# Chapter 6

## Programmable Safety Systems in Conventional Fieldbus Systems

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## 6.0 Introduction to fieldbus

Industrial communications have fundamentally changed industrial control architectures in the automation and process control sectors. This has presented a challenge to many, not only because of the bewildering choice that has recently become available, but also in the application of fieldbus technology. What is fieldbus? The International Electrotechnical Commission (IEC) has defined fieldbus as a "generic term for a serial, digital communications network, supporting multiple measurement, control and actuation devices on a shared medium."[1]

Fieldbuses are specifically designed for time-critical communication, although some also combine non-time critical data, such as device configuration and programming. The term fieldbus itself causes confusion. Some use it to describe process networks (used in the field of continuous processing, as opposed to discrete manufacturing) or a particular industrial network (usually with a capital 'F'), while others use the term to describe open, as opposed to proprietary industrial networks.

Many fieldbus technologies were originally proprietary, usually with complementary third party development licensed by the developer. The transition from proprietary to open technologies occurred as fieldbus became strategically important to controls manufacturers, keen to encourage widespread acceptance of their networking technology (already embedded in their devices). Customers applied pressure to controls manufacturers, recognising the importance of multi-vendor support, so continued technological development could take place through open technology forums.

Fieldbus technology has arisen as a result of the significant impact of recent developments in Distributed Control Systems (DCS), Programmable Logic Controllers (PLCs), Smart Instrumentation and Personal Computers (PCs) used in control and instrumentation systems. These in turn occurred due to the advances that have taken place in integrated electronics, microprocessors and data communications.

PSS-range programmable safety systems used within automation systems can be interfaced to PLCs via conventional fieldbus. This enables safety system status (monitoring), diagnostics and control signals to be easily integrated into standard programmable controllers. However, conventional fieldbus technologies may not be used for safety-related applications without specific protocol enhancements (for further details, please refer to Chapter 7).

### 6.0.1 OSI model and fieldbus

The International Standards Organisation (ISO) introduced the Open Systems Interconnection (OSI) basic reference model in the late seventies. The aim of the OSI model was to provide a universal framework for protocol development. The model comprises seven basic levels of communications functionality, known as layers. All seven layers would need to be specified for fully featured computer communications over a wide area, such as the Internet.

Industrial networks tend not to specify all these layers (being closed systems), but use a ‘collapsed stack’. This reduction increases protocol efficiency. For example, SafetyBUS p specifies the application layer, physical layer and transmission media, with Controller Area Network (CAN) defining the Media Access Control (MAC) methodology and physical signalling (Fig. 70). The OSI basic model illustrates the protocol layers and their function, with an example of a complete implementation using all the layers with

Ethernet. The incorporation of Industrial Ethernet into fieldbus standards will require the specification of additional layers.

| OSI Model | Description | Ethernet | CAN | SafetyBUS p |
|---|---|---|---|---|
| Application Layer | Software that implements a communication component | File server concepts | _ | Application layer specification - Object model, Media Access Control, protocol & safety communication validation |
| Presentation Layer | Coding and conversion of data to/from the application layer | ASCII, GIF, TIFF, JPEG & MPEG | _ | _ |
| Session Layer | Manages and co-ordinates communication sessions between the presentation and other layers | Netbios | _ | _ |
| Transport Layer | Ensures reliable transport of data; includes flow control, multiplexing, error checking & recovery | TCP | _ | _ |
| Network Layer | Message routing across multiple networks | IP, Routers | _ | _ |
| Data Link Layer | Physical addressing, topology, message framing & error control | Ethernet, bridges | Object layer Prioritised message handling and acceptance filtering, transfer layer, fault confinement, error detection & report, acknowledgement, message framing and arbitration | SafetyBUS p (physical layer) transceiver specification |
| Physical Layer | Defines electrical, mechanical, & procedural specification for the physical media | Wiring system, Thick/thin coax, fibre optic & unshielded twisted pair | Bit representation, transfer rate, signal level & timing and transmission medium | SafetyBUS p network media & physical layer specification |

Fig. 70: OSI model and fieldbus examples

The OSI model obtained widespread support from commercial and industrial developers in the mid eighties, with technologies such as Data Highway Plus (from Allen-Bradley) and Modbus Plus from AEG Modicon being based upon the simplified OSI model. The increasing intelligence and distribution of PLCs necessitated high bandwidth and more open standards. General Motors initiated the open Manufacturing Automation Protocol (MAP) standard, which enjoyed significant support initially, but ultimately proved too complex and costly.

