Train Communication Network

IEC 61375 - 3

Multifunction Vehicle Bus

This is the vehicle bus standardized in IEC 61375
for interconnecting rail vehicles

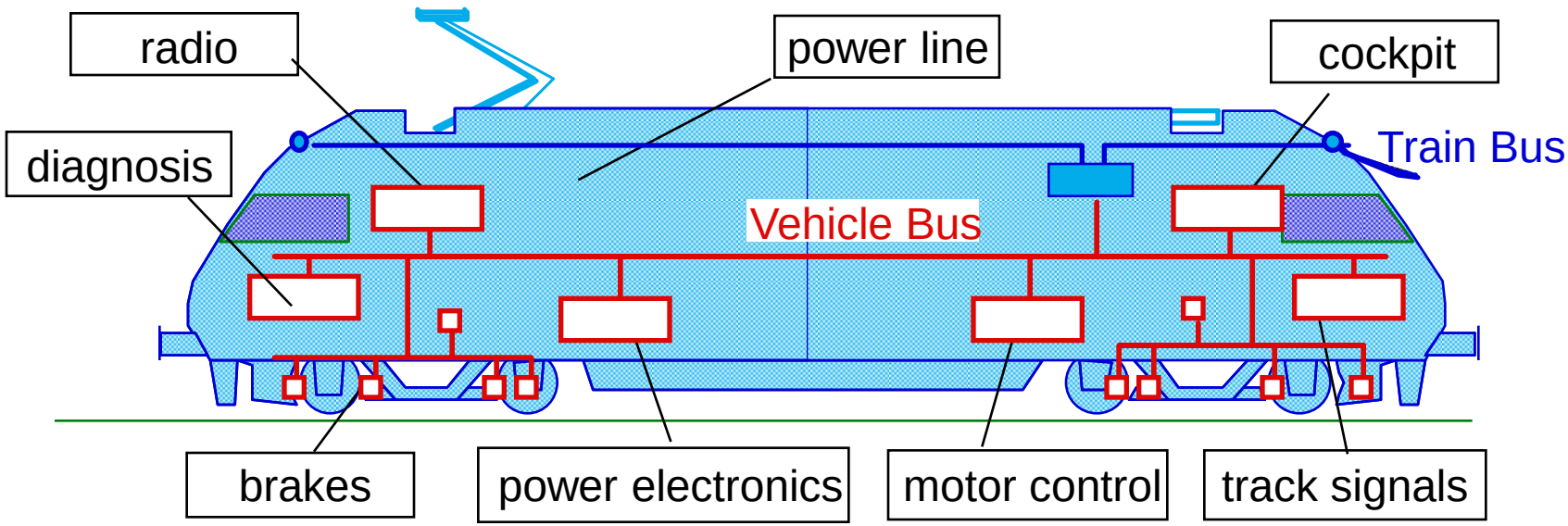
Introduction

MVB Outline

1. Applications in rail vehicles
2. Physical layer
    1. Electrical RS 485
    2. Middle-Distance
    3. Fibre Optics
3. Device Classes
4. Frames and Telegrams
5. Medium Allocation
6. Clock Synchronization
7. Fault-tolerance concept
8. Integrity Concept
9. Summary

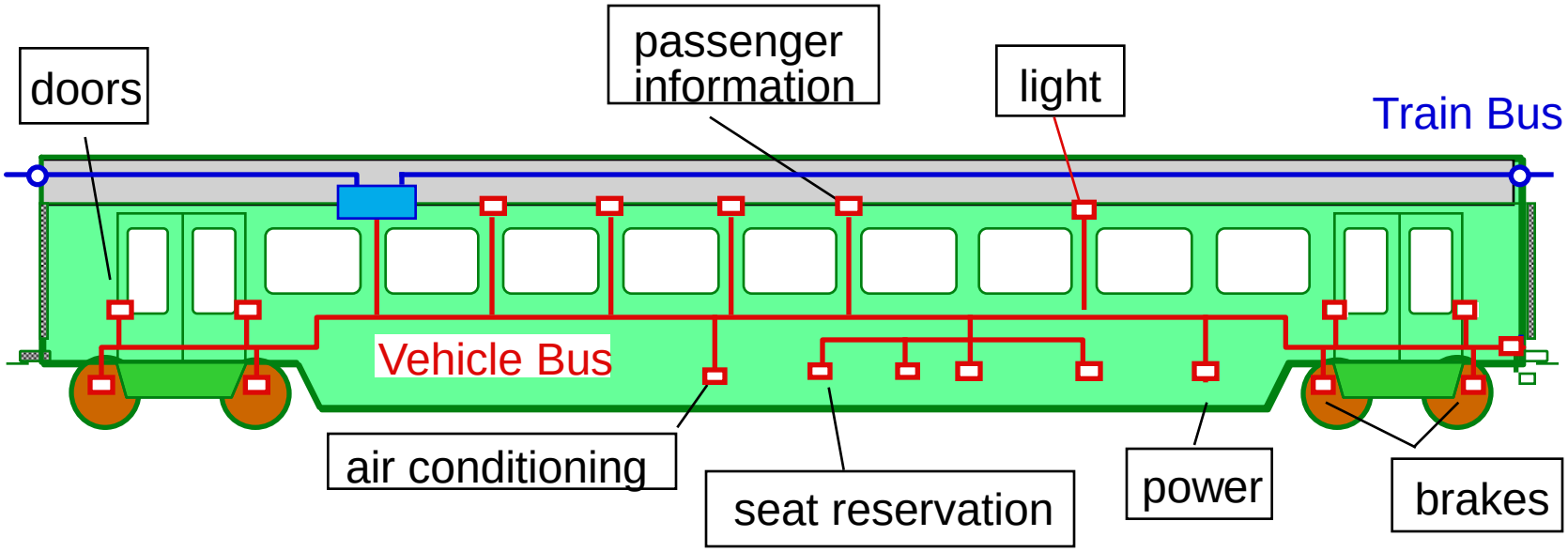
Multifunction Vehicle Bus in Locomotives

standard communication interface for all kind of on-board equipment



data rate	1'500'000 bits/second
delay	0,001 second
medium	twisted wire pair, optical fibres
number of stations	up to 255 programmable stations up to 4095 simple sensors/actuators
status	> 600 vehicles in service in 1998

Multifunction Vehicle Bus in Coaches



covered distance: > 50 m for a 26 m long vehicle
< 200 m for a train set

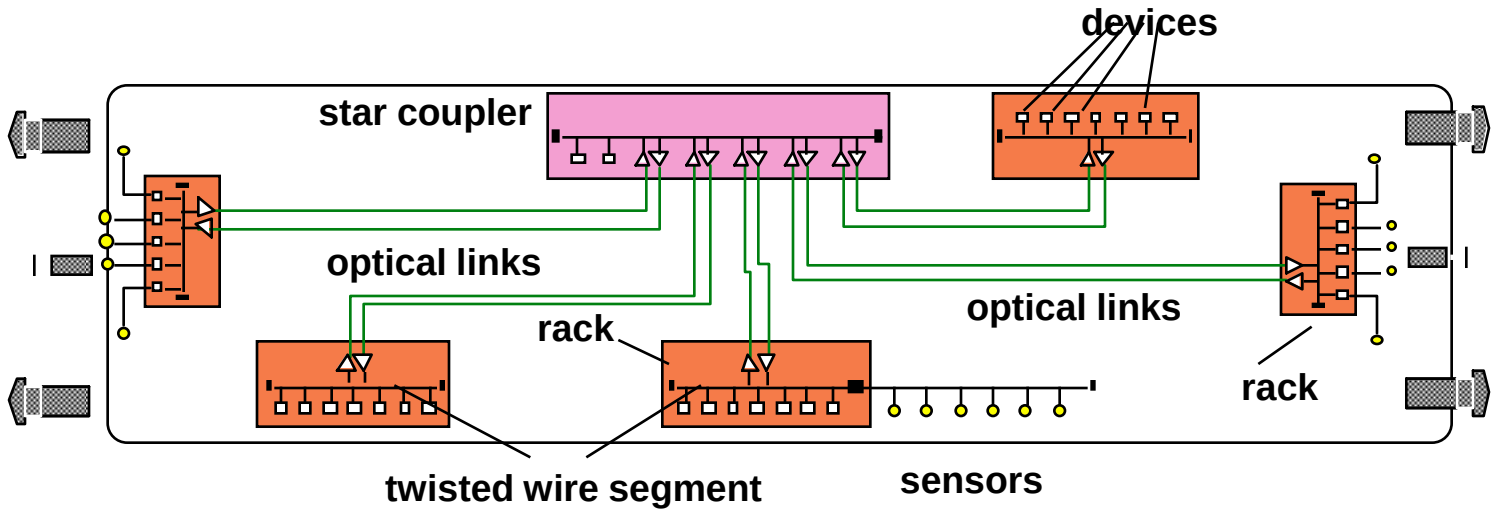
diagnostics and passenger information require relatively long, but infrequent messages

MVB Physical Media

- OGF optical fibres (2000 m)
- EMD shielded, twisted wires with transformer coupling (200 m)
- ESD wires or backplane with or without galvanic isolation (20 m)

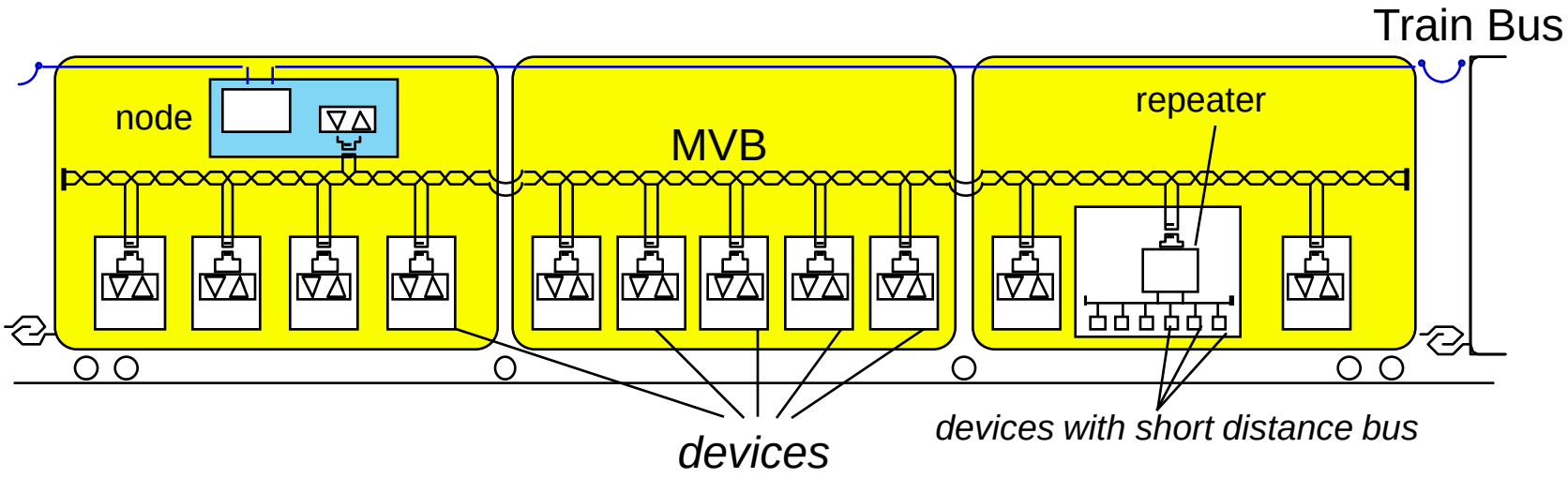
Media are directly connected by repeaters (signal regenerators)

All media operate at the same speed of 1,5 Mbit/s.



MVB Covered Distance

The MVB can span several vehicles in a multiple unit train configuration:

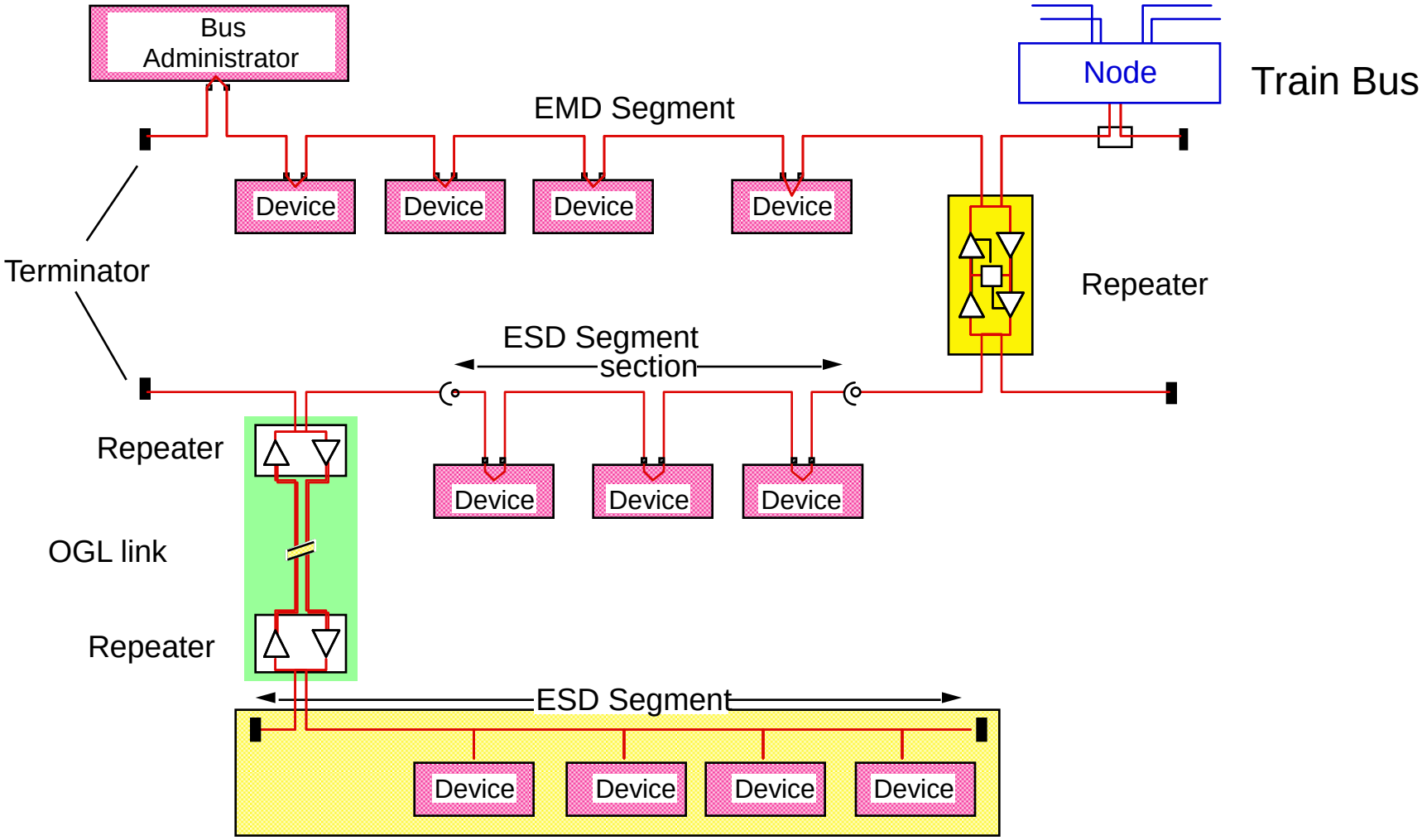


The number of devices under this configuration amounts to 4095.

MVB can serve as a train bus in trains with fixed configuration, up to a distance of:

> 200 m (EMD medium or ESD with galvanic isolation) or
> 2000 m (OGF medium).

MVB Topography



all MVB media operate at same speed, segments are connected by repeaters.

MVB Outline

1. Applications in vehicles
2. Physical layer
    1. ESD (Electrical, RS 485)
    2. EMD (Transformer-coupled)
    3. OGF (Optical Glass Fibres)
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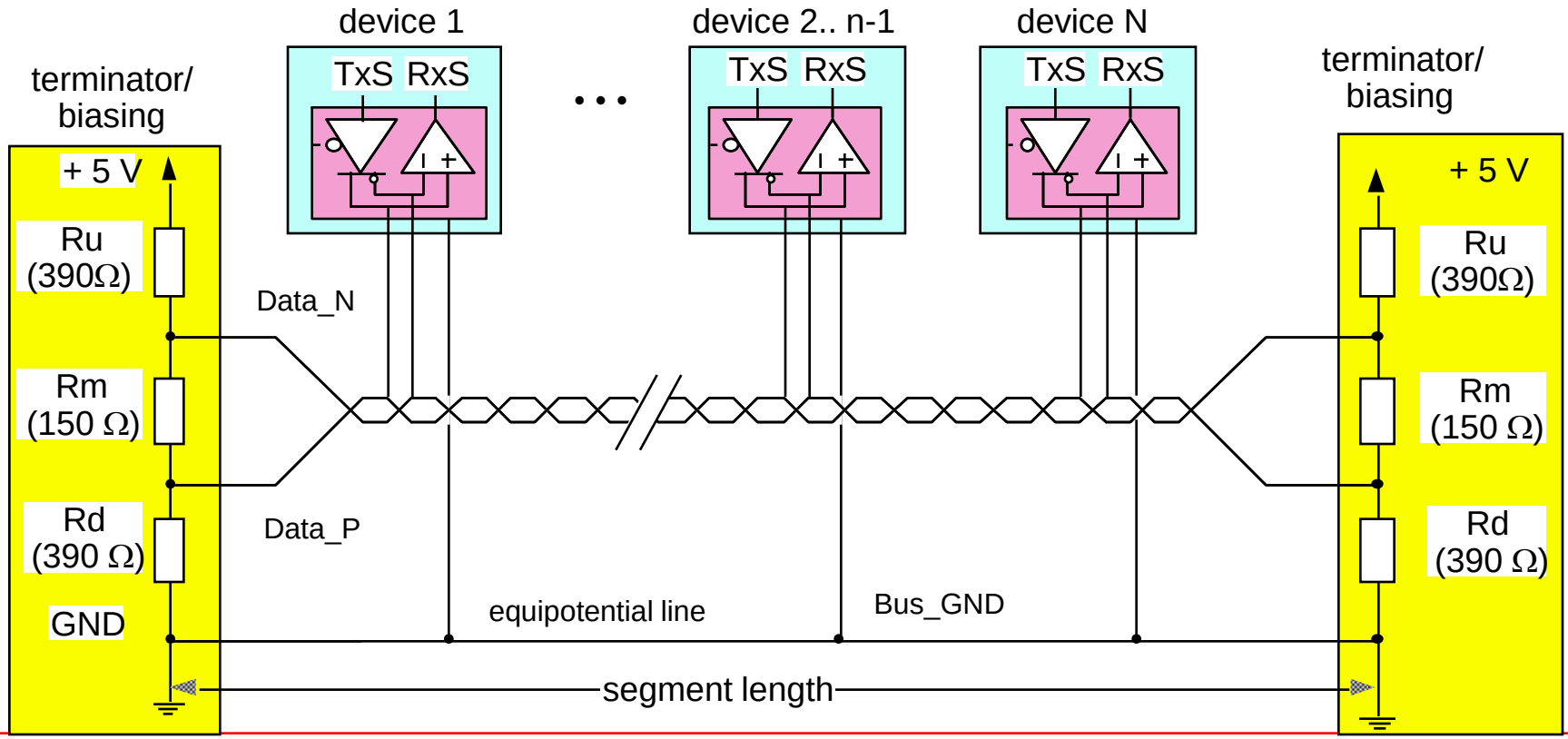
ESD (Electrical Short Distance) RS485

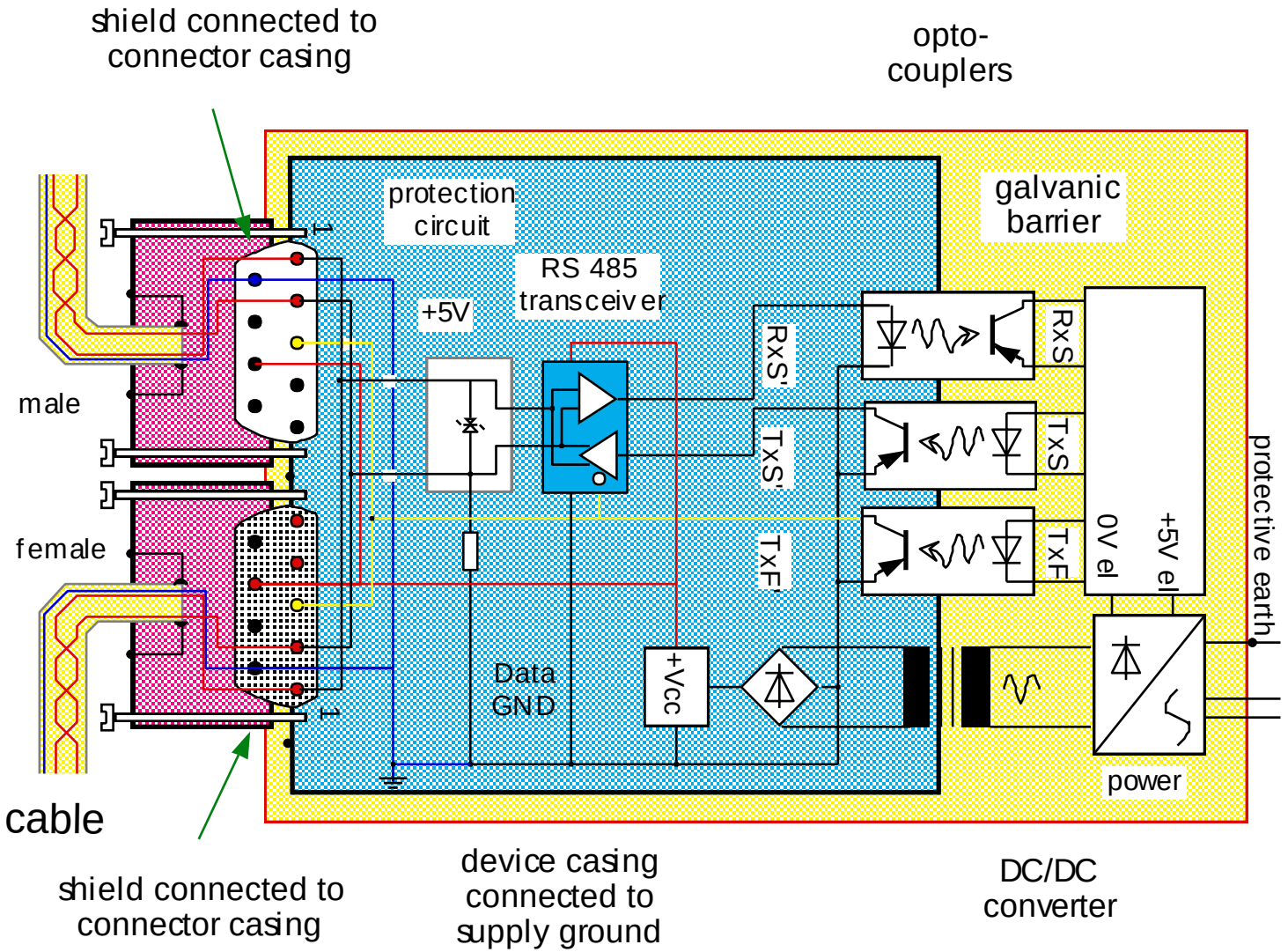
Interconnects devices over short distances (20m) without galvanic separation

