Bridging the Divide:  
Part III - DAC Applications Review

“Knowing is not enough; we must apply. Willing is not enough; we must do.”  
- Johann Wolfgang von Goethe

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INTRODUCTION

As mentioned in the first and second articles, a Digital-to-Analog Converter (DAC) can be used in a wide spectrum of applications. Because the DAC serves as the bridge between digital and analog domains, it is useful in many important applications. A common question often asked is “Since technology is moving into digital processes, will DACs eventually vanish from the electronics world?” Absolutely not! While it is certain that IC manufacturers integrate more features every year into a processor or FPGA, there will always be some type of interface required. The world of erratic and dynamic analog signals cannot be handled easily in a pristine 3.3V digital world. The DAC therefore will maintain an important role in the electronics industry.

While no list of applications is exhaustive, Figure 1 shows a number of common applications, along with a description of the typical function a DAC has within that system. In some applications, the function of a DAC is relatively straightforward. Others, such as Calibration, may not be immediately apparent. We will review the a few applications in this article: Audio DACs in CD Players, Calibration, and Motor Control.

<table>
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<tr>
<th>Application</th>
<th>DAC function summary</th>
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<tr>
<td>Audio Amplifier</td>
<td>DAC used to produce DC voltage gain with microcontroller commands.</td>
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<td>Audio DAC</td>
<td>A specialty DAC of high resolution (24 bits or more), and various sampling/speeds, is used in consumer audio systems, such as a CD player system.</td>
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<td>Audio Codec</td>
<td>Codec is a shortened acronym for ‘compressor-decompressor’ or, commonly, ‘coder-decoder’. A single codec can include both DACs and ADCs, with additional features such as signal processing, mixing, or filtering.</td>
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<td>Video Encoder</td>
<td>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 chips may include integrated DACs.</td>
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<tr>
<td>Display Electronics</td>
<td>The graphic controller will typically use a ‘lookup table’ to generate data signals sent to a video DAC for analog outputs such as “RGB” Red, Green, Blue signals to drive a display.</td>
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<tr>
<td>Data Acquisition Systems</td>
<td>Data to be measured is digitized by an 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.</td>
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<td>Calibration</td>
<td>The DAC provides dynamic calibration for gain and offset for accuracy in test and measure systems such as sensors.</td>
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<tr>
<td>Motor Control</td>
<td>Many motor controls require voltage control signals, and DAC is ideal for this application which may be driven by a processor or controller.</td>
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<tr>
<td>Data Distribution System</td>
<td>Many industrial and factory lines require multiple programmable voltage sources, and this can be generated by a bank of DACs or a single DAC, multiplexed. The use of a DAC allows the dynamic change of voltages as controlled by a processor.</td>
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Almost all digital potentiometers are based on the string DAC architecture covered in the first article. With some reorganization of the resistor/switch array, and the addition of an I2C/SPI interface, a fully digital potentiometer can be implemented.

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 amp and transmitter.

**Figure 1 – Common DAC Applications**

**AUDIO DACS - CONSUMER CD PLAYERS**

The DAC has an important role in consumer audio products – and the number of specialty Audio DACs has grown yearly as semiconductor manufacturers integrate more features into these high-value products. **Figure 1** shows a high resolution DAC used in a consumer CD player.

The first block in the diagram represents the optical reading ‘head’. The module contains a laser diode, mirrors and focus lenses, along with a photodetector to transform the reflected light into electrical signals. The second block consists of condition circuits, sampling, and an audio DSP, or a customized Application Specific Integrated Circuit (ASIC). In this application, a CD player will play a variety of audio signals – from rock music to classical symphonies with excellent linearity and low distortion and noise. As such, the DAC used is usually very high resolution (24bits or more). In addition, if this is an Audio DAC, it will have additional features and specific performance characterizations for audio application. In most CD players, an external Low Pass Filter (LPF) and/or a buffering circuit is used. The ultimate goal of this application is to produce the best sounding audio: low distortion and noise across the entire audio spectrum.

**CALIBRATION**

The DAC is very useful in calibration tasks, whether it be for simple conditioning circuits for ADC circuits or for highly complex industrial and factory systems. Depending on the application, there may be any number of parameters – such as voltage offset, gain adjustment, or current bias – which need to be adjusted dynamically to ensure consistent results. The factory world is becoming more and more automated each and every year. But with each level of automation, it also makes it more critical to correctly calibrate the circuit. What often is needed is a way to quickly detect an error at the output of a system, and then address it by introducing a
“correction” at the start of the process flow. Since that ‘correction’ is analog of nature, the DAC is the exact fit for this task in many applications.

