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HART®
COMMUNICATION PROTOCOL

2.4GHz DSSS O-QPSK Physical Layer Specification

HCF_SPEC-065, Revision 1.0

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Preface

Revision 1.0 of the WirelessHART™ Physical Layer Specification (HCF_SPEC-065) has been created to facilitate the need for wireless devices in the industrial instrumentation industry.

The HART Communication Foundation expresses its appreciation to the following individuals/companies for their contributions to the development of this specification:

NAME	COMPANY
Doug Arntson (editor)	Emerson Process (Rosemount)
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Introduction

The HART Protocol is a transaction-oriented communication service for process control devices. Designed to augment traditional 4-20 mA analog signaling, HART communicating devices provide relatively low-bandwidth, moderate response-time communication in industrial environments. Applications include remote process variable interrogation, parameter setting, and diagnostics.

Wired HART digital signaling is an extension of conventional analog signaling. Using modulated FSK or PSK signals, an audio frequency current is superimposed on a low-frequency (typically 4-20 mA) analog current. The two signals share much of the same hardware but differ in frequency. HART communicating devices signal with either current or voltage, and all signaling appears as voltage when sensed across a low impedance.

WirelessHART is an extension of wired HART. The conventional wired HART Physical Layer commonly uses twisted-pair copper cable as its medium and provides solely digital or simultaneous digital and analog communication to distances of at least 5000 feet (1500 meters). WirelessHART uses Radio Frequencies (RF) to communicate between devices up to 100 meters line of sight when transmitting with 0 dB. WirelessHART devices may be powered either by wire, battery, solar, or a combination there of.

For purposes of convenience, communicating devices are described in terms according to the OSI 7-Layer Communication Model. The Physical Layer specifies the signaling method, signal strength, device sensitivity, and environment. However, as regards hardware or software, no clear boundary exists between layers. Effectively, the division into layers should be viewed as a division into functions. The Physical Layer requirements for HART communication are the focus of this document. A representation of the relationship between the HART protocol communications layers (including firmware and hardware) is given in Figure 1.

