TECHNICAL WHITE PAPER

ADVANCED ONLINE PHYSICAL LAYER DIAGNOSTICS

The benefits seen when using Foundation Fieldbus™ or Profibus PA™ **advanced online physical layer diagnostics** to test and continuously monitor the network's communication quality, cable infrastructure, fieldbus power supplies, terminators, devices and segment protection electronics. Failure descriptions, causes and effects are described. A case study shows a comparison of work times required between 4-20 mA, fieldbus and fieldbus with diagnostics.

Prepared by:

Gunther Rogoll
Senior Manager Fieldbus Infrastructure
Ren Kitchener
Fieldbus Specialist Fieldbus Infrastructure

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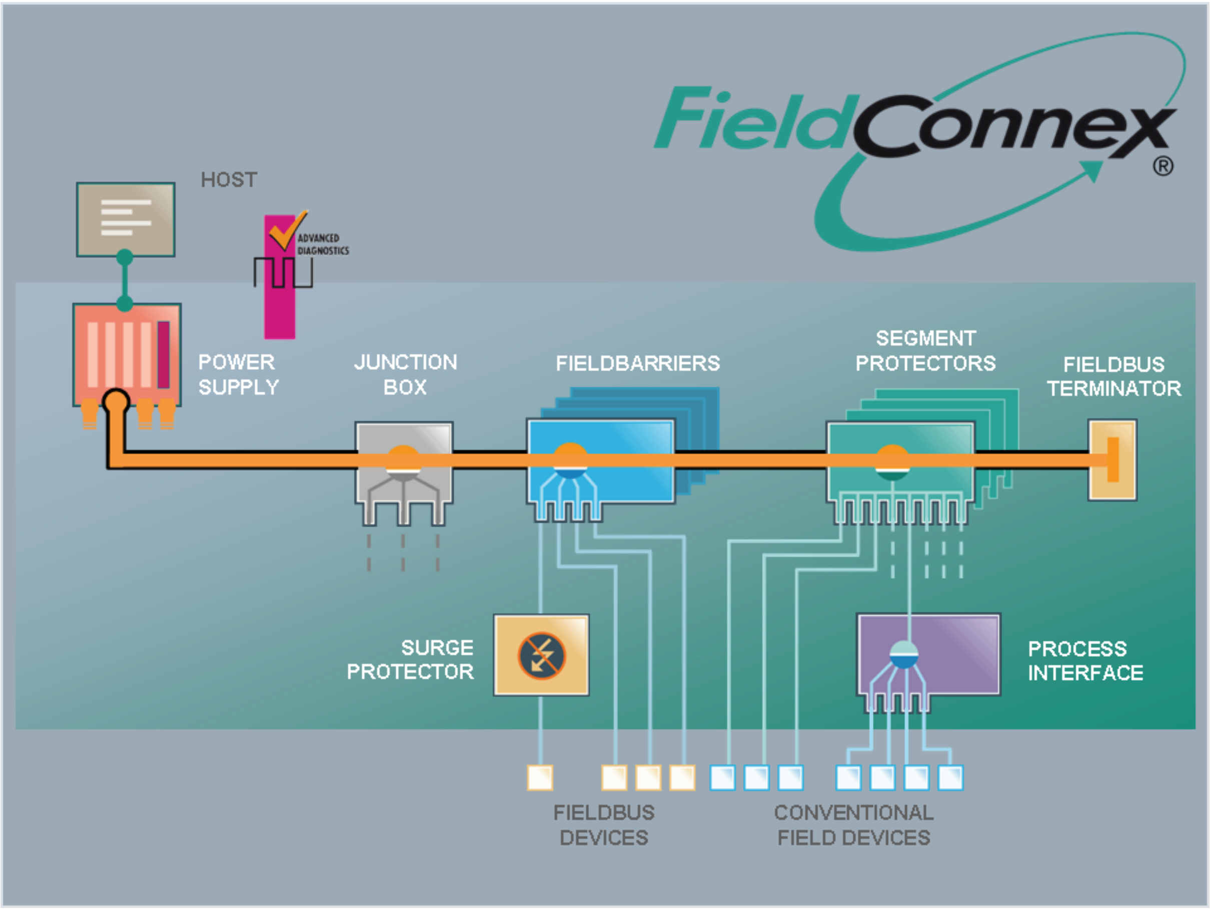

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1 Abstract

This paper covers the range of significant benefits, and describes reasons for the increased confidence in new technology, provided by advanced physical layer diagnostic equipment when applied to Foundation Fieldbus™ or Profibus PA™ fieldbus networks. Advanced physical layer diagnostics monitor the communication, cable infrastructure, fieldbus power supplies, terminators, devices and protection electronics, otherwise referred to as the physical layer. The paper also goes on to explain how the integration of physical layer diagnostics to every fieldbus segment can in fact reduce CAPEX & OPEX when used across the project lifecycle. Additionally, failure prevention or proactive maintenance is a key feature of any diagnostic system, and this paper considers the differences between basic physical layer diagnostics and advanced physical layer diagnostics.

2 Introduction

Classic 4-20 mA control and instrumentation systems have been the mainstay of countless production plants around the world for many decades. Whilst the reliability of 4-20 mA loops are acceptable, failures regularly occur, and many of the faults encountered on 4-20 mA loops cannot be detected or are not discernible; for example, a cable junction box could be filling with water and the shunted current drawn across the immersed terminals will result in an erroneous reading which will have repercussions on the plant's performance.

There are countless other faults that can occur, and many of them would be preventable if only the onset characteristics of the fault could be detected in good time. Unfortunately, to place automatic test equipment, sophisticated enough to provide such an early warning, to every 4-20 mA loop would cost more than the instruments they would be monitoring, so this option would always be discounted in view of cost and complexity.

Traditionally, the attention applied to the 4-20 mA cable systems and instruments during the construction and commissioning phases will involve manually operated test equipment or loop testers used by highly qualified engineers in a reactionary way – if a fault is discovered, a repair is made. Under 'time pressure', many loops may be left unchecked or not fully assessed for less obvious (but tolerated) faults that could cause problems later down the line during operation.

Bearing this in mind, and setting cost aside for the time being, it would be advantageous if automatic test equipment, providing computer generated sign-offs, could be attached to every 4-20 mA loop and operated at the 'touch of a button'. Taking this a stage further; it would be even more desirable if the same automatic test equipment could be left in place to continue monitoring the health of each 4-20 mA loop during the plant's operational lifetime.

With the introduction of fieldbus, with it's more robust digital communication when compared to 4-20 mA, we now find that one fieldbus trunk cable will service up to 32 fieldbus instruments. So, the option of attaching, and retaining, advanced automatic diagnostic test equipment on every trunk would actually be a feasible and cost effective consideration – even to say that it could actually reduce construction and commissioning expenditure (CAPEX) as well as operational expenditure (OPEX). The cost reductions can be quite apparent when you consider the key features offered by automatic diagnostic test equipment to each phase of the project lifecycle:

Phase: Construction and commissioning

Rapidly, and thoroughly, test every network at the 'touch of a button'. Print off fully completed

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and accurate test reports as well as computer generated sign-off sheets.

Phase: Construction, commissioning and operation

Test each trunk for conformity or continual conformity to the fieldbus standard IEC61158-2. Automatically identify and report any failure or fault that could lead to a failure.

Phase: Operation

Always be connected and available and will continue automatically monitoring and reporting 24 hours a day, seven days a week, year on year.

To put the capital expenditure into perspective; the cost to install the new generation of advanced physical layer diagnostic systems that would be required to service one hundred fieldbus segments supporting approximately 1,200 field devices, would equate to the cost of one skilled instrument & electrical engineer for only three months - not considering the cost of the supporting test equipment expenditure

Of course fieldbus reduces the ‘density’ of the field wiring, but if things do go wrong, the control system can lose sight of multiple devices and many control loops in one instance. So, the design, construction and proactive maintenance of a robust fieldbus network, will be a very important consideration.

