Precision Signal-Processing and Data-Conversion ICs for PLCs Now Have More Performance at Less Power, Size, and Cost

By Albert O’Grady [albert.ogrady@analog.com]

A *programmable-logic controller* (PLC) is a compact computer-based electronic system that uses digital or analog input/output modules to control machines, processes, and other control modules. A PLC is able to receive (input) and transmit (output) various types of electrical and electronic signals and use them to control and monitor practically any kind of mechanical and/or electrical system. PLCs are classified by the number of I/O functions provided. For example, a *nano* PLC incorporates fewer than 32 I/Os, a *micro* PLC has between 32 and 128 I/Os, a *small* PLC has between 128 and 256 I/Os, and so on. A typical PLC system is outlined in Figure 1.

PLC systems comprise input modules, output modules, and input/output modules. Since many of the inputs and outputs involve real-world analog variables—while the controller is digital—PLC system hardware-design tasks focus on the requirements for digital-to-analog converters (DACs) and analog-to-digital converters (ADCs), input- and output signal-conditioning, and isolation of the electrical wiring of the input- and output modules from the controller and each other.

Resolutions of I/O modules typically range from 12 bits to 16 bits, with 0.1% accuracy over the industrial temperature range. Analog *output* voltage and current ranges include ±5 V, ±10 V, or 0 V to 5 V, 0 V to 10 V, and 4 to 20 mA or 0 to 20 mA. Settling-time requirements for DACs vary from 10 µs to 100 ms, depending on the application. Analog *input* ranges can be as small as ±10 mV, from bridge transducers, as large as ±10 V, from actuator controllers, or 4-to-20 mA currents, in industrial process-control systems. Conversion times, depending on the required accuracy and choice of ADC architecture, vary from 10 samples per second to hundreds of kilosamples per second.

Digital isolators—optocouplers or electromagnetic isolators—are used to isolate the ADCs, DACs, and signal-conditioning circuitry on the field side of the system from the controller on the digital side. If the system must also be fully isolated on the analog side, a converter would be necessary on each channel of the input or output to maximize the isolation between channels—and isolated power would be necessary, via transformers or Analog Devices *iso*Power™ technology.[1]

The *i*CMOS® Process

Many Analog Devices products used in both the input- and output sections of PLC designs benefit from *i*CMOS,[2] a new high-performance fabrication process that combines high-voltage silicon with submicron CMOS and complementary bipolar technologies.

This powerful combination allows a single chip design to mix-and-match 5-V CMOS circuits with higher-voltage 16-, 24-, or 30-V CMOS circuitry—with multiple voltage supplies feeding the same chip. With this flexibility of combining components and operating voltages, submicron *i*CMOS devices can have higher performance, a more integrated feature set, and lower power consumption—and require significantly smaller board area than previous generations of high-voltage products. The *bipolar* technology provides accurate references, excellent matching, and high stability for ADCs, DACs, and low-offset amplifiers.

Thin-film resistors, with their 12-bit initial matching, 16-bit trimmed matching, and temperature- and voltage coefficients up to 20 times better than conventional polysilicon resistors, are ideal for high-precision, high-accuracy digital-to-analog converters. On-chip thin-film fuses allow digital techniques to be used for calibration of integral nonlinearity, offset, and gain in high-precision converters.

PLC Output Module

PLC-system analog outputs—commonly used to control actuators, valves, and motors in industrial environments—employ standard analog output ranges such as ±5 V, ±10 V, 0 V to 5 V, 0 V to 10 V, 4 to 20 mA, or 0 to 20 mA. The analog output signal-chain often includes digital isolation—to isolate the controller’s digital outputs from the DAC and analog signal conditioning. Converters in digitally isolated systems predominantly use 3-wire or 4-wire serial interfaces to minimize the required number of digital isolators or optocouplers.

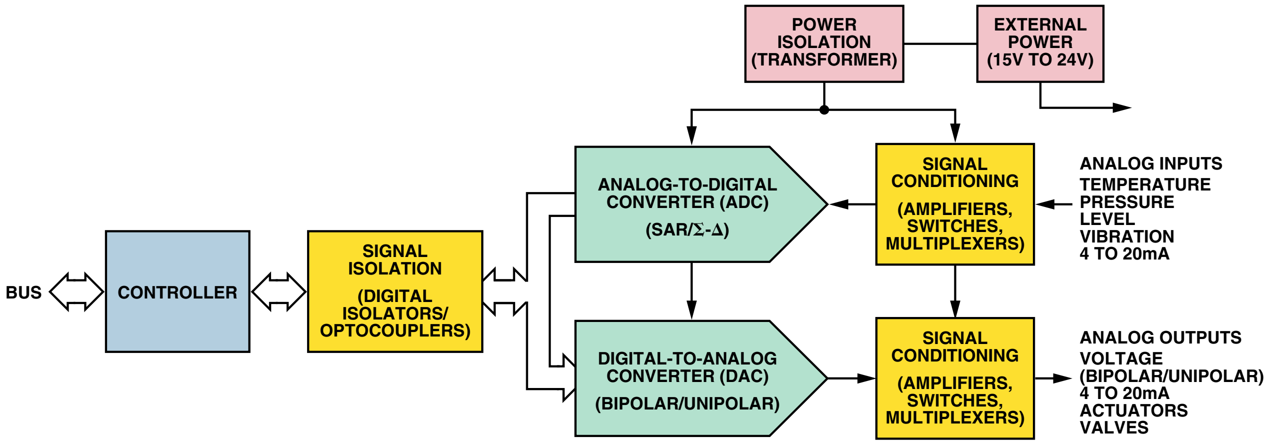

Figure 1. PLC system architecture, showing various I/O-module functions.

