# Introduction to Fieldbuses for Process Control

*Jonas Berge*

- Digital Communication Networks
- Automation Networking Application Areas
- History of Fieldbus
- Evolution of Control System Architecture
- Basic Network Differences

Taken from *Fieldbuses for Process Control*

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- *Fieldbuses for Process Control: Engineering, Operation and Maintenance,* by Jonas Berge, Chapter 1. Order Number: 1-55617-760-7

See Appendix B of this document to view the complete table of contents for *Fieldbuses for Process Control.*

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# 1

# Introduction

The first process control systems were understandably analog, simple devices with signal formats that were essentially determined by the need for an architecture with a minimum number of costly CPUs. Networking was introduced into industrial automation in the 1970s and first utilized in direct digital control (DDC) systems between computer and I/O (input/output). Later, it was used in distributed control systems (DCS) and programmable logic controller (PLC) systems to connect the controllers and operator consoles. However, digital communications in smaller devices such as transmitters on the plant floor was not seen until the 1980s, and true communication bus networking of field instruments did not gain wide acceptance until the 1990s.

At the other extreme, corporations network their plants across the globe to the corporate headquarters via the Internet. The coordination of production and other business functions has become an integral part of the corporate information technology (IT) structure. Networking has made it possible to collect more information from the plant and to disseminate it far and wide throughout the enterprise. Geographically distributed components with lots of "intelligence" are now expected to work together. Networking has become essential for automation and is changing the way plants and factories work.
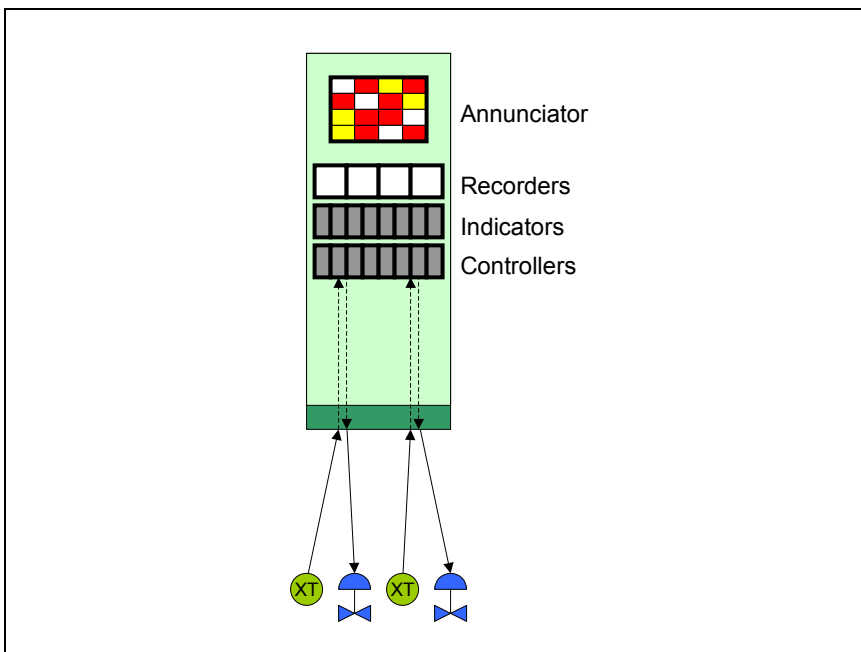
## Digital Communication Networks

Many networks, such as telephone, radio, and television, are primarily analog, but the trend is definitely toward all-digital communication. So too, the networking used in automation is

predominantly digital, that is, data is transmitted serially between devices as a stream of ones and zeroes. Digital communications now makes possible data transfer between devices such as transmitters, valve positioners, controllers, workstations, and servers.

## More Information

A major advantage of digital communications is that a great deal of information can be communicated on a single cable. Instead of one hardwired cable for each variable, thousands and even millions of pieces of information can be communicated along just one network cable. This makes it possible to extract much more information from each device than was realistically possible using analog signals. For example, before digital communications was introduced it was impossible to remotely transmit anything other than simple I/O. Tuning and controller settings had to be done locally (figure 1-1). Therefore all controllers had to be placed in large panels lining the walls of the control room to enable operation directly from the controller faceplate. Sensors and actuators were hardwired to their controllers using an individual dedicated pair of wires and transmitting nothing more than a single process or manipulated variable. The analog signal only traveled in one direction, from the transmitter to the controller or from the controller to the positioner.

**Figure 1-1. In the past, controllers had to be located in the control room panel.**

The advent of digital communications made it possible for the DCS and PLC controllers to be placed away from the control room in an auxiliary rack room. All the supervisory information for hundreds of loops and monitoring points could be transmitted to the operator console in the control room over a single network. Digital communications carry not only I/O like process and manipulated variables but also operational information such as setpoint and mode, alarms, and tuning in both directions to and from the control room. Communications thus enabled distributed processing, and diagnostic, configuration, range, identification, and other information could now be added, initially in controllers but then also in field instruments such as transmitters and valve positioners. Thanks to communications, field instruments now perform not only a basic measurement or actuation but also have features and functions for control and asset management.

## Multidrop

A second major benefit of digital communications is the capacity to connect several devices to the same single pair of wires to form a multidrop network that shares a common communications media (figure 1-2). Compared to running a separate wire for each device, this reduces the wiring requirement, especially for field-mounted instrumentation involving large distances and many devices. Even by putting just a few devices on each pair of wire, the amount of cable required is greatly reduced, translating into hardware and installation savings.
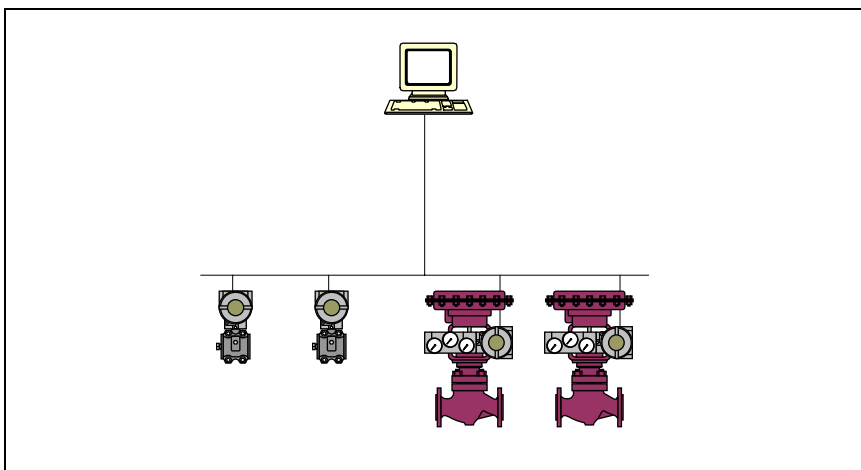
Figure 1-2.  Network nodes sharing a common media.

