

Complete Sensor-to-Bits Solution Simplifies Industrial Data-Acquisition System Design

By Maithil Pachchigar

Introduction

At the heart of many industrial automation and process-control systems, programmable logic controllers (PLCs) monitor and control complex system variables. Employing multiple sensors and actuators, PLC-based systems measure and control analog process variables such as pressure, temperature, and flow. PLCs are found in diverse applications—such as factories, oil refineries, medical equipment, and aerospace systems—that require high accuracy and robust, long-term operation. In addition, the competitive marketplace demands lower cost and shorter design times.

Thus, designers of industrial equipment and critical infrastructure encounter significant challenges in meeting their customers' stringent accuracy, noise, drift, speed, and safety requirements. Using a PLC as an example, this article shows how the versatile, low cost, highly integrated [ADAS3022](#) reduces complexity, solving many challenges encountered in the design of multichannel data-acquisition systems by replacing the analog front-end (AFE) stages. Ideally suited for precision industrial, instrumentation, power line, and medical data-acquisition cards with multiple input ranges, this high-performance device reduces cost and time to market while offering a small, easy-to-use footprint and true 16-bit precision at 1 MSPS.

PLC Application Example

Figure 1 shows a simplified signal chain for a PLC used in industrial automation and process-control systems. The PLC typically comprises analog and digital input/output (I/O) modules, a central processing unit (CPU), and power-management circuitry.

In industrial applications, analog input modules acquire and monitor signals from remote sensors located in harsh environments characterized by extreme temperature and humidity, vibration, and explosive chemicals. Typical signals include single-ended or differential voltages with 5 V, 10 V, ± 5 V, and ± 10 V full-scale ranges, or current loops with 0 mA to 20 mA, 4 mA to 20 mA, and

± 20 mA ranges. When long cables with substantial electromagnetic interference (EMI) are encountered, current loops are often used due to their inherently high noise immunity.

Analog output modules typically control actuators, such as relays, solenoids, and valves, to complete the automated-control system. They typically provide output voltages with 5 V, 10 V, ± 5 V, and ± 10 V full-scale ranges and 4 mA to 20 mA current-loop outputs.

Typical analog I/O modules include 2, 4, 8, or 16 channels. To meet stringent industry standards, these modules require protection against overvoltage, overcurrent, and EMI surges. Most PLCs include digital isolation between the ADC and the CPU and between the CPU and the DAC. High-end PLCs may also incorporate channel-to-channel isolation, as specified by the International Electrotechnical Commission (IEC) standards. Many I/O modules include per-channel software programmable single-ended or differential input ranges, bandwidth, and throughput rate.

In modern PLCs, the CPU performs numerous control tasks in an automated manner, employing real-time access to information to make intelligent decisions. The CPU may embody advanced software and algorithms, and web connectivity for diagnostic error checking and fault detection. Commonly used communication interfaces include RS-232, RS-485, industrial Ethernet, SPI, and UART.

Discrete Implementation of Data-Acquisition System

Industrial designers can build analog modules for PLCs or similar data-acquisition systems with discrete high-performance components, as shown in Figure 2. Key design considerations include input signal configuration and overall system speed, accuracy, and precision. The signal chain presented here utilizes the [ADG1208/ADG1209](#) low-leakage multiplexer, [AD8251](#) fast-settling programmable-gain instrumentation amplifier (PGIA), [AD8475](#) high-speed funnel amplifier, [AD7982](#) differential-input 18-bit PulSAR[®] ADC, and [ADR4550](#) ultralow-noise voltage reference. This solution provides four different gain ranges, but with maximum input signals of ± 10 V, designers will have to worry about the multiplexer's switching and settling times, as well as other analog signal conditioning challenges. In addition, achieving true 16-bit performance at 1 MSPS can be a major challenge, even when using these high-performance components.