Based on proven RS-485 technology (Profibus)

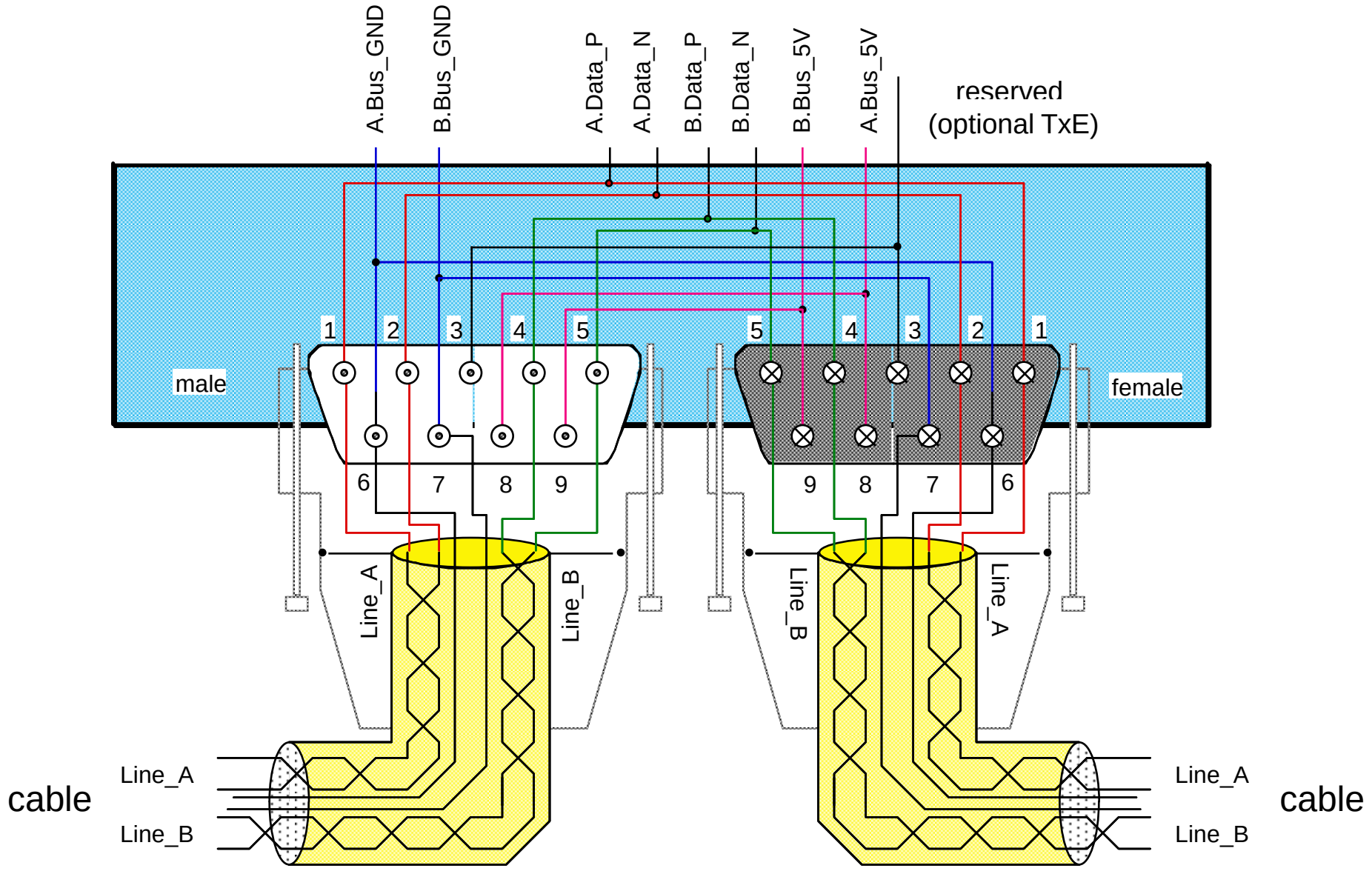
Main application: connect devices within the same cabinet.



ESD Device with Galvanic Isolation

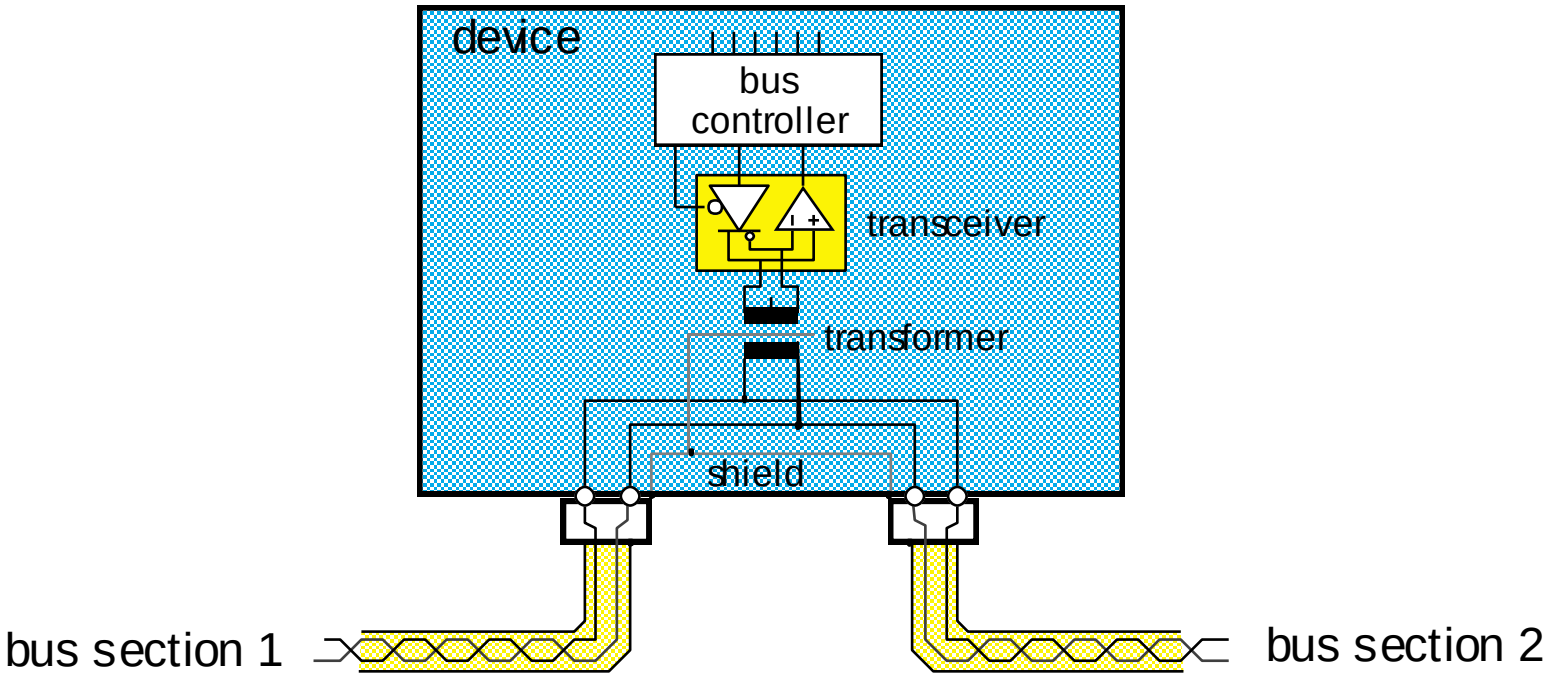


ESD Connector for Double-Line Attachment

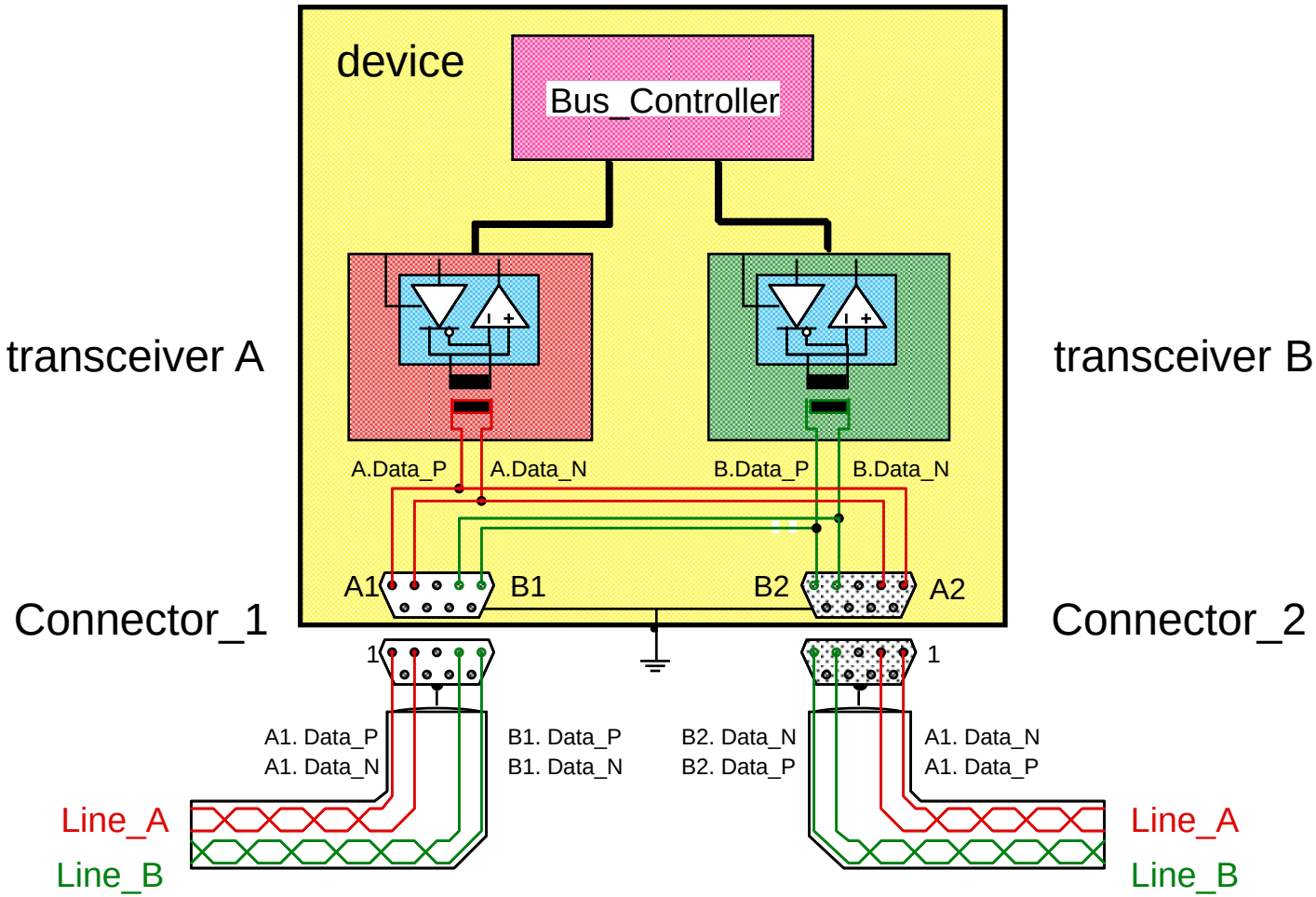


EMD (Electrical Medium Distance) - Single Line Attachment

- Connects up to 32 devices over distances of 200 m.
- Transformer coupling to provide a low cost, high immunity galvanic isolation.
- Standard 120 Ohm cable, IEC 1158-2 line transceivers can be used.
- 2 x 9-pin Sub-D connector
- Main application: street-car and mass transit



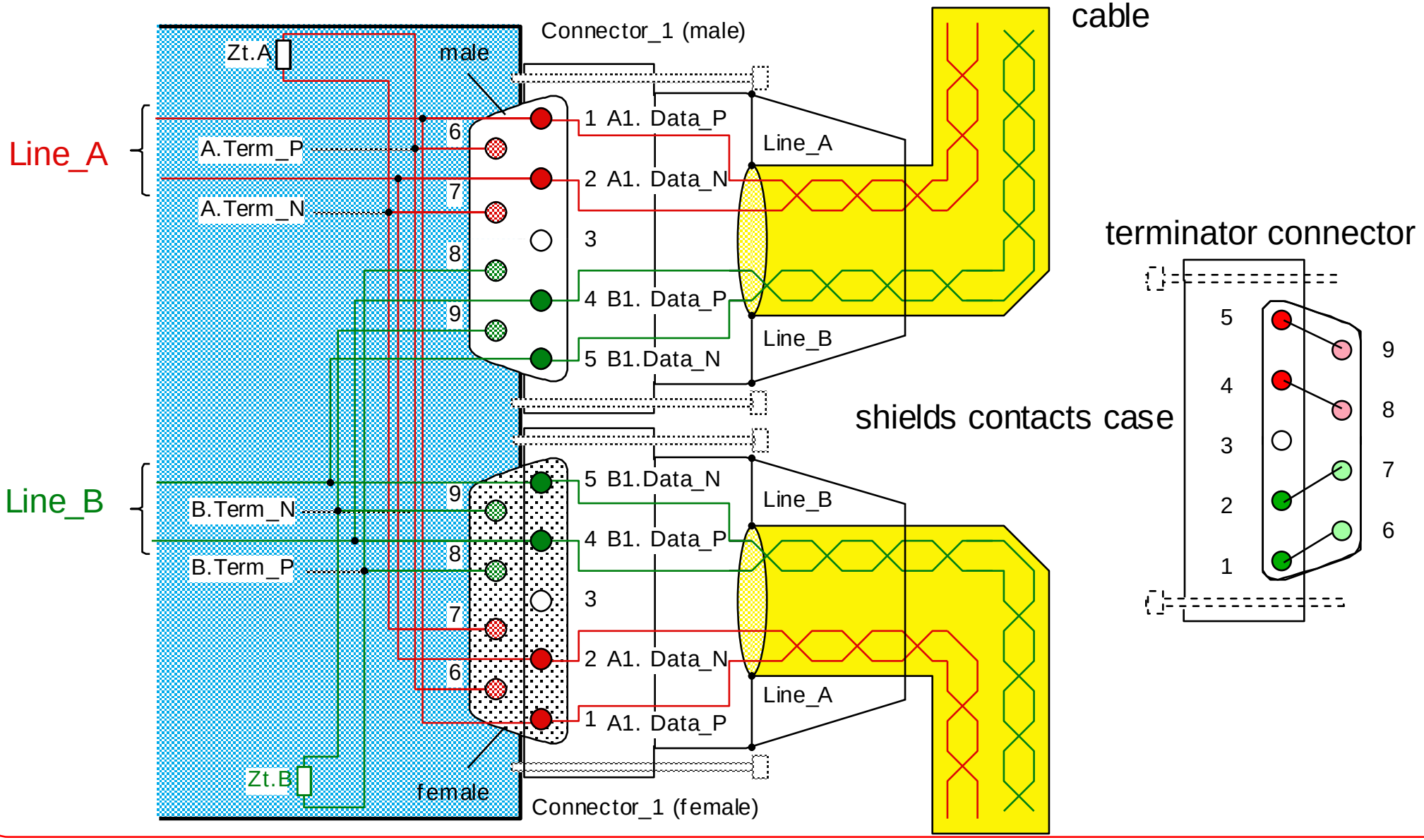
EMD Device with Double Line Attachment



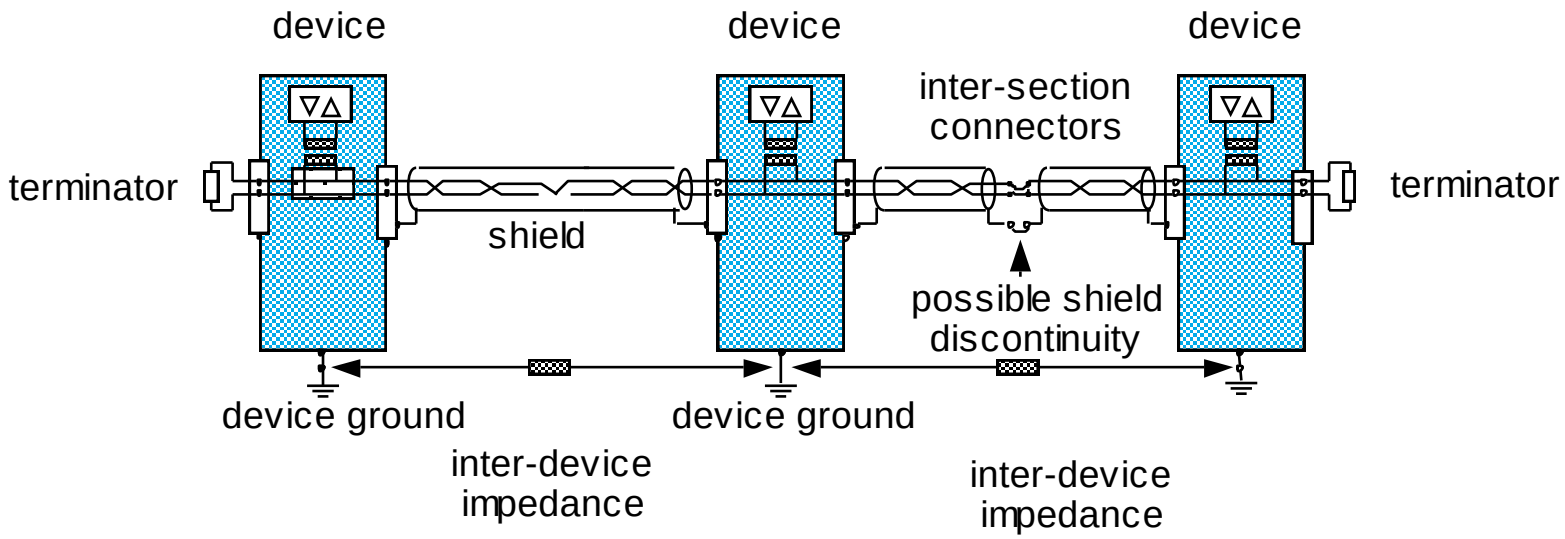
Carrying both redundant lines in the same cable eases installation

it does not cause unconsidered common mode failures in the locomotive environment (most probable faults are driver damage and bad contact)

EMD Connectors for Double-Line Attachment



EMD Shield Grounding Concept



Shields are connected directly to the device case

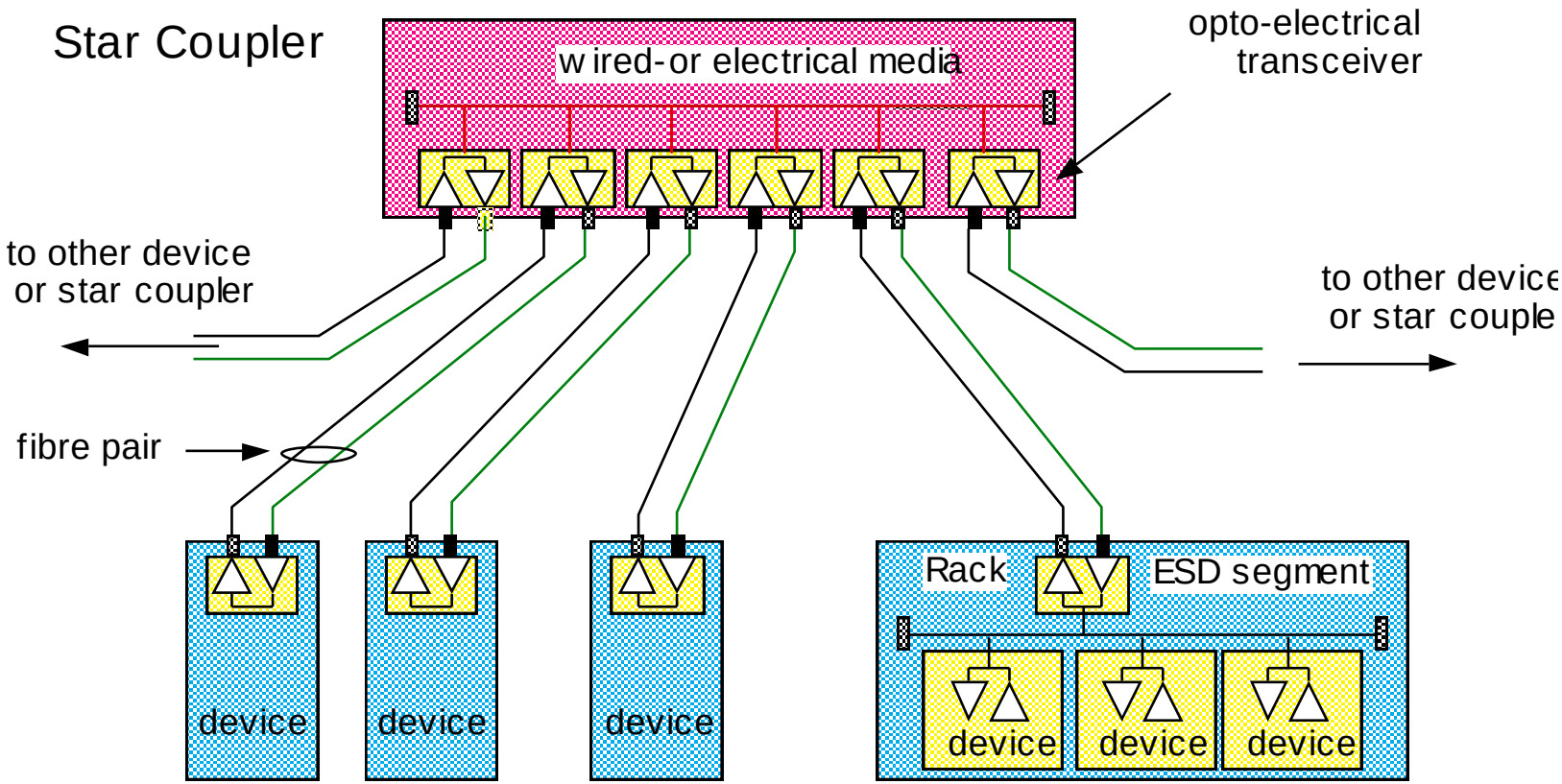
Device cases should be connected to ground whenever feasible

