

# **Chapter 02**

# **Industrial field bus systems**

# 1. Why Fieldbuses Exist?

## 1.1 Before Fieldbuses: The “Hard-Wired” Era

In early industrial automation systems, every sensor and actuator was individually wired to the control cabinet. This meant that:

- Each signal (temperature, pressure, switch, motor command, etc.) needed a separate cable.
  - Installation was expensive, bulky, and difficult to maintain.
  - Modifying the system required rewiring and stopping production.
- Imagine a bottling plant with hundreds of sensors and valves. Without a network, every single one needs its own wire back to the PLC — kilometers of cables, thousands of connection points, and endless troubleshooting.

## 1.2 The Need for Fieldbus Systems

To solve these issues, engineers created the idea of a Fieldbus to connect field devices (sensors, actuators, controllers) to automation systems efficiently.

Instead of many analog wires, one shared cable carries digital messages between all devices.

➤ Benefits:

- Fewer cables (cost and maintenance reduced).
- Faster communication and real-time control.
- Easier diagnostics and configuration.
- Standardization and interoperability.

## 1.3 What Exactly Is a Fieldbus?

A Fieldbus is not just a cable; it's a complete communication system, including:

| Layer             | Role   | Example                |
|-------------------|--|------------------------|
| Physical layer    | How bits are transmitted (voltage levels, wiring, connectors)  | RS-485, fibre optic    |
| Data link layer   | How access to the bus is shared and controlled                 | Token passing, CSMA/CA |
| Application layer | How devices interpret messages (profiles, object dictionaries) | PROFIBUS, CANopen      |

So, a *Fieldbus* often includes its own protocol, defining message format, addressing, timing, and data access.

➤ In short: “A Fieldbus = *communication medium + protocol rules + device profiles*”.

## 1.4 Why So Many Fieldbuses?

Different industries have different needs. No single bus can perfectly fit all applications.

| Sector                   | Needs   | Typical Network                          |
|--------------------------|---|--|
| Automotive               | Fast control, short distances, high reliability | CAN                                      |
| Building automation      | Flexible topology, moderate speed               | LonWorks                                 |
| Process industries       | Long cables, intrinsic safety                   | WorldFIP, FOUNDATION Fieldbus            |
| Factory automation       | Real-time I/O, high speed                       | PROFIBUS, Interbus                       |
| High-performance control | Deterministic, high-speed data                  | Industrial Ethernet (PROFINET, EtherCAT) |

## 1.5 How They Work Together?

A modern automation system uses multiple network layers, each specialized for a certain function:

| Automation Level       | Purpose                   | Typical Networks            |
|------------------------|---------------------------|-----------------------------|
| Enterprise (IT)        | Management, data analysis | Ethernet / TCP/IP           |
| Supervisory            | SCADA, monitoring         | Ethernet/IP, PROFINET       |
| Control / Cell         | PLCs, controllers         | PROFIBUS, CANopen, WorldFIP |
| Field/ Sensor-Actuator | Direct control of devices | AS-i, Interbus-S            |

So fieldbuses connect the physical process (machines, sensors) to the logic layer (controllers, PLCs) efficiently.

## 2. Fieldbus vs Protocol vs Network

Many students (and even engineers) get confused between network, protocol, and Fieldbus; so to make it crystal clear:

| Term     | Meaning   | Example                            |
|----------|---|------------------------------------|
| Network  | The entire communication infrastructure (medium + devices + configuration)            | PROFIBUS network in a factory      |
| Protocol | The set of communication rules that define how data is exchanged                      | PROFIBUS-DP protocol, CAN protocol |
| Fieldbus | A digital serial network specifically for industrial control (using its own protocol) | WorldFIP, Interbus, CAN, etc.      |

- So, each Fieldbus is a network that uses its own communication protocol.

For example:

- PROFIBUS is a Fieldbus that uses the PROFIBUS-DP protocol.
- CAN is both the network and the protocol (Controller Area Network).
- EtherCAT is an Industrial Ethernet protocol optimized for real-time control.

### 3. Common Features of All Fieldbuses

Despite their differences, all fieldbuses share certain fundamental characteristics:

1. Deterministic Timing: Messages are transmitted in a predictable order (essential for automation).
2. Multi-drop Connectivity: Many devices can share the same cable.
3. Real-Time Communication: Process data (sensor values, actuator commands) must be updated in milliseconds.
4. Distributed Intelligence: Each node (sensor, actuator) can have its own microcontroller to process data locally.
5. Robustness and Fault Tolerance: Designed for noisy industrial environments with electromagnetic interference.

