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TUTORIAL 4603

Process Control and PLC Tutorial

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Abstract: Programmable logic controllers (PLC) save time, money, and energy in process control systems. They simplify systems. A brief history of manufacturing processes sets the stage for how to use modern ICs to replace discrete components. The ICs allow easy system design and extend monitoring to improve equipment and personnel safety. The MAX15500/MAX15501, MAX5661, and MAX5134–MAX5139 serve as examples of ICs in process control.

Introduction

Industrial control, factory automation, and PLC (programmable control logic)—done well, they save time, materials, energy, and money. But where do we begin? Building a complete automated factory is such a huge job that some might give up before starting.

We are reminded of the explorer in Africa years ago who asked the native tribesman, "How does one eat an elephant?" The tribesman looked at the famous explorer in astonishment and replied, "We eat it just like everything else, one bite at a time." As with most big systems, industrial control is comprised of many smaller circuits. We are going to explore some of those small "bites."

The Process of Process Control

Assembly lines are a relatively new invention in human history. There have likely been many parallel inventions in many countries. We will mention just a few in a brief history of the evolution of what are becoming fully automated factories.

Samuel Colt, the US gun manufacturer, demonstrated interchangeable parts in the mid 1800s. Previously each gun was assembled with individually made pieces that were filed to fit. Mr. Colt showed the pieces for ten guns, then he assembled a gun by randomly grabbing pieces from bins. Early in the twentieth century Henry Ford expanded mass-production techniques. He used fixed assembly stations with the cars moving between positions. The employees learned just a few assembly tasks and performed those tasks for days on end. In 1954 George Devol applied for US Patent 2,988,237, which gave birth to the first industrial robot named Unimate. By the late 1960s General Motors® used a PLC (programmable logic controller) to assemble automobile automatic transmissions. Dick Morley, known as the "father" of the PLC, was involved with the production of the first PLC for GM, the Modicon. His US Patent 3,761,893 is the basis of many PLCs today. (For more information on the above four inventors, please see: www.wikipedia.org/; for their patents, search: http://patft.uspto.gov/netahtml/PTO/srchnum.htm).

How simple can process control be? **Figure 1** shows a common household space heater.

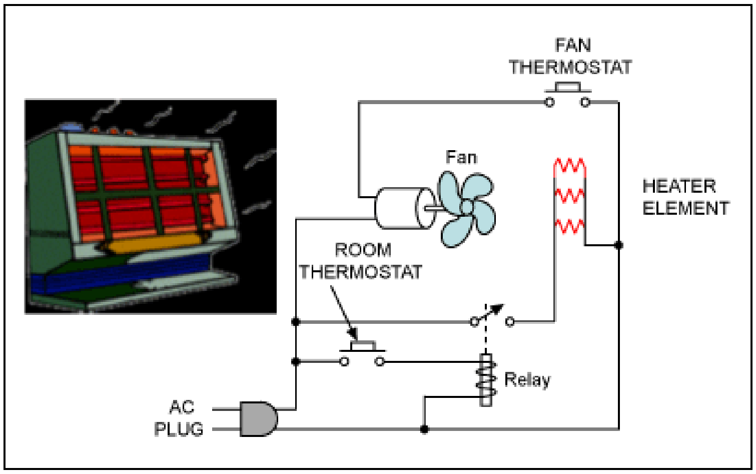

Figure 1. A household electric heater, a simple example of process control.

The components of the heater are enclosed inside one container, making system communications easy. Expanding on this concept might be a household forced-air heater with a remote thermostat. The communication paths are just a few meters and a voltage control is typically utilized.

Think now beyond a small, relatively simple process-control system. What is necessary in a factory such as **Figure 2**?

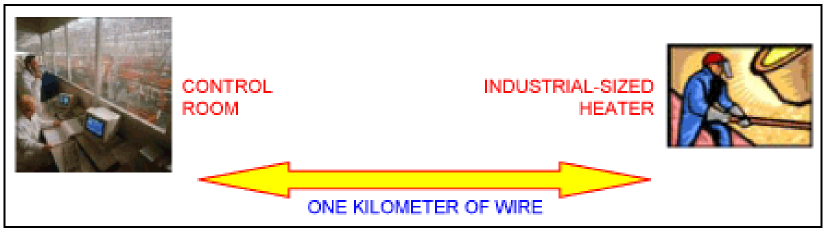

Figure 2. Longer-range factory communications.

