3 Industrial Communication Systems

Field bus: standards

3.3 *Bus de terrain standard*

Standard-Feldbusse

Prof. Dr. H. Kirrmann
ABB Research Center, Baden, Switzerland

Field busses: Standard field busses

3.1 Field bus types
- Classes
- Physical layer
- Networking

3.2 Field bus operation
- Centralized - Decentralized
- Cyclic and Event Driven Operation

3.3 Field bus standards
- International standard(s)
- HART
- ASI
- Interbus-S
- CAN
- Profibus
- LON
- Ethernet
- Automotive Busses

Which field bus ?

- A-bus
- Arcnet
- Arinc 625
* • ASI
- Batibus
- Bitbus
* • CAN
- ControlNet
- DeviceNet
- DIN V 43322
- DIN 66348 (Meßbus)
- FAIS
- EIB
- Ethernet
- Factor
- Fieldbus Foundation
- FIP
- Hart
- IEC 61158
- IEEE 1118 (Bitbus)
- Instabus
* • Interbus-S
- ISA SP50
- IsiBus
- IHS
- ISP
- J-1708
- J-1850
- LAC
* • LON
- MAP
- Master FB
- MB90
- MIL 1553
- MODBUS
* • MVB
- P13/42
- P14
- Partnerbus
- P-net
* • Profibus-FMS
- Profibus-PA
- Profibus-DP
- PDV
* • SERCOS
- SDS
- Sigma-i
- Sinec H1
- Sinec L1
- Spabus
- Suconet
- VAN
- WorldFIP
- ZB10
- ...

Worldwide most popular field busses

Bus	User*	Application	Sponsor
CANs	25%	Automotive, Process control	CiA, OVDA, Honeywell
Profibus (3 kinds)	26%	Process control	Siemens, ABB
LON	6%	Building systems	Echelon, ABB
Ethernet	50%	Plant bus	all
Interbus-S	7%	Manufacturing	Phoenix Contact
Fieldbus Foundation, HART	7%	Chemical Industry	Fisher-Rosemount, ABB
ASI	9%	Building Systems	Siemens
Modbus	22%	obsolete point-to-point	many
ControlNet	14%	plant bus	Rockwell

*source: ISA, Jim Pinto (1999)

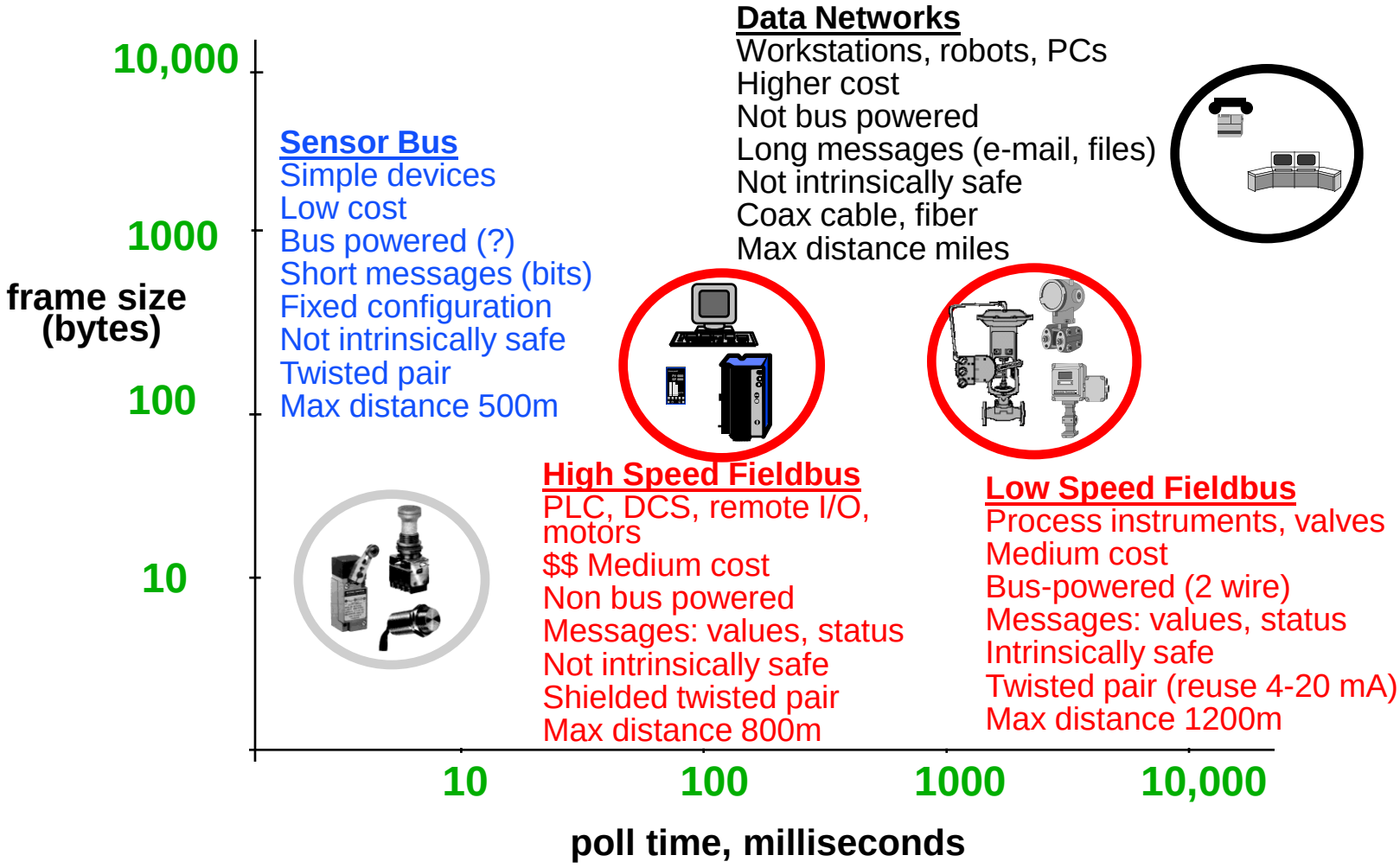
Sum > 100%, since firms support more than one bus

European market in 2002: 199 Mio €, 16.6 % increase (Profibus: 1/3 market share)

**source: Elektronik, Heft 7 2002

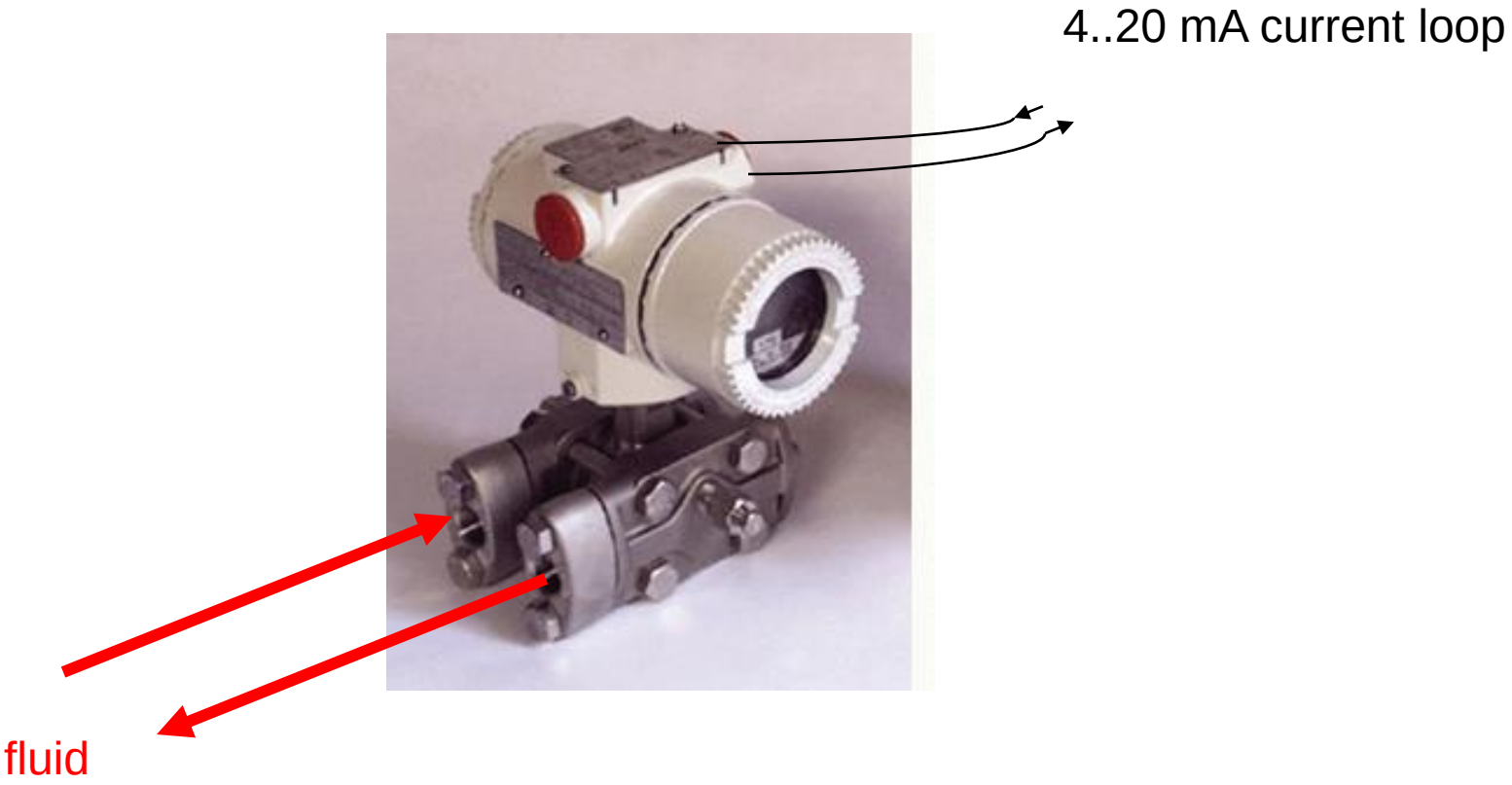
Different classes of field busses

One bus type cannot serve all applications and all device types efficiently...