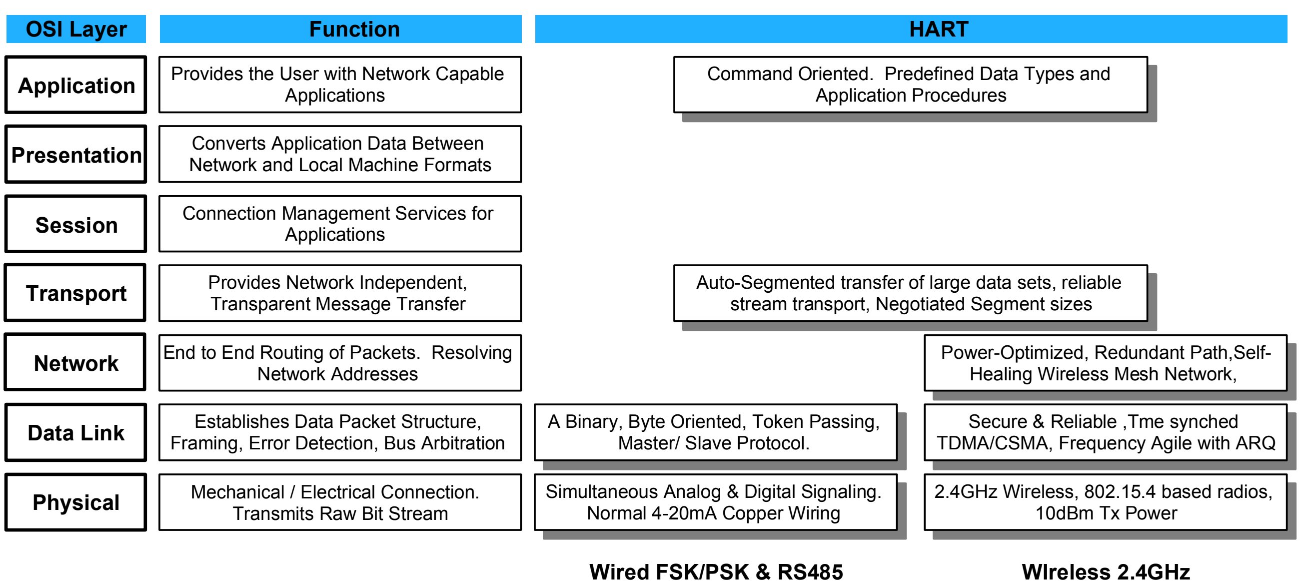

Figure 1. OSI 7-Layer Model

The Physical Layer

The lowest layer on the OSI model and probably the easiest to understand is the physical layer. With wired HART, this layer deals with the physical, electrical, and cable issues involved with making a network connection. Similarly with WirelessHART, this layer deals with radio characteristics making a network connection. It associates with any part of the network structure that doesn't process information in any way.

The physical layer is responsible for sending the bits across the network media. It does not define what a bit is or how it is used merely how it's sent. The physical layer is responsible for transmitting and receiving the data.

Items defined by the physical layer include RF transmitters, receivers, and transceivers. Any item that does not process information but is required for the sending and receiving of data is defined by this layer.

1. SCOPE

This specification defines the WirelessHART Physical Layer. This specification is used for devices implementing wireless mesh network communication as defined by the HART specifications. The Physical Layer is responsible for the signaling method, signal strength, device sensitivity, and environment for sending bits across the network media. This Wireless Physical Layer Specification is based on the IEEE STD 802.15.4-2006 2.4GHz DSSS Physical Layer employing O-QPSK modulation. This document includes:

- Specific Physical Layer requirements many of which are adopted directly from IEEE STD 802.15.4-2006. It also provides specific requirements on channels, transmit power, and receive sensitivity.
- Service definitions the Physical Layer provides to higher layers to send and receive data on the media. It also defines the local management parameters used to control the operation of the Physical Layer.
- Specifies Physical Layer requirements to ensure interoperability among HART devices.

2. REFERENCES

2.1 The HART Protocol Documents

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

HART Field Communications Protocol Specification. HCF_SPEC-12

Token-Passing Data-Link Layer Specification. HCF_SPEC-81

Network Management Specification. HCF_SPEC-85

2.2 Related HART Documents

References to other standards, clarifying documents and applicable patents are listed in this subsection.

WirelessHART User Guide. HCF_LIT-84

Coexistence Test Plan. HCF_LIT-85

Approved IEEE 802.15.4™ Transceivers. HCF_LIT-088

Note: 802.15.4 is a trademark of the Institute of Electrical and Electronic Engineers.

2.3 Related Communication Documents

The following are applicable IEEE documents:

IEEE 802.15.4-2006 *Wireless Medium Access Control and Physical Layer Specifications for Low-Rate Wireless Area Networks*

The following provides general guidelines for the specification of communication protocols.

ISO 7498-1 *Information Processing Systems — OSI Reference Model — The Basic Model*

2.4 Regulatory Documents

Devices should be designed to meet the requirements for their installation locale. The following is a partial list regulatory documents that a compliant product may be expected to meet:

IEC 61000-6-2. *Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments*. International Electrotechnical Commission

EN 300 328. *Radio Equipment and Systems (RES); Wideband transmission systems; Technical characteristics and test conditions for data transmission equipment operating in the 2,4 GHz ISM band and using spread spectrum modulation techniques* . European Telecommunications Standards Institute.

Federal Communication Commission. *CFR 47 Part 15. Telecommunications, Radio Frequency Devices*. U.S. Government Printing Office.

ARIB STD-T66. *Second Generation Low Power Data Communication System/Wireless LAN System*. Association of Radio Industries and Businesses (Japan)

3. DEFINITIONS

The HART Protocol Specifications must use a common and consistent vocabulary both within a specification and across all specifications. This section incorporates (by reference) definitions from the HART Field Protocol Specification (HCF_SPEC-13) and defines the terms unique to this specification.

