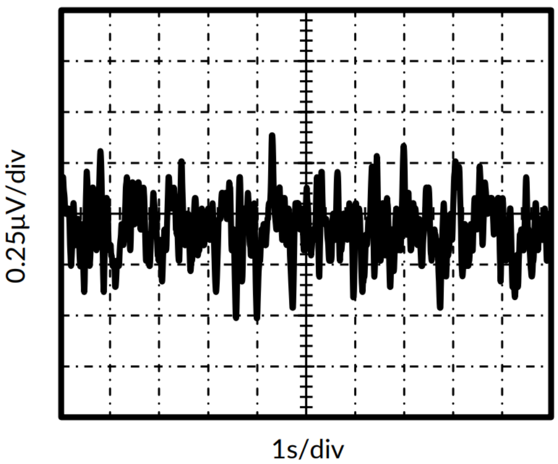


Figure 10. 0.1Hz to 10Hz Noise

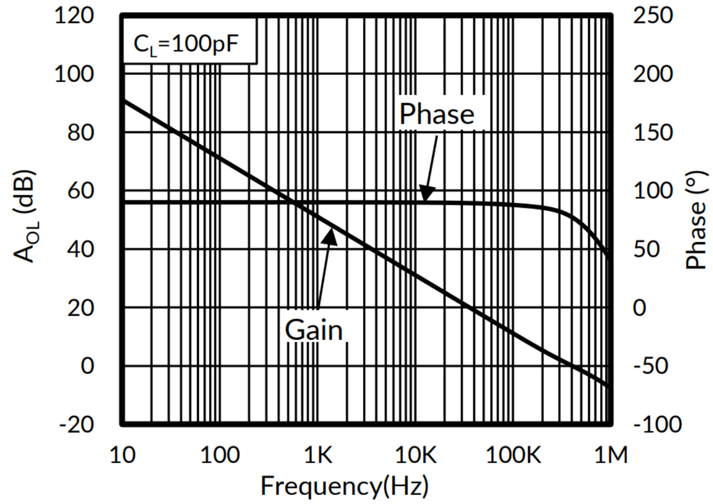


Figure 11. Open−Loop Gain and Phase vs. Frequency

DETAILED DESCRIPTION

Overview

The AT8541 is a zero-drift, low-power operational amplifier with rail-to-rail input and output capabilities. Operating within the range of 2V to 5.5V, this device is unity-gain stable and suitable for a broad spectrum of general-purpose applications. Its zero-drift architecture ensures ultra-low offset voltage and minimal offset voltage drift over time and temperature variations.

Feature Description

The AT8541 op amp is unity-gain stable and free from unexpected output phase reversal. It utilizes auto-zeroing techniques to achieve low offset voltage and minimal drift over time and temperature.

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

To achieve the lowest offset voltage and optimal precision performance, it is essential to optimize circuit layout and mechanical conditions. Avoid temperature gradients that induce thermoelectric (Seebeck) effects in thermocouple junctions formed by connecting dissimilar conductors. These thermally-generated potentials can be nullified by ensuring 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 AT8541 op amp operates over a power-supply range of +2V to +5.5V. 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.

Device Functional Modes

The AT8541 device has a single functional mode. The device is powered on as long as the power supply voltage is between 2V and 5.5V.

APPLICATION AND IMPLEMENTATION

Information in the following applications sections is not part of the RUNIC component specification, and RUNIC does not warrant its accuracy or completeness. RUNIC's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

APPLICATION NOTE

The AT8541 is a unity-gain stable, precision operational amplifier with very low offset voltage drift; these devices are also free from output phase reversal. Applications with noisy or high-impedance power supplies require decoupling capacitors close to the device power-supply pins. In most cases, 0.1uF capacitors are adequate.

Typical Applications

1. Bidirectional Current-Sensing

This single-supply, low-side, bidirectional current-sensing solution detects load currents from −1 A to 1 A. The single-ended output spans from 110 mV to 3.19 V. This design uses the AT8541 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.