3 Diagnostic Basics

The fieldbus types for the diagnostic systems described in this paper will consider Foundation Fieldbus™ and Profibus PA™

3.1 What is the physical layer?

The ‘physical layer’ is made up of; the trunk cable or main connecting cable and the spur cable or instrument connecting cable, terminals, terminators positioned each end of the trunk cable, fieldbus power supplies, device interface hardware, fault protection equipment (Segment Protectors etc) as well as the fieldbus communication physics (the signal etc).

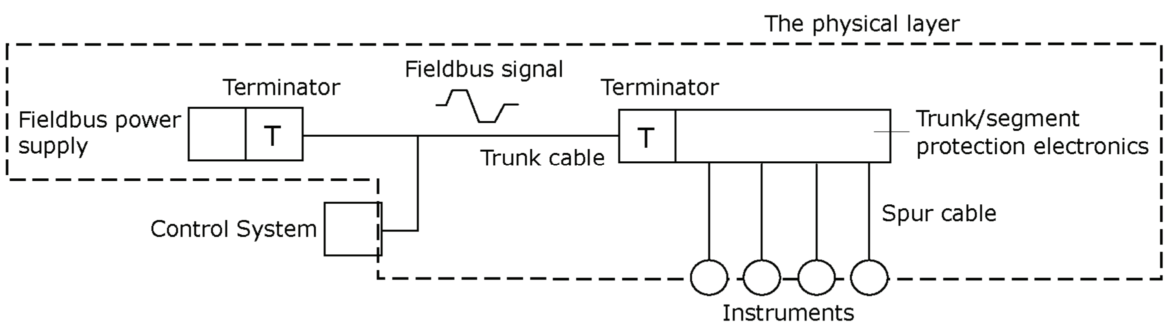

Fig. 2-1: The physical layer

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3.2 What are physical layer diagnostics?

Physical layer diagnostics is simply a piece of test equipment, that is connected to each fieldbus network via the trunk cable, which is able to continuously test, monitor and diagnose the entire network for physical component degradation, deviations that can lead to a fault, or a total segment failure. It will also confirm the network's compliance or continuing compliance with IEC61158-2, the fieldbus standard, strict design rules.

Physical layer diagnostics tools

Fig. 3-1 illustrates a typical on-line diagnostic system. Many different versions of fieldbus test equipment are gradually being introduced on to the market with varying degrees of price and performance.

The summary below describes the product range in basic terms:

Simple hand held devices:

Handheld physical layer diagnostic testers for rudimentary failure troubleshooting and offline testing.

Basic online devices:

Basic online physical layer diagnostic systems for rudimentary failure detection where they can be used for commissioning and kept in place for operational failure detection and alarm.

Mobile advanced devices:

Mobile advanced physical layer diagnostic systems used for advanced testing where the control system and associated fieldbus power supplies have not yet been made available for commissioning or for detailed operational failure troubleshooting.

Advanced online devices:

Online advanced devices are used for construction, commissioning and operational testing, fault finding, user defined reporting/documentation and early fault warning. Online systems are permanently connected to every segment and kept in place throughout the project lifecycle.

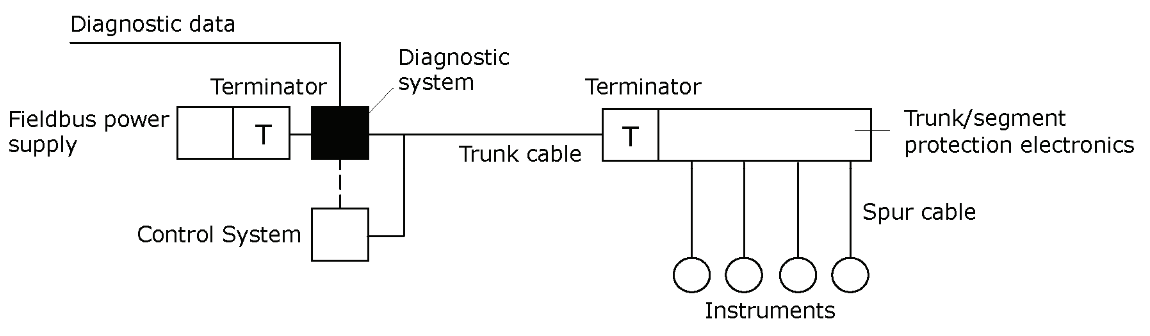

Fig. 3-1: Physical layer diagnostics

3.3 The evolution of diagnostics

Going back in time, primitive diagnostic coverage had been available in the form of instrument elevated zero outputs, simple I/O health checks and so on. The introduction of HART, certainly brought new benefits with its superior instrument and process diagnostics. However, HART devices have only limited diagnostic capability due to the restrictive bandwidth or processing 'power'. The introduction of fieldbus has accelerated the use of more sophisticated sensor and process diagnostics and recently, with the introduction of advanced physical layer diagnostics, the entire system can now be extensively monitored not only for failures, but also for a wider range of evolving failures.

Why are advanced physical layer diagnostics more beneficial

You could be lead to believe that physical layer diagnostics simply comprises a volt meter and a signal amplitude/noise analyzer connected to the trunk with an alarm warning feature. However, experience and extensive research has shown that the more measurement types taken and analyzed, the better the detection of a wider range of evolving faults will be. For example, changes in noise levels or signal levels cannot disclose the effects of power supply impedance drift or terminator capacitor drift – instead, jitter measurement is utilized to detect the minute changes caused by such evolving failures. See also 'jitter measurement explanation'. Furthermore, a greater breadth of diagnostic functions will lead to a more comprehensive reporting structure and reveal potential issues which may manifest themselves during plant operation.

Advanced physical layer diagnostics provides many more AC and DC measurements for analysis, and Fig. 3-3 shows the wider coverage of advanced physical layer diagnostic measurement types compared to those provided by basic physical layer diagnostics:

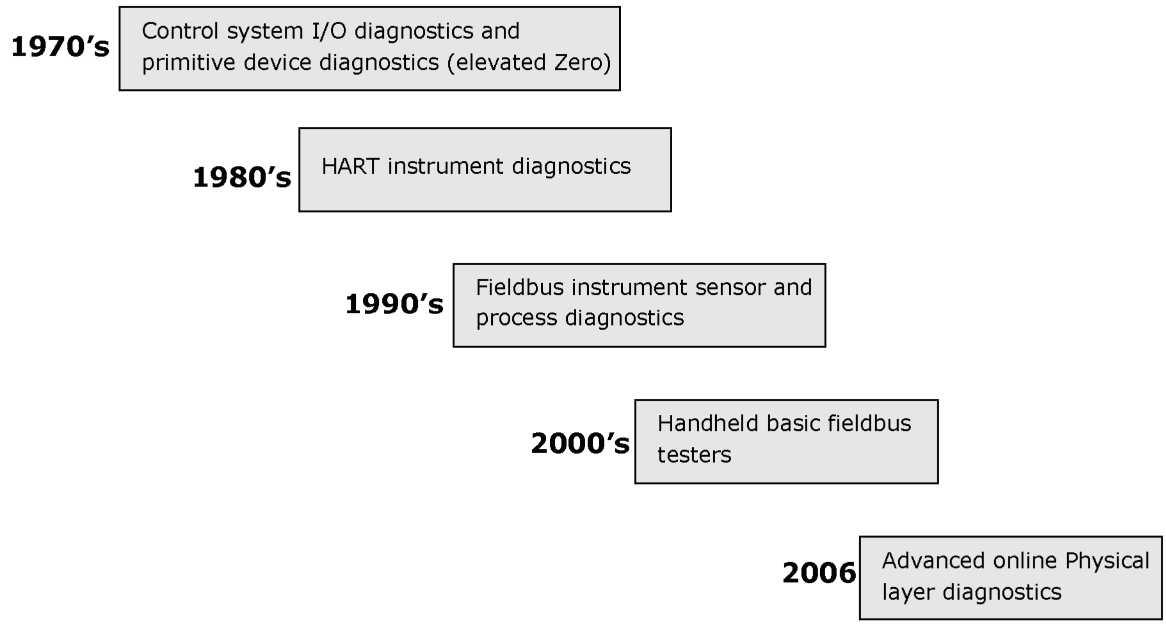

Fig. 3-2: Evolution of diagnostics

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The importance and limitations of online advanced physical layer diagnostics during operation

For any system, downtime failures can affect production, product quality and on rare occasions, lead to an environmental catastrophe or an unsafe situation. Therefore, early warning of a pending failure is the essence behind proactive maintenance and failure evasion - for fieldbus, this is an extremely important task to implement in view of the number of devices and control loops supported on one segment – and one that can be done cost effectively.

