TECHNICAL ARTICLE



DESIGN TRADE-OFFS FOR LOOP-POWERED TRANSMITTERS

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Loop-powered transmitters have progressed from purely analog signal conditioners to highly flexible smart transmitters, but the chosen design approach still depends on a system's performance, functionality, and cost requirements. This article presents three different bench tested transmitter designs.

In loop-powered designs, the 4 mA to 20 mA loop provides both power and data, so the system must operate on less than a 4 mA loop current. In fact, 3.6 mA or lower is a more typical target, as this represents a low alarm current on the loop. Other key considerations for a design are the target performance, functionality, size, and cost.

The first circuit we'll discuss (Figure 1) uses a purely analog signal chain.



Figure 1. Analog 4 mA to 20 mA loop-powered transmitter (reference to CN0289).

This circuit measures a resistive bridge pressure sensor, which is excited by a 5 V reference. An instrumentation amplifier gains up the sensor signal. Its voltage output is converted to a current by R1 and is summed with an offset current generated through R2. This current flows through R3 and is amplified via the op amp configuration, then through R4 to form the 4 mA to 20 mA output. As the current, consumed by the entire transmitter, returns through R4, it is included in the regulated 4 mA to 20 mA current, making the circuit loop powered.

Using 0.1% resistors, this circuit can achieve better than 1% max accuracy at 25°C. Calibration would greatly increase the accuracy, and allowing adjustments to R2 and R1 would cater for offset and gain calibration respectively. However, the accuracy is still limited by sensor performance and component drift over temperature, as the circuit does not easily allow calibration over temperature or sensor linearization.

This circuit consumes less than 1.9 mA (excluding sensor excitation), which is well below the 4 mA target.

In summary, this purely analog transmitter allows for a simple, low cost solution. However, the sensor cannot be linearized, it does not offer

calibration over temperature, and it provides no diagnostics. Any changes to the sensor or output range would also require hardware changes.

A number of drawbacks in the purely analog circuit can be resolved by adding digital processing capability, as shown in Figure 2.



Figure 2. 4 mA to 20 mA loop-powered transmitter (reference to CN0145).

This circuit measures an RTD temperature sensor, which is excited by a current source. A ratiometric measurement is taken between the RTD and precision resistor R1. The RTD signal is conditioned using a PGA, whose output is converted to digital by a 24-bit Σ - Δ ADC. This data can be manipulated using the ARM7 microcontroller, which can be used to calibrate and linearize the temperature sensor and the 4 mA to 20 mA output.

The 4 mA to 20 mA output is controlled via a PWM signal, which is able to achieve 12-bit resolution. Though similar to the previous architecture, the output uses an op amp's noninverting terminal as the control voltage for the 4 mA to 20 mA loop. A 1.2 V reference, along with R2, generates a current equivalent to 24 mA on the loop. This means a 0 V control voltage from the PWM results in a 24 mA output. As the control voltage on the PWM increases, the output current decreases. For a 4 mA current output, the PWM should be programmed to 500 mV. The advantage of this technique is that the PWM does not need to be buffered, reducing both current consumption and cost.

The current consumption of the entire RTD temperature transmitter was measured as 2.73 mA at 25°C and 3.13 mA at 85°C (excluding sensor excitation). This circuit meets the power consumption requirements, but there is little current left for any additional diagnostics or features once the sensor excitation current is added.

Though slightly higher in cost than the purely analog transmitter, the ability to fully calibrate and linearize the sensor and output offers significantly improved accuracy. It also has greater flexibility to allow for diagnostics, and changes in sensor type can easily be accounted for in software.



Figure 3. 4 mA to 20 mA loop-powered smart transmitter (reference to CN0267).

There are still some limitations though: the 4 mA to 20 mA loop can only transmit the primary variable, in this case temperature, and no other information. Additional diagnostics and system functionality may not be possible while staying within the power budget, and with higher input performance, the 4 mA to 20 mA output driver may become a significant source of system error. A circuit that overcomes these limitations is shown in Figure 3.

This circuit is truly a smart transmitter. As well as providing exceptional performance, it allows bidirectional communication over the 4 mA to 20 mA loop via the highway addressable remote transducer (HART®) protocol. The HART protocol operates over a traditional, low frequency loop by modulating a higher frequency 1.2 kHz, 2.2 kHz frequency shift keyed (FSK) digital signal over the standard 4 mA to 20 mA analog signals. HART communication enables, among other things, remote configuration transmission of diagnostic information, and device parameters, and additional measurement information.

Per Figure 3, a pressure sensor and RTD are measured independently on the ADuCM360 via dual precision, 24-bit Σ - Δ ADCs with on-board PGA. The low power Cortex[®]-M3 core calibrates and linearizes the pressure sensor input, and the RTD is used for temperature compensation. The microcontroller also runs the stack for the HART protocol and communicates via UART with the AD5700 HART physical layer modem. Lastly, the microcontroller communicates with the AD5421 loop-powered DAC via SPI to control the 4 mA to 20 mA loop. The AD5421 is a fully integrated, loop-powered 4 mA to 20 mA DAC; it includes the loop driver, 16-bit DAC, loop regulator, and diagnostic features.



Figure 4. HART communication.

With the ADC running at 50 SPS, the pressure sensor input was able to achieve 18.5 bits of effective resolution. On the output side, the AD5421 provides a guaranteed 16-bit resolution and INL of 2.3 LSB maximum.

The whole circuit consumes 2.24 mA typical (excluding sensor excitation), with 225 μA consumed by the AD5421, 157 μA by the AD5700,

1.72 mA by the ADuCM360, and the remaining current by other circuitry such as an on-board LED. The ADuCM360 is running with both 24-bit Σ - Δ ADCs and PGAs active and the following peripherals enabled: on-chip reference, clock generator, watchdog timer, SPI, UART, timers, flash, SRAM, and the core running at 2 MHz. This extremely low power consumption, along with HART communication, means that additional system diagnostics and functionality can easily be added to this system.

One aspect not discussed in any of the above circuits is isolation. Isolation is especially useful in thermocouple transmitter applications where the exposed sensor may be bonded directly to a metal surface. Optocouplers are one solution, though they typically require a relatively large bias current to ensure reliable behavior. New devices that overcome such challenges are the ADuM124x and ADuM144x 2-channel/4-channel micropower isolators.

These devices consume a mere $0.3 \ \mu$ A quiescent current per channel and 148 μ A/Mbps dynamic current per channel. They enable isolation in systems where it previously was not an option due to power constraints.

In conclusion, loop-powered transmitter designs can vary significantly in performance, functionality, and cost. The three solutions discussed provide different design trade-offs, starting from the simplest analog transmitter to a feature rich smart transmitter. New low power products enable a level of performance, functionality, and integration not previously achievable in smart transmitter designs.

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