AN-1313 APPLICATION NOTE

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Configuring the AD5422 to Combine Output Current and Output Voltage to a Single Output Pin

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INTRODUCTION

As technology continues to evolve, systems tend to have configurable output ranges to lessen the need for multiple product variants to support the various range options.

The circuit shown in Figure 1 uses the AD5422, a single channel, 16-bit, serial input, unipolar/bipolar voltage and current output DAC. The voltage output ranges available are 0 V to 5 V, 0 V to 10 V, −5 V to +5 V, or −10 V to +10 V. There is also a 10% overrange facility available on the voltage output ranges. The current output, which is accessed from a separate pin, can be programmed to the following ranges: 4 mA to 20 mA, 0 mA to 20 mA, or 0 mA to 24 mA.

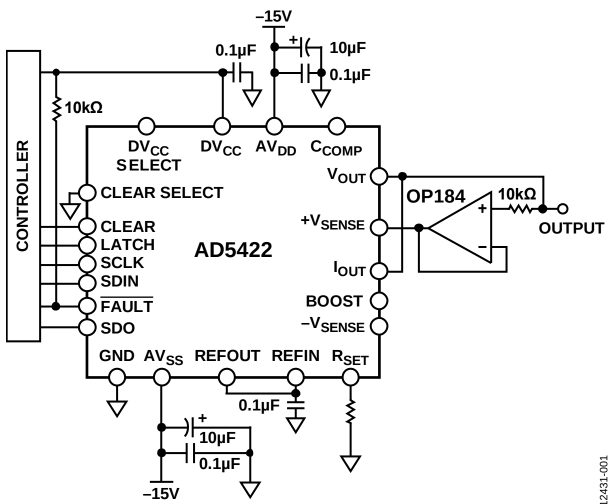

Figure 1. AD5422 I_{OUT} and V_{OUT} Connected Together

The current and voltage output pins can be connected together such that they are available on the same screw terminal in the end application. In this case, a buffer amplifier, or, alternately, a switch is required to prevent a current leakage path through an internal resistor on the $+V_{SENSE}$ pin when the device is in current output mode.

The internal structure of the voltage output block is shown in Figure 2.

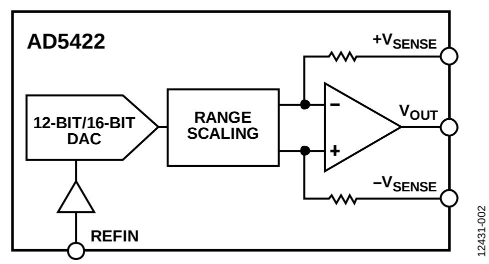

Figure 2. Voltage Output

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REVISION HISTORY

6/14—Revision 0: Initial Version

CIRCUIT DESCRIPTION

This application note uses integral nonlinearity (INL) to examine the effect of some variables involved in this circuit.

- Optional external boost transistor
- Internal/external R_{SET} resistor
- Unipolar/ bipolar supplies
- Choice of external buffer amplifier

In the case of the first two variables, the use of the external boost transistor and the choice of the R_{SET} resistor, these only affect the AD5422 when in current output mode. The voltage output mode is independent of these variables.

The two ranges examined during the linearity tests are 0 V to 10 V and 0 mA to 24 mA. An output load of 500 Ω is used for the current output tests, while the output is unloaded for the voltage output tests. Note that 0 V to 15 V supplies are used in the unipolar supply case and ±15 V supplies are used in the bipolar case. The two external buffers tested are the OP184 and the OP1177.

EXTERNAL BOOST TRANSISTOR

The addition of an external boost transistor, as shown in Figure 3, reduces the power dissipated in the AD5422 by reducing the current flowing in the on-chip output transistor (dividing it by the current gain of the external circuit). A discrete NPN transistor with a breakdown voltage greater than 40 V is used. The external boost capability has been developed for those who wish to use the AD5422 at the extremes of the supply voltage, load current, and temperature range.