Antenna Gain	The apparent power gain resulting from the antenna capability of concentrating power in a given direction.
Byte	8-bits, sometimes called an Octet.
Clear Channel Assessment	The assessment of RF signal strength on the channel prior to sending the first DLPDU of a transaction. If signal is detected the transaction is deferred to a later TDMA slot.
Coexistence	Coexistence is the ability of one system to perform a task in a given shared environment in which other systems have an ability to perform their tasks and may or may not be using the same set of rules (IEEE).
Data-Link Layer	Layer 2 in the OSI Basic Reference Model. This layer is responsible for the error-free communication of data. The Data-Link Layer defines the message structure, error detection strategy and bus arbitration rules.
Frequency Channels	The allocation of the frequency spectrum in a frequency range.
Interoperability	Interoperability is the ability for like field devices from different manufacturers to work together in a system and be substituted one for another without loss of functionality at the host system level.
Omni-directional Antenna	An antenna with a radiation pattern that, when viewed from above, is equally strong in all directions (i.e., the antenna sends or receives signals equally well in all directions)
Packet Error Rate	Average number packets (in percent) transmitted but not received correctly. For this specification, the reference PPDU for PER calculations is 20 bytes long (IEEE).
Physical Layer	Layer 1 in the OSI model. The Physical Layer is responsible for transmission of the raw bit stream and defines the mechanical and electrical connections and signaling parameters for devices.
Receiver Sensitivity	The minimum input signal required to produce a PER of less than 1% with a PPDU 20 bytes long (IEEE).

4. SYMBOLS/ABBREVIATIONS

802.15.4	IEEE STD 802.15.4-2006 in general. When referring to the Physical Layer it refers to the 2.4GHz DSSS Physical Layer employing O-QPSK modulation.
CCA	**C**lear **C**hannel **A**ssessment
dB	Relative power decibels (3dB/octave, 10 dB/decade)
dBm	Absolute power decibels; 0 dBm =1 mW; 10 dBm= 10 mW; 20 dBm= 100 mW; 30 dBm= 1000 mW
DLPDU	**D**ata-**L**ink **P**rotocol **D**ata **U**nit (i.e., a Data-Link Layer packet)
DSSS	**D**irect **S**equence **S**pread **S**pectrum
EIRP	**E**quivalent **I**sotropic **R**adiated **P**ower
ISM	**I**ndustry, **S**cientific, **M**edical Frequency bands
LoS	**L**ine **o**f **S**ight, an unobstructed distance between a transmitter and a receiver.
O-QPSK	**O**ffset - **Q**uadrature **P**hase **S**hift **K**eying
PER	See **P**acket **E**rror **R**ate
PPDU	**P**hysical **P**rotocol **D**ata **U**nit
RSL	**R**eceived **S**ignal **L**evel
SP	**S**ervice **P**rimitive

5. PHYSICAL LAYER REQUIREMENTS

The physical layer enables the transmission and reception of the protocol data across the physical radio channel. The WirelessHART Physical Layer is based on the IEEE 802.15.4 standard, adapting a sub-set of its parameters as requirements for the physical layer as outlined in the specification.

5.1 Requirements adopted from IEEE Std 802.15.4-2006

This specification incorporates, by reference, most of the requirements from Section 6 of IEEE STD 802.15.4-2006 Physical Layer. The adoption and tailoring of IEEE STD 802.15.4-2006 requirements is specified in Table 1

Table 1. 802.15.4 Physical Layer Requirements adopted by WirelessHART

802.15.4 Section	Adopted	Description
6.1	Partially	*General requirements and definitions* As indicated below for subsections 6.1.1 - 6.1.7
6.1.1	Partially	*Operating frequency range* Only 2450MHz band supported
6.1.2	Partially	*Channel assignments* Only Channels 11-25 of channel page 0 are supported.
6.1.3	Yes	*Minimum long interframe spacing (LIFS) and short interframe spacing (SIFS) periods*
6.1.4	Yes	*RF power measurement*
6.1.5	Yes	*Transmit power*
6.1.6	Yes	*Out-of-band spurious emission*
6.1.7	Yes	*Receiver sensitivity definitions*
6.2	No	*PHY service specifications* A simplified set of services are defined (see Section 5.7 in this document)
6.3	Yes	*PPDU format*
6.4	Partially	*PHY constants and PIB attributes* As indicated below for subsections 6.4.1 - 6.4.2
6.4.1	Yes	*PHY constants*
6.4.2	Partially	*PHY PIB attributes* While not directly supported, similar functionality (albeit simpler) is provided via the services specified in Section 5.7 of this document. In fact, most are constants in this specification. phyCurrentChannel is set when invoking the ENABLE.indicate primitive; phyTransmitPower is controlled by invoking the READ_TX_PWR_LEVEL WRITE_TX_PWR_LEVEL commands using the LOCAL_MANAGEMENT primitive; phyChannelsSupported are channels 11-15 and phyCurrentPage is 0; phyCCAMode is always 2; phyMaxFrameDuration is 266; phySHRDuration is 10
6.5	Yes	*2450 MHz PHY specifications*
6.6	No	*868/915 MHz band binary phase-shift keying (BPSK) PHY specifications* Only 2450MHz band supported
6.7	No	*868/915 MHz band (optional) amplitude shift keying (ASK) PHY specifications*

