Matrix protocol: matrix.org

Many apps. Recommendation: Element (element.io)

Mobile: Element X

Bus Systems

— Fundamentals —

users: @user: server

rooms: #room: server

// #VGU25:matrix.sensin.eu //

Th. Leize @leize:matrix.sensin.eu

VGU — Vietnamese–German University, Ho Chi Minh City

MSST — Mechatronics and Sensor Systems Technology

Vietnamese-German University

Dörrenbach

Outline — Which section will we discuss next?

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Table of Contents

1. Before we start . . .
2. Motivation
3. Basics
   - Signal
   - Error Detection
4. Bus Access
5. Ethernet, TCP/IP
6. Field buses and Device Buses
   - Serial Interfaces
   - HART
   - Profibus
7. Short range example: I^{2}C
8. Automotive Bus Systems
   - CAN
   - LIN
   - FlexRay

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Why do we need buses?

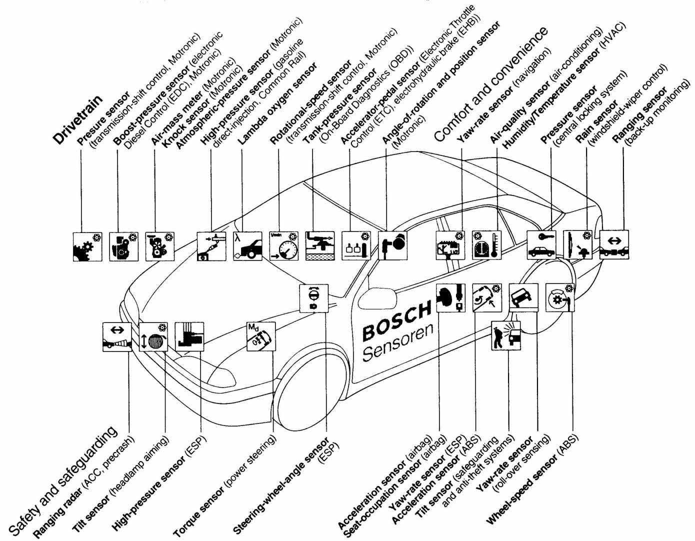
- Communication between computers
- Communication between other devices
  - in factories
  - inside of machines
  - in cars

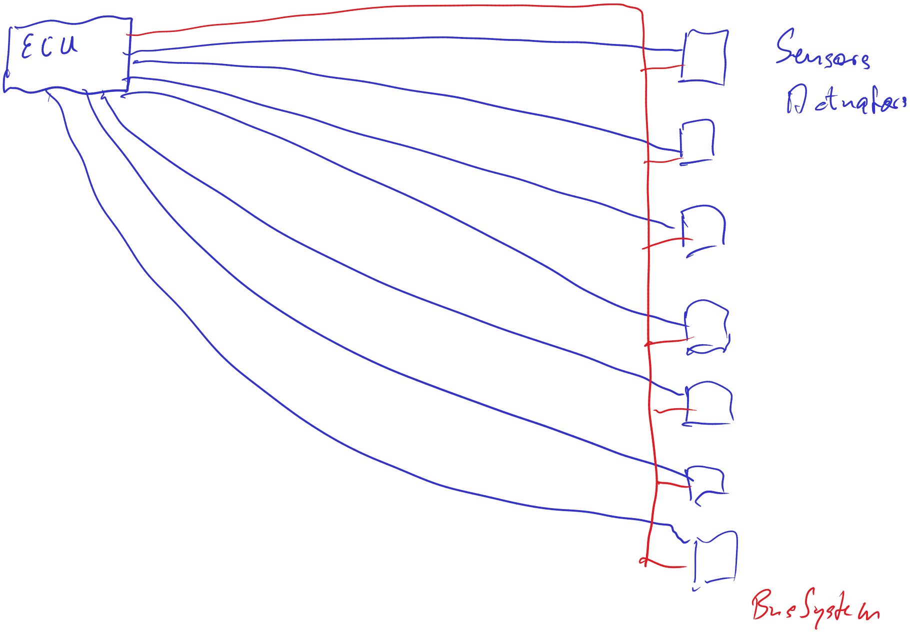
Why do we need buses?

