High Common-Mode Voltage Programmable Gain Difference Amplifier

AD628

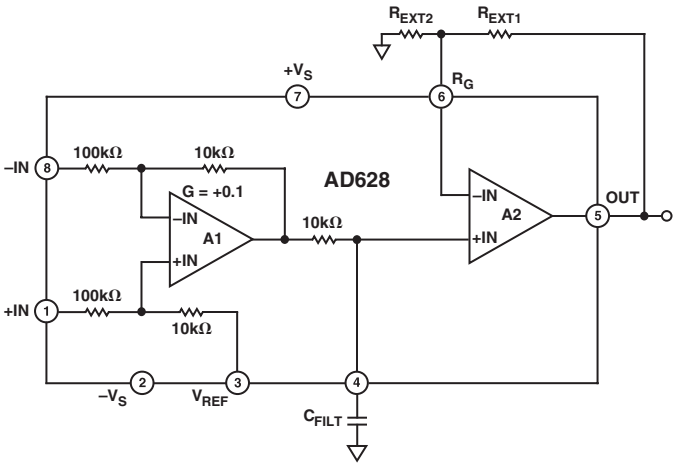
FEATURES

High Common-Mode Input Voltage Range
±120 V at V_S = ±15 V
Gain Range +0.01 to +100
Operating Temperature Range
–40°C to ±85°C
Supply Voltage Range
Dual Supply: ±2.25 V to ±18 V
Single Supply: +4.5 V to +36 V
Excellent AC and DC Performance
Offset Temperature Stability RTI
10 µV/°C Max
Offset
±1.5 V mV Max
CMRR RTI
75 dB Min, DC to 500 Hz, G = +1

APPLICATIONS

High Voltage Current Shunt Sensing
Programmable Logic Controllers
Analog Input Front End Signal Conditioning:
+5 V, +10 V, ±5 V, ±10 V, and 4–20 mA
Isolation
Sensor Signal Conditioning
Power Supply Monitoring
Electrohydraulic Control
Motor Control

FUNCTIONAL BLOCK DIAGRAM



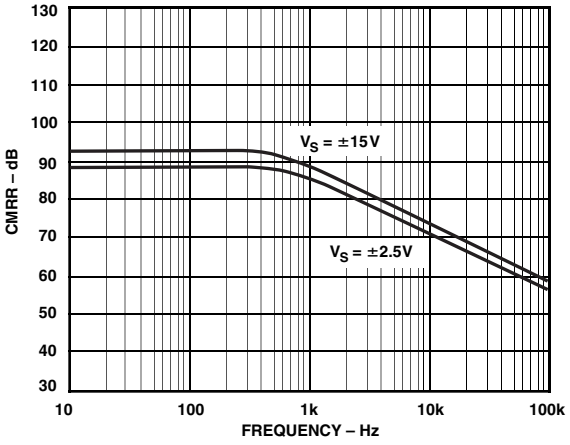


Figure 1. CMRR vs. Frequency of the AD628

GENERAL DESCRIPTION

The AD628 is a precision difference amplifier that combines excellent dc performance with high common-mode rejection over a wide range of frequencies. When used to scale high voltages, it allows simple conversion of standard control voltages or currents for use with single-supply A/D converters. A wideband feedback loop minimizes distortion effects due to capacitor charging of sigma-delta A/D converters.

A reference pin (V_{REF}) provides a dc offset for converting bipolar to single-sided signals. The AD628 converts +5 V, +10 V, ±5 V, ±10 V, and 4–20 mA input signals to a single-ended output within the input range of single-supply A/D converters.

The AD628 has an input common-mode and differential mode operating range of ±120 V. The high common-mode input impedance makes the device well suited for high voltage measurements across a shunt resistor. The buffer amplifier inverting input is available for making a remote Kelvin connection.

A precision 10 kΩ resistor connected to an external pin is provided for either a low-pass filter or to attenuate large differential input signals. A single capacitor implements a low-pass filter.

The AD628 operates from single and dual supplies and is available in an 8-lead SOIC package. Contact the factory for availability in an MSOP package. It operates over the standard industrial temperature range of –40°C to +85°C.

REV. A

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AD628—SPECIFICATIONS (T_A = 25°C, V_S = ±15 V, R_L = 2 kΩ, R_{EXT1} = 10 kΩ, R_{EXT2} = ∞, unless otherwise noted.)

Parameter	Conditions	Min	Typ	Max	Unit
DIFF-AMP + OUTPUT AMP					
Gain Equation	G = 0.1[R_{EXT4}/(R_{EXT4} + 10 kΩ)] (1+ R_{EXT1}/R_{EXT2})				V/V
Gain Range	Figure 4	0.01*		100	V/V
Gain Drift				5	ppm/°C
Offset Voltage		–1.5		+1.5	mV
vs. Temperature			4	8	µV/°C
CMRR		75			dB
	500 Hz	75			dB
Drift (RTI)			1	4	(µV/V)/°C
PSRR (RTI)	V_S = ±10 V to ±18 V	77	94		dB
Input Voltage Range					
Common-Mode				±120	V
Differential				±120	V
Dynamic Response					
Small Signal BW –3 dB	G = 0.1		600		kHz
Full Power Bandwidth			5		kHz
Settling Time	G = 0.1, to 0.01%, 100 V Step			40	µs
Slew Rate			0.3		V/µs
Noise (RTI)					
Spectral Density	1 kHz		300		nV/√Hz
	0.1 Hz to 10 Hz		15		µV p-p
DIFF-AMP					
Gain			0.1		V/V
Error		–0.1	+0.01	+0.1	%
vs. Temperature				5	ppm/°C
Nonlinearity				5	ppm
vs. Temperature			3	10	ppm
Offset Voltage (RTI)		–1.5		+1.5	mV
vs. Temperature				8	µV/°C
Input Impedance					
Differential			220		kΩ
Common-Mode			55		kΩ
CMRR (RTI)		75			dB
	Over Temperature	1	4		(µV/V)/°C
	500 Hz	75			dB
Output Resistance			10		kΩ
Error		–0.1		+0.1	%
OUTPUT AMPLIFIER					
Gain Equation			G = (1 + R_{EXT1}/R_{EXT2})		V/V
Nonlinearity	G = 1, V_{OUT} = ±10 V			0.5	ppm
Offset Voltage		–0.15		+0.15	mV
vs. Temperature				0.6	µV/°C
Output Voltage Swing	R_L = 2 kΩ	–13.8		+13.6	V
	R_L = 10 kΩ	–14.2		+14.1	V
Bias Current			1.5	3	nA
Offset Current			0.2	0.5	nA
CMRR	V_{CM} = ±13 V	130			dB
Open-Loop Gain	V_{OUT} = ±13 V	130			dB
POWER SUPPLY					
Operating Range		±2.25		±18	V
Quiescent Current				1.6	mA
TEMPERATURE RANGE		–40		+85	°C

Specifications subject to change without notice.