The resistance of long wires and EMI and RFI (electromagnetic and radio frequency interference) make voltage-mode control impractical. A current loop is a simple, but elegant solution. Wire resistance is removed from the equation because Kirchhoff's law tells us that the current anywhere in the loop is equal to all other points in the loop. Because the loop impedance and bandwidth are low (a few hundred ohms and < 100Hz), EMI and RFI spurious pick-up issues are minimized.

The Basics of a PLC

Current-control loops evolved from early twentieth century teletype impact printers, first as 0–60mA loops, and then as 0–20mA loops. Advances in PLC systems added 4–20mA loops. A 4–20mA loop has several advantages. Using 4mA as the lowest communication current means that a broken wire (open circuit) can be easily detected and sensors can be remotely powered by ~3.5mA on only two wires. The 4–20mA communication can be analog or digital.

In the past discrete component designs required careful design calculation and were comparatively large. Maxim has introduced several 20mA devices which greatly simplify the system design. First, consider the typical PLC function in **Figure 3**.

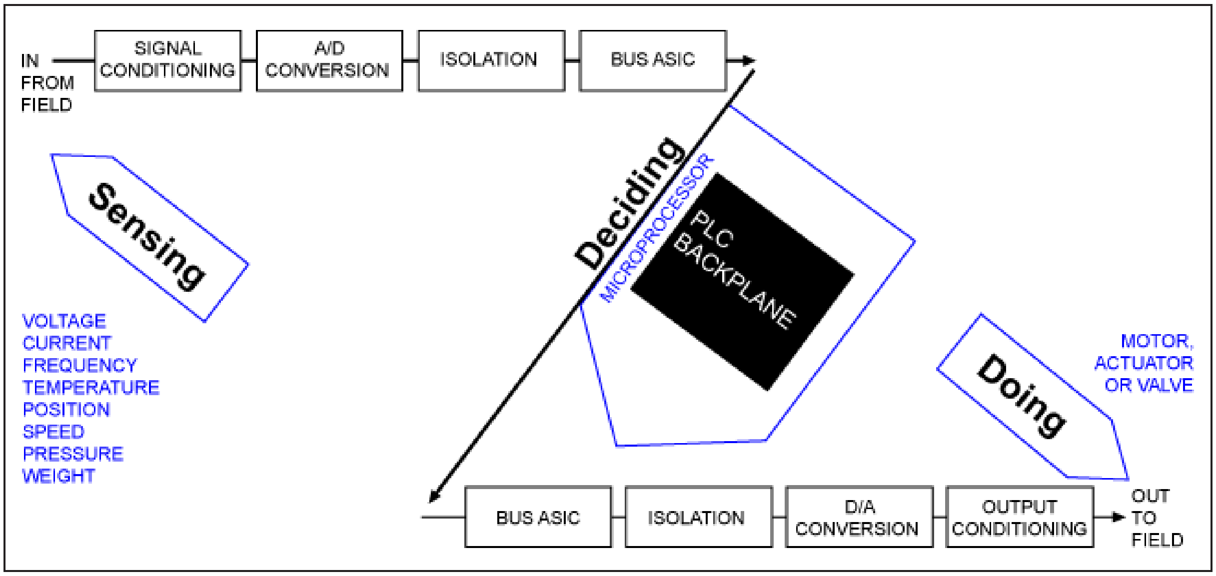

Figure 3. Simplified PLC block diagram.

A PLC is about accomplishing a task or doing a job. We first sense a physical parameter, process and decide a course of action, and command something to control a physical device. Following this model, the lower left block is the output signal conditioner which could be the MAX15500/MAX15501 integrated circuit.

The MAX15500/MAX15501 allows a choice of either short-range voltage control or longer-range current control. **Figure 4** indicates that, in addition to the basic communication which was previously done with discrete components, new monitoring and safety functions are now included.

