Low Cost, High Voltage, Programmable Gain In-Amp Using the AD5292 Digital Potentiometer and the AD8221 In-Amp

CIRCUIT FUNCTION AND BENEFITS

The circuit shown in Figure 1 provides a low cost, high voltage, programmable gain instrumentation amplifier (in-amp) using the AD5292 digital potentiometer and the AD8221 in-amp.

The circuit offers 1024 different gain settings that are controllable through a digital serial peripheral interface (SPI). The ±1% resistor tolerance performance of the AD5292 provides low gain error over the full resistor range, as shown in Figure 2.

The circuit provides a high performance in-amp that delivers a high common-mode rejection ratio (CMRR) over frequency and dynamic programmable gain for both single-supply operation at +30 V and dual-supply operation at ±15 V. In addition, the AD5292 has an internal 20× programmable memory that allows the user to customize the in-amp gain at power-up.

The circuit provides accurate, low noise, high gain and is well suited for signal instrumentation conditioning, precision data acquisition, biomedical analysis, and aerospace instrumentation.

Figure 1. Programmable Gain In-Amp (Simplified Schematic, All Connections Not Shown)
CIRCUIT DESCRIPTION

This circuit employs the AD5292 digital potentiometer in conjunction with the AD8221 in-amp, providing an overall low cost, high voltage, programmable gain in-amp.

The differential input signal, +IN and –IN, is amplified by the AD8221. The in-amp offers accuracy, low noise, high CMRR, and high slew rate.

The maximum circuit gain (G) is defined in Equation 1, where \( R_{AW\_MIN} \) is the wiper resistance of the AD5292 in the rheostat mode and represents the minimum value of the gain setting resistance (100 \( \Omega \)).

\[
G = 1 + \frac{49.4 \text{ k}\Omega}{R_{AB}} \leq 1 + \frac{49.4 \text{ k}\Omega}{R_{AW\_MIN}} \leq 500
\]

where \( R_{AB} \) is the total resistance across the A and B terminals of the AD5292 in rheostat mode.

The circuit gain formula for any particular AD5292 resistance can be calculated with the following equation:

\[
G = 1 + \frac{49.4 \text{ k}\Omega}{(1024 - D) \times R_{AB}/1024}
\]

where \( D \) is the decimal code.

Equation 2 is plotted in Figure 3 as a function of the decimal code.

The maximum current allowed through the AD5292 is 1 ± 3 mA, which limits the allowable circuit gain as a function of differential input voltage.

Equation 3 shows the maximum gain limit as a function of the differential input voltage (\( V_{IN} \)). This equation is derived by substituting \( R_{AB} = V_{IN}/3 \text{ mA} \) into Equation 1. The result of Equation 3 is plotted in Figure 4.

\[
G \leq 1 + \frac{148}{V_{IN}}
\]

Equation 1 limits the maximum circuit gain to 500. Equation 2 can be solved for \( D \), yielding Equation 4, which calculates the minimum allowable resistance (in terms of the digital code) in the AD5292 without exceeding the current limit.

\[
D \geq 1024 - \frac{49.4 \text{ k}\Omega \times 1024}{R_{AB} \times (G - 1)}
\]

where:

- \( D \) is the code loaded in the digital potentiometer.
- \( G \) is the maximum gain calculated from Equation 3.

When the input to the circuit is an ac signal, the parasitic capacitances in the digital potentiometer can cause a reduction in the maximum AD8221 bandwidth. A gain and phase plot is shown in Figure 5.
The AD5292 has a 20× programmable memory, which allows presetting the output voltage in a specific value at power-up. Excellent layout, grounding, and decoupling techniques must be used to achieve the desired performance from the circuits discussed in this application note (see MT-031 Tutorial and MT-101 Tutorial). As a minimum, use a 4-layer printed circuit board (PCB) with one ground plane layer, one power plane layer, and two signal layers.

**COMMON VARIATIONS**

The AD5291 (8 bits with 20× programmable power-up memory) and the AD5293 (10 bits, no power-up memory) are both ±1% tolerance digital potentiometers that are suitable for this application.

**REFERENCE**

MT-031 Tutorial. *Grounding Data Converters and Solving the Mystery of "AGND" and "DGND"*. Analog Devices.


