SIEMENS

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Catching the Process Fieldbus

An Introduction to PROFIBUS and PROFINET

2nd edition

Contents

Foreword

To the beginner, the world of industrial communications appears as a multi-layered, multidimensional, occasionally confusing mixture of fieldbuses, software packages, and media. During my twenty years of enthusiastic pursuit and promotion of industrial communications, I have become used to seeing that deer-in-the-headlights look of a newcomer to the field, and decided to see if I could take the fieldbus world, specifically that of PROFIBUS and PROFINET, and take away some of the mystery and magic that cloaks it.

My intent was not to write the definitive and comprehensive handbook on PROFIBUS and PROFINET. There are others who are far more qualified than I to undertake that task. I wanted to show that when industrial communications is understood and then installed with forethought and care, network operation can be both beneficial and painless.

To that end, we designed this book to speak to the beginner, to take that interested newbie by the hand and guide him/her through the bus route to communication success. However, this is not a how-to manual. Rather, think of it as a primer laying the groundwork for communication design, providing information for the curious to explore and motivation for the dedicated to go further.

So, we discuss BUS operations, protocol details, physical layers and networks, network design basics, installation tips and suggestions, commissioning, maintenance, plant asset management, and troubleshooting. All of these topics are designed to speak to the beginner – to take the whole of PROFIBUS and PROFINET as a fieldbus systems and spread them out for everyone to sample and to investigate.

Our hope is that you will leave this book with a firm understanding of what you will need to implement a PROFIBUS and PROFINET systems, and that you will look further into how PROFIBUS and PROFINET can help you and your organization improve safety, efficiencies, and productivity.

James Powell, P.Eng.

Acknowledgements

Chapter One
Introduction: a BUS

"The time has come," the Walrus said, "to talk of many things."[1]

Like Alice and the many adventurers before and after her, you are invited to join us on a journey of discovery. Instead of going down a rabbit hole, however, we ask you to step aboard a bus, grab a transfer ticket, and go for a ride. There will be no white rabbits, talkative caterpillars, or chubby oysters, but we can promise you plenty of adventure as we take the bus through networks, fieldbuses, and communication protocols.

BUS route

This bus makes the following stops:

- Introduction to Fieldbus
- Benefits of using a fieldbus
- PROFIBUS and PROFINET: genesis
- PROFIBUS decentralized peripheral (DP)
- PROFIBUS process automation (PA)
- PROFIsafe
- PROFIdrive
- PROFINET
- Next stops

Introducing fieldbus

PROFIBUS and PROFINET are each a fieldbus: a fieldbus is a two-way communication link between a controller or monitor and a field device. It is a network that is required for integrating process automation devices into a unified system. The key to fieldbus operational success is that the controller has to be able to not only talk to the field device but also have the field device talk back and alert the controller if needed. This digital dialogue in turn alerts the user when key events occur on the network, providing a host of data required to keep a process active. A fieldbus is the nerve network between the central brain (controller) and all the parts that keeps the process plant functioning at maximum capacity.

Two-way communication is the key aspect of fieldbus.

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[1] Carroll, Lewis. *Alice in Wonderland*. W.W. Norton & Company, 1971. p. 142.

A protocol is a set of rules (standard) defining how two or more devices can communicate.

Currently there are many open protocols available; HART, Foundation Fieldbus, DeviceNet, Modbus, EtherNet/IP to name a few.

This chapter introduces PROFIBUS and PROFINET as the primary communication protocols for process industries, and demonstrates the advantages these proven *fieldbuses* bring to industry.

Automation

Automation is defined as the use of technology to control a series of events with little or no human assistance. There are generally two categories of automation:

Open protocol is a protocol that is not owned by any one company and can be used by anyone.

- factory automation
- process automation

Factory automation refers to automation used in the manufacturing of discrete objects like cars and computers. Most of the information types coming in and going out are discrete variables – turn this on or that off. In addition, the factory processes tend to be very fast, so there is a need for a fast network.

Process automation refers to automation used in the production of goods that require some sort of formula or sequence of events like the making of cookie dough or mixing of chemicals. Most of the information coming in and going out comprises analog variables – add 7.341 kg of that or raise the temperature of this to 32.5 degrees C. In addition, process automation processes tend to be fairly slow (compared to factory automation), so there is a reduced need for speed.
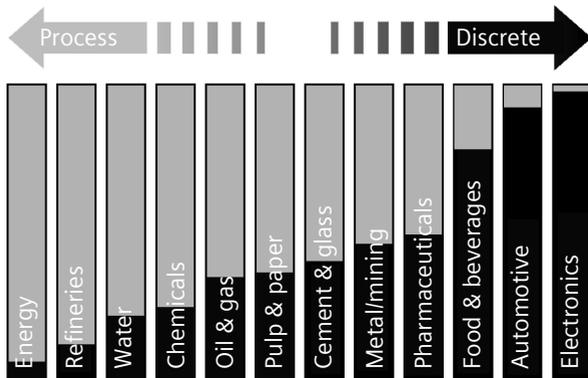
Most industries have a mix of factory and process automation. For example, a car assembly plant would be mainly factory automation, however to assemble a car also requires a lot of water so most car assembly plants also have a water treatment plant which is mainly process automation. PROFIBUS, or PROFINET with some PROFIBUS, are the only protocols that can do both process and factory automation well – meeting all requirements.

Many books on PROFIBUS and PROFINET talk about both types of automation but tend to focus on factory automation. This book also discusses both but focuses on process automation.

Relationship between instrument and control system[2]

In non-fieldbus control systems, there was a clear division between the field devices and the control system. Typically, the instrumentation technologist looked after the field devices and the control engineer scaled the 4–20 mA analog value coming into the control system. The control engineer still checked the accuracy and response rate, but wasn't overly concerned with the details of the instrument.
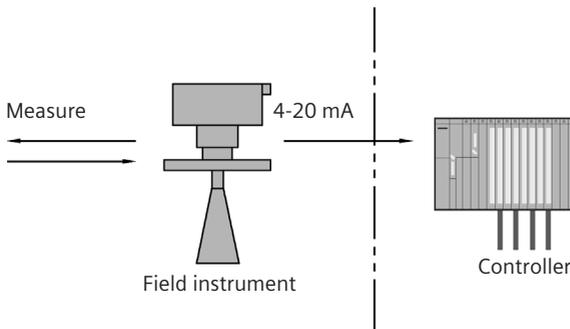
With PROFIBUS PA, the instruments are an integral part of the system, and the control engineer has full control of the devices. From the engineer's point of view, there is now no distinction between the instruments and the control system. It's an integrated whole.

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[2] Powell, James. *The Benefits of the Block Model Concept in Fieldbus Systems.* ISA, 2005.
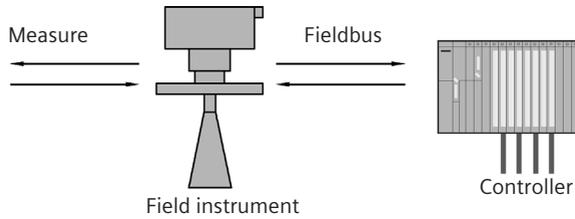
Having the instrument as part of the control system is a major paradigm shift as it gives the instrument a role that had been reserved for the control system. As with many major changes, it has both a wealth of benefits (discussed in the next section) as well as some challenges.

An ongoing challenge with the PROFIBUS and PROFINET approach is educating people about the benefits of the technology which can only be realized if the people involved know how to use it to its full potential.

Although control engineers and instrumentation technologists have always worked together, each group had its own tools and domain. Now, the instrument technologist needs access to the control system for setup and monitoring of the instruments. The technologist also needs to understand the block model as the control engineer does, and they need to co-operate fully to maximize the fieldbus benefits.

Benefits of using a fieldbus

A fieldbus in general, and PROFIBUS and PROFINET in particular, will improve efficiencies and reduce costs throughout a plant's life cycle. The key benefits are:

- optimized construction/installation
- faster commissioning
- higher accuracy
- reliable process variable verification
- enabled plant asset management

Optimize construction/installation

Without a fieldbus, there is at least one set of wires for each and every field device. Many field devices would require more than one

set of wires. This ends up being a lot of wires and a lot of wire runs. Fieldbus reduces 100s of wires down to just one PROFIBUS or PRO-FINET cable. This reduction saves on both installation costs and physical space.

Faster commissioning

With 4–20 mA devices, the end user has to scale the values in the field device and in the controller, and they have to match. With PROFIBUS PA, the analog input and output blocks have been moved from the controller into the field device, and now the end user can do the scaling from just one location.

Scaling a device is setting the range (high value and low value) of the output or input of a device.

I once commissioned a process plant with close to one thousand instruments wired into 4–20 mA input/out-puts. During the commissioning phase, an electrician and I worked for weeks verifying that the scaling in the field devices matched the scaling in the PLCs and HMI. The plant was a mile long and doing this verifica-tion involved considerable effort and walking.

Furthermore, to simulate a loop with 4–20 mA devices, values in the controller need to be over ridden. Barring that, the device can be unwired and a power supply with a potentiometer can be used to generate the desired value. In PROFIBUS and PROFINET, the val-ues in the field devices can be simulated, making it very easy and fast to simulate a control loop and significantly speeding up commissioning.

Lastly, to program/configure 4–20 mA devices, the device must be physically accessed using either the device key pads or a hand pro-grammer. With PROFIBUS and PROFINET, the field device is configured over the bus.

Commissioning through bus access improves operation efficiency as no travel time is required for someone to actually go to the device. It also promotes a higher level of safety because personnel do not have to access awkward or hazardous locations.

Similar 4–20 mA instruments from different vendors are pro-grammed differently. PROFIBUS and PROFINET effectively standard-ize instrumentation, ensuring that similar devices from different vendors have common core parameters and structure, unheard of

with other protocols. This commonality extends to different types of instruments as well. It also reduces training requirements and speeds up commissioning since people are able to move more easily from instrument to instrument.

To summarize, PROFIBUS and PROFINET speed up commissioning by:

- scaling in only one place
- simulating process values which speeds up loop checking
- configuring over the bus
- commonality between devices

Higher accuracy

All field devices today are using digital technology. Therefore, with 4–20 mA devices the device will have to take the digital value that it comes up with and convert it into an analog value to transmit it via the 4–20 mA loop. Then, at the controller, this signal will have to converted back into a digital signal. Accuracy is lost during these two conversions. PROFIBUS and PROFINET eliminate the need for these two conversions.

Accuracy for 4-20 mA is the elephant in the control room. It's accepted that accuracy is lost but few people talk about it or think about how big that elephant actually is. There are really three errors affecting accuracy to consider:

- transmit error when converting digital value into 4-20 mA
- transmission error in the transmission of that signal
- receive error when converting the 4-20 mA signal back to digital

The value of the transmit error depends very much on the design of the instrument. A value of +/- 0.015 mA for worst-case error appears to be a very good value because it sounds small enough to almost be insignificant.
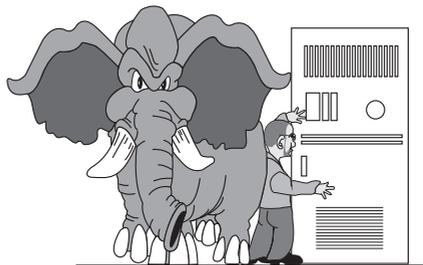
However, when doing the calculation it often does not look so good. Here are two examples:

1. For a level transmitter over a three-meter range, +/- 0.015 mA translates into +/- 2.8 millimeters.

   Here is how the calculation went: 0.015mA/ (20mA-4mA) = 0.00093. Take this value and multiply it by the full range of the instrument (which is three meters):

   0.0009375 X 3 = 0.0028 meters (which is 2.8 millimeters)

   The transmit error is very hard to determine since it depends very much on the wire used and the amount of induced noised on the line. For this discussion we will just ignore it.

   The receive error depends on the input card used. If a 10 bit 4-20 mA input card is used, then the receive error is +/- 2.9 millimeters on a three-meter range.

   Here is how the calculation went:

   - 10 bits gives 2^10 values =1024.
   - The range is three meters, so each division is 3/1024 = 0.0029 meters which is 2.9 millimeters.
   - Therefore missing one division gives the +/- 2.9 millimeter measurement error.

   This example shows a total error of +/- 5.7 millimeters. If the instrument's stated accuracy is one millimeter, 4-20 mA cannot provide the required accuracy.

2. A typical level radar on a 20-meter tank with a transmitter that can do three millimeter accuracy:

   - The transmit error will be 0.0009375 * 20 meters = 0.01875 meters (18.75 millimeters).
   - The receive error will be 20/1024 = 0.01953 meters (19.53 millimeters)
   - A total error rate of +/- 38.28 millimeters which is over ten times the measurement error stated for the radar. Just think about the amount of material that can occupy 38 millimeters!

   To benefit from the full accuracy capacity of the instrument, digital is the preferred solution. Good old 4-20 is really not so good after all.

Reliable process variable verification

Without two-way communication, the process variable could be wrong without the controller's knowledge. A dead instrument, for example, may not be noticed until something goes wrong in the process, a situation to be avoided. This process blindness has significant cost associations because the process potentially shuts down, possibly leading to:

- equipment damage
- lost inventory
- spillage to clean up
- possible environmental harm

Proper communication will keep the process moving safely and is a key component in plant asset management.

Enables plant asset management

Plant asset management is about getting the greatest benefit out of investment. Traditionally, asset management in the process world has focused only on instrumentation. PROFIBUS and PROFINET have expanded this definition to include a wide variety of devices such as computers, network switches, controllers, motors, and machines as well as instruments. PROFIBUS and PROFINET two-way communication is the enabler to a host of functions that will increase a plant's return on assets. Asset management is a large topic and is discussed in detail in *Chapter Eight*.

Faster and easier plant maintenance

With 4-20 mA, questions about an instrument must be taken to the instrument itself. The instrument must first be found and then it may require special safety equipment such as fall arrest harnesses to get to it – all of which take valuable time. With PROFIBUS and PROFINET, the instrument is accessible over the network. Although the instrument itself may still need to be visited, communications makes sure it is an informed visit.

Communications over the web adds another layer of convenience. A maintenance person on call is able to troubleshoot an instrument issue at 2:00 am from the comforts of home without being required to drive back to work.

PROFIBUS and PROFINET: genesis

The term *PROFIBUS* is an amalgamation of **PRO**cess **FI**eld**BUS** and defines an industrial protocol designed to meet all industrial automation requirements by networking a variety of process devices. No other protocol offers such a complete automation solution, and ARC[3] identifies "PROFIBUS' unique value proposition [to be] the ability to seamlessly integrate process instrumentation like pressure transmitters and flow meters with devices for the discrete and motion control side of the application like drives and sensors."[4]

The term PROFINET is an amalgamation of **PROFI**BUS and Ether-**NET**, and it extends the Profi-thinking found in PROFIBUS into the Ethernet/Internet world. Like PROFIBUS, it is designed to meet all industrial automation requirements.

PROFIBUS and PPROFINET are the only protocols that can service an entire plant. Unlike other protocols such as Foundation Fieldbus or DeviceNet where more than one protocol is required to create all the different applications in a process plant. Therefore with PROFIBUS and PROFINET, staff needs only to learn one way of thinking and know one protocol. This both simplifies the operations and reduces the amount of training required.

As an industrial automation protocol, PROFIBUS uses different aspects of itself and operates like a book with many chapters. The title of the book is *PROFIBUS DP*, and the chapters are *PROFIBUS PA*, *PROFIsafe*, and *PROFIdrive*. Each chapter presents a significant, but fractional piece of the whole. PROFIBUS DP defines the core protocol and each of the other PROFIs are defined within the PROFIBUS DP standard and add functionality to the core protocol.

PROFIBUS DP	DP: Decentralized Peripheral
PROFIBUS PA	PA: Process Automation
PROFIsafe	PROFIBUS for safety applications
PROFIdrive	PROFIBUS for drive applications

PROFINET is a second book by the same authors. It was designed so that it could use many of the chapters found in the PROFIBUS book with only minor changes. Thus PROFINET also has a chapter called PROFIBUS PA, PROFIsafe, and PROFIdrive

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[3] Founded in 1986, ARC Advisory Group is the leading research and advisory firm for manufacturing, energy, and supply chain solutions (www.arcweb.com).
[4] ARC White Paper, May 2004 *The Value Proposition of PROFIBUS in the Hybrid Industries.* p. 14.

Controlling PROFIBUS and PROFINET

In the 1980s and early 1990s, automation was restricted to numerous proprietary network protocols designed and owned by individual automation manufacturers:

If a user chooses PROFIBUS, she is not locked into any one vendor.

- Honeywell – DMCS
- GE Fanuc – GENIUS
- Modicon – ModbusPlus

These protocols worked, but users were then locked into that vendor for the life of the plant, effectively denying them access to instrumentation competitors and leaving them at the mercy of price control.

PROFIBUS and PROFINET, however, are open protocols controlled by PROFIBUS and PROFINET International which is an organization of companies. Open means that anyone can use it and that no one company controls it or has any say on who can use it.

Although both PROFIBUS and PROFINET have occasionally been called Siemens proprietary protocols, Siemens is actually only one of 1400 member companies that make up PROFIBUS and PROFINET International. Siemens is one of the companies involved in the initial development of PROFIBUS and PROFINET and is very active in PROFIBUS and PROFINET International (PI). However, neither Siemens nor any one of the other member companies has any say on who can and who cannot use the protocol.

PROFIBUS & PROFINET International – Member Short List		
ABB	Emerson	Endress + Hauser
Yokogawa	Vega	Siemens
GE Intelligent Platforms	Softing	Invensys / Foxboro
Rockwell	Schneider Electric	Fuji Electric

That's the way the whole thing started: PROFIBUS development

PROFIBUS has a significant design history as it developed to meet the market requirements for a network protocol. PROFIBUS began as part of a fieldbus project plan devised by an association of thirteen companies and five universities in Germany in 1987. The

member companies agreed upon a standard fieldbus concept for process automation and PROFIBUS FMS (Fieldbus Message Specification) was the first iteration. By 1993, the need for a faster and easier protocol led to PROFIBUS DP, and it replaced FMS.

DP-V0, the first version of the PROFIBUS DP specification, defined the overall command structure of the protocol and the functions for reading and writing time-critical data. Reading and writing of time-critical data is known as *data exchange* in the PROFIBUS world and is central to the functionality of PROFIBUS.
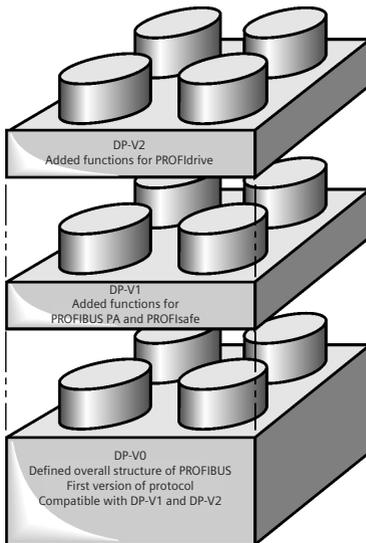
The second version of the PROFIBUS DP specification, DP-V1, added functions for process automation and safety application (PROFIBUS PA and PROFIsafe), and used the same overall command structure as defined in DP-V0 while ensuring interoperability. Interoperability is the ability to take any vendor's device, connect it to a PROFIBUS network, and have it work.

DP-V2 came next and added functions required for high speed drive applications while still using the same overall command structure defined in DP-V0.

All the different protocol versions can co-exist on the same network and function together. The only limitation lies in which commands

Interoperability is a PROFIBUS strength.

are supported by the master. A DP-V0 master can go into data exchange with a DP-V2 field device. The DP-V0 master, however, cannot use DP-V1 or DP-V2 commands on the field device since it does not know about these commands. An updated master matching the field device version would have to be in place.

PROFIBUS decentralized peripherals (DP)

PROFIBUS DP forms the core of the protocol, defining all the base functions that the rest of the PROFIBUS chapters use. PROFIBUS DP is often associated with the RS-485 based physical layer. The physical layer is how the digital information (the 1s and 0s) travel from one place to another. PROFIBUS DP can have many different physical layers such as RS-485, wireless, and fiber optics which can easily be interconnected. RS-485 is the most commonly used physical layer for PROFIBUS because of its ability to transmit at high speeds and its robustness in high noise industrial environments.

The RS-485 standard defines the electrical characteristics of the wire, and the voltage and current levels of the digital signal.

PROFIBUS DP is mainly used for high speed input/output devices and to link intelligent devices (such as drives systems). PROFIBUS has a large data packet (244 bytes) so that it can easily handle the information from a remote input/output rack or drive in one message. Since the data rates can go up to 12 mega bits per second, this information is delivered back to the controller in a very short time.

PROFIBUS DP has been very successful in both factory automation and in process automation.

Digital devices are simple ON/OFF devices– the light or the push button is ON or OFF.

- factory automation uses mainly discrete (digital) input and output devices, and PROFIBUS DP links remote I/O racks and connects drives
- process automation is mainly analog devices, and PROFIBUS DP links PROFIBUS PA segments, remote I/O racks, drives, and some instruments

Analog devices have a range of values – the valve is 75.25% open.

PROFIBUS process automation (PA)

PROFIBUS Process Automation (PA) refers to a set of features added to the PROFIBUS specification in release 1.0 (DP-V1) to make the protocol more useful in the process industries. PROFIBUS PA is often associated with the Manchester encoded Bus Powered (MBP) physical layer defined in the IEC 61158-2 standard. Since process indus-

tries use mainly analog input and output devices, a set of features were added to make it easier to link up many single function analog devices on a dedicated physical layer. The following features were added:

- bus power
- intrinsically safe design
- ability to configure over the bus
- device profiles

Bus power

Bus power is an important feature for network installation. If a device can communicate and be powered by just one cable, the end user saves money because only one cable, rather than two, is needed to run to the field device. In the process industries, where there are many single function analog field devices, operating bus powered devices saves money.

This feature, along with intrinsically safe design, was satisfied by introducing the Manchester encoded Bus Powered (MBP) physical layer defined in IEC-61158-2 standard.[5] See *Chapter Four* for more details on this physical layer.

Intrinsically safe

An intrinsically safe device keeps the voltage and current low enough so that it cannot generate a spark with enough energy to ignite the atmosphere and is therefore safe for use in many of the process industries. Many of these environments have airborne chemicals or particles that could explode if a spark is created.

Configuration over the bus

For a system with a large number of single function devices, effective configuration and maintenance of the devices can present problems related to physical access and downtime. The ability to configure and troubleshoot the device over the network eliminates access difficulty, and network troubleshooting saves time and possibly prevents downtime.

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[5] International Electrical Congress (IEC) is an international standards organization committed to creating and maintaining international and open standards for use in the electrical industries.

Device profiles

A profile is a standardizing of a field device from the bus point of view. It defines what the output is and what the core parameters of the device are. A standardized profile creates a commonality between:

- devices of the same manufacturer and type (pressure, temperature, level, flow, valve positioners)
- devices of the same type and different manufacturers
- devices of different types

For example, pressure, level, and temperature transmitters would all use the same analog input blocks and would all have their outputs in the same format.

The value to the end user is tremendous by reducing the engineering costs and training. Since the outputs are standard, special codes do not need to be designed in the controller to handle the inputs/outputs, reducing engineering costs. Furthermore, once it is understood how one type of PA field device works, the second one is easy as it works the same way. So personnel are trained on only one method of operation and can apply it across the system.

Physical layer

Bus power and intrinsic safety are part of the physical layer introduced in DP-V1, and configuration over the bus and the profile standard were also introduced in DP-V1. Most instruments make use of the new MBP physical layer. However, they do not have to,[6] and many instruments can be placed on the RS-485 physical layer because they do not require, or are not capable of using, the features of MBP.

Instruments may not use MBP because:

- the instrument requires more power than the bus can provide
- the instrument cannot be intrinsically safe
- the instrument process variable has a fast update rate

Instruments can be on either MBP or RS-485 physical layer and still be designed to the PROFIBUS PA profile standard.

For example, some flowmeters cannot be powered by the bus because they require too much power. These flowmeters also have a fast update rate. The Siemens meters are offered on both MBP and RS-485 (PROFIBUS PA and PROFIBUS DP), and both versions use the profile standard and can be configured over the bus.

[6] Having instruments on either MBP or RS-485 physical layer is unique to PROFIBUS. Other process fieldbuses only have one type of physical layer available.

NOTE: PROFIBUS PA (PROFIBUS DP-V1/MBP) is the focus of the PRO-FIBUS part of this book as it is the protocol best suited to two-wire process instruments due to the protocol's physical layers' intrinsically safe operation and long distances.

HART on PROFIBUS and PROFINET

Highway Addressable Remote Transducer (HART) is a well established protocol designed for connecting field devices to control systems. HART is often considered the transition between the 4–20 mA world and the purely digital world of PROFIBUS since it contains both a 4–20 mA signal and a digital signal. The digital signal is super imposed on the 4–20 mA signal and is used for configuration and troubleshooting. The 4–20 mA signal is used to transmit the main process variable.

HART is a fairly simple protocol and does not have the detailed profile concept of PROFIBUS PA. It is typically wired point-to-point and runs at 1200 bits per second. The communication channel does not have the electrical noise immunity of PROFIBUS PA.

The protocol was developed back in the mid-1980s by Rosemount and then turned into an open protocol in 1993 when the intellectual property was donated to the HART Communication Foundation (HCF), now the FieldComm Group. There is a huge installed base of HART instruments. Most HART instruments are connected to the control system via a 4–20 mA card and the digital signal is only used at the time of commissioning for configuration.

DP-V1 introduced a standardized method to encapsulate a HART message into a PROFIBUS package. This makes it very easy to add HART devices to PROFIBUS networks. A number of vendors such as CEAG, Pepperl+Fuchs, Siemens, and Stahl have made modules (called Remote I/O racks) for adding HART instruments to PROFIBUS networks.

Likewise, PROFINET has also made it easy for them to integrate HART into PROFINET via their 'Integration of HART into PROFINET' part of the specification.

Making it easy to integrate HART devices into a PROFI-BUS and PROFINET network was a brilliant idea since there is such a large installed base of HART instruments.

I had a customer who was interested in doing an upgrade to an existing plant, replacing most of the instruments. However, they wanted to keep a number that were in good condition, and while all of these were wired into 4–20 mA input cards, they were HART instruments. By using the HART on PROFIBUS feature, they were able to keep these instruments. Plus they were able to unlock the hidden diagnostic abilities in these instruments.

With PROFIBUS, the control system was set to check the health of the HART instruments regularly. When anything was reported, SIMATIC PDM drilled down to the instrument just like it was a PROFIBUS PA device. Setting the health monitoring required more work than with the PA instruments that they used, but it still worked very well and not replacing those old HART instruments saved a fair bit of money.

PROFIsafe

PROFIsafe added enhanced features to PROFIBUS and PROFINET, allowing it to be used in safety systems suitable for applications up to SIL-3 level as per the IEC-61508 standard. Safety systems require a very secure data transport method where the probability of having an undetected error is extremely low. To meet these high safety standards, the system must be able to catch the following errors:

- repetition of messages
- loss of messages
- insertion of message
- incorrect sequencing of messages
- corruption of transmitted data
- delay in receiving or transmitting data
- mixing standard messages with safety-related messages

To catch these errors, the following features were added:

- loop back of data (each message is confirmed)
- additional error checking

- consecutive numbering of messages
- time expectation of messages
- identification of transmitter and receiver

Loop back of data

This method of confirming information is similar to submitting credit card numbers over the phone. The number is provided and then repeated by the receiver to confirm that it has been accurately recorded, preventing surprises when the invoice comes at the end of the month. PROFIsafe does the same with data, repeating the message to make sure that it is accurate and reducing the probability of a bad message getting through. While PROFIBUS has error checking, PROFIsafe increases the safety net by looping the information back to catch bit errors.

Additional error checking

Error checking is a method for verifying that all the data arrived with no bit errors, making sure a binary 1 was not misread as a binary 0. There are different methods for doing this, including a standard error checking scheme by PROFIBUS. However, for safety systems, additional error checking was required to decrease the probability of an undetected bit error.

Consecutive number of messages

Messages are identified using unique consecutive numbers; if a message is lost or corrupted due to bit errors, the system knows about it. For example, if a controller receives messages 123, 124, then gets 126, it knows that it has missed 125.

Time expectation of messages

Messages not only have to get to their destination, they have to get there in an expected amount of time. This ensures that if communications is interrupted, both sides know about it as soon as possible.

Identification of transmitter and receiver

When dealing with safety, make absolutely sure that the controller is talking to the correct device and the device is talking to the correct controller. This helps keep a non-safety message from masquerading as a safety message.

PROFIBUS with ProfiSAFE was the first open protocol to be certified by TUV for applications up to SIL-3 level.

Safety systems and PROFIBUS and PROFINET

Safety systems have traditionally been hardwired using safety relays. While hardwired systems are very reliable, they are difficult to install and maintain, and installing a relay safety system requires considerable manual wiring. To change anything or to add to the system, rewiring becomes very costly and complicated because of the sheer volume of wires.

Automation controllers are more efficient since wiring requirements are reduced, and changing any logic or making additions are done through software. Currently PROFIsafe is widely used to link remote I/O racks on both PROFIBUS DP and PROFINET. This way, the input and output cards can be located close to the devices in the field. The next step in efficiency is to bring the protocol directly to the field instrument. PROFIBUS and PROFINET using PROFIsafe works very well in both of these topologies. Furthermore, with the additional information provided by PROFIBUS or PROFINET, safety engineers can determine the exact cause and time of a shutdown.

I once worked on a safety system in a steel plant. During the second phase of the expansion, we had to expand the system. Given the complexity of the system and the large number of wires, this was not an easy job, and one minor wiring problem caused the whole system to shut down during the expansion. Tracking down the problem took over an hour. The same problem in a PROFIBUS or PROFINET system would have been found in minutes.

Also, during production, whenever we had a safety trip, it would take us a while to figure out why the system shut down. The diagnostics in PROFIBUS or PROFINET make this task much easier and faster.

PROFIdrive

PROFIdrive adds features required to work with high speed drive applications, even though PROFIBUS DP and PROFINET works well for many of the drive applications in the process industries. However, in certain applications, particularly motion control, high speed synchronization of many drives is absolutely necessary.

For these applications, the standard PROFIBUS needs to be supplemented by these PROFIdrive key features:

- constant (Equidistant) cycle time
- clock synchronization
- data exchange between slave devices

Constant (equidistant) cycle time

In most applications, a small time variation during a scheduled process cycle does not matter. Thus turning on the wastewater pump at 1122 ms or at 1125 ms makes no difference to the process. However, if one axis of a high speed machine moves two ms later than it needs to, the process does care because in those two ms the machine has traveled a half a meter. For these applications, a constant cycle time is required, and PROFIdrive provides this reliability.

ms = milliseconds

Clock synchronization

Each drive works from its own clock. For the high speed machine with multiple axes, having two drives with their internal clock out of sync is a problem if they have to move at the same time. Synchronization ensures harmony.

Data exchange between slave devices

Given the requirement for high speed, the different devices cannot wait for the master or I/O-Controller to relay the information to each slave or I/O-Device separately. The data exchange function between slaves or I/O-Device was added to address this issue. It lets one slave or I/O-Device listen for required data coming from another slave or I/O-Device. Thus the one slave or I/O-Device would publish the data and the other slave or I/O-Device would subscribe to the data. In communications terms, this is referred to as a publisher/subscriber algorithm.

PROFINET

If PROFIBUS is a book, then PROFINET is another book by the same author. PROFINET was designed to be able to use large sections of the PROFIBUS protocol. For example, the PROFINET book also has chapters called PROFIdrive and PROFIsafe. The two protocols have

many similarities including the organization that controls them, PROFIBUS and PROFINET International (PI).

PROFINET was designed to be a single all-encompassing network for industrial automation with the following features:

- real-time I/O
- peer-to-peer integration
- motion control
- vertical integration of different buses
- safety
- security

PROFINET makes use of Ethernet technology that has been around in the office environment for years and powers the Internet. Ethernet defines:

- a physical layer
- an addressing scheme
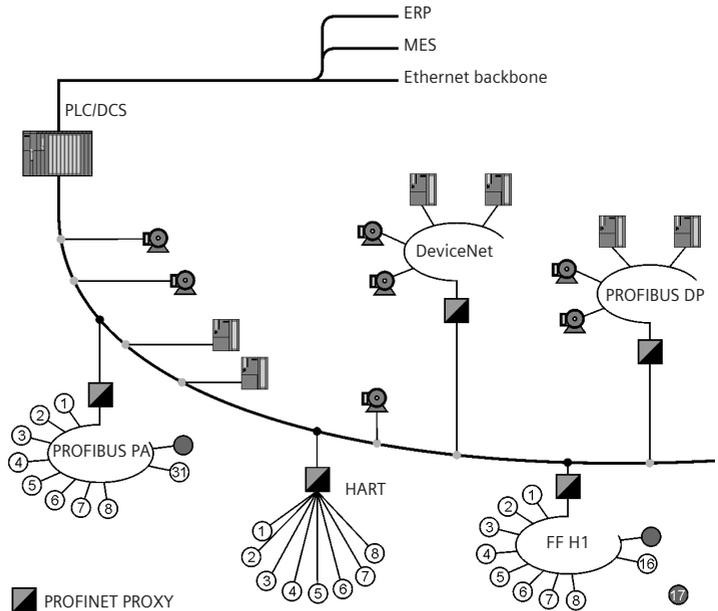
Physical layer: refers to the method of getting information from one device to another device. Chapter Four discusses how PROFIBUS and PROFINET can have many different physical layers. However, these other physical layers for PROFIBUS and PROFINET all use the same addressing scheme.

Addressing scheme: Ethernet defines its own addressing scheme which has a significant effect on how the network works and the range of applications that it can complete. In particular, this addressing scheme, in conjunction with its data handling capacity, makes it very easy for Ethernet-based protocols to be used both in local area networks and in a wide area network, spanning many different geographical areas. This gives Ethernet-based protocols significant advantage over protocols that are best used in a local area network.

A local area network is limited to a small geographical area such as a building. A wide-area network is located over a large geographical area such as a group of buildings or city or plant.

PROFINET was developed to take advantage of the following aspects of Ethernet:

- works well in both local and wide area networks
- joins local networks together efficiently
- can be purchased at low cost because of high Ethernet sales volume
- operates with high bandwidth so it is very fast and can handle a large amount of data

In designing PROFINET, PROFIBUS International (PI) could have simply encoded the PROFIBUS message into an Ethernet message just as Modbus TCP/IP has done. PROFIBUS also wanted to take full advantage of Ethernet's bandwidth and speed; therefore, PI designed a new protocol to make use of Ethernet addressing and functionality, but still keep the PROFIBUS intellectual property in mind. This optimum solution adopted all of Ethernet's functionality and maximized its benefits.

PROFINET can be used in a range of different applications such as:

- connecting different networks
- in very high speed drive applications
- in distributed control application
- applications using wireless communication

The list is ever growing as PI continually adds more functionality to PROFINET.

When asked whether to use PROFINET or PROFIBUS, the answer is "Yes." The two protocols complement each other. Similar to when using both Word® and Excel®,[7] a user can easily move from one protocol to the other to complete different tasks, and can apply common knowledge of one to the other. Each of the two protocols has applications it excels at, and it is up to end users to choose the

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[7] Word and Excel are both trademarks owned by Microsoft Corporation.

best ones for their applications. PI believes that both will continue to grow, but some point in the future, PROFIBUS will start to trail off as PROFINET takes over because of the advantages of Ethernet listed above. This will, however, take some time.

In process automation applications, PROFINET is used to join PROFI-BUS and other networks together.

Next BUS stops

The following chapters discuss how PROFIBUS and PROFINET work and how to use them. As an introductory look at PROFIBUS and PROFINET, the content is aimed at practical applications, limiting the theoretical to building a foundation of useful understanding.

The rest of this bus ride offers the following:

- details about how both protocols work
- profiles and how they are designed to help the process user
- different physical layers and network components
- how to design and build a PROFIBUS and PROFINET network
- how to operate a PROFIBUS and PROFINET network
- how to troubleshoot a PROFIBUS and PROFINET network

So sit back, don't lose your transfer, and let's go for a ride.

Chapter Two
How the PROFIBUS runs

*And you run, and you run to catch up with the sun, but it's sinking
Racing around to come up behind you again.*[1]

When PROFIBUS International extended the PROFIBUS protocol to DP-V1 so that it would work better in the process industries, it not only included additional protocol functions, but also implemented standards associated with how the devices worked.

This chapter examines how the protocol works, the key device standards that were added, and the benefits provided.

BUS route

The bus makes the following stops:

- Simple concepts – the basics to understanding PROFIBUS
- PROFIBUS bus scan – how it works
- Diagnostics
- Profiles – device standards

Simple concepts

PROFIBUS is based on a number of simple concepts and terms and this section defines them and then gathers them together to show how the protocol works.

Go Spartacus: master – slave and the token ring

The PROFIBUS protocol works by combining two fairly simple communication concepts called *master-slave* and *token ring* to form the basis of the protocol operation.

Master – slave: This relationship is at the heart of the PROFIBUS protocol. In a master-slave protocol, one device on the network is defined as the *master* and it is the device that is in command. All other devices on the network are called *slaves*. No slave can talk on the network unless the master first tells the device that it can.

To talk on the network means to transmit data.

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[1] Pink Floyd, "Time." *Dark Side of the Moon*, 1973.
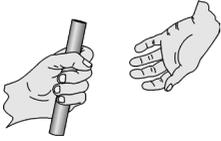
Token ring: This concept works like a relay race where a baton is passed from one runner to the next, and the next runner cannot race until he has the baton. PROFIBUS uses the same concept between different masters. A master can only talk on the bus when it has the token. This token passes from master to master one at a time in a circle. The token is permission for the master to talk and complete its function, and then it is passed along. When the token has finished its circuit, it begins again.

Master: The PROFIBUS world defines two different types of master:
- **Class one master**
  – typical controller (e.g. Distributed Control System [DCS], Programmable Logic Controller [PLC])
- **Class two master**
  – standard engineering work station used for setting up the network or troubleshooting (e.g. SIMATIC PDM)

Slave: Any device that is not a class one or class two master is a slave device. A slave device will only talk on the bus when talked to. The majority of devices on a PROFIBUS network are slave devices as they do the bulk of the hard work.

PROFIBUS message types

PROFIBUS has two different message types: time critical messages and non-time critical messages, differentiated by how fast they are delivered.

Time critical messages: Communicate input/output (I/O) information that is used for control. This arrives via cyclic services.

Non-time critical messages: Communicate configuration and advanced diagnostic information. This arrives via acyclic services.

Input data is the information coming from the field device and output data is information going to the field device.

Cyclic services: Cyclic services refers to a group of commands used during the data exchange between the master and slave. Called *cyclic* because the commands occur every bus cycle, they are typically issued by a class one master. The data in these messages are typically Input/Output (I/O) data used for control purposes. These messages are all time critical.

In PROFIBUS DP-V0, the format of the I/O data is not defined. However, for those devices designed to the PROFIBUS PA profile specification (DP-V1), the I/O are defined. The PROFIBUS PA profile specification is a standardization of a field device from the bus' point of view. That is, it defines what the I/O and the main parameters will be. This is discussed in more detail in the *PROFIBUS profiles* section in *Chapter Two*.

I/O data is either analog or digital. Analog data deals with variables that are represented by a floating point number. Two examples of floating point numbers would be 1.234 or 23.34458. These numbers would represent some real world measurement like the temperature in degrees C or the level in meters. Digital data deal with binary variables that are either an ON or OFF and are represented by a 1 for ON or a 0 for OFF. These numbers reflect the state of something in the real world such as if the light is on or off or if the tank is full or not.

Digital and analog are sent in a different format over PROFIBUS when the PROFIBUS PA profile is used.

An analog input/output variable when the PROFIBUS PA profile is used is sent as five bytes:

- the first four bytes are the IEEE[2] floating point representation of the main process variable (PV)
- the fifth byte is the status byte reflecting the health of the PV

IEEE Floating point value   Status byte

Byte 1	Byte 2	Byte 3	Byte 4	Byte 5
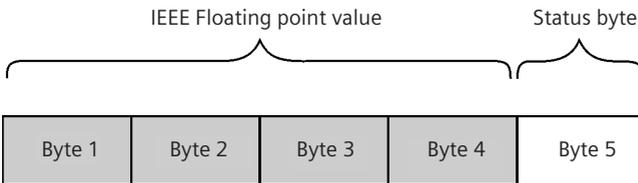
A digital input/output variable when the PROFIBUS PA Profile is used is sent as two bytes:

- the first byte reflects the value of the switch (either ON or OFF)
- the second byte is the status byte reflecting the health of the PV

Digital value   Status

Byte 1	Byte 2
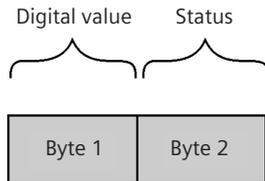
A byte is 8 bits long. A bit is a binary digit – a 1 or a 0.

Acyclic services: Acyclic services refers to a group of commands used after a data exchange between a master and slave. It is called

acyclic because it is initiated only on demand and it might take several cycles to complete the communication, and the master never knows exactly when it will be completed – it may take only 100 ms, it may take longer. Data communicated this way is often configuration information or advanced diagnostics that would only be used by a human operator. Therefore, taking a varying amount of time to update does not present a problem to the system operation.

PROFIBUS bus scan (the bus route!)

This section brings master-slave, token ring, multiple master, slaves, cyclic services, and acyclic services together to show how the PROFIBUS bus scan works. The actual operation of a bus scan is similar to the route a passenger bus takes on its rounds: each stop is planned and timed, and the whole route is preplanned.

