AN-1208
APPLICATION NOTE

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Programmable Bidirectional Current Source Using the AD5292 Digital Potentiometer and the ADA4091-4 Op Amp

CIRCUIT FUNCTION AND BENEFITS

The circuit in Figure 1 provides a programmable bidirectional Howland current source using the AD5292 digital potentiometer in conjunction with the quad ADA4091-4 op amp and the ADR512 voltage reference. This circuit offers 10-bit resolution over an output current range of ±18.4 mA. The AD5292 is programmable over an SPI-compatible serial interface.

The ±1% resistor tolerance of the AD5292 allows it to be placed in series with external divider resistors, as shown in Figure 5, to reduce the maximum output current without the need to match the resistors in the circuit. Reducing the I_{OUT} range serves to increase the sensitivity of the output current.

The AD5292 has an internal 20-times programmable memory that allows a customized I_{OUT} at power-up. The circuit provides accurate, low noise, and low tempco output voltage capability and is well suited for digital calibration applications.

CIRCUIT DESCRIPTION

Table 1. Devices Connected/Referenced

Product	Description
AD5292	Digital potentiometer, 10 bits, 1% resistor tolerance
ADA4091-4	Micropower, overvoltage protected (OVP), rail-to-rail op amp
ADR512	Low noise, precision 1.2 V reference

This circuit employs the AD5292 digital potentiometer in conjunction with the ADR512 reference and the ADA4091-4 op amp, providing a 10-bit, programmable, bidirectional current source. The circuit guarantees monotonicity, ±1 LSB DNL, and has an integral nonlinearity of ±2 LSB, typical.

The bipolar high voltage regulator consists of a low voltage reference followed by a noninverting and an inverting amplifier whose gains are set by the ratio of R_1 to R_2.and R_3 to R_4. The ADR512 1.200 V voltage reference has low temperature drift, high accuracy, and ultralow noise performance.

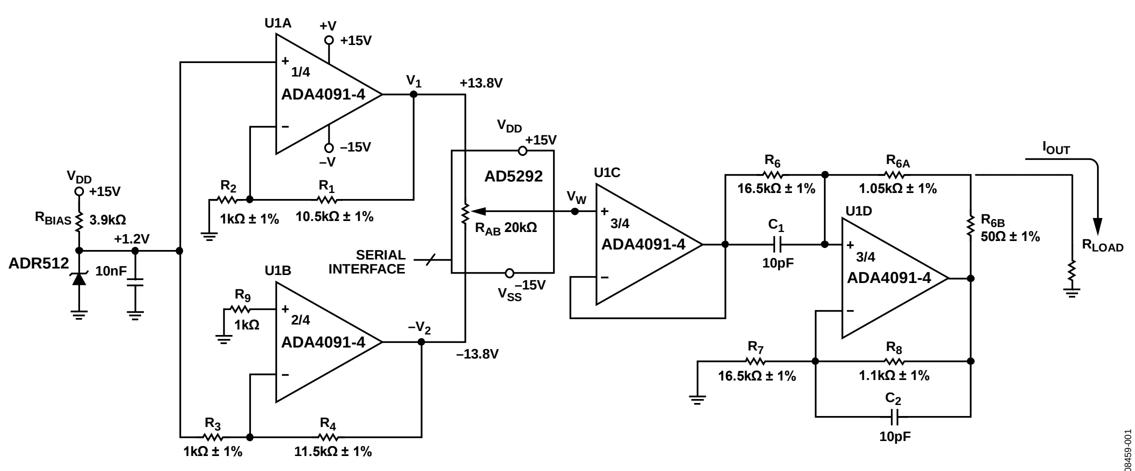

Figure 1. Programmable Bidirectional Current Source (Simplified Schematic: Decoupling and All Connections Not Shown)

The maximum resistor that ensures an ADR512 minimum operating current is defined in Equation 1.

$$R_{BIAS} = \frac{V_{DD} - 1.2\text{ V}}{1.5\text{ mA}} \quad (1)$$

As shown in Figure 1, the R_{BIAS} resistor is 3.9 kΩ, which sets the bias current of the ADR512 at 3.5 mA.

