Application Note

A Basic Guide to the HART Protocol

Joseph Wu

ABSTRACT

The Highway Addressable Remote Transducer (HART®) protocol is used in many factory automation and control systems. This protocol uses the established 4-20mA loop to send digital signals between a smart transmitter and a host for data that can be used for control, monitoring, or safety. This application note starts with an overview of 4-20mA systems and HART transmitters and discusses the protocols for developing HART enabled devices. This application note also discusses different TI devices with HART connectivity.

Table of Contents

Trademarks

FOUNDATION™ is a trademark of Fieldbus Foundation.
HART®, WirelessHART®, and HART-IP® are registered trademarks of FieldComm Group, Inc.
PROFIBUS® is a registered trademark of PROFIBUS Nutzerorganisation e.V.
All trademarks are the property of their respective owners.

1 Introduction to the HART Protocol

The Highway Addressable Remote Transducer (HART) protocol is a backward-compatible enhancement to 4-20 mA instrumentation that allows two-way communication with smart, microprocessor-based field devices.

For factory automation and control (FA&C) applications, 4-20 mA current loop communications are a common method to send data from a remote transmitter measuring a factory variable back to a host that receives and processes the data. The value of current is the primary variable sent by the remote transmitter. This primary variable represents some measure of temperature, flow, or pressure.

The HART signal is superimposed onto this 4-20 mA current loop and is modulated for two-way digital communications. The 4-20 mA loop is already a widely used standard in FA&C applications. Because this technology is backwards compatible and can be used with already-existing infrastructure means that HART is easy to adopt and cost effective.

HART is a command/response protocol where a host sends commands and a remote transmitter returns standardized responses. The data received by the commands can communicate device status and diagnostics. Data can also include the device measurement floating-point digital values, the engineering units of the primary variable, and other information about the remote transmitter.

The HART protocol can also be used for standardized operating procedures such as testing the current loop, range setting of the current loop, and calibration information from the transmitter. HART modifies the 4-20 mA system that sends only the primary variable as a current value and adds digital communication with more functionality.

1.1 Different Forms of the HART Protocol

The standard HART transmission is a frequency shift keyed (FSK) signal superimposed on the 4-20mA signal. The FSK bits are transmitted at 1200 bits per second (bps). FSK indicates that the bit signals are represented as two different frequency transmissions. Each frequency represents a digital 1 or digital 0.

An alternative to the standard FSK signal is a coherent 8-way phase-shift keyed (C8PSK) signal. This version of HART increases the digital transmission rate. This version uses a 3200-Hz carrier that has 8 different phases for information. Eight phases at 3200 Hz gives an effective bit transmission rate of 9600 bps. Similar to the standard FSK, C8PSK is compatible with the analog signaling on the 4-20 mA loop.

Additionally, HART protocol can be used in other signaling systems. Some manufacturers have developed devices using HART-based communication packets sent across RS-485.

WirelessHART® uses a 2.4 GHz time division multiple access (TDMA) communication built on the IEEE 802.15.4 standard to integrate wireless communication. This protocol was designed to work together with the existing HART protocol and HART devices. WirelessHART is basically a wireless mesh network used to connect field devices to a WirelessHART gateway.

HART-IP® uses internet protocol (IP) to send HART communication over Ethernet. HART-IP connects to individual devices and also wireless gateways to WirelessHART devices. HART-IP is basically HART using IP addressing. Ethernet connections use Ethernet-APL, which is a two-wire, loop-powered Ethernet physical layer used for rugged and hazardous conditions in process plants.

At the publication date of this application note, TI's existing HART capable devices feature the standard FSK HART. For this reason, only the HART FSK is discussed in this application note.

1.2 HART as an Enhancement to the 4-20 mA Loop

Figure 1-1 shows a basic block diagram of a remote transmitter installed on a 4-20mA loop.

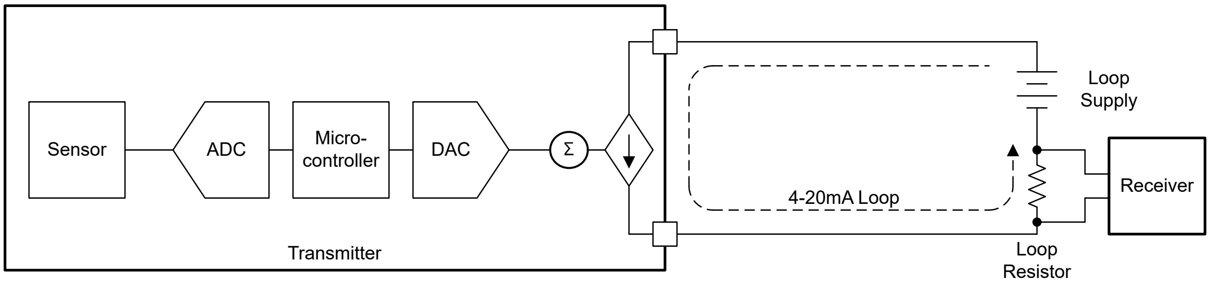

Figure 1-1. A Remote Transmitter on a 4-20 mA Loop

The remote transmitter takes measurements with a sensor and translates that current on the 4-20 mA loop. The measurement data can be a variable for industrial control: temperature, pressure, flow, or any other measurement required on a factory floor. This measurement is converted to a primary variable, which has a defined full-scale range. This primary variable is converted into a value that is proportional to the signal in the 4-20 mA loop. For example, 4 mA of loop current represents the zero-scale, and 20 mA of loop current represents the full-scale. If a temperature measurement from an oven has a full range of 0°C to 1000°C, then 4 mA of current in the loop represents 0°C and 20 mA of current in the loop represents 1000°C. Intermediate values are linearly translated to this scale. The value of the primary variable is measured by a receiver connected to a host. Recovering the primary variable involves using an analog-to-digital converter (ADC) to measure a resistor to determine the current in the loop.

As mentioned previously, HART communication uses the 4-20mA loop and adds a digital signal to the loop using a HART modem. The HART communication uses an FSK signal to modulate digital bits in the communication. The modem signaling sends two different frequencies that act as the 0 or 1 in the digital communications. Figure 1-2 shows the addition of HART to the transmitter.

