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

- radio
- power line
- cockpit
- diagnosis
- Vehicle Bus
- brakes
- power electronics
- motor control
- track signals

<table>
<thead>
<tr>
<th>data rate</th>
<th>1'500'000 bits/second</th>
</tr>
</thead>
<tbody>
<tr>
<td>delay</td>
<td>0,001 second</td>
</tr>
<tr>
<td>medium</td>
<td>twisted wire pair, optical fibres</td>
</tr>
<tr>
<td>number of stations</td>
<td>up to 255 programmable stations</td>
</tr>
<tr>
<td></td>
<td>up to 4095 simple sensors/actuators</td>
</tr>
<tr>
<td>status</td>
<td>&gt; 600 vehicles in service in 1998</td>
</tr>
</tbody>
</table>
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.
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).
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)
3. Device Classes
4. Frames and Telegrams
5. Medium Allocation
6. Clock Synchronization
7. Fault-tolerance concept
8. Integrity Concept
9. Summary
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.

![Diagram of ESD RS485 network]

- **Terminator/Biasing**
  - + 5 V
  - Ru (390Ω)
  - Rm (150Ω)
  - Rd (390Ω)
  - GND

- **Device Connections**
  - TxS
  - RxS
  - Data_N
  - Data_P

- **Equipotential Line**
  - 4 conductors:
    - Bus_GND
    - Equipotential line

- **Segment Length**
  - Device 1
  - Device 2..n-1
  - Device N
ESD Connector for Double-Line Attachment

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Multifunction Vehicle Bus

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1999 September, HK
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
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

Line_A
- Zt.A
- A.Term_P
- A.Term_N

Line_B
- B.Term_P
- B.Term_N
- Zt.B

Connector_1 (male)
- 1 A1. Data_P
- 2 A1. Data_N
- 3
- 4 B1. Data_P
- 5 B1. Data_N

Connector_1 (female)
- 1 A1. Data_P
- 2 A1. Data_N
- 3
- 4 B1. Data_P
- 5 B1. Data_N

Terminator connector

Cable

Shields contacts case
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

Star Coupler

Opto-electrical transceiver

device

equipment

Rack

ESD segment

device

device

device

device
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
recognize the transmission direction and forward the frame
decode and reshape the signal (using a priori knowledge about its 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)
MVB Outline

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8. Integrity Concept
9. Summary
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.
• 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 little endians
- 24 MHz clock rate
- HCMOS 0.8 μm technology
- 100 pin QFP

CPU parallel bus to traffic store

A19..1 address

D15..0 data

control

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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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8. Integrity Concept
9. Summary
The Manchester-coded frame is preceded by a Start Delimiter containing non-Manchester signals to provide transparent synchronization.
Different delimiters identify master and slave frames:

**Master Frame Delimiter**

- **active state**
- **idle state**

**Slave Frame Delimiter**

- **active state**
- **idle state**

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

<table>
<thead>
<tr>
<th>Size</th>
<th>Address</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 (33)</td>
<td>9 bits 4 12 8</td>
<td>MSD = Master Start Delimiter (9 bits)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F = F_code (4 bits)</td>
</tr>
</tbody>
</table>

slave frames sent in response to master frames

<table>
<thead>
<tr>
<th>Size</th>
<th>SSD</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 (33)</td>
<td>9 16 bits 8</td>
<td>SSD = Slave Start Delimiter (9 bits)</td>
</tr>
<tr>
<td>32 (49)</td>
<td>9 32 bits 8</td>
<td></td>
</tr>
<tr>
<td>64 (81)</td>
<td>9 64 bits 8</td>
<td></td>
</tr>
</tbody>
</table>

useful (total) size in bits

- 16 bits
- 32 bits
- 64 bits
- 128 bits
- 256 bits

F = F_code (4 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 throughput).
MVB Telegrams

Process Data

Master Frame (Request)                  Slave Frame (Response)

4 bits  12 bits                      256 bits of Process Data

Message Data

Master Frame

4 bits  12 bits

Supervisory Data

Master Frame                  Slave Frame

4 bits  12 bits                16 bits

Telegrams are distinguished by the F_code in the Master Frame

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Multifunction Vehicle Bus
Phase 1: 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.

- Application Processor
- Bus Controller
- Traffic Memory (Associative memory)
- Process Data Base

Two pages ensure that read and write can occur at the same time.
• 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

<table>
<thead>
<tr>
<th>Master Frame</th>
<th>Slave Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F_code</strong></td>
<td><strong>address</strong></td>
</tr>
<tr>
<td>0</td>
<td>single</td>
</tr>
<tr>
<td>1</td>
<td>single</td>
</tr>
<tr>
<td>2</td>
<td>device</td>
</tr>
<tr>
<td>3</td>
<td>reserved</td>
</tr>
<tr>
<td>4</td>
<td>reserved</td>
</tr>
<tr>
<td>5</td>
<td>reserved</td>
</tr>
<tr>
<td>6</td>
<td>reserved</td>
</tr>
<tr>
<td>7</td>
<td>reserved</td>
</tr>
<tr>
<td>8</td>
<td>all devices</td>
</tr>
<tr>
<td>9</td>
<td>device</td>
</tr>
<tr>
<td>10</td>
<td>device</td>
</tr>
<tr>
<td>11</td>
<td>device</td>
</tr>
<tr>
<td>12</td>
<td>device</td>
</tr>
<tr>
<td>13</td>
<td>group</td>
</tr>
<tr>
<td>14</td>
<td>device</td>
</tr>
<tr>
<td>15</td>
<td>device</td>
</tr>
</tbody>
</table>

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IEC 61375 Clause 3

1999 September, HK
MVB Outline

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7. Fault-tolerance concept
8. Integrity Concept
9. Summary
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

Sporadic 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

Periodic Data

Basic Period

Sporadic Data

Basic Period

event

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

- 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.

