Vehicular Communications

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Lecture 3

Intra-vehicle Communications

Outline

- Bus systems: basics
- Protocols
  - K-Line
  - CAN
  - LIN
  - FlexRay
  - MOST
  - In-car Ethernet
- ECUs
- Safety

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ISO/OSI Layers

Main

- Layered communication architecture
  - One layer ⇔ one function ⇔ one protocol
  - Layer interacts only with immediate base layer (layer below)
  - Interfaces follow rigid specification
    - commonly by standards body

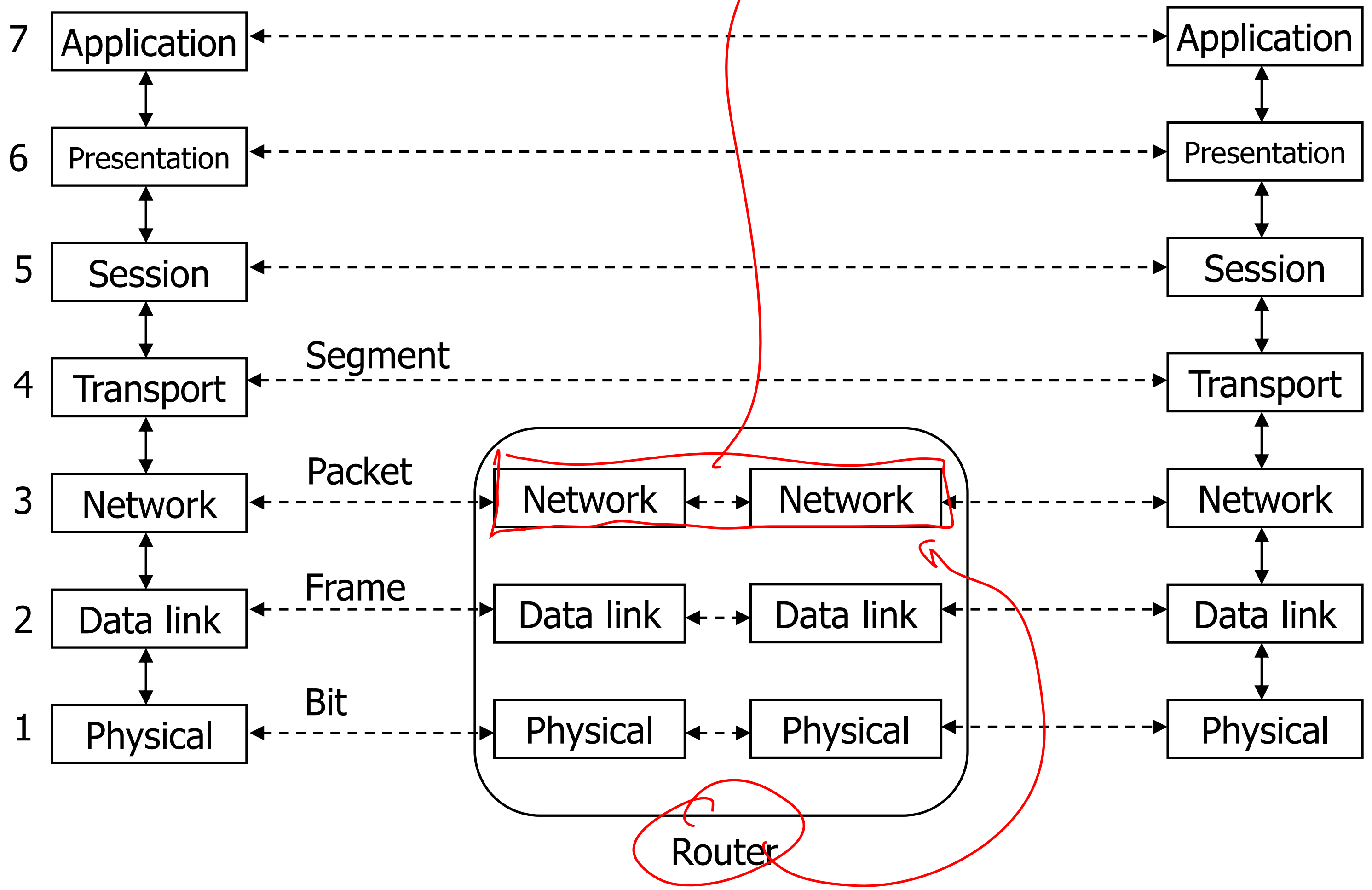
Interfaces between layers

- ISO/OSI layered communication model
  - Defines 7 layers
    - see next slide
  - Common architectures relax rigid guidelines
    - cf. TCP/IP

ISO/OSI Layers: Router

Network

Typically common network layer if the network protocol is the same of all nodes.



