Executive Summary

FOUNDATION fieldbus is a digital fieldbus technology which is widely used in process automation applications. It provides several advantages compared to legacy analog communication and thus is supported in an increasing number of field devices. Its functionality is defined by the FOUNDATION fieldbus standard.

This White Paper discusses the individual hardware and software aspects of implementing a FOUNDATION fieldbus H1 field device. While this implementation approach is applicable to a wide range of target platforms, it results in substantial development effort and a long implementation time if the implementation is performed by the manufacturer. It also requires in-depth fieldbus expertise. As a consequence, field device manufacturers are typically interested in reducing the associated expenses and in shortening the time-to-market. This goal can be reached by the following implementation approaches based on using pre-engineered hardware and software components.
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1. Introduction

In the past, process automation devices were based on proprietary or analog communication technology. For instance, the communication made use of 4..20mA\(^1\) or HART\(^2,3\) technology. Over the last couple of years, however, an increasing number of installations have been implemented based on digital fieldbuses, one of these being FOUNDATION fieldbus (FF).

The usage of digital fieldbus technology provides a set of functional benefits, including the high resolution measurement of values accompanied by no loss of accuracy and a highly reliable data transmission. It is based on standardized object models and access methods. The support of diagnostic and maintenance capabilities as well as asset monitoring and management functionality also contribute to the special advantages of digital fieldbuses.

In addition, the switch to fieldbus technology can result in considerable cost savings. A study performed by NAMUR, an international user association of automation technology in process industries, identifies a saving potential of 40+% related to the planning, cabling, commissioning, and maintenance of a fieldbus application in comparison with an application using conventional transmission technology (see Figure 1). A significant cost-cutting potential from implementing a FOUNDATION fieldbus application has also been shown in various case studies.\(^4\)

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**Figure 1:** Cost Saving Potential When Setting Up Fieldbus Applications  
(Source: NAMUR-AK 3.5)

\(^1\) 4..20mA communication technology provides an analog transfer of analog values.

\(^2\) HART communication technology allows transferring analog values digitally.

\(^3\) So far more than 80% of the field devices used are still based on 4..20mA communication technology, including HART.

\(^4\) See Chapter 8, “References” for details.
Due to the advantages of using digital fieldbuses, the number of implemented field devices is rapidly increasing. For instance, by the end of 2011 the Fieldbus Foundation reported more than 1.5 million sold FF field devices, which are installed in over 15,000 plants worldwide. Thus, FOUNDATION fieldbus has to be seen as an important representative of fieldbus technology, especially for process automation.

This increasing market potential leads to the decision of individual field device manufacturers to consider the implementation of an FF H1 field device as an important extension of their product portfolio. However, this plan may be jeopardized by the complex underlying technology\(^5\) that needs to be implemented for a FOUNDATION fieldbus H1 field device and which differs significantly from the communication technology that is used in legacy devices. As a consequence, the development of the fieldbus interface requires substantial expertise, which is often not available at the manufacturers. Thus, there is big interest in options for implementing FF H1 field devices with manageable resources and impacts.

This situation is examined in detail by this White Paper, which is targeted to device manufacturers planning to introduce a FOUNDATION fieldbus H1 field device into the market. It gives an introduction to the FF H1 fieldbus technology and discusses hardware and software aspects of a FOUNDATION fieldbus H1 field device implementation. In addition, this White Paper also presents development approaches, which have already proven to result in a shorter and more cost-efficient implementation of a FOUNDATION fieldbus H1 field device.

\(^5\) Individual peer-to-peer connections are replaced by a deterministic fieldbus communication, supporting cyclic and acyclic data exchange and providing additional information.
2. FOUNDATION fieldbus Overview

Once the first fieldbus standards\(^6,7\) had become available, it soon turned out that these specifications did not cover the specific requirements to be met by a fieldbus used in process automation. Thus in 1992, this situation led to the start of two independent initiatives for defining a fieldbus standard for use in hazardous environments, one being the Interoperable System Project (iSP)\(^8\) while the other, the WorldFIP\(^9\) project, was the result of a merger of the French and North American Flux Information Processus (FIP, earlier also known as Factory Instrumentation Protocol) organizations. When major end-users like Chevron or Exxon demanded not two but just one solution, the two initiatives merged in 1994 to form the Fieldbus Foundation. Using the results of both organizations\(^10\), the Fieldbus Foundation developed the FOUNDATION fieldbus standard\(^11\). In 1995 an initial implementation of this standard\(^12\) was started.

The FOUNDATION fieldbus standard defines an all-digital, serial, two-way communications system between hosts and remote I/O field devices (sensors and actuators). It implements the OSI layers 1 (Physical Layer), 2 (Data Link Layer) and 7 (Application Layer) (see Figure 2).