Example: Simple Comparison

| Before Fieldbus                   | With Fieldbus                       |
|-----------------------------------|-------------------------------------|
| 200 cables to connect 100 sensors | One bus cable for all sensors       |
| Analog voltage signals            | Digital messages                    |
| Difficult to change setup         | Reconfigurable software             |
| No built-in diagnostics           | Error detection and node monitoring |

➤ Summary :

- Fieldbuses were invented to simplify wiring and enable real-time communication.
- Each Fieldbus includes its own communication protocol.
- Different industries led to the creation of different buses (WorldFIP, CAN, PROFIBUS, etc.).
- All share goals: deterministic, digital, robust control of distributed devices.

### 4. WorldFIP (Factory Instrumentation Protocol)

#### 4.1 Overview and Origin

WorldFIP (Factory Instrumentation Protocol) is a French-developed fieldbus from the late 1980s.

It was designed mainly for process automation (industries such as petrochemicals, energy, and manufacturing) where reliable, real-time exchange of measurements and control commands is required.

WorldFIP later became part of the IEC 61158 standard (the international reference for fieldbuses).

## 4.2 Communication Principle

WorldFIP uses a deterministic and cyclic communication model.

- Communication is managed by a central coordinator called the *bus arbitrator*.
- It periodically polls each station (sensor or actuator) according to a predefined schedule.
- This ensures that each device communicates at a known, fixed time → deterministic behavior.

Messages in WorldFIP contain identifiers representing *variables*, not devices. This is an interesting concept: the system is data-oriented (based on variable names), instead of device-oriented.

## 4.3 Layers and Medium

- Physical layer: usually RS-485 twisted-pair or optical fiber.
- Data link: based on time-division multiplexing and token passing.
- Application: variable-oriented, using standard profiles for sensors, actuators, and controllers.

| Advantages   | Limitations   |
|--|---|
| -Deterministic: ensures predictable, real-time control.<br>-High reliability and simple diagnostics.<br>-Compatible with harsh industrial environments | -Configuration can be complex and time-consuming.<br>-Slower adoption internationally (replaced by PROFIBUS and Ethernet-based systems) |

**Example:** Used in nuclear plants and chemical processing units for time-critical measurement and control loops.

## 5. Interbus

### 5.1 Overview

Interbus was developed by Phoenix Contact (Germany) in 1984. It is one of the first sensor/actuator-level networks, optimized for factory automation: robotics, conveyors, and assembly lines.

### 5.2 Communication Principle

Interbus is based on a ring topology, though logically it operates as a master-slave system.

- One master controls the data exchange with all remote modules connected in a ring.
- The master sends a *telegram* that circulates through all devices and comes back — each node inserts or extracts its data while the message passes.

This mechanism gives Interbus very fast and predictable cycle times, since each device only delays the message by a fixed, known amount.

### 5.3 Layers and Medium

- Physical layer: shielded twisted pair or fiber.
- Access method: cyclic master-slave.
- Speed: up to 500 kbit/s or more, depending on cable length.

| Advantages  | Limitations   |
|---|---|
| <ul style="list-style-type: none"> <li>-Deterministic timing : uses synchronous cyclic scanning for predictable communication.</li> <li>-Simple wiring :a single cable connects all devices in a loop.</li> <li>-Ideal for distributed I/O modules located close to sensors and actuators.</li> </ul> | <ul style="list-style-type: none"> <li>-Topology is less flexible — requires a ring configuration.</li> <li>-Limited global adoption compared to PROFIBUS and Ethernet-based systems.</li> <li>-Scalability and integration options are more restricted.</li> </ul> |

**Example.:** Commonly used in automotive assembly lines, robotic arms, and packaging machines.

## 6. CAN (Controller Area Network)

### 6.1 Overview

CAN was created by Bosch in 1986 for automotive electronics — to allow multiple electronic control units (ECUs) to communicate without a central computer. It later became a powerful industrial fieldbus standard (ISO 11898).

### 6.2 Communication Principle

CAN uses a multi-master, message-based protocol.

- Any node can start transmitting when the bus is idle.
- Arbitration (priority) is managed by message identifiers — lower IDs have higher priority.
- If two nodes transmit at once, the one with the lower ID “wins” the bus without collisions.

This ensures deterministic priority handling and avoids data corruption.

### 6.3 Layers and Speed

- Physical layer: differential pair (CAN\_H, CAN\_L).

- Data link: CSMA/CR (Carrier Sense Multiple Access with Collision Resolution).
- Speed: up to 1 Mbit/s for short distances (~40 m), lower for longer cables.

| Advantages  | Limitations   |
|---|---|
| -High reliability with real-time priority-based arbitration system.<br>-Extremely robust : performs well in vehicles and noisy industrial environments.<br>-Widely adopted and cost-effective communication standard. | -Limited frame size : only 8 bytes of data per message.<br>-Not suitable for very large or complex networks.<br>-Limited data throughput compared to modern Ethernet-based solutions. |

**Example:** Used in cars, trains, medical devices, and industrial machines (CANopen protocol).

## 7. LonWorks

### 7.1 Overview

LonWorks (Local Operating Network) was developed by Echelon Corporation for building and process automation. It focuses on interoperability and distributed intelligence.

