SpaceFibre

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Contents

- SpaceFibre Applications
- SpaceFibre Network Level
- SpaceFibre Standard Update

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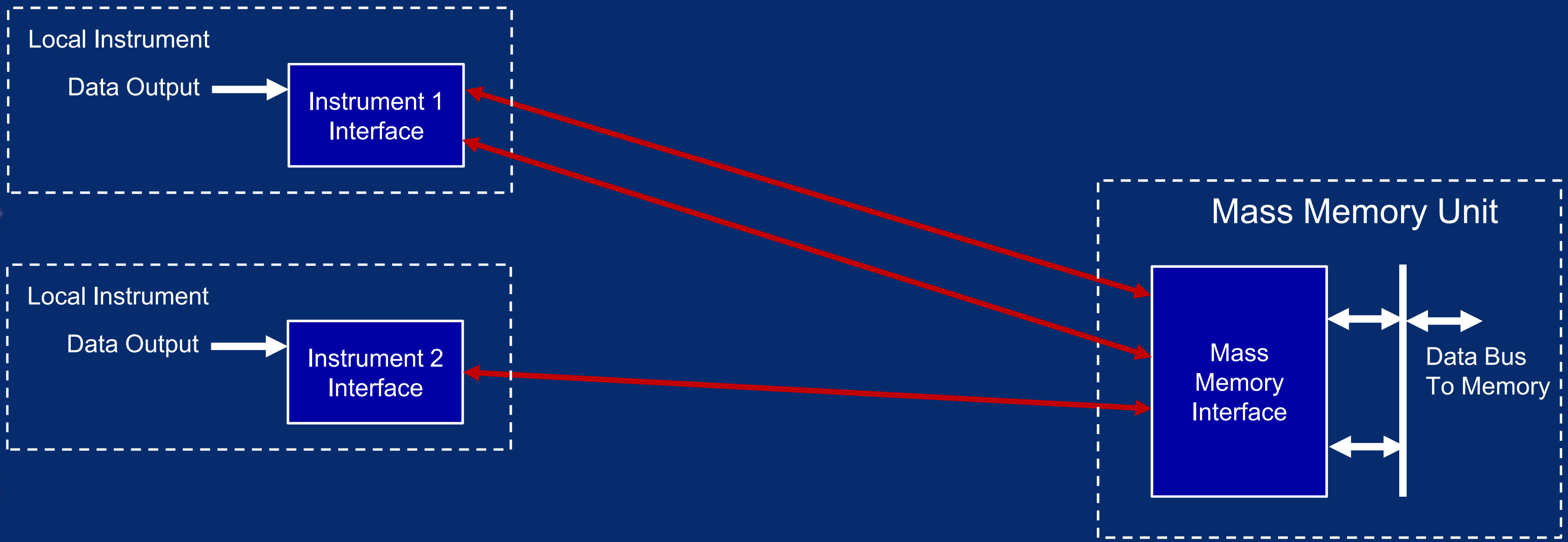
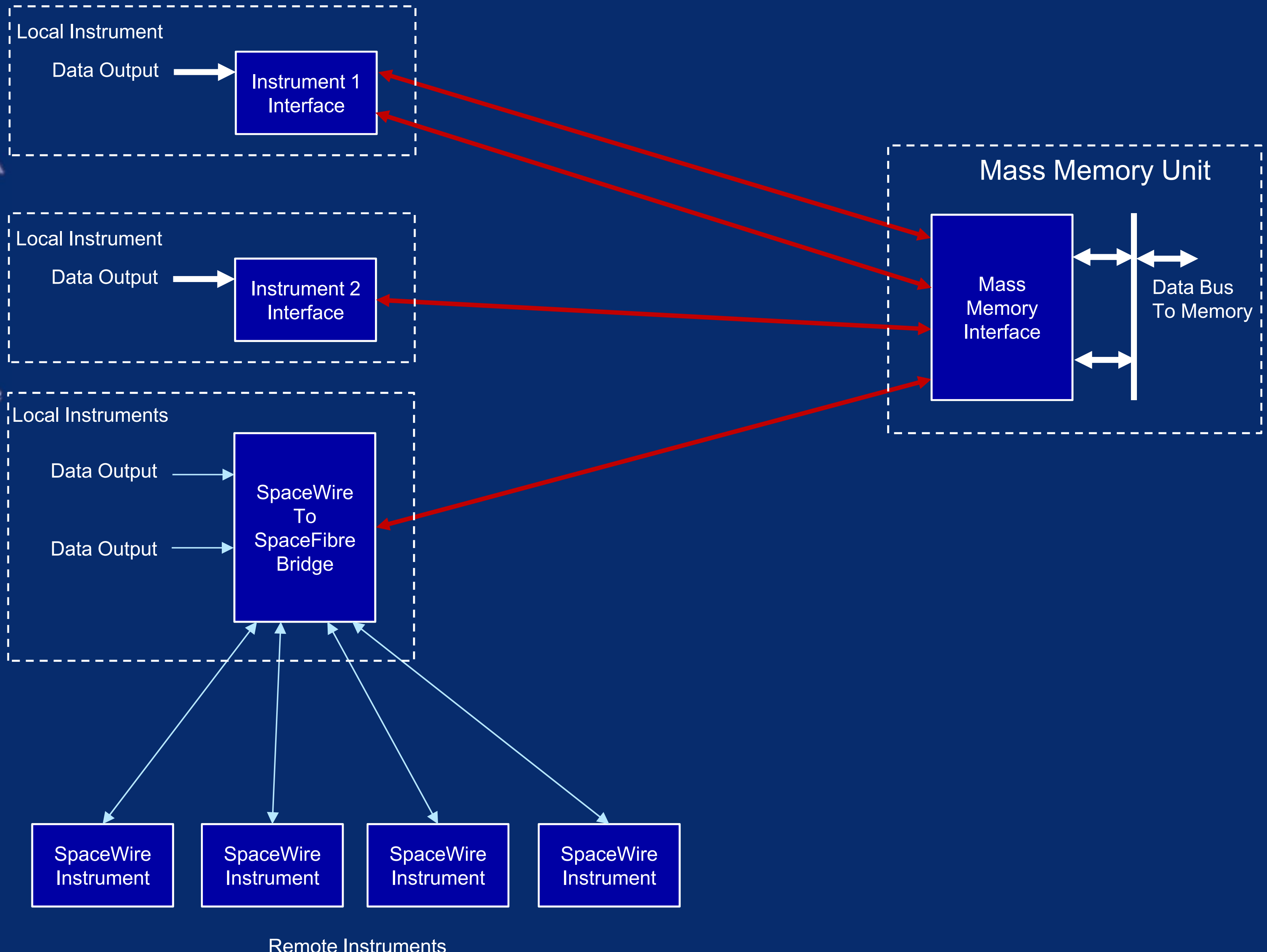
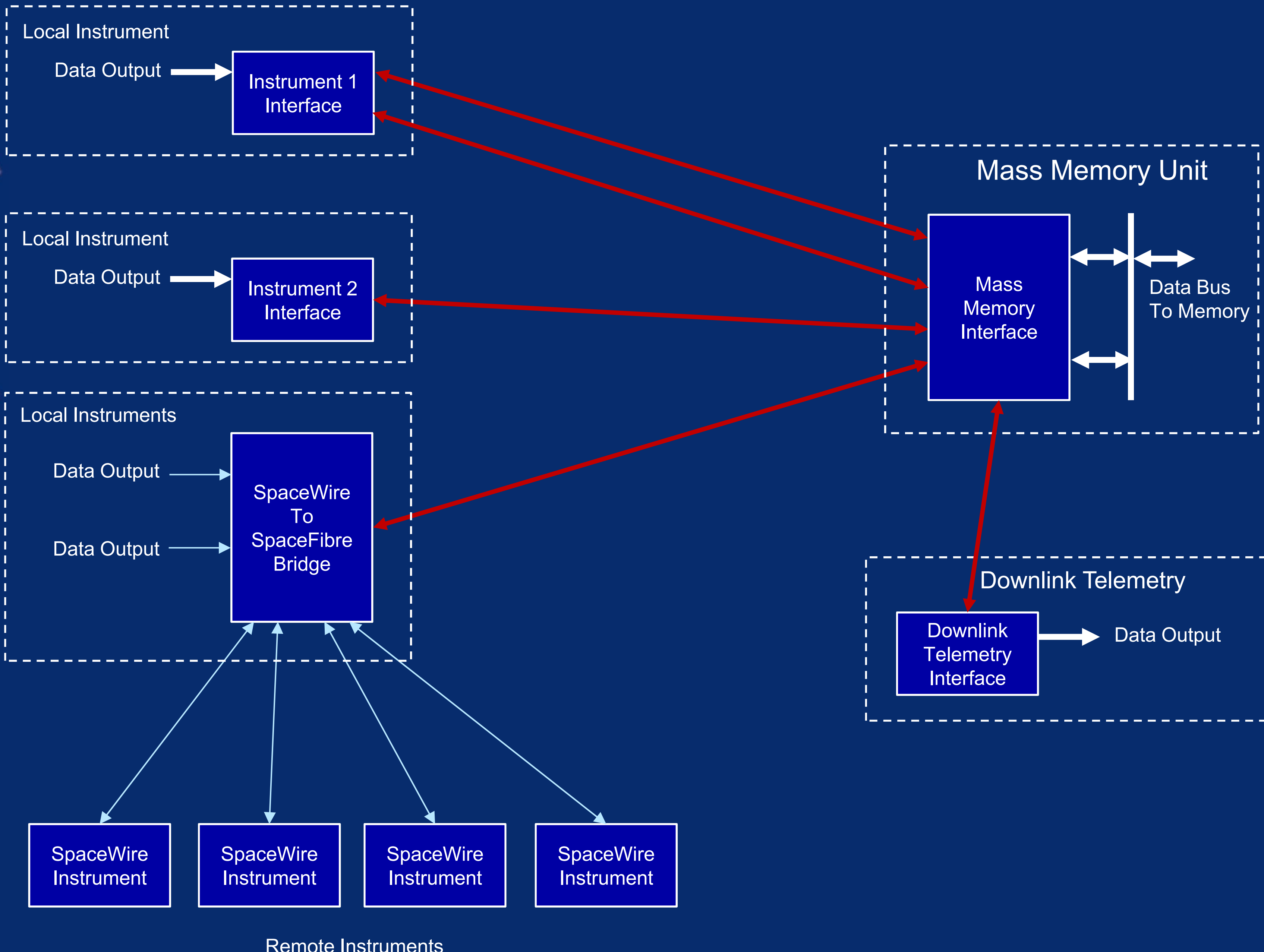
SpaceFibre Applications



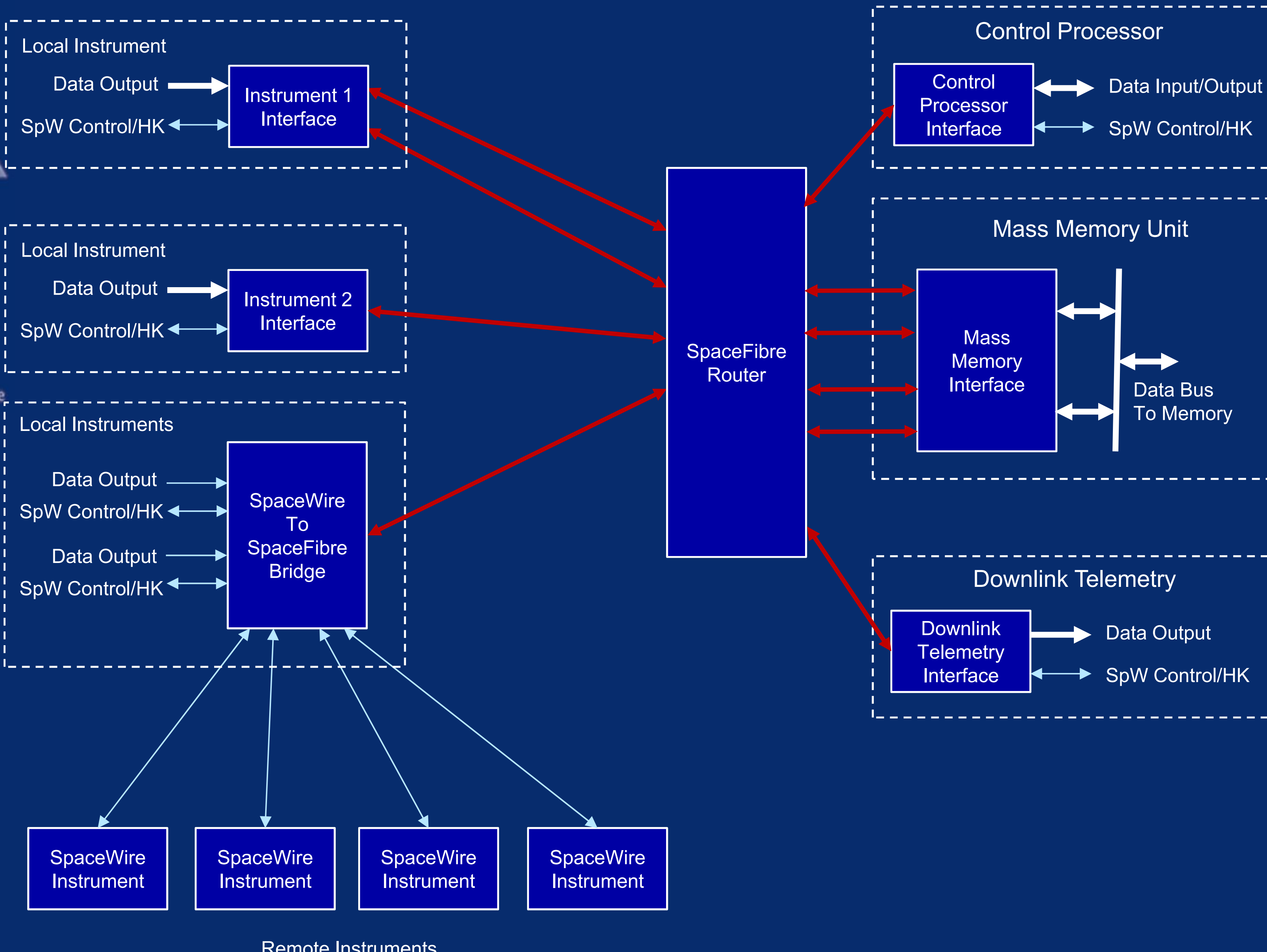
SpaceFibre Applications



SpaceFibre Applications



SpaceFibre Applications



Principal On-board Communications

- Instrument
  - Data to mass-memory
  - Configuration and control
  - Housekeeping
- Mass memory
  - Data from instruments
  - Data to downlink
  - Configuration and control
  - Housekeeping
- Downlink
  - Data from mass-memory
  - Configuration and control
  - Housekeeping

SpaceFibre Network Level

- SpaceFibre transfers SpaceWire packets
  - Destination address
  - Cargo
  - EOP
- Path and logical addressing can be used
- Routing concept identical to SpaceWire
- VCs can be used to provide
  - Virtual networks – like SpaceWire
  - Constrained virtual networks
  - Virtual point to point links
- Improved FDIR