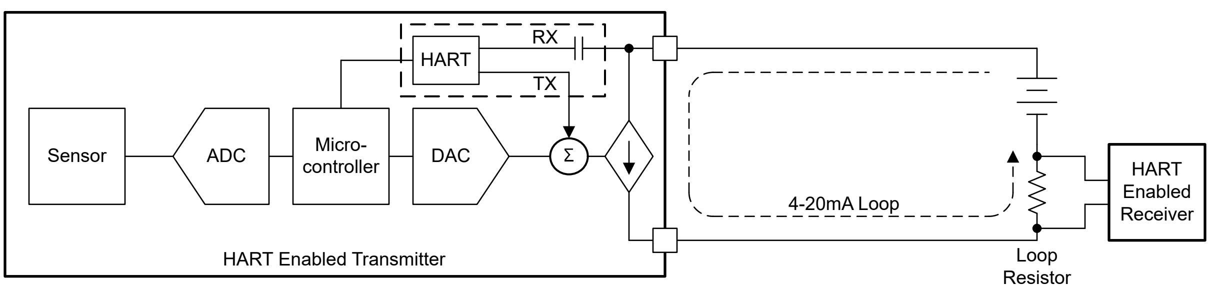

Figure 1-2. Adding HART to the 4-20 mA Loop

The transmitter incorporates a HART modem with a transmission shown as TX. The modem modulates the current in the loop to transmit the digital signal. The HART signal is added to the current value used to represent the primary variable. The modem also capacitively couples the voltage signal to receive the digital signal. This part of the modem is shown as receiver (RX) inside the remote transmitter.

Another HART enabled receiver connected to the host measures the voltage across the resistor in the loop to determine the primary variable. The host receives the primary variable measurement using a low pass filter to filter out the HART FSK signal. The resistor range for communication is from 230 Ω to 600 Ω, and 250 Ω is the typical resistance used in HART applications. At the same time, the host receives the HART FSK digital signal using a bandpass filter. Both the host and the field transmitter can send and receive data relating to the sensor and the HART enabled transmitter. This HART signal must be band pass filtered to be received by the remote transmitter.

1.3 The HART FSK Signal

The HART FSK digital signal is a sinusoid modulated on the 4-20mA loop. Nominally, the HART FSK is a 1-mA_{PP} sinusoid. Figure 1-3 shows a representation of the instantaneous current in the loop with a HART modulated signal. The 4-20mA current represents the primary variable.

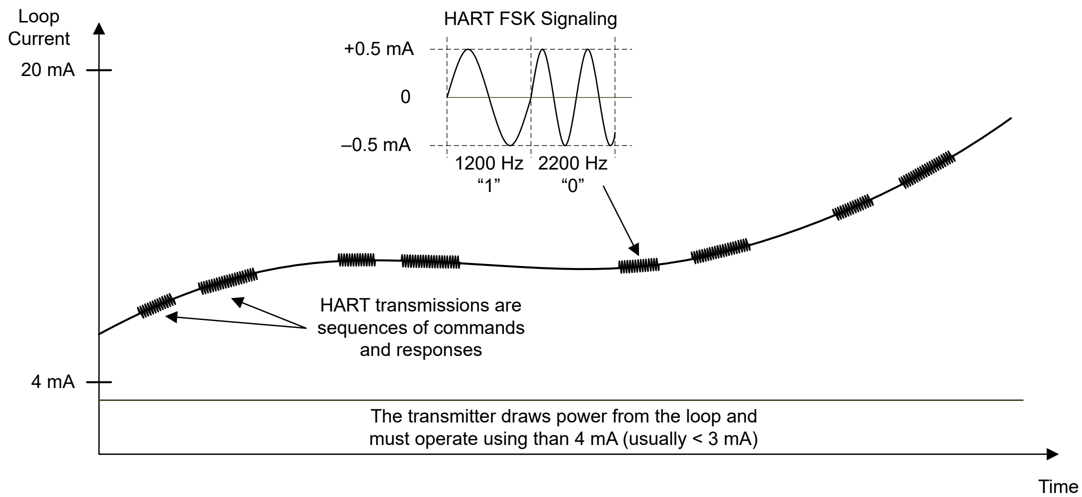

Figure 1-3. HART Transmissions on a 4-20 mA Loop

As previously mentioned, bits are represented as two different FSK signals. A 1200-Hz signal is a digital 1 and a 2200-Hz signal is a digital 0. The data is sent at 1200 baud and each bit is 833 µs long.

Note that many transmitters operate off of the loop power. This means that power applied to the loop is also used to power the transmitter. Because there is no other source of power and the loop's zero scale is 4 mA, the transmitter must operate with a current budget of under this amount of current. In some cases, a current of 3.5 mA can be used as an error signal, so the transmitter must effectively operate with a maximum budget of 3 mA.

The primary variable and the HART signal share the same transmission and each signal must be filtered to be received. Figure 1-4 shows the frequency content of the primary variable and the HART signal.

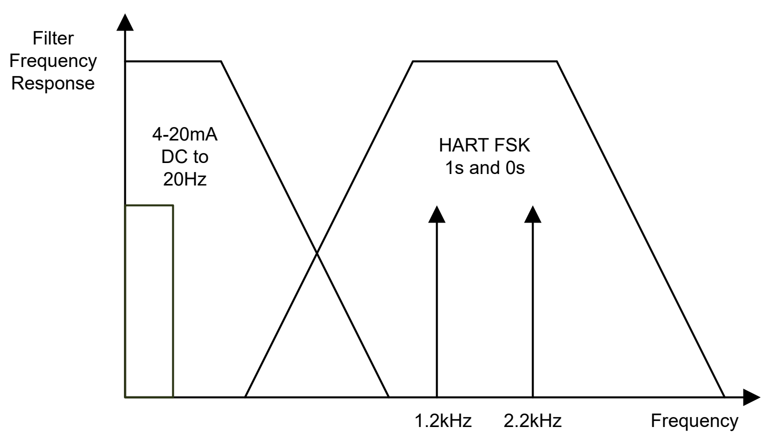

Figure 1-4. Filtering for the Primary Variable and HART FSK

In the HART-enabled receiver, the primary variable is read using a low-pass filter to measure the voltage across a resistor. This signal is generally under 20 Hz and the low-pass filter can have a cutoff frequency of 25 Hz. The HART transmission uses higher frequencies, with the FSK bits at 1200 Hz and 2200 Hz. This HART signal is received using a band-pass filter that typically operates from 500 Hz to 10 kHz.

1.4 HART Configurations

There are two basic methods of connecting to a HART device to the control system. Figure 1-5 shows a point-to-point connection of a control to HART enabled field transmitter device

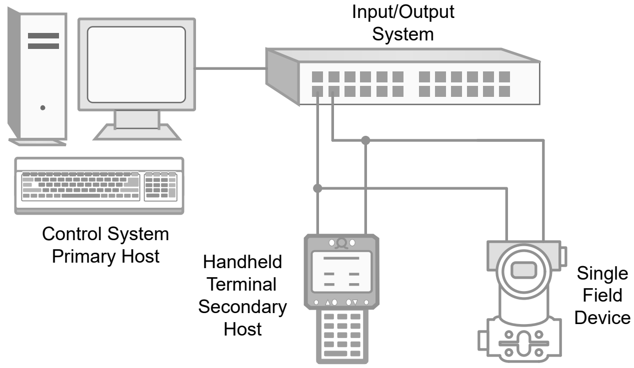

Figure 1-5. Point-to-Point Connection for a HART Host and a HART-Enabled Field Transmitter

A host can have multiple inputs through a switch. When there is communication, each input has a power supply and receiver. The host sends commands and receives data from a single field device. A secondary host can be used to send commands and receive data, but there is a single field device on the loop.