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.

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

- No event
- Start arbitration
- General poll
- Collisions
- Silence

Even devices:
- Even addresses (000, 010, 001, 011)
- Event read

Odd devices:
- Odd addresses (100, 110, 101, 111)
- Event read

Width of group address:
- n = 0
- n = 1
- n = 2
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.
The clock does not need to be generated by the Master.

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

Duplicate and non-duplicated segments may be connected
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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9. Summary
MVB Transmission Integrity (1)

1) Manchester II encoding

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

Clock

Data

Frame

Line Signal

violations

Start Delimiter

Manchester II symbols

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

<table>
<thead>
<tr>
<th>size in bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
</tr>
<tr>
<td>16 (33)</td>
</tr>
</tbody>
</table>

MD = Master frame Delimiter
CS = Check Sequence 8 bits

Slave Frame

<table>
<thead>
<tr>
<th>size in bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
</tr>
<tr>
<td>16 (33)</td>
</tr>
</tbody>
</table>

SD = Slave frame Delimiter

<table>
<thead>
<tr>
<th>size in bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
</tr>
<tr>
<td>32 (49)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>size in bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
</tr>
<tr>
<td>64 (81)</td>
</tr>
<tr>
<td>128 (153)</td>
</tr>
<tr>
<td>256 (297)</td>
</tr>
</tbody>
</table>

repeat 1, 2 or 4 x
MVB Transmission Integrity (3)

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

\[
\text{respond within } 1.3 \mu s < t_\text{ms} < 4.0 \mu s \\
\text{respond within } 4 \mu s < t_\text{sm} < 1.3 \text{ ms}
\]

5) Response time supervision against double frame loss:

\[
\text{accept if } 0.5 \mu s < t_\text{mm} < 42.7 \mu s
\]

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

input devices

output devices

poll

individual period

time

Bus Administrator

redundant vehicle bus (for availability only)

redundant input

redundant, integer output

confinement

application responsibility

spreader device (application dependent)

fail-safe comparator and enabling logic
MVB Integer and Available Set-up

- redundant vehicle bus (for availability)
- redundant bus administrator
- input devices
  - redundant input
  - poll
  - individual period
- output devices
  - available and integer output
  - switchover logic or comparator
  - comparator and enabling logic
- confinement
- spreader device (application dependent)
- redundant bus administrator
- available and integer set-up

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9. Summary
## MVB Summary

<table>
<thead>
<tr>
<th>Topography:</th>
<th>bus (copper), active star (optical fibre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium:</td>
<td>copper: twisted wire pair</td>
</tr>
<tr>
<td></td>
<td>optical: fibres and active star coupler</td>
</tr>
<tr>
<td>Covered distance:</td>
<td>OGF: 2000 m, total 4096 devices</td>
</tr>
<tr>
<td></td>
<td>EMD: 200 m copper with transformer-coupling</td>
</tr>
<tr>
<td></td>
<td>ESD: 20 m copper (RS485)</td>
</tr>
<tr>
<td>Communication chip</td>
<td>dedicated IC available</td>
</tr>
<tr>
<td>Processor participation</td>
<td>none (class 1), class 2 uses minor processor capacity</td>
</tr>
<tr>
<td>Interface area on board</td>
<td>20 cm² (class 1), 50 cm² (class 2)</td>
</tr>
<tr>
<td>Additional logic</td>
<td>RAM, EPROM, drivers.</td>
</tr>
<tr>
<td>Medium redundancy:</td>
<td>fully duplicated for availability</td>
</tr>
<tr>
<td>Signalling:</td>
<td>Manchester II + delimiters</td>
</tr>
<tr>
<td>Gross data rate</td>
<td>1,5 Mb/s</td>
</tr>
<tr>
<td>Response Time</td>
<td>typical 10 µs (&lt;43 µs)</td>
</tr>
<tr>
<td>Address space</td>
<td>4096 physical devices, 4096 logical ports per bus</td>
</tr>
<tr>
<td>Frame size (useful data)</td>
<td>16, 32, 64, 128, 256 bits</td>
</tr>
<tr>
<td>Integrity</td>
<td>CRC8 per 64 bits, HD = 8, protected against sync slip</td>
</tr>
</tbody>
</table>
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 versus IEC 61158-2 Frames

#### IEC 61158-2 frame

<table>
<thead>
<tr>
<th>Preamble</th>
<th>Start Delimiter</th>
<th>PhSDU</th>
<th>End Delimiter</th>
<th>Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0 1 0 1 0 1 0 1 0 1 N⁻¹ 1 0 N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹</td>
<td>1 N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹</td>
<td>Data</td>
<td>FCS</td>
<td>1 0 1 0 1 0 1 0 1 0 1 N⁻¹ 1 0 N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹ N⁻¹</td>
</tr>
</tbody>
</table>

#### MVB frame

<table>
<thead>
<tr>
<th>Start Delimiter</th>
<th>PhSDU</th>
<th>End Delimiter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 N⁻¹ 1 N⁻¹ 1 1 1</td>
<td>Data</td>
<td>8 bits</td>
</tr>
<tr>
<td>0 0 0 0 N⁻¹ N⁻¹ N⁻¹</td>
<td>Data</td>
<td>FCS v v</td>
</tr>
<tr>
<td>v v v v N⁻¹ N⁻¹ N⁻¹</td>
<td>Data</td>
<td>FCS v v</td>
</tr>
</tbody>
</table>

IEC 61158 frames have a lesser efficiency (-48%) than MVB frames.
To compensate it, a higher speed (2.5 Mbit/s) would be needed.