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6 For instance including PROFIBUS, CAN and Interbus.
7 The PROFIBUS specification work started back in 1987, when a publicly-funded collaborative project was launched by 18 companies and institutes in Germany, resulting in the specification of the PROFIBUS Fieldbus Message Specification (FMS) as a first PROFIBUS standard.
8 Among others, the iSP members included the companies Siemens, Yokogawa, Fisher and Rosemount, whose contributions focused particularly on individual fieldbus aspects like the Manchester Coded Bus Powered transmission technology, the PROFIBUS FMS protocol or the concept of Function Blocks and the Device Description. As a well-known communication expert, Softing had been invited by the iSP consortium to participate in the project.
9 Honeywell was one of the members of the WorldFIP consortium.
10 The contribution of iSP to FOUNDATION fieldbus included the PROFIBUS FMS protocol, but without the PROFIBUS layer 2. This eventually led to the continuation of the PROFIBUS standardization work and, in 1996, to the release of the PROFIBUS Process Automation (PA) application profile in competition with the FOUNDATION fieldbus standard. From the WorldFIP results, a subset of the IEC fieldbus is reused in FOUNDATION fieldbus.
11 Today, FOUNDATION fieldbus is standardized in IEC61158 Type 1.
12 Softing was one of the companies performing an initial FOUNDATION fieldbus implementation.
Figure 2: Comparison of OSI Layer Model and FOUNDATION fieldbus H1 Layer Model

The FF H1 model comprises the Physical Layer, the Data Link Layer, the Fieldbus Access Sublayer and the Fieldbus Message Specification. The latter three are implemented within the communication stack. The individual FF H1 layers refer to the Physical Layer, the Data Link Layer and the Application Layer of the OSI Model.

(Source: Fieldbus Foundation)

FOUNDATION fieldbus is available in two implementations, addressing different needs within the process automation environment. The FOUNDATION fieldbus H1 protocol today is generally used for the connection to field devices. It runs at a data transfer rate of 31.25Kbit/s and performs the data transfer based on Manchester Coded Bus Powered (MBP)\textsuperscript{13,14}, which is capable of supplying power to the individual field devices via the twisted-pair bus wire. As a consequence, the wiring overhead can be reduced significantly. MBP communication requires only 8Bits for encoding a character. FF H1 is suitable for use in hazardous and potentially explosive areas (Ex zones 0 and 1). Each FF H1 segment supports a length of 1,900m and allows connection of up to 32 field devices, depending on the specific environment. These limits can be extended using bridges. The FOUNDATION fieldbus High Speed Ethernet (HSE) implementation is additionally standardized. It supports a transfer rate of 100Mbit/s and can be used for connecting host systems like Distributed Control Systems (DCS) and linking devices via standard Ethernet cabling. While FF HSE in general also allows to connect field devices, this functionality is not used so far in field devices available on the market. Thus, two FOUNDATION fieldbus topologies are used, as shown in Figure 3.

\textsuperscript{13} The Manchester Coded Bus Powered transmission technology has been developed and standardized independently of the FF H1 communication and addresses the demands of process automation.

\textsuperscript{14} MBP is used by other fieldbuses as well, e.g. by PROFIBUS PA.
The capabilities of individual FF field devices are described by Device Description (DD) files. They not only provide information needed for a host system to understand the meaning of the field devices' data, but also a user interface for functions such as calibration and diagnostics. The interoperability of devices from various manufacturers is thus ensured. Optional Enhanced Device Description (EDD) files can be used to extend the description of the features supported by an individual FOUNDATION fieldbus field device.

FF defines functions and parameters for process control devices, such as transmitters, actuators, valves, and analyzers. These functions and parameters are used to adapt the devices to the respective application and process conditions. The functions are based on Function Blocks, and the associated parameters are classified as input, output, and internal parameters. FOUNDATION fieldbus also determines how the various services of the communication protocol are used. This means, for example, that process data that is exchanged cyclically is based on a standard format for all devices. In addition to the measured value and/or manipulated set point value, this format also features a status supplying information about the quality of the value and possible limit violations. It thereby provides the foundation for harmonized applications, simplified engineering, device exchangeability and increased reliability by means of standardized diagnostic information.
There are two main features FOUNDATION fieldbus communication excels in: First, the complete communication is based on a detailed communication schedule, including the calculation of all individual values within Function Blocks as well as the distribution of these values within the fieldbus. The overall schedule timing within the fieldbus is performed by the Link Master. This role can be performed not only by the host system, but by any device offering Link Active Scheduler functionality. Thus, a deterministic communication is reached when using FOUNDATION fieldbus. The second FF advantage is the support of Control in the Field, which allows performing closed loop calculations in a decentralized way without requiring a controller. This functionality is based on the distributed execution of Function Blocks available within the individual field devices rather than a centralized execution in the host system, and thus results in a faster distribution of calculated values via the fieldbus. An example illustrating Control in the Field as performed by two field devices is shown in Figure 4.

![ FOUNDATION fieldbus H1 Segment ](image)

**Figure 4:** Example of Control in the Field Performed by Two FOUNDATION fieldbus H1 Field Devices

The FF H1 communication schedule as well as the Control in the Field functionality are defined as part of the FOUNDATION fieldbus configuration.
3. Implementing a FOUNDATION fieldbus H1 Field Device

The implementation of an FF H1 field device has to follow the FOUNDATION fieldbus standard. Thus an implementation has to be focused on a set of individual areas, including the communication hardware as well as software components like the protocol stack and the Transducer Block. The individual implementation aspects regarding an FF H1 field device implementation are discussed in detail in the following sections.

