Part 6

FIELD BUSES

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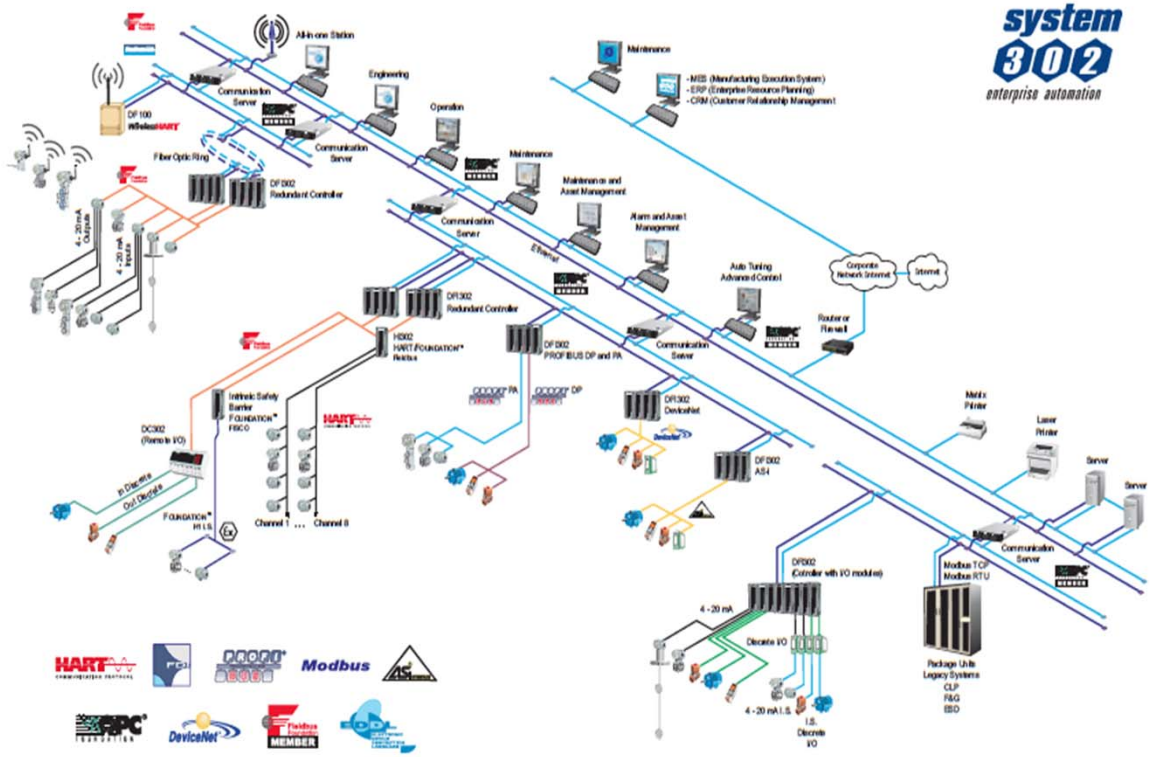
Fieldbus

Fieldbus is the name of a family of industrial computer network protocols used for real-time distributed control, now standardized as IEC 61158.

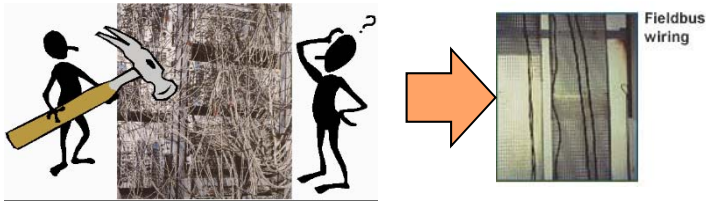
- Fieldbuses are communication technologies and products used in vehicular, automation and process control industries.
- Field buses are special *LANs* that are dedicated to data acquisition and the control of sensors and actuators.
- They typically run over low-cost twisted pair cable.
- They differ from many traditional *LANs* (such as Ethernet) in that they are optimized for the exchange of short point-to-point status and command messages.

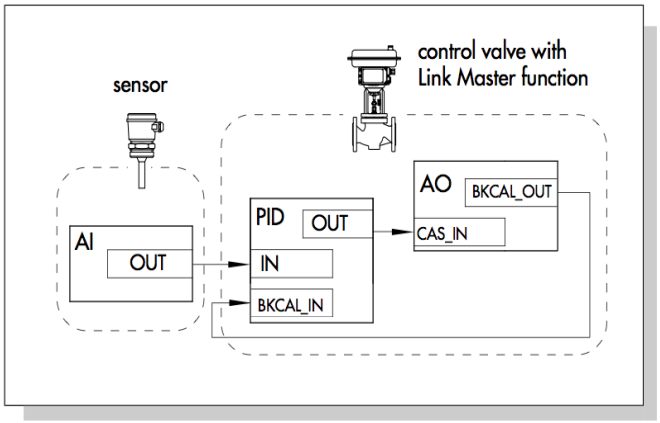


Fieldbus: Motivation

- It is the digital replacement of the analog 4-20 mA interface which is very widely used in industrial process control.
  - This interface has the serious disadvantage that it can only transmit analog values in one direction.
- With the introduction of intelligent sensors and actuators for the field use in process control, there arose a need for a bidirectional digital communication system to link these field devices to the master control system.
- This communication system should meet requirements for increased accuracy and transmission security, reduced cabling costs and remote calibration together with diagnosis and maintenance functions.

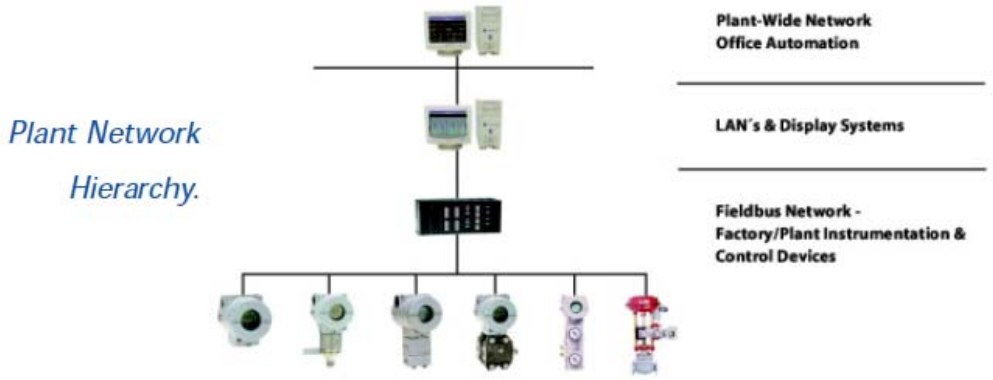
Lower Project cost:
Greatly reduced wiring costs.





Field Bus: Motivation

- Increase process availability: Improved on-line monitoring and diagnostics
- Avoid "unneeded trips" to the field with remote monitoring and diagnostic



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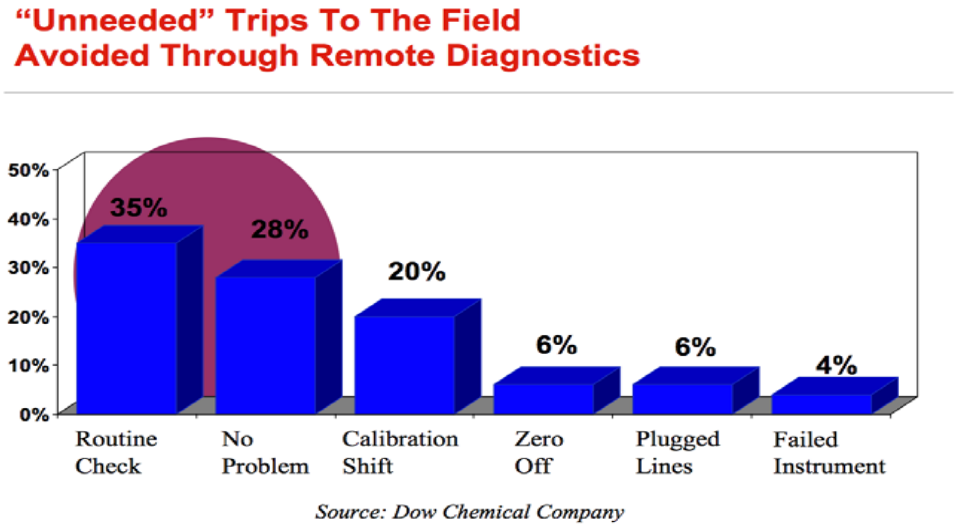


Field Buses: Motivation

Improved local intelligence in the devices:
Integrated data; Digital integration

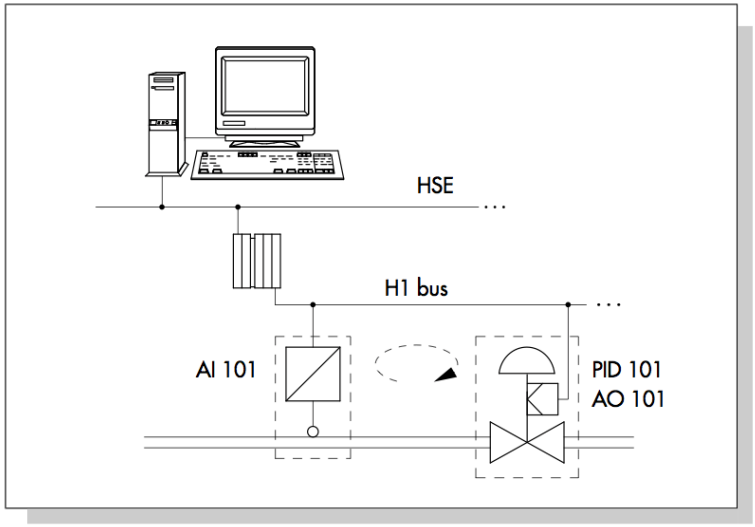
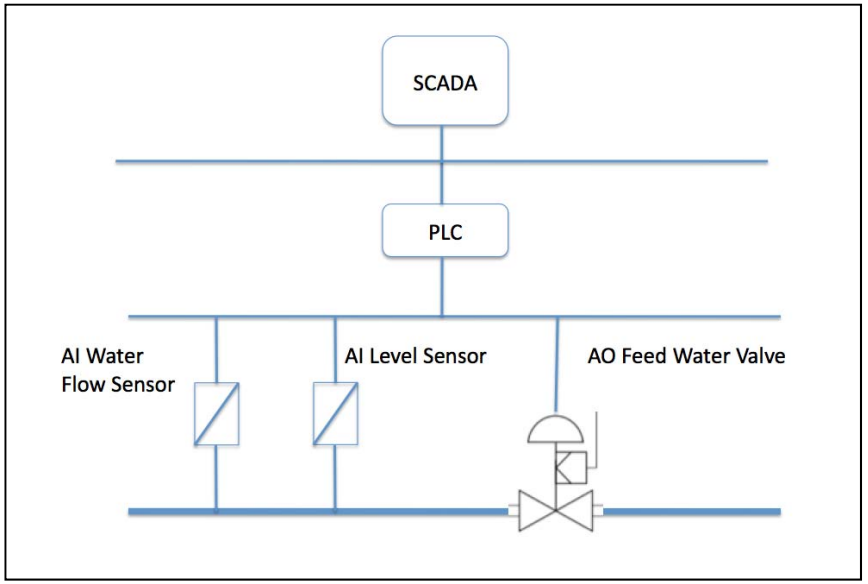