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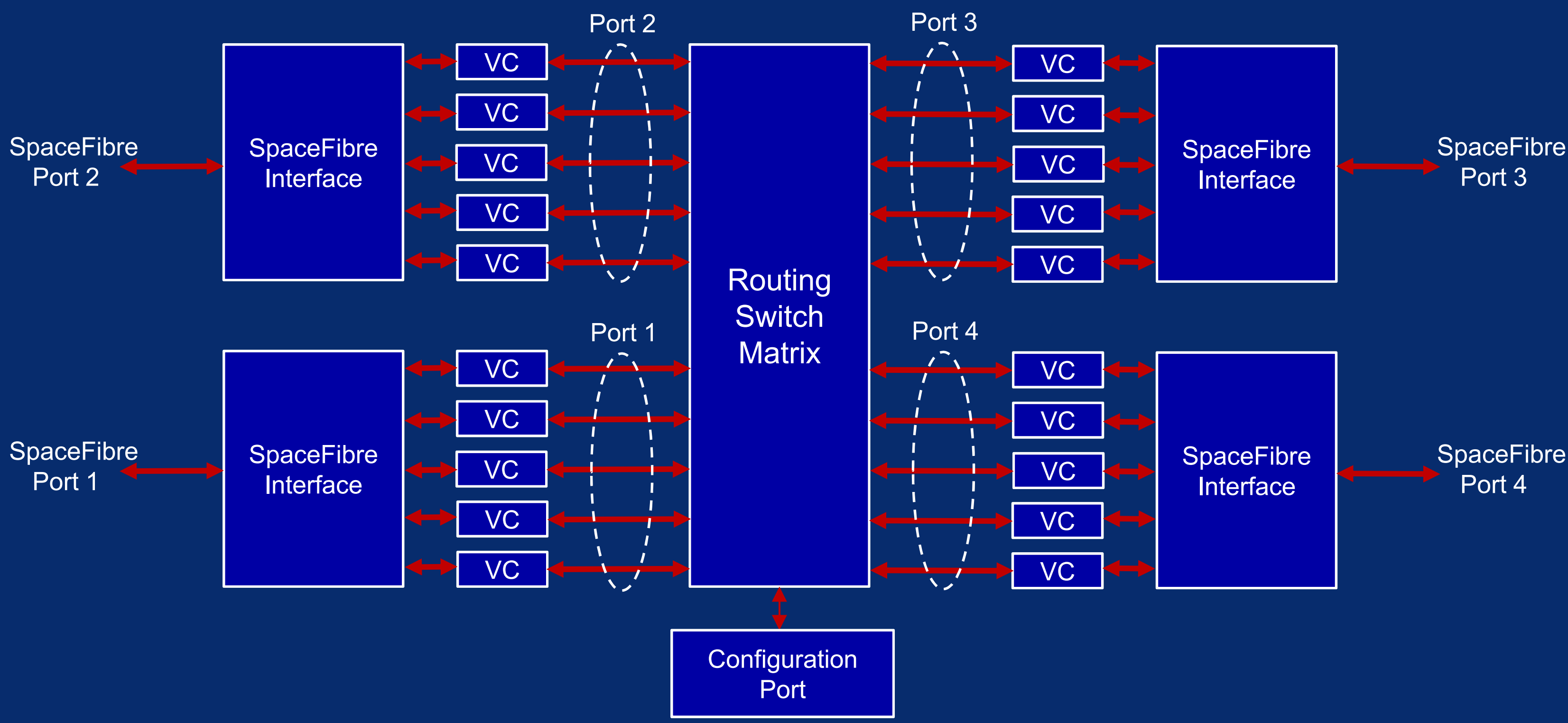
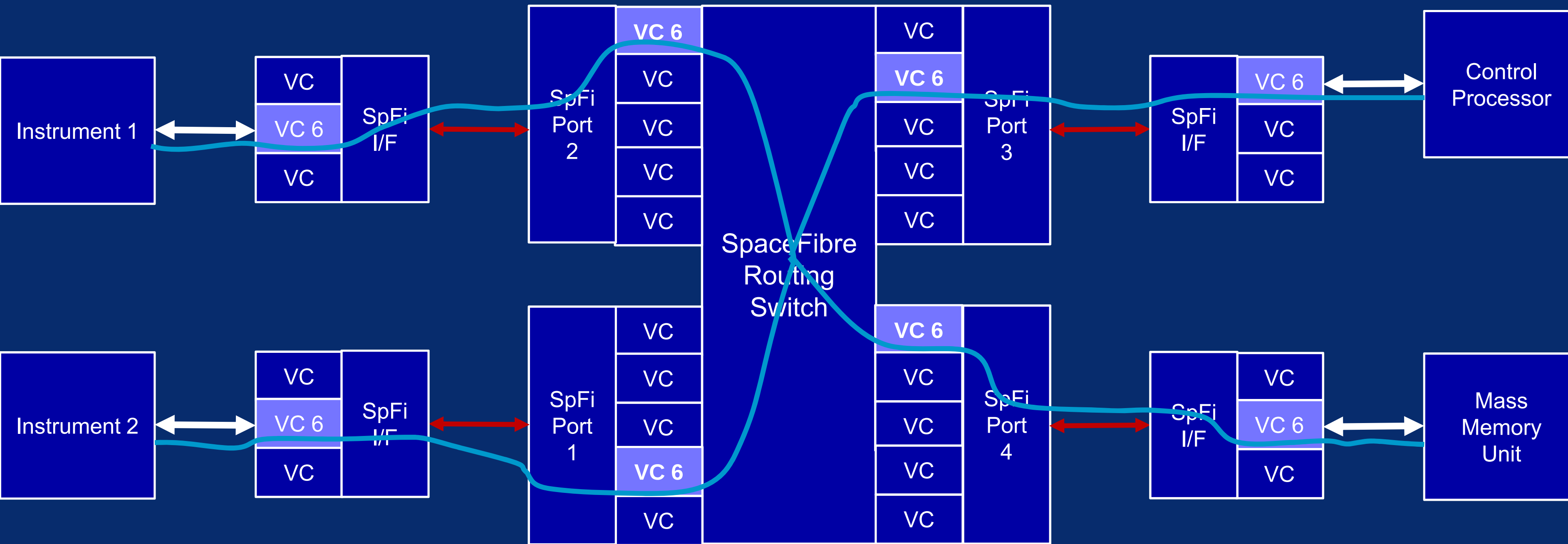
SpaceFibre Routing Switch

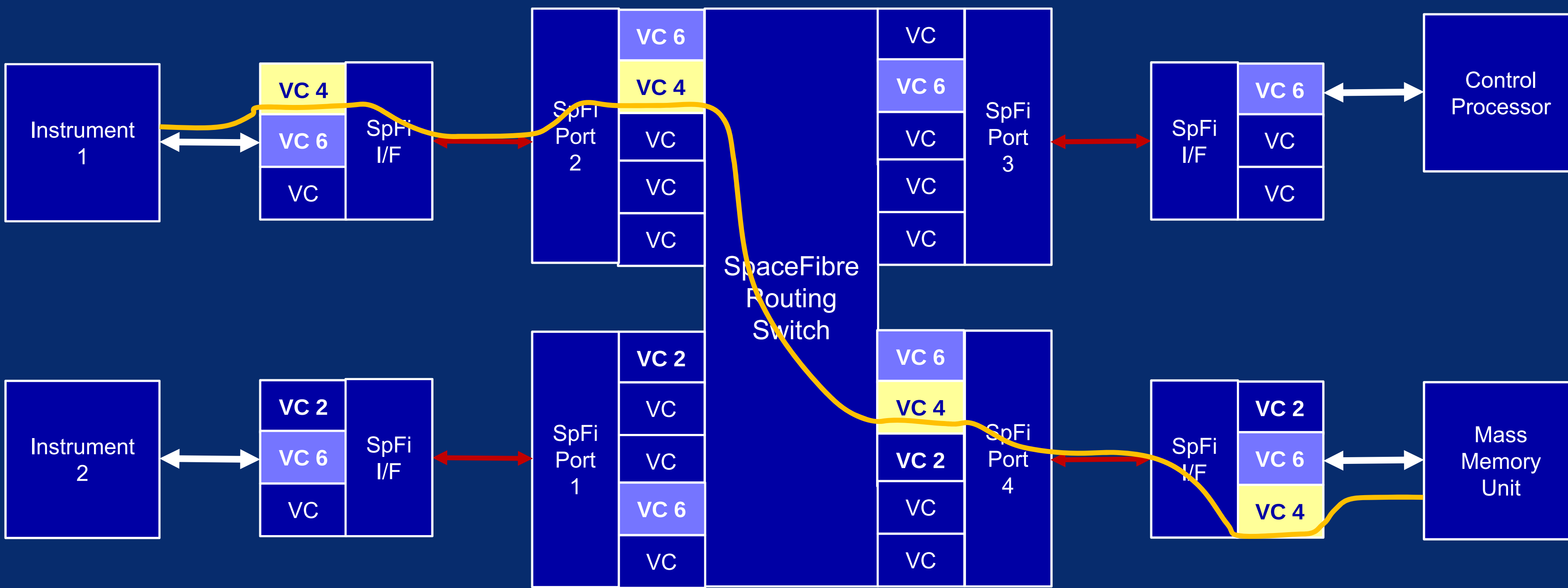


SpaceFibre Virtual Network

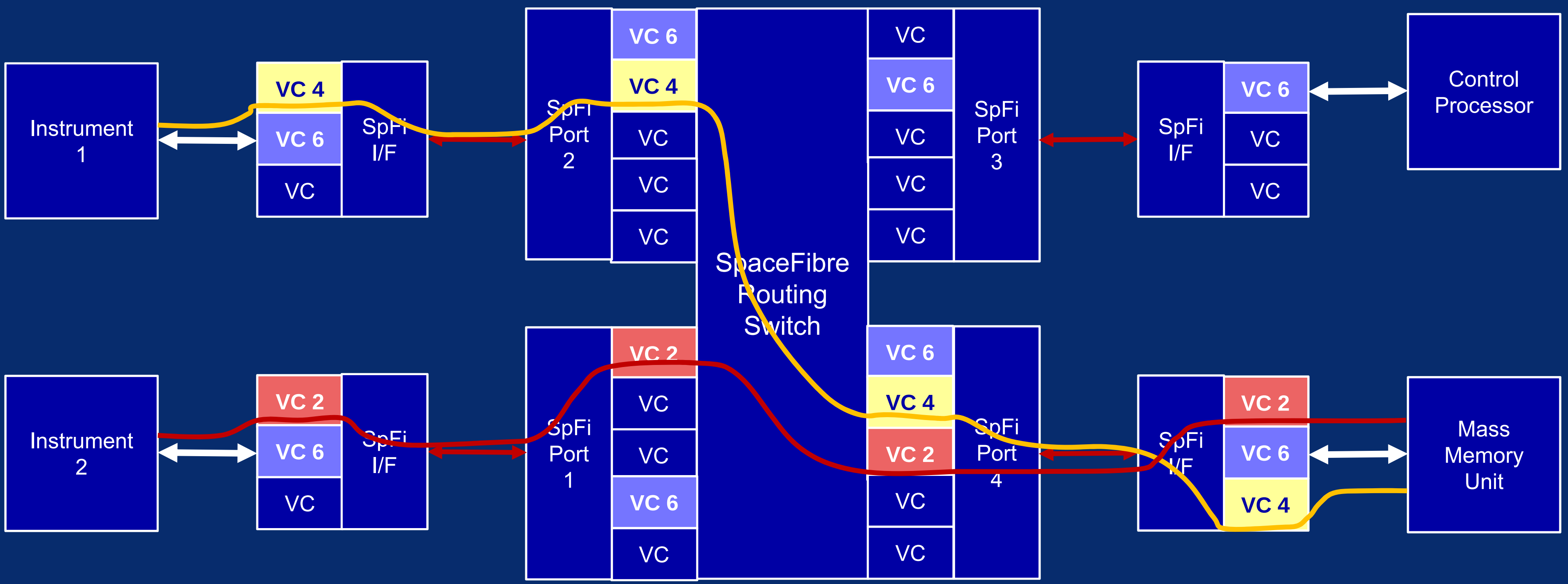


Virtual channel buffers are configured to support specific virtual channels
One set of buffers is always configured to support VC 0, the Configuration Virtual Network