3.1 FOUNDATION fieldbus H1 Hardware

The hardware of an FF H1 field device has to support a Physical Layer as required for MBP communication. As a consequence, an FF H1 field device comprises different hardware components which are required for connecting a device to the FF H1 network, for performing low-level operations within the FF communication, and for executing the FF H1 stack plus the associated Function Block application. An overview of the overall hardware structure of a FOUNDATION fieldbus H1 fieldbus interface is given in Figure 5.

![Hardware Block Diagram of FOUNDATION fieldbus H1 Field Device Fieldbus Interface](image_url)
3.1.1 Medium Attachment Unit

The Medium Attachment Unit (MAU) is the hardware component of an FF H1 field device that provides the direct connection of the device to the fieldbus. It therefore has to support the MBP transmission technology used for FF H1 communication.

The MBP implementation is based on the IEC61158-2 Type 3 ‘31.25Kbit/s Voltage-Mode’ standard. Here the direct current (DC) voltage of 9V to 32V provided by the bus power supply is overlaid by an information signal of 0.75V to 1V. This voltage modulation is generated by the transmitting field device by modifying the current drawn from the network. To obtain this information the voltage level is evaluated within the field device (i.e. the information signal is decoupled from the power supply). As long as no transmission is performed, the individual field devices are only allowed to draw a constant current, which is described by the device properties. Ideally, this current is 10mA.

This signal adaptation on the sender as well as the receiver side is performed by the MAU. In addition, this hardware component is responsible for the bus power extraction required for performing the device functionality as well as the fieldbus access of the field device.

There are different ways to implement the analog Medium Attachment Unit within an FF H1 field device. While it is possible to design this functionality based on discrete hardware components, this option is often not used due to the limited space available in field devices. An integrated MAU\textsuperscript{15} is chosen instead in order to implement the core fieldbus access functionality within an FF H1 field device. Integrated MAUs are available from various suppliers (e.g. SIM 1-2 from Siemens, AMIS-492x0 from ON Semiconductor).

3.1.2 Fieldbus Controller

The Fieldbus Controller acts as an interface between the digitized serial data stream provided by the MAU and the processor that executes the software part of the FOUNDATION fieldbus H1 protocol. Typically, the Fieldbus Controller implements the FF H1 Physical Layer as well as the time-critical part of the FF H1 Data Link Layer. In addition to decoding and encoding the MBP frame the Fieldbus Controller is responsible for the creation and verification of the cyclic redundancy check (CRC) polynomial used for ensuring the required data transmission reliability. The provided functionality may also include address recognition, filtering of received frames, timer management, and the Data Link Layer state machine.

\textsuperscript{15} Some additional discrete hardware components are still required, however, e.g. for implementing the intrinsically safe portion of the network access.
Figure 6: The Aniotek Fieldbus Controller UFC100-L1 Supporting the Implementation of FOUNDATION fieldbus H1 Field Devices

There are two different types of Fieldbus Controllers available for implementing an FF H1 field device: While one type is a general type of Fieldbus Controller for field device implementation (e.g. UFC100-L1 from Aniotek, YTZ420 from Yamaha)\(^\text{16}\), other Fieldbus Controllers are particularly targeted for use in a PROFIBUS PA field device (e.g. SPC4-2\(^\text{17}\) from Siemens).

3.1.3 Processor

The processor is used for executing the software part of the FOUNDATION fieldbus H1 protocol stack (i.e. the less time-critical part, which is not covered by the Fieldbus Controller). Here processors for embedded usage are required, which combine minimum current consumption with the appropriate computing power for implementing FF H1 field devices.

\(^{16}\) The FF H1 and PROFIBUS PA fieldbuses both use the same Physical Layer based on Manchester Coded Bus Powered communication according to the IEC61158-2 Type 1/Type 3 '31.25Kbit/s Voltage-Mode' standard, whereas the Data Link Layers of both protocols differ. As a consequence, it is possible to support both fieldbuses on a single field device hardware platform, including the Fieldbus Controller. Only the software part of the implementation has to be adapted to the concept and functionality of the individual fieldbus.

\(^{17}\) Nonetheless, the SPC4-2 Fieldbus Controller also allows the implementation of an FF H1 field device but involves a higher implementation effort.
As FF H1 is a relatively complex protocol, its implementation requires an address space >64KB. While this requirement can also be supported by an 8Bit processor, the usage of this platform results in a higher clock rate, which in turn implies a higher current consumption and is thus not adequate for embedded applications. Therefore, 16Bit or even 32Bit processors are typically chosen for the implementation of FF H1 field devices.

As an FF H1 field device implementation requires not only computing power, but also additional hardware capacities like RAM and Flash memory, timers, ports and serial interfaces, the hardware implementation often is based on a microcontroller, a typical example being the M16C family from Renesas.