OGF (Optical Glass Fibre)

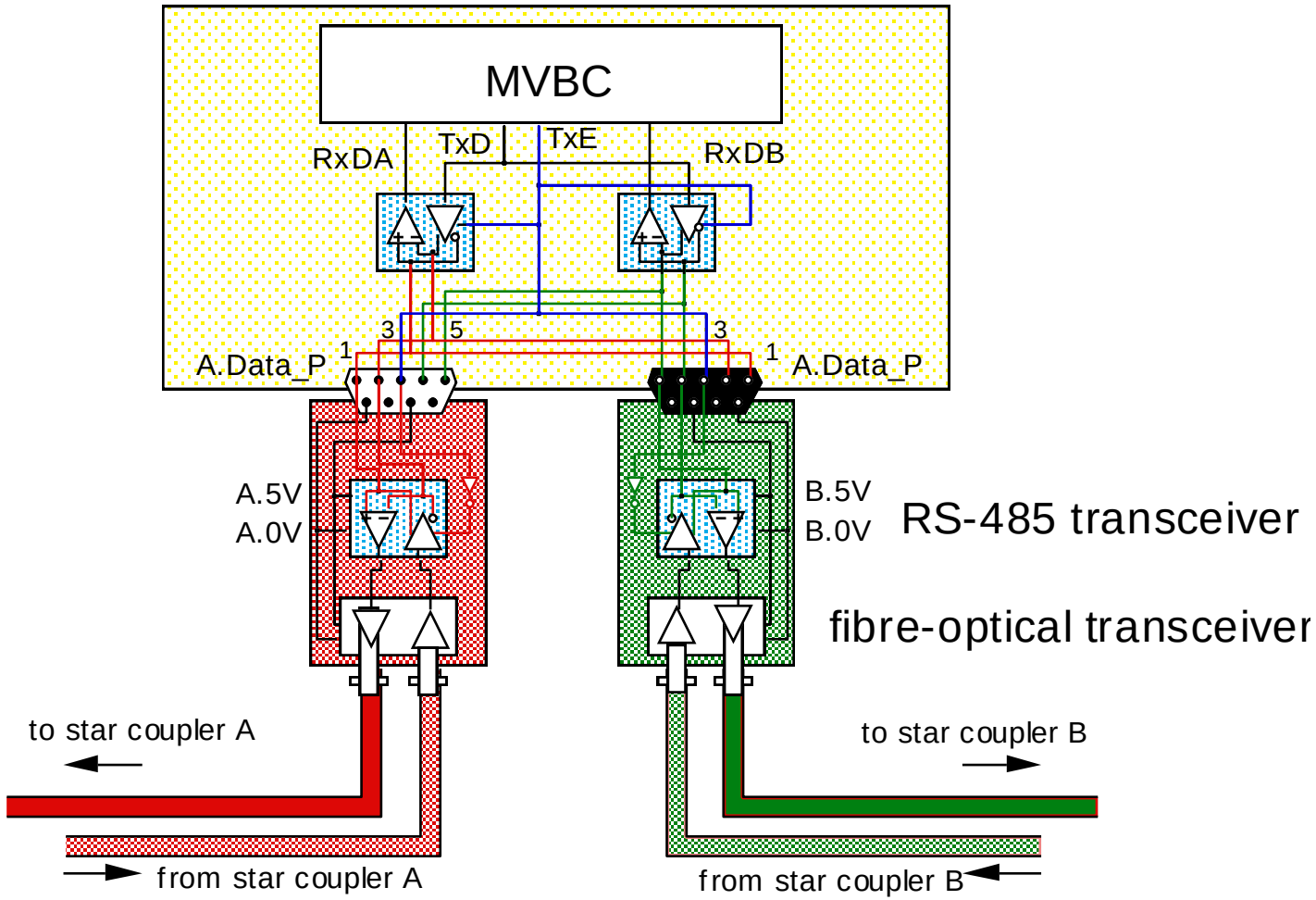
Covers up to 2000 m

Proven 240µm silica clad fibre

Main application: locomotive and critical EMC environment



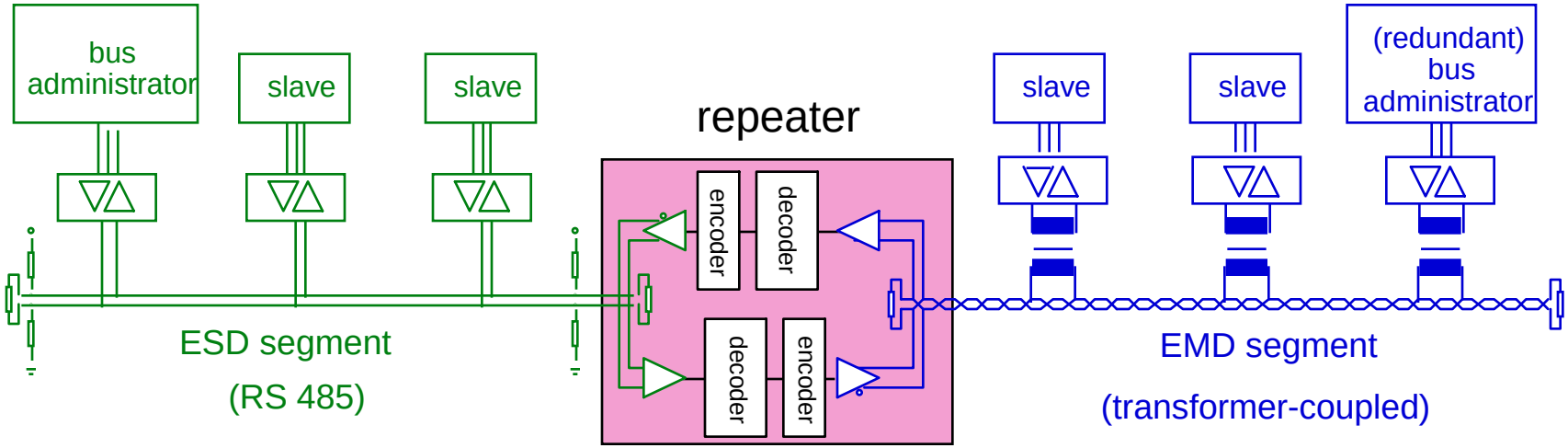
OGF to ESD adapter



Double-line ESD devices can be connected to fibre-optical links by adapters

MVB Repeater: the Key Element

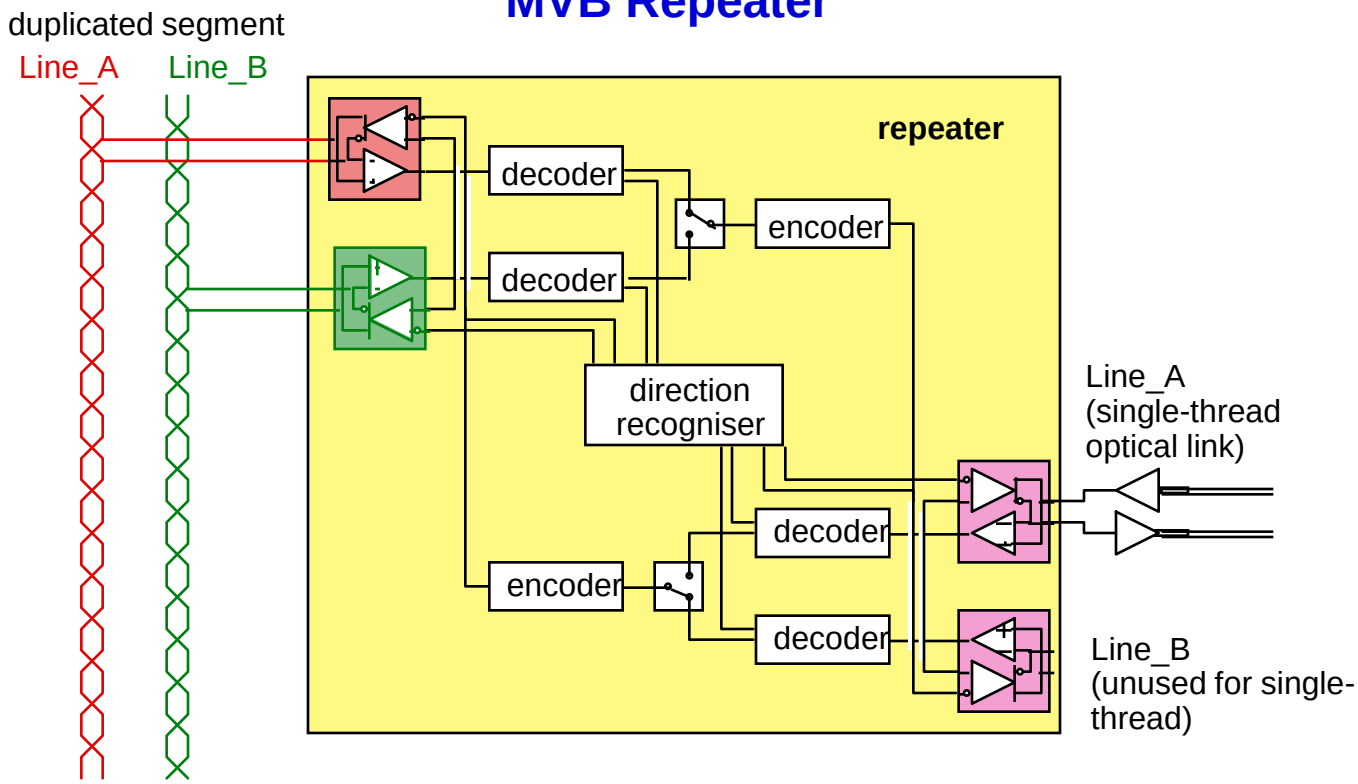
A repeater is used at a transition from one medium to another.



The repeater:

- decodes and reshapes the signal (knowing its shape)
- recognizes the transmission direction and forward the frame
- detects and propagates collisions

MVB Repeater



recognize the transmission direction and forward the frame
decode and reshape the signal (using a priori knowledge about ist shape)
jabber-halt circuit to isolate faulty segments
detect and propagate collisions
increase the inter-frame spacing to avoid overlap
can be used with all three media
appends the end delimiter in the direction fibre to transformer, remove it the opposite way
handles redundancy (transition between single-thread and double-thread)

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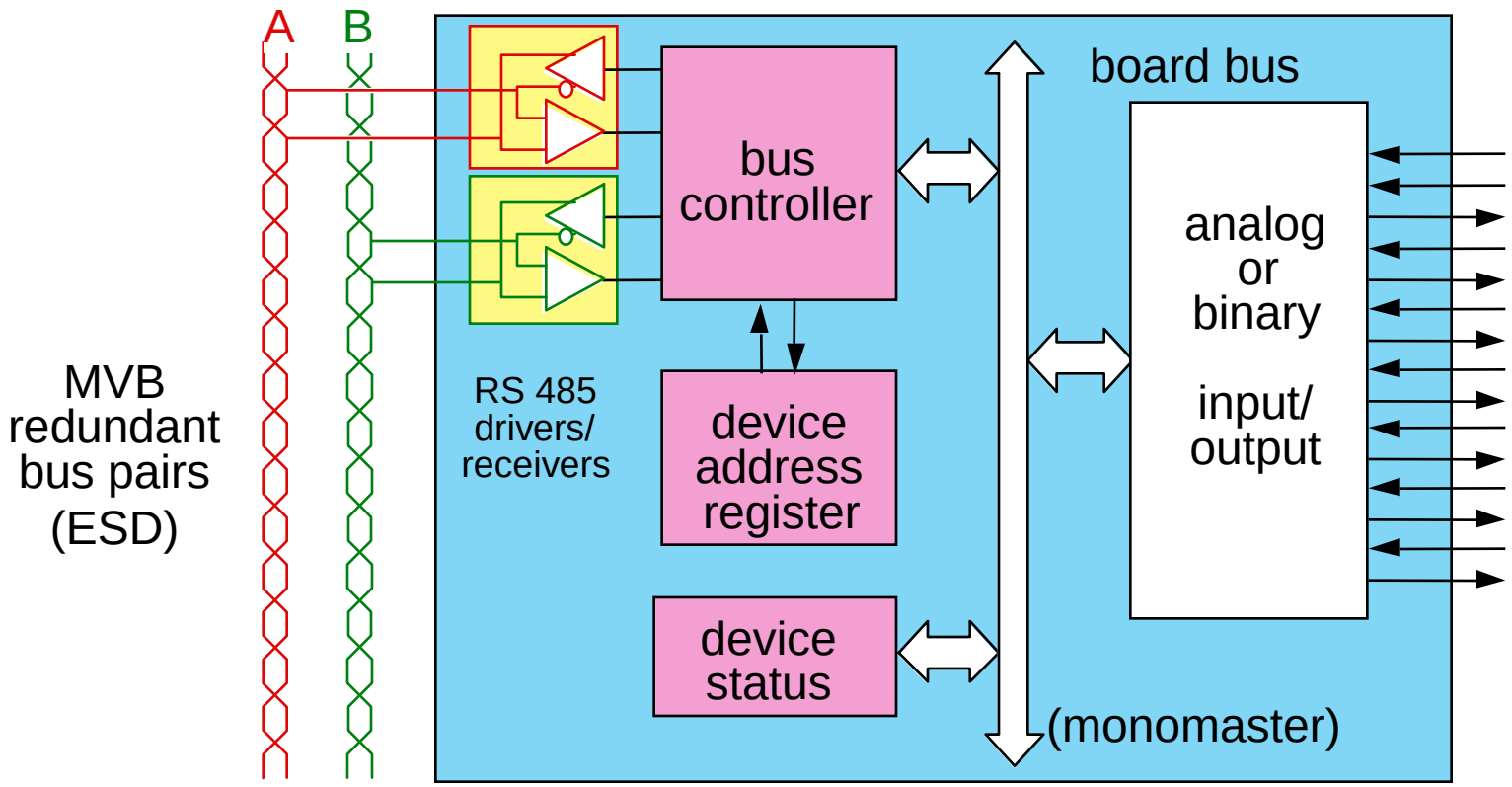
MVB Class 1 Device



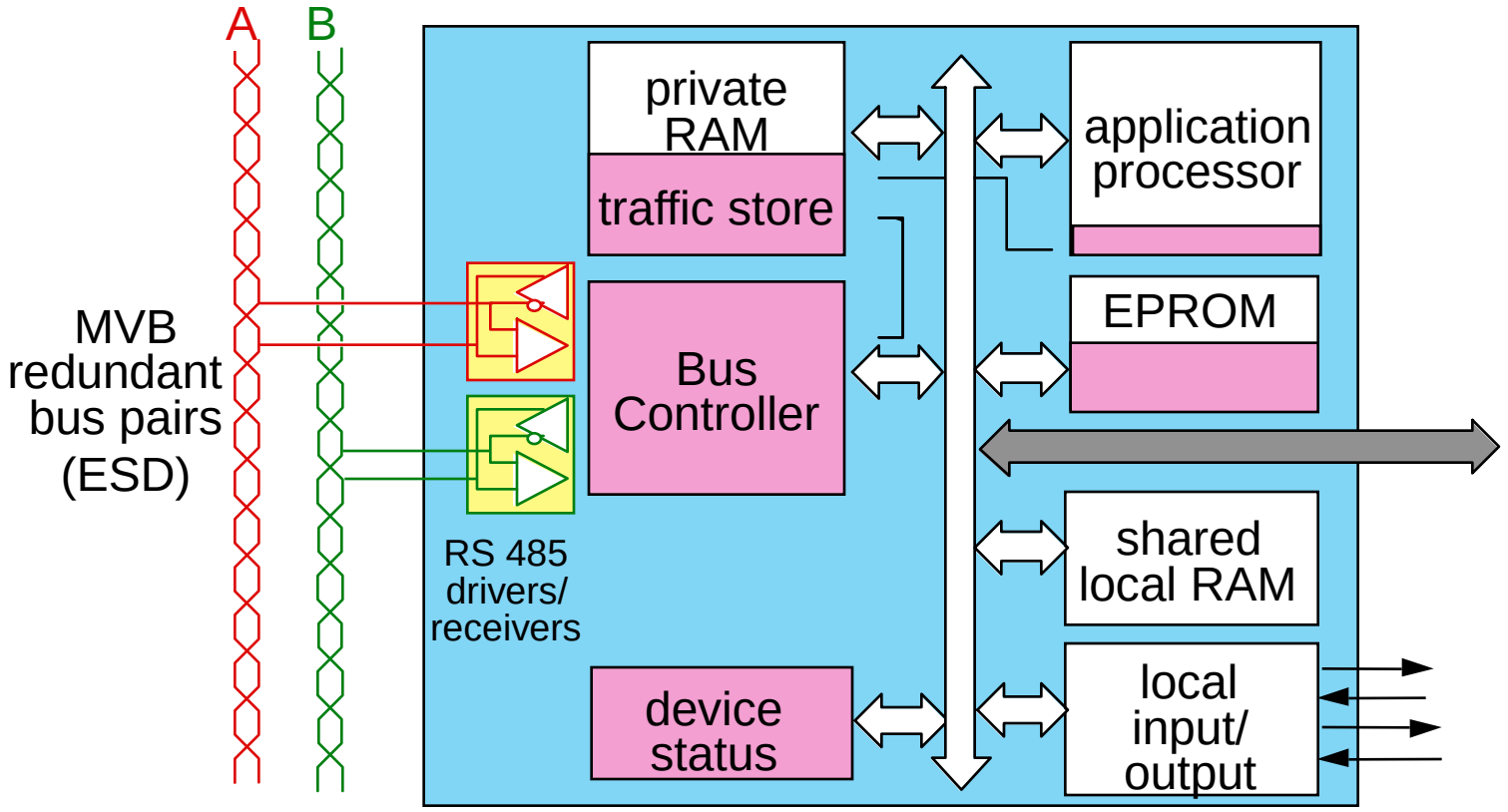
Class 1 or field devices are simple connections to sensors or actuators.

They do not require a micro-controller.

They do not participate in message data communication.

The Bus Controller manages both the input/output and the bus.

MVB Class 2-3 Device



- Class 2 and higher devices have a processor and may exchange messages.
- Class 2 devices are configurable I/O devices (but not programmable)
- The Bus Controller communicates with the Application Processor through a shared memory, the traffic store, which holds typically 256 ports.

MVB Class 4-5 Device

Class 4 devices present the functionality of a Programming and Test station

Class 4 devices are capable of becoming Bus Administrators.

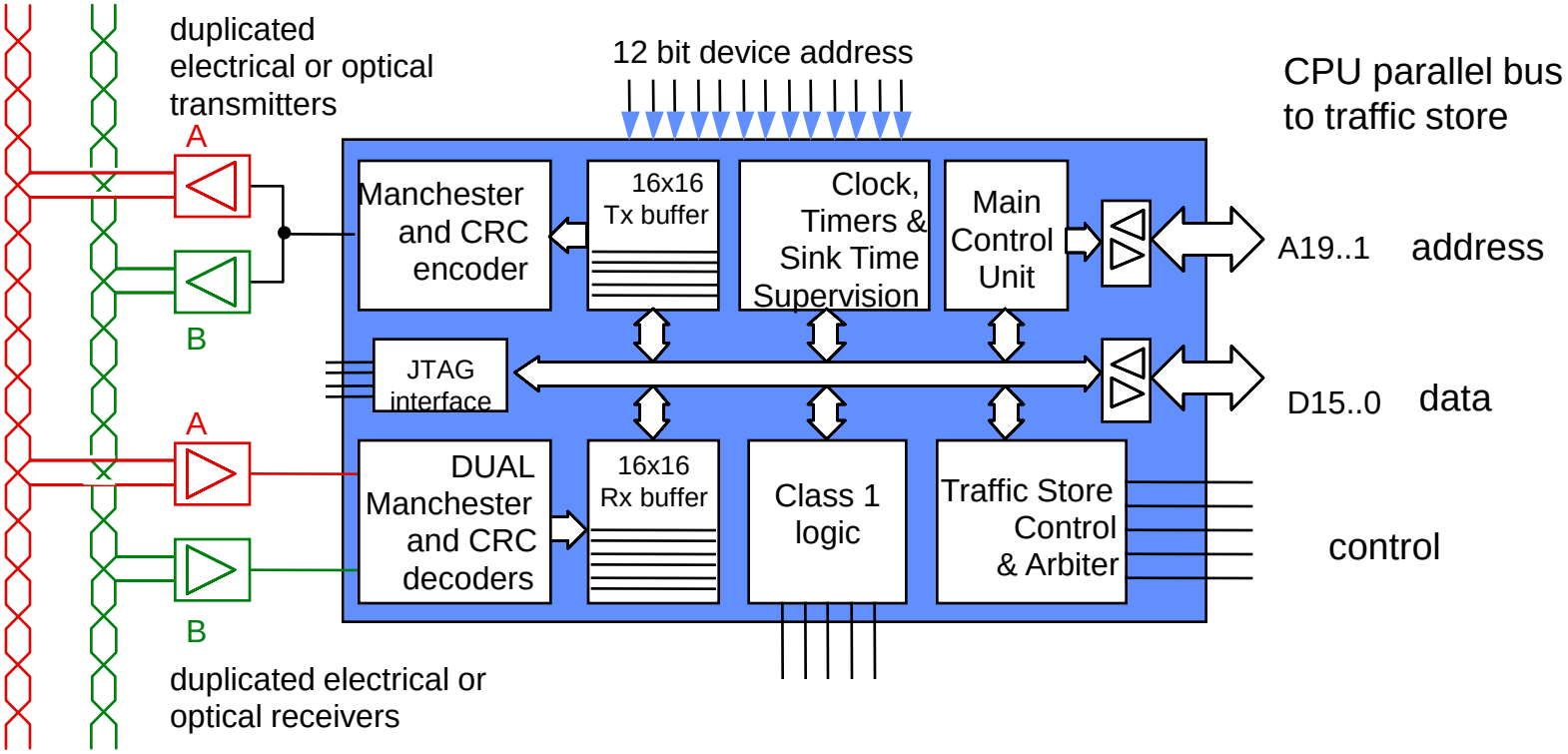
To this effect, they hold additional hardware to read the device status of the other devices and to supervise the configuration.

