HART Field Communication Protocol

Field Device Specification Guide

HCF_LIT-18, Revision 11.0

Release Date: 18 April, 2001

Date of Publication: 18 April, 2001

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1. SCOPE

The field device specification is written as a reference document for the Field Device developer. This document describes the content, structure and format for the complete specification of a HART compatible Field Device Specification (FDS). The FDS, in turn, specifies the capabilities, features, and operation of the Field Device as viewed from a HART perspective. A Device Description is not a suitable or adequate substitute for the FDS defined by this document.

While the resulting FDS is the property of the Field Device manufacturer, the FDS is, also, an important reference document for Host Application designers, System Integrators, and knowledgeable end users

The manufacturers device-specific documentation is widely referred to in the HART Protocol Specifications. As a result, manufacturers can expect knowledgeable end users and systems integrators to request this documentation. Manufacturers are strongly recommended to produce their device-specific documentation using this document.

Note: This Specification is applicable to Masters or Host Applications that also respond as a Field Device (i.e., a Slave).

1.1 Field Device Registration

Manufacturers are encouraged to register their Field Device with the HCF. The FDS should be registered with the HCF along with the HCF Quality Assurance Test results.

1.2 Conventions

In this document, text shown in italics between < > brackets is to be replaced by the corresponding data for the specific device. Text shown between " " quotes may be used literally. Modify the text if appropriate. (Do not include the quotes.)

2. REFERENCES

These documents published by the HART Communication Foundation are referenced throughout this specification:

HART Smart Communications Protocol Specification. HCF_SPEC-12

FSK Physical Layer Specification. HCF_SPEC-54

Command Summary Specification. HCF_SPEC-99

Common Tables Specification. HCF_SPEC-183

3. DEFINITIONS

Definitions for terms can be found in *HART Field Communications Protocol Specification.* Terms used throughout the *Requirements for Field Device Specifications* include: Analog Channel, Delayed Response, Delayed Response Mechanism, Busy, DR_CONFLICT, DR_DEAD, DR_INITIATE, DR_RUNNING, Field Device, Fixed Current Mode, Floating Point, Host, ISO Latin-1, Master, Multi-Drop, Not-A-Number, Packed ASCII, Preamble, Request Data Bytes, Response Data Bytes, Response Message, Slave, Slave Time-Out, Sub-Device, Time Constant, Trim, Units Code

Some other terms used only within the context of the *Field Device Specification Guide* are:

Additional Device Status	Status information returned by Command 48
Actuator	A field device whose primary purpose is to vary its output thus affecting the connected process. An actuator typically uses the analog 4-20mA Loop Current as a setpoint.
Analog Channel	A continuously variable electrical signal connecting a field device to the remainder of the data acquisition or control system. Some field devices support multiple analog channels (input or output). Each Analog Channel transmits a single Dynamic Variable to or from the field device.

Device category:

Current Output	Controller analog output, or separately-powered field device, sourcing / controlling a current into the signal loop
Transmitter	Two-wire transmitter, or separately-powered transmitter, sinking/controlling current from the signal loop
Actuator	Two-wire or separately-powered actuator, receiving a current signal from the loop
Non-DC-isolated Bus Device	Two-wire transmitter in fixed-current mode, drawing a constant current from the loop
DC-isolated Bus Device	Separately-powered device, connected to the loop for digital communication only; has no analog signal function

Device Status	Standard Device Status bits returned with every HART command response. See also **Additional Device Status** and **Extended Device Status**

Device Variable	A uniquely defined data item within a Field Device that is always associated with cyclical process information. A Device Variable's value varies in response to changes and variations in the process. All HART compatible field devices contain Device Variables. However, simple field devices may use only Dynamic Variables and not expose the underlying Device Variables at the Protocol Application Layer interface.
Dynamic Variable	The connection between the process and an analog channel. All HART field devices may contain Primary, Secondary, Tertiary, and Quaternary Variables that are mapped to the first 4 analog channels in a field device. These are collectively called the Dynamic Variables. The Primary Variable is always supported and is connected to the first 4-20mA channel, the same channel that always supports HART communication. The SV, TV, and QV may or may not be supported and, furthermore, may not have an associated Analog Channel.
Extended Field Device Status	Device Status information returned with some cyclical data commands (e.g., Command 9). See Common Tables 17. Extended Device Status Codes.
Input	A signal providing information to the Field Device. For example, and RTD is an input to a temperature transmitter and a valve / actuator has (at least) one input from a Host (i.e. the 4-20mA signal).
Lift Off Voltage	Minimum supply voltage required by a loop-powered field device (at its terminals) for correct operation
Output	A signal originating in the Field Device. For example, a transmitter has an output (the 4-20mA signal) to the Host and an actuator has an output to a control valve.
Primary Variable (PV)	The first (or only) **Analog Channel** supported by a Field Device (see *Command Summary Specification*).

4. ABBREVIATIONS

CN	Capacitance Number; capacitance as a multiple of 5000 pF
DC	Direct Current
FDS	Field Device Specification
FSK	Frequency Shift Keying Physical Layer
HCF	HART Communication Foundation
mA	Milliamp (10^{-3} Amp); unit of electrical current
PV	Primary Variable
pF	Picofarad (10^{-12} Farad); unit of electrical capacitance
C8PSK	Phase Shift Keying Physical Layer
QV	Quaternary Variable
SV	Secondary Variable
TV	Tertiary Variable

5. THE FIELD DEVICE SPECIFICATION

Topics included in any field device specification include:

- The overall function of the device (in general terms only);
- Process, host, and local user interfaces; and,
- The Field Device's use of HART commands.

The FDS arranges these topics using the outline shown in Figure 1.

The content of each section in the FDS is specified. When appropriate, recommended text (see Conventions, above) and table formats are included. In many cases, additional notes will be useful, and should be added following the tables.

When indicated in its description, a section may be optional. The need for including an optional section will depend on the features supported by the Field Device . Required sections must be included in all FDS's and optional sections must be included when they are applicable to the Field Device being described.

In addition to the sections shown in Figure 1, each FDS shall include a title page and table of contents.

