# EFFECTIVELY APPLYING THE AD628 PRECISION GAIN BLOCK

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### Introduction

The AD628 can be operated as either a differential/ scaling amplifier or as a pin-strapped precision gain block. Specifically designed for use ahead of an analog-to-digital converter, the AD628 is extremely useful as an input scaling and buffering amplifier. As a differential amplifier, it can extract small differential voltages riding on large common-mode voltages up to ±120 V. As a prepackaged precision gain block, the pins of the AD628 can be strapped to provide a wide range of precision gains, allowing for high accuracy data acquisition with very little gain or offset drift.

The AD628 uses an absolute minimum of external components. Its tiny MSOP provides these functions in the smallest size package available in the market. Besides high gain accuracy and low drift, the AD628 provides a very high common-mode rejection, typically more than 90 dB at 1 kHz while still maintaining a 60 dB CMRR at 100 kHz.

The AD628 includes a $V_{REF}$ pin to allow a dc (midscale) offset for driving single-supply ADCs. In this case, the $V_{REF}$ pin may simply be tied to the ADC's reference pin, which also allows easy ratio-metric operation.

### Why Use a Gain Block IC?

Real-world measurement requires extracting weak signals from noisy sources. Even when a differential measurement is made, high common-mode voltages are often present. The usual solution is to use an op amp or, better still, an in amp, and then perform some type of low-pass filtering to reduce the background noise level.

The problem with this traditional approach is that a discrete op amp circuit will have poor common-mode rejection and its input voltage range will always be less than the power supply voltage. When used with a differential signal source, an in amp circuit using a monolithic IC will improve common-mode rejection. However, signal sources greater than the power supply voltage or signals riding on high common-mode voltages can't handle standard in amps. In addition, in amps using a single external gain resistor suffer from gain drift. Finally, low-pass filtering usually requires the addition of a separate op amp, along with several external components. This drains valuable board space.

The AD628 eliminates these common problems by functioning as a scaling amplifier between the sensor, the shunt resistor, or other point of data acquisition, as well as the ADC. Its 120 V max input range permits the direct measurement of large signals, or small signals riding on large common-mode voltages.

### Standard Differential Input ADC Buffer Circuit with Single-Pole LP Filter

Figure 1 shows the AD628 connected to accept a differential input signal riding on a very high common-mode voltage. The AD628 gain block has two internal amplifiers: A1 and A2. Pin 3 is grounded, thus operating amplifier A1 at a gain of 0.1. The 100 kΩ input resistors and other aspects of its design allow the AD628 to process small input signals riding on common-mode voltages up to ±120 V.

The output of A1 connects to the plus input of amplifier A2 through a 10 kΩ resistor. Pin 4 allows connecting an external capacitor to this point, providing single-pole low-pass filtering.

### Changing the Output Scale Factor

Figure 1 reveals that the output scale factor of the AD628 may be set by changing the gain of amplifier A2. This uncommitted op amp may be operated at any convenient gain higher than unity. When configured, the AD628 may be set to provide circuit gains between 0.1 and 1000.
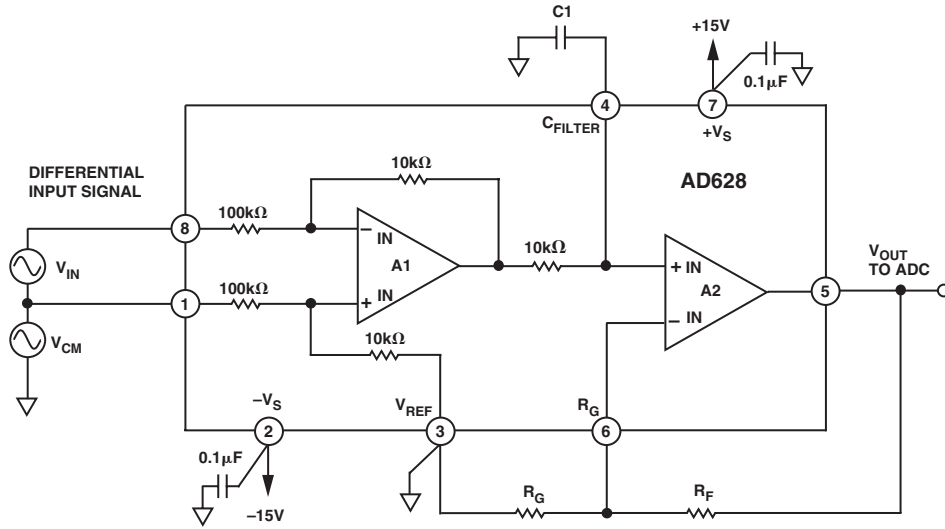
*Figure 1.  Basic Differential Input Connection with Single Pole LP Filter*