To understand this better, let's look at a system with two class 1 masters and one class 2 master (named master A, master B, and master C respectively).

Master A has 4 slaves: slave 1, slave 2, slave 3, and slave 4. Master B has 3 slaves: slave 5, slave 6, and slave 7. Master C has no slaves and is a class 2 master.

master A	class 1	slave 1, slave 2, slave 3, and slave 4
master B	class 1	slave 5, slave 6, and slave 7
master C	class 2	no slaves

The bus scan would go in the following order:

- Master A gets the token
- Master A sends outputs to slave 1 and asks for inputs
- Slave 1 sends inputs to master A
- Master A sends outputs to slave 2 and asks for inputs
- Slave 2 sends inputs to master A
- Master A sends outputs to slave 3 and asks for inputs
- Slave 3 sends inputs to master A
- Master A sends output to slave 4 and asks for inputs
- Slave 4 sends inputs to master A

⬇ Master A has a little bit of time to send an acyclic read or write to one of its slaves. However this time it has no acyclic commands pending, so it passes the token to master B.

- Master B sends outputs to slave 5 and asks for inputs
- Slave 5 sends inputs to master B
- Master B sends outputs to slave 6 and asks for inputs
- Slave 6 sends inputs to master B
- Master B sends outputs to slave 7 and asks for inputs
- Slave 7 sends inputs to master B

- Master B has a little bit of time to send an acyclic read or write to one of its slaves. In this case, it does have an acyclic read pending from the last time when it tried to read some information from slave 6, but got a return message that it was busy. Master B sends an acyclic read request to Slave 6
- Slave 6 has had enough time to gather up the information that master B wanted, so it responds to acyclic read request by sending the required information to master B

⬇ Master B then passes the token to master C.

- Master C is in the process of reading the configuration data from slave 2, so it sends an acyclic read to slave 2
- Slave 2 sends the requested configuration data to master C
- Master C passes the token to master A and the process starts over again

NOTE: This scan representation is a simplification, omitting network overhead messages for clarity.[3]

The schematic below is a visual representation of the bus scan.

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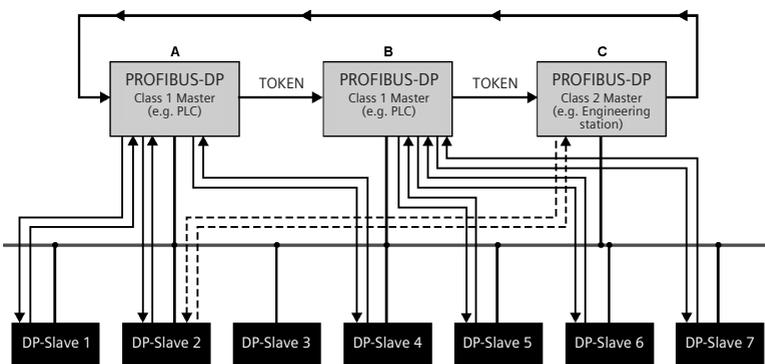
[3] For more details on the bus scan see *The New Rapid Way to PROFIBUS DP,* Manfred Popp and *PROFIBUS PA Instrumentation Technology for the Process Industry,*. Ch. Diedrich and Th. Bangemann.

Acyclic commands from a class one or class two master

Acyclic services provide a method for reading and writing non-time critical information to and from a field device. For this to work, both the field device and the master have to support DP-V1.

These acyclic commands can come from either a class 1 or class 2 master. The command codes from a class 1 master are different than from a class 2 master, complicating matters because the field device has to support both sets of commands. Field devices released from 1998 to about 2002 only support acyclic commands coming from a class 2 master, possibly because at that time no class 1 master supported acyclic commands. This has now changed.

Acyclic services in a class 1 master gives the controller these abilities:
- access to additional diagnostic data
- field device configuration change on the fly

Acyclic addressing–slot and index: Typically, class 2 masters such as SIMATIC Process Device Manager (PDM) are set up so the end users do not need to know anything about acyclic addressing in order to use the software – they just request a parameter and there is a file in the software that looks after the addressing. However, when using a class 1 master such as a PLC or DCS to read/write configuration parameters, knowledge of the addressing procedure is required. Currently there are few applications which require that a class 1 master have access to acyclic data.

This addressing is in the form of a slot and absolute index[4] number which behave much like X and Y coordinates do on a map. The information is located at a certain slot number and a certain absolute index, and could be one variable or a group of variables.

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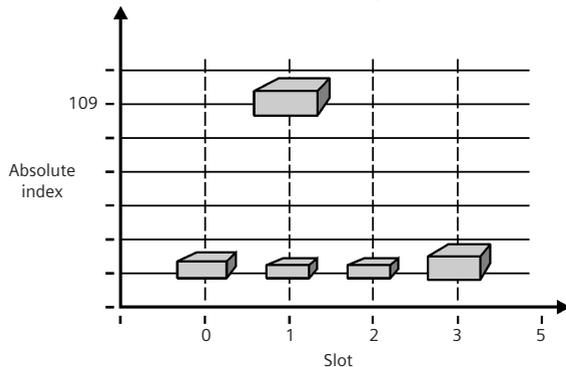
[4] The absolute index is sometimes called just the *index*. This varies from document to document.

Example: to know the internal temperature of the device, read slot 1, absolute index 109.

GSD and EDD/DTM: Cyclic information and basic protocol information for a device is defined in the General System Data (GSD) file. This is a text file that is used by a Class 1 master for configuring the slave on the bus.

Electronic Device Descriptions (EDD) files and/or Device Type Managers (DTM) define all the acyclic communications to the slave. These would be used by a Class 2 master for configuring the slave's internal parameters.

PROFIBUS message

The actual PROFIBUS message passed from master to slave and from slave to master is one that is described in a number of documents.[5] For the end user, the format of the message is of little value other than to know that the raw data length is set to 244 bytes of data. This is relevant to PROFIBUS because it can handle a lot more data in one message compared to many other industrial protocols such as DeviceNet or Modbus RTU.

Start-up sequence

A specific sequence of events must occur for a slave to join the PROFIBUS network. Familiarity with this sequence is necessary for troubleshooting the network and is also a key to understanding how PROFIBUS works.

The PROFIBUS master continually scans the network looking for nodes with which it is not already in a data exchange. Each scan sends out one message to one of these nodes asking if anyone is there. When a slave receives one of these probe-node messages, it replies, thereby notifying the master that it is there.

Next, the master scans again to issue a *get diagnostics* message inquiring if the slave is already assigned to another master and if it is functioning properly. If it gets a negative response, then the start-up sequence ends and the master goes on looking for other lost nodes. If it gets a positive response to that message, the master then goes to *set parameters*. The *set parameters* message configures the slave

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[5] For more details on the PROFIBUS message, please refer to either *The New Rapid Way to PROFIBUS DP* by Manfred Popp or *PROFIBUS PA Instrumentation Technology for the Process Industry,* Ch. Diedrich and Th. Bangemann.

for bus communications, setting essential bus parameters in the slave and also locking the slave to that master. The slave will then respond with a *short acknowledge* confirming reception.

```
   STARTUP
      ↓
GET DIAGNOSTICS
      ↓
SET PARAMETERS
      ↓
CHECK CONFIGURATION
      ↓
GET DIAGNOSTICS
      ↓
 DATA EXCHANGE
```
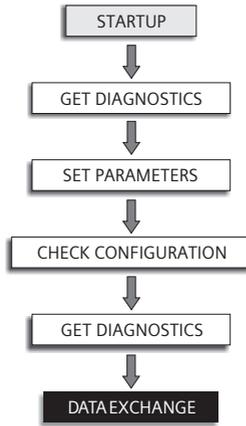
The master then issues a *check configuration* telling the slave what it thinks it is, how many modules the slave has, and how much data it will send and receive. Again the slave will just respond with a short *acknowledge.*

The master next issues a second *get diagnostic* message so that it can verify that there were no problems with the parameters and the configuration that it sent to the slave. If is all is well, the slave sends back a diagnostic message confirming *all is well,* and the master and slave then enter into data exchange. Data exchange is the state all the slaves should be in and should stay in.

However, if there is any problem in the parameters or the configuration, the slave will not go into data exchange and the master will continue looking for other lost slaves. Interestingly enough, eventually the master finds that same slave and again tries the same parameters and configuration, ending up with the same results. This means repeated diagnostic messages to the same slave until the problem is fixed. Also that slave will not join the network until the problem is fixed. A problem in the network configuration prevents a slave from joining and generates a large number of error messages.

Each PROFIBUS slave contains a timer to track the time passed since the master last talked to it. If this time exceeds the watchdog time value, the slave requires the master to repeat the start-up sequence before going into data exchange.

Diagnostics

Diagnostics are a fundamental function of a fieldbus protocol, and PROFIBUS provides complete diagnostic functionality to the network, ensuring that the instruments can report any conditions back to the master and that a variety of actions can be implemented to deal with the matter.

Cyclic diagnostics

Two-way communication is the foundation of any effective fieldbus like PROFIBUS because it is crucial that the slave device can alert the master of an event. In all PROFIBUS devices (DP V0 and above), a slave can signal the master to request that diagnostics be read during the next cycle. The slave simply sets a diagnostics request flag in its data exchange reply message, requesting a diagnostic request.

After the slave issues the request for a diagnostic request, the master issues the command in the next bus cycle. The diagnostic response message is made up of the diagnostic message plus an extended diagnostic.

NOTES:

- The main diagnostic message tells of errors or problems relating to controller configuration. All of these messages are defined by PROFIBUS International.
- The extended diagnostics are all related to the field device itself.

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diagnostic message + extended diagnostic

- Diagnostic message (PI[†] defined):
- wrong cyclic data configuration
- wrong data sizes   — Controller configuration
- incorrect module
- wrong identification number

Extended diagnostic
(Profile and Device defined):

- electronic failure
- configuration invalid
- electronic temperature too high   Device failure
- restart carried out   — or
- measurement failure   Device configuration
- more diagnostics available

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† PI stands for PROFIBUS and PROFINET International which is the independent organization that manages the PROFIBUS and PROFINET protocols.

Diagnostics in DP-V1: In addition to the cyclic diagnostic message, a device written to DP-V1 PROFIBUS PA profile specifications will also provide two additional sources of diagnostics: cyclic status byte and acyclic diagnostic messages.

Cyclic status byte: All devices written to the PROFIBUS PA profile specification return a status with each and every input variable. This status byte provides mainly information on the health of the process value (PV) determining whether it is a good value. This status byte also communicates high and low alarms.

Most of the error codes have pre-defined meanings and the values are defined by PI. Other codes are reserved for the instrument manufacturer to reflect the particular error conditions of their device.

The good quality and uncertain quality codes are the same for all PROFIBUS PA devices. The bad quality codes change depending on the device. For example, where a hex 10 would be a bad code sensor failure in a temperature transmitter, it means *Loss of Echo* (LOE) in a radar device.

Status codes for good quality	
Values in hex notation	**Description**
0x80	Data is GOOD.
0x84	A parameter in the function block has been changed: status active for 10 s.
0x89	Active low warning.
0x8A	Active high warning.
0x8D	Active low alarm.
0x8E	Active high alarm.

Status codes for uncertain quality	
Values in hex notation	**Description**
0x4B	Value is a substituted value (normally used in Failsafe).
0x4C/0x4F	Initial value.
0x47	Last usable value.

Status codes for bad quality	
Values in hex notation	**Description**
0x10	The LOE timer has expired: this could be caused by LOE or by sensor malfunction: value is BAD.
0x01	There is an error in the configuration of the function blocks in PROFIBUS PA.
0x1F	The function block, or the transducer block, has been placed out of service.

Condensed status byte: When profile V3-01 introduced the condensed status byte, it redefined the error codes:

- fewer error messages
- more meaningful error messages
- easy separation of process from maintenance alarms by having them bit-mapped so they can be easily filtered
- introduced new codes for three levels of maintenance alerts; maintenance required, maintenance demanded, maintenance alarm

Devices released prior to 2006 only support the expanded status byte shown above and referred to it as the standard *status byte*. Generally, all devices released after 2006 support the condensed status byte. Many of these devices give the user the option of choosing between the expanded status byte and the condensed status byte.

Many of the codes in the condensed status byte have not changed from the codes in the expanded status byte. For example, code for a good status remains *hex 80*. The chart below provides more examples:

Condensed status (GOOD)		
Hex value	**Status — GOOD**	**Description**
0x80	GOOD – OK	No error or special condition is associated with this value.
0x84	GOOD – update event	Set if the value is good and the block has an active Update event. (This status remains active for 20 seconds.)
0x86	GOOD – activate advisory alarm	Set if the value is good and the block has an active Alarm.
0x80...0x8E	GOOD – limit check/ update event	Same as the original status codes.
0xA4...0xA7	GOOD – mainte-nance required	Value is valid. Maintenance is recommended within a medium-term period.
0xA8...0xAB	GOOD – mainte-nance demanded	Value is valid. Maintenance is recommended within a short-term period.
0xBC...0xBF	GOOD – function check	Device performs internal function check without influencing the process. Value is valid.

Condensed status (UNCERTAIN)		
Hex value	Status — GOOD	Description
0x45	UNCERTAIN – substitute set	Output of Failsafe logic only.
0x4F	UNCERTAIN – initial value	Default value as long as no measured value is available or until a diagnosis is made that affects the value and the status accorded to it.
0x68...0x6B	UNCERTAIN – maintenance demanded	Usability of the process value depends on the application. Value is potentially invalid. Cause can be determined by reading the extended diagnostics. Maintenance is demanded within a short-term period.

Acyclic diagnostic

PROFIBUS' acyclic communication channel allows instrument manufacturers to provide highly detailed diagnostic information that cannot fit into either the status byte or the cyclic diagnostic message. After the user is alerted of an error state by the diagnostic request and the status byte, two messages can be received via acyclic communications:

- an acyclic diagnostic message
- an acyclic extended diagnostic message
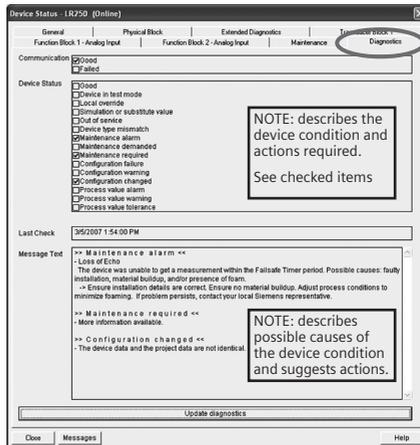
Acyclic diagnostic message: This message is the same as the cyclic extended diagnostic message. However, this information is repeated as an acyclic message because engineering tools such as SIMATIC PDM only have access to acyclic information.

Acyclic extended diagnostic message: The acyclic extended diagnostic message gives more details on the device health and operating status. This information is read by a class 1 master or class 2 master. An engineering work station has the advantage here in that it uses the information in the EDD (or DTM) to display all diagnostic information, both the diagnostic and the extended diagnostic, in a user friendly manner:

Instrument error example

Let's look at what happens when there is a process error on an ultrasonic probe. Here are the application details:

- A SITRANS Probe LU is measuring the water level of an open channel.
- Liquid soap is added to the water and the turbulence generates foam, causing the Probe LU to go into a loss-of-echo state.
- When the foam passes, the Probe LU again locks onto the echo and the loss-of-echo error goes away.

Here are what the Class 1 Master sees and the subsequent sequence of events:

- The loss-of-echo timer trips, causing the status byte to change to a fault value.
- This change generates a message in the acyclic extended diagnostics, causing a bit to set the acyclic diagnostic message (the same as the cyclic extended diagnostic message).
- Next a bit is set in the cyclic diagnostic message.
- Then the slave sets the bit in the return data exchange message, indicating that it has a diagnostic message.
- The result is that the Class 1 Master issues a diagnostic read message on that slave.

Very heavy foam ➡ Loss of Echo (LOE) ➡ Status byte changes

⬇

Acyclic Extended Diagnostics

⬇

Acyclic Diagnostics = Cyclic Extended Diagnostics

⬇

Cyclic Diagnostics

⬇

Diagnostic read flag is set

⬇

Controller issues diagnostic request
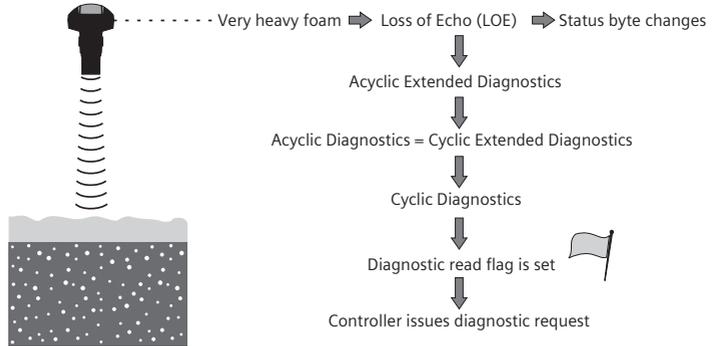
When the foam disappears, the following occurs:

- The Probe LU locks onto the echo and the loss of echo disappears, again causing a status byte change.
- This change also clears the error in the acyclic extended diagnostics, causing a bit to set in the acyclic diagnostic message indicating that an error has left. This message is the same as the cyclic extended diagnostic message.
- A change in the cyclic extended diagnostic message prompts a bit to set in the cyclic diagnostic message indicating that there is cyclic extended diagnostic information.
- Then the slave sets the bit in the return data exchange message indicating that it has diagnostic message.
- The Class 1 Master issues a diagnostic read message on that slave.

Foam disappears ➡ Lock on Echo ➡ Status byte changes

⬇

Acyclic Extended Diagnostics clears

⬇

Acyclic Diagnostics = Cyclic Extended Diagnostics
sets "error disappears" bit

⬇

Cyclic Diagnostics

⬇

Diagnostic read flag is set

⬇

Controller issues diagnostic request
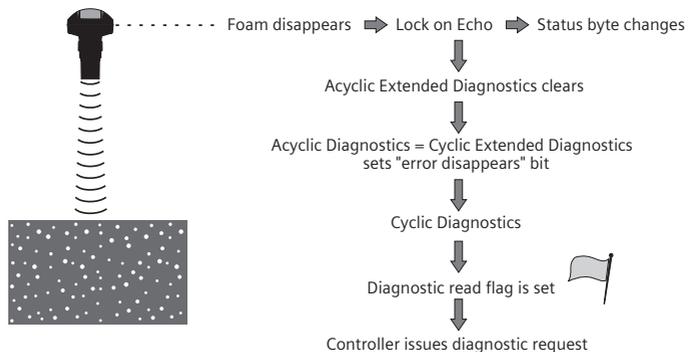
One change in a process condition – such as foam appearing and disappearing – causes two changes in a status byte and two diagnostic requests. Each diagnostic request is logged by the control-

ler's fault table, and the changes in the status may also be logged. Therefore, one process change can cause up to four entries into the fault table!

For the operator, the status byte is the key. In this example, operations should be just monitoring the status byte, and when it goes to a bad state, maintenance should be contacted. Maintenance would use a Class 2 Master such as SIMATIC PDM to tell them the device is in loss of echo. A trip out to the instrument would then show why it happened – problem solved.

At first glance, the diagnostic information that is spread over cyclic and acyclic channels appears complex. However, for the most part, the system will take care of all this and the first time user just has to know the following:

• monitor the status byte
• monitor the controller's fault table

When an error occurs in the field device, use the configuration software to pull up the user friendly device diagnostic page – this will provide everything you need to know.

PROFIBUS profiles

Device profiles are a wonderful PROFIBUS feature, and their use greatly increases the protocol's usability. A device profile refers to a standard based on a "representation of a device in terms of its parameters, parameter assemblies, and state model that describes the device's data and behavior as viewed through a network."[6] Thus, a profile offers a standardization of the device from the network point of view for the purpose of data exchange, configuration, and functionality.

PROFIBUS profiles lead the way for device standardization.

PROFIBUS has profiles for a wide selection of equipment. For example, there are profiles for:

- drive systems
- process automation (level, temperature, flow, and pressure transmitters, valve positioners)

_____
[6] International Electrochemical Commission (IEC) Standard TS 61915:2003, p. 15.

- robots and numerical control
- encoders
- hydraulic drives
- devices for semiconductor manufacture
- low voltage switchgear
- dosing and weighing
- liquid pumps

This is by no means a complete list and it is ever expanding.

Before the establishment of profiles, individual vendors would define their own most important parameters resulting in completely different parameters definitions. This difference created many problems with end users because most ended up with devices from many different vendors, creating network havoc when switching from one vendor's device to another. This confusion has been minimized with the profile definition, which now commonly defines the most important parameters shared by all vendors. It also defines the format of the output variable and a status word that informs the user of the health of the output.

Profile standard key benefits:
- Ease of use – the profile standard creates great similarities between devices and also between different devices; thus PROFIBUS field instruments are easy to use, even in a large, mixed instrument network.
- Easy interchangeability – the ability to switch from one vendor's device to similar devices from another vendor. PROFIBUS profile standard makes this easier than with any other protocol.

A profile defines:
- The data that is presented on the network and the format for that data.
- Standard functions that the network can use to get and manipulate data (i.e. Analog input block with scaling).
- Standard parameters required to set up the device.
- Methods or procedures to communicate parameters to the device over the communication network.

The PROFIBUS profile standard defines basic parameters that each device of a particular type must have and where to get them. It also defines how the process variable is presented on the network. Adhering to the PROFIBUS profile standard allows for a great deal of similarity in devices, regardless of vendor.

The remaining discussions on profiles will focus on the profile for process automation that defines profiles for level, flow, temperature, pressure transmitters, and valve positioners.

Profile example – setting up a level device[7]

This example compares the work required to switch between a level monitor from vendor A and vendor B. The following tasks are required to do this integration:

1. Configure the device.

2. Set up the communication network.

3. Set up the master.

For comparison, here are two setups: one without profiles and then another with profiles.

Without profiles: Each device is programmed by a series of parameters that do basically the same thing. However, the confusing part is that the names and the order of these parameters are different. Furthermore, what is achieved with one setting in one product may take several settings for the other product.

As shown by the *Quick Setup* on both vendors' tanks, neither the parameters nor the terminology are the same, even though the tank conditions are. These variations can complicate the programming task, require more training, take extra time, and add to the installation cost because each device is separately entered.

Both devices also require communications setup and define the information to be passed on the network. Here again, both devices have different setup parameters and present different information.

The master device must be programmed to retrieve this data from the devices, and then special codes are added to change the information (scaling, format) to the required form. The routine used for Vendor A is completely different from that for Vendor B. Also, each device sends out a status indicator. The status indicators are different, and each has to be checked and alarms configured in the human machine interface (HMI).

All these differences complicate the installation task.

---

[7] This section is adapted from *Benefits of the Profile Concept,* James Powell. ISA, 2004.

Vendor "A"

Vendor "B"

100%

0%
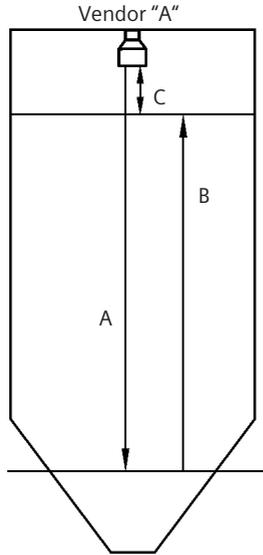
A = Empty
B = Span
C = Near blanking

Quick Setup
P001 Operation
P002 Material
P003 Measure response
P004 Transducer
P005 Units
P006 Empty distance
P007 Span
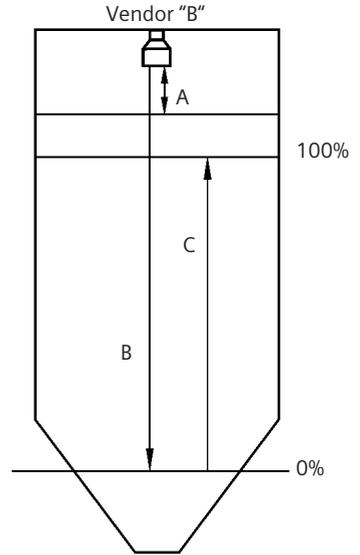
A = Blocking distance
B = Empty distance
C = Full level

Quick Setup
C1 Empty distance
C2 Full level
C3 Blocking distance
D3 Units
D4 Operation mode
D5 Level application

The data presented to the master device differ also.

Vendor A	Vendor B
Byte 0 to 1: Status word (bit mapped as per tank, 0 = OK, 1 = error) **Byte 2 to 3:** Level in tank 1 as a percentage of span multiplied by 100 **Byte 4 to 5:** Level in tank 2 as a percentage of span multiplied by 100	**Byte 0 to 3:** Distance measure in tank 1 **Byte 4 to 5:** Status for tank 1 (value of 1000 = OK) **Byte 6 to 9:** Distance measure in tank 2 **Byte 10 to 11:** Status for tank 2 (value of 1000 = OK)

With profiles: Each PROFIBUS device has a data file associated with it that is referred to as a *dot GSD* (.gsd) file. This tells the master what the device is and what variables the device can provide. Just load this file into the configuration software for the master and pick the required information (in this case, it would be level, distance, or volume). The operation is easy, and it is the same for every vendor that conforms to the profile.

When configuring the device, both devices would have a different GSD file, but would present the same information on the network. Therefore switching from one to the other would be simply deleting one and dragging in the new device and putting it at the same address.

IEEE Floating point value   Status byte

Byte 1	Byte 2	Byte 3	Byte 4	Byte 5
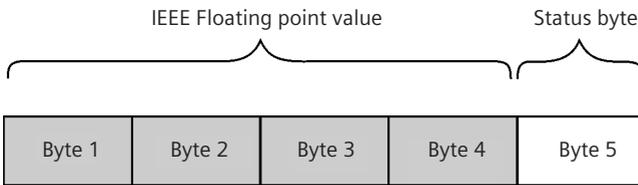
The definition of a tank is defined in the profile standard so it is the same for both devices. Therefore the core parameters are the same for both devices, and there is only one set of core parameters to remember.

Sensor offset

Level high
(default 100)

Calibration
point high

Level

Level low
(default 0)

Calibration
point low

Level offset
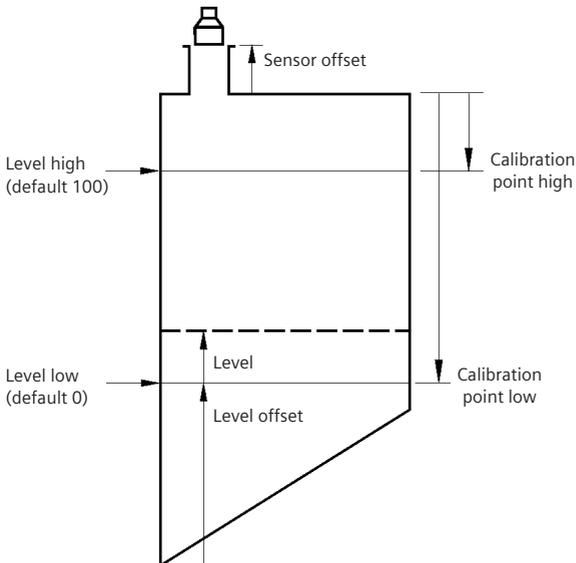
Built into the profile is a definition of the output and a method for scaling. The scaling is done in the device by using an analog input block, called *input* because the data is viewed from the PROFIBUS master perspective. The output of this block consists of IEEE floating representation of the process variable plus a status byte.

The process variable can be scaled in the device to match what the HMI wants. The status word is read by the PROFIBUS master and is alarmed there.

The result of the profile is that no special programming is required in the PROFIBUS master to do scaling or to monitor status.

Conclusion

Profiles simplify the installation and configuration of different field devices. Without profiles, there are:

- two setup configurations that do not look similar
- two routines in the master to adjust the incoming data
- two routines in the master to monitor the health of the devices
- added code in the HMI to indicate error status

With profiles, there are:

- no special routines in the master for adjusting data
- no special routines in the master to monitor the health of the devices
- no special code in the HMI to indicate error status
- two setup configurations that are very similar

Operation of a profile field instrument

For the computers that run large DCS or PLC control systems, a computer language has developed that uses predefined *blocks*, a language familiar to control engineers. It is also known as a function block diagram (FBD) or simply as a block diagram.

Each block is a graphical representation of a computer program that does a type of task like compare two values or turn on a pump. The blocks have inputs and outputs, and are programmed graphically by simply drawing lines between the blocks. Each block performs a function or a series of functions that are read from left to right, top to bottom. One block flows into the next block. Some blocks will stop the flow on that line depending on the result of a

calculation. A complicated block can be defined by connecting a series of simpler blocks, providing levels of programming, thereby making a complex task easier to understand.
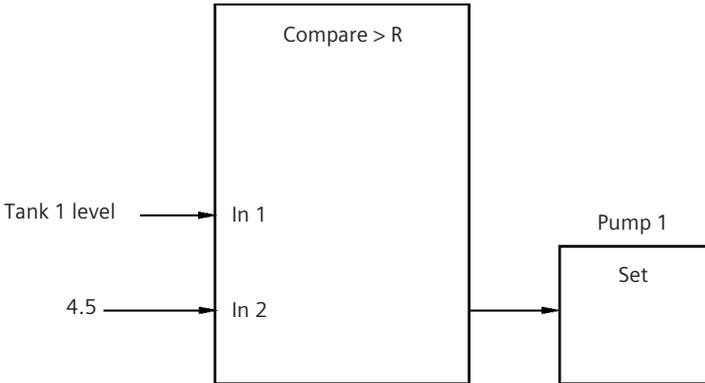
Starting from the left, this block diagram shows how the first block is a compare function. It compares the two entries to see if one is larger than the other. In this case, it checks to see if variable Tank 1 level is greater than 4.5 meters. If true, the block connected to it will be executed. This second block is a set block that will, for example, turn on pump 1. If the level is not greater than 4.5 meters, the block to the left is not executed and the pump remains off. This simple example can be expanded into a pump control algorithm and combined to make one block called *Pump Control*.

For PROFIBUS, the instrument itself is now viewed as comprising a series of blocks; level, pressure, or temperature devices would all follow this operation.
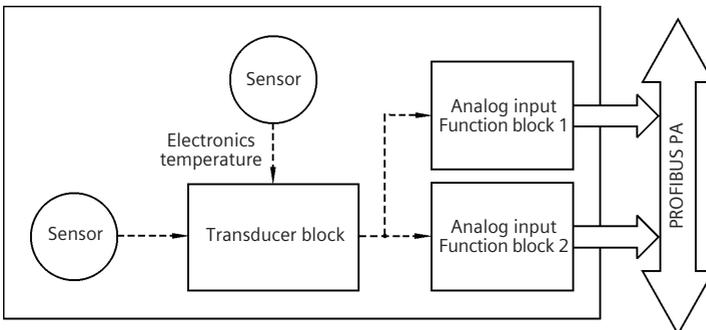
The sensor information is fed into a transducer block, which then sends information into analog input function blocks. Note that the analog blocks are called *input* blocks because the information flow is from the control system's point of view. These analog input blocks are similar to the analog input blocks for a 4–20 mA input except that, in this case, they do not run in the main controller and they provide status information as well.

An internal temperature sensor also feeds into the transducer block. This sensor checks the instrument health by monitoring the temperature and informing the user before something bad happens as a result.

The transducer block, a level device in this example, is also defined in terms of multiple blocks. All of these blocks (with the exception of the sensor technology block) are defined in the PROFIBUS Profile Standard V 3.0.
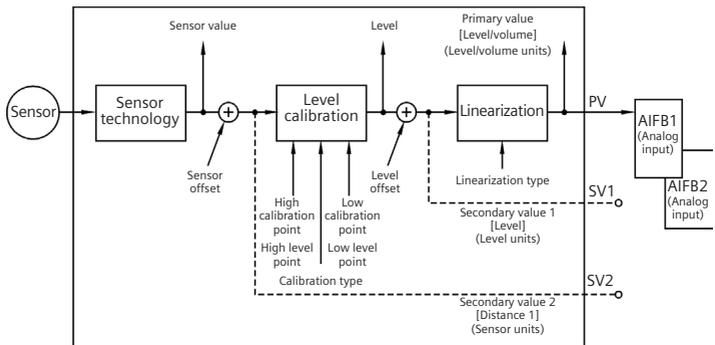
As with subroutines in most computer languages, the values passed between blocks also have a status indicator that indicates that the calculation (or in this case, the process variable) is OK. This status indicator is a logical result of using the block model structure as the blocks can also perform self-diagnostics, alerting the control system to any kind of problem in the instrument itself.

Using blocks, control engineers see the instrument presented in a language they know. The analog input and output function block that was previously executed in the main controller is now executed in the instrument itself. In fact, from the control engineer's point of view, where the code is executed matters naught since it is really just one system to look at and modify at will.

Evolution of the profile standard

The first released version of the profile standard document, Profile V.3.0, was published in 1999, and it defines the standardized output and standardized device parameters. Within this defined standard are two types of devices:

- Class A device – uses the block model but not the standardized transducer block or standardized parameters
- Class B device – uses the full profile standard

The Class A device was defined to make it easier for manufacturers to comply to the standard and release a product. It is no longer acceptable for PROFIBUS certification. For the end user, Profile V.3.0 Class B is the recommended device type. This is the device type that will give the end users all the main benefits. Today, most released PROFIBUS PA devices are designed to Profile V.3.0 Class B or above.

An earlier draft version, Profile V. 2.0, was released in 1996.

Updates

Since the release of the profile standard in 1999, there have been two minor updates:

- Version 3.01 released in 2004
- Version 3.02 released in early 2009

Version 3.01: aimed at error/diagnostic messages and the flow of those messages. It added an alternative status byte called **Condensed Status**, with the following effect:

- reducing the number of error messages
- creating a progression of alert steps for maintenance messages (maintenance required, maintenance demanded, maintenance alarm)
- easy filtering between process and maintenance alarms. The condensed status codes are bitmapped so that a simple bit filter can separate process and maintenance alarms
- permitting full user control over error messages (i.e. end users can go into an instrument and choose if an error should be an error, a warning, or not to be an alert)

In addition, it required that all profile devices include Identification and maintenance functions (see below).

Version 3.02: brings in many numerous integration improvements:

- improves the speed of uploading/downloading by a factor of six
- improves device integration through better version handling

PROFIBUS International is constantly working on improving the profile standard. Instrumentation is a rapidly growing field, both technologically and in market size, and fieldbus communication is an integral component of that growth. PROFIBUS is committed to that growth and to maximizing communication potential so that companies can reap the benefits of effective networks.

Identification and maintenance functions (I&M Functions)

This specification was added with PROFIBUS DPV1 and was made mandatory for all Profile 3.01 devices. It defines basic identification and maintenance information about the device:

- Order number of the field device
- Hardware version
- Software version
- Device type
- Vendor ID

This information is essential for asset management and troubleshooting.

Next BUS stop: The PROFINET of things

From explaining how PROFIBUS works, we now move to how PROFINET works. So sit back and relax as we present PROFINET.

Chapter Three
The PROFINET of things

Don't stand by the water and long for fish; go home and weave a net.[1]

Connectivity is now so commonplace that most people rarely think about how devices as varied as computers and home thermostats to factories and process plants are connected to the internet via Ethernet based protocols. Ethernet, a collection of networking technologies, hums quietly in the background while the connected world goes about its business.

PROFINET is an Ethernet based protocol that uses much of the pro-fi-thinking that makes up PROFIBUS DP and PA. It is the future of automation communications, and complements and extends both PROFIBUS DP and PA.

Ethernet based protocols have taken over the office and the home. It has also made strong inroads into factory automation for numer-ous good reasons:

- Easy to wire
- Versatile topologies; it fits anywhere
- Uses different media (i.e. wired, wireless, fiber optic)
- Very fast so it moves a lot of data
- Simple to use
- Great noise immunity[2]

Collectively, these reasons have convinced numerous experts world-wide to suggest that Ethernet protocols will completely take over both factory and process automation.

However, before we get carried away (apply brakes here!), there are still some limits:

- Narrow application experience
- Shortage of available process automations devices[3]
- Cannot yet be used in IS environments

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[1] Chinese proverb. Origin unknown.
[2] Lab tests have shown that PROFINET has as good or better noise immunity than PROFIBUS DP or PA. Field experience is also showing this as well.
[3] Please note that there is a good selection of factory automation devices.

Until PROFINET can master these requirements, both PROFIBUS DP and particularly PROFIBUS PA will play a strong role for some time to come. However, that said, since PROFINET integrates both DP and PA so easily, PROFINET becomes the perfect backbone network. Use PROFINET where possible; use PROFIBUS DP when no PROFINET device is available or when required; and use PROFIBUS PA for instruments. Since all three employ similar thinking and are easily integrated, one can simply move from one to another, taking full advantage of the benefits of Ethernet and the great overall connectivity.

Let's cast the Profi Net and see where it will take us!

Bus Route

The bus makes the following stops:

- How it works
- Simple concepts – Foundation terms
- PROFINET bus scan – how it works
- Start-up cycle
- Device diagnostics

Additional features

- Profiles
- Identification and maintenance
- Naming and addressing – device replacement
- Network diagnostics
- Proxy – how we integrate other protocols

Picking a device - Conformance classes

PROFINET for process automation

Simple concepts

Before presenting how the PROFINET protocol works, it is imperative that the concepts and terminology are clearly defined, thereby explaining how PROFINET works.

Ethernet: a physical layer for transporting 1s and 0s from point A to point B as defined in the IEEE 802.3 standard, which also defines the electrical method for connecting devices. PROFINET is only one of a large number of protocols that use this physical layer.

Ethernet switches: Ethernet switches do more than just physically connect the devices. They add intelligence by directing the message to the correct port (since they know who is connected). Furthermore, they prioritize when two messages try to go down the same port by sending the higher priority message first and holding back (buffering) the other one. PROFINET IO has the priority set very high so that its messages pass through the switch first. Switches are at the heart of Ethernet communications. Ethernet switches may be standalone devices or embedded in automation devices like IO rack's head modules.

Full-duplex Ethernet: any one device can send and receive at the same time. The switches manage all this traffic, ensuring nothing collides.

PROFINET Devices

IO-Controller: controls the process. It is a Programmable Logic Controller (PLC) or a Distributed Control System (DCS) or a Programmable Automation Controller (PAC); the same as a Class 1 master in PROFIBUS.

IO-Device: an input/output device; the same as a slave device in PROFIBUS.

IO-Supervisor: an engineering station; the same as a Class 2 master in PROFIBUS.

IO-CONTROLLER

IO-SUPERVISOR

SWITCH
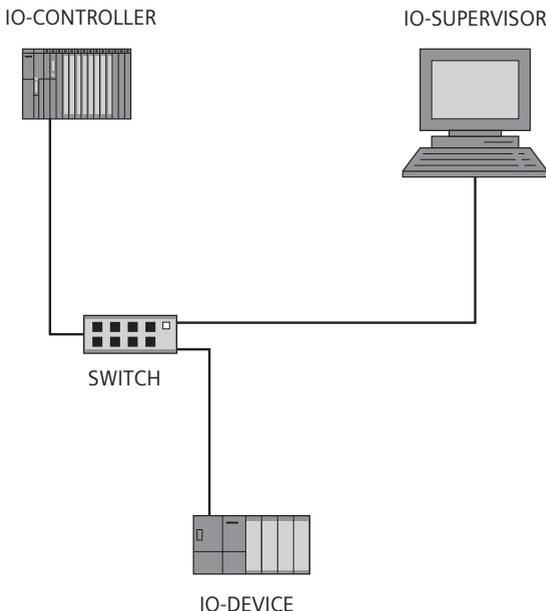
IO-DEVICE

Consumer/Provider: with PROFIBUS, the master polls the slave every cycle and the slave responds when spoken to. The controller is the master and the input output devices are the slaves. Since Ethernet physical layer allows for messages to go out at the same time, it is more efficient to move to a Consumer/Provider model. An IO-Device *provides* input data that is *consumed* by the IO-Controller. Similarly, the IO-Controller *provides* output data that is *consumed* by the IO-Device. Both devices can talk to each other at the same time since PROFINET uses full-duplex Ethernet.

PROFINET message types

Just as with PROFIBUS, PROFINET has two different message types: cyclic and acyclic.

Cyclic messages: a group of commands that pass time sensitive input and output information between IO-Device and an IO-Controller. These messages are scheduled and monitored by fail-safe timers on both ends of the communication, ensuring that updates occur. PROFINET has two methods for sending cyclic messages:[4]

- Real-time IO: for most applications and uses standard Ethernet switches and electronics.[5]
- Isochronous real-time (IRT): for high speed applications and requires PROFINET IRT switches and electronics.

Cyclic addressing (slot, sub-slot): PROFIBUS DPV1 devices organize its acyclic information using a slot and index format[6], making information access easy. PROFINET uses this similar idea for its cyclic data.

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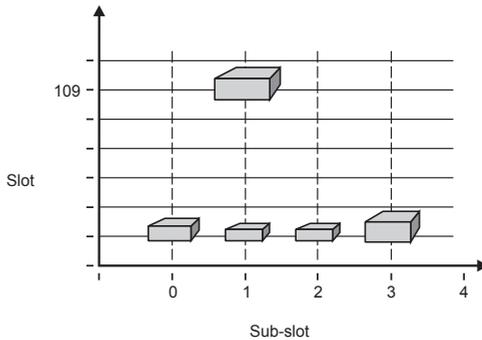
[4] Both methods can be used together in one network. Real time IO for standard IO and IRT for high speed IO.
[5] See *Chapter 4* for more information about switches.
[6] See *Chapter Two*.