- Communication between computers
- Communication between other devices
  - in factories
  - inside of machines
  - in cars

Example: Cars

Automotive systems and their sensors





ECU
Sensors
Actuators
BusSystem

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Signal Media

Signal type:

- analogue
- digital

Signal Media may be:

- Wireless
  - Different frequency ranges
  - Different modulations
- Wired
  - Coaxial cables (Thick & thin Ethernet)
  - Twisted pair (shielded STP, unshielded UTP)
  - Fibre optic (nowadays mostly used for backbones)

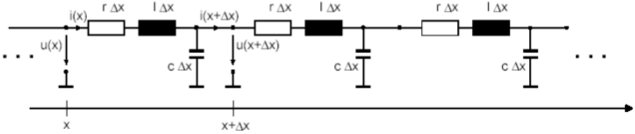
Path Loss in Wired and Wireless Media

Examples for path losses for

- UTP:
  approx. 13 dB per 100 m, that is 130 dB for 1 km.
- 1 Ghz radio, free space:
  First meter: 30 dB, then 20 dB per decade.
  For 130 dB loss this reaches 1000 km.

Signals on Wires

Waves: Damping (even frequency dependent)
Reflections



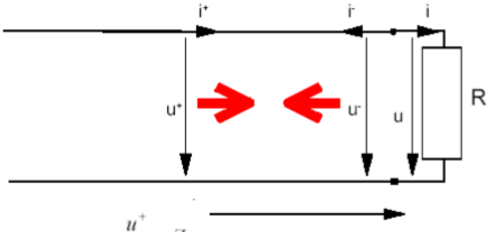
Assume all r=0 gives general solution:

$$u(x,t) = f^+\left(x - \frac{1}{\sqrt{lc}}t\right) + f^-\left(x + \frac{1}{\sqrt{lc}}t\right)$$

$$i(x,t) = \frac{1}{\sqrt{l/c}} f^+\left(x - \frac{1}{\sqrt{lc}}t\right) - \frac{1}{\sqrt{l/c}} f^-\left(x + \frac{1}{\sqrt{lc}}t\right)$$

$$\frac{1}{\sqrt{l \cdot c}} = v \qquad \sqrt{l/c} = Z$$

Signals on Wires contd.



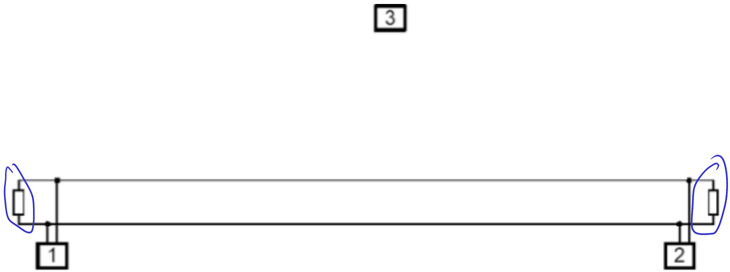
$$u = u^+ + u^-$$
$$i = i^+ + i^-$$
$$\frac{u}{i} = R$$
$$\frac{u^+}{i^+} = Z$$