ISO/OSI Layers: Functions in Detail

- Physical Layer
  - Specifies mechanical, electrical properties to transmit bits
  - Time synchronization, coding, modulation, ...

FEC = Forward Error Correction

- Data Link Layer
  - Checked transmission of frames
  - Frame synchronisation, error checking, flow control, ...

link flow

- Network Layer
  - Transmission of datagrams / packets
  - Connection setup, routing, resource management, …
- Transport Layer
  - Reliable end to end transport of segments → end-to-end flow control

TCP / Unreliable → UDP

ISO/OSI Layers: Functions in Detail

- Session Layer
  - Establish and tear down sessions
- Presentation Layer
  - Define Syntax and Semantics of information
- Application Layer
  - Communication between applications

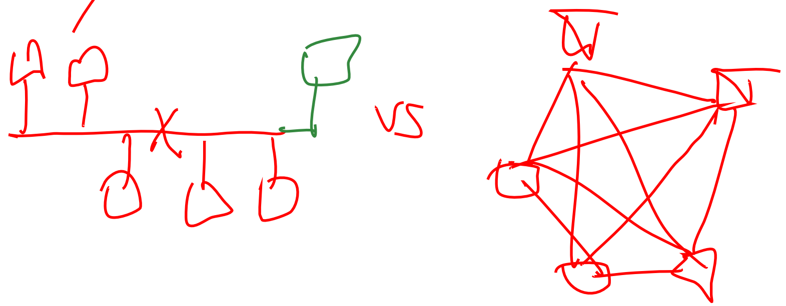
→ Application layer of TCP/IP stack (Internet stack)

- Our focus in this lecture:
  - Physical Layer
  - Data Link Layer

→ (With bus systems, some features (e.g., routing) are not needed.

Why bus systems?

- Lower cost — than dedicated P2P connection systems
  - Material
  - Weight
  - Volume — critical aspects in a vehicle



- Higher modularity
  - customizability of vehicles
  - cooperation with Original Equipment Manufacturers (OEMs)
- Shorter development cycles
  - Re-usability of components
  - Standard protocols and testing plans ⇨ less errors

History

(ECU)

- First micro processors in vehicles in 1980s
- Communication via point to point connections

There were few connections

- Simple control lines, little real data transmission
- True data transmission for connection external diagnosis equipment
- Birth of standard for character transmission
  - via K-Line (ISO 9141)
- Finally: introduction of data busses for in-vehicle communication
- Later standardized as CAN (ISO 11898)
- Use in series production models starts 1991

Overview and Use Cases

- State of the art
  - K-Line and CAN are part of On Board Diagnosis (OBD) connector
  - Enables, e.g., reading engine parameters, catcon, oxygen (lambda) sensor
  - Mandatory for newly registered vehicles in both EU und U.S.

Use Cases

- Driveline
  - Engine and transmission control
- Active Safety
  - Electronic Stability Programme (ESP)
- Passive Safety
  - Air bag, belt tensioners

Time constraints are crucial!

- Comfort
  - Interior lighting, A/C automation

Loose-time

- Multimedia and Telematics
  - Navigation system, CD changer

Real-time

RTK = Real-time kinematics

GNSS (Global Navigation Satellite System)

GPS → US Navy
Galileo → EU
Beidou → China
Glonass → Russia

Classification: On board communication

- Complex control and monitoring tasks
  - Data transmissions between ECUs / to MMI
  - E.g., engine control, ext. sensors, X-by-Wire

Man-Machine Interface (also HMI)

Everything-by-wire

- Simplification of wiring
  - Replaces dedicated copper wiring
  - E.g., central power locks, power windows, turn signal lights
- Multimedia bus systems
  - Transmission of large volumes of data
  - E.g., Navigation unit, Radio/CD, Internet

Internal control

Internal vehicle navigator → needs to have the map and upload contents.

OBD

Classification: Off board communication

- Diagnosis
  - Readout of ca. 3000 kinds of errors
  - Garage, exhaust emission testing
- Flashing SW flashing
  - Initial installation of firmware on ECUs
  - Adaptation of ECU to make, model, extras, ...
- Debugging
  - Detailed diagnosis of internal status
  - During development

~ Personal computer

From the source

To From

Classification by use case

ON-board

OFF-board

Application	Message length	Message rate	Data rate	Latency	Robustness	Cost
Control and monitoring		★★	★★	★★★	★★★	★★
Simplified Wiring				★	★★	★
Multimedia	★	★★	★★★	★	★	★★★
Diagnosis						★
Flashing	★★		★★		★	
Debugging		★	★	★★		