The title of the FDS should be: "HART Field Device Specification: <*manufacturer s name*> <*model name or number*> revision <*device revision*>". The title page should also include the manufacturer s document reference number and document revision number, and the release date. Preferably, the author s name, the company address and the date of printing should be included.

> Note: HART Specifications require that the revision number of this document comply with requirements found in the *Command Summary Specification* and the revision number match that returned in Identity Commands.

The Table of Contents shall list the sections found in the FDS. Only level 1 (*x*) through level 3 (*x.x.x*) sections shall be listed along with their section number, headings and page numbers.

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Figure 1. FDS Outline

5.1 Introduction (Section 1 of the FDS)

5.1.1 Scope (1.1 of the FDS)

This section defines the scope of the FDS. It must clearly delineate the topics covered and those not covered by the FDS. In some cases, the following text may be sufficient:

> "The <manufacturer s name> <description of device> <model name or number>, revision <device revision> complies with HART Protocol Revision <HART major.minor revision level>. This document specifies all the device specific features and documents HART Protocol implementation details (e.g., the Engineering Unit Codes supported). The functionality of this Field Device is described sufficiently to allow its proper application in a process and its complete support in HART capable Host Applications.."

5.1.2 Purpose (1.2 of the FDS)

This section defines the purpose and objectives of the FDS. In some cases, the following text may be sufficient:

> "This specification is designed to compliment other documentation (e.g., the <model name or number> User Manual) by providing a complete, unambiguous description of this Field Device from a HART Communication perspective."

5.1.3 Who should use the document? (1.3 of the FDS)

This section defines the target audience of the FDS. In some cases, the following text may be sufficient:

> "The specification is designed to be a technical reference for HART capable Host Application Developers, System Integrators and knowledgeable End Users. It also provides functional specifications (e.g., commands, enumerations and performance requirements) used during Field Device development, maintenance and testing. This document assumes the reader is familiar with HART Protocol requirements and terminology. "

5.1.4 Abbreviations and Definitions (1.4 of the FDS)

List and explain any special terms, acronyms and abbreviations used in the document. (It is not necessary to include standard HART terms which should already be familiar to users of the document.)

5.1.5 References (1.5 of the FDS)

List any other documents which could help the user to understand this one. The list could include:

- HCF documents
- The manufacturer s User Manual, or other documentation on installation, setup or operation of the device
- Related documents on hazardous area applications, such as approval certificates.

Include the title, revision, publication information, and a source from which the document can be obtained.

5.2 Device Identification (Section 2 of the FDS)

This section describes the Field Device in sufficient detail to allow its physical and electrical identification (e.g., using the HART Protocol). This section begins with a table summarizing Field Device identification data (see Figure 2). This table includes:

- The Manufacturer Name and ID code. The Manufacturer ID is shown in both decimal and hexadecimal.
- The Field Device's Model Name and Device Type Code (in decimal and hexadecimal). Since the same firmware is often used in several products or marketed under different model names in different countries, the model name may be a list of several names.
- The device revision and HART Protocol Revision supported. *Note: Both the major and minor Protocol revision number is included while only the Protocol major revision number is returned in HART Identity Commands (e.g. Command 0).*
- The Physical Layers supported and Physical Layer device Category. All HART compatible devices support FSK and, in addition, a device may support C8PSK and or RS-485. The Field Device Physical Layer types typically include: Current Output; Transmitter; Actuator; Non-DC-isolated Bus Device; and DC-isolated Bus Device. Since Field Devices typically support more than one category (e.g., depending on whether the Loop Current is Active), this field normally has more than one entry.

In addition to this table, a physical description or picture is included in the section. These contain enough detail to allow the physical identification of the Field Device (as opposed to mounting or wiring details). For example, the location and description of the Field Device's name plate may be included.

Manufacturer Name:		Model Name(s):	
Manufacture ID Code:	(Hex)	Device Type Code:	(Hex)
HART Protocol Revision		Device Revision:	
Number of Device Variables			
Physical Layers Supported		Notes:	
Physical Device Category			

Figure 2. Device Identification Summary Table

5.3 Product Overview (Section 3 of the FDS)

This section is used to specify the overall purpose and application areas of the Field Device. This is not intended to replace other definitive product and application data, but should set the scene sufficiently for the reader to understand the communication-related features and performance goals of the Field Device described in the rest of the document.

Topics which could be included are:

- Device function, purpose, major features
- Process connections (overview only)
- External interfaces of the device (electrical and non-electrical)
- A brief description of other equipment needed for use of the device
- Any important interface specifications for associated equipment.

5.4 Product Interfaces (Section 4 of the FDS)

This section describes the device s electrical, mechanical or other interfaces.

5.4.1 Process Interface (4.1 of the FDS)

This section describes all interfaces between the device and the measured or controlled process. It should include electrical and non-electrical interfaces to external sensors or actuators, and also any sensors or actuators included physically within the device itself. The signals at these interfaces may (or may not) be directly represented by Device Variables (see Section 5.5).

5.4.1.1 Sensor Input Channels

These are the inputs to the device, from sensors measuring the process (or local conditions in the device itself). Sensor inputs may be analog or discrete (on/off). They may be electrical signals from an external sensor, such as millivolts, ohms, microamps or frequency for analog inputs; volts, milliamps or a contact closure for discrete inputs. For each input, provide its:

- Name; and functional description

For analog connections, specify

- Signal type (e.g., voltage, capacitive, frequency; and etc.) and range;
- Transducer type(s) and connection options.

For discretes, specify:

- Values for the two logical states it represents
- Sensor on these values (if appropriate).

Sensor inputs may also be specified as Dynamic or Device Variable, if the instrument is specified in terms of the measured process variable, rather than the intermediate signal from an internal or external transducer.

> Note: Frequency is an analog signal, not a discrete. For a frequency signal, specify the electrical signal amplitude (with tolerance limits), as well as the frequency range.

5.4.1.2 Actuator Output Channels

These are the outputs from the device, to an external actuator controlling the process. Actuator outputs may be analog or discrete (on/off). They may be electrical signals to an external actuator, such as volts, milliamps, phase or frequency for analog outputs; volts, milliamps or contact closure for discrete outputs. For each output, provide its:

- Name; and functional description

For analog connections, specify

- Signal type and range;
- Transducer type(s) and connection options.

