HART Communication Networks Are Improved by Small, Flexible, Low-Power Modem ICs

By Tracey Johnson

The need to measure, control, and communicate with machinery and equipment has existed since the earliest days of the Industrial Revolution, with instrumentation systems employing sensors and actuators becoming the backbone of the modern manufacturing plant. Communication employing 4-mA-to-20-mA analog current signals to carry data and settings over wires has long been in widespread use. But instrumentation has matured from those purely analog systems to the "smart" systems used today, augmenting communications capability by the likes of the HART® *(highway addressable remote transducer)* protocol. Simply put, dc and low-frequency current signals are modulated by independent, higher-frequency signals that switch between a pair of frequencies (Figure 1)—a technique known as frequency-shift keying (FSK).
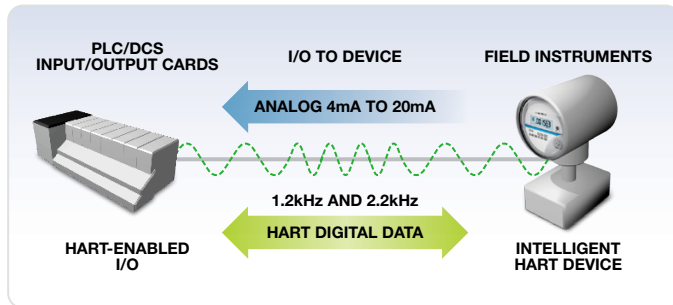

Figure 1. HART communication.

This article describes the technology's implementation, provides some application examples, discusses some of the devices employed by modern silicon integrated-circuit technology to aid the system designer, and—to illustrate the technology—introduces today's most compact, lowest power, and widest supply-voltage, fully compliant HART *modem* (modulate-demodulate) IC—the Analog Devices AD5700.

What Is HART Communication?

The primary form of communication used in analog transmitters is a current loop with a normal range of 4 mA to 20 mA, employing a transmitter, a receiver, and a power supply. It enables features such as remote calibration, fault interrogation, and transmission of process variable data. Low-power transmitters and receivers must operate on the minimum current, 4 mA or less, depending upon the "headroom" required for error indication. These current loops are reliable, robust, and highly immune to environmental interference over long communication distances. A significant disadvantage, however, is that a single loop allows only one-way communication *from* a sensor, or *to* an actuator, and can only transmit one process variable.

The introduction of the HART standard provided a means to create "smart" transmitters, by adding digital communication capability, sharing the same twisted-pair line used for traditional 4-mA-to-20-mA instrumentation. A 4-mA-to-20-mA analog current is modulated by a 1-mA peak-to-peak FSK signal—without interrupting the original primary variable transmission—while still

leaving headroom for operating the loop. The HART protocol has become the global standard for sending and receiving digital information over analog wires between smart devices and a control or monitoring system.

Inside a HART Modem IC

The AD5700-1 complete HART modem IC (Figure 2) integrates all the necessary filtering, signal detection, modulation, demodulation, and signal generation needed—substantially reducing the number of external components required. Housed in a small 4-mm × 4-mm, 24-lead LFCSP package, it requires only a single 2-V to 5.5-V supply and operates over the −40°C to +125°C extended temperature range.
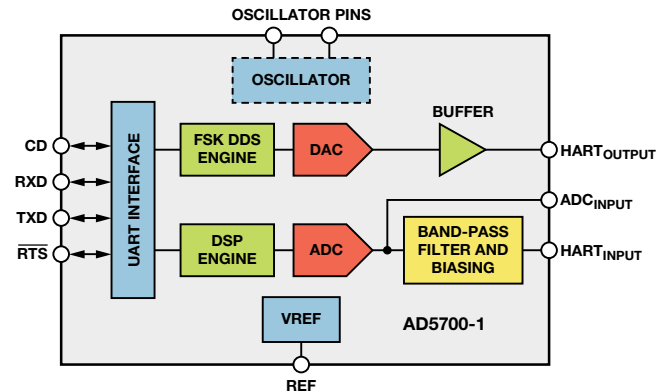

Figure 2. Block diagram of the AD5700-1; the -1 option includes an internal 0.5% precision RC oscillator.