They also have a large number of ports, so they can supervise the process data transmission of any other device.

Class 5 devices are gateways with several link layers (one or more MVB, WTB).

The device classes are distinguished by their hardware structure.

MVBC - bus controller ASIC

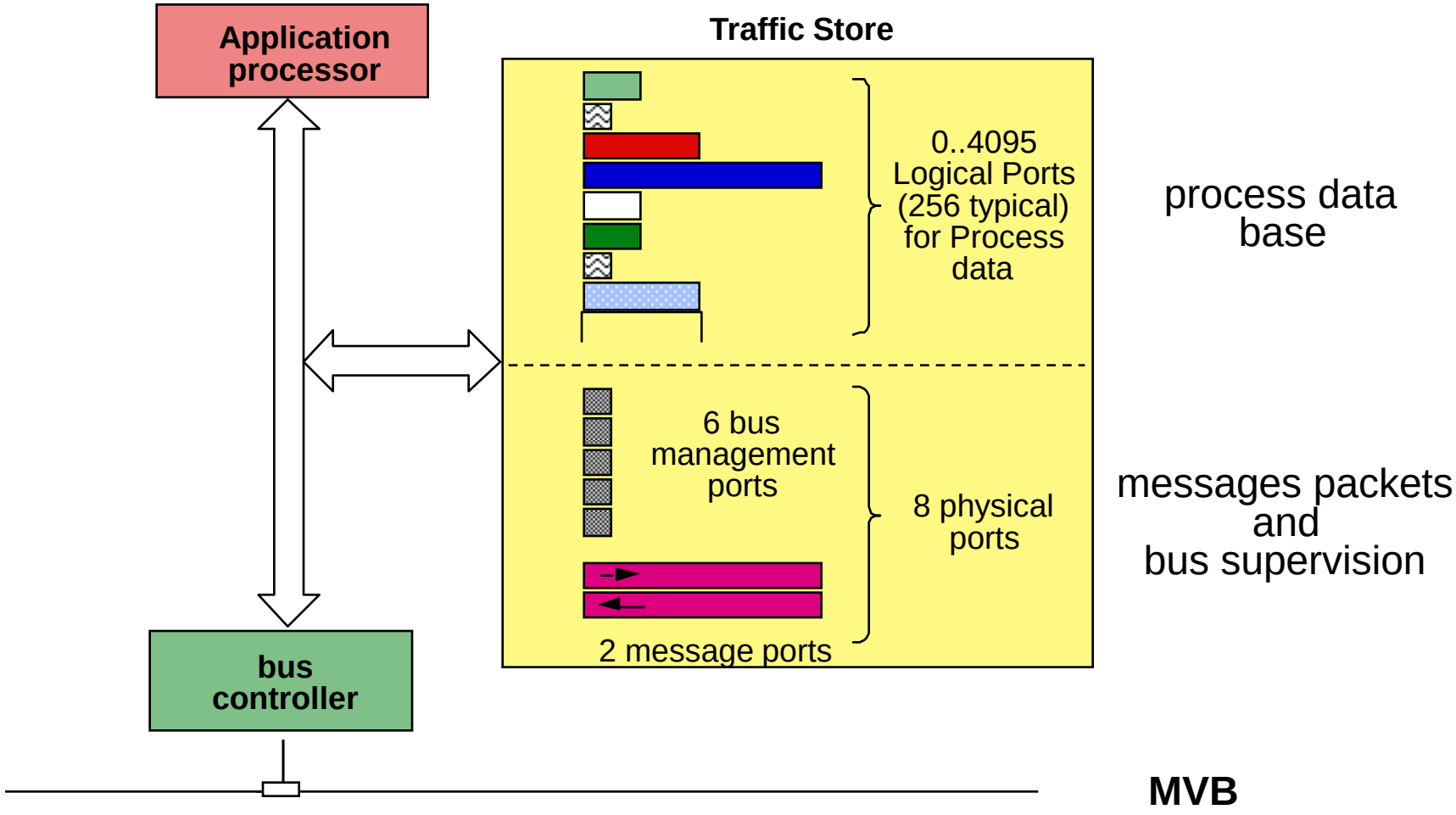


- Automatic frame generation and analysis
- Adjustable reply time-out
- Up to 4096 ports for process data
- 16KByte.. 1MByte traffic store
- Freshness supervision for process data
- In Class 1 mode: up to 16 ports
- Bit-wise forcing
- Time and synchronization port

- Bus administrator functions
- Bookkeeping of communication errors
- Hardware queueing for message data
- Supports 8 and 16-bit processors
- Supports big and lirttle endians
- 24 MHz clock rate
- HCMOS 0.8 µm technology
- 100 pin QFP

MVB Bus Interface

The interface between the bus and the application is a shared memory, the *Traffic Memory* , where Process Data are directly accessible to the application.



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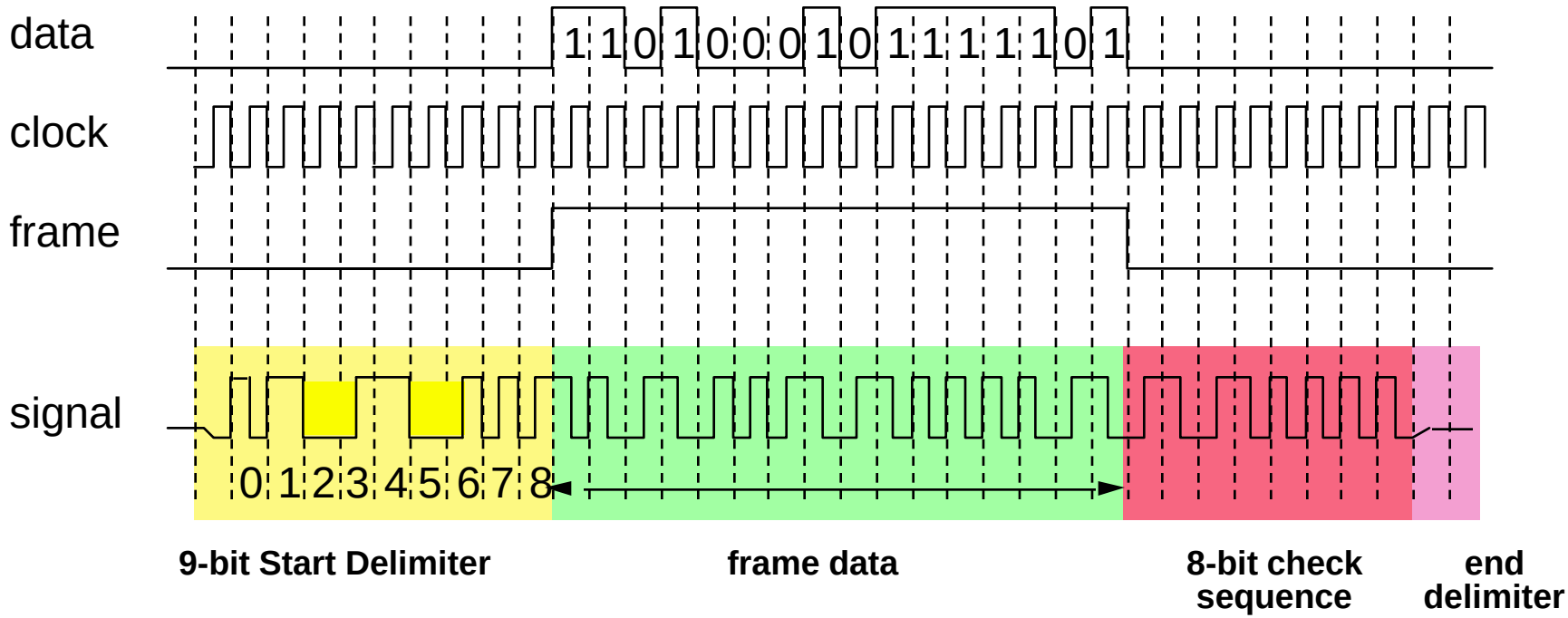
MVB Manchester Encoding

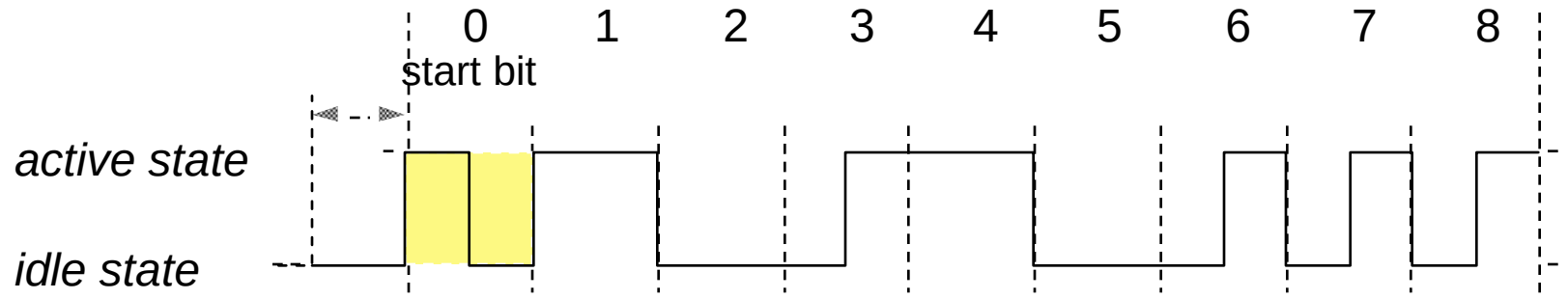


The Manchester-coded frame is preceded by a Start Delimiter containing non-Manchester signals to provide transparent synchronization.

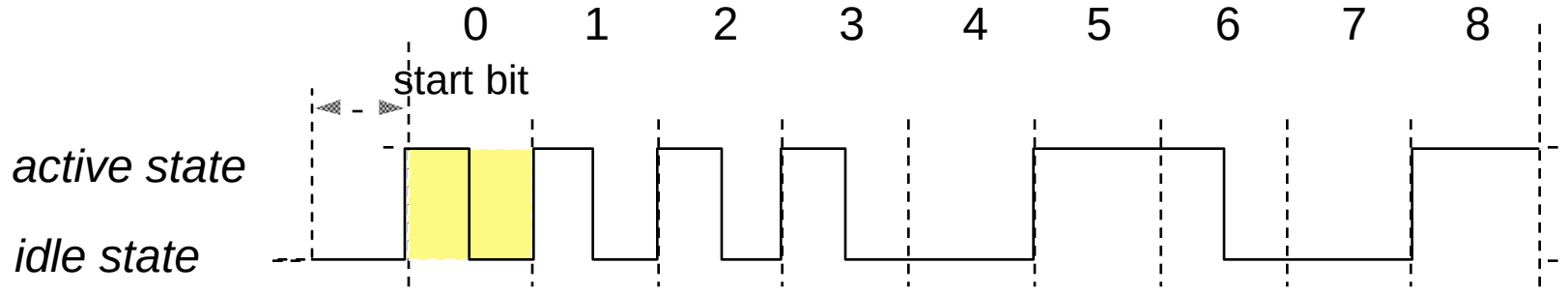
MVB Frame Delimiters

Different delimiters identify master and slave frames:

Master Frame Delimiter



Slave Frame Delimiter

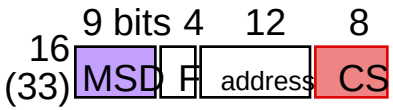


This prevents mistaking the next master frame when a slave frame is lost.

MVB Frames Formats

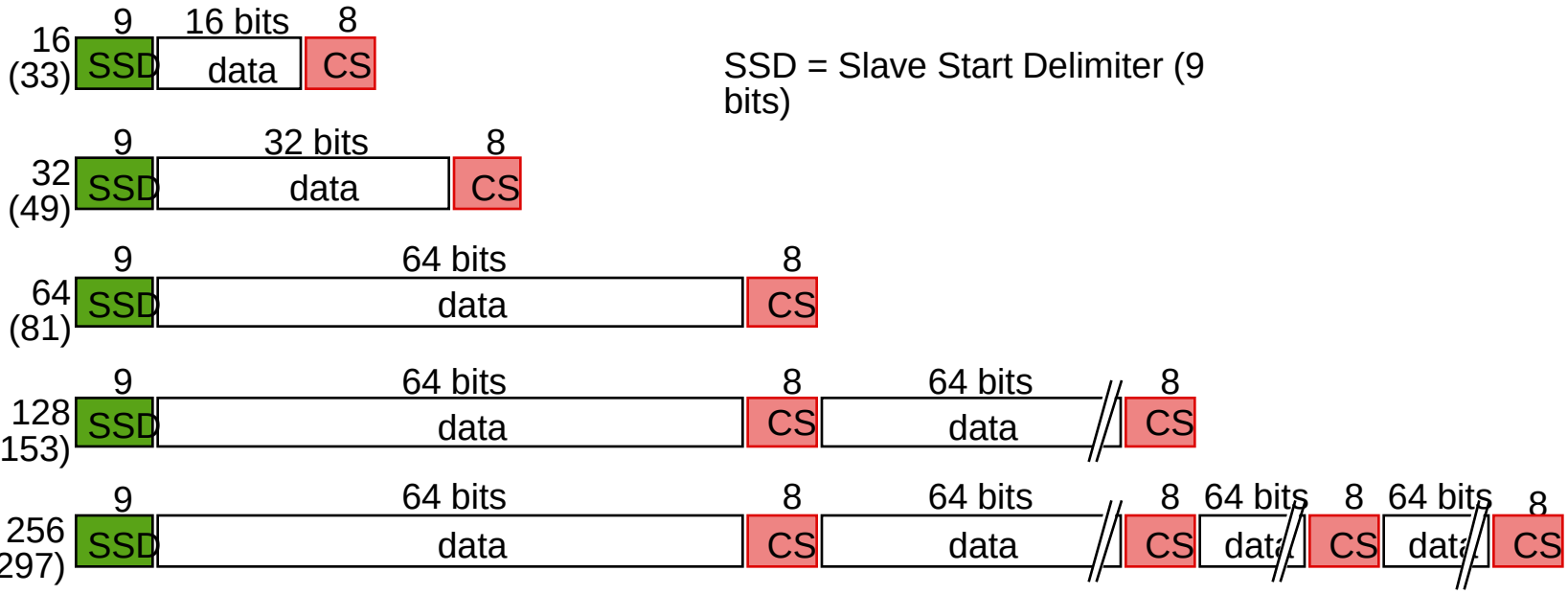
The MVB distinguishes two kinds of frames:

master frames issued by the master



MSD = Master Start Delimiter (9 bits)
CS = Check Sequence (8 bits)
F = F_code (4 bits)

slave frames sent in response to master frames

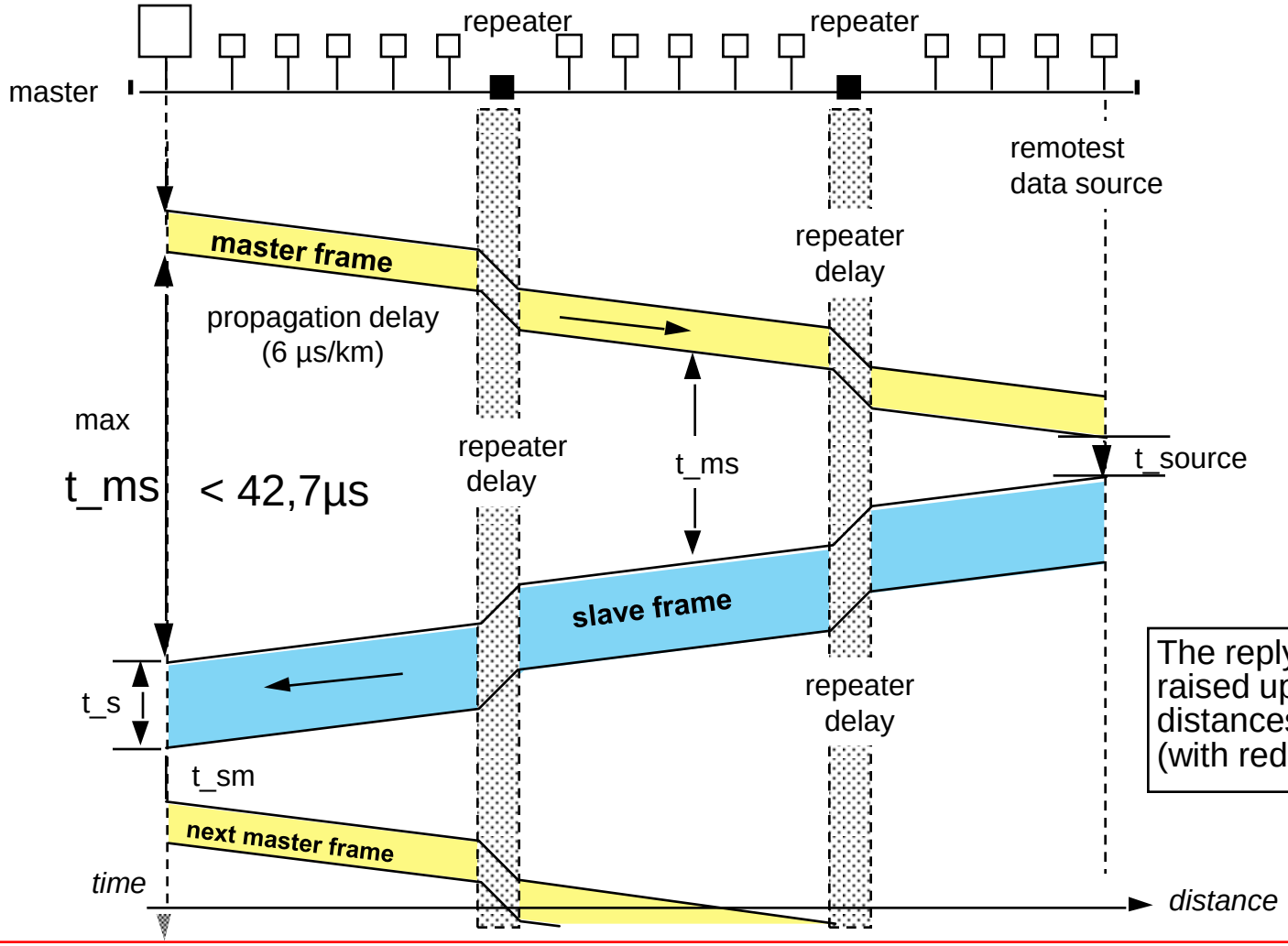


SSD = Slave Start Delimiter (9 bits)

useful (total) size in bits

MVB Distance Limits

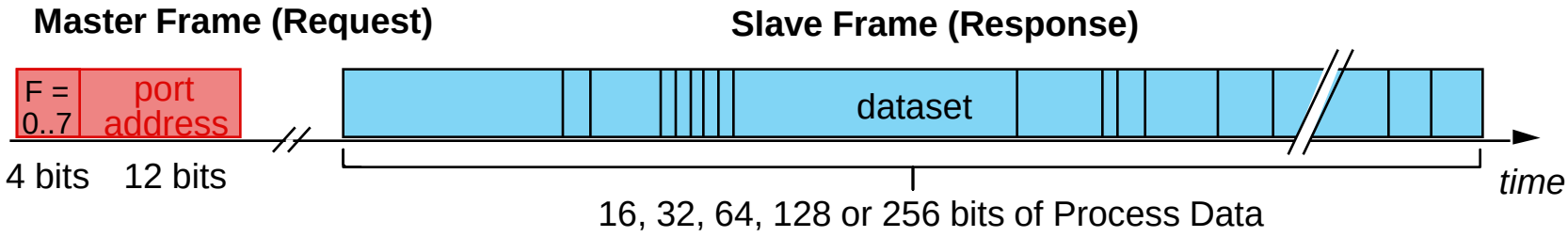
The distance is limited by the maximum allowed *reply delay* of 42,7 µs between a master frame and a slave frame.



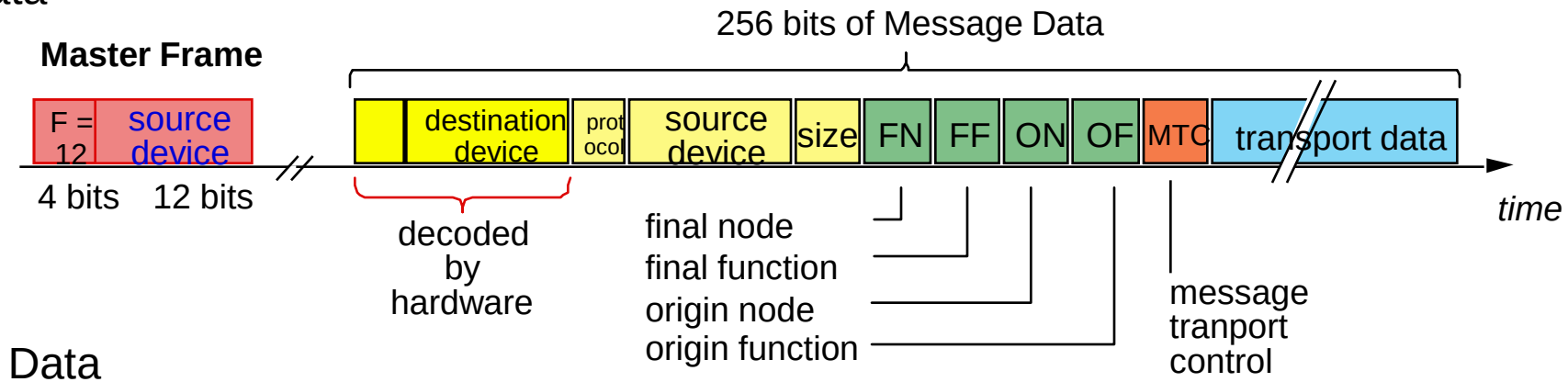
The reply delay time-out can be raised up to 83,4 µs for longer distances
(with reduced troughput).