Acyclic messages: a group of commands that communicate both time-critical and non-time critical messages. The time-critical messages are messages such as alarm messages. Non-time critical messages are messages such as configuration and advanced diagnostic information. This would occur between an IO-Controller or IO-Supervisor and an IO-Device. It is called acyclic because it is initiated only on demand and it may take several messages to complete the communication.

Acyclic addressing (slot, sub-slot, and index): PROFIBUS DPV1 devices organize information using a slot and index format[7], making information access easy. PROFINET extends this model to slot, sub-slot, and index.

Z
INDEX

Z CO-ORDINATE

SUB-SLOT

Y

X CO-ORDINATE

SLOT   Y CO-ORDINATE

X
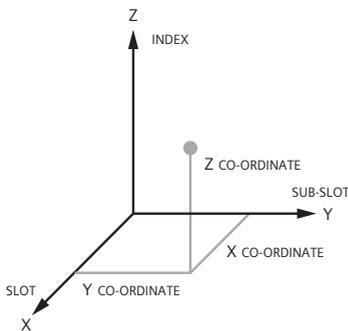
Similar to X and Y and Z co-ordinates on a 3-D map, the information is located at a certain slot, sub-slot, and index. With the map, anything in the device can be found.

This extension makes it simpler to integrate PROFIBUS DP and PA devices into PROFINET. The Proxy acts as a gateway and defines PROFIBUS addresses as slots in its data map; then the PROFIBUS slots and index become sub-slot and index.

GSD and EDD/DTM[8]: In PROFIBUS, cyclic information and basic protocol information for a device was defined in the General System Data (GSD) file. PROFINET extends this to include some information on acyclic information as well. In addition, the new GSD files are not only text-based files, they are written in Extensible Markup Language (XML) which encodes descriptive data into a file that is easy to read for both machine and human.

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[7] See *Chapter Two*.
[8] Please see *Chapter Seven* for more details on GSD and EDDL/DTM.

Both[9] Electronic Device Descriptions (EDD) files and Device Type Managers (DTM) have been incorporated to provide easy access to acyclic information such as configuration and diagnostic data.

PROFINET bus scan real-time IO

PROFINET combines the messaging and relationship protocols presented above to connect devices. Multiple IO-Supervisor, IO-Controller, IO-Device, cyclic messages, and acyclic messages come together much like the traffic on a road – often independent of each another but guided by PROFINET's overall structure.

Communicating

PROFINET and PROFIBUS are related but handle aspects of communications differently. When the network is established with PROFINET, the IO-Controller initiates connections to all of its IO-Devices and tells each how often it requires updates on the inputs, as well as how often the IO-Device can expect updates on the outputs. With this schedule in place, and the connections made, the messages occur as needed. Unlike PROFIBUS, there is no central direction of who can talk and when. Instead, each device knows precisely when it needs to talk.

The switches are also in play, preventing two messages from colliding. Real-time IO is assigned a high priority giving IO traffic primacy over acyclic and other Ethernet communications.

Like PROFIBUS, there are watchdog timers in place to ensure that all the communications occur within a set period of time. Also like PROFIBUS, information about what basic cyclic communications and protocol information for each IO-Device is defined in the GSD file for that IO-Device.

The IO-Supervisor configures and diagnoses IO-Devices and communicates to other devices on the network using acyclic messages which are defined in the EDD file or DTM. These acyclic messages are lower priority messages that are not scheduled. Lower priority status means that it has to wait at a switch[10] until any higher priority messages get through to the device. Like a fire truck zooming by regular traffic, real-time IO goes first.

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[9] See *Chapter Seven.*
[10] The switch must support priority (IEEE 802.1p). This would be standard in a PROFINET approved switch.

IO-CONTROLLER

IO-SUPERVISOR

READ CONFIG.

OUTPUT

SWITCH

INPUT

IO-DEVICE

When both the IO-Controller and IO-Supervisor try to talk to an IO-Device at the same time, the Switch holds back the IO-Supervisor message and lets the IO-Controller talk first.

IO-CONTROLLER

IO-SUPERVISOR

READ CONFIG.

SWITCH

Once the IO-Controller is done, the Switch lets the IO-Supervisor message through.

IO-DEVICE

PROFINET bus scan
Isochronous Real-Time (IRT)

IRT is a PROFINET communication system designed for high speed applications such as drives that need to co-ordinate multiple axes of a fast moving machine and highly precision applications. IRT is not necessarily faster. It can run at the same update cycle. But the main difference is the determinism (Jitter). Therefore it is used for motion control applications due to the higher accuracy.

Jitter is called thus because when you plot the timing variants on a graph, it looks like it is jittering.

In these applications, it is necessary to know when communications will occur within a very small variant – jitter. For PROFINET IRT, update times faster than one millisecond with less than one micro-second jitter are possible. Special hardware creates a reserved channel/time slice where only scheduled IRT traffic can occur – none other. It still has additional time where other traffic can occur, but by using the reserved channel, PROFINET IRT achieves very high throughput.

The diagram below shows generally how IRT works. The network software reserves a part of every cycle time for only IRT traffic, similar to a highway commuter line and open only if there is more than one person in the car. In this case, only an IRT message can talk during the IRT channel. Special logic routines determine the size of the IRT channel related to the number of messages to ensure fast communications. The IRT channel size is dependent on the calculated number of IRT messages. All other traffic uses the open channel lane.
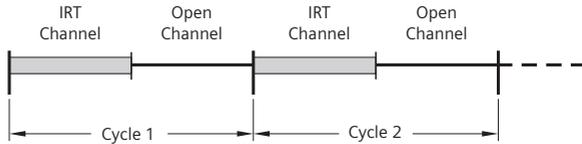
Realistically, most applications in factory automation and process automation do not need this speed or precision – real-time IO will do fine.[11] The advantage of real-time IO over IRT is that real-time IO does not need special hardware – it uses regular Ethernet switches.

---

[11] Remember that this is not an either or question. If the application requires both, you can use both on the same network and I/O Controller.

Start-Up cycle

For an IO-Device to connect to an IO-Controller, a particular sequence of events must occur. Familiarity with this sequence is helpful when troubleshooting the network and for understanding how PROFINET works.

```
         STARTUP
            │
            ▼
    CONNECT REQUEST
            │
            ▼
    CONNECT RESPONSE
            │
            ▼
    PARAMETERIZATION
            │
            ▼
  PARAMETERIZATION DONE
            │
            ▼
    APPLICATION READY
            │
            ▼
      REAL-TIME IO
```
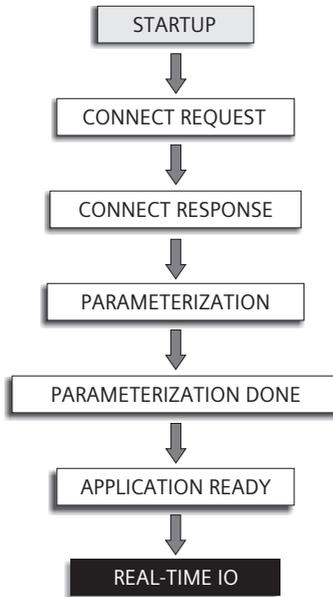
The IO-Controller uses either Discovery and Configuration Protocol (DCP) or Dynamic Host Configuration Protocol (DHCP)[12] to find an IO-Device. Once found it will try to connect to it by sending a *Connect Request.* When it gets a *Response,* it tries to *Parameterize* it, checking several things:

- protocol information such as supported functions
- identification information such as the PROFINET identification number
- module configuration.

If there are problems with this information, the IO-Device issues a bad connect response to the IO-Controller and the process stops but will be repeated some time later until the problem is fixed. If

---

[12] DCP is part of PROFINET. DHCP is a standard Internet protocol. DCP is the default method to find an IO-Device.

there are no problems, the IO-Device issues an *Application Ready* and goes into data exchange with the IO, which contains a timer to track how much time has passed since the master last talked to it. If this exceeds a watchdog time value, the slave requires the master to repeat the start-up sequence before completing data exchanges.

Device diagnostics

With the master/slave protocol in PROFIBUS, a method for alerting the master is required. Over the long life of PROFIBUS, diagnostics has been improved, particularly benefitting PROFINET with improved diagnostics and communications. PROFINET uses the real time channel to send diagnostic and alarm information all based on different priority levels. When there is either a device related or process related alarm or diagnostic, the IO-Device can immediately send a message to the IO-Controller notifying it of the problem – no waiting involved. Instant and detailed information is provided.

IO-CONTROLLER   IO-DEVICE

DATA
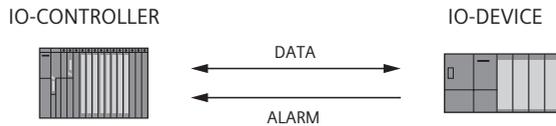
ALARM

Process and diagnostic alarms: An IO-device can have two categories of alarms.
- Process alarms are designated to the process; for example, an over-current alarm on a drive or a high temperature alarm on a temperature sensor.
- Diagnostic alarms monitor the hardware or physical wiring, such as a wire-break or failed module electronics.

Both types are reported via the same message type but with different headers so that the IO-controller knows where to route the message. Process alarms go to operators and diagnostic alarms go to maintenance.

Status byte: introduced into PROFIBUS DPV1 and lives on in PROFINET for the purpose of telling the user that the process variable is trustworthy.[13]

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[13] See *Chapter Two.*

Additional features

Profiles: a standardization of a device from the bus' point of view.[14] PROFIBUS profiles have either been ported whole to PROFINET or modified to use the additional data sizes available with Ethernet and the extended data structures. Profiles in PROFINET are basically the same as in PROFIBUS.

The profiles are a good example of how the PROFIBUS intellectual property is preserved in PROFINET. A user experienced with Profiles in PROFIBUS will find almost the same standard in PROFINET.

Identification and maintenance functions (I&M Functions)

This PROFINET specification was also copied over from PROFIBUS DPV1 and contains basic identification and maintenance information about the device:

- Order number of the field device
- MAC address
- Hardware version
- Software version
- Device type
- Vendor ID

This information is essential for asset management and troubleshooting.

What is in a name?

PROFINET uses three methods for identifying a device:

- PROFINET name
- IP address
- MAC ID

The PROFINET name is the key name for the end user. From this name, the IO-Controller assigns an IP address and records the device's MAC address. The IO-Controller[15] uses a PROFINET protocol for this called *Discovery and Configuration Protocol* (DCP).

The Internet Protocol (IP) address is a 32-bit address expressed as a series of numbers with a period '.' between them, e.g. 192.168.0.1.

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[14] See *Chapter Two*.
[15] Alternately, the system can be set up to use a central IT Ethernet protocol called Dynamic Host Configuration Protocol (DHCP). This is not recommended since it this is normally controlled by IT which offers procedural challenges.

This overall address is divided up into the Network ID and Host ID via the network mask. The network mask uses binary '1' to indicate the network part of the address. For example, 255.255.255.0, which is 11111111.11111111.11111111.00000000 in binary, means that the network part of 192.168.0.1 is 192.168.0 and that the device address (host ID) on the sub-network is 1.

The IP address is used by the IO-Controller and the IO-Supervisor to open a channel to an IO-Device and for acyclic communications. An advantage of the IP address is that it can be used across different sub-networks.

Media Access Control (MAC) address is the unique hardware address of the device and is assigned by the manufacturer. Some devices will permit a number change, but this is generally not recommended. This is a 48-bit hexadecimal number, e.g. 00-14-A2-01-23-4B.

The MAC ID is used by the IO-Controller for cyclic data exchange because it is considerably faster than using the IP address. The IP address has to be decoded by the IO-Device by running the IP part of the stack while the lower level address MAC ID can be processed very quickly. A[16] disadvantage is that all devices must be on the same sub-net – no routers permitted.

Simple device replacement

Once a PROFINET network is set up, replacing a device is simple through the use of standard Ethernet protocols. With the IT protocol called *Link Layer Discovery Protocol* (LLDP) each device and switch can identify their neighbors. Then if one of these devices fails and another device is plugged into the same port on the switch, the network tells the new device who it is and its IP address. The digital chat would go something like this:

Fred used to be connected there and he was tall and thin and he went away; now you are connected at the same spot and you are tall and thin, so your name must be Fred and here is Fred's IP address.

All identity assignments occur without the user doing anything. A new device can be powered up and plugged into the network – PROFINET does the rest!

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[16] The PROFINET specification does permit using UDP for real time messages allowing transmission through a router. But this approach has not been widely adopted by device makers.

The replacement device must be the same type as the unit it is replacing. The determining factor is the GSD file. If the replacement device can use the same GSD file, it will be accepted.

Some devices use a replaceable memory card to simplify device replacement. In either case, no computer is needed to configure the replacement device.

Network diagnostics

PROFINET network diagnostics uses standard IT protocols, specifically the Simple Network Management Protocol (SNMP)[17] which provides a vendor-neutral reporting of network failures or status.

Web services

Each PROFINET device can have its own web server where it can provide any information that the vendor thinks is useful. This area has been left fairly open by PROFINET, and the vendor can decide on what to do with this feature. Many have developed simple web pages that identify the product as well as providing both simple and advanced diagnostics.

Picking a device – conformance classes

Although PROFINET has many functions like cyclic data, simple device replacement, and IRT; not all of them need to be used when implementing PROFINET – some of the higher functions like IRT can be omitted. To accommodate this discretion, PROFINET has three levels of conformance classes A, B, and C. If you pick Class C, you also get all of Class A and B functions. If you pick class B, you also get all of Class A functions. If you pick Class A, you only get Class A functions.

Class A Device: very basic and includes the following:

- cyclic data exchange using real time IO
- acyclic services for parameterization
- identification and maintenance functions
- device and basic network diagnostics

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[17] This is covered in more detail in *Chapter Nine*.

Class B Device: expanded functionality, adding the following:

- simple device replacement
- simple network management protocol for network troubleshooting

Class C Device: most functionality, adding the following:

- isochronous real-time functionality

End users must be alert to the functions they are getting and generally Classes B and C are chosen to access the simple device exchange functionality.

It should also be noted that there are a number of other advanced optional functions not included in the conformance classes. Function such as fast start up, I-device, shared device, shared inputs, media redundancy, controller redundancy, etc.

Proxy

A time proven maxim espoused by PROFINET is that it does not compete against other protocols, rather, it integrates them using PROFINET Proxy. A proxy is a representation of a device from one network on another network. At its heart, it is a gateway where PROFINET has done all the work; all the cyclic data is available for easy mapping onto the other network as defined in the PROFINET proxy standard. The PROFINET proxy also includes methods for the engineering stations to drill through the proxy to obtain acyclic information.

PI differentiates a proxy from a gateway. Both map variables from one network to another, but a PROFINET proxy defines how that mapping is done in the specification.

PROFIBUS and PROFINET International have spent a lot of time specifying a series of proxies so that PROFINET can easily integrate other networks. For example, proxies already exist for:

- PROFIBUS DP
- PROFIBUS PA
- Modbus RTU
- DeviceNet
- HART
- Foundation Fieldbus
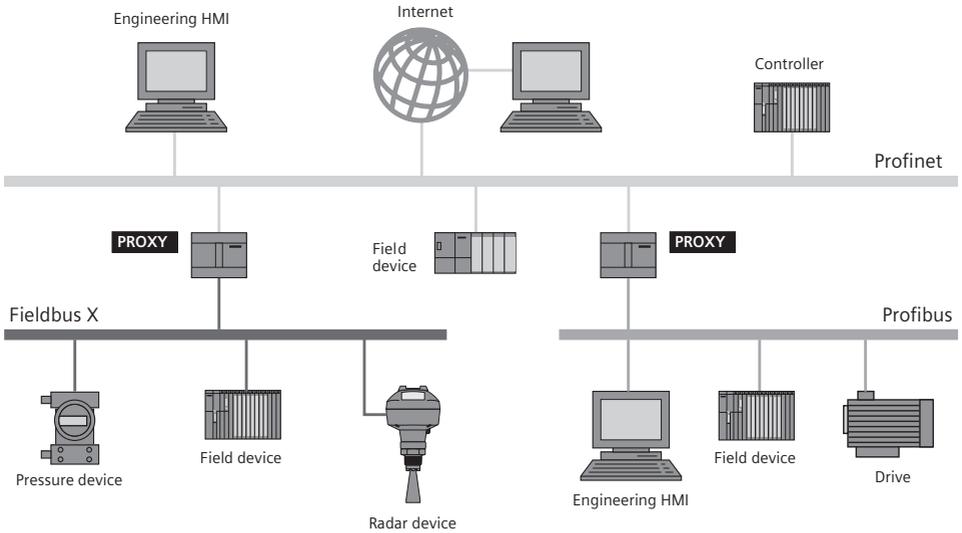
PROFINET for process automation:

PROFINET has added a number of features required for use in the process industries. Some of these features include:

- **Configuration in run:** the ability to make configuration changes while the controller is still in run mode, a necessity since processes need to keep running. There are few opportunities for a short pause.
- **Redundancy methods:** since processes do not like to be stopped, having controller, device and media redundancy is important.
- **Time stamp of data:** When looking at variables in a process, precise time that the value occurred can be very important.
- **Easy integration of existing fieldbuses:** (PROFIBUS DP, PROFIBUS PA, HART, Foundation Fieldbus).

With these features, PROFINET is making great progress into process automation. As discussed in the introduction to this chapter, there are really only a few things holding it back at this point:

- narrow application experience
- shortage of available process automation devices
- cannot yet be used in IS environments

The application experience and number of available devices are increasing all the time. The test labs are all busy testing new PROFI-NET devices. We are seeing PROFINET used in more and more applications increasing our confidence in its physical layer.

The ability to use Ethernet in an IS environment is currently being worked on. However, although we are seeing significant advances, we are still years (a decade) from having an international standard with products that you can purchase.

Given this situation, both PROFIBUS DP and particularly PROFIBUS PA will play a strong role for some time to come. However, that said, since PROFINET integrates both DP and PA so easily, PROFINET becomes the perfect backbone network. Use PROFINET where possible; use PROFIBUS DP when no PROFINET device is available or when required; use PROFIBUS PA for instruments. As presented in this chapter, all three employ similar thinking, one can easily move to another, taking full advantage of the benefits of Ethernet and the great overall connectivity.

Next BUS stop:
Physical layer and network components

The next chapter discusses the different physical layers that PROFIBUS and PROFINET can have and the different components that make up a PROFIBUS and a PROFINET network.

Chapter Four
Physical layers and network components

Just believe and you can't go wrong. In the light, you will find the road.[1]

A passenger bus runs on different roads: freeways, highways, and side streets, all with on-ramps, stop signs, and lights at different junctions. Likewise, PROFIBUS and PROFINET run on various physical media: wires, light, and radio waves.

Like a roadway providing alternate directions through intersections, PROFIBUS and PROFINET go through different boxes (couplers, repeaters) to head in a variety of paths. These paths (physical layers) are in the form of various electronic media. This chapter discusses the different electrical media used and then goes into the different ways to connect them – much like intersections join up different roads.

BUS route

This bus makes the following stops:

- Physical layers
- Intrinsically safe/hazardous environments
- Choosing a physical layer
- Network components
- Redundancy
- Choosing network components

Physical layers

The physical layer is how the data, the 1s and 0s, are transferred from one point to another point on the network; it is the road the PROFI bus runs on and the actual physical link between devices. Just as different roads are designed for specific transportation functions, PROFIBUS and PROFINET also have a number of different physical layers with their own specific uses, including RS-485, (PROFIBUS DP), IEC 61158-2 MBP (PROFIBUS PA), twisted-pair copper (PROFINET), fiber optics, and wireless.

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[1] Led Zeppelin, "In the Light." *Physical Graffiti*, 1974.

RS-485 (PROFIBUS DP)

Recommended Standard 485 (RS-485) refers to a physical layer that uses a differential voltage to transmit the data. An electrical circuit in the receiving device measures the voltage between the two incoming lines and looks at the difference between them to determine which is a **0** and which is a **1**. The diagram shows the two incoming voltages A and B: the voltage difference is shown by the arrow and is a value of A-B. If this is between -1.5 V and -6 V, it's a logical **1** and if it is between +1.5 V and +6 V, it's a logical **0**.
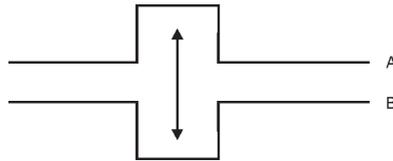
Noise: An advantage to the RS-485 standard is its electrical noise immunity. If electrical noise (n) is introduced onto the A line, the same noise would also be introduced onto the B line. Thus when the difference is calculated:

$$(A+n) - (B+n) = A - B + n - n = A - B$$

The noise is cancelled out.

Twenty some odd years ago, I was troubleshooting a Modbus RTU network on RS-485 that was used to join a Human Machine Interface (HMI) to a Programmable Logic Controller (PLC). RS-485 has great noise immunity, so I was surprised by the very noisy waveform on the test oscilloscope.

I had already checked out grounding and normally RS-485 works so well so I was puzzled by this anomaly. Later in the investigation, I noticed the RS-485 cable tie-wrapped to the 440 VAC power cable leading to the main motors, a major violation of wiring guidelines – power cables and communications cables must be separate.

The moral of this story: even though RS-485 has great noise immunity, it is not immune to bad installation.

Number of devices: RS-485 can have as many as 32 devices on one segment. A segment is a section of the network where the same electrical signal flows uninterrupted. The 32 device limit is set by the natural limitations of an electrical circuit. After the signal has been sensed by 31 receivers (one sender plus 31 receivers = 32 devices), the signal degrades to the point where it cannot be read correctly. The number of devices can be expanded by using repeaters.

A device in this case is any electrical apparatus that sits on the segment.

Network speed: The speed of the network can be set to different baud rates ranging from 9.6 k baud to 12 megabits baud, with the typical baud rate being 1.5 megabits bits per second.

Distance: There is also a proportional relationship between the baud rate and the maximum distance that the segment can be run. As the distance increases, the maximum baud rate drops exponentially.

The RS-485 physical layer has been around since at least the 1980s and is used in many

Speed (bits per second)	Distance (m)
9.6 K	1200
19.2 K	1200
45.45 K	1200
93.75 K	1200
187.5 K	1000
500 K	400
1.5 M	200
3 M	100
6 M	100
12 M	100

Baud rate = transmission speed and is measured in bits per seconds.

industrial applications with different protocols. Most Programmable Logic Controllers (PLCs) use RS-485 for inter-PLC communications and for communications between a programmer and the PLC. Some of the other protocols using RS-485 are:

- Modbus RTU (Modicon proprietary protocol that is now open)
- DF-1 (Allen-Bradley proprietary protocol)
- SNP (GE FANUC proprietary protocol)

k = kilobits
M = megabits

NOTE: The PROFIBUS version of RS-485 is a modification of the original standard. The original standard could only transmit at a maximum rate of 187.5 k bits per second. PROFIBUS extends this to 12 megabits per second.

Conclusion

RS-485 is the ideal main physical layer for PROFIBUS DP for the following reasons:

- it has great noise immunity
- can go a long distance
- can have up to 32 devices on one segment
- can transmit data up to 12 mega bits per second

Twisted-Pair Copper (PROFINET)

Ethernet supports a variety of speeds and transmission methods over twisted-pair copper. Interestingly enough, even though they use different methods and different wiring requirements, all transmission methods have a 100-meter limit on the distance between a switch and a device. Furthermore, they all use a differential signal much like RS-485 but at different voltage levels and encoding methods.
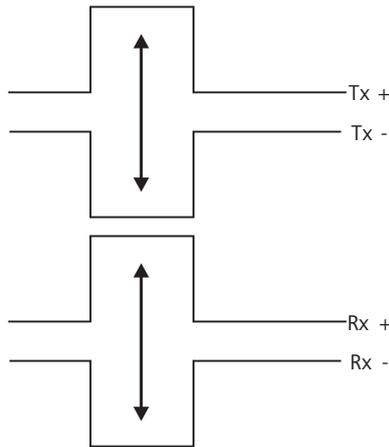
When referring to twisted-pair copper, the nomenclature is xx Base y, the xx refers to the speed in megabits per second and the y refers to the physical layer. In this example of twisted-pair copper, the physical layer is T for twisted pair. For example, 100 Base T refers to 100 megabit per second on twisted-pair copper.

PROFINET, as with other Ethernet based protocols, can use different twisted-pair copper baud rates. 10 Base T is occasionally used, while 1000 Base T is used more often. The most common speed for

PROFINET is 100 megabits per second and it is called *100 Base TX, full duplex*. Full duplex means that it uses two twisted-pair wires (i.e. four wires) so that it can send and receive at the same time.

100 Base T full duplex uses three voltages -1, 0, and 1 volts and encodes the values using Multi-Level Transmit 3 (MTL3) encoding to encode 1s and 0s onto the three voltage levels. In addition, it uses a 4B/5B block encoding to encode 4 bits in 5 bits. The transmission rate is called 100 mbps, but because of the 4B/5B encoding, its real transmission rate is 125 mbps. By encoding 1s and 0s onto three voltage levels and encoding 4 bits into a 5-bit block, the robustness of the physical layer increases. Bit error is rarer because of the redundancy.

Conclusions:

This physical layer has great noise immunity, a result of the following:

- using a differential signal
- MTL3 line encoding (for 100 Base T)
- 4B/5B block encoding (for 100 Base T)
- PROFINET Ethernet cables for 100 Base T also have additional shielding

Design is simple because the only limitation is that the maximum length from switch to device cannot be more than 100 meters.

Fiber optics (PROFIBUS DP or PROFINET)

The fiber optics layer uses light to transmit data. PROFIBUS and PROFINET have a number of different fiber optic solutions available, depending on cost and distance. Generally, the greater the distance, the higher the costs.

Light pulse

Electrical
pulse
in

Fiber optic cable

Electrical
pulse
out
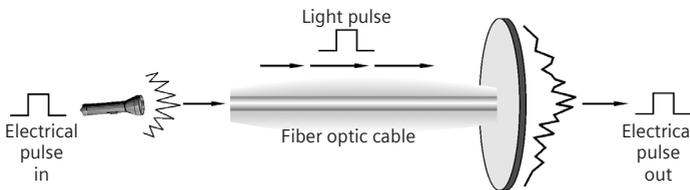
A modem is a device that translates a signal from one transmission technology to another.

Fiber optics operation begins with an electrical signal which is converted into light, transmitted along the fiber optic cable and then converted back from light to an electrical pulse at its destination.

Ground loops are electrical currents that travel along the ground cable and may interfere with communications.

Light can go both ways along the cable, travels very quickly, and can transmit the signal very long distances over high quality fiber.

Because fiber optic modems translate the electrical information into light, they also provide electrical isolation. Thus in two areas with different grounds,[2] fiber optics connect them without the danger of creating ground loops.

Electrical noise is made up of electromagnetic waves that can induce voltages onto copper cables. However, electromagnetic waves have no effect on light; hence, there is no electrical noise – making fiber optics ideal for areas with much ambient electrical noise.

Many PROFINET switches have fiber optics as an option in the configuration, making it simple to incorporate fiber optics into a PROFINET network design.

Fiber optics conclusion
- extends network over large distances
- solves grounding problems
- effective in high noise applications
- offers more versatile topologies

The US navy likes using the fiber optic PROFIBUS ring for many of their aircraft carriers. I remember being told about the major grounding problems that ships have. At first I was surprised until I realized that a ship is a metal container bobbing up and down in water acting very much like a varying capacitor and creating different grounding potentials all over the ship.

Fiber optics is a perfect solution for ships. Plus, in the case of a war ship, the ability to set up redundancy is also a big benefit.

Wireless (PROFIBUS DP or PROFINET)

In a wireless network, data is transmitted through the air from a source to a receiver. The electrical signal is translated into electromagnetic waves that can travel great distances, depending on the modems. Also because of the translation into electromagnetic

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[2] Grounding is also referred to as *earthing*.

waves, one side has no electrical connection to the other (providing great isolation), making wireless a practical solution to grounding problems.

There are numerous wireless solutions available for PROFIBUS using different radio and infra-red technologies. (A full list can be found on the PROFIBUS website. Go to www.PROFIBUS.com/meta/productguide and search for 'wireless.')

PROFINET also has a number of wireless solutions all based on different wireless Ethernet options. The most popular is Wi-Fi (IEEE 802.11 (b,g,a,h,n)), familiar to anyone with a smart phone. Bluetooth is also supported. There are also long distance options and short distance options available.[3]

One big difference between PROFIBUS DP and PROFINET wireless options is that all of the PROFIBUS DP wireless options use proprietary solutions for the wireless part, while most of the PROFINET wireless options use open Ethernet standards. As a result, wireless is used far more for PROFINET than it has been for PROFIBUS DP.

Wireless technology can save on physical wiring costs. Laying wires from one device to another costs money, both in the actual wire used and in the labor to lay it properly.

Wireless is also the only option for some applications where it can be difficult, if not impossible, to run the wires, such as near rotating machines or through barriers such as roads.

Wireless technology conclusion
- extends range
- solves grounding problems
- saves on wiring costs
- excels in applications where it is difficult or impossible to run wires

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[3] See www.profinet.com for a full list.

Wireless is getting a lot of press these days but most of the technology used by current wireless providers has actually been established for quite some time. Let me give an example:

Fifteen years ago I worked on a project using wireless spread spectrum modems to connect a remote PLC back to a Honeywell DCS using Modbus. The client needed four analog values brought back that were important to the process. The modems cost $2,000 each with a total project cost at $10,000. The facility had run out of room in the cable run, and to run another would require digging up a major road at an estimated cost of $500,000. Thus, the $10,000 was a small investment and the client gladly paid it.

Manchester Encoded Bus Powered (MBP) (IEC 61158-2) (PROFIBUS PA)

The IEC 61185-2 standard defines a physical layer that uses a special method called *Manchester encoded Bus Powered* (MBP) to deliver power and communications on the same two wires and information is transmitted by varying the power draw on the power cable.
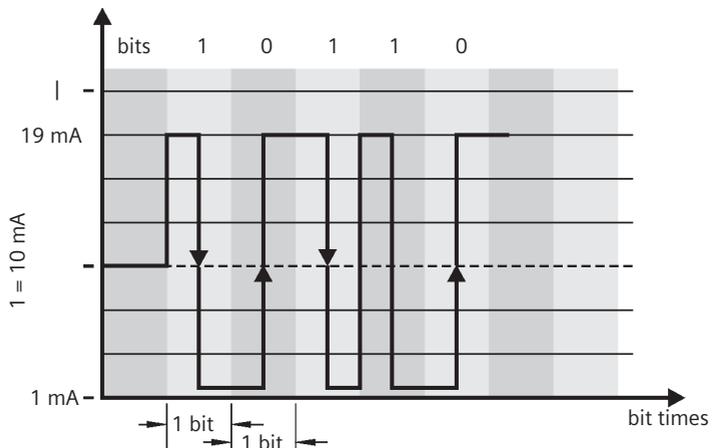
The voltage level on the bus has to be a minimum of 9 V DC,[4] but can be as high as 32 V DC. The baud rate is fixed at 31.25 Kbits/second. This is the main physical layer used for PROFIBUS PA.

The minimum base current is 10 mA. The physical layer works by having the devices vary the power draw over time. The transmission of a **1** or a **0** depends on when the power is increased or decreased. If the power goes from a high to a low during a pre-defined bit time, then it is a logical **1**. If the power goes from a low to a high, then it is a logical **0**. At the beginning of the message is a startup sequence so that all the devices on the network can coordinate bit times. Electrically this is far more complex than RS-485 and the above description is a simplification of how the physical layer works.

MBP used for PROFIBUS PA is the same physical layer used by Foundation Fieldbus H1.

Number of devices: This physical layer can handle a maximum of 32 devices (31 field devices plus one coupler). PROFIBUS works fine at this number. However, as described in *Chapter Five*, the network topology options are reduced once the number of devices goes above 24.

Network speed: The speed of MBP is always fixed at 31.25 kbits/second.

Distance: For non-IS applications, the MBP segment can not exceed 1900 meters (6232 ft). For IS applications, it can not exceed 1000 meters (3280 ft).

MBP conclusion
- provides communication and power on the same two wires, saving considerable installation costs because power and communication do not require separate lines.
- Intrinsically Safe (IS) aka MBP-IS. See *Intrinsically Safe* below.
- MBP has considerable electrical noise immunity, so it can be used in industrial settings where there is much electromagnetic noise.

RS-485-IS (PROFIBUS DP)

RS-485-IS is a modification of RS-485 to run at lower power levels. *IS* means Intrinsically Safe (see below). There is a special coupler to do the physical layer translation between RS-485 and RS-485-IS,

[4] To pass PI certification, the device must be able to power up with 9 V DC applied. There are some uncertified PROFIBUS PA devices that require more than this to power up, another good reason to use only certified PROFIBUS PA devices.

and RS-485-IS also uses different wiring and is limited to a maximum speed of 1.5 Megabits per second.

NOTE: The Siemens ET200 remote I/O rack operates on RS-485-IS, and it's a cost effective solution for remote I/O in IS environment.

Intrinsically safe/hazardous environments

Process plants often have areas where explosive substances may be in the air, and an electrical spark could trigger an explosion. The IEC[5] has defined different zones based on how often an explosive mixture is present:

- Zone 0 has the highest frequency
- Zone 1 has less than Zone 0
- Zone 2 has even less than Zone 1

The IEC definitions are accepted globally. However, many countries have other classifications running in parallel so different terminology is possible. For example in North America, Class I Div 1 corresponds to Zone 0 and Zone 1.

The fieldbus approach to explosive environments is to limit the energy going to the bus and the devices to a level where it is impossible for a spark or thermal effect to be generated. The devices designed to this concept are said to be intrinsically,[6] or naturally, safe.

WARNING! This section on Intrinsically Safe/ FISCO/ FNICO and RS-485-IS is meant only as an introduction. An entire book could be written on this topic. When attempting an IS project, please educate yourself further on this technology. The different vendors who sell IS products all have detailed documentation. Please remember that lives are at risk when dealing with IS!

The power is limited by using a special coupler that clamps the power at a particular level depending on the area that it is designed for. Typically when dealing with IS environments, an MBP physical layer is used. When MBP is used in IS environments, it is referred to as MBP-IS. However, PROFIBUS does offer a second option called RS-485-IS.

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[5] International Electrical Congress (IEC) is an international standards organization committed to creating and maintaining international and open standards for use in the electrical industry.
[6] Intrinsic: belonging to the essential nature or constitution of a thing.

The importance of Intrinsically Safe areas is a hard one for rookie engineers to appreciate. I remember my first safety training and then going into my first chemical plant. I was fresh out of university and knew it all. I started to learn respect when I went into the control room and asked the dumb question "why are the walls so thick?"

So that the people inside could survive if there were an explosion. Ouch!

I continued my respect lessons when I entered in an area where a chlorine warning detector went off. The warning level meant that the fumes were not lethal but higher than they should be. Two seconds later when I breathed in the non-lethal fumes, I knew these chemicals demanded our respect – I still remember the pain in my lungs and the panic I felt.

Fieldbus Intrinsically Safe Concept (FISCO)

To get approval for an IS application, there are a number of calculations that have to be done. However, for MBP, a group of engineers discovered that they were able to simplify these calculations by looking at the physical layer and noting the following:

- only one power source
- all others are power sinks
- constant power draw

With this, they came to this conclusion: PROFIBUS devices can be almost Intrinsically Safe plug-and-play as long as the current sum is under the maximum current supplied by the IS coupler when the current draws of the different instruments are added.

It should be noted that there are several limitations on the physical layer:

- requires class A cable
- maximum distance is 1000 meters
- maximum spur line length is 60 meters
- needs a FISCO approved power supply and coupler
- a typical FISCO coupler provides 14 V, 110 mA
- instruments are FISCO approved

With these limitations, the FISCO approved field devices would be approved for use in a Zone 0 or above environment.

Fieldbus Non-Incendive Concept (FNICO) and FISCO ic

The FNICO standard operates under the same principle as FISCO, but is applied to a Zone 2 area meaning that some of the requirements on power supply are relaxed, thereby allowing more instruments on one segment. In the beginning of 2008, FNICO has been replaced by FISCO ic, which applies similar rules as FNICO.

The limitations on the physical layer are:

- class A cable
- maximum distance is 1000 meters
- maximum spur lines length is 30 meters
- FISCO approved power supply and coupler[7]
- FNICO and FISCO ic couplers provide 17.5 V, 350 mA
- FISCO[8] approved instruments only

Choosing a physical layer

Many physical layers are available:

- RS-485
- Twisted pair copper
- MBP
- Wireless
- RS-485-IS
- MBP-IS
- Fiber optic

Here are some guidelines for choosing the right one for the application:

Twisted-pair copper is the main road for general automation using PROFINET and forms the backbone of the top network. PROFINET is the preferred solution since it is the easiest to design and implement. However, some controllers only support PROFIBUS DP and some field devices only support PROFIBUS DP. In these cases, PROFIBUS would have to be used.

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[7] Standard IS limits the power at the coupler. An alternate method, the High-Powered Trunk concept (HTP), can be far more cost effective and limits power out in the field. More details at www.profibus.com.
[8] Currently this statement is accurate as there are no FISCO ic approved devices or barriers yet. This will change in time and should be verified when designing the IS segment.

- RS-485 is the main road for general automation using PROFI-BUS DP
- Use fiber optics in these conditions:
  – long distances
  – grounding issues (like between buildings)
  – high electrical noise

- Use wireless in these conditions:
  – long distances
  – high wiring costs
  – poor access to run wires
  – moving equipment

Currently most instrumentation is offered with either RS-485 or MBP-IS. Some of the 4-wire instruments are starting to offer PROFI-NET. As discussed in Chapter Three, it will be some time before 2-wire instruments will have PROFINET. In the meantime, use MBP-IS for instrumentation in IS areas. For non-IS areas use either RS-485 or MBP depending on the instruments and application.

Network components

This section presents how to join the roads together.

Switches (PROFINET):

A switch connects one PROFINET device to another. General Ethernet has a variety of different kinds of switches and functions available. PROFINET requires a switch with these requirements:

- It must support two-way communications - full duplex.
- It must store and forward messages so that two messages can come in at the same time for the same node and both make it there.
- It must be auto crossing so that it is not as sensitive to the type of cable used.
- It must support 100 megabits-per-second speed full duplex, but also support 10 megabit, half duplex for legacy systems.
- It must be an industrial grade switch and not a commercial grade switch.

In general, these requirements are not very sophisticated so most switches do support these. It should also be mentioned that many IO-Controllers and IO-Devices also have 2-port or 4-port switch built

in. The main purpose of these built-in ports is to permit simple line topologies.

Managed versus unmanaged switch: An unmanaged switch does not have any additional diagnostics other than simple LEDs indicating send and receive. A managed switch, however, includes diagnostics support such as SNMP – Simple Network Management Protocol – and other advanced features such as web access and Telnet. A managed switch tends to be more expensive than an unmanaged switch and may also require some configuration.

PROFINET allows using either a managed or unmanaged switch. However, a managed switch is recommended, and the added cost will be worth it after the switch's diagnostics solve the first network problem.

When looking at a price of an Industrial grade Ethernet (PROFINET) switch compared to a commercial grade, you may be tempted to use the commercial grade. If you are just using Real Time IO, the standard Ethernet commercial grade modem will work - at least for a while - but there are good reasons to spend extra on the industrial unit.

Back when we used phone modems for remote access to industrial sites, we installed a commercial grade modem in a water pumping station. The modem worked fine – for a while. After about a month, it had to be replaced – it simply stopped working. The next month, the same thing happened. Finally we replaced it with an industrial grade modem. That was over ten years ago. The industrial grade modem simply keeps on working. It has greater temperature range and is designed to withstand the voltage spikes prevalent in industrial plants. Our conclusion was that the motor control center located three feet from the modem burned out the commercial unit. However, the Industrial equipment could handle it!

Routers (PROFINET)

A router joins multiple networks together. They are typically sub networks (subnets) that connect to a larger network. Like a home router which joins a home Ethernet network to the internet, routers isolate the traffic on one network from that of another.

For PROFINET, both real time IO and IRT require that all the devices be on the same subnet. One device cannot be separated from another by a router. However, routers are still used to join different PROFINET networks and also to connect a PROFINET network to the main plant or to office networks. Because a router will only let the packets intended for the subnet onto the subnet, it will prevent an office network from slowing down the control network. However, it still lets control engineers in the office pull data from the control network.

System Diagnostics and IO-Controller configuration usually can be done through a router since the software usually uses TPC/IP or ISO on TCP to communicate to the IO-Controller.

Repeaters (PROFIBUS DP and PA)

A repeater is a device that *repeats* an electrical signal thereby returning it to full strength. Each time an electrical signal is read, the power levels are reduced. Also, the longer the distance it travels, the lower the power levels. Eventually it gets to a point where the electrical signal cannot be read because the value levels are too small.

A repeater takes the low signal it reads on one segment and repeats it on a second segment, returning it to full strength. All the different physical layers of the network have only a limited number of repeaters because each repeater introduces a delay in the signal. PROFIBUS requires that communication occurs within a certain time in order to meet the determinism requirement of the control system. If there are too many repeaters in any one communication path, then this time limit (watchdog timer) is exceeded which is a serious error since the controller would no longer be able to control the processes. Often repeater manufacturers will require that some of the PROFIBUS timing parameters (also called PROFIBUS bus parameters) be adjusted so that the PROFIBUS watchdog timer will not be exceeded.

1. To *read* a signal means that the electrical circuit senses if the value is a **1** or a **0**.

2. Deterministic is knowledge of an impending event within a fixed time period. This is a requirement of advanced control systems.