Classification by Society of Automotive Engineers (SAE)

no control

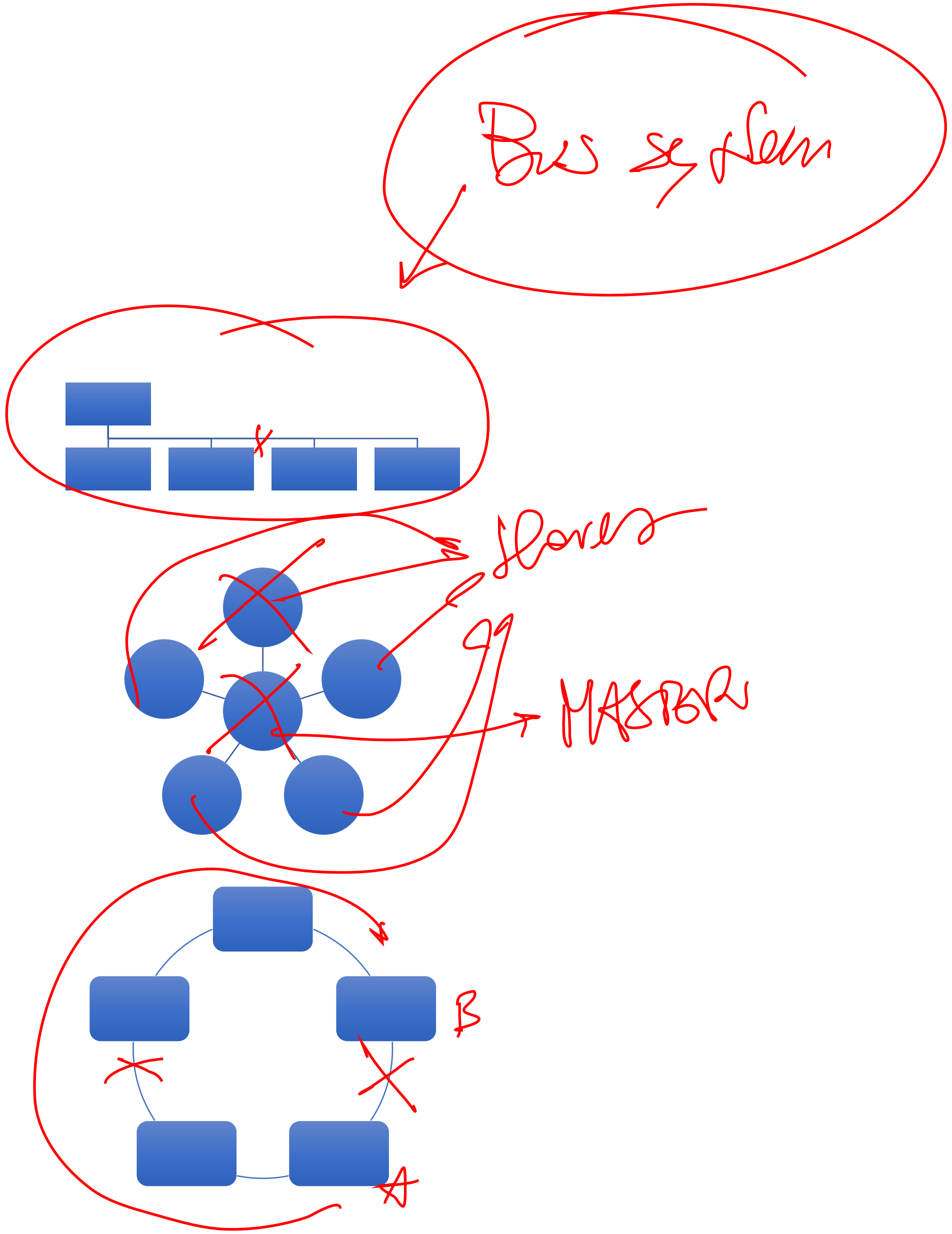
Class A	Data rate ~ 16 kBit/s	Cheap	Diagnosis, Sensor-Actor
Class B	Data rate ~ 64 kBit/s	Error correcting	Networking ECUs
Class C	Data rate ~ 1 MBit/s	Real time requirements	Drive train
Class D	Data rate ~ 10 MBit/s	Low latency	X-By-Wire, Multimedia

Active / passive safety

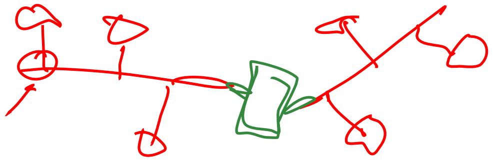
Network Topologies

- Line
  - √ Cost
  - √ Complexity
  - ☐ Robustness
- Star
  - ☐ Cost
  - √ Complexity
  - (√) Robustness
- Ring
  - √ Cost
  - ☐ Complexity
  - √ Robustness

