


Brendan Cronin
Marketing Engineer,
Analog Devices, Inc.

DESIGNING DACS INTO PRECISION INDUSTRIAL 10 V APPLICATIONS

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Circuit Description

Many modern industrial and instrumentation systems have access to several different supplies, the most common being 15 V for the analog circuitry and 3 V or 5 V for the digital logic. The majority of these applications require the outputs to drive large external loads with 10 V swings. This article discusses the various trade-offs encountered in selecting digital-to-analog converters (DACs) for these applications, and proposes detailed circuit diagrams for their use.

Analog output systems found in industrial applications, such as programmable logic controllers (PLC), process control, or motor control require unipolar or bipolar voltage swings of 0 V to 10 V or >10 V. One possible solution is to choose a bipolar output DAC that can directly generate the required output voltages. An alternative solution is to use a low voltage single-supply (LVSS) DAC, amplifying the output voltage to the desired output level. Selecting the best method for the application requires the user to understand the output requirements and recognize the key benefits or limitations of each solution.

Bipolar DACs that can directly generate the required output swing have several benefits and limitations that are worth considering. The key benefits include:

- ▶ **Simplicity**—the design of the board is less complicated, as the required output levels of 0 V to 10 V or >10 V are directly available through hardware or software configurations. In addition, fault protection modes are normally integrated, thus easing system design.
- ▶ **Improved manufacturability and reliability** as discrete components such as amplifiers, switches, and resistors are not required. Voltage references are sometimes also integrated.
- ▶ **Measurement of system errors and total unadjusted error (TUE)**—linearity, noise, offset, and drift specifications are guaranteed, and the overall system error or TUE is easy to compute by summing of the various error sources within the DAC. TUE is sometimes specified on the data sheet.
- ▶ **Endpoint errors**—in some cases, bipolar DACs include calibration features that allow system offset and gain error adjustments to be made on-the-fly.

The key drawbacks of bipolar DACs include:

- ▶ **Limited flexibility**—the integrated high voltage amplifier may not be optimum for the application. The output amplifier is typically optimized for specific load and noise requirements. Even though the range specified on the data sheet may match the actual load in the system, other parameters such as settling time or power consumption may not satisfy the system specifications.

- ▶ **Cost and board area**—bipolar DACs are usually designed on larger geometry processes, resulting in chips and packages that are larger and more expensive.

Using a low voltage DAC with external signal conditioning is an alternative way to generate the required high voltage output swings and spans required in industrial applications. Again, there are important trade-offs that are worth considering. The key benefits of a discrete solution include:

- ▶ **LVSS DACs** tend to have higher levels of desired logic integration and higher speed logic interfaces, thus freeing up the microcontroller for additional tasks.
- ▶ The output may have to provide large currents or drive large capacitive loads that cannot be handled by the bipolar DAC's on-chip amplifier. Discrete solutions allow an optimum standalone amplifier to be selected to suit the application.
- ▶ An overrange feature (10.8 V output on a 10 V nominal span) can be easily implemented, allowing the end user additional flexibility in applications such as those that require valves that have worn down over time to be opened or closed.
- ▶ **Cost**—LVSS DACs are typically less expensive than bipolar DACs, reducing the overall bill of materials cost.
- ▶ **Reduced board area**—LVSS DACs are designed in low voltage submicron or deep submicron processes, and are available in small packages.

The key drawbacks with a discrete solution include:

- ▶ **Additional design time** needs to be spent on optimizing the board and designing endpoint adjustment circuitry.
- ▶ **Calculation of overall error or TUE** becomes more difficult as additional error sources must be considered.
- ▶ **Reduced manufacturability and reliability** with the increase in the number of discrete components.
- ▶ The application must have a low voltage supply (5 V or 3 V) available.

In summary, there are a number of elements that need to be considered in the design of precision industrial 10 V applications. Clearly, the designer must have a good understanding of the output load requirements and the overall error that can be tolerated in the system. In addition, board area and cost are important elements in selecting the optimum solution. For applications that must drive large capacitive loads (1 μ F), yet require low noise and fast settling (<10 s for 20 V span), a discrete implementation is almost always the best approach. While bipolar DACs will never rival a discrete solution on flexibility, their combination of simplicity and easy TUE calculations makes them attractive in a broad range of industrial and instrumentation applications.

