ANALOG DEVICES

Circuit Note
CN-0435

Circuits from the Lab® Reference Designs

Circuits from the Lab® reference designs are engineered and tested for quick and easy system integration to help solve today's analog, mixed-signal, and RF design challenges. For more information and/or support, visit www.analog.com/CN0435.

Devices Connected/Referenced	
CN-0414	Quad-Channel Analog Input with Open-Wire Detection and HART Compatibility for PLC/DCS Applications
CN-0418	Quad-Channel Analog Output and HART Compatibility for PLC/DCS Applications
CN-0416	RS-485 Transceiver
ADALM-UARTJTAG	JTAG and Serial Programmer
EVAL-ADICUP3029	Ultra Low Power, Arduino Form Factor Development Platform for IoT Applications

Analog I/O System with HART and Modbus Connectivity for PLC/DCS Applications

EVALUATION AND DESIGN SUPPORT

Circuit Evaluation Boards

- **CN-0414 Circuit Evaluation Board (EVAL-CN0414-ARDZ)**
- **CN-0418 Circuit Evaluation Board (EVAL-CN0418-ARDZ)**
- **CN-0416 Circuit Evaluation Board (EVAL-CN0416-ARDZ)**
- **ADALM-UARTJTAG Board**
- **Arduino Form-Factor Development Platform (EVAL-ADICUP3029)**

Design and Integration Files

- **PLC/DCS Wiki User Guide**
- **Schematics, Layout Files, Bill of Materials, Software**

CIRCUIT FUNCTION AND BENEFITS

Programmable logic controllers (PLC) and distributed control systems (DCS) are used for monitoring and controlling both smart (HART capable) and analog-only field instruments found in industrial automation applications.

The circuit shown in Figure 1 represents a simple DCS system composed of a host and a single node with two 4-channel isolated analog input boards and two 4-channel isolated analog output boards controlled locally by an Arduino form factor baseboard. The RS-485 transceiver interfaces with a PC or other host, from which the user can exchange data with the node using the Modbus protocol.

Analog input data is read locally and made available over a serial interface utilizing the industry-standard Modbus protocol, ensuring data integrity and compatibility with a range of software applications and libraries. Similarly, analog outputs are set by writing to Modbus registers, which are then translated to analog voltage or current signals.

Each node can have any combination of up to four analog input and output boards. Multinode systems of up to 16 nodes, as shown in Figure 2, can be designed using the hardware and software infrastructure provided. The circuit supports point-to-point HART communication, which can be extended to a multidrop HART network, consisting of several HART devices on the same channel.

Both analog inputs and analog outputs are galvanically isolated per board (groups of four), and analog inputs feature open-wire detection, simplifying fault detection and diagnosis. These features enhance robustness when working in a harsh industrial automation setting.

Rev. 0

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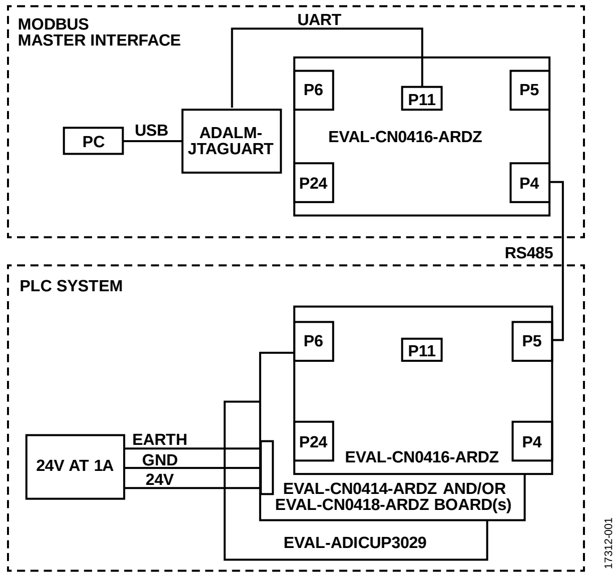

