HART® FIELD COMMUNICATION PROTOCOL

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An introduction for users and manufacturers

WHY COMMUNICATION ?

'4-20 mA' is a tried, tested and widely-used standard, so why do we need to update it? Because only a limited amount of information (the measured variable) is sent by a 4-20 mA signal.

'Smart' field devices using the HART (Highway Addressable Remote Transducer) protocol enhance operations because digital data is transmitted along with the 4-20 mA signal - without interfering with it! This has two important benefits: firstly, existing cabling and current control strategies remain secure; secondly, the additional data - typically tag numbers, measured variables, range and span data, product information and diagnostics - can be used during installation, calibration, maintenance and operations to cut costs substantially and improve the management and utilization of 'smart' instrument networks.

HART permits two-way communications, so instrument parameters can be interrogated and even adjusted from anywhere on the cable.

HART also has an all-digital mode that allows many instruments to be connected to a single cable, cutting installation costs dramatically yet retaining all HART advantages.

The HART protocol is supported by major instrument suppliers and the HART Communication Foundation, so interoperability is assured, along with easy integration with higher level host systems and equipment.

Features of the HART protocol

- **field proven concept that is easy to understand and use**
- **compatible with existing 4-20 mA systems**
- **simultaneous point-to-point 4-20 mA and digital communication**
- **alternative multi-drop mode**
- **measured variables, tag number, range and span settings, device information, diagnostics and simple messages transmitted**
- **digital response time of 500mS; burst mode response of 300mS**
- **open architecture; freely available to any vendor and every user**

METHOD OF OPERATION

The HART protocol operates using the frequency shift keying (FSK) principle, which is based on the Bell 202 [1] communication standard. The digital signal is made up from two frequencies - 1200 Hz and 2200 Hz, representing bits 1 and 0 respectively. Sine waves of these frequencies are superimposed on the DC analog signal cables to give simultaneous analogue and digital communications. Because the average value of the FSK signal is always zero, the 4-20 mA signal is not affected.

This produces genuine, simultaneous communication with a response time of approximately 500mS for each field device, without interrupting any analog signal transmission that might be taking place.

Up to two master devices may be connected to each HART loop. The primary one is generally a management system or a PC while the secondary one can be a hand-held terminal or laptop computer. A standard hand-held terminal - called the HART Communicator - is available to make field operations as uniform as possible. Further networking options are provided by gateways.

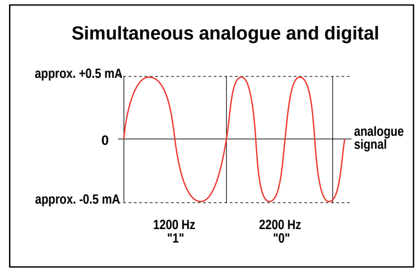


Figure 1
Because the mean harmonic signal value is zero, digital communication makes no difference to any existing analogue signal.