SPECIFICATIONS (T_A = 25°C, V_S = 5 V, R_L = 2 kΩ, R_{EXT1} = 10 kΩ, R_{EXT2} = ∞, unless otherwise noted.)

Parameter	Conditions	Min	Typ	Max	Unit
DIFF-AMP + OUTPUT AMP					
Gain Equation	G = 0.1[R_{EXT4}/(R_{EXT4} + 10 kΩ)] (1+ R_{EXT1}/R_{EXT2})				V/V
Gain Range	Figure 4	0.01*		100	V/V
Offset Voltage	V_{OCM} = 2.25 V	–3.0		+3.0	mV
vs. Temperature			6	15	µV/°C
CMRR		75			dB
	500 Hz	75			dB
Drift (RTI)			1	4	(µV/V)/°C
PSRR (RTI)	V_S = 4.5 V to 10 V	77	94		dB
Input Voltage Range	V_{REF} = 2.5 V				
Common Mode*		–12		+17	V
Differential			±15		V
Dynamic Response					
Small Signal BW –3 dB	G = 0.1		440		kHz
Full Power Bandwidth			30		kHz
Settling Time	G = 0.1, to 0.01%, 30 V Step		15		µs
Slew Rate			0.3		V/µs
Noise (RTI)					
Spectral Density	1 kHz		350		nV/√Hz
	0.1 Hz to 10 Hz		15		µV p-p
DIFF-AMP					
Gain			0.1		V/V
Error		–0.1	+0.01	+0.1	%
Nonlinearity				3	ppm
vs. Temperature			3	10	ppm
Offset Voltage (RTI)				2.5	mV
vs. Temperature				10	µV/°C
Input Impedance					
Differential			220		kΩ
Common-Mode			55		kΩ
CMRR (RTI)		75			dB
	Over Temperature		1	4	(µV/V)/°C
	500 Hz	75			dB
Output Resistance			10		kΩ
Error		–0.1		+0.1	%
OUTPUT AMPLIFIER					
Gain Equation		G = (1 + R_{EXT1}/R_{EXT2})			V/V
Nonlinearity	G = 1, V_{OUT} = 1 V to 4 V			0.5	ppm
Offset Voltage				0.15	mV
vs. Temperature				0.6	µV/°C
Voltage Swing	R_L = 2 kΩ	1		4	V
	R_L = 10 kΩ	0.9		4.1	V
Bias Current			1.5	3	nA
Offset Current			0.2	0.5	nA
CMRR	V_{CM} = 1 V to 4 V	130			dB
Open-Loop Gain	V_{OUT} = 1 V to 4 V	130			dB
POWER SUPPLY					
Operating Range		±2.25		+36	V
Quiescent Current				1.6	mA
TEMPERATURE RANGE		–40		+85	°C

*Greater values of voltage are possible with greater or lesser values of V_{REF}.
Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS*

Supply Voltage . . . . . ±18 V
Internal Power Dissipation . . . . . See Figure 2
Input Voltage (Common Mode) . . . . . ±120 V
Differential Input Voltage . . . . . ±120 V
Output Short Circuit Duration . . . . . Indefinite
Storage Temperature . . . . . –65°C to +125°C
Operating Temperature Range . . . . . –40°C to +85°C
Lead Temperature Range (10 sec Soldering) . . . . . 300°C

*Stresses greater than those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

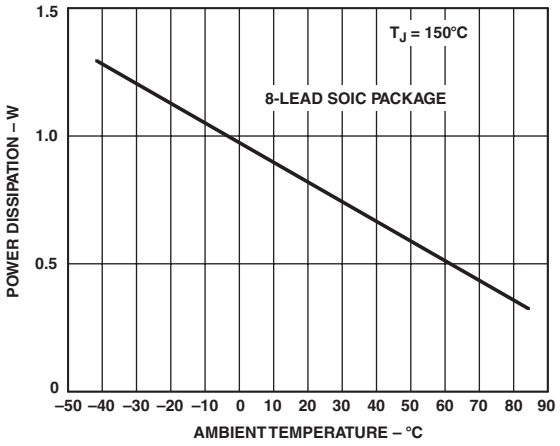


Figure 2. Maximum Power Dissipation vs. Temperature

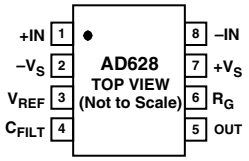
ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option
AD628AR	–40°C to +85°C	8-Lead SOIC	R-8
AD628ARM	–40°C to +85°C	8-Lead MSOP	RM-8
(Contact Factory)			
AD628AR-EVAL		Evaluation Board	

CAUTION

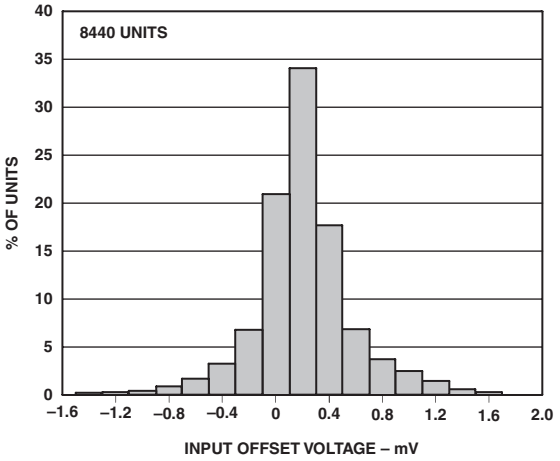
ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the AD628 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