MVB Telegrams

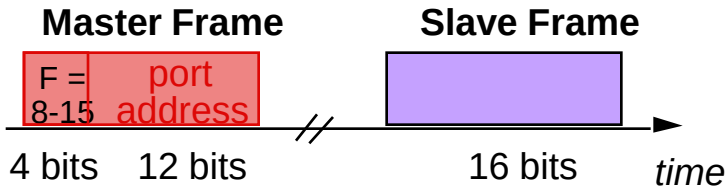
Process Data



Message Data



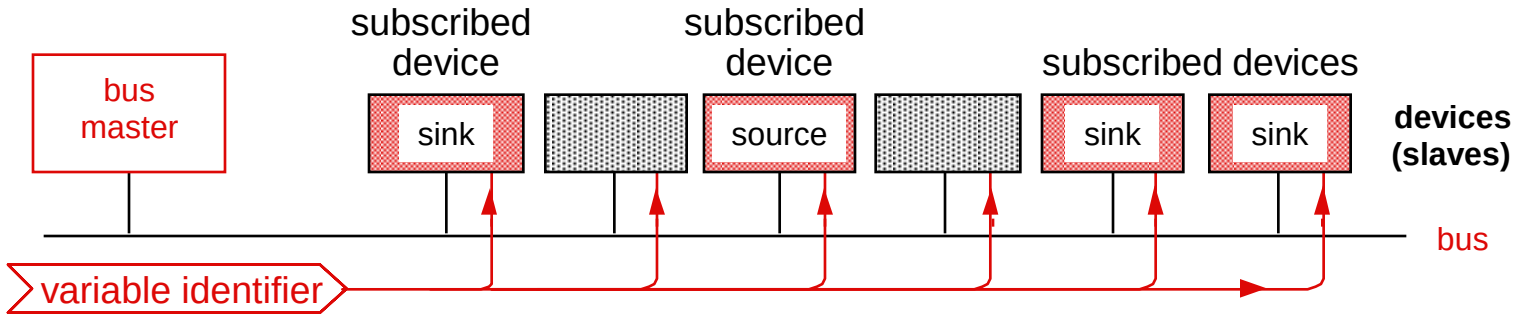
Supervisory Data



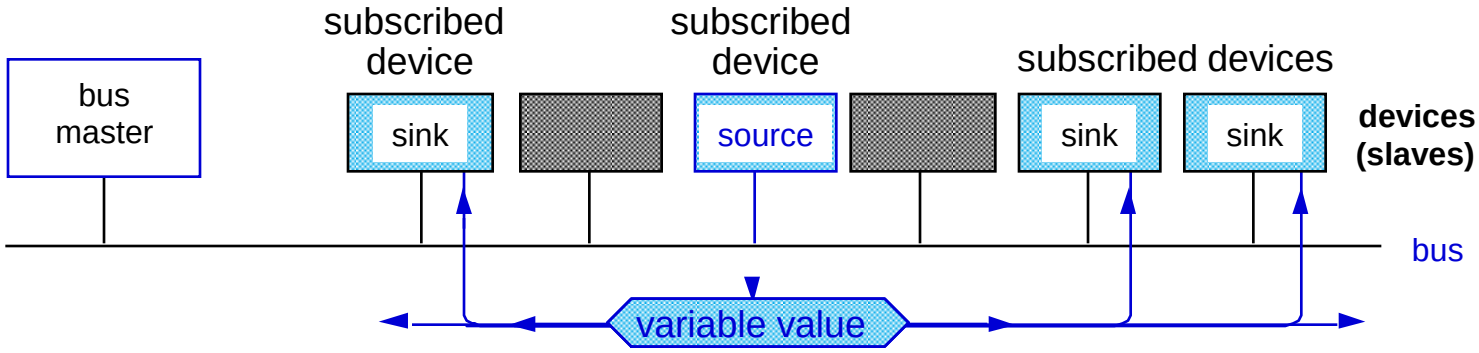
Telegrams are distinguished by the F_code in the Master Frame

Source-addressed broadcast

Phase1: The bus master broadcasts the identifier of a variable to be transmitted:

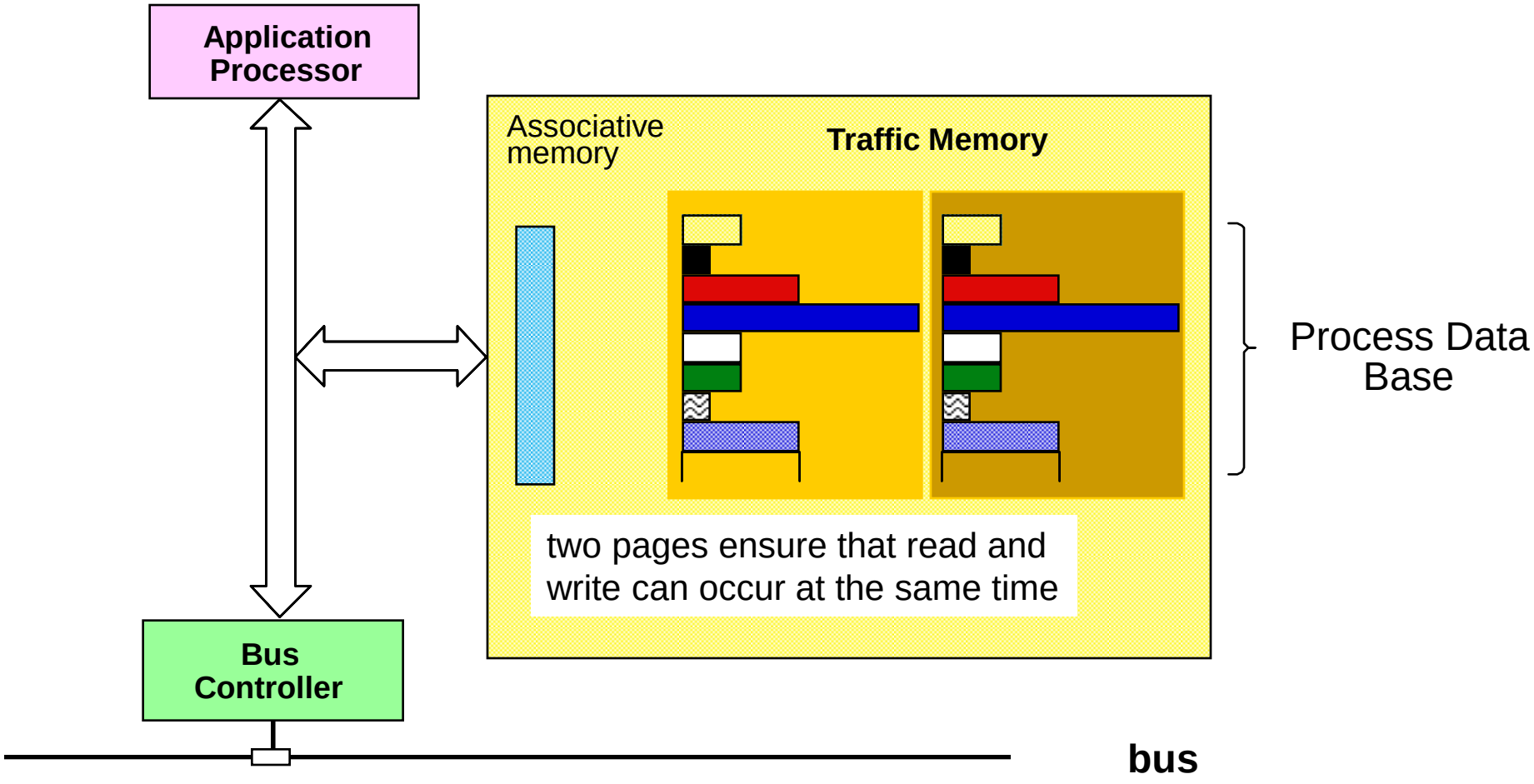


Phase 2: The device which sources that variable responds with a slave frame containing the value, all devices subscribed as sink receive that frame.

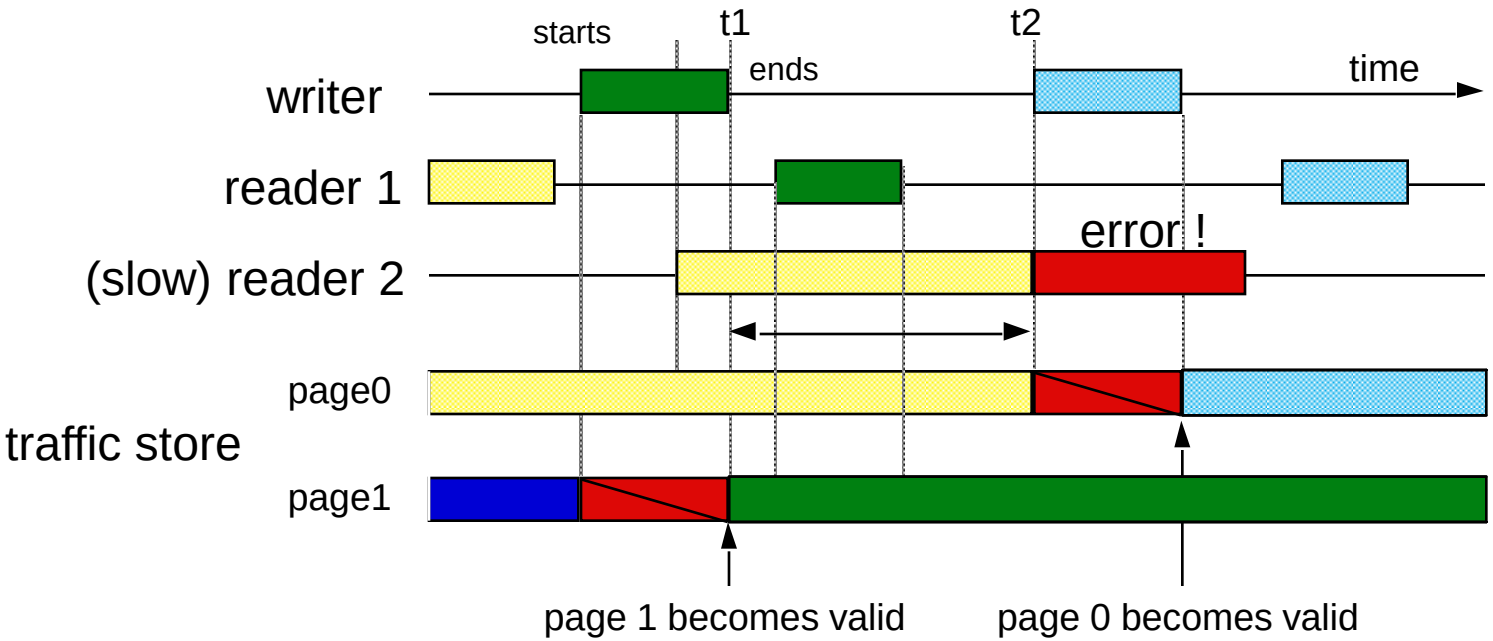


Traffic Memory

The bus and the application are (de)coupled by a shared memory, the *Traffic Memory,* where process variables are directly accessible to the application.



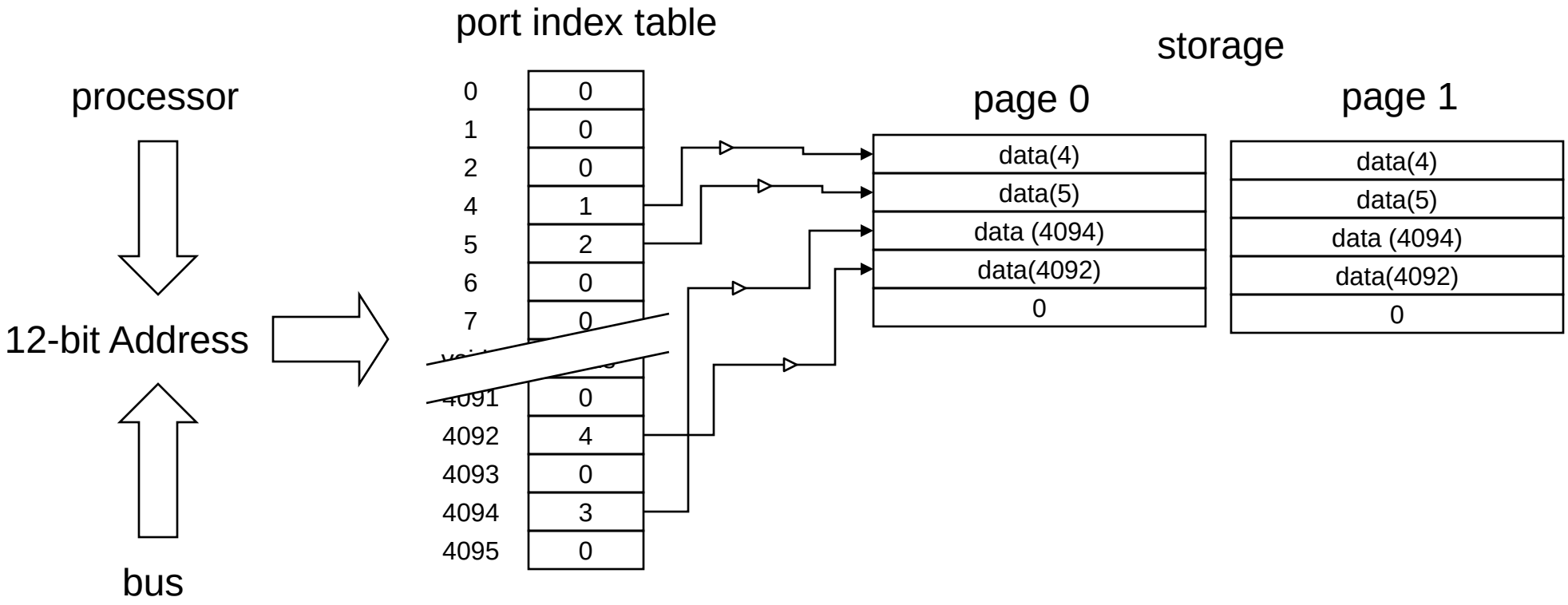
Restriction in simultaneous access



- there may be no semaphores to guard access to a traffic store (real-time)
- there may be only one writer for a port, but several readers
- a reader must read the whole port before the writer overwrites it again
- therefore, the processor must read ports with interrupt off.

Operation of the traffic memory

In content-addressed ("source-addressed") communication, messages are broadcast, the receiver select the data based on a look-up table of relevant messages.
For this, an associative memory is required.
Since address size is small (12 bits), the decoder is implemented by a memory block:



MVB F_code Summary

Master Frame			Slave Frame			
F_code	address	request	source	size	response	destination
0				16		
1			single	32		all
2	logical	Process_Data	device	64	Process_Data	devices
3			subscribed	128	(application	subscribed
4			as	256	-dependent)	as
5		reserved	source	-		sink
6		reserved		-		
7		reserved		-		
8	all devices	Master_Transfer	Master	16	Master_Transfer	Master
9	device	General_Event	>= 1devices	16	Event_Identifier	Master
10	device	reserved	-	-		
11	device	reserved	-	-		
12	device	Message_Data	single device	256	Message_Data	selected device
13	group	Group_Event	>= 1devices	16	Event_Identifier	Master
14	device	Single_Event	single device	16	Event_Identifier	Master
15	device	Device_Status	single device	16	Device_Status	Master or monitor

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Master Operation

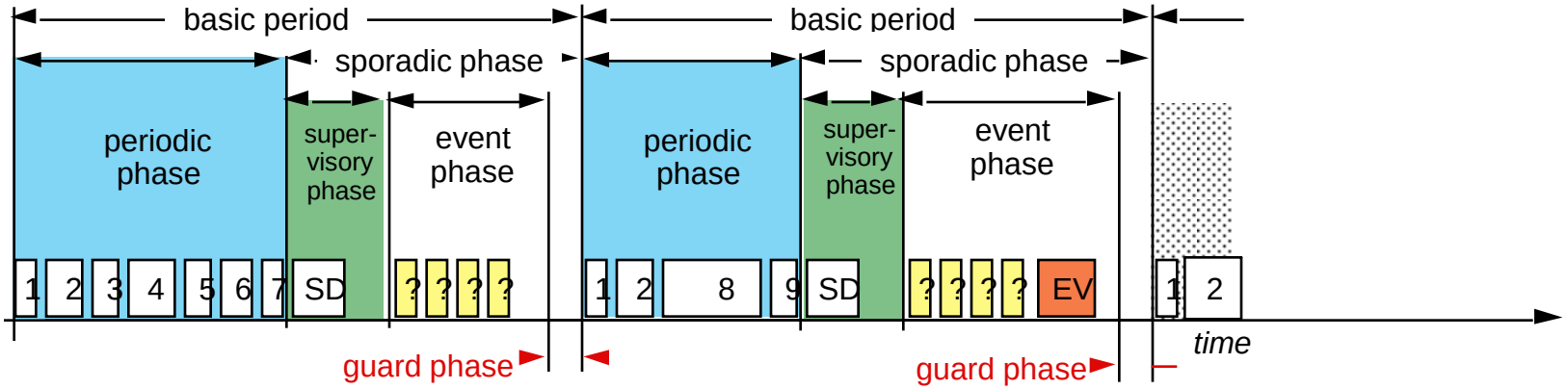
The Master performs four tasks:

1) Periodic Polling of the port addresses according to its Poll List

2) Attend Aperiodic Event Requests

3) Scan Devices to supervise configuration

4) Pass Mastership orderly (last period in turn)



The Administrator is loaded with a configuration file before becoming Master

Bus Traffic

State Variable

State of the Plant
Response in 1..200 ms

... commands, position, speed

Periodic Transmission

Spurious data losses will be compensated at the next cycle

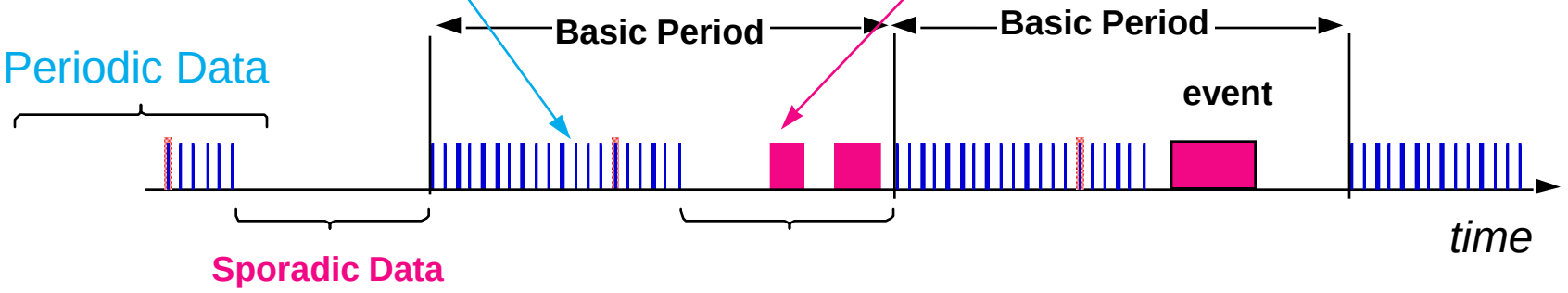
Messages

Events of the Plant
Response at human speed: > 0.5 s

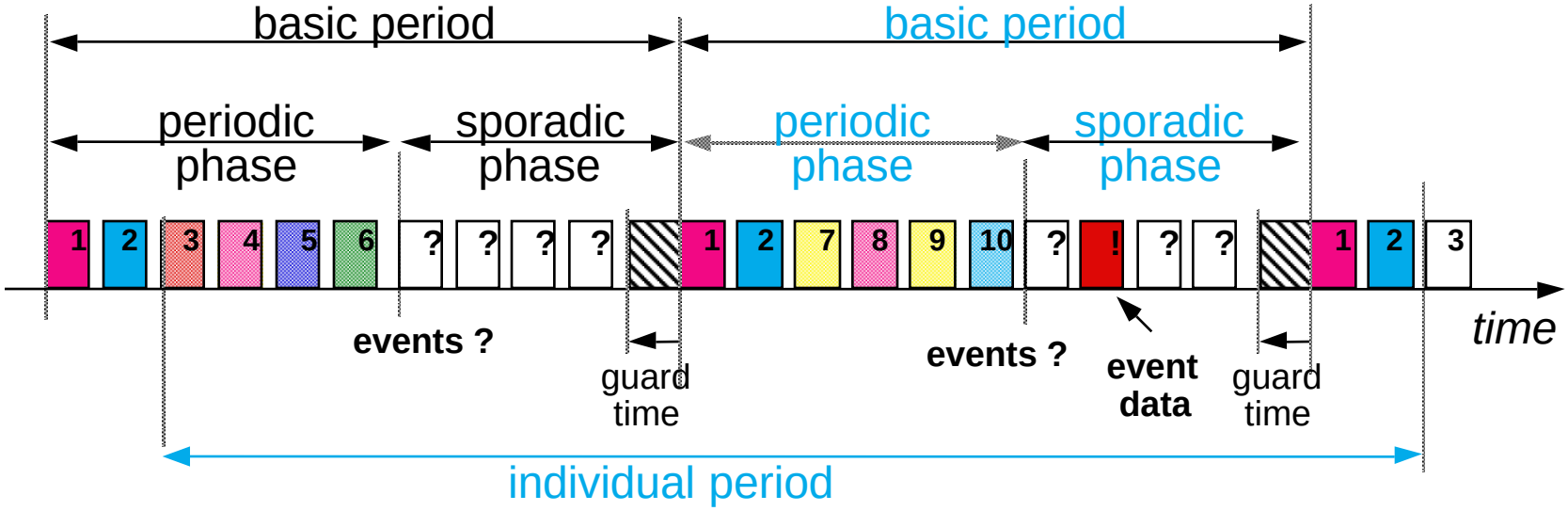
- Diagnostics, event recorder
- Initialisation, calibration

On-Demand Transmission

Flow control & error recovery protocol for catching all events



MVB Medium Access



A basic period is divided into a periodic and a sporadic phase.