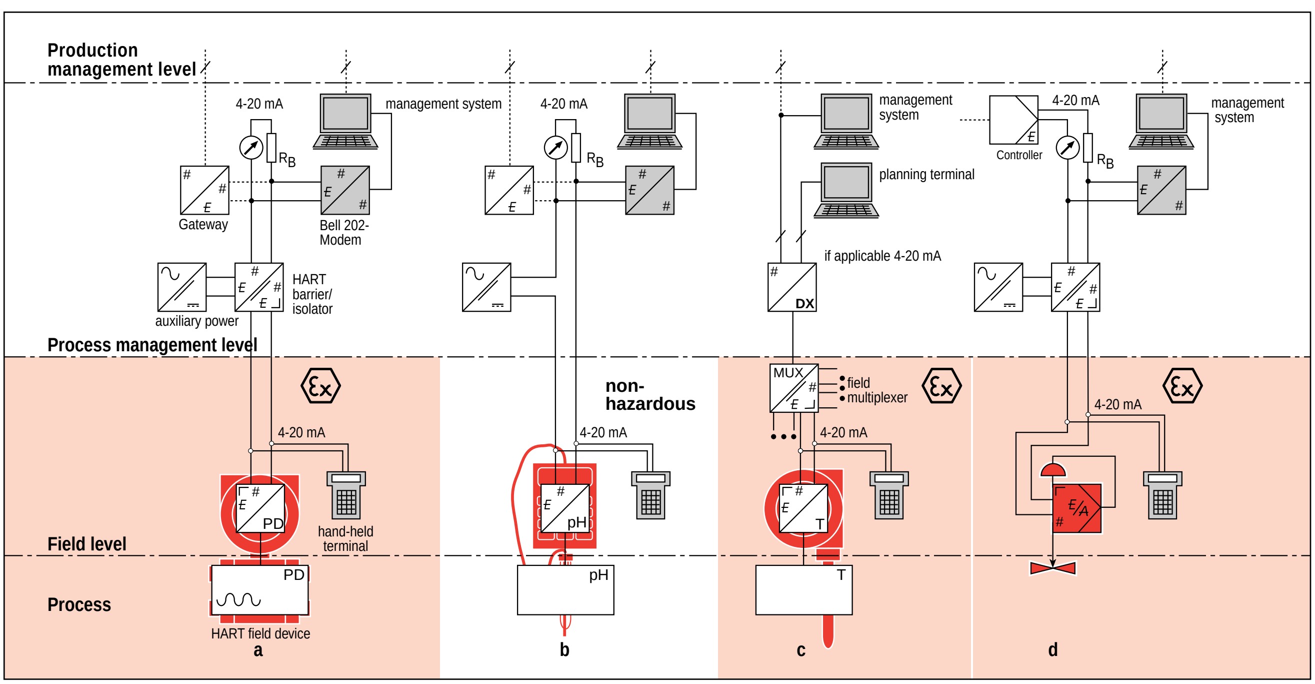


Figure 2
Point-to-point mode: with provision for one 4-20 mA device and up to two masters, e.g. one management system and a hand-held terminal.

POINT-TO-POINT

Figure 2 shows some examples of point-to-point mode. The conventional 4-20 mA signal continues to be used for analog transmission while measurement, adjustment and equipment data is transferred digitally.

The analog signal remains unaffected and can be used for control in the normal way. HART data gives access to maintenance, diagnostic and other operational data.

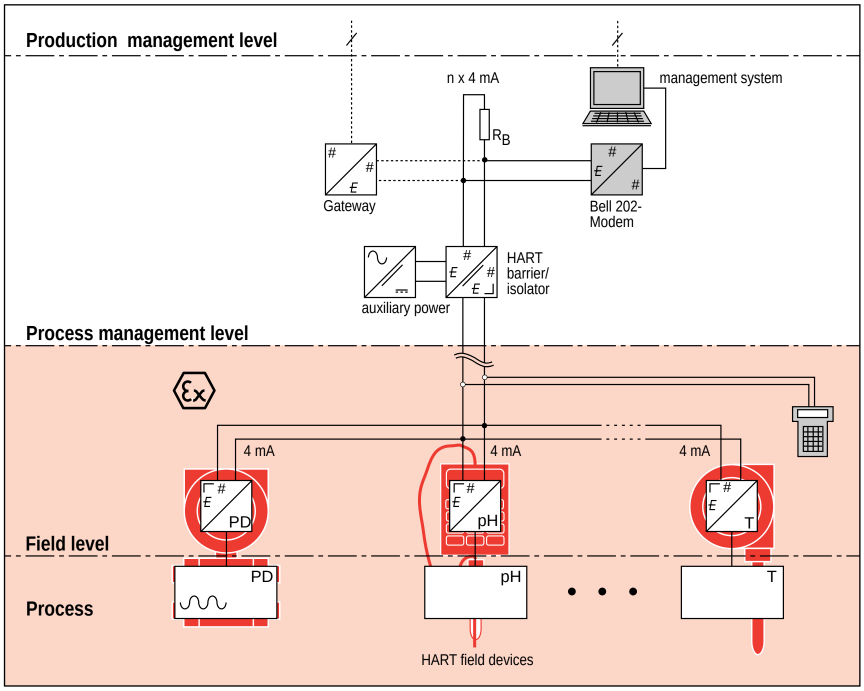


Figure 3
With multi-drop mode, installation costs are considerably reduced. As many as 15 field devices can be operated from one auxiliary power supply. Management systems and hand-held terminals can be used.

