Keywords: sensor transmitter, smart sensor, industrial process control, PLC, industrial automation, measurement and automation, thermocouple, high-efficiency DC-DC converter

APPLICATION NOTE 6508

HOW TO IMPLEMENT A 4-20MA TRANSMITTER WITH THE MAX12900

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Abstract: This application note explains how to implement a 3-wire 4–20mA transmitter provided by the MAX12900.

Introduction

The 4–20mA current loop is the prevailing process control signal used in many industries. It is an ideal method of transferring process information because current does not change as it travels from transmitter to receiver. It is also much simpler and cost effective. However, voltage drops and the number of process variables that need to be monitored can impact its cost and complexity. **Table 1** summarizes the advantages and disadvantages of 4–20mA loops.

Table 1. Advantages and Disadvantages of 4–20mA Current Loops

Advantages	Disadvantages
Main standard in many industries	Current loops can only transmit one process signal
Simple to connect and configure	Multiple loops must be created in situations where there are numerous process variables. Running so many wires can lead to problems with ground loops if independent loops are not properly isolated
Signal does not degrade with distance	Isolation requirements become more complicated as the number of loops increases
Less sensitive to noise	—
Absence of a current indicates a fault	—

All 4–20mA sensor transmitters can be divided into three groups by their configurations:

1. 2-wire (loop-powered) 4–20mA sensor transmitter
2. 3-wire 4–20mA sensor transmitter
3. 4-wire 4–20mA sensor transmitter

A loop-powered 4–20mA sensor transmitter is the most cost effective and desirable solution that allows receiving the power and transmitting the data over a 2-wire 4–20mA current loop. However, if a sensor itself consumes more than 3–4mA of 4–20mA loop budget, then it requires an additional power source not combined with the 4–20mA loop source. Such sensors require two power sources and a 4-wire connection to be connected to PLC. A 3-wire sensor transmitter is a simplified version of a 4-wire sensor configuration that allows engineers to eliminate one connection wire by separating the 4–20mA current (data) loop from the power loop and supply enough power to the sensor. **Figure 1** shows an illustration of 2-, 3-, and 4-wire sensor connections. **Table 2** summarizes the relative advantages and disadvantages of each type of transmitter.

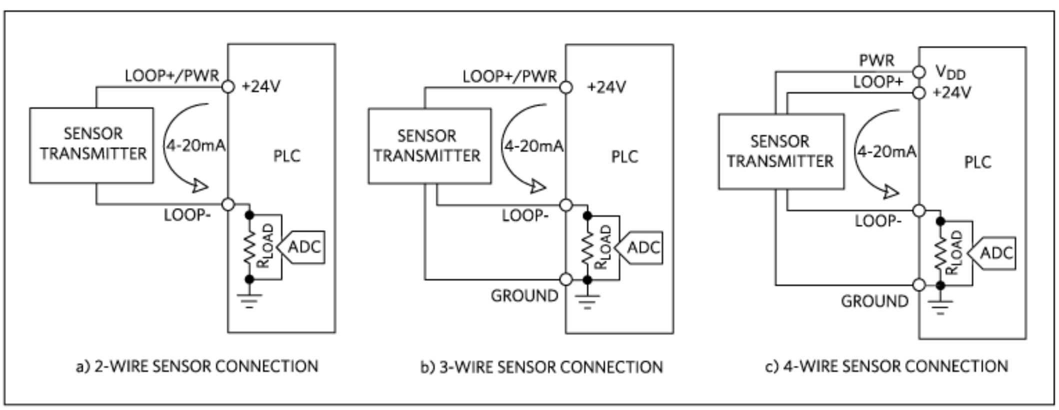

Figure 1. Sensor transmitter connection types.

Table 2. Summary of Advantages/Disadvantages of 4–20mA Sensor Types

	2-Wire	3-Wire	4-Wire
Advantages	• No local power required • Low cost • Hazardous area approval	• Cheaper than 4-wire • Easier to implement • Displays, communications • Powered outputs, relays	• External power • AC signals allowed • Isolation of loop power • Displays, communications • Powered outputs, relays
Disadvantages	• Voltage drops in loop cause problems • No powered outputs, relays	• No isolation of loop power • Care needed with power and loop paths	• Higher cost • More wiring • Not suitable for hazardous areas

Using the MAX12900 as a 2-, 3-, or 4-Wire Sensor

The MAX12900 is an ultra-low-power, highly integrated analog front-end (AFE) for a 4–20mA sensor transmitter. It integrates the following 10 building blocks in a small package:

- A wide input supply voltage low-dropout (LDO) regulator
- Two conditioner circuits for pulse-width modulated (PWM) inputs
- Two low-power and low-drift general purpose operational amplifiers (op-amps)
- One wide bandwidth, zero-offset drift operational amplifier
- Two diagnostic comparators
- A power-up sequencer with power-good output to allow for a smooth power-up
- A low-drift voltage reference

A key advantage of the MAX12900 is that it can convert PWM digital data from microcontrollers that do not have a dedicated DAC output into a current signal over a 4–20mA loop with 2-, 3-, or 4-wire configurations. This is equivalent to an ultra-low-power, high-resolution digital-to-analog converter, and is realized with the combination of two PWM signals received from a microcontroller, the two conditioner circuits, and an active filter built with the integrated low-power op amp. The outputs of the two conditioner circuits provide a stable PWM amplitude over voltage, supply, and temperature variation. The wide bandwidth amplifier in combination with a discrete transistor converts a voltage input into a current output and allows HART® and FOUNDATION Fieldbus H1 signal modulation. The zero-offset operational amplifier and the low-drift voltage reference provide negligible error over a wide temperature range. The low-power operational amplifier and comparators provide building blocks for enhanced diagnostic features. Supply-rail monitoring, output current readback, and open-circuit and failure detection are a few examples of diagnostic features. All these features, as well as ultra-low power and high-accuracy, make the MAX12900 ideal for loop-powered smart sensor transmitters.

In this application note we consider the application of the MAX12900 in designs of 2- and 3-wire industrial sensors.

Configuring the MAX12900 as a 2-Wire (Loop-Powered) Transmitter

Figure 2 illustrates a simplified block diagram and model of how the MAX12900 can be configured as part of a loop-powered (2-wire) sensor design. This configuration is required for sensors that must operate in hazardous environments and must conform to the ATEX Directive 94/9/EC and achieve IECEx certification. This implementation is only possible where the current consumed by the transmitter is less than 4mA. The PWM signals from the microcontroller are conditioned using the MAX12900's on-chip conditioner . A lowpass filter can be constructed to filter the PWM signal using an external RC network and one of the on-chip op amps. External transistors are used for the voltage-to-current conversion.