Since the gain of A1 is 0.1, the combined gain of A1 and A2 equals:

$$\frac{V_{OUT}}{V_{IN}} = G = 0.1\left(1 + \left(R_F/R_G\right)\right)$$

Therefore:

$$\left(10G - 1\right) = \frac{R_F}{R_G}$$

For ADC buffering applications, the gain of A2 should be chosen so the voltage driving the ADC is close to its full-scale input range. The use of external resistors $R_F$ and $R_G$ to set the output scale factor (i.e., gain of A2) will degrade gain accuracy and drift essentially to the resistors themselves.

A separate $V_{REF}$ pin is available for offsetting the AD628 output signal, so it is centered in the middle of the ADC's input range. Although Figure 1 indicates ±15 V,

the circuit may be operated from ±2.25 V to ±18 V dual supplies. This $V_{REF}$ pin may also be used to allow single-supply operation; $V_{REF}$ may simply be biased at $V_S/2$.

**Using an External Resistor to Operate the AD628 at Gains Below 0.1**

The AD628 gain block may be modified to provide any desired gain from 0.01 to 0.1, as shown in Figure 2.

This connection is the same as the basic wide input range circuit of Figure 1, but with Pins 5 and 6 strapped, and with an external resistor $R_G$ connection between Pin 4 and ground. The pin strapping operates amplifier A2 at unity gain. Acting with the on-chip 10 kΩ resistor at the output of A1, $R_{GAIN}$ forms a voltage divider that attenuates the signal between the output of A1 and the input of A2. The gain for this connection equals 0.1 $V_{IN}$ ((10 kΩ + $R_G$)/$R_G$).
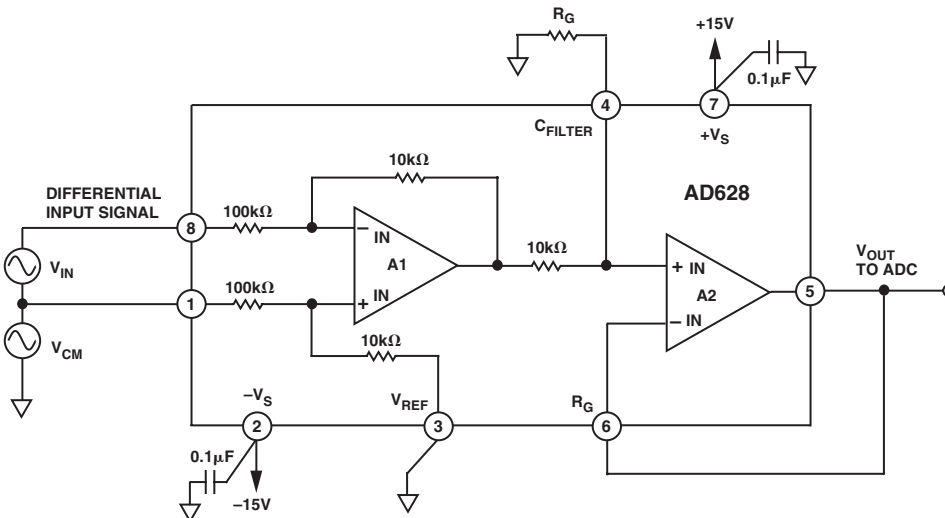