$$u^- = r \cdot u^+ \quad mit \quad r = \frac{R - Z}{R + Z}$$

reflection coefficient

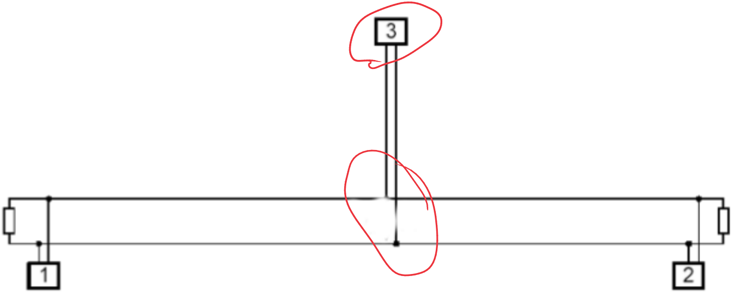
- $R = Z$: No reflection. $\rightarrow r = 0$
- $R = \infty$ (open end). $\rightarrow r = 1$
- $R = 0$ (short circuit). $\rightarrow r = -1$

Connecting Nodes A

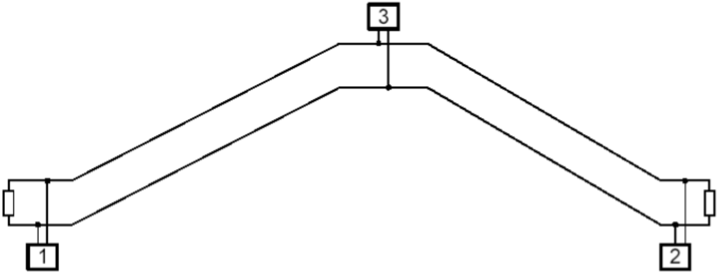


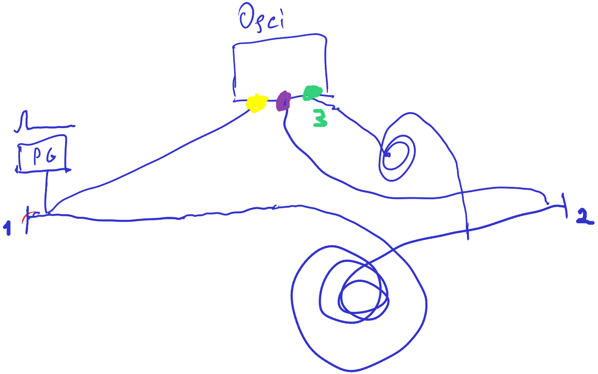
Connecting Nodes B

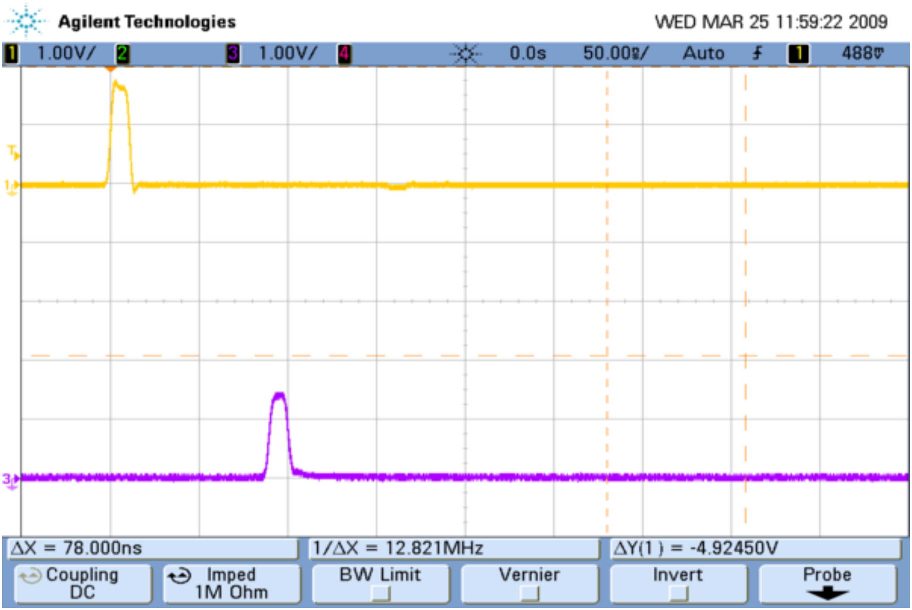
reflections

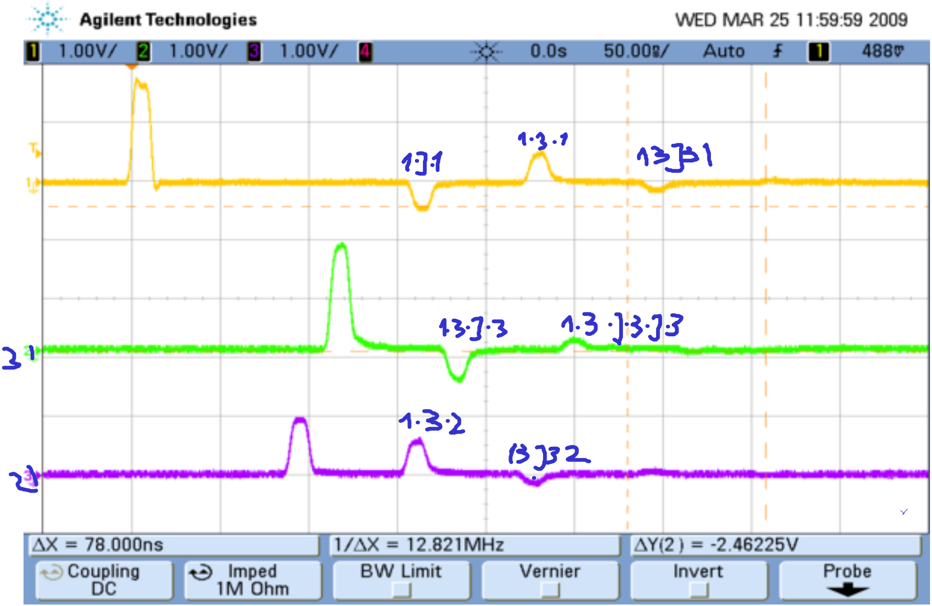


Connecting Nodes C




Osci
PG
1
2
3


Agilent Technologies
WED MAR 25 11:59:22 2009
1 1.00V/
2
3 1.00V/
4
0.0s
50.00ns/