source: ABB

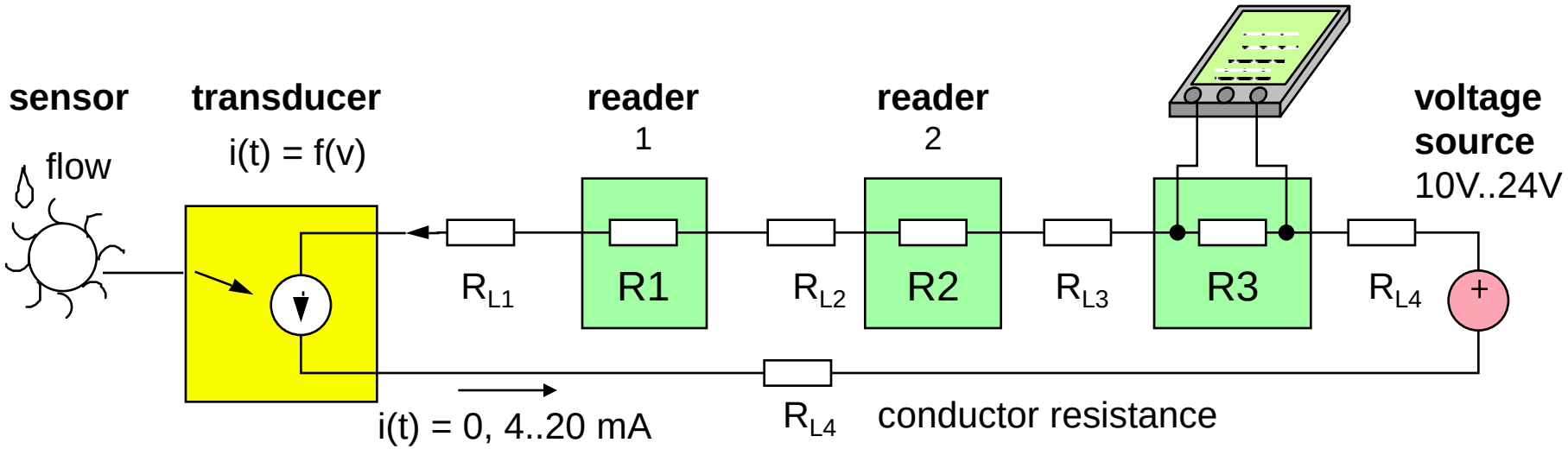
Field device: example differential pressure transducer



The device transmits its value by means of a current loop

4-20 mA loop - the conventional, analog standard (recall)

The 4-20 mA is the most common analog transmission standard in industry



The transducer limits the current to a value between 4 mA and 20 mA, proportional to the measured value, while 0 mA signals an error (wire break)

The voltage drop along the cable and the number of readers induces no error.

Simple devices are powered directly by the residual current (4mA), allowing to transmit signal **and** power through a single pair of wires.

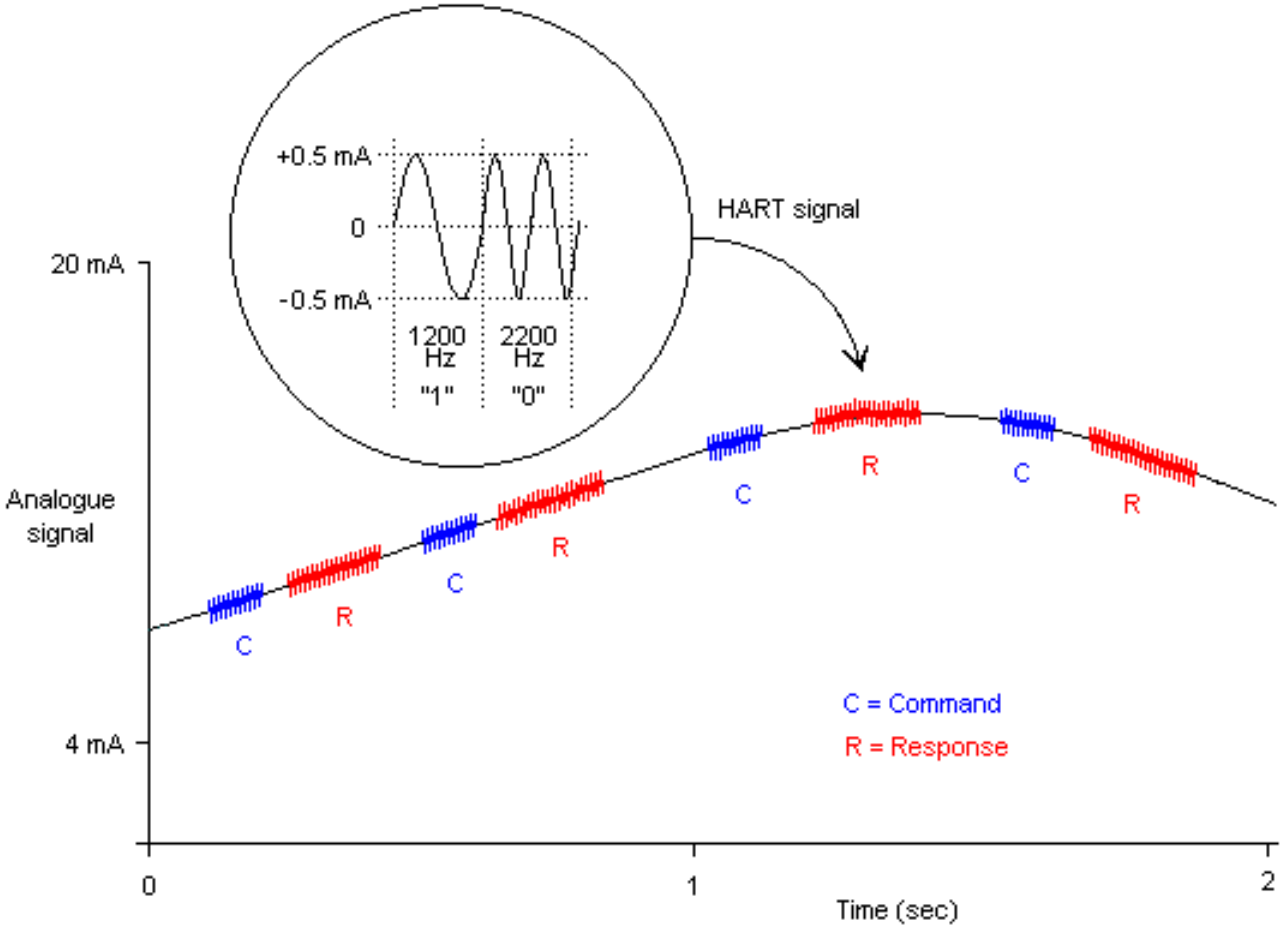
Remember: 4-20mA is basically a point-to-point communication (one source)

3.3.2 HART

Data over 4..20 mA loops

HART - Principle

HART (Highway Addressable Remote Transducer) was developed by Fisher-Rosemount to retrofit 4-to-20mA current loop transducers with digital data communication.



HART modulates the 4-20mA current with a low-level frequency-shift-keyed (FSK) sine-wave signal, without affecting the average analogue signal.

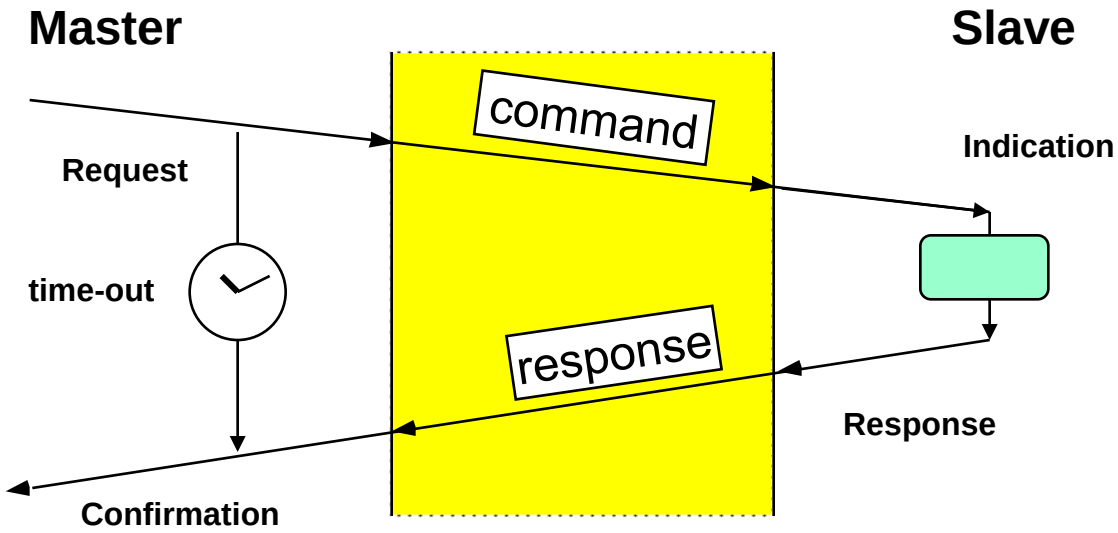
HART uses low frequencies (1200Hz and 2200 Hz) to deal with poor cabling, its rate is 1200 Bd - but sufficient.