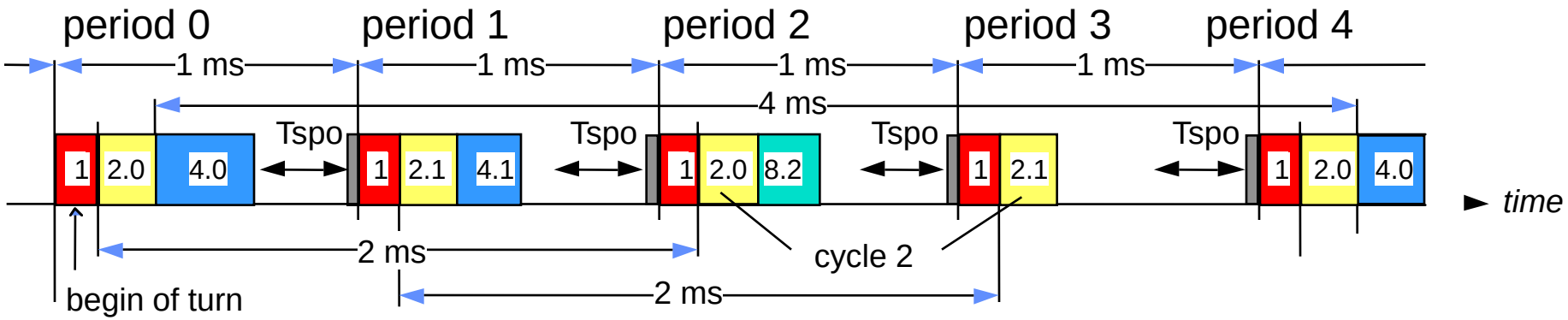
During the periodic phase, the master polls the periodic data in sequence.

Periodic data are polled at their individual period (a multiple of the basic period).

Between periodic phases, the Master continuously polls the devices for events.

Since more than one device can respond to an event poll, a resolution procedure selects exactly one event.

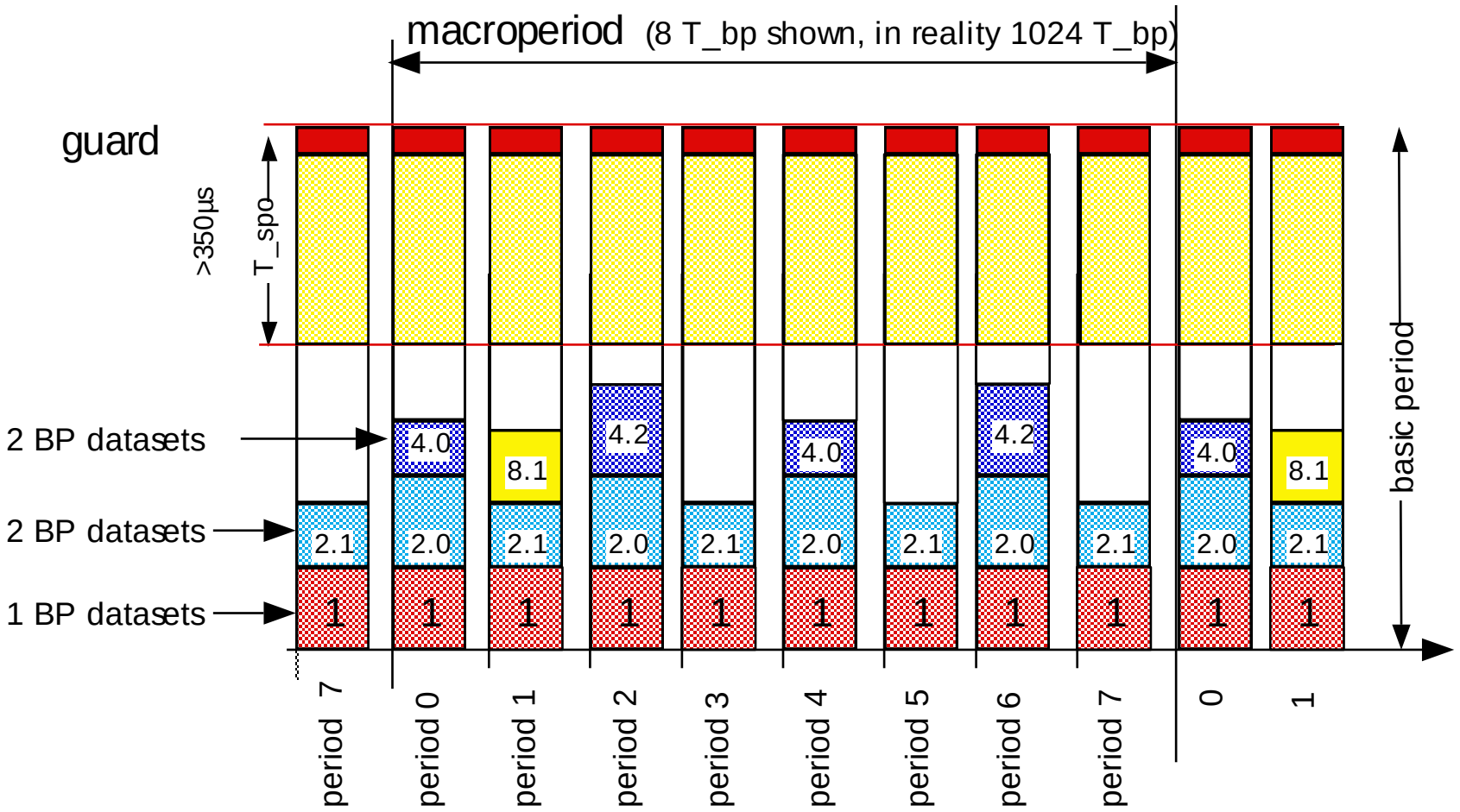
MVB Bus Administrator Configuration



The Poll List is built knowing:

- the list of the port addresses, size and individual period
- the reply delay of the bus
- the list of known devices (for the device scan
- the list of the bus administrators (for mastership transfer)

MVB Poll List Configuration



The algorithm which builds the poll table spreads the cycles evenly over the macroperiod

MVB Event Resolution (1)

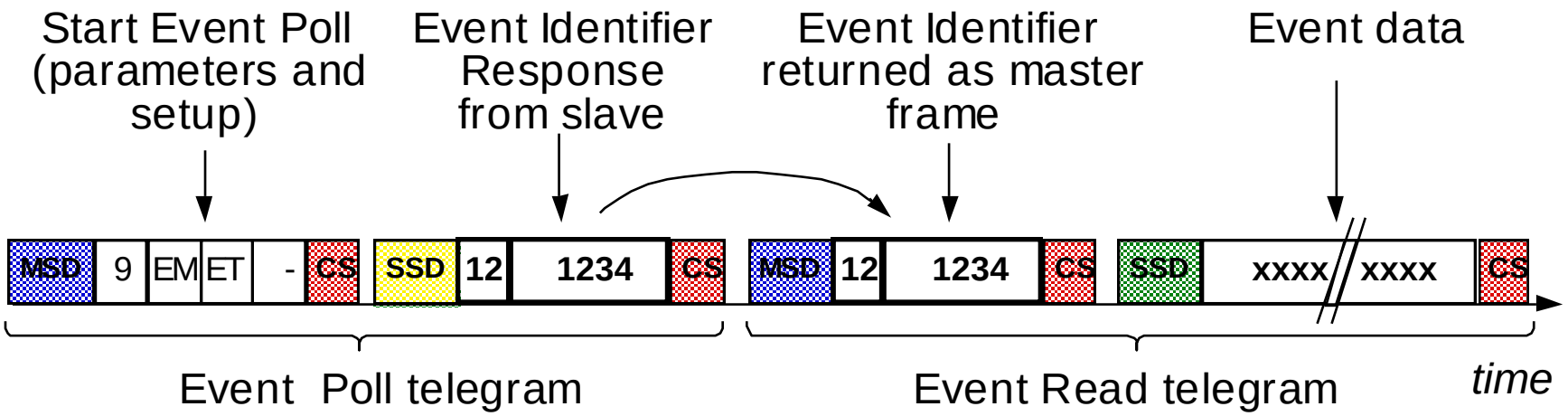
To scan events, the Master issues a General Event Poll (Start Poll) frame.

If no device responds, the Master keeps on sending Event Polls until a device responds or until the guard time before the next periodic phase begins.

A device with a pending event returns an Event Identifier Response.

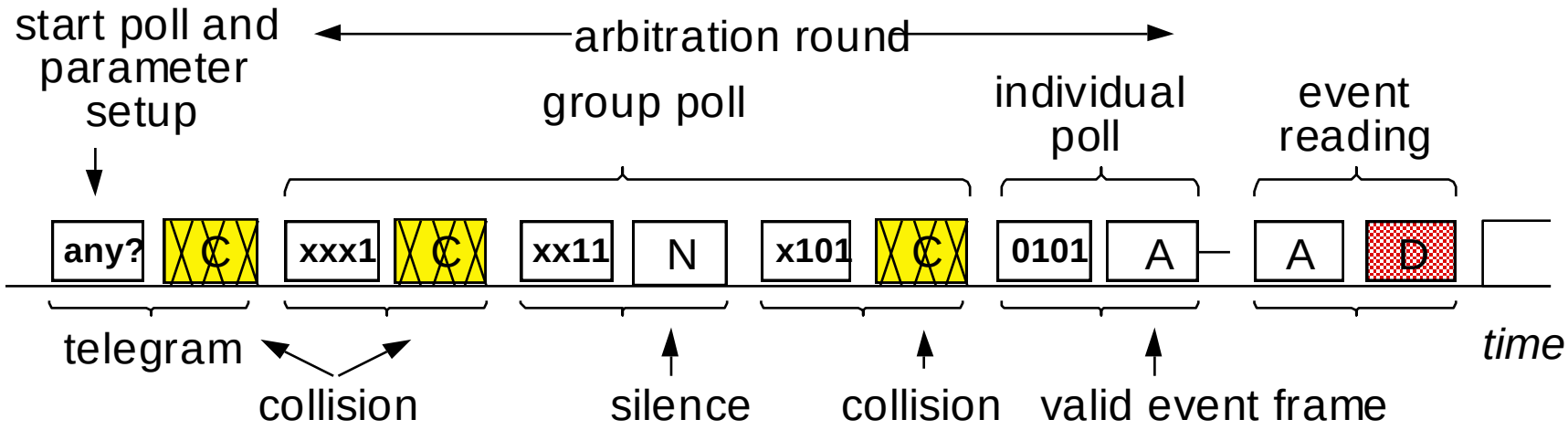
If only one device responds, the Master reads the Event Identifier (no collision).

The Master returns that frame as an Event Read frame to read the event data



MVB Event Resolution (2)

If several devices respond to an event poll, the Master detects the collision and starts event resolution

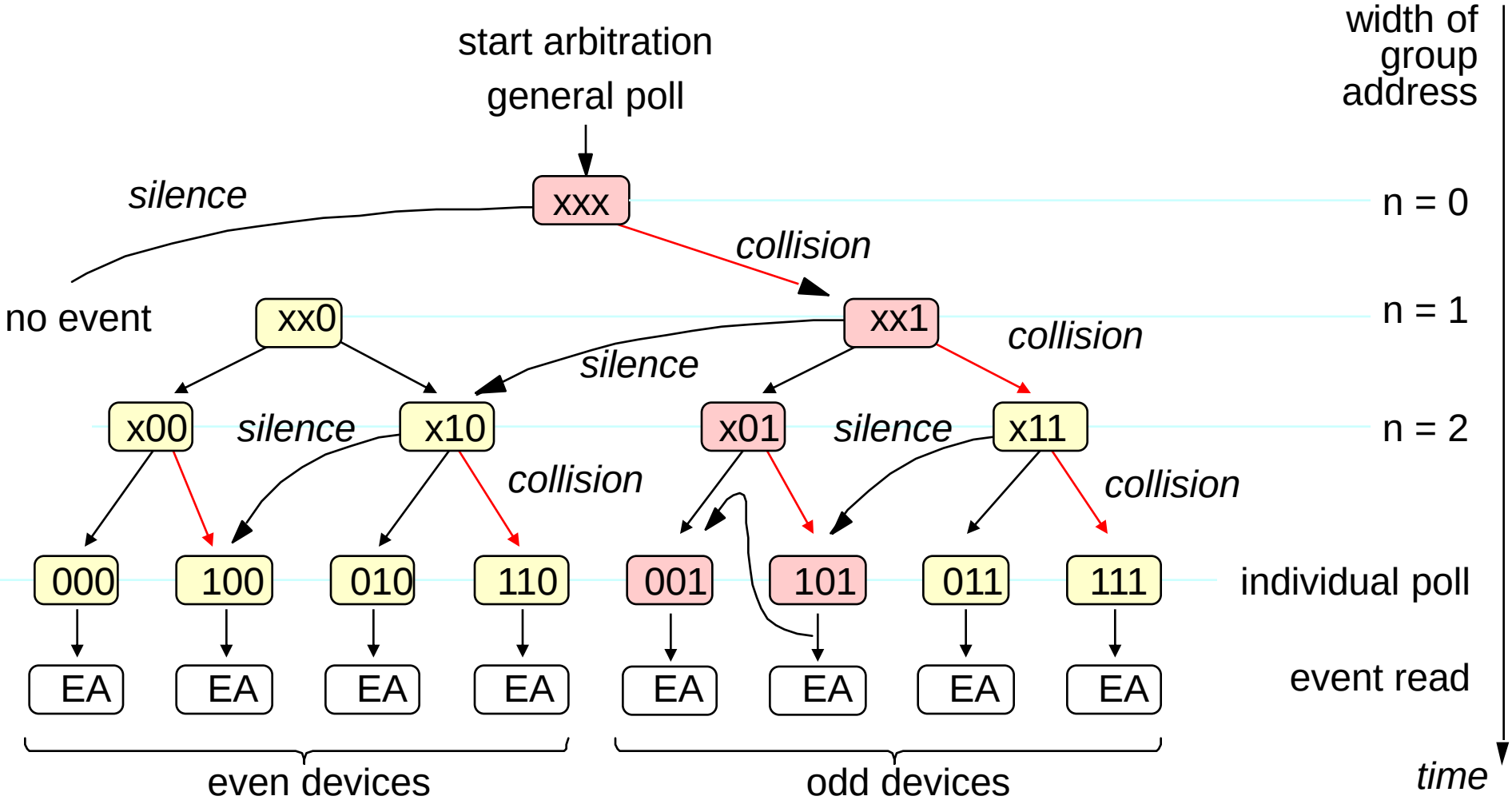


The devices are divided into groups on the base of their physical addresses. The Master first asks the devices with an odd address if they request an event.

- *If only one response comes, the master returns that frame to poll the event.*
- *If there is no response, the master asks devices with an even address.*
- *If collision keeps on, the master considers the 2nd bit of the device address.*

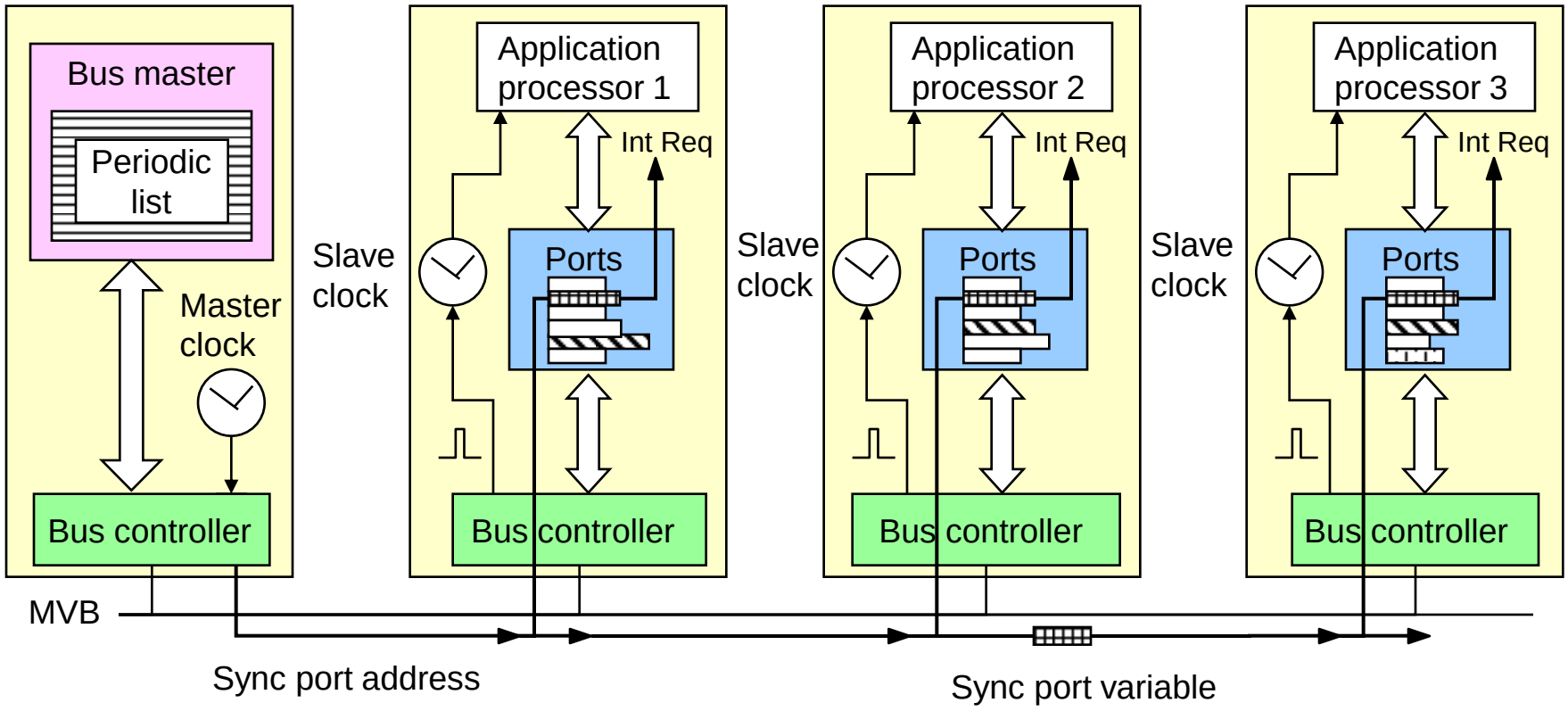
MVB Event Resolution (3)

Example with a 3-bit device address: 001 and 101 compete

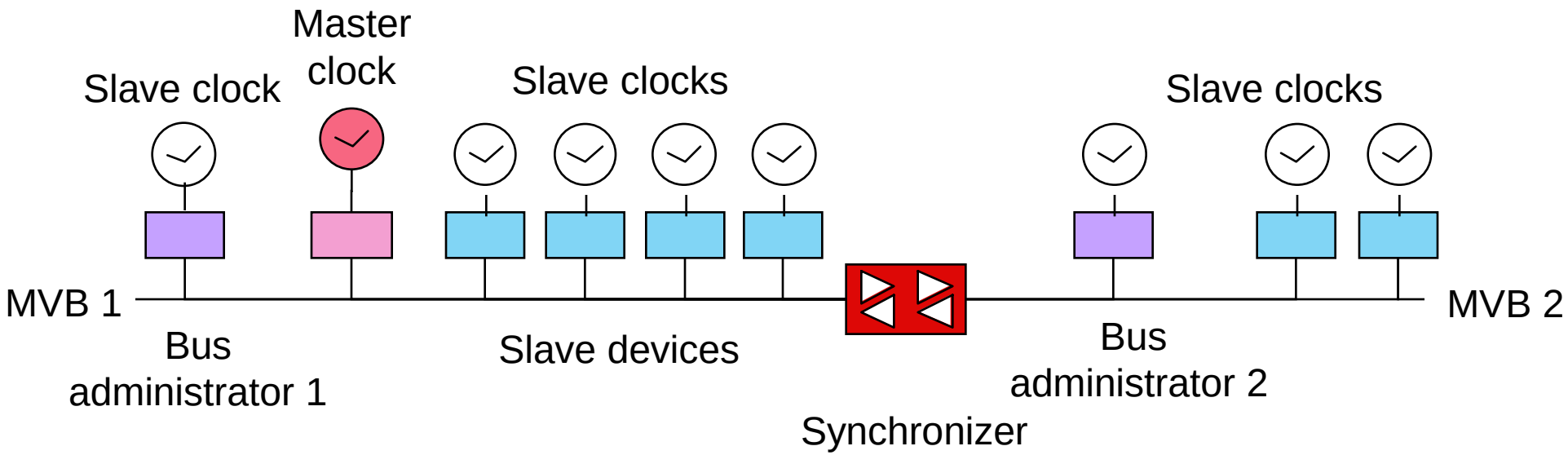


MVB Time Distribution

At fixed intervals, the Master broadcasts the exact time as a periodic variable. When receiving this variable, the bus controllers generate a pulse which can resynchronize a slave clock or generate an interrupt request.



MVB Slave Clock Synchronization



The clock does not need to be generated by the Master.

The clock can synchronize sampling within 100 µs across several bus segments.

MVB Outline

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MVB Fault-tolerance Concept

Transmission Integrity

MVB rather stops than provides false data.
The probability for an undetected transmission error (residual error rate) is low enough to transmit most safety-critical data.

This is achieved through an extensive error detection scheme

Transmission Availability

MVB continues operation is spite of any single device error. In particular, configurations without single point of failure are possible.

This is achieved through a complete duplication of the physical layer.