MULTI-DROP

This mode requires only a single pair of wires and, if applicable, safety barriers and an auxiliary power supply for up to 15 field devices (see Figure 3).

Multi-drop connection is particularly useful for supervising installations that are widely spaced, such as pipelines, feeding stations and tank farms.

HART instruments can be used in either mode. In point-to-point operations, the field device has address 0, setting the current output to 4-20 mA. In multi-drop mode, all device addresses are greater than zero and each device sets it's output current to 4 mA. For this mode of operation, controllers and indicators must be equipped with a HART modem.

HART devices can communicate using company-leased telephone lines [2]. In this situation only a local power supply is required by the field device and the master can be many kilometres away. However, most European countries do not permit Bell 202 signals to be used with national carrier equipment so HART products should not be used in this way.

Any number of field devices can be operated on leased lines, as long as they are individually supplied with auxiliary power, independently of the communication. If only one power supply is used for all the field devices, the number is limited to 15.

HART Protocol Structure

HART follows the basic Open Systems Interconnection (OSI) reference model, developed by the International Organization for Standardization (ISO) [3]. The OSI model provides the structure and elements of a communication system. The HART protocol uses a reduced OSI model, implementing only layers 1, 2 and 7 (see Figure 4).

OSI reference model

Open Systems Interconnection

	Layer	Function	HART
7	Application	provides formatted data	HART instructions
6	Presentation	converts data	
5	Session	handles the dialogue	
4	Transport	secures the transport connection	
3	Network	establishes network connections	
2	Link	establishes the data link connection	HART protocol regulations
1	Physical	connects the equipment	Bell 202

Figure 4
The HART protocol implements layers 1, 2 and 7 from the OSI model.

Structure of a HART message

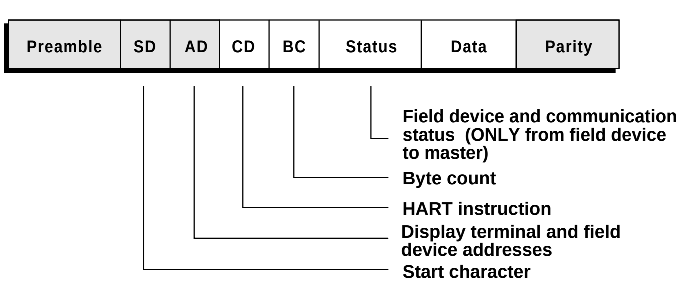


Figure 5
The HART message structure offers a high degree of data integrity.

Layer 1, the Physical layer, operates on the FSK principle, based on the Bell 202 communication standard:

Data transfer rate: 1200 bit/s
Logic '0' frequency: 2200 Hz
Logic '1' frequency: 1200 Hz

The vast majority of existing wiring is used for this type of digital communication. For short distances, unshielded, 0.2 mm^2 two-wire lines are suitable. For longer distances (up to 1500m), single, shielded bundles of 0.2 mm^2 twisted pairs can be used. Beyond this, distances up to 3000m can be covered using single, shielded, twisted 0.5 mm^2 pairs.

A total resistance of between 230 ohms and 1100 ohms must be available in the communication circuit, as indicated in Figures 2 and 3 by R_B.

Layer 2, the Link layer, establishes the format for a HART message. HART is a master/slave protocol. All the communication activities originate from a master, e.g. a display terminal. This addresses a field device (slave), which interprets the command message and sends a response.

The structure of these messages can be seen in Figure 5. In multi-drop mode this can accommodate the addresses for several field devices and terminals.

A specific size of operand is required to enable the field device to carry out the HART instruction. The byte count indicates the number of subsequent status and data bytes.