Token-ring



Network Topologies



- Coupling of bus elements
  - Repeater
    - Signal amplification
    - Signal refreshing
  - Bridge
    - Medium / timing adaptation
    - Unfiltered forwarding
  - Router
    - Filtered forwarding
  - Gateway
    - Address adaptation
    - Speed adaptation
    - Protocol adaptation

1 – Phy	
Bus 1	**Bus 2**

Extending the same bus system

2 - Lnk	
1 - Phy	1 - Phy
Bus 1	**Bus 2**

Optical fiber

Ethernet

3 - Net	
2 - Lnk	2 – Lnk
1 - Phy	1 - Phy
Bus 1	**Bus 2**

7 - App	
3 - Net	3 - Net
2 - Lnk	2 – Lnk
1 - Phy	1 - Phy
Bus 1	**Bus 2**

Network Topologies

- Medium and Data transmission

No wireless connection without smartphone (typically)

- Medium
  - Optical
    - Fiber line
  - Electrical
    - One wire
    - Two (multi) wire
  - Wireless
    - Bluetooth
    - WiFi

CAN

- Data transmission
  - Unicast
  - Broadcast
  - Multicast

Network Topologies

- Concurrent bus access for typical wiring
  - Shared data line connected to pull-up resistors
  - Transistors can pull data line to GND (signal ground)
  - Base state
    - transistors non-conductive
    - pull up resistors raise bus level to *high*
  - One or more ECUs turn transistor conductive
    - This connects bus to signal ground
    - Bus level is *low* independent of other ECUs (⇨ dominant state)
  - Wired OR (if *low* ≙ 1) / Wired AND (if *low* ≙ 0)

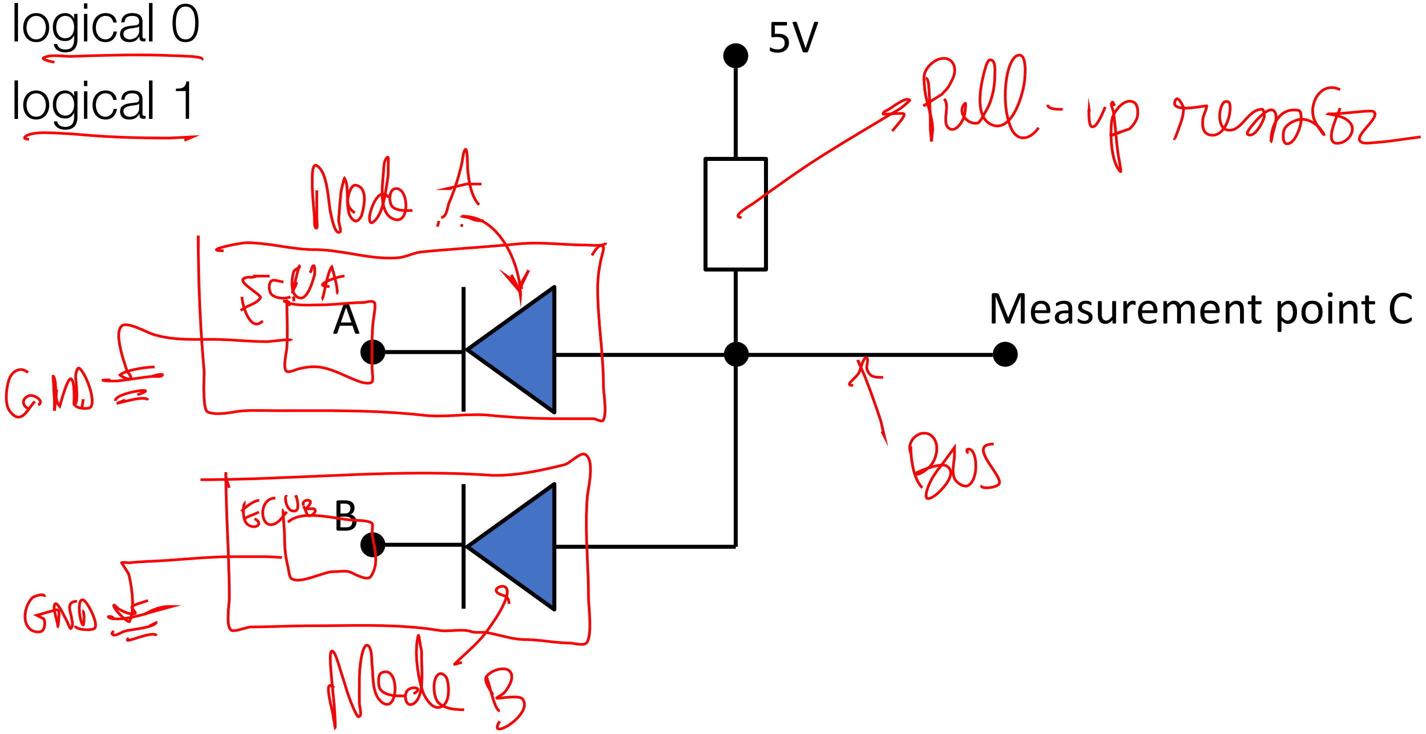
Bosch!