Two architectures are commonly used in PLC-system analog output modules: *DAC per channel* and *sample-hold per channel*. The first uses a dedicated DAC in each channel to generate its analog control voltage or current. A variety of available multiple DACs provide economy of space at low per-channel cost—but channels requiring interchannel isolation usually employ single-channel DACs. Figure 2 shows a typical DAC-per-channel configuration. The simplest DACs are low-voltage single-supply types, operating from a 2.5-V to 5.5-V supply with an output range of 0 V to V_{REF}. Their output signal may be conditioned to generate any required voltage- or current range. Bipolar-output converters, which require dual supplies, are available for use in output modules that must supply bipolar output voltage ranges.

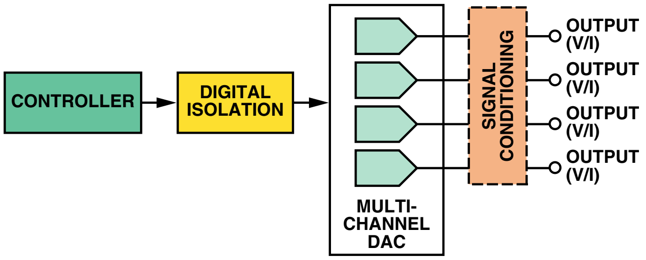

Figure 2. DAC-per-channel architecture.

Table 1, in the Appendix (page 7), shows a selection of 16-bit multichannel D/A converters suitable for implementing PLC output modules. These products offer either bipolar or unipolar output ranges, with settling times of 10 µs. Other members of these families, available with 12-bit and 14-bit resolution, are pin-compatible with the 16-bit versions—allowing a direct upgrade path from 12 bits to 16 bits with no hardware changes and minimal software changes. Most of these devices include an on-chip reference, thus offering a fully integrated output solution.

Quad D/A converters are ideally suited to nonisolated multichannel output designs where up to four different output configurations can be implemented using external signal-conditioning circuitry. For example, Figure 3 shows how the AD5664R,[3] a 16-bit quad voltage-output DAC, can deliver its specified 0-V to 5-V output range—or be connected for a variety of standard output voltage ranges, or for current-sink output, using an external quad op amp. In the bipolar-output configurations, the external output of its internal reference provides the necessary tracking offset voltage. The AD5664R operates from a single 5-V power supply, includes an internal 2.5-V, 5 ppm/°C reference, and is available in a tiny 3 mm × 3 mm LFCSP package.

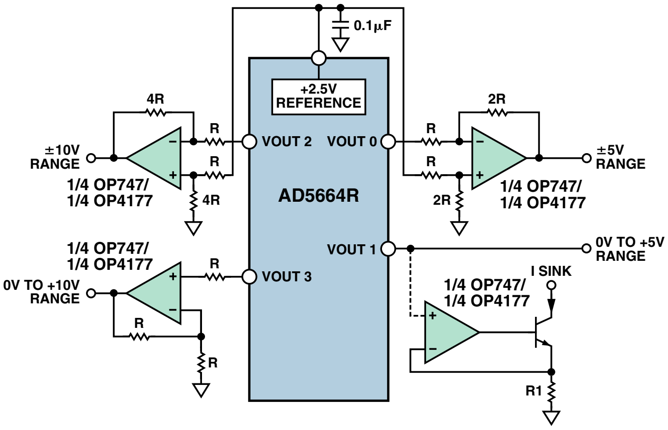

Figure 3. Implementing ±5-V, ±10-V, 0-V-to-10-V, 0-V-to-5-V, and current-sink outputs using a multichannel D/A converter.

Figure 4 shows a single-channel converter in an isolated 4-to-20-mA current-loop control circuit. The AD5662,[4] available in an SOT-23 package, is ideally suited to applications where full isolation between the analog output channels is required.

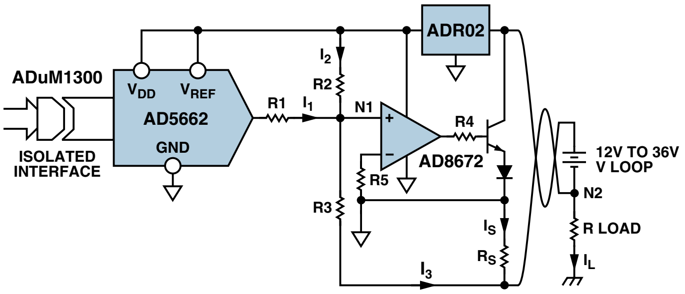

Figure 4. A 4-to-20-mA current-control circuit.