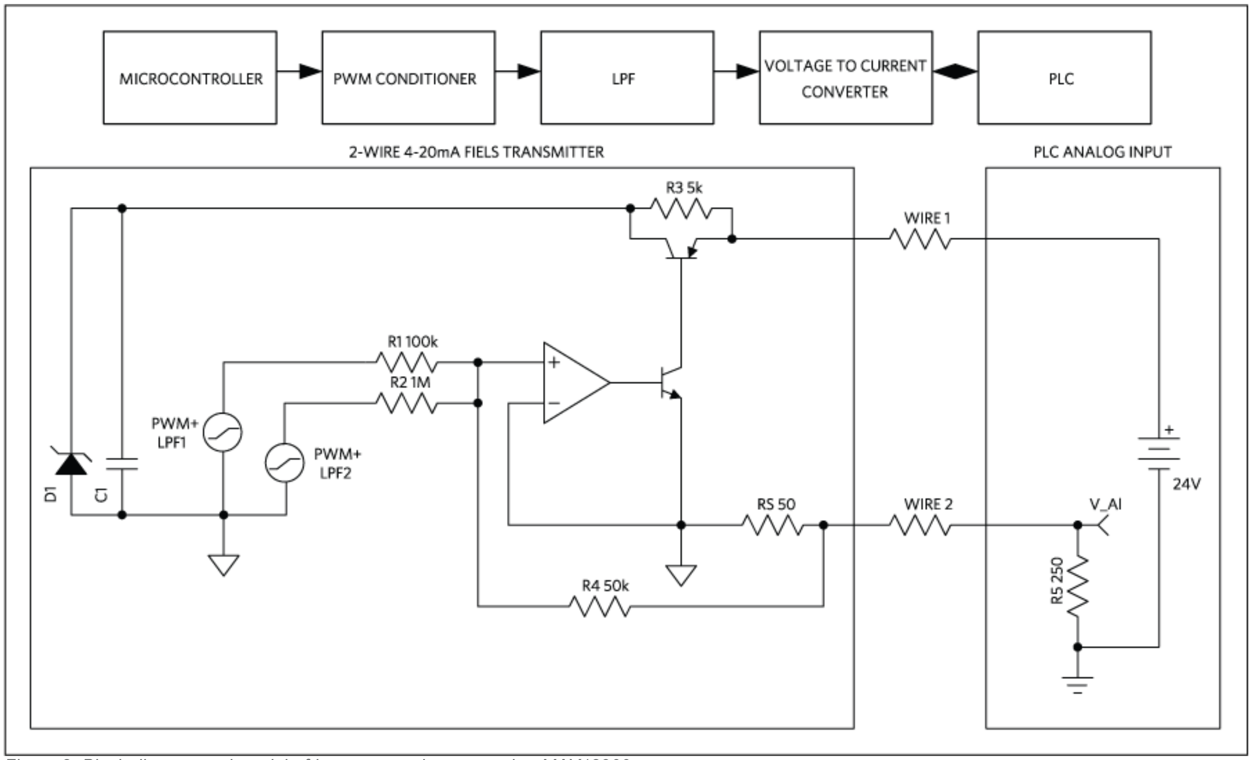

Figure 2. Block diagram and model of loop-powered sensor using MAX12900.

Figure 3 shows a circuit-level implementation of the 2-wire loop-powered sensor. (In Figure 2, note that the teal blocks are all integrated within the MAX12900.)

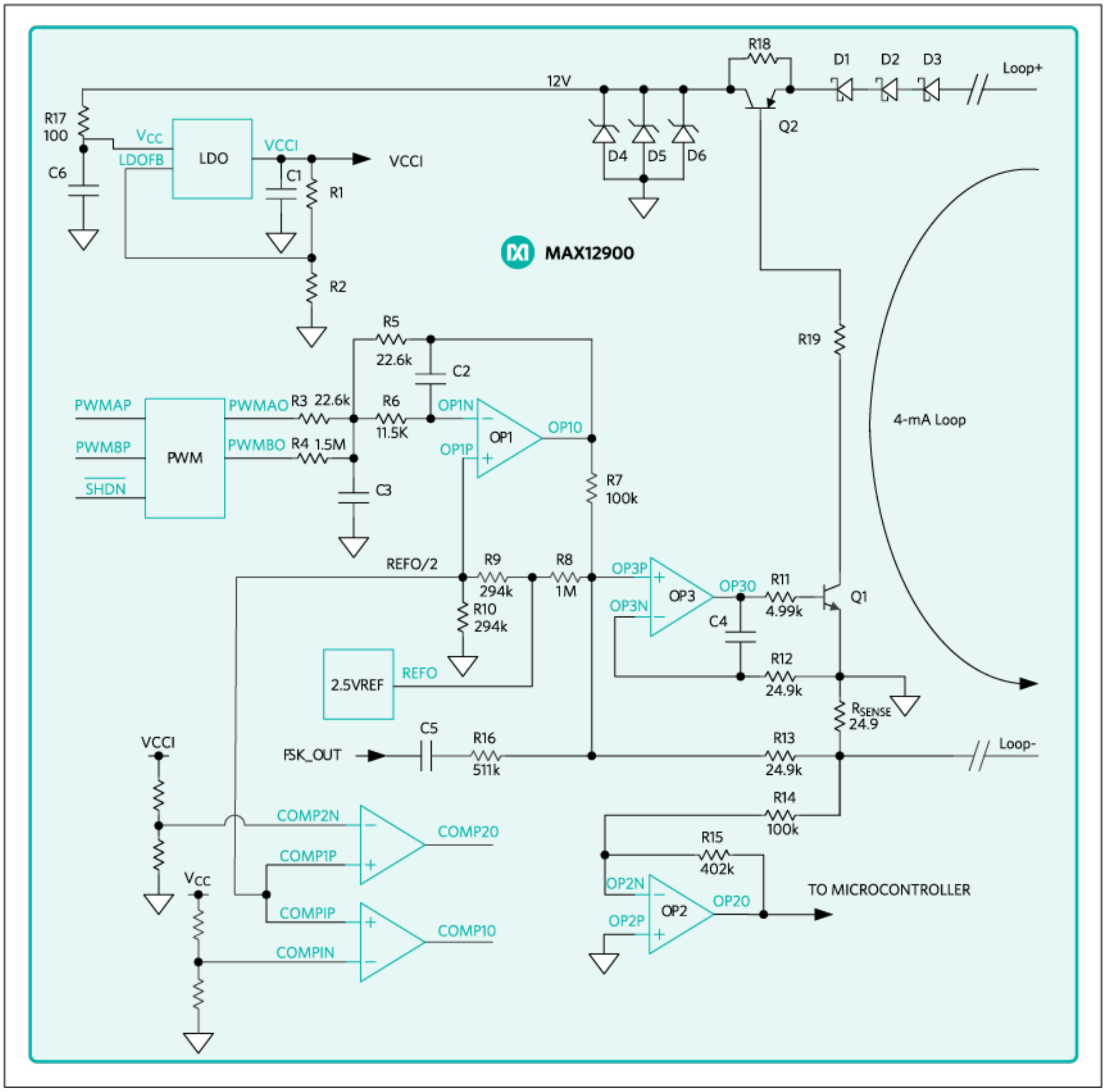

Figure 3. Configuration of loop-powered 4-20mA transmitter using MAX12900.