Besides the FF H1 protocol stack, an FF H1 field device also includes additional software for the device application. Depending on the selected hardware platform, it is possible to either execute all software components on a single processor, which results in a higher processor load, or to distribute the execution of the complete device software to more than one processor (e.g. dual-processor solution)\textsuperscript{18}. In the second case, more effort has to be spent on implementing the necessary data exchange between the individual processors.

3.1.4 Additional Hardware Components

Besides the hardware components described above additional hardware components are required for implementing a FOUNDATION fieldbus H1 field device. These hardware components may include additional RAM memory extending the processor's internal RAM or a (serial) EEPROM or FRAM, which is used for storing non-volatile communication and Function Block parameters.

Hardware jumpers are often used in addition. They provide functionality like address selection or write protection. FF H1 field devices, in particular, require the implementation of a Simulate Jumper for certification purposes.

\textsuperscript{18} While a single-processor solution typically means the usage of only one hardware board, the implementation of an FF H1 field device based on multiple processors may result in a combination of several hardware boards (e.g., one hardware board executing the device application plus a piggy-back hardware board executing the FF H1 protocol stack).
3.2 FOUNDATION fieldbus H1 Protocol Stack and Function Block Application

As described above, the FF H1 protocol makes use of the OSI layers 1 (Physical Layer), 2 (Data Link Layer), and 7 (Application Layer). While the Physical Layer as well as parts of the Data Link Layer are implemented in hardware (see Sections 3.1.1 and 3.1.2), the rest of the FF H1 protocol stack is implemented in software. To ensure optimum performance, the protocol stack needs to be available in a format executable on the individual target processor. This format is the result of the porting process, during which the protocol stack is compiled and linked for the target hardware platform and real-time operating system by using a specific development tool chain.

In addition to the protocol stack, which is responsible for the pure data exchange via the fieldbus, the FF H1 field device implementation also requires a Function Block application. This component acts as an interface between the FF H1 protocol stack on one side and the specific device functionality on the other side and ensures that all device functions and parameters as well as access to this data are standardized throughout the network. To achieve this, the Function Block application follows an object-oriented approach and allows implementing all the different types of FF H1 field devices. The block diagram of a Function Block application for implementing a simple FF H1 transmitter is shown in Figure 7.

Figure 7: Block Diagram of Function Block Application for Simple Transmitter Interfacing the FOUNDATION fieldbus H1 Protocol Stack

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19 An FF H1 implementation does not necessarily require the use of an operating system. However, this communication protocol deals with different tasks, which are more or less time-critical and thus are associated with various priorities (e.g. data exchange with the application, data exchange with the fieldbus). Without the assistance of an operating system, this type of functionality would have to be implemented in another way, maybe resulting in a long and confusing code. Thus, the use of a real-time operating system is recommended when implementing an FF H1 field device.
The standard forming the base of the Function Block applications refers to the individual supported parameters and blocks. The device parameters are defined according to the individual FF H1 device profiles. In general they can be divided into three groups, as shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Process Values</td>
<td>All Measuring, Signal, and Status Values Required for Controlling the System</td>
</tr>
<tr>
<td></td>
<td>Typically Dynamic Process Values are accessed cyclically.</td>
</tr>
<tr>
<td>Operating and Standard Parameters</td>
<td>Data Describing the Capabilities As Well As Configuration and Parameterization Objects of the Individual Device</td>
</tr>
<tr>
<td></td>
<td>Typically Operating and Standard Parameters are accessed acyclically.</td>
</tr>
<tr>
<td></td>
<td>Operating and Standard Parameters can be split into objects whose implementation is mandatory or optional.</td>
</tr>
<tr>
<td>Manufacturer-Specific Parameters</td>
<td>Additional Data Supported by the Device</td>
</tr>
</tbody>
</table>

Table 1: Parameters of FOUNDATION fieldbus H1 Field Devices

The uniform and systematic access to the different field device parameters within the FF H1 network is standardized using a block model. The different block types given in Table 2 are supported.