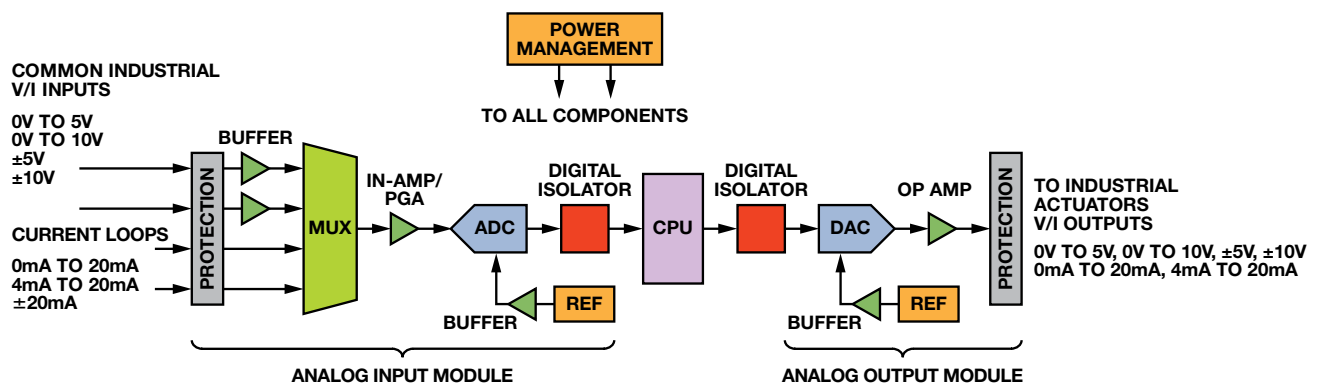


Figure 1. Typical PLC signal chain.

The AD7982 specifies a 290-ns transient response from a full-scale step. Thus, to guarantee the specified performance while converting at 1 MSPS, the PGIA and funnel amp must settle in less than 710 ns. The AD8251 specifies 785-ns settling time to 16 bits (0.001%) for a 10-V step, however, so the maximum throughput that can be guaranteed for this signal chain will be less than 1 MSPS.

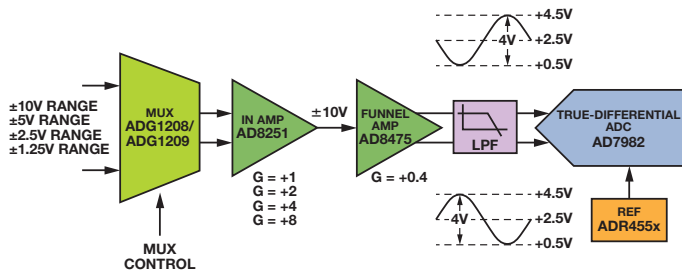


Figure 2. Analog input signal chain using discrete components.

Integrated Solution Simplifies Data-Acquisition System Design

Manufactured in *i*CMOS®, a proprietary, high-voltage industrial process technology, the 16-bit, 1-MSPS ADAS3022 data-acquisition IC integrates an 8-channel, low-leakage multiplexer; a high-impedance PGIA with high common-mode rejection; a precision, low-drift 4.096-V reference and buffer; and a 16-bit successive-approximation ADC, as shown in Figure 3.

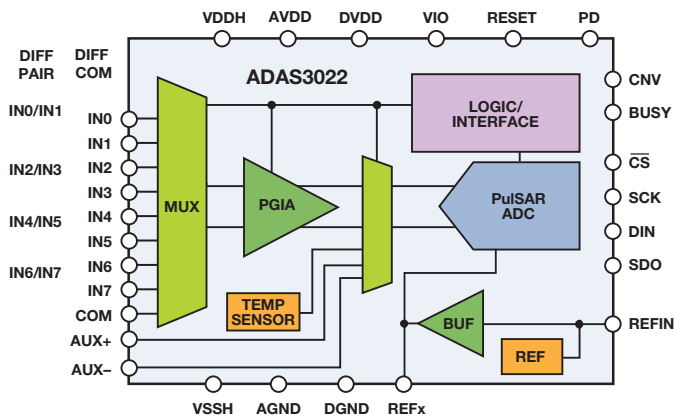


Figure 3. Functional block diagram of ADAS3022.

This complete sensor-to-bits solution utilizes only one-third of the board space of discrete implementations, helping engineers to simplify their designs while reducing the size, time to market, and cost of advanced industrial data-acquisition systems. Eliminating the necessity to buffer, level shift, amplify, attenuate, or otherwise condition the input signal, and the concerns regarding common-mode rejection, noise, and settling time, it alleviates many of the challenges associated with designing a precision 16-bit, 1-MSPS data-acquisition system. It delivers the best-in-class 16-bit accuracy (± 0.6 -LSB typical INL), low offset voltage, low drift overtemperature, and optimized noise performance at 1 MSPS (91-dB typical SNR), as shown in Figure 4. The device is specified over the -40°C to $+85^{\circ}\text{C}$ industrial temperature range.