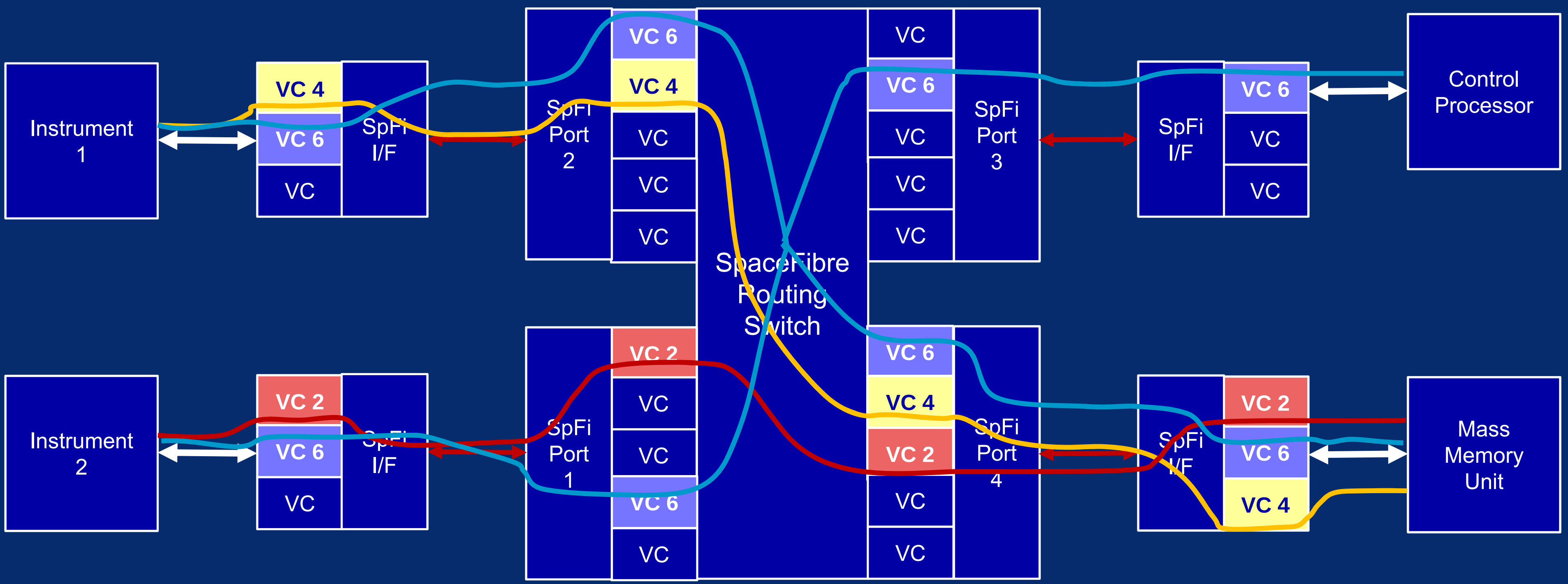
SpaceFibre Virtual Point to Point Link



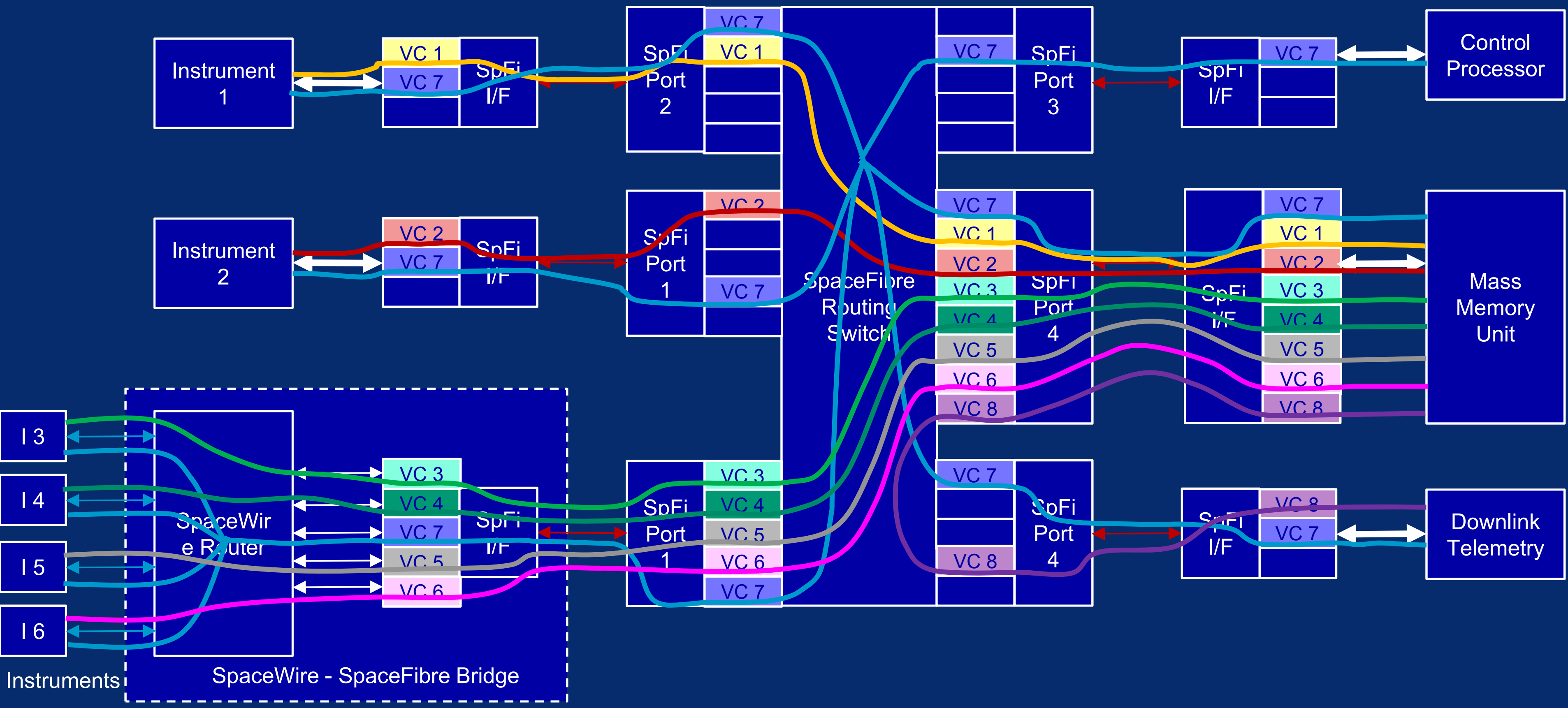
SpaceFibre Virtual Point to Point Link



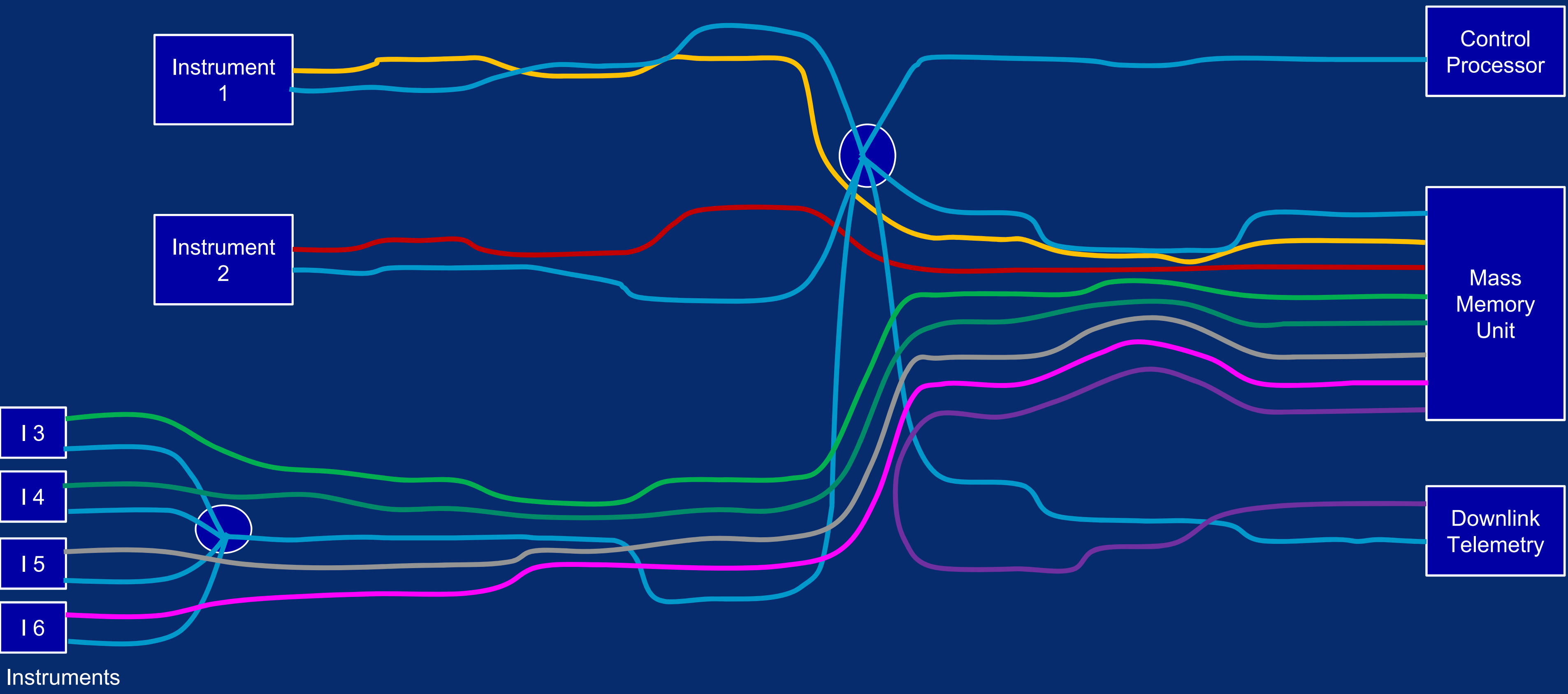
Simple SpaceFibre Network



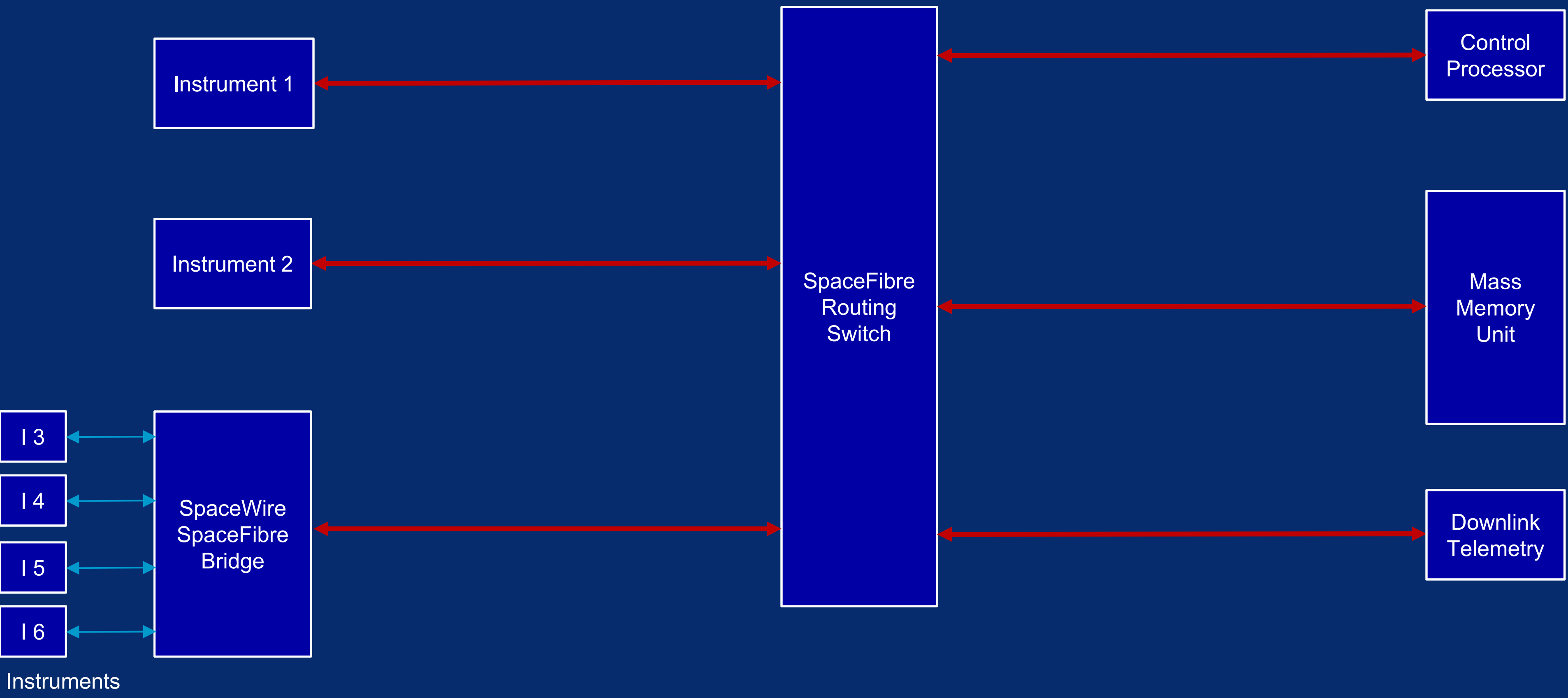
Spacecraft Data Handling Application



Spacecraft Data Handling Application



Spacecraft Data Handling Application



Impact on spacecraft mass

- Mass saving
  - 13 cables 2m each 90g = 2.34 kg
- Replaced with
  - 6 cables 2m each 60g = 0.72 kg
  - Saving of 1.6 kg
- Plus redundancy
  - Saving of 3.2 kg

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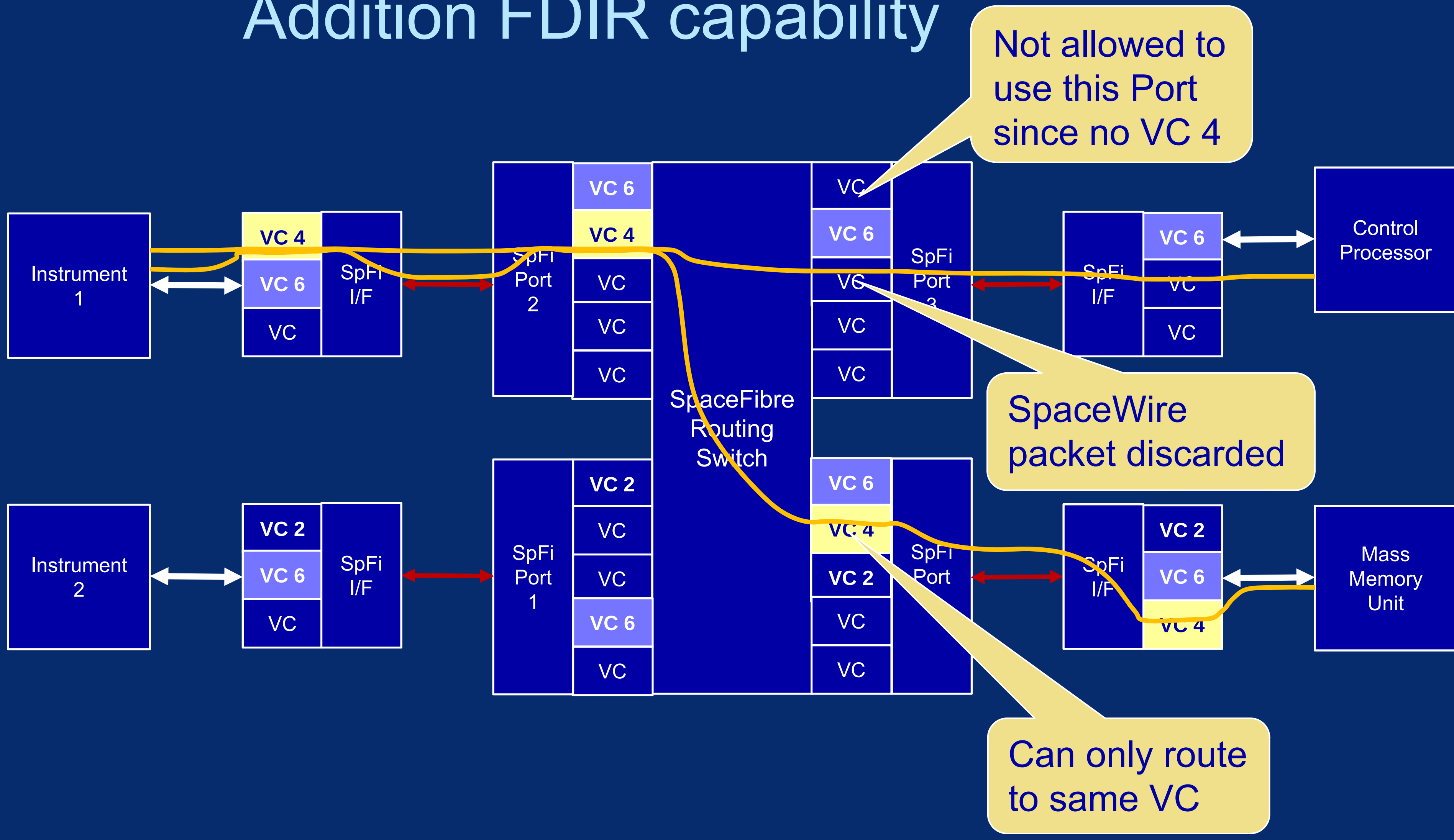
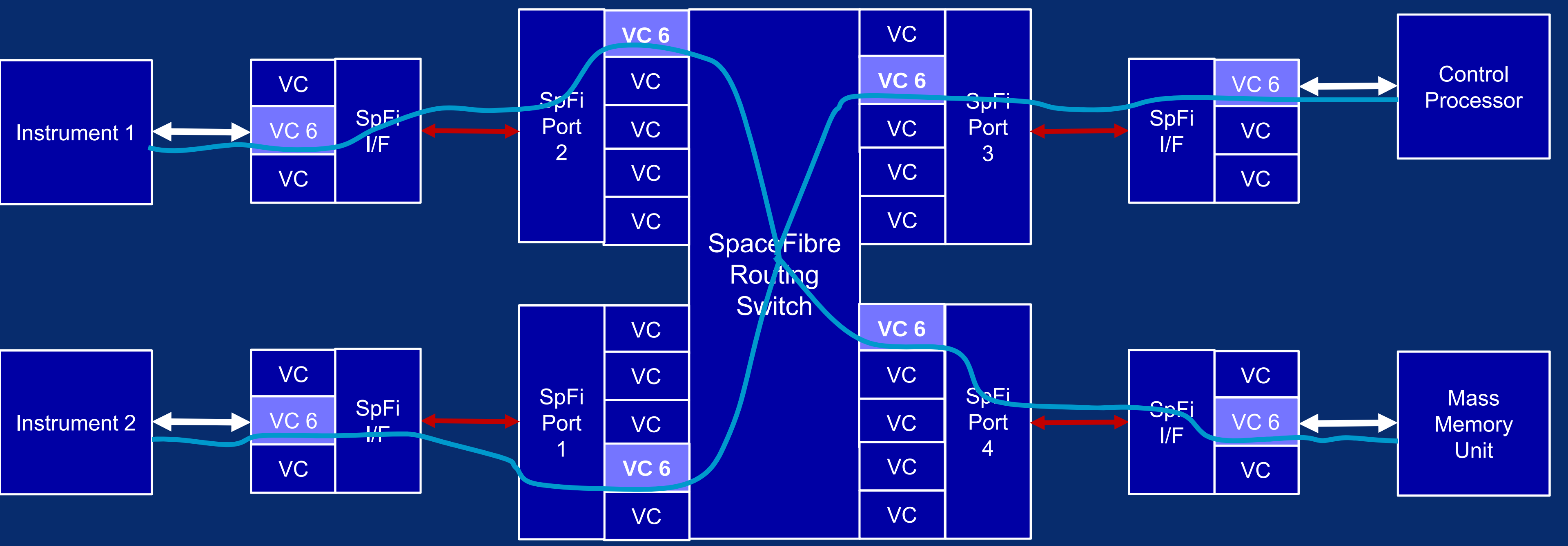
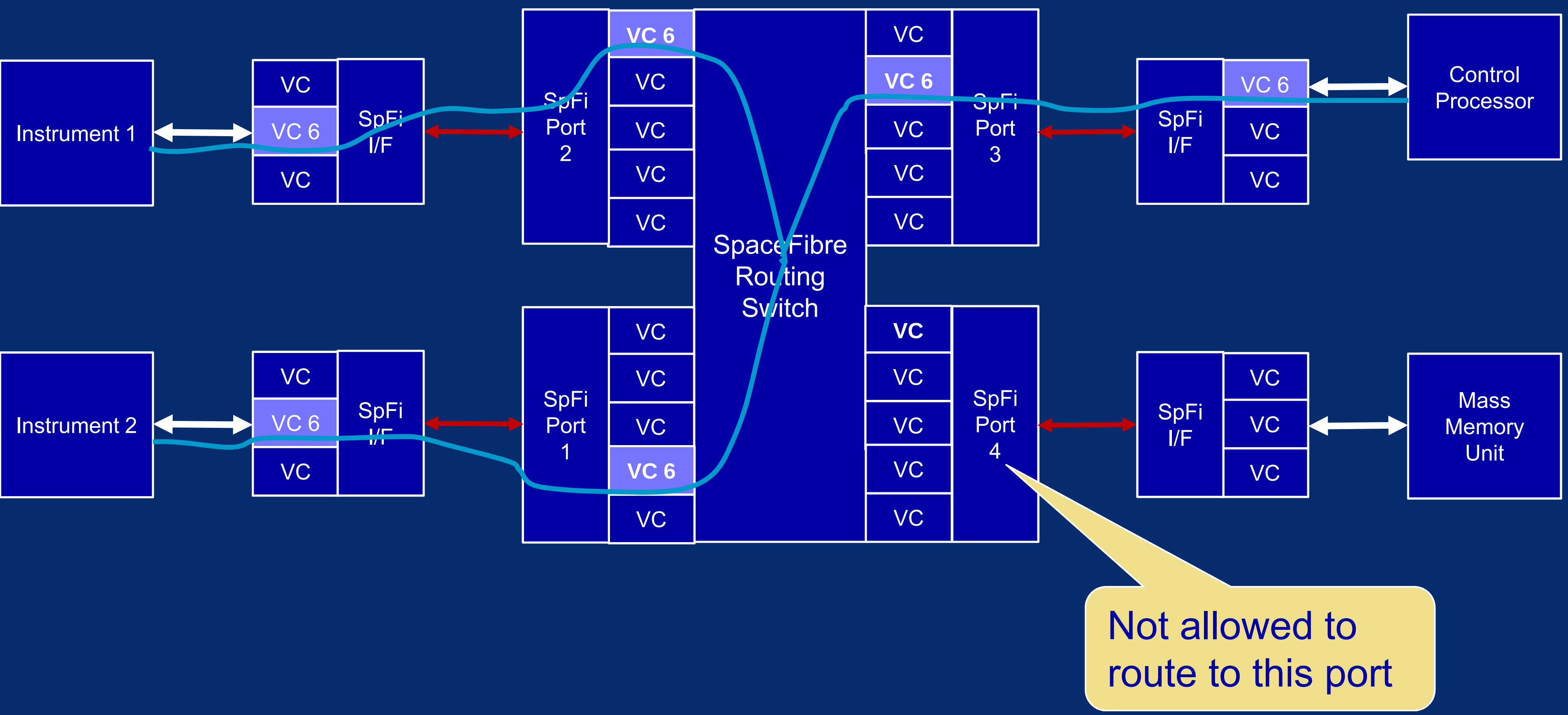
Addition FDIR capability



VN routing to all destinations



VN routing to restricted destinations



SpaceFibre Network Level

- Overview of intended SpaceFibre network operation
- Targeted at spacecraft data-handling applications
- VC buffers configured to specific VCs
- Can only route information within same VC/VN
- Provides additional FDIR capability
- Using redundancy of information
  - (address and VC number)
  - to detect faults
- Scheduling can be used with VNs for deterministic control applications

SpaceFibre Standard Update

SpaceFibre Standard Update E1

- Retry layer completed.
- Lane initialisation state diagram simplified.
- Data word identification state diagram simplified.
- Control symbols changed to improve robustness.
- Service interfaces improved (not yet finished).
- Quality of service specification improved.
- Management parameters added (more work yet).
- Electrical connectors and cable assemblies added to physical layer.
- Other corrections and clarifications throughout the document.