For discretes, specify:

- Values for the two logical states it represents
- Sensor on these values (if appropriate).

Actuator outputs may also be specified as a Dynamic or Device Variable, if the instrument is specified in terms of the controlled process variable, rather than the intermediate signal form to an internal or external transducer.

> Note: Frequency is an analog signal, not a discrete. For a frequency signal, specify the electrical signal amplitude (with tolerance limits), as well as the frequency range.

5.4.2 Host Interface (4.2 of the FDS)

This section describes all interfaces between the Field Device and the Host including electrical and non-electrical interfaces. HART communication is carried on at least one of these signals.

5.4.2.1 Analog Outputs

These are electrical signals communicating a process-related value from the Field Device to the Host. The most common signaling uses a 4-to-20mA current loop signal.

Number and name each analog output. Specify the corresponding Dynamic Variable (i.e., PV, SV, TV, QV). Describe its purpose, and its functional relationship to the input measurements. Specify the signal type and range. For a frequency signal, specify the electrical signal amplitude (with tolerance limits), as well as the frequency range.

Specify whether the output carries HART communication. If it does, then specify its capacitance number (CN), that is, the terminal to terminal+case capacitance, as a multiple of 5000pF.

Using the table in Figure 3 summarize the analog output's specifications. For separately-powered current outputs, specify the maximum acceptable load resistance. Each of the table entries are described as follows.

Linear Over-Range

For each analog output, specify the extent of any linear over-range capability, before the output saturates and becomes unrepresentative of the process. If further out-of-range values are used to indicate device malfunction (see below), specify a tolerance for the saturation values. Otherwise, it is sufficient to state a "less than" value for downscale over-range and a "greater than" value for upscale over-range.

	Direction	Values (percent of range)	Values (e.g., in mA)
Linear Over-Range	Down	-n% ± n%	n to n mA
	Up	+n% ± n%	n to n mA
Device Malfunction Indication	Down: less than	-n%	n mA
	Up: greater than	+n%	n mA
Maximum Current		+n%	n mA
Multi-Drop Current Draw			n mA
Lift-Off Voltage			n V

Figure 3. Analog Output Characteristics

Device Malfunction Indication

For each analog output, specify values, if any, used to indicate device malfunction. Preferably, specify a tolerance for these values; or at least, state a "less than" value for downscale indication and a "greater than" value for upscale indication. Note: there is a NAMUR recommendation for these values for a 4-to-20mA signal (but many smart transmitters do not follow it, especially at the low current end).

Maximum Loop Current

For a two-wire loop-powered device, state the maximum current ever taken in normal operation or when indicating a malfunction. (Together with the lift-off voltage (see below) this allows proper design of the loop and its power supply.)

Multi-Drop Current Draw

State the nominal current taken by the device when in Multi-Drop mode. (This is commonly 4.0mA, but may be higher for some devices.)

Lift-off Voltage

State the minimum supply voltage required at the device terminals to guarantee correct operation (including HART communication) in normal operation and when indicating a malfunction.

5.4.2.2 Discrete Outputs

These are on/off electrical signals representing the measured or derived process conditions, usually as compared to a reference level, as a warning or alarm signal. Name each discrete output. Describe its purpose, and its functional relationship to the input measurements. Specify the signal type and the values it takes for the two logical states it represents. Include tolerances on these values if appropriate.

> Note: Frequency is an analog signal, not a discrete. For a frequency signal, specify the electrical signal amplitude (with tolerance limits), as well as the frequency range.

5.4.2.3 Analog Inputs

These are electrical signals communicating a process-related value from the Host to the Field Device . The most common signaling uses a 4-to-20mA current loop signal.

Name each analog input. For each analog input, specify the corresponding Dynamic Variable (i.e., PV, SV, TV, QV). Describe its functional relationship to the device s outputs. Specify the signal type and range.

Specify whether it carries HART communication. If it does, then specify its capacitance number (CN), that is, the terminal to terminal+case capacitance, as a multiple of 5000pF, and its input resistance (at HART signal frequencies).

Using the table in Figure 4 summarize the analog input's specifications. Each of the table entries are described as follows.

Linear Over-Range

For each analog input, specify the extent of any linear over-range capability, before the device saturates and ceases to respond normally. Specify these values as a "less than" value for downscale over-range, and a "greater than" value for upscale over-range.

	Direction	**Values (percent of range)**	**Values (e.g., in mA)**
Linear Over-Range	Down	-n% ± n%	n to n mA
	Up	+n% ± n%	n to n mA
Maximum Current		+n%	n mA
Multi-Drop Current Draw			n mA
Lift-Off Voltage			n V

Figure 4. Analog Input Characteristics

Maximum Loop Current

For a two-wire loop-powered device, state the maximum current allowed during normal operation. (Together with the lift-off voltage (see below) this allows proper design of the loop and its power supply.)

Multi-Drop Current Draw

State the nominal current taken by the device when in Multi-Drop mode. (This is commonly 4.0mA, but may be higher for some devices.)

Lift-Off Voltage

If the input signal also provides power to the device, state the minimum drive voltage required at the device terminals to guarantee correct operation (including HART communication).

5.4.2.4 Discrete Inputs

These are on/off signals from the host to the device, possibly representing a control signal, or perhaps used to modify the device s action in some way. Name each discrete input, describe its functional relationship to the device s outputs. Specify the signal type and values for the two logical states it represents. Include tolerances on these values if appropriate.

> Note: Frequency is an analog signal, not a discrete. For a frequency signal, specify the electrical signal amplitude (with tolerance limits), as well as the frequency range.

5.4.2.5 Alternative Physical Layers for HART

For a device offering alternative physical layers for HART communication (such as RS-485), specify all necessary details of that connection, and any variations from the HART standard (for example: baud rate, parity options, timing rules). State whether the alternative can be used at the same time as FSK or C8PSK is in use on the analog signal loop.

5.4.3 Local Interfaces, Jumpers And Switches (4.3 of the FDS)

This section describes any user configuration options, controls or displays contained physically on or within the device itself.