The primary goal of the diagnostic system is to monitor and announce small changes or characteristics of a developing fault long before it becomes destructive so that it can be repaired or rectified. This goal will also include the physical layer compliance and continuing compliance with the appropriate standards. Applying online advanced physical layer diagnostics, combined with existing diagnostic capabilities, will provide an indication of many developing faults. Being online, and on every line, means that a fault, intermittent fault or evolving fault can be picked up immediately at any time and on any segment or on any part of the segment. The time stamp is important because many failures or propagating failures can be random and/or intermittent or linked to an external event.

Diagnostic systems alone will not guarantee high reliability. There are the obvious faults that can occur, where the diagnostic warnings will be of little preventative use, for example, a direct trunk short or open circuit caused by someone cutting through the trunk cable or a bad network design resulting in too little voltage getting through to the instruments. Whilst these fault types are undesirable, there are protective measures that can be put in place to protect the network from such failures. With careful consideration to the common points of failure i.e. trunk cable and terminals, terminators, power supplies, then mechanical and/or electronic protection can be applied to those areas to great effect and therefore reduce the probability of these types of failure to a very low level – or even eliminate the risk altogether.

The other significant advantage with online equipment is that at no time during monitoring, troubleshooting, testing, or validation would you need to retrieve and refer to wiring diagrams. Track down terminals points to connect test or diagnosis equipment to. Disturb control room cabinet wring or patch cable. Have to go on site and open up junction boxes until a specifically pinpointed repair is required. Therefore, the potential to introduce errors are minimized and the time taken for troubleshooting is dramatically reduced.

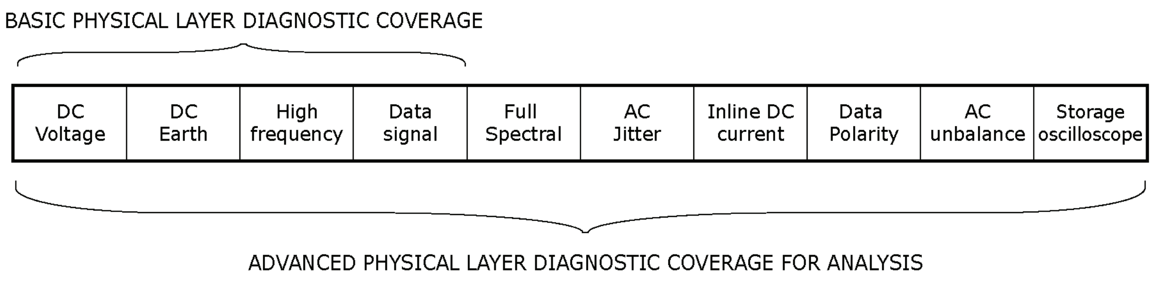

Fig. 3-3: Basic and advanced physical layer diagnostic coverage

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The disadvantage of using 'offline' handheld fieldbus testers

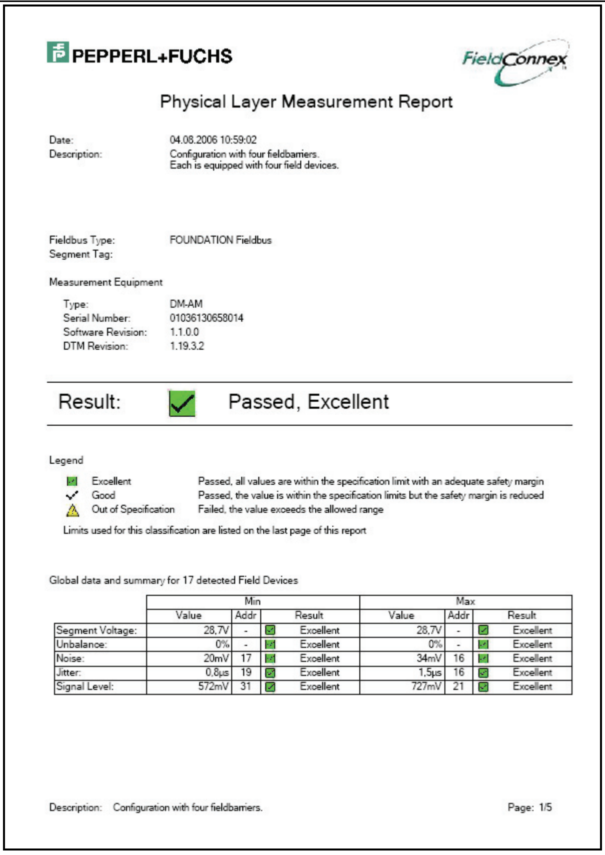
Handheld fieldbus testers are only utilized for reactive troubleshooting whenever there is a segment failure (when it's too late) or whenever the control system has announced that data has been corrupted in the form of a reported data retransmission record.

Data retransmissions will affect the control loop bandwidth, and in some cases, multiple re-transmissions will cause the control system to instigate a segment shutdown or force a loop to manual operation.

The retransmission corruption is in fact a failure, and therefore, any indication of a potential data corruption must be picked up long before a data retransmission is allowed to occur. This is not a simple task, and to cover it effectively requires highly advanced online diagnostic measurements and analytical software.

4 Diagnostic information and reporting

As stated earlier, a greater breadth of diagnostic functions will lead to a more comprehensive reporting structure. Although the measurement types may be extremely complex in themselves, the information delivered must be tailored to the recipient skill level; an operator may observe a rudimentary diagnostic warning, and must be able to act upon it appropriately i.e. the operator may decide from the information provided to call the maintenance engineer for immediate attention, or the operator may decide to schedule the repair for the next shift or even during a scheduled shutdown. On the other hand, the information provided will be more detailed, specifically designed for extensive troubleshooting by an 'expert' maintenance engineer or even a remote 'expert' engineer.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Physical Layer Measurement Report

Date: 04.08.2006 10:59:02
Description: Configuration with four fieldbarriers. Each is equipped with four field devices.