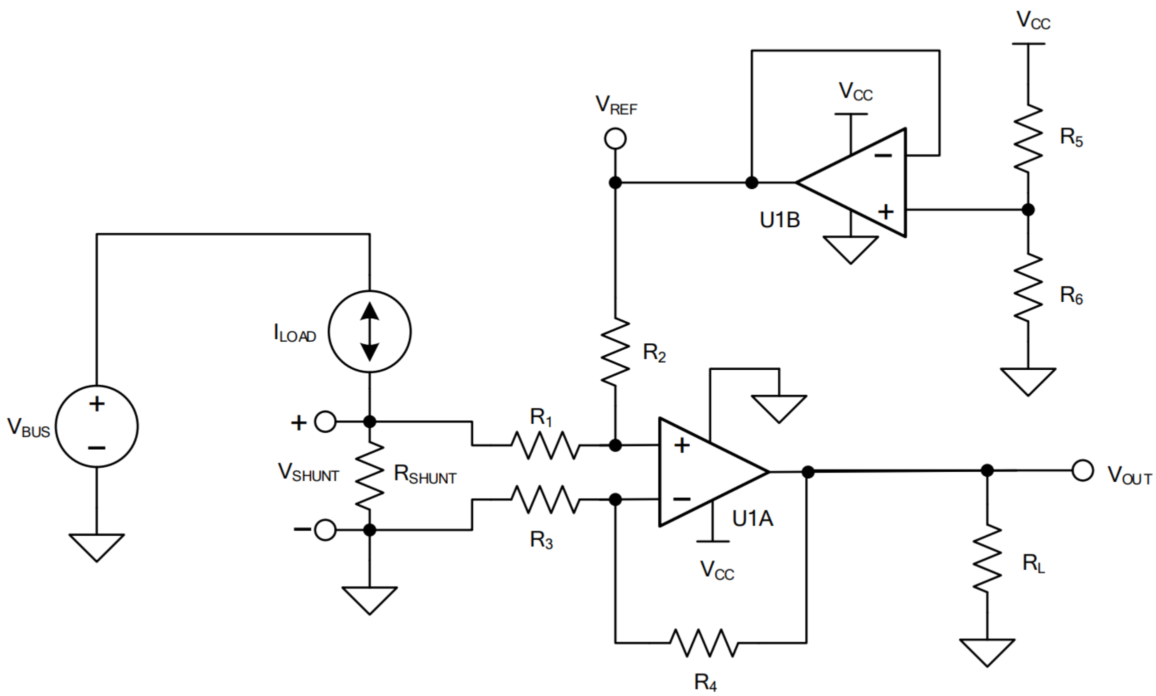


Figure 12. Bidirectional Current-Sensing Schematic

2. Design Requirements

This solution has the following requirements:

• Supply voltage: 3.3V

• Input Current: −1A to 1A

• Output Voltage: 1.65V ±1.54V (110mV to 3.19V)

3. 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

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

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

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

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 R4/R3 matches R2/R1. 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 100mV. Equation 2 calculates the maximum value of the shunt resistor given a maximum shunt voltage of 100mV and maximum load current of 1A.

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

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 −100mV to 100mV. 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 AT8541, that has a common-mode range that extends below the negative supply voltage. Finally, to minimize offset error, note that the AT8541 has a typical offset voltage of ±3uV (±30uV 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 AT8541 must be considered. Equation 3 and Equation 4 depict the typical common mode range and maximum output swing, respectively, of the AT8541 given a

3.3V supply.

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

$100mV < V_{OUT} < 3.2V$ (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.