The boost transistor can also be used to reduce the amount of temperature-induced drift in the part. This minimizes the temperature-induced drift of the on-chip voltage reference, DAC, and current/voltage circuitry, which improves on drift and linearity.

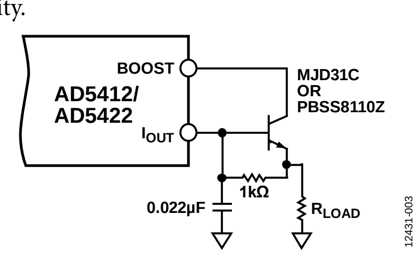

Figure 3. External Boost Configuration

Figure 4 shows an INL vs. code plot with and without the external boost transistor in place.

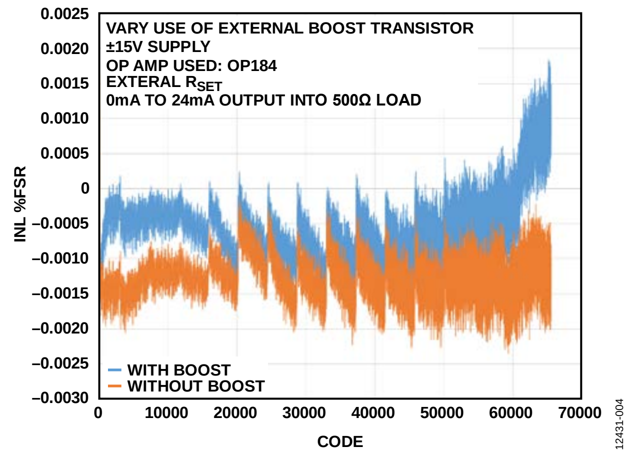

Figure 4. Current Output Mode With/Without Boost Transistor

EXTERNAL CURRENT SETTING RESISTOR

R_{SET} is an internal sense resistor used as part of the voltage-to-current conversion circuitry (see Figure 5). The stability of the output current over temperature is dependent on the stability of the value of R_{SET}. As a method of improving the stability of the output current over temperature, an external precision 15 kΩ low drift resistor can be connected to the R_{SET} pin of the AD5422 to be used instead of the internal R_{SET} resistor.

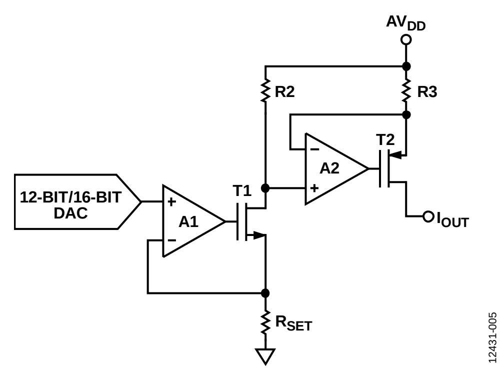

Figure 5. Voltage to Current Conversion Circuitry

When shorting V_{OUT} and I_{OUT} using the external buffer amplifier method described in this application note, it is recommended that the external R_{SET} resistor be used for best accuracy and load regulation results.

POWER SUPPLIES AND OUTPUT CONFIGURATION

Note that 0 V to 15 V is used for the unipolar supply option, while ±15 V is used for the bipolar option. These supplies are used to power AV_{DD}/AV_{SS} of the AD5422, as well as V+ and V− of the external buffer amplifier.

Regardless of whether V_{OUT} and I_{OUT} are shorted together, when using unipolar supplies, output linearity is measured from code 256, as the gain of the output amplifier drops when the footroom collapses as the output approaches AV_{SS}.

When V_{OUT} and I_{OUT} are shorted together, and OP184 is used as the external buffer amplifier, note that although the OP184 can operate with unipolar supplies, it has a V_{OL} specification of 125 mV in unipolar mode. This limits the minimum achievable zero-scale output voltage. Figure 6 demonstrates I_{OUT} linearity using both unipolar and bipolar supplies.