voltage

logical

Network Topologies

- Wired OR
  - Example (assuming negative logic)
    - 5V = logical 0
    - 0V = logical 1



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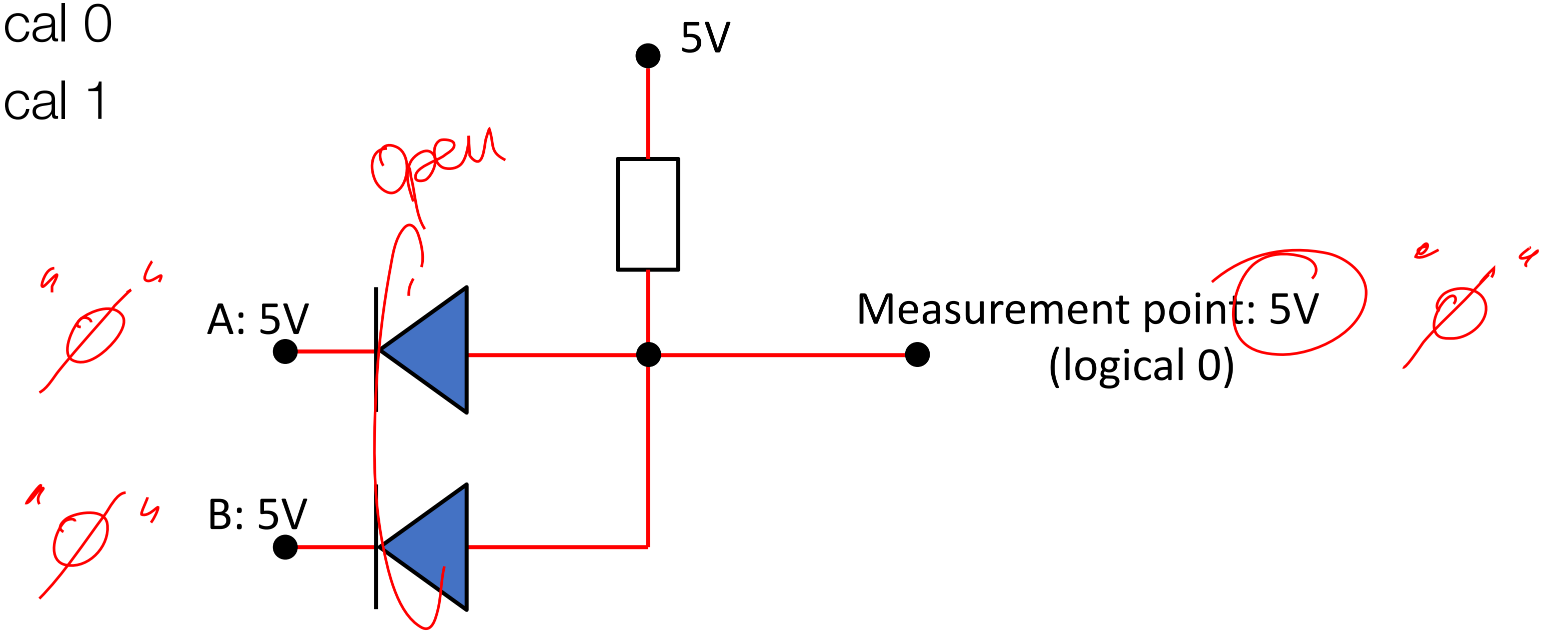

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Single bit connections!

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Network Topologies

- Wired OR
  - Example (assuming negative logic)
    - 5V = logical 0
    - 0V = logical 1