Figure 1. PLC (or Single-Node DCS) Modbus System Functional Block Diagram

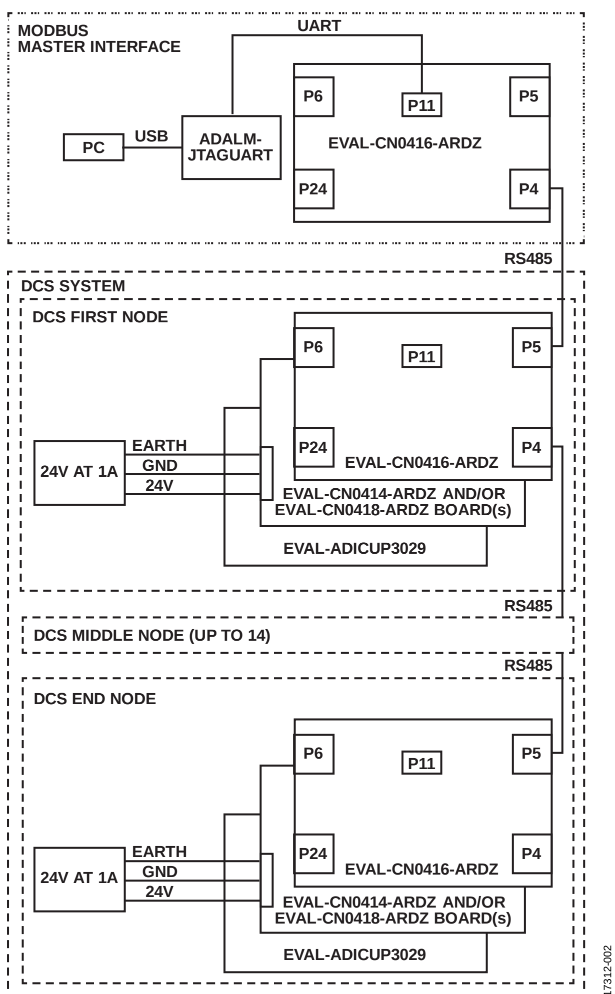

Figure 2. Multinode DCS Modbus System Functional Block Diagram

CIRCUIT DESCRIPTION

The application focuses on demonstrating the development of a PLC/DCS system controlled by a Modbus master and exemplifies how the latest features of key components are used. A single node system is often referred to as a PLC, whereas a larger system is often referred to as a DCS.

Each node can control up to 16 analog field devices, sensors or actuators, either HART-compatible or analog-only, and systems can be extended to include as many as 16 individual nodes. The system can also be used for general-purpose precision analog data acquisition applications such as instrumentation, analog datalogging, or test and measurement.

PLC/DCS Topologies

Several connection topologies are supported. In a single-node (PLC, or single-node DCS) system, the host computer can be connected directly to the USB serial port on the EVAL-ADICUP3029 platform board via a micro-USB cable, which is appropriate for laboratory test and measurement applications where the distance between the host and node is less than 2 m.

In this point-to-point topology, groups of four analog inputs and outputs per board are still isolated from the host computer. Though generally not associated with lab equipment, the Modbus protocol provides a convenient and standard method for communicating with the node. HART connectivity allows configuration of smart sensors and actuators.

As the distance between the host and nodes increases beyond 2 m, signal integrity, noise pickup, and electrical faults become a greater concern. The EVAL-CN0416-ARDZ provides robust RS-485 connectivity to the host in these situations. In a single-node, point-to-point system, either full or half-duplex communication is supported, over distances up to 1 km, depending on baud rate.

For multinode (better described as a DCS), the EVAL-CN0416-ARDZ includes daisy-chain ports, switchable half/full-duplex operation, and switchable termination, allowing systems of between 2 and 16 nodes to be assembled.

Because Modbus is used as a serial communication protocol to transmit information between devices over a serial link, a simple, reliable, and robust system can be obtained regardless of the scale. The PLC/DCS application hardware stack is composed of three different reference designs.