One of the most common sensor types is a type that measures temperature. So, next we attempt to design a temperature sensor transmitter using the MAX12900 with the industry-standard MAX31856 precision thermocouple to digital converter. The MAX31856 interfaces to the thermocouple and provides data to an SPI interface. A microcontroller is also required, both to read the data from the MAX31856 and to provide two PWM outputs to the MAX12900. The MAX12900 EV kit (MAX12900EVKIT) uses the low-power STM32L071 microcontroller for this purpose. The starting point in this design is the analysis of the power budget for worst-case scenarios (highest current consumption across all conditions of temperature and voltage). This helps us decide if a 2-, 3- or 4-wire implementation is possible.

According to the MAX12900 EV kit's data sheet, the combination of the MAX12900 with the low-power microcontroller consumes 3.5mA maximum. The MAX31856 consumes 2mA maximum from a 3.3V supply. Because the total power consumption for both parts exceeds 4mA, it is not possible to design a 2-wire sensor transmitter.

Table 3. Power Budget for Temperature Sensor Design

Device	Current Consumption (mA)
MAX31856	2
MAX12900 + STM32L071	3.5
Total:	**5.5mA (> 4mA)**

Using the MAX12900 in a 3-Wire Transmitter

Having eliminated the possibility of using a 2-wire solution, we next consider the challenges in implementing a 3-wire design. The first challenge relates to the available power supply. In a 3-wire solution, there is only one power-rail voltage available. However, this 24V supply (from the PLC) is too high for the microcontroller and MAX31856, which both operate off a 3.3V supply. There are several approaches to solving this problem. The first option is to use a DC-DC converter, such as the MAX17550 to generate a 3.3V supply from the +24V supply to power the MAX31856 and the microcontroller, as illustrated the **Figure 4**. The MAX17550 is an ultra-small, high-efficiency, synchronous step-down DC-DC converter that can provide up to 25mA of current. A 2-channel digital isolator, MAX12930, is used to isolate the sensor/MCU PWM interface to the MAX12900. In Figure 4, the components within the dotted box are an isolated power domain with a floating ground that is different from the PLC's ground reference.

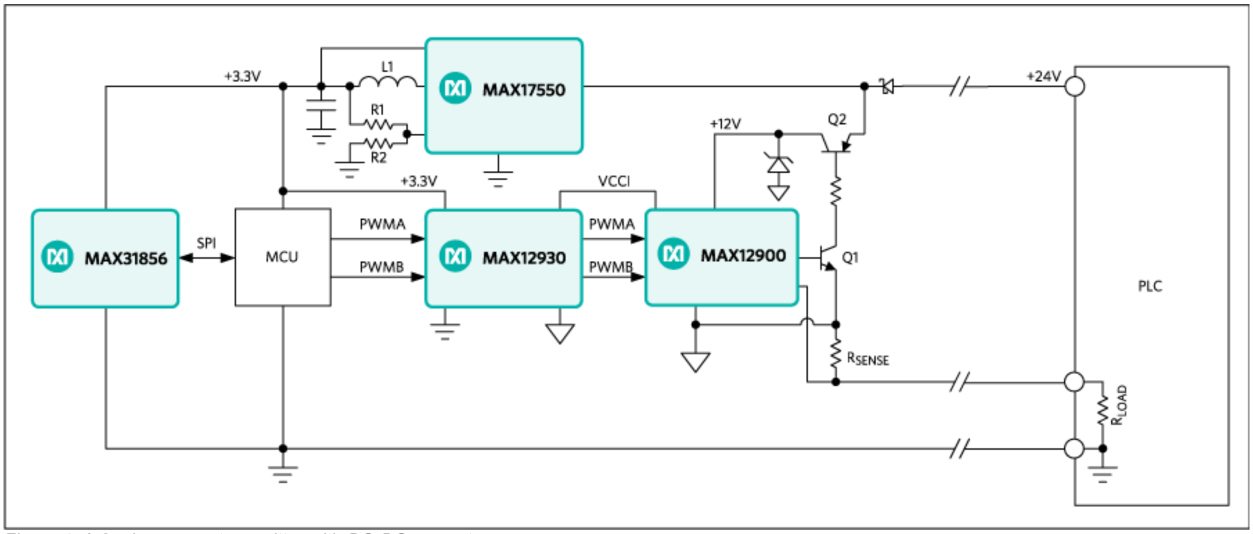

Figure 4. A 3-wire sensor transmitter with DC-DC converter.