Fig. 2: Complete control loop based on the FOUNDATION fieldbus

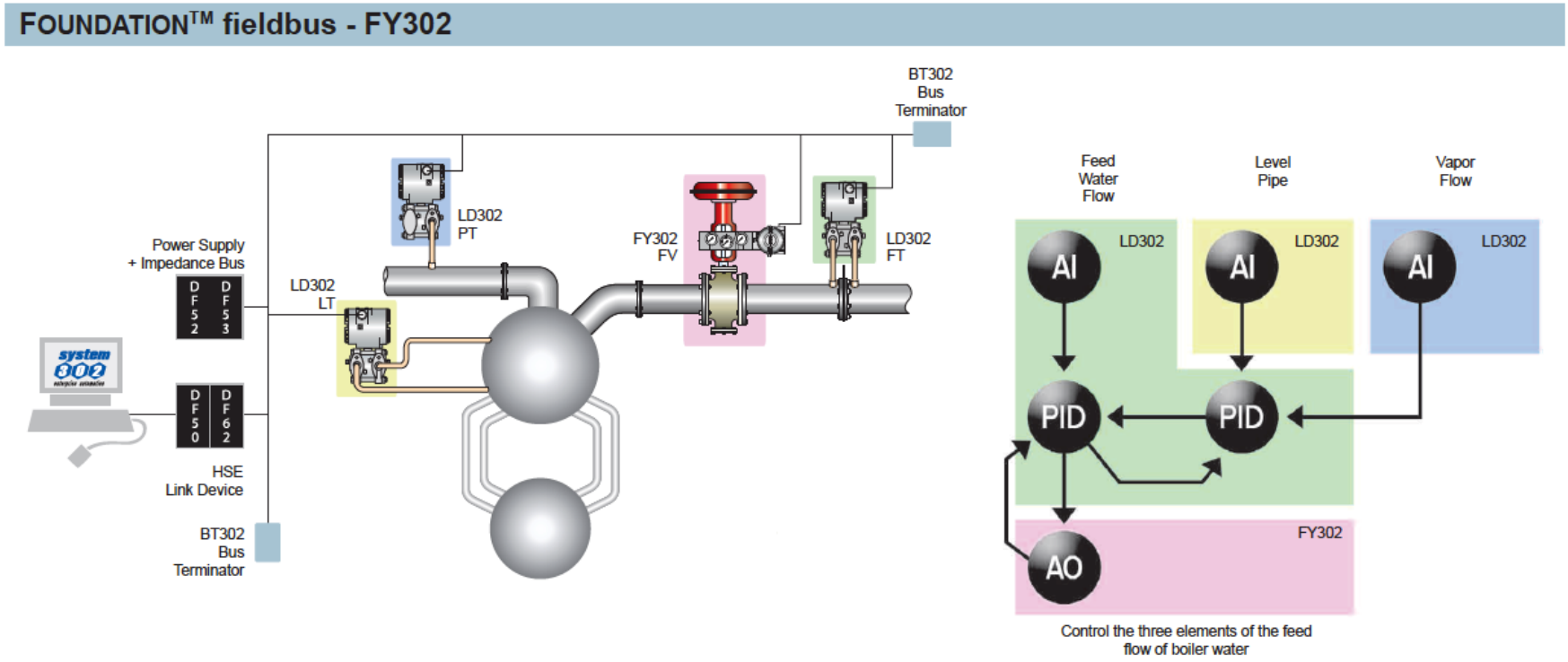


Field Buses: Motivation

Asset Management benefits:

Fewer people to manage assets

Improved interoperability between manufacturers



Field Bus Motivation: Intra-vehicular communication

- A typical vehicle has a large number of electronic control systems

- The growth of automotive electronics is a result of:
  - Customers wish for better comfort and better safety.
  - Government requirements for improved emission control
  - Reduced fuel consumption

- Some of such control systems
  - Engine timing
  - Gearbox and carburetor throttle control
  - Anti-block systems (ABS)
  - Acceleration skid control (ASC)

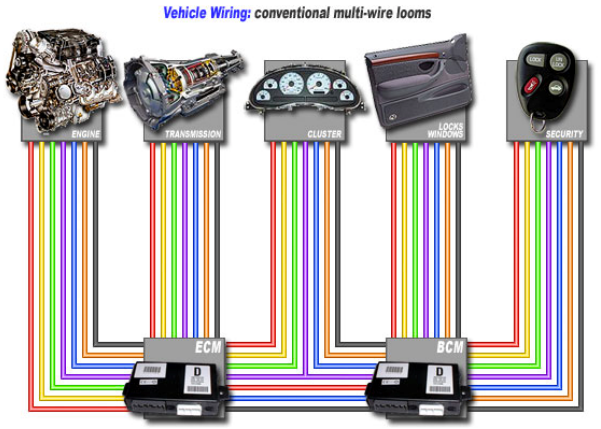
Field Bus Motivation: Intra-vehicular communication

- The complexity of the functions implemented by these electronic control systems necessitates communication between them.

- In addition, a number of systems are being developed which will cover more than one device. For example

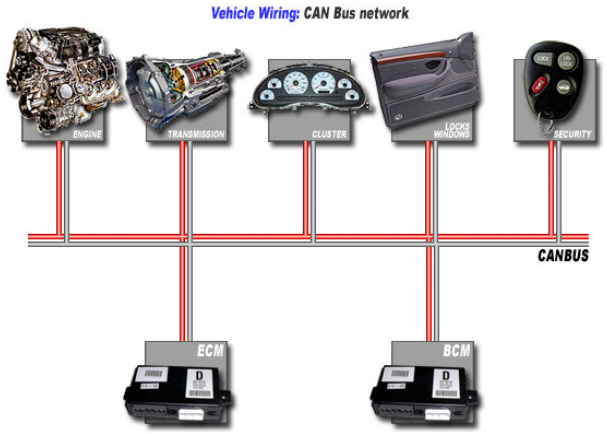
  - ASC requires the interplay of the engine timing and carburetor control in order to reduce torque when drive wheel slippage occurs.

  - In the electronic gearbox control, the ease of gear changing can be improved by a brief adjustment to ignition timing



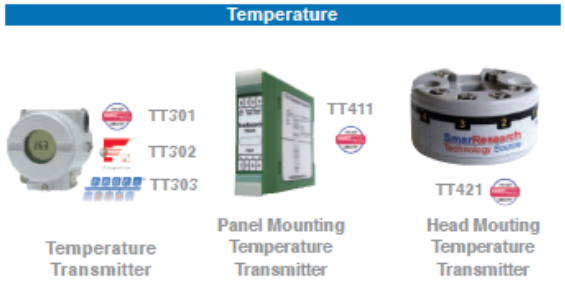
How do we connect these control devices?

- With conventional systems, data is exchanged by means of dedicated signal lines.
- But this is becoming increasingly difficult and expensive as control functions become ever more complex.
- In the case of complex control systems in particular, the number of connections cannot be increased much further.
- Solution: Use Fieldbus networks for connecting the control devices



Field Devices

- Sensors, valves, actuators, and starters are examples of I/O that are called field devices.
- The capabilities of field devices have increased rapidly as has their ability to communicate.
- If there were no standard, communication between industrial devices by different manufacturers would be a big problem.



Field Devices

- Simple industrial digital devices like sensors can be interchanged.
- They typically operate on 24 volts or 110 volts and their outputs are digital so any brand can be used.
- In other words, we could replace a simple digital photo sensor from one manufacturer with a different brand because it is only an on/off signal.

Level Transmitter

Programmable Logical Controller LC700

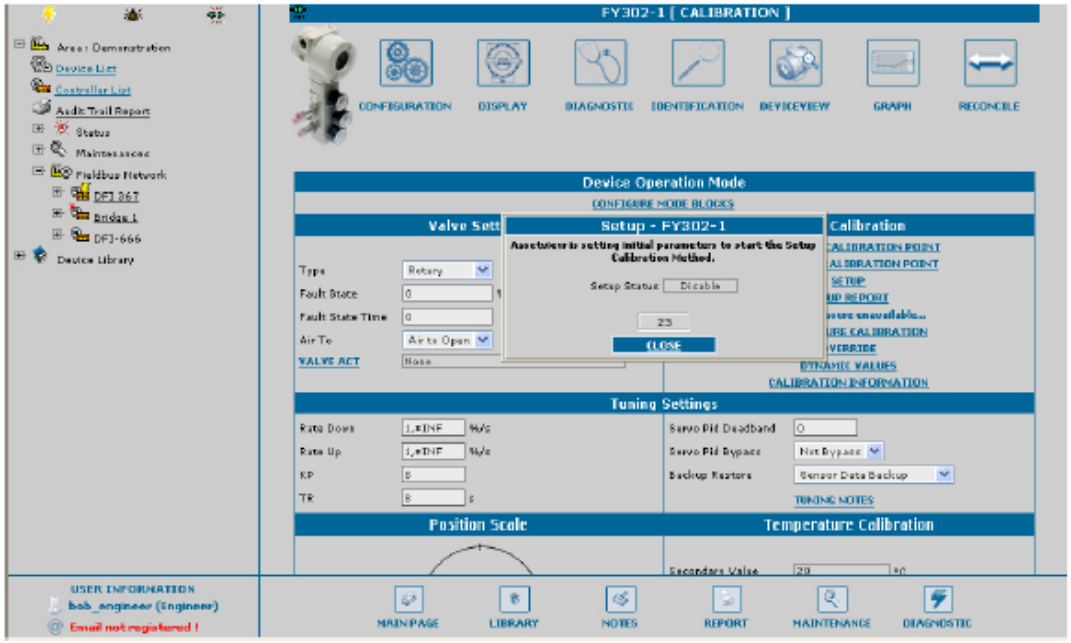
Field Devices

- Intelligent Valve Positioner
  - On-board microprocessor: perform an accurate and quick valve positioning
  - Distributed control: receives a setpoint from the process main controller and regulates the valve exactly to the target position
  - Built-in Sensing: actual valve position is read by the magnet sensor (Hall effect) and fedback to the on-board controller
  - Diagnosis for control valves maintenance

Source: www.smar.com/PDFs/catalogues/FBTUTCE.pdf

Field Devices

- Parameterisation & Diagnostic: Fourteen different types of function blocks are supported, and up to twenty function blocks can be running simultaneously.



Field Devices Function Blocks

Block Type	LD292 LD302	TT302	IF302	TP302	FY302	FP302	FI302	FB700	DC302	FR302	DT302	HI302-O	HI302-N	HI302-I
Resource (RS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Diagnostics Transducer (DIAG)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Display Transducer (DSP)	X	X	X	X	X	X	X			X	X			
Analog Input (AI)	X	X	X	X							X			
Discrete Input (DI)									X					
Multiple Analog Input (MAI)								X				X		X
Multiple Discrete Input (MDI)								X	X			X		X
PID Control (PID)	X	X	X	X	X	X	X	X	X	X	X			
Enhanced PID Control (EPID)		X	X	X	X	X	X	X						
Advanced PID Control (APID)	X				X	X	X				X			
Arithmetic (ARTH)	X	X	X	X	X	X	X	X	X	X	X	X		
Splitter (SPLT)		X	X	X	X	X	X	X						
Signal Characterizer (CHAR)	X	X	X	X	X	X	X	X			X	X		
Integrator (INTG)	X	X	X	X		X	X	X				X		
Analog Alarm (AALM)	X	X	X	X	X	X	X	X	X	X	X	X		
Input Selector (ISEL)	X	X	X	X	X	X	X	X	X	X	X	X		
Setpoint Ramp Generator (SPG)		X	X	X	X	X	X	X						

Types of Industrial Buses

- Very simple field devices only require a few bits of digital information to communicate an 'off or 'on' state.
  - These are usually associated with real time control applications where update times of a few msecs are required.
- Alternatively, complicated devices require multi-byte length messages and may only require update times of 10-100 msecs depending upon the application.
  - These systems require larger packets due to a large amount of data to be transferred.