The ADA4091-4 is an op amp that offers low offset voltage and rail-to-rail output. The ADR512, in combination with the ADA4091, offers a low tempco and low noise output voltage.

The R_1 and R_2 resistors adjust the gain in the noninverting amplifier, U1A. The output voltage, V_1, defines the maximum positive output current range. Equation 2 and Equation 3 are used to calculate the resistor values.

$$V_1 \approx \frac{I_{OUT}}{1.33 \times 10^{-3}} \quad (2)$$

$$V_1 = 1.2 \times (1 + \frac{R_1}{R_2}) \quad (3)$$

The maximum negative output current range is adjusted by R_3 and R_4, which define the output voltage, V_2, in the inverting amplifier, U1B. Equation 4 and Equation 5 are used to calculate the resistor values.

$$V_2 \approx \frac{I_{OUT}}{1.33 \times 10^{-3}} \quad (4)$$

$$V_2 = 1.2 \times (-\frac{R_1}{R_2}) \quad (5)$$

The resistors, which are shown in Figure 1, are chosen to provide a gain of +11.5 and −11.5 in the noninverting and the inverting amplifier, respectively. This provides a bipolar regulated voltage of ±13.8 V. These voltages can be used to power other circuits with a maximum output current of +17 mA.

Equation 6 and Equation 7 calculate the output current of the Howland current source, and Figure 2 shows the maximum I_{OUT} versus code.

$$I_{OUT} = \frac{R_{6A} + R_{6B}}{R_7 \times R_{6B}} \times V_W = \quad (6)$$

$$= \frac{(1.05\text{ k}\Omega + 50\ \Omega) \times V_W}{16.5\text{ k}\Omega \times 50\ \Omega} = 1.33 \times 10^{-3} \times V_W$$

$$V_W = \frac{D \times (V_1 - V_2)}{1024} + V_2 = \frac{D \times 27.6}{1024} - 13.8 \quad (7)$$

where D is the code loaded in the digital potentiometer.

$$R_{6A} + R_{6B} = R_8 \quad (8)$$

$$R_5 = R_7 \quad (9)$$

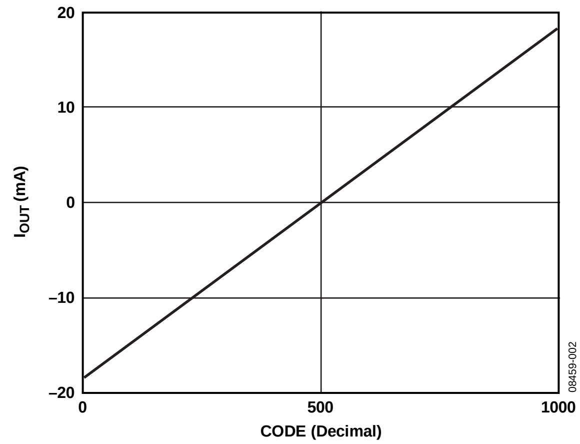

Figure 2. Maximum Output Current Versus Decimal Code

Typical INL and DNL plots are shown in Figure 3 and Figure 4.