Another possible solution to the power-supply problem is to use an ultra-low quiescent current linear regulator, the MAX15006AATT+, which can provide a fixed 3.3V voltage and up to 50mA of current to the sensor, as illustrated in **Figure 5**.

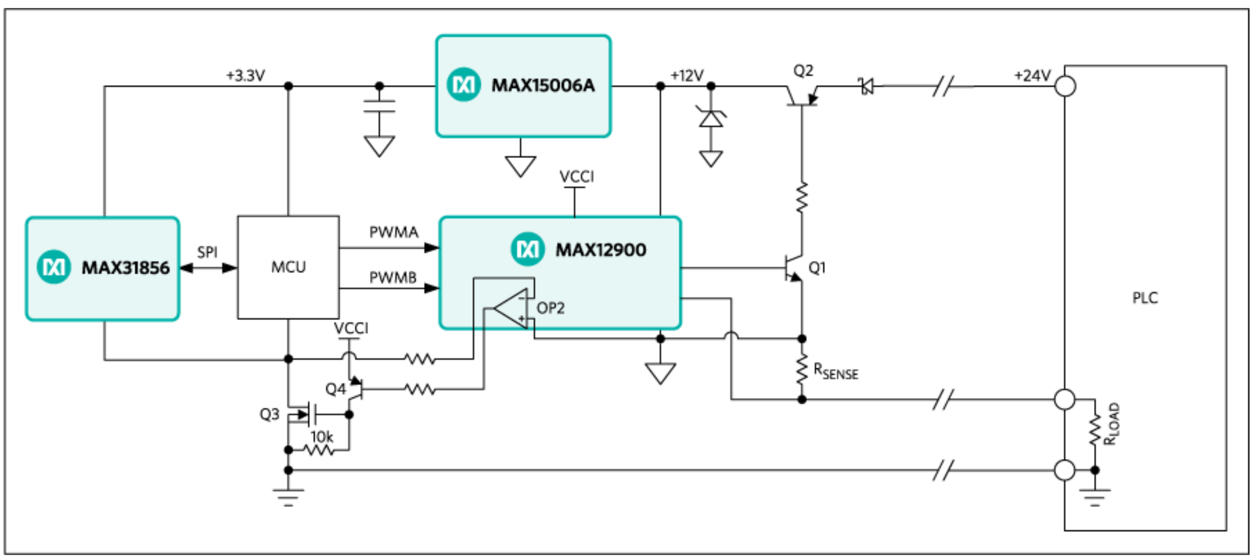

Figure 5. A 3-wire sensor transmitter with linear regulator.

The second issue to consider in the design is the "floating ground" of the transmitter. The sensor itself, the microcontroller, and the MAX12900 transmitter must have a common ground for proper communication. At the same time, that ground is a “floating” point relative to the PLC ground. The “floating ground” depends on the transmitted data and loop load conditions. There also several approaches to deal with this. One option is to put a digital isolator between the microcontroller and the transmitter, for example, the 2-channel, low-power MAX12930 (as shown in Figure 4) to isolate PWMA and PWMB inputs to the transmitter.

Another alternative is to use some active circuitry that constantly monitors and maintains a common ground level for the sensor and microcontroller. This option is made possible by the convenient presence of a general-purpose op amp, namely OP2, on board the MAX12900. This implementation also requires an n-channel small-signal MOSFET, Q3, and a general-purpose pnp transistor, Q4, to match the voltage drops on R_{LOAD} and R_{SENSE}.

Using the MAX12900 in a 4-Wire Transmitter

Having shown how the MAX12900 can be used in 2-wire and 3-wire transmitters, implementing a 4-wire solution is straightforward, as separate power and ground loops are available for both the sensor and the PLC.

Conclusion

Maxim’s MAX12900 ultra-low-power AFE for 4–20mA transmitters offers an unrivalled level of flexibility in its applications, and is ideal for use in designs with industrial control and automation sensors whose signals need to be converted into a 4–20mA current signal.

Related Parts		
MAX12900	Ultra-Low-Power 4-20mA Sensor Transmitter	Free Samples
MAX12900EVKIT	Evaluation Kit for the MAX12900	
MAX12930	Two-Channel, Low-Power, 3kV$_{RMS}$ and 5kV$_{RMS}$ Digital Isolators	Free Samples
MAX17550	60V, 25mA, Ultra-Small, High-Efficiency, Synchronous Step-Down DC-DC Converter with 22μA No-Load Supply Current	Free Samples
MAX31856	Precision Thermocouple to Digital Converter with Linearization	Free Samples

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