PIN CONFIGURATION

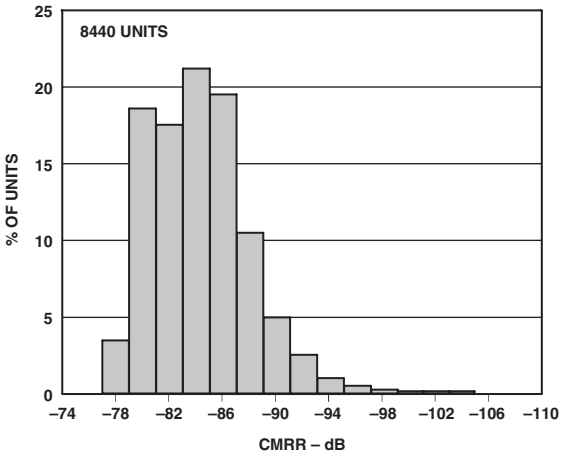


PIN FUNCTION DESCRIPTIONS

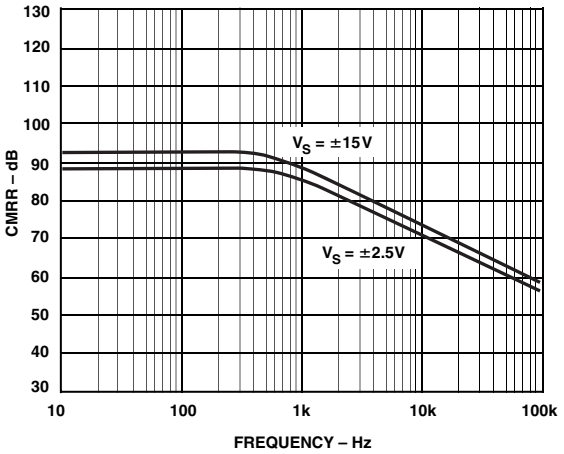
Pin No.	Mnemonic	Function
1	+IN	Noninverting Input
2	$-V_S$	Negative Supply Voltage
3	V_{REF}	Reference Voltage Input
4	C_{FILT}	Filter Capacitor Connection
5	OUT	Amplifier Output
6	R_G	Output Amplifier Inverting Input
7	$+V_S$	Positive Supply Voltage
8	–IN	Inverting Input



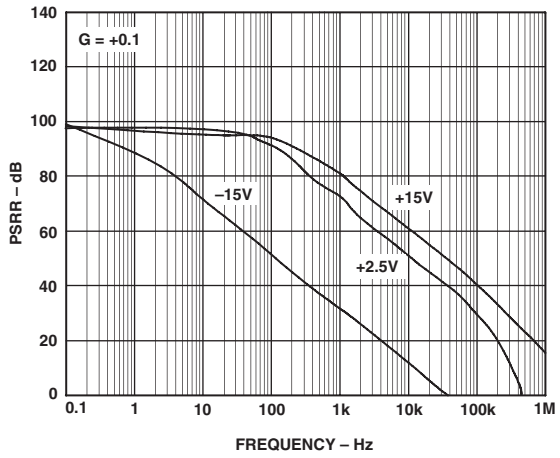
TPC 1. Typical Distribution of Input Offset Voltage, V_S = ±15 V, SOIC Package



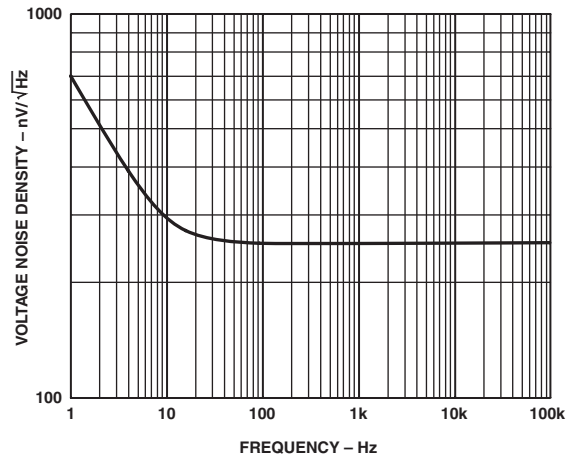
TPC 2. Typical Distribution of Common-Mode Rejection, SOIC Package



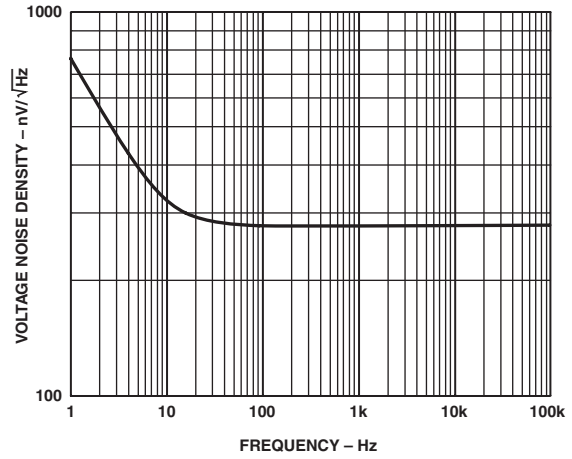
TPC 3. CMRR vs. Frequency



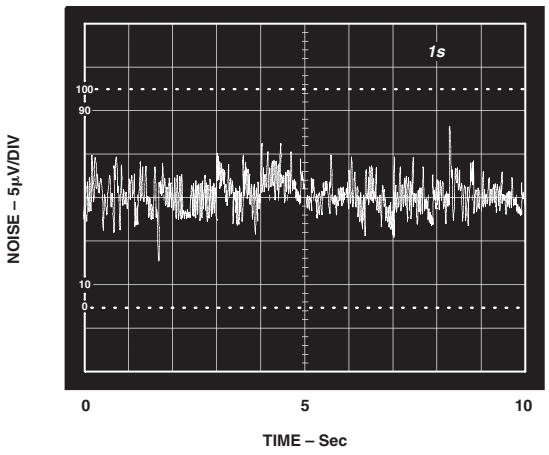
TPC 4. PSRR vs. Frequency, Single and Dual Supplies



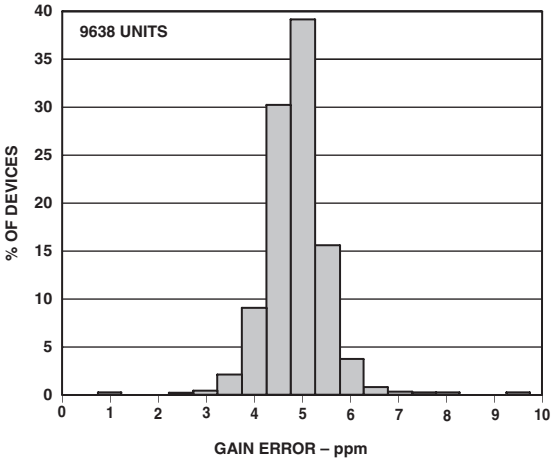
TPC 5. Voltage Noise Spectral Density, RTI, V_S = ±15 V