Layer 2 improves transmission reliability by adding the parity character derived from all the preceeding characters; each character also receives a bit for odd parity.

The individual characters are:

1 start bit
8 data bits
1 bit for odd parity
1 stop bit

Layer 7, the Application layer, brings the HART instruction set into play. The master sends messages with requests for specified values, actual values and any other data or parameters available from the device. The field device interprets these instructions as defined in the HART protocol. The response message provides the master with status information and data from the slave.

To make interaction between HART compatible devices as efficient as possible, classes of conformity have been established for masters, and classes of commands for slaves. There are six classes of conformity for a master as seen in Figure 6. For slave devices, logical, uniform communication is provided by the following command sets:

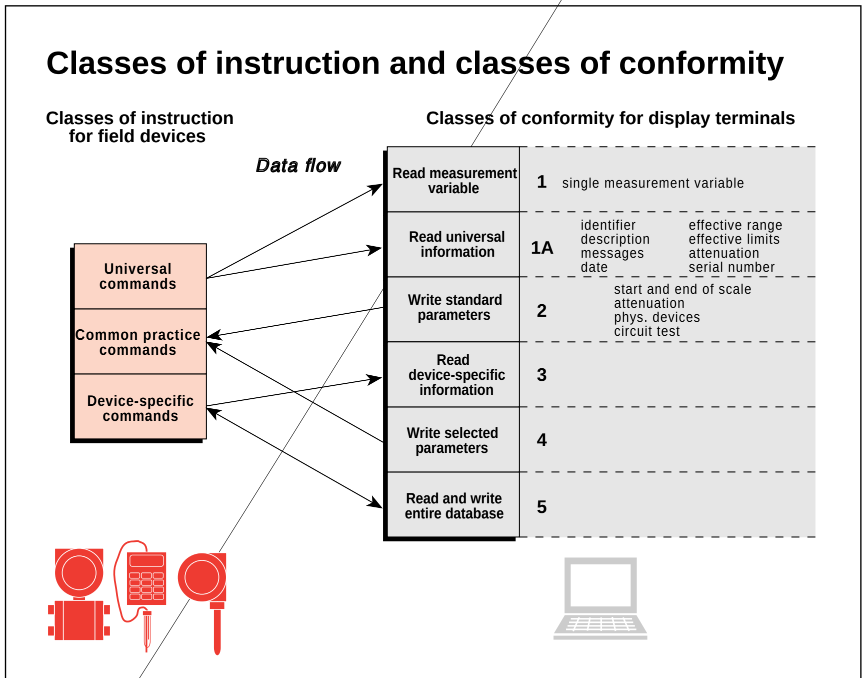


Figure 6
Classes of instruction and classes of conformity

Universal commands
understood by all field devices.

Common practice commands
provide functions which can be carried out by many, though not all, field devices. Together, these commands comprise a library of the most common field device functions.

Device-specific commands
provide functions which are restricted to an individual device, permitting special features to be incorporated that are accessible by all users.

Examples of all three command sets can usually be found in a field device, including all universal commands, some common-practice commands and any necessary device-specific commands.

OPERATING CONDITIONS

The HART standard [4] requires level 3 resistance to interference in the lines in accordance with IEC 801-3 and -4. This satisfies the general requirement for noise resistance.

Connecting or disconnecting a user, or even a breakdown of communication does not interfere with transmission between the other units.

Intrinsically safe applications deserve special mention. Barriers or isolators must be able to transmit the Bell 202 frequencies in both directions (see Figure 2). As can be seen in Figure 3, in multi-drop mode it is also possible to interconnect field devices in accordance with DIN VDE 0165.

HART AT A GLANCE

- Simultaneous analog and digital communication. The analog signal contains the process information; the digital is used for two-way communication of both process and device information.

- Accepts other analog units. With simultaneous analog and digital communication, you can also use analog indicators, recorders and controllers while communicating with 'smart' field devices.

- A process management system and a hand-held terminal can both communicate simultaneously, as shown in Figure 2.