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Physical Layer Connectors

- SpaceFibre specification
  - Characteristics of cable and connectors
  - If possible open specification of specific implementation
- Based on high performance connectors
  - Axon AxoMach
  - Designed for spaceflight applications
  - Very high bandwidth
  - Cable assemblies
  - PCB mounting connectors
  - Cable mass 60 g/m for SpFi full duplex
  - Connector mass approx 25 g

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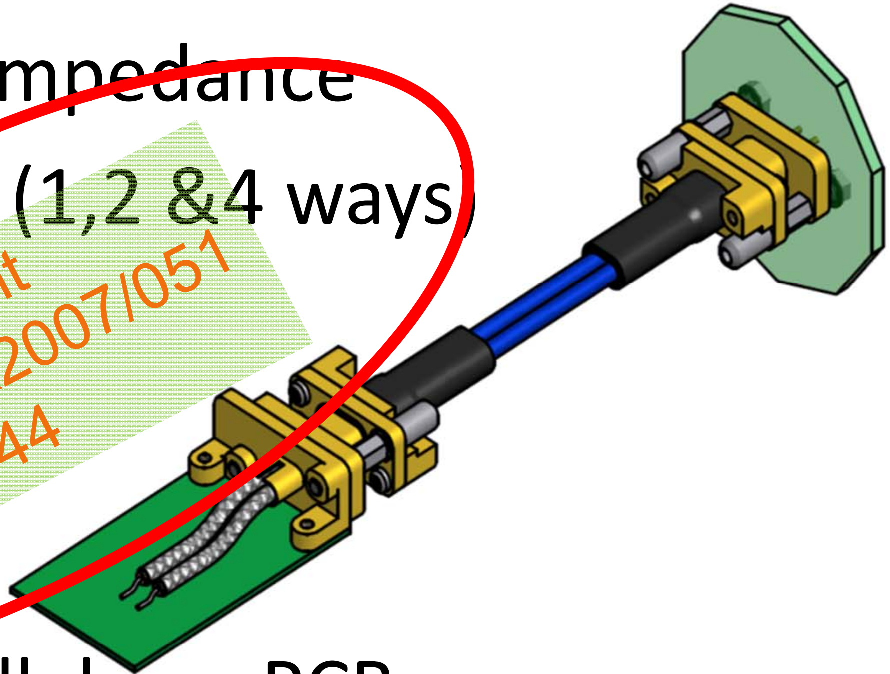
axoMach^{tm} (R&T CNES)

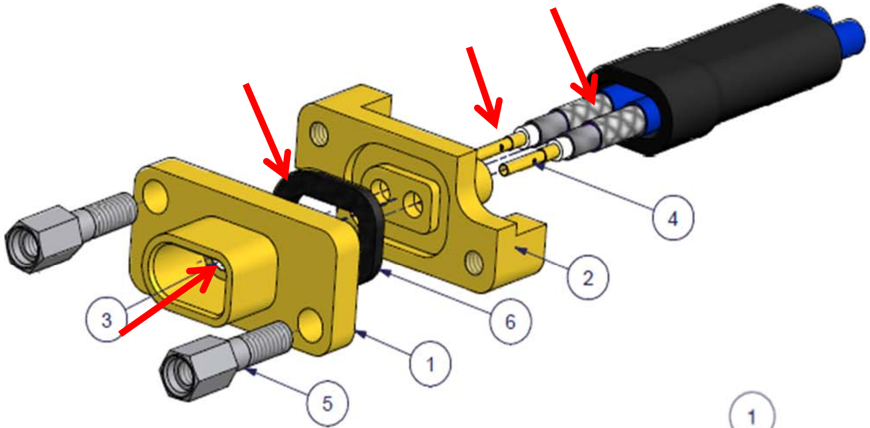
- 2 coaxials space cable media ax2.4S per way
- 100 Ohm differential impedance
- Up to 10Gb/s per way (1,2 &4 ways)
- Low skew
- Low size
- E.M.I. improved
- Surface mount & parallel gap PCB terminations

Patent N°PCT/FR2007/051 144

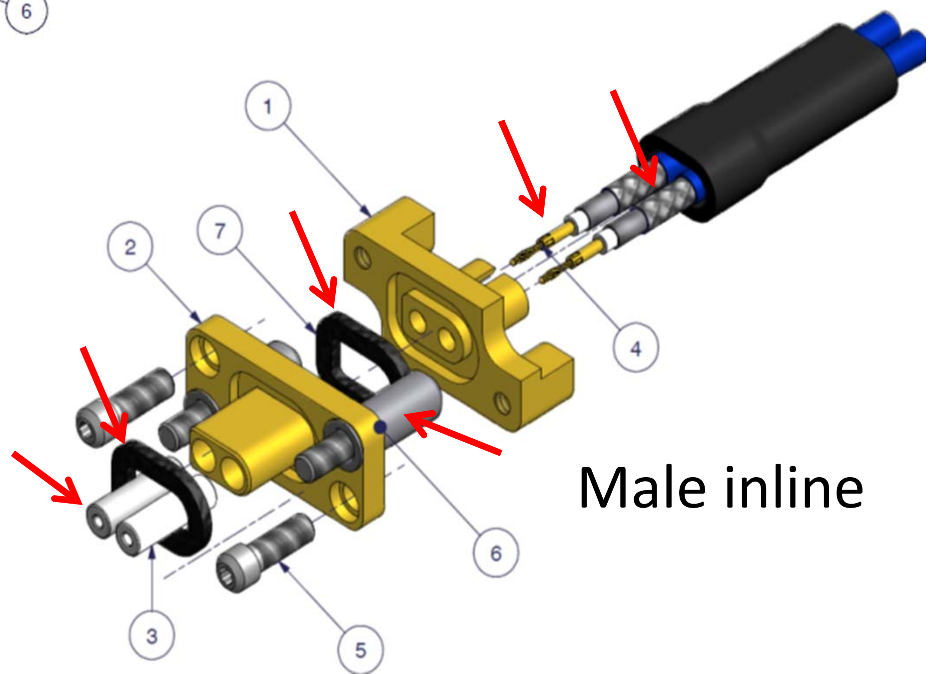


Design : heritage of microD

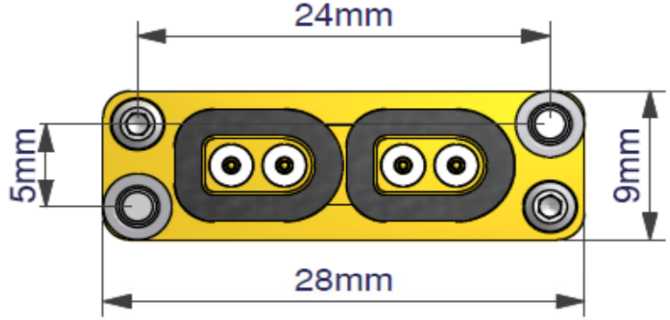
- MicroD space contacts
- PTFE inserts (Zc=100 Ohms)
- twin-coaxials (2 times **ax2.4S**)
- EMI gasket
- Retractable jack screw

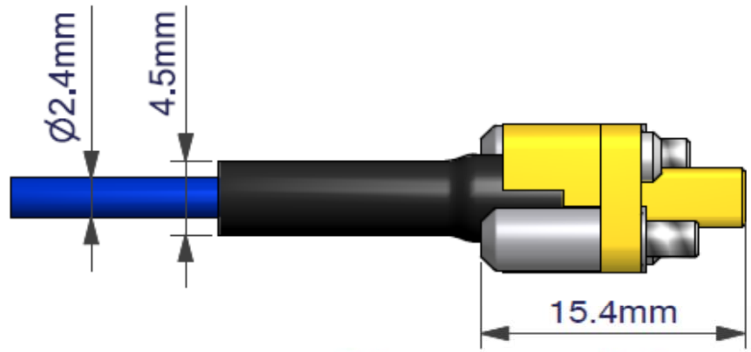


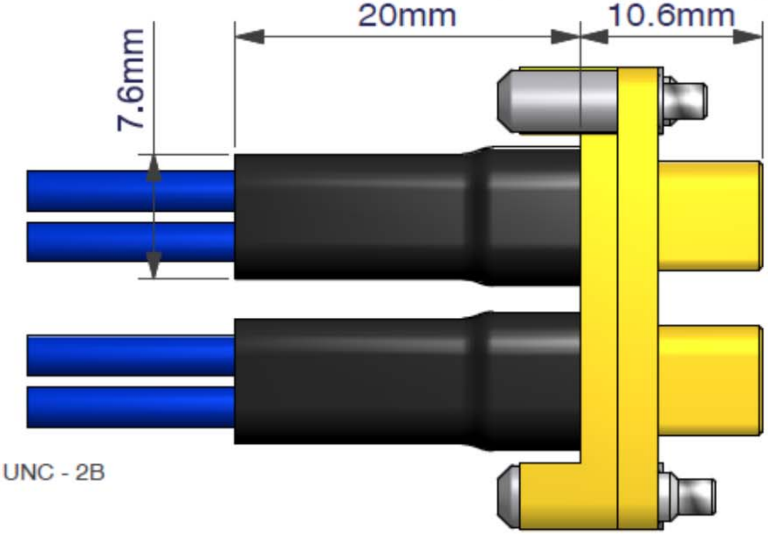
Female inline

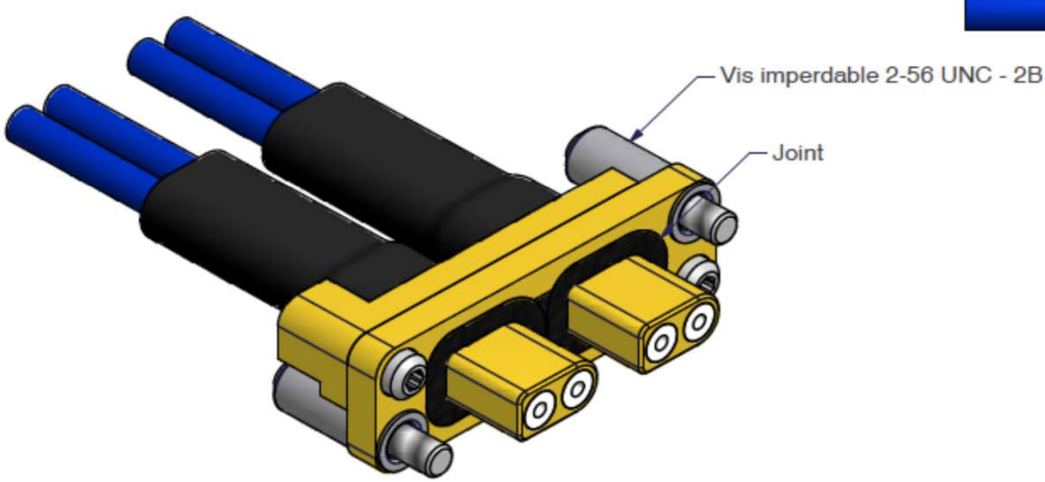


Male inline









Gamme de contrôle: GC8251

Matière: Alu 6061 T6

Traitement: 2.54µm Au + 5µm Ni

Sauf indications contraires
Dim : mm / Angles : deg
Tol. géné: ± mm
± 3°
Ra:

AXON'CABLE SAS
51210 MONTMIRAIL - FRANCE
TEL : +33 3 26 81 70 00
FAX : +33 3 26 81 28 83
www.axon-cable.com

TITRE :
Ensemble Mâle INLINE 2 voies

Nom Fichier :

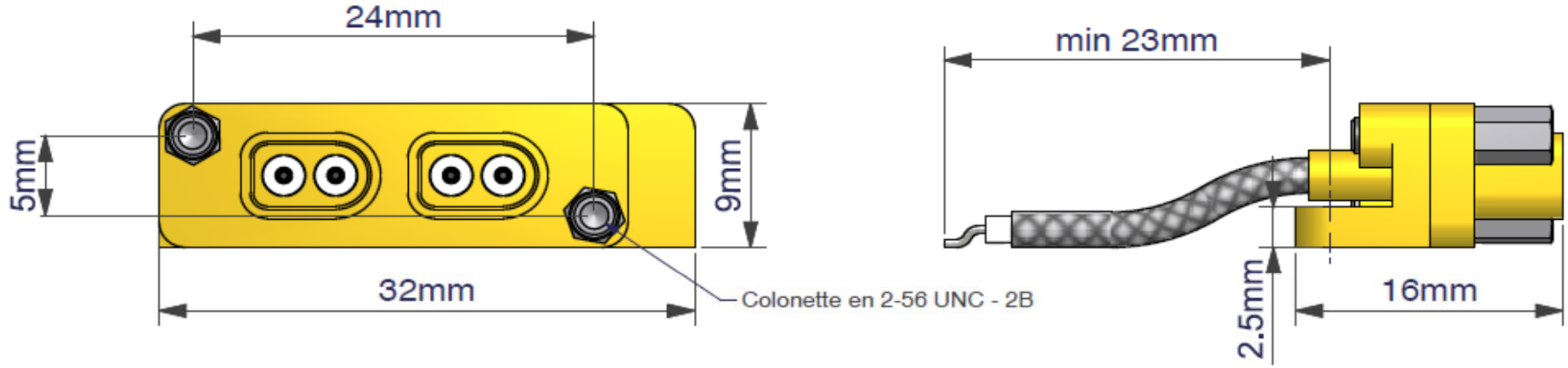
Format A3

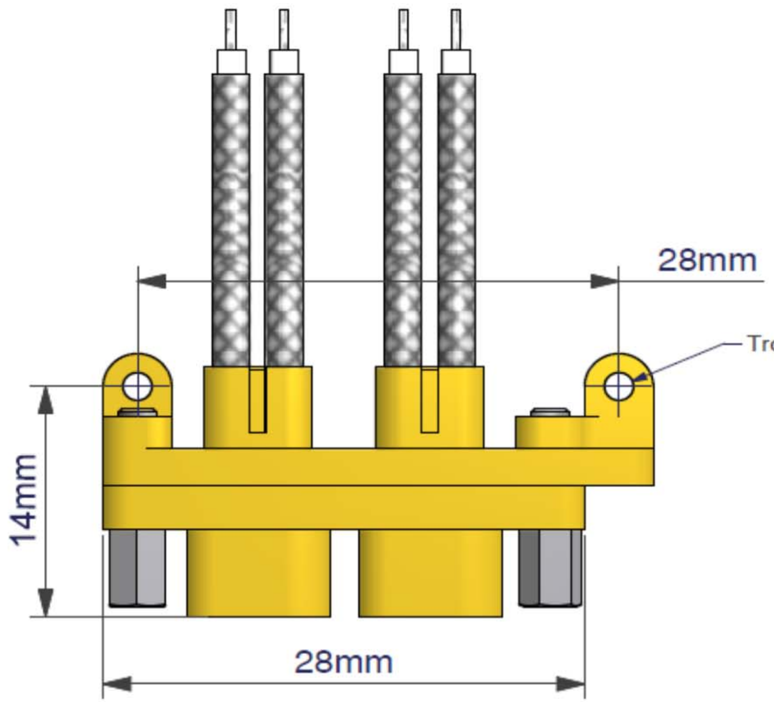
Echelle:

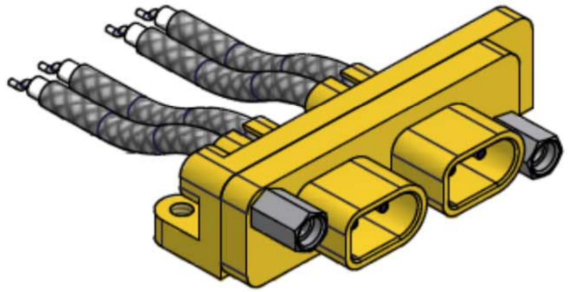
REF. AXON' :
Haut Débit 2 voies

Indice
A Prod. A Doc.