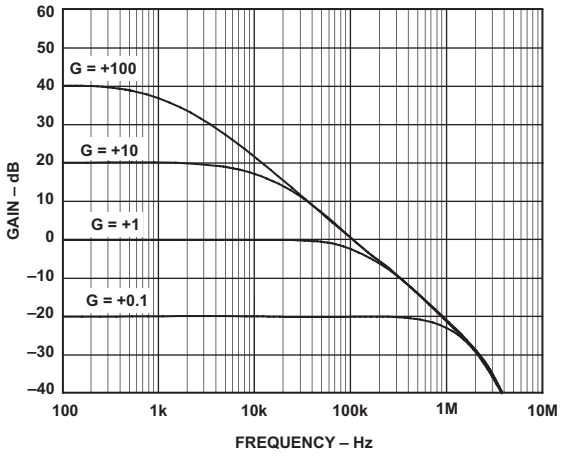
TPC 6. Voltage Noise Spectral Density, RTI, V_S = ±2.5 V



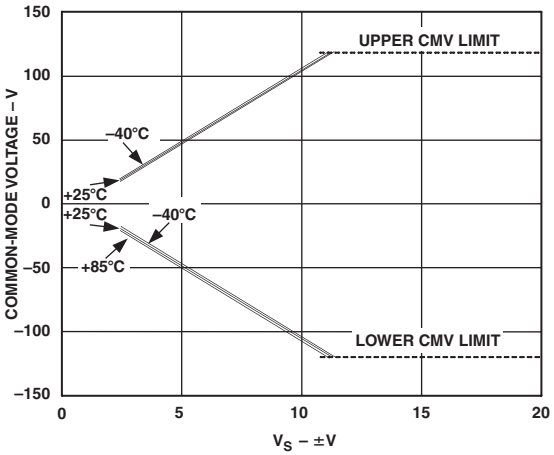
TPC 7. 0.1 Hz to 10 Hz Voltage Noise, RTI



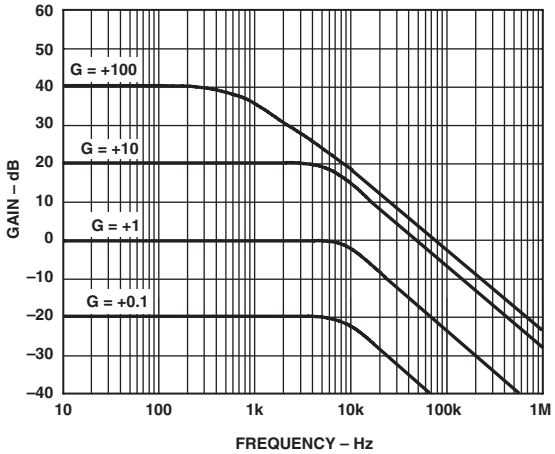
TPC 10. Typical Distribution of +1 Gain Error



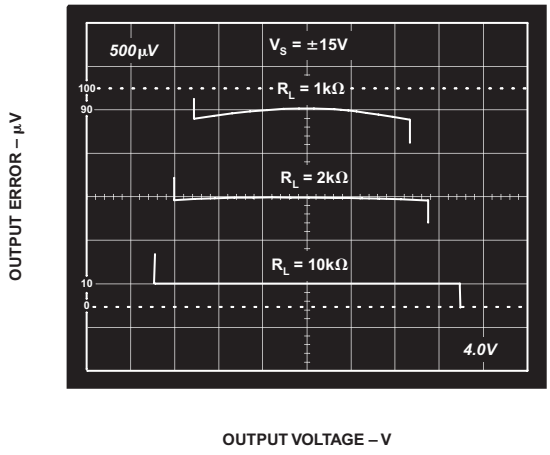
TPC 8. Small Signal Frequency Response, V_{OUT} = 200 mV p-p, G = +0.1, +1, +10, and +100



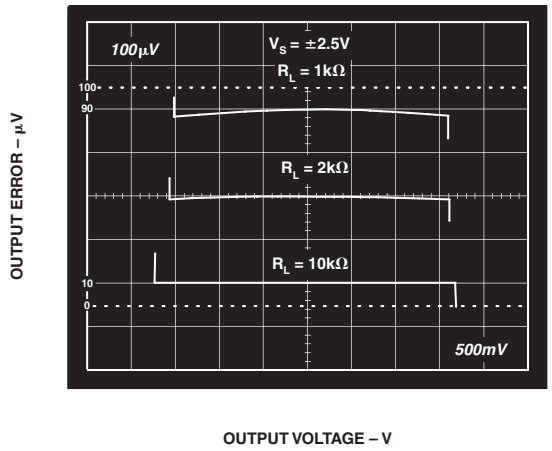
TPC 11. Common-Mode Operating Range vs. Power Supply Voltage for Three Temperatures



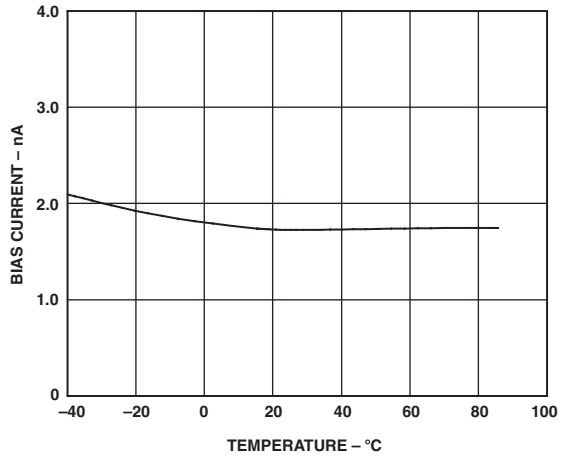
TPC 9. Large Signal Frequency Response, V_{OUT} = 20 V p-p, G = +0.1, +1, +10, and +100



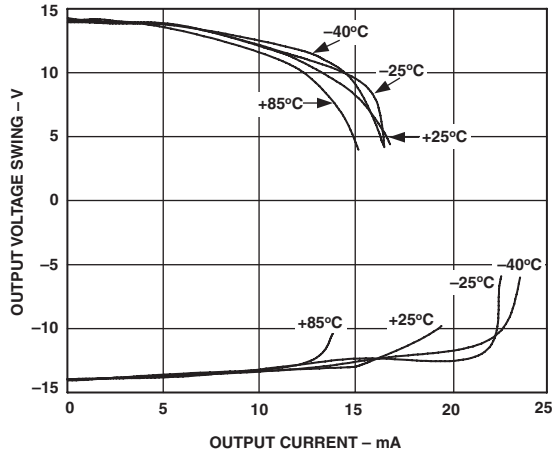
TPC 12. Normalized Gain Error vs. V_{OUT}, V_S = ±15 V



