The Signal and Data Processing Techniques for HART Protocol Based Industrial Process Parameters Monitoring System and Control

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Abstract

This research investigates signal and data processing techniques specifically designed for a HART (Highway Addressable Remote Transducer) protocol based industrial process parameter monitoring and control system, leveraging the unique characteristics of the HART communication standard to extract and analyze rich digital information superimposed on the standard 4-20 mA analog current loop, enabling real-time monitoring, advanced diagnostics, and optimized process control by utilizing techniques like frequency shift keying (FSK) demodulation, data parsing, and intelligent algorithms for data interpretation and anomaly detection, while maintaining compatibility with existing analog instrumentation infrastructure.

Keywords

HART protocol, Frequency Shift Keying (FSK), Master-Slave, HART Modem, 4-20 mA Analog Signal, Smart Transmitter

Introduction

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. The digital data is organized into packets with specific header information including device address, command code, and data content. Real-time monitoring of pressure, temperature, flow rate, level, and other process parameters using smart field instruments. Electing HART compliant devices and ensuring compatibility with the host system is important for successful implementation. Electing HART compliant devices and ensuring compatibility with the host system is important for successful implementation.

The Hart FSK Signal and Hart Protocol Structure

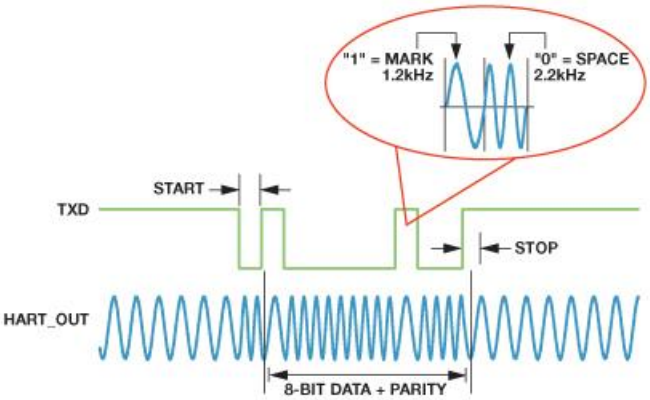

Figure 1 HART Transmissions Signal on a 4-20 mA Current Loop

The HART FSK digital signal is a sinusoid modulated on the 4-20mA loop. Nominally, the HART FSK is a 1-mA Peak to Peak sinusoid signal. Figure 1 shows a representation of the instantaneous current in the loop with a HART modulated signal. The 4-20mA current represents the primary variable. As 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.

HART Bytes

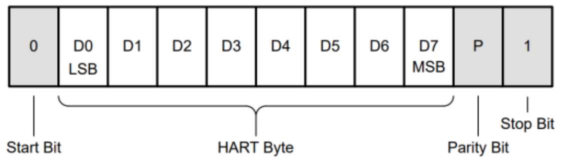

Figure 2 The Basic Structure of HART bytes

The 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 2. 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.

Fields in the Hart Data Frame Structure

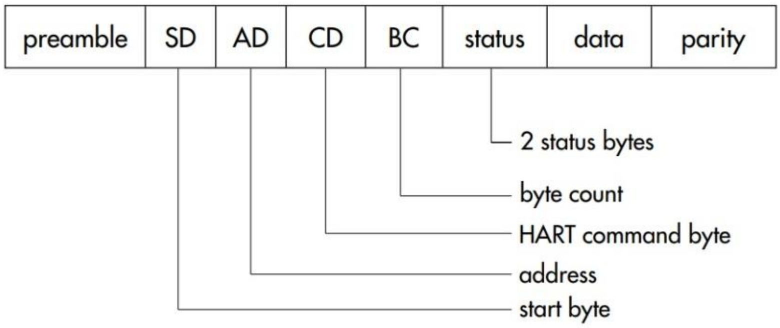

Figure 3 The Hart Data Frame Structure

Field Name	Length (in bytes) Purpose	Purpose
Preamble	5 - 20	This is the beginning of transmission and uses a consecutive set of 0XFF bytes.
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.
Address	1 or 5	The address indicates primary or secondary host.
Expansion	0 - 3	Expansion bytes are used for potential expansion.
Command	1	The command byte tells the device or host what information is being transferred or operation to perform.
Byte count	1	This byte indicates the number of data bytes in the data frame.
Data field	0 - 253	This value describes the size of the data field including the status

		bytes.
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.