Repeater

Segment A

Segment B

Re-generate
original signals
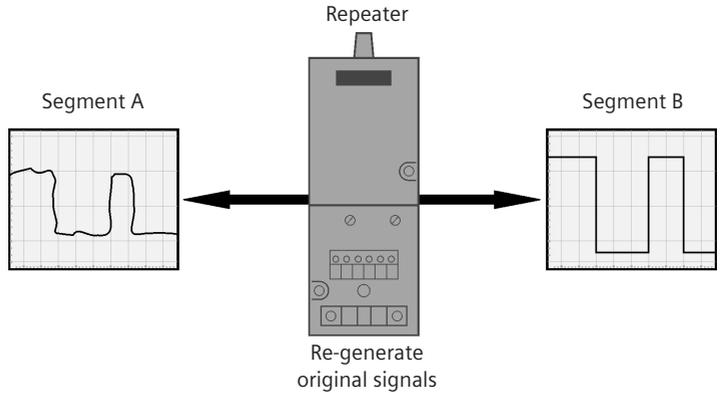
The repeater most common to process automation is the one used for RS-485. Many of these modems will allow as many as nine repeaters in any communication path. Thus between any two devices that talk (master – master / master – slave), there can be no more than nine repeaters; however, the total number of repeaters in the entire system can be much greater than that.

Besides being used to extend the length of the network and the number of devices on the network, repeaters are also used to create spur lines for RS-485. Generally, RS-485 is wired using a method called daisy chaining. Wires are run directly from one device to another. Spur lines, however, are tapped from a main cable and another cable is dropped down to a field device.

When RS-485 is running at 1.5 meg or higher, spur lines are not allowed. When it is running at lower speeds, a limited number and a limited total length of spur lines are permitted, but not recommended. They restrict the maximum baud rate and introduce reflections on the line that reduce the robustness of the entire system. They are generally a bad idea for RS-485. However, since a repeater refreshes the signal, it can be also used to create the same topology as spur lines. Some manufactures (e.g. Procentec and Phoenix Contact) have created special repeaters designed to create spur lines in PROFIBUS DP.

Field device

Repeater

Field devices
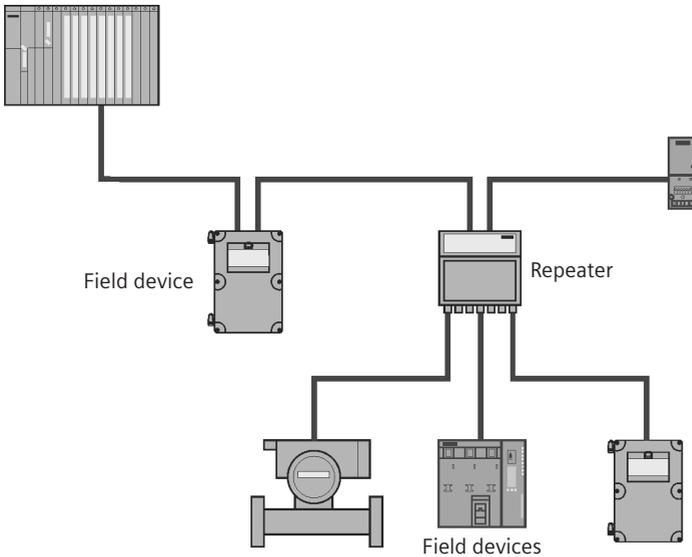
RS-485 repeaters technology summary
- extends the total length of the network for a given speed
- increases the number of devices on the network
- allows different topologies (spur lines)

MBP repeaters
While there are MBP repeaters available, they are of limited use for PROFIBUS. PROFIBUS has the DP highway joining all the PA side streets together, and if one of the PA segments gets overloaded, a PA coupler or link/coupler can be added to create a new segment. This is typically far easier, more cost-effective, and gives better performance than a MBP repeater.

RS-485-IS coupler
This device converts RS-485 to its Intrinsically Safe version called RS-485-IS. This coupler limits the overall baud rate to 1.5 meg. It also uses different wires and different termination than regular RS-485. This device is only used when there are devices on RS-485-IS to connect to.

Connecting PROFIBUS DP or PROFINET to PROFIBUS PA

Traditionally PROFIBUS PA devices have been connected to the main controller via a PROFIBUS DP to PA coupler/link/gateway. Until recently, only three companies made these devices: Siemens, ABB, and Pepperl+Fuchs. Recently, however, IFAK Systems and PROCENTEC have entered the market with solutions as well with a direct PROFINET to PROFIBUS PA proxy. Here is a summary of the current possible solutions:

Company	Product Name	PROFIBUS DP Connection	PROFINET Connection	Comments
Siemens	DP/PA Coupler	DP fixed at 45.45 k bits per second	Not direct. Can use a PROFINET to DP proxy	PA side uses the same address space as DP side
Siemens	DP/PA Link/Coupler	Any baud rate	Not direct. Can use a PROFINET to DP proxy	PA side uses a different address space than on the PA side
ABB	DP/PA Linking Device	Any baud rate	Not direct. Can use a PROFINET to DP proxy	PA side uses the same address space as DP side
Pepperl+Fuchs	Segment Coupler for PROFIBUS PA (SK1)	DP fixed at 93.75 k bits per second	Not direct. Can use a PROFINET to DP proxy	PA side uses the same address space as DP side
Pepperl+Fuchs	PROFIBUS Power Hub System (SK3)	Any baud rate	Not direct. Can use a PROFINET to DP proxy	PA side uses the same address space as DP side
IFAK Systems	IsNet PA	No	Connects directly to PROFINET via isNET PNGate head module	Comes in either a 2 channel or 4 channel version
Procentec	COMbricks	Any baud rate	Connects directly to PROFINET	Also includes advanced communications

Siemens PROFIBUS DP/PA coupler: The Siemens coupler converts a RS-485 physical layer into MBP physical layer. In many ways it is similar to a repeater except that instead of repeating the message in the same electrical method, it repeats the message using a different electrical method. Like a repeater, it is typically invisible on the network and the addresses on one side of the coupler are part of the same address space as the addresses on the other side of the coupler.

Siemens DP/PA Coupler provides a low-cost, low performance solution.

There are two versions on this coupler: one for IS applications and one for the non-IS.[9] The newer non-IS coupler can be configured with an address. When configured with an address it provides feedback on the current and the voltage level on the PA segment. The couplers require that the DP side be fixed at 45.45 kilo bits per second.

Siemens PROFIBUS DP/PA link: The PROFIBUS DP/PA Link module is an innovative Siemens device that creates a true sub network by setting up a PROFIBUS DP slave on one side and a PROFIBUS DP (PA) master on the other. In this configuration, the PROFIBUS DP side of the network can run at any baud rate just like the P&F coupler but differs in that the address space on the PA side is different from the DP side. Therefore, with the Siemens link module, more instruments will fit onto one DP network because it is no longer limited to the 0 to 125 address space of DP.

Siemens DP/PA link modules are a slightly higher cost, but far better performance.

Master

PROFIBUS DP (any rate up to 12 M bit/s)

DP/PA link module with two couplers and one power supply.

PROFIBUS PA (31.25 K bit/s)   PROFIBUS PA (31.25 K bit/s)

Different address space than the DP network above.

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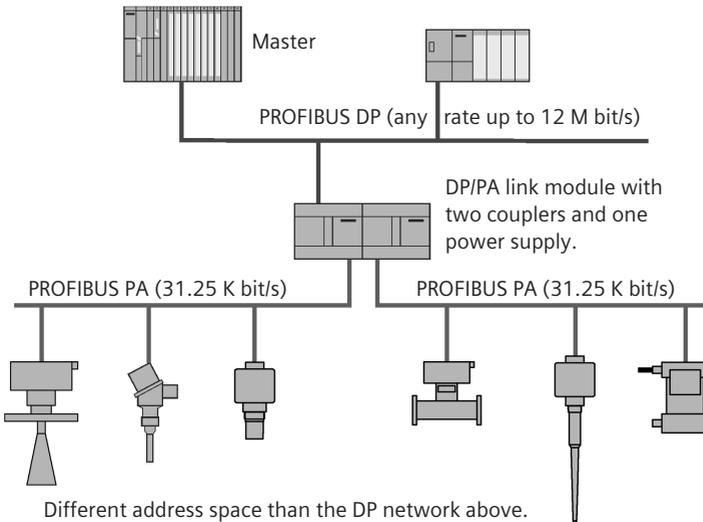
[9] It is worth noting that the Siemens non-IS coupler can supply 1 A and 31 V DC of power, the largest amount on the market and very useful for getting the maximum number of devices and the maximum length.

Another advantage of the link module is related to the update times of the field instruments. For example, when using the Siemens couplers with as many as 100 field instruments on it, updating the main process variable of each field instrument uses the following calculation:

$$100*15.5 + 20ms = 1.57 \text{ seconds}$$

However, if several link modules, each with 20 instruments, are used then the update times are almost five times faster:

$$20*15.5 + 20ms+1ms = 0.331 \text{ seconds}$$

The link module needs a coupler (either IS or non-IS version) to function and it can use up to a maximum of five. The overall design rules for using this module are fairly simple:

- a maximum of 244 bytes of output and 244 bytes of input data available (so you have to verify that the total number of input/output bytes read on the PA side does not exceed these limits)
- no more than 64 devices in total[10]
- maximum of five couplers

See *Chapter Five: Intelligent Design* for more discussion on the design rules.

The PROFIBUS specification states that the data in the communication packet is a maximum of 244 bytes, giving a maximum of 244 bytes of input data and 244 bytes of output data. This applies to almost all the PROFIBUS masters that I have worked with. However, there are exceptions to this rule. Some of the very first PROFIBUS interface cards had some limitations. For example, APACS DCS, a legacy DCS product, is limited in that the input data can only be a maximum of 122 bytes. The output data can still be 244 bytes as normal, but not the input.

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[10] Older link modules can only handle a maximum of 32 devices.

I discovered this on a service call. They called me in because the service people commissioning the network did not have enough training and could not commission the DP/PA link modules. The information that they were missing was that when working with a non-Siemens host, you have to use a GST-Tool (free download from the Siemens website) to combine the field instrument's GSD files with the DP/PA Link module's GSD file. This part we got working in no time at all. Then we discovered that the designers had overlooked the 122 byte limitation on the input data. We ended up having to move a couple of instruments over to other segments. Both of these problems could have been easily avoided by simply reading the manual – the devil is in the details!

ABB PROFIBUS DP/PA linking device: The ABB solution is transparent and the devices on the PA side of the network are part of the same address space as the DP side. Furthermore, the ABB link module does not have an address on the DP side and is invisible to the network.

ABB has a head station the PROFIBUS DP network plugs into. There are different versions of the head station, each with its own number of channels: 1, 2, and 4. Each channel can then have as many as five power link modules plugged into it with one PA segment per power link module. The power link module is available in either an IS or a non-IS version.

This design offers a similar way to increase the update rates as the Siemens Link module. For example, if 80 devices are spread over four power link modules connected to a one channel head station, update times can be quadrupled simply by switching to the four channel version and then using one channel per power link module.

When configuring the DP master, it can be set to any DP baud rate and the ABB linking device will work. Note that the PA slave device GSD files have to be converted using a software tool by ABB, and configuration is easy once that is done.

This is really an effective way to convert DP to PA. The linking device acts as an invisible gateway between the two networks. When troubleshooting the linking device, remember that the messages on the DP side are different from the messages on the PA side. The only real disadvantage is the 124 device limit for one DP network.

Pepperl+Fuchs PROFIBUS power hub (SK3) system: This Pepperl+Fuchs solution is also a transparent solution.

The power hub comes in different models with different options:

- number of channels
- FISCO and FISCO ic
- power and gateway redundancy (see Media and Power Redundancy below)
- advanced loop diagnostics

Each channel has its own PA master, so this product offers a way to increase the update rates. Simply reducing the number of devices on a channel increases the update rate.

When configuring the DP master, it can be set to any DP baud rate, and the Pepperl+Fuchs power hub will work. Note that the PA slave device GSD files have to be converted using a software tool by Pepperl+Fuchs, and configuration is easy once that is done.

The loop diagnostics are definitely something that should be considered. They have a module for the power hub and software tool that monitors the physical layer and assists during commissioning, monitoring, and troubleshooting the PA physical layer. The module records the actual PA waveform and it can then be accessed over the DP network. In general, the Pepperl+Fuchs Power hub is an impressive device.

Pepperl+Fuchs Segment Coupler for PROFIBUS PA (SK1): A similar idea to both the ABB and Siemens Coupler with the exception that the baud rate on the DP side is fixed at 93.75 k bits per second. Intrinsic safety is selectable on the field side.

This is Pepperl+Fuchs low end solution and it's suited for applications where the low speed on the DP side is acceptable.

IFAK Systems isNetPA and isNet PNgate: A PROFINET proxy with a head module (isNet PNgate) and up to five isNetPA attached modules. Each module can support either two or four channels. Each channel is independent of the other channels and forms one PROFIBUS PA segment. Altogether, a nice solution for attaching PA instruments to a PROFINET controller.

PROFIBUS PA (31.35K bit/s)

PROFINET

CLASS 1 DI V.1
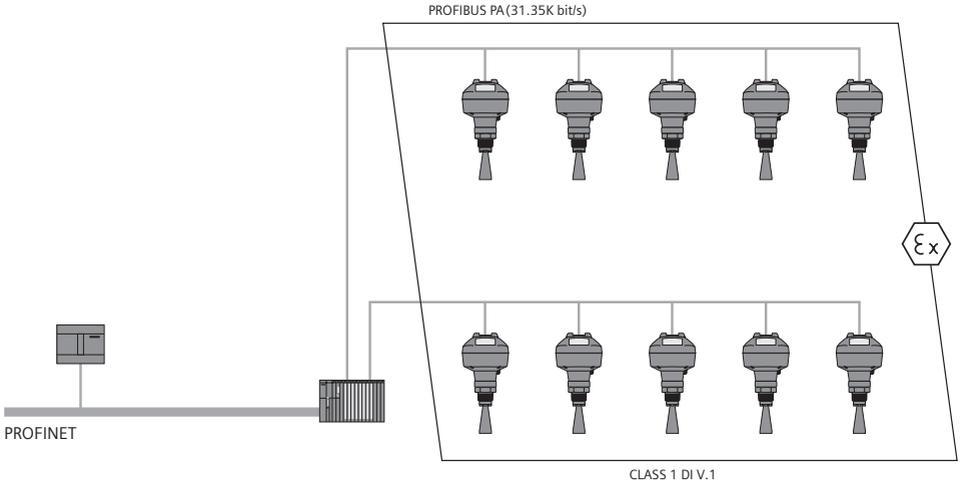
PROCENTEC COMbricks PROFIBUS DP to PROFIBUS PA link/coupler: A transparent solution like the Pepperl+Fuchs power hub product. The DP side can go at any baud rate and there can be up to nine PROFIBUS PA modules in one COMbrick rack. Each PROFIBUS PA module supports one segment. These modules also have the additional option of having a built-in bus monitor called ProfiTrace, one of the leading PROFIBUS bus monitors on the market. Its presence adds troubleshooting options to the system.

PROFINET

PROFIBUS PA

PROFIBUS DP

85
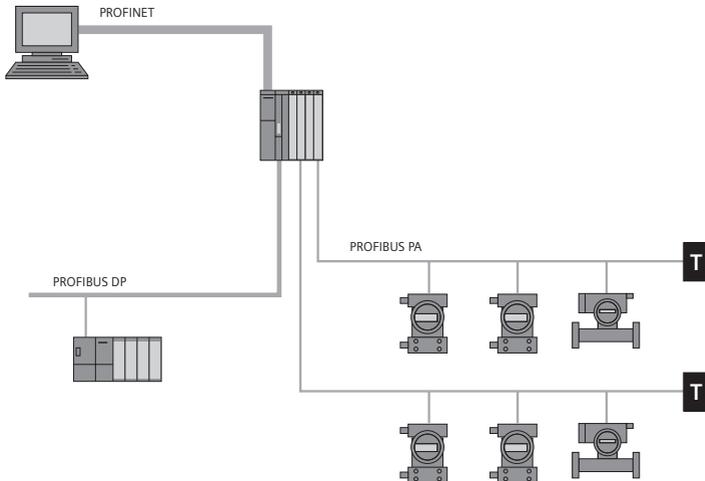
Redundancy

In some applications in process automation, the process must continue even if there is some sort of failure. One common term for this is *high availability*. Redundancy helps keep the system going by having multiples of something so that if one fails, another takes its place.

There are several different forms of redundancy:

- master redundancy
- media redundancy
- device redundancy
- power redundancy

PROFINET and PROFIBUS DP and PA have master and media redundancy and device redundancy available.

- Master redundancy is like having two bosses – a primary one and a secondary one. If the primary boss is out, reporting switches to the secondary (backup) boss.
- Media redundancy is like having two separate roads to your house, another way in is always available if one way is blocked or damaged. Thus, in a network, two cables will go to the same node so that if one cable is lost, there is still communication to that device.
- Device redundancy is when multiple devices are doing the same thing – either input or output. If one fails then the other can take over.

PROFIBUS PA also has power redundancy possible.

- Power redundancy is like a car with two gas tanks. If one tank runs out of gasoline, there is always the second tank to keep the car going.

PROFIBUS DP master and media redundancy

There are numerous options and manufacturers offering both master and media redundancy for RS-485 (PROFIBUS DP). Siemens, ABB, and Pepperl+Fuchs, to name a few, all have both master and media redundancy available.

The Siemens solution is to use the special S7-400H series of fault tolerant, high availability PLCs. Some I/O have the built-in ability to switch between the primary and secondary PROFIBUS DP cable and others use a special module called a Y-Link.

In addition to these RS-485 solutions for media redundancy, fiber optic modems are also an option. Many of these can be set up to provide a ring redundancy. This means that to each fiber optic module, there are always two paths back to the master. Therefore, if one path is cut off, the other is available.

PROFINET master and media redundancy

As with PROFIBUS DP, PROFINET has numerous options and manufacturers who offer both master and media redundancy.

For twisted-pair copper, the standard is to use Media Redundancy Protocol (MRP) with its ring topology. For IRT, Media Redundancy for Planned Duplication (MRPD) can also be used.

As with PROFIBUS DP, fiber optics is also an option.

PROFIBUS PA master, media, and power redundancy

For PROFIBUS PA, both Siemens and Pepperl+Fuchs offer:

- power supply redundancy
- coupler redundancy
- links to DP redundancy

In addition, Siemens offers a true ring topology which provides full media redundancy by providing redundant paths to any slave on the ring.

Power supply and coupler (PA Master) redundancy: Pepperl+Fuchs handles the coupler and/or power supply redundancy very easily by using plug-in modules to their power hub, making all the hardware just add-ons to the coupler or couplers. The user has a choice between having only power redundancy or having power redundancy and coupler (PA Master) redundancy. Full PROFIBUS DP redundancy is also available, and the advanced diagnostic module lets the user monitor the health of the physical layer. A big advantage of the Pepperl+Fluchs solution is that it is completely transparent to the network with no special configuration.

In addition, Pepperl+Fuchs and others offer intelligent junction boxes that increase availability by adding short circuit protection. Thus if a PA slave shorts out, the network does not go down.

The Siemens solution uses an active field splitter that takes PA cables from two separate DP/PA couplers and channels one to the

PA segment. If communications or power from one of the PA couplers/power supply fails, then the active field splitter will switch to the other line keeping communications going. To get PA master redundancy in this design, the user has to add one more link module and have redundant PROFIBUS DP going to the node.
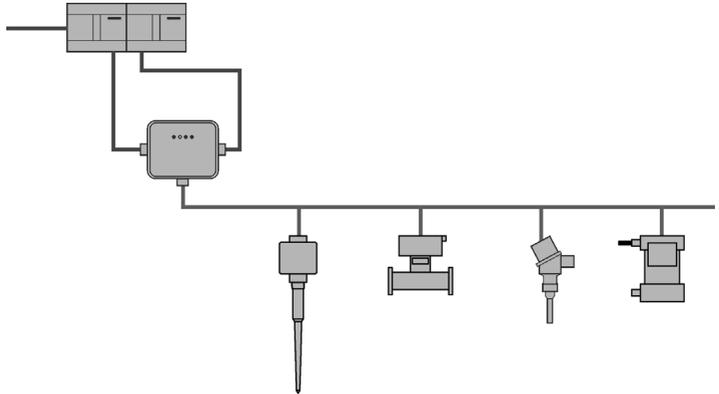
PROFIBUS PA media redundancy: Siemens and Moore Hawke both offer PROFIBUS PA media redundancy. The Moore Hawke solution provides only one special junction box in the ring and is therefore limited. This junction box does the switching between the two incoming lines.
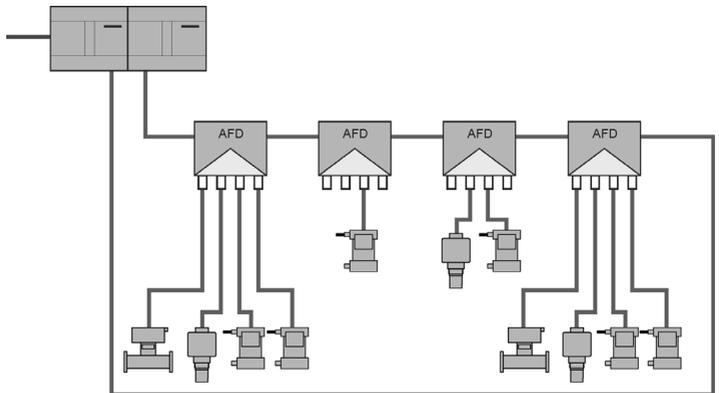
The Siemens solution is to use a ring with multiple junction boxes called Active Field Distributors (AFD). AFD will do the following:

- auto terminate the bus
- provide short circuit protection on PA drops so that if a PA slave is shorted out, the network does not go down
- show diagnostic lights indicating the slaves are fine or where a wire break has occurred

The couplers supporting this structure provide additional helpful features through PROFIBUS addresses:

- current and voltage of the PA segment
- local Life List
- wire break/short circuit diagnostics

A Life List shows all devices that are communicating on the network.

The Siemens PA ring has a number of benefits:

- increased availability of the network which means less down-time for the process
- easier troubleshooting because of better network diagnostics
- easier to switch out devices for maintenance due to the short circuit protection
- easier to design and install the network due to the auto-termination and short circuit protection

Summary

Redundancy has a number of benefits:

- increased availability of the network which means less down time for the process
- easier troubleshooting because of better network diagnostics

In general, the ring structure is the preferred solution for all applications. However, the requirement for increased availability is the key. If it is an important control loop, the increased availability is worth the added costs. However, if it is a tank farm application where the increased availability does not affect profits as much, it is probably not worth the extra expense.

Choosing network components

Choosing some of the network components will be easy based on the design and layout (*Chapter Five*). For example, with 40 devices on PROFIBUS DP, a repeater will be required. Picking the brand and model of repeater will require more thinking. One advantage the designer has with PROFIBUS and PROFINET is the availability of options.
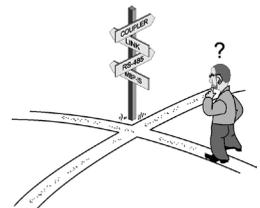
When using PROFIBUS PA, some sort of DP to PA link and/or coupler is required. Because the basic functionality varies considerably between bands and models, the designer has to remember that the choice of linking device affects the design.

When using PROFINET, picking the correct switch is the key. With plenty available options, it is recommended that you spend some time selecting the best one for your application.

In general, there is an interaction between the physical layer, the components, and the network design. When starting this process, the designer needs a clear vision of the end user network requirements and be willing to change components, physical layers, and network design as it is laid out. Design is not linear. It is recursive, and depending on the designer experienced it may take several iterations to get it right.

Next BUS stop: intelligent design

Now all the pieces have been discussed, the next chapters concentrate on the following:

- network design – what are the rules?
- install the network
- set up the network
- operate the network
- troubleshoot the network

Chapter Five

Intelligent design: PROFIBUS DP/PA and PROFINET basics

Art has to move you and design does not, unless it's a good design for a bus.[1]

A well designed PROFI bus moves data quickly and reliably, and to design a good PROFIBUS and PROFINET networks, these guidelines need to be followed:

- following all the design rules and installing the network correctly ensures the PROFIBUS and PROFINET networks will work properly and be error free
- not following the design rules can add to costs incurred through troubleshooting time spent, and changing a failed design in the field takes surprisingly large amounts of time and money as the process stops while repairs are made. In other words, it pays to follow the rules!

PROFIBUS uses two main physical layers – RS-485 and MBP – and the distinction is reflected in the PROFIBUS designation:

- PROFIBUS DP – typically[2] refers to the PROFIBUS DP protocol running on RS-485
- PROFIBUS PA – typically refers to the PROFIBUS DP protocol running on Manchester encoded Bus Powered (MBP) (IEC-61158-2) physical layer

PROFINET typically uses a twisted-pair physical layer, although wireless (Wi-Fi) and fiber optics are also very popular.

When working on a network design, it is very important to remember that it is a recursive process. The first design attempt will often not look much like the finished product because of the many factors to be considered as the design progresses.[3]

There is more than one right answer – many different designs will solve the same problem.

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[1] David Hockney, British artist, (1936 -)
[2] The protocol itself is also referred to as PROFIBUS DP and so when it is run on other physical layers such as fiber optics it is still called PROFIBUS DP.
[3] See *Chapter Four* for the discussion on the interaction between the design, the choices of physical layers, and the components.

This chapter deals mainly with the general design rules. Please note that selected components add additional rules. For example, different types of DP/PA connecting devices come with their own sets of rules.

BUS route

This bus makes the following stops:

- PROFINET basic design
- PROFIBUS DP basic design
- PROFIBUS PA basic design
- PROFIBUS PA design examples
- Design tools
- Calculating data update rates
- PROFIBUS PA design suggestions

PROFINET basic design rules

PROFINET forms the backbone of the automation solution by linking drives, motor starters, digital I/O, and PROFIBUS DP and PA networks. Process plants often have a mixture of analog and digital I/Os alongside an increasing number of Variable Frequency Drives (VFDs). The ability to join these different devices easily within one system is a key strength of PROFINET.

Presented below are the basic PROFINET design rules; for a much more detailed treatment of this topic, please see the *PROFINET Design Guidelines* by PROFIBUS and PROFINET International (order number 8.062). It expands on these rules and goes into great detail on designing for performance which is outside the scope of this book.

Fundamental design rules for PROFINET running on copper:

1. Pick your topology and any sub-networks based on your application.

   PROFINET can have a number of different topologies; star, line, ring, tree, or any combination thereof.

   Star topology: The star configuration is one of the simplest configurations, using switches that link all the devices.
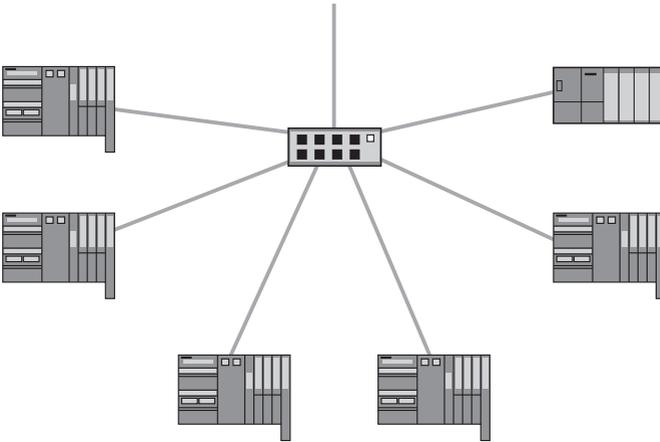
Line topology: The line configuration is popular topology. IO-Devices often have a two-port switch built in. Joining them and using their internal switches is both easy and cost effective.
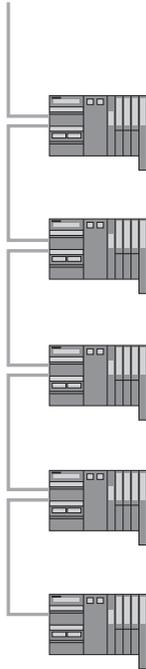
Ring topology: The ring topology is used for applications that require redundancy.
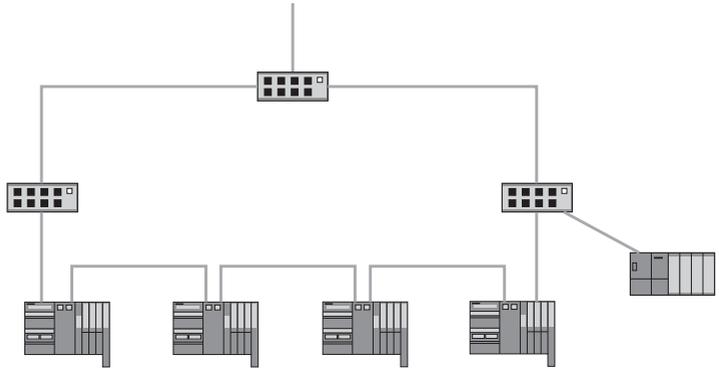
**Tree topology:** The tree topology is a variation on the star topology.
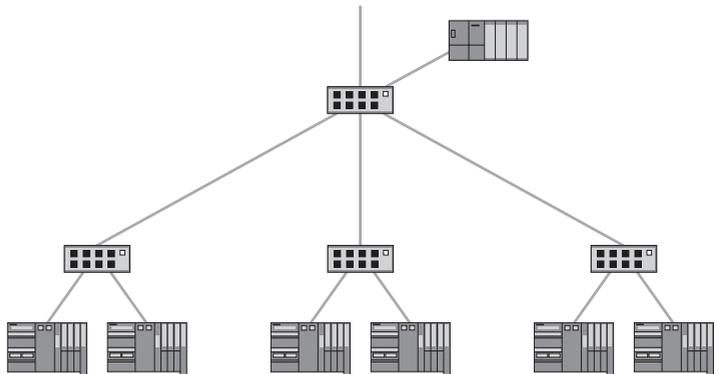
PROFINET is very versatile and can adapt to the application requirements and layout. Basically almost anything works. When laying out a network, the main concern is where best to place the switches and devices. However, keep in mind the effect on the system if a switch fails or a cable is damaged because a failure can drop any number of devices from the network. Also remember that your choice in topology will have an impact on performance as well.[4]

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[4] Please refer to *PROFINET Design Guidelines,* PI order number 8.062

2. Do not exceed 100 meters between the switch and device.

    PROFINET copper cables going from switch to switch or from switch to device cannot be longer than 100 meters. For more distance, there are two options; use a small switch as a repeater or use fiber optics. Many switches support fiber optics, just be sure that the correct fiber is picked to support the length – different fibers support different distances.
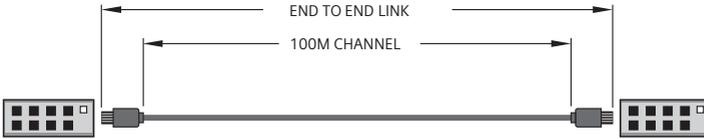
3. Select the correct switch based on the application requirements.

    Switches are very important devices and the proper selection is critical for a good network. It must support the PROFINET functions that the application needs. For example, if the application needs IRT, then the switch will need to support IRT.

    The next consideration is the use of either a managed or unmanaged switch. From a technical point of view the recommendation is easy – always use a managed switch because the additional diagnostics is worth the added price. Realistically, however, for some small systems the value of these diagnostics may not be worth the costs.

    Here are the basic questions to ask when ordering a switch:

    - Managed or unmanaged?
    - Transmission rate required?
    - Number of ports?
    - Type of port connector?
    - Fiber optics?
    - Mounting?
    - Enclosure degree of protection?
    - Approvals required?
    - Operating temperature?
    - Supply voltage?
    - PROFINET diagnostics?
    - PROFINET IRT?
    - Redundancy supported?
    - VLAN?
    - IP routing?

    Many of these requirements depend on both the design and the application. For example, the number of ports determines how many switches are used and the layout. Standardizing at the beginning can make the design easier and save overall costs. For most sites, it is best to standardize on one switch configuration, minimizing spare parts and make things easier for maintenance later on.

4. Follow recommended grounding practices.

   PROFIBUS and PROFINET International recommend connecting the cable shield to ground at every device and using an equipotential grounding grid. An equipotential grounding grid is a network of interconnected grounding rods that ensure all parts of the plant are on the same ground.

PROFIBUS DP basic design

PROFIBUS DP forms the backbone of the typical PROFIBUS network, linking drives, motor starters, digital I/O, and PROFIBUS PA segments. Process plants often have a mixture of analog and digital I/Os alongside an increasing number of Variable Frequency Drives. The ability to join all of these different devices easily within one network is a key strength of PROFIBUS.

Basic design rules for PROFIBUS DP running on copper RS-485

1. Do not exceed 32 nodes on one segment.
2. Nodes must be daisy chained (no spur lines[5]).
3. Terminate each segment at the extreme ends.
4. Do not exceed 125 directly addressed devices per PROFIBUS DP interface card.
5. No more than nine[6] repeaters between the master and any of its field devices in any communication path.
6. Correlate maximum length per segment to baud rate.
7. Follow recommended grounding practices.
8. Design for maximum baud rate, but run it at the lowest possible baud rate.

Detailed explanation of the rules

1. Do not exceed 32 nodes on one segment.

   After an RS-485 electrical signal has been sampled by 31 devices (1 sender + 31 receivers = 32 nodes), the signal degrades to a point where it cannot be read again. This degradation is just a physical limitation of the RS-485 standard. However, some PROFIBUS DP devices use new RS-485 chips on the market that do

Profihub is a RS-485 repeater used to create spur lines for DP.

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[5] Spur lines can be used if the network speed is less than 1.5 meg. However, please note that PROFIBUS International does not recommend using drop cables at any speed.
[6] Nine is the maximum. Many designers prefer not to go past four due to the time delays introduced by the repeaters.

not degrade the signal to the same extent, permitting more than 31 devices on one segment. Nonetheless, the rule still stands because the only way to identify these devices is to examine each PROFIBUS interface board, a time-consuming exercise.

NOTES:
- A *segment* is an area of the network where there is only one electrical signal (i.e. no repeaters). The diagram shows one segment since there are no repeaters.
- A *node* is any device occupying a connection on the network, including devices that have addresses (like I/O racks and drives) and those that do not (like repeaters and couplers).

2. Nodes must be daisy chained.

NOTES:
- A *daisy chain* connects the wires from one device directly to the next device and then out again to the next device (shown in the diagram).
- When devices are wired in a daisy chain, and one device fails, the rest are not affected.
- *Reflections* are images of the original signal (waveform) that are transmitted back along the wire and interfere with the original signal much like waves disturb the water surface line when splashing the side of a bathtub.
- A *drop cable* or *spur line* is a cable tapped from a T connection, and only one cable going from the main cable to the device.
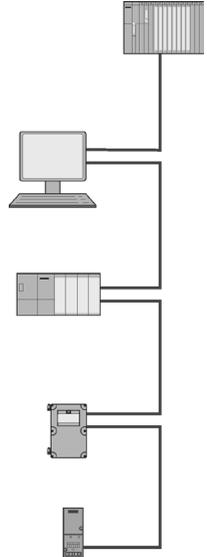
RS-485 has always recommended the daisy chain method for wiring because T junctions create reflections on the electrical signal. Reflections make it difficult to read the signal – the larger the reflection, the greater the difficulty.

The size of the reflections increases with the size of the spur line (length of cable coming off the T junction) and the speed of the network. At low baud rates, some spur lines can be tolerated. However, at a 1.5 meg baud rate and above, no spur lines are tolerated.

From a wiring perspective, it can be useful to have a spur line or even multiple spur lines, and repeaters can be used to create them.[7]

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[7] Manufacturers, including Phoenix Contact and Procentec, market special repeaters that create multiple spur lines. Procentec's Profihub product is pictured on the previous page.

3. Terminate each segment at the extreme ends.

Biasing the network means adding an electrical voltage or current to the network.

PROFIBUS DP uses a special active termination on the segment. Most RS-485 based networks use just one terminating resistor across A and B, referred to as passive termination because there is no power. PROFIBUS uses active termination which has a pull-up and pull-down resistor to bias the network. Biasing the network improves the signal-to-noise ratio of the signal. This is useful at any baud rate because it improves the signal quality. However, because of the short bit times at high baud rates, this active termination is a requirement. Active termination must always be powered to ensure reliable communications.
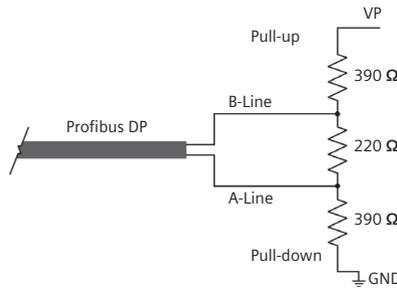
We built a PROFIBUS DP network in the Siemens Level and Weighing Learning Center in Peterborough. One end of the network was terminated at the PLC. The other end was terminated at the last application simulation rack. We ran the network at 1.5 meg, and it worked fine. Our marketing department would often come in and power one rack and do some testing and communications worked even though there was no active termination on the last rack.

One day during a training session, the students on the last rack finished early and powered down the rack. Suddenly, the other five stations lost communications. It turned out that the network would run without one active terminator if the network was lightly loaded, but it would not run at all if the network was heavily loaded.

One way to ensure that active biasing is always on is to use a separately powered termination box.

WARNING: Active termination at both ends of the segment is crucial to prevent the network from crashing. Therefore it is best not to terminate at an I/O rack because turning off the I/O rack will turn off the active termination and crash your network. Using a separately powered termination block will prevent this.


4. Do not exceed 125 addressed devices per PROFIBUS DP interface card.

PROFIBUS address range of 0 to 127	
Address 127	reserved for broadcast messages (i.e. messages that are sent to all devices on the network)
Address 126	reserved for new devices whose addresses can only be set over the network (i.e. no dip switches)
Addresses 0 to 125	available for masters and all slaves
Address 2	used for the main controller
Address 0 or 1	used for the engineering station (if you have a permanent engineering station, then use address 1, reserving 0 for a visitor)

WARNING: No two devices can have the same address. If two devices are given the same address then errors will occur on the bus. See *Chapter Eight* for more on these errors.

5. No more than nine repeaters between the master and any of its field devices in any communication path. There can be more than nine repeaters in total on the network. However, the master can only talk through a maximum of nine repeaters to get to its slave because of the time delays introduced by each repeater.

Controller

Slave

6. Correlate maximum length per segment to baud rate.

   This chart applies to PROFIBUS DP Class A cables only. While the PROFIBUS DP wiring guidelines define different grades of wires, Class A cables are preferred.
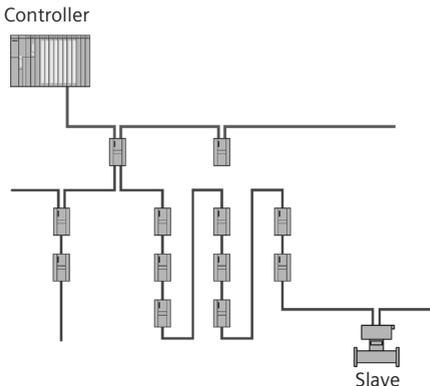
Baud Rate (Kbaud)	Max. Segment Length
9.6	1,200m
19.2	1,200m
45.45	1,200m
93.75	1,200m
187.5	1,000m
500	400m
1,500	200m
3,000	100m
6,000	100m
12,000	100m

   WARNING: Ensure a minimum length of one meter between devices on the network.

   WARNING: If there are only two devices on the segment, have at least two meters of cable between the two devices to get a good signal.

7. Follow recommended grounding practices.

   For PROFIBUS DP, the recommended grounding practices are:

   • connect all cable shields to ground
   • use a grounding cable to go from cabinet to cabinet in the same segment

   The goal of the grounding cable is to ensure that all the devices on one segment have the same earth potential. Connecting the cable shield to ground at all devices in a segment provides the best protection against high frequency electrical noise.

8. Design for maximum baud rate, but run at the lowest possible baud rate.[8]

   This is the only listed rule that is really a best practice. Designing to a high baud rate and running at a lower baud rate has these benefits:

   • leaves a lot of room for expansion
   • increase robustness of the system

   Design the network as if it will run at 12 meg, but install it to run at the slowest possible baud rate that will still provide the desired update rates.

   Example: A network is designed to run at 12 meg and it is discovered after installation that it has an update rate of 1 millisecond. The application only requires a 20 milliseconds update time. Dropping the speed to 1.5 meg, results in a 10 milliseconds

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[8] This design idea is attributed to Professor Andy Verwer, principal lecturer at the Manchester Metropolitan University Department of Engineering and Technology. His source is not known to the authors, but it is a very good idea.

update time which still meets the 20 milliseconds requirement. Therefore running at 1.5 meg creates a robust network that does not exceed any of the limits. In addition, there is room for subsequent expansion since the maximum segment length for 1.5 meg is 100 meters more than the 12 meg speed to which the network was designed.

PROFIBUS PA basic design rules

PROFIBUS PA physical layer has more latitude for network layout than PROFIBUS DP's physical layer, including a variety of topologies such as trunk, star, or tree.

- **trunk topology:** the network uses one main cable that uses spur lines. This popular topology is also the recommended one to use with PA.

- **star topology:** a variation of trunk topology where one line goes to a junction box and all spur lines come from that one junction box.

- **tree topology:** looks very much like a tree with branches coming from other branches. This topology is not used very much.