Fieldbus Type: FOUNDATION Fieldbus
Segment Tag:

Measurement Equipment
Type: DM-AM
Serial Number: 01036130658014
Software Revision: 1.1.0.0
DTM Revision: 1.19.3.2

Result: Passed, Excellent

Legend
Excellent — Passed, all values are within the specification limit with an adequate safety margin
Good — Passed, the value is within the specification limits but the safety margin is reduced
Out of Specification — Failed, the value exceeds the allowed range
Limits used for this classification are listed on the last page of this report

Global data and summary for 17 detected Field Devices

	Min			Max		
	Value	Addr	Result	Value	Addr	Result
Segment Voltage:	28,7V	-	Excellent	28,7V	-	Excellent
Unbalance:	0%	-	Excellent	0%	-	Excellent
Noise:	20mV	17	Excellent	34mV	16	Excellent
Jitter:	0,8µs	19	Excellent	1,5µs	16	Excellent
Signal Level:	572mV	31	Excellent	727mV	21	Excellent

Description: Configuration with four fieldbarriers. Page: 1/5

Fig. 4-1: Measurement Report

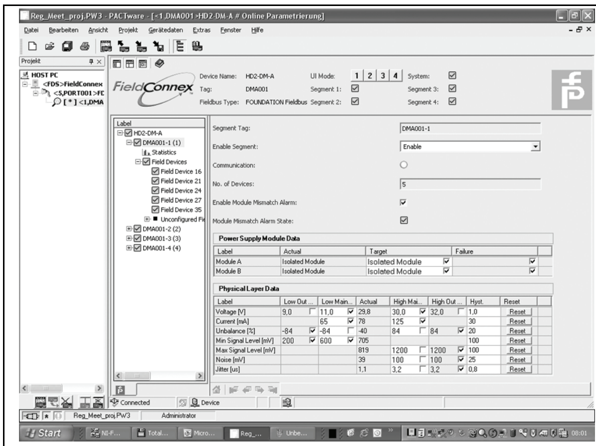

Fig. 4-2: Diagnostic summary

Good diagnostic measurements require good analytical software, which is generally too complex for handheld devices to implement. Furthermore, measurements sometimes have a relationship with other measurements, and to decode the relationship requires extremely sophisticated software analysis.

The information generated by the advanced mobile and online diagnostic module software must be able to serve many user skill levels:

The construction/commissioning engineer

The construction and/or commissioning engineer will need advanced information to assess and track down failures, dormant faults or tolerated faults that would have been missed during normal commission activity. On the other hand, to speed the process up for ‘fault free’ segments, all that will be required is simplified ‘pass/fail’ readouts together with a hard copy signoffs for the work carried out.

The operator

The operator will need general information about the health of a fieldbus segment. The operator’s needs are to be informed of any deviation from an initial defined health of the physical segment and to be able to assess the correct action to take, should a propagating failure be detected or announced. This could be a decision to call out a maintenance engineer immediately, place the loop into manual operation, request for maintenance at the next scheduled shutdown and so on.

The maintenance engineer

Maintenance will need full access to technical information in order to apply the right corrective action should a fault or propagating fault occur, be detected or be reported. They will also need summaries or conclusive reporting in order to quickly pinpoint the cause of the problem. Historic alarms will also be stored in the specific alarm management tool so that any reported failure can be traced back to the actual event time.

4.1 The failure trail

Obviously the diagnostics will not help prevent faults such as trunk short or open circuits should they occur. Nevertheless, the diagnostic software will have at least recorded the failure event and time as well as the data leading up to the failure event - in the same way that an aircraft’s ‘black box’ will work. Therefore, it will provide a useful time-stamped ‘failure trail’ that can be used to pinpoint who or what may have caused the failure or disaster more decisively and also be used to help implement measures to prevent the failure or disaster from reoccurring.

4.2 The fieldbus oscilloscope

The fieldbus oscilloscope bridges the gap between automatic diagnosis and manual troubleshooting where further in-depth information can be assessed by competent engineers from an inbuilt dedicated digital storage oscilloscope with a vast selection of fieldbus specific trigger point options.

An oscilloscope is by far the best tool for troubleshooting unusual or complex network faults, and integrating the oscilloscope within the diagnostic module has many advantages:

Fig. 4-3: Oscilloscope example with zoom capability, fieldbus specific trigger point options and digital storage.

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Valuable time saving during failure or downtime

Integrating an oscilloscope into the diagnostic module can save a great deal of downtime – time spent finding and reading the drawings, tracking down the correct terminals and connecting the test probes to the terminal points in the control room marshalling cabinets and so on.

Eliminated cable and junction box disturbance

Also, disturbance to the control room marshalling cabinet cable network, patch bays, or having to open field junction boxes to connect oscilloscopes, can lead to, or add, additional faults. Using an inbuilt online oscilloscope eliminates the need to disturb any hardware until a specific targeted repair is required.

A record also for remote use

The oscilloscope data can be recorded, in a very simple way, on the maintenance terminal. This way, a record can be found, and the information can also be sent to a remote expert for additional troubleshooting, again saving valuable time.

5 Advanced diagnostics infrastructure

The integration of advanced physical layer diagnostics into fieldbus power supplies

To further decrease cost, one online physical layer diagnostic module should be able to monitor several fieldbus segments at the same time. A good compromise between performance, device complexity and hardware cost, results in a single diagnostic module which manages four segments simultaneously. In order to minimize wiring efforts, the diagnostic module should be a part of the fieldbus power supply system or backplane.

Today's 'state of the art' fieldbus power supplies offer integrated advanced diagnostic modules, single segment power supplies (with optional redundancy) grouped on a backplane to keep the wiring and maintenance simple and the cost low. This configuration is gaining a great deal of customer interest and in the near future, the majority of fieldbus power supplies will be supplied with advanced physical layer diagnostics as standard.

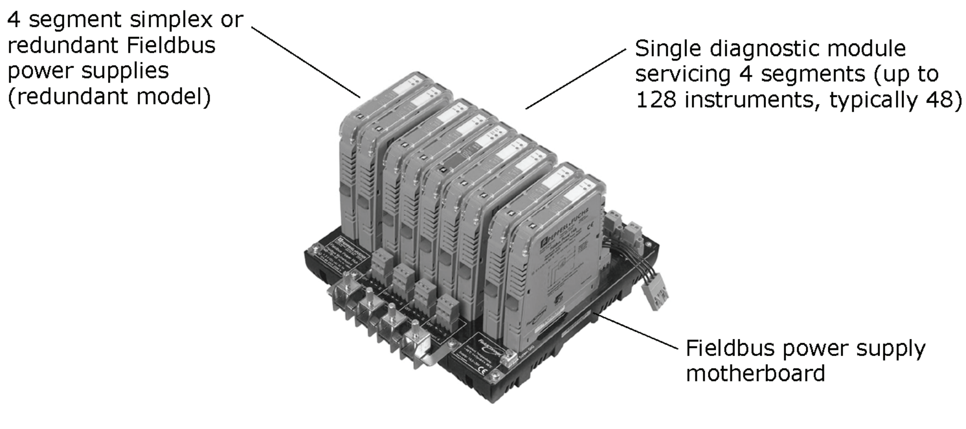

Fig. 4-4: Example, integration of advanced physical layer diagnostic into a fieldbus power supply

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5.1 Diagnostic information – integration into the system backbone

The information from the diagnostic hardware could be transferred through a dedicated diagnostic network or through the fieldbus itself. But the most effective way is to use a separate or dedicated network, where several diagnostic modules can be connected, through Ethernet, to the system backbone. Status information is handled by the operator station and full access is provided by the instrument management station.

Important consideration:

Transmitting the diagnostic information trough the fieldbus segments, the required additional host interfaces and power supplies will significantly increase the control system cost.

Also, the availability of the diagnostic information depends on the availability of the fieldbus segment through which the information is transferred. If a fatal error on a segment occurs, the diagnostic information can not be send to the host when it is needed the most.