- Multi-drop connection is permitted. Several 'smart' devices can be connected to a single twisted pair of wires, reducing wiring costs.

- Can be used with leased telephone lines, so multi-drop connections can cover great distances using inexpensive interface technology.

- Provides an open message structure. This enables new HART devices with new features to be added, thereby retaining compatibility with existing units.

- The protocol allows up to 256 variables in each field device, any four of which are transmitted on demand. Thus, devices with several measurement functions (e.g. Coriolis mass flow meters) can transmit several variables in each message.

TECHNICAL DATA

DATA TRANSMISSION

Type of data transmission:
Frequency shift keying (FSK) in accordance with Bell 202, relating to the transfer rate and the frequency for bit information '0' and '1'.

Transfer rate:
1200 bit/s

'0' bit information frequency:
2200 Hz

'1' bit information frequency:
1200 Hz

Signal structure:
1 start bit, 8 data bits, 1 bit for odd parity, 1 stop bit

Transfer rate for simple variables:
approx. 2/s (poll/response)
approx. 3/2 (burst mode, optional)

Maximum number of units in bus mode:
with a central power supply: 15

Multiple variable specification:
max. number of variables per field unit: 256
max. number of variables per message: 4

Maximum number of master systems:
two

Data integrity:

Physical layer:
error rate destination circuit: $1/10^5$ bit

Link layer:
recognizes: all groups of up to three corrupt bits and practically all longer and multiple groups.

Application layer:
Communication status transmitted in a response message.

HARDWARE RECOMMENDATIONS:

Type of connection and length limitations:

Distance (m)	Line type	min. conduct. area AWG/(mm²)
≤ 1.500	multiple 2-wire, twisted, common shielding	24/0.2
> 1.500 ≤ 3.000	single 2-wire, twisted, shielded	20/0.5

The following rule of thumb for determining the max. line length for a particular application can be taken from the restrictions governing the signal:

$$l = \frac{65 \cdot 10^6}{(R \cdot C)} - \frac{(C_f + 10.000)}{C}$$

where

l length in meters,

R resistance in ohms, load plus internal resistance from the barrier/isolator,

C line capacity in pF/m,

C_f maximum internal capacitance for the Smart field units in pF.

Consider the example of a pressure transducer, a control system and a simple shielded pair with

R = 250 ohms,
C = 150 [pF/m],
C_f = 5.000 [pF]

$$l = \frac{65 \cdot 10^6}{(250 \cdot 150)} - \frac{(5.000 + 10.000)}{150}$$

$$l = 1.633 \text{ [m]}$$

Then as is:
In intrinsically safe applications, there may be further restrictions.

For an in-depth examination of whether a particular hook-up will work, refer to the specification for the Physical layer in the HART document [4].

HART COMMUNICATION FOUNDATION

The HART Communication Foundation is an independent, non-profit corporation, organized to serve growing industry interest in the HART Protocol and the needs of HART users.

The Foundation's mission is to coordinate, promote, and support the application of HART technology worldwide. Educating the industry on this important technology is a key role.

Foundation operating costs are offset by membership and training/support service fees. Membership is open to all suppliers, end users, and others interested in promoting use of the HART Protocol.

The Foundation provides a cooperative forum for ensuring the interoperability of field and control devices using the HART protocol. Technical committees guide protocol enhancements and maintain its open structural standards.

Foundation operation is guided by a member elected Board of Directors, an Executive Committee, and a full time Administrative Director. Key issues are decided by members through the General Assembly.

For information on the HART Protocol specifications, development tools, training courses, or Foundation membership please contact the address on the next page.