The second basic method of connecting a HART device to the control system is multi-drop mode. In multi-drop mode, multiple field devices are connected in parallel. Using this mode, there is no primary variable and the current is fixed at 4 mA for each field device. Figure 1-6 shows multiple field transmitters set up in multi-drop mode.

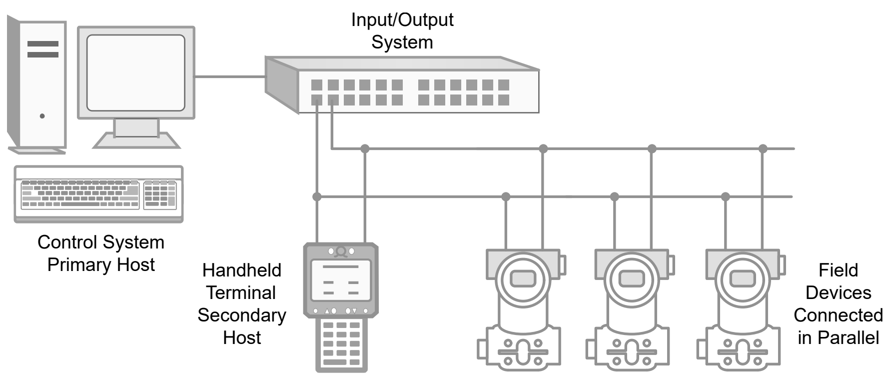

Figure 1-6. Field Transmitters Set Up in HART Multi-Drop Mode

Each of the devices are identified through a unique address. In this way, the host can communicate with an individual device on the loop. Different revisions of HART allow for different numbers of addresses:

- Address 0: Default address for point-to-point devices
- Addresses 0 to 15: Address range for HART revision 5 or earlier for multi-drop loop devices
- Addresses 0 to 63: Address range for HART revision 6 or newer for multi-drop loop devices

1.5 HART Protocol Structure

As a protocol, all HART transmissions are organized into sets of bytes. The following sections describe the basic communication, byte and frame construction, and device addressing.

1.5.1 HART Communication

The HART protocol communication is half-duplex. The host can communicate with a field transmitter and the field transmitter can communicate back to the host. However, there is a single communication line across the 4-20mA loop, and only one or the other can send commands or data at any given time.

There are two modes of HART communication between a host and a field device. The first mode of communication is a request-response mode. The host sends a command and the field transmitter responds. Communications are initiated by the host device.

Second, some HART devices support burst mode communication. In burst mode, the host sends a command to initiate a burst mode response. Once started, the field transmitter responds with a repeated HART response. For example, the response can be a digital readout of the primary variable. The field transmitter repeatedly sends out the value of the primary variable, until the host sends a command to stop burst mode. Figure 1-7 and Figure 1-8 show the frame communication for HART devices in request-response and in burst mode. The transmitted primary variable can be in units for a variety of measurements used for process control.

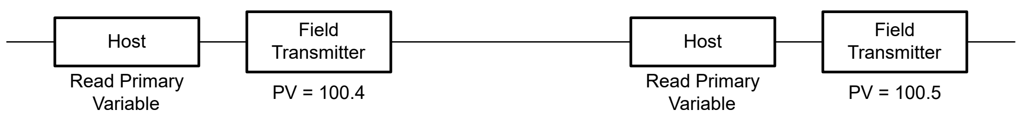

Figure 1-7. HART Communication in Request-Response Mode

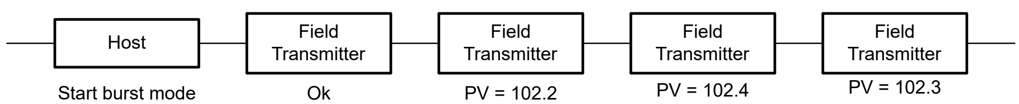

Figure 1-8. HART Communication in Burst Mode

With long HART packets and a baud rate of 1200 bps, request-response mode communications are as fast as two to three data updates per second. Burst mode increases the data update to three to four updates per second.

1.5.2 HART Bytes

With each transmission, HART uses a basic byte structure. This structure is similar to the UART format. A HART byte is shown in Figure 1-9.

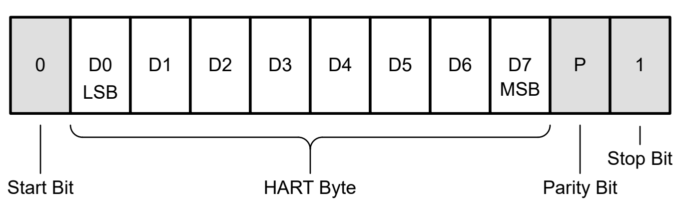

Figure 1-9. The HART Protocol Byte

The first transmitted bit is a 0, which indicates a start bit. The next eight bits are the HART byte, transmitted as least significant bit (LSB) first, ending with the most significant bit (MSB). The next bit is an odd parity bit and the last bit is a 1, indicating a stop bit. Each HART byte is transmitted using this 11-bit format.

1.5.3 HART Data Frame Structure

HART uses a specific data frame structure for communication. The host sends a command and the remote transmitter device sends a frame with a specific structure as a response. The HART frame has 9 sections of HART bytes that are sent in a specific order.

Table 1-1 shows the different fields in the HART communication packet.

Table 1-1. Fields in the HART Data Frame Structure

Field Name	Length (in bytes)	Purpose
Preamble	5 - 20	The HART frame starts with a preamble of 5 to 20 bytes. This is the beginning of transmission and uses a consecutive set of 0xFF bytes. This preamble transmission establishes the carrier detect and synchronization for the frame.
Start byte	1	The start byte (also known as the delimiter) is used at the start of the HART data frame to indicate where the packet originated. The start byte can indicate the host number and the message and address format and also indicates if the packet is a response from a field device, or data from a field device in burst mode. The delimiter specifies address type, number of expansion bytes, the physical layer, and the origination of the data frame.
Address	1 or 5	The HART address is 1 or 5 bytes. The address indicates primary or secondary host, or 4-bit polling address from a device. The long frame uses five bytes total comprised of 14 bits used for the expanded device type and three additional bytes for a device ID number. The address also can indicate burst mode operation.
Expansion	0 - 3	Expansion bytes are used for potential expansion. This field is 0 to 3 bytes long and the length is indicated in the start byte. These bytes are reserved for protocol enhancements that can be implemented in the future.
Command	1	The command byte tells the device or host what information is being transferred or operation to perform. The byte indicates numerical value for the command to be executed.
Byte count	1	This byte indicates the number of data bytes in the data frame. This value describes the size of the data field including the status bytes
Status bytes	2	The status bytes are used for device transmissions to the host and contains information on communication errors, status of commands, and device information.
Data field	0 - 253	This section is from 0 to 253 bytes of data transferred between the field transmitter device and the host and vice versa based on the command. The byte count field mentioned previously is indicated by 1 byte, which counts a maximum of 255. The byte count includes both the status and the data bytes. Universal and common-practice commands are up to 33 bytes of data long.
Checksum	1	The HART frame concludes with a checksum. This single byte is the XOR of all bytes from the start byte to last byte of data.