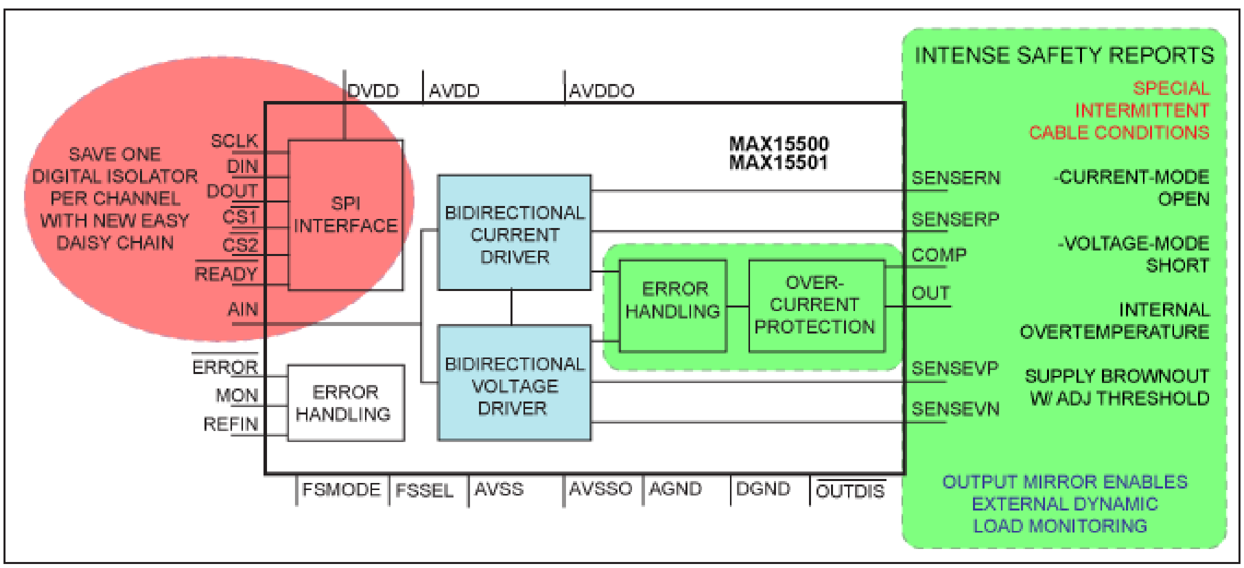

Figure 4. The MAX15500/MAX15501 output conditioner family. Device features include: ±12V force sense output into 1kΩ; ±24mA into 750Ω; 100µs settling time to 14 bits; 40µs settling time to 12 bits.

Cabling in factories is subject to movement and vibration which, in time, will cause wires to open or short to other conductors. Equipment and personnel must remain safe which necessitates careful monitoring. As a cable fails, there is usually a period of intermittent operation prior to complete failure. The MAX15500 family has intelligent monitoring to manage these varied concerns.

Because of extreme factory EMI, RFI, and power-surge conditions, any monitoring must be reliable and not subject to nuisance tripping. So the MAX15500 family incorporates a minimum 260ms timeout for opens and shorts. This is long enough to avoid false error reports caused by the harsh environment, and short enough to catch short mechanical cable errors. In addition, the errors are latched and presented to a separate hardware interrupt pin. This allows the microprocessor time to react to short cable outages. The processor can then poll the MAX15500 registers for the exact condition and clear the error condition interrupt. Extra safety is provided to monitor more than cable conditions; chip temperature and thus the environment over temperature are also monitored. Brownout with an adjustable threshold is important to the system reliability. This brownout threshold is programmable between ±10V to ±24V in 2V steps.

For safety, the outputs of the MAX15500/MAX15501 are protected against overcurrent conditions, a short to ground, or supply voltages up to ±35V. To accommodate customer requirements the MAX15500/MAX15001 provide programmable overrange capabilities. Certain customers use 105% and 120% of full-scale overrange for testing or emergency operation, despite partial faults or high noise conditions. The MAX15500/MAX15501 are provided in a 32-pin, $5mm^2$ TQFN package with an exposed pad to maximize thermal performance.

The MAX15500/MAX15501 output conditioners are HART® compliant. The HART (highway addressable remote transducer) protocol is used to piggyback bidirectional digital data on 4–20mA control wires. It is similar to the 1200 baud, Bell 202 protocol used to communicate caller ID on landline telephones.