5.4.3.1 Local Controls And Displays

Briefly describe the use of any external controls or displays.

5.4.3.2 Internal Jumpers And Switches

The following could be included in this section:

- Configuration of operational functions
- Options for the indication of device malfunction (refer to Section 5.4.2 for actual values)
- Selection of write protection (refer to Section 5.12.10 for the operation of this function).

5.5 Device Variables (Section 5 of the FDS)

This section documents all Device Variables. Device Variables are numbered consecutively, starting at 0. The meaning of a Device Variable must never be changed. However, a device may have different operating modes that can result in a particular Device Variable being unavailable. Each Device Variable must be listed in a separate section (i.e., Sections 5.0 to 5.n of the FDS).

If the Field Device does not expose its Device Variables then state "This Field Device does not expose any Device Variables."

For each Device Variable supported:

- The section heading shall be:

  "5.<n> Device Variable <n> <Device Variable name>"

- The section shall begin with a short functional description. If there are modes when the Device Variable is not available they must be documented and a reference to the Command 48 (see Section 5.7.3) data that indicates when this condition provided.
- The functional description shall indicate whether the Device Variable represents a process connection, or is derived by computation:
  - For process connection values, provide a cross reference to the appropriate subsection (see Section 5.4.1), or
  - For derived values, define and/or explain the algorithm used (for complex algorithms, it may be convenient to refer to an appendix);
- A table (see Figure 5) summarizing the properties of the Device Variable shall be included. This table lists the Device Variable's:
  - Number, name and classification (see Common Table 21).
  - Engineering units. This is actually a reference to a table later in the FDS (see Section 5.11).
  - The Device Family (if any) and Device Family Commands it supports.
- The section shall include any other notes needed to fully understand the function or application of the Device Variable.

Device Variable			
Number :	<number>	Name	<name>
Classification:		Unit Codes	<reference>

Device Family	<code> or "None"	<name or blank>	
Device Family Commands	<list ...>		

Figure 5. Summary of Device Variables Properties

5.6 Dynamic Variables (Section 6 of the FDS)

This section documents the HART Dynamic Variables (PV, SV, TV and QV). Specify how many Dynamic Variables are supported. If this depends on device configuration, give details. Use one of the following formats (i.e., Section 5.6.1, 5.6.2 or 5.6.3) depending on how the Dynamic Variables are defined.

5.6.1 Fixed Dynamic Variables

If the Dynamic Variables are defined directly, without reference to Device Variables, specify each one (see Figure 6). Engineering unit codes is normally a reference to a table (see Section 5.11) Add notes as needed.

	Name	Description	Units
PV			
SV			
TV			
FV			

Figure 6. Dynamic Variables

5.6.2 Fixed Dynamic Variables, Referred to Device Variables

If the Dynamic Variables have a fixed mapping from the Device Variables already defined, specify the relationship in a table of Dynamic Variable number against Device Variable number and name (see Figure 7).

Dynamic Variable	Device Variable number	Name
PV		
SV		
TV		
FV		

Figure 7. Dynamic Variables (Fixed Mapping)

5.6.3 Dynamic Variables with Configurable Mapping

If the Dynamic Variables have a configurable mapping from the Device Variables, list the Device Variables available for mapping and describe any limitations. If this depends on device configuration, give details.

5.7 Status Information (Section 7 of the FDS)

This section defines all status information provided by the Field Device including: the Field Device Status byte; the Extended Device Status byte; and status information returned in Command 48.

5.7.1 Field Device Status (7.1 of the FDS)

Define the use of Field Device Status bits. Describe any special features in the use of status bits. In particular, describe the events or situations which cause bits Device Malfunction, More Status Available, or Non-Primary Variable Out of Limits to be set. Provide references to Section 7.3 of the FDS (if appropriate).

5.7.2 Extended Device Status (7.2 of the FDS)

Define the use of the Extended Device Status bits. Describe any special features in the use of status bits. For example, describe the events or situations which cause bits Device Needs Maintenance, Device Variable Alert or other Extended Device Status bits to be set. Provide references to Section 7.3 of the FDS (if appropriate).

5.7.3 Command #48 - Additional Device Status (7.3 of the FDS)

State the number of data bytes returned by Command 48 and provide a functional definition for all status information. For each byte and bit, list its:

- meaning
- class (mode / error / warning / other).

Note any particular features or interpretation of these status bits. Specify which of these bits also cause the Field Device Status or Extended Device Status bits to be set. Figure 8 shows a suitable format. Add notes as needed.

State how these bits are set and cleared (for example, by power up, reset or self-test HART commands, or by continuous self-testing).

Byte	Bit	Meaning	Class	Standard status bits set
0	0			
	1			

Figure 8. Command #48 Status

5.8 Universal Commands (Section 8 of the FDS)

This section documents the use of HART Universal Commands in the device.

Since all devices must implement all Universal Commands exactly as specified, it is only necessary to record any additional features or quirks in their use. For example, the Protocol allows a Field Device to return null in place of the Primary Variable Transducer Serial Number returned in Command 14.

Describe any additional features, functionality or restrictions implemented in the Field Device. *Any tailoring of the Universal Command implementation must comply with Protocol requirements.* List any parameters defined in HART Universal Commands which are *not* used in this device.

> Note: The individual Command Specification indicates the parameters (if any) that are optional for a given command.

5.9 Common-Practice Commands (Section 9 of the FDS)

This section documents the use of Common Practice Commands in the device. Common Practice Commands are optional. However, if supported, a Common Practice Command must be implemented exactly as specified. Use Section 7.3 of the FDS to document the "Additional Device Status" data returned by Command #48.

5.9.1 Supported Common Practice Commands (9.1 of the FDS)

List the Common Practice Commands which are implemented. Describe any additional features, functionality or restrictions implemented in the Field Device. *Any tailoring of the Common Practice Command implementation must comply with Protocol requirements*. List any parameters defined in HART Common Practice Commands which are *not* used in this device.

> Note: The individual Command Specification indicates the parameters (if any) that are optional for a given command.