Feuille: 1/1







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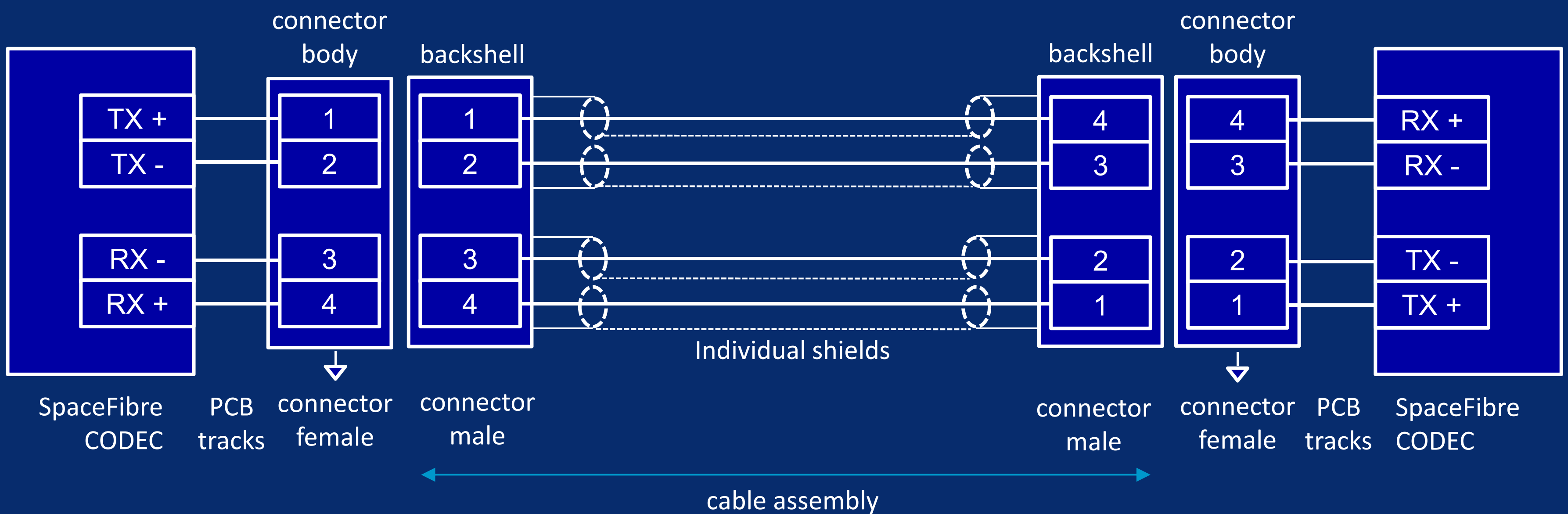
TITRE : Ensemble Femelle QFX 2 voies

Format A3
Echelle:

REF. AXON' : Haut Débit 2 voies

Indice A Prod. A Doc.
Feuille: 1/1

SpaceFibre Flight Cable Assembly



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SpaceFibre Flight/EGSE Cable Assembly

SpaceFibre EGSE Cable Assemblies

- External Serial ATA (eSATA) connectors used
  - Low cost
  - Small
  - High performance
- Crossover cable assemblies

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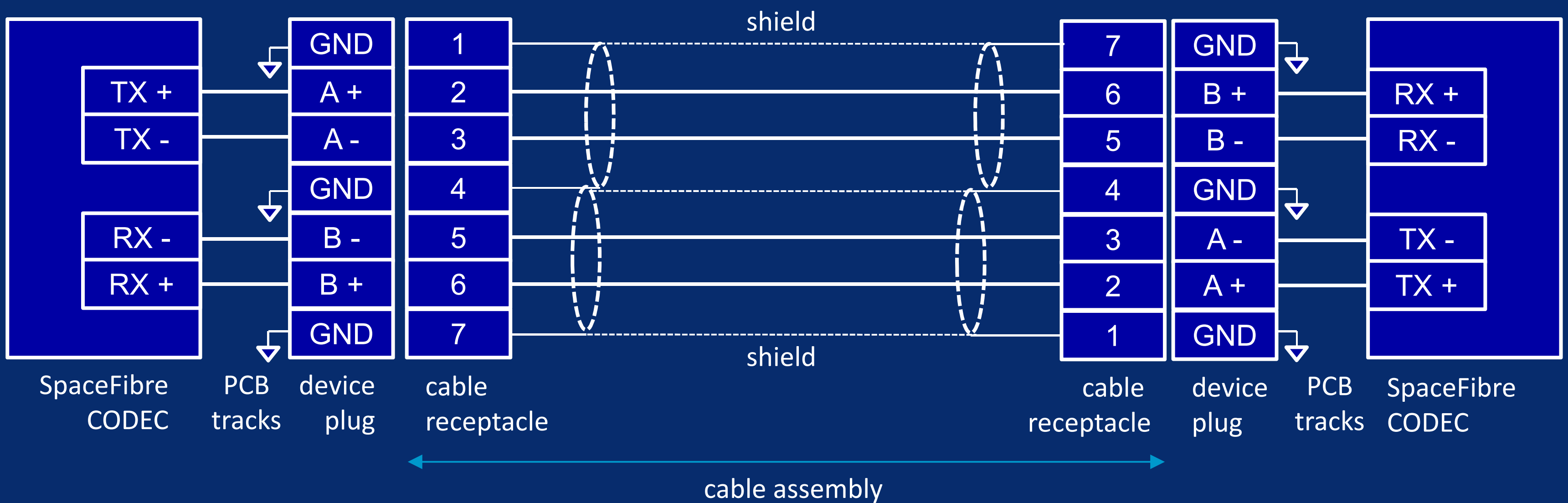
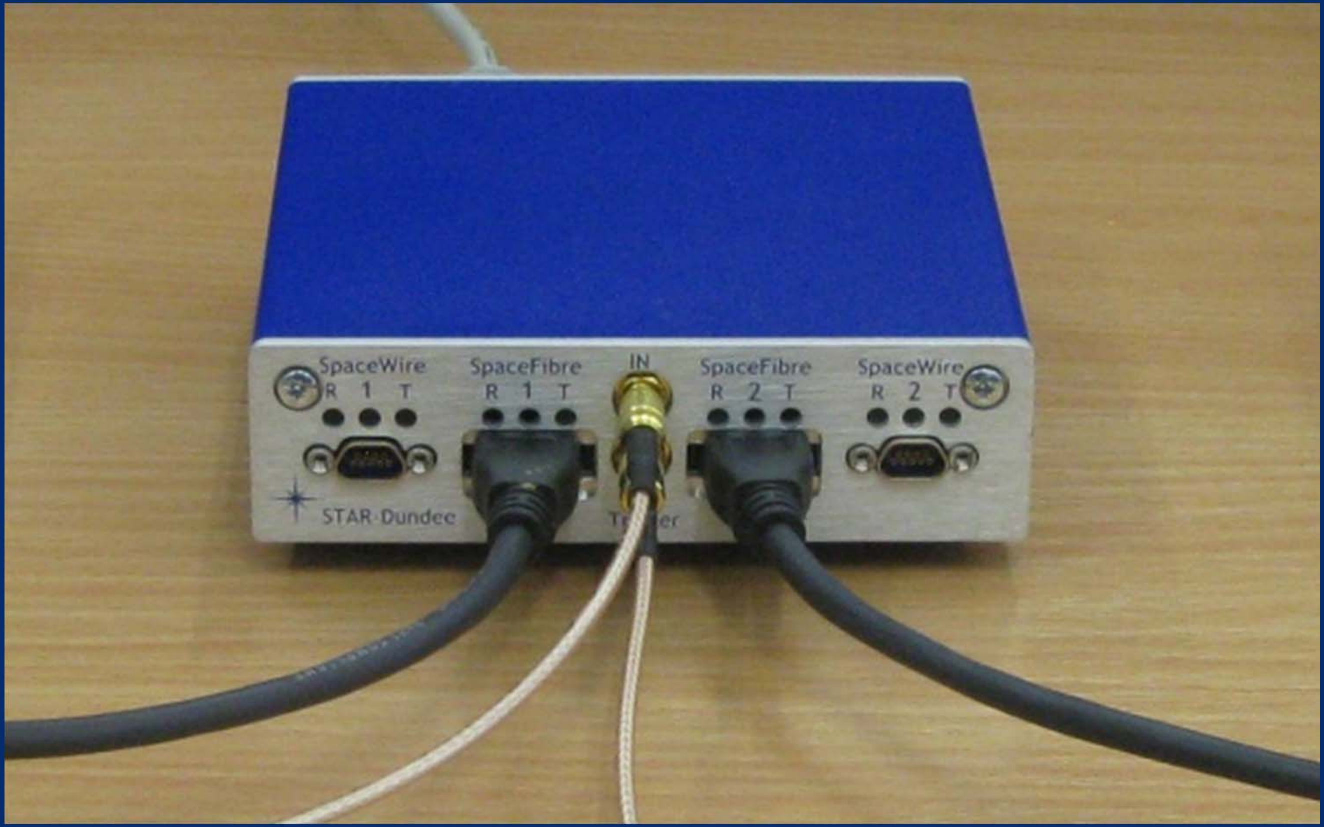
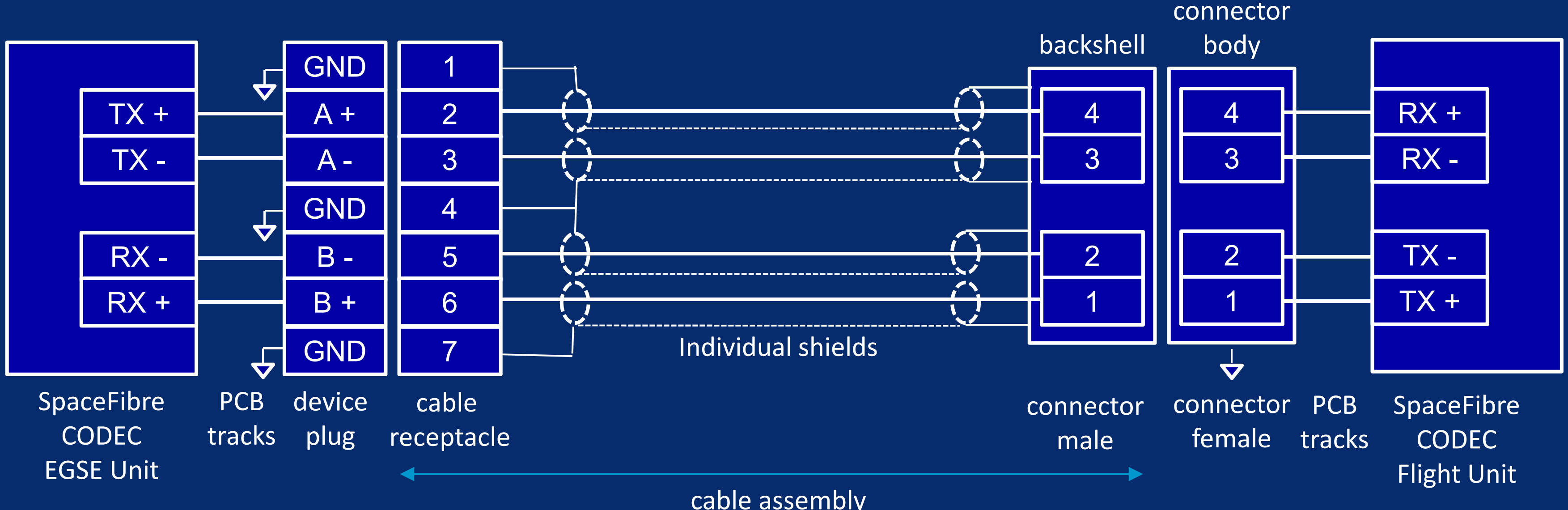
SpaceFibre EGSE Cable Assembly

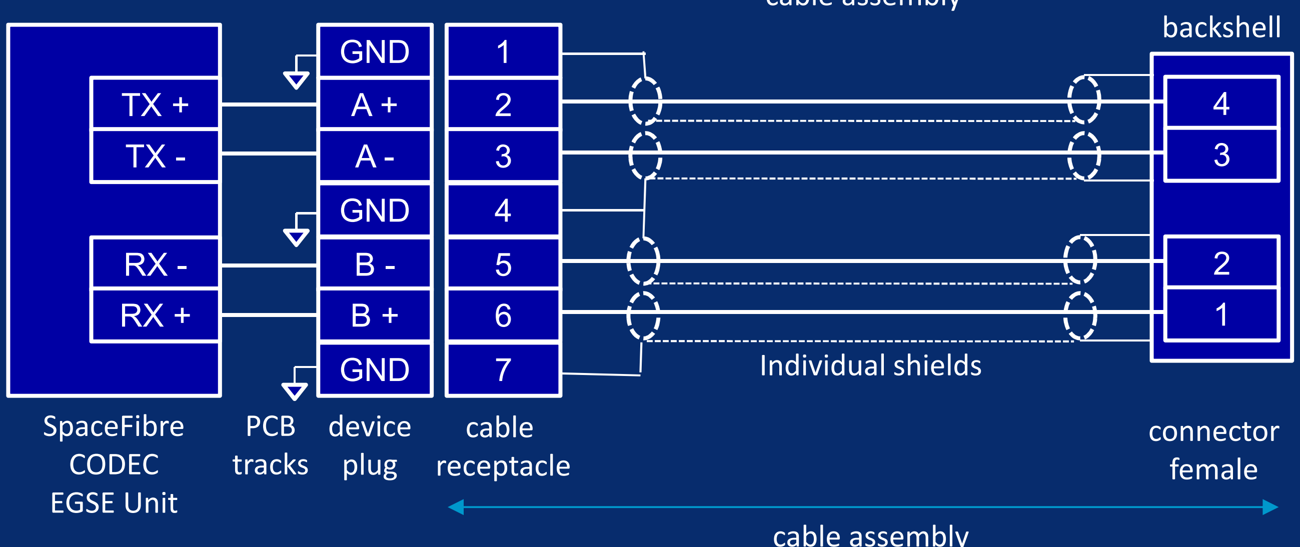


SpaceFibre EGSE Cable Assembly



SpaceFibre Flight to EGSE Adaptor





SpaceFibre Flight/EGSE Adaptor

Quality of service

- Reminder about the QoS mechanism
  - Bandwidth reserved
  - Priority
  - Scheduled

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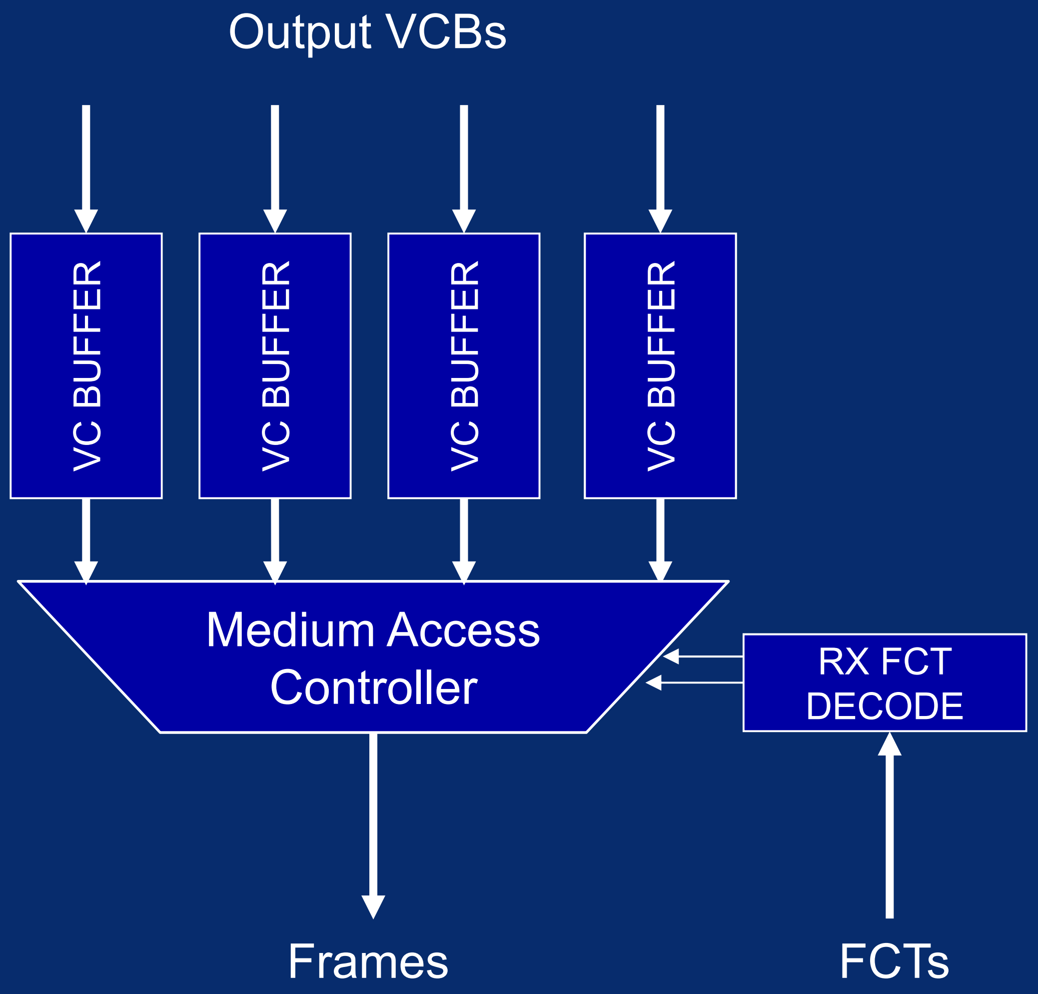
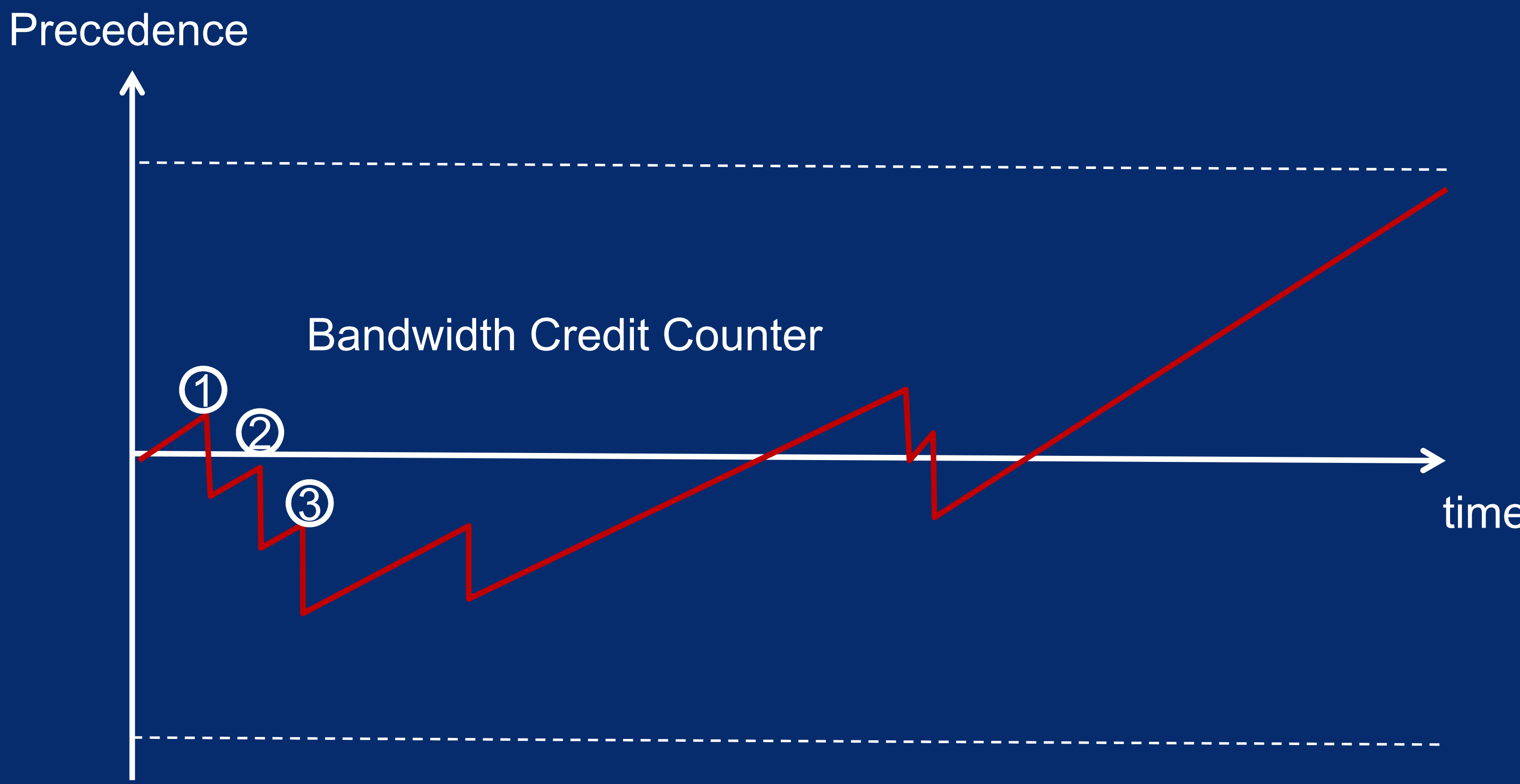
Medium Access Controller