802.15.4 Section	Adopted	Description
		Only 2450MHz band supported
6.8	No	*868/915 MHz band (optional) O-QPSK PHY specifications* Only 2450MHz band supported
6.9	Partially	*General radio specifications* As indicated below for subsections 6.9.1 - 6.9.9
6.9.1	Yes	*TX-to-RX turnaround time*
6.9.2	Yes	*RX-to-TX turnaround time*
6.9.3	Yes	*Error-vector magnitude (EVM) definition*
6.9.4	Yes	*Transmit center frequency tolerance*
6.9.5	No	*Transmit power* See Subsection 5.5 of this document
6.9.6	Yes	*Receiver maximum input level of desired signal*
6.9.7	Yes	*Receiver ED*
6.9.8	Yes	*Link quality indicator (LQI)*
6.9.9	Partial	*Clear channel assessment (CCA)* CCA mode is fixed to 2 (carrier sense).

5.2 Frequency Allocations

The transceiver shall employ DSSS and operate in the following license-free ISM band:

Table 2. Transceiver Specifications

Frequency	Communication Rate (kchip/s)	Modulation	Bit Rate (kb/s)	Symbol Rate (ksymbol/s)	Symbols
2400-2483.5 MHz	2000	O-QPSK	250	62.5	16-ary Orthogonal

5.3 Channel Numbers and Frequency Assignments

5.3.1 2.4 GHz Worldwide frequency allocation

Based on 802.15.4 standard, the 2.4 GHz spectrum supports channel assignments 11-26, the center of which frequency is listed below. Since channel 26 is not legal in many locales, it must not be supported and is not listed.

Table 3. Frequency Assignments

Channel Number	Frequency (GHz)	Channel Number	Frequency (GHz)	Channel Number	Frequency (GHz)
11	2.405	16	2.430	21	2.455
12	2.410	17	2.435	22	2.460
13	2.415	18	2.440	23	2.465
14	2.420	19	2.445	24	2.470
15	2.425	20	2.450	25	2.475

5.4 Radio Transceivers

WirelessHART can be implemented with readily available 'off the shelf' or custom radio transceivers that are compliant to IEEE 802.15.4 and meets the criteria listed below. This standard is intended to conform to worldwide regulations in Europe, Canada, Japan, China, and the United States.

5.4.1 802.15.4 Unspecified or improved required radio performance:

- Time to switch between channels shall be 12-symbol periods max (0.192 ms).
- Recommended radio Turn-on Time: 4 ms maximum. (Cold start; includes frequency lock and settling time).

5.4.2 Approved 802.15.4 transceivers for WirelessHART

See *Approved IEEE 802.15.4 Transceivers for WirelessHART*

5.5 Transmit Power

Transmit power is the Equivalent Isotropic Radiated Power of the device. All WirelessHART devices must provide a nominal EIRP of +10 dBm (10 mW) ±3 dB.

In addition, manufacturers must ensure their devices comply with localized transmit power regulations applicable to the device's installation.

In both cases the transmit power must be representative of the manufacturer's production device with power source (batteries, solar, or otherwise) at 95% to 100% of rated capacity. All devices should be provided with an omni-direction antenna. Representative transmit power data including maximum output power and radiation patterns for all antennae supported by the product must be available in the product manual or upon request.