Analog Input Board

The CN-0414 shown in Figure 3 is designed to measure four fully differential or eight single-ended voltage and four current signals. The heart of the circuit is an AD4111 low power, low noise 24-bit, Σ-Δ analog-to-digital converter (ADC) with integrated ±10 V and 20 mA analog front ends.

The voltage inputs support an input range of up to ±10 V. The AD4111 incorporates a unique feature that enables open wire detection on ±10 V voltage inputs while operating on a 5 V or 3.3 V single power supply, while previous solutions would typically require a supply greater than ±10 V.

The current inputs support input ranges of 0 mA to 24 mA. The input impedance of the circuit is 250 Ω (60 Ω internal to the AD4111), with all inputs referenced to isolated ground. The 250 Ω input impedance on the current inputs is necessary to make the AD5700-1 HART-compliant modem to work in conjunction with the AD4111.

The analog front end of the circuit, the AD4111 and the AD5700-1 are isolated from the processing side through ADuM5411 and ADuM3151, to offer significant space savings over discrete transformer-based solutions.

The CN-0414 board is powered by a 9.5 V to 36 V dc power supply that is typical of industrial automation systems, and therefore makes it easy to retrofit into your system.

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Figure 3. Analog Input Board

Analog Output Board

The CN-0418 shown in Figure 4 is a quad channel voltage and current output board based on the AD5755-1 DAC with dynamic power control.

This circuit provides 4 mA to 20 mA current outputs, as well as unipolar or bipolar voltage outputs (±10 V). The board also includes the AD5700-1 HART modem, to give a complete analog output solution with HART connectivity. External transient protection circuitry is also included, which is important for applications located in harsh industrial environments.

The current and voltage outputs are available on separate pins, but only one is active at a time, thus allowing both output pins to be tied together and connected to a single terminal. Analog outputs are short-circuited, and open-circuit protected.

The AD5755-1 contains integrated dynamic power control using a dc-to-dc boost converter circuit, allowing reduced power consumption in the current output mode.

The AD5755-1 has four CHART pins, corresponding to each of the four output channels. The HART signal can be coupled into these pins and appears on the corresponding output if that output is enabled.

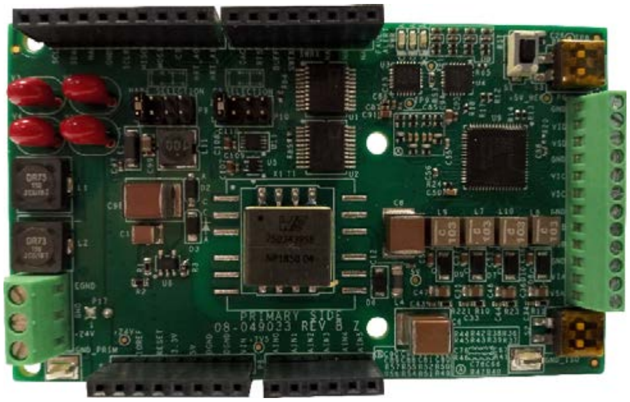

Figure 4. Analog Output Board

RS-485 Transceiver Board

The CN-0416 shown in Figure 5 is an isolated and non-isolated RS-485 transceiver board, which allows easy implementation of data transmission between multiple systems or nodes, especially over long distances.

The circuit uses the ADM2682E RS-485 transceiver for isolated communications and the LTC2865 for non-isolated RS-485 communications. Both can be configured to either full duplex or half-duplex operation and with open or terminated transmission lines.

The circuit has on-board RJ-45 jacks, which allow the use of common CAT5 Ethernet cables for fast physical wiring of nodes. The termination resistance is set by default to the CAT5 cable characteristic impedance of 100 Ω but can be configured to support the standard RS-485 cable impedance of 120 Ω.

The ADM2682E is capable of a data rate up to 16 Mbps and has true fail-safe receiver inputs with adjusted differential voltage threshold. It provides 5 kV signal isolation using the *i*Coupler data channel and 5 kV power isolation using the *iso*Power integrated dc-to-dc converter.

The LTC2865 is capable of a data rate up to 20 Mbps and has full fail-safe receiver inputs. An internal window comparator determines the fail-safe condition without the need to adjust the differential input voltage thresholds.