Graceful Degradation

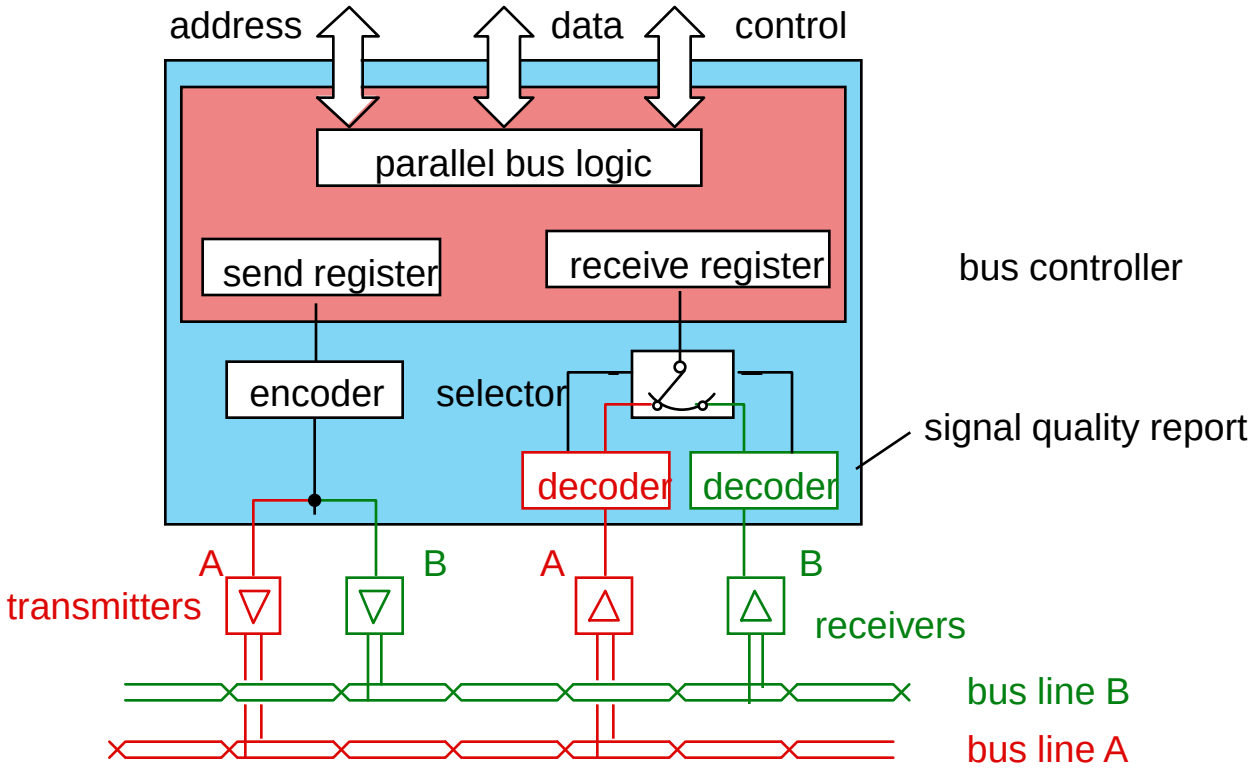
The failure of a device affects only that device, but not devices which do not depend on its data (retro-action free).

Configurability

Complete replication of the physical layer is not mandatory.
When requirements are slackened, single-thread connections may be used and mixed with dual-thread ones.

MVB Basic Medium Redundancy

The bus is duplicated for availability (not for integrity)

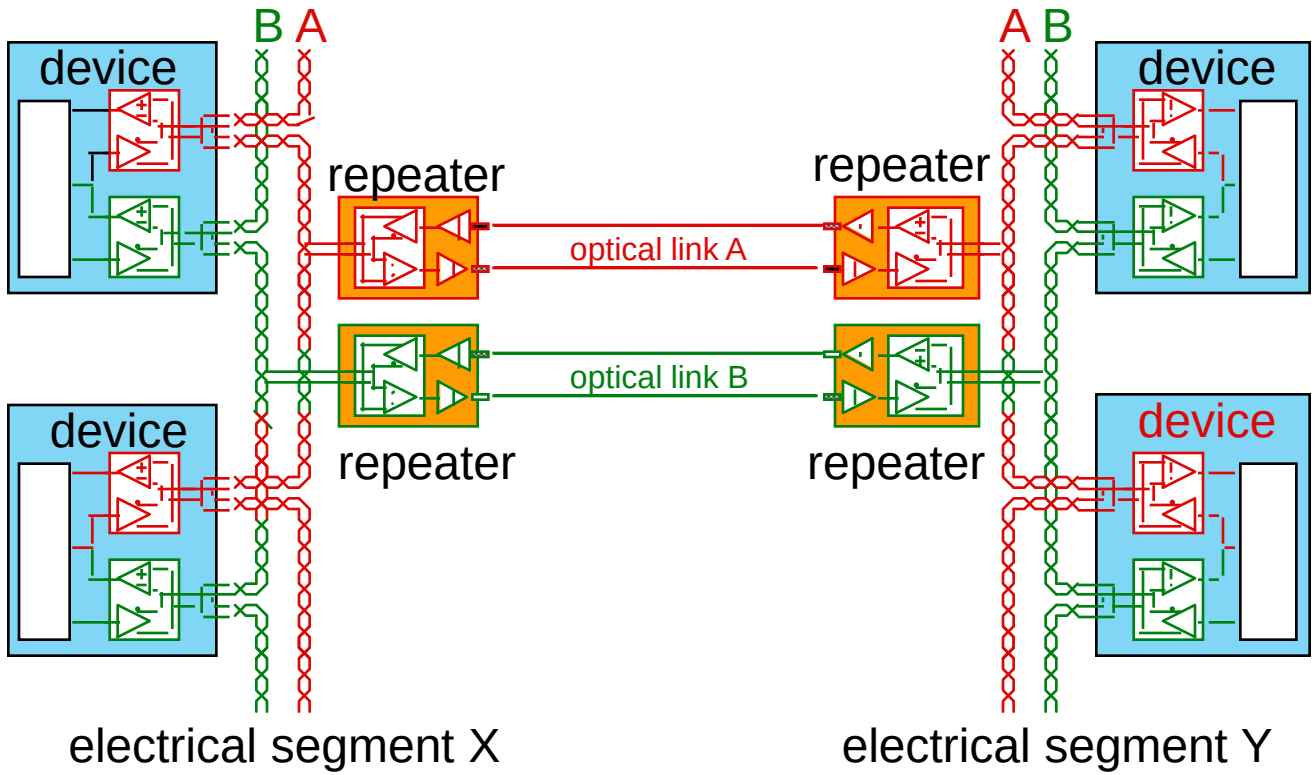


A frame is transmitted over both channels simultaneously.
The receiver receives from one channel and monitors the other.
Switchover is controlled by signal quality and frame overlap.
One frame may go lost during switchover

MVB Medium Redundancy

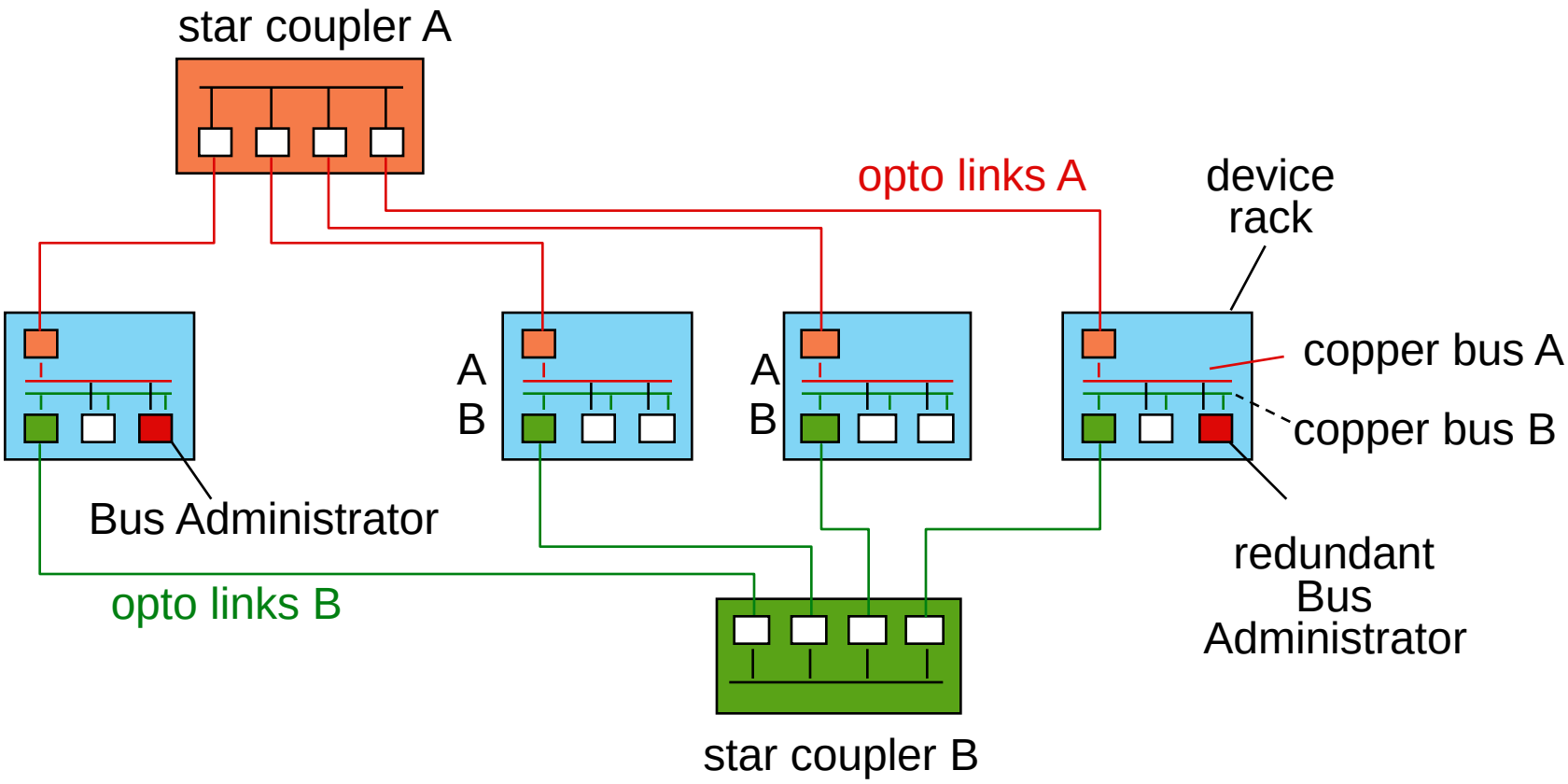
The physical medium may be fully duplicated to increase availability.

Principle: send on both, receive on one, supervise the other



Duplicated and non-duplicated segments may be connected

MVB Double-Line Fibre Layout



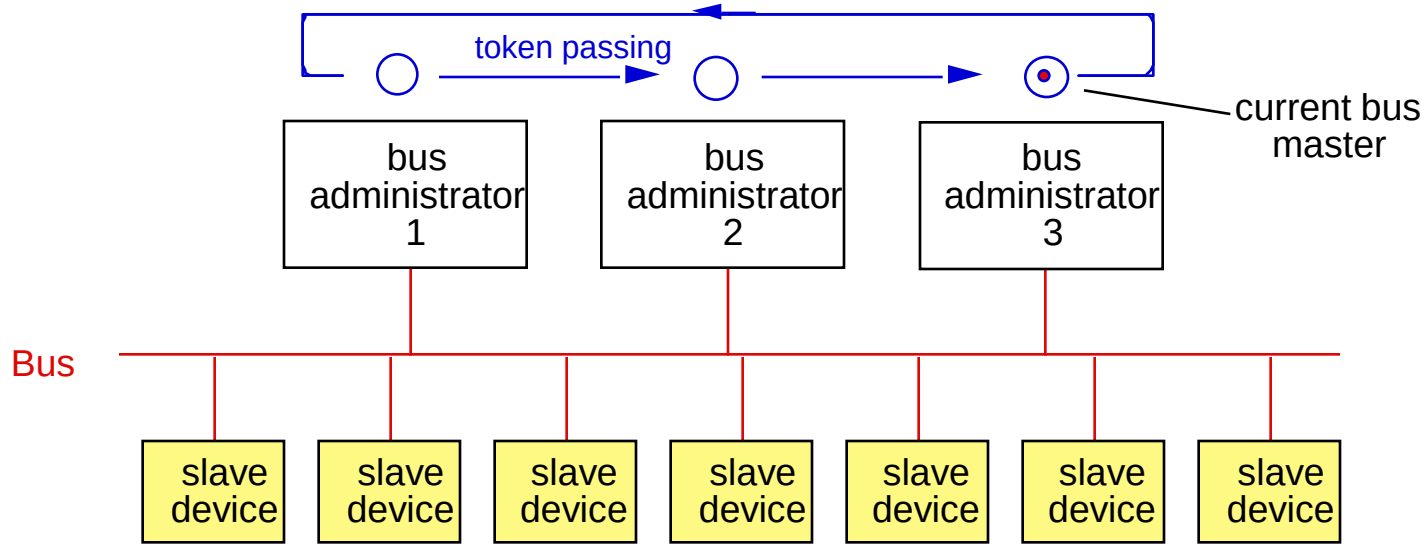
The failure of one device cannot prevent other devices from communicating.
Optical Fibres do not retro-act.

MVB Master Redundancy

A centralized bus master is a single point of failure.

To increase availability, the task of the bus master may be assumed by one of several *Bus Administrators*

The current master is selected by token passing:



If a bus administrator detects no activity, it enters an arbitration procedure. If it wins, it takes over the master's role and creates a token.

To check the good function of all administrators, the current master offers mastership to the next administrator in the list every 4 seconds.

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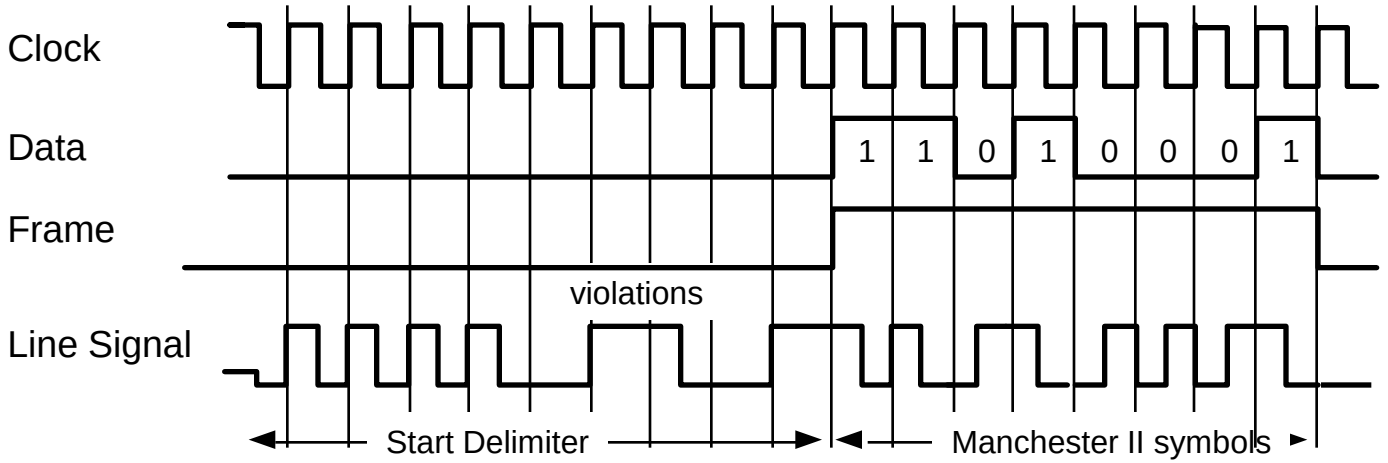
MVB Transmission Integrity (1)

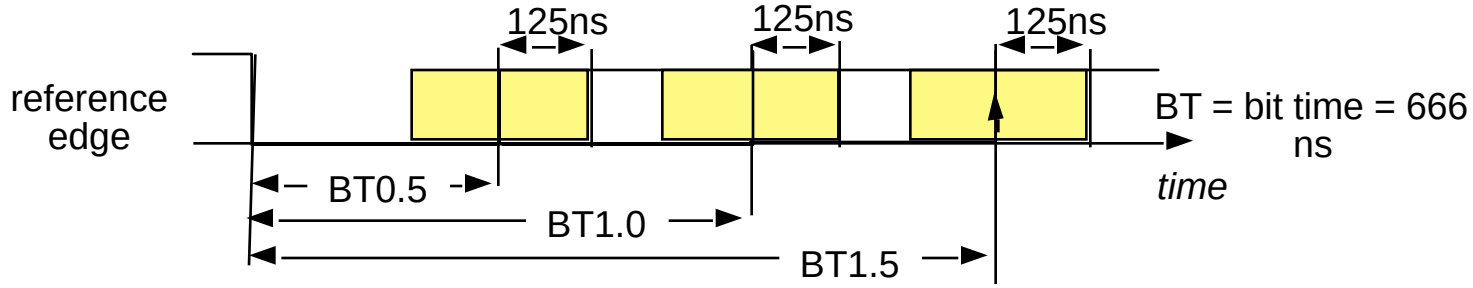
1) Manchester II encoding

Double signal inversion necessary to cause an undetected error, memoryless code



2) Signal quality supervision

Adding to the high signal-to-noise ratio of the transmission, signal quality supervision rejects suspect frames.

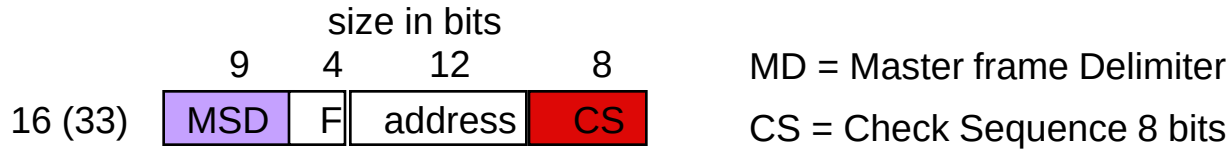


MVB Transmission Integrity (2)

3) A check octet according to TC57 class FT2 for each group of up to 64 bits, provides a Hamming Distance of 4 (8 if Manchester coding is considered):

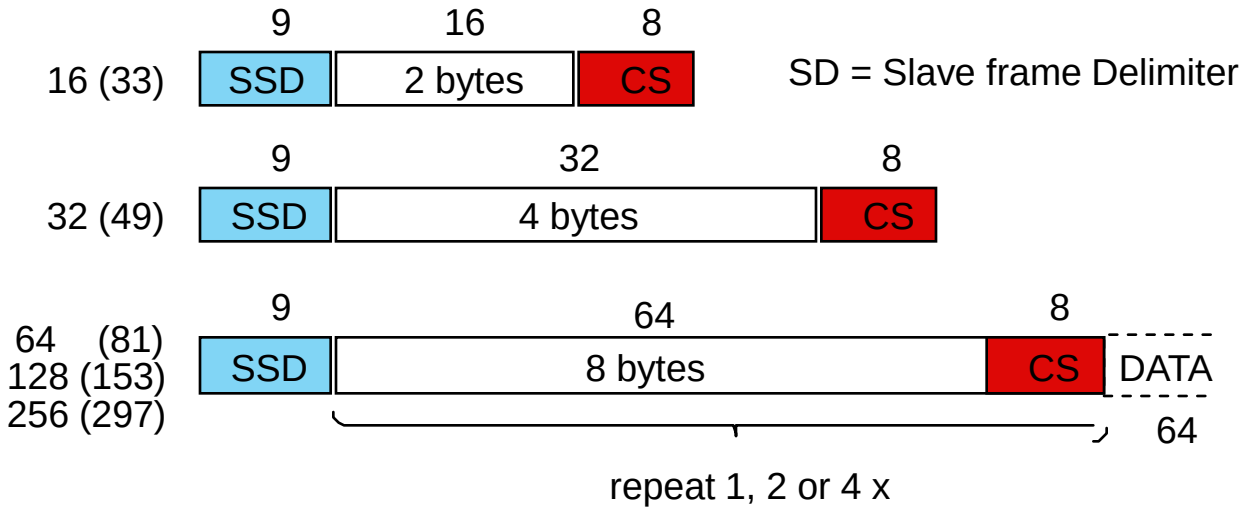
(Residual Error Rate $< 10^{-15}$ under standard disturbances)

Master Frame



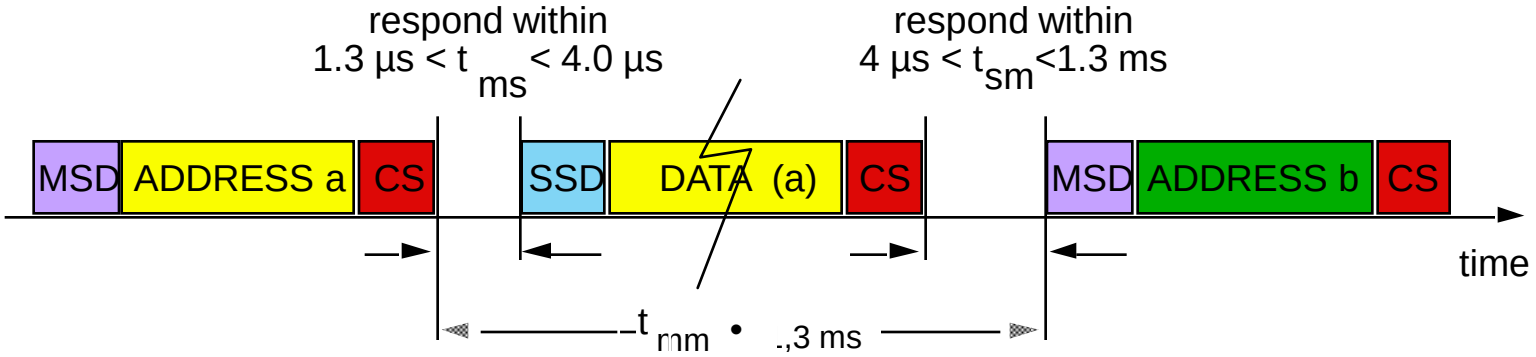
useful (total) size in bits

Slave Frame

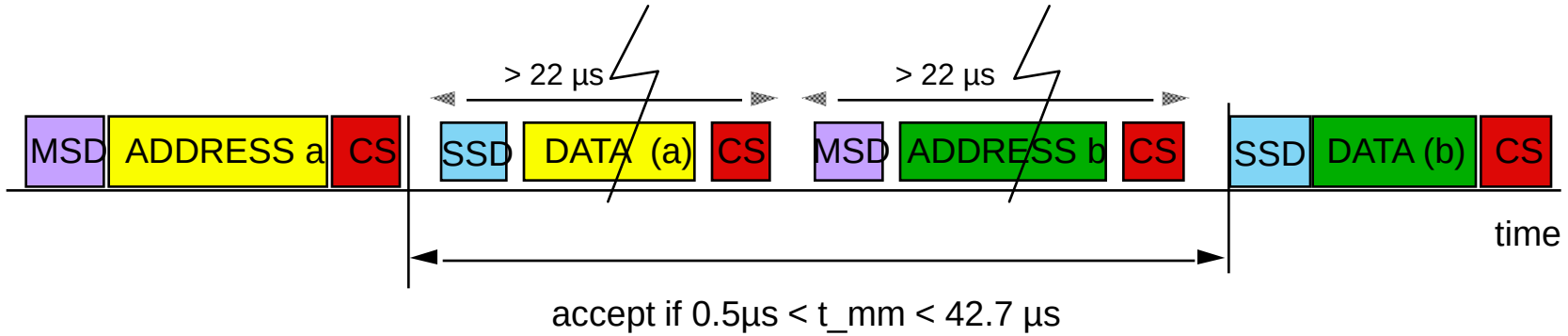


MVB Transmission Integrity (3)

4) Different delimiters for address and data against single frame loss:



5) Response time supervision against double frame loss:



6) Configuration check: size at source and sink ports must be same as frame size.