The communicating devices on the network are called *nodes*, and each node is given a different address that distinguishes it from the other devices. This makes it possible to interrogate and send messages to any one specific device.

In the simplest form of communication, a device such as a host workstation or PLC is the master that sends requests to read or write a value to other devices such as field instruments, which are called *slaves* (figure 1-3). The slave that was addressed then responds to the request. An example of this is a HART® or PROFIBUS master configuration tool or handheld terminal writing a parameter in a slave positioner from time to time, acyclically. In networks with no specific master or slaves such as FOUNDATION™ Fieldbus this method is called "client/server": a device acting as a client requests, and the device acting as server responds. Another example of the master/slave configuration is a master PLC reading a process value from a slave transmitter and then after executing a control algorithm writing the output to a slave positioner. For PROFIBUS closed-loop control this reading and writing is repeated cyclically.
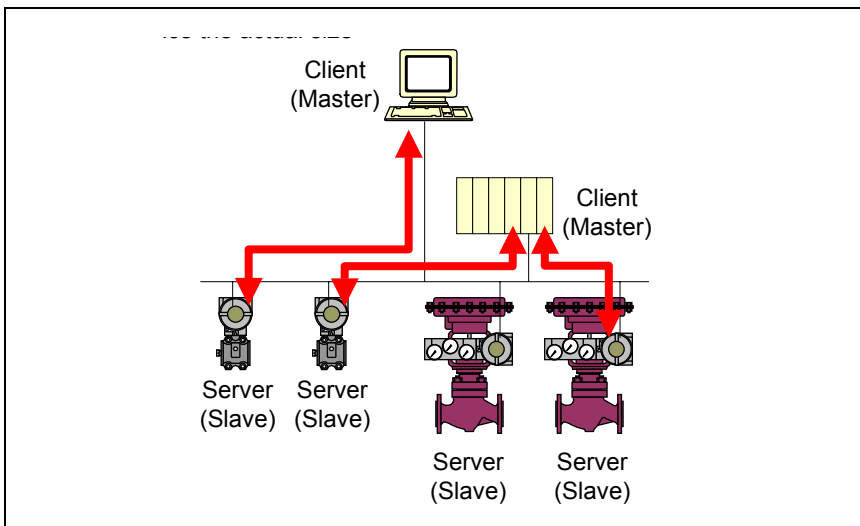


**Figure 1-3.  Client-server (master-slave) relationship.**

Another mode of communications that is ideal for cyclic communication is where a device acting as a "publisher" broadcasts a value that is then used by all interested devices, which act as "subscribers" (figure 1-4). This is very efficient because the value is transmitted directly from one field device to another in one single communication, reaching several subscribers at once. This method

is used by FOUNDATION Fieldbus for closed-loop control. Communicating from one device to another without going through a central master is called peer-to-peer communication.
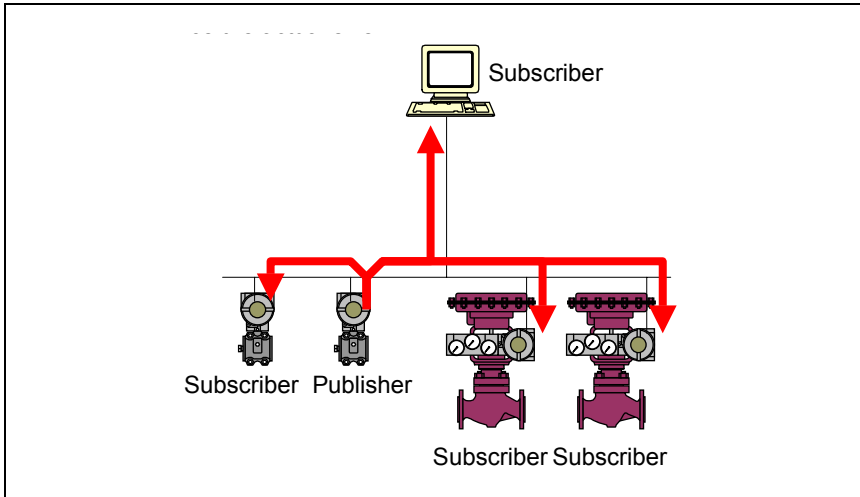


**Figure 1-4.  Publisher-subscriber relationship.**

A third mode of communication is when a device acting as a "source" transmits a message to a device acting as a "sink" without the sink having to solicit the data ([figure 1-5](#)). While the state remains the same it is not communicated. The transmission is only made when there is a change of state sometimes called "report by exception", e.g. when an alarm occurs. This configuration is ideal for environments where operators want devices to report process alarms or fault events as they occur, while otherwise remaining silent.

Rather elaborate schemes are used by all protocols to ensure that no two devices communicate at the same time. This and other aspects of digital communications networks are explained in chapter 11 of *Fieldbuses for Process Control*.

## Robust

In a 4-20 mA analog system value is transmitted by the infinite variation of a current. A signal error just changes a valid signal into another valid signal. The signal from even the most accurate analog transmitter may be totally inaccurate by the time it reaches the controller. Digital communications has the advantage of being a very robust signal with only two valid states (one and zero). It is transmitted directly or encoded in some form and is therefore less
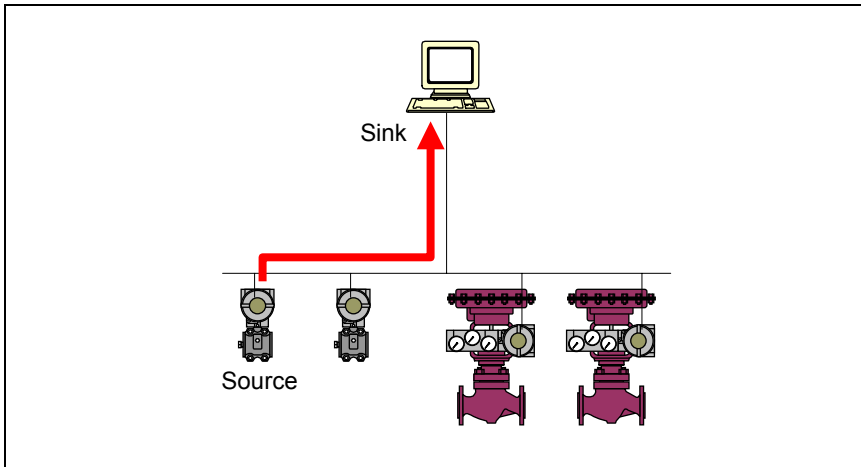
**Figure 1-5. Source-sink relationship.**

sensitive to distortion than an analog signal. Even more impor-
tantly, by using error-checking techniques it is possible to detect if
the digital signal has been distorted, and if it has, to discard the
message and possibly ask to have it retransmitted. Signal distor-
tion cannot be detected in an analog system because a distorted
signal still looks like a valid process signal. An analog signal that
should be 19 mA may jump between 18.97 and 19.03 mA because
of electrical interference or be limited to 18 mA because of insuffi-
cient supply voltage. There is no way to tell this, however, because
it is still a valid signal. Operators may suspect a noisy or limited
signal, but there is no way to tell what is distortion and what is the
real process change. However, a received digital signal is true to
what was originally transmitted. The superior fidelity of digital
signals over analog signals is why they are used in compact disks
as well as in automation; it results not only in higher accuracy but
also in greater confidence level.