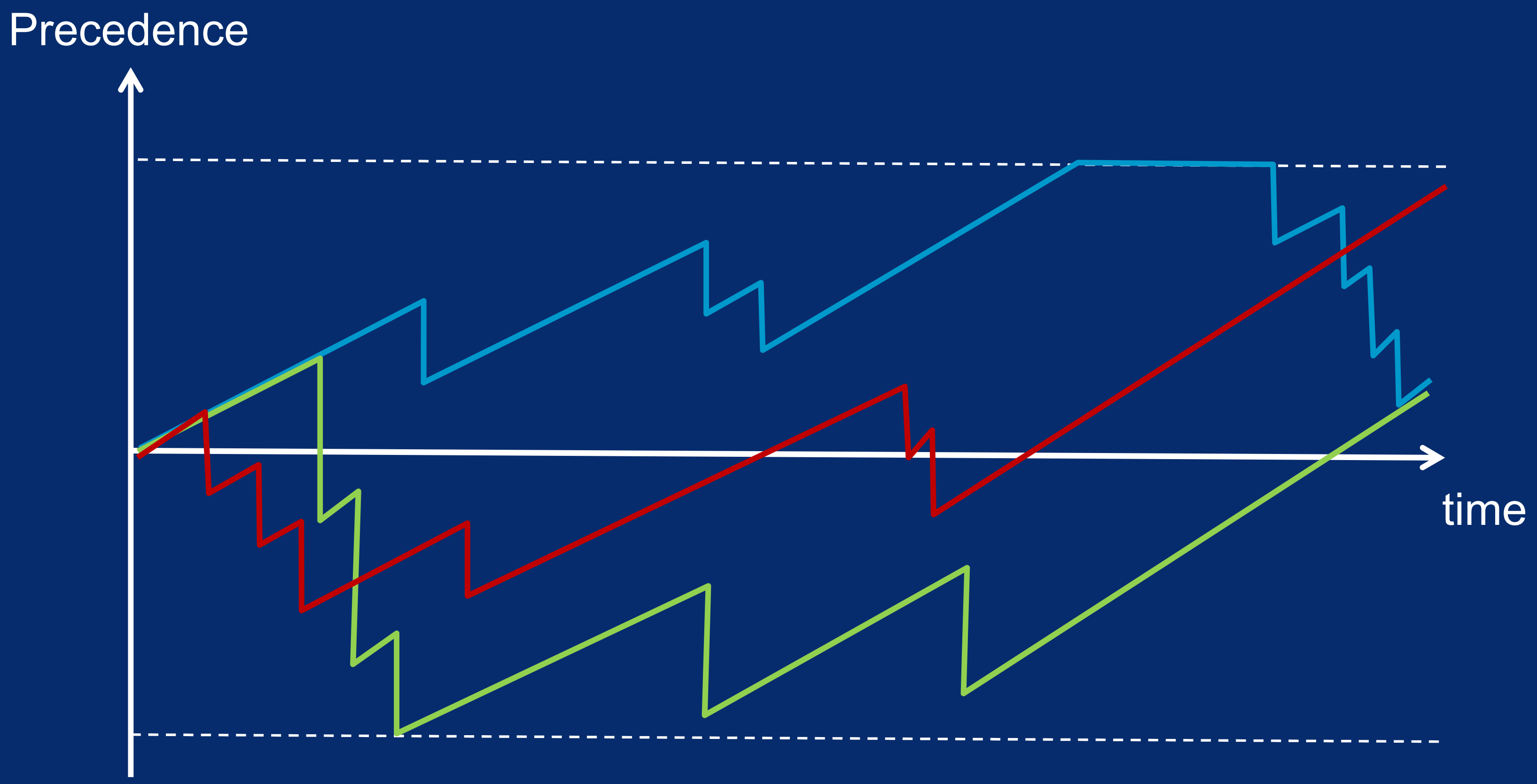
Medium Access Controller

- Determines
  - Output VCB permitted to send next frame
- Depends on:
  - Which output VCBs have data to send
  - Which input VCBs at other end of link have room
  - Arbitration or QoS policy in force for each virtual channel

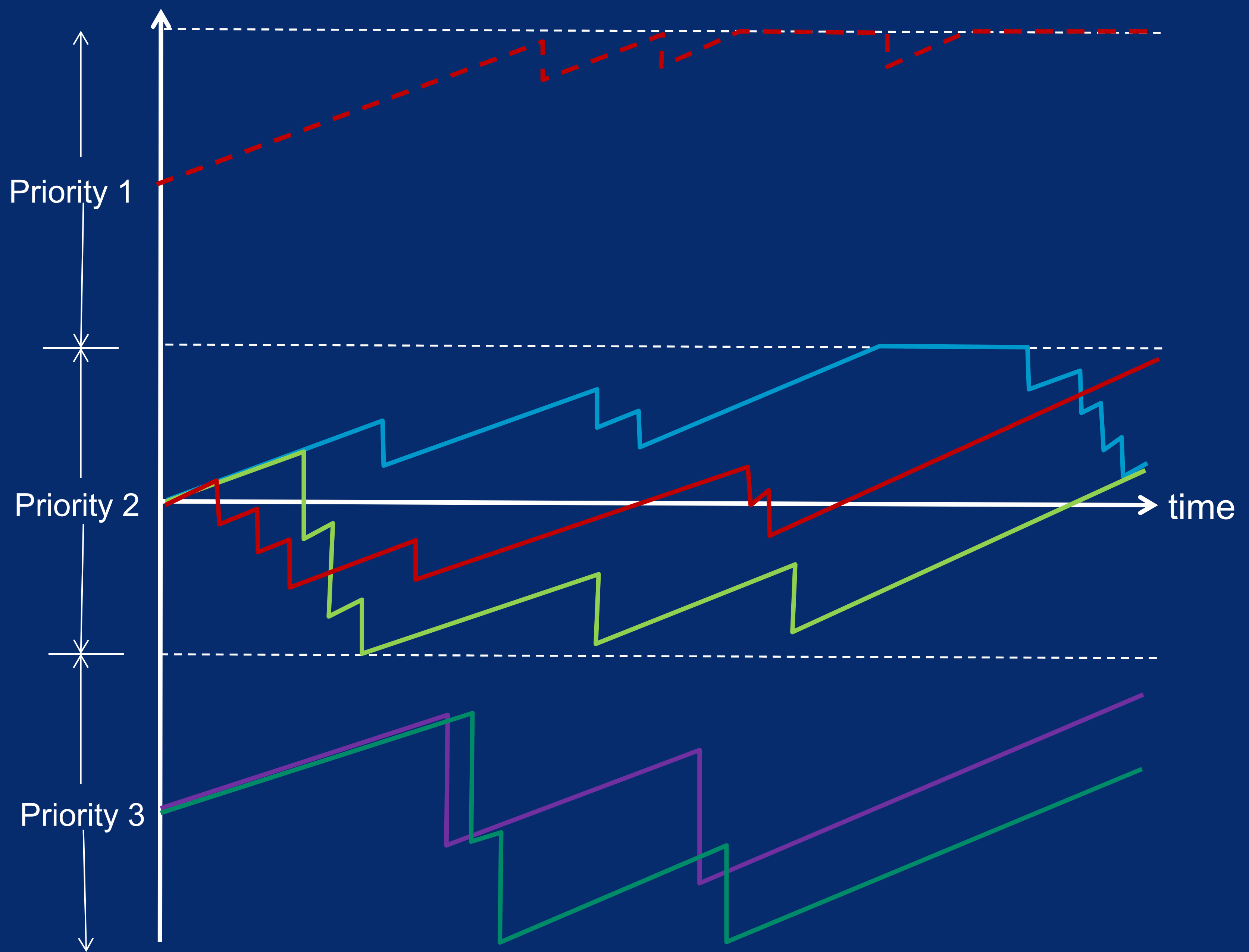
QoS: Bandwidth Reserved



QoS: Bandwidth Reserved



QoS Priority



FDIR Support in QoS

- Bandwidth credit counter also supports fault detection:
  - Excessive bandwidth utilisation
    - When BW credit counter reaches negative limit
  - Under utilisation of allocated bandwidth
    - When BW credit counter stays at maximum limit for long period of time
- Can be used to detect
  - Babbling idiots
  - Faulty units
- All provided with simple, low cost, mechanism

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Scheduled Precedence

- Time divided into time-slots
  - E.g. 64 time-slots of say 1 ms each
- Each VC allocated time-slots in which it is permitted to send data frames
- During a time-slot
  - If allowed to send in that time-slot
  - VC competes with other VCs also allowed to send in that time-slot
  - Based on precedence (priority and BW credit)
- A fully deterministic system would have one VC allowed to send in each time-slot

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Scheduled Precedence

Time-slot	1	2	3	4	5	6	7	8
VC 1								
VC 2								
VC 3								
VC 4								
VC 5								
VC 6								
VC 7								
VC 8								

Configured for Priority and BW Reserved Only

Time-slot	1	2	3	4	5	6	7	8
VC 1								
VC 2								
VC 3								
VC 4								
VC 5								
VC 6								
VC 7								
VC 8								

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Mixed Deterministic and Priority/BW-Reserved

Time-slot	1	2	3	4	5	6	7	8
VC 1								
VC 2								
VC 3								
VC 4								
VC 5								
VC 6								
VC 7								
VC 8								

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SpaceFibre Update

Overview

1. Retry layer completed
   - Fastest error recovery time (3-5us at 2.5Gb/s)
   - Supports any link speeds (no timeouts used)
   - Recovers from nominal errors and detects non nominal link error conditions (i.e. multiple bit flips)
2. Lane initialization state machine simplified
   - Same functionality, 40% reduction in complexity.
3. More robust control word encoding scheme
   - Any single bit flip in the line is ALWAYS detected by the combination of encoding and retry layer.
4. SpaceFibre specifications completed
   - Management and physical layer described

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Retry Layer features

Recovers from an error as fast as possible.

- A NACK is sent when any type of error is detected.
  - 8B10B disparity error
  - CRC error
  - Out of sequence frame (data, idle, FCT..)
- Retry starts as soon as a NACK is received.
  - Current data frame is aborted
- Broadcasts have higher priority than data frames at all times. (i.e. even when an error occurs)

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Retry Layer features (2)

Reliable link under any type of error

- Including the loss of NACKs, ACKs or any other word.
- Nominal errors (i.e. single bit flips) are always recovered.
- Non-nominal conditions (i.e. multi bit flips) are detected before there is a change that the link reliability is compromised.
- Fatal errors such as unexpected hardware resets do not affect the link operation and user data integrity.

Supports any link speeds without configuration

- It does not use timeouts, so it can work with any link speed (i.e. multiple lanes or SpaceWire links)

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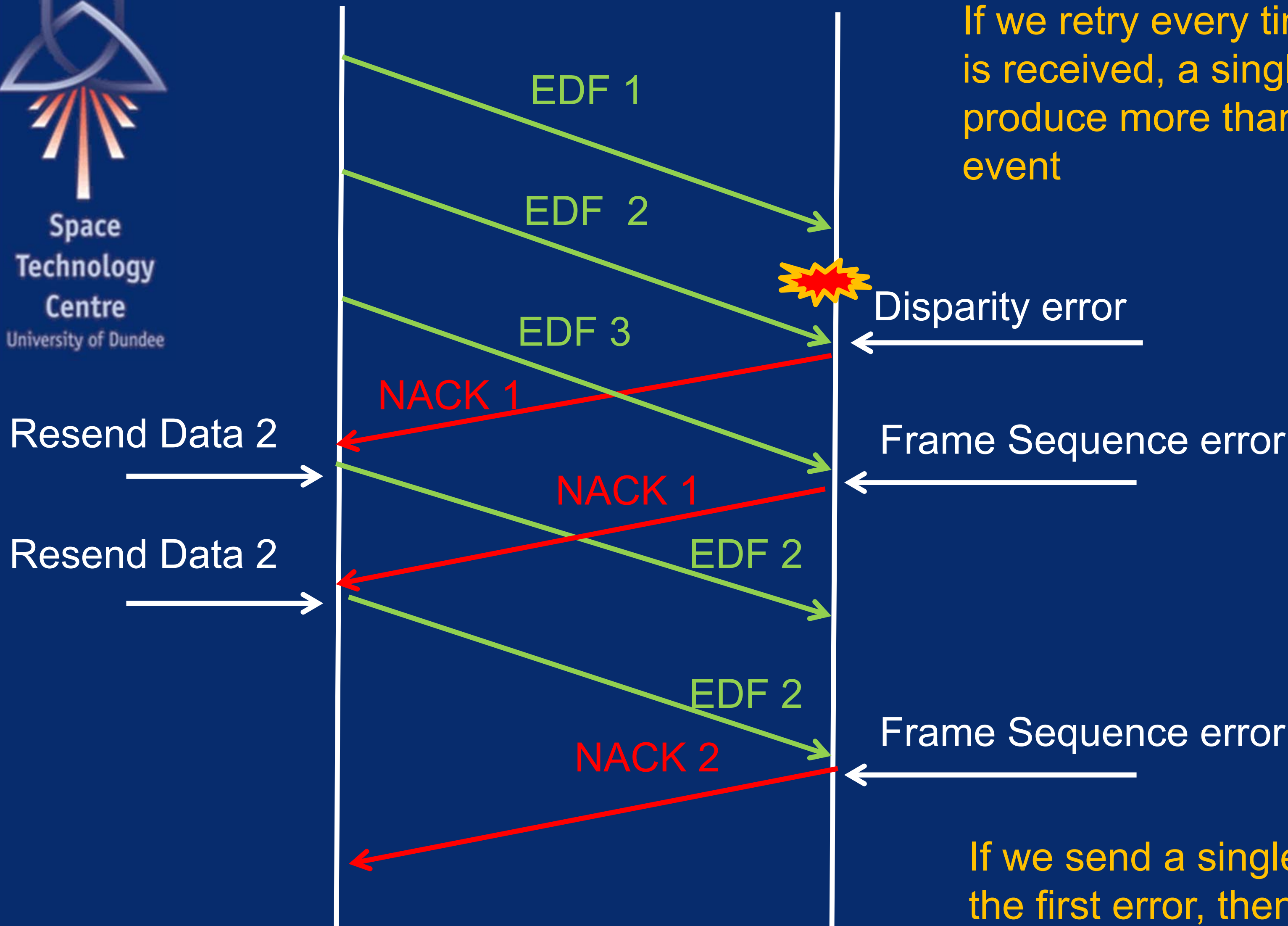
Retry Layer naïve approach

If we retry every time a NACK is received, a single error can produce more than one retry event



If we send a single NACK for the first error, then this NACK could get lost.