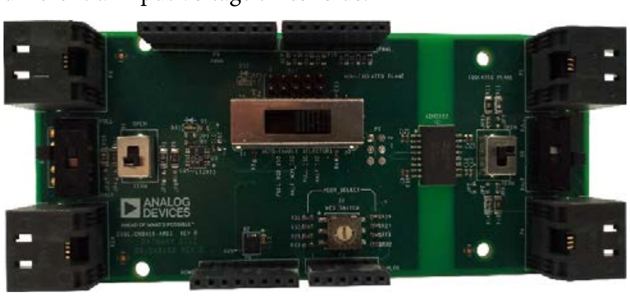

Figure 5. RS-485 Transceiver Board

HART-Compatible Field Devices Wiring

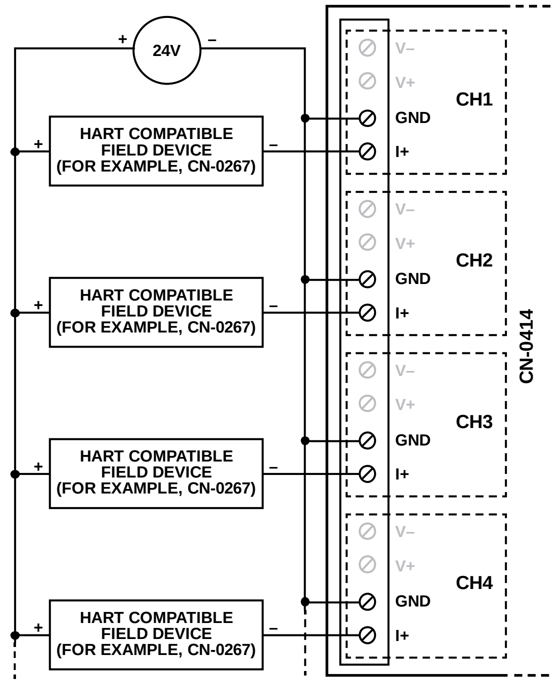

Figure 6. HART-Compatible Field Devices Wiring

HART Networks

HART devices can operate in one of two network configurations, point-to-point or multidrop.

In point-to-point mode, the 4 mA to 20 mA signal is used to communicate one process variable, while additional process variables, configuration parameters, and other device data are transferred digitally using the HART protocol. The 4 mA to 20 mA analog signal is not affected by the HART signal and can be used for control. The HART protocol gives access to secondary variables and other data that can be used for operations, commissioning, maintenance, and diagnostic purposes.

Modbus Protocol

The software running on the EVAL-ADICUP3029 implements the Modbus protocol, a de-facto and open industrial communication standard. Modbus provides a robust means of exchanging data with individual nodes, with CRC error detection ensuring data integrity. Being an open standard, there are numerous open-source and commercial Modbus software libraries available, targeting various platforms (such as Windows®, Linux®, embedded platforms, among others).

The software also provides a simple command-line interface (CLI) mode, allowing systems to be verified manually from a serial terminal, without requiring any additional software on the host.

Hardware and Software Stack

The PLC/DCS node system software and hardware stack is show in in Figure 7.