If Commands 34, 55, or 64 are supported then any limitations in the permitted values for the damping time constant must be documented

5.9.2 Burst Mode (9.2 of the FDS)

If the Field Device supports Burst-Mode (i.e., Commands 105, 107, 106 and 109), list the commands which can be represented in burst messages.

> Note: If Burst-Mode is implemented, Commands 1, 2, 3 and 9 must support Burst-Mode.

If the Field Device does not support Burst-Mode then simply state "This device does not support Burst-Mode" in this section.

5.9.3 Catch Device Variable (9.3 of the FDS)

If Commands 113 and 114 are supported then this section documents the Device Variables that can be acquired using he "Catch Device Variable" mechanism. If the Field Device does not support this feature then simply state "This device does not support Catch Device Variable " in this section.

5.10 Device-Specific Commands (Section 10 of the FDS)

This section documents the Device-Specific Commands implemented in the Field Device.

5.10.1 Public, Device-Specific Commands (10.1 — 10.n of the FDS)

List the public HART Device-Specific Commands for this device. Each command is its own subsection. Device-Specific Commands must follow the requirements in the Command Summary Specification. For each command, provide:

- The command number and command name
- A functional description of the command
- The command's operation (i.e., read/write/command)
- Request Data (byte stream position, data format and descriptions);
- Response Data (byte stream position, data format and descriptions); and
- Command-specific response codes.

The command's operation (e.g., read or write) is normally embedded in the command name. Figure 9 shows an appropriate format for a command specification.

10.n <Command x> <Name of the command>

<Brief functional description of command's purpose, operation, etc.>

Request Data Bytes

Byte	Format	Description
0		
1 ...		

Response Data Bytes

Byte	Format	Description
0		
1 ...		

Command-Specific Response Codes

Code	Class	Description
0	Success	No Command-Specific Errors
1 ...		Undefined

Figure 9. Command Specification Format

The format field indicates the data type using the notation shown in Table 1. If several properties are packed into a single byte the bits in the byte may be specified using the format:

"<byte>.<first bit> - <byte>.<last bit>"

Table 1 Example of Legal HART Data Formats

Bits	Each individual bit in the byte has a specific meaning. Only values specified by the command may be used. Bit 0 is the least significant bit.
Date	The Date consists of three 8-bit binary unsigned integers representing, respectively, the day, month, and year minus 1900. Date is transmitted day first followed by the month and year bytes.
Enum	An integer enumeration with each numeric value having a specific meaning. Only values specified in the Common Tables Specification may be used.
Float	An IEEE 754 single precision floating point number. The exponent is transmitted first followed by the most significant mantissa byte.
Latin-1	A string using the 8-bit ISO Latin-1 character set. Latin-1 strings are padded out with zeroes (0x00).
Packed	A string consisting of 6-bit alpha-numeric characters that are a subset of the ASCII character set. This allows four characters to be packed into three bytes. Packed ASCII strings are padded out with space (0x20) characters.
Unsigned-*nn*	An unsigned integer where nn indicates the number of bits in this integer. Multi-byte integers are transmitted MSB — LSB.

For enumerated and bit field parameters, the description field must include a reference to a table of values. Tables of enumerated values may be included here if they apply only to a single command. Otherwise, tables should be listed in Section 11 of the FDS.

Note any special features or restrictions in the use of each command.

5.10.2 Non-Public Commands (an Attachment to the FDS)

Non-Public Commands are only used during the manufacture of the field device. Any command that may be used in the field must be published in Section 10 of the FDS. Non-Public Commands are specified using the format described in Section 5.10.1. However, these commands are placed in an attachment that is distributed only to internal manufacturing support personnel.

5.11 Tables (Section 11 of the FDS)

Section 11 of the FDS must have numbered subsections for each table. Document any device-specific codes used (unless already included in command descriptions, in which case include a cross-reference to that section must be provided). Where possible, specify subsets of standard HART Common Tables.

For each section with a table containing engineering unit codes, provide the unit conversion algorithms used.

5.12 Performance (Section 12 of the FDS)

This section documents a variety of factors relating to the performance of the device. Host Application Designers, Systems Integrators and others need to understand these factors when designing installations with the Field Device.

5.12.1 Sampling Rates (12.1 of the FDS)

This section documents features relating to the sampling and reconstruction of analog signals. Figure 10 shows a suitable tabular format for the basic information. Add notes as needed.

Primary sensor sample	n per second
sensor sample	n per second
PV digital value calculation	n per second
SV digital value calculation	n per second
	n per second
Analog output update	n per second

Figure 10. Sampling Rates

State the typical sampling rate of each analog or digital sensor input, as "n per second" or "1 per n seconds". Specify any pre-sample filtering, if this exceeds the normal requirements of sampling theory. State the typical update rate of each HART Device and Dynamic Variable, and of the Analog Channels.

Note any operational conditions which may cause these to vary. Specify any filtering or slew-rate limiting applied, if this exceeds the basic HART specification requirements. Note any special response to an input step-change. These are important for proper design of calibration procedures.

5.12.2 Power-Up (12.2 of the FDS)

This section describes the behavior of the device when power is applied.

State the typical start-up delay after power-up, before the device is fully operational. (Also state the *maximum* delay, if noticeably different, and describe what may affect it.) State whether the device will respond to HART commands during this period.

State the values assigned to output signals at power-up, and by what process they begin updating.

State whether any operational mode (for example, fixed current mode) is affected.

5.12.3 Device Reset (12.3 of the FDS)

This section describes the effect of Device Reset (Command 42), and any other methods of Device Reset. The device must respond to the Command 42 before executing the Device Reset.

State the typical time taken to perform the reset, before the device is again fully operational. (Also state the *maximum* delay, if noticeably different, and describe what may affect it.) State whether the device will respond to HART commands during this period.

State which data are reset, and to what values.

State whether any operational mode (for example, fixed current mode) is affected.

Describe any other methods of reset available in the device (for example, push-button or switches), and their effects, if different from the HART Master Reset. Particularly, note if any different default values are used.

5.12.4 Self-Test (12.4 of the FDS)

This section describes the effect of the Self-Test (Command 41). The device must respond to the Command 41 before executing the Self-Test.