The AD5662 has a maximum output voltage span of 5 V, provided by the ADR02[5] voltage reference, which derives a precise, regulated supply from the variable loop voltage. The 5-V DAC-output span is converted to a 4-to-20-mA current output using an operational amplifier and transistor circuit. Since the noninverting input of the op amp (N1) is a virtual ground, the op amp regulates the current, I_S, to maintain equal voltage drops across R_S and R_3, hence

$$R_S I_S = R_3 I_3$$

Current summation at N2 provides the loop current,

$$I_L = I_S + I_3 = I_3\left(\frac{R_3}{R_S} + 1\right)$$

Summing the currents at N1:

$$I_3 = I_1 + I_2 = V_{DAC}\frac{1}{R_1} + V_{REF}\frac{1}{R_2}$$

$$I_L = V_{DAC}\frac{R_3 + R_S}{R_1 R_S} + V_{REF}\frac{R_3 + R_S}{R_2 R_S}$$

The 4-mA offset component of the loop current is provided by the reference:

$$\frac{R_3 + R_S}{R_1 R_S} V_{REF}$$

The programmable 0-to-16-mA component of the loop current is provided by the DAC:

$$\frac{R_3 + R_S}{R_2 R_S} V_{DAC}$$

Sample-hold per channel

An alternative architecture uses switched capacitors and buffers as *sample-and-hold amplifiers* (SHAs) to store selected output samples from a single high-performance DAC, as shown in Figure 5. The samples are switched among the various capacitors, using an analog multiplexer. Since the *hold* accuracy of the system is determined by the droop rate of the capacitor, the channels are refreshed frequently to maintain the desired accuracy. Depending on the output requirements, the DAC can be either a low-voltage single-supply converter or a bipolar-output converter. The buffer, which may provide signal conditioning, presents high input impedance to the capacitor and offers low output impedance for driving the output load.

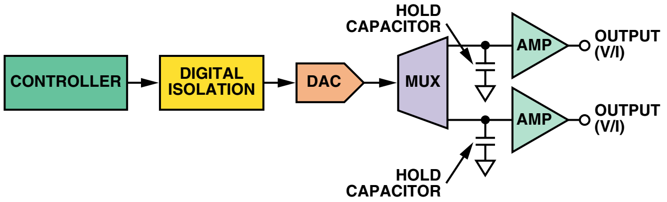

Figure 5. Single-DAC architecture.

Table 2 shows a selection of single-channel, 16-bit D/A converters, with full-scale settling times from 4 μs to 10 μs. Well-suited to sample-and-hold output architectures, they are provided in small-form-factor surface-mount packages.

Switches and Multiplexers

For sample-and-hold and other data-acquisition applications, where low-capacitance switching with low glitch and low charge injection are called for, the ADG12xx/ADG13xx family of ±15-V switches and multiplexers, designed on *i*CMOS, are useful.

For other applications, where very low on resistance is necessary, the ADG1408 and ADG1409 ±15-V multiplexers offer a maximum of 9 Ω over the full signal range. Besides having low R_{ON}, their excellent on-resistance *flatness* (with voltage level) makes them an ideal solution in applications where low distortion is essential for reliable, predictable circuit performance.

Table 3 tabulates capacitance, charge injection, and R_{ON} for a selection of *i*CMOS switches and multiplexers. They are compared with a popular earlier type, the ADG508/ADG509.

Galvanic Isolation for Power and Digital Signals

In PLCs, process control, data acquisition, and control systems, digital signals are transmitted from a variety of sensors to a central controller for processing and analysis. To maintain safe voltages at the user interface, and to prevent transients from being transmitted from the sources, galvanic isolation is required. The most commonly used isolation devices are optocouplers, transformer-based isolators, and capacitively coupled isolators.

The popular *optocouplers* contain light-emitting diodes (LEDs)—to convert electrical signals to corresponding light intensities—and photodetectors to convert the light back to electrical signals. In general, their LEDs are characterized by low conversion efficiencies—and the photodetectors by slow response; overall, optocouplers tend to have limited life, as well as excessive performance variation over temperature, speed, and power consumption. They are generally limited to 1- or 2-channel configurations and require external components to configure complete functions.

A new approach to isolation has been developed at Analog Devices, combining chip-scale transformer technology with integrated CMOS inputs and outputs. These *i*Coupler® devices are easy to use—with smaller size, lower cost, and lower power requirements than optocouplers. Available in a wide variety of channel configurations and performance levels, with standard CMOS interfaces, *i*Couplers require no external components—and provide high performance and stability over temperature, supply voltage, and life. A typical *i*Coupler isolation IC, the ADuM2400[6] quad isolator, with its interfaces and coupling transformers, is shown in Figure 6.