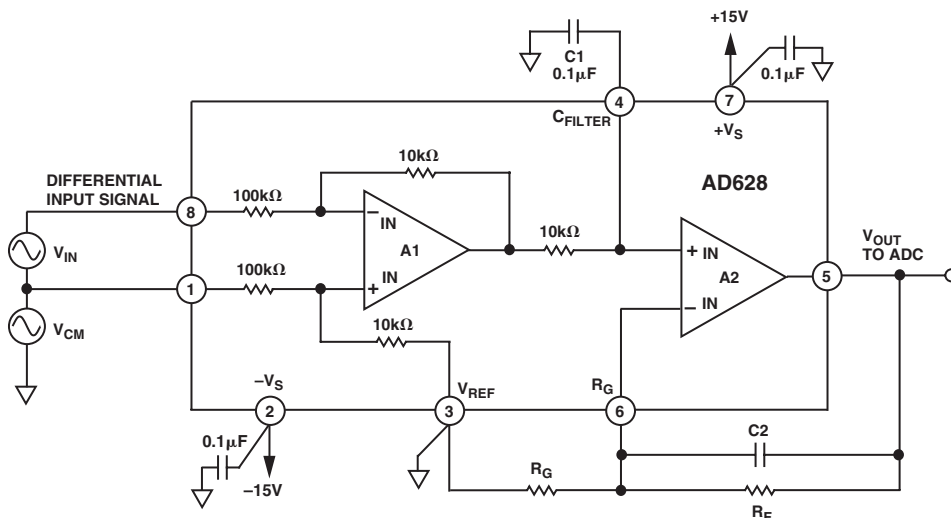*Figure 2. AD628 Connection for Gains Less Than 0.1*

*Figure 3. Differential Input Circuit with Two-Pole Low-Pass Filtering*

**Differential Input Circuit with Two-Pole Low-Pass Filtering**
The circuit in Figure 3 is a modification of the basic ADC interface circuit. Here, two-pole low-pass filtering is added for the price of one additional capacitor (C2).

As before, the first pole of the low-pass filter is set by the internal 10 kΩ resistor at the output of A1 and the external capacitor C1. The second pole is created by an external RC time constant, in the feedback path of A2, consisting of capacitor C2 across resistor $R_F$. Note that this second pole provides a more rapid roll-off of frequencies above its RC "corner" frequency ($1/(2\pi RC)$) than a single-pole LP filter. However, as the input frequency is increased, the gain of amplifier A2 eventually drops to unity and will not be further reduced. So, amplifier A2 will have a voltage gain set by the ratio of $R_F/R_G$ at frequencies below its –3 dB corner and have unity gain at higher frequencies.
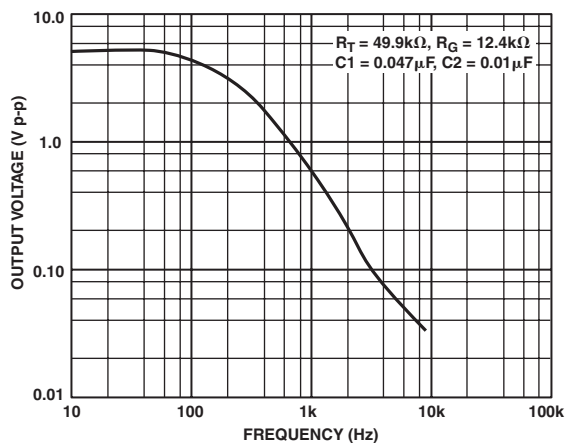


*Figure 4. Frequency Response of the Two-Pole LP Filter*

Figure 4 shows the filter's output versus frequency using components chosen to provide a 200 Hz –3 dB corner frequency. There is a sharp roll-off between the corner frequency and approximately 10× the corner frequency. Above this point, the second pole starts to become less effective and the rate of attenuation is close to that of a single-pole response.

**TABLE I**

Two-Pole LP Filter
Input Range: 10 V p-p F.S. for a 5 V p-p Output
$R_F$ = 49.9 kΩ, $R_G$ = 12.4 kΩ

| | –3 dB Corner Frequency | | | |
|---|---|---|---|---|
| | **200 Hz** | **1 kHz** | **5 kHz** | **10 kHz** |
| Capacitor C2 | 0.01 μF | 0.002 μF | 390 pF | 220 pF |
| Capacitor C1 | 0.047 μF | 0.01 μF | 0.002 μF | 0.001 μF |

**TABLE II**

Two-Pole LP Filter
Input Range: 20 V p-p F.S. for a 5 V p-p Output
$R_F$ = 24.3 kΩ, $R_G$ = 16.2 kΩ

| | –3 dB Corner Frequency | | | |
|---|---|---|---|---|
| | **200 Hz** | **1 kHz** | **5 kHz** | **10 kHz** |
| Capacitor C2 | 0.02 μF | 0.0039 μF | 820 pF | 390 pF |
| Capacitor C1 | 0.047 μF | 0.01 μF | 0.002 μF | 0.001 μF |

Tables I and II provide typical filter component values for various –3 dB corner frequencies and two different full-scale input ranges. Values have been rounded off to match standard resistor and capacitor values. Capacitors C1 and C2 need to be high Q, low drift devices; low grade disc ceramics should be avoided. High quality NPO ceramic, Mylar, or polyester film capacitors are recommended for the lowest drift and best settling time.