List the activities or functions of the self-test procedure, and its typical duration, before the device is again fully operational. (Also state the *maximum* delay, if noticeably different, and describe what may affect it.) State whether the device will respond to HART commands during this period.

State whether the same self-test is executed at power up and reset. Describe any continuing background self-test functions.

(Operational modes should not be affected by self-test.)

5.12.5 Command Response Delay (12.5 of the FDS)

State the minimum, typical and maximum response delays, before the device responds to a HART command. This is timed from the end of the stop bit of the Check Byte of the master request (STX), to the beginning of the start bit of the first preamble character of the response (ACK)

If the delay depends significantly on a particular command, document this relationship.

Figure 11 shows a suitable tabular format.

Minimum	n ms
Typical	n ms
Maximum	n ms

Figure 11. Command Response Delay

5.12.6 Busy and Delayed-Response (12.6 of the FDS)

Note any circumstances in which the Busy Response Code is returned (implying that the command should be repeated after a short interval). Note if (and when) a delayed-response mechanism is supported.

> Note: Busy and Delayed Response may only be used when indicated in the individual command specification.

5.12.7 Long Messages (12.7 of the FDS)

State the largest size of data field used for any command, and/or in a response (including the two status bytes).

5.12.8 Non-Volatile Memory (12.8 of the FDS)

Describe the technology used for non-volatile memory. State which data are retained.

5.12.9 Operating Modes (12.9 of the FDS)

In general, the use of alternative operating modes is discouraged. "Fixed-current" mode, using command #40, is an exception, common to most HART devices. Another possible mode is calibration mode, in which the device may not respond to cyclical process data commands.

If the device has these or other alternative operating modes, describe their functions and how a mode is selected and deselected. For fixed current mode, note any "automatic" return to normal operation, for example by time-out, reset or power cycle. Define exactly what are the differences in function and capability while in each mode.

The operating mode in affect must be indicated in the Command 48 data.

5.12.10 Write Protection (12.10 of the FDS)

State whether the device has a write-protection function. If it does, describe:

- The method used: hardware switches (see Section 5.4.3), commands, and/or passwords.
- Its effect on the operation of the device
- Its effect on HART commands (for example, which commands are rejected in write protect mode)
- Its effect on any local operator interface access.

5.13 Annexes

Further device information may be included in appendices. Any complex algorithms for sensor checks or other self-testing could well be described here.

Three appendices are required.

5.13.1 Annex A. Capability Checklist

This is a brief overall checklist of the capabilities of the device.

Manufacturer, model and revision	
Device type	
HART Protocol revision	
Number and type of process connections	
Number and type of host connections	
Number of Device Variables	
Number of Dynamic Variables	
Mappable Dynamic Variables?	q Yes q No
Number of Common-Practice Commands implemented	
Number of device-specific commands	
Bits of additional device status	
Alternative operating modes?	q Yes q No
Burst-Mode?	q Yes q No
Capture Device Variables?	q Yes q No
Write-protection?	q Yes q No

5.13.2 Annex B. Default Configuration

This is a complete list of the default device configuration (parameter values, variable mapping, switch or jumper positions, etc.) which will be supplied from the factory if no special requirements are specified when ordering the Field Device.

5.13.3 Annex C. Revision History

Changes to the document should be listed, cumulatively, for each new revision of the document. This provides version control and maintains continuity with earlier revisions. All changes to commands and data must comply with the requirements in the *Command Summary Specification*.

ANNEX A. EXAMPLE SPECIFICATION

See the following page

HART¤ Field Device Specification:

Acme Instrument Company ABC123 revision 2

Document D012345, rev. 2

Initial release: 16 September 1998

Current release: 24 January 2001

Author: Charles Featherstonhaugh
Acme Instrument Company
23450 West 99th Street
Anytown
Somecountry

¤ HART is a registered trademark of the HART Communication Foundation

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Scope

The Acme Instrument Company temperature transmitter, model ABC123, revision 2 complies with HART Protocol Revision 6.0. This document specifies all the device specific features and documents HART Protocol implementation details (e.g., the Engineering Unit Codes supported). The functionality of this Field Device is described sufficiently to allow its proper application in a process and its complete support in HART capable Host Applications.

1.2 Purpose

This specification is designed to compliment other documentation (e.g., the *ABC123 Installation Manual*) by providing a complete, unambiguous description of this Field Device from a HART Communication perspective

1.3 Who should use this document?

The specification is designed to be a technical reference for HART capable Host Application Developers, System Integrators and knowledgeable End Users. It also provides functional specifications (e.g., commands, enumerations and performance requirements) used during Field Device development, maintenance and testing. This document assumes the reader is familiar with HART Protocol requirements and terminology.

1.4 Abbreviations and definitions

ADC	Analog to Digital Converter
CPU	Central Processing Unit (of microprocessor)
DAC	Digital to Analog Converter
EEPROM	Electrically-Erasable Read-Only Memory
Ni120	120-ohm Nickel (temperature sensor)
Pt100	100-ohm Platinum (temperature sensor)
ROM	Read-Only Memory
RTD	Resistance Temperature Detector

1.5 References

HART Smart Communications Protocol Specification. HCF_SPEC-12. Available from the HCF.

ABC123 Installation Manual, Document IMAN123-2003. Available from the Acme Instrument Company.

2. DEVICE IDENTIFICATION

Manufacturer Name:	Acme Instrument Company	**Model Name(s):**	ABC123
Manufacture ID Code:	239 (EF Hex)	**Device Type Code:**	230 (E6 Hex)
HART Protocol Revision	6.0	**Device Revision:**	2
Number of Device Variables	None		
Physical Layers Supported	FSK		
Physical Device Category	Transmitter, Non-DC-isolated Bus Device		

The ABC123 is a designed to mount on a DIN-rail. The name plate is located opposite the field terminals and indicates the model name and revision.

3. PRODUCT OVERVIEW

The ABC123 is a simple DIN-rail-mounting two-wire loop-powered temperature transmitter, with a 4-to-20mA output. An external RTD or thermocouple temperature sensing element is required. Revision 2 includes additional options for sensor type.

The ABC123 replaces the earlier models ABC121 and ABC122, providing improved accuracy while maintaining 100% compatibility.