The following sections briefly describe some sections of the HART data frame.

1.5.3.1 HART Start Byte

After the a transmission of the HART preamble (several bytes of 0xFF), the start byte delimiter is sent. The delimiter describes information within the frame being sent. Figure 1-10 shows the structure of the delimiter.

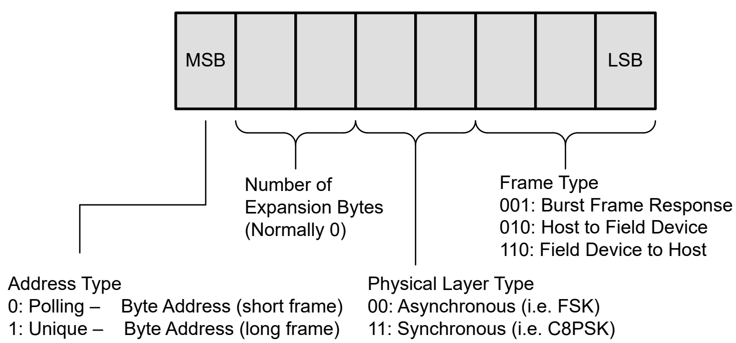

Figure 1-10. HART Start Byte

The MSB of the delimiter indicates the type of address used for the frame. If the bit is zero, the address is the 4-bit polling address. If the bit is one, the address uses the unique device ID to indicate descibe the device. Next, two bits are used for HART expansion. These bits are normally zeros.

Two bits describe the type of physical layer used for the HART transmission. Bits 00b describe an asynchronous FSK transmission, while bits 11b describe a synchronous C8PSK transmission.

The final three bits describe the type of frame and origin of the transmission. Bits 001b indicate that the frame is a transmission of a device in burst mode. Bits 010b indicate the frame is a transmission from a host to a field device. Bits 110b indicate the frame is a transmission from a field device to a host.

1.5.3.2 HART Device Addressing

There are two forms of addressing for indicating the HART address. There is a short frame address of one byte and a long frame address of five bytes.

The short frame address byte is eight bits (without the start, parity, or stop bits). The first bit indicates a primary or secondary host. The second bit indicates a burst mode transmission. The third and fourth bits are always zeros and the last four bits indicate the HART address. A HART short frame address is shown in Figure 1-11.

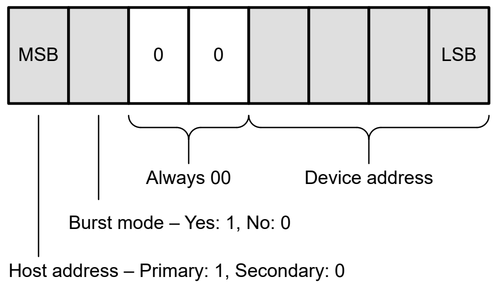

Figure 1-11. HART Short Frame Address Byte

The long frame address is composed of five bytes shown in Figure 1-12. Devices are identified with an expanded device type plus a device ID number, totaling 38 bits within the five bytes. In the first byte, bit 1 indicates a primary or secondary host and bit two indicates the burst mode. The expanded device type uses the last six bits of the first byte concatenated to the second byte (14 bits). The the last three bytes of the long frame address indicate the device ID number for the device (24 bits).

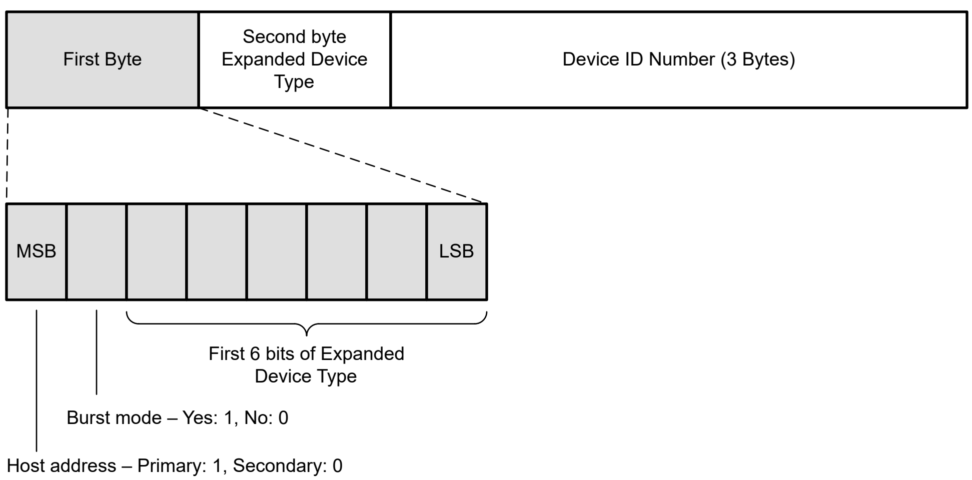

Figure 1-12. HART Long Frame Address

1.5.3.3 HART Commands

The HART command is sent in a single byte after the expansion bytes in the frame. Commands from a host to a field device can read information from a device such as variables, status, or device information. Commands also can write to a field device to set polling addresses, and write descriptors and messages.

Commands are classified into several categories. First, there are universal commands that are required for all field devices and must be supported for the HART protocol. Second, common-practice commands are implemented for many, but not all devices in a standard format. There are also device-specific commands that can be used for a particular device or device manufacturer. Finally, there are device family commands that can be used for standard functions for a set of device types or manufacturer defined measurements for generic access to the family.

Universal commands are defined for commands 0 - 30, 38, and 48 and describe basic transactions between the host and the field device. Universal commands read device identification, dynamic variables, and other information. These commands also write polling addresses and other identifying information to the device memory. To be compliant with the HART protocol, universal commands must be implemented. Note that with a single byte, basic commands are limited from 0 to 255. Command 31 indicates a 16-bit command number shown in the data field which significantly expands possible commands to a field device.

Common-practice commands are defined from 32 to 121 (except 38 and 48) and are not used in all field devices. When used, common-practice commands must be implemented as described in the protocol. Additional common-practice commands include commands 512 - 767 through expansion.

Commands 122 - 126 are intended for factory use, and 129 and 254 to 511 are reserved. There are additional device-specific commands depending on sensor or actuator type for field devices, and other commands for wireless devices, and WirelessHART within the 16-bit expansion.

2 HART Protocol and Test Specifications

HART was established in the mid-1980s by Rosemount Incorporated, currently owned by Emerson Electric. This protocol is based on the Bell 202 modem communication standard. The HART protocol is now governed by the FieldComm Group. FieldComm maintains the protocol and oversees any changes or revisions to the protocol. FieldComm also registers HART compliant devices. At the publication date of this application note, HART is currently on Revision 7.