HART uses Bell 202 modem technology, ADSL technology was not available in 1989, at the time HART was designed

Transmission of device characteristics is normally not real-time critical

HART - Protocol

Hart communicates point-to-point, under the control of a master, e.g. a hand-held device



Hart frame format (character-oriented):

preamble	start	address	command	bytecount	[status]	data	data	checksum
5..20 (xFF)	1	1..5	1	1	[2] (slave response)	0..25 (recommended)		1

HART - Commands

Universal commands (mandatory):

- identification,
- primary measured variable and unit (floating point format)
- loop current value (%) = same info as current loop
- read current and up to four predefined process variables
- write short polling address
- sensor serial number
- instrument manufacturer, model, tag, serial number, descriptor,
- range limits, …

Common practice (optional)

- time constants, range,
- EEPROM control, diagnostics,…

total: 44 standard commands, plus user-defined commands

Transducer-specific (user-defined)

- calibration data,
- trimming,…

HART - Importance

Practically all 4..20mA devices come equipped with HART today

About 40 Mio devices are sold per year.

more info: http://www.hartcomm.org/

http://www.thehartbook.com/default.asp

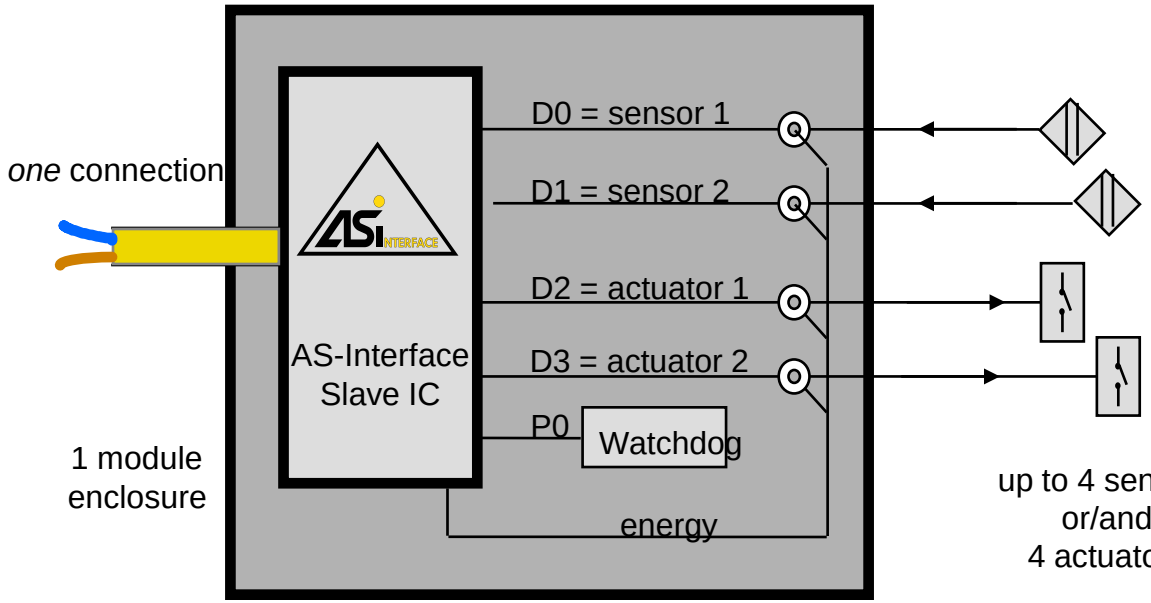
3.3.3 ASI

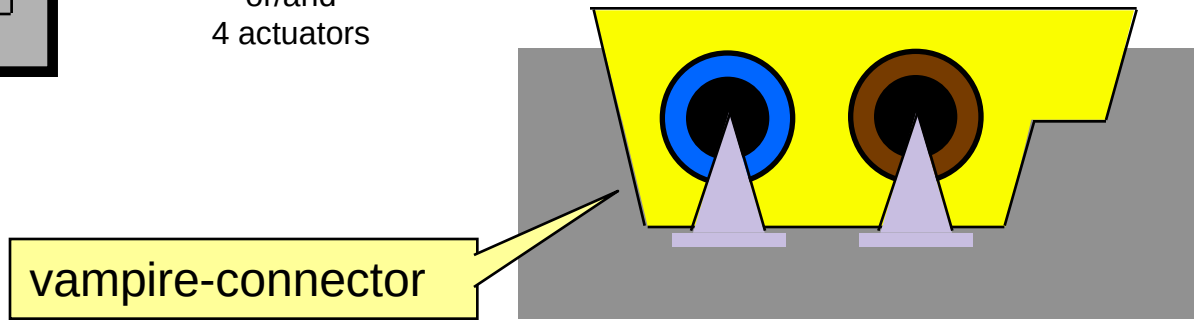
Small installation bus

ASI (1) - Sensor bus Wiring

ASI = Actor-Sensor Interface
Very simple sensor bus for building automation, combining power and data on the same wires, transmitting mostly binary signals

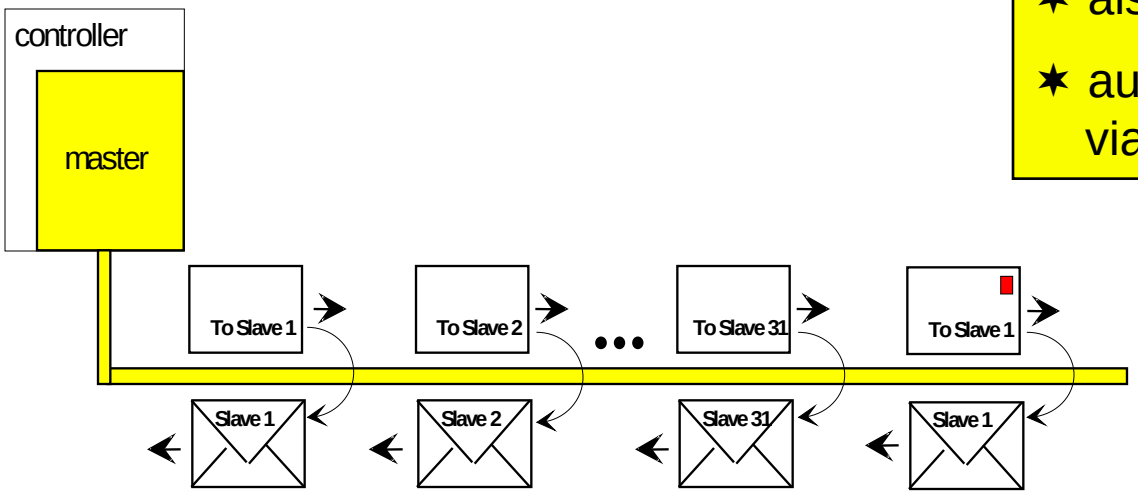
- **mechanically coded flat cable**
  - **two wires for data and power**
- **insulation piercing connectors**
  - **simple & safe**
  - **protection class up to IP67, even after disconnecting**
- **directly connected slaves**
  - **sensors, actuators**
  - **valve terminals**
  - **electrical modules etc.**