### 6.0.2 Automation data communications

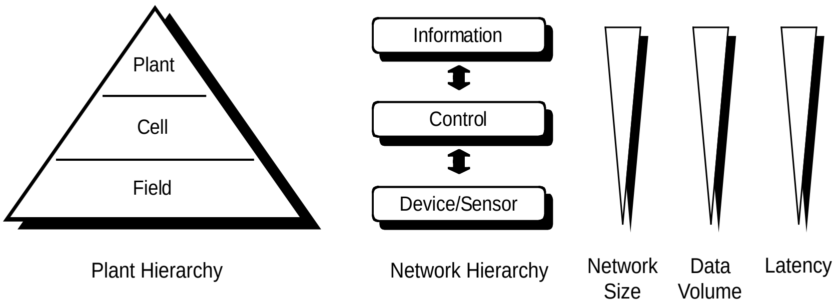


Fig. 71: Plant communications hierarchy and characteristics

Communications between a PLC and device level equipment requires relatively slow, small data transfers, while communication between PLCs or PLC operator stations requires faster, larger data transfers. Historically, this created two distinct segments for industrial networks in the mid eighties. Token passing protocols based on RS 485 were introduced by a number of manufacturers to solve PLC and operator communications. Token passing was favoured over Ethernet for determinism, despite Square D originally introducing the use of Ethernet PLC in the mid seventies. Later, other manufacturers also utilised Ethernet, with some, such as Allen-Bradley and Siemens, supporting both. Phoenix Contact's Interbus (formerly Interbus-S) was one of the first fieldbuses to gain widespread popularity, particularly in the European automotive industry. It is predictable (deterministic) over large distances.

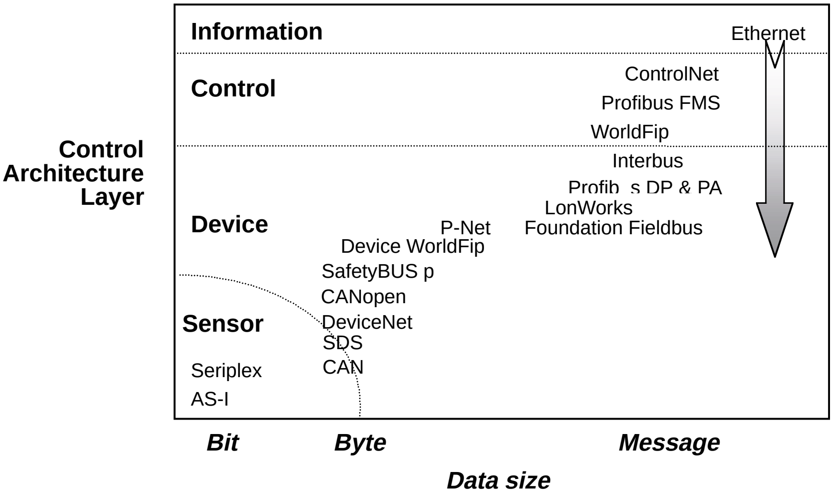


Fig. 72: Network positioning Source: After Piggin

Integrated plant control systems offered by automation manufacturers have corresponded to the automation pyramid paradigm. Fieldbus networks have provided the communication strategy, enabling total and seamless integration. The distinct requirements of each layer necessitate the provision of different fieldbus technologies. The characteristics of the different networks balance the need for real-time control (time critical), with small message sizes in the device layer, against a less timely response (non-time critical), with much larger message sizes in the information layer. The control layer can support a mixture of time critical and non-time critical data, such as I/O data, operator displays, motion control, and the downloading of device configuration data and program data (e.g. robots and PLCs). This network hierarchy is subject to change, with the introduction of Industrial Ethernet solutions incorporating many of the popular fieldbus protocols. Those residing in the control layer are the most likely to be affected.