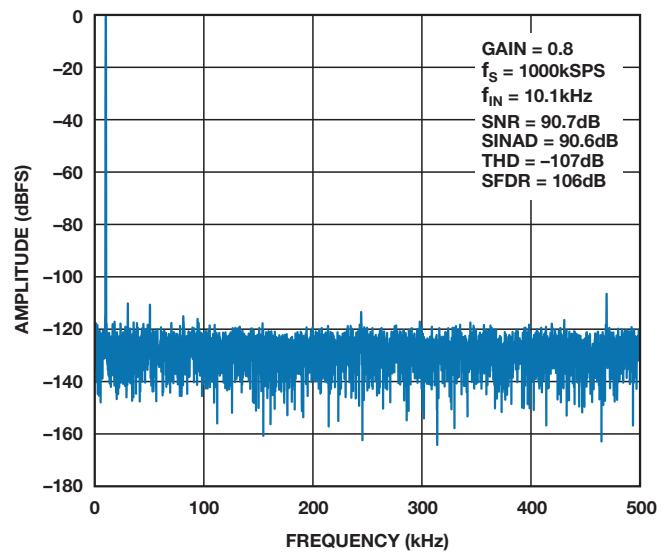
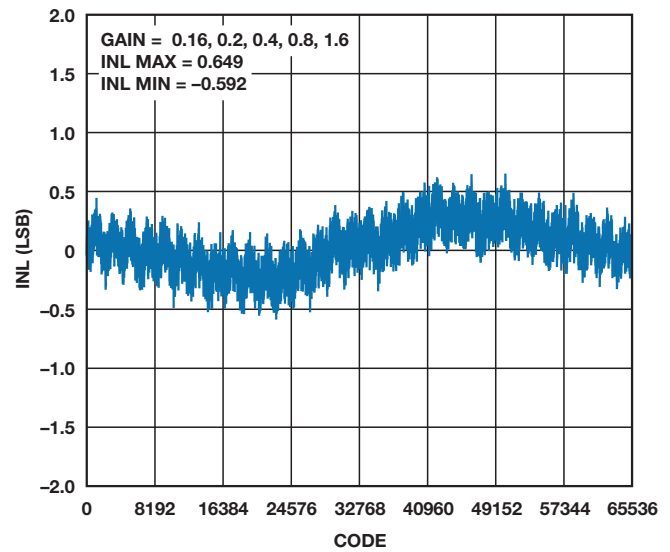


Figure 4. INL and FFT performance of the ADAS3022.

The PGIA has a large common-mode input range, true high-impedance inputs ($>500\text{ M}\Omega$), and a wide dynamic range, allowing it to accommodate 4-mA to 20-mA current loops, accurately measure small sensor signals, and reject interference from ac power lines, electric motors, and other sources (90-dB minimum CMR).

An auxiliary differential input channel can accommodate $\pm 4.096\text{ V}$ input signals. It bypasses the multiplexer and PGIA stages, allowing direct interface to the 16-bit SAR ADC. An on-chip temperature sensor can monitor the local temperature.

This high level of integration saves board space and lowers the overall parts' cost, making the ADAS3022 ideal for space-constrained applications, such as automatic test equipment, power-line monitoring, industrial automation, process control, patient monitoring, and other industrial and instrumentation systems that operate with $\pm 10\text{-V}$ industrial signal levels.

