Process Field Bus

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Timeline

1986

- Master development plan “fieldbus” created in Germany
- 21 companies, including Siemens, involved

1989

- First promoted by *Bundesministerium für Bildung und Forschung (BMBF)*
- Goal to implement a bit-serial field bus for factory and process automation

1999

- Published openly as part of standard **IEC 61158** *Digital data communication for measurement and control - Fieldbus for use in industrial control systems*

System Structure: Introduction

- *Profibus* is a multi-master system
- Operation of multiple systems over a single bus
- Three protocols available
  - FMS *(field-bus message specification)*
  - DP *(decentralized peripheral)*
  - PA *(process automation)*
- Devices are categorized in different types
  - Masters
  - Slaves

System Structure: Layer

Profibus in the OSI reference model [1]

Layer	**Name**	**Content**
Layer 8	User Layer	Profiles
Layer 7	Application Layer	FMS / DP / PA protocol
Layer 2	Data Link Layer	FDL protocol
Layer 1	Physical Layer	Transmission Technology

Device Type: Master

- Active station
- Control the data traffic on the bus
- When having the *bus access token*:
  send messages without external requests

Device Type: Slave

- Passive station
- No self-initiated bus access
- Immediate response to data requested by a master
- Can only be controlled by a single master

Physical Layer

- *Profibus FMS* and *Profibus DP*
  - Mostly using RS 485 transmission
  - Optical transmission via FOC *(fibre optical cable)* possible
- *Profibus PA*
  - Uses MBP *(Manchester bus powered)*, providing power supply

Type	Transmission technology
0	copper cable with RS 485
1	synchronous MBP
2	synthetic FOC
3	glass FOC
4	HCS FOC

Transmission technology (IRC 61784) [1]

Physical Layer: RS 485

- Bus-topology
- Twisted-pair cables with 150Ω
- Data rates from $9.6 kbit/s$ to $12 Mbit/s$
- Distance between repeaters $100m$ to $1200m$
- UART coding
  - Start = 0, Parity = EVEN, Stop = 1
  -

Start	Databit 1	2	3	4	5	6	7	8	Parity	Stop

Mainly used with *Profibus DP*

Physical Layer: FOC

- Star-, bus or ring-topology
- Fibre optical cables
- Distance between repeaters up to 15km

Physical Layer: MBP

- Bus-topology
- Stations are powered through the bus
- Safe in explosion-hazardous environments, power can be reduced to a bare minimum
- Data rate is fixed to $31.25 kbit/s$
- Bus length up to $1900m$
- Allows branches up to $60m$ to field devices
- Manchester coding

Physical Layer: MBP

Manchester coding

- Every bit is coded as a change
  - Positive change: “0”
  - Negative change: “1”
  - Every bit has the same average value
  - Average used to power the peripherals
  - Time synchronization possible with every bit

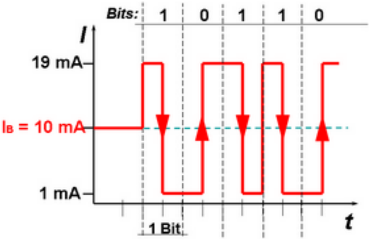

Figure: Manchester coding

Mainly used with *Profibus PA*

Data Link Layer

The data transmission in *Profibus* is handled by the *fieldbus data link (FDL)* layer.
FDL consists of three functions:

- Medium Access Control *(MAC)*
- Fieldbus Link Control *(FLC)*
- Fieldbus Management *(FMA)*

Data Link Layer: MAC

- Make sure only one station transmits data on the bus
- When multiple masters are present
  - Masters need the access token to send data
  - Token is cyclically passed via token telegram
  - To ensure that all master stations can access the bus, token must be passed on after a certain timeout
- Slaves only respond to requests by a master

Profibus FDL combines master-slave and token passing in a hybrid access principle

Data Link Layer: FMA

Fieldbus Management provides function to manage the layer 1 and 2

- Reset the layers
- Set parameters
- Get parameters
- Inform the user about events or errors
- Activate/Deactivate *service access point (SAP)*