Types of Industrial Buses

- Two basic categories: **device** and **process**.
  - *Device-type* buses are intended to handle the transmission of short messages a few bytes in length.
    - ✓ Most devices in a device bus are discrete.
    - ✓ They would be devices such as sensors, push buttons, limit switches, etc (bit oriented systems).
  - Device buses can be broken into two categories: bit-wide and byte-wide buses.
    - ✓ Byte-wide buses can transfer 50 or more bytes of data at a time.
    - ✓ Bit-wide buses typically transfer 1 to 8 bits of information to/from simple binary type devices.
    - ✓ Byte type systems are excellent for higher level communication, and bit-type systems are best for simple, physical level I/O devices such as sensors and actuators.

Types of Industrial Buses

Process Buses

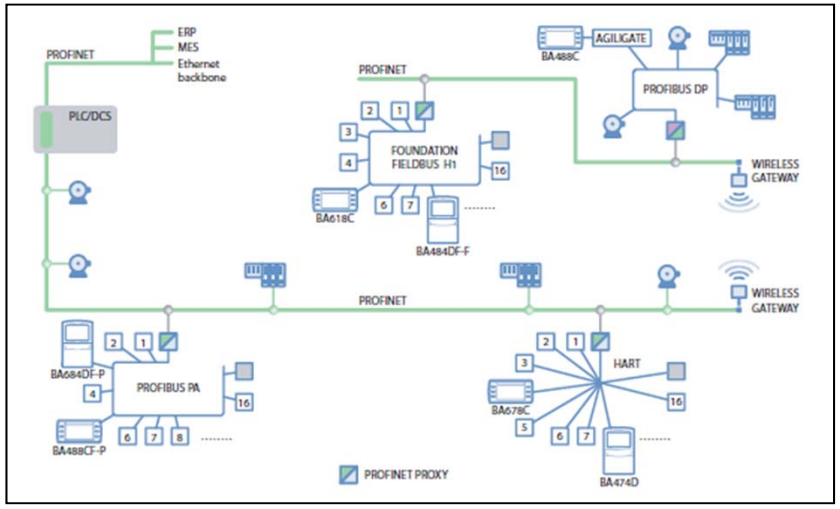
- Capable of communicating several hundred bytes of data per transmission.
- Are slower because of their large data packet size.
- Most analog control devices do not require fast response times.
- Process controllers typically are smart devices.
  - ✓ They are typically controlling analog types of variables like flow, concentration, temperature, etc.
  - ✓ Most devices in a process bus network are analog.
  - ✓ These processes are typically slow to respond.
- Process buses are used to transmit process parameters to process controllers.

Fieldbus Standard: IEC 61158

- IEC 61158 - Digital data communications for measurement and control – Fieldbus for use in industrial control systems

IEC Standard buses:

- CAN
- Profibus
- Foundation Fieldbus (FF) H1
- Foundation Fieldbus HSE
- ControlNet
- Interbus-S
- P-net

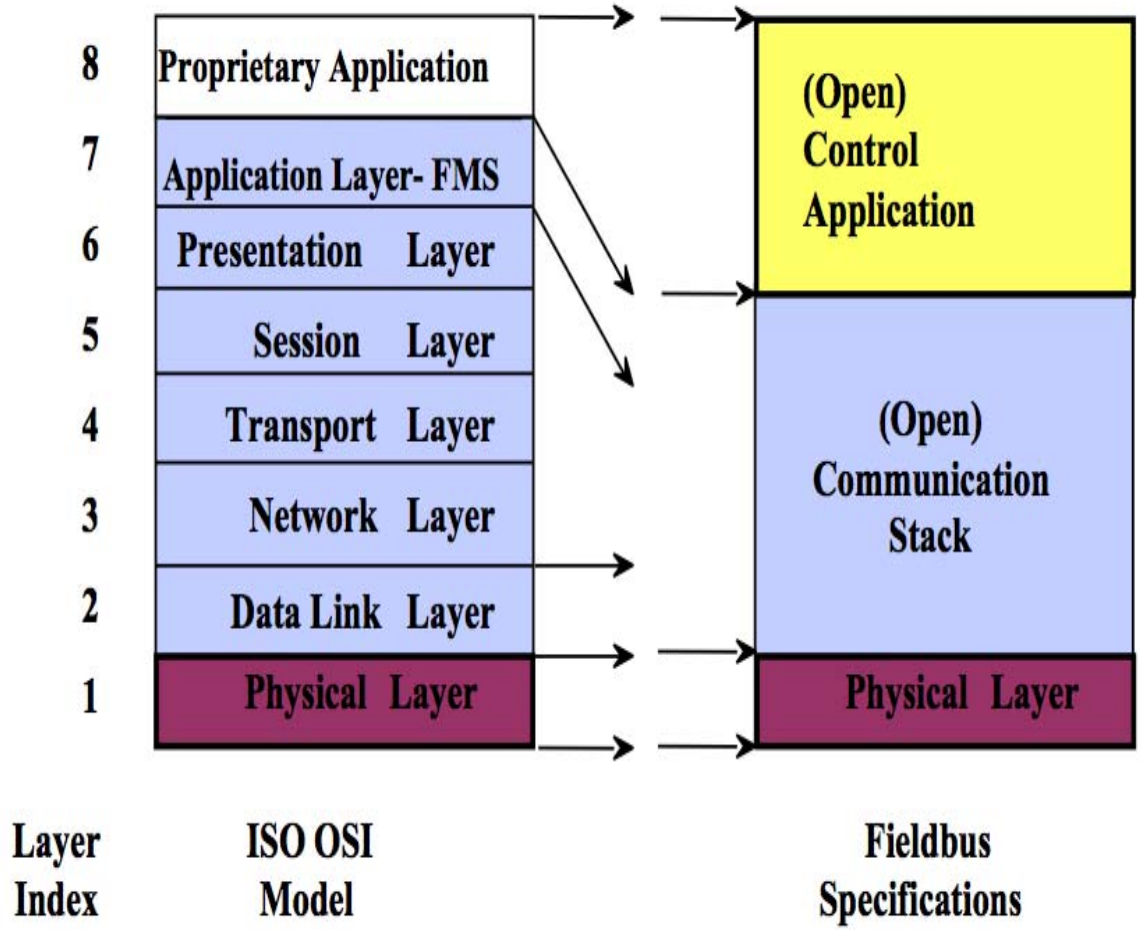


- Defacto Standard buses:
  - HART
  - MODBUS

Fieldbus OSI Layered View

Fieldbus specification based on ISO/OSI communication model

- **Physical Layer [1]** What types of signals are present, levels, representation of 1's and 0's, what type of media, connects, etc.
- **Link Layer [2]** Techniques for establishing links between to communicating parties.
- **Network Layer [3]** Method of selecting the node of interest, method of routing data.
- **Transport Layer [4]** Ensuring what was sent arrives at the receiver correcting any correctable problems.
- **Session Layer [5]** Not applicable to Fieldbuses.
- **Presentation Layer [6]** Not applicable to Fieldbuses.
- **Application Layer [7]** Meaning of data.
- The best way of covering layer 7 is to define standard profiles for standard devices.



Source: http://www.fieldbusinc.com/downloads/fieldbus_comparison.pdf

Fieldbus OSI Layered View

Physical Layer Comparison

Bus Technology	Standards	Pwr w/Comm	Comm Type	Comm Speed	IS Possible	Max Distance	# devices
FF H1	IEC 61158, ISA SP50	Yes	All Digital	31.25 Kbs	Yes	1.9km, 9.5 km	32 per seg
Profibus PA	IEC 61158	Yes	All Digital	31.25 Kbs	Yes	1.9km, 9.5 km	32 per seg
FF HSE	IEC 8802, IEEE 802.3	No	All Digital	100 Mbs, 1 Gbs	No	100 m	Unlimited
ProfiNet	IEC 8802, IEEE 802.3	No	All Digital	100 Mbs, 1 Gbs	No	100 m	Unlimited
MODBUS	IEEE 1451.2, TIA-485	No	All Digital	9.6 Kbs – 12 Mbs	No	1512 m	247 per seg
Profibus DP	IEEE 1451.2, TIA-485	No	All Digital	9.6 Kbs – 12 Mbs	No	1512 m	247 per seg
HART	Bell 202, 4-20mA	Yes	Digital over analog	1.2 Kps – 9.6 Kps	Yes	3.0 km	1 w/Analog, 64

Source: http://www.fieldbusinc.com/downloads/fieldbus_comparison.pdf

Fieldbus OSI Layered View

Data Link Layer Comparison

Bus Technology	Standards	Data Link Type	Error Detection	Deterministic	Comm Relationships	Time Features
FF H1	IEC 61158, ISA SP50	Token Passing	16-bit CRC	Yes	Client/server, pub/sub, sink/source	TM distributes time
Profibus PA	IEC 61158	Token Passing	16-bit CRC	Yes	Master/slave	None
FF HSE	IEC 8802	Token Passing	16-bit CRC	No	Client/server, pub/sub, sink/source	TM distributes time
ProfiNet	IEC 8802	Token Passing	16-bit CRC	No	Master/slave	None
MODBUS	None	master/slave address scheme	1-bit	No	Master/slave	None
Profibus DP	IEC 61158	master/slave address scheme	1-bit	No	Master/slave, pub/sub	None
HART	None	Flat addressing	CRC	No	Master/slave	None

Source: http://www.fieldbusinc.com/downloads/fieldbus_comparison.pdf

Fieldbus OSI Layered View

Application Layer Comparison

Bus Technology	Standards	Data Transfer	Supports Control in the Field	Peer to Peer Comm	Alerts and Trends in Devices	Time Features
FF H1	IEC 61158, ISA SP50, Function block application based on IEC 61804 (Draft)	AI, AO, DI, DO, PID, PD, CS, MIO, many more	Yes	Yes	Yes	Single sense of time
Profibus PA	IEC 61158	AI, AO, DI, DO	No	No	Yes	None
FF HSE	IEC 61158	Same as H1	Yes	Yes	Yes	Single sense of time
ProfiNet	IEC 61158	Same as DP	No	No	Yes	None
MODBUS	IEC 61158	Registers	No	No	No	None
Profibus DP	IEC 61158	AI, AO, DI, DO	No	No	No	None
HART	IEC 61158	Commands	Yes	No	No	None

Source: http://www.fieldbusinc.com/downloads/fieldbus_comparison.pdf

Benefits of Fieldbus

- Greatly reduced wiring costs
- Reduced installation and startup time
- Improved on-line monitoring and diagnostics
- Easy change-out and expansion of devices
- Improved local intelligence in the devices
- Improved interoperability between manufacturers

Fieldbus Advantages

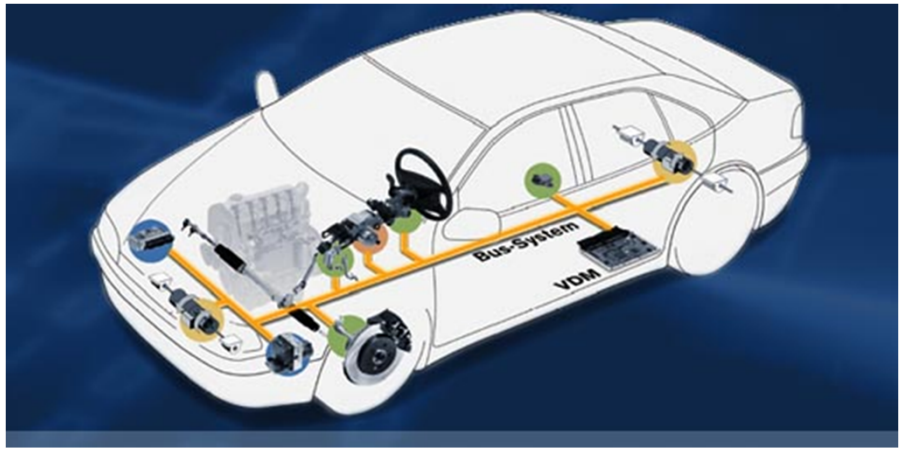
- Reduces the complexity of the control system in terms of hardware outlay.
- Resulting in the reduced complexity of the control system, project design engineering is made simpler, more efficient and conversely less expensive.
- By selecting a recognized and well established system, this will make the Fieldbus equipment in your plant or plants interchangeable between suppliers.
- The need to be concerned about connections, compatibility and other potential problems is eradicated.