## Interoperability

A potential problem with digital communications is that there are
many different ways to do it. The method of representing, encod-
ing, and transmitting the data is called the *protocol*. Manufacturers
have devised many different protocols, and products designed for
one protocol cannot work with those designed for another. One of
the goals of standardization committees is to define a standard
protocol that all devices can follow, thus making it possible for
products from different manufacturers to interoperate, that is,
work with each other. A key point is that a system's power is not
defined by the capability of each of its individual devices but by
the ability of these devices to communicate with each other. Two

best-in-class and ever so powerful devices that don't integrate seamlessly do not create a solution as powerful as two simpler devices that use a standard protocol. For the same reason, the sub-systems for basic, critical, and advanced control in a plant must also have open interfaces. Chapter 11 of *Fieldbuses for Process Control* describes exactly how some of these protocols used in process control work, their similarities as well as their differences. It is not necessary to understand how the buses work in order to use them, however. The buses are designed such that the complexity of their function is hidden; as a result, they are easy to use.

## Automation Networking Application Areas

Networking is used in all areas of automation. In factory automation, process automation and building automation networks perform diverse tasks. Likewise, there are distinct differences between tasks performed for applications in different industry sectors that all have unique characteristics and consequently varying requirements. The way devices are connected, configured, and exchange data also differ.

There is no one-size-fits-all for industrial networks; rather, buses are optimized for different characteristics. For example, factory automation and process automation are often used in harsh and hazardous environments where people, nature, and expensive machinery are at stake or where a production interruption is costly. These requirements contrast significantly with building automation, for example, where keeping costs low is a main driving force.

### Factory Automation

Factories with assembly-line manufacturing, as in the automotive, bottling, and machinery industries, are predominantly controlled using discrete logic and sensors that sense whether or not, for example, a process machine has a box standing in front of it. The network types ideal for simple discrete I/O focus on low overhead and small data packets, but they are unsuitable for larger messages like configuration download and the like. Examples of this network type are Seriplex®, Interbus-S, and AS-I (AS-Interface), which are sometimes called *sensor buses* or *bit level buses*. Other more advanced protocols oriented toward discrete logic include DeviceNet™, ControlNet™, and PROFIBUS (DP and FMS application profiles). These buses are sometimes referred to as *device buses* or *byte-level buses*. Factory automation involves fast-moving machinery and therefore requires quicker response than slower processes. Traditionally, these tasks have been handled by PLCs.

## Process Automation

Process plants in industry segments like refining, pulp & paper, power, and chemicals are dominated by continuous regulatory control. Measurement is analog (here meaning scalar values transmitted digitally), and actuation is modulating. Of course, process industries also use some discrete control and the predominantly discrete manufacturing industries use some discrete. Fieldbus on/off valves are already available in the market, as are small remotely mounted I/O modules for discrete sensors. In the past, a DCS or single-loop controller did this.

Process-related networks include FOUNDATION Fieldbus, PROFIBUS (PA application profile), and HART—they are the focus of this book. All these buses as a category are now typically referred to as fieldbus (without the capital *f*), though some would argue that one or the other does not belong. These three protocols were specifically designed for bus-powered field instruments with predefined parameters and commands for asset management information like identification, diagnostics, materials of construction, and functions for calibration and commissioning. In terms of size, the networks used in industrial automation are considered to constitute local area networks (LAN) spanning areas no greater than a kilometer or two in diameter and typically confined to a single building or a group of buildings. Networks that extend only a few meters are insufficient, and networks that span cities or even the globe are overkill.

## Field and Host Tier Networks

Even within control systems for the process sector there is a need for different network characteristics at each tier of the control system hierarchy. At the field end there are instruments such as transmitters and valve positioners that have their specific needs, and at the host level there are workstations, linking devices, and controllers that have other needs (figure 1-6).

When fieldbus began to evolve, the process industry put a large number of requirements on the field-level network that were not met by other types of networks. Many new design considerations needed to be taken into account. On the upper tier, data from all the field-level networks have to be marshaled onto a single host-level network that also serves any tasks the plant may have that seem related to factory automation.
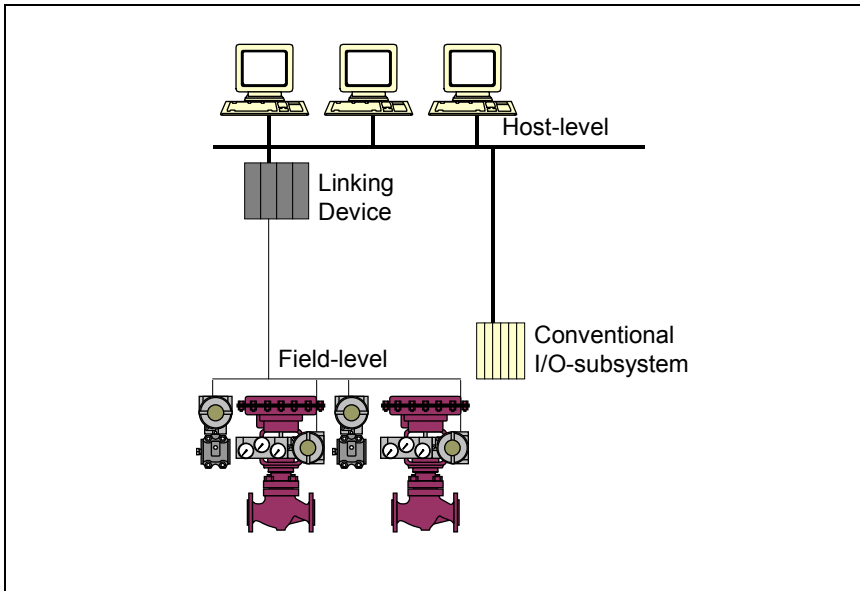
**Figure 1-6.  Two-tiered automation network architecture.**

## Field Level

At the field level, the dominant protocols for process instruments are HART, FOUNDATION Fieldbus H1, and PROFIBUS PA. HART is significantly different from the other two in that it is a so-called smart protocol, that is a combination of digital communication simultaneously superimposed on a conventional 4-20 mA signal. As such, the HART protocol has been an ideal intermediate solution in the transition from analog. HART is compatible with existing analog recorders, controllers, and indicators while at the same time it makes possible remote configuration and diagnostics using digital communication. The HART protocol does allow several devices to be multidropped on a single pair of wires, but this is a capability infrequently explored because of the low update speed, typically half a second per device. For a vast majority of installations HART devices are connected point to point, that is, one pair of wires for each device and a handheld connected temporarily from time to time for configuration and maintenance. Both FOUNDATION Fieldbus H1 and PROFIBUS PA are completely digital and even use identical wiring, following the IEC 61158-2 standard. However, beyond that there are major differences between these two protocols, and depending on the desired system architecture one may be more suitable than the other.

