Circuits from the Lab®
Reference Designs

Circuits from the Lab® reference designs are engineered and tested for quick and easy system integration to help solve today's analog, mixed-signal, and RF design challenges. For more information and/or support, visit https://www.analog.com/CN0531.

Devices Connected/Referenced			
AD5791	1 ppm, 20-Bit, ±1 LSB INL Voltage Output DAC	LT3471	Dual 1.3 A, 1.2 MHz Boost/Inverter
AD8675	36 V Precision, 2.8 nV/√Hz Rail-to-Rail Output Op Amp	LT3042	20 V, 200 mA, Ultralow Noise, Ultrahigh PSRR RF Linear Regulator
AD8676	Ultraprecision, 36 V, 2.8 nV/√Hz Dual Rail-to-Rail Output Op Amp	LT3093	−20 V, 200 mA, Ultralow Noise, Ultrahigh PSRR Negative Linear Regulator
LTC6655	0.25 ppm Noise, Low Drift Precision References		

Programmable 20-Bit, Linear, Precision, Bipolar ±5 V DC Voltage Source

EVALUATION AND DESIGN SUPPORT

Circuit Evaluation Boards
CN-0531 Reference Design Board (EVAL-CN0531-PMDZ)
ADICUP3029 Arduino Form-Factor Development Platform (EVAL-ADICUP3029)
Design and Integration Files
Schematics, Layout Files, Bill of Materials

CIRCUIT FUNCTION AND BENEFITS

Precision dc voltages are a critical component of scientific instrumentation and measurement equipment, automated test equipment, factory automation and control, chemical analysis, and many other high precision applications. The most demanding applications require single digit, part per million temperature drift, subppm linearity, and low, predictable noise performance.

The circuit shown in Figure 1 is a programmable 20-bit voltage source that enables these demanding applications. The output range is −5 V to +5 V with ±1 LSB integral nonlinearity (INL), ±1 LSB differential nonlinearity (DNL), and exceptionally low noise and low drift across the entire output range.

On-board power converters produce the required supply rails from a single voltage supply provided by the development platform board. Low noise, high power supply rejection ratio (PSRR) voltage regulators ensure that the switching noise is minimized. A high precision, high stability, on-board hermetically sealed voltage reference ensures the high precision and accuracy of the 20-bit system.

The output of the circuit is a buffered voltage with an option for a remote sense connection to compensate for lead resistance or allow for the insertion of an external power stage, if necessary, providing drive flexibility for the desired end application.
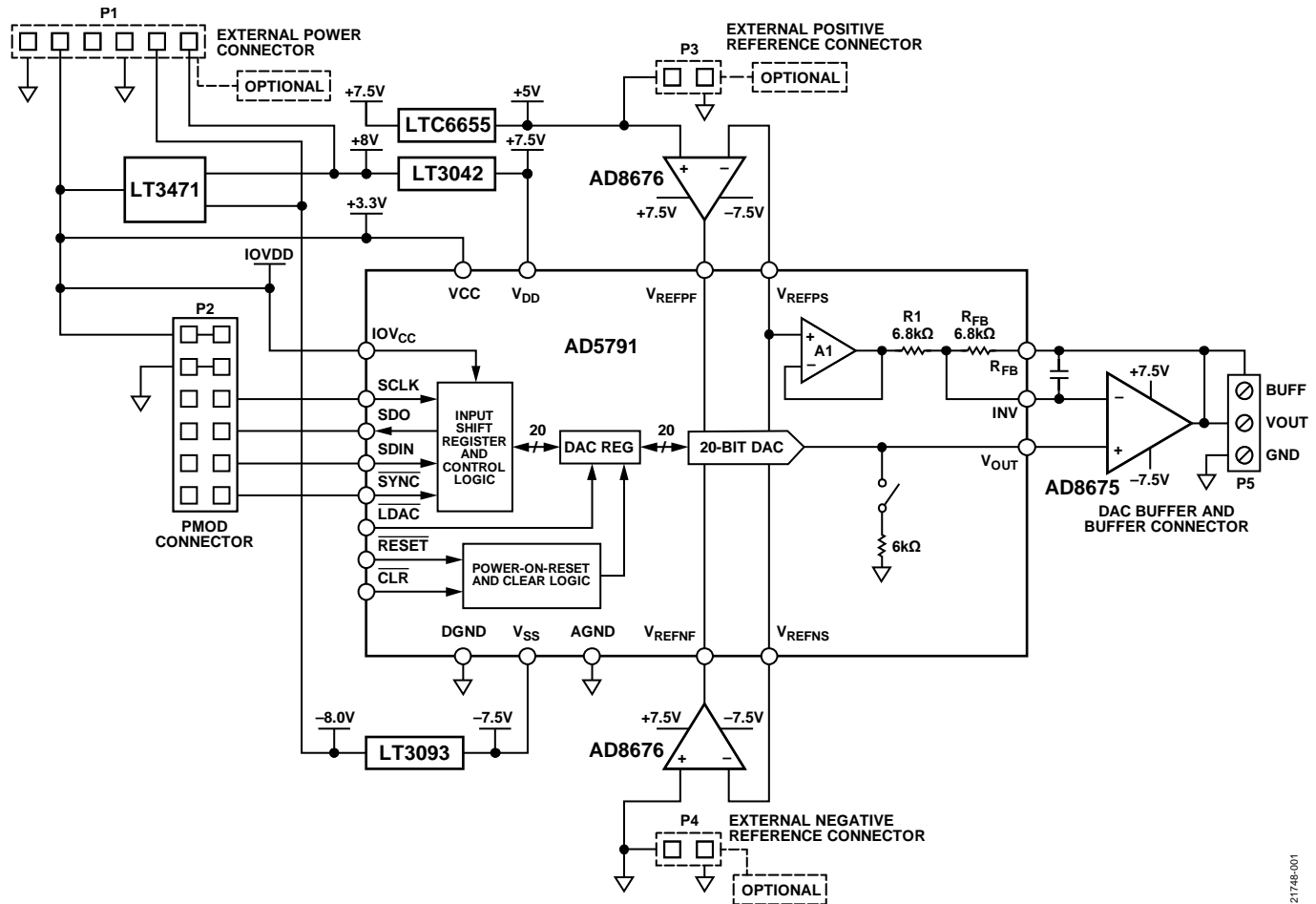
Figure 1. EVAL-CN0531-PMDZ Simplified Block Diagram