## 6.1 Fieldbus standards

Significant fieldbus standard development began with IEC 61158, the aim being to produce a single universal standard. This was supported by Foundation Fieldbus, which was a merger between two rival groups, Interoperable Systems Project (ISP) and WorldFIP North America. As work on IEC 61158 was protracted and had substantially broadened in scope, the European Committee for Electrotechnical Standardisation (CENELEC) developed EN 50170 to provide an interim fieldbus standard for Europe. This originally comprised Danish (P-Net), French (WorldFIP) and German (Profibus) national standards. Other technologies are in the process of being added as amendments to EN 50170 (ControlNet, Foundation Fieldbus and Profibus PA), enabling users greater choice within Europe, since EN (fieldbus) standards have legal ramifications in public supply contracts, effectively excluding non-Euro norm technologies.



American fieldbus organisations viewed this as tantamount to a restriction of trade. The ‘fieldbus wars’ were characterised by the polarisation between these two standards, with Profibus supporters being the most active in the campaign against the original IEC 61158 standard.

The peaceful conclusion to the “single” universal international (IEC) standard resulted in the incorporation of eight fieldbus technologies, six of which could not be considered interoperable. The IEC standard will now comprise an additional seven parts in parallel with the original committee product. Market demand in the intervening period saw a number of fieldbus systems become de-facto standards, with manufacturers and fieldbus organisations racing to obtain European and International standardisation to secure global markets. IEC 61784 (Profile sets for continuous and discrete manufacturing) will provide an overview of the technologies in IEC 61158.

| | IEC 61158 | EN 50170 | EN 50254 | ISA S50.02 |
|---|---|---|---|---|
| ControlNet™ | Type 2 | *Volume 6 (prA3)* | | |
| Foundation™ Fieldbus | Type 5 | Volume 4 (A1) | | |
| IEC Fieldbus | Type 1 | | | Parts 2,3,4,5,6 |
| Interbus | Type 8 | | Volume 2 | |
| P-Net | Type 4 | Volume 1 | | |
| Profibus | Type 3 | Volume 2 & 5 (A2) | Volume 3 | |
| Swiftnet | Type 6 | | | |
| WorldFIP | Type 7 | Volume 3 | Volume 4 | |

| | IEC 62026 | ISO 11898 | EN 50325 | EN 50295 | ANSI 709.1 |
|---|---|---|---|---|---|
| AS-i | Part 2 | | | EN 50295 | |
| CAN | | ISO 11898 | | | |
| CANopen | prEN voting 2001 | ISO 11898 | Part 4 | | |
| DeviceNet | Part 3 | ISO 11898 | Part 2 | | |
| LonWorks | Formerly Part 4 | | - | | ANSI 709.1 |
| SDS | Part 5 | ISO 11898 | Part 3 | | |
| Seriplex | Part 6 (in preparation) | | | | |

Fig. 73: Fieldbus standards activity, showing technical equivalence of various international standards



### 6.1.1 De facto ‘open’ standards

Whilst IEC 61158 was in preparation, a number of fieldbus technologies were introduced during the mid eighties and early nineties.

#### 6.1.1.1 Profibus

Work began on Profibus (PROcess FieldBUS - based on earlier Siemens networks) in 1986. This was undertaken by the German Government, with co-operation from automation manufacturers (Klockner-Moeller, Robert Bosch and Siemens), as well as users. The Profibus specification was completed in 1989. Control of the specification was then passed to the PNO (“Profibus Nutzerorganisation” / Profibus User Group). Profibus has token passing between master controllers and master-slave operation for communication between controllers and slave devices. Profibus originally comprised two distinct and interoperable technologies, Profibus DP (Decentralised Periphery – device level) and Profibus FMS (Fieldbus Message Specification – control level). Profibus PA was defined in 1995 for process automation. ProfiSafe is a safety profile extension to Profibus and is currently under development.

#### 6.1.1.2 CAN

Controller Area Network (CAN) was developed by Robert Bosch GmbH and Intel in the eighties for the automotive industry, to reduce wiring costs and provide additional functionality in cars (a development of the RS 485 specification). It was published as an ISO standard, ISO 11898, in 1993. CAN's inherent robustness for use in harsh and critical environments, such as engine management, gearbox, ABS braking systems and airbags, matches many of the performance requirements within industrial automation.