At the field level, instruments appear in large quantities, often in the hundreds or thousands. The wire runs are very long, as the net-

work cable must run from the control room all the way into the field, up towers, and then branching out to devices scattered throughout the site. Because there is a limit to the number of devices that can be multidropped on each network, even a medium-sized plant may have many network cables running into the field, although substantially fewer than if point-to-point wiring was used. The field-level networks were therefore designed to enable very long wire runs and to allow field devices to take their power from the network. Only a single pair of wires carries both the device's power and the digital communications signal. This eliminates the need for a separate power cable, thus keeping the wiring simple and inexpensive.

As another measure to keep costs down, designers chose a moderate field-level network speed so normal instrument-grade cable could be used instead of special data cable. No special connectors, couplers, or hubs are required either, which makes it possible to use rugged and weatherproof connections. The grade of cable used for conventional instrument connections on most sites is more than sufficient for fieldbus networking. As a result, it is possible to reuse that cable when an existing plant is migrated to fieldbus. In hazardous process environments where flammable fluids are present intrinsic safety is many times the preferred protection method. The field-level networks were therefore designed to allow safety barriers to be installed on the bus.

Because designers chose a moderate field-level network speed the devices connected to it do not require a great deal of CPU processing power to handle the communication quickly. As a result, they also consume very little power. Because the low power consumption results in low voltage drop along the wire, it is therefore possible to multidrop several devices on the network even for long wire distances and even when using intrinsic safety barriers. Another great advantage of field-level networks is that they provide a lot of freedom when it comes to network topology since wires can be run quite freely. Finally, these fieldbus networks were also designed to operate in the often rather harsh, electrically noisy environment found on site.
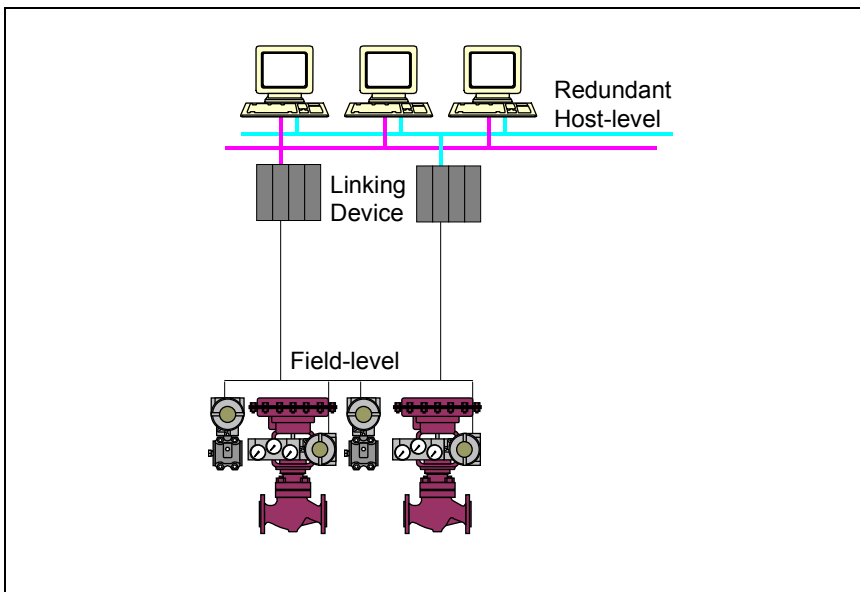
## Host Level

At the host level, the Ethernet network standard is already the dominant wiring technology (). There are many protocols built on Ethernet wiring, including FOUNDATION Fieldbus HSE, PROFInet, Modbus/TCP, and the like. Sites employing fieldbus instrumentation and asset management software can expect to

encounter a steep rise in bandwidth requirements and must there-
fore have a high-speed network at the host level.

The field-level networks have made it possible to retrieve so much
more data from the field instruments that an information explosion
has resulted, one that old proprietary control level networks are
unable to cope with. Ethernet provides the throughput required to
transfer the large amount of data used for traditional plant opera-
tion and historical trending; for new capabilities for remote diag-
nostics, maintenance, and configuration; and for the quick
response necessary for factory automation task. Ethernet was cho-
sen for these applications because its high speed enables it to carry
all this information. Moreover, Ethernet is already a standard and
consequently is well understood and widely used. A large variety
of equipment and solutions for Ethernet is available. Ethernet wir-
ing is discussed in chapter 3 of *Fieldbuses for Process Control*.



**Figure 1-7.  Host-level network redundancy for availability.**

In many applications, one of the key requirements for the host-
level protocol is availability. The network must be fault tolerant—
up and running even in the presence of a fault. This is extremely
critical at the host level since the entire site is operated and super-
vised over this network. Downtime can be very disruptive and
cause heavy losses; a complete breakdown of the network would
be extremely serious. Though Ethernet originated in the office
environment, rugged industrial-grade (as opposed to commercial-

grade) accessories and wiring schemes can be used. The host-level network was designed so redundancy may be used, making the network fault tolerant. Industrial-grade networks that use several layers of redundancy and industrial-hardened components can handle many simultaneous faults.

Physical remoteness is less important for the host-level network because it is typically confined within the control room, and the distance Ethernet provides is therefore sufficient. An advantage of an established standard like Ethernet is that several media options are available. On copper wire Ethernet is unsuitable for the field because it does not run long distances. It is therefore limited to use within the control room (i.e., a "hostbus" rather than a fieldbus). However, optical fiber Ethernet can run very long distances, as can radio signals, making Ethernet suitable for remote applications.

**Table 1-1. Comparison of field and host level characteristics**

|  | **Field Level** | **Host Level** |
|---|---|---|
| Speed | Low | High |
| Distance | Long | Short* |
| Two-wire | Yes | No |
| Multidrop | Yes | No* |
| Bus power | Yes | No |
| Intrinsically safe | Yes | No |
| Media redundancy | No | Yes |
| Note: Fiber-optic Ethernets can run long distances. Using the old coaxial cable wiring Ethernet can also be multidrop, but this introduces other problems. | | |

The host-level network ties together all the subsystems the process automation system might have. In addition to the basic control function, a plant often has package units for auxiliary functions such as boilers or compressors that are bought ready-made. They have their own controls that need to be integrated with the rest of the system (figure 1-8). For example, a refinery may have a safety shutdown system, a paper mill may have a web scanner, and a chemical plant may have an advanced control system. Subsystems based on a standard protocol on Ethernet can simply be plugged into the rest of the system.