CIRCUIT DESCRIPTION

Digital to Analog Conversation

The core of the circuit shown in Figure 1 is the AD5791, a 20-bit digital-to-analog converter (DAC) with a serial peripheral interface (SPI), offering ±1 LSB INL and ±1 LSB DNL performance and 7.5 nV/√Hz noise spectral density. The AD5791 also exhibits an extremely low temperature drift of 0.05 ppm/°C. The precision architecture of the AD5791 requires force sense buffering of its voltage reference inputs to ensure specified linearity.

The amplifiers chosen to buffer the reference inputs must have low noise, low temperature drift, and low input bias currents. The recommended amplifier for this function is the AD8676, an ultraprecision, 36 V, 2.8 nV/√Hz, dual op amp, exhibiting a low offset drift of 0.6 μV/°C and an input bias current of 2 nA. In addition, the AD5791 is characterized and factory calibrated using this dual op amp to buffer its voltage reference inputs, further enhancing confidence in this combination of components.

The circuit can be software configured in two modes, bipolar or unipolar. Figure 1 shows the bipolar configuration in which the output voltage ranges between −5 V to +5 V by using a single 5 V reference buffered by the AD8676. To determine the output voltage in bipolar mode, use the following equation:

$$V_{OUT} = \left(2 \times V_{REF}\right) \times \frac{Code}{2^{20}-1} - V_{REF} \tag{1}$$

where:
V_{OUT} is the output voltage.
V_{REF} is the reference voltage (5 V on CN-0531).
Code is the 20-bit code programmed into the DAC.

When configured in unipolar mode, R1 is internally connected in parallel with R_{FB}, and the output range is 0 V to 5 V (see Figure 1). To determine the output voltage in unipolar mode, use the following equation:

$$V_{OUT} = V_{REF} \times \frac{Code}{2^{20}-1} \tag{2}$$

Voltage Reference

A programmable voltage source is only as good as its voltage reference, which determines the output span of the source. The extremely small 0.05 ppm/°C gain drift of the AD5791 results in the voltage reference becoming a limiting factor for gain accuracy and drift in most applications.

The LTC6655BHLS8-5 provides a highly stable and accurate 5.0 V reference for the CN0531. This reference has an initial accuracy of 0.025% with 2 ppm/°C maximum temperature drift, and 0.25 ppm noise (0.1 Hz to 10 Hz). The hermetic package is insensitive to humidity and provides an outstanding thermal hysteresis of 30 ppm.

Long-term drift is exceptional, typically 20 ppm/√kHr. Long-term drift cannot be extrapolated from accelerated high temperature testing, which is an erroneous technique that delivers drift numbers that are wildly optimistic. The only way long-term drift is determined is to measure the drift over the time interval of interest, and the LTC6555 has undergone extensive characterization over thousands of hours of operating time. Refer to the LTC6655 data sheet and Design Note 229 for further information on these methods.

The level of performance of the LTC6655 is rivaled only by more exotic and expensive voltage references that employ heaters, closed-loop temperature control, and insulated packaging, thus this device is an optimal combination of performance, power, and cost for the CN-0531.