4. Application Curve

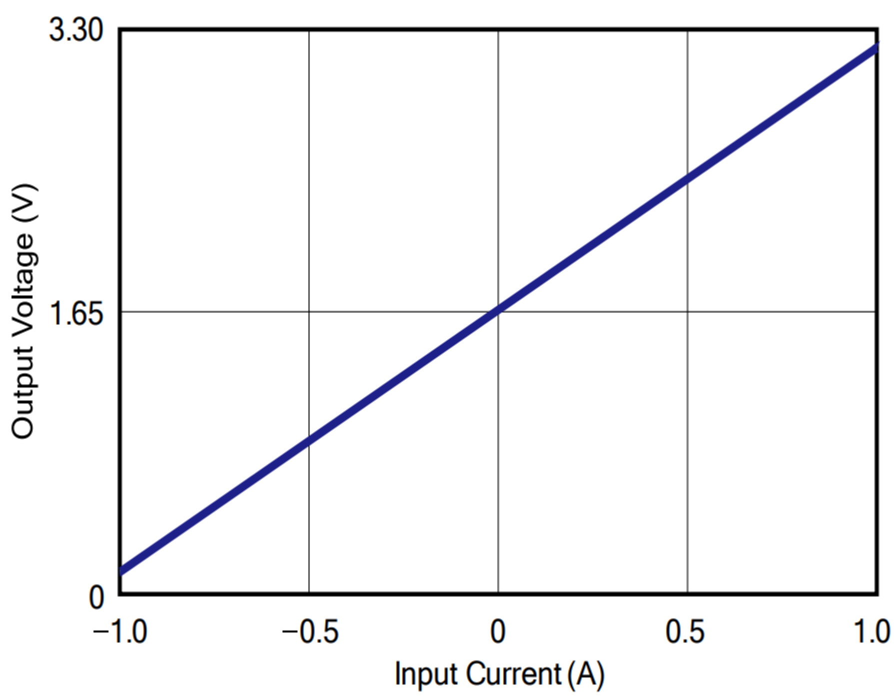


Figure 13. Bidirectional Current-Sensing Circuit Performance: Output Voltage vs Input Current

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 0.1uF 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 susceptibility.