Data Link Layer: Error handling

Errors can be caused by

- Faulty transmitters
- Badly shielded cables
- Signal reflections
- Large divergences in time synchronization between stations

Error rate is smaller than 10^{-4} and can be reduced further by error detection and correction

Data Link Layer: Error detection and correction

Error Detection

- Hamming distance of 4 by adding a checksum to each packet
- At least 4 bits must change to result in an undetected error
- This results in *integrity class 2* after standard **IEC 870-5-1**

Send Data with No acknowledge (SDN) service

- Mainly used for synchronization and status messages
- The erroneous telegram is discarded
- Telegram from the next cycle is used instead

Data Link Layer: Error detection and correction

Send Data with Acknowledge (SDA)

- Mainly used between masters, slaves may not always send an acknowledgement
- When the sender does not get a response, the telegram is retransmitted

Send and Request Data (SRD)

- Service used between masters and slaves
- Acknowledgement is packed on top of the data telegram
- When the sender does not get a response, the telegram is retransmitted

Application Layer: Addressing

- Every station has a unique address, coded in 1 byte

Address	**Use**
0	reserved for tools, e.g. programming devices
$1 - n$	*n* master stations
$n - 125$	slave stations
126	reserved as *delivery address*
	used for changing the address of a slave during runtime
127	reserved as broadcast address

Components used for the infrastructure, e.g. repeaters transmit the data transparently and do not require an address

Application Layer: Telegram Formats

- Without data field
- Variable length from 4 – 249 byte, payload 1 – 246 byte

SD2	LE	LEr	SD2	DA	SA	FC	PDU	FCS	ED

SD2: Delimiter, LE: Length, LEr: Length repeated, DA: Destination Address, SA: Source Address, FC: Function Code, PDU: Protocol Data Unit, FCS: Frame Check Sequence, ED: End Delimiter

- Fixed payload length of 8 bytes
- Token telegram
- Short telegram
- Telegram Delimiter, featuring a Hamming distance of 4

SD1	SD2	SD3	SD4	ED	SC
0x10	0x68	0xA2	0xDC	0x16	0xE5

Application Layer: FMS

- FMS master controls the relationship with FMS slaves
- Replaced by *Profibus DP*

Application Layer: DP

- *Profibus DP* masters are separated into classes
  - Class 1: control a DP system and the slaves assigned, mostly PLC based
  - Class 2: tool for commissioning, engineering and maintenance, mostly PC based
  - Class 3: clock master, used for time synchronization

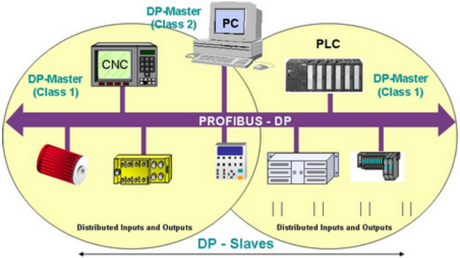

Figure: Structure of a DP system [1]

Application Layer: DP - Cyclic process data

Data exchange between masters and slaves is separated into three phases: [1]

Phase	Action
Diagnosis	Master requests diagnostic data from slaves
Initialization	Master sets parameters and checks configuration of slaves
Data Exchange	Master sends and requests data from the slaves

Application Layer: DP - Data Exchange

Class 1 master station:

- Relationship with a slave is called *MS0*
- Data exchange is cyclic
- Master sends output data to a slave
- Slave immediately responds with input data
- Master continues with the next slave or restarts the cycle

The minimum cycle time T_{BCycle} can be calculated:

$$T_{BCycle} = \frac{380 + (N_{Slaves} \cdot 300) + (N_{Bytes} \cdot 11)}{Bitrate} + 75\mu s \qquad (1)$$

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Application Layer: DP - Data Exchange

Class 2 master station:

- Can exist in addition class 1 masters
- Can simultaneously be a class 1 master
- Relationship with a slave is called *MS1*
- Acyclic communication with a slave in an existing MS0 relationship

Application Layer: PA

- Uses the same protocol as *Profibus DP*
- Can be connected to an existing *Profibus DP* network
  - Using a DP/PA coupler
  - The faster *DP* network is used as a backbone

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