Basic design rules for PROFIBUS PA
1. Maximum spur lengths must correlate to number of spur lines.
2. Use Class A, PROFIBUS PA cable and use only one cable manufacturer.
3. Total cable length depends on coupler used, though it can not exceed 1900 meters.
4. Ensure that there are more than nine volts at each slave.
5. Total number of devices depends on the current draws.
6. Terminate at the extreme ends of the segment.
7. Follow recommended grounding practices.
8. Intrinsically Safe (IS) design affects maximum spur lengths and total length.

101
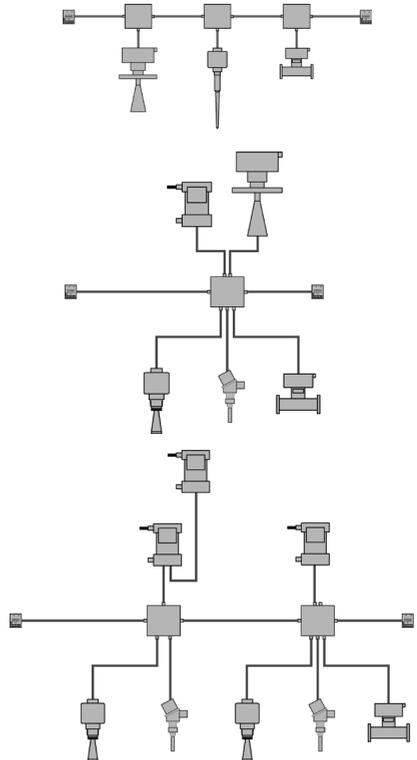
Detailed explanation of the rules

1. Maximum spur lengths must correlate to number of spur lines.

    The maximum length of each spur line depends on the total number of spur lines. Note that the maximum spur length also depends on it being a non-IS or IS network.

Number of spur lines	Maximum length for non-IS	Maximum length for IS
1-12	120 m	60 m
13-14	90 m	Not applicable
15-18	60 m	Not applicable
19-24	30 m	Not applicable
25-32	<1 m	Not applicable

NOTE: This chart assumes the following:

a. Class A cable is being used. PROFIBUS PA defines classes of cables (like PROFIBUS DP). It is best to always use Class A cable.
b. Only one instrument per spur line.
c. Network is following a star design.
d. Trunk line MUST be longer than the longest spur line.
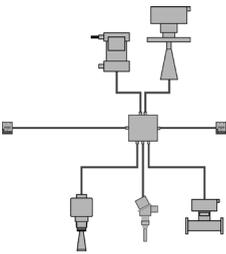
However, should the network be designed with other topologies, these same principles still apply. In actuality for reflections, the star topology as shown is a worst case situation due to the physics of wave propagation. Any design that keeps its spur lengths within the limits stated in this chart will work. These guidelines are conservative, but in network design it is a good idea to be conservative; it costs too much money to change a design after it is installed.

For an IS application, there is an alternate method referred to as the High Powered Trunk Concept (HPTC). Instead of having the power limited at the coupler, the power is limited in a field junction box. The high power trunk cable and junction box must be in the 'safe' area. A number of manufacturers make junction boxes with built in barriers for this sort of application and it can be cost effective on the right site. The Siemens AFDiS junction box designed for HPTC applications differs from others in that it has a built-in PA repeater. This feature allows for 31 spur lines all at 120 meters so the above chart does not apply.

2. Use Class A PROFIBUS PA cable and use only one cable manufacturer.

   IEC 61158-2 defines different cable classes and states that mixing cable types is possible, and for short lengths and a low number of devices, mixing has little impact. However, for long lengths with a high number of devices, mixing can lead to network problems (i.e. bit errors and lost messages) and is to be avoided.

   While PROFIBUS PA and DP cables may look similar (diameter and wire size), they have very different electrical characteristics and should not be interchanged.

   The 24-spur/line length correlation and limitations are very real. I had a customer who did not believe this chart, so he added one more instrument on a spur line and it 'worked.' Then he added another and it still 'worked.' He then added a third, and instruments started dropping off the network and error messages appeared on his Distributed Control System (DCS).

   Our investigation found that he had set his PROFIBUS retry rate to 3, and once he went to 25 spur lines, errors were actually generated but were not seen until he added two more spur lines and the errors accumulated enough to be reported. Once he went back to 24-spur lines, the network returned to an error-free state. The numbers look strange, but this is just physics and it is what it is.

NOTE: Different manufacturers have different specifications for PA cable. While they all meet the IEC 61158-2 standard, they use different capacitance and inductance values. Thus mixing cables from different sources on the same network can lead to reflections. Best practice is to use one cable supplier throughout the segment.

3. Total cable length and the coupler.

   The total length cannot exceed 1900 meters (6232 ft) for non-IS applications using Class A cable, and 1000 meters (3280 ft) for IS applications using Class A cables. However, this maximum length also depends on the power draw on the network and the voltage supplied by the coupler. Different couplers supply different voltages, but all devices on the network must have at least nine volts (see rule 4 below). Therefore, with some couplers, the full length might not be supported.

   Total length = the length of the main trunk cable plus the sum of all spur lines.

To calculate the length of the segment, add up the length of the main trunk cable and the sum of all the spur lines:

$$L\text{ segment} = L\text{ trunk} + \Sigma L\text{ spurs}$$

4. Minimum nine volts at each slave.

In order to power up, a PROFIBUS PA slave requires at least nine Volts. Use Ohm's law to calculate the worst case voltage drop on the network, verifying that it never goes under the required nine volts. Here are the steps (an example is shown in the following section):

I. Calculate the total current draw of the field instruments' *I segment*.

$$I\text{ segment} = \Sigma I\text{ n} + I\text{ max. fault current}$$

For PROFIBUS PA devices, there are two possible currents:

- the nominal current draw
- the fault current: the maximum current the device will pull in a fault state. For many devices, this value is 0 mA and is not even stated. Check the specifications to determine the device fault current.

II. Calculate the worst-case voltage drop.

$$V\text{ drop} = I\text{ segment} * (R\text{ loop} * L\text{ segment})$$

III. Calculate the voltage at the last devices and verify that it is over nine volts.

$$V\text{ last} = V\text{ coupler} - V\text{ drop}$$

NOTES:[9]
- typical loop resistance of a class A cable is 44 ohms/km
- coupler voltage is 31 V DC +/- 1 V for the Siemens non-IS coupler
- coupler voltage is 13.5 V DC for the Siemens IS coupler

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[9] These values are given as a reference and are subject to change. Please consult the manufacturer for the official values prior to doing a calculation for a real application.

5. Total number of devices depends on current draws.

   Because **I segment** must be less than the current supplied by the coupler, the specifications of the coupler have a big impact on the number of devices allowed on a segment. For non-IS applications, Siemens has a DP/PA coupler that provides 1 A of current ensuring the maximum number of devices are permitted.

6. Terminate the extreme ends of the segment.

   PROFIBUS PA termination is very different than DP. PROFIBUS PA uses a capacitor (1μF) and a resistor (100 ohm) in series, and the network needs to be terminated at the far ends. PA normally uses a trunk line design and the terminations are located at the ends of the trunk.

   Determining what is trunk line and what is spur line in some designs is not always clear. The good news is that it also does not matter as long as all the defined spur lines are under the recommended maximum defined in the first rule above.

7. Follow recommended grounding practices.

   For both IS applications and non-IS[10] applications, PROFIBUS International[11] recommends connecting the cable shield to ground at every device and using an equipotential grounding grid. An equipotential grounding grid is a network of interconnected grounding rods that ensure all parts of the plant are on the same ground.

8. Intrinsically Safe design affects maximum spur lengths and length.

   Follow the same rules as for general purpose applications as described above, with these exceptions:

   • maximum length cannot exceed 1000 meters
   • use only Class A cables
   • spur lines must be less than 60 meters in length
   • must use an IS coupler or IS barrier

Grounding practices are a bit like religion— they vary from region to region. PI's recommendations are good to follow, but please verify local regulations are followed, especially in an IS application.

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[10] For non-IS application, some manuals recommend connecting the cable shield to ground at one point only and carry the shield continuously from device to device in one segment (i.e. have a continuous shield wire running through the entire segment).
[11] *Installation Guideline for Cabling and Assembly.* PROFIBUS International, Order No. 8.022.

I have been told that equipotential grounding grids are fairly common in Europe for IS applications. It is not very common in North America which is unfortunate since it provides excellent grounding. We have found that sometimes grounding systems are not very well done in North America.

One of my customers, a bio-fuel company, came up with a good innovation connected to this. Since they are dealing with an IS application and could not trust the grounding system that was in place, they ran a separate grounding cable from field device to field device to ensure that all instruments were in fact on the same ground. Then they would connect the cable shield to ground at all field devices and couplers.

PROFIBUS PA design example

In this example, a process plant has a ten-tank tank farm:

Tanks 1 to 4	SITRANS Probe LU for level
Tanks 5 to 10	SITRANS LR250 for level
All tanks	SITRANS TH400 temperature transmitter

This is a non-IS application using the Siemens DP/PA link module and a one amp DP/PA coupler.

Plant layout drawing
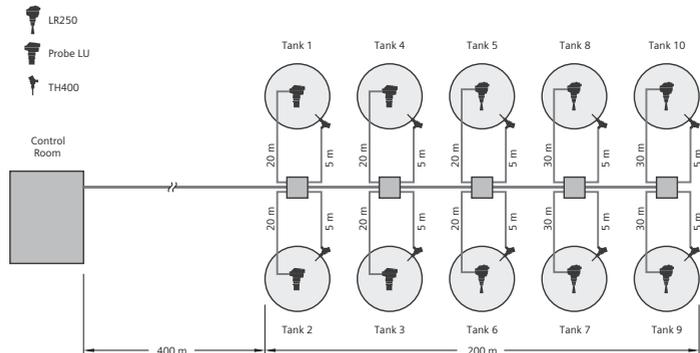
Simplified network drawing
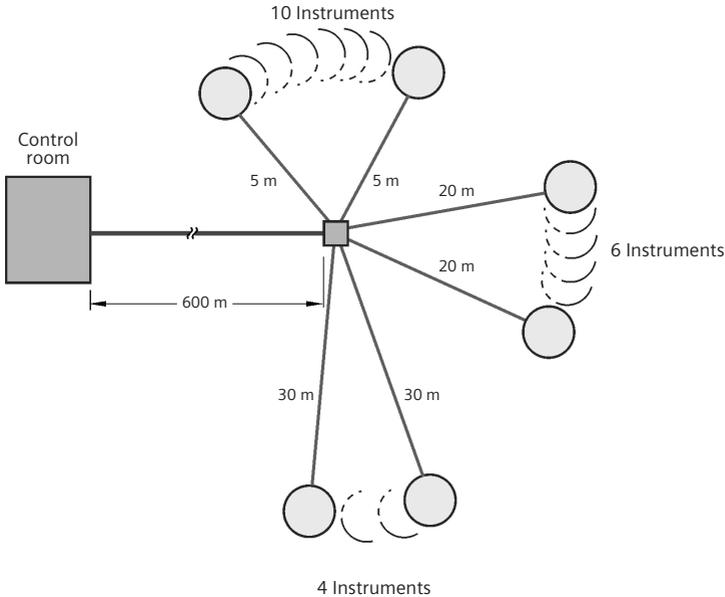
Step one:
Calculate the length of the segment by adding the estimated lengths.

L segment = L trunk + Σ L spurs

> **L segment** : 600 + 6*20 + 10*5 + 4*30 = **890**
> **(600 + 120 + 50   + 120)**

Step two:
Add up all the current draws of the PA slaves (**I segment**). Check the manuals/specifications for each device to get the different nominal currents and to see if there are any fault current values. (There are no fault currents for the devices in this example, so that information does not have to be included.)

I segment = sum of I_n plus the largest of all the fault currents.

I segment = Σ In + Imax fault current

> **I segment** : 4* current of PROBE LU + 6* current of LR250 +
> 10* current of TH400 = **275 mA**
> **[4*(20mA) + 6 * (15mA) + 10 * (10 mA) = 80 +
> 90 + 105]**

From this information, the worst case voltage drop can be calculated.

NOTE: Don't forget to define which Class A cable is being used. Look up the resistance of the cable in the cable specifications. (For this example, the value is 44 ohms/km.)

$$V_{drop} = I_{segment} * (R_{loop} * L_{segment})$$

V_{drop} : .275 A * (44 ohms/km * .890km) = **10.769 V**

The coupler supplies a minimum of 30 V DC, therefore:

$$V_{last} = V_{coupler} – V_{drop}$$

V_{last} : 30 V – 10.8 V = **19.2 V**

Conclusion: the voltage is well over the nine V minimum.

Step three:
Verify the chart for the spur lengths for 20 instruments and note that each spur line can be a maximum length of 30 meters. Now in this example, four of the spur lines are estimated to be 30 meters long. Note that the estimated lengths are conservative estimates and that the length of those spur lines should not exceed 30 meters. Other than that, this is a good design and will work very well when installed.

I was troubleshooting a network and at first it looked like all the cable lengths were fine, until I found rolled up cable tucked behind a cabinet. During the initial installation, extra cable was left going into the last cabinet. The plan was to move the cabinet, so the installer had just rolled up the cable and put a small section through the hole into the cabinet, leaving the rest with the intention of moving the cabinet later – the cabinet was never moved. The result was that the network was an extra 100 meters longer than anyone thought – hence the performance problems.

The design and the install must match.

Design tools

A number of different manufacturers[12] have design tools for designing a PA network. These tools can be very useful. However, sometimes the easy approach works the best. One such method is to use Excel[13] to lay out each segment with estimated length in columns and then program the formulas as shown above.[14] It's also easy to include additional information such as cable number, tag name, serial number, and manual reference, making all this data an integral part of the documentation. This tool is easy to design and maintain, and it can begin with estimated lengths. As the data becomes available during commissioning, it's simple to switch to installed lengths.

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[12] Pepperl+Fuchs and ABB to name two.
[13] Excel is a trademark owned by Microsoft.
[14] Cargill, Mark. *Efficient Design of a Successful PROFIBUS Project.* Presented at 2007 UK PROFIBUS Conference.

Calculating data update rates

The design of the network determines the update rate and the responsiveness of the engineering and troubleshooting tools such as SIMATIC PDM. The total time it takes to read a variable will vary slightly depending on both the coupler manufacturer and possibly the field devices themselves. The chart shows examples of the time required for data from two of the major manufacturers. These numbers were tested in a lab setting and then confirmed by some field trials.

Siemens (Link Coupler and Coupler):

- PA 1 AI or 1 AO device takes about 15.5 ms to update
- each additional AI or AO variable adds about 2 ms
- PROFIBUS adds an additional 20 ms of overhead time
- when using any acyclic reads/writes, add another 100 ms. Please note that measured time varied from 40 to 100 ms. 100 ms would be a sufficient maximum.

Pepperl+Fuchs (SK1)

- PA 1 AI or 1 AO device takes about 12.5 ms to update
- each additional AI or AO variable adds about 2 ms
- PROFIBUS adds an additional 30 ms of overhead time
- when using any acyclic reads/writes, add another 100 ms. Please note that measured time varied from 40 to 100 ms. 100 ms would be a sufficient maximum.

Data transmission time

NOTE: During these tests we found that several manufacturers' manuals and other books on PROFIBUS state a value of 10 milliseconds as the update rate. We now know that this value is not correct. Many of these manuals and books are now in the process of being updated.

Each PROFIBUS PA slave has at least one analog input (AI) or analog output (AO) block or digital input (DI) or digital output (DO). For a message to go from the master to the slave, for the slave to process this and send the return message, and then for the master to be ready to send another message takes about 15.5 milliseconds. If the slave has two AI blocks, this time increases to 17.5 milliseconds. Once all the slaves have completed the data exchange, then

the PROFIBUS master has a number of functions it has to perform including:

- token rotation
- looking for new stations

These tasks take about 20 milliseconds to perform. If the master is set up to do regular acyclic read/writes or a configuration program such as SIMATIC PDM is used, this time needs to be accounted for. Although this time does vary, a value of 100 milliseconds is a sufficient maximum amount of time acyclic communications could take.

To include acyclic communication time or not – that is the question!

In most systems, the controller is not doing acyclic communications, and the only source of acyclic communications is the configuration/diagnostic software. In this situation, the user has to consider the following:

- how often the configuration/diagnostic software is going to be used
- how sensitive the application is to having the cycle times periodically increase by up to 100 milliseconds

Even if the maintenance crew uses the configuration/diagnostic software regularly, the percentage of total bus time is still going to be small, probably less than 1%.[15] In most applications, having the cycle times increase by up to 100 milliseconds (1% of the time) is not going to affect the process in any way. Therefore, in most applications, acyclic communications should not be included in the time estimate.

In a small number of systems, the controller does regular acyclic communication to field devices. In these systems, some value for acyclic communication should be added to the total time estimate, depending on the type of communications. For example, if the internal temperature of the transmitter is being read via acyclic services, then 40 milliseconds would be more than sufficient. If large amounts of data are being written or read from the device, then an estimated 100 milliseconds should be part of the calculation.

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[15] This percentage does not apply to startup situations where the maintenance crew could be doing uploads and downloads continuously throughout the day.

Example one

- a Siemens DP/PA Coupler
- twenty instruments on each segment
- each instrument has only one process variable

| Calculation:	
Time to read/write PV to 20 instruments	= 15.5 ms * 20 = 310 ms
PROFIBUS overhead	= 20 ms
Total update time	= **330 ms** (310 + 20)

15 Instruments
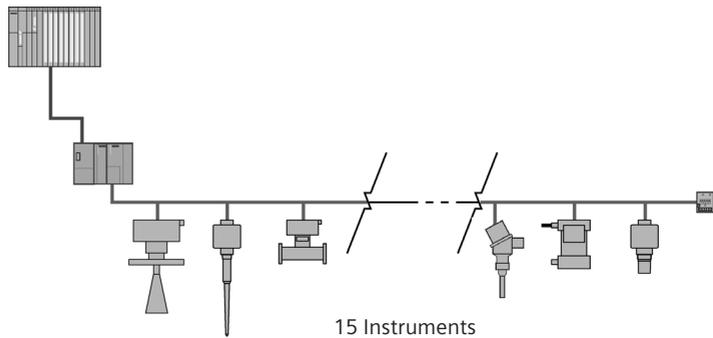
Measuring the update times with a bus monitor shows an update variable in the range of 310 milliseconds to 350 milliseconds. Acyclic reads or writes will increase the update time to around 450 milliseconds for a few of the data exchanges.

Example two

- Siemens DP/PA Link module with a PROFIBUS DP network
- runs at 1.5 meg
- DP network has a 10 milliseconds scan (updates every 10 milliseconds)
- link module is connected to five Ex couplers, each with six instruments
- each instrument has one process variable

Calculation:	
Time to read/write PV to 30 instruments	= 30*15.5 = 465 ms
PROFIBUS overhead	= 20 ms
Total update time	= **485 ms** (465 + 20)
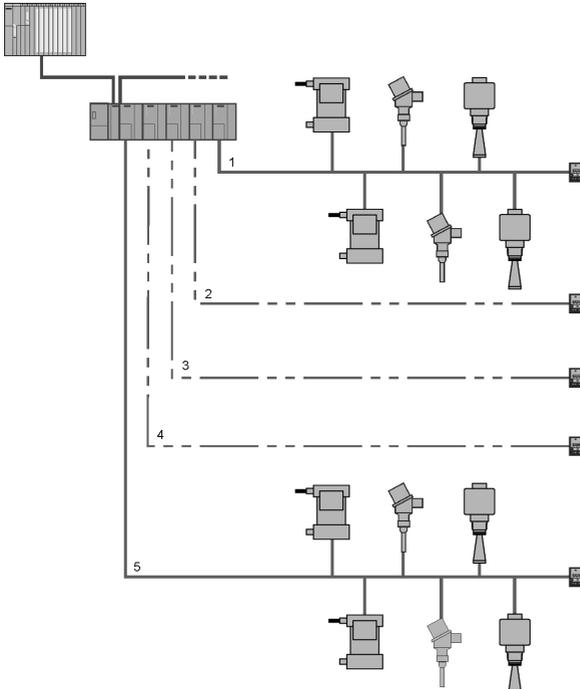
The DP/PA link module is a PROFIBUS slave on the DP side and PROFIBUS master on the PA side, creating a true sub-network. The information in the link module is constantly being updated. As a result, to get all the data to and from the DP master, twice the DP bus scan time is required (at minimum), and the update rate will be:

$$485 \text{ ms} + 2*10 \text{ ms} = \textbf{505 ms}$$

From the controller's point of view, the data update rate varies between 480 milliseconds to 510 milliseconds (approximately). Because of the nature of asynchronous behavior, the update rate will generally be under 500 milliseconds. Furthermore, if there were any acyclic reads or writes, the update rate increases to 605 milliseconds for a few of the data exchanges.

Performance of configuration/diagnostic software

Chapter Two discusses how there is a little time available for acyclic communications after all the cyclic data exchange is done. This is

how configuration/diagnostic software such as SIMATIC PDM communicates to the field instruments. For many processes, having an update rate exceeding one second would not present a problem, thus each link and coupler can be loaded to the maximum number. PROFIBUS can certainly handle this and it will reduce total capital costs by maximizing the use of the hardware. However, when configuration/diagnostic software is used to commission or troubleshoot a failed instrument, the performance will be poor. The configuration software can only talk to the field devices after all cyclic data has been read. If the update time is one second, then the configuration software can only talk every second. Since it can take several messages to read data, the slower the network, the slower the performance of the configuration software will be.

Field experience suggests as many as 20 instruments can be used on a DP/PA link module without denigrating performance. Thirty instruments on one DP/PA link module jeopardizes performance, while 40 to 60 instruments per link module definitely degrades software performance. Please note that these numbers are arbitrary and depend on the delay tolerance for the data update in the configuration software.

Determining what is acceptable configuration software performance and what is not is very personal. Many of our demo systems have five or six instruments on a link module and I never really notice the speed. I have been to customer sites where they have had 24 instruments per link and I have thought to myself that this is slow. However, it is still useable.

In fact, I have a customer who will often put 30 instruments on one link module and is fine with it. His position is that even though the configuration software is slow, it is still a lot faster than entering the values by hand! Also, how often do you use the configuration software compared to cost savings of loading up the link modules?

PROFIBUS PA design suggestions

In this section, simple design suggestions and the benefits of each are presented for three different general applications:

- non-IS application
- IS application
- designed for speed

Non-IS applications

Design: use a Siemens DP/PA Link module with one 1 A coupler (or one channel of a P+F power hub or ABB DP/PA link) and put on 18 devices.
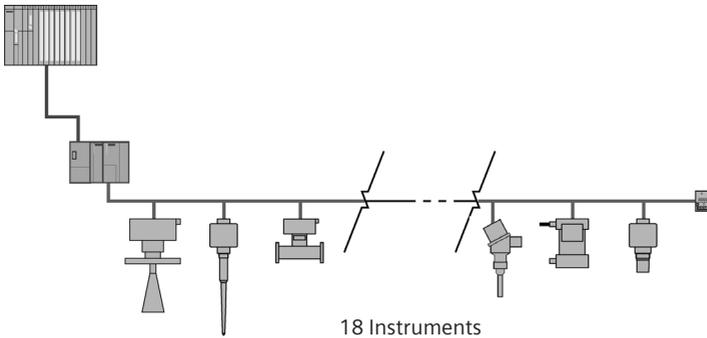

18 Instruments

This design ensures:

- versatile wiring because 30 meter spur lines can be used
- room to expand since the segment can have an additional four devices. This option is valuable as more instruments are often required when production starts so don't limit network expansion by designing to the maximum number.
- the configuration/diagnostic software performance is acceptable

IS applications

Design: use a Siemens DP/PA Link module with a number of Ex couplers (or a P+F power hub or ABB DP/PA link), designing the network for extra room to add one instrument to each segment if necessary. Use the calculations outlined in the PROFIBUS PA basic design rules section in this chapter to determine how many devices are allowed on each segment (typically four to six devices depending on current draw). Make sure not to exceed 18 to 25 devices in total per link module (or per channel of the P+F and ABB links).
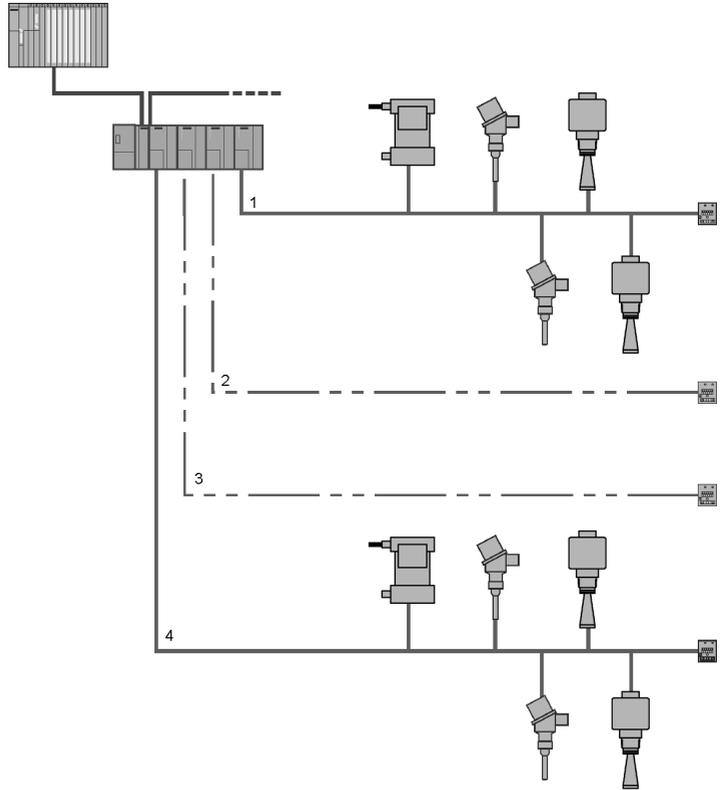
This design ensures:

- room to expand
- the configuration/diagnostic software performance is acceptable

PROFIBUS PA – designing for speed

Some control loops have a requirement that the control loop update times are less than 300 milliseconds. For these applications, the Siemens DP/PA link module (or one channel of ABB Link or P+F power hub) is the device to use. Design the network to the IS application but limit the total number of devices by half.

At 15 devices, the update time to the link module will be:

15*15.5 ms + 20 ms = 232.5 ms + 20 ms = **252.5 ms**

15 Instruments
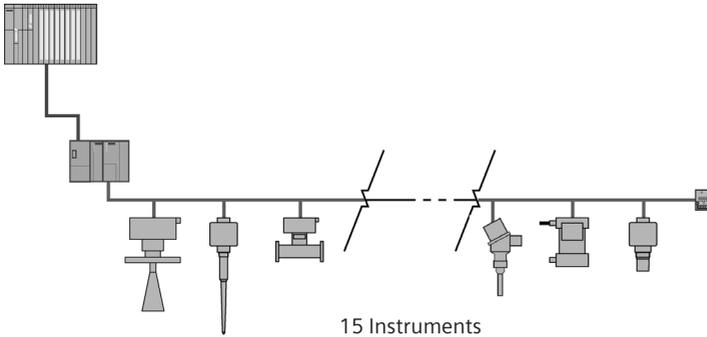
Depending on the update rate on the PROFIBUS DP network and the controller scan time, reducing to 15 devices will definitely speed up the network.

This area is where the new PROFINET to PA proxies will have a big impact. With both the IFAK and PROCENTEC PROFINET to PA proxies, it is cost effective to break the PA segments into fairly lightly loaded segments - 10 to 15 per segment. Then each segment has its own PA master so the speed is very fast and there is no PROFIBUS DP cycle time to be concerned about. Direct PROFINET to PA is fast and has great configuration tool update times.

Next BUS stop: installation

After designing a network, the next stop is installing and commissioning that network.

The rest of this bus ride offers the following:

- how to build a PROFIBUS and PROFINET network
- how to operate a PROFIBUS and PROFINET network
- how to troubleshoot a PROFIBUS and PROFINET network

So grab a seat; the bus is starting to fill up.

NOTES

Chapter Six
Installation

*Network: anything reticulated or decussated, with interstices bet-
ween the intersections.*[1]

Once a good network is designed, the next step is to install it. Mis-
takes made here can haunt the network for the entire life of the
installation, so it is crucial to proceed carefully and according to the
design guidelines. Installation shortcomings are the predominant
source of network problems.

BUS route

This bus makes the following stops:

- Connection hardware
- Network layout drawings
- Cable separation
- Installation method
- Installation best practice
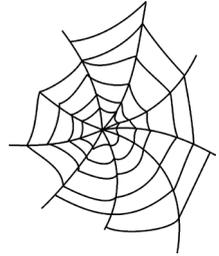
Connection hardware

Typically, a designer picks all of the intelligent devices before
designing the network, and then picks how to connect them after
the network is laid out. This section describes the hardware
required to connect the network.

PROFINET connections

Connecting PROFINET is relatively easy. For the copper connection
there are limited options:

- RJ45 (IP20)
- Push-Pull-RJ45 (IP65)
- M12

Picking the correct
interconnection
technology is very
important.

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[1] Johnson, Samuel. *A Dictionary of the English Language,* (1755).
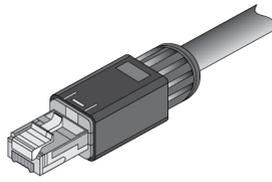
IP20 version of the
RJ45 connector
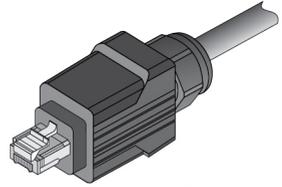
IP65 version of RJ45
(Push-Pull) connector

PLUG   SOCKET
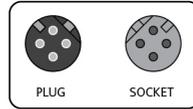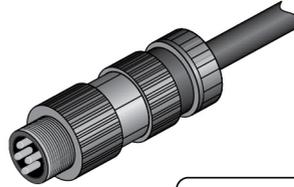
M12 connector

The IP rating measures how rugged an environment the connector can be used in. IP20 is suitable for inside industrial cabinets; therefore, RJ45 plugs are the most common.

The IP65 rated push-pull RJ45 connectors would be used outside of cabinets. For even harsher environments, the M12 connectors are most suitable.

PROFINET Wire

Not all wires are the same. While office grade cables and connectors can look a lot like PROFINET cables, they are not at all suitable. Do not use them!

OUTER
SHEATH

FILM
SHIELD

SINGLE
WIRE
SHEATH

BRAIDED
SHIELD

INNER
SHEATH

COPPER
WIRE
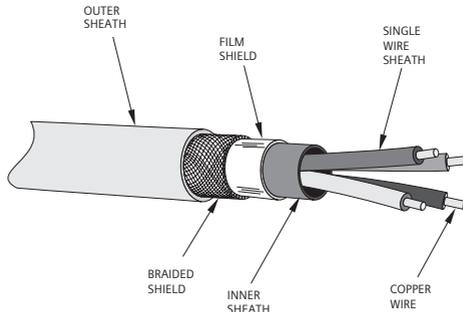
All wires are the same – right? Wrong! Using the correct cable is like pouring the right foundation for your house. If you mess up the foundation, the whole house will come down. PROFINET is no different than any other network this way although it does have a hidden danger - the office internet!

With all networks make sure to use the correct wire as specified by whatever standard. This applies to PROFIBUS DP and PA and to PROFINET. However, one thing that we have seen with PROFINET is that there is a real danger of an office grade cable being used in a PROFINET network. There are green office Ethernet cables, so why not use them in the plant? Shielding and grounding is the answer. We have seen customer getting into trouble by using office grade cables many times. Bottom line - don't do it. A careful inspection will show that the cables are not robust enough..

PROFIBUS DP connections

Connecting PROFIBUS DP is relatively straightforward since all nodes are typically daisy chained together, and the only possible connector is at the field device. For PROFIBUS DP, these typically fall into the following types:

- DB-9 connectors
- M12 connectors
- terminal connectors (less common)

The DB-9 connector is the most commonly used, and the majority of PROFIBUS DP devices come with a female DB-9 connector on board. IP65/IP67 devices typically have M12 connectors. A small number of PROFIBUS DP devices come with terminals that have to be wired directly.

DB-9 connectors: Devices with DB-9 connections will require PROFIBUS DB-9 connectors, and they can be purchased from a variety of manufacturers such as Siemens and Wago, differing only slightly in design, quality, and costs. Please note that PROFIBUS DB-9 connectors are different than the standard DB-9 connectors used for RS-232 applications, having special built-in circuits to reduce reflec-

DB-9 connector

tions. While they are far more expensive than standard DB-9 connectors, the reduced reflections prove their value, despite the higher cost.

> I once worked on a design for a small PROFIBUS DP network that had several PROFIBUS DB-9 connectors. The budget was tight and when my manager saw how much we were spending on connectors, he laughed and told me to "try again." I knew the special circuits reduced reflections, but since the network was so small, I figured that we might not need them – so I gave in to my manager's wishes and changed the connectors.
>
> Big mistake! Commissioning was a nightmare; we had intermittent problems all over the place and the waveform was horrible. We had to change all the connectors to other non-PROFIBUS, but more expensive, connectors and drop the baud rate. We did get the network working error free, but it was not a pleasant activity and I will never go cheap on connectors again!

There are several types of DB-9 connectors, depending on how the wire is connected inside. Two standard types are:

- push-in vampire (inverted V-shaped insulation displacement) connectors – can go together quickly, but when used more than once the clamping teeth can bend, causing difficulties when reused.
- screw terminal connectors – take a bit longer to put together and the screws must be firmly tightened. The benefit of the screw terminal connectors is that it is easy to check that the connection is being made.

M12 connectors: These connectors are discussed in the PROFIBUS PA section as well. They work very well; however, there have also been reports of intermittent problems caused by incorrect installation of M12 connectors. Apparently, it is very easy to install these connectors incorrectly. New users should approach the installation of these connectors with caution.

Terminal connectors: Some field devices are wired into terminal blocks on the devices. While this method works fine, disconnecting

the device from the network can interrupt the network. Devices with DB-9 connectors, however, can simply be unplugged.

Devices using terminals that have to be unwired, may possibly disconnect the rest of the PROFIBUS network. For this reason, some sites use quick disconnects like M12 connectors with non DB-9 devices. (See *PROFIBUS PA* below.)

> **WARNING:** M12 connectors can be a source of potential problems if they are not installed correctly (see *Quick connect system* below). Installers should make sure that they follow the installation instructions for these connectors.

PROFIBUS PA

Since PROFIBUS PA networks are usually in a trunk topology, there are two connection locations:

- Connecting spur lines to the trunk
- Connecting spur lines to the devices

Connecting spur lines to the trunk requires one of the following:

- terminal strips
- terminal box
- T-connector

Connecting spur lines to the devices requires one of the following:

- direct wire
- quick disconnect system

Connecting spur lines to trunk

Terminal strips: Use a regular terminal strip that any electrician would have in his toolbox. Twist the communication wires (A, B, and shield) together and then clamp them in a terminal strip, placing it in a junction box that can be sealed against the environment. This simple solution connects PA spur lines to the main trunk line using a method similar that used with 4–20 mA relay boxes. However, while simple, please note that terminal strips offer none of the advantages of the PROFIBUS PA junction boxes.
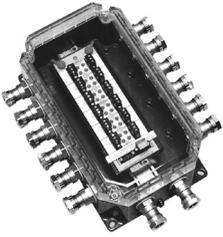
Moore Hawke
junction box

Siemens junction box

PROFIBUS PA junction boxes[2] offer numerous special features that vary between models and manufacturers. The end user needs to select features based on requirements and budgets.

- Short circuit protection: valuable in a running system when a PA slave needs to be replaced or added. During the removal or installation process, it is very easy to touch the (+) and (-) leads, short circuiting the segment and crashing the entire network.
- Overvoltage and over-current protection: can protect the network from lightning strikes.
- Auto termination of a segment: although PROFIBUS PA segments are normally terminated at the DP/PA coupler and in the field, it is common to forget to terminate at the end of the trunk during commissioning. Auto-termination eliminates this potential problem.
- M12 or ⅞" connections option: both connectors make it easy to connect or disconnect devices from the network. They can be located either at the field device or at the junction box, or at both locations. They can speed up the final connection of the network and are also very helpful when removing or replacing a field instrument (see *Quick connect system* below).
- Media redundancy features: See *Media redundancy* at the end of Chapter Four.

T-connectors: Siemens sells a T-connector for PROFIBUS PA, and while this method works, there are potential problems unless these rules are followed:

- they are installed as per the instruction manual of the T-connectors
- they need to be tightened correctly
- if the connection is loosened, the wire and possibly the top part of the connector need to be replaced
- only the correct Siemens PA cables are to be used. The connectors are impedance matched with a certain Siemens cable. Also the cable diameter matters, so be sure to match the connection with the correct cable.

NOTE: Junction boxes are generally the better choice.

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[2] Some manufactures such as Moore Hawk, Siemens, and Weidmuller make junction boxes special to PA.

Connecting spur lines to the field devices

Direct wire: In most cases, the PROFIBUS PA cable is wired directly into the terminal on the field devices.

Quick connect system: M12 and ⁷⁄₈" are the two different quick connection systems used. The M12 is metric and small, and the ⁷⁄₈" is imperial and a little bigger than the M12. They both have a male connector that fits on the outside of the field instrument and the cable female connector screws into it. This same method can also be used at the junction box.

Quick connection systems are easy to work with and when installed ahead of time, they can speed up the final stages of commissioning. However, this convenience adds additional cost and needs to be carefully installed.

Beginner designers should avoid these connectors and use the direct wire as it is fairly easy to install these connectors incorrectly. Installers need to be aware of the following:

- by not carrying on the shield, the network is vulnerable to electrical noise
- by not sealing them properly, water can get in
- by not tightening them enough, intermittent interruption in communications can occur

Network layout drawings

When designing a network, a layout drawing identifying the location of every field device and junction box is a crucial component. The drawing confirms that the network conforms to all the design rules, and then communicates the relevant information to the network installer. A proper network layout drawing should include the following:

Layout drawings are worth their weight in gold!

- locations of all devices
- device name and tag
- names of the devices
- all addresses (PROFINET name and IP address for PROFINET)
- locations of junction boxes
- wire labels
- estimated lengths at each device

PA line #1 black from PLC panel (do not forget the grounding cable)

BOILER

TTS-SHO (7m)

TTR-RHO (1m)

End resistor is a tee accessory

(8m) LDP-TS4

(2m)

(6m) LDP-TS4

COOLING TOWER

Tee connectors out of doors must be installed inside plastic boxes

(7m)

(6m) LDP-TS4

(1m)

(2m) LDP-TS4

VACUUM SYSTEM

(3m)

(5m) LDP-TS4

2 x #20 shielded black cable to level switch intrinsically safe panel

LDP-TS4

FS-TS3

(4m)

(2m) TT-TS2

FS-TS2

(24m)

(12m)

BIO TS5

LDP-TS4

BIO TS4

TT-TS4

DBOX-1

MISC-TS6

(10m)

LSH-TS6

GLY-TS10

(11m)

LUT-TS10

(10m)

TT-TS10

(11m)

LSL-TS6

(20m)

(24m)

FCT-PP2

TT-SHGLC

TT-RHGLC

LEGEND

DBOX-1 — PA star distribution box. This box receives a PA line and generates 8 PA branches, one branch accepts one instrument. The installer must find the best location to install this box. This box must have easy access for technical persons.

Tee for single branch in PA line. It is recommended to use a special tool to strip the cable fine.

LSL-TS6 — Level switch: Intrinsically safe: Must be connected to a unique level switch panel with a 2 x #20 shielded cable + grounding.

FCT-PP2 — Electronic instrument with PROFIBUS PA. Needs PROFIBUS PA 2 wire blue cable for PA and 314 green-yellow cable for grounding.

(XX m) — Estimated lengths

Layout drawing

This drawing needs to be a living document as the designer needs to keep the information current by recording any changes in the design during installation. Estimated lengths become installed lengths, and the locations may change to reflect practical implementation as locations and even the process itself can change. The designer's network calculations are part of this document, and the document should confirm all the PROFIBUS and PROFINET design rules have been followed.

Cable separation

PROFINET and PROFIBUS DP and PA use low voltage communication grade cables. Each region has specific electrical codes that state how far apart different classes of cables need to be from one another. It is very important to follow the local electrical code. The specific distances and details vary from region to region; however, they all agree that communication cable and power cables should not be run side by side. Also, if they have to cross, they should only cross at right angles.


```
┌──────────────────────┐      [> 200mm a]      ┌──────────────────┐
│   Communications     │◄──────────────────────►│   > 300V Power   │
│       cable          │                        │      cables      │
│ (PROFIBUS/PROFINET)  │      (> 600mm b)       └──────────────────┘
└──────────────────────┘
         ▲
         │
[> 200mm a]   (> 50mm b)
         │
         ▼
┌──────────────────────┐              [a Recommendations from PI]
│   <= 300V Power      │              (b Recommendations from Ontario
│       cables         │                  Electrical Safety Code)
└──────────────────────┘
```
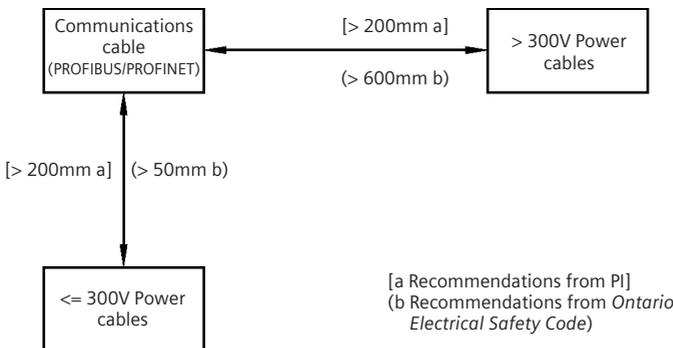
PROFIBUS and PROFINET International PI has published guidelines[3] on cable separation. These recommendations may be different from the local regulations. For example, in the diagram above, the recommendations from PI and from the Ontario Electrical Safety Code[4] for two different levels of power cables are compared, and they are dif-

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[3] *PROFIBUS Recommendation for Cabling and Assembly,* PI order number 8.022, *PROFINET Cabling and Interconnection Technology,* PI order number 2.252.
[4] Ontario Electrical Safety Code, 23rd Edition/2002 by Electrical Safety Authority, referenced section *60-308 Separation from Other Conductors*.

ferent. Since they both state minimum values, best practice is to use the more severe rating from the PI recommendations and local regulations.