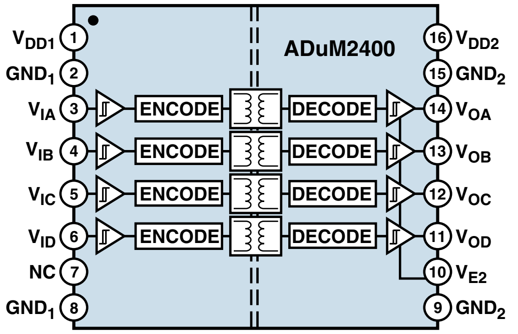

Figure 6. Block diagram of ADuM2400 quad isolator.

*i*Couplers have two- to four-times faster data rates and timing specifications than commonly used high-speed optocouplers—and they operate with as little as 1/50 the power of optocouplers, with correspondingly less heat dissipation, improved reliability, and reduced cost. Table 4 shows available channel configuration options.

Providing isolated power from the system side to the field side in fully isolated systems is another challenge that has an emerging solution. Traditional techniques employed in transferring power across an isolation barrier include either a separate, relatively large, expensive dc-to-dc converter, or a difficult-to-design-and-interface discrete assembly. A newer and better approach, currently available to supply up to 50 mW, is to use a complete, fully integrated isolation solution involving signal- and power transfer across an isolation barrier using microtransformers. The ADuM524x *iso*Power family of products provides isolation up to 5 kV, for both signal and power, within a single component—eliminating the need for a separate, isolated power supply and significantly reducing the total isolation system cost, board area requirements, and design time. A typical device is shown in Figure 7. All products have achieved UL, CSA, and VDE safety approval.

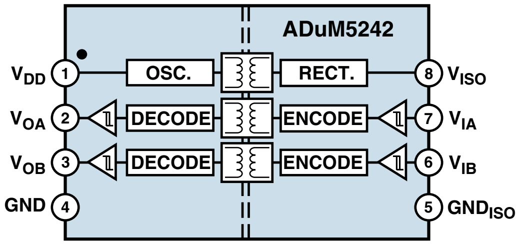

Figure 7. Block diagram of ADuM5242[7] dual-channel isolator with integrated dc-to-dc converter (0-/2-channel directionality).

PLC Input Module

The choice of architecture and input-module products for PLC systems depends upon the input signal levels that need to be monitored. The signals, from various types of sensors and process-control variables to be monitored, can involve input signal ranges from to ±10 mV to ±10 V. The table below indicates some of the sources and their typical input-range requirements.

A variety of A/D converter types can be used for industrial and PLC applications—including successive-approximation (SAR), flash/parallel, integrating (including sigma-delta), and ramp/counting. The selection of an ADC for a particular application is primarily dictated by the input-signal range required by the input transducer—as well as the required accuracy, signal-frequency content, maximum signal level, and dynamic range. The most widely used architectures are successive-approximation and sigma-delta.

Successive-approximation ADCs provide resolutions from 12 bits to 18 bits with high throughput rates; they are ideally suited to multichannel multiplexed applications, where a number of input channels need to be monitored at reasonably high sample rates.

Sigma-delta architectures provide resolutions from 16 bits to 24 bits. They employ high oversampling rates and digital filtering to achieve their high resolution and accuracy—but at lower throughput rates than are achieved by SAR types. Sigma-delta architectures generally incorporate programmable-gain amplifiers (PGAs) on the front end; in converter-per-channel applications, this allows a direct interface—without signal conditioning—between the sensor and the ADC.

A key requirement when measuring low-level signals from thermocouples, strain gages, and bridge-type pressure sensors is the ability to perform a differential measurement to reject common-mode interference and provide a more stable reading in the presence of noise. In industrial applications, for example, differential inputs are used to cancel common-mode noise or interference from motors, ac power lines, or noise sources that inject noise into the analog inputs of the A/D converter.

Single-ended inputs, which are lower in cost, provide twice the number of input channels for the same number of input pins, since they require only one analog input per channel and are all referenced to the same ground point. They are mainly used in applications with high signal levels, low noise, and a stable common ground.

Figure 8 shows many of the elements that could be included in a discrete implementation of an isolated PLC input module—including excitation, input signal conditioning, a fault-protected multiplexer to handle a number of input signals, a programmable-gain amplifier, and an A/D converter. Many of these functions, formerly assembled with discrete collections of ICs and passive elements, are now available—fully integrated and characterized—in A/D-converter and analog front-end ICs.