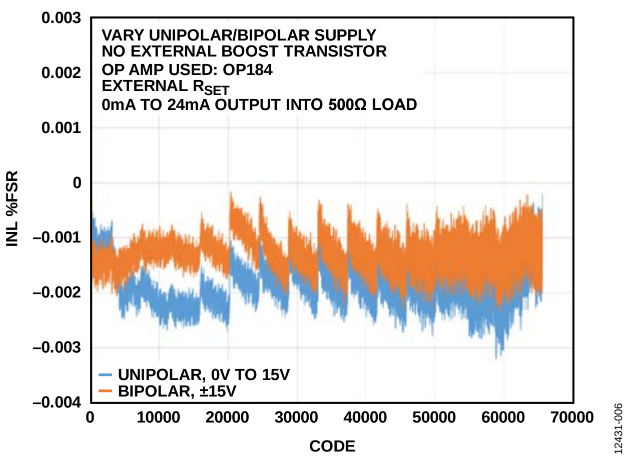

Figure 6. Current Output Mode Unipolar/ Bipolar Supplies

OPERATIONAL AMPLIFIER

The OP184 has input/output rail-to-rail capability and is guaranteed to operate up to 36 V supply voltage. It also has a fast slew rate of 4 V/µs. Input voltage noise is as low as 3.9 nV/√Hz. The amplifier input offset voltage is 350 µV maximum.

A lower cost alternative is the OP1177 (not rail-to-rail I/O) which has an input offset voltage of 100 µV maximum. The OP1177 has a footroom of 1 V, so it is suitable for systems with bipolar supplies. It has a slew rate of 0.7 V/µs and an input voltage noise of 7.9 nV/√Hz.

Figure 7 and Figure 8 show linearity plots for I_{OUT} and V_{OUT}, respectively, using both the OP184 and OP1177. This application note includes a discussion of things to consider when choosing the optimum external buffer amplifier component for your application.

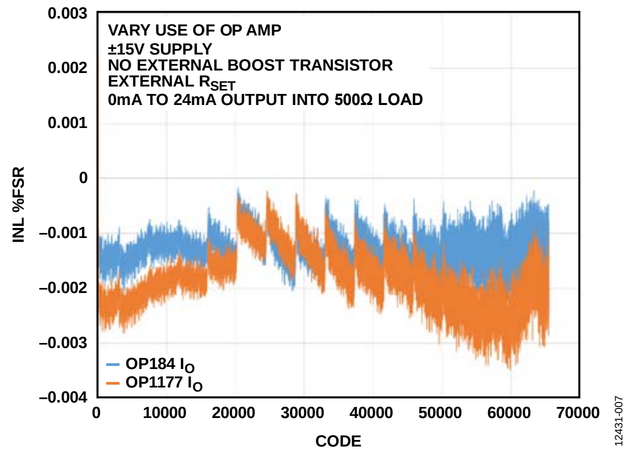

Figure 7. Current Output Linearity—OP1177/OP184

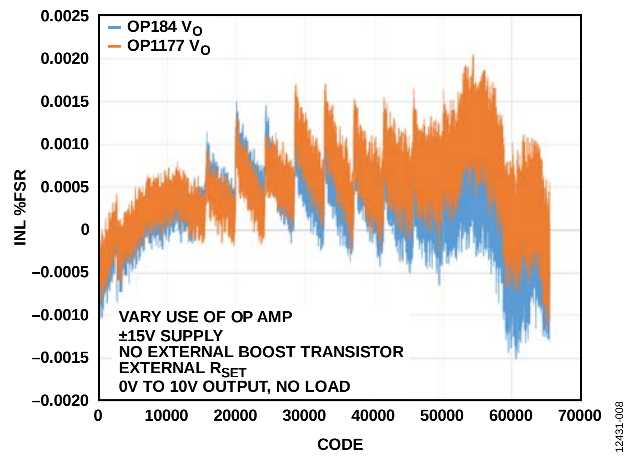

Figure 8. Voltage Output Linearity—OP1177/OP184

OP AMP CONSIDERATIONS

Some key operational amplifier specifications to consider are

- Slew rate
- Rail-to-rail operation
- Minimum output voltage
- Offset voltage/error

The slew rate determines how fast the output of the amplifier can move from one voltage level to another. The amplifier used in any application needs to be fast enough to change its output, at least as fast as the maximum slew rate of its input signal. In the case of the AD5422, the voltage output slew rate is 0.8 V/µs.