Additionally, the communication bandwidth of an H1-fieldbus is not designed to send the

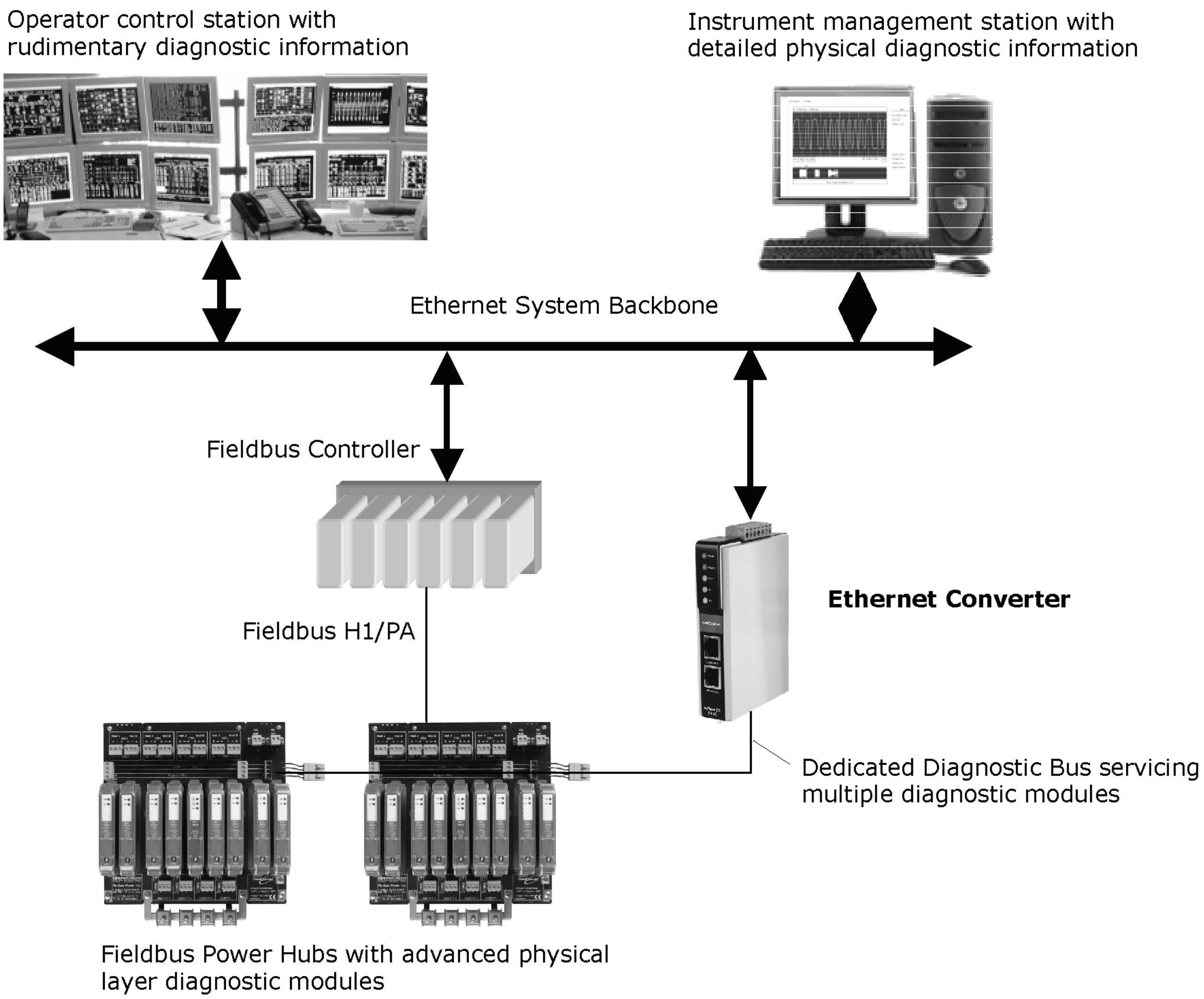

Fig. 5-1: Advanced physical layer diagnostic infrastructure

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amount of data which is necessary to adequately analyze the physics of a fieldbus segment.

Therefore, routing the diagnostic data through an autonomous digital cable is the only reliable, efficient and cost effective approach to take.

6 Failure cause, effect and detection

Potential causes of failures and their effect

Without doubt, a well designed and maintained fieldbus segment will operate without any problems for many years. Nevertheless, like any electronic system, failures are bound to occur on some segments at some point in their operational lifetime.

Fieldbus failures can develop or occur at any time without warning. Failures or faults can range from an insignificant change, to a nuisance alarm or a fatal crash.

This next section will cover the details of a wide range of failure types – not just the obvious textbook faults covered by basic fault finding. It must also be remembered that many of the failures covered below could also apply to classic 4-20 mA systems:

Pole-to-shield faults (Unbalance)

A cable pole, either negative or positive, may directly create a low resistance contact to the shield. This is a common fault, set up usually when cable ends are being drawn through the instrument housing, or when a cable has been fractured during construction. However, not all faults are direct short circuits or low resistive contacts – they may be capacitive or be of high resistance: A cable may have unacceptable capacitive unbalance due to poor installation or manufacturing deficiencies, which is further compounded by device unbalance, or the cable may have water ingress that will exhibit a low conductivity from the beginning. Although these types of faults can be tolerated, a subsequent or compound fault will normally lead to a failure - for example, one pole may have a capacitive short fault to ground and the other pole may be shorted directly to the cable shield. Unbalance will increase the sensitivity to noise and therefore increase the probability of communication errors.

Pole-to-pole faults

Just as a pole to shield fault is a possible fault scenario, then a pole to pole fault also has an equal likelihood of occurring. A direct low resistance short circuit on a trunk is a fault that cannot be tolerated, and the segment will fail. Once again, not all faults are direct short circuits, and some could be resistive for example, device filter capacitors or over voltage protection semiconductors could be leaking, cable or junction box could be filled with water and so on.

Crosstalk, noise and interference

Noise comes in many forms and can span the entire frequency spectrum. Noise can be picked up from nearby variable frequency drives, or the cable itself can be subject to vibration. Noise can also be induced by electromagnetic interference or picked up from neighboring cable as crosstalk.

Earth loops and earthbound noise are another form of low and high frequency noise that can be transmitted through the cable shield which is then picked up by the trunk and spur cable. In fact, earth faults are often considered the worst enemy to signal quality and are often the source of many problems.

The fieldbus standard sets limits to the permitted noise levels across the entire frequency spectrum from DC up to tens of Megahertz, and the most destructive noise lies within the communication bandwidth where the levels are not allowed to exceed 75mV peak to peak.

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Terminator faults

Simple terminators are considered common points of failure - even with redundant power supplies with so called electronic ‘redundant terminators’, there will always be a single or simplex terminator on the field side of the trunk.

Terminators fail due to the resistor breaking to an open circuit causing the loss of termination, or in some cases failing to a low resistance causing severe signal distortion. Capacitors can fail in a manner of ways: Open circuit leading to loss of termination, short circuit leading to a fatal segment crash or component destruction or drift to a low capacitance, as well as failing to a resistive or conductive state leading to gradual loss of the terminator.

Redundant electronic terminators and automatic terminators are prone to operation failure due to complex electronic sensing and switching components. Automatic terminators could deactivate at inconvenient points along a segment, leaving long lengths of free un-terminated trunks.

NOTE: The redundant terminators are not redundant in the strict sense, but a failure of any single component, in any way will not lead to a fatal crash in comparison to a simplex terminator. Instead it will cause a slight tolerable change in the network impedance which will be picked up by the advanced diagnostic module so that a repair can be made or scheduled.