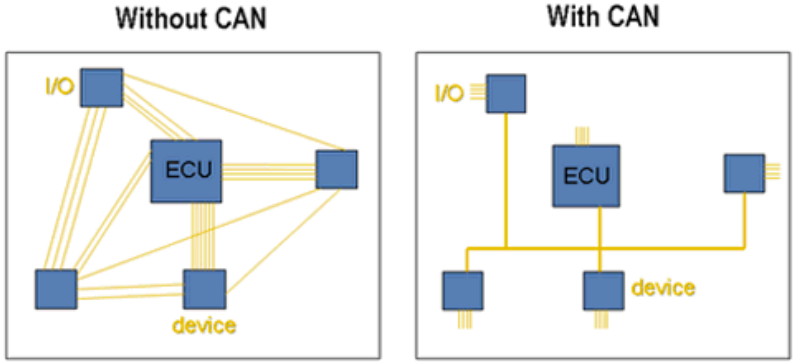
Widely Used Fieldbuses

- There are many fieldbus standards that exist, each developed for a specific purpose.
  - Automotive fieldbus is functionally different from process plant control
- Some widely used Fieldbus technologies:
  - CAN (Controller Area Network)- A number of different data rates are defined, with 1Mbps (Bits per second) being the top end, and 10kbps the minimum rate
  - ProfiBus (Process Field bus) - A maximum distance of 1200 meters may be achieved using a maximum data rate of 94kps
  - Foundation - provides up to 32 devices on a H1 segment running at 31.25 kps, on a single twisted pair wire that can be run up to 1900 Meters, or HSE [High Speed Ethernet] which runs at 100 Mbps over standard Ethernet.
  - HART (Highway Addressable Remote Transducer) - communicates at 1200 bps and provides a host with two or more digital updates per second from a field device. Uses the Bell 202 Frequency Shift Keying (FSK) standard to superimpose digital communication signals at a low level on top of the 4-20mA

Controller Area Network (CAN)

- Controller Area Network (CAN) is a fast serial bus that is designed to provide an efficient, reliable and very economical link between sensors and actuators.
- CAN uses a twisted pair cable to communicate at speeds up to 1Mbit/s with up to 40 meters or 50Kbit/s with up to 1KM.
- Originally developed to simplify the wiring in automobiles.
- CAN fieldbuses are now used in machine and factory automation products as well.





CAN networks significantly reduce wiring.

CAN features

- Any node can access the bus when the bus is quiet. If the bus is free, any node may begin to transmit.
- Peer-to-peer and multi-cast reception
  - There is no master that controls when individual nodes have access to read and write data on the CAN bus
- Non-destructive bit-wise arbitration to allow 100% use of the bandwidth without loss of data:
  - If multiple nodes try to transmit a message onto the CAN bus at the same time, the node with the highest priority (lowest arbitration ID) automatically gets bus access.
  - Lower-priority nodes must wait until the bus becomes available before trying to transmit again.
- Variable message priority based on 11-bit (or 29 bit) packet identifier
- Automatic error detection, signaling and retries
- Data packets 8 bytes long

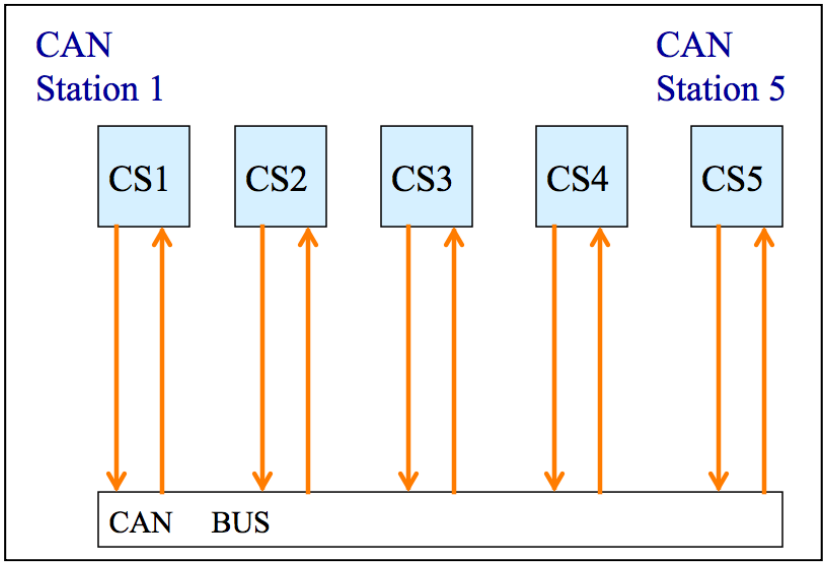
▪ **CAN Frame --** an entire CAN transmission: arbitration ID, data bytes, acknowledge bit, and so on. Frames also are referred to as *messages*.

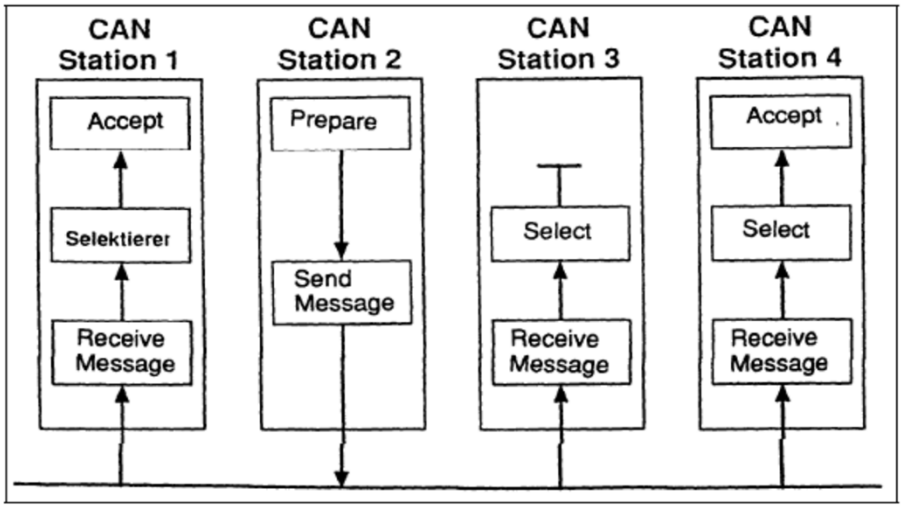
[+] Enlarge Image

Figure 2. The standard CAN frame format.

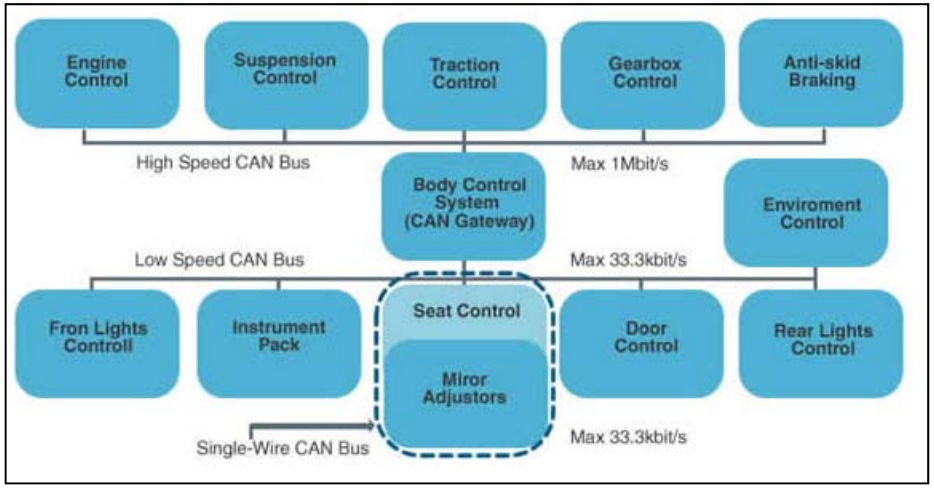
CAN architecture

Peer-to-peer and multi-cast reception.





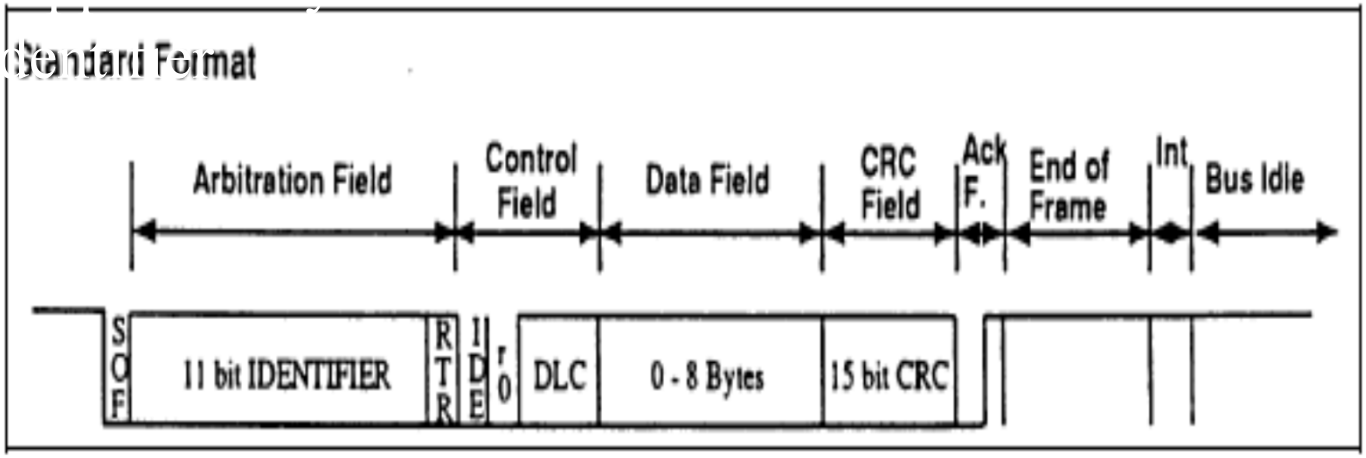
Broadcast transmission and acceptance filtering by CAN nodes



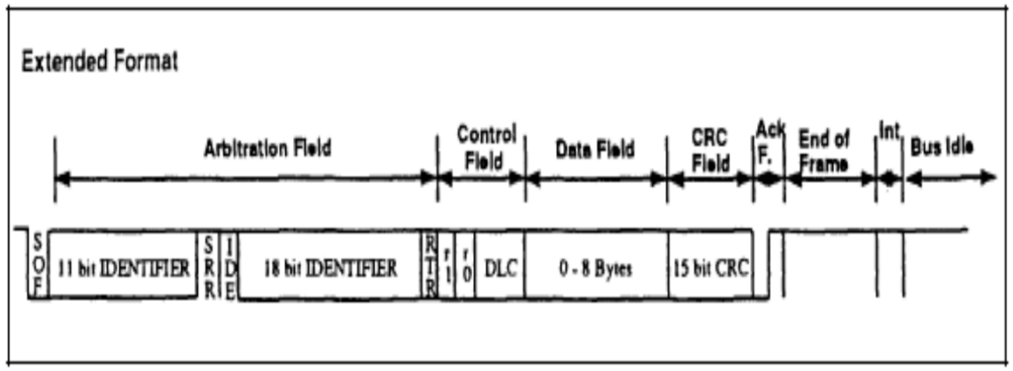
Tradeoff: CAN bus versus point-to-point connections

- By introducing one single bus as the only means of communication as opposed to the point-to-point network, we traded off the channel access simplicity for the circuit simplicity.
- Since two devices might want to transmit simultaneously, we need to have a MAC protocol to handle the situation.
- CAN manages MAC issues by using a unique identifier for each of the outgoing messages. Identifier of a message represents its priority.
- If two or more nodes begin sending messages at the same time, the message with the more dominant ID (which has more dominant bits, i.e., zeroes) will overwrite other nodes' less dominant IDs, so that eventually (after this arbitration on the ID.) only the dominant message remains and is received by all nodes.
- This mechanism is referred to as priority based bus arbitration. Messages with numerically smaller values of IDs have higher priority and are transmitted first.