The host-level network tier makes large systems possible by linking together field-level networks from different areas around the site. Intra-area control and supervision becomes possible. The host-
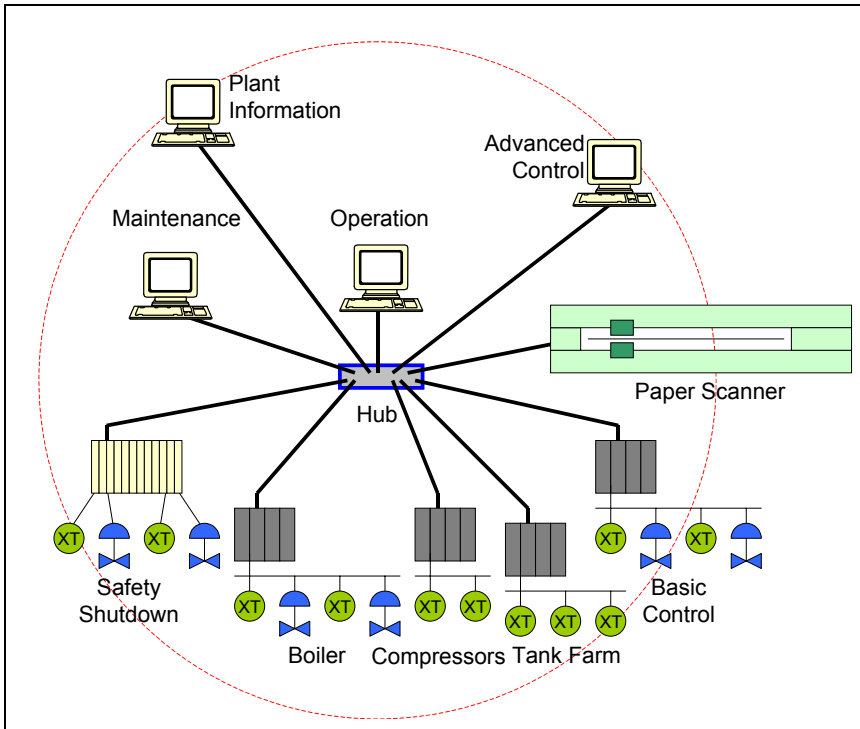
**Figure 1-8.  A standard host- level network ties distributed subsystems together.**

level protocol is also the link to business systems, either directly or via historians and other plant information software.

It is important to remember that the Ethernet standard is not a complete protocol. Essentially, Ethernet only specifies different options for cables and how devices on the network access the bus. Ethernet does not specify data formats or the semantics of the data. Even when used with other technologies like TCP/IP and UDP the protocol is incomplete. Several control system manufacturers have been using Ethernet for many years, but each one has implemented it with data formats and functionality different from the others. Even with TCP/IP, most of the Ethernet networks used in control systems on the market today are in fact proprietary since other devices cannot access and interpret the information even though connected on the same wire and existing without conflict. As a result, take great care when buying products and systems for Ethernet; they are often not as they appear to be. TCP, UDP, and IP are discussed in chapter 4 of *Fieldbuses for Process Control*.

*It is a good idea to look for complete open protocols based on Ethernet so devices and subsystems from different sources can talk to each other, even peer to peer.*

## Homogeneous Network Architecture

Because of their almost opposite requirements, different network features are required at the field and host levels. Because the field-level network is slow it is unsuitable for the host level, and because the host level has too limited a distance it is unlikely it will be seen in the field. The field-level network takes the place of the traditional protocols for smart instruments and I/O subsystems, and the host-level network takes the place of the control network and business network. The host-level network in the control system uses the same networking technology as the business network so they can be integrated seamlessly. A simple router between the networks safeguards performance by keeping pure business communication traffic separate from pure control communication traffic.

For easy and tight system integration it is important to select a homogeneous network architecture in which the protocols at the higher and lower tiers are essentially the same but just traveling on different media. This will ensure transparency and a minimum of problems with communication mapping and interoperability. Fortunately, there are protocols available in such "suites." Good combinations would be FOUNDATION Fieldbus H1 and HSE or PROFIBUS PA and PROFInet. If a proprietary protocol is used at the host level or somewhere in the link between the instruments and the operator important functionality and interoperability may be lost. This may force engineers to perform time-consuming mapping of parameters between protocols.

The use of the same technology throughout the system greatly simplifies the initial engineering and deployment of the system as well as its ongoing operation and management. Engineers can readily work with different parts of the system without retraining.

# History of Fieldbus

The history of process control networks is very much the history of the IEC 61158 Fieldbus standard.

## Lack of Interoperability

When digital communications first began to appear every vendor invented its own protocol independently of others. Soon many dif-

ferent proprietary protocols were in the market, and products could only work with other products from the same vendor. Moreover, documentation on the operation of these protocols was typically not available, and the technology was generally protected by patents. Other manufacturers would have to pay high licensing fees to implement the technology in their products—if they were allowed to do so at all.

This situation resulted in several disadvantages. One was that no vendor had a range of products wide enough to provide all the parts a site required. The selection of equipment was very limited, so it was always necessary to mix and match equipment from different suppliers. Moreover, one supplier is never the best at everything, so it was desirable to buy the device types from the manufacturers that were specialists in each particular area. Because the equipment from different suppliers had incompatible protocols a site was stuck with a few undesirable options: either choosing the preferred device despite its poor integratibility with the rest or settle for the less-than-best device to gain better integration. Most of the time, however, it was not possible to network the parts together, resulting in isolated islands of automation.

In one common scenario, a PLC and a DCS would have to be connected, but digital integration of the system was impossible since each component communicated using a different protocol. If the manufacturers allowed licensing and provided proper documentation, a communication driver could be developed—but at great expense in time and money. A third party often developed the drivers, and when communication problems arose the parties would point fingers at each other. To complicate matters further, one driver was required for every combination of hardware and software, producing an unmanageable situation for suppliers too. Many times no communication at all was possible, and to pass data subsystems had to fall back on conventional analog and discrete signals. Because of the protocol differences third-party field instruments could not be integrated with the DCS to fully benefit from their intelligence, nor could one supplier's handheld terminal or other configuration tool work with a device from another.

## The Need for a Standard

Once a proprietary system had been purchased the plant was essentially "locked in" by the manufacturer. To maintain system integration the plant would have to purchase replacement transmitters from the system supplier, who was also the only one that could do system expansions. Because the system supplier at this

point no longer had any competition, replacement parts and extras would be much costlier than they were for the first system. Many plants were aware of this but were still willing to pay the price of being tied to a single manufacturer simply because of the high cost of struggling with system integration in a situation where incompatible protocols required drivers.