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20 While access to Operating and Standard Parameters is performed acyclically from the point of view of the FF H1 protocol services, this communication may take place on a periodic basis from the end user's point of view. This applies, for example, to the reading of view objects by a SCADA system.
<table>
<thead>
<tr>
<th>Block Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function Block²¹</td>
<td>Cyclic Access to Dynamic Process Parameters During Operation</td>
</tr>
<tr>
<td></td>
<td>The following FOUNDATION fieldbus H1 Function Blocks are defined:</td>
</tr>
</tbody>
</table>
| 1. Initial Set of Function Blocks²² | • Analog Input (AI)  
(Read Access to Analog Device Value)                                                                                                       |
|                  | • Discrete Input (DI)  
(Read Access to Digital Device Value)                                                                                                       |
|                  | • Manual Loader (ML)  
(Setting of Output by Operator)                                                                                                               |
|                  | • Bias/Gain (BG)  
(Gain Capability by Computing an Output Value From a Bias Setpoint, an Input, and a Gain Value)                                           |
|                  | • Control Selector (CS)  
(Selection of One Control Signal)                                                                                                                                 |
|                  | • Proportional/Derivative (PD)  
(Proportional-Derivative Control)                                                                                                               |
|                  | • Proportional/Integral/Derivative (PID)  
(Proportional-Integral-Derivative Control)                                                                                                       |
|                  | • Ratio (RA)  
(Application of Adjustable Ratio Setpoint)                                                                                                 |
|                  | • Analog Output (AO)  
(Write Access to Analog Device Value)                                                                                                                                 |
|                  | • Discrete Output (DO)  
(Write Access to Digital Device Value)                                                                                                                                 |
| 2. Advanced Set of Function Blocks²³ | • Device Control (DC)  
(Setpoint Control for Multi-State Discrete Devices)                                                                                      |
|                  | • Output Splitter (OS)  
(Calculation of Several Outputs)                                                                                                                                 |
|                  | • Signal Characterizer (SC)  
(Characterization of Any Function Defining an Input/Output Relationship)                                                                            |
|                  | • Lead Lag (LL)  
(Dynamic Compensation of an Input Value)                                                                                                                                 |
|                  | • Dead Time (DT)  
(Delay of Continuous Signal by Amount of Time)                                                                                                                                 |

Table 2: Types of FOUNDATION fieldbus H1 Blocks

²¹ Function Blocks describe generic models for FF H1 field device functionality like input or output. They are thus identical for all types of FF H1 field devices.
²² Defined in the Fieldbus Foundation Document FF-891.
²³ Defined in the Fieldbus Foundation Document FF-892.
<table>
<thead>
<tr>
<th>Block Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function Block (Continued)</td>
<td>2. Advanced Set of Function Blocks (Continued)</td>
</tr>
<tr>
<td></td>
<td>• Integrator (IT) (Accumulation of Measured Value to a Total Value as a Function of Time)</td>
</tr>
<tr>
<td></td>
<td>• Setpoint Ramp Generator (SPG) (Setpoint Generation Following a Profile as a Function of Time)</td>
</tr>
<tr>
<td></td>
<td>• Input Selector (IS) (Selection of One Input)</td>
</tr>
<tr>
<td></td>
<td>• Arithmetic (AR) (Performance of Popular Measurement Mathematical Functions)</td>
</tr>
<tr>
<td></td>
<td>• Timer (TMR) (Performance of Various Timing Functions)</td>
</tr>
<tr>
<td></td>
<td>• Analog Alarm (AAL) (Alarm Reporting Based on Analog Value)</td>
</tr>
<tr>
<td></td>
<td>• Totalizer (TOT) (Accumulation of Measured Value to a Total Value Based on Operator Interaction)</td>
</tr>
<tr>
<td>Transducer Block</td>
<td>Converter Mapping Between Process Data and Function Blocks</td>
</tr>
<tr>
<td></td>
<td>The Transducer Block is used to perform pre-processing and calibration of device data according to specific device settings.</td>
</tr>
<tr>
<td></td>
<td>At least one Transducer Block has to be available for a FOUNDATION fieldbus H1 field device.</td>
</tr>
<tr>
<td>Resource Block</td>
<td>Access to Device-Specific Data Identifying the Individual Physical Device Properties</td>
</tr>
</tbody>
</table>

Table 2: Types of FOUNDATION fieldbus H1 Blocks (Continued)

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24 Defined in the Fieldbus Foundation Document FF-893
25 Transducer Blocks map the generic Function Blocks to the individual properties of a specific field device. Standardized Transducer Blocks are available for various device classes like pressure transmitters or temperature transmitters.
The coupling of the various blocks to the FF H1 communication within the Function Block application and their execution control is performed by the Function Block Shell. Thus, this component can be seen as a kind of run-time environment for FF H1 blocks.

### 3.3 Transducer Block Implementation

An FF H1 Function Block application typically results in a large number of parameters to be handled. For instance, depending on the respective device profile, a simple FF H1 transmitter has to support at least 80 (fixed and variable) parameters, which are accessed by the fieldbus via blocks. During the implementation of an FF H1 field device, these blocks have to be designed in an individual and device-specific way. Especially the pre-processing performed within the Transducer Blocks is an important task here. It handles individual FOUNDATION fieldbus H1 read and write requests by mapping the individual device parameters to Function Blocks.

One approach to internally implement an individual Transducer Block is based on a data structure representing all supported parameters. This data structure is used as an internal cache memory, storing the latest available parameter values to support a faster execution of individual FF H1 read and write requests. While write requests are usually forwarded directly to the device, the individual device parameters are read cyclically in the background and the appropriate values are copied to the Transducer Block’s cache memory. When an FF H1 read request needs to be executed, the data from the internal cache memory is read. This handling is shown in Figure 8.

