ADC161S626,DAC122S085,LM7705,LMP2015, LMP2016,LMP7702

Bridging the Divide: A DAC Applications Tutorial (Precision Signal Path)

Literature Number: SNAA129

SIGNAL PATH | designer®

Expert tips and techniques for energy-efficient design

No. 121

Bridging the Divide: A DAC Applications Tutorial

— *Bill McCulley, Applications Engineer*

Digital-to-Analog Converters (DACs) are used to transform digital data into an analog signal. Since the decades following the Nyquist-Shannon sampling theorem, engineers have developed and used DACs in applications, but it is only in the past 25 years that monolithic DACs have become widely available. According to the theorem, any sampled data can be reconstructed perfectly—provided it meets bandwidth and Nyquest criteria. So, with proper design, a DAC can reconstruct sampled data with precision. The digital data may be generated from a microprocessor, Application-Specific Integrated Circuit (ASIC), or Field-Programmable Gate Array (FPGA), but eventually the data requires conversion to an analog signal in order to have impact on the real world. The world of erratic and dynamic analog signals cannot be handled easily in a pristine 3.3V digital world. In that regard, the DAC serves as the bridge from digital to analog domains – and hopefully ends with an accurate and true representation of the signal.

DAC Applications

DACs are used in a wide spectrum of applications. While IC manufacturers are integrating more features into a microprocessor or FPGA every year, there will always be some type of analog conversion for interfaces. The DAC therefore will maintain an important role among applications in the electronics industry. While no list of applications is exhaustive, *Table 1* shows a number of common DAC applications, along with a description of typical functions. In some applications, the function of a DAC is relatively straightforward. In other applications, such as calibration, the use of DACs may not be immediately apparent.

Calibration

Depending on the application, a number of parameters such as voltage offset, gain adjustment, or current bias may require adjustment to ensure consistent results. The ability to adjust these parameters is important for applications such as sensors, factory line systems, or test and measurement equipment. This adjustment or correction can be done manually by plant engineers as part of a periodic maintenance inspection. However, as the industrial world becomes more automated, the adjustment of those parameters needs to become dynamic. This drives the need to immediately measure an error at the output of a system, and then resolve it by introducing a "correction" at the start of the process flow. Since that correcting signal is analog in nature, a DAC is a good fit for calibration in many applications.

A basic application that may require calibration is a pressure sensor system. A graphical depiction of a pressure sensor system is shown in *Figure 1*. The system takes a low-level voltage signal from