Transmit Path

Figure 2 shows the main blocks involved in the modulation: the FSK *direct digital synthesis* (DDS) engine, the DAC (switched resistor string type), and the buffer. The digital data to be transmitted arrives via the UART. The modulator is enabled by bringing the $\overline{RTS}$ *(request to send)* signal low. The modulator converts a bit stream of UART-encoded HART data at the TXD input, to a binary sequence of 1200 Hz ("1") and 2200 Hz ("0") tones (Figure 3). The DDS produces a stream of sinusoidal digital words at either frequency, and the DAC converts it to an approximately 493-mV p-p analog sine wave. This sinusoidal signal is internally buffered and appears at the HART_OUT pin. The DDS engine inherently generates *continuous phase signals,* thus avoiding any output discontinuity when switching between frequencies. A key benefit of the internal buffering on HART_OUT is the resulting high drive capability, eliminating the need for external analog buffers and the issues they imply. The HART_OUT pin, dc biased to 0.75 V, should be capacitively coupled to the load. See the AD5700/AD5700-1 data sheet for more detailed information.
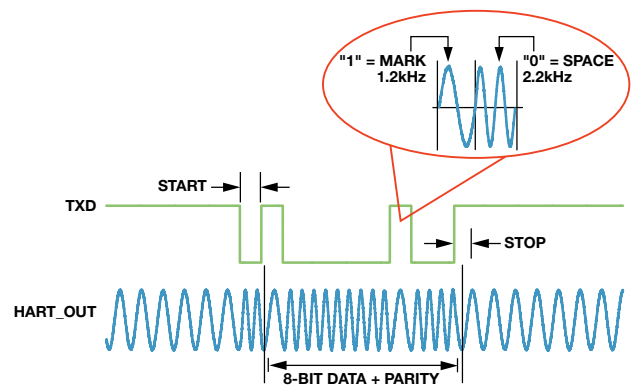

Figure 3. AD5700/AD5700-1 modulator waveform.

Receive Path

When $\overline{RTS}$ is logic high, the modulator is disabled and the demodulator is enabled, that is, the modem is in receive mode. The receiver demodulates the FSK modulated signal on the HART_IN pin. In this mode, the relevant blocks are the internal band-pass filter, the ADC, and the DSP engine. A high on CD (carrier detect) indicates that a valid carrier is detected. The demodulated data is sent to the host processor via the RXD pin on the UART interface.

The receive architecture was chosen to make the AD5700 robust against noise and interferers in harsh industrial environments. A combination of analog and digital filtering results in excellent sensitivity and a highly accurate output on the RXD pin. The HART bit stream follows a standard UART frame with a start bit, 8-bit data, one parity bit, and a stop bit. In demodulation mode, the modem has two filter configuration options: an internal filter (HART signal is applied to HART_IN) and an external filter (filtered HART signal is applied directly to ADC_IP). The external filter mode supports the use of the AD5700 in explosion-proof and intrinsically safe environments. Included is a 150-kΩ resistor, which limits current to a sufficiently low level to comply with intrinsic safety requirements. This option is recommended for operation in safety-critical applications, where the modem must be isolated from the high voltage of the loop supply. In this case, the input has higher transient voltage protection and should, therefore, not require additional protection circuitry, even in the most demanding of industrial environments.

Additional Blocks

The three remaining blocks shown in Figure 2 are the previously mentioned UART interface, the internal reference, and the oscillator. $\overline{RTS}$ and TXD are the important signals for modulation, while CD and RXD are important for demodulation. The AD5700 can accept an external 2.5-V reference, which can only be used if the AVDD supply is greater than 2.7 V. The use of the internal or external reference option is controlled by the polarity of the REF_SEL pin. For clocking, the device supports numerous schemes to allow a simple low-cost configurable solution. The AD5700 can use an external crystal, ceramic resonator, or CMOS input. The AD5700-1 is the first HART modem IC to incorporate an internal, low-power, 0.5% accurate oscillator, reducing the required external circuitry as well as overall cost. The many functions integrated on-chip greatly simplify the design of HART-compatible systems, resulting in more reliable, cost-effective, and robust networked solutions.

Low-Power Application Example

Low power is important because all circuitry powered by the loop must consume less than 3.5 mA. An example of the application of HART communication within a loop is shown in Figure 4. An AD5700 HART modem is interfaced with an AD5421 16-bit, serial-input, loop-powered, 4-mA-to-20-mA DAC and the ADuCM360 microcontroller, on an AD5700 evaluation board, to demonstrate a loop-powered transmitter circuit for two shared data channels measuring pressure ("0") and temperature ("1").
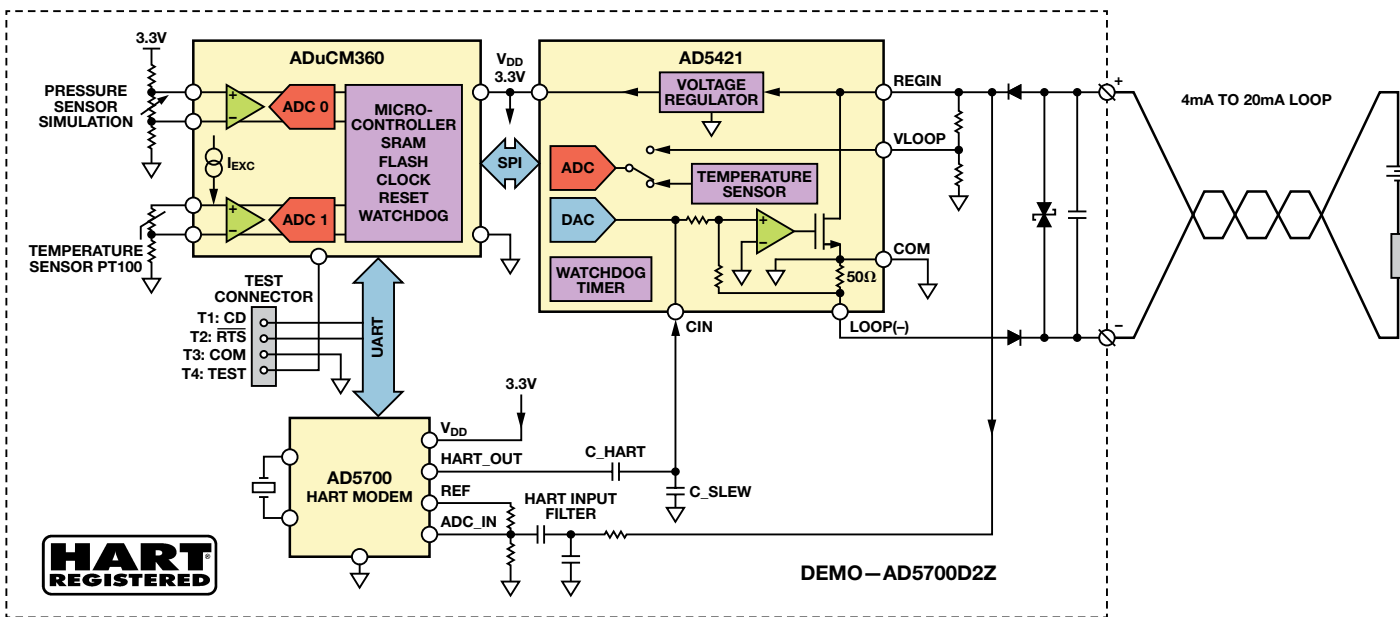