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26 This approach can be used, for example, for implementing a dual-processor solution, which may result in a slow internal communication interface. A single-processor solution usually implements a different communication interface.
This type of data handling within the Transducer Block is implemented by a device-specific software program, for instance using the C programming language. Depending on the number of parameters handled by a single Transducer Block, this implementation may result in quite a huge program for handling the high number of parameters, and thus require extensive development and testing. A sample Transducer Block code for writing data to the device based on the situation from Figure 8 is presented in Figure 9.

```c
... write_handler ()
    {
        ... switch (index)
            {
                ... 1200:
                    check_range ();
                    build_sending_frame ();
                    send_data ();
                    break;
                1202:
                    ...
                    }
        ...
    }
```

Figure 8: Handling of Read and Write Requests Within a Transducer Block

Figure 9: Transducer Block Code Sample for Sending Data to the Device
Due to the specific supported device capabilities, the individual Transducer Block implementation varies from device to device. However, it is possible to standardize this implementation with respect to the logical data exchange between the Transducer Block and the device. These standardized solutions are discussed in the following sections 27.

3.3.1 Transducer Block Implementation Based on Serial HART Protocol

One option for exchanging data between the Transducer Block and the device is to use the serial HART protocol, which is often available in devices for internal data exchange. This implementation approach can be used in particular when migrating an existing HART device to support FF H1.

To be able to use the serial HART protocol for data exchange between the Transducer Block and the device, a HART master has to be available, which manages the data transfer.

The execution of the individual HART commands is triggered by the individual FF H1 read and write requests. For write requests the Transducer Block program creates the corresponding HART commands, which are then executed via the HART master, whereas for read requests the current value kept in the internal cache memory is returned 28. The necessary cyclic update of the parameter values in the internal cache memory in the background is also part of the Transducer Block program and performed using HART commands.

One or more HART commands can be associated with an individual FF H1 read or write request.

3.3.2 Transducer Block Implementation Based on Modbus RTU Protocol and Other Serial Protocols

Another typical approach for implementing an FF H1 field device is to make use of the serial Modbus RTU protocol for data exchange between the Transducer Block and the device. This approach is similar to the data exchange via a serial HART protocol as discussed in Section 3.3.1, only that here the data exchange is managed by a Modbus RTU master.

This procedure can also be easily adapted to allow the use of other serial protocols for data exchange between the Transducer Block and the device, including proprietary ones. The implementation of data exchange via non-serial protocols is more complicated, however, as these require their own hardware.

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27 From the electrical point of view these various ways to implement the logical data exchange typically result in using UART and TTL Voltage Level technology, respectively.

28 The main reason for this implementation approach is the slow performance of the physical data transfer of HART TTL level communication. The small bandwidth in combination with the large amount of data to be transferred suggests a transfer rate of at least 19.2Kbit/s.
3.3.3 Transducer Block Implementation for 4..20mA Devices

For migrating 4..20mA devices to FOUNDATION fieldbus H1 no standard approach is available. The reason is the current required by these devices: A 20mA current consumption at a voltage of 8V would result in a current consumption of about 60mA to 70mA from the FF H1 network. This would mean that only one or two FF H1 field devices could be used within an intrinsically safe trunk, which typically disqualifies the device for practical use.

In addition, a special Medium Attachment Unit would be required in order to support the increased current consumption, resulting in higher hardware costs.

3.4 Add-On Files for FOUNDATION fieldbus H1 Field Devices

For using an FF H1 field device, a DD file is additionally available in order to describe its capabilities. An overview of this file can be found in Chapter 2.

The DD file of a FOUNDATION fieldbus H1 field device is required for its registration. In addition, other means can be provided for accessing the device capabilities, e.g. a Device Type Manager (DTM) file according to the Field Device Tool (FDT) standard.

3.5 Certification and Registration of FOUNDATION fieldbus H1 Field Devices

The FF H1 certification process comprises three individual tests. One test is the FF H1 Physical Layer Conformance Test, during which the device is checked against the appropriate Physical Layer requirements of the Fieldbus Foundation. The Physical Layer Test is performed by self-certification or by an accredited testing laboratory as part of the certification test.

The second test to be passed by an FF H1 field device is the FOUNDATION fieldbus H1 Conformance Test according to the Conformance Test Kit (CTK). This test addresses the implementation of the FF H1 protocol stack (OSI Data Link and Application layers). The test has to be performed by an accredited testing laboratory.

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29 According to the specification 4..20mA devices work with a voltage of 8V to 10V. Thus the given current consumption from the FOUNDATION fieldbus H1 network already applies to 4..20mA devices working with a voltage at the lower end of this range.

30 Softing has the FF H1 Physical Layer Conformance Test according to the Fieldbus Foundation document FF-830 at its disposal and is accredited to perform the official certification test.

31 Softing has the FF H1 Conformance Test Kit at its disposal and thus supports the performance of an individual pre-certification test prior to the official certification test. As a consequence, any related issues can probably be solved at an early stage.
The third test required for certification of an FF H1 field device is the FF H1 Interoperability Test according to the Interoperability Test Kit (ITK)\textsuperscript{32}. This test focuses particularly on the implemented Function Block application. The FF H1 Interoperability Test is performed by the Fieldbus Foundation and requires the successful completion of the FF H1 Physical Layer Conformance Test as well as the FF H1 Conformance Test.