CAN: message format



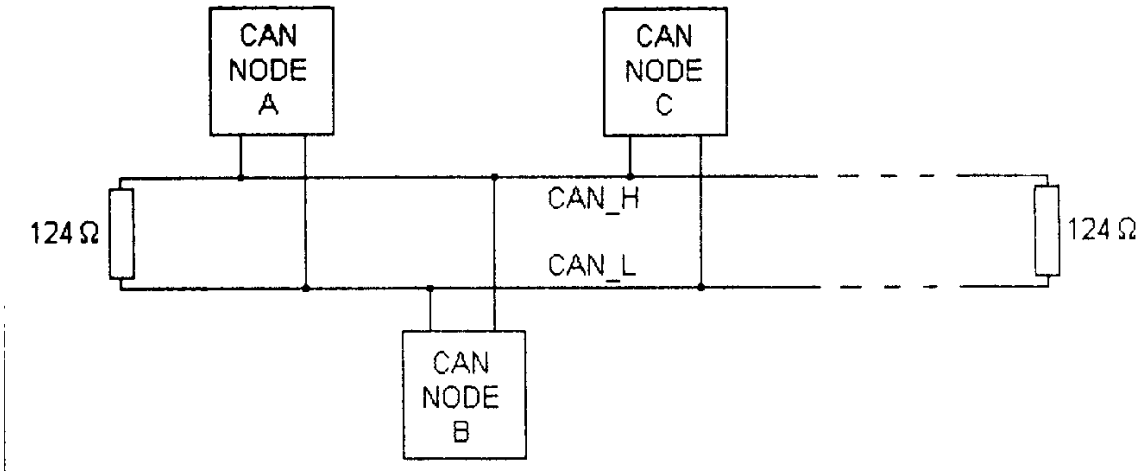
Message frame for standard format (CAN Specification 2.0A)



Message frame for standard format (CAN Specification 2.0A)

Physical CAN connection

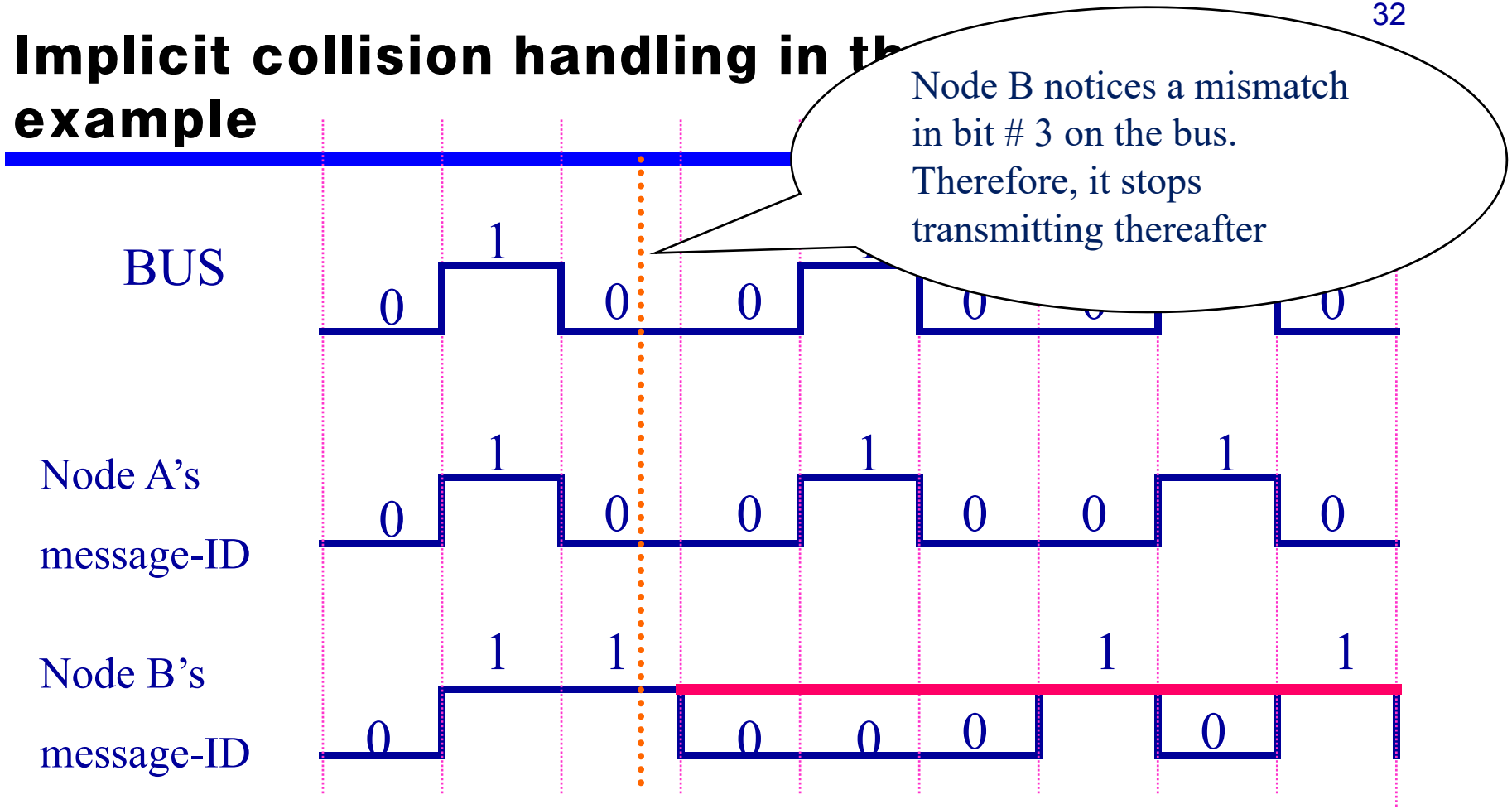
- De-facto mechanical standard for CAN requires nodes to have both male and female 9-pin D-sub connectors electrically wired to each other in parallel within the node.
  - pin 2: CAN-Low (CAN-)
  - pin 3: GND (Ground)
  - pin 7: CAN-High (CAN+)
  - pin 9: CAN V+ (Power)



Implicit collision handling in the CAN bus

- If two messages are simultaneously sent over the CAN bus, the bus takes the "logical AND" of all them
- Hence, the messages identifiers with the lowest binary number gets the highest priority
- Every device listens on the channel and backs off as and when it notices a mismatch between the bus's bit and its identifier's bit

Implicit collision handling in th example



Unlike the MAC protocols we learnt, in CAN a collision does not result in wastage of bandwidth.

Hence, CAN achieves 100% bandwidth utilization

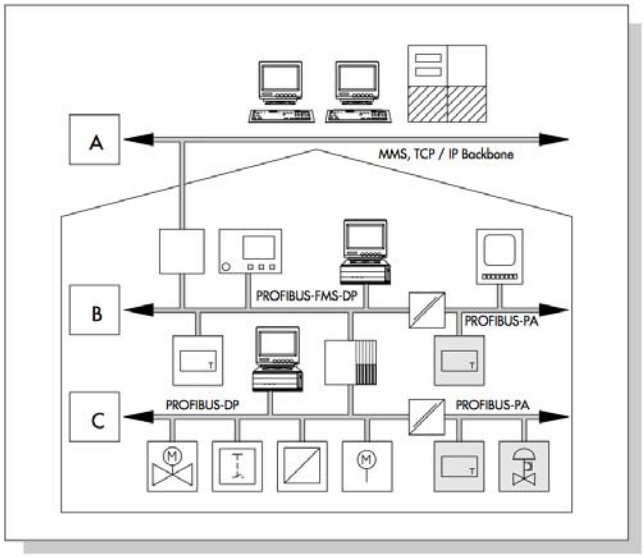
PROFIBUS (Process Field Bus)

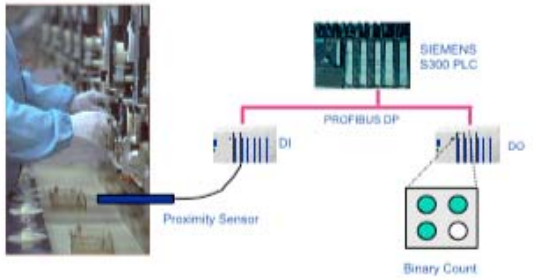
- An industrial control network used for factory automation, process control, motion control and safety networks.

The topology used is the **serial bus**, terminated at both ends.

Why? Read National Instruments Profibus Overview Reference from (http://www.ni.com/white-paper/6958/en)

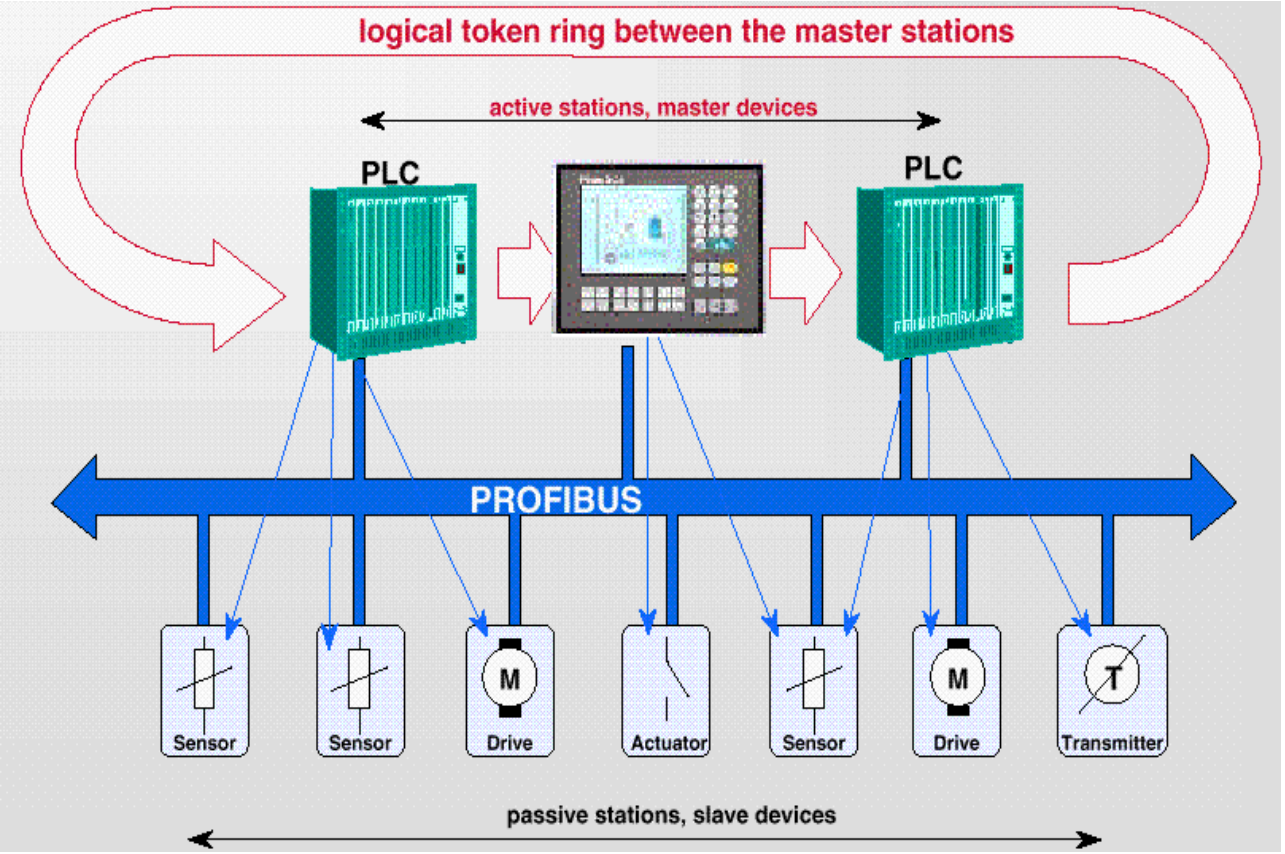
Profibus is based on the token passing and master-slave system.