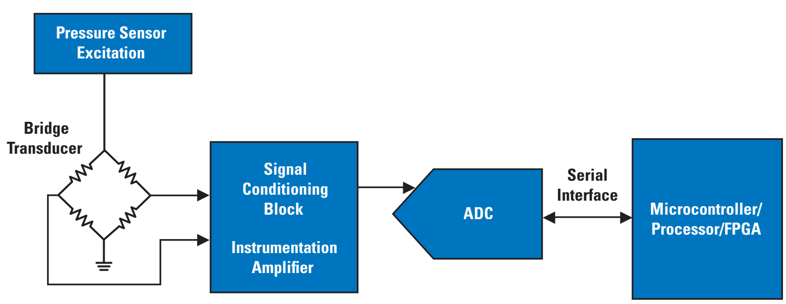

Figure 1. Pressure Sensing System Diagram

National Semiconductor

Bridging the Divide: A DAC Applications Tutorial

Application	DAC Function Summary
Audio Amplifier	DACs are used to produce DC voltage gain with microcontroller commands. Often, the DAC will be incorporated into an entire audio codec which includes signal processing features.
Video Encoder	The video encoder system will process a video signal and send digital signals to a variety of DACs to produce analog video signals of various formats, along with optimizing of output levels. As with audio codecs, these ICs may have integrated DACs.
Display Electronics	The graphic controller will typically use a "lookup table" to generate data signals sent to a video DAC for analog outputs such as Red, Green, Blue (RGB) signals to drive a display.
Data Acquisition Systems	Data to be measured is digitized by an Analog-to-Digital Converter (ADC) and then sent to a processor. The data acquisition will also include a process control end, in which the processor sends feedback data to a DAC for converting to analog signals.
Calibration	The DAC provides dynamic calibration for gain and voltage offset for accuracy in test and measurement systems.
Motor Control	Many motor controls require voltage control signals, and a DAC is ideal for this application which may be driven by a processor or controller.
Data Distribution System	Many industrial and factory lines require multiple programmable voltage sources, and this can be generated by a bank of DACs that are multiplexed. The use of a DAC allows the dynamic change of voltages during operation of a system.
Digital Potentiometer	Almost all digital potentiometers are based on the string DAC architecture. With some reorganization of the resistor/switch array, and the addition of an I^2C compatible interface, a fully digital potentiometer can be implemented.
Software Radio	A DAC is used with a Digital Signal Processor (DSP) to convert a signal into analog for transmission in the mixer circuit, and then to the radio's power amplifier and transmitter.

Table 1. Common DAC Applications

the sensor and sends it to a processor for further action. In more detail, the bridge transducer in the diagram receives a signal (excitation) from a pressure sensor and produces an output voltage based on the pressure level. Altogether, the sensor/bridge function is considered a pressure bridge transducer[1]. Due to the low amplitude of the transducer's signal, an instrumentation amplifier (in amp) is typically used for the signal conditioning function. This adds gain for small differential signals with low noise. Depending on the application, additional amplifiers may be used to filter the signal for anti-aliasing or buffering the signal to an ADC for sampling. The ADC then transmits the data code to a microcontroller or FPGA. Typically, the interaction between a mixed-signal IC like an ADC or DAC will be through an I^2C compatible, SPI, or Microwire® serial interface.

Applications such as pressure sensing usually require high precision and accuracy over a range of conditions such as temperature, parasitic errors across circuit boards, or lot-to-lot tolerance of passive components. Over time, the errors introduced in a system can become large when gain is added with each measurement. With a DAC, that calibration can be implemented into the system to dynamically correct the error as the system operates. A graphical depiction for calibration of the pressure sensor system is illustrated in ***Figure 2*** on the following page. It should be noted that this is not an actual schematic, but an illustration on how calibration could be achieved with DACs. While it does not include aspects such as circuit power supply, passive components, bypassing, and voltage reference circuits, this diagram shows how calibration may be implemented.