The analogue output of this device is linear with temperature over the working range of all supported sensor types. Supported RTD sensors are Pt100 and Ni120. Supported thermocouples types are J, K, R, S and T.

4. PRODUCT INTERFACES

4.1 Process Interface

4.1.1 Sensor Input Channels

The main temperature sensor ("external sensor") input provides four terminals, marked 1, 2, 3 and 4, for connection of two-, three- or four-wire RTD sensors, or for two wires from a thermocouple. Refer to the Installation Manual for connection details. Operating ranges correspond to the capabilities of each sensor type.

An additional internal temperature sensor is mounted near the sensor terminals. This provides cold junction compensation when a thermocouple is used as the main sensor.

4.2 Host interface

4.2.1 Analog Output 1: Process Temperature

The two-wire 4-to-20mA current loop is connected on two terminals marked "L+" and "L-". Refer to the Installation Manual for connection details.

This is the only output from this transmitter, representing the process temperature measurement, linearised and scaled according to the configured range of the instrument. This output corresponds to the Primary Variable. HART Communication is supported on this loop. This device has a CN number of 1.

A guaranteed linear over-range is provided. Device malfunction can be indicated by down-scale or up-scale current. The direction is selectable by the user; see Section 4.3 below. Current values are shown in the table below.

	Direction	Values (percent of range)	Values (mA or V)
Linear over-range	Down	-0.6% ± 0.1%	3.89 to 3.92 mA
	Up	+105.0% ± 1.0%	20.64 to 20.96 mA
Device malfunction indication	Down: less than	-1.0%	3.84 mA
	Up: greater than	+110.0%	21.60 mA
Maximum current		+112.5%	22.0 mA
Multi-Drop current draw			4.0 mA
Lift-off voltage			10.5 V

4.3 Local Interfaces, Jumpers And Switches

4.3.1 Local Controls And Displays

This device has no external local controls or displays.

4.3.2 Internal Jumpers And Switches

Device Malfunction

The direction of indication of a detected malfunction by the analog current output is user-selectable to up or down, by means of a two-position jumper inside the instrument. Refer to the Installation Manual for details. See also Section 4.2.1.

Write Protection

A second jumper inside the instrument provides a write-protect function. When the jumper is absent, "write" and "command" commands are disabled. Refer to the Installation Manual for details. See also Section 12.10.

5. DEVICE VARIABLES

This Field Device does not expose any Device Variables.

6. DYNAMIC VARIABLES

Two Dynamic Variables are implemented.

	Meaning	Units
PV	Temperature of external sensor	degC, degF
SV	Temperature of cold-junction sensor	Follows PV units

For RTD sensors, the PV is derived from the sensor s resistance, using a polynomial equation. For thermocouples, the PV is derived from the millivolt input signal, using a combination of table look-up and linear interpolation, with compensation for the cold junction temperature.

The SV is available in either case.

Both PV and SV values are smoothed. (See Section 12.1.)

7. STATUS INFORMATION

7.1 Device Status

Bit 4 ("More Status Available") is set whenever any failure is detected. Command #48 gives further detail. (See Section 7.2.)

Bit 1 ("Non-Primary Variable Out Of Limits") refers to the internal cold-junction temperature sensor. (This event does *not* set bit 7 ("Field Device Malfunction").

7.2 Extended Device Status

The Field Device cannot predict, in advance, when the maintenance will be required. This bit is set if a sensor break is detected. "Device Variable Alert" is set if either the PV or SV is out of limit.

7.3 Additional Device Status (Command #48)

Command #48 returns 2 bytes of data, with the following status information:

Byte	Bit	Meaning	Class	Device Status Bits Set
0	0	ROM checksum error	Error	4,7
	1	EEPROM checksum error	Error	4,7
	2	RAM test failure	Error	4,7
	3	CPU test failure	Error	4,7
	4	DAC failure	Error	4,7
	5	ADC failure	Error	4,7
	6	Watchdog time-out	Error	4,7
	7	Not used		
1	0	External sensor open circuit	Error	4,7
	1	Not used		
	2	Not used		
	3	Not used		
	4	Not used		
	5	Not used		
	6	Not used		
	7	Not used		

"Not used" bits are always set to 0.

All bits used in this transmitter indicate device or sensor failure, and therefore also set bit 7 and bit 4 of the Device Status byte.

These bits are set or cleared by the self-test executed at power up, or following a reset or self-test command. They are also set (but not cleared) by any failure detected during continuous background self-testing.

8. UNIVERSAL COMMANDS

Command #3 returns PV and SV for a total of 14 bytes of response data). See Section 6.

Command #14: Units for sensor limits and minimum span are fixed as degC (unit code 32 decimal). Sensor serial number is not used, and returns 0.

9. COMMON-PRACTICE COMMANDS

9.1 Supported Commands

The following common-practice commands are implemented:

34	Write Damping Value
35	Write Range Values
38	Reset "Configuration Changed" Flag
40	Enter/Exit Fixed Current Mode
41	Perform Device Self-Test
42	Perform Master Reset
43	Set (Trim) PV Zero
44	Write PV Units
45	Trim DAC Zero
46	Trim DAC Gain
48	Read Additional Device Status
59	Write Number Of Response Preambles
79	Write Device Variable
80	Read Device Variable Trim Points
81	Read Device Variable Trim Guidelines
82	Write Device Variable Trim Point
83	Reset Device Variable Trim

Command #34 accepts only a limited set of values for damping time: 0, 0.5, or any multiple of 0.5 up to 120 seconds. Other requested values are replaced by the nearest acceptable value.

Command #48 returns 2 bytes of data. (See Section 7.2.)

9.2 Burst Mode

This Field Device does not support Burst Mode.

9.3 Catch Device Variable

This Field Device does not support Catch Device Variable.

10. DEVICE-SPECIFIC COMMANDS

The following device-specific commands are implemented:

130 Read Sensor Type And Connection

131 Write Sensor Type And Connection

10.1 Command #130: Read Sensor Type and Connection

Reads the sensor type and number of wires.