Being locked in can be dangerously costly, so many governments prevent the use of proprietary technologies in public projects. Many instrument suppliers were also displeased with the situation. Despite the fact that they often had higher-performance products, the instrument suppliers were unable to compete with the systems suppliers simply because of the incompatibilities. Furthermore, adapting their products to a myriad of protocols was extremely costly, driving up product prices. As is often the case when standards are lacking, there was anarchy in the market.

## Standardization

Because the situation was clearly intolerable, in 1985 industry experts began work on a vendor-independent fieldbus standard. Networking is a key element of an open system, and it was paramount that an interoperable fieldbus be developed that was supported by multiple vendors and based on a freely available standard without licensing. Standardization is an enormous task that not only involves the development of a technology but has economic and political implications for factories, manufacturers, and even nations.

Because of the unique needs of the process control environment no existing standard for networking could be used. A new technology had to be developed for the standard that provided bus power, intrinsic safety, the ability to communicate long distances over normal instrument wires, and so on. This development process led to an international fieldbus that could not move as fast as other networks that used an existing platform from telecommunications or automotive industry. Nevertheless, it filled an important need. Many of the systems suppliers who participated in developing the standard had vested interests in the old technology and a comfortable market share in the proprietary paradigm. Standards allow competitors to take away customers that had previously been locked in to a particular supplier's proprietary technology. Thus, these proprietary suppliers had a responsibility to their shareholders to see the fieldbus standard fail so they could avoid tougher competition.

Naturally, some companies and nations wanted to see their exist-ing technology and national standards adopted as the international fieldbus.

These factors further contributed to the delay in the ratification of the single fieldbus standard. The world failed to agree on a single standard protocol, and as a result several competing and noncom-patible bus technologies are now being included in a multi-part standard that is not yet fully completed. Parts of both FOUNDATION Fieldbus and PROFIBUS, though not HART, are elements of this standard, but devices of these two types cannot communicate with each other since the protocols are not compatible.

## Industry Groups

Frustrated with the delays in the development of standards, manu-facturers and end users formed organizations to fast-track the cre-ation of open fieldbus specifications. In 1992, the Interoperable Systems Project (ISP) was formed to develop a technology partly based on PROFIBUS and soon thereafter WorldFIP to develop another based on FIP. Because these are open organizations that develop and maintain the technology, both projects have the open-ness of a true international standard. The organizations split and merged, but for the process industries organizations had by 1994 essentially crystallized into the Fieldbus Foundation and Profibus International.

FOUNDATION Fieldbus and PROFIBUS PA have a common heritage in the ISP technology; therefore, the concept of block, parameter, mode, and status is very similar. The FOUNDATION H1 technology was released soon after followed by PROFIBUS PA in 1996. FOUN-DATION HSE was released in 2000, and by 2001 PROFInet was already on its way. For several years now, manufacturers have been delivering products based on these specifications, and plants are already reaping their benefits. Large parts of the specifications are being adopted as national standards and will soon also become an international standard. However, some parts of both technolo-gies are still under the control of the organizations.

During fieldbus's long gestation period some originally propri-etary protocols such as HART and Modbus were opened up and made available to other manufacturers. These were tremendously successful in filling the gap and now have an enormous installed base and will keep selling for years to come.

## Advantages of Standards

Once the standards were in place plants could truly begin to bene-
fit from integration without paying the high price of being tied to a
single manufacturer (figure 1-9). Standards have already resulted
in compatible equipment now available from several suppliers.
More than one company now manufactures device types that are
based on the same fieldbus technology. This has led to a competi-
tive open market, a desirable development because it reduces
prices. Sites that employ standards are protected from proprietary
solutions that force them to be dependent on a single vendor. Simi-
larly, the plants that have adopted standards have many more
options available for devices and software. This enables them to
find solutions for their very diverse application needs, needs that
cannot be met by a single supplier but require equipment from sev-
eral manufacturers. Device manufactures can once again concen-
trate on true innovations rather than tweaking communication
protocols.



Figure 1-9.  The world's first H1 fieldbus plant. (Courtesy of Smar)

## Evolution of Control System Architecture

Field signaling and system architecture developed in very close-
knit fashion. Every improvement in signal transmission has subse-
quently led to an increased level of system decentralization and
better access to field information. In the pneumatic era the control-

ler was typically situated in the field and there operated locally. There was therefore no system to speak of. With the analog current loop it became easier to bring a signal from the transmitters in the field to a central controller in the control room and then from there back out to the valves again. In the completely centralized direct digital control (DDC) architecture the complete control strategy was executed in a computer. Because all the functions were concentrated into a computer the entire system with all of its loops would fail if there were even a single fault. For this reason, it was not uncommon to have local pneumatic controllers existing in the field on standby, ready to be put in operation once the DDC failed. Clearly, the centralized architecture had some serious availability issues, which led in the early 1970s to the introduction of more decentralized programmable logic controller (PLC) and distributed control system (DCS) architecture.

## DCS and PLC Architecture

The DCS and PLC emerged with the advent of digital communication, but these architectures were also designed based on 4-20 mA for field transmitters and valve positioners. However, the DCS was a great improvement over the DDC in that the controls were now distributed over several smaller controllers that shared the tasks, each one handling perhaps thirty control loops. This had the immediate benefit that a single fault would only affect part of the plant, not all of it as with the DDC. In other words, a higher level of distribution increased the availability of the system.

A secondary benefit was that the configuration could be better structured where separate plant units were also kept separate in configuration and controllers. The DCS and PLC architectures are characterized by conventional I/O (input/output) subsystems or "nests" in which racks of I/O modules are networked to their respective centralized controller via an I/O-subsystem network. Field instruments were predominantly conventional analog devices. The controllers are networked with each other and to the workstations via a control-level network. There may also be a plant-level network at the very top that links the workstations to the business environment. The DCS evolved over many years, and such capabilities as communications interfaces for smart instruments that used the manufacturer's proprietary protocol became an option. This allowed some degree of configuration and check. Not all of the smart instrument protocols allowed simultaneous 4-20 mA and communication. For this reason, many were unable to use the communication feature. However, most DCS models did not provide HART interface because all the system manufacturers

had their own competing proprietary protocols. Thus, plants were inclined to buy the field instruments from the system supplier rather than from third parties.