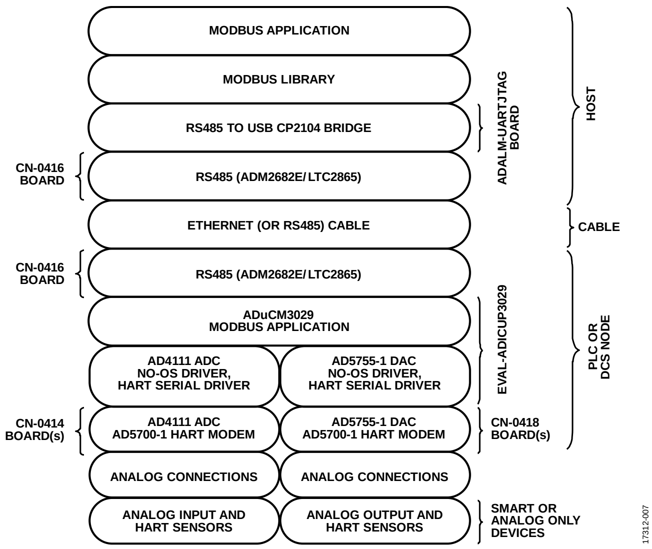

Figure 7. PLC/DCS Node System Software and Hardware Stack

After configuring the PLC/DCS hardware, the user would typically select an appropriate Modbus library according to the language (such as C, Python, MATLAB) and host platform (such as Linux, Windows, embedded). A simple test application must then be written, providing translation of analog and HART parameters to Modbus register addresses and values.

The CN-0435 User Guide provides a complete description of the Modbus register map for this application, and Modbus compliance is verified using an open-source Modbus debugger.

Several example top-level applications are also provided, built on an open-source Modbus library, and include the following:

- Detect system configuration: query all Modbus nodes and display configuration.
- Read or write output holding registers: check or change the state of output holding registers off all detected boards.
- Read analog input registers: check the state of input registers off all detected boards.
- Read analog data: read a single analog input or all analog inputs and display data to the console.
- Write analog data: write analog outputs to generate a voltage or a current.
- Analog echo: read analog voltage or current from an analog input board and write the same analog voltage or current to an analog output board.

COMMON VARIATIONS

The CN-0435 software reads analog input values and writes analog output values, with no local processing. The software can be extended to include functions such as fault monitoring and response, or closed-loop PID control loops, offloading these functions from the host computer and saving bandwidth on the communication bus.

A Raspberry Pi can be used as a compact and low-cost host solution. The Raspberry Pi provides wired or wireless Ethernet connectivity, and it can be directly connected to the USB-UART of the EVAL-ADICUP3029.

Three most common Modbus version are used today, Modbus ASCII, Modbus RTU and Modbus TCP. All Modbus messages are sent in the same format. The only difference among the three Modbus types is in how the messages are coded.

The number of devices that can be connected through Modbus depends on the physical layer and data protocol. If a RS-485 physical layer is used along with the Modbus RTU or Modbus ASCII data protocols, the maximum number of nodes that can be addressed is 32, whereas if an Ethernet physical layer is used along with the Modbus TCP data protocol, 247 nodes can be addressed.

The device address is a number from 0 to 247. Messages sent to Address 0 (broadcast messages) can be accepted by all slaves, but numbers from 1 to 247 are addresses of specific devices.

The Arduino form factor of the CN-0414 and CN-0418 ensures compatibility with development platforms that support a wide range of other automation communication protocols including process field net (PROFINET), process field bus (PROFIBUS), Ethernet for control automation technology (EtherCAT), EtherNet/IP, Modbus Plus, and others.

CIRCUIT EVALUATION AND TEST

The following sections will outline the necessary equipment and general steps needed to get started with the reference demo. DCS systems can be assembled and tested for basic functionality using the software's CLI option. For detailed instructions and supplemental information, see the Distributed Control System (DCS) Demo Wiki User Guide.

Equipment Needed

The following equipment is needed:

- PC with a USB port and Windows 7 (32-bit) or higher
- Serial terminal program such as TeraTerm or Putty
- One or more EVAL-CN0414-ARDZ circuit evaluation board and/or EVAL-CN0418-ARDZ circuit evaluation board for every node
- One or more EVAL-CN0416-ARDZ circuit evaluation board for the Modbus interface and another EVAL-CN0416-ARDZ board for every node
- One ADALM-UARTJTAG evaluation board with an additional EVAL-CN0416-ARDZ board (or other half-duplex RS-485 adapter)
- One EVAL-ADICUP3029 evaluation board for each node
- Micro USB cable
- One RJ-45 cable for the RS-485 interface and another for every node
- PLC system software or pre-built hex file
- A 24 V DC at 1 A power supply

Getting Started

The following are the basic steps for setup:

1. Plug the USB cable from EVAL-ADICUP3029 to the PC and flash the firmware onto the every used board.
2. Configure the hardware. Follow the Distributed Control System (DCS) Demo Wiki User Guide. Ensure that the jumpers and switches are set on each board correctly. Optionally, for analog input boards, connect sensors or signal sources, respectively, for analog output boards connect actuators or multimeters.
3. For each node, stack the platform and shield boards on top of each other in the following order:
    - EVAL-CN0416-ARDZ (top)
    - EVAL-CN0414-ARDZ or EVAL-CN0418-ARDZ (optional)
    - EVAL-CN0414-ARDZ or EVAL-CN0418-ARDZ (optional)
    - EVAL-CN0414-ARDZ or EVAL-CN0418-ARDZ (optional)
    - EVAL-CN0414-ARDZ or EVAL-CN0418-ARDZ (optional)
    - EVAL-ADICUP3029 (bottom)
4. Connect RJ-45 cables between nodes and the RS-485 adapter (which may be the ADALM-UARTJTAG and EVAL-CN0416-ARDZ).
5. Connect the RS-485 adapter to the host.
6. Press the 3029_Reset button or power cycle the system.

For complete details, see the Distributed Control System (DCS) Demo Wiki User Guide.

Functional Block Diagrams

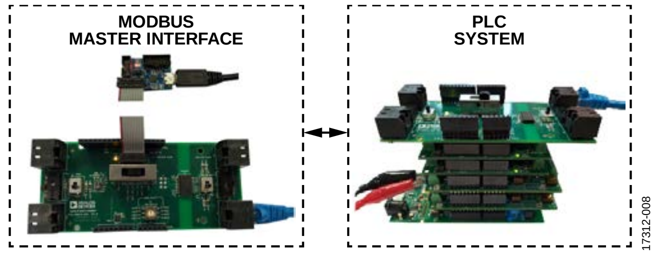

Figure 8. Single-Node PLC Analog I/O System

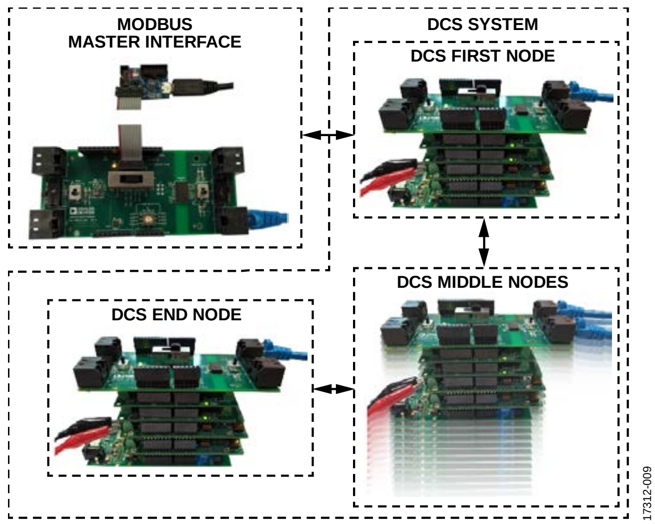

Figure 9. DCS Analog I/O System

LEARN MORE

CN-0414 Design Support Package:
www.analog.com/CN0414-DesignSupport

CN-0418 Design Support Package:
www.analog.com/CN0418-DesignSupport

CN-0416 Design Support Package:
www.analog.com/CN0416-DesignSupport

ADALM-UARTJATG Design Support Package:
www.analog.com/ADALM-UARTJATG-DesignSupport

EVAL-ADICUP3029 User Guide

ADICUP3029 GitHub Repository

Data Sheets and Evaluation Boards

CN-0414 Circuit Evaluation Board (EVAL-CN0414-ARDZ)

CN-0418 Circuit Evaluation Board (EVAL-CN0414-ARDZ)

CN-0416 Circuit Evaluation Board (EVAL-CN0414-ARDZ)

ADALM-UARTJATG Circuit Evaluation Board (ADALM-UARTJATG)

ADICUP3029 Development Platform (EVAL-ADICUP3029)

REVISION HISTORY

7/2019—Revision 0: Initial Version