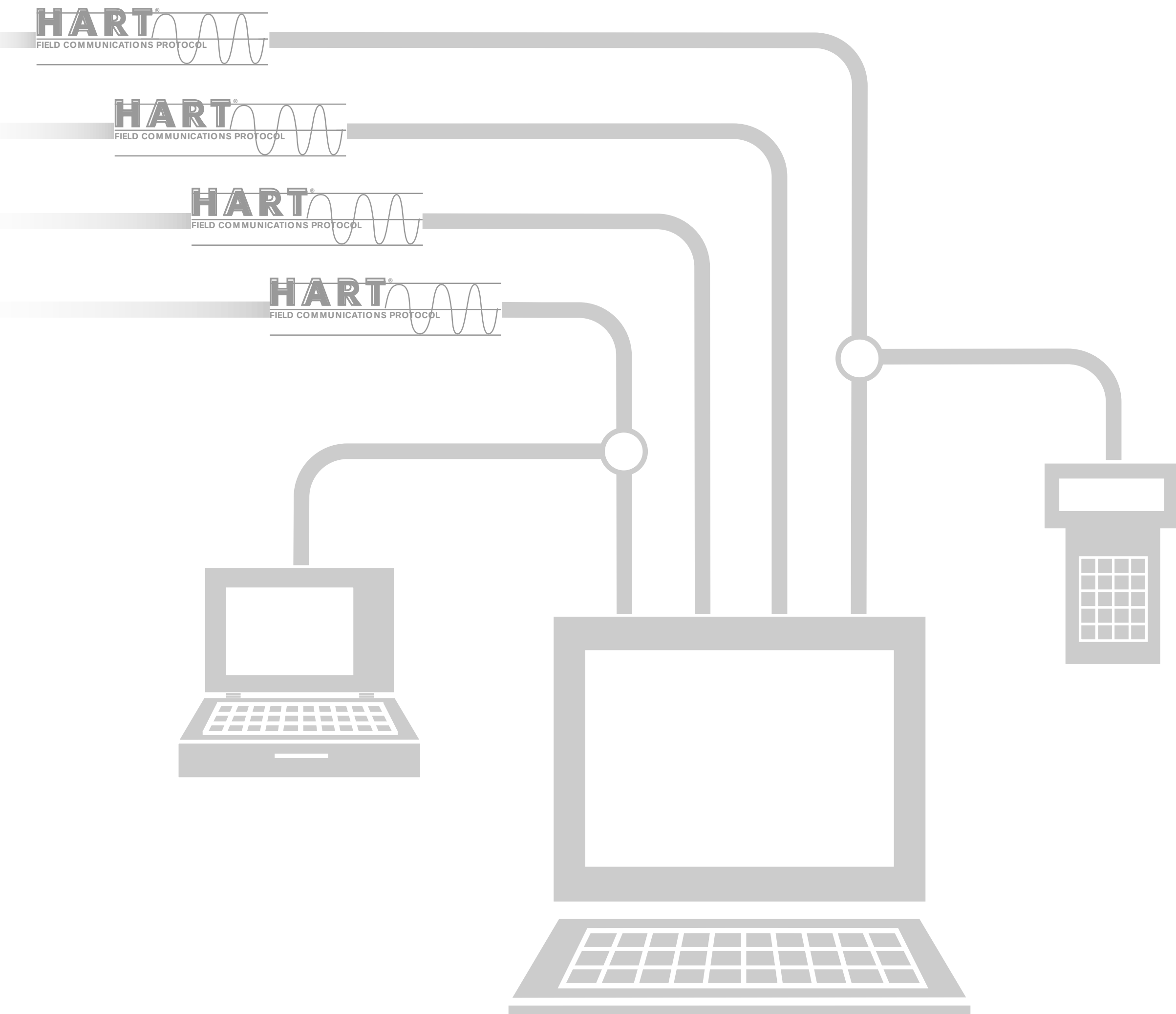
Bibliography

[1] Bell System Technical Reference: PUB 41212, "Data Sets 202S and 202T Interface Specification", July 1976.

[2] Appendix to Bell System Technical Reference PUB 41004, "Data Communications Using Voiceband Private Line Channels", October 1973.

[3] DIN ISO 7498: Informationsverarbeitung, Kommunikation Offener Systeme, Basis-Referenzmodell, Beuth Verlag, Berlin.

[4] HART Smart Communications Protocol Specification, Rev. 5.1.4, January 1991.



This introduction reflects the current state
of the commitment and lays no claim to completeness.

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