Layout Example

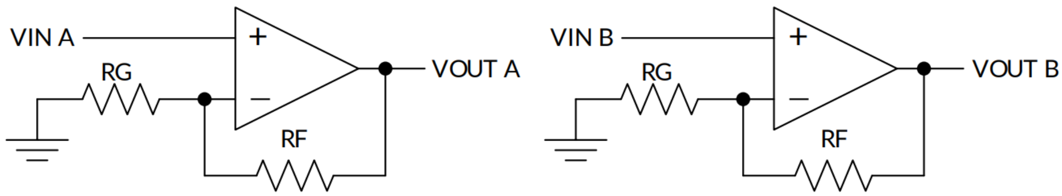


Figure 14. Schematic Representation

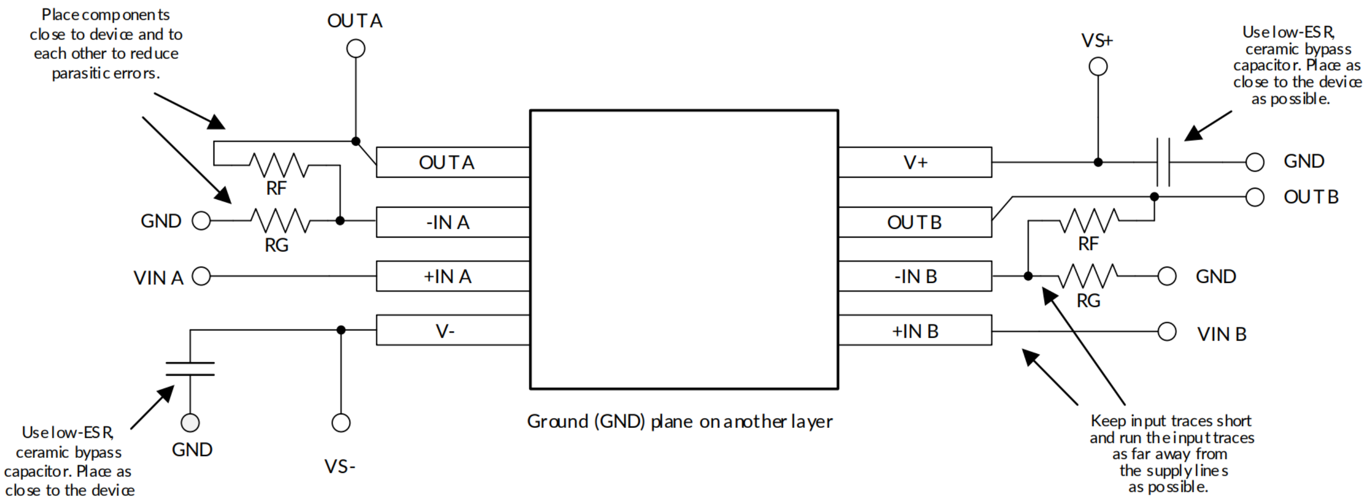
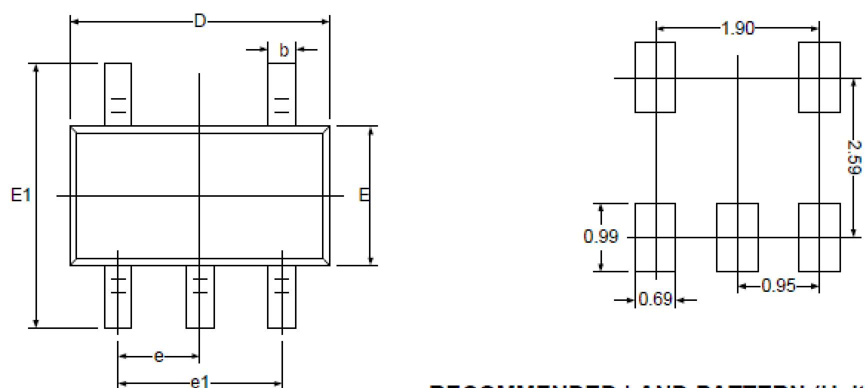


Figure 15. Layout Example

NOTE: Layout Recommendations have been shown for dual op-amp only, follow similar precautions for Single and four.

OUTLINE DIMENSIONS

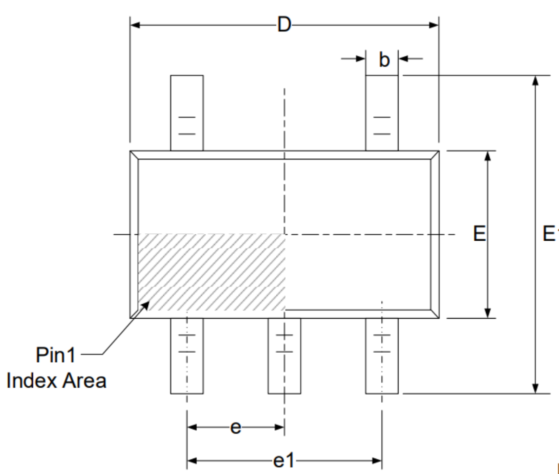
SOT23-5

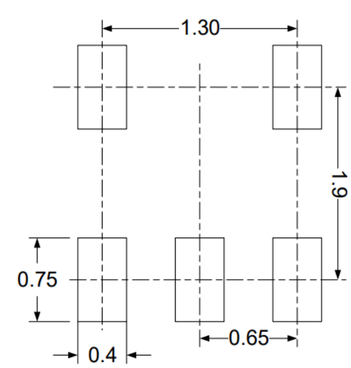


RECOMMENDED LAND PATTERN (Unit: mm)