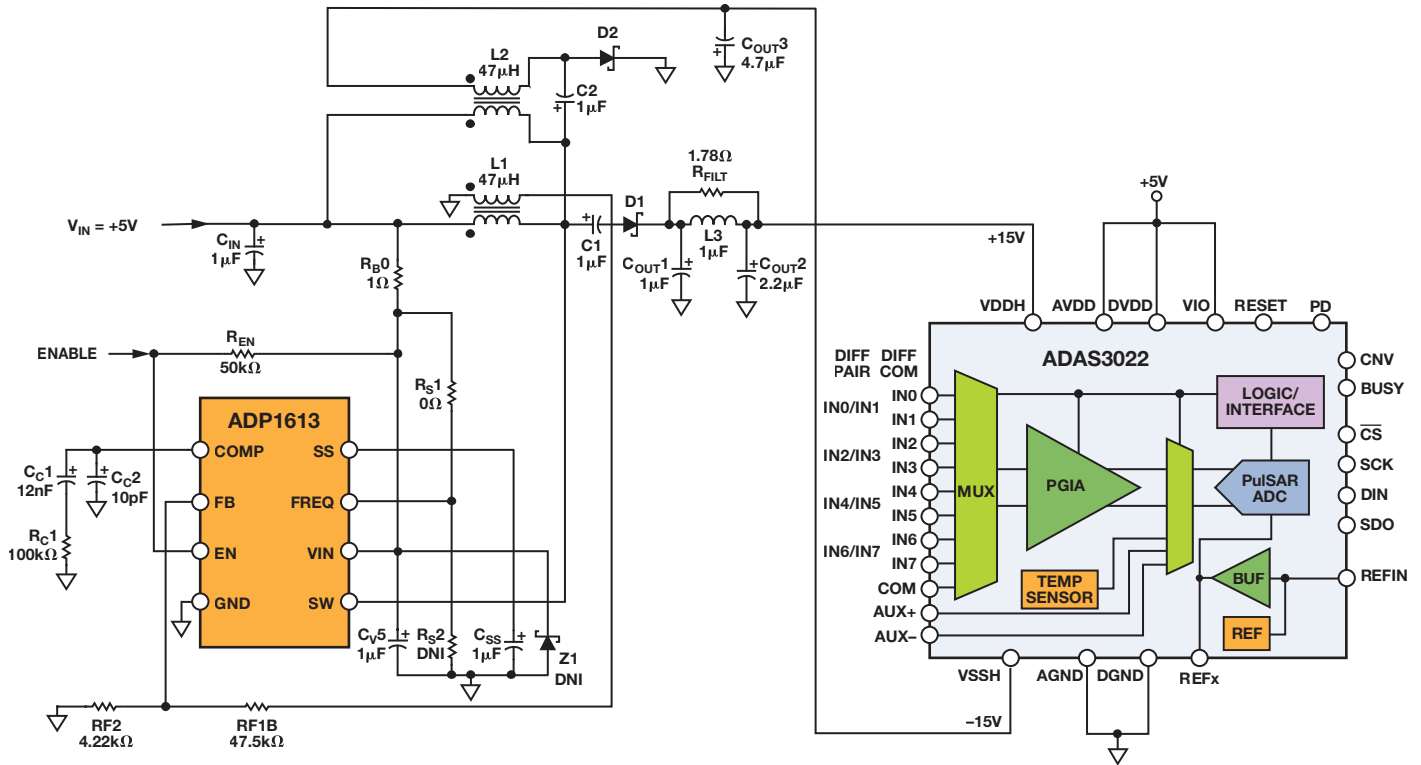


Figure 5. Complete 5-V, single-supply, 8-channel data-acquisition solution with integrated PGA.

Figure 5 shows a complete 8-channel data acquisition system (DAS). The ADAS3022 operates with $\pm 15\text{-V}$ and $+5\text{-V}$ analog and digital supplies, and a 1.8-V to 5-V logic I/O supply. The ADP1613 high-efficiency, low-ripple dc-to-dc boost converter allows the DAS to operate with a single 5-V supply. Configured as a single-ended, primary inductance Ćuk (SEPIC) topology using the ADIsimPower™ design tool, the ADP1613 furnishes the $\pm 15\text{-V}$ bipolar supplies required for the multiplexer and PGA without compromising performance.

The noise performance of the ADAS3022 and the discrete signal chain are compared in Table 1, which uses the input signal amplitude, gain, equivalent noise bandwidth (ENBW), and input-referred (RTI) noise of each component to calculate the total noise of the complete signal chain.