As a result the implemented FOUNDATION fieldbus H1 certification process ensures the supported high quality of the individual FF H1 field device implementation, its full functionality as well as the interoperability, easy installation, and supported performance of the field device.

\textsuperscript{32} Softing has the FF H1 Interoperability Test Kit according to the Fieldbus Foundation specification FF-946 at its disposal and thus supports the performance of an individual pre-certification test prior to the official certification test. As a consequence, any related issues can probably be solved at an early stage.
4. Reducing the Implementation Effort of FOUNDATION fieldbus H1 Field Devices

As can be seen from the description in Chapter 3 the complete implementation of a full-featured FF H1 field device with all its individual capabilities is quite an extensive task and addresses various hardware and software aspects. Thus, many device manufacturers are interested in identifying the best ways to reduce the implementation effort of FF H1 field devices without compromising on the requested flexibility. Here implementation kits based on pre-engineered hardware and software components can help to significantly reduce the associated development costs as well as the time-to-market.

4.1 FOUNDATION fieldbus H1 Fieldbus Device Communication Kit

The FOUNDATION fieldbus H1 Fieldbus Device Communication Kit makes use of pre-engineered, standardized hardware and software components and thus provides a universal approach for implementing all types of FF H1 field devices. It consists of a ready-to-use hardware board as well as the FF H1 protocol stack plus most of the standardized Function Blocks described in Section 3.2.

The hardware board included in the FOUNDATION fieldbus H1 Fieldbus Device Communication Kit meets the various requirements discussed in Section 3.1 and thus eliminates the need for customer-specific hardware development. This board is integrated into a device as an add-on piggy-back board and provides all the means for executing the FF H1 protocol stack plus the appropriate Function Block application. In addition, it is also capable of supplying power from the fieldbus to the field device hardware.

The device implementation, on the other hand, runs on the device’s main board. As a result, a dual-processor solution is implemented, separating the FF H1 implementation from the pure device functionality. The Softing embedded communication module FBK-2 as part of an FF H1 field device implementation is shown in Figure 10. As can be seen, this board is small enough to fit into most devices.

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33 The FOUNDATION fieldbus H1 Fieldbus Device Communication Kit is a product offered by Softing.
The software part of the FF H1 Fieldbus Device Communication Kit is pre-compiled and executable on the hardware board. Thus, no porting of the FF H1 protocol stack is required when using the FOUNDATION fieldbus H1 Fieldbus Device Implementation Kit.

As a consequence, the Transducer Block implementation (see Section 3.3) is the only major task to be performed when using the FOUNDATION fieldbus H1 Fieldbus Device Communication Kit. This implementation task is further simplified by providing the aforementioned serial HART or Modbus RTU protocol as the default means of data exchange between the Transducer Block and the device. However, a different serial protocol (e.g. a proprietary one) can be implemented as well when using the FOUNDATION fieldbus H1 Fieldbus Device Communication Kit, thus providing added flexibility.

The FOUNDATION fieldbus H1 Fieldbus Device Communication Kit thus reduces the implementation effort compared to a full-featured FF H1 field device implementation. The manufacturer can focus on the specific device implementation without needing in-depth FF know-how.

The FOUNDATION fieldbus H1 Fieldbus Device Communication Kit has already successfully passed the FOUNDATION fieldbus H1 Physical Layer Conformance Test as well as the FOUNDATION fieldbus H1 Conformance Test as described in Section 3.5. Thus the certification process of a field device implemented based on the FF H1 Fieldbus Device Communication Kit is reduced to the Interoperability Test.
4.2 FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit FFeasy

In comparison to the FOUNDATION fieldbus H1 Fieldbus Device Communication Kit, the FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit FFeasy\(^\text{34}\) simplifies the implementation of an FF H1 field device even more. To achieve this, a standardized Function Block application including a pre-defined Transducer Block implementation is added to the FOUNDATION fieldbus H1 Fieldbus Device Communication Kit. This Function Block application can be adapted to the needs of the individual field device.

For supporting this type of standardization, some assumptions regarding the field device have to be made. For instance, these standardizations restrict the available Function Blocks\(^\text{35}\) and the supported number of flexible parameters\(^\text{36}\).

These standardizations have the advantage that the complete development process of an FF H1 field device requires no programming, but can be performed simply by configuring the Function Block application. This task requires no specific FF H1 know-how and can be done by any device manufacturer. As a result, the development time is shortened significantly.

The scope of delivery of the FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit FFeasy also includes the appropriate DD file required for certification.

The FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit FFeasy has already successfully passed the FOUNDATION fieldbus H1 Physical Layer Conformance Test, the FOUNDATION fieldbus H1 Conformance Test as well as the FOUNDATION fieldbus H1 Interoperability Test as described in Section 3.5. Thus the certification process of a field device implemented based on the FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit is reduced even further to a pure re-certification.

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\(^{34}\) The FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit FFeasy is a product offered by Softing.