Request Data Bytes

Byte	Format	Description
None		

Response Data Bytes

Byte	Format	Description
0-3	Float	Sensor type code (see Section 11.1)
4	Enum	Number of wires (see Section 11.2)

Command-Specific Response Codes

Code	Class	Description
0	Success	No Command-Specific Errors
1-15		Undefined
16	Error	Access Restricted
17-31		Undefined
32	Error	Busy
33-127		Undefined

10.2 Command #131: Write Sensor Type and Connection

Writes the sensor type and number of wires. For thermocouple sensor types, the number of wires must be set to 2. For RTD sensor types, the number of wires can be 2, 3 or 4.

Request Data Bytes

Byte	Format	Description
0-3	Float	Sensor type code (see Section 11.1)
4	Enum	Number of wires (see Section 11.2)

Response Data Bytes

Byte	Format	Description
0-3	Float	Sensor type code (see Section 11.1)
4	Enum	Number of wires (see Section 11.2)

Command-Specific Response Codes

Code	Class	Description
0	Success	No Command-Specific Errors
1-4		Undefined
5		Too few data bytes received
6		Undefined
7		In Write Protect Mode
8-10		Undefined
11	Error	Invalid Sensor Type
12	Error	Invalid Number of Wires
13-15		Undefined
16	Error	Access Restricted
17-31		Undefined
32	Error	Busy
33-127		Undefined

11. TABLES

11.1 Sensor Type Codes

0	Undefined
1	Pt100, α=0.385
2	Pt100, α=0.392
3	Ni120
4 - 128	Undefined
129	Thermocouple type J
130	Thermocouple type K
131	Thermocouple type R
132	Thermocouple type S
133	Thermocouple type T
134 - 249	Undefined
250 - 255	Reserved

11.2 Number of Wires Codes

0 - 1	Undefined
2	Two wires
3	Three wires
4	Four wires
5 - 249	Undefined
250 - 255	Reserved

11.3 Temperature Unit Codes

(subset of HART Common Table 2, Unit Codes)

32	degrees Celsius
33	degrees Fahrenheit

11.4 Unit Conversion

Internally, the transmitter uses degrees Celsius. Conversion to and from degrees Fahrenheit is made using the equation:

$$C = (F - 32) \times 5/9.$$

12. PERFORMANCE

12.1 Sampling Rates

Typical sampling rates are shown in the following table.

Primary temperature sensor sample	10 per second
Internal (cold-junction) sensor sample	1 per second
PV digital value calculation	5 per second
SV digital value calculation	1 per second
Analog output update	5 per second

Note: both temperature calculations use an equally-weighted running mean of the last 3 input values.

12.2 Power-Up

On power up, the transmitter goes through a self-test procedure (see section 12.4), which takes approximately 2 seconds. During this period, the device will not respond to HART commands, and the analog output is set at 4.0mA.

When the self-test is satisfactorily completed, and the first measurement has been made, the PV and SV values are set, and the analog output moves to a value representing the measurement. The slew rate of this movement is limited by the configured "damping time". Only after the PV and SV are correctly set, will the device respond to HART commands.

If the self-test fails, all live measurement data (PV, SV, current and percent of range) are set to "Not A Number", and the analog output is set to the configured malfunction-indicating current. The device will attempt to respond to HART commands.

Fixed-current mode is cancelled by power loss.

12.3 Reset

Command 42 ("Device Reset") causes the device to reset its microprocessor. The resulting restart is identical to the normal power up sequence. (See Section 12.2.)

12.4 Self-Test

The self-test procedure is executed at power up, following Command 42 ("Device Reset"), or following Command 41 ("self-test"). The self-test includes:

- Microprocessor
- RAM
- Program ROM
- Configuration storage EEPROM
- Analog-to-Digital converter
- Digital-to-Analog converter
- Cold-junction (internal) temperature sensor
- Primary (external) temperature sensor.

This self-test takes about 2 seconds. During self-test following power-up or reset, the analog output is set to 4.0mA and the device will not respond to HART commands.

During self-test following a self-test command, the analog output is held at its last value; the device may respond normally to HART commands, or may return "busy" status.

Continuous self-testing is also part of the normal device operation. The same checks are made, but over a longer period, between measurement function cycles.

12.5 Command Response Times

Minimum	20ms
Typical	50ms
Maximum	100ms *

* During self-test following a self-test command, the device may take up to 250ms to respond.

12.6 Busy and Delayed-Response

The transmitter may respond with "busy" status if a further command is received while self-test is underway.

Delayed-response is not used.

12.7 Long Messages

The largest data field used is in the response to Command 21: 34 bytes including the two status bytes.

12.8 Non-Volatile Memory

EEPROM is used to hold the device s configuration parameters. New data is written to this memory immediately on execution of a write command.

12.9 Modes

Fixed current mode is implemented, using Command 40. This mode is cleared by power loss or reset.

12.10 Write Protection

Write-protection is provided, selected by an internal jumper (see Section 4.3.2). When the jumper is present, all commands are available. When the jumper is absent, no "write" or "command" commands are accepted.

12.11 Damping

Damping is standard, affecting only the PV and the loop current signal.

ANNEX A. CAPABILITY CHECKLIST

Manufacturer, model and revision	Acme Instruments ABC123, rev. 2
Device type	Transmitter
HART revision	6.0
Device Description available	Yes
Number and type of sensors	2 (one external, one internal)
Number and type of actuators	0
Number and type of host side signals	1: 4 - 20mA analog
Number of Device Variables	0
Number of Dynamic Variables	2
Mappable Dynamic Variables?	No
Number of common-practice commands	17
Number of device-specific commands	2
Bits of additional device status	8
Alternative operating modes?	No
Burst mode?	No
Write-protection?	Yes

ANNEX B. DEFAULT CONFIGURATION

Parameter	Default value
Lower Range Value	0
Upper Range Value	100
PV Units	degC
Sensor type	Pt100, α=0.385
Number of wires	3
Damping time constant	1 second
Fault-indication jumper	Up-scale
Write-protect jumper	Installed (i.e. write enabled)
Number of response preambles	5

ANNEX C. REVISION HISTORY

C1. Changes from Rev 1.0 to Rev 2.0

Support was added for HART 6 Universal Commands and the Sensor Trim Commands.