Table-1 The major sections of the HART Protocol data frame

HART Start Byte

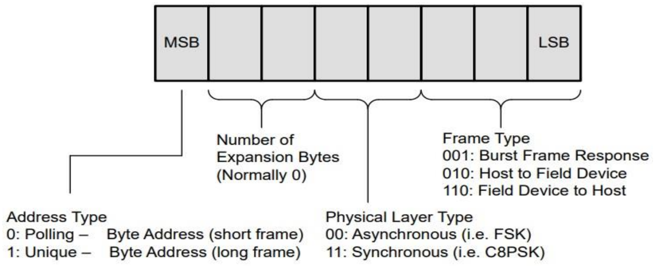

Figure 4 HART Start Byte

After the transmission of the HART preamble (several bytes of 0xFF), the start byte delimiter is sent. The delimiter describes information within the frame being sent.

HART Addressing

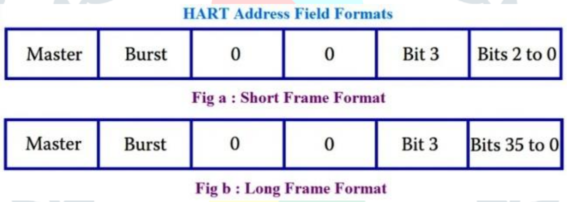

Figure 5 HART Device Addressing

HART addressing is of two types: polling address and unique identifier. Polling address is single byte and is also known as "short address." Unique identifier is of 5 bytes and also called "long address."

(A) HART Short Frame Address Byte

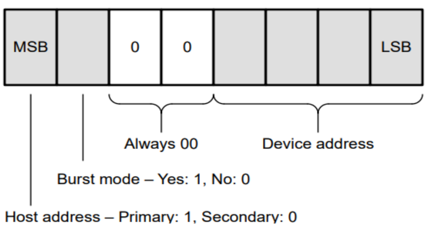

Figure 6 The Short Frame Address Byte

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 6.

(B) Figure HART Long Frame Address

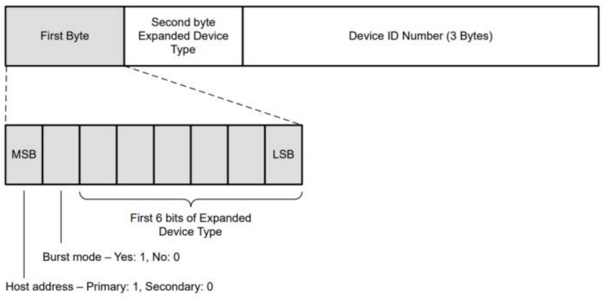

Figure 7 HART Long Frame Address

The long frame address is composed of five bytes shown in Figure 7. Devices are identified with an expanded device type plus a device ID number, total 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 last three bytes of the long frame address indicate the device ID number for the device (24 bits).

HART Commands

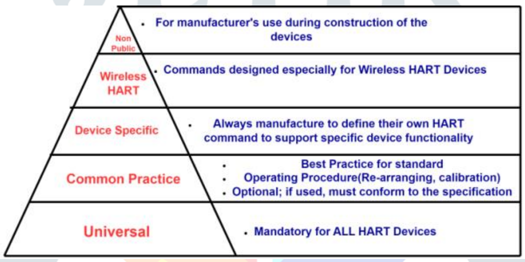

Figure 8 The Types of HART Commands

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. The HART Command Set provides uniform and consistent communication for all field devices. The command set includes three classes: Universal, Common Practice, and Device Specific. Host applications may implement any of the necessary commands for a particular application.

(A) Universal Commands

All devices using the HART Protocol must recognize and support the universal commands. Universal commands provide access to information useful in normal operations (e.g., read primary variable and units).

(B) Common Practice Commands

Common Practice commands provide functions implemented by many, but not necessarily all, HART communication devices.

(C) Device Specific Commands

Device Specific commands represent functions that are unique to each field device. These commands access setup and calibration information, as well as information about the construction of the device. Information on Device Specific commands is available from device manufacturers.

HART Protocol Compared to the OSI Protocol Model

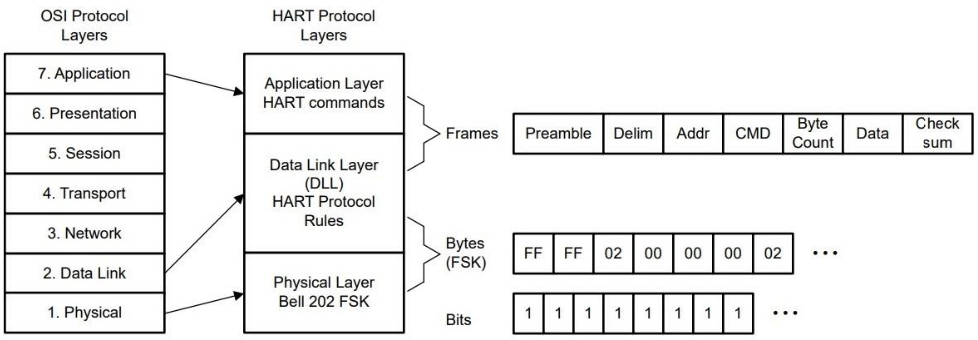

Figure 10 HART Protocol Compared to the OSI Protocol Model

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 defines 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.