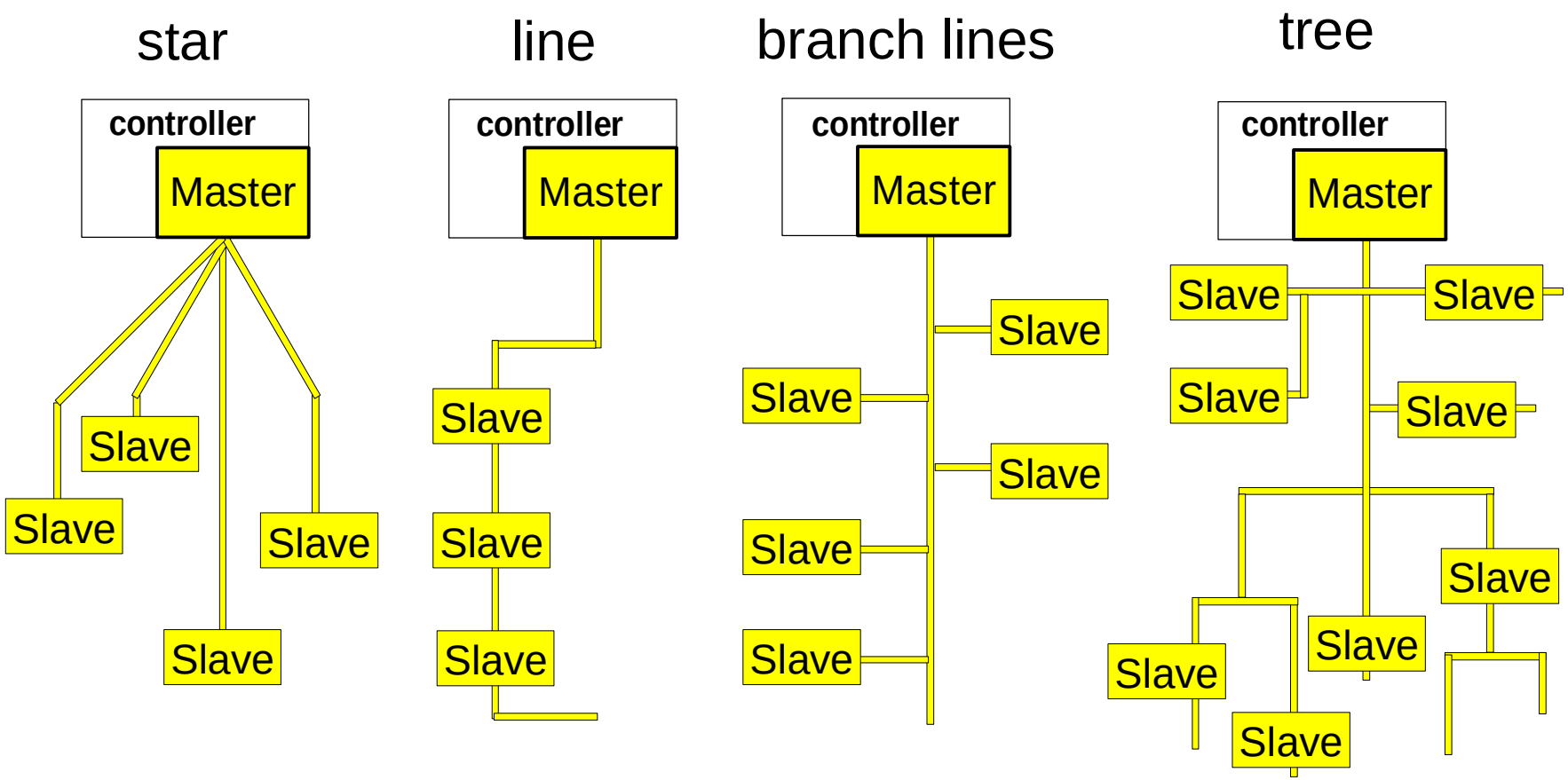


ASI (2) - Data sheet

- ✶ master-slave principle
- ✶ up to 31 slaves on one line
- ✶ cycle time < 5 ms
- ✶ each slave can have up to 4 digital inputs + 4 digital outputs
- ✶ additional 4 parameter bits / slave
- ✶ Max. 248 digital Inputs and Outputs
- ✶ also possible: analogue I/O (but ..)
- ✶ automatic address numbering via bus connection



ASI (3) - Topography



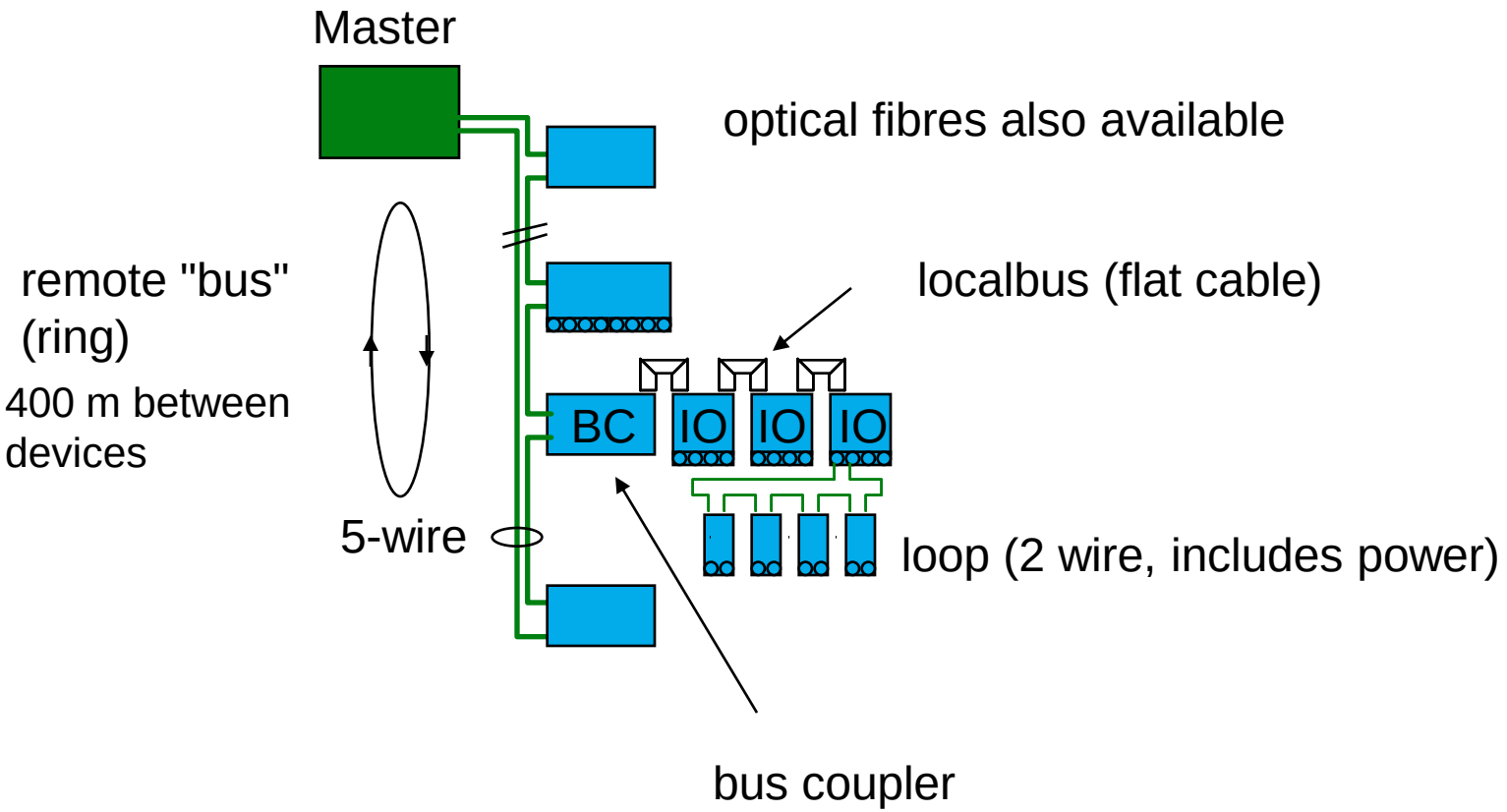
- ✶ unshielded 2-wire cable
- ✶ data and power on one cable
- ✶ extension: 100 m (300 m with extender)

- ✶ no terminating resistor necessary
- ✶ free tree structure of network
- ✶ protection class up to IP67

3.3.4 Interbus-S

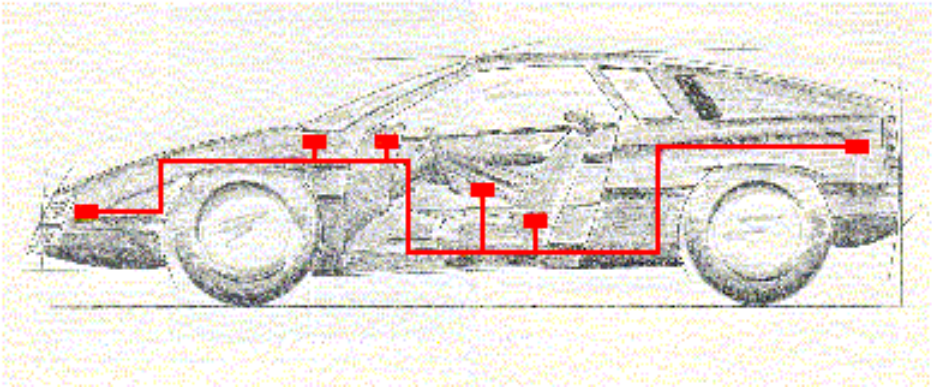
Discrete Manufacturing bus

Interbus-S (2) - Topology



Interbus-S (4) - Analysis

+	-
+ standard in CENELEC	– market centered on manufacturing
+ 1700 products, 270 manufacturers, 375.000 applications	– limited number of variables (4096 bits)
+ good experience in field wiring (intelligent wiring bar)	– ring structure sensitive to disruptions
+ easy to engineer	– sensitive to misplacement
+ easy to program (IEC 61131)	– clumsy and slow message service
+ far extension (400m .. 13 km)	– medium user community
+ good response time	– few and costly tools
+ conformance test	– strong ties to Phoenix Contact



3.3.5 CAN

Automotive bus

CAN (1) - Data Sheet

Supporters	Automotive industry, Intel/Bosch, Honeywell, Allen-Bradley
Standard	SAE (automotive), ISO11898 (only drivers), IEC 61158-x (?)
Medium	dominant-recessive (fibre, open collector), ISO 11898
Medium redundancy	none
Connector	unspecified
Distance	40m @ 1 Mb/s (A); 400m @ 100kb/s (B); 1000m @ 25kb/s (B)
Repeaters	unspecified (useless)
Encoding	NRZ, bit stuffing
User bits in frame	64
Mastership	multi-master, 12-bit bisection, bit-wise arbitration
Mastership redundancy	none (use device redundancy)
Link layer control	connectionless (command/reply/acknowledgement)
Upper layers	no transport, no session, implicit presentation
Application Protocols	CAL, SDS, DeviceNet (profiles)
Chips	comes free with processor (Intel: 82527, 8xC196CA; Philips: 82C200, 8xC592; Motorola: 68HC05X4, 68HC705X32; Siemens: SAB-C167

CAN (2) - Analysis

+	”Unix" of the fieldbus world.	-

+ strong market presence, Nr 1 in USA (> 12 Mio chips per year)

+ supported by user organisations ODVA, Honeywell, AB.