I have been troubleshooting different industrial networks for close to 25 years and my number one complaint with field installations has always been cable separation. I can not count how many times I have seen a communication cable tie-wrapped to a power cable. I started my career as an induction motor design engineer. Now, as a controls/network engineer, I have been able to show many times how induction, the ability of an electromagnetic field to 'induce' a voltage into a nearby cable, still works.

The bottom line here is that you need to make sure that your power cables and communications cables are separated. This will have a big impact on the volume of noise on your communication cables.

Installation method

Following these steps will help create an effective and high quality network.

- Train the installers properly.
- Create and maintain a verification check list.
- Thoroughly verify the installation.

Training installers

"If you think education is expensive, try ignorance." Derek Bok, American educator and former president of Harvard University.

All electrical contractors know how to install conventional wiring systems (i.e. 4–20 mA systems). However, in general, most electrical contractors do not know how to install PROFIBUS and PROFINET networks. Hiring a certified PROFIBUS and PROFINET installer may be an option, but if one can't be found or isn't available, training may be required.

Even though PROFINET is using standard Ethernet from a software point of view, its grounding and wiring requirements are different than 'standard' office grade Ethernet. Therefore just because a contractor has installed Ethernet before does not mean they know how to install PROFINET.

Trained PROFIBUS and PROFINET installers have taken the certified PROFIBUS installer course available at many PROFIBUS and PROFI-NET training and competence centers. As a caution, please verify that they have the certificate and check any references from other PROFIBUS and PROFINET sites they have worked on.

Training the installers is also an option, and this training should include hands-on exercises to solidify theory with practice. The first few connections they make will not be the best. By having them practice it, the questionable connections end up in the garbage and not on the network!

Two key documents published by PI, on recommended assembly and recommended commissioning,[5] are mandatory reading for new installers and act as a guide to these key topics:

- stripping wires
- color codes
- tightening connectors
- cable separation
- how to handle communication cable

Stripping wires: PROFINET and PROFINET DP and PA all have tools to help strip cable for the different connectors. Learning to use this useful tool takes some practice. The length of wire put through the tool depends on the connector used, and the number of turns required varies among tools.

Color codes: most of the DB-9 connectors for PROFIBUS DP are color coded:

- A is green
- B is red

Confirm that the connectors are color coded and ensure all the installers know the importance of following the color code.

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[5] *PROFIBUS Recommendation for Cabling and Assembly,* PI order number 8.022. *PROFIBUS Recommendation for Commissioning,* PI order number 8.032., *PROFINET Commissioning Guideline,* PI Order No: 8.082, PROFINET Cabling and Interconnection Technology, PI order number 2.252.

PROFIBUS PA color code:

- PA + is green
- PA - is red

PROFINET (two pair) color code:

Signal	Function	Wire Colours	Contact Assignment	
			RJ 45	M12
TD +	Transmit Data +	Yellow	1	1
TD –	Transmit Data –	Orange	2	3
RD +	Receive Data +	White	3	2
RD –	Receive Data –	Blue	6	4

NOTE: Some connectors may not be coded.

Tighten connectors: While every installer knows terminal connections have to be tight, exceptions still occur and loose connections are still the most common network problem.

Cable separation: This is an important consideration because communication grade cable cannot be placed in the same tray as power cables.

Handling communication cables: Communication cables are not power cables and are designed to have a particular resistance, capacitance, and inductance per meter of cable. Pulling hard on a cable or bending it too much will change these values and will affect the signal.

Creating a verification check list

The PROFIBUS and PROFINET document *Recommended Commissioning*[6] has samples of verification check lists – the things that need to be verified during and after the installation. The check list helps to ensure that the network has been installed correctly and as designed.

Here are the suggested questions for the list:

- is the cable laid according to plan?
- record the as-installed length and verify that the design is still valid?

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[6] *PROFIBUS Recommendation for Commissioning,* PI order number 8.032, *PROFINET Commissioning Guideline,* PI Order No: 8.082.

- has the cable been well treated and are the bend radii observed?
- are the terminations in place as per drawing?
- is the ground done according to plan?
- are all connections tight?

Verify the installation

This time consuming activity requires that the check list is verified against the installation. This means that someone actually goes to each connector and each device, and determines that it is installed correctly. While the temptation to skip this step can be strong, it will pay off in the long run.

The Siemens Level and Weighing Learning Center has a complete PROFIBUS network which I had the pleasure of designing. I also helped with the installation and troubleshooting. We followed the design rules, had a network drawing, and trained everyone involved, but it still did not start up smoothly. After we had finished the wiring checkout, we started bringing up the network one station at a time and problems came up showing errors and missed stations. At this point, I stopped the work, created a check list, and verified the network to find the following:

• line A going to Line B
• loose connectors
• failed DB-9 connector

The bottom line is that even though you may be reluctant to go over a network manually once it is all set up, there are definite benefits to doing so. Mistakes are easily made.
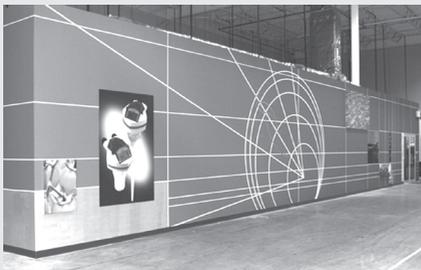
Installation best practice

For the best possible installation, ensure the following:

- the recommended installation method is followed
- buy quality interconnection technology

In this chapter, many different options have been discussed for inter-connection technology. Many studies[7] have shown that the installation costs can be considerable lower for fieldbus installations than for conventional centralized wiring. However, the actual amount depends on the overall design philosophy; many advanced featured connection methods increase the installation cost (reducing overall savings compared to conventional) but also increase the system's robustness, both during commissioning and in production.

For example, if a simple terminal box is used for connecting PA spur lines, the installation costs are low. However, if when installing or replacing an instrument, the A and B lines are shorted, then the entire segment is down until the short is found – not an easy thing to find!

Installation costs will be considerably higher when doing the same installation using the new Siemens Active Field Distributor (AFD) junc-tion boxes rather than the terminal boxes. However, if a line is shorted when installing or replacing an instrument then only that spur line will be affected, not the whole segment. Also, a junction box light indi-cates the short, and troubleshooting time is reduced considerably.

The same logic applies for PROFINET's use of unmanaged versus managed switches. Managed switches, cost more but have the advantage of additional diagnostics if a problem occurs.

NOTE: As best practice, do not be cheap on the installation connec-tion hardware. A low cost connector will probably not save money in the long run for either PROFIBUS DP or PROFINET. For PROFIBUS PA, it is a different story. The new 'smart' junction boxes can also be a point of failure, and field experience has shown that simple good quality terminal strips in sealed boxes work very well.

Next BUS stop: commissioning

Now that the network is installed, it is time to make it work! So the next stop on your Profi trip is commissioning!

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[7] Litz, Dr. Lothar. Ed. "The Value Proposition of PROFIBUS in the Process Industries," *FuRIOS 2 (Fieldbus is Ready for Practical use)*. Technical University Kaiserslautern, March 2005 and ARC Whitepaper. April 2005.

Chapter Seven
Commissioning

Thoughts without content are empty, intuitions without concepts are blind.[1]

This chapter discusses how to set up and commission the wired-in network using the following steps:[2]

1. Set up the network configuration.
2. Bring the field devices online.
3. Set up the field devices.
4. Check the network to make sure field devices are working correctly.

Commissioning a network effectively requires that these steps are completed in the prescribed order.

NOTE: In a PROFIBUS and PROFINET network, a field device is more than a piece of hardware; it's a combination of these elements:

- physical device
- network address
- GSD file
- may have either an EDD or DTM

Furthermore, the field device must match the network definition of these elements.

BUS route

This bus makes the following stops:

- Network configuration
- Network configuration software
- Field device configuration/parameterization
- Setting up field devices
- Using configuration software – best practice
- Upload and download speed
- Verify the field devices and network are working correctly

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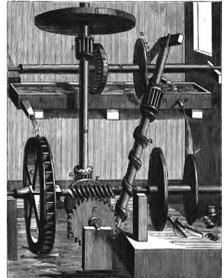
[1] Kant, Immanuel. *Critique of Pure Reason* [1781], trans. Norman Kemp Smith (N.Y.: St. Martins, 1965), A 51/B 75.
[2] A perpetual motion machine designed by Robert Fludd (1574-1637), an English physician and inventor who is credited with being the first person to accurately discuss the circulation of blood through a network of veins in the body.

Network configuration

General system data files

The General System Data (GSD[3]) file contains general information about a slave device and all information concerning cyclic data and cyclic diagnostic data. The network configuration software requires this file to configure the slave device on the network.

This file is very static in that it generally remains unchanged for long periods of time.

In PROFIBUS, the GSD file extension of the GSD file can vary, and many vendors will provide several variations of this file for different languages. They all work the same. The only difference would be the language in which the error messages and comments are written. Here is the conventional format:

- short form of company name
- followed by the PROFIBUS identification number in hexadecimal
- a separating period (.)
- GS plus single letter indicating the language of the file (D = default [language independent], G = German, E= English, F= French, etc.)

EXAMPLE: A file for a Siemens device with a PROFIBUS identification number of hexadecimal 8123 is SIEM8123.GSD.

Hexadecimal refers to base 16 counting system. We normally work in base 10 – number 1 to 10. Base 16 is numbers 1 to 9 plus, A,B,C,D,E,F. F = 16.
A hexadecimal number is referred to as a hex number and is preceded by an x. x80 = hex 80.

In PROFINET, the GSD is no longer just a text file, it is now written In XML (Extendable Markup Language) with the file extension of .xml. Otherwise, the information that it contains is very similar to PROFIBUS GSD file.

Profile mode: When setting up a field device, the device can be identified by either of two numbers:

- vendor specific PROFIBUS identification number – giving access to all the vendor specific parameters for advance configuration and data retrieval.
- PROFIBUS profile identification number (selectable in the field device) – permitting the exchange of similar devices from different vendors without reconfiguring the controller and the use of profile EDD or DTM for setting the field device.

The ability to set up a field device using a generic EDD or DTM is a beneficial feature if the vendor does not support the type of device configuration software used by the network.

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[3] GSD is a German acronym for *Gerätestammdaten*, translated as *general systems data*.

NOTE: To use a field device in profile mode in PROFIBUS, install the profile GSD file. These are downloadable from the PROFIBUS website. Go to www.profibus.com and search for *profile GSD.*

PROFINET has Profiles but does not support Profile mode. PROFINET devices only support a vendor specific GSD files. The infrastructure for this feature exists so this may be added sometime in the future. Perhaps when Ethernet is added to IS instruments, PI will also add this feature. In the meantime, they did take the auto-adapting to past GSD file revisions found in PROFIBUS Instrument Profile V3.02 and added this to PROFINET. Also, in combination with Simple Device Replacement feature, maybe Profile mode is not really needed for PROFINET.

Network configuration software (PROFIBUS)

Vendors have different network configuration software, all using the same GSD files and looking and working basically the same way, using this similar three-window design:

- hardware catalog window
- network layout window
- module information window

Commonalities include:

- graphical layout of the network
- GSD (Device) library – to either the right side or left side (can generally be moved to either side)
- additional information on each device – usually on the bottom

Using the GSD file is also similar across software packages.

- Verify if the GSD file is already in the library of devices. If not, import GSD file.
- In some software packages, the device library may have to be regenerated.
- Add the device by clicking on it and dragging it onto the network.

Configure the module on the field device if required (more on this below).

Most vendors have a copy of their GSD files posted on their website.

Network configuration software (PROFINET)

Just as with PROFIBUS, vendors have different network configuration software, all using the same GSD files, and looking and working basically the same way using this similar three-window design:

- hardware catalog window
- network layout window
- module information window

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- graphical layout of the network
- GSD (Device) library – to either the right side or left side (can generally be moved to either side)
- additional information on each device – usually on the bottom

Using the GSD file is also similar across software packages.

- Verify if the GSD file is already in the library of devices. If not, import GSD file.
- In some software packages, the device library may have to be regenerated.
- Add the device by clicking it and dragging it onto the network.

Configure the module on the field device if required (more on this below).

Most vendors have a copy of their GSD files posted on their website.

This process for PROFINET is really exactly the same as for PROFI-BUS. The only difference is that the PROFINET cable is drawn in green and the PROFIBUS is in purple.

Setting up a PA device using network configuration software

A standard PROFIBUS PA device will be defined by a virtual[4] rack that can have different modules inserted into it. These modules correspond to the different AI/AO, DI/DO blocks in the device. Most configuration software permits a drag and drop of the virtual rack onto the network, and then a drag and drop of these modules into the virtual rack.

For many PA devices, the standard modules are automatically placed in the virtual rack when the rack is dragged over. For example, when the level radar device SITRANS LR250 is brought over to the network, the LR250 virtual rack came with one analog input block and one free place. This analog input block corresponds to the analog input block described in *Chapter Two.*

_____

[4] 'Virtual' in this context means *not real* or *imaginary*. There is no physical rack. We are just imagining that there is a rack so that we can put pretend modules into it to config-ure what is being sent over the bus. The terminology is historical and comes from when PLCs and DCSs used remote I/O racks with modules in them.

The default configuration can easily be changed. To add a second analog input block, highlight the free place module in the left lower window and hit the delete button. Then highlight the analog input block under LR250 in the right window and drag it onto Slot 2 in the lower left window.

Bringing the field devices online

Once all the devices are configured in the network software, the network configuration has to be converted into machine code (compiled) and downloaded to the controller. Then when the controller is placed in run mode, the field devices will go into data exchange.

In PROFINET, each device is identified by its PROFINET name. The first thing the IO-Controller does is to identify all IO-Devices by their names and assign IP addresses based on that and record all their MAC addresses. All the end user has to do is to set the PROFINET name in each IO-Device and the system will take care of the rest.

PROFIBUS is a bit different; each device is identified by an address. One possible problem which would prevent all devices going into data exchange lies with the addresses of the PROFIBUS DP or PA devices. The addresses will either be configurable over the network, or via switches or dip switches on the devices. Most PA devices are configurable over the network and are shipped at address 126. Thus when the PA devices are powered, most will all be at address 126 and no communication is possible.

One way of thinking about this is to image a room full of people with the first name Dave. When you say "hello Dave," you will get back many replies – all coming at slightly different times making it difficult to understand any of them clearly. This is what would happen to the controller who attempts to talk to address 126.

Dave Bignell, former
CEO of Siemens
Milltronics

Successful installations treat a PROFIBUS PA device as a combination of the following:

• physical device
• network address
• GSD file
• either an EDD or DTM

If you go in with this mindset, then regardless of your startup process, you will be successful. Problems occur when people treat a PROFIBUS device like a 4–20 mA device.

I helped with a project[5] in the Canadian oil sands in Alberta, and they learned the hard way about matching the GSD and EDD to the physical device.[6] They went into the project not knowing this and just got caught on one device. There was one device that had two different versions out with two different GSD files. They had the wrong one so the device would never go into data exchange. However, they quickly understood that they could have easily avoided the problem altogether if only they had only realized this going into the project.

To overcome this problem of multiple devices at the same address in PROFIBUS, the following choices are available:

• Set up the device on a bench and set the address prior to installing it.
• Power up the devices one at a time and set the network address over the network.
• Many companies will set the address and set the tag name before the device is shipped. The address and tag name have to be defined at the time of ordering and there is normally a small fee associated with this service.

The first option is the preferred method. Once the devices are powered up, many have a local user interface for setting the address. Others will require configuration software to set the device address.

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[5] Dutton, Don. Powell, James. *PROFIBUS–A Successful Oil Sands Application.* ISA Calgary transactions 2007.
[6] Both HART and Foundation Fieldbus have similar issues.

When bringing the devices online, the field device also needs to be configured. Do not be concerned with error lights on the DP/PA Link modules or controllers during this process. It is normal for a non-configured field instrument to complain that it cannot process the main process variable. The only communication errors that need to be addressed are those generated by the device configuration software. (See *Chapter Nine: Troubleshooting*.)

Field device configuration/parameterization

Device configuration software

There are currently two competing technologies for configuring field devices:[7]

- Electronic Device Description Language (EDDL)-based software
- Field Device Tool/ Device Type Manager (FDT/DTM) software

From a practical point of view, both EDDL solution and FDT/DTM do the same thing: provide a way of reading and writing configuration parameters to field devices and viewing advanced diagnostics.

Both the EDD and DTM describe how to read and write the configuration parameters via the acyclic communication channel in PROFIBUS or PRO-FINET. The GSD file describes all the base protocol information and all the information available via the cyclic communication channel. Depending on the software, either of the following are required to set up a field device:

- a GSD file and an EDD
- a GSD file and a DTM

NOTES:
- SIMATIC PDM (an EDDL based software) configures a field device using the Electronic Device Description (EDD) for that device.
- PACTware and Fieldcare (FDT based software) use the DTM for that field device.

Electronic device description (EDD)

EDDs are text based files that describe:

- all parameters in a field device
- how to read and write those parameters
- all parameter interactions

Interpreters read a program and then translate the program into machine code dynamically, while compilers do the translation all at once. Compilers produce code that is faster, but interpreters are more versatile.

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[7] A third technology called *Field Device Integration* (FDI) is discussed below.

- how to display those parameters
- simple procedures for setup and troubleshooting

EDDs are written using Electronic Device Description Language (EDDL) which is an international standard (IEC 61804-3). The standard was released in 2006 and is used by PROFIBUS, HART, and Foundation Fieldbus. The standard is controlled by the EDDL Cooperation Team (ECT) made up of representatives from PROFIBUS International, HART Communication Foundation, Fieldbus Foundation, OPC Foundation, and (just recently) the FDT Group (see *Field Device Tool [FDT]* and D*evice Type Manager [DTM]* below).

The EDDL interpreters are also moving towards IEC 61804-3 compliance. Both Siemens SIMATIC PDM and Emerson AMS have stated that they will be complying with the IEC standard.

Both EDDL and FDT have been doing some marketing lately claiming to be the answer to your configuration needs. Truth be told, both have their short comings and both are in a bit of a mess.

EDDL is currently supported by more devices, but it is really up to the end user to do the research when putting a system together. Depending on the instruments that you want to use, you might be forced to use both for the next while. The good news is that at least the EDDL software and the FDT that I have used have been similar enough so that using either is not a problem.

For basic setup, PROFIBUS offers a good work-around for the EDD and DTM support issue among vendors. If you have a device that only supports one of these and you have the other type of software, you can define your device as a profile device and use a Profile EDD or DTM.

This will let you set up the device for simple applications. For more complex applications or for advanced troubleshooting, you will still need to use the other type of software. However, by using the *Profile* mode, you can at least deal with the basics.

Enhanced electronic device descriptions (enhanced EDD)

To create EDDL (an international standard), the EDDL Cooperation Team standardized the existing language across the three protocols and the three major interpreters (SIMATIC PDM, Emersion AMS, Emerson HART hand-held 375). This was done in IEC 61804-2. After looking at the language, they realized that enhancements were necessary to fulfill requirements. These enhancements were developed and incorporated into IEC 61804-3.
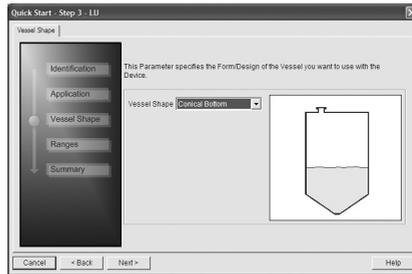
For the end user, these enhancements mean that manufacturers can now provide added functions such as graphical quick start wizards that were not possible before.

These new EDDs (called Enhanced EDD) use the enhancements described in IEC 61804-3.

Field device tool (FDT) and device type manager (DTM)

The initial limitations in the core EDD programming language were eliminated by the new enhancements. Before these limitations were completely solved, a new standard was developed to provide standard configuration software for field devices. This was first developed in a PROFIBUS International working group and then taken over by the Field Device Tool (FDT) group.

The FDT standard addresses configuration software. Described as a frame application, it provides standard plugs that other software can tap into to provide communication to field devices. The software that accesses these standard plugs is called Device Type Manager (DTM) and it can be divided into two types:

- device DTM software – does the same thing as EDDs
- communication DTM – provides the connection to the communication interface(s)
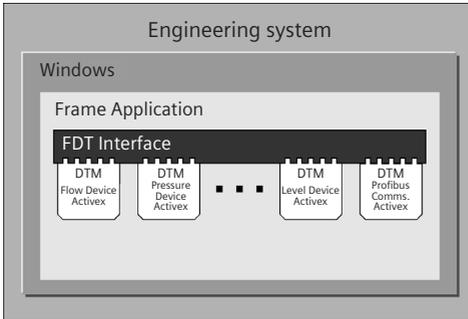
The FDT/DTM solution enjoys a fair bit of success, largely the result of PACTware™, a standard software package developed by a consortium of companies, based on the FDT standard, and sharing the source code.

Field device integration (FDI)

In the spring of 2007, the FDT Group joined the EDDL Cooperation Team and announced a new solution called Field Device Integration (FDI) that combines the best of both FDT/DTM and EDDL.

FDI specification has just been released. FDI takes the client server architecture of OPC UA and uses EDDL to separate out basic parameterization and visualization. This is an evolution of both EDDL and FDT/DTM technology. The proof-of-concept demonstrators look good. The major vendors have also announced that they are migrating their instrument configuration software to FDI. However, this will take some time.

Most device DTMs are generating from an EDD. Numerous tools exist that will take an EDD and convert it into a basic DTM. Once that is done, a programmer enhances it.

Setting up a field instrument

All PROFIBUS PA transmitters operations are described by this diagram. Even if just one analog input block is used, two blocks still need to be set up:

- transducer block
- analog input function block

PA Transmitter
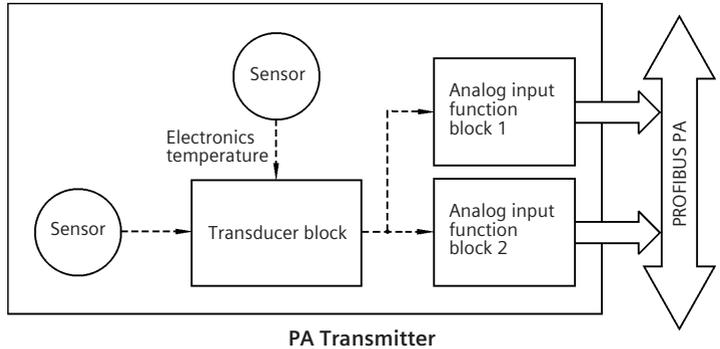
Instrumentation users familiar with HART instruments will use the configuration software and set up the scaling in the transducer block, but will notice the value coming back to the HMI is not correct because with PA devices two blocks need to be set up.

All PROFIBUS PA actuators operations are described by this diagram. Similar to the transmitter, the user has to set up two blocks:

- transducer block
- analog output function block

Quite often instrumentation people familiar with HART instruments will forget to set up the second block. In this case, it is the analog output block. In addition, when sending a value to the actuator's analog output block, a common mistake is to forget to include the status byte which will need to be a value of hexadecimal 80 (good) for the actuator to work.

PA Actuator
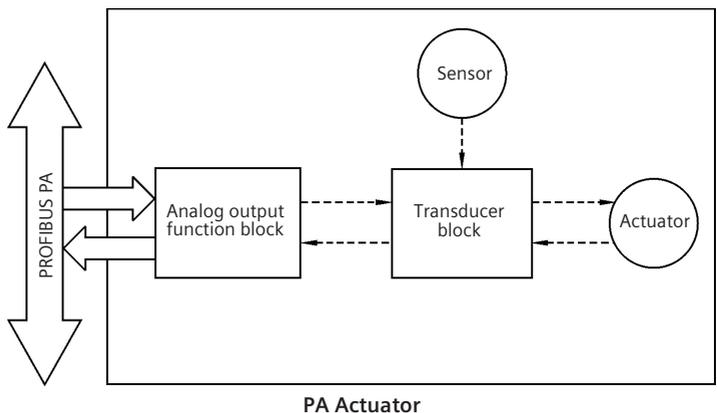
It is also important to change these profile devices as little as possible when setting up. While profile devices are designed to allow for considerable flexibility, most applications are not. If too many things are changed, the configuration can be far more complicated than necessary. For example, this level device transducer block shows it is possible to have four different units defined for Sensor Value, Level, Primary Value, and the AIFB1 output. To follow the information flow, four different units need to be tracked which would be difficult (i.e., this parameter is in inches, this one is in feet, and that one is in meters, while the output is in millimeters).
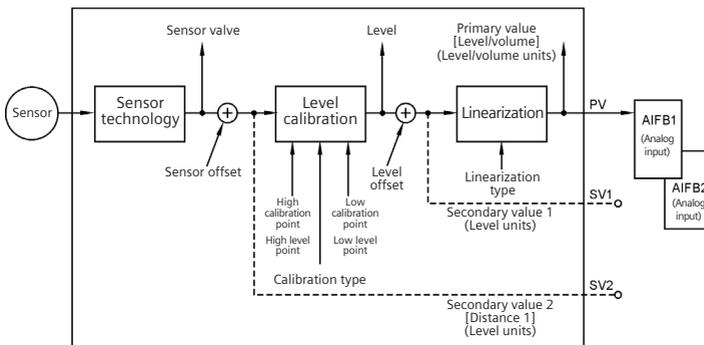
Example

Setting up a SITRANS PROBE LU (level ultrasonic) for a simple application and the parameters to be changed.

Application:
- 10 meter high tank
- flat bottom
- level varies from empty to a maximum of 9 meters
- customer wants to display the level in feet

Span 9 m
(29.5 ft)

10 m
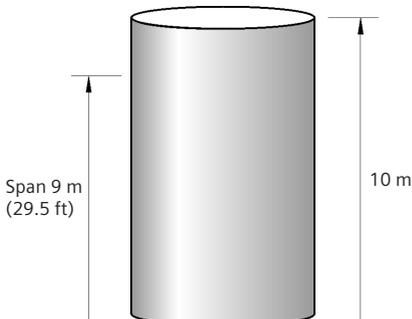
Define the range of the application in the level calibration block of the transducer block using the information from the block diagram.

- the two key parameters to be set are *Calibration High* and *Calibration Low*
- the default measurement units going into the calibration block is meters
- the default unit coming out of the calibration block is % of range

It is simplest to keep the default units and only change the units in AIFB1. Set the following:

- *Calibration High* to 1 meter
- *Calibration Low* to 10 meters
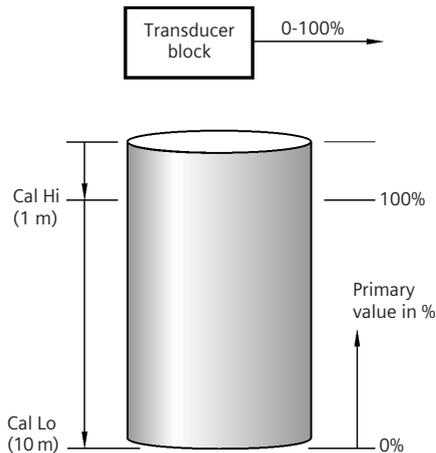
After the calibration block, the value then goes into the linearization block which converts level into volume. This block is defaulted to OFF. Since volume is not required, the defaults are left alone.

Therefore, the values going into AIFB1 will be in the range of 0 to 100 % of full scale. To scale this so that the user will see the level in feet, set the following:

- output scale lower value to *0*
- output scale upper value to *29.5*

- output units to *feet*
- function to *Volume/Level* so that the AIFB1 picks *PV* and not one of the other values coming from the transducer block
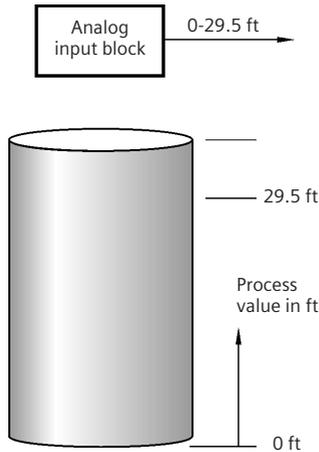
The last step is to download the values to the field instrument and verify that the value showing on the network is as expected.

Using configuration software – best practice

In theory, the default parameters in the software and the default parameters in the device match. New parameters can thus be downloaded to a field device regardless of the state the device is in. However, experience confirms that there can be strange interactions between software and device, depending on how the two have been programmed. These situations can be avoided if these guidelines are followed:

- When setting up a new device for the first time, always do a factory reset on the device. In a startup situation, the person doing the configuration is typically not the person who first opened the box. Therefore, the device could have been altered before it gets to the field. Doing a factory reset on a field device will restore all the factory defaults, which should match the default parameters in the configuration software. This way, both the device and software are starting off in the same state.

- If possible, before configuring a field device, upload all the default parameters from the field device. The configuration software default values should match the field device's default parameters. This step ensures that they do.
- After performing a download to the field device, always follow it with an upload. After the upload, verify that all the changes were accepted by the field device – i.e. are reflected in the uploaded parameters. This is a good double-check of both the software and the data entry.

Upload and download speed in PROFIBUS

As discussed in Chapter Two, PROFIBUS was optimized for very fast cyclic data exchange. Controlling the process is the most important part of PROFIBUS and communicating configuration and diagnostic data is a secondary priority. However, this priority scheme can result in long wait times for uploads and downloads, generally not a problem when only a few transactions are done. However, during commissioning, these wait times can be a problem as they idle the team.

There are three effective ways to deal with this situation:

- Accept that uploads and downloads are going to take a fair bit of time, and plan to have other things to do while waiting. Customers generally understand that this process is still faster than going to the instrument and entering the values by hand.
- Use a laptop with the configuration software on board and go to the link module or coupler, unplug it from the network, and then directly into a PROFIBUS interface card in the laptop. This turns off cyclic communications and reduces a three minute download to a 30 second download. This great work-around is effective when doing a lot of acyclic communications.
- Preconfigure/commission each instrument before installing them in the network. This fast and systematic approach is effective in reducing wait times. While not all of the instruments may be configured ahead of time, the remainder will require only a minor adjustments over the network.

NOTE: Profile 3.02 released in 2009 has a method of grouping parameters that increases uploads and downloads by a factor of six, dramatically improving this situation.

Verify the field devices and network are working correctly

Once the field device is configured and the expected value is found, go into the advanced diagnostics available in the device configuration software to verify that the device has no errors. This step is important because an error in the field device related to processing the main process variable will generate diagnostic requests on the bus which could look like a bus error.

Chapter Nine goes into great details on how to troubleshoot a network, beginning with verifying the network, the first and crucial step of the process.

A bus monitor is the best way to verify that the network is functioning well (see *Chapter Nine*).

Next BUS stop: using the network

You now have a fully functional PROFIBUS and PROFINET network. The next stop on our Profi jouney is how to make optimum use of a PROFIBUS and PROFINET network.

NOTES

Chapter Eight

Plant asset management, maintenance, and operations

"Whoops" is a word that should never be said by some professions – pilots, racing car drivers, and hair colorists come immediately to mind but dentists also have to be up in the top five.[1]

To keep the bus running properly in a new installation, existing maintenance and operation practices need to be reconsidered. Maintaining a plant with a PROFIBUS and PROFINET network requires staff trained in network diagnostics, and an operations attitude that includes preventive actions. The following are necessary to gain maximum benefits from a PROFIBUS and PROFINET network:

- a well trained staff
- a properly equipped maintenance office
- a willingness to change processes and embrace the new diagnostics

The key benefit of a maintenance and operations staff well trained in PROFIBUS and PROFINET is an overall decrease in operating costs. Because more diagnostic information is available, quicker troubleshooting and faster repairs leads to reduced system downtime.

In addition, process improvements may also be possible since the operations staff will have more detailed information about the process and can make positive changes.

This alignment of maintenance and operations with the new fieldbus paradigm is the cornerstone of asset management.

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[1] Stubbs, Richard. *Still Life. Thoughts of a Man Hurriedly Going Nowhere*. Pan 1998.

BUS route

This bus makes the following stops:

- Plant asset management
- Human assets
- Virtual assets
- Physical assets (including the new diagnostics)
- Impact and benefits for the end user

Plant asset management

Plant asset management is about getting the greatest benefits out of investments in a plant. There are various ways of looking at asset management and the ARC presents a particularly good model called *Design, Operate, Maintain Model for Asset Lifecycle Management.*[2] It divides asset management into three elements:

- human assets: the employees in a company and the knowledge base that they maintain
- virtual assets: the processes and the information in place to manage the physical assets. This includes documentation and written procedures on how to manage the physical assets.
- physical assets: the actual devices and objects in the plant

One of the strengths of this model is its acknowledgement of the interactions and interdependencies among these three elements.

If these three elements are managed correctly, the company's return on its assets can be significantly increased. PROFIBUS and PROFINET have a significant impact on each of these elements:

- revenue is increased by reducing waste through improved process monitoring and minimizing downtime
- operational costs are reduced by shifting away from reactive maintenance, leading to the reduction of troubleshooting time and potential accidents
- capital costs are reduced by speeding up commissioning and design times

Return on assets is the revenue generated minus the operational costs and divided by the capital costs.

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[2] Snitkin, Sid. *Asset Lifecycle Management – A New Perspective on the Challenges and Opportunities.* ARC White Paper, July 2008.

Human assets

Employees are valued by a company for their knowledge store and for what is done with it. When working with PROFIBUS and PROFINET, knowledge of the system and the network is crucial to the success of both the installation and the operation of the process. The same applies to both operations and maintenance staff.

> I went to one site where the maintenance crew was given no training on the network or tools, and they continued to treat the instruments like 4–20 mA instruments. It was amazing to see how much a little bit of training on PROFIBUS and SIMATIC PDM did to both the efficiency of the maintenance crew and their morale.
>
> What used to take a few hours could now be done in minutes. The crew went from feeling defeated by the system to feeling empowered. It was heartening to see the change!

Training

Operations people need a basic understanding of the system, particularly if both the process and maintenance alarms go through the main operator station. The ability to differentiate between the two types of alarms allows the operation people to summon either process engineers or the maintenance crew.

Both the maintenance group and the process engineers need to know the following:

- a rudimentary understanding of the system – where everything is and how it all fits together
- a detailed understanding of the depth of the new information available from the PROFIBUS and PROFINET network
- how to access this new information quickly

Opportunities for both maintenance and process improvements are discovered with a comprehensive understanding of the new information available through the PROFIBUS and PROFINET network. Ranging from the fairly simple (minimum and maximum electronics temperature of an instrument) to the complex (valve usage information).

"I hated every minute of training, but I said, *Don't quit. Suffer now and live the rest of your life as a champion.*"
—*Muhammad Ali*

This data can be used by both maintenance and process engineering, albeit for different purposes.

Example: the number of times a valve has opened and closed.

- maintenance personnel determines when the valve needs to be replaced
- process engineers determine if the valve PID loop has been tuned correctly because it's moving too much

Ideally, specialized detailed training for all personnel before going into full network operation will make startup easier. Also, periodic refresher courses are a real benefit because there is a lot to learn. It takes time for people to absorb the information and to rejuvenate memories dulled by time lags between training and implementation.

Virtual assets

Virtual assets are the processes, procedures, and information that keeps a company running. To get optimum benefits from PROFIBUS and PROFINET, a company has to have different processes and procedures. The following sections examine this topic from the perspective of the maintenance and the process engineering departments.

Maintenance department

With conventional I/O, maintenance tools and processes are completely different than for process engineers. The maintenance person would have his/her multi-meter and the process engineer would have his/her DCS terminal. They would go about their jobs in a completely different manner. With PROFIBUS and PROFINET, the tools and processes come together. Maintenance now requires a DCS workstation where they can do the following:

- view the incoming status bytes
- view network status
- run the device configuration/diagnostic software over the network

Setup suggestions:
- set up customized Human Machine Interface (HMI) screens for the maintenance department. In particular, all PROFIBUS PA profile devices with incoming status bytes should be linked to identifying colors on an overview screen with a second screen to list all the instruments showing the status byte.

These overview screens can identify problems and the status byte screens provide the details. Changes in the status byte from the **OK** to a **non-OK** state should also be logged on the HMI data logger so the maintenance people can see momentary problems as well.

- include any available network diagnostics on the HMI indicating the health of the switches, repeaters, and other components.
- have a networked computer with configuration/diagnostic software to view all field devices on the different PA networks from a remote location. Device configuration/diagnostic software can generally connect remotely over PROFINET to the field device. This feature has significant savings potential. It provides maintenance personnel instant troubleshooting data, thereby avoiding the time costs of actually travelling to plant locations.
- establish a separate test bench setup, with a separate copy (single tag version) of the device configuration/diagnostic software. This way instruments are set up one at a time before going out into the field. A networked computer may be used, but it is not recommended. The switch of configurations from networked to local often leads to confusion and errors – one configuration can be confused with the other. Given the low costs of computers and single tag software, it is a far better idea to have two separate stations.

Full maintenance procedure:

System alerts maintenance that there is a problem with one of the field devices or network components.

- Run the device configuration/diagnostic software to get more details.
- Determine the type of maintenance required.
- If a new instrument is required, it can be set up with the correct address and configuration before going to the field. Replacing the instrument is then plug and play.

Process engineering department

Traditionally, process engineers left the instruments to the instrument technicians and concentrated only on the process variable. Now that the instrument configuration/diagnostic software is available, staff should be encouraged to use the new information available in the instruments through PROFIBUS and PROFINET. Instead

of having just one variable to examine, PROFIBUS and PROFINET provide many others to help the process engineer to analyze the process:

- internal electronic temperature of the instrument
- knowledge of process variable reliability
- device specific diagnostics

If the internal temperature of the instrument is going up, it is either a maintenance issue that the device is about to fail or something is going wrong with the process and more heat than normal is being generated. This is new information for a process engineer and potentially very valuable.

Knowledge of the process variable reliability is also new information for the process engineer and can indicate process changes.

During the field trials[3] of the SITRANS Probe LU (Level Ultrasonic) on PROFIBUS PA, we had set up several in various locations in a wastewater plant. I set up code in the PLC to log any change in the status byte. When a non-OK status occurred, the program used acyclic communications to log all the diagnostic messages. One Friday, I reviewed the data and saw how one of the Probe LUs had lost its echo for ten minutes on Thursday at 3:15 pm. From the other units' process variables, I could see that the levels started to raise just before the echo processing problem occurred. The unit with the problem was pointed at an overflow junction. From local weather information, I knew that at 3:00 pm on Thursday there was a very large rain storm. This caused a large influx of water to go over the overflow junction creating turbulence, preventing the Probe LU from locking onto the correct echo and causing the loss of echo.

We would not have seen this with a 4–20 mA instrument, but the PROFIBUS unit provided this extra information. In this case, the fact that an overflow occurred during a rain storm and that it caused turbulence does not add much value to the operator of the wastewater plant. However, it is easy to see that this sort of information could be useful in other applications and certainly provides a different view on the process.

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[3] Powell, James. "Examining Field Instruments under the Fieldbus Microscope." *Control Engineering Europe,* September 2007.

In general, the instrument can provide the process engineer with a wealth of additional information not available with conventional I/O. The challenge for the process engineer and the employer is to change procedures so that this new information can be used.

> Having process engineers look at additional information and diagnostics in the instruments to get a better picture of their process is really uncharted territory for most companies. However, the potential for process improvements and cost reductions is amazing. Providing the training up front is a worthwhile investment.
>
> Using PROFIBUS is like getting a new pair of glasses which helps you see things you didn't know were there – try it and be amazed!

Physical assets

Physical assets are the real devices that can be touched. While traditional asset management has focused on field devices, PROFIBUS and PROFINET, have taken a much wider view and included devices such as:

- motor control centers
- controllers
- field devices
- drives
- computers
- network components
- the network itself
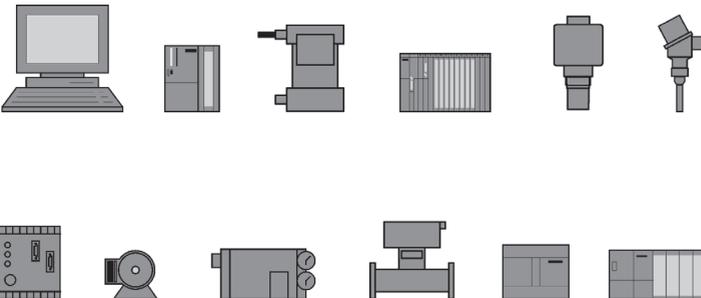
Managing physical assets

For managing these assets, PROFIBUS and PROFINET have defined standard identification information such as:

- tag name
- serial number
- part number
- device type
- manufacturer
- software version
- hardware version
- date of installation

With PROFIBUS and PROFINET, this valuable information is part of the configuration/diagnostic software of the system and can be easily accessed at any time, benefitting both maintenance and general management.