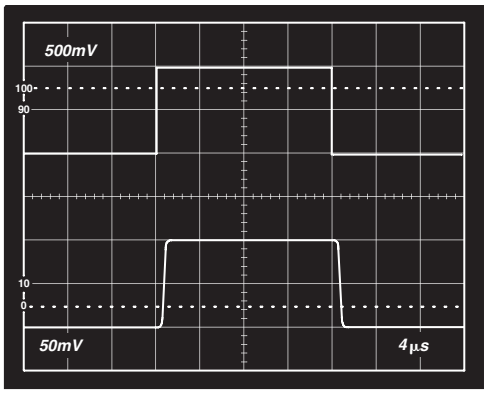
TPC 13. Normalized Gain Error vs. V_{OUT}, V_S = ±2.5 V



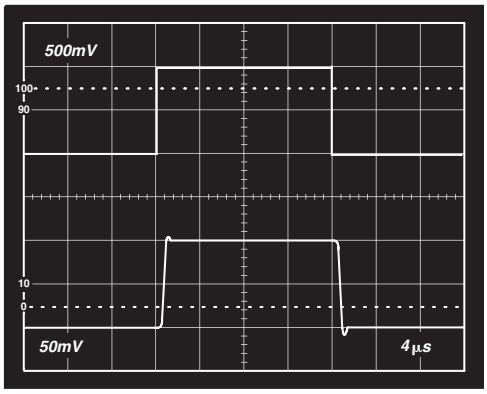
TPC 14. Bias Current vs. Temperature, Buffer



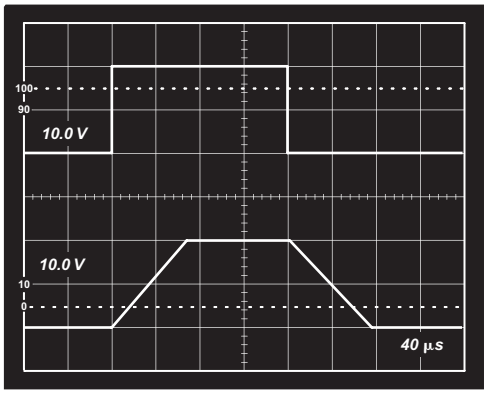
TPC 15. Output Voltage Operating Range vs. Output Current



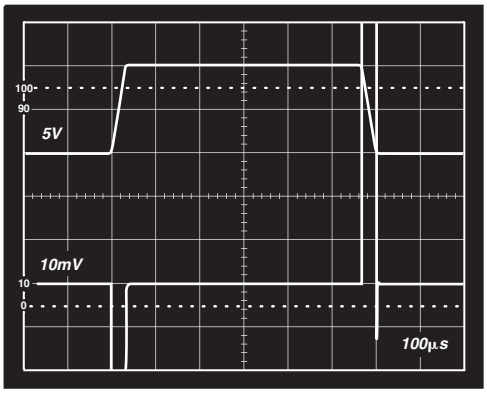
TPC 16. Small Signal Pulse Response, R_L = 2 kΩ, C_L = 0 pF, Top: Input, Bottom: Output



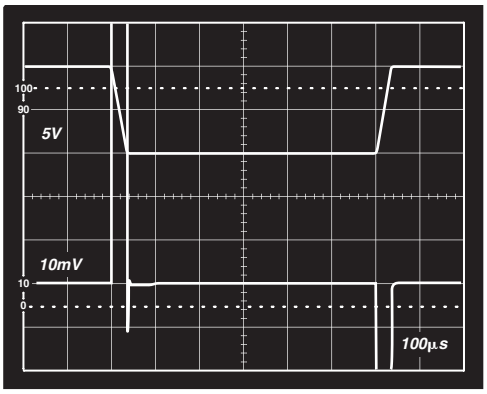
TPC 17. Small Signal Pulse Response, R_L = 2 kΩ, C_L = 1000 pF, Top: Input, Bottom: Output



TPC 18. Large Signal Pulse Response, R_L = 2 kΩ, C_L = 1000 pF, Top: Input, Bottom: Output