Auto
1
488mV
T
1
3
ΔX = 78.000ns
1/ΔX = 12.821MHz
ΔY(1) = -4.92450V
Coupling
DC
Imped
1M Ohm
BW Limit
Vernier
Invert
Probe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1 1.00V/
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0.0s
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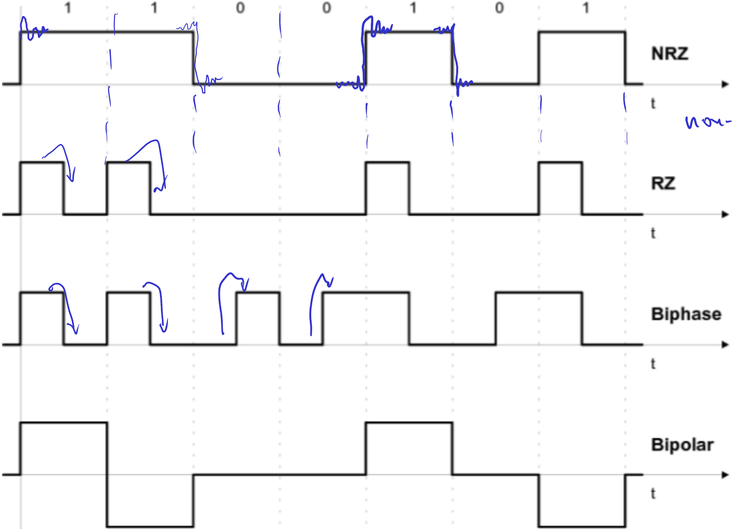
Signal Formatting

Here are a few examples for signal encoding:



"1"

"0"

non-return to zero

return to zero

Error Detection 1: Parity Bit

0 1 0 1   ~~1~~ 0 1 0 1 0 1

odd parity
even parity
"check sum"

sender $\xrightarrow{\text{bits + ch}}$ receiver → ch'] == ?