Registration for HART compliant devices are first tested by the manufacturer. Manufacturers run a set of physical layer tests as well as tests for the response to HART commands. After the manufacturer has tested the HART device, FieldComm tests the devices again to verify compliance to the HART protocol to confirm the registration.

2.1 The OSI Protocol Model

The HART protocol follows the seven-layer Open Systems Interconnection (OSI) protocol model. The OSI model describes seven layers that computer systems use to communicate over a network. Figure 2-1 shows a comparison between the OSI protocol model and the HART protocol.

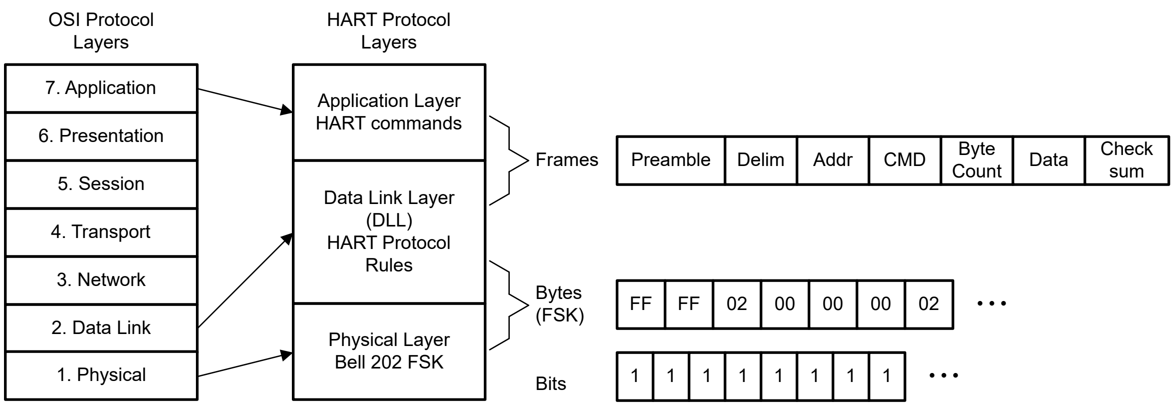

Figure 2-1. HART Protocol Compared to the OSI Protocol Model

Of the seven layers of the OSI model, the HART protocol uses three layers to describe network communication.

At the bottom, there is a HART Physical Layer. This is the FSK format for the HART transmission based on the Bell 202 standard. This signal sends data at 1200 baud and is superimposed on the 4-mA to 20-mA analog measurement signal.

Next, the HART Data Link Layer (DLL) defines the communication format and timing rules between the host and the transmitter device. There can be two different hosts on a bus, and in multi-drop mode, there can be as many as 15 devices (HART versions 3 to 5) or 62 devices (HART version 6 or later) connected in parallel.

Finally, there is an Application Layer that has some human or computer interaction that define commands, responses, and data formats that are used in the protocol. As previously mentioned, commands are broken up into several categories for the application layer. These commands are the universal commands, the common-practice commands, and device-specific commands.

Each of the layers use tests to verify different rules in the HART protocol. Testing for HART registration is divided into the three layers, covering the physical layer, the data link layer, and the application layer commands.

2.2 HART Protocol Specifications

The following is a list of HART protocol specifications. The specifications outline how HART devices respond to commands and describe the physical layer of the protocol.

- HART Communication Protocol Specification (HCF_SPEC-13 FCG TS20013)
- FSK Physical Layer Specification (HCF_SPEC-54 FCG TS20054)
- Token-Passing Data Link Layer Specification (HCF_SPEC-81 FCG TS20081)
- Command Summary Specification (HCF_SPEC-99 FCG TS20099)
- Universal Command Specification (HCF_SPEC-127 FCG TS20127)
- Common Practice Command Specification (HCF_SPEC-151 FCG TS20151)

The specifications above can be viewed online at the FieldComm website but cannot be downloaded by non-member companies. The specifications can be purchased as a bound book. Member companies can download an electronic copy in a PDF. Companies purchase membership from the FieldComm Group.

2.3 HART Test Specifications

The following is a list of HART protocol test specifications. These test specifications describe the details of HART testing for the different layers of the protocol. The test specifications describe how the tests are constructed and what different test failures look like.

- FSK Physical Layer Test Specification (HCF_TEST-2 FCG TT20002)
- Token-Passing Data Link Layer Test Specification (HCF_TEST-1 FCG TT20001)
- Universal Command Test Specification (HCF_TEST-3 FCG TT20003)
- Common Practice Command Test Specification (HCF_TEST-4 FCG TT20004)

For the test specifications, only the table of contents can be viewed online at the given website. Non-member companies must purchase the bound book.

The four test protocols govern the tests required for HART registration. The physical layer test specification covers the physical aspects of the HART signal on the loop. This covers the Frequency Shift Key (FSK) signal shape and frequency, the tolerable noise within the frequency bands of operation, the timing between the FSK and digital signals to the board, and the output impedance of the board itself.

The token-passing data link layer tests (DLL tests) govern the communication between the HART host and the remote transmitter. Universal command tests (UAL tests) cover commands that must be supported by all HART devices. Common-practice command tests (CAL tests) cover commands that are often implemented in HART devices. The DLL, UAL, and CAL tests require a specialized HART tester that transmits different commands in different formats to check the response of the device.

3 TI HART Enabled Devices

Texas Instruments produces several devices designed to integrate a HART FSK signal. Some devices are digital-to-analog converters (DACs) with a voltage or current output that couple in a HART signal that can be modulated on the output. Other devices are modems that send and receive HART signals through either a UART interface or SPI.

Table 3-1 shows a list of TI devices that provide device connectivity to the HART protocol. The following sections describe these devices in more detail.

Table 3-1. Device Reference

Device Type	TI Device	DAC Resolution	Features	HART Connectivity
DAC for field transmitter device	DAC161S997	16-bit	Field transmitter device with precision DAC with internal reference, integrated op-amp, SPI, and matched resistors for setting current loop drive	HART signal capacitively coupled out to DAC from C2 pin
	DAC161P997	16-bit	Field transmitter device with precision DAC with internal reference, integrated op-amp, single-wire interface, and matched resistors for setting current loop drive	
Current output DAC	DAC8750	16-bit	Single-channel programmable current output DAC with internal reference for 4-20mA current loop applications	HART signal capacitively coupled out to DAC through HART-IN pin
	DAC7750	12-bit		
Current and voltage output DAC	DAC8760	16-bit	Single-channel programmable current and voltage output DAC with internal reference for 4-20mA analog output applications	HART signal capacitively coupled out to DAC through HART-IN pin
	DAC7760	12-bit		
	DAC8771	16-bit	Single-channel programmable current and voltage output DAC, with internal reference and buck-boost converter for analog output applications	HART signal capacitively coupled into DAC through HART-IN_x pin
	DAC8775	16-bit	Four-channel programmable current and voltage output DAC, with internal reference and buck-boost converter for analog output applications	
HART modem device	DAC8740H		HART modem with UART interface	HART signal capacitively coupled into modem on MOD_IN or MOD_INF depending on input filtering, HART sinusoid out on MOD_OUT
	DAC8741H		HART modem with SPI	
	DAC8742H		HART modem with SPI and UART interface	
HART modem device with DAC	AFE881H1	16-bit	Field transmitter device with precision DAC with 0.15-V to 1.25-V output range, internal reference, and ADC	HART signal capacitively coupled into modem on MOD_IN or MOD_INF depending on input filtering, HART sinusoid out on MOD_OUT
	AFE781H1	14-bit		
	AFE882H1	16-bit	Field transmitter device with precision DAC with 0-V to 2.5-V output range, internal reference, and ADC	
	AFE782H1	14-bit		