**Using the AD628 to Create Precision Gain Blocks**

Real-world data acquisition systems require amplifying weak signals enough to apply them to an ADC. Unfortunately, when configured as gain blocks, most common amplifiers have both gain errors and offset drift.

In op amp circuits, the usual two resistor gain setting arrangement has accuracy and drift limitations. Using standard 1% resistors, amplifier gain can be off by 2%. The gain will also vary with temperature because each resistor will drift differently. Monolithic resistor networks can be used for precise gain setting, but these components increase cost, complexity, and board space.

The gain block circuits of Figures 5 to 9 overcome all of these performance limitations, are very inexpensive, and offer a single MSOP solution. The AD628 provides this complete function using the smallest IC package available. Since all resistors are internal to the AD628 gain block, both accuracy and drift are excellent.

All of these pin-strapped circuits (using no external components) have a gain accuracy better than 0.2%, with a gain TC better than 50 ppm/°C.

**Operating the AD628 as a +10 or –10 Precision Gain Block**

Figure 5 shows an AD628 precision gain block IC connected to provide a voltage gain of +10. The gain block may be configured to provide different gains by strapping or grounding the appropriate pin. The gain block itself consists of two internal amplifiers: a gain of 0.1 difference amplifier (A1) followed by an uncommitted buffer amplifier (A2).

The input signal is applied between the $V_{REF}$ pin (Pin 3) and ground. With the input tied to Pin 3, the voltage at the positive input of A1 equals $V_{IN}$ (100 k$\Omega$/110 k$\Omega$) which is $V_{IN}$ (10/11). With Pin 6 grounded, the minus input of A2 equals 0 V. Therefore, the positive input of A2 will be forced by feedback from the output of A2 to be 0 V as well. The output of A1 must then also be at 0 V. Since the negative input of A1 must be equal to the positive input of A1, both will equal $V_{IN}$ (10/11).

This means that the output voltage of A2 ($V_{OUT}$) will equal

$$V_{OUT} = V_{IN}(10/11)(1 + 100\,k/10\,k) =$$
$$V_{IN}(10/11)\,11 = 10\,V_{IN}$$

The companion circuit in Figure 6 provides a gain of –10. This time, the input is applied between the negative input of A2 (Pin 6) and ground. Operation is exactly the same but now the input signal is inverted 180° by A2. With Pin 3 grounded, the positive input of A1 is at 0 V, so feedback will force the negative input of A1 to zero as well. Since A1 operates at a gain of 1/10 (0.1), the output of A2 that is needed to force the negative input of A1 to zero is *minus* 10 $V_{IN}$.

The two connections will have different input impedances. When driving Pin 3 (Figure 5), the input impedance to ground is 110 k$\Omega$, while it is approximately 50 G$\Omega$ when driving Pin 6 (Figure 6). The –3 dB bandwidth for both circuits is approximately 110 kHz for 10 mV and 95 kHz for 100 mV input signals.
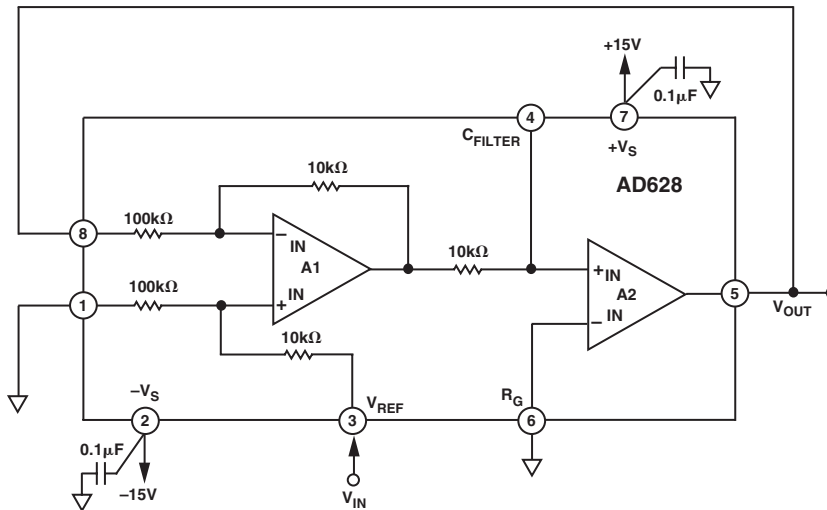