+ numerous low cost chips, come free with many embedded controllers

+ application layer definition

+ application layer profiles

+ bus analyzers and configuration tools available

+ Market: industrial automation, automobiles

– limited product distance x rate (40 m x Mbit/s)

– sluggish real-time response (2.5 ms)

– non-deterministic medium access

– several incompatible application layers (CiA, DeviceNet, SDS)

– strongly protected by patents (Bosch)

– interoperability questionable (too many different implementations)

– small data size and limited number of registers in the chips.

– no standard message services.

3.3.6 Profibus

The process bus

Profibus - Family

PROFIBUS-DP (Distributed Processing)

Designed for communication between programmable logic controllers and decentralized I/O, basically under the control of a single master
Replaces parallel signal transmission with 24 V or 0 to 20 mA by " intelligent DIN rail"

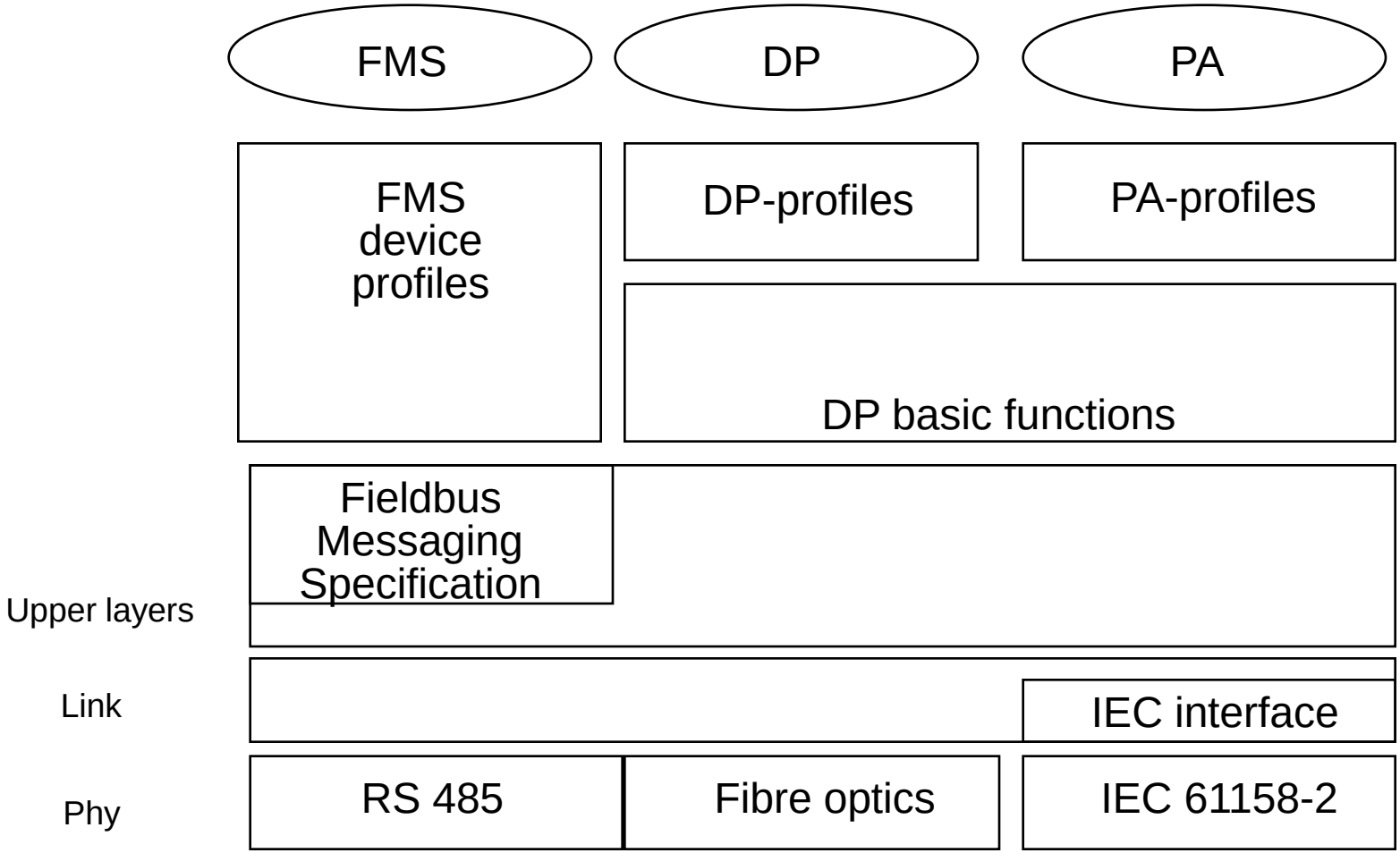
PROFIBUS-PA (Process Automation)

Permits data communication and power over the bus using 2-wire
Connects sensors and actors on one common bus line even in intrinsically-safe areas. (chemical industry)
Physical Layer according to international standard IEC 61158-2.

PROFIBUS-FMS (Field Messaging Specification)

General-purpose for peer-to-peer communication at the cell level.
Can be used for extensive and complex communication tasks.
Academic approach (layer 7 services based on MMS, ISO 9506).
Disappearing

Profibus - Stack



Profibus - Data sheet

Topography:	bus
Medium:	•TWP @ 31.25 kbits/s (intrinsic safety), 10 devices (PA) •RS 485 @ 19.2 kbit/s.. 500 kbit/s (FMS) •RS 485 or fibres @ 1.5 Mbit/s (12 Mbit/s) (DP)
Signaling:	PA: Manchester II, preamble, delimiters DP, FMS: UART 11 bit/character
Integrity	CRC8, HD = 4
Collision	none under normal conditions
Medium redundancy	not supported by the controller
Medium Access	DP: central master, cyclic polling **(see: 3.1.2)** FMS, PA: token passing
Communication chip	dedicated chips for 12 Mbit/s
Processor integration	can use UART interface on most processors directly
Cycle Time	depends on number of slaves (cyclic, not periodic)
Address space	8 bit device address
Frame size (useful data)	up to 512 bits in Process Data, 2048 bits in messages
Link Layer Services	•SDN Send Data with No acknowledgement •SDA Send Data with Acknowledgement •SRD Send and Request Data with reply •CSRD Cyclic Send and Request Data with reply

Profibus - Analysis

MS-DOS of the fieldbus world

+

Standardized by CENELEC (EN 50 170-3)

Wide support by Siemens
(Profibus DP is backbone of Simatic S7) and active Profibus User Organization (PNO) with >1000 companies.

200,000 applications, > 2 Mio devices

Low entry price (originally simple UART protocol at 500 kbit/s with RS 485 drivers)

Several implementations based on most commons processors and micro controllers (8051, NEC V25, 80186, 68302).

Development tools available (Softing, I-tec).

Extended Application Layer (FMS) and Network Management (SM7, SM2)

Market: industry automation

-

– Exists in four incompatible versions (FMS, DP, PA, 12 Mbit/s), evolving specifications.

– Most products do not implement all the Profibus functionality, interoperability is questionable outside of one manufacturer

– Additional protocols exist within Siemens

– Weak physical layer (RS 485 at 1,5 Mb/s); to remedy this, a 12 Mb/s version has been developed (does not significantly improve response time, but limits distance).

– Complex configuration - all connections must be set up beforehand (except network management): tools required.