3.1 TI DACs with HART Connections

The DAC161S997 (SPI) and DAC161P997 (single-wire interface) are 16-bit delta-sigma DACs. With an external NPN transistor, these devices can be used to construct a low-power, high-precision, industrial 4-20mA transmitter. The DAC, an internal op-amp, and several internal precision resistors are used to construct a voltage-to current (V-I) stage for the transmitter. For this device, a HART FSK signal can be capacitively coupled into an RC filter internal to the device. Figure 3-1 shows a block diagram of the DAC161S997 in a field transmitter application. The HART FSK signal is modulated onto the current loop from a connection to the C2 pin.

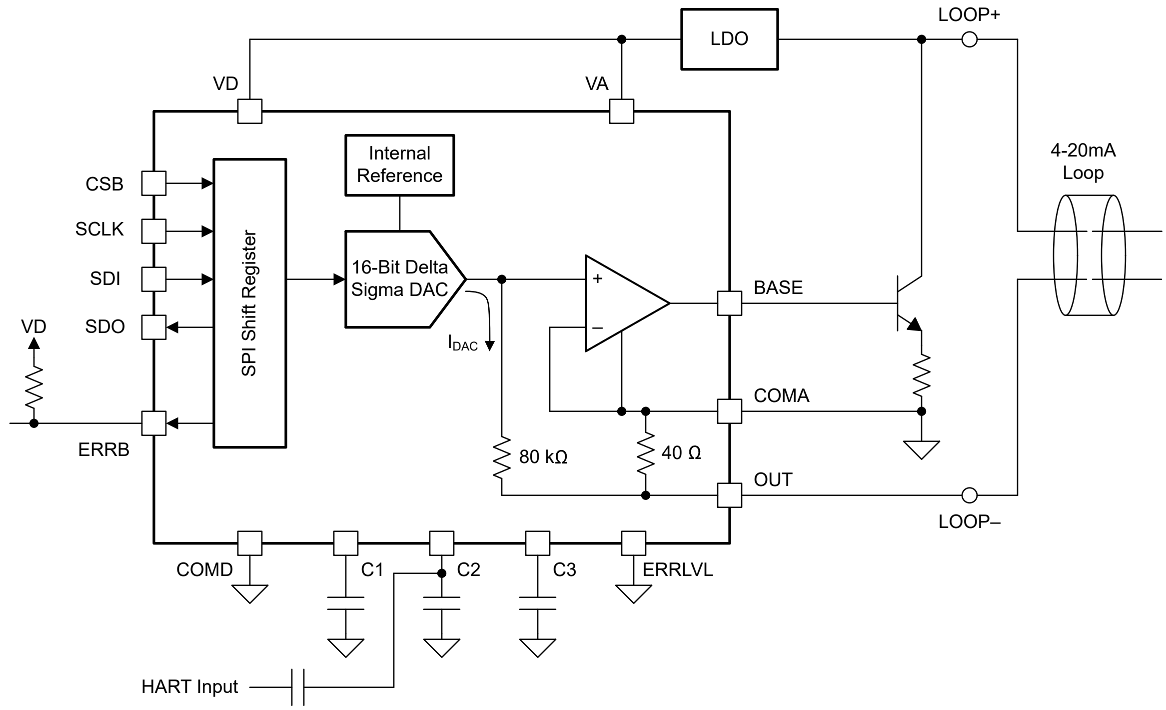

Figure 3-1. Block Diagram of the DAC161S997 in a Field Transmitter Application

Some HART-enabled DACs are used in systems other than the 4-20mA loop. These systems incorporate programmable logic controllers (PLCs) or distributed control systems (DCS) where a specific output voltage or current is required.

The DACx750 are precision, fully integrated, 16-bit and 12-bit DACs and have a variety of programmable output current ranges for industrial process control applications. These devices use SPI for communications, and operate with either a single 10-V to 36-V supply, or dual supplies of up to ±18 V. Similarly, the DACx760 have the same function but add voltage outputs to the device. An input pin capacitively couples in a HART FSK signal to the DAC output. Figure 3-2 shows the block diagram of the DAC8760. The HART signal is modulated onto the current or voltage output through the HART-IN pin.