Analog Input-Module Low-Level Signal Ranges

Input	±10 mV	±25 mV	±50 mV	±80 mV	±0.25 V	±0.5 V	±1 V	±1.25 V	±2.5 V	±5 V	±10 V
Strain Gage	✔										
Thermocouple											
K				✔							
T		✔									
J				✔							
N			✔								
E				✔							
R		✔									
S		✔									
B		✔									
U			✔								
L				✔							
Resistor											
48 Ω				✔							
150 Ω					✔						
300 Ω						✔					
600 Ω							✔				
6 kΩ											✔
RTD											
Cu10 Std			✔								
Ni St/Kl						Ni100	Ni120/200		Ni500	Ni1000	
Pt Std							Pt100		Pt200	Pt500	Pt1000
Air Conditioning					Pt100	Pt200		Pt500	Pt1000		

For example, the AD761x (16-bit) and AD763x (18-bit) families of *i*CMOS PulSAR® ADCs with internal references provide programmable input voltage ranges (0 V to 5 V, 0 V to 10 V, ±5 V, and ±10 V) that allow the designer to change inputs on-the-fly. For these devices, all switching is done via internal registers, eliminating data latency and providing improved channel switching speeds. Table 5 shows a selection of 16-bit/18-bit PulSAR ADCs ideally suited to PLC applications.

Another, more highly integrated example is the AD7792/AD7793/AD7794/AD7795/AD7798/AD7799 family of sigma-delta ADCs. Besides their ultralow noise (40 nV) and low power requirement (400 µA), the family also provides features such as an on-chip PGA (gains from 1 to 128), voltage reference, sensor-excitation current sources, and clock—in a small TSSOP package. The combination of very low noise and low power makes these devices ideal for applications requiring high-accuracy measurements.

These ADCs can be connected directly to the sensor interface in many applications, including PLCs, temperature measurement, weigh scales, pressure- and flow measurement, and general measurement equipment. Their update rate is programmable from 4 Hz to 500 Hz, and they offer simultaneous rejection of both 50-Hz and 60-Hz signals at selected update rates. Table 6 shows features and functions offered by the AD779x family of converters.

Figure 9 shows a typical configuration using the AD7794/AD7795 to measure input signals from bridge transducers and resistance-based temperature sensors.

When high-precision fault-protected analog measurement with voltage-input capability up to ±10 V is needed in PLCs and industrial I/O, and where high throughput for multiple channels is important, the AD7732 (two fully differential input channels), AD7734 (four single-ended input channels), and AD7738 (four fully differential or eight single-ended input channels) are ideal.

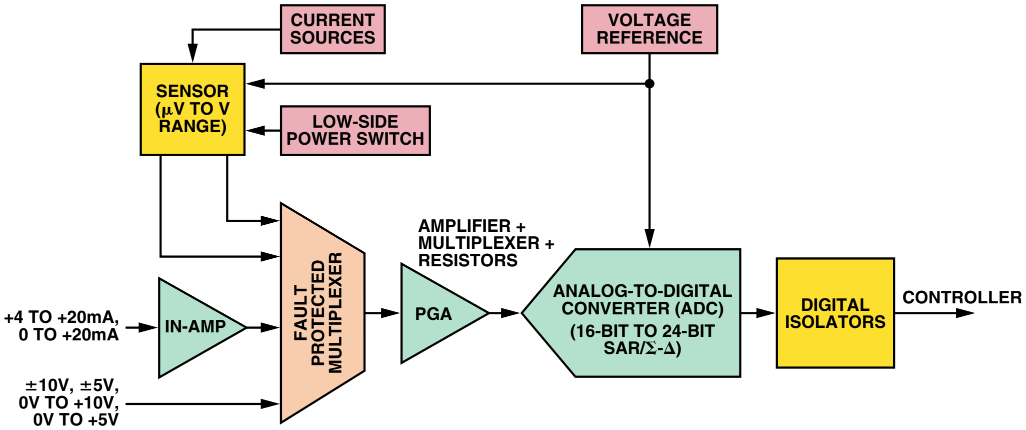

Figure 8. Functions embodied in a typical discrete PLC input module.