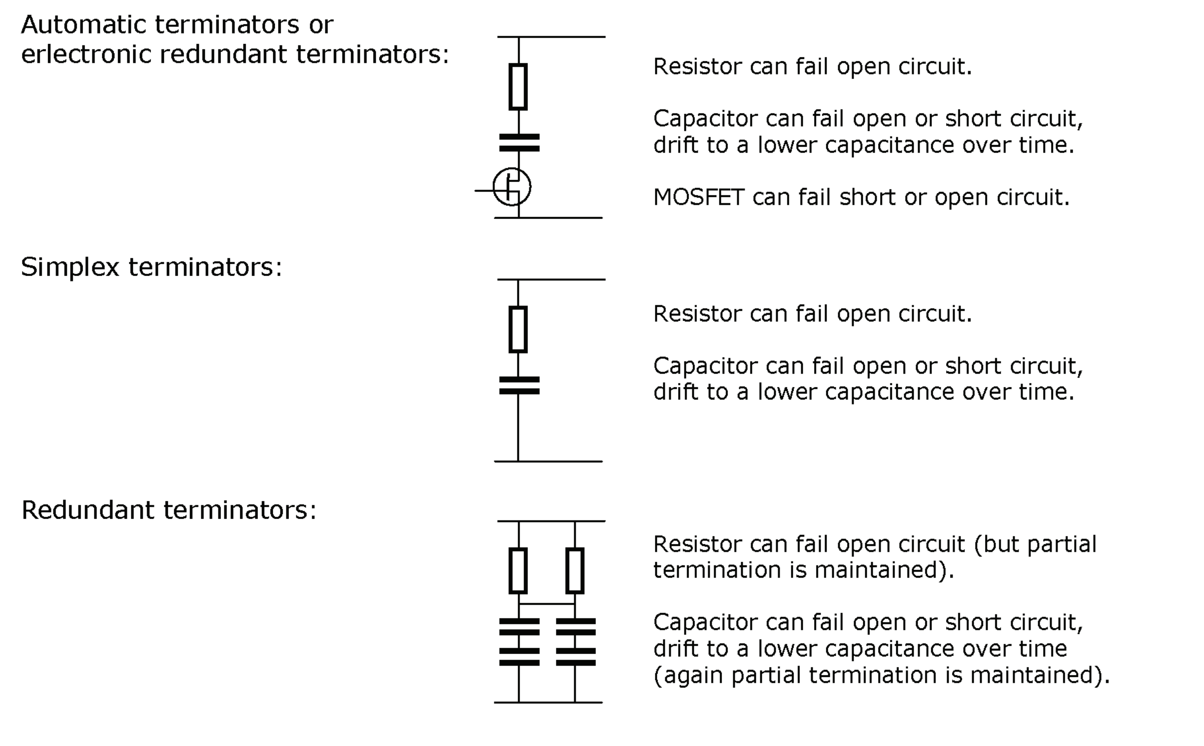

Fig. 6-1: Different implementations of fieldbus terminators

Over/under termination

A system can tolerate a degree of over or under termination depending on the network configuration and the signal quality to start with. Other influencing factors involve the quality of the fieldbus power supply/power conditioners and the device loading.

A failed or missing terminator at the end of a long trunk cable will always leave the cable open to signal reflections and it will create signal distortion. Even though a laboratory test can demonstrate that this can be tolerated with short lengths of cable, in the field and in real life, it can be a very different story.

Power supply drift or impedance failure

Passive impedance of fieldbus power supplies is set by fixed, robust, passive power inductors so impedance change is impossible. On the other hand, the impedance of active fieldbus power supplies depends on capacitors and transistors, and these components can drift over time or fail even when power supplies are arranged as a redundant pair.

Impedance drift or failure of active fieldbus power supplies will not always lead to signal attenuation. What will usually happen is that the signal tops will 'droop' or 'rise' depending on whether it's too capacitive or too inductive:

Drooping or rising signals can lead to 'jitter errors' at first, and then they can lead on to multiple data retransmissions before a fatal error occurs. (See Fig. 6-2)

Water ingress

Water ingress within the cable or around terminals across two poles, caused by gland failure, junction box seal failures or split/fractured/porous cables, will not induce noise. Instead, it will conduct electricity resulting in a measurable increase or change in trunk current or earth leakage.

In fact, water ingress is more complex than just treating it as a conductive path, and it can actually do nothing - take condensation for example, in its purest form, water has no conductivity. It's only when conductive impurities are added or dissolved, then the water will conduct. As soon as conductivity is established, pole to pole faults will immediately suffer from galvanic corrosion where the terminals and cable can be completely 'dissolved' within days.

Device failures

Many devices have FDE – fault disconnection electronics. The idea of FDE is that if destructive 'jabber' is detected, then the device is automatically disconnected from the segment. However, not all device failures can be prevented - the device impedance can drift to a destructive level long before a segment or spur protector can operate effectively. Many devices have a diode bridge network to allow bipolar connection to the trunk. These bridges can also fail to low impedance, or they can fail short circuit.

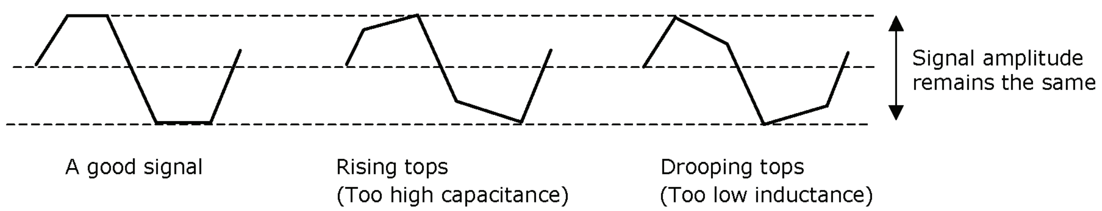

Fig. 6-2: Impedance effects on communication signal forms

Transient voltage suppression (TVS) and surge arrestors

Surge arrestors or transient voltage suppressors are always utilized within power supplies, spur protection and devices to prevent high voltage surges from destroying or damaging sensitive internal electronic components.

Although surge arrestors or TVS's (protection diodes) can prevent many high voltage spikes from destroying devices or components, they are in fact a common point of failure themselves. The TVS, which are connected directly across the trunk, can drift or leak or they can effectively fail to short circuit, which is the common failure mode for such devices. TVS diodes are inactive under no electrical or thermal stress during normal operation and so they should last indefinitely. But they can be weakened after a high voltage surge, and this often results in an increase in current leakage or a problematic impedance change.

Device noise filter capacitors

Devices, power supplies and protection circuits commonly use small capacitors for noise filtering. They are arranged across the poles, and from pole to shield:

Because there are many devices attached to a single segment, then the number of failure points will be proportionally high (12 devices = 36 capacitors). The capacitors can fail open circuit, short circuit and can drift to a lower capacitance with differing effects, where some can be destructive or if left unattended, they could lead to a compound failure.

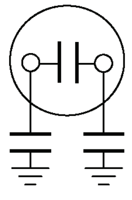

Fig. 6-3: Noise filter arrangement

Signal polarity inversion

Many devices are bipolar, means they can be connected in any polarity to a fieldbus segment. However, a few devices, power supplies or repeaters are not bi-polar, and they have the potential to be accidentally cross-wired. This will invert the data signal, which in some cases can be tolerated by the system, but intercommunication between devices will fail. If devices during construction and commissioning are cross wired, many of the faults would not be picked up until operation commences.

Power supply health and failure

The fieldbus power output voltage could fall to unacceptable limits over time. Even with redundant power supplies, the voltages can fall due to a combination of failures i.e. the OR diode fails short circuit, and one of the power supply outputs falls to a lower voltage, at a low impedance. For redundant power supplies, any one of the two power supplies could fail, where a replacement will be required on an urgent basis.

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6.1 Detection of failures by the advanced measurement techniques

Having considered the failure types, it can be seen that a vast range of measurement techniques will be required if an early warning of any potential failure is to be detected in good time and for extensive fault detection.