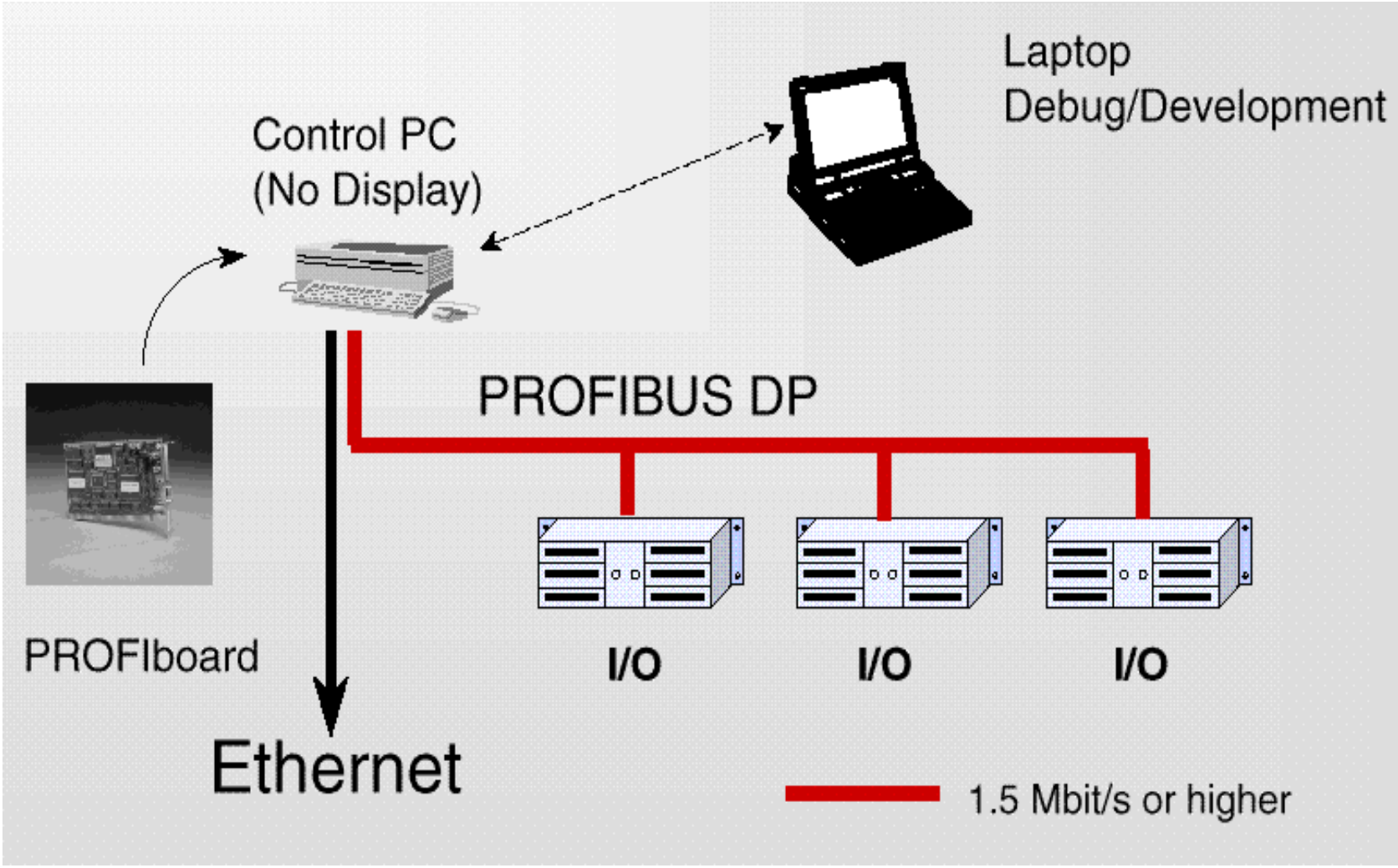


PROFIBUS - Token Ring

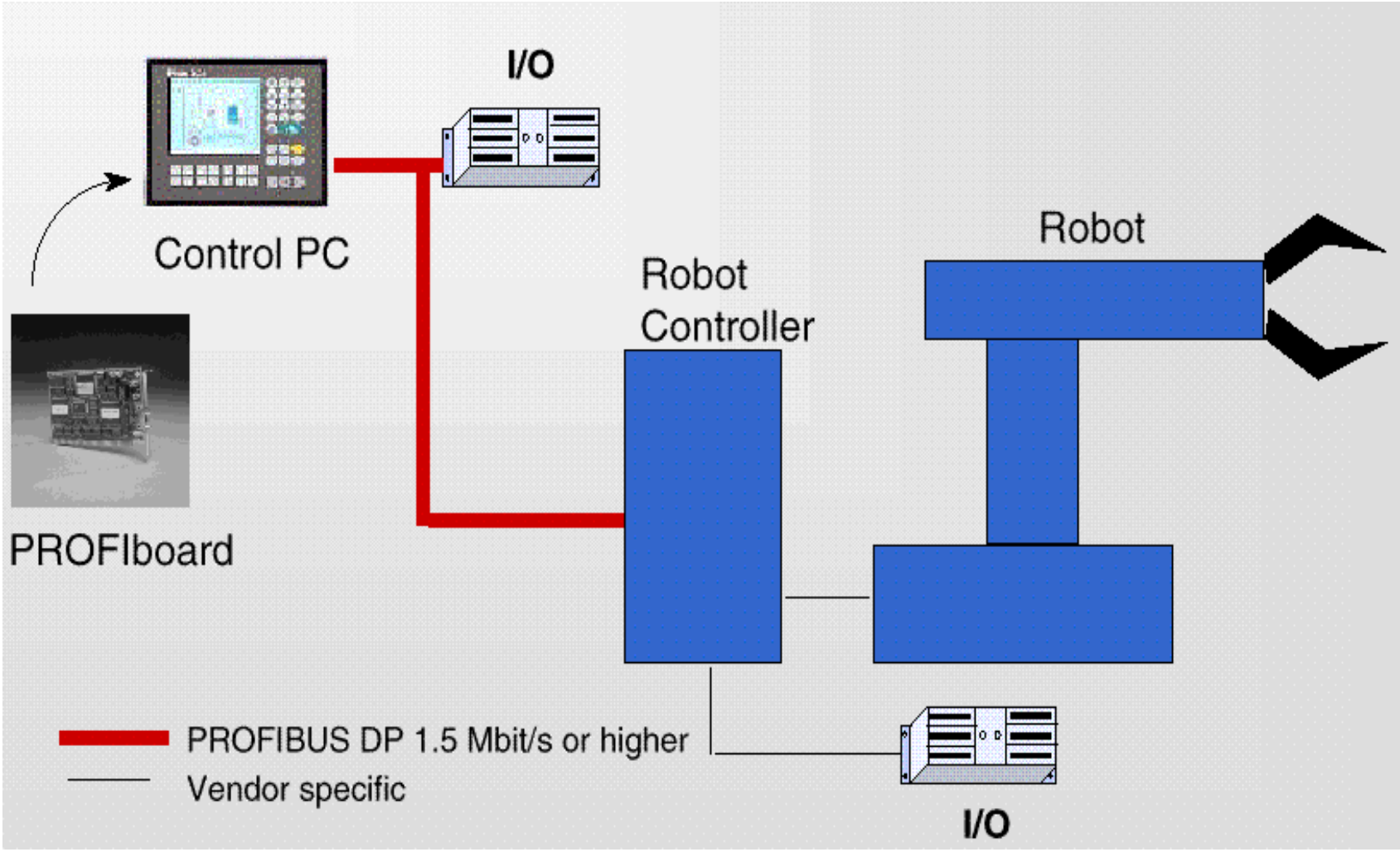
How does the token passing works?
Do slaves initiate the communication?