A	+	B	=	C
0		0		0
0		1		1
1		0		1
1		1		1

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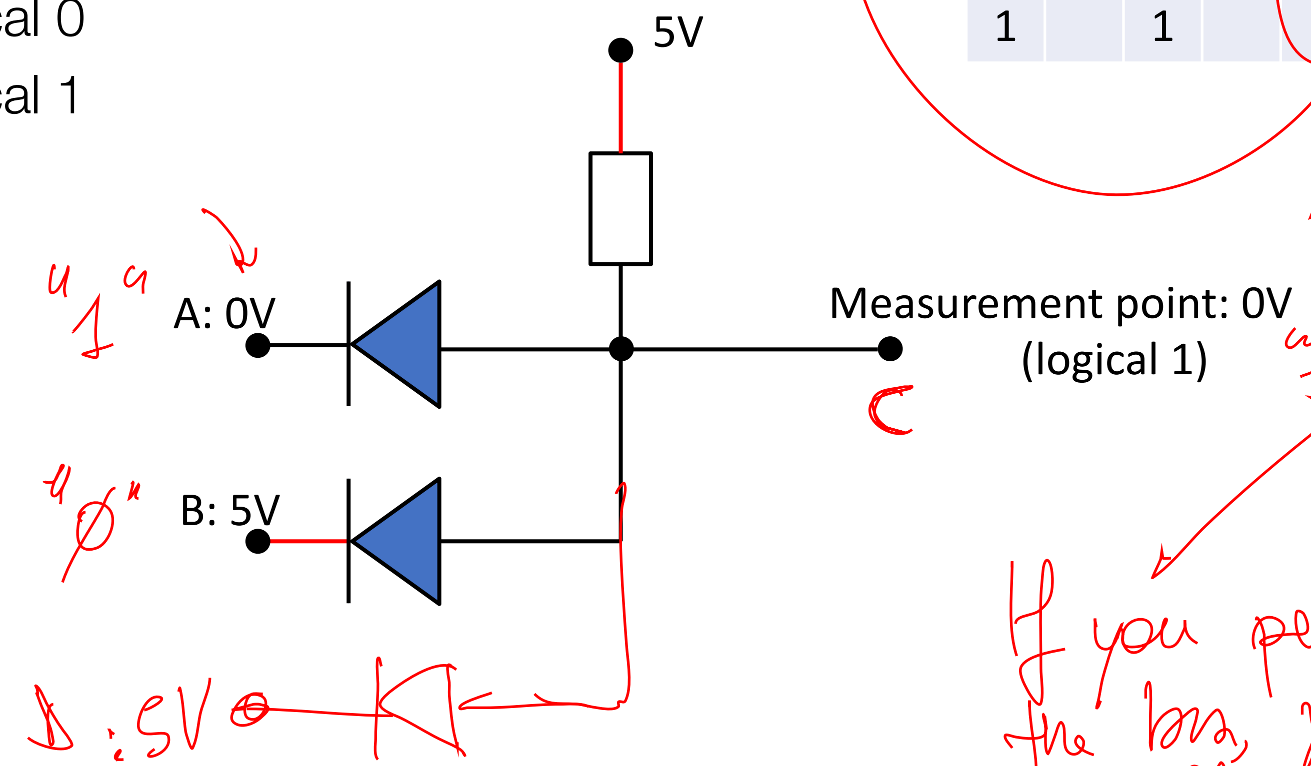
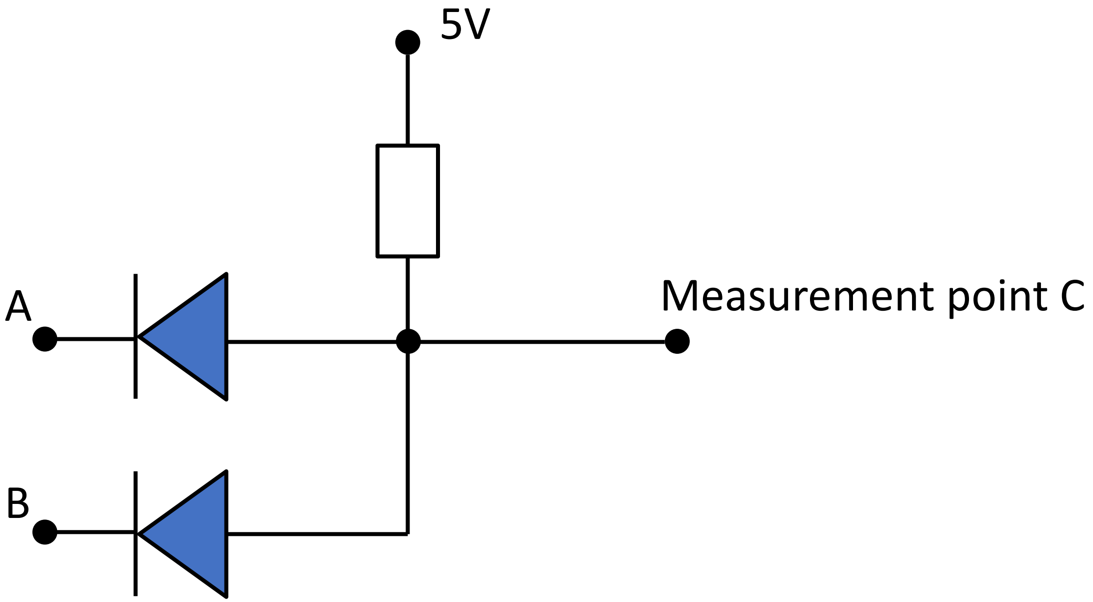