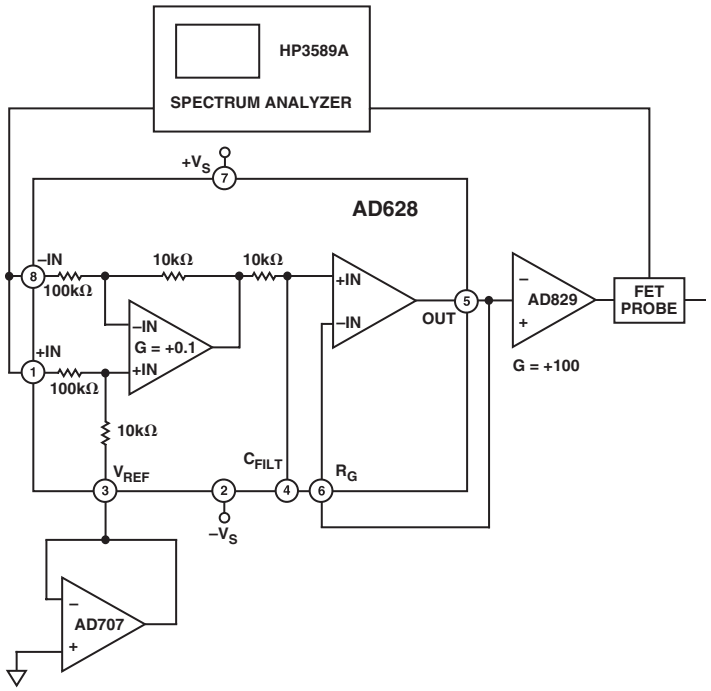


TPC 19. Settling Time to 0.01%, 0 V to +10 V Step

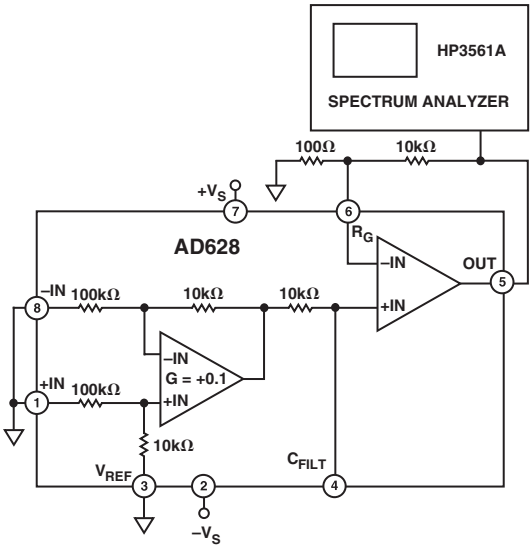


TPC 20. Settling Time to 0.01%, 0 V to –10 V Step

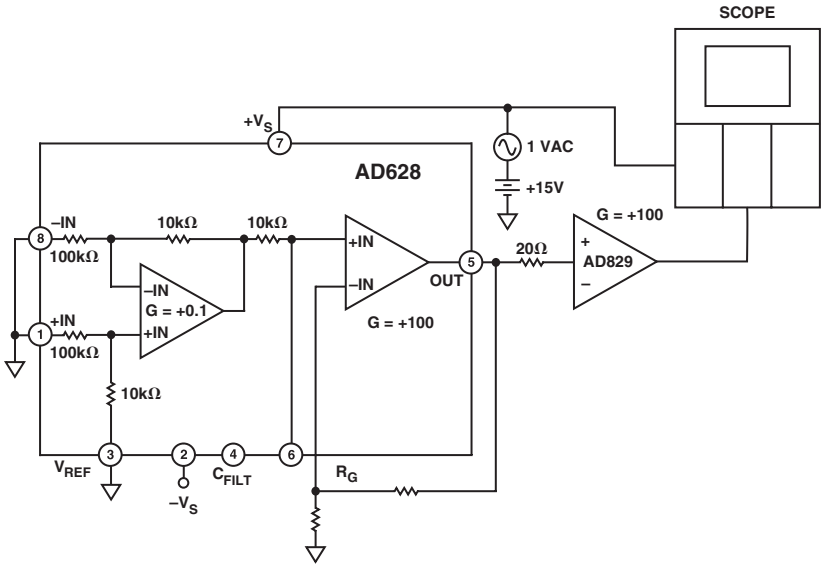
Test Circuits



Test Circuit 1. CMRR vs. Frequency



Test Circuit 3. Noise Tests



Test Circuit 2. PSRR vs. Frequency

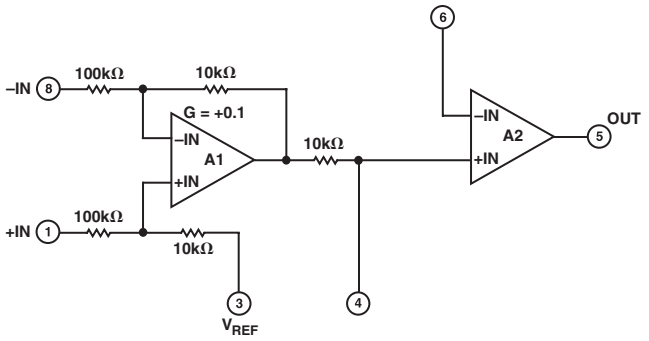


Figure 3. Simplified Schematic

THEORY OF OPERATION

The AD628 is a high common-mode voltage difference amplifier, combined with a user configurable output amplifier (see Figures 3 and 4). Differential mode voltages in excess of 150 V are accurately scaled by a precision 11:1 voltage divider at the input. A reference voltage input is available to the user at Pin 3. The output common-mode voltage of the difference amplifier will be whatever voltage is applied to the reference pin. If the uncommitted amplifier is configured for gain, connecting Pin 3 to one end of the external gain resistor establishes the output common-mode voltage at Pin 5.

The output of the difference amplifier is internally connected to a 10 kΩ resistor trimmed to better than ±0.1% absolute accuracy. The resistor is connected to the noninverting input of the output amplifier and is accessible to the user at Pin 4. A capacitor may be connected to implement a low-pass filter, a resistor to further reduce the output voltage, or a clamp circuit to limit the output swing.

The uncommitted amplifier is a high open-loop gain, low offset, low drift op amp, with its noninverting input connected to the internal 10 kΩ resistor. Both inputs are accessible to the user.

Careful layout design has resulted in exceptional common-mode rejection at higher frequencies. The inputs are connected to Pin 1 and Pin 8, which are adjacent to the power Pin 2 and Pin 7. Since the power pins are at ac ground, input impedance balance and, therefore, common-mode rejection are preserved at higher frequencies.

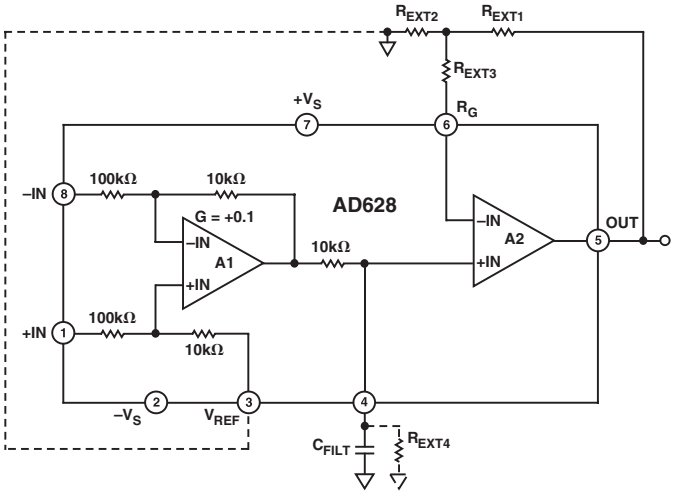


Figure 4. Circuit Connections

APPLICATIONS

Gain Adjustment

The AD628 system gain is provided by an architecture consisting of two amplifiers. The gain of the input stage is fixed at 0.1; the output buffer is user adjustable as follows:

$$G = 1 + \frac{R_{EXT1}}{R_{EXT2}}$$

The system gain is then:

$$G = 0.1 \times \left(1 + \frac{R_{EXT1}}{R_{EXT2}}\right)$$

At 2 nA maximum, the input bias current of the buffer amplifier is very low and any offset voltage induced at the buffer amplifier by its bias current may be neglected (2 nA × 10 kΩ = 20 μV). However, to absolutely minimize bias current effects, R_{EXT1} and R_{EXT2} may be selected so that their parallel combination is 10 kΩ. If practical resistor values force the parallel combination of R_{EXT1} and R_{EXT2} below 10 kΩ, a series resistor (R_{EXT3}) may be added to make up for the difference. Table I lists several values of gain and corresponding resistor values.