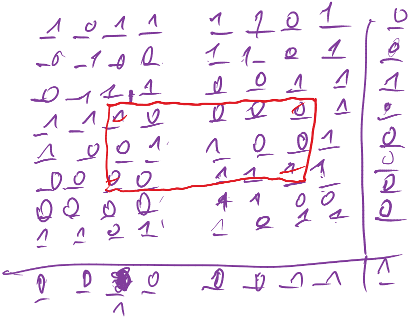
9, 7, 5, 3, 1 bit error? ✓
8, 6, 4, 2 bit errors? ↯

Hamming-Distance: What is the minimum error number that is not detected?

Here: 2

Error Detection 2: 2-Dim Parity

even



⇒ Hamming-Distance: 4

Error Detection 3

lookup Table

data				checkbits		
0	0	0	0	0	0	0
1	1	0	1	0	0	0
0	1	1	0	1	0	0
0	0	1	1	0	1	0
0	0	0	1	1	0	1
1	0	0	0	1	1	0
0	1	0	0	0	1	1
1	0	1	0	0	0	1
1	1	1	0	0	1	0
0	1	1	1	0	0	1
1	0	1	1	1	0	0
0	1	0	1	1	1	0
0	0	1	0	1	1	1
1	0	0	1	0	1	1
1	1	0	0	1	0	1
1	1	1	1	1	1	1

3 $5\frac{1}{2}$

There are different ideas for detecting errors:

- parity bit
- two-dimensional parity bit
- see example on this slide
- CRC — cyclic redundancy check

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Error Detection 4: CRC

Cyclic redundancy check

bits are coefficients of a polynomial with coeff. mod 2 (only 0,1 allowed)

10 11 01 $\rightarrow$ $1\cdot x^5 + 0x^4 + 1\cdot x^3 + 1\cdot x^2 + 0x + 1\cdot x^0$

Polynomial division:

$$(\text{data stream}) / \left(\begin{array}{c}\text{generating}\\ \text{Polynomial}\end{array}\right) = (\text{factor}) + \frac{(\text{remainder})}{(\text{gen Poly})}$$

checksum

CRC

CRC – Cyclic Redundancy Check

- Mathematical idea with polynomials
- Several CRC algorithms in use (see examples)

CRC-CCITT (CRC-4)	$x^4 + x + 1$	10011
CRC-CCITT (CRC-16)	$x^{16} + x^{12} + x^5 + 1$	
IBM-CRC-16	$x^{16} + x^{15} + x^2 + 1$	
CRC-32	$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$	
CAN-CRC	$x^{15} + x^{14} + x^{10} + x^8 + x^7 + x^4 + x^3 + 1$	
Bluetooth	$x^5 + x^4 + x^2 + 1$	

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- Priority
- time slot.

Master - Slave

Listen, if free:
("carrier sense")
- Handle collissions

Bus Access — Types

There are different types of bus access:

- Controlled
  - Master – Slave
  - Token Passing (logical token ring)
- By Chance
  (event driven)
  - CSMA/CD (carrier sense multiple access with collision detection)
  - CSMA/CA (carrier sense multiple access with collision avoidance)
- Time Scheduled
  - TDMA (time division multiple access)

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Please switch to different slides

There are additional slide sets for different bus systems....

- CSMA/CD -> Ethernet -> TCP/IP
- CSMA/CA -> CAN
- Master-Slave -> Profibus, I^2C, LIN, HART
- Token–Passing -> Profibus
- TDMA -> FlexRay

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2 Motivation

3 Basics

4 Bus Access

5 Ethernet, TCP/IP

6 Field buses and Device Buses

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Ethernet and TCP/IP

There is a separate set of slides on Ethernet and TCP/IP.
Experiments available.