\(^{35}\) The Softing FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit FFeasy supports up to four instances of the Analog Input Function Block. Thus the use case of the FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit is limited to field devices of transmitter type.

\(^{36}\) The Softing FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit FFeasy supports up to 25 flexible parameters.
5. Summary

The implementation of an FF H1 field device must meet a variety of hardware and software requirements defined by the FF standard. Depending on the required functionality and the available fieldbus know-how, this implementation may involve a great deal of development time and effort when performed without pre-engineered fieldbus communication components.

A field device implementation based on the FOUNDATION fieldbus H1 Fieldbus Device Communication Kit or even better the FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit significantly reduces the involved time and effort. These approaches, however, are associated with some drawbacks, e.g. regarding the hardware used and the supported functionality. A summary of the provided field device characteristics plus individual aspects of the different implementation approaches discussed in this White Paper can be found in Table 3.
<table>
<thead>
<tr>
<th>Field Device Characteristics</th>
<th>Full FOUNDATION fieldbus Implementation</th>
<th>FOUNDATION fieldbus H1 Fieldbus Device Communication Kit</th>
<th>FOUNDATION fieldbus H1 Fieldbus Device Configuration Kit FFeasy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Hardware Requirements</td>
<td>Space Available for Piggy-Back Board</td>
<td>Type: Transmitter</td>
<td></td>
</tr>
<tr>
<td>High Number of Field Devices Per Year</td>
<td>Serial Communication for Internal Data Exchange</td>
<td>Functionality Describable by ≤ 25 Flexible Parameters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Small to Medium Number of Field Devices Per Year</td>
<td>Space Available for Piggy-Back Board</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Serial Modbus / HART Communication for Internal Data Exchange</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small to Medium Number of Field Devices Per Year</td>
<td></td>
</tr>
<tr>
<td>Integral Parts</td>
<td>Protocol Stack</td>
<td>Pre-Engineered Hardware Firmware</td>
<td>Pre-Engineered Hardware Firmware Function Block Application</td>
</tr>
<tr>
<td>Implementation Work</td>
<td>Hardware Development</td>
<td>Function Block Application Development</td>
<td>Configuration Only</td>
</tr>
<tr>
<td></td>
<td>Function Block Application Development</td>
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<tr>
<td></td>
<td>Protocol Stack Porting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upgrade Possibility</td>
<td>None Required</td>
<td>None Required</td>
<td>Functionality Upgrade Using Identical Hardware Based on Field Device Communication Kit</td>
</tr>
<tr>
<td>Typical Implementation Duration</td>
<td>9-15 Months</td>
<td>3-6 Months</td>
<td>&lt;1 Week</td>
</tr>
</tbody>
</table>

Table 3: Field Device Characteristics Met By Different FOUNDATION fieldbus H1 Implementation Approaches and Mapping to Individual Implementation Aspects

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37 The exact duration depends on the field device type, the functionality of the individual field device and the individual hardware and software implementation tasks required.

38 The information given is based on Softing’s implementation offering for FF H1 field devices.
Besides FF H1, PROFIBUS PA is another fieldbus standard used in process automation. While this fieldbus differs from FF H1 in both concept and functionality, it is based on the same Physical Layer defined in the IEC61158-2 standard. Thus, once an FF H1 field device has been implemented, a major step towards a parallel implementation of the PROFIBUS PA fieldbus has already been made. A key aspect here is that the implementation of a PROFIBUS PA field device does not require different hardware.

In addition the software development effort can be reduced as well if both implementations are based on the Softing Field Device stack. For instance this solution provides an identical interface and allows the re-use of parts of the Transducer Block structures and the source code. The implemented data exchange between the Transducer Block and the device can also be re-used. The exact percentage of savings that can be achieved in a subsequent PROFIBUS PA implementation cannot be given as a general figure, however, as it depends on the complexity of the FOUNDATION fieldbus H1 field device implemented in the first place.
6. About Softing

The Softing Industrial Automation segment is part of the Softing group founded in 1979.

Softing Industrial Automation is a global specialist in industrial communication technologies such as fieldbuses and Industrial Ethernet. With over 30 years of experience, Softing delivers connectivity, diagnostic products, and services to customers in the factory and process automation industry, serving the market from different subsidiaries.

The Softing products are tailored to the needs of system integrators, device vendors, machine and equipment manufacturers, or end users and are known for their ease of use and functional advantages. Implementation projects have been successfully performed with many international customers from various countries, including Europe, U.S.A., Japan, China, and Korea. Softing’s relationship with its customers is shaped by a high degree of flexibility for meeting individual requirements as well as by a long-term partnership.

Softing has been involved in the FOUNDATION fieldbus technology since the very beginning of the Interoperable System Project in 1992. Today, the majority of certified FF host systems and field devices use Softing technology. The Softing FF offering is proven-in-use in a wide variety of applications of a large number of manufacturers and end-users around the world.

Softing offers a complete set of options for implementing FF H1 field devices. These options combine high-quality products and professional services, available from a single source. Customers benefit from the provided in-depth technical experience and the quality resulting from field-proven products.

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