One particular application that can require calibration is shown in Figure 4 below, which is a Pressure Sensing System. The circuit takes a low level voltage signal from the sensor and feeds it into an ADC/Processor for display or further actions. Looking at the diagram blocks, the Bridge Transducer on the diagram receives a signal from a pressure sensor, and produces an output voltage based on the pressure sensor. Altogether, the sensor/bridge function is considered a Pressure Bridge Transducer. Due to the small signal, an instrumentation amplifier (In Amp) is used to amplify small differential signals. Depending on the signal amplitude, a gain can be added to ensure the signal is full-scale for input to the ADC. The In Amp also buffers the signal sent to an appropriate ADC, which samples the signal and sends the data code to the microcontroller or FPGA.

More importantly for many customers, the application may require high precision and accuracy, over a variety of conditions. These can include changes in temperature, changing parasitic errors across the board, and even the tolerance of each different lot of components. In many cases, the overall error introduced outside of product itself can eventually become large. In this application, a method to ‘calibrate’ or correct the gain error and the transducer offset dynamically is done by a pair of DACs. As seen in the Figure 3, the DAC Gain Adjust and the DAC Transducer Offset receive data codes for the appropriate corrections by the microcontroller. The microcontroller can be easily programmed (with either a lookup table or internal software comparison routines) to send the appropriate calibration data to the DACs. From the DACs, the analog voltage is passed through another pair of In-Amps to allow pre-scaling and buffering. The signals for offset and gain calibration are then sent to the primary In Amp non-inverting inputs.

A link to an abbreviated schematic is shown at the end of the article. The schematic does not include all aspects of design, such as power supply, bypassing and voltage reference circuits. But it should allow you to see how this application could be implemented using a DAC and In Amps for dynamic calibration of the sensor circuit. The DAC function is done with a DAC122S085 which is a 2 channel, 12-bit DAC. The dual part converts the data code from the microcontroller via a SPI interface and applies the voltage signals to the In-Amp calibration circuits.

Some notes to consider in reviewing the schematic. In this case, we have selected LMP7702 and LMP2016 opamps, which are used together to create an InAmp. The InAmp function
could also be implemented with an integrated In-Amp, depending on application requirements. An example of an integrated In-Amp is LM P8358 (http://www.national.com/pf/LM/LM P8358.html).

Also, even the best Rail-to-Rail output amplifiers cannot output zero volts when operating from a single supply voltage. This can result in error accumulation due to amplifier’s output saturation voltage being amplified by following amp stages. One way to mitigate this situation is to introduce a small negative supply voltage can prevent the amplifiers output from saturating at zero volts and will help maintain an accurate zero. The other benefit is it allows use of the full input range of an ADC. In the schematic, we’ve added a small negative voltage of -0.23V to each In A mp in the circuit, using an LM 7705 negative bias generator.

**MOTOR CONTROL**

While a complete review of numerous motor types will not be covered in this short article, it is important to know some of the most common motors used today. The primary types of motors include: DC motors (Brushed, Brushless), AC motors (Synchronous, Inductive), Electrostatic motors, as well as other variants of these types. While there are some motor applications which require no closed loop control, most do require some method of control. That control is typically achieved with controller, a DAC, a motor driver, and a feedback path containing the data as 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 costs of service and maintenance. The DC Brushless motor itself has 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. **Figure 4** illustrates one way to architect a DC motor control system using a DAC.
As mentioned before, the DAC will typically be driven by a microcontroller or a specialized controller IC for motor control applications. The DAC will receive the input data code, in this case, via a parallel interface, and convert the data code to current outputs. The motor driver circuit shown can be implemented in several ways. While there are integrated ICs specifically for that task, it can also be designed with simple power operational amplifiers, such as LM675. The architecture of the driver circuit will depend on the requirements of the DC motor, such as the total power, the continuous and maximum current, and the voltage range, among other requirements. During operation, the motor/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. In this regard, the DAC serves a role in ‘closing the control loop’. As you can see, the DAC plays a key role in the control motor applications. The DAC’s importance in motor control can be seen by the number of manufacturers which integrate the DAC function into their motor driver ICs, thereby adding value to the product.

CONCLUSION

The DAC plays a pivotal role in applications, in as much degree as the ADC and the operational amplifier. If one considers the opamp as the ‘glue’ between mixed-signal components, it could be concluded that the three central components on the signal path are the Opamp, ADC and DAC. From the analog domain to the digital domain and back again, the DAC could be considered the dénouement of a circuit. The signal, having done its work, returns to its analog home. The DAC will continue to play a key role in many applications – including ones that have not yet been envisioned!

For design engineers who want to learn more about this interesting device, I have included several references in the footnotes to continue their journey into the world of DACs.³

Footnotes

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

(2) Link to “DAC Calibration.pdf”

(3) Online DAC webinars at National’s Powerwise University:
http://www.national.com/AU/design/0,4706,174_0_00.html
http://www.national.com/AU/design/0,4706,179_0_00.html
http://www.national.com/AU/design/0,4706,203_0_00.html

Textbooks:
“Data Conversion Handbook”, Walt Kester, ADI/Newnes, 2004
“Analog Circuits (World Class Designs)”, Robert Pease, Newnes, 2008