The following discussion explains how a precision 10 V output can be implemented using a dual-supply bipolar output DAC and a low voltage single-supply DAC and external signal conditioning.

Circuit Overview: Dual-Supply Bipolar Output DAC

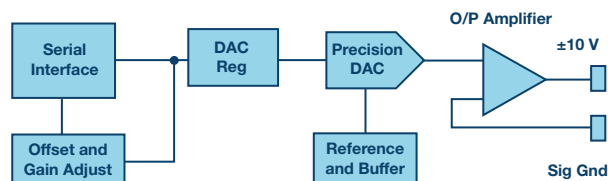


Figure 1. Functional block diagram of AD5764 bipolar DAC.

The functional block diagram (shown in Figure 1) illustrates the main components of a bipolar output DAC. It consists of a precision DAC, reference, reference buffer, offset and gain adjustment, and output amplifier. Integrating precision voltage references to suit 16-bit applications has proved difficult, but recent process improvements and design techniques now allow voltage references with excellent drift and thermal characteristics to be designed and integrated on-chip. Fault protection modes such as thermal shutdown, short-circuit protection, and output control during conditions such as power-up/power-down, are key features that bipolar DACs normally integrate, hence easing system design. The DAC provides the digital code to voltage output conversion relative to the reference. The adjustment blocks provide the ability to offset and scale the DAC's transfer function.

More on the AD5764

The **AD5764** quad, 16-bit serial input, voltage output DAC operates from supply voltages of 12 V up to 15 V. It has a nominal full-scale output range of 10 V and includes output amplifiers, reference buffers, precision reference, and proprietary power-up/power-down control circuitry. It also features an analog temperature sensor and digital offset and gain adjust registers per channel. The AD5764 is designed on Analog Devices' industrial CMOS (iCMOS[®]) manufacturing process technology, which combines high voltage complementary bipolar transistors with submicron CMOS.

Circuit Overview: Low Voltage Single-Supply DAC and External Signal Conditioning

Figure 2 shows how a LVSS DAC can be used to generate a 10 V output range for industrial applications. It consists of five distinct blocks: LVSS DAC, reference, offset adjust, reference buffer, and output amplifier.

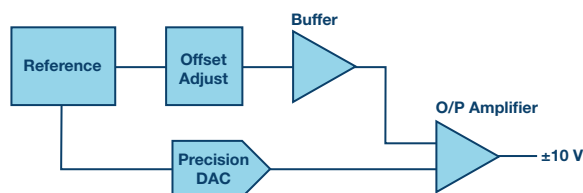


Figure 2. Block diagram of a discrete ± 10 V analog output.

The DAC provides the digital code to voltage output conversion relative to the reference. The offset adjust provides the ability to offset the DAC's unipolar transfer function to generate a bipolar output, and the ability to calibrate the 0 V endpoint. The reference buffer provides load isolation for the reference and the offset adjustment block (a number of DACs can share this buffered output). The output amplifier sums in the offset adjustments and provides the required gain to increase the output swing to the desired level. In addition, the output amplifier provides the ability to drive large capacitive loads to the supply rails.

The circuit in Figure 3 illustrates how a precision LVSS 16-bit DAC can be amplified to achieve output swings of 10 V. The DAC has a 0 to 2.5 V output range and is connected to the noninverting input of amplifier U3. This input has a noninverting gain of $(1 + R2/R1)$, or 8 in this example. The inverting input of the op amp is connected to 1.429 V created by the reference and resistor divider network, U6. This input has an inverting gain of $(-R2/R1)$, or -7 in this example. Thus, the output of this circuit with the DAC programmed to zero code 0000h is

$$(0/65535\ 2.5\ 8) - (7\ 1.429\ \text{V}) = -10\ \text{V}.$$

With the DAC programmed to full-scale code FFFFh, the output is

$$(65535/65535 \cdot 2.5 \cdot 8) - (7 \cdot 1.429 \text{ V}) = +10 \text{ V}.$$

In general the output voltage for any input code can be calculated as follows:

$$V_{OUT} = \left[V_{REF} \times \left(\frac{D}{2^{16}} \right) \times \left(\frac{R1 + R2}{R1} \right) - V_{REF} \times \left(\frac{R2}{R1} \right) \right]$$