Table I. Nearest Standard 1% Resistor Values for Various Gains (See Figure 4)

Total Gain (V/V)	A2 Gain (V/V)	R_{EXT1} (Ω)	R_{EXT2} (Ω)	R_{EXT3} (Ω)	R_{EXT4} (Ω)
0.01	0.1	1 k	∞	0	1.1 k
0.02	0.2	2 k	∞	0	249 k
0.05	0.5	4.99 k	∞	0	10 k
0.1	1	10	∞	0	∞
0.2	2	20 k	20 k	0	∞
0.25	2.5	25.9 k	18.7 k	0	∞
0.5	5	49.9 k	12.4 k	0	∞
1	10	100 k	11 k	0	∞
2	20	200 k	10.5 k	0	∞
5	50	499 k	10.2 k	0	∞
10	100	1 M	10.2 k	0	∞

Voltage Level Conversion

Industrial signal conditioning and control applications typically require connections between remote sensors or amplifiers and centrally located control modules. Signal conditioners provide output voltages up to ±10 V full scale; however, A/D converters or microprocessors operating on single 3.3 V to 5 V logic supplies are becoming the norm. Thus, the controller voltages require further reduction in amplitude and reference.

Furthermore, voltage potentials between locations are seldom compatible, and power line peaks and surges can generate destructive energy between utility grids. The AD628 is an ideal solution to both problems. It attenuates otherwise destructive signal voltage peaks and surges by a factor of 10 and shifts the differential input signal to the desired output voltage.

Conversion from voltage-driven or current-loop systems is easily accommodated using the circuit in Figure 5. This shows a circuit for converting inputs of various polarities and amplitudes to the input of a single-supply A/D converter.

Note that the common-mode output voltage can be adjusted by connecting Pin 3 and the lower end of the 10 kΩ resistor to the desired voltage. The output common-mode voltage will be the same as the reference voltage.

The design of such an application may be done in a few simple steps:

1. Determine the required gain. For example, if the input voltage must be transformed from ±10 V to 0 V to +5 V, the gain is 5/20 or 0.25.
2. Determine if the circuit common-mode voltage must be changed. An AD7715-5 A/D converter is illustrated for this example. When operating from a 5 V supply, the common-mode voltage of the AD7715 is 1/2 the supply or 2.5 V. If the AD628 reference pin and the lower terminal of the 10 kΩ resistor are connected to a 2.5 V voltage source, the output common-mode voltage will be 2.5 V.

Table II shows resistor and reference values for commonly used single-supply converter voltages.

Table II. Nearest 1% Resistor Values for Voltage Level Conversion Applications

Input Voltage (V)	ADC Supply Voltage (V)	Desired Output Voltage (V)	V_{REF} (V)	R_{EXT1} (kΩ)
±10	5	2.5	2.5	15
±5	5	2.5	2.5	40
+10	5	2.5	2.5	40
+5	5	2.5	2.5	90
±10	3	1.25	1.25	
±5	3	1.25	1.25	
+10	3	1.25	1.25	
+5	3	1.25	1.25	

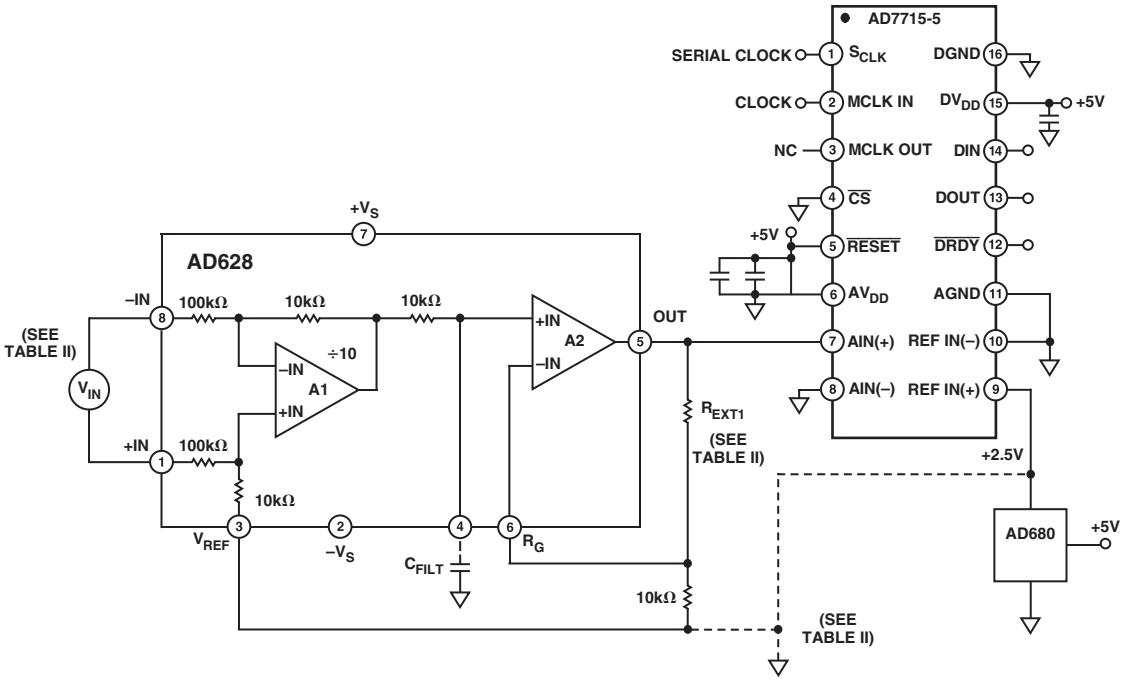


Figure 5. Level Shifter

Current Loop Receiver

Analog data transmitted on 4–20 mA current loop may be detected with the receiver shown in Figure 6. The AD628 is an ideal choice for such a function, since the current loop must be driven with a compliance voltage sufficient to stabilize the loop, and the resultant common-mode voltage will often exceed commonly used supply voltages. Note that with large shunt values a resistance of equal value must be inserted in series with the inverting input to compensate for an error at the noninverting input.

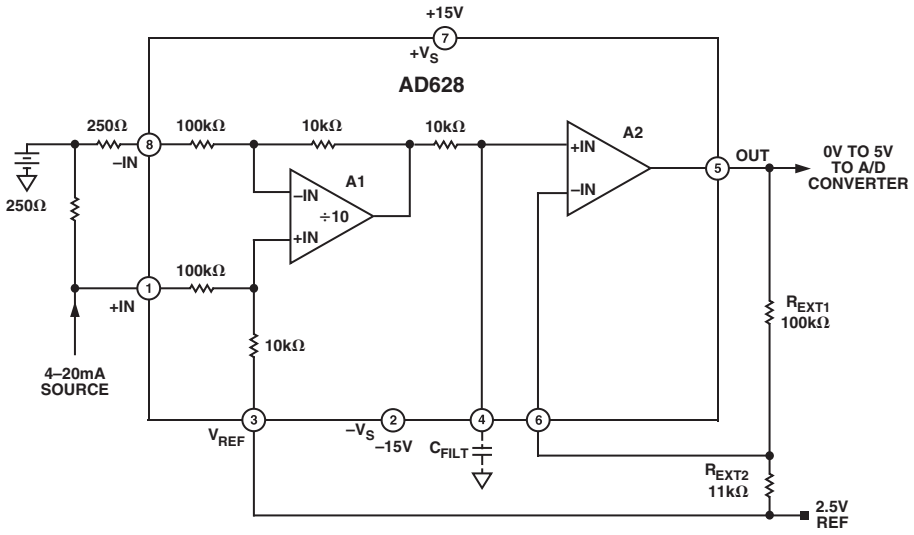


Figure 6. Level Shifter for 4–20 mA Current Loop

Monitoring Battery Voltages

Figure 7 illustrates how the AD628 may be used to monitor a battery charger. Voltages approximately eight times the power supply voltage may be applied to the input with no damage. The resistor divider action is well suited for the measurement of many power supply applications, such as those found in battery chargers or similar equipment.