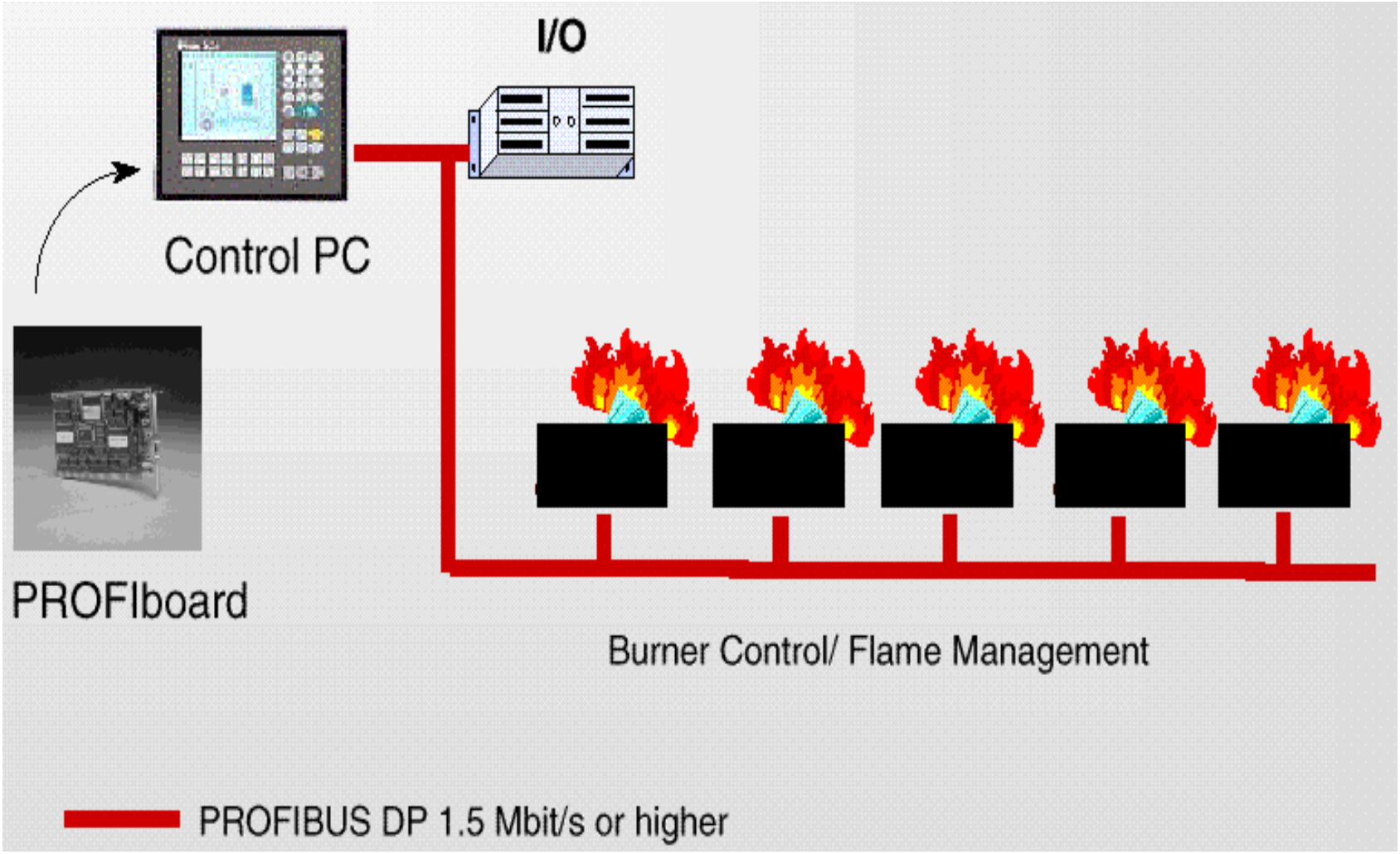
PROFIBUS – Control Applications



PROFIBUS - Robot Application

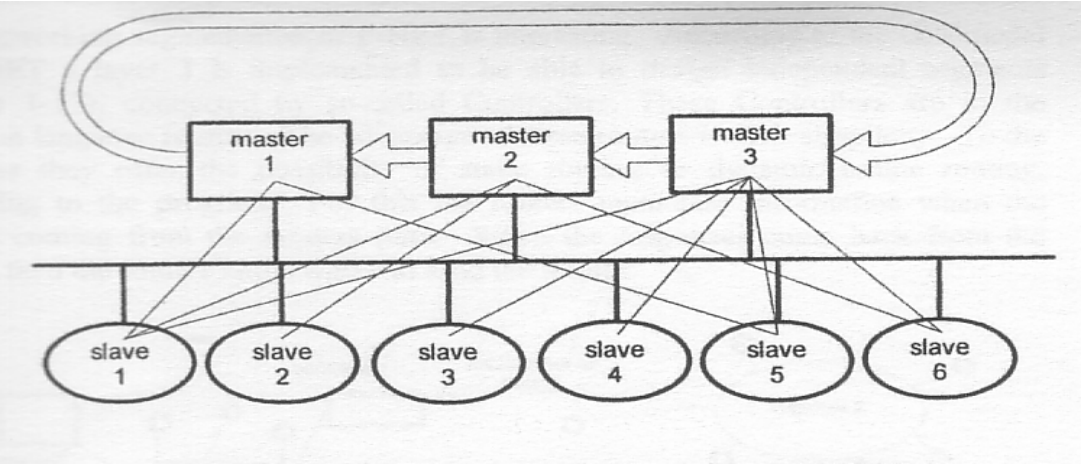


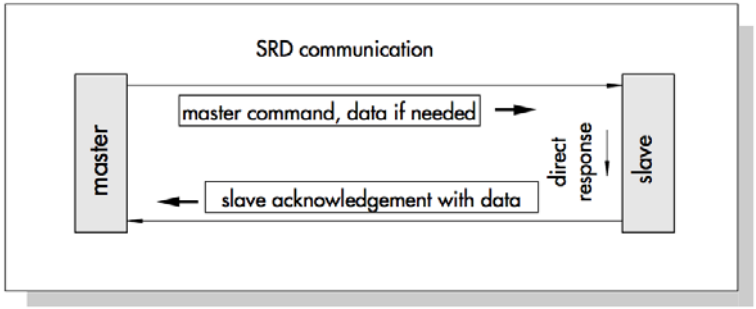
PROFIBUS - Furnace/ Oven



PROFIBUS (Process Field Bus)

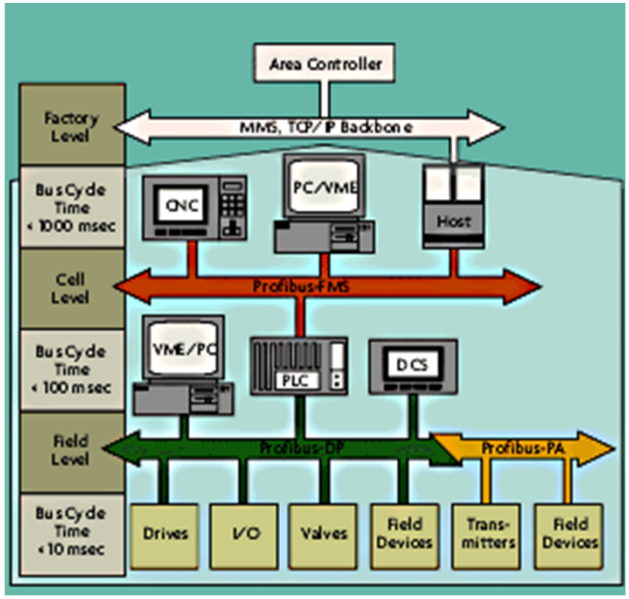
- **Master-slave method**. The Profibus is a network that is made up of two types of devices connected to the bus: master devices and slave devices. It is a bidirectional network, meaning that one device, a master, sends a request to a slave, and the slave responds to that request. Thus, bus contention is not a problem because only one master can control the bus at any time, and a slave device must respond immediately to a request from a master.
- Each master receives the token within a precisely defined time frame which allows him to have sole control over the communication network within that time frame.
- Because a request from a master to a slave device is heard by all devices attached to the bus, some mechanism must exist for a slave device to recognize that a message is designated for it and then respond to the sender. Hence, each device on a PROFIBUS network must have an assigned address.
- A 7-bit device address serves to identify the bus participants in the network. The addresses range from 0 to 127, and the following are reserved: 126: default for automatic address assignment via the master; 127: sending broadcast telegrams.





PROFIBUS (Process Field Bus)

- Origin: Profibus FMS (Field bus Message Specification)
  - was tailored for demanding communication tasks
  - Subsequently in 1993, the specification for the simpler and thus considerably faster protocol PROFIBUS DP (Decentralized Peripherals) was completed.
- Two variations of PROFIBUS
  - **PROFIBUS DP** (Decentralized Peripherals)
  - **PROFIBUS PA** (Process Automation)



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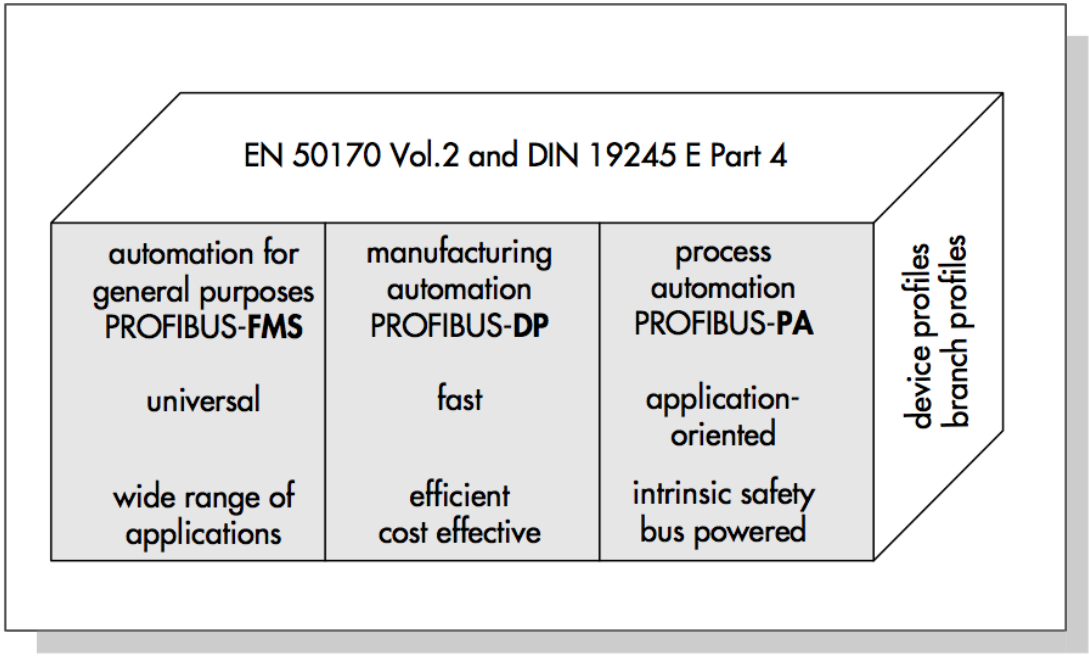


Source: http://www.samson.de/pdf_en/l453en.pdf

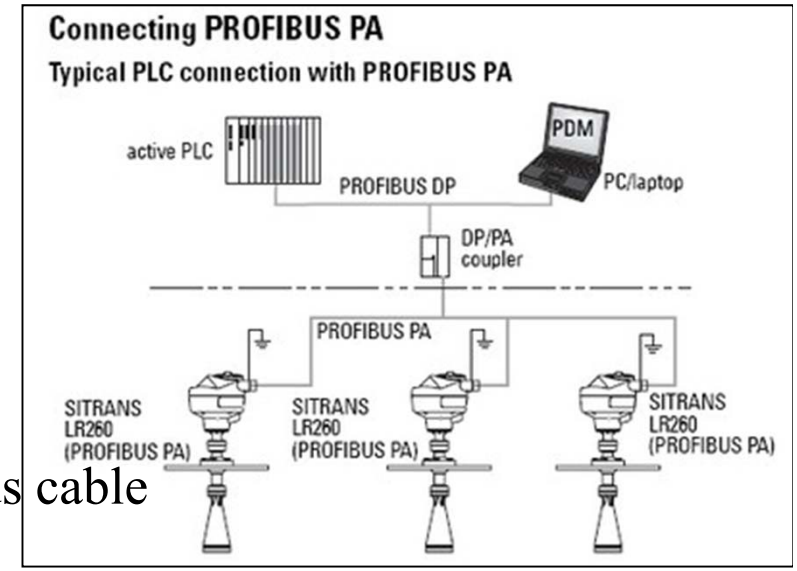
PROFIBUS (Process Field Bus)

- **PROFIBUS DP** (Decentralized Peripherals)
- used to operate sensors and actuators via a centralized controller in production technology. The many standard diagnostic options, in particular, are focused on here.
- PROFIBUS-DP for high speed requires less than 2 ms for the transmission of 1 Kbyte of input and output data. In this way even extremely time-critical communication tasks can be solved.

PROFIBUS (Process Field Bus)

PROFIBUS PA (Process Automation)

- used to monitor measuring equipment via a process control system in process engineering.



Intrinsic Safety: This PROFIBUS variant is ideal for explosion-hazardous. A weak current flows through bus lines in an intrinsically safe circuit so that explosive sparks are not created, even if a malfunction occurs.

Bus Supply: field devices are powered over the bus cable

Up to 32 devices per line segment (in hazardous areas depending on the supply current

In compliance with IEC 61158-2 which was specified especially for explosion-hazardous areas and power supply over the bus.

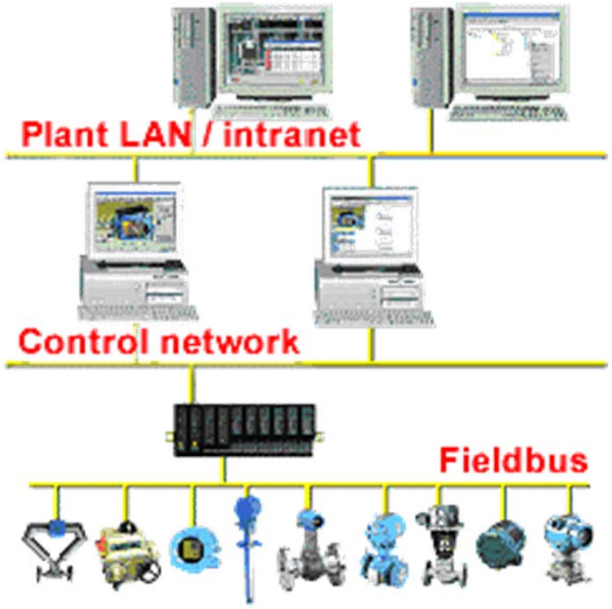
PROFIBUS (Process Field Bus)

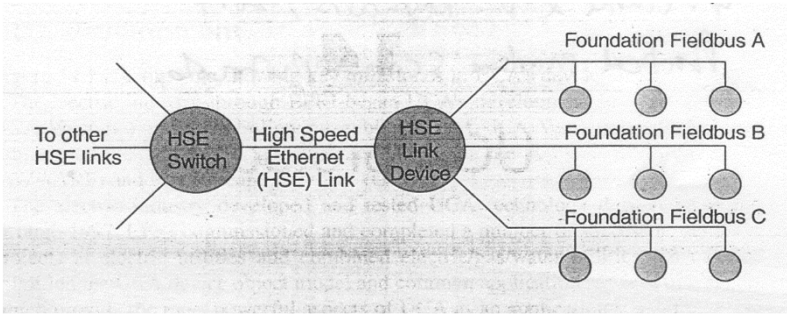
Bit-transmission layer

- EIA-485:
  - ✓ Bit rates from 9.6 kbit/s to 12 Mbit/s can be used.
  - ✓ The cable length between two repeaters is limited to 100 to 1200 m, depending on the bit rate used. This transmission method is primarily used with PROFIBUS DP.
- Fiber Optics:
  - ✓ Star-, bus- and ring-topologies are used.
  - ✓ The distance between the repeaters can be up to 15 km.
- Manchester Bus Powered(MBP)
  - ✓ The bus topology can be up to 1900 m long and permits branching to field devices (max. 60 m branches).
  - ✓ The bit rate here is a fixed 31.25 kbit/s.
  - ✓ This technology was specially established for use in process automation for PROFIBUS PA.