where D represents the input code in decimal format for the precision 16-bit DAC (0 to 65535) as in this example. With $V_{REF} = 2.5\text{ V}$, $R1 = R$, and $R2 = 7\text{ R}$. A nonvolatile memory digital potentiometer is used to adjust the system's zero offset error, hence offset values are retained even with the power shut off. The resistor network formed by U7, U6, and R3 can be chosen to provide the required adjustment range at 0 V. Other output ranges required in PLC analog output modules, such as +5 V, 5 V, +10 V or 10.8 V (in the case where over-range may be important), can be easily configured.

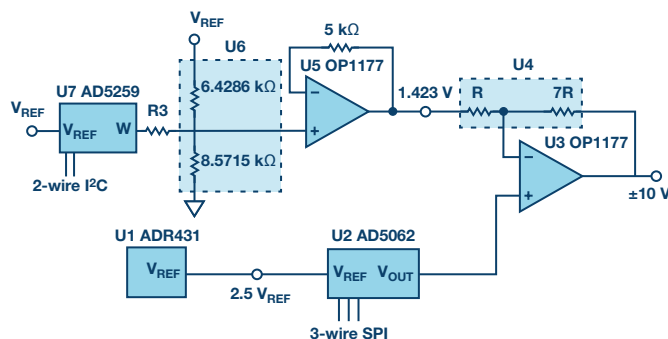


Figure 3. Circuit detail of a precision 10 V analog output.

The circuit consists of the following components: U1—[ADR421](#), precision, low noise 2.5 V reference, 3 ppm/°C drift, MSOP package, U2—[AD5062](#), 16-bit, 1 LSB max INL, 5V/3V supply, serial input *nanoDAC*™, SOT-23 package, U3 and U5—[OP1177](#), precision op amp, 15 V supplies, MSOP package U4 and U6—precision resistor network with ESD protection, U7—[AD5259](#), 256 tap nonvolatile digital potentiometer, MSOP package.

More on the AD5062

The 16-bit AD5062 is guaranteed monotonic and features 1 LSB max DNL and INL. Its unipolar output has 50 V max offset error and 0.02% max gain error. Its high speed serial interface supports clock speeds up to 30 MHz. It is available in a tiny SOT-23 package.

Conclusion

More and more industrial and instrumentation applications are requiring precision converters to accurately control and measure various processes. Additionally, these end applications are demanding increased flexibility, reliability, and feature sets while simultaneously reducing costs and board area. Component manufacturers are addressing these challenges and offering a number of products to address the needs of system designers for current and future designs.

As can be seen from this article, there are many different approaches in selecting the right components for precision applications, each offering their own associated drawbacks and benefits. As the accuracy of the systems increases, even more thought needs to be put into the selection of the right component to suit application needs.

For more information on any of the above mentioned products visit www.analog.com/DAC.

About The Author

Brendan Cronin is a DAC product marketing engineer at Analog Devices in Limerick, Ireland. He can be reached at brendan.cronin@analog.com.

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**Analog Devices, Inc.
Worldwide Headquarters**

Analog Devices, Inc.
One Technology Way
P.O. Box 9106
Norwood, MA 02062-9106
U.S.A.
Tel: 781.329.4700
(800.262.5643, U.S.A. only)
Fax: 781.461.3113

**Analog Devices, Inc.
Europe Headquarters**

Analog Devices, Inc.
Wilhelm-Wagenfeld-Str. 6
80807 Munich
Germany
Tel: 49.89.76903.0
Fax: 49.89.76903.157

**Analog Devices, Inc.
Japan Headquarters**

Analog Devices, KK
New Pier Takeshiba
South Tower Building
1-16-1 Kaigan, Minato-ku,
Tokyo, 105-6891
Japan
Tel: 813.5402.8200
Fax: 813.5402.1064

**Analog Devices, Inc.
Asia Pacific Headquarters**

Analog Devices
5F, Sandhill Plaza
2290 Zuchongzhi Road
Zhangjiang Hi-Tech Park
Pudong New District
Shanghai, China 201203
Tel: 86.21.2320.8000
Fax: 86.21.2320.8222

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