Output Buffer Stage

The AD5791 employs a voltage output, segmented R-2R DAC architecture, which inherently has excellent full-scale and zero-scale error, and the INL and DNL both have a 1 LSB maximum. The output is unbuffered with a constant resistance of 3.4 kΩ, requiring additional signal conditioning in most applications, ideally preserving the dc accuracy and noise specifications of the AD5791.

The AD8675 is a suitable amplifier with an 10 μV typical offset, a 0.6 μV/°C maximum drift, and a 2 nA maximum bias current.

By default, the AD5791 R_{FB} path is connected to the output of the buffer. For applications requiring higher drive capability or remote sense, the on-board connection can be opened and feedback connected remotely at the output of a power buffer stage, for example.

Power Tree

The CN-0531 power tree, shown in Figure 2, consists of an LT3471 boost/inverting converter followed by the LT3042 (positive) and the LT3093 (negative) ultralow noise, ultrahigh PSRR linear regulators.

The LT3471 allows the circuit to operate from a single 3.3 V or 5 V supply provided by the development platform board. The output voltages are set to ±8 V, which are then regulated to ±7.5 V by the LT3042 and the LT3093. The LT3042 and the LT3093 provide an exceptional 80 dB and 75 dB PSRR, respectively, at the 1.2 MHz switching frequency of the LT3471, ensuring minimal switching feedthrough at the DAC output.
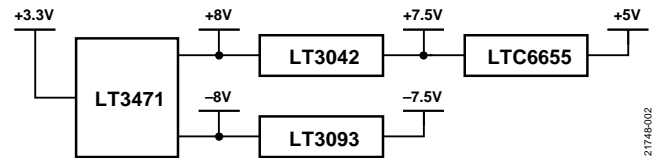

Figure 2. Simplified Power Block Diagram

CN-0531 Linearity Measurements

The following data shown in Figure 3 demonstrates the precision performance of the circuit shown in Figure 1 configured in bipolar mode by using a 6½ digit, Truevolt digital multimeter (DMM). Figure 3 shows the INL of the CN-0531 as a function of the DAC code. The results are within the AD5791 data sheet specifications of ±1 LSB.
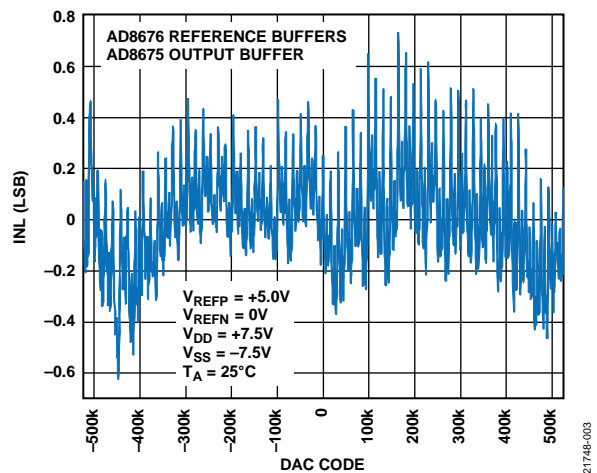

Figure 3. INL vs. DAC Code, ±5 V Span

Noise Calculations and Measurements

The 7.5 nV/√Hz output noise spectral density of the AD5791 is entirely due to its 3.4 kΩ source impedance. The AD8676 output buffer has a voltage noise density of 2.8 nV/√Hz and a current noise density of 0.3 pA/√Hz, producing a negligible 1 nV/√Hz looking into the output resistance of the AD5791. The total noise of the DAC and output amplifier is then

$$\sqrt{7.5^2 + 2.8^2 + 1^2} = 8.0 \ nV\sqrt{Hz}$$

This value is the expected noise when the output is set to 0 V. As the DAC output increases, the noise is dominated by the LTC6655BHLS8-5 reference. Figure 4 shows the output power spectral density for an output voltage of 5.0 V.
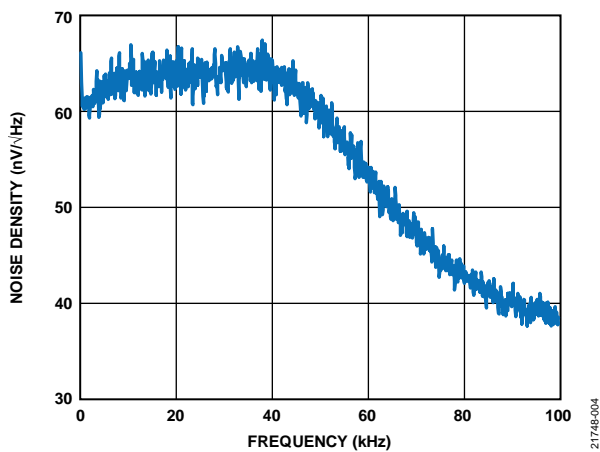
Figure 4. Noise Power Spectral Density, V_{OUT} = 5.0 V

COMMON VARIATIONS

The AD5791 can support a wide variety of output ranges from 0 V to ±10 V. The configuration as shown in Figure 1 can be used to generate symmetrical or asymmetrical ranges as required. For the unity-gain mode of operation, set the RBUF bit of the AD5791 internal control register to Logic 1.