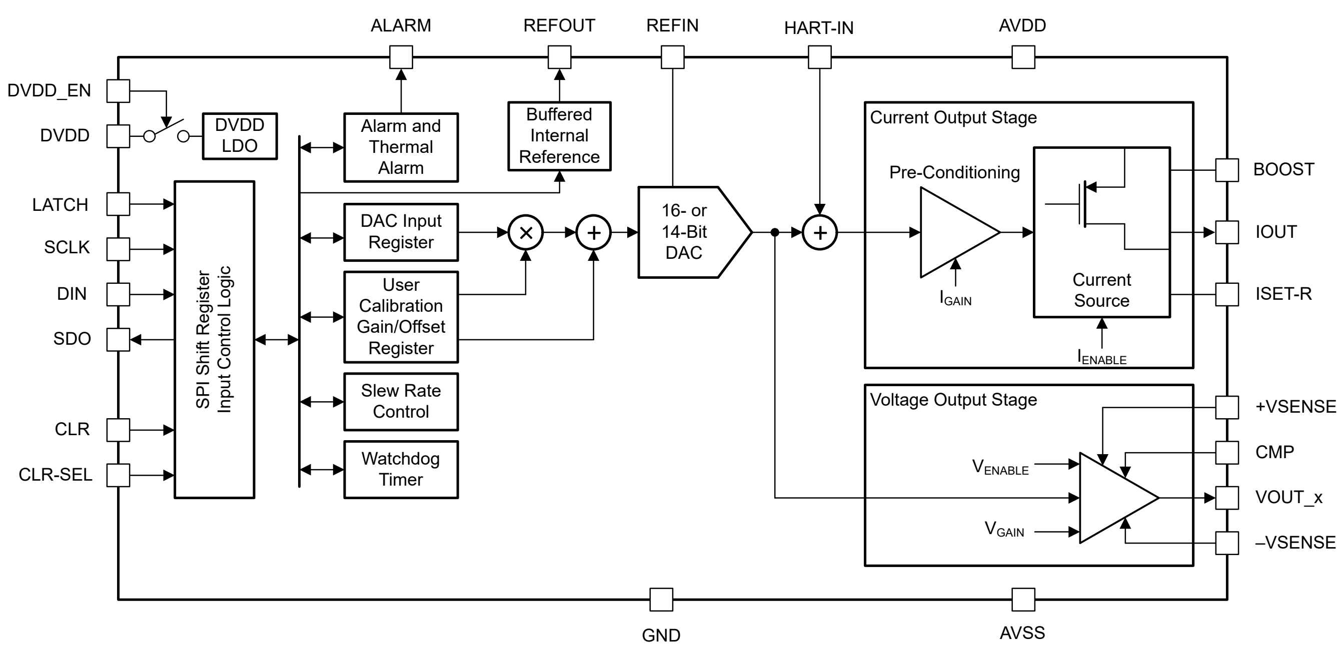

Figure 3-2. Block Diagram of the DAC8760

The single-channel DAC8771 and quad channel DAC8775 have both current and voltage outputs for industrial process control applications, but these analog outputs have bipolar ranges. Another added feature is an integrated buck-boost converter used for powering the DAC outputs. A block diagram for the DAC8775 is shown in Figure 3-3. The HART signal is modulated onto the current or voltage output through the HART-IN pin.

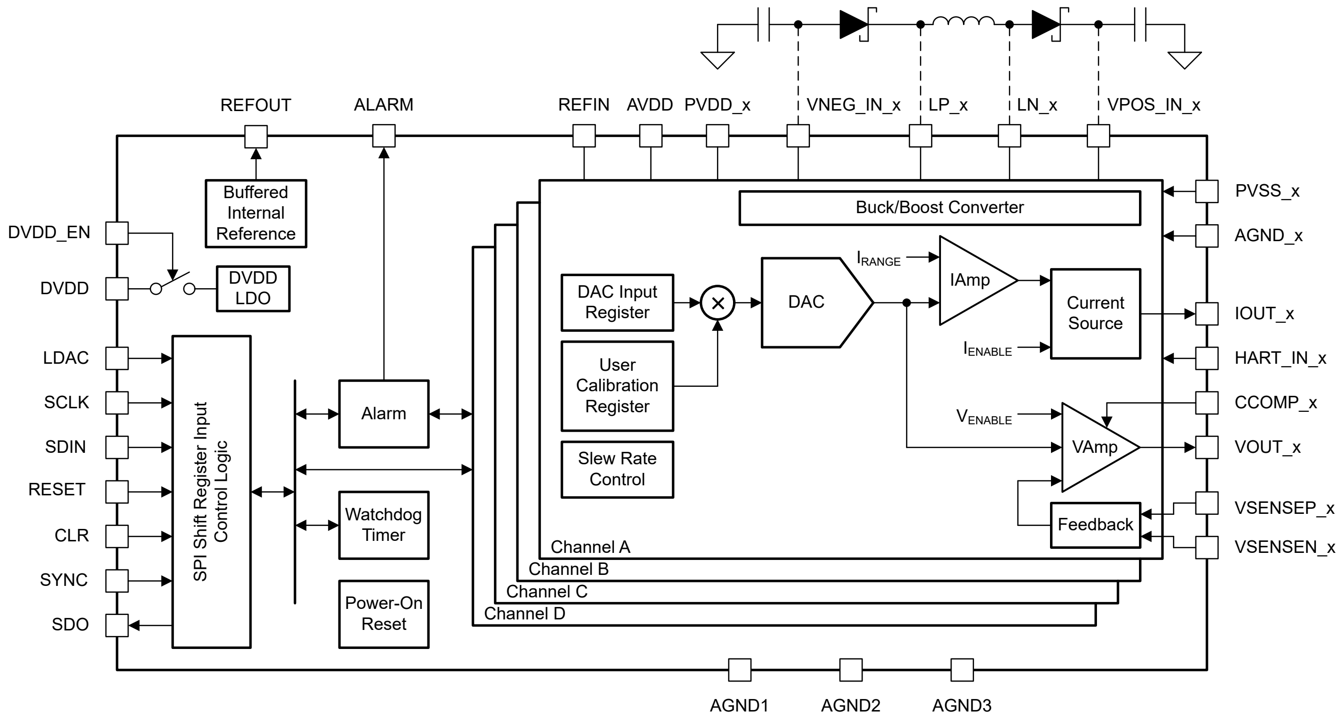

Figure 3-3. Block Diagram of the DAC8775

3.2 TI HART Modems

The DAC874xH devices are a family of HART compliant modems that are also FOUNDATION™ Fieldbus and PROFIBUS® PA compatible. This family of devices are low-power modems design for industrial process control and industrial automation applications.

The DAC8740H is a HART modem that translates a HART FSK signal to UART signal and vice versa. The DAC8741H is register based and uses SPI instead of UART for communication. The DAC8741H uses a FIFO buffer for HART communication and data is transferred by reading and writing registers to exchange data with a FIFO buffer. The DAC8742H is able to use both UART and SPI for the transfer of HART data. Figure 3-4 shows a block diagram of the DAC874xH HART modem device. The HART modulated signal comes out of the MOD_OUT pin and the HART signal is received through either the RX_IN or RX_INF pin depending on external filtering.