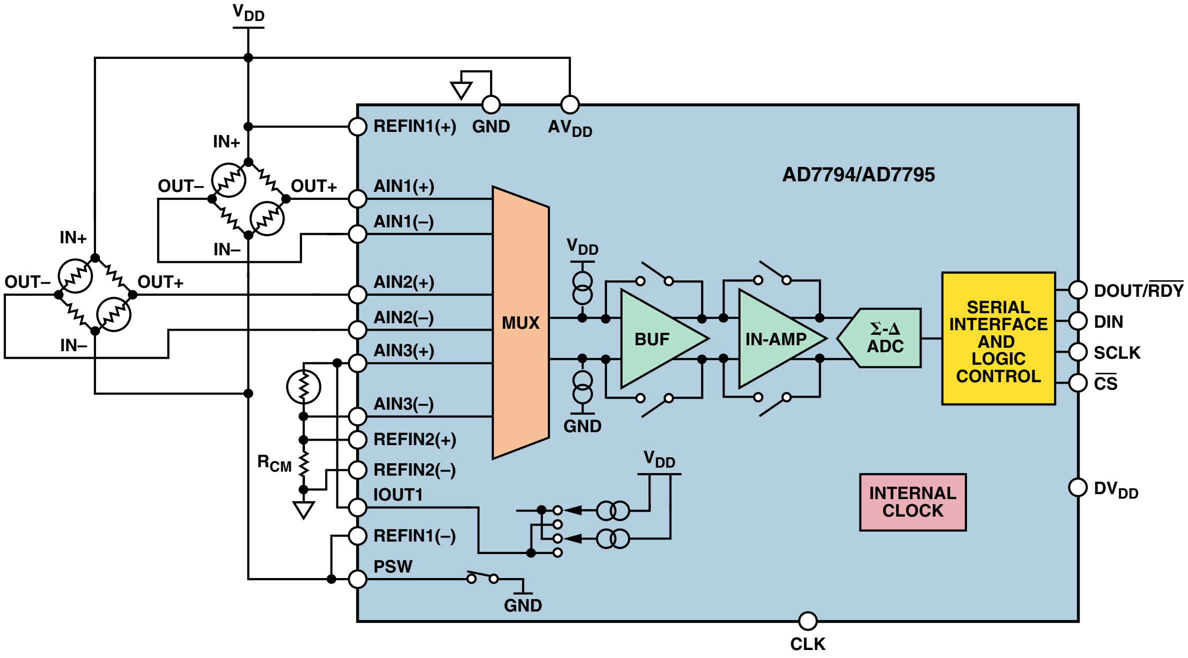

Figure 9. Low-level measurement using AD7794/AD7795.

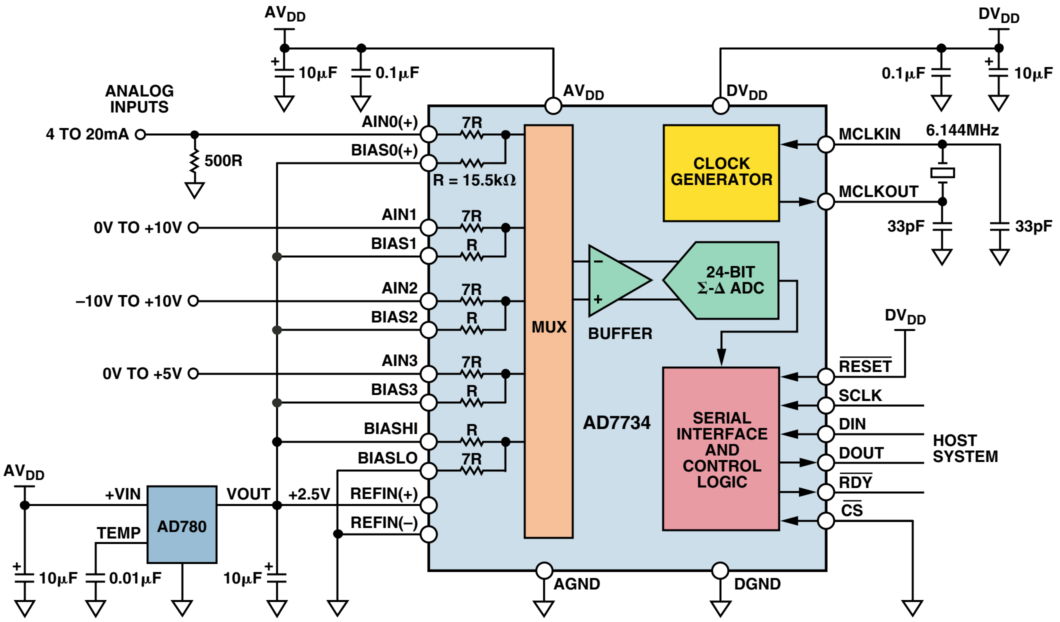

Figure 10. High-voltage signal acquisition using the AD7734.

Figure 10 shows a typical configuration using the AD7734 to measure high level signals typically seen in PLC- and process-control applications. The analog front-end features four single-ended input channels with unipolar or true-bipolar input ranges to ±10 V, while operating from a single 5-V analog supply. Analog input overvoltage of ±16.5 V can be accepted without degrading the performance of adjacent channels, and the device can signal over-range and under-range voltages.

Voltage References

Stable, accurate, low-noise standalone references are important in some PLC applications. Table 7 outlines a wide selection of high-performance voltage references, ranging from high-accuracy, low-noise ICs for high-end industrial applications to general-purpose, low-power devices for hand-held battery-powered applications.

Amplifiers (Instrumentation and Operational)

Instrumentation amplifiers (in-amps) measure the difference between two input voltages (while rejecting any signals that are common to both inputs), apply a fixed or programmable gain, and provide a single-ended output, biased by the voltage applied at a *reference* terminal. Since inadequate *common-mode rejection* (CMR) can cause large, time-varying errors that are difficult to remove at the output, modern in-amps provide from 80 dB to 120 dB of dc- and low-frequency CMR. In-amps provide an important function in extracting small signals from transducers and other signal sources in data-acquisition, PLC, and industrial process-control applications. As with all dc amplifiers, an in-amp must have low dc offset voltage and drift.

The AD8220[8] is an example of a highly versatile instrumentation amplifier that can be used in a variety of applications, such as signal conditioning between sensors—such as strain gages—and ADCs, in medical applications, programmable logic controllers, data-acquisition cards, and analog I/O cards. It offers resistor-programmable gains from 1 to 1000, with 80-dB CMR, 1-mV offset, and 10-μV/°C drift.