The DS8500 HART Protocol Modem for Generation of Signals

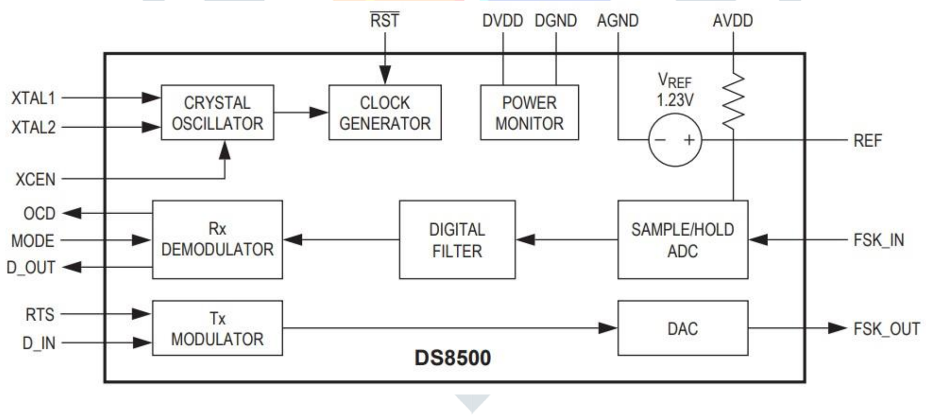

Figure 11 The functional Block Diagram of DS8500 HART Protocol Modem

The DS8500 is a single-chip modem with Highway Addressable Remote Transducer (HART) capabilities. The device integrates the modulation and demodulation of the 1200Hz/2200Hz FSK signal, has very low power consumption, and needs only a few external components due

to the integrated digital signal processing. The input signal is sampled by an analog-to-digital converter (ADC), followed by a digital filter/demodulator. This architecture ensures reliable signal detection in noisy environments. The output digital-to-analog converter (DAC) generates a sine wave and provides a clean signal with phase-continuous switching between 1200Hz and 2200Hz. Low power is achieved by disabling the receive circuits during transmit and vice versa. The DS8500 is ideal for low-power process control transmitters.

Result

(A) Modulator Output

The digital outputs are shaped in the Wave Shaper block to a trapezoidal signal. This circuit controls the rising and falling edge to be inside the standard HART wave shape limits. Figure 6 shows the transmit-signal forms captured at Tx for mark and space frequency. The slew rates are SR_m = 1860 V/s at the mark frequency and SRs = 3300 V/s at the space frequency. For Analog Reference Voltage A_{REF} = 1.235 V, Tx will have a voltage swing from approximately 0.25 to 0.75 VDC

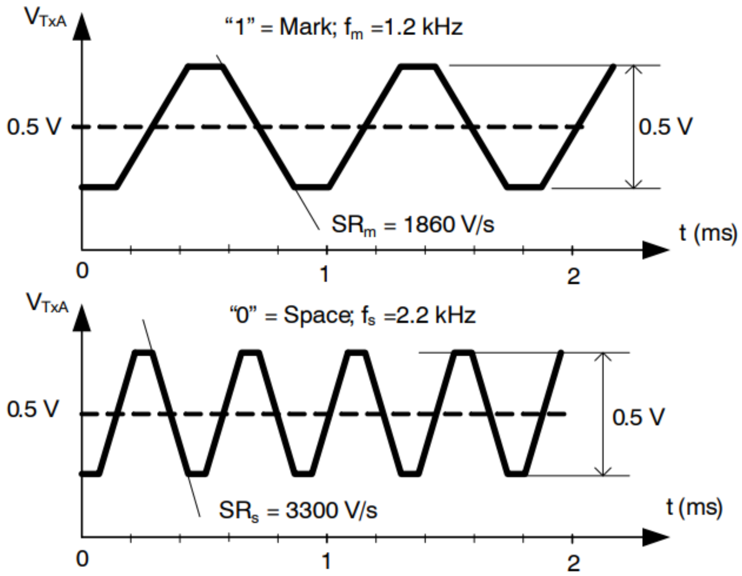

Figure 12 Modulator shaped output signal for Mark and Space frequency at Tx pin.