Each type of device also comes with its own diagnostics, with the complexity dependent on the device. PROFIBUS and PROFINET allow the field device to communicate these diagnostics back to the user in graduated steps. Profile 3.01 in PROFIBUS defines four states for diagnostics:

- good
- maintenance required
- maintenance demanded
- maintenance alarm
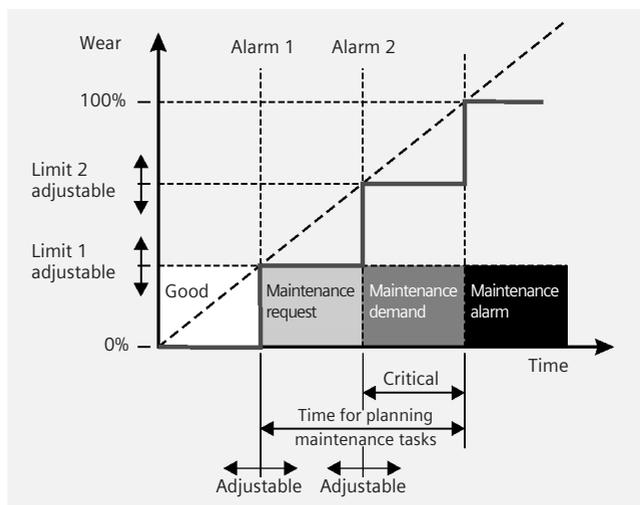
Good: Everything is fine.

Maintenance required: A problem is developing; the maintenance crew should look into it within a defined period of time.

Maintenance demanded: A problem is getting worse; the maintenance crew needs to deal with it immediately before the device fails.

Maintenance alarm: Immediate action is required. A problem has caused the device to no longer work correctly. The process variable is no longer valid.

If all the diagnostics in a field device are in the Good state, then the condensed status byte reports *Good*. Otherwise the most severe state is reported via the condensed status byte.

Some diagnostics use all four states. For example, an actuator leakage alarm in a valve positioner can be set up to alert the user that maintenance is required once the calculated leakage reaches a certain value. Maintenance is demanded at another value and a maintenance alarm at a third value. It is up to the user to define these values (although default values are provided).

Other diagnostics use only two states. For example, electronic failure alarm has two possible states:

- Device is fine.
- Maintenance alarm.

This Profi-thinking has been ported over to PROFINET as well.

New field instrument diagnostics

PROFIBUS and PROFINET are referred to as enablers of advanced diagnostics because they allow critical diagnostics for process field devices to be communicated back to the user.

Device diagnostics – level, temperature, flow, and pressure transmitters

Level, temperature, flow, and pressure transmitters all provide the following information:

- constant monitoring of the process variable (PV) reliability
- detailed information on why it cannot process the PV
- internal electronic temperature

The status byte indicates if the PV is trustworthy, and if the instrument is having difficulty determining the value, it may be either a configuration or a process issue. In both cases, the configuration/diagnostic software provides detailed information on what is happening and provides guidance on how to fix it.

>>Maintenance Alarm<<
−Loss of echo
The device was unable to get a measurement within the Failsafe Timer period. Possible causes: faulty installation, material buildup and / or presence of foam.
➡Ensure installation details are correct. Ensure no material buildup. Adjust process conditions to minimize foaming. If problem persists, contact your local Siemens representative.

The ability to monitor the internal electronics temperature is a valuable diagnostic tool, and its central purpose is to provide an instrument failure alert. However, it also provides additional information about the process and the effect it has on the instruments.

Periodic observation of this variable can monitor how hot the instruments are getting and if there are any changes or trends, providing early warning of a process problem should temperatures vary from the expected. It will also alert maintenance if the temperature exceeds the instrument specs. The life of the instruments can thus be extended by adding heat shields or fans that will lower the instrument's operating temperature.

Device diagnostics and valve positioners

Valve positioners[5] provide the same information as level, temperature, flow and pressure, and add the following:

- partial stroke test
- set point deviation
- actuator leakage
- sticktion
- dead band
- valve seat wear
- number of strokes
- number of changes of direction
- average valve position

Knowing this diagnostic information provides valuable valve and process quality data for both maintenance personnel and process engineers. Maintenance can determine stresses and wear on the valve: the more it moves, the more it wears. Process engineers can reach their own conclusions regarding the process; if the valve does not move much or remains at a particular value longer than it

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[5] The amount of information varies from vendor to vendor. The past few years, Siemens has made significant investments to upgrade and clarify the diagnostic messages in most of its instruments.

should, the valve may be improperly sized for the process. However, if a valve has a high number of cycles or changes direction, the control loop could require tuning.

Leakage alarms can alert the maintenance department of an actuator air leak which can affect process valve performance, not to mention the cost of generating that lost air. Awareness of a problem and its extent is the first step towards fixing the problem.

Sticktion or slipstick data showing the amount of resistance to valve/actuator motion will help maintenance decide when maintenance on the valve is required and can tell the process engineer of a possible cause of process quality deterioration. The positioner determines the sticktion and dead band values upon auto-calibration.

The partial stroke test can be used to measure a valve's performance. The valve is moved by a user defined amount and the response is measured. By comparing this response to a base line response, valve performance can be tracked over time and deterioration measured. The user can define how often to perform this test and when to be notified.

NOTE: In safety applications where the valve will only close down in an emergency, valve positioners can also be applied to the ON/OFF-type valves. As a preventative maintenance measure for safety systems, the valves are occasionally moved just a little with the following benefits:

- assurance that the valve will operate in an emergency and will not fail to close
- advance warning of a failing valve

Valve diagnostics designed for preventive maintenance are the most exciting diagnostics instruments have today.

A consultant I worked with had a project where the control system cost 100K, but the valves on the project were going to cost over 400K. These valves wear down and have to be replaced, although some will last many years while others will not even last a year. The better you can anticipate lifespan and optimize the use time before replacement, the more money you can save. Given the capital costs, the opportunity to save money is significant!

Impact and benefits to the end user

With PROFIBUS and PROFINET, it is much easier to align a company's human, virtual, and physical assets to maximize the return on assets. ARC terms this new environment *the digital plant*[6] and sees it as a strategy for excellence in asset management. The benefits of the new processes become clear when the impact on the following is examined:

- commissioning
- maintenance
- operations

Impact on commissioning

The first step in commissioning a new field device is for the engineer to determine where best to add the new field device on the network. Drawings are modified and then the wire is run for when the field device arrives. The device is first powered up on the lab bench and then connected to the configuration/diagnostic software. Here, the maintenance technician sets the tag name and the bus address and may even configure the device depending on the application. Then the field device is actually installed and connected to the bus. Hereafter, everything is done over the network as the field device can be configured and the control system verified via the simulation function in the field device.

When configuring the field device, maintenance personnel know they need to configure the analog input block and transducer block for a transmitter, and an analog output block and transducer block for an actuator. The analog input block is the same for all transmitters (level, pressure, temperature, flow). The analog output block is the same for all actuators. The scaling is done only in one place, the device, and verifying matching scaling in the controller and the HMI is not required. The transducer blocks will be same for the same type of device. This makes moving from field device to field device far easier, requiring less time reading manuals and generating fewer mistakes.

After setting up the field device, the last step is to upload all the parameters into the configuration/diagnostic software to create a

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[6] Snitkin, Sid. *Asset Lifecycle Management – A New Perspective on the Challenges and Opportunities.* July 2008. p. 23.

permanent record. On this record will be important device information such as:

- part number
- serial number
- software version
- date of commissioning
- hardware version

This information is now part of the system and does not have to be recorded separately.

Experience proves that this process is very fast and removes or reduces many of the time-wasting steps required for conventional I/O:

- number of drawing changes required is reduced because the wires do not go back to the control room
- fewer wires are required because the new runs need only to go back to a junction box, reducing installation costs
- fewer electricians or less time required
- do not have manage major differences between devices
- do not have to walk to the device to commission it
- do not have to walk to the device to simulate it in the control system
- do not have to verify that scaling in the device matches the controller and HMI
- do not have to record device information by hand

Removing all these steps from the instrument commissioning process significantly reduces the cost. This ARC study[7] cites a 14.8% decrease in engineering costs and 23.5% decrease in cable and wire. A FuRIOS[8] study, using real examples, identified 338 Euro cost savings per point for fieldbus over remote I/O.

Impact on maintenance

Maintenance personnel are now empowered like never before, beginning their day by looking at the maintenance screen of the HMI and determining the following:

- which devices, if any, require immediate attention
- the devices they can examine at a later time
- instruments that only need to be periodically examined to determine the optimal maintenance time

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[7] Humphrey, David. *The Value Proposition of PROFIBUS in the Hybrid Industries.* ARC, May 2004.
[8] Litz, Dr. Lothar, Ed. FuRIOS 2 *(Fieldbus is Ready for Practical use)*. Technical University Kaiserslautern, March 2005.

Maintenance time will then be split between these three activities with only the occasional reactive emergency problem. Furthermore, when they have to investigate an instrument, the first step does not require any walking – they simply connect to the instrument over the network and have the instrument tell them the problem and possibly even the solution. In addition, since the PROFIBUS and PROFINET profile standards provide a commonality among different devices and different manufacturers, it is easier to move from device to device.

PROFIBUS and PROFINET contribute to a significant shift away from reactive maintenance, which requires waiting for something to break before fixing it. There are three types of maintenance:

- **reactive:** wait until something breaks before fixing it
- **preventive:** use statistical analysis to determine when something should fail, and then fix it before it happens. Thus, if the statistical pattern points to a valve needing maintenance every six months, preventive repair can be scheduled every five months, avoiding unscheduled downtime.
- **predictive:** uses intelligence in the field device to estimate when something will fail and then have the device send a notification.[9] Predictive maintenance requires two-way communications so the device can be told what to look for and then relate back what it has found. Thus, a valve positioner can monitor its own valve signature and then alert the user when the valve needs replacing.

Predictive maintenance is of great interest to industry as it significantly reduces costs. The instruments today have the intelligence to predict when maintenance is needed. However, knowing something will happen is not useful unless it can be communicated to the control system. This is where PROFIBUS and PROFINET come in.

The field instruments and devices have the ability to tell the control system that something is wrong, and built into the PROFIBUS and PROFINET standard are three levels of alerts, supporting full predictive maintenance:

- maintenance required
- maintenance demanded
- maintenance alarm

Predictive maintenance reduces total maintenance cost for a device to 10% of what it is for reactive maintenance.

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[9] Estimations are that predictive maintenance reduces total maintenance cost for a device to 10% of what it is for reactive maintenance. *The Value proposition of PROFIBUS in the Process Industries.* ARC Whitepaper, April 2005, p.12.

With conventional I/O, trouble with a device is only indicated when something else happens – the tank overflows or the end product fails quality control for example. When this happens, the urgency of the problem is very high and there is the additional problem of the cleanup. In the PROFIBUS and PROFINET world, advanced knowledge gives time to react so the following can be avoided:

- accidents
- bad product
- downtime (lost production)

Calculating cost is difficult, since it will vary among applications and even from year to year, but the costs are thought to be high.

By using PROFIBUS and PROFINET instead of a 4–20 mA solution, the user will see a reduction in:

- overall maintenance cost because of the shift away from reactive maintenance
- potential accidents, bad product, and lost production
- troubleshooting time, because the maintenance person can now:
- connect to the instrument over the network
- get detailed diagnostics from the field device
- have an easier time working with instruments from multiple vendors

I worked in a process plant where during commissioning. I had to verify that the scaling in the field devices matched the scaling in the controllers and matched the scaling in the HMIs. This was a huge job that took a lot of time. Six months into production, we were still finding problems with the scaling. I am willing to bet that there are still errors in the scaling of some of the variables. In a large system it is hard to get all the scaling to match and virtually impossible to keep it that way – it just takes one person to make a minor correction in one instrument and then forget to make the same change in the controller and HMI.

In a PROFIBUS system, the scaling is done in the field device and then passed up, so there is no chance to have mistakes in the scaling of the value. This means that the operators will see the correct values.

Impact on operations

Operations will first benefit from improved maintenance, and they'll also benefit from the additional information.

When an operator starts working with PROFIBUS and PROFINET systems, the first thing to notice is that more accurate data is displayed. The increased accuracy is because the digital signal in the field device does not have to be translated to 4–20 mA and then back into a digital signal – it just remains digital with no conversions. In addition, the chance of making a scaling mistake is removed, so the operator is guaranteed to see the correct value.

Traditionally, operators will monitor the values on the screens, balance the numbers in their heads, and check to see if things makes sense. This is done all the time in 4–20 mA plants and is quite often how problems are found. The common phrase is "value x does not make sense – something is wrong there..."

With PROFIBUS and PROFINET a status value tells the operator if the value can be trusted, speeding up the determination if something is wrong. The operator does not have to wait to see if the other numbers do not match with the problem one. PROFIBUS and PROFINET systems eliminate the need for this level of operator experience by providing the error information.

By using PROFIBUS and PROFINET instead of 4–20 mA, the user will see:

- improved accuracy
- less dependency on the experience of the operators to catch problems
- faster detection of problems

Furthermore, the process engineer has new information to work with, and how to leverage this information to make process improvements is a new area yet to be explored to its potential.

Next BUS stop: troubleshooting

Next stop is how to verify the network health and how to troubleshoot network problems.

Chapter Nine
Network health verification and troubleshooting

The participant's perspectives are clouded while the bystander's views are clear.[1]

Making sure that the network operates as it has been designed and meets the needs of the client is the focus of this chapter, so we get off the bus at this last stop for network health verification and troubleshooting. Network health verification makes sure the network is indeed working well and error-free, troubleshooting for problems affecting communications.[2]

Many of the networks on the market like Modbus RTU or DeviceNet are somewhat delicate, for lack of a better term, and if just one thing is wrong, they will simply not work. PROFIBUS and PROFINET are very different in this respect. They are a very robust networks so several things can go wrong with them and they will still work. However, this is a double-edged sword as problems will not always be readily visible. Successful troubleshooting requires taking a step back and doing a holistic analysis of the network to define the individual causes of the problem.

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[1] Chinese proverb.
[2] Excerpts from this chapter can also be found in these articles: James Powell. *A Guide to Troubleshooting PROFIBUS PA Networks.* PTO White paper (www.us.profibus.com), 2005. James Powell. *Troubleshooting PROFIBUS PA – A Practical example.* PROFIBUS UK Conference proceedings, 2008.

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BUS route

This bus makes the following stops:

- Network problems
- Tools for PROFIBUS
- Tools for PROFINET
- Troubleshooting procedure
- Troubleshooting for PROFIBUS
- A practical example
- Troubleshooting for PROFINET

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Network problems

Most of the PROFIBUS and PROFINET networks I have been brought in to troubleshoot have actually been working. That is, communication was occurring; there were errors but the system was in data exchange and generally working.

IMPORTANT! Just because a network is working does not mean that there are no problems.

Common sources
- design and installation shortcomings
  - improper configuration/setup of field devices
  - application problems

All of these problems have what appears at first glance to be a similar effect on the network.

So, for example, when the red trouble light blinks on the PROFIBUS DP/PA link module in a process plant's panel, it may have many sources:

- design and installation problems causing a slave to drop off the network
- improper configuration of a field device returning a faulty status byte
- application situation is affecting the field device and it cannot process the primary variable properly so it returns a faulty status byte
- faulty/bad device

Furthermore, the problem is often intermittent so the red light on the links and controllers will not be on constantly. Thus, depending on when the panel is viewed, the user may not even know of the problem.

Question: What are the three most common sources of network problems?

Answers:

1. wiring
2. wiring
3. wiring
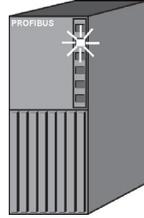
I have investigated a number of networks not because the customer was complaining about the network, but because the customer was complaining about a process or device problem of some sort.

I have also heard statements like this one: "the system is working fine, but there must be some sort of tuning problem with the process, because every so often, two of the pumps will turn off for no apparent reason." After examining the controller's fault table, it became clear that the pump turned off because the device had dropped off the network and then rejoined the network a few minutes later.

Over 90% of network problems can be traced to the physical layer.

The physical layer, wiring, is the most common source of problems. A network is much like the wiring in a home; if it is not done correctly then the appliances won't work, or even worse, flooding, fires, and accidents can happen.

The sources of PROFIBUS network difficulty can be isolated to two main areas:

1. Physical layer problems
   - bad termination or missing termination
   - too many terminations
   - bad connections
   - bad cables
   - bad grounding
   - not enough power
   - too long of a network

2. Device problems
   - incorrect configuration, application issues, a misapplied or improperly installed sensor
   - bad device
   - poor implementation of PROFIBUS in the firmware and hardware of the device

Likewise, the sources of PROFINET network difficulty can be isolated to two main areas:

1. Physical layer problems

   - bad connections
   - bad grounding
   - bad cables
   - failure of a port in a switch

2. Device problems

   - incorrect configuration such as wrong name
   - application issues
   - bad device
   - poor implementation of PROFINET

The potential problems for PROFIBUS and PROFINET are very similar.

Physical layer problems (PROFIBUS and PROFINET)

Having a loose connection is a remarkably common problem!

Bad connections: Typically, a bad connection is a loose connection, and the common problem has a simple solution: tighten the connector for PROFIBUS or replace the connector with PROFINET. Occasionally, the connector itself can have a mechanical failure, but this is fairly rare.

Poor grounding: Poor grounding practices can result in electrical noise induced into both communication buses and into field devices, causing both the devices and the bus to not work properly. Grounding practices apply to the electrical grounding for the entire plant and includes both the communication network and all devices on and off the bus. For example if the field devices are properly grounded, but the variable frequency drive is not, the network will still have problems. Grounding problems are often frustrating as they can be intermittent, so they are difficult to identify and then require a lot of persistence to solve. See *Chapter Six* for recommended grounding practices for PROFIBUS and PROFINET.

Bad cables: One would think that cables should never fail or cause problems. However, all cables can experience wire breaks and partial breaks. Communication grade cables also have electrical characteristics that are particularly sensitive to how they are handled. PROFIBUS DP, PA, and PROFINET cables all have to meet specific electrical characteristics to transmit the 1s and 0s as required. If the installer pulls the cable too hard, violates the bending radius, or the wires get pinched, problems can occur.

Network too long: If the network is too long communication errors will occur, which will affect PROFIBUS DP, PA and PROFINET. However, these errors are more common with PROFIBUS DP and PROFINET.

Physical layer problems (PROFINET only)

Failure of a port in a switch: Switches are important to an Ethernet network and are generally highly reliable. However, as with all electrical equipment, they can fail. Multiport switches typically do not fail completely but will fail in one port.

Physical layer problems (PROFIBUS only)

Bad or missing terminators: With a bad terminator, something is electrically wrong with the network terminators, either a failed component or a short circuit. While the terminators for both PROFIBUS PA and DP are fairly simple components, and little usually goes wrong with them, they can occasionally fail.

Bad or missing terminators cause errors, and for PROFIBUS DP the effect thereof depends on the baud rate and distance. At low baud rates and distances, the network may still work even if there are errors. At high baud rates and/or greater distances, the network may not work at all. For PROFIBUS PA it is an absolute condition – no terminators means no communications. When there is one terminator and a small network, the network will probably work although there may be bit errors.

Too many terminators: As with many things in life, too much of a good thing is not a good thing, which is certainly the case for terminators for both DP and PA.

- **PROFIBUS DP** – too many terminators will generally cut off part of the network because the common source of additional termination is the DB-9 connector with the small termination

switch. When the switch is turned on, it cuts the outgoing line removing it from the network. This is a fairly common problem for PROFIBUS DP networks.

• **PROFIBUS PA** – too many terminators will simulate a longer network by reducing the waveform to one similar to that of a much longer network. In short networks, the system will still operate. However, in long networks communications problems are the natural result.

Not enough power: This problem occurs only on PROFIBUS PA where a slave device requires a minimum of nine volts DC to power up. While the device may power up for a time with a lower voltage, it will eventually drop off if it powers up at all. Low voltage has a number of causes:

• network too long
• too many devices
• wrong cable selection

Device problems (PROFIBUS and PROFINET)

While not nearly as common as physical layer problems, device performance difficulties are also disruptive. Generally, network device troubles are the result of how they are designed and how they are configured.

NOTE: Both device type problems and physical layer problems can generate diagnostic messages and both look the same, each presenting a diagnostic problem for troubleshooting.

Incorrect configuration / application issues / misapplied or improperly installed sensors: If a field device is not configured correctly for the application or if there is any other problem, it will have difficulty determining the process variable. The status byte for the PROFIBUS PA slave will then be in a non-OK state, making the red lights on a PROFIBUS DP/PA link module blink. The slave will also alert the master to read *extended diagnostic.*

At first glance, all that shows in the controller is a diagnostic request being logged and the ubiquitous red lights. Until the diagnostic message is decoded, it looks the same as many other physical layer problems; a bad connector that causes intermittent bit errors can generate a similar sequence of events.

Bad device: A device that has failed or partly failed. If a device has completely failed, it will not appear on the network. A bad device

may possibly take the entire network with it, depending on how it has failed. PROFIBUS DP, PA, and PROFINET devices are designed so that this should not happen. However, given the limitations of electronics, failure is always a possibility.

Poor implementation of PROFIBUS or PROFINET in devices: When the device designers have just not done a very good job and it simply does not work properly. However, using PROFIBUS and PROFINET International-certified devices and controllers all but eliminates this problem.

New PROFIBUS PA users often submit this common technical support call when they first install an instrument. The complaint is that after they added the device, red lights appeared on their link module even though the address had been set correctly. My first question is about the status byte, and the common response is "what status byte?" Next I ask about the configuration of the field device and generally they reply that they have not configured the field device.

These support calls merely reflect a lack of technical training. Once the user knows the instruments have to be configured, all is well. The light goes on so that the red light can go off.

Tools

The tool set required for PROFIBUS is different from the one required for PROFINET.

PROFIBUS tools:

Here is what is required for effective PROFIBUS troubleshooting or for verifying that the network is healthy:

- screwdriver
- multimeter
- PROFIBUS documentation (in addition to this book, the reference section in the appendix has a list of many useful documents)
- field device configuration/troubleshooting software (e.g. SIMATIC PDM or similar software)
- PROFIBUS bus monitor

- PROFIBUS DP and PROFIBUS PA bus tester
- oscilloscope (10 MHz or better for PA, 200 MHz or better for DP)

Screwdriver: for checking that all connections are tight.

Multimeter: for continuity checks when doing wiring verification – also to verify that PROFIBUS PA devices are over nine volts.

PROFIBUS documentation: proper information is the key to a successful network and PROFIBUS is no different – use the latest guidelines and follow them.

Field device configuration/troubleshooting software: while a device problem may look like a network problem, configuration/ diagnostic software tools like SIMATIC PDM provide a quick and easy clarification. Configuration/diagnostic software gives access to each of the field devices, allowing the user to verify operation and to discover problems.

PROFIBUS bus monitor: a good PROFIBUS bus monitor is essential for verifying that everything is working correctly.

Oscilloscope and PROFIBUS DP and PA bus testers: an oscilloscope can be used for both DP and PA to discover many things about the physical layer. So far, bus testers for PROFIBUS come in two versions – one for DP and one for PA. Bus testers look at the electrical characteristics of the network and provide a clear message about it. Oscilloscopes and bus testers do much the same thing. Bus testers are great for a first look at a network and great for beginners and intermediates, giving an **OK** message on a good network and a **Bad** message on a bad network. However, a network that is in between good and bad can be a problem for a bus tester in that it will give a false reading. Oscilloscopes, however, provide a picture of the waveform. An experienced user can get a lot of information and determine not only if the network is good or bad, but if it is somewhere in between.

PROFINET tools

Here is what is required for effective PROFINET troubleshooting or for verifying that the network is healthy:

- Cable tester
- PROFINET diagnostic tool
- PROFINET documentation (in addition to this book, the reference section in the appendix has a list of many useful documents)
- Managed switch
- Oscilloscope (optional)

Cable tester: for testing both the connector itself and the cable, a remarkably valuable tool for commissioning a network.

PROFINET diagnostic tool: a good PROFINET diagnostic tool is essential to verify that everything is working correctly. In the Troubleshooting PROFINET section below, PROFINET diagnostic tools are divided into two types of tools: basic and detailed.

PROFINET documentation: proper information is the key to a successful network and PROFINET is no different – use the latest guidelines and follow them.

Managed switch: diagnostic information from a switch is very valuable. A managed switch provides this information and is the key to both good troubleshooting and to good network maintenance.

Oscilloscopes: not required for most problems. However, for some issues in the physical layer it is useful to see exactly what is going on.

General troubleshooting procedure

The general procedure for troubleshooting PROFIBUS DP, PA, or PROFINET is the same:

Check list:

1. Verify the network is error-free.
   - confirm that all configured stations are in data exchange
   - check the controller's diagnostic buffer
   - use a bus monitor or diagnostic tool to verify that there are no errors
2. Check the physical layer.
   - use a bus checker or diagnostic tool
   - review the physical installation (check all wires and connections)

However, since the tools and networks are different, the details of the procedure are also different. For clarity, the following section is divided up into two sections:

- Troubleshooting PROFIBUS
- Troubleshooting PROFINET

It is frequently possible to do more than one step at a time. Often a bus monitor and an oscilloscope can be attached simultaneously.

Troubleshooting PROFIBUS

Verify the network is error free

The quick way to determine that the network is error-free is to connect a good bus monitor. However, there are several tasks described in the following paragraphs that can be done first which will indicate the health of the network. These additional checks are also very useful in the absence of a bus monitor.

Confirm that all configured stations are in data exchange: This process depends greatly on the type of system used. If using a Siemens Step 7 or PCS7 system, going online with the Hardware Config program provides a list of all devices in data exchange and which ones have errors. Other systems have similar programs.

If a device is missing . . .

- check to see if the device has been installed.
- check the device to see if it has power (for PROFIBUS PA, determine if the voltage is greater than nine volts).
- is the address set correctly?
- use a configuration program to check the field device and if it can be talked to. If the master has the wrong GSD file, then the field device will not enter into data exchange with the master. However, the configuration program will still talk to the device and the diagnostic section will determine why it is not going into data exchange.

Check the status byte: For PROFIBUS PA profile standard devices, the fifth byte of the returned value is the status byte, indicating the veracity of the process variable. If the value is a hex 8x (where x is any value) then the process variable is OK. If the status byte is a value of hex 00, then there are no communications to that device,[3] or we are looking at the wrong memory location. If the device is in error, use a configuration/diagnostic program such as SIMATIC PDM to troubleshoot the field device by looking at the device diagnostic information.

It is very important for all the devices to report their status as **OK** because a non-OK status generates a *diagnostic read request* to the master. This request is easily confused with physical layer problems.

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[3] Be careful with the software used to read the status byte. Some will automatically zero the status byte when communication is lost, others will not. For example SFC 14 in S7-300 or 400 will zero the status byte; however, in a Siemens softPLC, SFC14 will not automatically zero the status byte if communication is lost.

While doing technical support on PROFIBUS, I have often worked over the phone, troubleshooting a network off site. The SIMATIC PDM LifeList program can be very helpful in these situations. I ask the customer to run the program and then to tell me if any field device is reporting problems.

If a device indicates problems, the customer double clicks it to run PDM and activate the *Device Diagnostics* screen. From here, we can easily figure out the problem with the field device. The whole process is very straight forward, and I can talk almost anyone, even a new user, through the process.

Check the controller's diagnostic buffer: Use the diagnostic buffer to look for protocol errors (missed packets, parity errors, re-appearing stations) or diagnostic requests from slave devices. Missed packets, parity errors, or re-appearing stations indicate a physical layer issue. Diagnostic requests can be caused by either physical layer problems or device issues.

Please note that the diagnostic buffer might not tell the full story because of the different setup parameters available on PROFIBUS masters. A particularly significant PROFIBUS setup parameter governs the number of retries and is set to different values for different baud rates and masters. For high baud rates it is set to **3**, which means the master will not report an error until it has failed to communicate to a slave three times in a row. If it talks to the slave on the second attempt, then there is no error message. This situation can lead to confusion and misinterpreted fault allocation. For example, take the case where the network has one or two retries every bus scan, and no errors show as the three threshold is not reached. Then one more device is added and the retry rate goes to three, generating errors. The immediate conclusion, albeit incorrect, is that the new device is at fault when it was actually a pre-existing problem that remains concealed. Using a PROFIBUS bus monitor will avoid this situation by providing an independent view of the network and showing all the retries.

Using a PROFIBUS bus monitor: There are numerous user-friendly PROFIBUS bus monitors on the market (e.g. ProfiTrace by Procentec

and bus-check by Softing). PROFIBUS has been released long enough that the bus monitors have gone from being fairly difficult to relatively easy.

ProfiTrace PROFIBUS bus monitor

For the beginner, a bus monitor can be used to determine the following:

- the network baud rate
- who is on the bus
- number of retries for each station
- number of illegal responses
- diagnostic messages
- data exchange rates
- a method for recording and exporting message traces

NOTE: a good indicator of network health is the total number of retries. Ideally that number should be zero.

Recording and exporting messages is crucial to getting advanced technical support. The global network for PROFIBUS support is available on www.profibus.com which also provides regional contacts. Thus, a message trace file can be sent to a PROFIBUS network engineer who can read it to understand the situation.
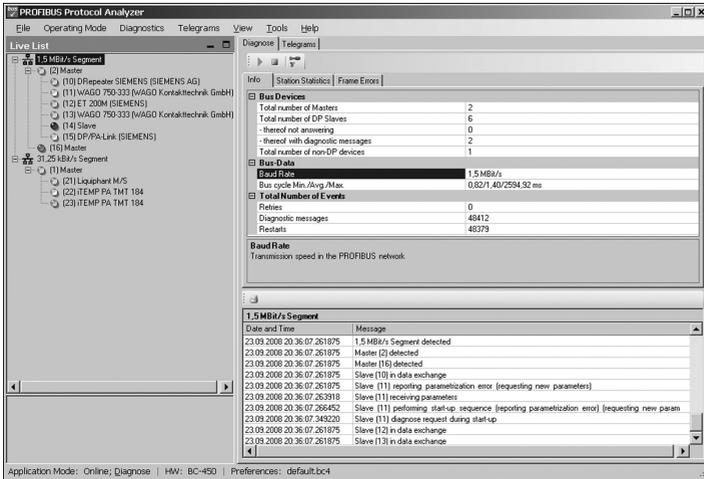
bus-check PROFIBUS bus monitor

Check the physical layer

The physical layer is the most common source of network problems and there are two approaches to testing the layer, each with its advantages. The best idea is to use both approaches.

- Use a variety of diagnostic equipment designed to verify the physical layer, including diagnostic couplers and bus testers. This newer approach to diagnostics is generally simpler to use.
- The standard and reliable oscilloscope. The oscilloscope is an established diagnostic tool, and while it lacks the more modern analytical approach to diagnostics, it can provide the experienced user with a great deal of valuable information. The oscilloscope works for both PROFIBUS DP and PA.

Diagnostic equipment

PROFIBUS DP has the following available:

- Diagnostic repeaters are used in a system that is working and provide information about the physical layer. Some examples of information types provided are:
  - wire break of PROFIBUS cable
  - short circuit of one of the conductors to the shield
  - loose contacts
  - too many nodes in a segment
  - faulty PROFIBUS messages

- Cable testers are used to test the cable during commissioning and depending on the kind of tester, sometimes they can be used during the maintenance phase as well. There are a couple of manufacturers that make this type of device, each with different features. Some information types they can provide are:
  - breaks in the wires and cable shield, short circuits
  - too few terminators or too many terminators
  - topology scan
  - distances between nodes and overall cable length.

PROFIBUS PA has the following available:

- Diagnostic couplers are used in a system that is working and provides information about the physical layer. There are several manufacturers making this type of device. Each one on the market has different features. Some information examples provided are:
  - voltage level
  - total current draw
  - local life list
  - segment noise
  - device communication signal level
  - signal jitter
  - Cyclic Redundancy Check (CRC) error counter
  - number of received framed errors
  - oscilloscope readings

- Cable and bus testers test the cable during commissioning and during the maintenance phase as well. At time of publication both Softing and MTL make a PROFIBUS PA cable tester, an easy-to-use device that provides the following:
  - signal levels of devices
  - topology scan
  - number of retransmitted messages
  - voltage level
  - overall pass or fail

## Oscilloscope and PROFIBUS DP

Viewing the signal:

- use an oscilloscope with the following minimum requirements:
  - 200 MHz
  - digital
  - two channels

- – ability to subtract the two channels
- – DC coupling
- channel one: Line A to ground
- channel two: Line B to ground
- monitor 2-1
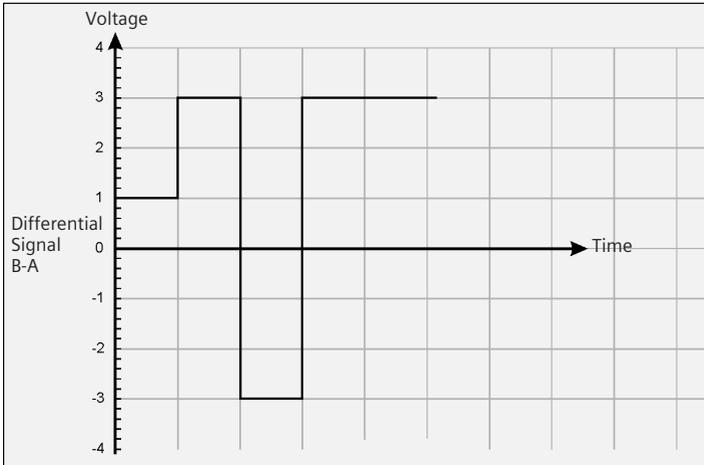
Ideal wave form for RS-485
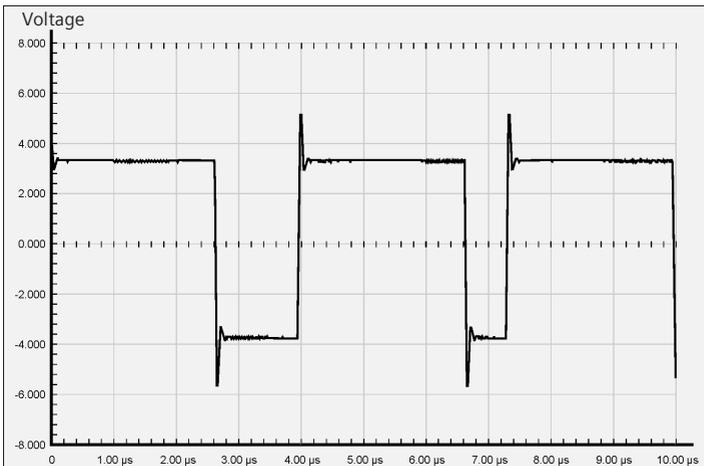
Small PROFIBUS DP network running at 1.5 meg
with active terminators on and working properly
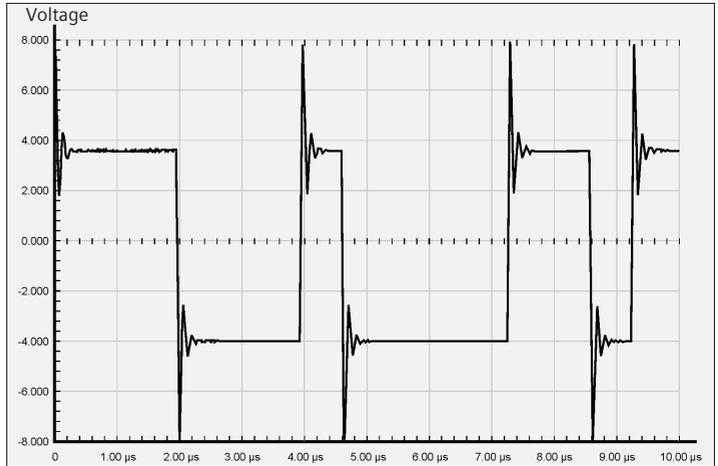
Small PROFIBUS DP network running at 1.5 meg
with active terminators turned off and working properly
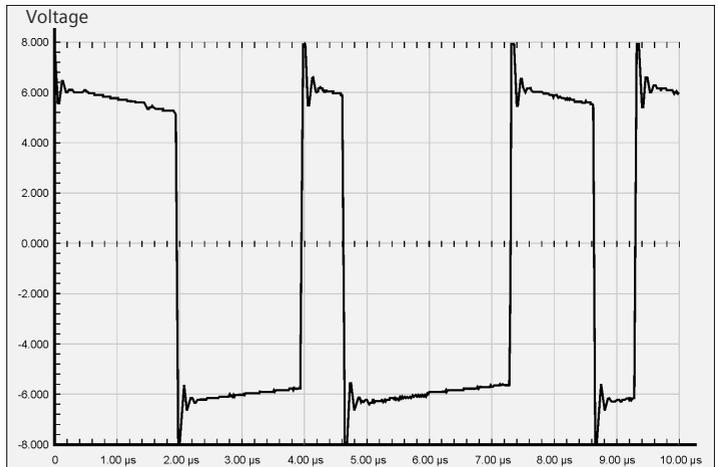
Small PROFIBUS DP network running at 1.5 meg
with no terminators and with some communications

The waveform should have:[4]

- positive and negative values about equal (within 0.5 V)
- voltage difference should be between 4 V and 7 V
- square tops and bottoms

Here are some common problems and the effects on the waveform:

- network too long – the top and the bottom of the waveform will be rounded
- missing terminator – reflections will occur, distorting the waveform and/or canceling it out depending on the standing wave. Typically, a square wave turns into a staircase.

The waveform examples above are from a real network. The network was very short in length, and only had two devices on it. It was set up to run at 1.5 meg, and the first waveform is pretty good. It shows some distortions, but generally is very square and is close to an ideal waveform. The second waveform shows what happens when one terminator is turned off. Notice how the distortions increase considerably. Since the network is short and the loading is low, there is still communication. The third waveform shows what happens when both terminators are turned off. The distortions increase even more and the peak-to-peak voltage also increases.

Oscilloscope and PROFIBUS PA

Viewing the signal:

- use an oscilloscope with the following minimum requirements:
  - 10 MHz or better
  - digital
- AC coupling
- 20 micro second/div.
- 200 milli-volt/div.
- connect lead across the (+) positive and (–) negative leads

NOTE: Peak-to-peak-voltage should be around 800 mV. The longer the PA network, the lower the peak-to-peak voltage.

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[4] The PROFIBUS document, *Installation Recommendation for Commissioning'* Order No: 8.032 has a great section on troubleshooting PROFIBUS DP and using an oscilloscope.
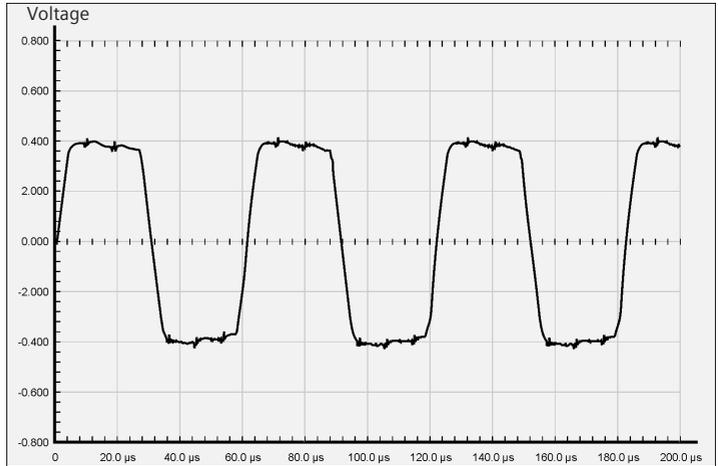
Voltage

Ideal wave form when devices are communicating
(peak-to-peak voltage is around 800 mV)

A waveform with one missing terminator looks far different, particularly with the increase in voltage levels. If both terminators were missing, the peak-to-peak voltage would be even higher and there would be no communication possible.
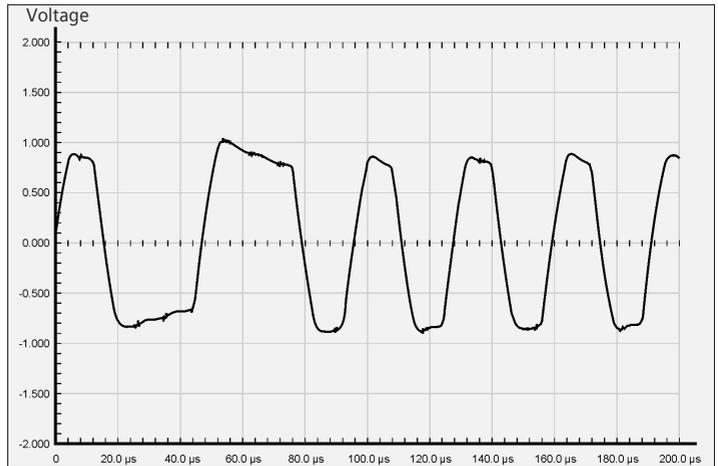
Voltage

Waveform with one missing terminator

The distortions at the top and bottom of the waveform are caused by reflections. Mixing cable manufacturers can also cause this type of

distortion and increase the peak-to-peak voltage slightly. Using different manufacturers' cables also presents another problem because the IEC 61158-2 standard states a range of values for Class A cable. Thus a manufacturer will pick one set of values while another manufacturer will choose a different one in the same range. Mixing cables is permissible under the IEC 61158-2 standard, but is not recommended because of the resulting reflections.

If the waveform is completely distorted with peak-to-peak voltages considerably lower than 800 mV, the problem is either low power or too many devices. Furthermore, strange spikes indicate a problem or too much noise in the system.