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UART

UART – Universal Asynchronous Receiver and Transmitter

It's an asynchronous, character wise, bit serial communication

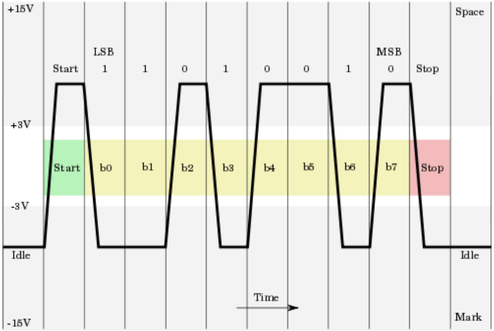
Parameter options: Fixed baud rates; 1/1.5/2 stop bits; 5/6/7/8 data bits; no/1/0/even/odd parity

Typical character frame:

Start	bit 0	b1	b2	b3	b4	b5	b6	bit 7	parity	stop
0	LSB							MSB		1

RS-232

- RS 232 C = EIA 232 = CCITT V.24 = DIN 66020
- Point to point connection
- Signal relative to ground
- serial interface on PCs



[Wikipedia]

RS 232 Pins

Pin numbers for RS-232 sockets and plugs
Big (older) ones (25 pins) and small ones (9 pins)

Name	Meaning	Pin # 25-pin	Pin # 9-pin	
CG	Common Ground	1	-	-
TxD	Transmit Data	2	3	Out
RxD	Receive Data	3	2	In
RTS	Request to Send	4	7	Out
CTS	Clear to Send	5	8	In
DSR	Dataset Ready	6	6	In
GND	Signal Ground	7	5	-
DCD	Data Carrier Detected	8	1	In
DTR	Data Terminal Ready	20	4	Out
RI	Ring Indicator	22	9	In

Different Serial Bus Systems

- RS 232 C = EIA 232 = CCITT V.24 = DIN 66020
  serial interface e.g. at PC's
  Signals relative to ground
  Point to point
- RS 422 = EIA 422 = CCITT V11 = DIN 66259 Part 4
  Signals differential -> more stable to interferences
  Point to point
- RS 485 = EIA 485 = ISO 8482 (differs a wee bit)
  Multi-device, bus system.
  Everything else as RS 422

Current Loop

- DIN 66258
- Point to point
- UART characters
- Older than RS 232
- Less sensitive on interferences
- Power supply by this current possible

HART

HART – Highway Addressable Remote Transducer

- Is a very popular device bus system to reuse the old 4 – 20 mA wires.
- May be used in two modes:
  - Analogue + Digital
    Analogue signal still transmitted
    point to point
  - Digital ("Multi drop")
    Master-Slave bus system with up to 15 devices. Current = 4 mA
    Secondary master (e.g. hand-held) possible
- Standard: IEC 61158
- "1" = 1200 Hz / "0" = 2400 Hz
- Gateways to Profibus frequently used

Hart 2

- Open protocol since late 1980s
- "WirelessHART" defined since 2008
- Datagram structure as follows:
  - 3 bytes preamble
  - 1 Start byte
  - address (1 byte short frame, 5 bytes long frame)
  - 1 byte command
  - 1 byte byte-count
  - 2 bytes status (only slaves)
  - 0..24 bytes data
  - 1 byte checksum

Field Buses

Field buses have special requirements:

- smart sensors need digital bus
- short answer times $\rightarrow$ short messages
- high data security needed
- sometimes needs to be intrinsically safe
- sometimes devices not accessible
- network management at remote station
- network management, device parametrisation and diagnosis needs to be manufacturer independent
- sometimes redundancy needed