Table 1. Noise Performance for the ADAS3022 and the Discrete Signal Chain

Noise	ADG1209	AD8251	AD8475	AD7982		Total Noise		ADAS3022	Input Signal
	RTI	RTI	RTI	RTI	SNR	RTI _{Total}	SNR	SNR	
	($\mu\text{V rms}$)	($\mu\text{V rms}$)	($\mu\text{V rms}$)	($\mu\text{V rms}$)	(dB)	($\mu\text{V rms}$)	(dB)	(dB)	(V rms)
Gain = 1 ($\pm 10\text{ V}$)	6.56	124	77.5	148	95.5	208	90.6	91.5	7.07
Gain = 2 ($\pm 5\text{ V}$)	6.56	83.7	38.8	74.2	95.5	119	89.5	91.0	3.54
Gain = 4 ($\pm 2.5\text{ V}$)	6.56	68.2	19.4	37.1	95.5	80.3	86.8	89.7	1.77
Gain = 8 ($\pm 1.25\text{ V}$)	6.56	55.8	9.69	18.5	95.5	60.0	83.4	86.8	0.88

The single-pole low-pass filter (LPF) between the AD8475 and AD7982 (Figure 2) attenuates the kick coming from the switched-capacitor input of the AD7982 and limits the amount of high-frequency noise. The -3 -dB bandwidth ($f_{-3\text{dB}}$) of the LPF is 6.1 MHz ($R = 20 \Omega$, $C = 1.3 \text{ nF}$), allowing fast settling of the input signals while converting at 1 MSPS. The ENBW of the LPF can be calculated as

$$\text{ENBW} = \pi/2 \times f_{-3\text{dB}} = 9.6 \text{ MHz.}$$

Note that this calculation ignores the noise from the voltage reference and LPF as it does not significantly affect the total noise, which is dominated by the PGIA.

Consider an example using the ± 5 -V input range. In this case, the AD8251 is set for a gain of 2. The funnel amplifier is set to a fixed gain of 0.4 for all four input ranges, so a 0.5-V to 4.5-V differential signal (4 V p-p) will be applied to the AD7982. The RTI noise of the ADG1208 is derived from the Johnson/Nyquist noise equation ($e_n^2 = 4K_B T R_{\text{ON}}$, where $K_B = 1.38 \times 10^{-23} \text{ J/K}$, $T = 300\text{K}$, and $R_{\text{ON}} = 270 \Omega$). The RTI noise of the AD8251 is derived from its 27-nV/ $\sqrt{\text{Hz}}$ noise density as specified in the data sheet for a gain of 2. Similarly, the RTI noise of the AD8475 is derived from its 10-nV/ $\sqrt{\text{Hz}}$ noise density using a gain of 0.8 (2×0.4). In each calculation, ENBW = 9.6 MHz. The RTI noise of the AD7982 is calculated from its 95.5-dB SNR as specified in the data sheet using a gain of 0.8. The total RTI noise of the entire signal chain is calculated based on the root-sum-square (rss) of the RTI noise from the discrete components. The total SNR of 89.5 dB can be computed from the equation $\text{SNR} = 20 \log(V_{\text{IN,rms}}/\text{RTI}_{\text{Total}})$.

Although the theoretical noise estimate (SNR) and the overall performance of the discrete signal chain is comparable to that of the ADAS3022, especially at lower gains ($G = 1$ and $G = 2$) and lower throughput rates (much less than 1 MSPS), it's not an ideal solution. The ADAS3022 can reduce cost by about 50% and board space by about 67%, as compared to the discrete solution, and it can also accept three additional input ranges ($\pm 0.64 \text{ V}$, $\pm 20.48 \text{ V}$, and $\pm 24.576 \text{ V}$) that the discrete solution cannot offer.

Conclusion

The next generation of industrial PLC modules will demand high accuracy, reliable operation, and functional flexibility, all in a small, low-cost form factor. The ADAS3022, with industry leading integration and performance, supports a wide range of voltage and current inputs to handle a variety of sensors in industrial automation and process control. An ideal fit for PLC analog input modules and other data-acquisition cards, the ADAS3022 will enable industrial manufacturers to differentiate their systems while meeting stringent user requirements.

References

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Circuit Note CN0201. [Complete 5 V, Single-Supply, 8-Channel Multiplexed Data Acquisition System with PGIA for Industrial Signal Levels](#).

MT-048 Tutorial. [Op Amp Noise Relationships; 1/f Noise, RMS Noise, and Equivalent Noise Bandwidth](#).

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