The waveform also indicates if the physical layer is working well. If the waveform is fine, the problem is related to either the devices or the connections going to the devices. Please be aware that with grounding issues and noise issues the problems can be intermittent. Therefore, the waveform should be monitored for a time and measured at more than one point on the network to catch all problems.

Reviewing the physical installation (DP and PA)

Reviewing the physical layer requires a fair bit of simple physical labor, starting with a network diagram identifying device locations, their addresses, and how they are connected. Then comes the fun part, beginning at one end of the network and tracing the communication cable section by section, segment by segment until the end. Check for the following:

- bad connections: use a screwdriver to tighten all the connections. (Even networks that work properly often have loose connections and this should always be the first activity.)
- note where the terminations are and verify that they are in the correct locations. Make sure there are not more than two on any one segment.
- check where the wires are run and verify that they are not too close to power cables. This is another common wiring problem in the field. Laying a communication cable on top of a power cable or tie-wrapping it to a power cable will induce noise into the communication cable and should be avoided.
- note the approximate distances on the network diagram and verify that they fall in line with the design standards.

A practical example
This case is based on an actual event.

The site
This chemical company provides product to the petrochemical industries. All the instruments are located in hazardous environments and use the intrinsically safe feature of PROFIBUS PA. The site comprises a Siemens APACS DCS with two PROFIBUS DP networks that use Satelline-3Asd wireless modems to connect to 15 PROFIBUS DP/PA link modules, located in cabinets all around the plant.


The details
The wireless modems use a licensed frequency for transmission and are capable of transmitting long distances. However, the environment with its obstacles and electromagnetic noise is not friendly to wireless technology.

Each link module is configured for 20 to 25 instruments with about six to eight instruments per PROFIBUS PA segment using PROFIBUS DP/PA Ex couplers.

The two PROFIBUS DP networks are both set up to run at 9600 baud with special PROFIBUS DP bus parameters for the radio modems. The retry limit was set to five, a value the customer had received from the wireless modem manufacturer. This is high, especially for 9600 baud.

The layout of the two networks
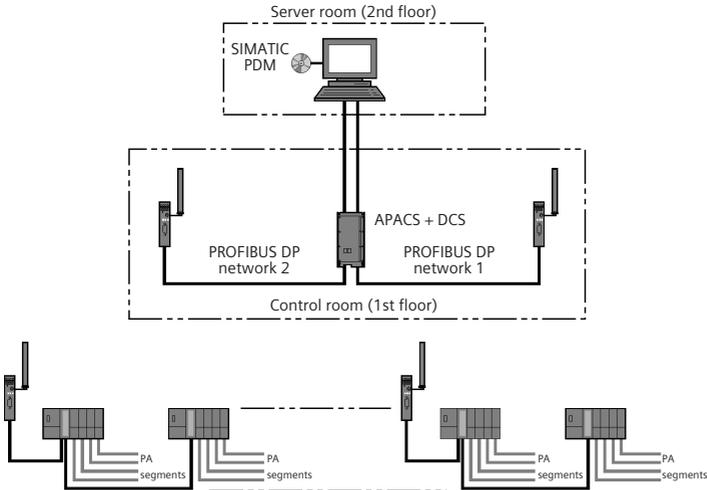
The problems
- cannot communicate to some of the field devices
- PROFIBUS errors on the DCS
- PDM sometimes loses connection

NOTE: the site remained functional, and all the key data was provided within a couple of seconds, meeting the site requirements.

The troubleshooting

The process followed at this site was a variation on the one outlined at the beginning of this chapter. Troubleshooting began on the PROFIBUS DP side and then moved on to the PROFIBUS PA side of the network.

The first step was a visual inspection of both PROFIBUS DP networks along with some of PA nodes. A visual inspection provides familiarity with the site and gives information on locations and conditions.

PROFIBUS DP segments: The next step is connecting the PROFIBUS bus monitor to both DP networks multiple times, taking traces, and monitoring performance.
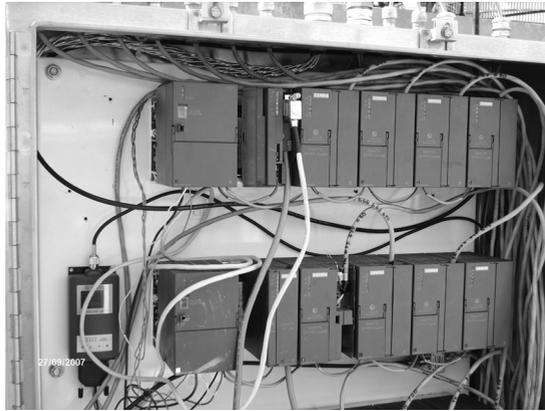
As it turns out, the visual inspection provided the most significant information for the two PROFIBUS DP networks. At installation, several PROFIBUS DP wiring guidelines had been contravened: cable types were mixed and powered terminators were not used. However, since the network was running at 9600 baud and the copper wires were going less than 100 meters, these violations had little or no impact on the error rate.[5]

The other installation problem lay with several antennas which were not mounted correctly. At installation, they were possibly not tightened enough and they had slipped. After consulting the PROFIBUS bus monitor and examining the retry rates to the different stations, it became clear that the stations with the greatest retry rates were also the ones with the slipped antennas.

Fixing the antennas improved performance to a point where the DCS was no longer getting PROFIBUS error messages. Retries still occurred, but given the high electrical noise and the number of obstacles in the chemical plant, there were limits to how much the performance of the wireless network could be improved.

PROFIBUS PA segments: The PROFIBUS PA segments proved to be far more interesting and far more challenging. The first phase of the investigation was to attach the PROFIBUS bus monitor and the oscilloscope to each PROFIBUS PA segment to get an overview of what was going on. SIMATIC PDM verified that each field device provided an OK status. Normally the DCS would have been used to verify the status bytes; however, DCS was not easily accessed at this site so it was far easier to use PDM.

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[5] Please note that even though this is a real example, it is certainly not the recommended wiring method. As you can see from the panel photo, the wiring is not very neat.

Since these segments were located in intrinsically safe areas, a hot work order was required   before each cabinet was opened.[6] This process required about an hour for each cabinet.

NOTE: Checking out a large network in an intrinsically safe area requires a considerable amount of time.

Problems discovered

Problem one
The waveforms from segment two, with the angled peaks and valleys, indicate a problem as they are not consistent with the ideal waveform. The peak-to-peak voltage is too high and the peaks and valleys are distorted. Although the bus monitor indicated zero retries and zero errors on this segment, and all the instruments were functioning properly, the overall results indicated problems. That similar waveforms were showing up for most of the segments, many of which were having communication problems, suggested that a deeper analysis was required.

An ideal waveform has a peak-to-peak voltage of around 800 mV. If a terminator is missing, peak-to-peak voltage sits around 1.5 V with distortions at the top and bottom. However, increasing the size of the network lowers the peak-to-peak voltage.

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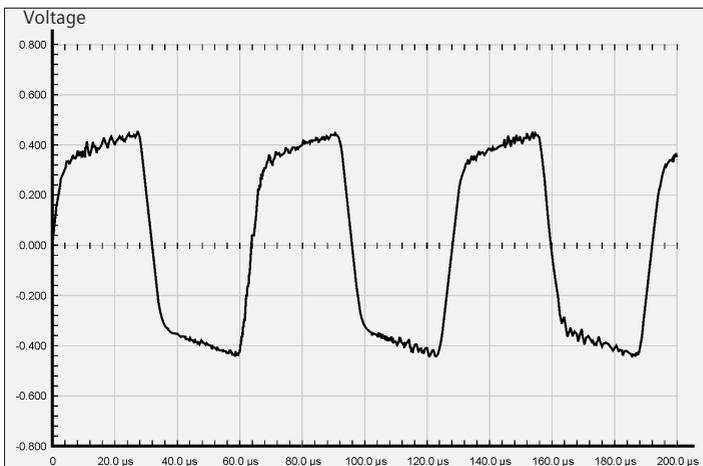
[6] A hot work order requires that each area is checked for chemical vapor and all necessary people are notified.

The puzzle: The segment's peak-to-peak is over 800 mV – within acceptable range

- the distortion at the top and bottom is similar to when a segment is missing a terminator – but it had the required two terminators
- the run was under 500 meters – not long enough to cause any distortion

Thus, all the conditions for a reliable installation appeared to be in place, yet the problems still existed.

The conclusion: After verifying that there were indeed two terminators on this network, the wiring came under investigation. By using the specifications and several lab bench tests, the source of the problem was determined to be at the T-connectors and mixed cable types.

The site used Siemens T-connectors and Belden PROFIBUS PA cable. The Siemens T-connectors are vampire connectors designed to match the impedance of the Siemens PROFIBUS PA cable. The IEC 61158-2 standard does not state an exact specification for class A cable; rather it states a range. Vendors will then produce within that range, but cables from different vendors may not match. Mixing cable types produces reflections similar to those of a missing terminator, just to a lesser degree. This site had unknowingly mixed cable types.

However, given the modest length of their wire runs, mixing the cable types did not present a problem for communications. The bus monitor supported this conclusion. Had this been a non-IS environment with long wire runs, then this wire practice would have been a problem. The ultimate solution would have been to switch out the T-connectors for PROFIBUS PA junction boxes.

Problem two

This waveform suggests interferences from power cables or variable frequency drives in segment one.

The puzzle: Tracing the wire runs did not identify any sources of electrical noise.

The conclusion: During the wire tracing procedure, the cabinets holding the T-connectors with the M12 connectors were opened. These cabinets had not been sealed correctly and water was dripping from the M12 connectors. Plus, the M12s were connected by only a half turn. A tight connection requires several complete turns, and these connectors were just barely touching. After the connectors were dried and tightened, the waveform cleaned up.
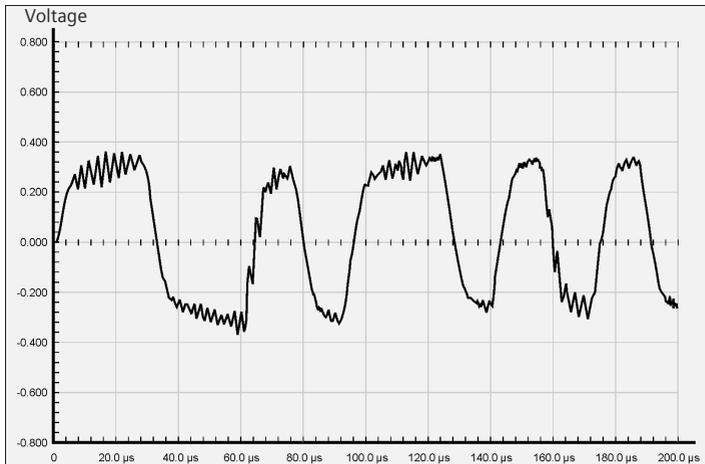
Problem three

Segment one also indicated difficulty in communicating to a Siemens radar level transmitter (SITRANS LR250). The PROFIBUS bus monitor program indicated framing errors and illegal messages. The first conclusion is that electrical noise from the loose and wet connectors in the waveform is the cause.
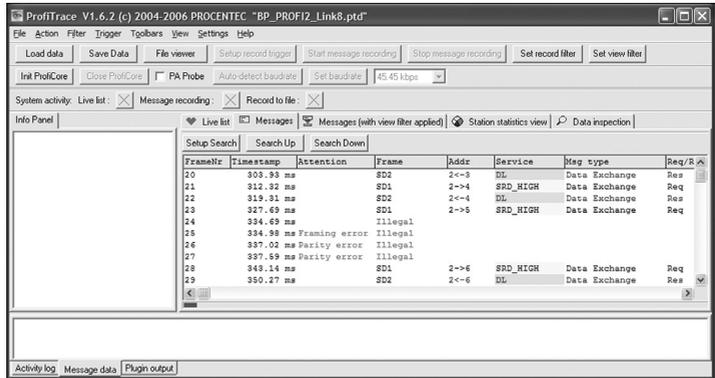
The puzzle: Once the connectors were dried and tightened, the communication problem with the SITRANS LR250 did not correct itself.

The solution: Framing errors and illegal messages can be caused by having two devices with the same address. Addresses for each field device were verified and two devices were found at the same address. The address of one of the devices was changed and the bus errors disappeared.

Problem four
Segment ten had a blinking power light on the PROFIBUS DP/PA coupler. This blinking is rare as this light is generally solid green. The manual for the DP/PA coupler indicated that the segment was drawing too much power, limiting the current and causing the light to flicker. This segment carried numerous SITRANS LR250 radar devices and SITRANS TH400 temperature transmitters, and while cyclic communication to the radar devices was functional, some of the temperature transmitters had lost communications. All indications suggested the segment was overloaded with too many devices and was possibly too long as well.

The puzzle: The segment was not overloaded with too many devices and it was not very long.

The solution: Opening one of the temperature transmitters immediately clarified the situation – water shot out from around the seal. The unit itself had been installed correctly, except that the conduit end was not sealed. Water came through the conduit until the temperature transmitter housing was completely filled. Several other transmitters had been installed the same way and were drenched as well.

Surprisingly, communication to all the radar devices on this segment still occurred, and it was in full data exchange. A download with SIMATIC PDM returned communications errors on the long messages; however, given that several of the instruments were underwater, any communications activity was remarkable.

The water-logged instruments were the same ones behind the customer's report of connection loss – not a big surprise. Once the water-filled instruments were replaced and the conduits were properly sealed, the problem disappeared.
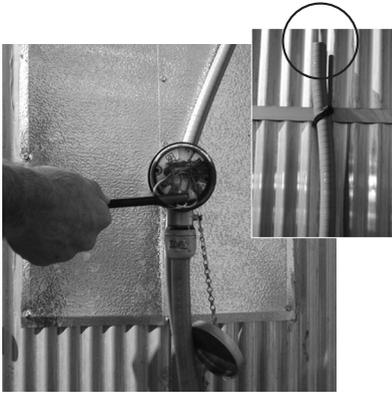
Summary

This site visit confirmed that PROFIBUS provides a robust network. The site installation problems should have shut down the network, yet the operators were still getting enough data to meet their update requirements.

Systematic troubleshooting is the most effective approach to network problems. However, as this example shows, interpreting the data required some art because a test result can have more than one source:

- noise on the waveform, generally caused by electrical noise, can also be caused by a poor connections and water ingress.
- a waveform that suggests a missing terminator may also be caused by mixed cable types.
- bus or framing errors usually originating from a noisy line, can also be caused by two devices with the same address.
- overload conditions in a segment, often the result of too many devices, may be caused by a wet device.

When troubleshooting, mind the following to guide the process and remember that things are not always as they first appear:

- always do a physical inspection and check the following
  - conditions   - conduit
  - connectors   - devices
  - connections   - power cables
  - couplers   - grounding
- always correlate addresses with devices
- make sure each segment has proper termination
- check number of devices per segment
- check segment lengths and repeater placements
- use bus monitor program to check for error messages
- use configuration software (e.g. SIMATIC PDM) to check and test device responses
- use an oscilloscope to verify that the physical layer works properly

Troubleshooting PROFINET procedure

Verify the network is error free

As with PROFIBUS, determining that PROFINET is error free is not as straight forward as one would think. Network speed puts greater requirements on the capture software, especially with IRT. Switches only pass information down a line that is intended for the IO-Device at the end of the line. Capturing this information is the function of TAPS and diagnostic software. These are described below.

However, expanding on this, there are a few simple things that can be done first to determine the health of the network:

Confirm that all configured stations are in data exchange: This process depends greatly on the type of system used. If using a Siemens Step 7, PCS7 system, or TIA Portal, going online with the Hardware Config program provides a list of all IO-Devices in data exchange and those with errors. Other systems have similar programs.

Complete the following if a device is missing:

- verify that the IO-Device was installed
- check that the PROFINET name was written down to the device
- confirm the device has power
- check the switch the device is plugged into to see if the port is active (many switches have diagnostic lights on them to indicate activity).
- verify if the address set correctly?
- check the Discover and Configuration Protocol (DCP) browser to see if you can see the IO-Device. This is built into many PROFINET configurators. Also try pinging the IP address (using the command prompt command ping).

Check the IO-Controller's diagnostic buffer: Use the diagnostic buffer to look for protocol errors (dropped connections, re-appearing stations) or diagnostics from IO-Devices. Dropped connections or re-appearing stations indicate a physical layer issue. Diagnostics messages can be caused by either physical layer problems or device issues.

Please note that the diagnostic buffer might not tell the full story. In real time I/O, messages are sent from the IO-Device to the IO-Controller and from the IO-Controller to the IO-Device without acknowledgment. The receipt of the message on the other side is monitored via a watchdog timer. Lost packets are possible under this scheme. To verify no lost packets, a bus monitor would be required. When viewing messages on a bus monitor, low priority messages such as missed frame or bad frames may not be passed on depending on how the messages are viewed and the switch is configured.

If you are using managed switches and Simple Network Management Protocol (SNMP) then the port statistics will show this sort of information. Alternately, some switches can be set up to report this sort of information and other information via diagnostic alarms.

Using PROFINET diagnostic equipment

PROFINET diagnostic equipment can be divided up into two categories; basic troubleshooting aids and detailed data and performance analyses.

Basic troubleshooting aids: There are a number of tools on the market, and three of the more popular ones are Netilities by PRO-CENTEC and PRONETA by Siemens, and PROFINET Commander by PROFI Interface Center. Note that the functions vary and it is best to research them. Furthermore, they are in their developmental infancy and will expand over time.

Netilities has a similar look and feel to ProfiTrace, minus the detailed protocol analysis, valuable for PROFIBUS users who have used ProfiTrace. Features include the following:

- Live list
- Summary of network problems (IO-Device missing, double addresses, etc.)
- Topology scan (requiring managed switches)
- Access to I&M data
- Configuration information on IO-Devices
- How to set IO-Device names and IP addresses
- Summary report
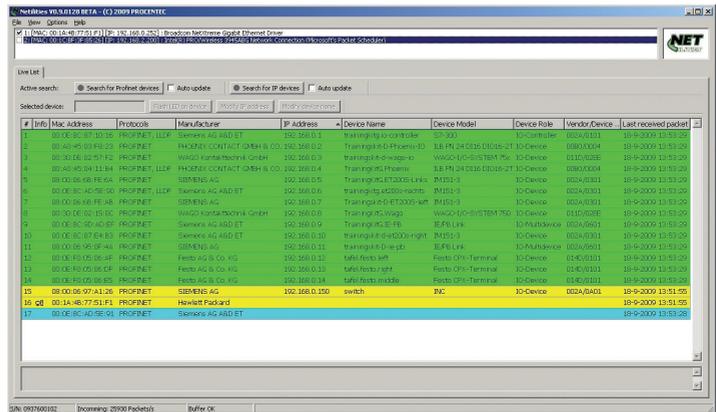
Users of ProfiTrace will find this very accessible. To connect to the network, it would use either an aggregating TAP or port mirroring (see *How to capture data* section below).

PRONETA[7] is a free software package from Siemens that will do some of what Netilities does plus complete IO checkouts with the Siemens PROFINET IO. Its features include:

- Live list (accessible nodes)
- Topology scan (requiring managed switches)
- Access to I&M data
- Distributed IO Check (Siemens PROFINET IO)

This is a simple package that just plugs into an empty port on the switch.
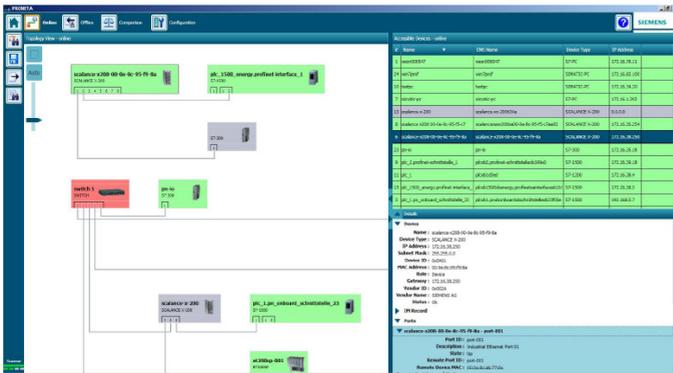
PROFINET Commander is a simple PROFINET IO-Controller and troubleshooting tool. Like Netilities, it is made by experts in troubleshooting which in this case is the PROFI Interface Center. As such it is a great tool for quickly testing out a system without having to the PLC up and running. They are also constantly adding new features. Some of the current features are:

- PROFINET Browser (set name, IP, reset, flash LEDs)
- Easy configuration of IO-Devices (CC-B support)
- Easy configuration of PROFINET Commander as a PROFINET IO-Controller supporting RT communications
- Read inputs and write outputs (cyclic, acyclic)
- Easy access to acyclic data (I&M, Parameters, Diagnostics, IO)
- Diagnostics

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[7] Picture taken from PRONETA application note Entry ID 67460624, figure 3.6,

PROFINET Commander just plugs into any port on the network replacing the IO-Controller.

Detailed data and performance analysis: The most popular software for Ethernet data analysis is Wireshark, a free software package easily downloadable from the internet (www.wireshark.org) and it gives a view of each and every command on the network and decodes the PROFINET commands. To connect to the network, this would use either a TAP or port mirroring (see How to capture data section below).

Complementing Wireshark are two packages that ride on top and provide a more detailed picture of what is going on:

- NetProfi by Siemens
- netAnalyzer by Hilscher

These packages tend to do similar things although each would have their own set of features. They also go along with the hardware that each vendor sells for collecting the Ethernet date.

NetProfi by Siemens

netAnalyzer by Hilscher

NOTE: recording and exporting messages are crucial to getting advanced technical support. The PROFINET global support network[8] also provides regional contacts. Thus, a message trace file can be sent to a PROFINET network engineer who can read it to understand the situation.

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[8] www.profinet.com

Capturing the data

The diagnostic software talked about above generally can gather some information by just being connected anywhere on the network. However, to get the detailed information, the software has to be connected to the network in a special way. Here are three of the more popular ways to capture data off an Ethernet network:[9]

- Port mirroring on an Ethernet switch
- Aggregating TAP
- Passive TAP

Port mirroring on an Ethernet switch: Ethernet switches will only pass data down a port intended for the device at the end of the wire. However, many switches will 'mirror' the data going down one port onto another port so it can be viewed with capture software. If the port that the IO-Controller is connected to is mirrored, the data going from and to the IO-Controller will be visible.

While port mirroring is an excellent way to look at the data, it does have limitations:

- In the process of mirroring, many switches will introduce additional jitter in the mirror message. This is not a problem for straight data analysis but will provide false information for performance analysis.
- Because it combines both the incoming and outgoing data into one stream, it also may be too slow to capture all IRT traffic.
- For RT IO traffic it may also drop lower priority messages in order to fit everything in.

NOTE: This information is available in the switches' manuals. Again, the wise choice of a switch is important as not all are the same.

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[9] A good reference on this topic is the whitepaper 'Industrial Ethernet real time capture guide' by the Profi Interface Center
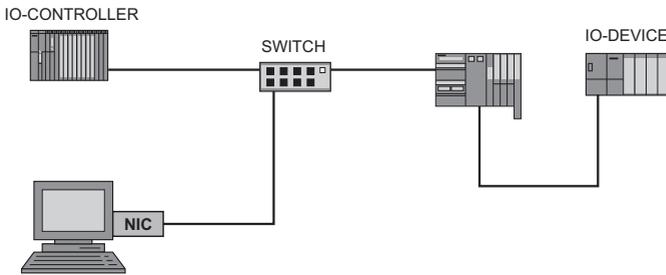
Aggregating TAP: A TAP is a Test Access Point. An aggregating TAP combines the input data and the output data (Rx and Tx) from the Ethernet cable into one stream of data going to the input line of the monitoring computer's Ethernet card, called a Network Interface Card (NIC). This physical device would generally be inserted between the IO-Controller and the switch.

Aggregating TAPs are easy to use, but like port mirroring they too can introduce additional jitter into the data stream and they may not be fast enough for IRT. Typically these are fine for RT IO but not for IRT. Data can also be looked at, but is not recommended for performance analysis.
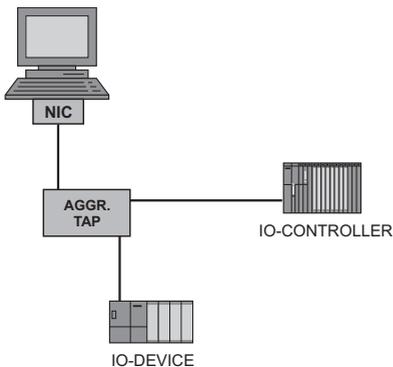
Passive TAP: A passive TAP takes the outgoing signal and splits it to one input line in the computer and takes the outgoing signal and splits it to a second input line in the computer. This best solution for IRT covers both performance and data analysis – it's a physical device that would normally be inserted between the IO-Controller and the switch and connected to the two Network Interface Cards (NIC).

Passive TAPs are easy to use and are really the best solution to physically capturing the data. However, a challenge on the software side is that two NICs are required as well as either two instances of Wireshark or a method to combine both streams. NetProfi by Siemens and netAnalyzer by Hilscher offer a method for combining the two streams. The benefit of a combined stream is that it makes it easy to see what is going on and when.
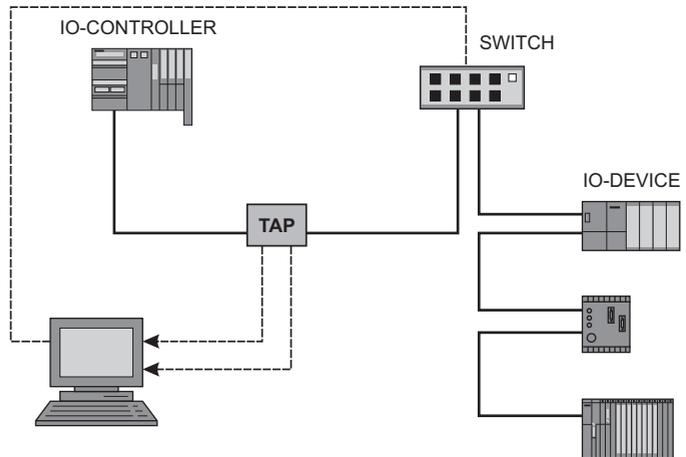
Check the physical layer

The physical layer is the most common source of network problems. For managed switches Simple Network Management Protocol (SNMP) can provide a list of the lines with excessive numbers of lost/bad messages. Otherwise, check the network software to see if any nodes are dropping out and then re-appearing. These all tend to point to a physical layer problem.

1. The most common problems are with the cables:
   • Bent cable
   • Bad connection in connectors
   • Cable too long

   A cable tester is essential. Look for the following features:

   • Detects short circuits, wire breaks, swaps, miss-wiring, and split pairs
   • Test cable shield

- Determines length of cable
- Support for the connectors used (RJ45 or M12)
- Message test

2. The switches' ports can be another problem source. If the cable is OK and the problem with that leg still exists then either switch ports or swap out the entire switch.

   These two processes will catch most PROFINET problems, with the exception of grounding/noise. When checking the different sections of the network, verify that proper grounding techniques were followed. However, if the cable tests fine, the switch switches, and the grounding checks out, it is time to pull out the oscilloscope and look at the waveform of both the Tx and Rx side. To see the signal, use a passive TAP that is rated for the network speed. See below for the ideal waveform for 100BaseT. The data is encoded into one of three voltages at a transmit rate of 125 MHz:

   - +1 V
   - 0 V
   - -1 V

   Viewing the signal:

   - use an oscilloscope with the following minimum requirements:
     - 200 MHz
     - digital
     - two channels
     - ability to subtract the two channels
     - DC coupling
   - channel one: Line Rx+ to ground
   - channel two: Line Rx- to ground
   - monitor 2-1

Repeat with the channels connected to Tx+ and Tx-.
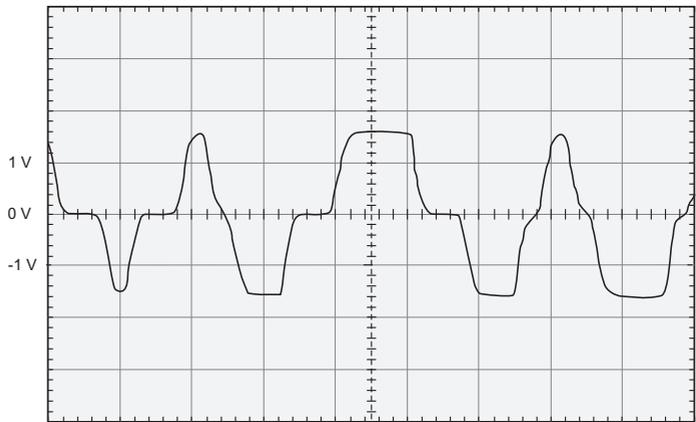
The waveform should have:

- positive and negative values about equal
- voltage difference should be about 2 V peak to peak
- square tops and bottoms
- no noise apparent

Reviewing the physical installation in PROFINET

At the end of commissioning a PROFINET network, be sure to set aside time for a full physically layer review. Using the Link Layer Discovery Protocol in the managed switches, have the diagnostic software produce a topology diagram of the network. Go through the network, testing out each cable, verifying that the cable and connectors are good and that the cable is not too long. Next use the Simple Network Management Protocol in your managed switches to verify that there are no lost/bad messages.

Destination BUS stop

We hope you have enjoyed your ride on this leg of the PROFIBUS and PROFINET road trip. We are happy to report your journey into the wonderful world of PROFIBUS and PROFINET for process automation has just begun!

The next stop that we recommend is for you to do a small system and get some hands-on experience. The PROFIBUS and PROFINET world is well populated with many resources and we recommend you explore them. Appendix C provides an extensive list but the available resources grow daily, so explore and enjoy!

Appendix A: Acronyms

Term	Meaning
AIFB	Analog Input Function Block
AMS	Asset Management Software
CC-A	Conformance class A
CC-B	Conformance class B
CC-C	Conformance class C
CIR	Configuration in Run
DB-9	9-pin connector used for PROFIBUS DP
DCS	Distributed Control System
DCP	Discovery and Configuration Protocol
DD	Device Description (short form term for EDD)
DHCP	Dynamic Host Configuration Protocol
DP/PA Link	PROFIBUS DP to PROFIBUS PA Link
DP-V0	First version of the PROFIBUS specification
DP-V1	First addition to the PROFIBUS specification – added functions for Process Automation
DP-V2	Third Version of the PROFIBUS specification – added functions for Drive Systems
DTM	Device Type Manager
EDD	Electronic Device Description
EDDL	Electronic Device Description Language
FB	Function Block
FDT	Field Device Tool
FDI	Field Device Integration
FF	Foundation Fieldbus
Fieldcare	Endress & Hauser's Field Device Tool
FISCO	Fieldbus Intrinsically Safe Concept
FNICO	Fieldbus Non-Incendive Concept
GSD	General System Data
HART	Highway Addressable Remote Transducer
HCF	HART Communication Foundation
HMI	Human Machine Interface
HSE	High Speed Ethernet
I/O	Input / Output
IE/PB Link	Industrial Ethernet to PROFIBUS Link
IEC	International Electrical Congress
IEC-61158-2	PROFIBUS PA and FF physical layer
IP	Internet Protocol

I&M	Identification and Maintenance functions
IRT	Isochronous Real-Time
IS	Intrinsically Safe
ISA	Instrumentation, Systems, and Automation Society
IT	Information Technology
LAS	Link Active Scheduler
LLDP	Link Layer Discovery Protocol
M12	Screw in connector for PROFIBUS and PROFINET
MBP	Manchester encoded, Bus Powered
MBP-IS	Manchester encoded, Bus Powered - Intrinsically Safe
MAC ID	Media Access Control Identification
NIC	Network Interface Card
OLM	Optical Link Module
OPC	Object linking and embedding for Process Control
OPC-UA	Object linking and embedding for Process Control Unified Architecture
OS	Operator Station
PACTware	Open Field Device Tool
PCS7	Process Control System 7 (Siemens Distributed Control System)
PDM	Process Device Manager
PI	PROFIBUS and PROFINET International
PID	Proportional Integral Derivative
PLC	Programmable Logic Controller
PROFIBUS	PROcess Field BUS
PROFIBUS DP	PROFIBUS Decentralized Peripheral
PROFIBUS PA	PROFIBUS Process Automation
PV	Process Variable
RIO	Remote Input Output
RS-485	Recommended Standard
RS-485 IS	Form of RS-485 that is Intrinsically safe
RT	Real Time
S7-300	Medium size Siemens Programmable Logic Controller
S7-400	Large Programmable Logic Controller
SNMP	Simple Network Management Protocol
SV	Secondary Variable
TB	Transducer Block
TCO	Total Cost of Ownership
XML	Extensible Markup Language

Appendix B: Definitions

Acyclic Data – data read over the acyclic communication channel, and this data could take several bus scans to be read. The total amount of time that this process takes is random and therefore acyclic.

Baud Rate – the speed of the network in bits per second.

Class 1 Master – a type of device on a PROFIBUS network and the traditional master in process control systems. Refers to a Distributed Control System (DCS) or Programmable Logic Controller (PLC).

Class 2 Master – a type of device on a PROFIBUS network and the traditional engineering work station. An example of a class 2 master is SIMATIC PDM.

Cyclic Data – data that is read in every bus scan. It's the input and output data used for control and is time sensitive.

Deterministic – the knowledge that something is going to occur with a fixed time period. This is a requirement of advanced control systems.

EDD – the Electronic Device Description is a collection of text files describing all the acyclic data in a field device and how to read and write them. EDDs are used by configuration software such as SIMATIC PDM to configure field instruments.

EDDL – Electronic Device Description Language is the language that EDDs are written in. EDDL is an international standard defined in IEC 61804-2 and IEC 61804-3.

Ethernet – Ethernet is a type of physical layer defined in the IEEE 802.3 standard used for communications in a local area network.

FDT – Field Device Tool is standard program interface (software) for configuring field devices. FDT uses Device Type Managers to program field devices. FDT software is an alternative to EDD based software such as SIMATIC PDM.

FDI – Field Device Integration is the evolution of FDT and EDD technology. It is for configuration of field devices and is based on OPC-UA (Object Linking and Embedding for Process Control – Unified Architecture) and EDD technology.

FF – Foundation Fieldbus is a digital protocol used to configure and troubleshoot field instruments.

FISCO – Fieldbus Intrinsic Safe Concept. A standard that makes it easy to place FISCO approved instruments into zone 0 and above environments.

FNICO – Fieldbus Non-Incendive Concept. A similar standard to FISCO. It is makes it easy to place FISCO approved instruments into zone 2 environments.

Full-duplex – Full-duplex refers to a communication link that is bi-directional allowing for both devices to talk and listen at the same time.

GSD – General System Data (or Generic Slave Description) is a text file in PROFIBUS and a XML file in PROFINET defining all the protocol information and cyclic data of a field device. It is used by the network configuration software to identify the slave and to set up the data exchanged between the master and the slave during cyclic data exchange. GSD was also originally the German acronym for Gerätestammdaten.

Gateway – A gateway is a device that joins two different networks together. For example, to connect a Modbus device to a PROFIBUS network, a Profibus to Modbus gateway is needed.

HART – Highway Addressable Remote Transducer is an industrial protocol used to configure and troubleshoot field instruments. It is often considered a transition between the 4–20mA technology and full digital technology since it uses both.

IEC – International Electrical Congress is an international standards organization committed to creating and maintaining international and open standards for use in the electrical industries.

I/O-Controller – A type of device on a PROFNET network and the traditional master in process control systems. Refers to a Distributed Control System (DCS) or Programmable Logic Controller (PLC).

I/O-Device – A type of device on PROFINET that provides input data or realizes output data into the real world.

I/O-Supervisor – A type of device on a PROFINET network and the traditional engineering work station. An example is SIMATIC PDM.

ISA – Instrumentation, Systems, and Automation Society is a world wide organization that develops standards, certifies industry professionals, provides education and training, publishes books and technical articles, and hosts conferences and exhibitions.

Interchangeability – The ability to switch from one vendor's device to another vendor's similar device. Interchangeability is a key benefit of PROFIBUS Profile standard.

Intrinsically Safe – An intrinsically safe device keeps the voltage and current low enough so that it cannot generate a spark of sufficient energy to ignite the gas/particles in the atmosphere making it safe for use.

Interoperability – The ability to connect different devices from different

manufacturers on the same network and have them work correctly. This is a core strength of PROFIBUS.

Managed Switch – A type of switch that provides additional advanced diagnostics.

Master – A type of device on PROFIBUS that controls communication to slave devices. One PROFIBUS network can have several Masters on it, and they share communications by using a token ring protocol.

MBP – Manchester encoded Bus Powered. This is the physical layer defined in IEC-61158-2 that is used for PROFIBUS PA

MBP-IS – This is the same physical layer as MBP, with the addition of power limiters on the power supply so that the power draws will not exceed those defined for intrinsically safe operation.

Modem – This is a device that translates a signal from one transmission technology to another. For example an optical modem converts an electrical signal into light and then back again.

Physical Layer – Refers to medium used to get the ones and zeros from point A to point B. This layer of the protocol is all about wires and voltage and current levels.

PROFIBUS – Process Fieldbus. Automation communication protocol designed to meet all industrial and process communication needs.

PROFIBUS DP – DP stands for Decentralized Peripheral and was designed for remote input output devices. This forms the core protocol of PROFIBUS. If PROFIBUS were a book, it would be called PROFIBUS DP.

PROFIdrive – A chapter in the PROFIBUS book or PROFINET book that adds functions to the core protocol for high speed drive applications.

PROFIsafe – A chapter in the PROFIBUS book or PROFINET book that adds functions to the core protocol for safety applications.

PROFIBUS PA – A chapter in the PROFIBUS book or PROFINET book that adds functions to the core protocol for process control applications. PA refers to Process Automation.

PROFINET – A second book by the same authors as PROFIBUS. PROFINET is an Ethernet based protocol that makes use of many sections of the PROFIBUS protocol and make optimal use of Ethernet.

Profile – A profile is a standardization of a field device from the bus point of view. It defines the output and the core device parameters.

Protocol – Refers to a set of rules. In industrial communications, it simply refers to a set of rules defining how something is done. For example, how to get information from point A to point B. Since one set of rules can be

made up of many different sets of rules, one protocol can be made up of different sub-protocols.

Proxy – A type of gateway defined in PROFINET which, aside from joining two networks together, also defines how the date is set as well. Think of it as a very easy-to-use gateway.

Slave – A type of device on PROFIBUS that will only talk on the network after a Master device has requested information.

Switch – A device that directs the traffic on an Ethernet network. It reads the incoming packet and directs it to the correct port where the target device is located.

TCO – Total Cost of Ownership is a financial term used in asset management referring to all the costs associated with ownership. In process automation, it is the sum of the cost of the device plus the cost of commissioning plus the cost of maintaining the device.

Token Ring – A type of protocol using a virtual token that is passed from master to master. The master can only talk on the bus when it has the token. When it is has finished talking on the bus, the master passes the token onto another master.

Appendix C: Additional Resources

There are many resources available to learn more about PROFIBUS and PROFINET. Here are some of them:

Internet:

The key website for information on PROFIBUS and PROFINET is www.profibus.com or www.profinet.com (both addresses take you to the same website). For English speakers, www.us.profibus.com (or www.us.profinet.com as both addresses take you to the same website) is also an excellent site.It should be noted that there is also a considerable amount of misinformation about PROFIBUS and PROFINET on the internet. It is best to stick to known sites like these two.

Training

PROFIBUS and PROFINET International (PI) have a network of certified training centers all around the world. These are all excellent courses. The official website (www.profibus.com or www.profinet.com) has links to them.

In addition, there are many non-certified training courses available. These tend to be offered by large companies like Siemens or by independent training companies. When investigating a non-certified course, check for references and also verify that the trainers are certified by PI.

Printed material

PI publishes the following guides that have been referenced a number of time in this book. They are available for download from www.profibus.com and www.profinet.com or they can also be ordered:

PROFIBUS Planning. PI, Order # 8.012

PROFIBUS Recommendation for Cabling and Assembly. PI Order # 8.022

PROFIBUS Installation Recommendation for Commissioning. PI,Order # 8.032

PROFINET Design Guidelines, PI Order # 8.062

PROFINET Guidelines for Cabling and Interconnection Technology, PI Order # 2.252

PROFINET Guidelines for Commissioning, PI Order # 8.082

ISA publishes the following, also an introductory level book but aimed at a higher technical skill level. This is an excellent book to read next, and it provides far more information about the details of the protocol.

Mitchell, Ronald W. *PROFIBUS A pocket Guide*. 2004 ISA, ISBN 1-55617-862-X.

For those who want to learn a lot about PROFIBUS and how it works, the following two books provide in-depth knowledge:

Popp, Manfred. *The New Rapid Way to PROFIBUS DP from DP-V0 to DP-V2*. PI Order No.:4.072.

Diedrich, Ch. and Th. Bangemann. *PROFIBUS PA Instrumentation Technology for the Process Industry.* ISBN-13: 978-3-8356-3125-0.

For those who want to learn a lot about PROFINET and how it works, the following book provides in-depth knowledge:

Popp, Manfred. *Industrial communications with PROFINET,* PI Order No.:4.182.

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Catching the Process Fieldbus
An Introduction to PROFIBUS and PROFINET

"This book is a must read if you want to get started with PROFIBUS or PROFINET. Just the right balance between theory and real life experience!"
Karsten Schneider
Chairman of PROFIBUS and PROFINET International

"The second edition of this classic work adds valuable information about PROFINET's role in process automation, supplementing the widely-used PROFIBUS protocol. With some theory and a lot of practical experience presented, this book is THE place to start learning about PROFIBUS and PROFINET for process.

Carl Henning, Deputy Director, PI North America