### 7.2 Architecture

- Each node contains a Neuron chip with built-in communication and control logic.
- Communication uses a peer-to-peer model (no central master).
- Data is exchanged using network variables — standardized objects representing physical quantities.

### 7.3 Medium and Layers

- Physical layer: twisted pair, power line, or RF.
- Data link: token passing (predictable timing).
- Speed: up to 1.25 Mbit/s.

| Advantages  | Limitations   |
|---|---|
| -Fully distributed control architecture : no single point of failure.<br>-Supports multiple transmission media: twisted pair, fiber optics, and power line.<br>-Highly scalable and flexible :suitable for both small and large automation systems. | -Proprietary origin (initially developed and controlled by Echelon).<br>-Requires dedicated Neuron chip hardware for network nodes.<br>-Less open and standardized compared to newer Ethernet-based fieldbuses. |

**Example:** Used in building automation systems — lighting, HVAC, access control.

## 8. PROFIBUS (Process Field Bus)

### 8.1 Overview

PROFIBUS (Process Field Bus) was developed in Germany (Siemens, 1989) as a unified standard for both factory and process automation. It is now one of the most widely used industrial fieldbuses worldwide.

### 8.2 Versions

- PROFIBUS-DP (Decentralized Peripherals): Fast cyclic I/O exchange between PLCs and field devices.
- PROFIBUS-PA (Process Automation): Slower but supports intrinsic safety for hazardous environments.

### 8.3 Communication Model

- Master-Slave architecture
- Access control based on token passing among masters, and polling of slaves.
- Data exchanged cyclically (real-time) and acyclically (configuration, diagnostics).

### 8.4 Physical and Data Link Layers

- Physical: RS-485 (DP), MBP (PA).
- Data link: Fieldbus Data Link (FDL).
- Speed: up to 12 Mbit/s for DP.

| Advantages  | Limitations   |
|---|---|
| <ul style="list-style-type: none"><li>- High-speed and deterministic communication ideal for automation and control.</li><li>-Flexible network topology (bus, tree, or mixed structures).</li><li>-Fully standardized under IEC 61158 and IEC 61784.</li><li>-Supported by a vast ecosystem of compatible industrial devices and vendors.</li></ul> | <ul style="list-style-type: none"><li>-Requires specialized configuration tools and GSD files for setup.</li><li>-Less suitable for ultra-high-speed control compared to modern Ethernet-based systems.</li><li>-Increasingly being replaced by PROFINET and other Ethernet technologies.</li><li>-Legacy installations may face integration issues with newer digital systems.</li></ul> |

**Example:** Used in factory automation, process plants, conveyor systems, chemical and pharmaceutical industries.

## 9. Industrial Ethernet

### 9.1 Overview

Ethernet was originally designed for office communication — not real-time control. But modern enhancements have turned it into Industrial Ethernet, capable of deterministic performance.

### 9.2 Variants and Protocols

Industrial Ethernet is a family of protocols built on standard Ethernet hardware but adapted for real-time behavior:

| Protocol    | Developer | Main Feature                             |
|-------------|-----------|--|
| PROFINET    | Siemens   | Real-time and isochronous control        |
| EtherCAT    | Beckhoff  | Extremely fast, on-the-fly data exchange |
| EtherNet/IP | Rockwell  | Based on standard TCP/IP and CIP objects |
| Powerlink   | B&R       | Deterministic TDMA-based timing          |

**Example:** Used in robotic manufacturing cells, automotive factories, and motion control systems.

| Advantages   | Limitations  |
|--|--|
| -High bandwidth (typically 100 Mbps to 1 Gbps or more).<br>-Uses standard cabling and readily available hardware.<br>-Seamless integration with IT and enterprise networks.<br>-Supports flexible and complex topologies (star, line, ring, tree). | -More complex setup and configuration requirements.<br>-Sensitive to configuration errors and network traffic issues if not properly managed.<br>-May require managed switches and real-time extensions for deterministic performance.<br>-Higher cost for industrial-grade components compared to traditional fieldbuses. |

## 10. Other Field Networks

Besides the main ones, other specialized networks exist:

- AS-Interface (AS-i): simple 2-wire bus for sensors/actuators.
- DeviceNet: built on CAN, used in North America.
- Modbus: older, simple protocol (serial or TCP-based).
- FOUNDATION Fieldbus: for process industries, similar to PROFIBUS-PA but with more distributed intelligence.