This next section will cover the measurement types and how they are used to assess a fault or more importantly, a propagating fault:

TYPE OF FAULT DETECTED	FAULT DETECTION DESCRIPTION
▪ Device noise filter and diode bridge DC leakage ▪ TVS DC leakage ▪ Inferred device voltage changes ▪ Water ingress ▪ Terminator DC faults ▪ Device current failures ▪ Pole to Pole DC faults.	These faults can be detected by very small changes in trunk current and incremental current changes over time. Often, trunk current changes are more detectable than changes in signal level, and it is ideal for the early warning of developing pole to pole water ingress which can lead to rapid galvanic corrosion, onset of terminator capacitor leakage, device filter capacitor or diode bridge leakage, protection diode (TVS) leakage and device current failures or drift.
▪ TVS and device bridge impedance change ▪ Active power supply drift or impedance failure, ▪ Under/over termination ▪ Pole to Pole AC faults.	Jitter measurement is by far the most important measurement to make for any propagating AC fault detection. Jitter measurement ignores specific or discrete failures like noise level or signal attenuation; instead it concentrates on communication data detection accuracy. It can detect a multitude of changes caused by network impedance variations, signal distortion, network resonance, active fieldbus power supply impedance drift, terminator capacitor or resistor drift, device filter capacitor drift, device impedance faults and full bandwidth noise influences. Noise influence or signal attenuation/distortion may individually meet the required specification limits, but added together could result in a failure. Jitter measurement ignores specific or discrete failure, instead it concentrates on the problems of data detection accuracy and how 'good' the data is. Should a data signal tend towards failure, jitter detection will pick this up long before a corrupted data retransmission can take place.
▪ General attenuation faults ▪ Device communication level faults ▪ Over/under terminator faults	Signal level measurement can be used to detect attenuation caused by severe active power supply impedance failure or drift, cable attenuation, over/under termination or a device impedance failure. Fieldbus will still operate with very low signal levels, but data can fail long before warning that signal levels are falling below acceptable limits. Jitter measurement in combination with signal level measurements, enables targeted trouble shooting diagnosis.

TYPE OF FAULT DETECTED	FAULT DETECTION DESCRIPTION
▪ AC and DC shield to pole faults ▪ Cable unbalance ▪ Water ingress ▪ Device noise filter capacitor drift.	Not all ‘pole to shield’ faults are simple short circuits. This measurement can view capacitive and resistive faults at various degrees and it can assess which pole is at fault. Capacitive faults or unbalance can be caused by de-coupling capacitors failing within instruments or it may be that a cable has abnormally high unbalance due to a manufacturing defect or it could be due to installation problems. It is also ideal for early warning of developing pole to shield water ingress.
▪ Crosstalk, noise and interference detection	Noise measurement can detect destructive in-band noise as well as a full spectral analysis that can detect low frequency noise such as resonance caused by terminator faults, power supply impedance faults, cross talk, cable microphonics, motor drive pickup and earth loops or earth bound noise and so on.
▪ Power supply health and failure detection.	Trunk voltage measurement is used to detect any possible current loading problems and to monitor the health of the power supply for early warning of any failure. Trunk voltage measurements are a common activity for any trouble shooting engineer however, once a trunk has been simulated, installed and commissioned, then the voltage levels at each device should have already been addressed. Never the less, by measuring trunk current, and knowing the cable parameters, then a voltage calculation at each device can be inferred - meaning that an engineer will not have to go all the way out on site to measure the voltage at a device. For example, if there is no change in trunk current, then recording the voltage at each device will not be a necessary task.
▪ Signal polarity inversion.	This measurement will detect signal inversion of a device during construction and commissioning, or if a device has been replaced incorrectly during operational repair or after calibration. Inverted signals are caused by incorrect polarity connection of some devices and power supplies. In some circumstances, inverted signals can be tolerated, but many systems or devices will not accurately detect them and will often fail or create many data retransmissions.

The importance of jitter measurement

"Jitter" measurement deviation is the most accurate indication of a developing fault. This has also been agreed by the FF Physical Layer working group (Chevron, Emerson, MTL, P+F, Relcom and Yokogawa) concluding that jitter measurement is the only beneficial parameter to analyze, when testing network impedance and power supply performance.

Jitter measurement is also the only parameter that can effectively be measured to verify the

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fieldbus power supply's conformance with IEC61158-2 and compatibility with other devices. Passing jitter measurement testing will give the power supply the standard FF.831 tick mark. Continued measurement of jitter will also verify the power supply's continued compliance with FF.831 and its operational health.

Jitter analysis will observe small changes that are not normally significant enough to cause data retransmissions or any other alarms. Jitter measurement ignores the singular effects of noise, attenuation and distortion. For example, the noise levels may just be within limits and the signal attenuation and distortion may also just be within limits so that no alarms are given, but collectively, they may cause data detection to fail. Jitter measurement will be able to detect the onset of failure long before any other measurement parameter is able to react without a false alarm.

6.2 Deciding which diagnostic hardware/software to chose

Jitter error is caused by signal distortion, noise and network resonance. Jitter errors are basically zero crossing errors where zero crossing is the only measurement that is used to detect the actual 1's and 0's of the data transmission:

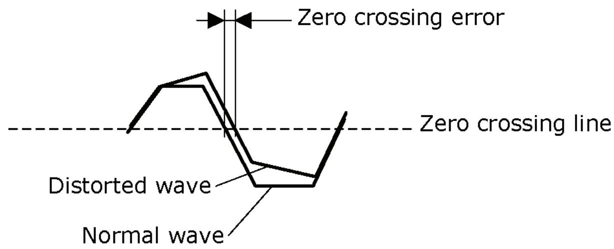

Fig. 6-4: Jitter explanation

Deciding which diagnostic module or system to purchase will depend on the needs of the contractor, the needs of the purchaser and/or operator or even the project scheduling.

The choice should be based on features, performance and cost, although the cost difference is very marginal between online systems, and the cost must be weighed up against the broader range of savings seen across the project lifecycle.

In some cases, the control system and associated fieldbus power supplies will not be available during construction or pre-commissioning and therefore, a portable mobile advanced diagnostic system and analytical software with portable mobile fieldbus power supplies will be the only option. By ensuring that the control system, if not, at least the fieldbus power supply hubs fitted with advanced diagnostic equipment, are installed at an early stage during the project lifecycle, the project would realize significant cost and time saving benefits.

The table below summarizes the differences between the physical layer diagnostic product variants currently on the market:

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Measurement	Mobile advanced diagnostics	Advanced online diagnostics	Handheld fieldbus testers	Basic online diagnostics
Trending and logging of all measurements over time for early warning of a potential fault.	YES	YES	NO	YES (limited)
Trunk current measurement	NO	YES	NO	NO
Jitter measurement	YES	YES	NO	NO
Data signal amplitude	YES	YES	YES	YES
Shield to pole AC and DC unbalance as a percentage for each pole.	YES	YES	NO	NO
Direct pole to pole short circuit	YES	YES	YES	YES
Full spectral frequency analysis	YES	YES	**NO** (some yes)	**NO** (some yes)
High frequency noise measurement	YES	YES	YES	YES
Digital storage oscilloscope	YES	YES	NO	NO
Trunk voltage	YES	YES	YES	YES
Advanced software analysis and hardcopy printout	YES	YES	NO	NO
'Signal inverted' warning	YES	YES	NO	YES
Segregated diagnostic information bus - operation not affected by any segment failure	YES	YES	YES	NO
Draws **zero** current from the bus	YES	YES	NO	NO
No need to track down terminals or interfere with cable systems or junction boxes	NO	YES	NO	YES
Simultaneous monitoring of all segments.	NO	YES	NO	YES
'Leave in place' transition from construction through to operation	NO	YES	NO	YES

The choice

From the above table, it can clearly bee seen that advanced online diagnostic option will offer the best overall performance, features and assistance with superior early warning, reporting and application across the project lifecycle, among other powerful and useful differentiators.