MVB Safety Concept

Data Integrity

Very high data integrity, but nevertheless insufficient for safety applications (signalling)
Increasing the Hamming Distance further is of no use since data falsification becomes more likely in a device than on the bus.

Data Transfer

- critical data transmitted periodically to guarantee timely delivery.
- obsolete data are discarded by sink time supervision.
- error in the poll scan list do not affect safety.

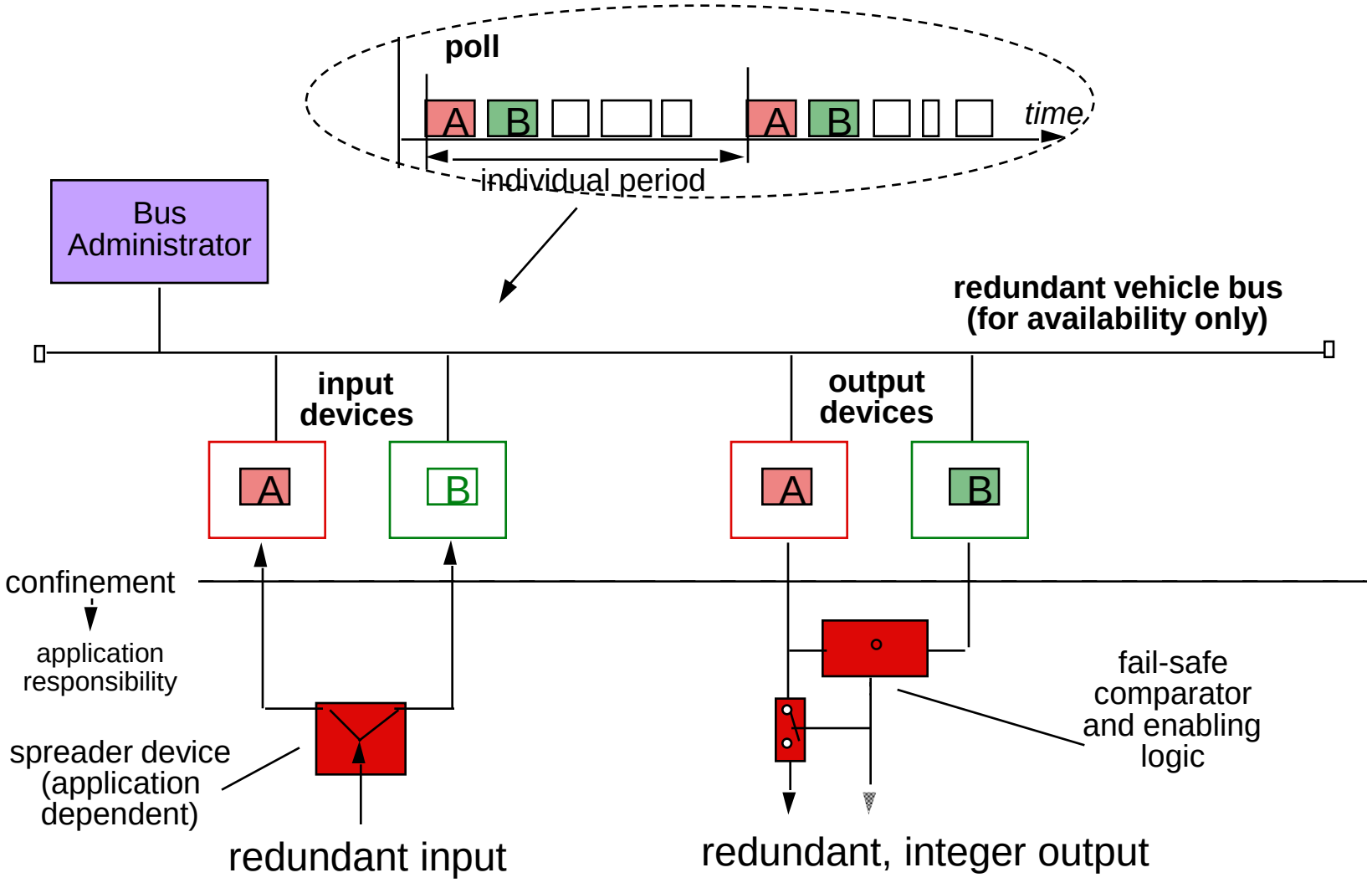
Device Redundancy

Redundant plant inputs A and B transmitted by two independent devices.
Diverse A and B data received by two independent devices and compared.
The output is disabled if A and B do not agree within a specified time.

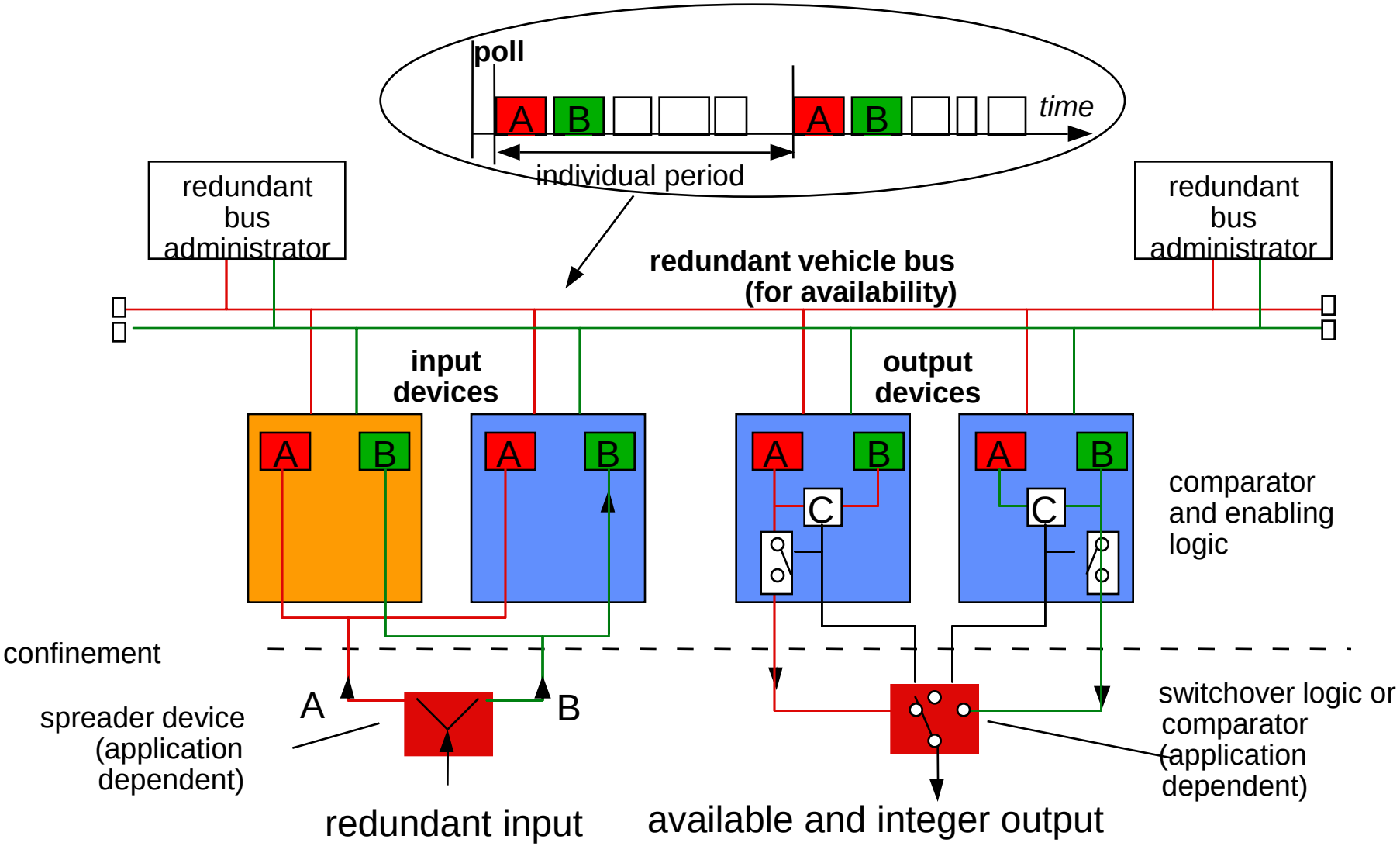
Availability

Availability is increased by letting the receiving devices receive both A and B. The application is responsible to process the results and switchover to the healthy device in case of discrepancy.

MVB Integer Set-up



MVB Integer and Available Set-up



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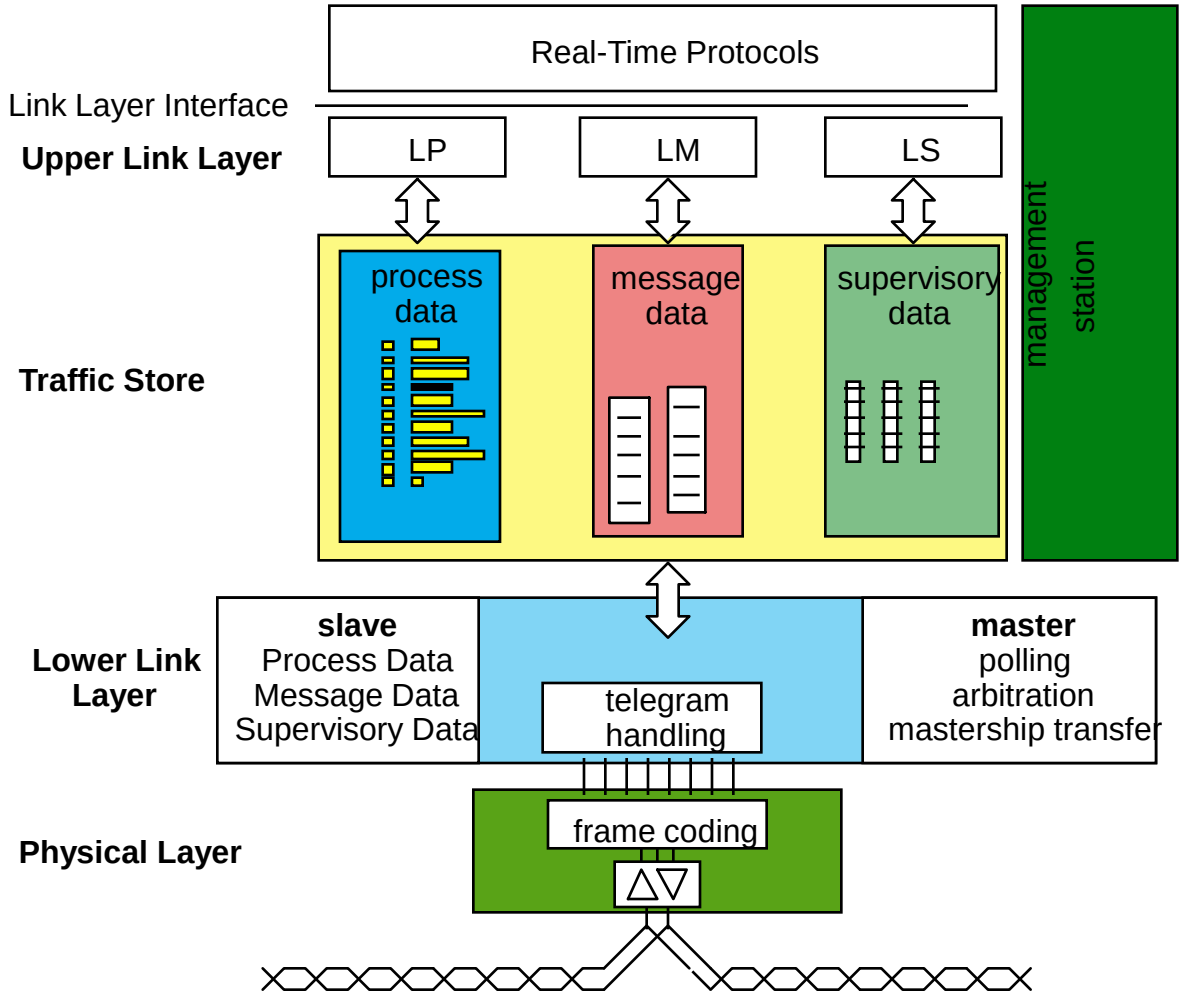
MVB Summary

Topography:	bus (copper), active star (optical fibre)
Medium:	copper: twisted wire pair optical: fibres and active star coupler
Covered distance:	OGF: 2000 m, total 4096 devices EMD: 200 m copper with transformer-coupling ESD: 20 m copper (RS485)
Communication chip	dedicated IC available
Processor participation	none (class 1), class 2 uses minor processor capacity
Interface area on board	20 cm2 (class 1), 50 cm2 (class 2)
Additional logic	RAM, EPROM , drivers.
Medium redundancy:	fully duplicated for availability
Signalling:	Manchester II + delimiters
Gross data rate	1,5 Mb/s
Response Time	typical 10 µs (<43 µs)
Address space	4096 physical devices, 4096 logical ports per bus
Frame size (useful data)	16, 32, 64, 128, 256 bits
Integrity	CRC8 per 64 bits, HD = 8, protected against sync slip

MVB Link Layer Interface



MVB Components

Bus Controllers:

- BAP 15 (Texas Instruments, obsolete)
- MVBC01 (VLSI, in production, includes master logic
- MVBC02 (E2S, in production, includes transformer coupling)

Repeaters:

- REGA (in production)
- MVBD (in production, includes transformer coupling)

Medium Attachment Unit:

- OGF: fully operational and field tested (8 years experience)
- ESD: fully operational and field tested (with DC/DC/opto galvanic separation)
- EMD: lab tested, first vehicles equipped

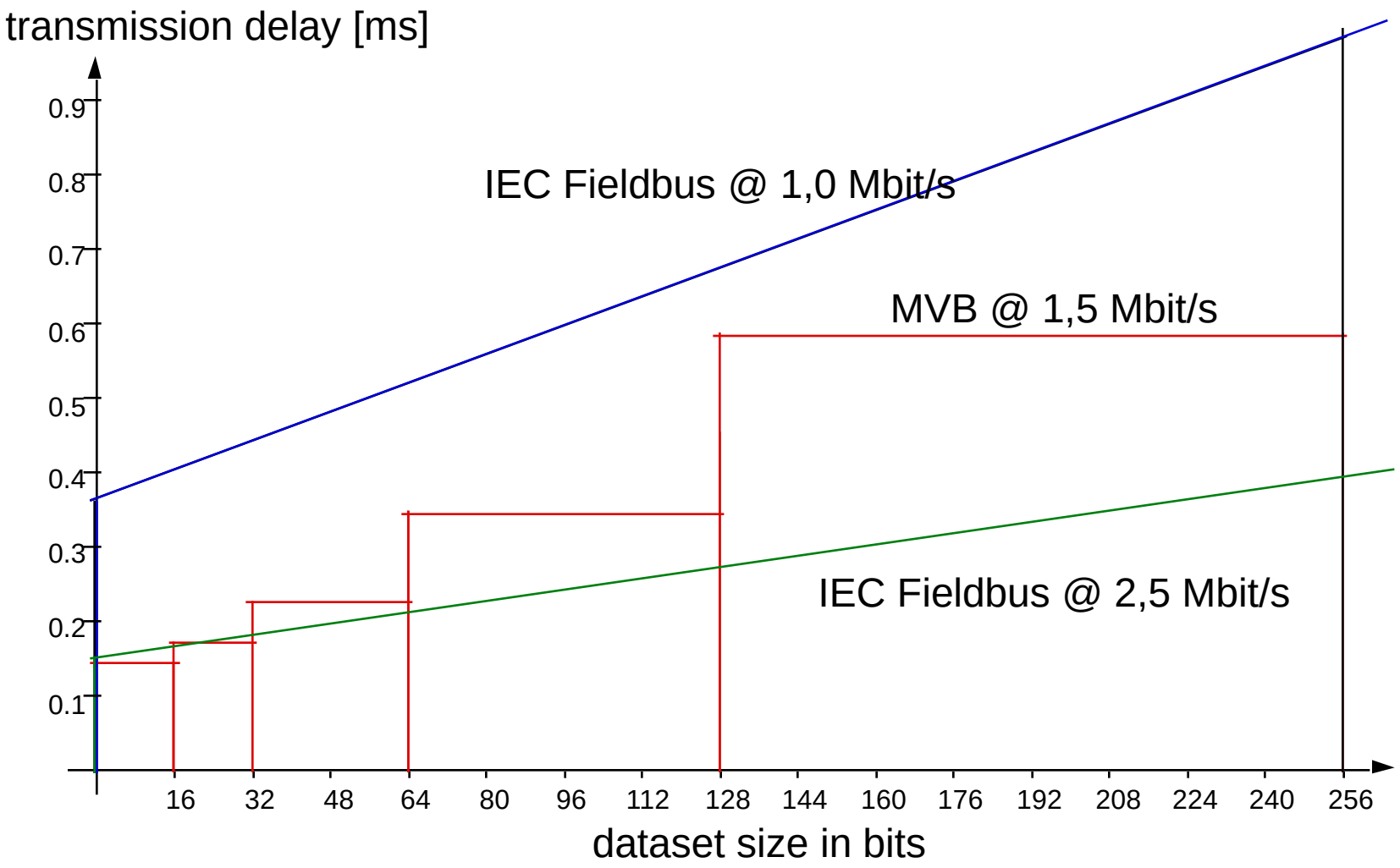
Stack:

- Link Layer stack for Intel 186, i196, i960, 166, 167, Motorola 68332, under DOS, Windows, VRTX,...

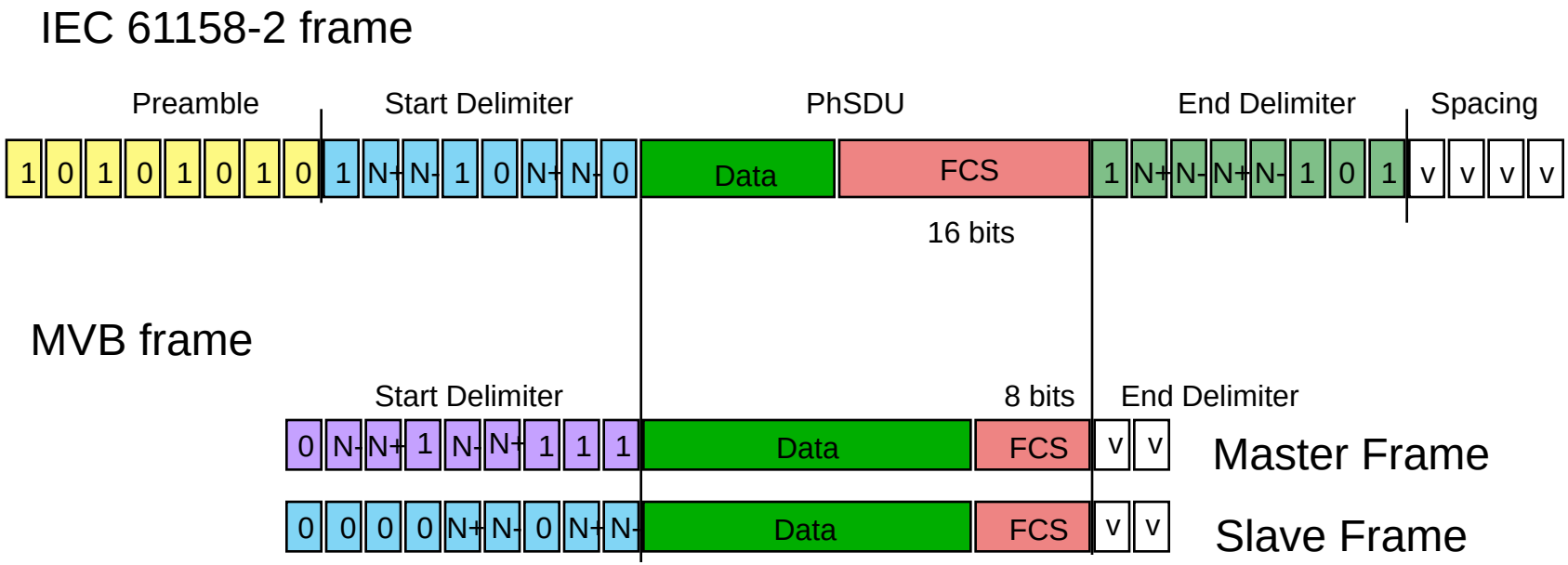
Tools:

- Bus Administrator configurator
- Bus Monitor, Download, Upload, remote settings

MVB Throughput (raw data)



MVB versus IEC 61158-2 Frames



IEC 61158 frames have a lesser efficiency (-48%) then MVB frames

To compensate it, a higher speed (2,5 Mbit/s) would be needed.