The MAX15500/MAX15501 also have a unique adjunct to the SPI™ bus that reduces the component count necessary to provide galvanic ground isolation through optical isolators. This is a special self-timing SPI, daisy-chain protocol. It reduces the number of control wires and optical isolators necessary when multiple SPI devices must be controlled across a galvanic isolation barrier.

More Functionality in a Smaller PCB (PC Board) Area

Producing discrete, selectable voltage (bipolar and unipolar) or current-output conditioning circuits can be an intimidating task. This is especially true as one begins to understand the necessity of providing control of full-scale gain variations and the multiple reset levels for bipolar and unipolar voltages and 0mA and 4mA currents. **Figure 5** simplifies those functions and more, as they are integrated into the MAX5661 current-and voltage-output DAC.

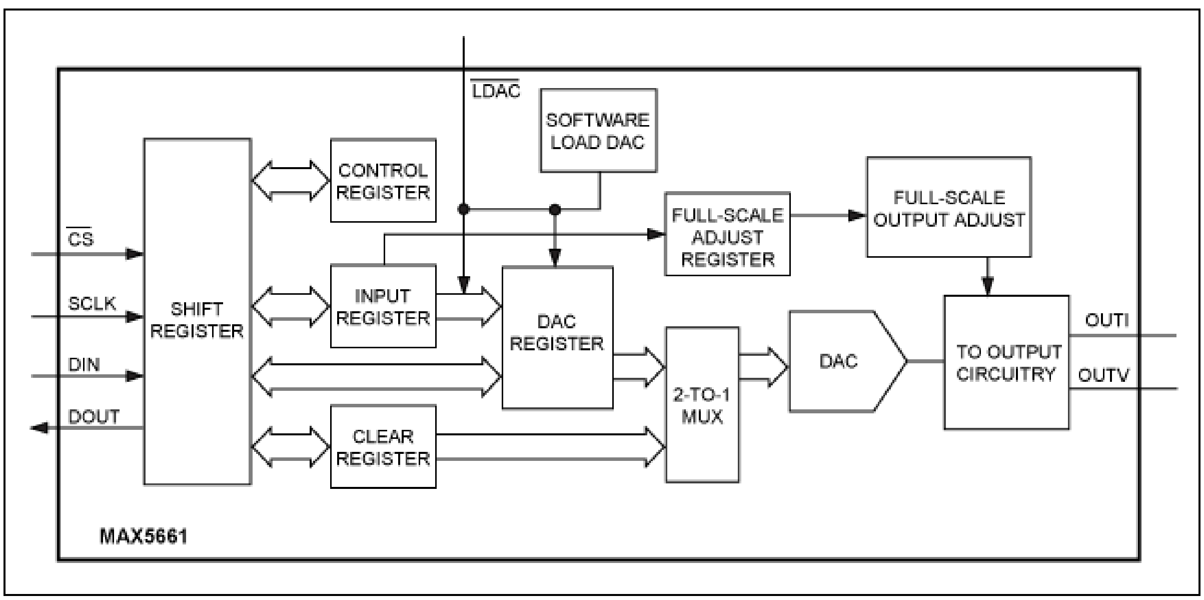

Figure 5. A simplified functional block diagram of the MAX5661.

The MAX5661 makes design easy by using programmability to solve the discrete design headaches. The following parameters are effortlessly selectable:

- Voltage output
  - Unipolar range: 0 to +10.24V ±25%
  - Bipolar range: ±10.24V ±25%
- Current output
  - Unipolar low range: 0 to 20.45mA
  - Unipolar high range: 3.97mA to 20.45mA
- Full-scale output gain
  - Adjustment for up to ±25% overrange With 10-bit resolution or granularity
- Asynchronous reset or clear to zero or any preset 16-bit number

All this capability is provided using flexible, analog power supplies with voltage output ±13.48V to ±15.75V, and current output +13.48V to +40V. Differential voltage-output remote sensing is afforded through force-sense connections on the voltage-output amplifier. A fault output-interrupt pin indicates open-circuited current output, short-circuited voltage output, or clear a state. This is driven by a voltage-output current limit; for current, a dropout detector senses an out-of-regulation current output. An active-low LDAC pin is supplied to permit asynchronous DAC updates and synchronize multiple DACs in a system.

All this MAX5661functionality is contained in a small 10mm x 10mm LQFP package.