Figure 4. AD5421 loop DAC and AD5700 HART modem as a loop-powered data transmitter with HART communication.

This circuit has been compliance tested, verified, and registered as an approved HART solution by the HART Communication Foundation. The details of the product registration are available on their website.

The most important constraint in such 4-mA-to-20-mA loop-powered applications is that the entire circuit must draw less than 3.5 mA (the "low alarm" setting, 0.5 mA below the 4-mA signal floor). This is where the low power specification of the AD5700 becomes most important. Here, every microamp counts, so if each IC in the design can individually draw a small enough current, the 3.5-mA budget will not be surpassed, and the application will function as required. With typical transmit and receive currents of 124 μA and 86 μA, respectively, and corresponding maximum specified current drain of 140 μA and 115 μA, respectively, the AD5700 will not contribute significantly to the overall current budget.

Conclusion

Besides the industry's lowest power HART modem IC, Analog Devices also offers complete HART solution capability, including microcontroller products, amplifiers, precision references, switches, ADCs, and current-output DACs. The AD5700 HART modem has been designed to interface easily with: the AD5421, which was used above in the loop-powered smart transmitter application example; the AD5422 16-bit voltage- and current-output DAC, useful for field instruments or analog I/O cards; and the AD5755-1 16-bit, quad DAC with innovative dynamic power control technology, for multichannel applications. In addition, components designed to mate easily together are available for the entire signal chain. When combined with the AD5700/AD5700-1, system design is simplified, reliability is enhanced, and quick, easy deployment of robust HART-compliant systems is enabled.

Author

Tracey Johnson [tracey.johnson@analog.com], an applications engineer in the Precision Digital-to-Analog Converter Group, is principally focused on industrial converters for process-control applications—including HART-enabled smart transmitters. In 2003, Tracey graduated from the University of Limerick, Ireland, with a bachelor's degree in electronic engineering. She joined Analog Devices as a design evaluation engineer in the DAC Group and has served in that role for seven years.

The AD5700 single-chip HART modem is registered with the HART Communication Foundation as part of a smart field instrument demo solution. It makes possible the industry's lowest power, complete HART modem that is fully compliant with the HART communication protocol, accurately encoding and decoding HART communication signals in noisy, harsh industrial environments and ensuring a reliable communication interface that is quick and easy to implement and register with the HART Communication Foundation. It requires 60% fewer external support components than alternative solutions and can provide greater than 75% saving in board area.

DAC and Transmitter IC for Loop-Powered Applications
AD5421
• 4mA to 20mA transmitter
• Intelligent power management

Ultralow Power Analog μC
ADuCM360
32-bit Cortex™ M3 MCU
24-bit Σ-Δ ADCs
1mA Operating Current

Integrated Precision DACs for Industrial Automation
AD5422
• 16-bit resolution
• Current source and voltage output
• On-chip precision force and sense amplifier
• Comprehensive diagnostics

First Data Converter with Dynamic Power Control
AD5755
75% Cooler
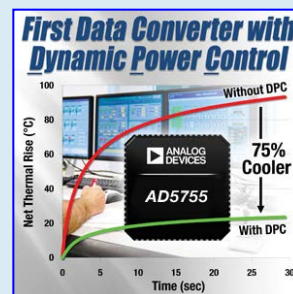
Industry's Lowest Power Complete HART Modem
AD5700 HART Modem
• 38% lower power
• 75% board space saving
• Internal 0.5% oscillator