If you perceive "1" on the bus, you cannot detect a collision

Network Topologies

- Wired AND
  - Example (assuming positive logic)
    - 5V = logical 1
    - 0V = logical 0

In wired OR
0V is logical 1



Network Topologies

- Wired AND
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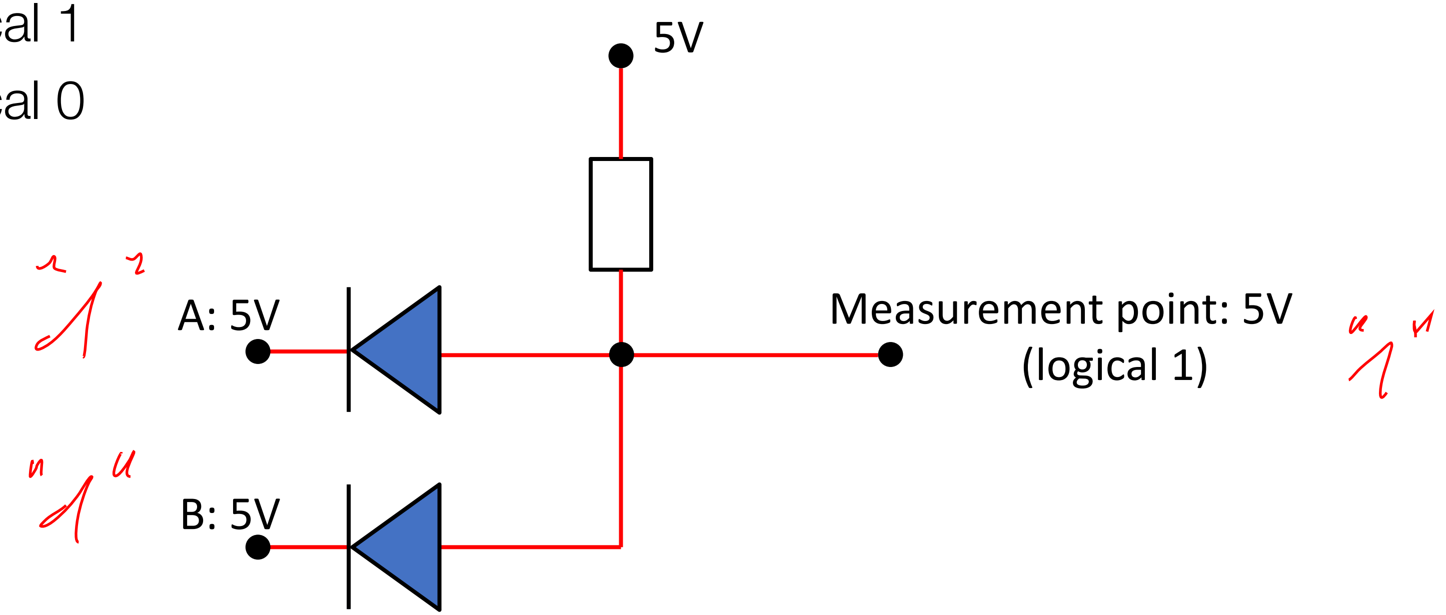
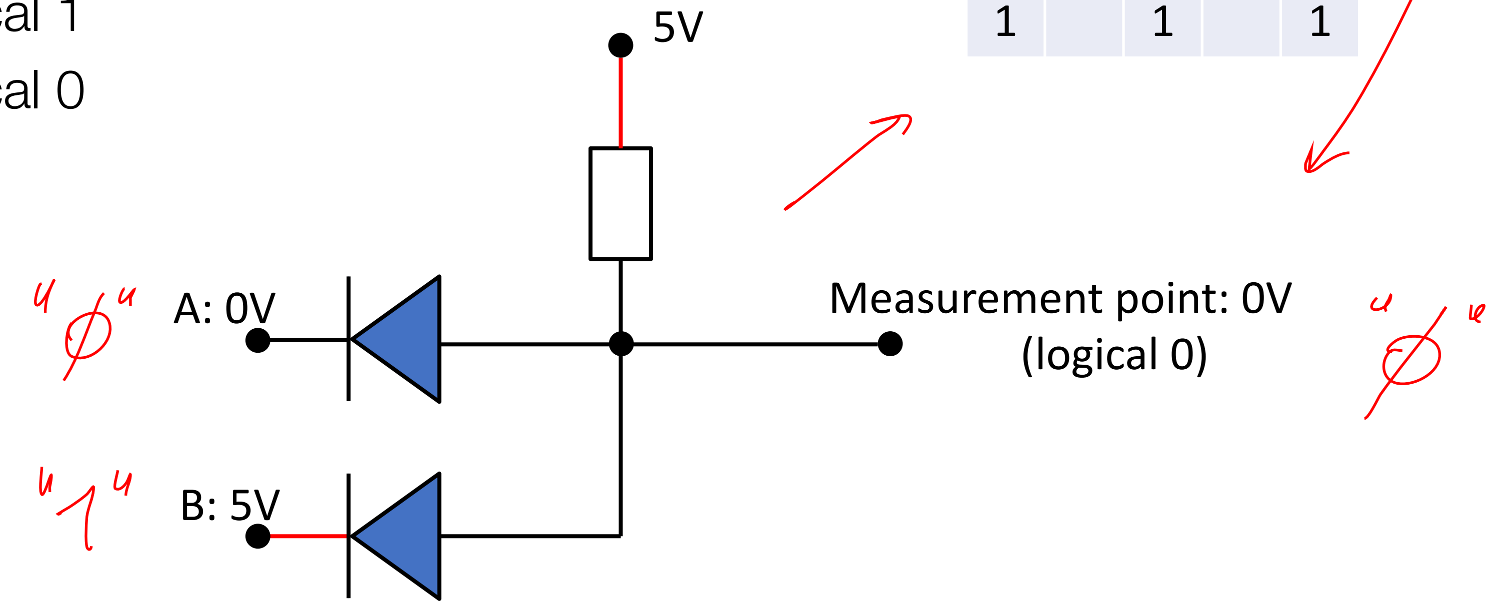