A DCS can often have, in all, as many as four different tiers of networking, each with a different technology: device, I/O subsystem, controllers, and plant-wide integration to business applications (figure 1-10). All these levels of hardware and networking result in a rather complex and costly system.
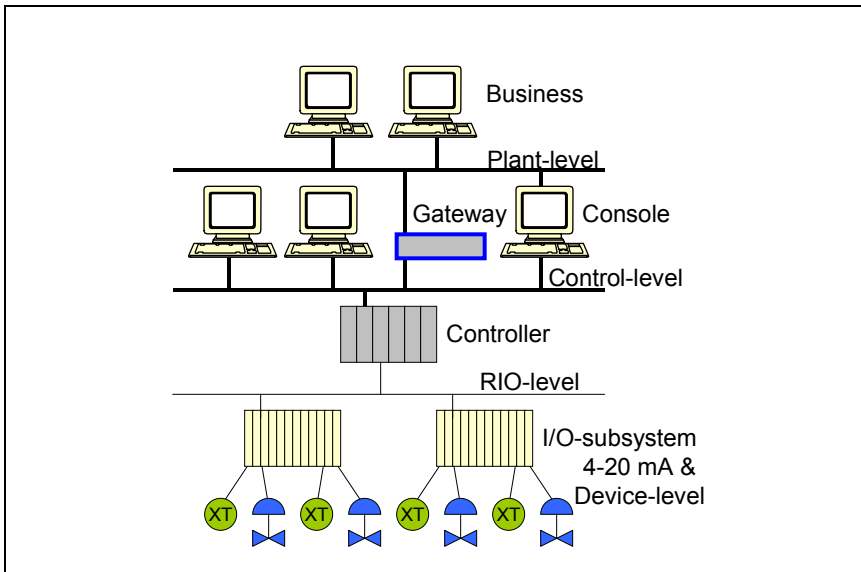


**Figure 1-10.  The traditional DCS and PLC architecture has multiple network levels.**

When introduced, the DCS was christened "distributed" because it was less centralized than the DDC architecture. By today's standards, however, the DCS is considered centralized. This architecture is relatively vulnerable because just one failure may have widespread consequences. Because of this vulnerability, redundancy of controllers, I/O-subsystem networking, I/O modules, and the like is a must to avoid a total loss of control. Of course, redundancy at every level means complexity and high price.

## FCS Architecture

The FOUNDATION Fieldbus specification is uniquely different from other networking technologies in that it is not only a communications protocol but also a programming language for building control strategies. One of the possibilities that a standard

programming language and powerful communications features enable is the ability to perform control that is distributed into the field devices rather than a central controller. For example, it is common for the valve positioner to act as a controller for the loop it is part of. It executes the PID function block but only for its own loop, not for other loops. This new architecture based on field device capability is called Field Control System (FCS) and is an alternative to DCS (figure 1-11) in that the architecture is not controller-centric. It does not treat every field device as a peripheral. Because of its decentralized nature the FCS architecture has advantages like high availability, greater scalability, and lower cost. The FCS architecture has evolved from the concept of the DCS carrying the original concept further, and the result is a system that is more distributed and therefore less vulnerable to faults.

In the FCS architecture the instruments on the field-level networks are connected to the workstations via a linking device to the host-level network. Thus, there are only two network tiers in a FCS. Typically, the field instruments perform the regulatory control that in the process industries accounts for the bulk of the automation tasks. The linking device or a central controller may perform discrete logic and sequence controls. When control is performed in the field devices the number of central controllers that is required is drastically reduced and in some cases eliminated altogether. This dramatically cuts the cost of the system. In other words, wire savings are not the only hardware savings that can be achieved by using bus technology. Since the central controllers have the computation-intensive regulatory controls offloaded they are freed up to execute other controls with higher performance, thus improving controls.

Because in the FCS no one controller handles multiple loops the problem of a single fault affecting a large part of the plant is largely eliminated. However, even in an FCS a centralized controller can often be found handling discrete I/O and controls since these functions are still seldom networked. Whenever a plant uses centralized controllers, it should employ redundancy if availability is a necessity.

It may at first be hard to comprehend how small field device controllers could replace a "unit controller" to control a large plant. The secret behind this concept is that each device handles only one loop. By networking hundreds or thousands of devices together the combined power of the microprocessors exceeds that found in earlier systems. The control task is broken up into its components
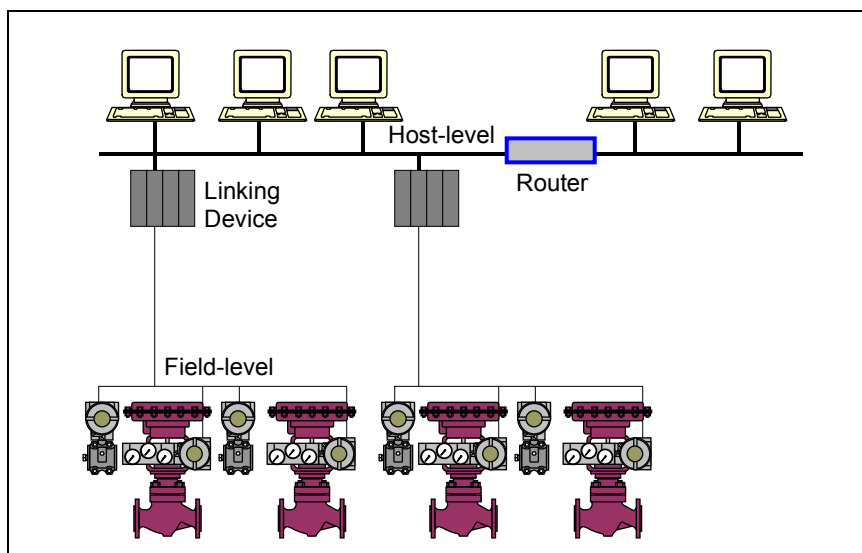
**Figure 1-11.  FCS architecture with control in the field devices.**

and distributed among the field devices working in parallel, with
each device responsible for its loop. Since these devices work
simultaneously a true multitasking system is achieved, something
that cannot be realized using only a single processor. The net result
is therefore very good performance, and the more devices that are
added the more powerful the system becomes. This increased
power has made it possible to eliminate the need to scale analog
values. For centralized systems, this scaling had not always been
possible because it loaded the processor too much. Floating-point
format is now used throughout the control strategy.

## Host versus System

Because a 4-20 mA signal carries only a single piece of information
and only in one direction, operators had no way of determining
what was going on within analog field devices. It was impossible
to perform configuration, diagnostics, and other checks from the
system console. In the cases where smart instruments had been
adopted a handheld terminal was usually used to extract any addi-
tional information. Conventional and even smart devices were not
integrated within the control system. The operator's view extended
down to the controllers and possibly to the I/O subsystem, but no
further. Because the field instruments were isolated entities, they
were treated as separate from the control system rather than part of
it.