5.6 Output Power Control

The device power level must be controlled (programmable) at discrete, monotonic levels from -10 dBm to +10 dBm EIRP (with ±4dBm of error in actual power level). See Command 797 for more information.

5.7 Device Sensitivity

Device Sensitivity is defined as the combined sensitivity of the receiver and the antenna as a system. All devices shall achieve a system (radio, circuit card, cabling, and connectors) device sensitivity of -85dB or better.

6. PHYSICAL LAYER SERVICES

This section describes the operation of the Service Primitive (SP) supplied by the Physical Layer. In addition to specifying the individual SP, time sequence diagrams are included to indicate the order in which the SP should be used and the order of event occurrence at the protocol layer boundaries.

All SP's described here must be supported by the device unless otherwise stated. The mapping of these SP's into an implementation is entirely a local matter and is in no way restricted by this specification.

In the definition of the SP's, parameters are defined. Some parameters are optional and may not be present in all invocations of the SP. Optional parameters are distinguished by enclosing them within square brackets ("[","]") in the SP definitions.

6.1 Message SP's

The HART Physical Layers do not specify the services they provide. However, the Physical Layer must provide SPs and these are specified in this section. The following SPs specified by the time sequence diagrams in Figure 2 and the following descriptions must be supported by the underlying Physical Layer.

The Physical Layer interface is determined by a set of transmit and receive SPs. At any given instant the interface may undertake either a transmit or receive SP sequence, but not both simultaneously (i.e., the interface is half duplex). To make the specification clearer a suggested mapping of the interface SP into typical modem control signals is supplied.

6.1.1 Enabling / Disabling the Transceiver

ENABLE.request(state, channel)

This SP is used to enable/disable the Physical Layer and a place it in transmit or receive mode (state) on the specified frequency channel. An `ENABLE.request` may only be issued if the interface is in an idle state. (i.e., no pending `TRANSMIT.indicate` or `TRANSMIT.confirm`).

ENABLE.confirm(state, channel)

This SP is passed back by the Physical Layer to confirm its ability to accept data for transmission, or to indicate that it will accept no further data.

ENABLE.indicate()
A receive SP passed by the Physical Layer to indicate the start of a message. (i.e. indicates the delimiter has been received by the Physical Layer.)

6.1.2 Clear Channel Assessment

CCA.request( )
This SP will cause the Physical Layer to perform a CCA. The Physical Layer must be enabled and in receive mode.

CCA.confirm(status)
This SP is passed back from the Physical Layer indicating the result of the CCA.request. Error status will be returned if the Physical Layer was unable to perform the CCA (i.e. because the transceiver was off). Status includes: { TranceiverOff, ChannelBusy, ChannelIdle }.