Retry Layer actual operation

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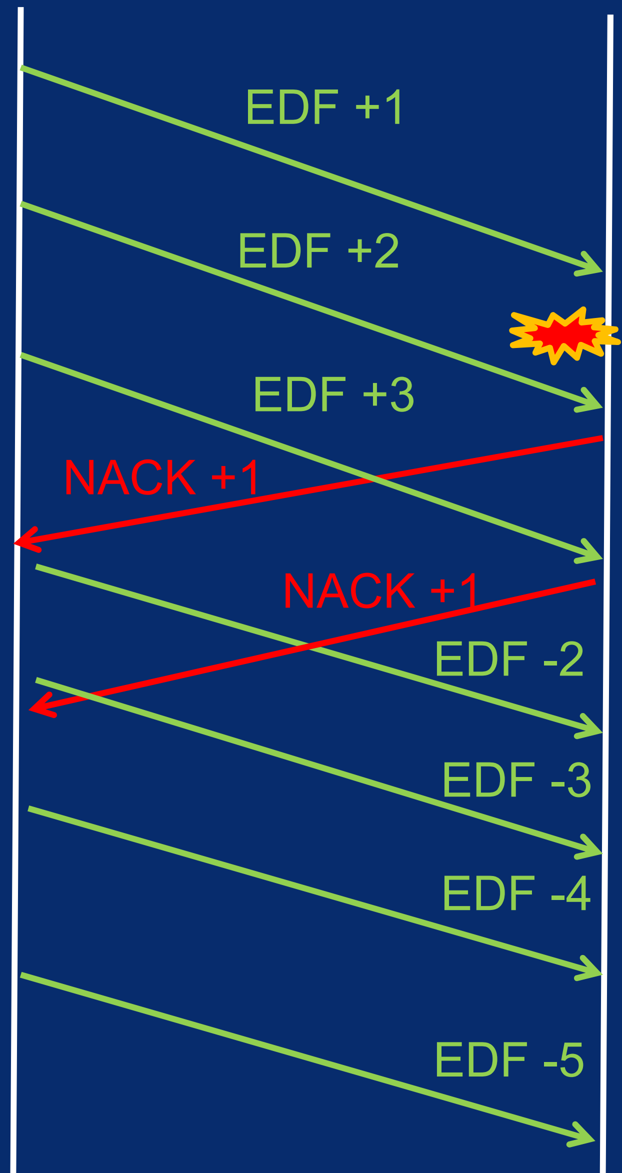
NACK received, use negative sequences

NACK discarded because sequence is not negative



- There are positive and negative sequence numbers (sequence polarity)
- The receiver changes the polarity when an error occurs.
- The sender changes the polarity when a NACK is received

The **worst case recovery time** is the round trip delay plus the transmission time of a data frame.

- This is **less than 4us** with a 100m cable length @2.5Gb/s in a prototype implementation.

Retry Layer additional features

- Broadcasts that are delayed due to a retry event are marked with a flag in EBF word.
- When a retry occurs, new broadcasts have priority over data to be resend.
- A single ACK word can acknowledge more than one frame.
- ACK word usage of bandwidth is limited.
  - 16 words must be sent between ACK words.
  - This helps to guarantee the bandwidth allocated to data frames

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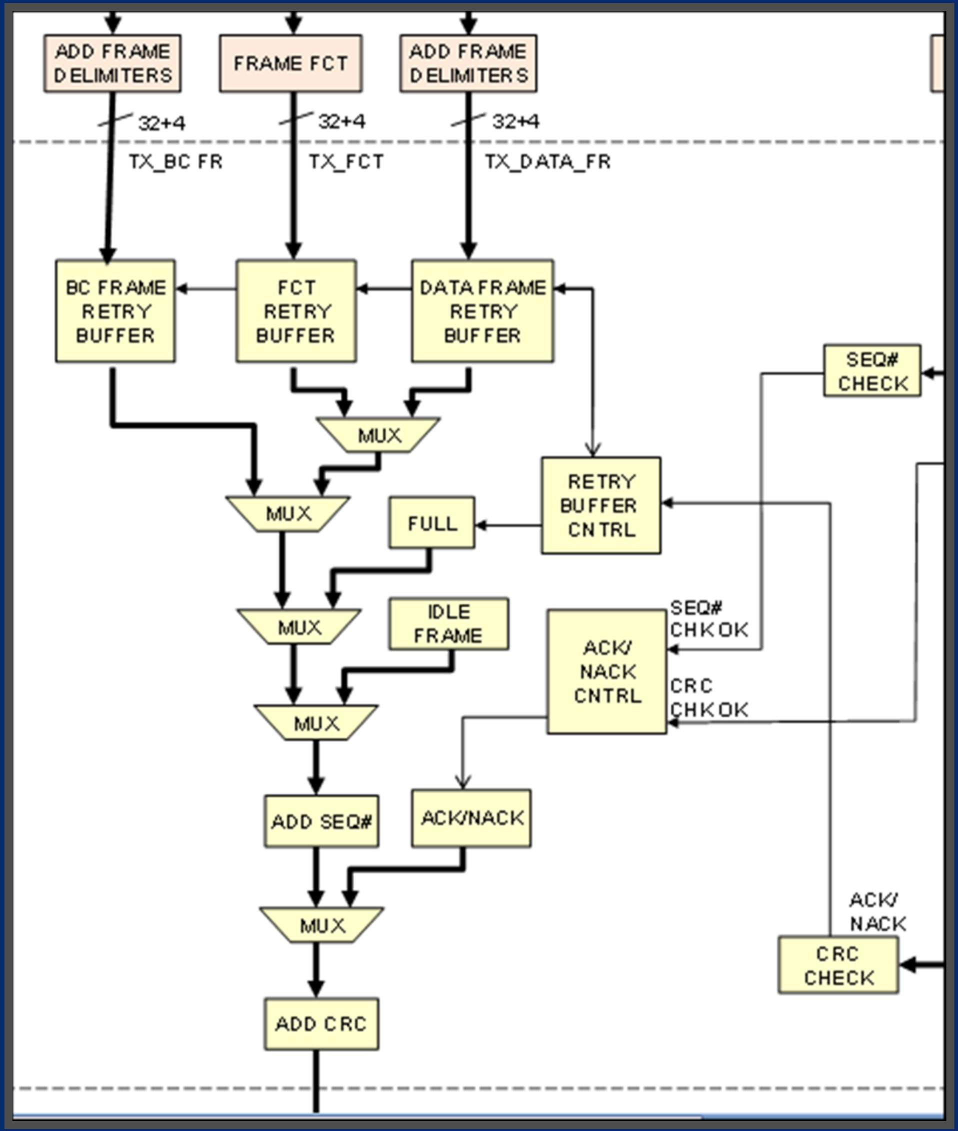
Retry Layer TX implementation



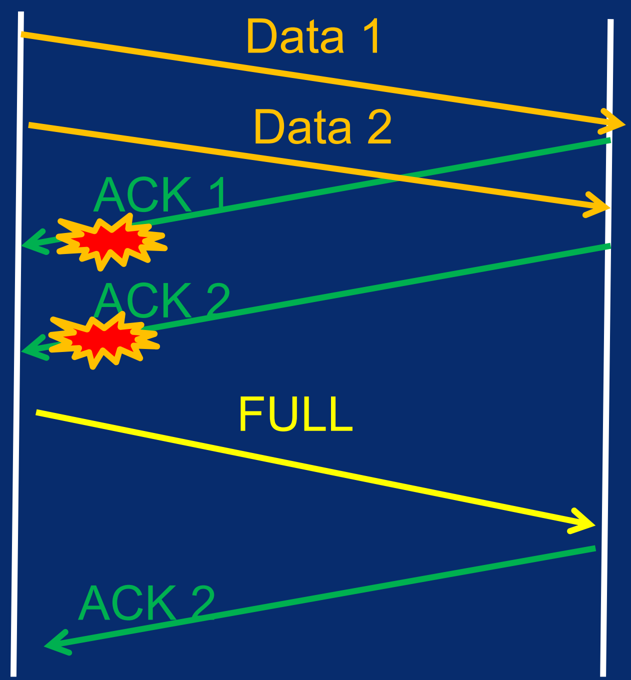
Three Separate retry buffers for:

1. Broadcast Frames
2. FCTs
3. Data frames

Retry buffer control module removes frames acknowledged by the ACKs received

Retry buffer full condition

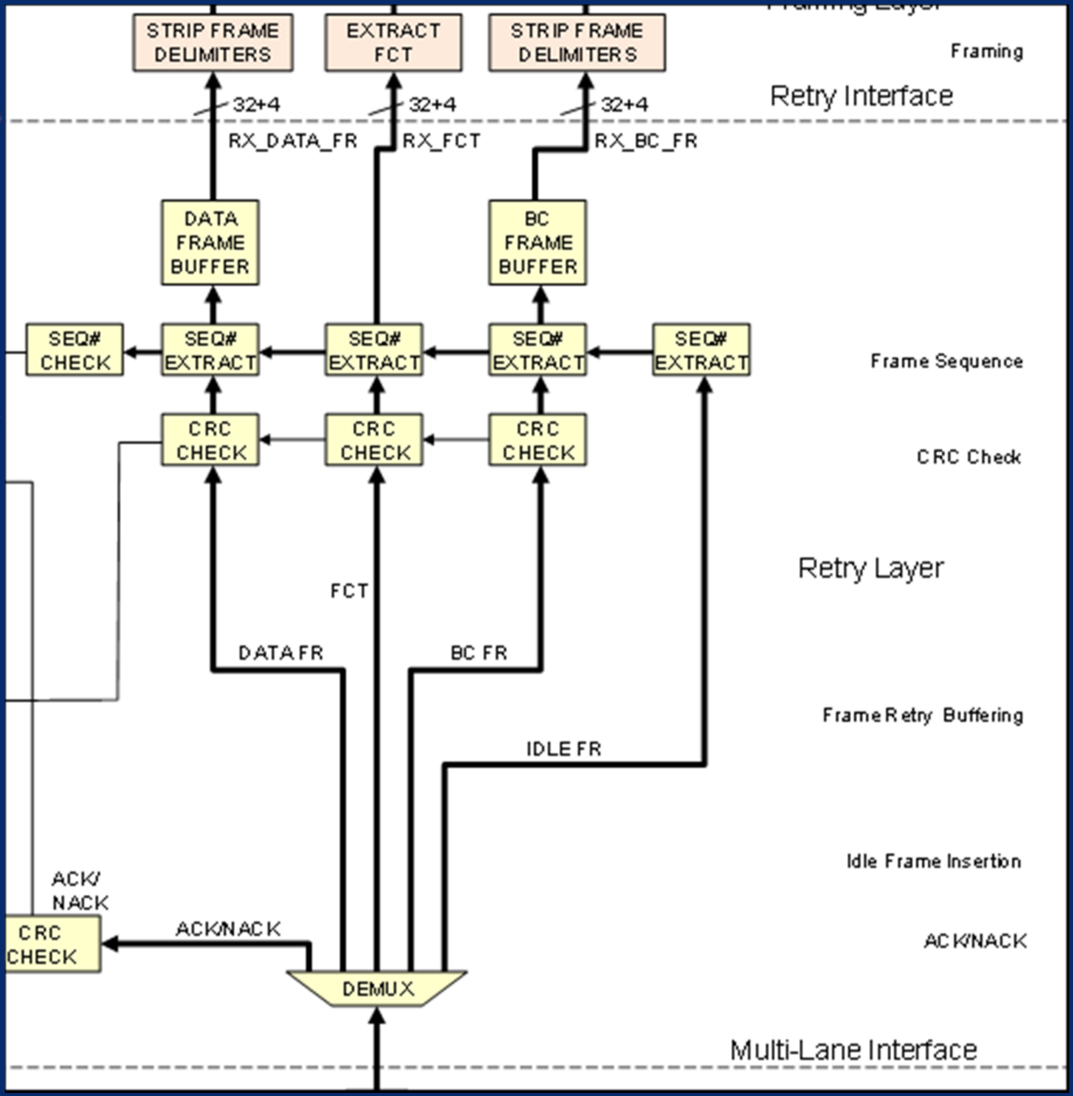
- The retry buffers holds frames and FCTs until they are acknowledged.
- One or more retry buffer can get full if:
  1. The retry buffer is small and can not hold the amount of data sent before an ACK is received.
  2. One or more ACKs are lost due to the cable being disconnected and connected.
     - We need to request to send a new ACK using the FULL word



- When the retry buffer is full, a FULL word is sent

- When a FULL word is received, and ACK is sent

Retry Layer RX implementation



The Demux is implemented with the word identification state machine, which keeps track of which frame type is currently receiving.

If the CRC is correct the sequence number is checked against the expected value.

A Data frame and Broadcast frame buffer is used to temporally store one frame until the CRC at the end is checked.

Lane initialization state machine

- State machine now described using only 11 states instead of the original 19 states.
  - Error recovery state machine is removed as its functionality is already covered by the retry layer
- Lane is disconnected when the lane receive error counter overflows
  - This indicates that the BER is too high.
  - BER is measured by decreasing the error counter every N words (i.e. leaky bucket algorithm)
- Functionality is the same as the previous version.
  - Supports AutoStart, inverted RX polarity, Standby and LossOfSignal or receive error overflow indication.
- Implementation requires less than half of the original hardware resources.

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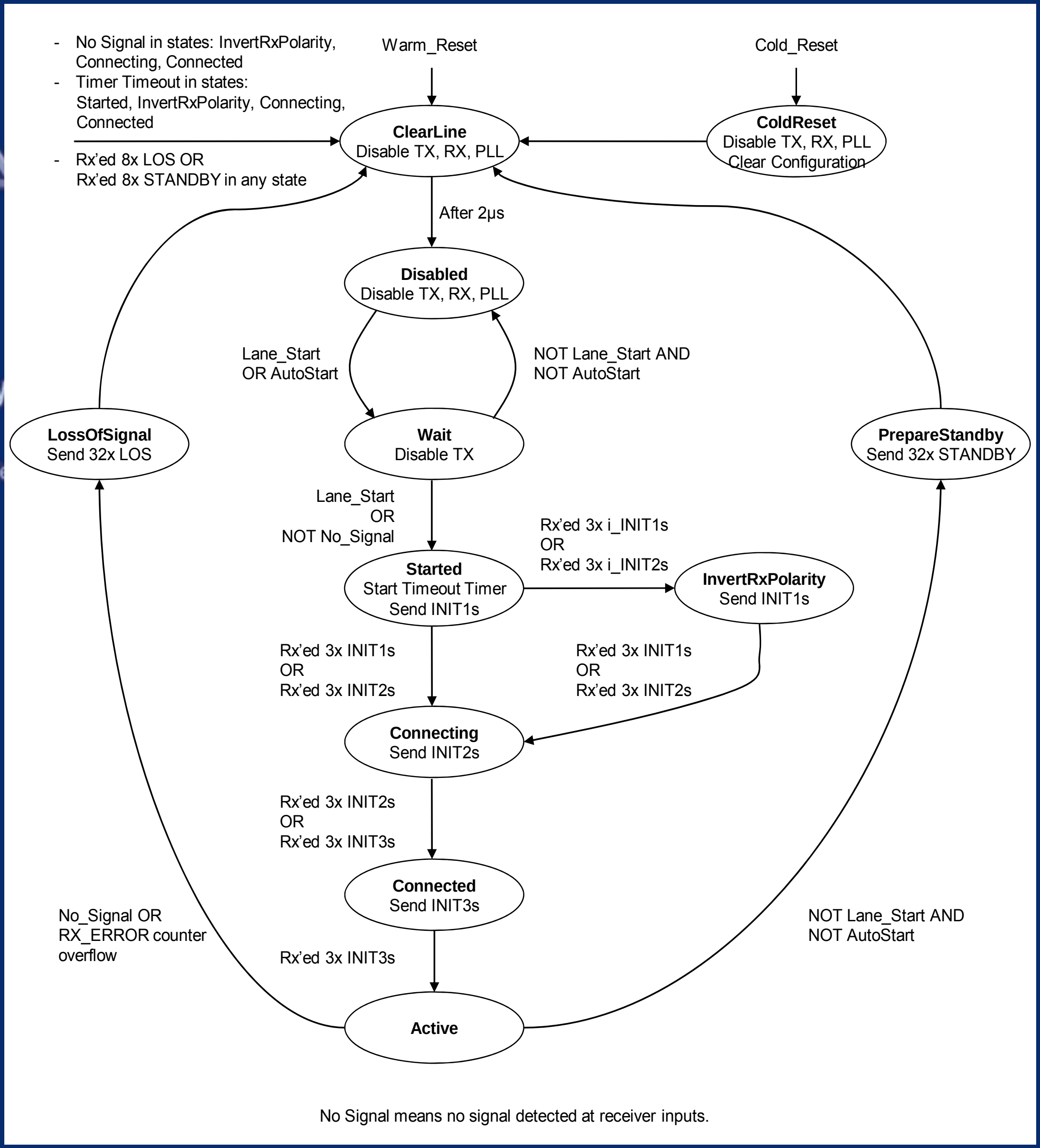
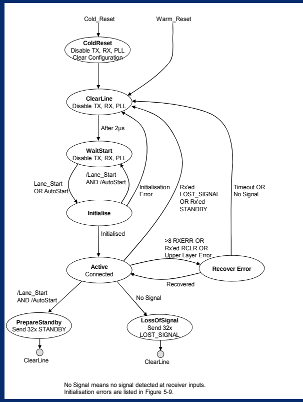
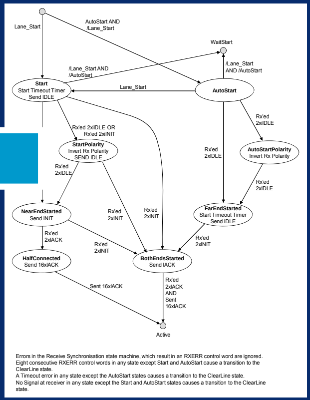
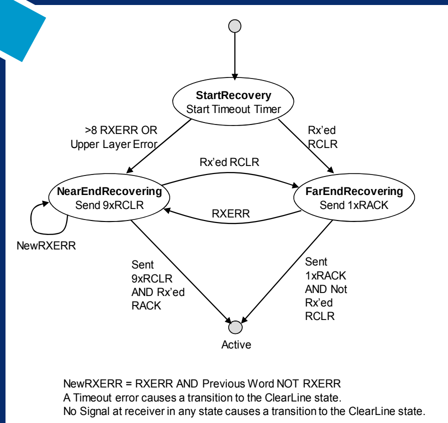
Simplified state machine



OLD state machine







Typical initialization sequence

1. Disabled
   – Leave state when lane enabled
2. Wait
   – Leave state when in Start mode or signal is received.
3. Started
   – Sends INIT1s to start connection
   – Leave state when INIT1 or INIT2 received
4. Connecting
   – Sends INIT2s to indicate that it is receiving words.
   – Leave state when INIT2 or INIT3 received
5. Connected
   – Sends INIT3s to exchange connection parameters
   – Leave state when INIT3 received
6. Active
   – Sends user data
   – Leave state when in either end an errors occurs or is disabled.