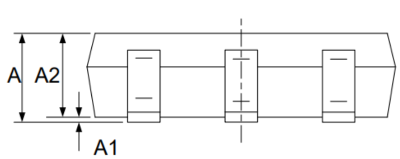
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min.	Max.	Min.	Max.
A	1.050	1.250	0.041	0.049
A1	0.000	0.100	0.000	0.004
A2	1.050	1.150	0.041	0.045
b	0.300	0.500	0.012	0.020
c	0.100	0.200	0.004	0.008
D	2.820	3.020	0.111	0.119
E	1.500	1.700	0.059	0.067
E1	2.650	2.950	0.104	0.116
e	0.950(BSC)		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°

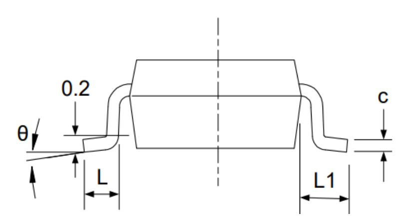
SOT353(SC70-5)





RECOMMENDED LAND PATTERN (Unit: mm)





Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min.	Max.	Min.	Max.
A	0.900	1.100	0.035	0.043
A1	0.000	0.100	0.000	0.004
A2	0.900	1.000	0.035	0.039
b	0.150	0.350	0.006	0.014
c	0.080	0.150	0.003	0.006
D	2.000	2.200	0.079	0.087
E	1.150	1.350	0.045	0.053
E1	2.150	2.450	0.085	0.096
e	0.650 (BSC)		0.026 (BSC)	
e1	1.300 (BSC)		0.051 (BSC)	
L	0.260	0.460	0.010	0.018
L1	0.525		0.021	
θ	0°	8°	0°	8°

ORDERING INFORMATION

Part Number	Buy Now
AT8541	* *

NOTICE

1. It is important to carefully read and follow the warnings, cautions, and product-specific notes provided with electronic components. These instructions are designed to ensure the safe and proper use of the component and to prevent damage to the component or surrounding equipment. Failure to follow these instructions could result in malfunction or failure of the component, damage to surrounding equipment, or even injury or harm to individuals. Always take the necessary precautions and seek professional assistance if unsure about proper use or handling of electronic components.
2. Please note that the products and specifications described in this publication are subject to change without prior notice as we continuously improve our products. Therefore, we recommend checking the product descriptions and specifications before placing an order to ensure that they are still applicable. We also reserve the right to discontinue the production and delivery of certain products, which means that not all products named in this publication may always be available.
3. This means that while ATI may provide information about the typical requirements and applications of their products, they cannot guarantee that their products will be suitable for all customer applications. It is the

responsibility of the customer to evaluate whether an ATI product with the specified properties is appropriate for their particular application.

4. ATI warrants its products to perform according to specifications for one year from the date of sale, except when damaged due to excessive abuse. If a product fails to meet specifications within one year of the sale, it can be exchanged free of charge.
5. ATI reserves the right to make changes or discontinue products or services without notice. Customers are advised to obtain the latest information before placing orders.
6. All products are sold subject to terms and conditions of sale, including those pertaining to warranty, patent infringement, and limitation of liability. Customers are responsible for their applications using ATI products, and ATI assumes no liability for applications assistance or customer product design.
7. ATI does not grant any license, either express or implied, under any patent right, copyright, mask work right, or other intellectual property right of ATI.
8. ATI's publication of information regarding third-party products or services does not constitute approval, warranty, or endorsement.
9. ATI retains ownership of all rights for special technologies, techniques, and designs for its products and projects, as well as any modifications, improvements, and inventions made by ATI.
10. Despite operating the electronic modules as specified, malfunctions or failures may occur before the end of their usual service life due to the current state of technology. Therefore, it is crucial for customer applications that require a high level of operational safety, especially in accident prevention or life-saving systems where the malfunction or failure of electronic modules could pose a risk to human life or health, to ensure that suitable measures are taken. The customer should design their application or implement protective circuitry or redundancy to prevent injury or damage to third parties in the event of an electronic module malfunction or failure.