In an FCS the field instruments are an integral part of the system as a whole. All that remains of what used to be called the system is the workstations and linking devices. The workstations that connect directly to the host-level network are simply referred to as the host (figure 1-12).
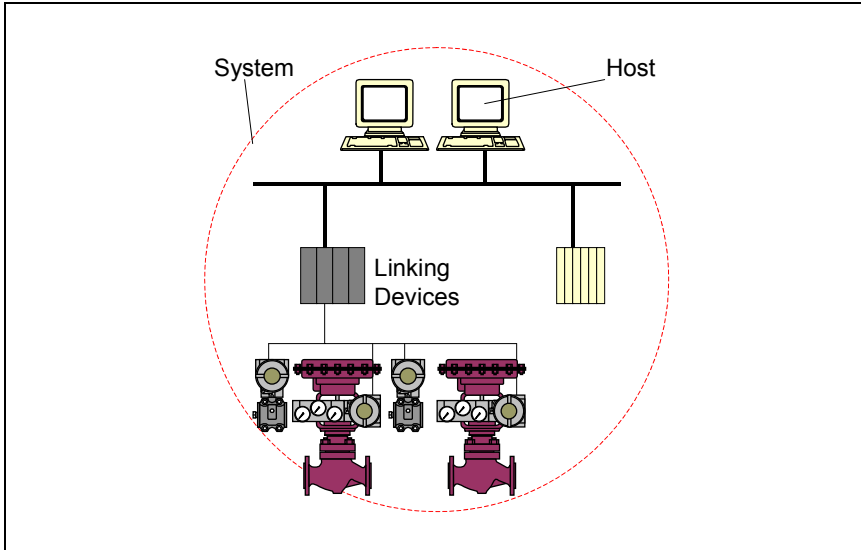


**Figure 1-12.  Field devices, and host, are integral parts of the system.**

# Basic Network Differences

It is technically possible to use FOUNDATION Fieldbus or PROFI-BUS PA technology in any kind of system architecture. Systems based on conventional architecture can also benefit from the wire reduction made possible by field-level networks. However, few traditional systems have native support for fieldbus.

## Communications Subsystem Differences

The communications interfaces required by a host are different for the pure digital communication in FOUNDATION Fieldbus and PROFIBUS on the one hand and for the hybrid of analog and digital for HART on the other. For PROFIBUS and FOUNDATION Fieldbus a single integrated network architecture is used for I/O as well as for asset management. Because its communication speed is low HART relies on the analog 4-20 mA signal for real-time process I/O and a HART device is therefore connected point to point. In most systems, the 4-20 mA only connects to conventional I/O modules via individual wires, and any communication with the device is performed with a temporarily connected portable hand-

held terminal. However, plants should enhance HART installations by integrating a permanently fixed communications subsystem that is connected in parallel with conventional I/O. This brings full field device data into the control room, making it easy to benefit from device intelligence. A HART multiplexer is connected to all smart devices, giving the device configuration tool complete access (figure 1-13). Alternatively, an I/O subsystem with built-in HART capability may be used. Without digital integration many plant operation improvements are simply not possible.
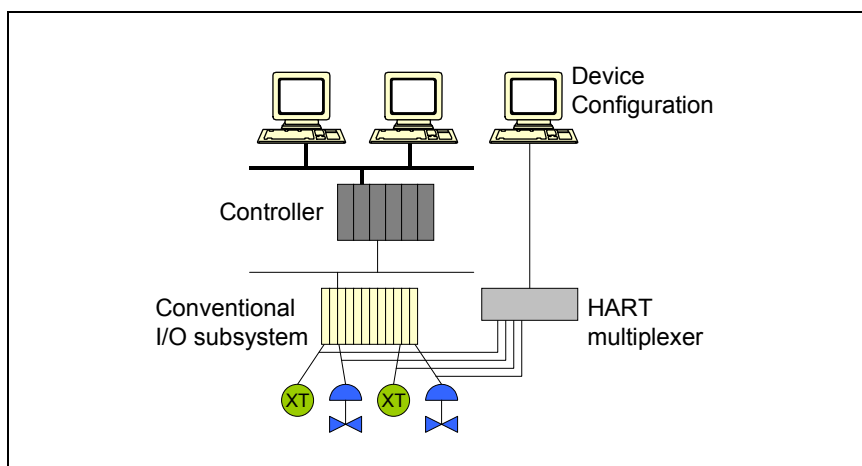


**Figure 1-13.  A HART multiplexer taps the digital signal from smart instruments.**

Because HART blends the benefit of digital communications with complete analog compatibility the transition from pure 4-20 mA to HART became easy and HART's success was assured. In a pure digital system based on FOUNDATION Fieldbus or PROFIBUS, full information access comes built in since all communication is digital, the networking infrastructure is in place for I/O, and no additional hardware or wiring is required.

## Other Technical Differences

The HART and PROFIBUS technologies do not have a control strategy programming language. FOUNDATION Fieldbus has a standard function block language and publisher/subscriber communication. It therefore has the ability to constitute an FCS, but it can also be used in a DCS or PLC. HART and PROFIBUS are only used in DCS or PLC architectures, be it a traditional embedded PLC or PC-based software logic. A traditional DCS using FOUNDATION Fieldbus would not achieve the controller reduction and network

simplification savings achieved by the FCS. Thus, one of the main criteria for selecting a bus technology is what architecture is desired. For a DCS or PLC, either one can be used; for a full-fledged FCS only FOUNDATION Fieldbus is possible. FOUNDATION Fieldbus has a number of useful communication features not offered by most other protocols. These include automatic device detection and address assignment for Plug-and-Play installation and time synchronization. PROFIBUS has PROFIsafe for communication between instruments in safety- related systems, which FOUNDATION and HART do not offer.

## Commercial Differences

Of course, there are other criteria to consider when selecting the principal network to be used in the system. Are the device types and tools the plant requires available in a version that has the desired protocol? Are there multiple vendors of the product types the plant requires so as to ensure a competitive price now and in the future? Do the manufacturers of the products that will be used have good local support through either their own offices or representatives, or do the products have to be imported without support?

## EXERCISES

1.1    Is all networking digital?

1.2    Is HART a master/slave protocol?

1.3    Is FOUNDATION Fieldbus also a control strategy programming language?

1.4    Is publisher/subscriber a more efficient way of communicating cyclic data than master/slave (client/server)?

1.5    Which type of automation generally requires faster network response times, factory automation or process automation?

1.6    Is Ethernet a protocol?

1.7    Does a distributed architecture increase availability?

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2.   *Draft PROFIBUS Profile, Fail Safe with PROFIBUS*, Revision 1.0, Order No. 3.092, April 1999.

3.   *Technical Description, Order Number 4.002*, PROFIBUS Nutzenorganisation e.V., September 1999.

4.   *Technical Overview, FD-043*, Revision 2.0, Fieldbus Foundation, 1998.

# Appendix A

# Solutions to Exercises

## Chapter 1

1.1    No. For example, telephone and television systems are networks that, at least for now, are still very analog.

1.2    Yes.

1.3    Yes.

1.4    Yes, it requires fewer transactions. Master/slave needs to make one read transaction and then one write transaction for each recipient, whereas publisher/subscriber only needs a single direct transaction from originator to all recipients.

1.5    Factory automation.

1.6    No. It is just a physical and data link layer, but nevertheless an essential platform for many protocols.

1.7    Yes. Any fault affects a smaller part of the plant.

# Appendix B

## Table of Contents of
# Fieldbuses for Process Control

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**Product Code: REMC7201**