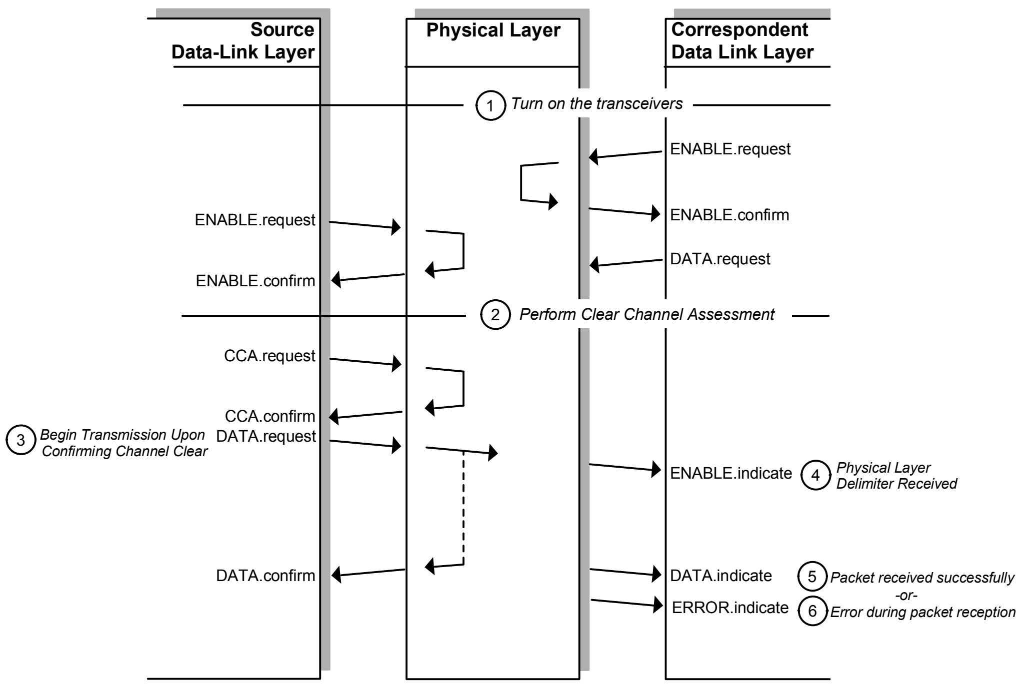

Figure 2. Physical Layer Message SP's

6.1.3 Data Communication Services

DATA.request(data)
This is the SP used to pass a data packet to the Physical Layer.

DATA.confirm(status, data)
Returned by the Physical Layer to indicate the packet has been transmitted. Status includes: { Success, TranceiverOff, ReceiverOn, TransmitterBusy }.

DATA.indicate(rsl, data)
This SP is passed back from the Physical Layer to indicate the reception of a packet. The data field contains the packet received and the rsl indicates the estimated receive signal level for this packet.

ERROR.indicate(status, data)
Returned by the Physical Layer to indicate an error in received data or its handling. Status includes: { ReceiveBufferOverflow, PacketIncomplete }.

6.2 Management SP's

Management SP's supports the configuration of the Physical Layer. Both mandatory and optional management services allow the Physical Layer to be configured. In addition, this allows management of the device's non-volatile memory to be isolated from the Physical Layer implementation.

LOCAL_MANAGEMENT.request(service, [data])
This SP is used to configure Physical Layer properties. Services and properties supported are specified in Table 4

LOCAL_MANAGEMENT.confirm(service, status, [data])
This SP is used to return the results of a corresponding LOCAL_MANAGEMENT.request. The status shall return the results of executing the request.

LOCAL_MANAGEMENT.indicate(service, status, [data])
This SP is used to return the results of a corresponding LOCAL_MANAGEMENT.request. The status shall return the results of executing the request.

Table 4. Local Device Management Commands

Service	Data	Description
RESET		Initialize the physical layer
READ_TX_PWR_LEVEL		Read the transmit power level setting in dBm
	Signed-8 txPwrLevel	
WRITE_TX_PWR_LEVEL		Write the transmit power level setting in dBm
	Signed-8 txPwrLevel	
WRITE_SLEEP_STATE		Write the sleep state of the physical layer
	Unsigned-8 sleepState	One of: { **sleep**, **awake** }
WRITE_RCV _OVERFLOW_ENABLE		Enable the receive overflow error indication. This will be reported in the ERROR.indicate() service status
	Boolean rcvOverflowEnable	

ANNEX A. EXPECTED COMMUNICATION DISTANCES

Expected Communications Distance Outdoors (Open field, Line-of-Sight)

Transmit power is a device parameter that will effect communication distance.

Nominal LoS distance with a 0 dBm transmitter: 100 meters

Nominal LoS distance with a 10 dBm transmitter: 200 meters

Note: These estimates assume an unity gain omni-directional antenna, the PER should be less than or equal to of 1%, a device receive input level of -82 dBm and no interference.

Expected Communications Distance Indoors (Non-Line of Sight)

Transmit power is a device parameter that will effect communication distance.

Nominal distance with a 0 dBm transmitter: 35 meters

Nominal distance with a 10 dBm transmitter: 75 meters

Note: These estimates assume an unity gain omni-directional antenna, the PER should be less than or equal to of 1%, a device receive input level of -82 dBm, no interference and multi-path fading effects due to multiple reflections (e.g., due to obstacles).

ANNEX B. REVISION HISTORY

A1.Revision 1.0

Initial Revision*.

* October 2008 – document updated to reflect the new HCF logo and copyright information.