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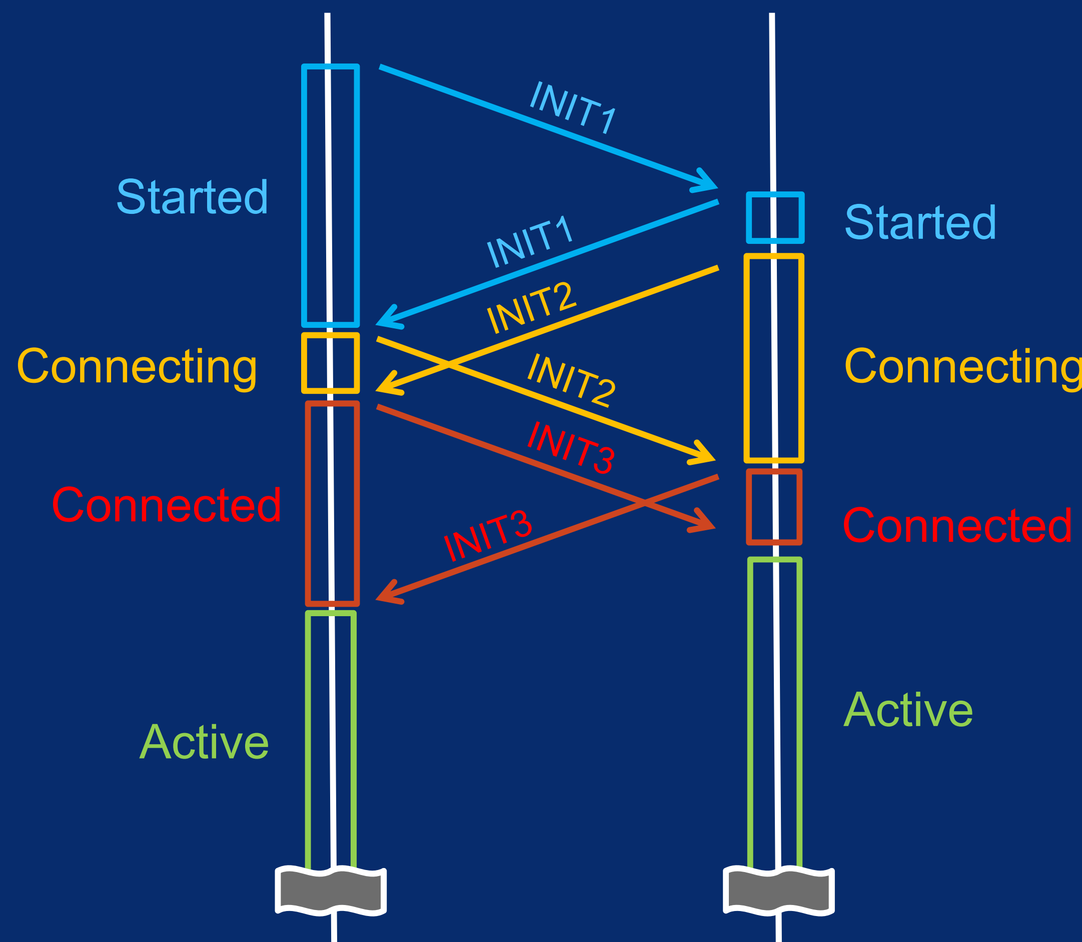
Link Initialisation - Handshaking

INIT1	INIT1
INIT1	INIT2
INIT1	INIT2
INIT1	INIT2
INIT1	INIT2
INIT2	INIT2
INIT2	INIT2
INIT2	INIT2
INIT2	INIT2
INIT3	INIT2
INIT3	INIT2
INIT3	INIT2
INIT3	INIT3
INIT3	INIT3
INIT3	INIT3
INIT3	INIT3
INIT3	IDLE
INIT3	IDLE
INIT3	IDLE
INIT3	IDLE
INIT3	FCT +1 (1)
INIT3	FCT +32 (0)
IDLE	FCT +33 (1)
IDLE	FCT +34 (2)
IDLE	FCT +35 (3)
IDLE	FCT +36 (4)
FCT +1 (1)	FCT +37 (5)



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Robust control words encoding

- A control word begins with a comma
  - Comma symbol K28.7 is used so that a single bit flip error in a data word can not convert it into a control word.
- Second character indicates type of control word.
  - They are selected to have polarity so any single bit flip occurred before will produce a 8B10B disparity error.
  - They are selected to maximize the hamming distance (number of different bits) between them, so more than three bit flips are required to convert one valid character into another valid one. The hamming distance is 4.

Medium Access Control and QoS rules

- A Virtual Channel can send a data frame:
  - If there is user data in the input buffer
  - If there is space at the destination
  - If It is scheduled to send data in the current TimeSlot.

- The Virtual Channel (VC) with higher precedence will be selected.

  Precedence = Priority Precedence + BW credit

  - Priority precedence depends on the priority level of the VC.
  - BW credit depends on the amount of data sent respect to the reserved bandwidth of the VC.
  - BW credit only matters on VCs with same priority

- Indicate to the user if a VC is using too much bandwidth or it is idle more than expected.

QoS schemes supported

- Deterministic scheduling scheme
  - All VCs scheduled at different timeslots.
- Simple priority scheme
  - Each VC is set to a different priority levels
- Simple Bandwidth allocation
  - All VCs set to same priority level
- Different priorities with bandwidth allocation
  - Bandwidth arbitration between multiple VCs for payload data
  - Command and Control set to use higher priority VCs
- Different priorities with bandwidth allocation and scheduling
  - Some slots are reserved for VCs with deterministic requirements.

SpaceFibre versus Rapid IO

	Rapid IO **(Xilinx srio_ds696)**	**SpaceFibre**
Automatic retry	Yes	Yes
Power management	Yes	Yes
Scrambling	Yes	Yes
Worst case retry reaction time	Timeout value	**Delay of the line**
Virtual Channels	1	**8**
Flow control	Yes	Yes
Priorities	Yes (3 levels)	Yes (8 levels)
BW allocation	No	**Yes**
Scheduling	No	**Yes**

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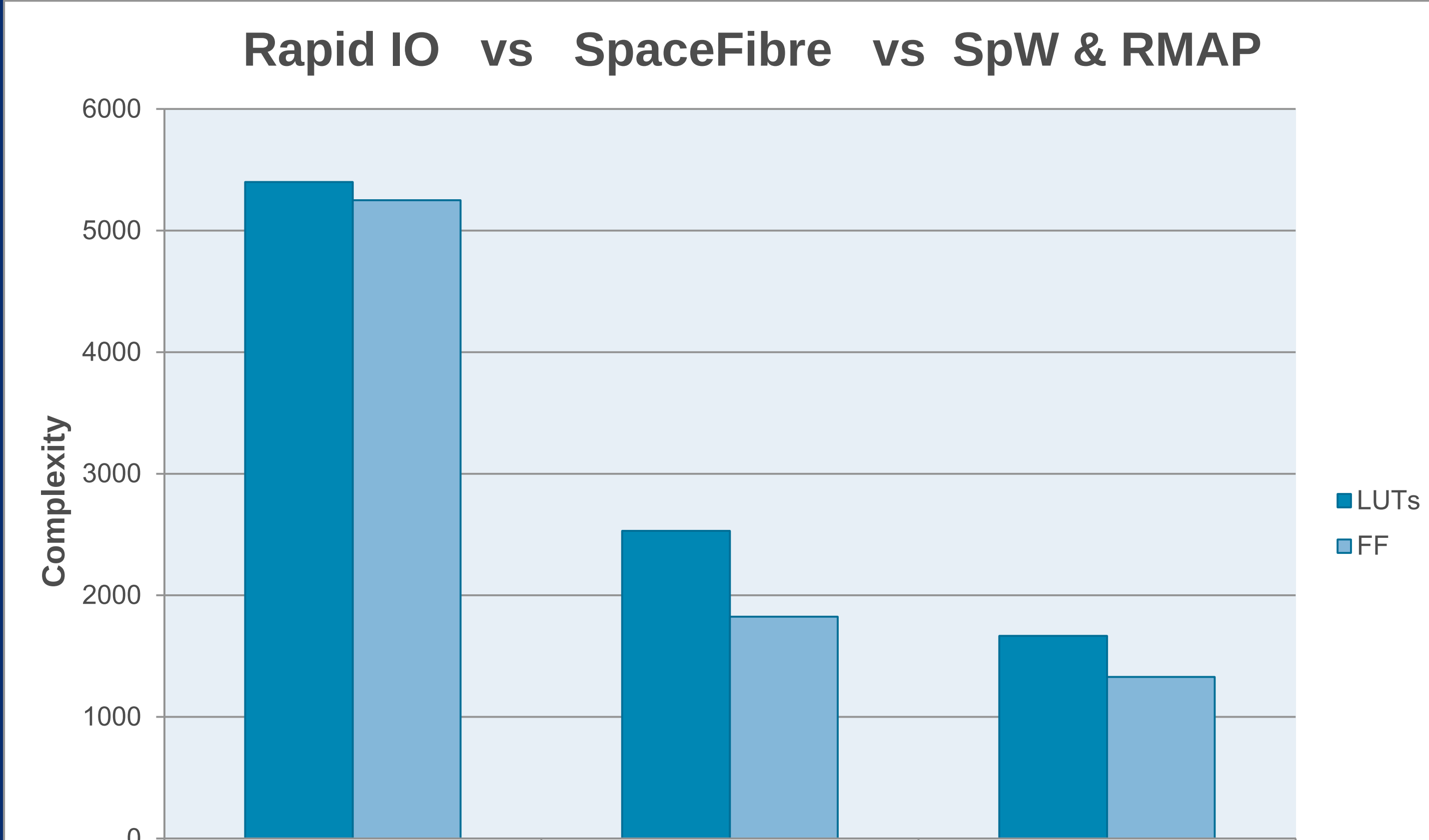
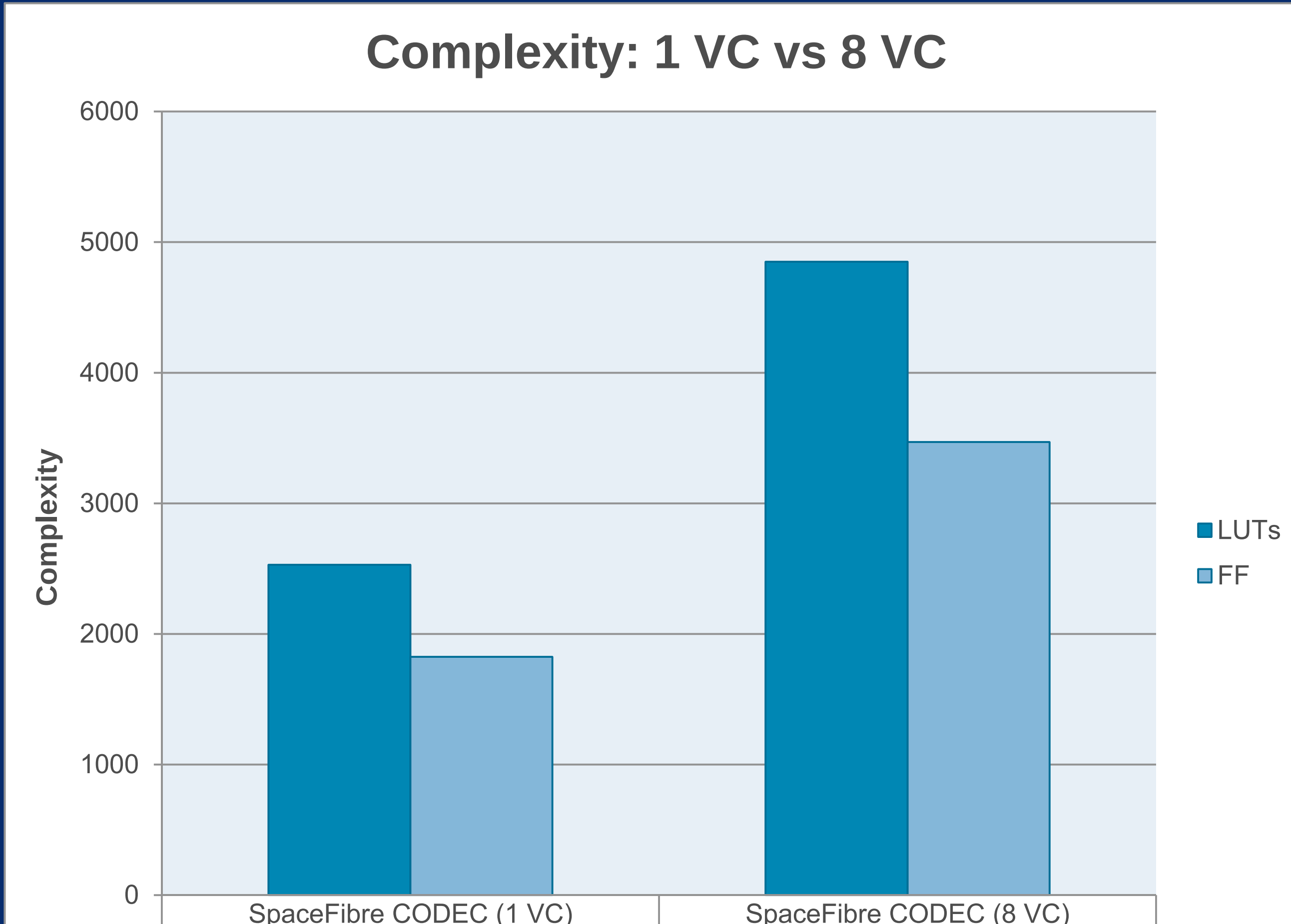
SpaceFibre smaller than RAPID IO



	Rapid IO Total	SpaceFibre CODEC (1 VC)	SpaceWire RMAP+CODEC
LUTs	5400	2530	1667
FF	5250	1825	1329

Rapid IO v2.1 x1 (Based on Xilinx srio_ds696, Spartan 6 results)

SpaceFibre cost of multiple VCs



	SpaceFibre CODEC (1 VC)	SpaceFibre CODEC (8 VC)
LUTs	2530	4850
FF	1825	3470

SpaceFibre Next Steps

SpaceFibre FDIR

- FDIR
  - Fault detection
    - Parity/disparity
    - Invalid 8B/10B codes
    - Enhance Hamming distance
    - CRC
    - Over and under utilisation of expected bandwidth
  - Fault isolation
    - Galvanic isolation
    - Data framing – time containment
    - Virtual channels – bandwidth containment
  - Fault recovery
    - Link level retry
    - Graceful degradation on lane failure
    - Babbling idiot protection
    - Error reporting

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SpaceFibre Next Steps

- Provide TKL2711 interface to CODEC
- Complete Multi-Lane layer specification
- Include Multi-Lane layer in CODEC
- Complete SpaceFibre specification
- Add Network layer

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