CAN on its own is a low-level arbitration protocol 'building block', requiring physical layer specification (cable & connectors), and necessitating higher level protocols to provide sophisticated 'plug and play' functionality. The low cost of silicon has also been a significant factor in the popularity of CAN as a base technology for many other fieldbus technologies. Development of higher layer protocols for industrial CAN-based systems was a principal objective in the formation of the CAN-in-Automation (CiA) user group in 1992.

The CAN Application Layer (CAL) was first published in 1993 by the CiA, and was based on an existing higher layer protocol developed by Philips Medical Systems. This was introduced to provide an application-independent application layer and a means for open communication between different manufacturers' modules, reducing the effort required for specific protocol development.

#### 6.1.1.3 CANopen

CANopen is a higher-level CAN protocol introduced in 1993 by CAN in Automation (CiA). CANopen comprises a family of profiles based upon CAL, which provides standard objects for multi-master and broadcast communications (Communication Profiles) and device definitions that describe device functionality (Device Profiles). Unlike some protocols, CANopen nodes have the capability to communicate directly, without a master. CANopen has proven particularly successful in the embedded automation market within Europe. CANopen was originally developed for motion control applications, examples being material handling systems, printing and textile machines. Other applications for CANopen networks include public transport, off-road vehicles, medical equipment, maritime electronics and building automation. Early safety-related use of CANopen should be expected in transport applications.

#### 6.1.1.4 AS-Interface

AS-Interface (formerly Actuator Sensor Interface, AS-i) is a sensor bus, initially developed by a consortium in 1991. AS-Interface is managed by the AS-I International Association. AS-I is a bit level network, with message sizes of only four bits, and has been viewed as a digital wire replacement. Analogue capability has since been added, and the maximum number of slaves on the network has been doubled to 62. AS-I can be used as a standalone network or with other networks, via gateways. AS-I has proved successful in the automotive industry, being used on machine tools, welding machines and associated equipment. The Safety at Work concept is the safety-related implementation of AS-I.

#### 6.1.1.5 DeviceNet, ControlNet

Allen-Bradley launched DeviceNet in 1994 and ControlNet the following year as complementary multi-master technologies, using the producer/consumer paradigm and object modelling. The Producer Consumer protocols allow multiple nodes (network devices) to listen to the same data simultaneously, without the need for multiple transmissions to each node, as is the case with earlier source destination protocols. This improves both network performance and flexibility. Allen-Bradley subsequently gave the intellectual property rights to the Open DeviceNet Vendor Association (ODVA) and ControlNet International (CI) respectively. DeviceNet is based upon CAN and supported by CiA.

DeviceNet is a general-purpose bus suitable for most device level communications, benefiting from a variety of messaging types to provide efficient and information rich communications. ControlNet uses coaxial cable and is based on a Rockwell ASIC microchip. ControlNet was designed as a high performance control level network for discrete and process automation applications, offering guaranteed determinism with a mix of time-critical and non-time critical data with media redundancy. DeviceNet Safety is in the initial stages of development; ControlNet is likely to support safety-relevant use at a later date.

## 6.2 Recent developments in fieldbus technology

Two recent fieldbus developments are beginning to significantly impact automation: the introduction of safety-related fieldbus technologies and the industrial use of Ethernet. Safety fieldbus offers distinct advantages over conventional hard-wired safety systems, including reduced complexity through the removal of parallel wiring and improved system diagnostics. The use of Ethernet at the control and device level is being driven by familiarity, cost and the opportunity to web enable devices.

### 6.2.1 Ethernet and fieldbus convergence

The control architecture paradigm, composing plant, centre, cell, station and device has been reduced to three layers: information, control and device/sensor (or field). Ethernet has previously been used for communication between controllers and business systems and is now used in conjunction with device networks, replacing control network functionality and extending to the device level, further flattening the network hierarchy.

Various fieldbus organisations are developing fieldbus protocol enhancements so that Ethernet can be used in place of control and device level networks. Those undertaking TCP/IP encapsulation include:

- DeviceNet & ControlNet - Ethernet/IP (Industrial Protocol)
- Fieldbus Foundation HSE
- Interbus (hybrid, TCP/IP channel though Interbus)
- Modbus/TCP
- Profibus - ProfiNet.