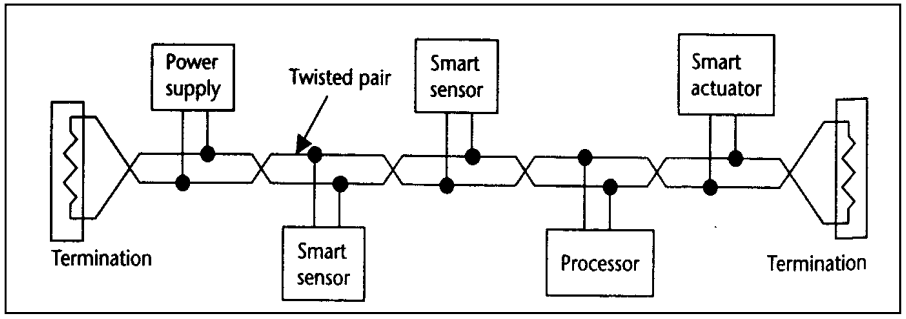
FOUNDATION fieldbus

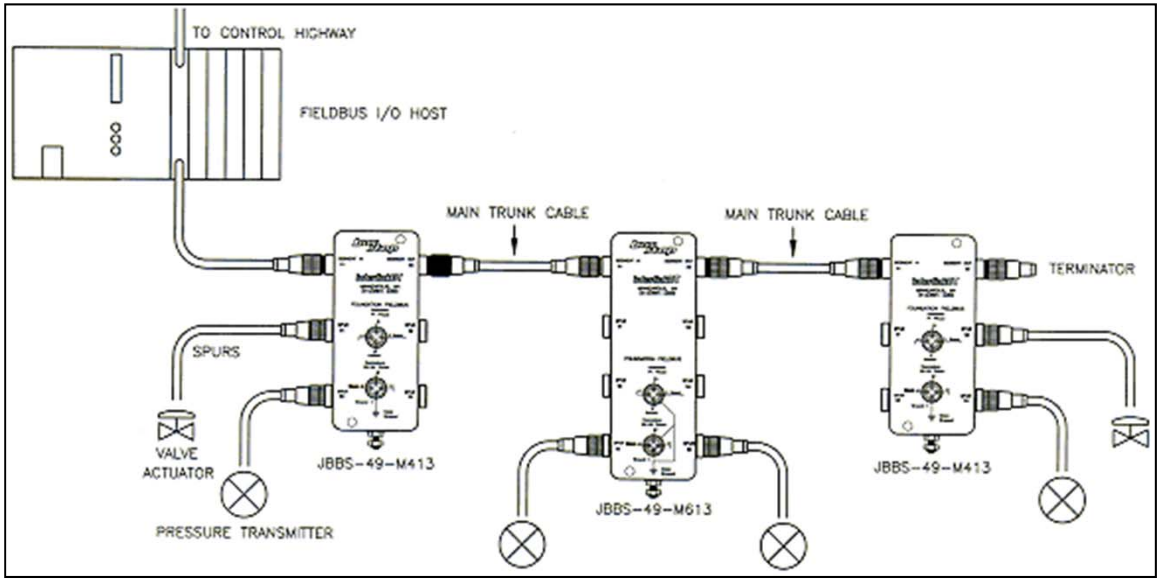
- FOUNDATION fieldbus is an all-digital, serial, two-way communications system that serves as the base-level network in a plant or factory automation environment.
- Two implementations:
  - H1 works at 31.25 Kbit/sec and generally connects to field devices.
  - HSE (High-speed Ethernet) works at 100 Mbit/sec

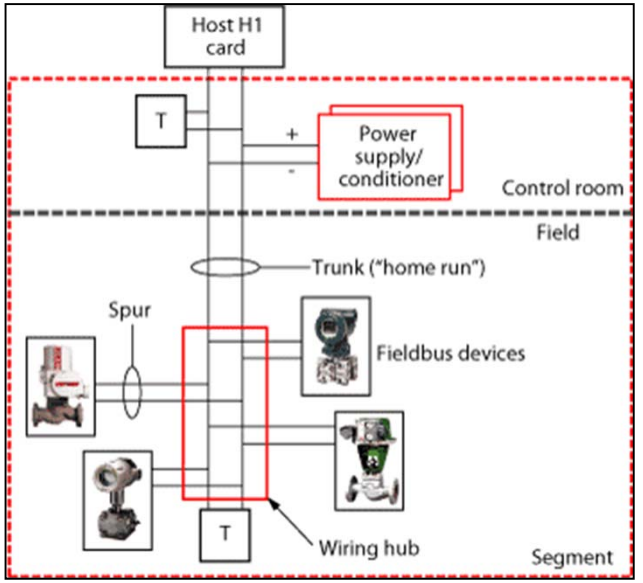




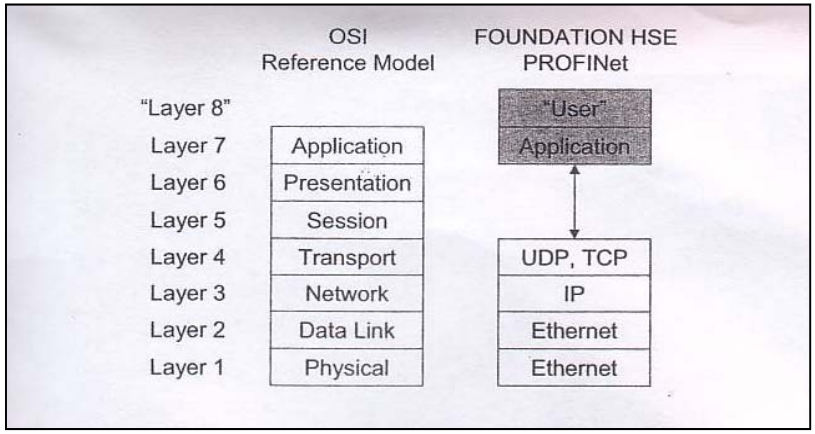
FOUNDATION fieldbus

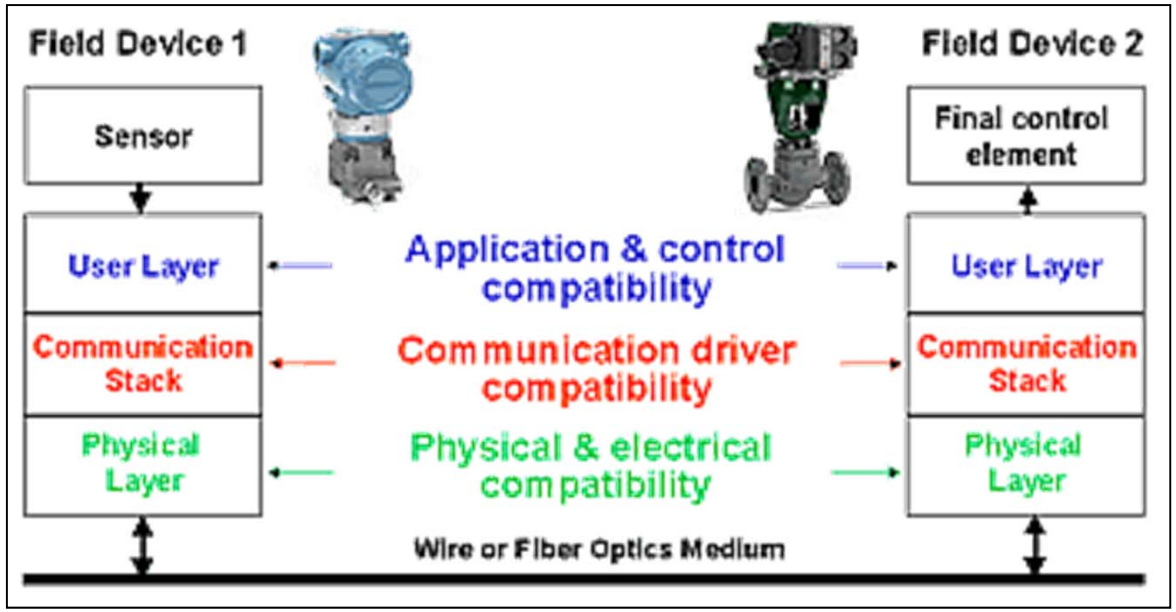




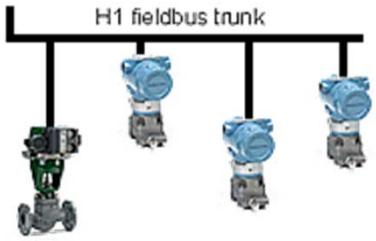


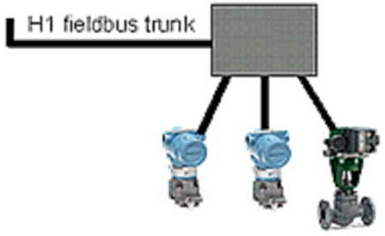
Interoperability

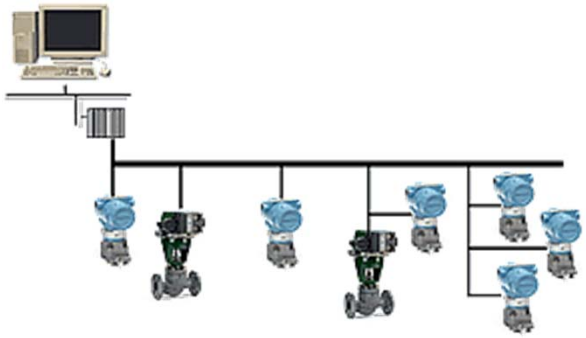


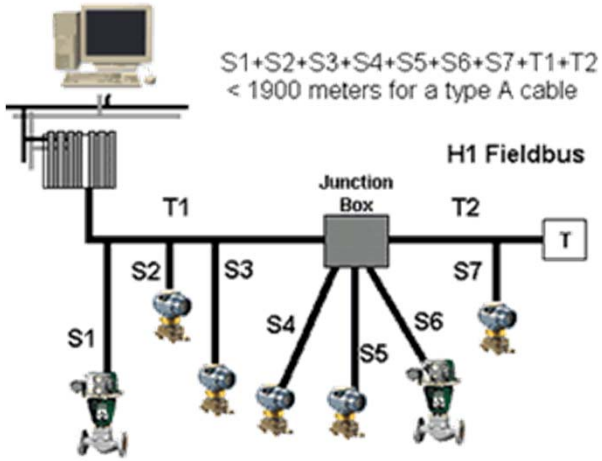


Wiring and Segment Length









FOUNDATION fieldbus