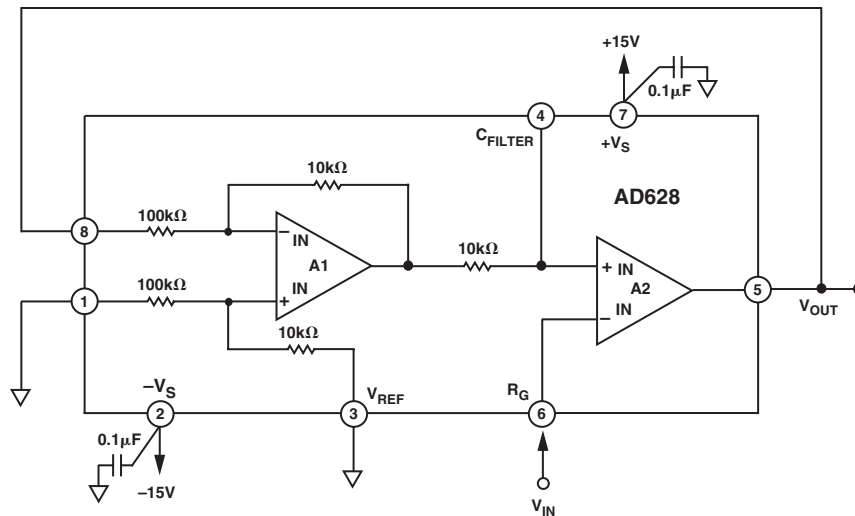*Figure 5. Circuit with a Gain of +10 Using No External Components*

Figure 6. Companion Circuit Providing a Gain of –10

**Operating the AD628 at a Precision Gain of +11**

The gain of +11 circuit (Figure 7) is almost identical to the gain of +10 connection, except that Pin 1 is strapped to Pin 3, rather than being grounded. This connects the two internal resistors (100 k$\Omega$ and 10 k$\Omega$) that are tied to the plus input of A1 in parallel. So, this now removes the 10 k$\Omega$/110 k$\Omega$ voltage divider between $V_{IN}$ and the positive input of A1. Thus modified, $V_{IN}$ drives the positive

input through approximately a 9 k$\Omega$ resistor. Note that this series resistance is negligible compared to the very high input impedance of amplifier A1. The gain from Pin 8 to the output of A1 is 0.1. Therefore, feedback will force the output of A2 to equal 10 $V_{IN}$. The –3 dB bandwidth of this circuit is approximately 105 kHz for 10 mV and 95 kHz for 100 mV input signals.
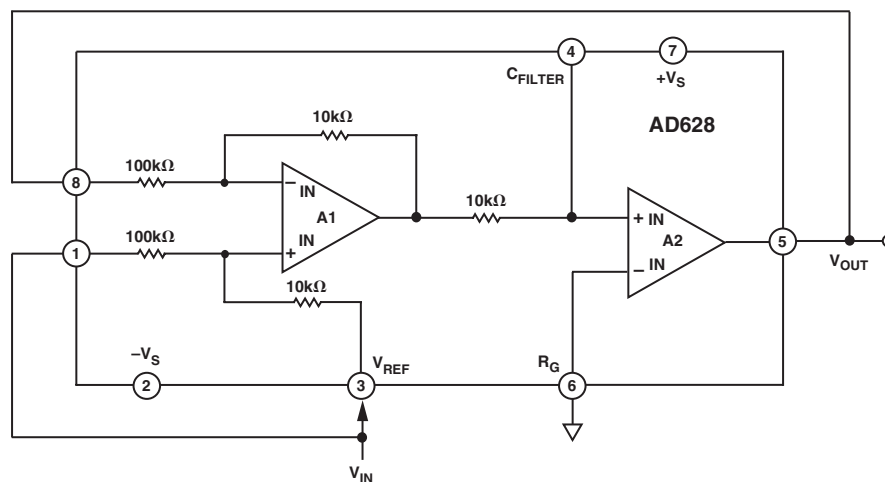


Figure 7. A Gain of +11 Circuit

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**Operating the AD628 at a Precision Gain of +1**

Figure 8 shows the AD628 connected to provide a precision gain of +1. As before, this connection uses the gain block's internal resistor networks for high gain accuracy and stability.