Not every amplifier can operate from rail-to-rail. Headroom and footroom voltage requirements should be taken into account. For unipolar supply applications, it is recommended to use an op amp with input/output rail-to-rail capability.

The minimum output voltage of the amplifier needs to be considered, especially if the output needs to be driven to 0 V. The AD5422 zero-scale error is the deviation in the output voltage from the ideal of 0 V. The minimum output voltage capability of the amplifier can have an obvious impact on the expected zero-scale output and so the acceptable margins, per application, need to be considered here.

Ideally, if both inputs of an amplifier are at exactly the same voltage, then the output should be at zero volts. In practice, a small differential voltage must be applied to the inputs to force the output to zero. This is known as the input offset voltage. Again, this is a consideration when assessing the target overall application specifications.

ALTERNATIVE APPROACH TO USING AN EXTERNAL BUFFER AMPLIFIER

The use of an external switch could also be considered when shorting the V_{OUT} and I_{OUT} terminals of the AD5422 as shown in Figure 9. When the AD5422 is in I_{OUT} mode, the switch is opened, so there is no current path back into the AD5422. Note that the V_{OUT} pin is in high impedance state when the AD5422 is programmed in I_{OUT} mode.

Alternatively, when the AD5422 is in V_{OUT} mode, the switch is closed, so the V_{OUT} feedback loop is closed (similarly, in this case, the I_{OUT} pin is in high impedance state when the AD5422 is programmed in V_{OUT} mode).

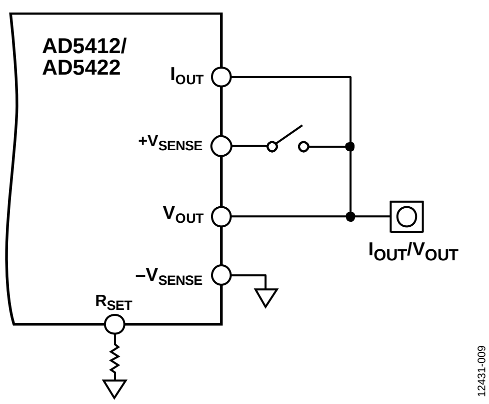

Figure 9. Use of External Switch

When choosing the appropriate switch for the application, the on-resistance and power supply range of the switch should be taken into consideration. With a typical resistance of 70 kΩ in the AD5422 $+V_{SENSE}$ feedback path, an external switch on-resistance of 10 Ω, for example, introduces only 0.014% error. However, depending on the magnitude of the on-resistance of the chosen switch, this error could become significant in the application. Another consideration when using this method is that a control line is required to drive the switch.

The ADG5401 could be used in this application. It has a low on-resistance of 6.5 Ω and can operated from dual supplies of up to ±22 V. One cheaper alternative is the ADG417, which has a typical on-resistance of 25 Ω, with a maximum dual supply of ±22 V.

FOR FURTHER INFORMATION

It may be helpful to refer to the data sheets or circuit notes listed here.

AD5420, *Single-Channel, 12-/16-Bit, Serial Input, 4 mA to 20 mA, Current Source DAC, HART Connectivity*

ADG417, *LC²MOS Precision Mini-DIP Analog Switch*

ADG5401, *High Voltage Latch-Up Proof, Single SPST Switch*

CN-0278, *Complete 4 mA to 20 mA HART Solution with Additional Voltage Output Capability*

CN-0321, *Fully Isolated, Single Channel Voltage and 4 mA to 20 mA Output with HART Connectivity*

OP184, *Precision Rail-to-Rail Input and Output Operational Amplifiers*

OP1177, *Precision Low Noise, Low Input Bias Current Operational Amplifiers*

AN12431-0-6/14(0)