Profibus

Profibus – Process Field Bus

- 1987 German funded research project with companies
- since 1991: DIN 19245 / since 1999: IEC 61158/IEC 61784
- different types available (may be connected to one network)
  - PROFIBUS DP (Decentralized Peripherals)
    - Physical layer: RS 485, twisted pair cables with impedances of 150 ohms
    - 9.6 kbit/s to 12 Mbit/s
  - PROFIBUS PA (Process Automation)
    intrinsically safe
    - Physical layer: Manchester bit coding
    - 31.25 kbit/s
    - (low) power on the same line

Profibus Physical Layer

Profibus DP

- Topology: line or tree
  - repeaters allowed
  - max. 32 devices in each segment
  - 9.6 kbit/s to 12 Mbit/s
  - glass fibre cable also usable → less sensitive
- EIA RS 485 with UART characters
- 1 Start bit (0)
- 1 Stop bit (1)
- even parity
- 8 data bits
- no gaps between characters but 3 character times gap between datagrams

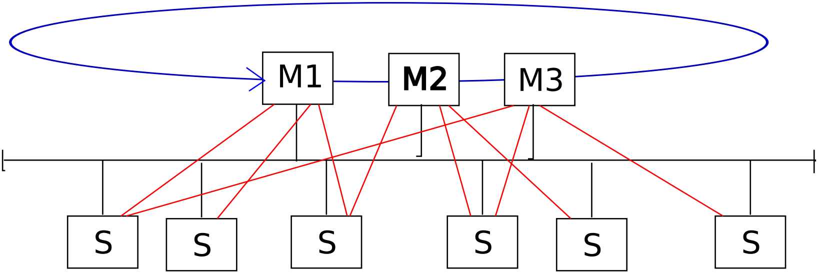
Profibus - Layer Usage

- Short messages
- no fragmentation/de fragmentation of long messages
- no routing
- ISO/OSI layers 1,2,7

Profibus – Bus Access

Hybrid Algorithm:

- Master-Slave between control device and sensors/actuators
- Token Passing between masters



Master-Slave

Token-Passing

Profibus – Error Checking

- UART detects errors:
  - frame errors (e.g. no stop bit)
  - overrun error
  - parity errors
- frame check sequence in datagram
- gives total hamming distance of 4 (without start and end character)
- Error states defined and handled:
  - Multiple tokens
  - No token
  - mal-functioning devices
  - Switching on/off/adding/removing devices

Master devices

There are two types of master devices:

- Master class 1: normal operation
- Master class 2: parametrisation and network configuration

Slaves have slots and there are "profiles" defined.

Profibus: Real Time Ability, Cycle

- There is a defined maximum cycle time
- This is measured and controlled by each master
- There is a defined sequence:
  1. Cyclic data exchange with each slave
  2. Acyclic services
  3. life-list monitoring
- There are 2 priorities:
  - Alarm messages and answers to these
  - Everything else

Profibus – Datagram Services

There are different types of datagram services:

- Broadcast:
  - SDN: Send data with no acknowledge
- Point to point:
  - SDA: Send data with acknowledge
  - SRD: Send and request data
  - CSRD: Cyclic send and request data

Profibus – (μC) Programming

The master knows about all slaves and their slots.

In the master's memory all data is available and the cyclic services update these contents in each cycle.

μC usually use dual-port RAM for this memory

Profibus – Datagrams

Different types of datagrams start with different start bytes:

- Data length = 3, fixed:
  SD1, DA, SA, FC, FCS, ED
- Data length = 11, fixed:
  SD3. DA, SA, FC, data (8 bytes), FCS, ED
- Data length = 4 to 249, variable:
  SD2, LE, LEr, SD2, DA, SA, FC, data, FCS, ED

DA: destination address, SA: source address
LE: Length, LEr: Length repeatet
FC: Frame control (command)
FCS: Frame check sequence
ED: End delimiter
Data length calculated from DA, SA, FC, data

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Short range: I^2C

Please see separate set of slides on this bus type.

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CAN, LIN and FlexRay

Please note there is a separate set of slides in automotive bus systems.
Exercises to be done