The input signal is applied between the $V_{REF}$ pin and ground. As Pins 1 and 8 are grounded, the input signal runs through a 100 k$\Omega$/110 k$\Omega$ input attenuator to the plus input of A1. The voltage equals $V_{IN}$ (10/11) = 0.909 $V_{IN}$. The gain from this point to the output of A1 will equal 1 + (10 k$\Omega$/100 k$\Omega$) = 1.10. Therefore, the voltage at the output of A1 will equal $V_{IN}$ (1.10) (0.909) = 1.00. Amplifier A2 is operated as a unity gain buffer (as Pins 5 and 6 tied together), providing an overall circuit gain of +1.

**Increased BW Gain Block of –9.91 Using Feed Forward**

The circuit of Figure 6 can be modified slightly by applying a small amount of positive feedback to increase its bandwidth, as shown in Figure 9. The output of amplifier A1 feeds back its positive input by connecting Pins 4 and 1 together. Now, Gain = –(10 – 1/11)= –9.91

The resulting circuit is still stable because of the large amount of negative feedback applied around the entire circuit (from the output of A2 back to the negative input of A1). This connection actually results in a small signal –3 dB bandwidth of approximately 140 kHz. This is a 27% increase in bandwidth over the unmodified circuit in Figure 6. However, gain accuracy is reduced to ±2%.
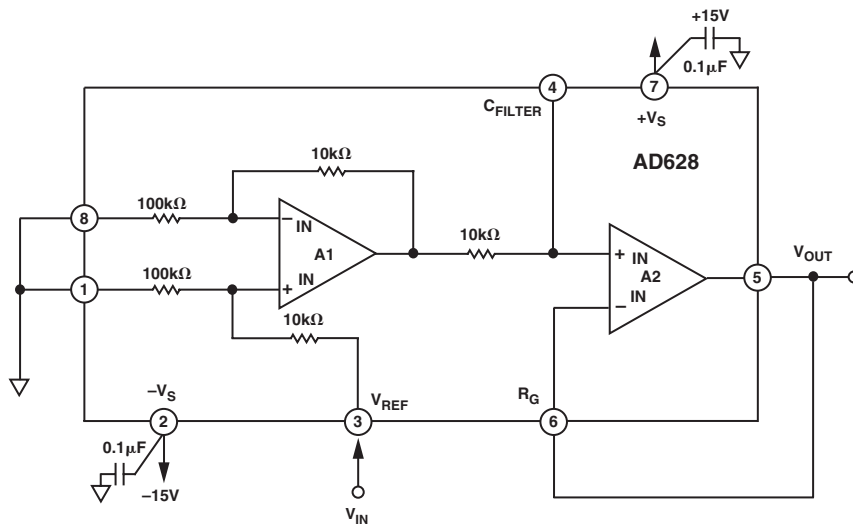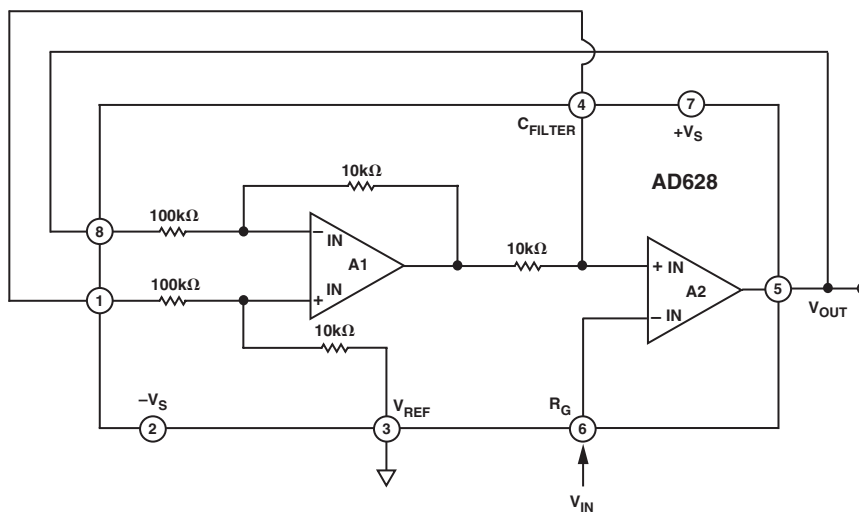


Figure 8. AD628 Precision Gain of +1



Figure 9. Precision –10 Gain Block with Feed Forward

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