Encapsulation utilises the advantages of the network model (the existing application and user layers), with Ethernet being used as a physical layer and transport mechanism.

These developments are anticipated to meet the increasing data requirements for process monitoring, which can be achieved at minimal additional cost by increasing the speed of Ethernet to 100 Mbps. The increase in speed will also reduce the likelihood of collisions, making the network appear more deterministic. Devices can be connected directly to switching hubs (port switching) in order to eliminate collisions; this means that traffic on a particular portion of the network is only to or from a certain device. Ethernet has a high overhead and does not utilise bandwidth as efficiently as fieldbus networks, hence the hesitation to use Ethernet for control (lack of determinism) and the need to increase speed and segregate or limit networks. The Industrial Ethernet Association was formed in 1999 to address these issues by standardising messaging, interfacing, connectors and suitable deterministic architectures.

The Industrial Automation Open Networking Alliance (IAONA) is a relatively new trade group that has combined formerly separate European and American operations to encourage the growth of open networking in industrial automation. IAONA announced an agreement towards the end of 2000, involving the Interface for Distributed Automation (IDA) consortium and the ODVA, and resulting in a common strategy for the future development of Ethernet products for industrial automation. This is a significant development with wide industry support and offers a real prospect of interoperability between different Ethernet protocols. This new co-operation is working to remove implementation barriers to industrial Ethernet networks. IAONA will be the umbrella organisation and will co-ordinate technical working groups and publish the solutions as IAONA specifications, prior to submission as standards.

Another recent development has been the announcement by ControlNet International, Fieldbus Foundation, ODVA and Profibus International to agree to support the OPC (OLE for Process Control) working group that will produce the DX specification. The OPC DX standard will provide interoperable data exchange and server-to-server communications across Ethernet networks.  This will be an extension of the existing OPC data access specification, which is supported by many of today's leading automation suppliers and provides for the interchange of HMI and controller data.

## 6.3 PSS fieldbus connections

The PSS can communicate with a number of the most common fieldbus systems via standard communications modules or external gateways. The following networking technologies are currently supported with PSS:

- Interbus
- PROFIBUS-DP
- CANopen
- DeviceNet
- Ethernet
- Modbus RTU

As mentioned earlier, these standard fieldbus systems are not suitable for the transfer of safety-related data in their current stage of development. However, new safety standards are now enabling the use of programmable electronics and networks in safety systems, where older standards have previously prohibited their use. The introduction of IEC 61508 and related industry-specific standards has allowed the technological development and application of a safety fieldbus, which will incorporate additional protocol layers to ensure the guaranteed and deterministic delivery of safety-relevant data for safety-related applications. Specific information on the Pilz safety fieldbus, SafetyBUS p, is provided in Chapter 7.

## 6.4 The future of fieldbus

The ideal of a single fieldbus remains distant, although with Ethernet the possibility of a universal media is possible. Interoperability between protocols on the same wire, however, is still a distant possibility. De facto standards have occupied the vacuum that international standards failed to fill, and most continue to show strong presence in the market. Albeit, there are signs of losers in the predictable market 'shake out'.

Web access and familiarity drives Ethernet, with the cost of devices a factor (cheaper than proprietary ASICs). With many fieldbus Ethernet protocols being given away, it does look compelling. However, Ethernet does not make sense at the simple proximity sensor level because of the huge overhead, so sensor/device networks are likely to have scope for the future. The price of Ethernet embedded hardware cannot compete against device components like CAN, which cost less than $1 (Ethernet still requires additional processors). Ethernet could increase architectural complexity and have cost implications, where switches, hubs, or fibre is concerned, unless a linear multi-drop architecture is used with switches embedded in each device. Control networks are likely to be most affected by Ethernet's resurgence, except in more specialist/demanding (e.g. redundant) applications.

Safety-related use of fieldbus is still in its infancy, but is showing strong initial growth, with more solutions promised soon. It provides similar benefits to conventional fieldbus systems and is enjoying the same revolutionary impact that these systems had when parallel hard-wiring was first replaced.

1. IEC 61158 Fieldbus standard for industrial communication.
   Draft Part 1 Introductory Guide p.15
   Piggin, R. (1999) Application and Development of Fieldbus Technology EngD Executive Summary University of Warwick