Provide Multiple PLC Outputs with Voltage or Current Conditioning

Obviously several MAX5661 16-bit devices could be utilized to provide this extra capability, but suppose one needs less resolution and lower cost in a PLC system? Maxim offers precision DACs with resolutions from 6-bits up to 16-bits with more than 2500 separate part-number variations. The selection includes channel counts from 1 to 4 and 8, 16, and 32. Interfaces include parallel and high-speed serial SPI and I²C choices. Alternatives presented are fast settling times, (< 1µs), small size (SOT23, QFN, µMAX®) and high accuracy (≤ 1 LSB INL).

A recent addition to the Maxim precision DAC family are the MAX5134–MAX5137, and MAX5138/MAX5139. These DACs include six buffered voltage-output parts with choices. All devices operate with low-power +2.7V to +5.25V power supplies and a 3-wire SPI-/QSPI™-/MICROWIRE™-/DSP-compatible serial interface.

The MAX5134–MAX5137 are pin-compatible and software-compatible, 16-bit and 12-bit DACs. The MAX5134 is a quad-channel 16-bit device with an INL of ±8. Also a quad-channel device, the MAX5135 is 12-bit DAC with an INL of ±1. The MAX5136 is a dual-channel 16-bit part with an INL of ±8, and the MAX5137 is also a dual-channel 12-bit device with an INL ±1. Each DAC is available in an ultra-small (4mm²), 24-pin TQFN package, and is specified over the -40°C to +105°C extended industrial temperature range.

The MAX5138/MAX5139 are also single-channel, pin-compatible and software-compatible DACs in a smaller (3mm²), 16-pin TQFN package. The MAX5138 is a 16-bit DAC with a typical INL of ±2, and the MAX5139 is a 12-bit DAC with a typical INL of ±0.25.

The high-performance MAX5134–MAX5139 feature a choice of a precision 10ppm/°C internal reference or external reference for rail-to-rail output operation. A hardware input pin controls resetting the DAC outputs to zero or midscale upon power-up or reset. This feature provides additional safety for applications that drive valves or other transducers that need to be off during power-up. The hardware load DAC (active-low LDAC) pin provides simultaneous updates of multiple DACs. The serial interface features an active-low READY output for easy daisy chaining of several MAX5134–MAX5139, MAX15500/MAX15501, and the MAX5661 devices.

A cost effective application example of a PLC with four outputs would include one MAX5135 quad 12-bit DAC and four MAX15500 output conditioners.

Summary

The high linearity of the Maxim DACs and output conditioners makes these devices ideal for precision control and instrumentation applications. Thus, in a simple but elegant way the Maxim parts complement one another and give circuit designers choices without fear of complicated, large, discrete circuit blocks. Easy design implementation means that the choice of voltage or current drivers is stress free. This allows the busy engineer to concentrate on the propitiatory portions of the system design. The waste reduction and the efficiency improvements of precision control do, indeed, improve our environment.

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QSPI is a trademark of Motorola, Inc.

Related Parts		
MAX15500	Industrial Analog Current/Voltage Output Conditioners	Free Samples
MAX15501	Industrial Analog Current/Voltage Output Conditioners	Free Samples
MAX5134	Pin-/Software-Compatible, 16-/12-Bit, Voltage-Output DACs	Free Samples
MAX5135	Pin-/Software-Compatible, 16-/12-Bit, Voltage-Output DACs	Free Samples
MAX5136	Pin-/Software-Compatible, 16-/12-Bit, Voltage-Output DACs	Free Samples
MAX5137	Pin-/Software-Compatible, 16-/12-Bit, Voltage-Output DACs	Free Samples
MAX5138	Low-Power, Single, 16-/12-Bit, Buffered Voltage-Output DACs	Free Samples
MAX5139	Low-Power, Single, 16-/12-Bit, Buffered Voltage-Output DACs	Free Samples
MAX5661	Single 16-Bit DAC with Current and Voltage Outputs for Industrial Analog Output Modules	Free Samples

More Information
For Technical Support: http://www.maximintegrated.com/support
For Samples: http://www.maximintegrated.com/samples
Other Questions and Comments: http://www.maximintegrated.com/contact

Application Note 4603: http://www.maximintegrated.com/an4603
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