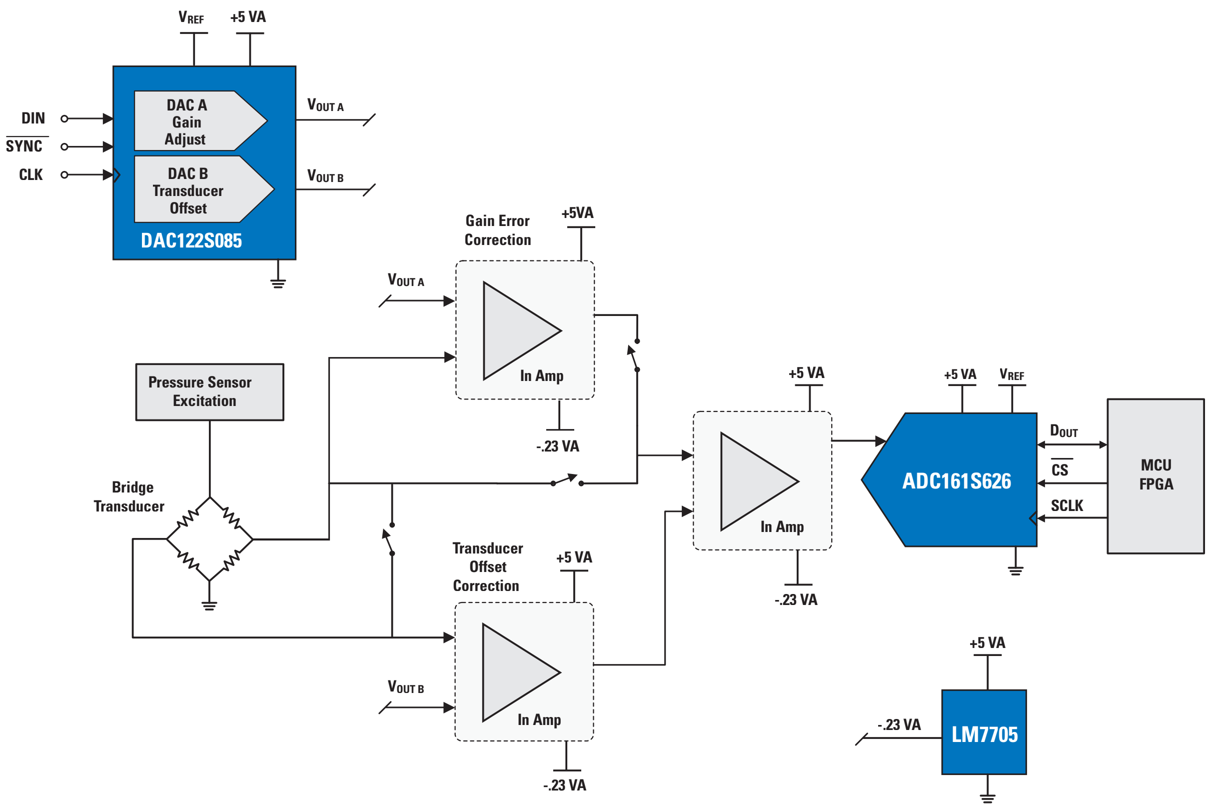

Figure 2. Simplified Example of a Calibrated Pressure Sensing Diagram

As shown in *Figure 2*, a gain-adjust DAC and a transducer-offset DAC receive data code inputs for calibration by the microcontroller which monitors the outputs of the ADC. The microcontroller can be programmed easily (with either an internal lookup table or software comparison routines) to send the appropriate calibration data to the DACs based on the measured data errors. From the DACs, the calibration signals are passed through a pair of in amps to allow pre-scaling and buffering, and then they are applied as an adjustment to the primary in amp inputs. The DAC functions in this illustration are implemented with a 2-channel, 12-bit DAC (National's DAC122S085). DAC A sends the corrective gain signal through the gain pre-scale stage (in amp) which is then fed to the primary in amp to the ADC. DAC B sends a corrective offset signal for transducer DC error through another pre-scale stage (in amp) and then fed to the primary in amp. Switches, as graphically depicted, allow the change between calibration modes. Precision op amps such as the LMP7702 or LMP2015/LM2016 op amps can be used to implement the in amp functions or an integrated device like the LMP8358 amplifier could be used, depending on the application. Finally, rail-to-rail output amplifiers—as good as they perform—do not produce a true ground (0V) when operating from a single-supply rail. This can result in error due to the amplifier's output saturation voltage being amplified by following stages. One way to mitigate this is to introduce a small negative supply voltage that prevents the

Bridging the Divide: A DAC Applications Tutorial

amplifier output from saturating at zero volts, helping maintain an accurate zero and a full scale for the 16-bit ADC, ADC161S626. In this circuit, a small negative voltage of -0.23V has been added using the LM7705 negative-bias generator.

Motor Control

While a complete review of motor types will not be covered in this article, it is important to know some of the most common motors used today. The primary types include: DC motors (brushed, brushless), AC motors (synchronous, inductive), electrostatic motors, and other variants. While there are several motor applications that require no closed-loop control, most motor systems do require some method of control. That control is typically achieved with a controller, DAC, motor driver, and a feedback path that contains the data measured by a sensor.

One of the most popular motors is the DC brushless motor (BLDC). It has some significant advantages over the DC brushed motor, including higher efficiency, less mechanical wear, and lower cost of service and maintenance. The DC brushless motor itself has several sub-types, including stepper- and reluctance-type motors. DC brushless motors have become very common among consumer products, industrial and factory systems, robotics, tools, and other applications. The DC motor is typically used with a Variable Reluctance Sensor (VRS) or a Hall-Effect sensor, which is used to measure the position and speed of the motor. In the newest DC motors available, the sensor electronics may be integrated into the entire mechanism of the motor.