– Little used outside of Europe (identified in USA / Asia with Siemens/Germany)

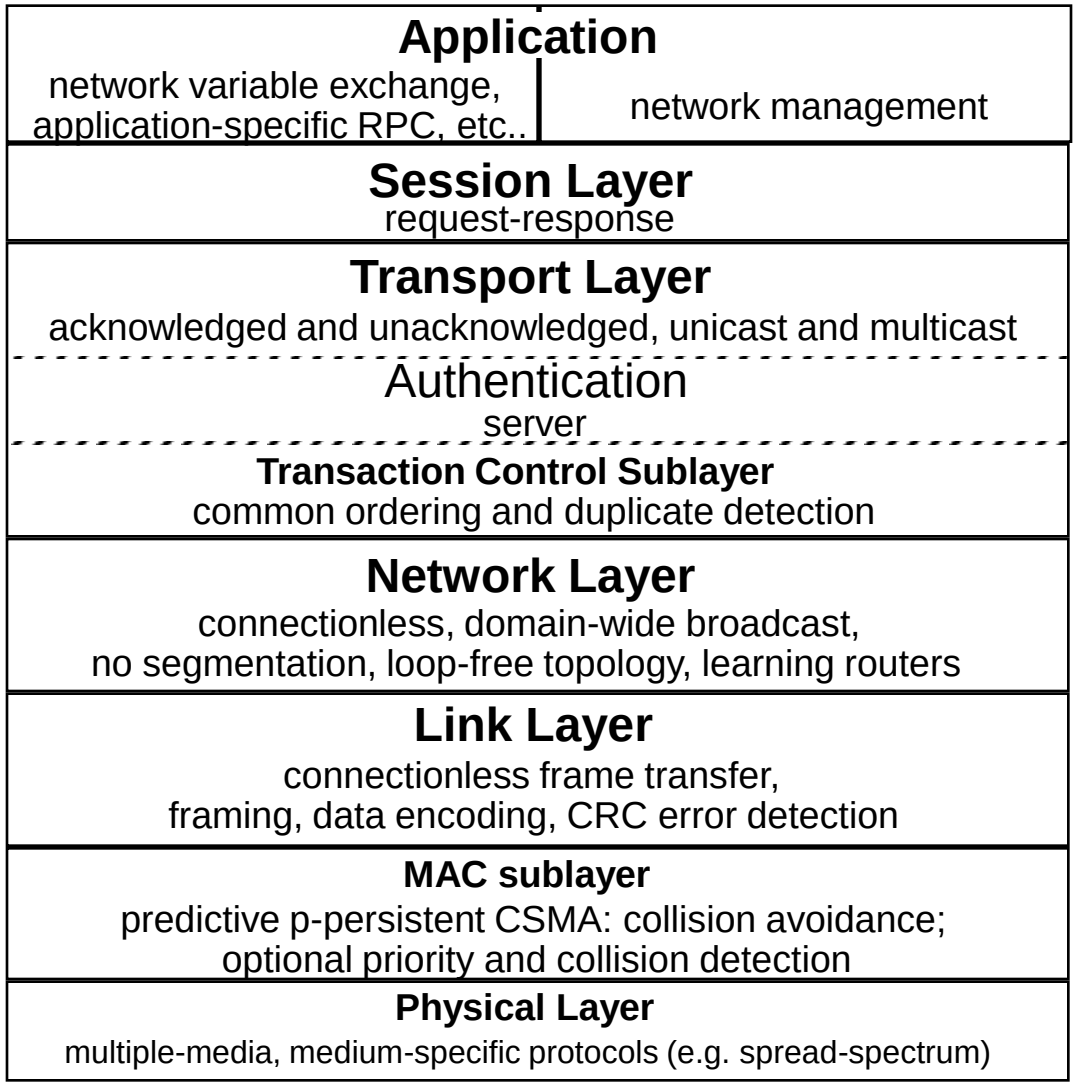
3.3.7 LonWorks

The building automation bus

LON (1) - Data sheet

Topography:	bus
Medium:	STP 150 Ohm @ 1.25 Mbit/s 300m, transformer-coupling UTP 100 Ohm, @ 78 kbit/s, 1300m, transformer-coupling reduced to 100m with free topology power line carrier @ 9.6 kbit/s, limited by -55dB radio @ 4.9 kbit/s
Communication chip	Neuron chip (Motorola, Hitachi)
Medium redundancy:	none
Signalling:	Differential Manchester for STP, UTP
Medium access:	p-persistent CSMA/CD
Response Time	3 ms (single call/reply), 400 exchanges/s @ 1.25 Mbit/s
Address space	32385 stations
Frame size (useful data)	up to 1824 bits
Integrity	CRC16, HD = 2 against steps, =1 against sync slips)
Higher-level protocols	full 7-layer stack
Application	programmed in Neuron-C
Support	LONMark group (www.echelon.com)

LON (2) - Stack


Application
network variable exchange, application-specific RPC, etc..
network management
Session Layer
request-response
Transport Layer
acknowledged and unacknowledged, unicast and multicast
Authentication
server
Transaction Control Sublayer
common ordering and duplicate detection
Network Layer
connectionless, domain-wide broadcast, no segmentation, loop-free topology, learning routers
Link Layer
connectionless frame transfer, framing, data encoding, CRC error detection
MAC sublayer
predictive p-persistent CSMA: collision avoidance; optional priority and collision detection
Physical Layer
multiple-media, medium-specific protocols (e.g. spread-spectrum)

LON (3) - Analysis

\+ "Macintosh" of the fieldbus world -

+ several media, products, protocols, networking, support, starter kits, tools and documentation.
+ easy, plug-and-play access.
+ low chip costs (10$), but a LON subprint costs about 500$.
+ only fieldbus in industry (except for IEC's TCN) which supports interoperability of networks of different speeds.
+ only fieldbus to provide authentication.
+ standard network variable types definition (SNVT).
+ standard device description (LonMarks), access to IEC 1131.
+ market: building automation

– sluggish response time: > 7ms per variable.

– cannot be used in a fast control loop such as drives or substation protection.

– non-deterministic medium access (p-persistent CSMA)

– low data integrity due to the use of differential manchester encoding and lack of frame delimiter / size field.

– no conformance testing

– can only be accessed through Echelon tools

– strong ties to Echelon (net profit in 01Q1: 20’000 $)

3.3.8 Ethernet

The universal bus

To probe further: "Switched LANs", John J. Roese, McGrawHill, ISBN 0-07-053413-b
"The Dawn of Fast Ethernet"

The Ethernet consortia

Ethernet/IP (≠Internet Protocol), Rockwell Automation

www.rockwellautomation.com

IAONA Europe (Industrial Automation Open Networking Alliance, (www.iaona-eu.com)
ODVA (Open DeviceNet Vendors Association, www.adva.org)
CIP (Control and Information Protocol) DeviceNet, ControlNet

ProfiNet

Siemens (www.ad.siemens.de), PNO (www.profibus.com)
« Industrial Ethernet » new cabling: 9-pin D-shell connectors
« direct connection to Internet (!?) »

Hirschmann (www.hirschmann.de)
M12 round IP67 connector

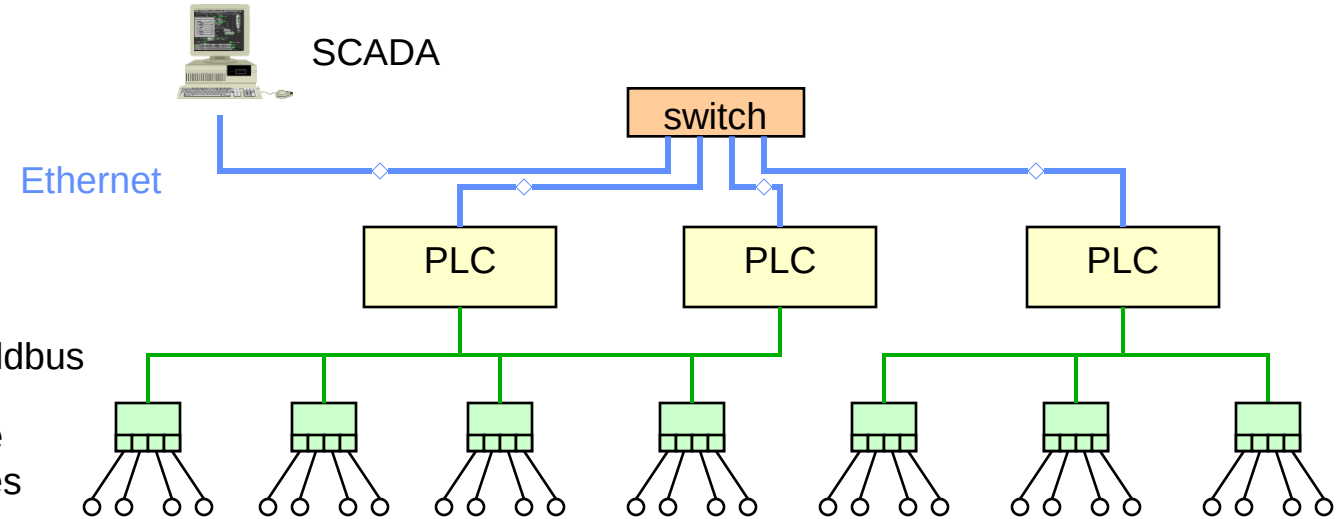
Fieldbus Foundation (www.fieldbus.org): HSE FS 1.0

Schneider Electric, Rockwell, Yokogawa, Fisher Rosemount, ABB

IDA (Interface for Distributed Automation, www.ida-group.org) -
Jetter, Kuka, AG.E, Phoenix Contact, RTI, Lenze, Schneider Electric, Sick
www.jetter.de