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7 CAPEX & OPEX Savings

Using advanced online or mobile physical layer diagnostics

Fieldbus is still relatively new, and the 'manning' levels required for construction, commissioning and operation of a fieldbus plant is often sized according to the equivalent 4-20 mA system. This next section will demonstrate the time and/or manpower savings seen with not only fieldbus technology, when compared to 4-20 mA technology, but more significantly, the savings seen when using advanced physical layer diagnostics.

Notes and estimates

This case study will consider:

Number of instruments	1,200
Number of segments	100 (12 instruments per segment)
Man day	8 hours
Mean time to repair (MTTR) a fault	4 hours

Every project varies with regard to engineering staff levels and time schedules. Other factors such as the process or the product to be manufactured and the environment also play an important part in overall expenditure, so the estimates are general, but they do give an overview of the vast savings potential.

Some contractors will allow a team up to 30 minutes for construction testing, pre-commissioning checks and repair per instrument loop. The range seems to vary between 10 minutes per loop (a check), and up to 2 hours per loop (a check inclusive of repair work) depending on the project definition. For a 4-20 mA system, 30 minutes per 4-20 mA loop will result in over 2 ¼ months worth of qualified and experienced engineering based on an 8 hour shift per day, and a full working week. This case study will consider a shorter time estimate.

Pre-commissioning can be grouped with construction, but for simplicity, pre-commissioning is grouped with commissioning where the common aspect of control loop checking is ignored as this will be the same for any hardware model.

Instrument failures will in fact be the same for any model as there are exactly the same numbers of instruments for a classic 4-20 mA system as there will be for a fieldbus system. Based on a MTBF of 200 years per instrument, for 1,200 instruments, one would anticipate a failure of 6 instruments each year, and with a MTTR of 4 hours, this will occupy 3 days each year for repair time. Nevertheless, as this will be the same for all models, it can be ignored for this case study.

Equally, any repair work of cable or cable systems will be the same for fieldbus with diagnostics and without diagnostics. The only difference being downtime – a repair to prevent a fault may take the same time as a repair to fix a failure, and therefore, this can be ignored as they will be the same.

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Task	MODEL		
	4-20 mA	Fieldbus without diagnostics	Fieldbus with diagnostics
Constructional checks - each cable will be checked for: continuity, pole to pole and each pole to shield isolation and a test sheet completed. Allowing for time to read the drawings and locate the terminals and connect the cable testers. **NOTE:** For fieldbus, additional cable resistance and capacitance checks are required. For fieldbus with diagnostics, the cable can be checked at the same time as pre-commissioning checks are performed.	5 minutes per cable	10 minutes per segment	Not required
	1,200 instrument cables: 1,200 x 5 = 6,000 minutes or 12 ½ days	100 segments: 100 x 10 = 1,000 minutes or 2 days	Not required
Construction failures: anticipated percentage of cable failures and the time taken to repair the fault based on a **4 hour 'mean time to repair' (MTTR).** **NOTE:** Fieldbus has the same number of spur cables as the 4-20 mA model, plus an additional trunk cable.	1% predicted failure = 12, 4-20 mA loops	1% predicted failure = 1, trunk, 12 spurs	Not required
	12 x 4h = 6 days	13 x 4h = 6 ½ days	Not required
Pre/commissioning instrument checks **4-20 mA Analogue** - each instrument should be tested with a loop calibrator or handheld tester to ensure correct device polarity, operational voltage test and loop current check for both analogue inputs and analogue outputs with a test sheet completed. **Fieldbus** - each network should be tested to ensure correct device communication, signal and noise quality, tag number and address validation, power supply voltage test with a test sheet completed. **NOTE:** The advanced diagnostic model will test many more physical layer parameters in a shorter time.	10 minutes per cable	60 minutes per segment	8 minutes per segment
	1,200 instrument cables: 1,200 x 10 = 12,000 minutes or 25 days	100 segments: 100 x 60 = 6,000 minutes or 12 ½ days	100 segments: 100 x 8 = 800 minutes or 1.6 days
Pre/commissioning failure: anticipated failures and the time take to repair the fault based on a **4 hour 'mean time to repair' (MTTR)** **NOTE:** Fieldbus with diagnostics will include the predicted cable failures.	0.5% predicted failure = 6, 4-20 mA loops	0.5% predicted failure =~ 1 segment	1.5% predicted failure =~ 2 segments
	6 x 4h = 3 days	1 x 4h = 1/2 day	2 x 4h = 1 days
Operational maintenance over a 1 year period observing and inspecting every loop/segment for anomalies and to perform regular shutdown repair and maintenance tasks. Often, the maintenance shift will react to failures passed on from the operating crew. **NOTE:** For fieldbus, additional communication checks will need to be performed using oscilloscopes and hand held analyzers. The diagnostic system will test many more physical layer parameters.	15 minutes per cable	60 minutes per segment	8 minutes per segment
	1,200 x 15 = 18,000 minutes or 37.5 days	100 x 60 = 6,000 minutes or 12 ½ days	100 segments: 100 x 8 = 800 minutes or 1.6 days
Construction and commissioning times in man-days	46.5 man-days	21.5 man-days	2.6 man-days
Operational maintenance times in man-days	37.5 man-days	12.5 man-days	1.6 man-days

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Savings summary

In summary, fieldbus, with its automatic device commissioning and reduced cable infrastructure, will reduce the amount of time taken for construction, commissioning and operation testing and maintenance. Fieldbus with online test equipment will go on to reduce the time even further to a very significant level if the system is implemented and operated effectively. An analogy to support the claims are seen with ATE (automatic test equipment) when used to repeatedly test the same circuit card on a production line. The testing is extremely fast even though the circuit cards may have to be manually loaded. From the fieldbus model, it can be seen that there are many repeated circuits that are already connected in place, and therefore, the time saving benefits can easily be validated.

8 Conclusion and summary

Fieldbus has made it truly 'cost-possible' to utilize advanced automatic online diagnostics for every single segment during the construction and commissioning phases, and to retain the same hardware/software for the operation phase, where this would not have been feasible or economic for an equivalent 4-20 mA system.

From the figures and estimates provided in this paper, it can be seen that the implementation of online advanced physical layer diagnostics will pay for itself in a very short timeframe, and will no doubt pay for itself after the first expected failure.

Because the online diagnostic modules are permanently integrated into the network infrastructure ('always to hand'), the time taken to implement diagnostic troubleshooting, compliance testing, report generation, maintenance checks or analysis is significantly reduced.

Online advanced diagnosis, with its greater breadth of measurements, can provide early warning of many more propagating failures and so reduce downtime, which could not be achieved by using manually operated test equipment, handheld fieldbus diagnostic testers, or even systems supporting basic online physical layer diagnostic capability.

The advanced diagnostic fault finding capability and selective reporting will take a lot of the guesswork out of the decision making process. This enables a degree of de-skilling and reduction in 'man' power.

Online advanced diagnostics can reduce the time and frequency for scheduled maintenance, as many of the reported propagating faults can be tolerated or repaired during operation, and routine checks are actually performed automatically in real time 24 hours a day, seven days a week.

During construction, commissioning and operational maintenance, records and proof of testing/checking ensures complete testing, quality checking and test consistency as well as verified conformance or continuing conformance with the fieldbus standards.

The diagnostic data is sent through an autonomous data bus and not on a fieldbus segment or an expensive fieldbus I/O port. This will increase the data reliability in a cost-effective way.

Finally, fieldbus networks with online advanced physical layer and applications layer diagnostics, attached to a software validated network, combined with mechanical and electronic protection will no doubt be extremely reliable when proactively maintained – even to say that it could be more reliable than the equivalent 4-20 mA model. Furthermore, implementing online advanced diagnostics and reporting, when compared with the alternatives, will result in a significant reduction in CAPEX and OPEX.

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