Operational amplifiers are the "workhorses" of analog circuitry, and Analog Devices offers one of the largest op-amp stables available in the marketplace today. Innovative design, combined with recent IC process developments, such as the high-voltage *i*CMOS and high-performance *i*Polar™, have made possible the introduction of devices for the industrial marketplace with dramatically improved performance and far greater functionality—in one-quarter the board space of older process geometries. Table 8 and Table 9, respectively, outline single- and multichannel amplifier products that are frequently used in PLC applications. They easily handle the high supply voltages generally required to support a ±10-V output range, and they feature low offset voltage and low supply current—and are housed in a small package.

CONCLUSION

Industrial system designers of PLCs continue to push for higher performance and functionality on a shrinking budget with ever shrinking board area. To provide integrated circuits capable of meeting these stringent requirements and compete for *all* significant sockets in the signal chain, Analog Devices has developed important new manufacturing processes. The *i*CMOS process technology combines high-voltage silicon with submicron CMOS and complementary bipolar technologies to make possible analog ICs capable of 30-V operation (required for many industrial applications) in a smaller footprint with higher performance at lower cost. *i*Coupler isolation technology, based on chip-scale transformers—rather than the LEDs and photodiodes—can be integrated with CMOS semiconductor functions for low-cost isolation. The *i*Polar trench-isolation process permits supply voltages of up to ±18 V and offers a dramatic improvement in performance over conventional bipolar amplifiers, while reducing power consumption by half—and package size by as much as 75%. These technologies meet present needs well—and face a brilliant future. ▶

REFERENCES—VALID AS OF NOVEMBER 2006

[1] http://www.analog.com/Analog_Root/static/pdf/isolators/techDocs/isoPower.pdf
[2] ADI website: www.analog.com (Search) *i*CMOS (Go)
[3] ADI website: www.analog.com (Search) AD5664R (Go)
[4] ADI website: www.analog.com (Search) AD5662 (Go)
[5] ADI website: www.analog.com (Search) ADR02 (Go)
[6] ADI website: www.analog.com (Search) ADuM2400 (Go)
[7] ADI website: www.analog.com (Search) ADuM5242 (Go)
[8] ADI website: www.analog.com (Search) AD8220 (Go)

APPENDIX: SELECTION TABLES

Updated versions of these tables can be found at *www.analog.com*. Click on the appropriate product listings.

Table 1. 16-Bit Multichannel D/A Converters Targeted at DAC-Per-Channel Applications

Part Number	Number of Channels	Output Range	INL (LSB)	Reference	Settling Time (μs)	Package
AD5668	8	Unipolar	8	Int/ext	6	TSSOP
AD5678	4 × 12-bit 4 × 16-bit	Unipolar	8	Int/ext	6	TSSOP
AD5544	4	Unipolar/bipolar	4	Ext	2	TSSOP
AD5664	4	Unipolar	6	Ext	4	LFCSP, MSOP
AD5664R	4	Unipolar	8	Int/ext	4	LFCSP, MSOP
AD5666	4	Unipolar	32	Int/ext	6	TSSOP
AD5764	4	Bipolar	—	Int/ext	8	TQFP
AD5663	2	Unipolar	6	Ext	4	LFCSP, MSOP
AD5663R	2	Unipolar	8	Int/ext	4	LFCSP, MSOP

Table 2. Single-Channel 16-Bit D/A Converters

Part Number	Output Range	INL (LSB)	Reference	Settling Time (μs)	Package
AD5570	Bipolar	0.4	Ext	12	SSOP
AD5660	Unipolar	16	Int	8	MSOP, SOT-23
AD5662	Unipolar	8	Ext	8	MSOP, SOT-23
AD5062	Unipolar	0.5	Ext	4	SOT-23
AD5063	Unipolar/bipolar	1	Ext	4	MSOP
AD5060	Unipolar	1	Ext	4	SOT-23
AD5061	Unipolar	0.5	Ext	4	SOT-23

Table 3. *i*CMOS Switches and Multiplexers

Part Number	Function	Capacitance/ Channel (pF)	Q_{INJ} (pC)	R_{ON} (Ω)
ADG1211	Quad SPST switch	1.2	–0.3	260
ADG1212	Quad SPST switch	1.2	–0.3	260
ADG1213	Quad SPST switch	1.2	–0.3	260
ADG1236	Dual SPST switch	1.6	–1	260
ADG1204	4:1 mux	4.2	–0.7	260
ADG1208	8:1 mux	7	0.4	270
ADG1209	Dual 4:1 mux	4.5	0.4	270
ADG1308	8:1 mux	15	2	300
ADG1309	Dual 4:1 mux	10	2	300
ADG1408	8:1 mux	90	20	9
ADG1409	Dual 4:1 mux	45	20	9
ADG508F	8:1 mux	50	4	400
ADG509F	Dual 4:1 mux	25	4	400