The AD5791 also offers a gain of 2 mode of operation that generates a symmetrical bipolar output range from a single positive voltage reference, as described in the AD5791 data sheet, removing the necessity to generate a negative voltage reference. This mode, however, results in larger full-scale and zero-scale errors. To select this mode, set the RBUF bit of the AD5791 internal control register to Logic 0.

CIRCUIT EVALUATION AND TEST

Getting Started

The basic steps and equipment required to test the CN-0531 reference design follow. For more information and complete details on the setup instructions, see the CN0531 user guide.

Figure 5. Photograph of the EVAL-CN0531-PMDZ Reference Design Board

Equipment Needed

The following equipment is needed:

- A PC with a USB port
- A serial terminal program, such as Tera Term or PuTTY
- The EVAL-CN0531-PMDZ reference design board
- The EVAL-ADICUP3029 development platform board
- The **ADuCM3029_demo_cn0531.hex** file
- A microUSB to USB Type A cable
- A 6½ digit or higher, Truevolt DMM

Functional Block Diagram

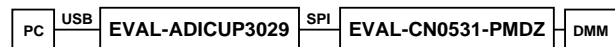Figure 6 shows a test setup of the function block diagram of the CN-0531.

Figure 6. Test Setup Functional Block Diagram

Test

Use the following steps to test this circuit:

1. Connect the EVAL-CN0531-PMDZ to the EVAL-ADICUP3029 using the P8 connector (see Figure 7).

Figure 7. EVAL-CN0531-PMDZ Connected to EVAL-ADICUP3029

2. Connect a DMM to the EVAL-CN0531-PMDZ.
3. Plug the USB Type A connector into the PC and the microUSB connector into the EVAL-ADICUP3029.
4. Flash the EVAL-ADICUP3029 with the **aducm3029_CN0531_demo.hex** firmware.
5. Press the **3029_Reset** button on the EVAL-ADICUP3029.
6. Open a serial terminal connecting the EVAL-ADICUP3029 to the PC and type the help command.

7. Using the serial terminal, configure the CN-0531 into unipolar and set the output voltage to 2.5 V. The serial terminal should look something like Figure 8.

8. Verify that the output voltage set in the serial terminal matches the voltage shown on the DMM in Figure 9.
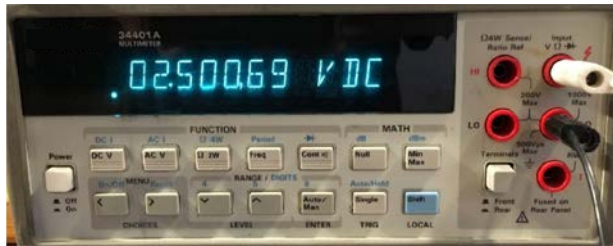

Figure 8. Console Session

Figure 9. DMM Readout

LEARN MORE

CN-0531 Design Support Package.

Egan, Maurice. "The 20-Bit DAC Is the Easiest Part of a 1-ppm-Accurate Precision Voltage Source," *Analog Dialogue*, Vol. 44, April 2010.

MT-015 Tutorial, *Basic DAC Architectures II: Binary DACs*. Analog Devices.

MT-016 Tutorial, *Basic DAC Architectures III: Segmented DACs*, Analog Devices.

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

MT-035 Tutorial, *Op Amp Inputs, Outputs, Single-Supply, and Rail-to-Rail Issues*, Analog Devices.

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

DN-229 Don't Be Fooled by Voltage Reference Long Term Drift and Hysteresis. Analog Devices.

Data Sheets and Evaluation Boards

CN-0531 Reference Design Board (EVAL-CN0531-PMDZ)

ADuCM3029 Development Platform (EVAL-ADICUP3029)

AD5791 Data Sheet

AD5791 Evaluation Board

AD8676 Data Sheet

AD8675 Data Sheet

LTC6655 Data Sheet

LTC6655 Evaluation Board

LT3471 Data Sheet

LT3471 Evaluation Board

LT3042 Data Sheet

LT3042 Evaluation Board

LT3093 Data Sheet

LT3093 Evaluation Board

REVISION HISTORY

2/2021—Revision 0: Initial Version