DACs, when not integrated into a customized IC, are often used as a key function for a motor driver control system. ***Figure 3*** shows a depiction in which a motor control system could be integrated with a DAC. It should be noted that this is not an actual schematic, but a depiction of how a motor control system could be architected.

Typically, the DAC will be driven by a micro-controller or a specialized controller. The DAC will receive the input data code and convert the data code into current outputs to the appropriate

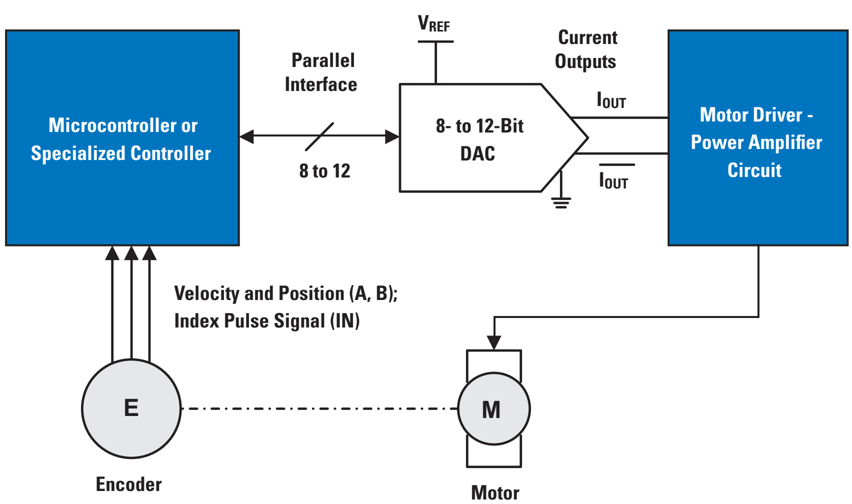

Figure 3. Motor Control Example

motor driver circuitry. The motor driver circuit can be implemented in several ways. While there are integrated driver ICs for that task, it can also be designed with a power operational amplifier. The architecture of the motor driver circuit will depend on the requirements of the DC motor—including the total power, continuous and maximum current, and voltage range. During operation, the motor with an encoder sends velocity and position signals to the microcontroller. Depending on the encoder, these signals may also include an index pulse signal. The microcontroller then adjusts the speed and direction of the motor by changing the data codes sent to the DAC. The DAC's important role in "closing the control-loop" can be seen by the number of manufacturers integrating DAC functions into their motor driver ICs, thereby adding value to their products.

Conclusion

The DAC, just like the ADC and the operational amplifier, plays a key role in a myriad of applications. If one considers the ubiquitous op amp as the "glue" between mixed-signal components, then it can be concluded that the three central components on a signal path are the op amp, ADC, and DAC. As the signal passes from the analog domain to digital and back again, the DAC could be considered the *dénouement* of a circuit. The signal, having done its work, returns to the analog domain. The DAC will continue to play a key role in many electronics applications—including ones that have not yet been envisioned.

Reference Footnotes:

(1) Pressure Bridge Transducers - http://wiki.xtronics.com/index.php/Pressure_Transducer_Primer

National Semiconductor
2900 Semiconductor Drive
Santa Clara, CA 95051
1 800 272 9959

Mailing address:
PO Box 58090
Santa Clara, CA 95052

Visit our website at:
national.com

For more information, send email to:
new.feedback@nsc.com

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Audio	www.ti.com/audio	Communications and Telecom	www.ti.com/communications
Amplifiers	amplifier.ti.com	Computers and Peripherals	www.ti.com/computers
Data Converters	dataconverter.ti.com	Consumer Electronics	www.ti.com/consumer-apps
DLP® Products	www.dlp.com	Energy and Lighting	www.ti.com/energy
DSP	dsp.ti.com	Industrial	www.ti.com/industrial
Clocks and Timers	www.ti.com/clocks	Medical	www.ti.com/medical
Interface	interface.ti.com	Security	www.ti.com/security
Logic	logic.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Power Mgmt	power.ti.com	Transportation and Automotive	www.ti.com/automotive
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Mobile Processors	www.ti.com/omap		
Wireless Connectivity	www.ti.com/wirelessconnectivity		
		TI E2E Community Home Page	e2e.ti.com

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265