Network Topologies

- Wired AND
  - Example (assuming positive logic)
    - 5V = logical 1
    - 0V = logical 0

A	·	B	=	C
0		0		0
0		1		0
1		0		0
1		1		1



$\sim 10^5\ Km/s = 10^8\ m/s$

Network Topologies: Wave Effects

- Wave effects: Reflections and ends of wire or connectors
- Non negligible at high data rates, i.e., short bit lengths
- Propagation velocity of a signal on in-vehicle bus:
  - $c \approx \frac{1}{3} c_0$ → $3 \cdot 10^5\ Km/s$ (vacuum)
- Signal delay on typical in-vehicle bus:
  - $t = \frac{l}{c} \approx 200\text{ns}$ — bus dimension
- Wave effects problematic if:
  - $t_{bit} < 10t = 20\ ns = 2 \cdot 10^{-8}\ s$
- Countermeasures
  - Add terminator plugs (resistor)
  - Minimize use of connectors

$L\ [b/pdu]$

$R\ [b/s]$

$T_{pdu} = \frac{L}{R}\ [s/pdu]$

$\frac{1}{R}$

$l = c \cdot t = 10^8\ m/s \cdot 200 \cdot 10^{-9}\ s = 20\ m$

$\frac{1}{R} > 2 \cdot 10^{-8}\ s \rightarrow R < \frac{1}{2} 10^8\ b/s = 5 \cdot 10^7\ b/s = 50\ Mb/s$

$R > 50\ Mb/s$

$$t_{bit} = \frac{1}{R} \quad [s/bit]$$

Bit coding

	logical 0	logical 1
Non return to Zero (NRZ)		
Manchester (original variant)		

Busy modulation

Not vertical: reading!

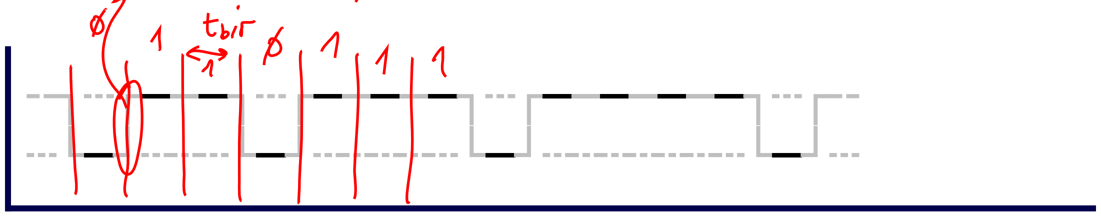
NRZ

5V

0V

High V → "1"

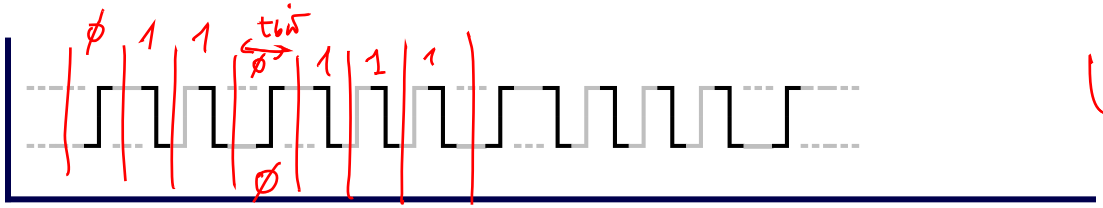
Low V → "0"



Manchester

"0" → low V → high V

"1" → High V → low V



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