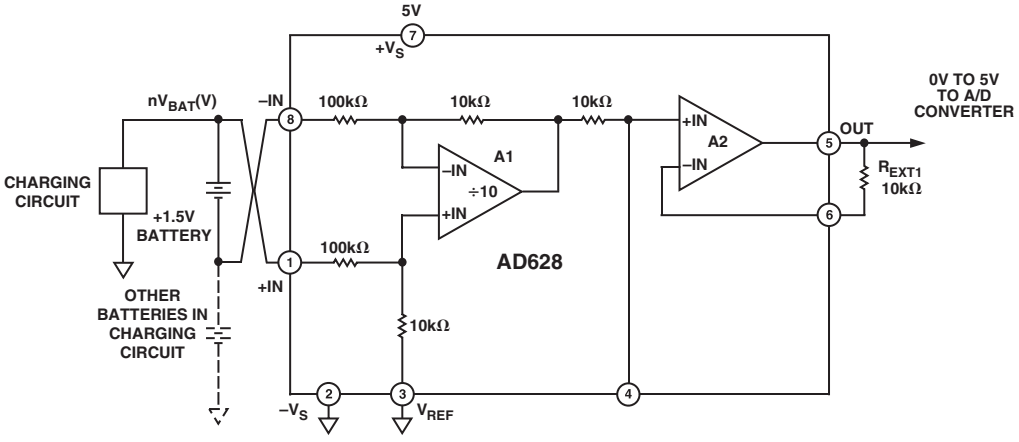


Figure 7. A Battery Voltage Monitor

Filter Capacitor Values

A capacitor may be connected to Pin 4 to implement a low-pass filter. The capacitor value will be:

$$C = 15.9/f_t \ (\mu F)$$

where f_t is the desired 3 dB filter frequency.

Table III shows several frequencies and their closest standard capacitor values.

Table III. Capacitor Values for Various Filter Frequencies

Frequency (Hz)	Capacitor Value (μF)
10	1.5
50	0.33
60	0.27
100	0.15
400	0.039
1k	0.015
5k	0.0033
10k	0.0015

Kelvin Connection

In certain applications it may desirable to connect the inverting input of an amplifier to a remote reference point. This eliminates errors resulting in circuit losses in interconnecting wiring. The AD628 is particularly suited for this type of connection (see Figure 8).

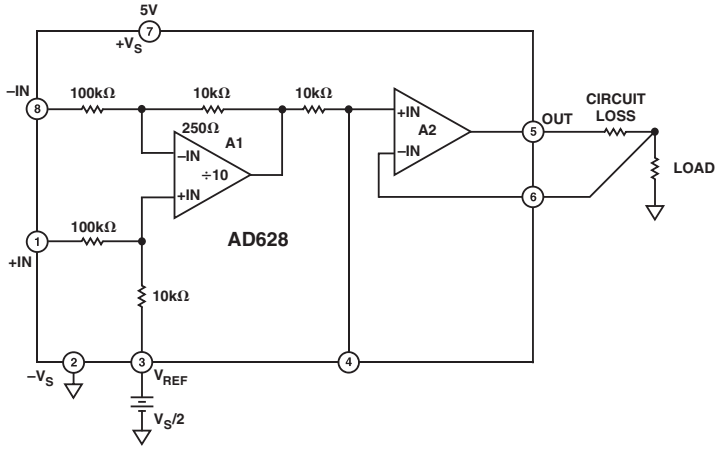
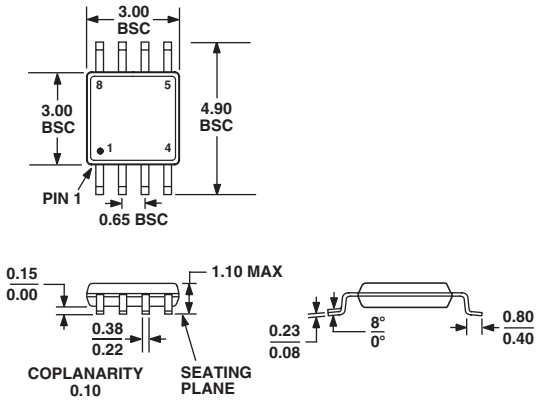


Figure 8. Kelvin Connection

OUTLINE DIMENSIONS

8-Lead MSOP Package [MSOP]
(RM-8)

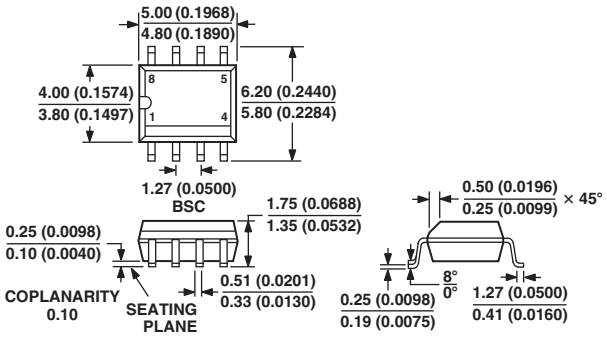
Dimensions shown in millimeters



COMPLIANT TO JEDEC STANDARDS MO-187AA

8-Lead Standard Small Outline Package [SOIC]
Narrow Body
(R-8)

Dimensions shown in millimeters and (inches)



COMPLIANT TO JEDEC STANDARDS MS-012AA
CONTROLLING DIMENSIONS ARE IN MILLIMETERS; INCH DIMENSIONS
(IN PARENTHESES) ARE ROUNDED-OFF MILLIMETER EQUIVALENTS FOR
REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN

Revision History

Location	Page
1/03—Data Sheet changed from REV. 0 to REV. A.	
Change to ORDERING GUIDE	4

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