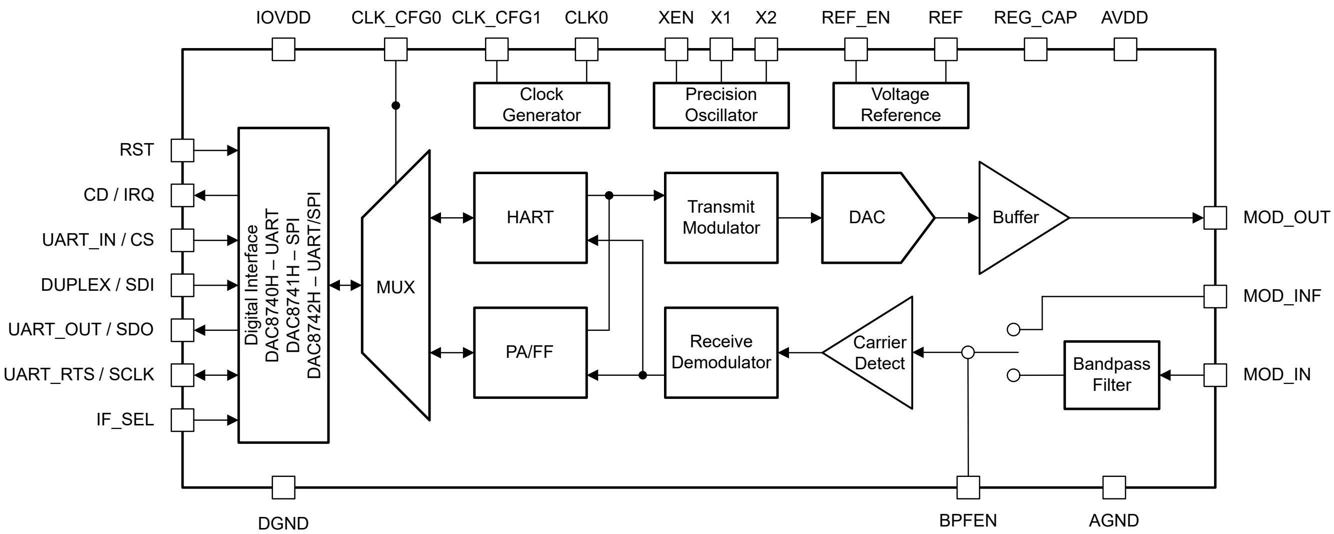

Figure 3-4. Block Diagram of the DAC874xH HART Modem

The AFEx81H1 and AFEx82H1 devices are also HART modems but integrate a 16-bit or 14-bit voltage DAC. The output voltage can be used with a V-I stage to set the loop current for a remote transmitter.

With external gain, the output voltage of the DAC can be used to set the system to different voltage output ranges. The AFEx81H1 has a DAC output range of 0.15 V to 1.25 V and the AFEx82H1 has a DAC output range of 0 V to 2.5 V. Figure 3-5 shows a block diagram of these devices. The HART modulated signal comes out of the MOD_OUT pin and the HART signal is received through either the RX_IN or RX_INF pin depending on external filtering.

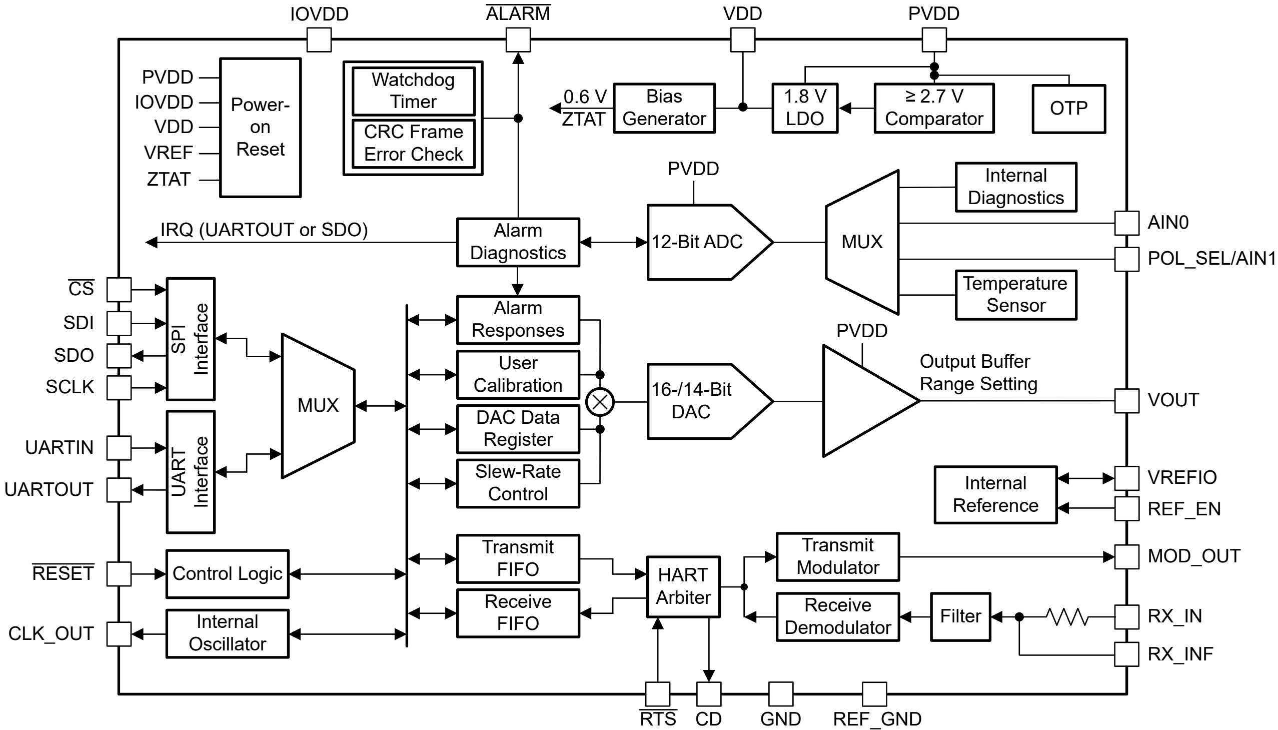

Figure 3-5. Block Diagram of the AFEx81H1 and AFEx82H1 HART Modem

4 Conclusion

The HART protocol is an enhancement to the 4-20mA loop that adds digital communication to an established analog system. This communication protocol is widely-used for factory automation and control. This application note describes the basics of the HART protocol, showing the implementation in existing 4-20mA loops, the FSK as part of the physical transmission, and the data structure. The HART protocol specifications and the HART protocol test specifications guide developers in creating HART enabled devices through the registration process with FieldComm Group. TI produces many DAC devices that can easily integrate HART signals into FA&C applications.

5 References

- Texas Instruments, *DAC161S997 16-Bit SPI-Programmable DAC for 4-20 mA Loops*, data sheet.
- Texas Instruments, *DAC161P997 Single-Wire 16-bit DAC for 4- to 20-mA Loops*, data sheet.
- Texas Instruments, *DACx750 Single-Channel, 12-Bit and 16-Bit Programmable Current Output Digital-to-Analog Converters for 4-mA to 20-mA Current-Loop Applications*, data sheet.
- Texas Instruments, *DACx760 Single-Channel, 12- and 16-Bit Programmable Current and Voltage Output Digital-to-Analog Converters for 4-mA to 20-mA Current-Loop Applications*, data sheet.
- Texas Instruments, *DAC8771 Single-Channel,16-Bit Voltage and Current Output Digital-to-Analog Converter with Adaptive Power Management*, data sheet.
- Texas Instruments, *DAC8775 Quad-Channel, 16-Bit Programmable Current Output and Voltage Output Digital-to-Analog Converter with Adaptive Power Management*, data sheet.
- Texas Instruments, *DAC874xH HART® and FOUNDATION Fieldbus™ and PROFIBUS PA Modems*, data sheet.
- Texas Instruments, *DAC874xH HART® and FOUNDATION Fieldbus™ and PROFIBUS PA Modems*, data sheet.
- Texas Instruments, *DAC8742H, HART and FOUNDATION Fieldbus / PROFIBUS PA Modem*, data sheet.
- Texas Instruments, *AFEx81H1 16-Bit and 14-Bit, Low-Power DACs With Internal HART® Modem, Voltage Reference, and Diagnostic ADC for 4-mA to 20-mA Loop-Powered Applications*, data sheet.