Table 4. Digital Isolators

Part Number	Number of Channels	Channel Configuration (Forward/Reverse Channels)	Isolation Rating (kV rms)
ADuM1100	1	1/0	2.5
ADuM1200	2	2/0	2.5
ADuM1201	2	1/1	2.5
ADuM1300	3	3/0	2.5
ADuM1301	3	2/1	2.5
ADuM1400	4	4/0	2.5
ADuM1401	4	3/1	2.5
ADuM1402	4	2/2	2.5
ADuM2400	4	4/0	5
ADuM2401	4	3/1	5
ADuM2402	4	2/2	5

Table 5. Programmable-Input-Range 16-Bit/18-Bit PulSAR ADCs

Part Number	Resolution (Bits)	Data Bus Interface	Sample Rate (kSPS)	Supply Range (V)	Maximum Operating Power (mW)	Reference (V)	Analog Input Range Reference (Int/Ext)	Pin Count and Package
AD7610	16	Serial/ parallel	250	±16.5	38	5	0 V to +10 V, ±5 V, ±10 V	48-lead LQFP, LFCSP
AD7612	16	Serial/ parallel	750	±16.5	100	5	0 V to +10 V, ±5 V, ±10 V	48-lead LQFP, LFCSP
AD7631	18	Serial/ parallel	250	±16.5	100	5	0 V to +10 V, ±5 V, ±10 V	48-lead LQFP, LFCSP
AD7634	18	Serial/ parallel	670	±16.5	100	5	±10 V uni, ±20 V bi, diff	48-lead LQFP, LFCSP

Table 6. Functionality Offered by the AD779x Σ-Δ ADC Family

Part Number	Resolution	Channels	PGA	Reference	Current Sources	Temperature Sensor	Reference Detect	Sensor Detect
AD7792	16	3	Yes	Yes	Yes	Yes	No	Yes
AD7793	24	3	Yes	Yes	Yes	Yes	No	Yes
AD7794	24	6	Yes	Yes	Yes	Yes	Yes	Yes
AD7795	16	6	Yes	Yes	Yes	Yes	Yes	Yes
AD7798	16	3	Yes	No	No	No	Yes	Yes
AD7799	24	3	Yes	No	No	No	Yes	Yes

Table 7. Voltage References

Reference Family	Characteristics	Voltage Output Options (V)	Key Specifications
ADR43x	XFET® series reference	2.048, 2.5, 3.0, 4.096, 4.5, 5	±0.04% accuracy 3.5 mV p-p (0.1 Hz to 10 Hz)
ADR0x	Ultracompact, high precision	2.5, 3.0, 5, 10	±0.1% accuracy low drift: SOIC: 3 ppm/°C TSOT-23 and SC70: 9 ppm/°C
ADR39x	High precision, micropower series reference	2.048, 2.5, 4.096, 5	±6 mV accuracy low power: 120 μA max 5 mV p-p (0.1 Hz to 10 Hz)
ADR5xx	High performance shunt references	1.0, 1.2, 2.048, 2.5, 3.0, 4.096, 5	±0.2% accuracy tempco: 40 ppm/°C
ADR36x	High precision, low power series reference	2.048, 2.5, 3.0, 3.3, 4.096, 5	±3 mV initial accuracy quiescent current: ≤ 190 μA 8.25 mV p-p (0.1 Hz to 10 Hz)
ADR44x	Ultralow noise, LDO XFET series reference	2.048, 2.5, 3.0, 4.096, 5	±0.04% accuracy 1.0 mV p-p (0.1 Hz to 10 Hz) tempco: B-Grade: 3 ppm/°C

Table 8. Single-Channel Amplifiers Frequently Used in PLC and Analog Signal-Conditioning Applications

Product	Power Supply (V)	Offset (mV)	Slew Rate (V/μs)	I_{SUPPLY} (mA/Amplifier)	Package
AD8671	36	0.075	4	3	MSOP
AD8675	36	0.050	1	3	MSOP
AD8677	36	0.075	0.6	1.2	TSOT
OP1177	36	0.060	0.7	0.4	MSOP
OP07D	36	0.15	0.2	0.4	SOT-23
AD820	36	1	3	0.8	MSOP
AD8641	36	0.5	5	0.7	SC70
OP07	36	0.075	0.2	0.2	SOIC

Table 9. Multichannel High-Supply-Voltage Amplifiers Frequently Used in PLC and Analog Signal-Conditioning Applications

Product	Power Supply (V)	Offset (mV)	Slew Rate (V/μs)	I_{SUPPLY} (mA/Amplifier)	Package
ADA4004-4	36	0.100	2.7	1.7	LFCSP
AD8674	36	0.060	0.7	0.4	TSSOP
AD8513	36	0.4	3	0.8	TSSOP
AD8625	26	0.5	5	0.7	TSSOP
OP482	36	3	8.5	0.25	SOIC
OP4177	36	0.06	0.7	0.4	TSSOP
AD824	36	01.4	3	0.8	SOIC
AD8643	26	0.5	5	0.7	TSSOP
OP747	36	0.1	0.2	0.3	TSSOP