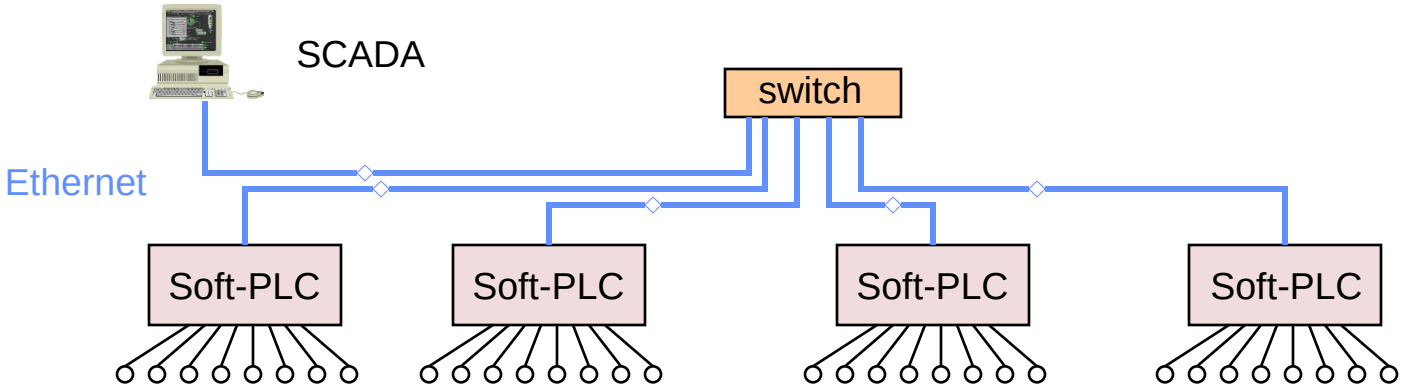
Ethernet - another philosophy

Ethernet + Fieldbus (classical)



cheap field devices
decentralized I/O
cyclic operation

Ethernet as Fieldbus (trendy)



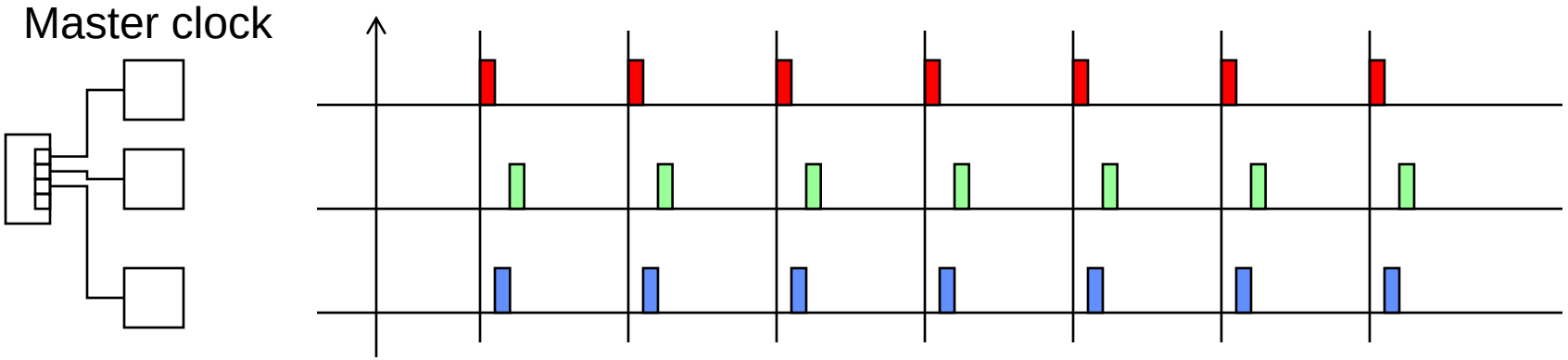
costly field devices
Soft-PLC as concentrators
Event-driven operation

This is a different wiring philosophy.
The bus must suit the control system structure, not the reverse

The "real-time Ethernet"

The non-determinism of Ethernet makes it little suitable for the real-time world.
Several improvement have been made, but this is not anymore a standard solution.

Method 1: Common clock synchronisation: return to cyclic.



Method 2: IEEE 1588 (Agilent)

PTP precision time protocol

Method 3: Powerlink

B&R, Kuka, Lenze, Technikum Winterthur

www.hirschmann.de, www.br-automation.com, www.lenze.de, www.kuka.de

Method 4: Siemens Profinet V3

synchronization is in the switches

Ethernet and fieldbus roles

Ethernet is used for the communication among the PLCs and for communication of the PLCs with the supervisory level and with the engineering tools

Fieldbus is in charge of the connection with the decentralized I/O and for time-critical communication among the PLCs.

Time- and safety-critical busses for cars

Contrarily to those who say « fieldbus is dead, Ethernet takes it all »
automobile manufacturers are developing several real-time busses for X-by-wire:

www.can.bosch.com

BOSCH

www.flexray-group.com

BMW Group

DAIMLERCHRYSLER

PHILIPS

BOSCH

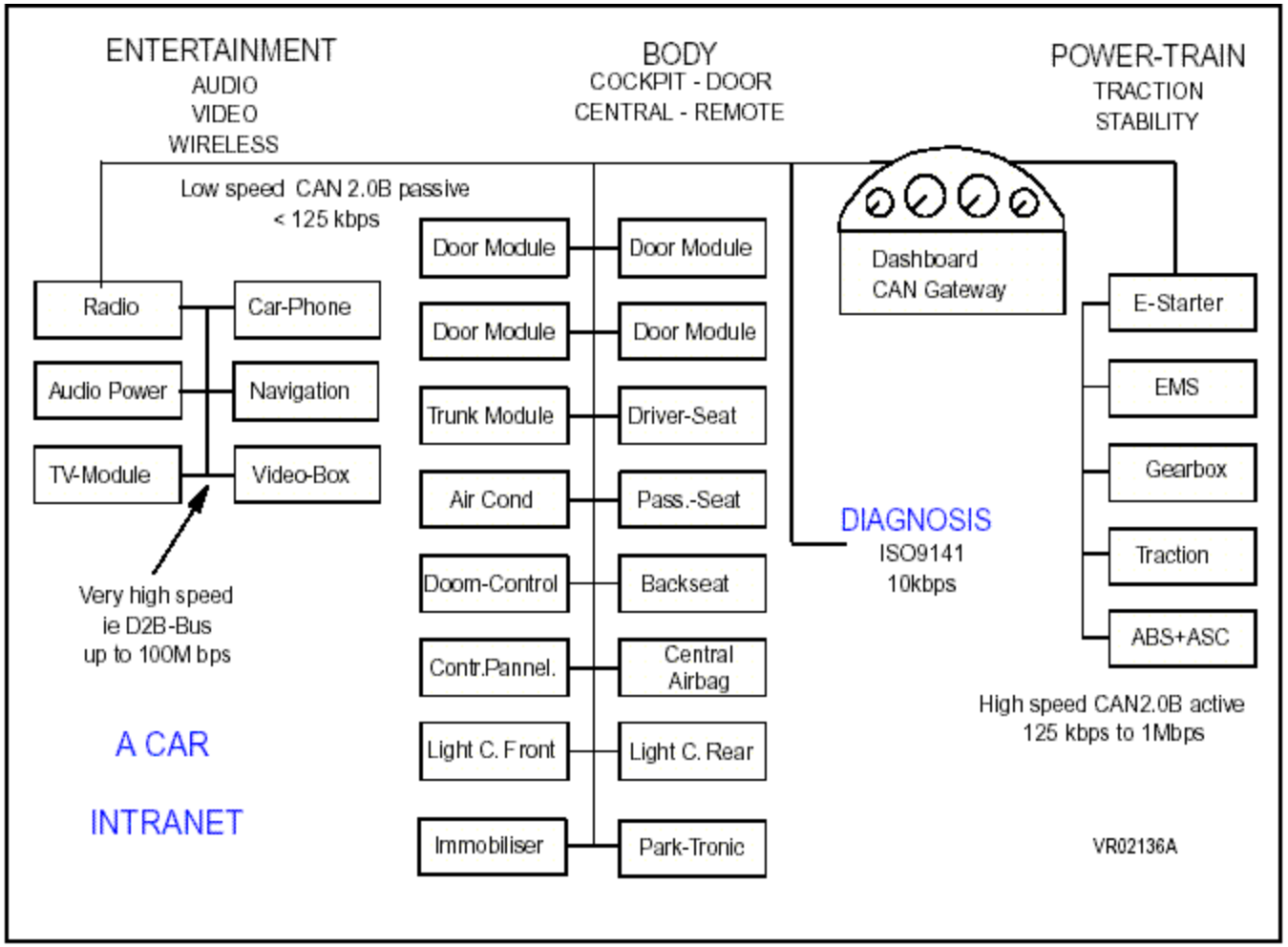
TTTech

Audi

Honeywell

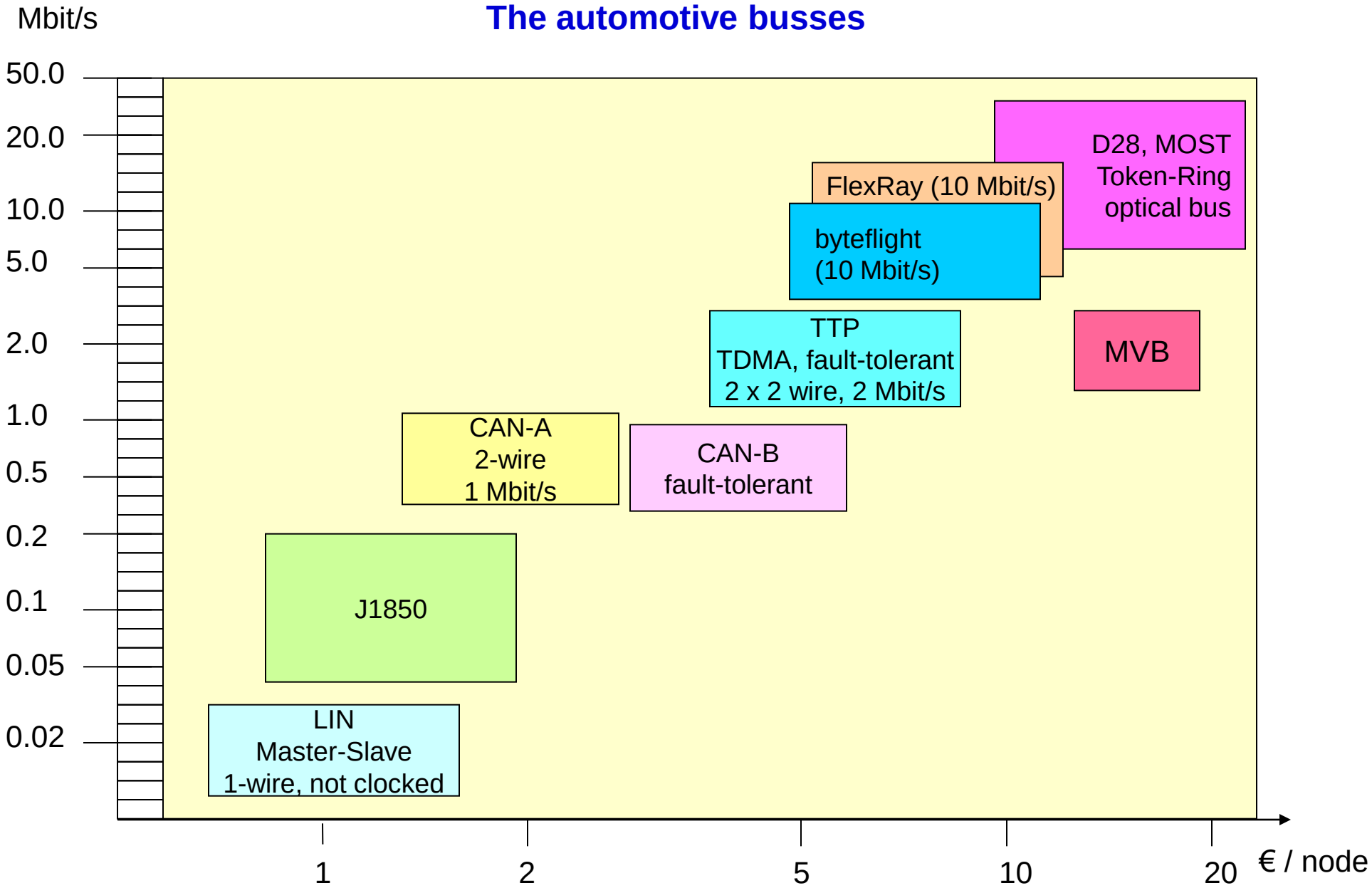
www.tttech.com

Car network



extreme low cost, low data rate (100 kbit/s) for general use (power slides)
extreme reliability, excellent real-time behavior for brake-by-wire or drive-by-wire

The automotive busses



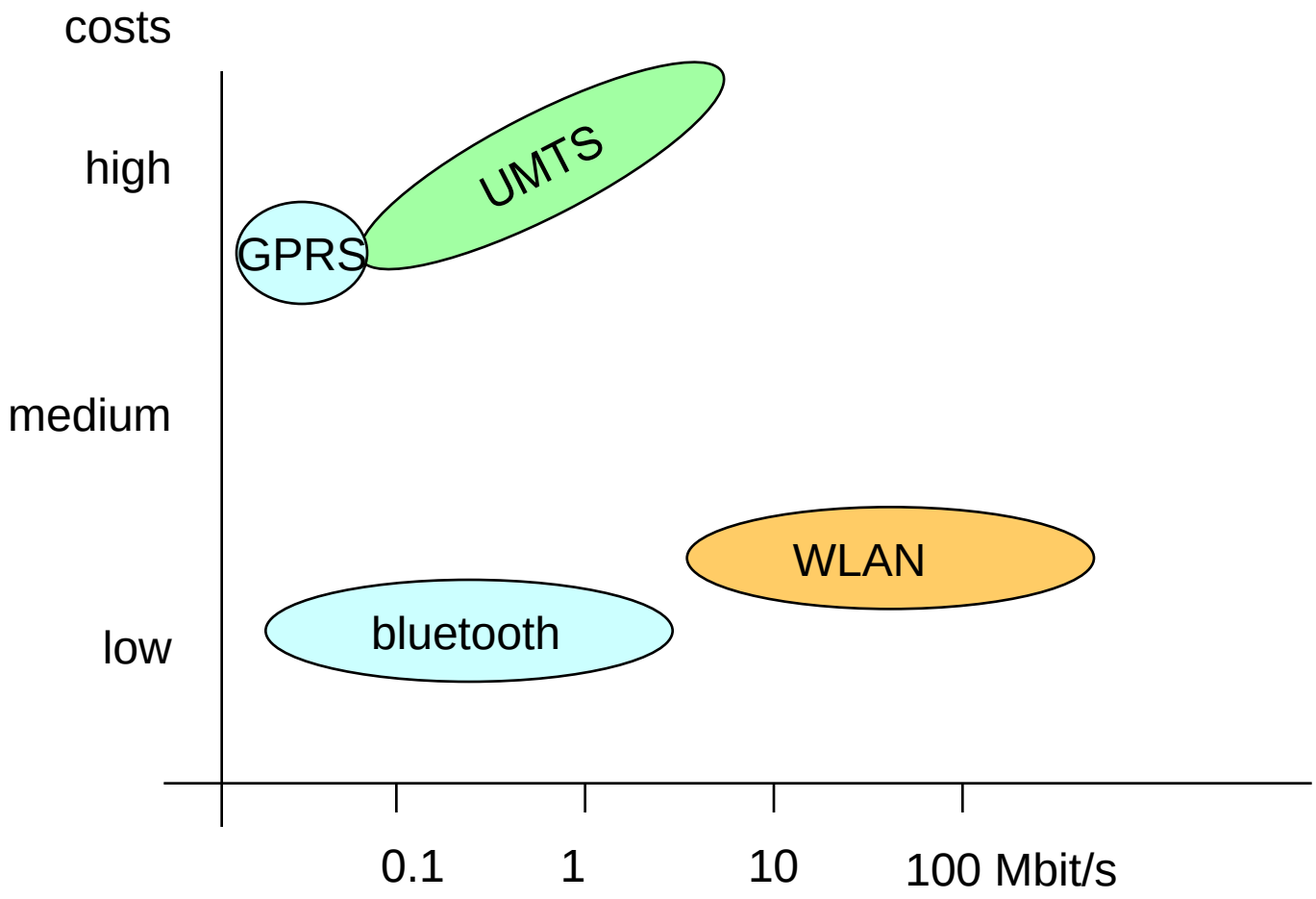
Wireless fieldbus

Increasingly, fieldbus goes wireless (802.11b, 802.11g. Bluetooth, ZigBee, WiMax

Advantages: mobility, no wiring

Disadvantages:
Base stations are still costly,
work in disturbed environments and metallic structures costs
mobile = batteries
distance = 30m in factories
lifetime > 5 years ?
privacy

Wireless Technologies



source: aktuelle Technik, 4/05

Safety bus: The organisations

- www.fieldbus.org
- www.iec.ch
- www.interbusclub.com
- www.nfpa.org
- www.odva.org
- www.phoenixcon.com
- www.pilz.com
- www.profibus.com
- www.roboticsonline.com
- www.rockwellautomation.com
- www.safetybus.com
- www.tuv.org

Future of field busses

Non- time critical busses are in danger of being displaced by LANs (Ethernet) and cheap peripheral busses (Firewire, USB)

In reality, these "cheap" solutions are being adapted to the industrial environment and become a proprietary solution (e.g. Siemens "Industrial Ethernet")

The cost objective of field busses (less than 50$ per connection) is out of reach for LANs.

The cabling objective of field busses (more than 32 devices over 400 m) is out of reach for the cheap peripheral busses such as Firewire and USB.

Fieldbusses tend to live very long (10-20 years), contrarily to office products.

There is no real incentive from the control system manufacturers to reduce the fieldbus diversity, since the fieldbus binds customers.

The project of a single, interoperable field bus defined by users (Fieldbus Foundation) failed, both in the standardisation and on the market.

Fieldbus Selection Criteria

Installed base, devices availability: processors, input/output

Interoperability (how likely is it to work with a product from another manufacturer

Topology and wiring technology (layout)

Power distribution and galvanic separation (power over bus, potential differences)

Connection costs per (input-output) point

Response time

Deterministic behavior

Device and network configuration tools

Bus monitor (baseline and application level) tools

Integration in development environment

Assessment

Which are the selection criteria for a field bus ?

Which is the medium access and the link layer operation of CAN ?

Which is the medium access and the link layer operation of LON ?

Which is the medium access and the link layer operation of Profibus ?

Which is the medium access and the link layer operation of Interbus-S ?

What makes a field bus suited for hard-real-time operation ?

How does the market influence the choice of the bus ?