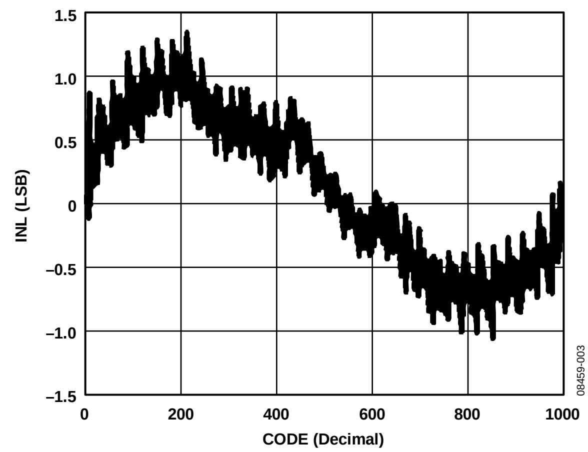

Figure 3. INL Versus Decimal Code

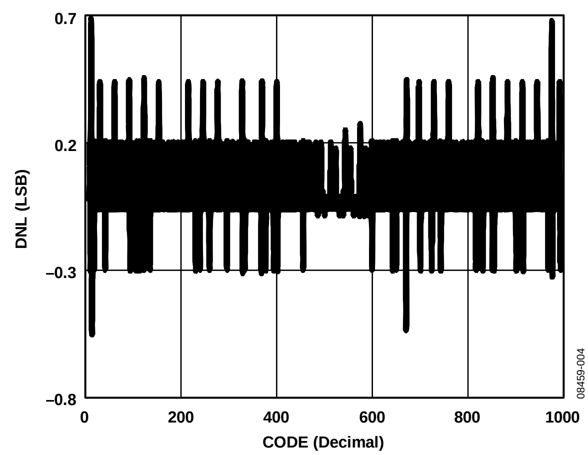

Figure 4. DNL Versus Decimal Code

As shown in Figure 1, the bidirectional current source operates over the maximum output range of ±18.4 mA. To improve the circuit accuracy the maximum output current, I_{OUT}, should be decreased by recalculating the resistor value in the U1C and U1D op amps or by reducing the voltage reference across the AD5292. This gives the full 10-bit resolution over a limited output current range.

The U1C and U1D op amp resistors can be recalculated using Equation 6 and Equation 7, but care should be taken to minimize errors when selecting standard resistor values from the calculated values. Decreasing the reference voltages, V_1 and V_2, in the AD5292 can be accomplished by recalculating the bipolar output regulator and the U1A and U1B output voltages or by using two external resistors, as shown in Figure 5.

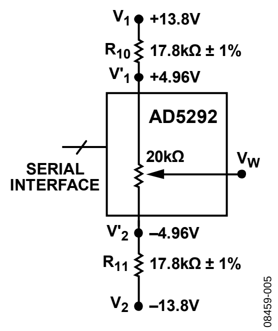

Figure 5. Improvement in Accuracy Using Reduced Reference Voltages (Simplified Schematic: Decoupling and All Connections Not Shown)

The resistors in series with the AD5292 are useful when the voltage references, V_1 and V_2, are the main system power supplies. Traditionally, digital potentiometers have a ±20% end-to-end resistor tolerance error. This affects the circuit accuracy because of the mismatch error between the digital potentiometer and the external resistors. The industry leading ±1% resistor tolerance performance of the AD5292 helps to overcome the mismatch resistance error.

The AD5292 has 20-times programmable memory, which allows presetting the circuit output current to 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 note (see MT-031 Tutorial and MT-101 Tutorial). As a minimum, a 4-layer PCB should be used with one ground plane layer, one power plane layer, and two signal layers.

COMMON VARIATIONS

The AD5291 (eight bits with 20-times 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.

The ADA4091-2 dual op amp can be used when the voltage references, V_1 and V_2, are not necessary.

LEARN MORE

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

MT-032 Tutorial, *Ideal Voltage Feedback (VFB) Op Amp*, Analog Devices.

MT-087 Tutorial, *Voltage References*, Analog Devices.

MT-091 Tutorial, *Digital Potentiometers*, Analog Devices.

MT-095 Tutorial, *EMI, RFI, and Shielding Concepts*, Analog Devices.

MT-101 Tutorial, *Decoupling Techniques*, Analog Devices.

Data Sheets

AD5292 Data Sheet

AD5291 Data Sheet

AD5293 Data Sheet

ADR512 Data Sheet

ADA4091-2 Data Sheet

ADA4091-4 Data Sheet

REVISION HISTORY

4/13—Rev. B to Rev. C

Changed Document Title from CN-0177 to AN-1208 .... Universal

3/11—Rev. A to Rev. B

Change to Figure 1 1

3/10—Rev. 0 to Rev. A

Changes to Circuit Function and Benefits Section 1

9/09—Revision 0: Initial Version

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