## 11. Summary Table

| Network            | Type       | Speed       | Topology   | Access Method     | Typical Use          |
|--------------------|------------|-------------|------------|-------------------|----------------------|
| <b>WorldFIP</b>    | Process    | 1 Mbit/s    | Bus        | Token passing     | Process control      |
| <b>Interbus</b>    | Factory    | 500 kbit/s  | Ring       | Master-slave      | I/O modules          |
| <b>CAN</b>         | General    | 1 Mbit/s    | Bus        | CSMA/CR           | Automotive, industry |
| <b>LonWorks</b>    | Building   | 1.25 Mbit/s | Any        | Token passing     | HVAC, lighting       |
| <b>PROFIBUS-DP</b> | Factory    | 12 Mbit/s   | Bus        | Token/polling     | PLC-device           |
| <b>Ethernet/IP</b> | Industrial | 100 Mbit/s+ | Star, Line | Switched Ethernet | Real-time automation |

### 12.1 Key Concepts

Throughout this chapter, we explored the major industrial field networks — WorldFIP, Interbus, CAN, LonWorks, PROFIBUS, and Industrial Ethernet — that form the backbone of industrial automation and control systems.

Each of these networks was developed to solve a specific set of industrial challenges:

| Generation                            | Objective   | Example Technologies                       |
|---------------------------------------|---|--|
| <b>1st generation (1980s–1990s)</b>   | Replace analog wiring (4–20 mA loops) with digital serial communication   | WorldFIP, Interbus, PROFIBUS               |
| <b>2nd generation (1990s–2000s)</b>   | Enable modular, distributed, and reliable control                         | CAN/CANopen, DeviceNet, LonWorks           |
| <b>3rd generation (2000s–present)</b> | Integrate real-time industrial control with Ethernet and IP-based systems | PROFINET, EtherCAT, Ethernet/IP, POWERLINK |

The main goal of all fieldbuses is the same:

To provide real-time, deterministic, and robust communication between sensors, actuators, and controllers in an industrial environment.

### 12.2 Comparison and Complementarity

No single fieldbus fits every situation. They differ by architecture, communication model, speed, and application domain.

- WorldFIP: deterministic and variable-oriented, mainly in process control.
- Interbus: cyclic, ring-based, efficient for I/O-level automation.
- CAN: simple, reliable, widely used in vehicles and compact machines.
- LonWorks: distributed intelligence and flexibility for buildings.
- PROFIBUS: standard and universal, highly popular in both process and factory automation.

- Industrial Ethernet: high speed and integration with IT systems — the future direction.

These systems often coexist in the same factory, forming a hierarchical architecture:

| Level                       | Communication Type         | Typical Network           |
|-----------------------------|----------------------------|---------------------------|
| <b>Enterprise / IT</b>      | Non-real-time (management) | TCP/IP, standard Ethernet |
| <b>Control / Automation</b> | Real-time                  | PROFIBUS-DP, CANopen      |
| <b>Field / Device</b>       | Deterministic cyclic data  | Interbus, AS-i            |

This hierarchy ensures that information flows efficiently from the sensor level up to enterprise management systems (ERP, MES).

### 12.3 Transition Toward Industrial Ethernet

The last two decades have seen a major convergence:

- Classic fieldbuses (PROFIBUS, CAN, etc.) are gradually being replaced or complemented by Ethernet-based systems.
- Industrial Ethernet protocols (PROFINET, EtherCAT, Ethernet/IP) combine high bandwidth, determinism, and compatibility with existing IT infrastructure.

This transition is driven by:

1. The need for higher data rates (e.g., machine vision, diagnostics).
2. The demand for integration with enterprise networks.
3. The rise of Industry 4.0 and Industrial IoT (IIoT), requiring seamless data exchange between the field and the cloud.

Ethernet technologies are now evolving with Time-Sensitive Networking (TSN) — a set of IEEE standards providing guaranteed latency and synchronization — effectively merging IT and real-time control networks.

### 12.4 Future Trends

The field of industrial communication is evolving toward:

- Unified architectures: integration of field, control, and enterprise networks using Ethernet and OPC UA.
- Plug-and-play interoperability: devices from different manufacturers communicating without complex configuration.
- Wireless fieldbuses: Industrial Wi-Fi, 5G URLLC (Ultra Reliable Low Latency Communication) for mobile robots and remote sensors.
- Cybersecurity: encryption and authentication now crucial for networked industrial systems.

## 12.5 Final Thoughts

Fieldbuses revolutionized industrial automation by replacing thousands of analog cables with intelligent, deterministic, digital communication networks. Even though many traditional buses (like WorldFIP and Interbus) are now legacy technologies, their concepts — deterministic timing, distributed control, and data abstraction — remain the foundation of today's Industrial Ethernet and future cyber-physical systems.

➤ In short:

Fieldbuses laid the groundwork for Industry 4.0. The modern factory network is now an evolution, not a replacement — combining the robustness of classic fieldbuses with the openness of Ethernet and the intelligence of IoT.