(B) Demodulator Output

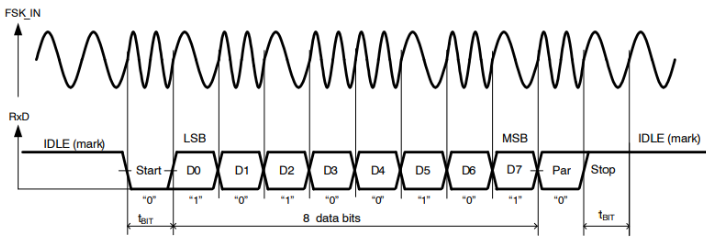

Figure 13 Modulation Timing of Output Signal

The demodulator accepts a FSK signal at the Rx input and reconstructs the original modulated signal at the Rx output. Figure 7 illustrates the demodulation process. This HART bit stream follows a standard 11-bit UART frame with Start, Stop, 8 Data and 1 Parity bit (odd). The communication speed is 1200 baud.

(C) Generation of Data as per HART Frame

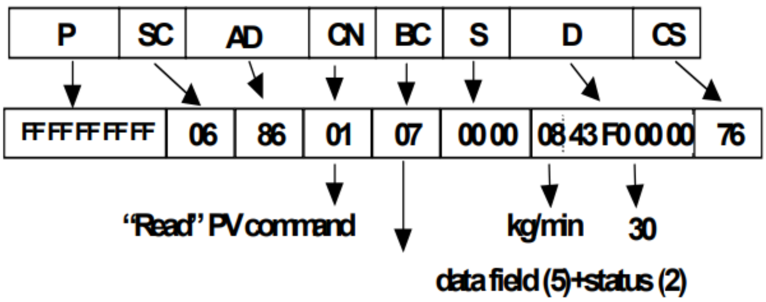

Figure 14 HART frame data for a Process Parameter Measurement

Figure 13 represents the HART frame data for a flow measurement of 30 kg/minute. The message from the slave to master is of the short format type (SC=06), the flow transmitter address is equal to 86, the command number associated with the measurement of the primary variable is 01, the status or response code is zero, which means that no communication, command or field errors are present. Finally, it is important to note that the measured data (30
kg/min.) uses the standardised single precision floating-point format.

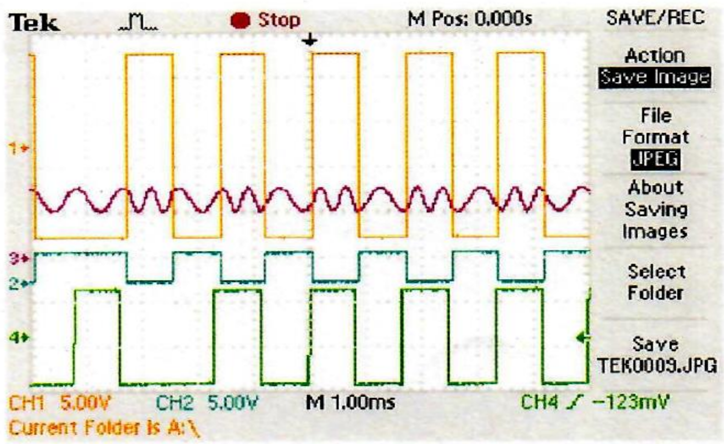

Figure 15 Actual Waveform of Data Generated through HART Modem

To change the clock frequency of the modulator, it is necessary to recalculate the number of samples into which the generated sine wave will be divided. Accordingly, the new memory table values must be calculated for the revised data. In addition, for the new number of samples, new counter data values must be selected. Figure 14 shows waveforms for sending modulated data:
Channel 1 (yellow/top line): Loop Data
Channel 2 ((magenta/second line): HART OUT
Channel 3 (green/third line) DATA IN
Channel 4 (light green/forth line): DATA OUT

Conclusion

A HART data monitoring system provides a robust and cost-effective solution for industrial process monitoring by leveraging the HART protocol to extract rich, detailed information from field devices beyond the basic analog current loop signal, enabling advanced diagnostics, improved process optimization, preventative maintenance, and efficient troubleshooting while utilizing existing wiring infrastructure, ultimately leading to enhanced operational efficiency and asset management in industrial settings. HART allows for additional process variables and device diagnostics to be accessed beyond the primary 4-20mA signal, providing a deeper understanding of equipment health and process conditions.

Reference

[01] Applying Foundation Field-bus, By B. R. Mehta and Y. J. Reddy, ISA
[02] HART Communication Protocol: A Practical Guide, By James Powell, Kindle Edition
[03] Application Note: A Basic Guide to the HART Protocol, Texas Instruments Incorporated, November-2023
[04] HART Communications Protocol For Beginners: Look At The Protocol From A Practical Point of View, By Abe Mumm, Independently Published, July-2021
[05] HART Communication Foundation, HART Application Guide, 2003