ESA-EOP needs for SpaceFibre

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Gb/s communications: high priority in Earth Observation

Product needs and priorities
- IP cores, components, standards

Feedback to SpaceFibre specification
- Comparable to ECSS-E-ST-50-12C? (or not?)

Conclusions

This presentation represents an attempt to express the view of those who have to select SpaceFibre for future EO missions
Increasing data rates in Earth Observation

- Instruments generating higher data rate: Examples
  - next generation SAR with Dig.BeamForming: 8.7 Gb/s
  - multi-spectral imagers (multi Gb/s)

- Higher downlink capabilities (under development)
  - Optical InterSatellite to EDRS (European Data Relay Satellite)
  - K-band data downlink (25.5 to 27 GHz => 4 times more Bw than X-band)

![Diagram showing the process of Instrument, RF Up Conversion, High Power Amplification, Mux channels and Propagation]

- SSMM
- Coding + Modulation
- ‘2’ channels
- Isoflux or Steerable antenna
- Propagation
### Example of Variable Coding Modulation (VCM)

<table>
<thead>
<tr>
<th>Scheme (Modul-Code)</th>
<th>Es/No (FER 1E-08)</th>
<th>((\eta) = \text{Effic. (info_bit/symbol)})</th>
<th>Data rate (Mb/s) @ 500 Mbaud</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK- 1/2</td>
<td>1.150</td>
<td>0.994</td>
<td>494</td>
</tr>
<tr>
<td>QPSK- 3/5</td>
<td>2.380</td>
<td>1.194</td>
<td>593</td>
</tr>
<tr>
<td>QPSK- 2/3</td>
<td>3.250</td>
<td>1.328</td>
<td>660</td>
</tr>
<tr>
<td>QPSK- 3/4</td>
<td>4.180</td>
<td>1.494</td>
<td>742</td>
</tr>
<tr>
<td>QPSK- 4/5</td>
<td>4.750</td>
<td>1.594</td>
<td>792</td>
</tr>
<tr>
<td>QPSK- 5/6</td>
<td>5.250</td>
<td>1.662</td>
<td>825</td>
</tr>
<tr>
<td>QPSK- 8/9</td>
<td>6.350</td>
<td>1.774</td>
<td>881</td>
</tr>
<tr>
<td>QPSK- 9/10</td>
<td>6.570</td>
<td>1.796</td>
<td>892</td>
</tr>
<tr>
<td>8PSK- 3/5</td>
<td>5.65</td>
<td>1.791</td>
<td>889</td>
</tr>
<tr>
<td>8PSK- 2/3</td>
<td>6.77</td>
<td>1.993</td>
<td>989</td>
</tr>
<tr>
<td>8PSK- 3/4</td>
<td>8.06</td>
<td>2.241</td>
<td>1,113</td>
</tr>
<tr>
<td>8PSK- 5/6</td>
<td>9.50</td>
<td>2.493</td>
<td>1,238</td>
</tr>
<tr>
<td>8PSK- 8/9</td>
<td>10.84</td>
<td>2.661</td>
<td>1,321</td>
</tr>
<tr>
<td>8PSK- 9/10</td>
<td>11.13</td>
<td>2.694</td>
<td>1,338</td>
</tr>
<tr>
<td>16APSK- 2/3</td>
<td>9.00</td>
<td>2.657</td>
<td>1,319</td>
</tr>
<tr>
<td>16APSK- 3/4</td>
<td>10.20</td>
<td>2.988</td>
<td>1,484</td>
</tr>
<tr>
<td>16APSK- 4/5</td>
<td>11.00</td>
<td>3.188</td>
<td>1,583</td>
</tr>
<tr>
<td>16APSK- 5/6</td>
<td>11.60</td>
<td>3.323</td>
<td>1,650</td>
</tr>
<tr>
<td>16APSK- 8/9</td>
<td>12.90</td>
<td>3.548</td>
<td>1,762</td>
</tr>
<tr>
<td>16APSK- 9/10</td>
<td>13.10</td>
<td>3.592</td>
<td>1,784</td>
</tr>
<tr>
<td>32APSK- 3/4</td>
<td>12.73</td>
<td>3.735</td>
<td>1,855</td>
</tr>
<tr>
<td>32APSK- 4/5</td>
<td>13.64</td>
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<td>32APSK- 5/6</td>
<td>14.28</td>
<td>4.154</td>
<td>2,063</td>
</tr>
<tr>
<td>32APSK- 8/9</td>
<td>15.69</td>
<td>4.435</td>
<td>2,202</td>
</tr>
<tr>
<td>32APSK- 9/10</td>
<td>16.05</td>
<td>4.490</td>
<td>2,230</td>
</tr>
</tbody>
</table>

- **RF chain is the same** for a given symbol rate
- **about 15 dB** difference in Es/No (plus the back-off)
- **Efficiency** \((\eta)\) and data rates factor between **1 and 4.5**
- **Peak data rate** 2.23 Gb/s per channel → (2 channels 4.46 Gb/s)
- **Modulator informs SSMM about data rate**

- **Two Standards:** **DVB-S2** and **CCSDS131.2-0-1**
  - common modulation and performance (energy ; spectral eff.), but different complexity
  - Coding is different (LDPC in DVB & SCCC in CCSDS)

Flexibility is ideal to compensate for ‘propagation’ ‘elevation angle’ and seasonal variations

**Modulation_order * coding eff. = \(\log_2(32) * 9/10 = 4.5\)**
Need for full products, standards, and priorities

- Products:
  - CoDec IP cores => to ensure miniaturisation and adoption by everyone
  - components (non proprietary and non-ITAR sensitive)
    - Digital part (with codec IP core + additional functionality)
    - Analogue (also cables, connectors, drivers, etc.)
  - Supporting Standards
    - for CoDec
    - Upper layer protocols

- Timely for project & Scaleable : applicable to CoDec, components, Stds
  - start simple (for first projects)
  - build up gradually
Flexibility for very diverse architectures

**LEAST COMMON MULTIPLE (LCM)**
- \(5\) Instrument_a
- \(5*3\) Instrument_b
- \(5*2*2\) EGSE
- \(5*2*3\) Modulator
- \(5*2*2*2\) Computer unit
- \(5*2*5\) Processing unit
- \(5*2*2*3\) Mass Memory

Serial links
Least Common Multiple (LCM) : Coder /Decoder (CoDec)

CoDec is the ENABLER:
- Compatibility challenge is on the SERIAL side
- LCM for PARALLEL side: ‘n’ times 8 bits (in SpaceWire: ‘n’ is 1)
  - good interface to make it scaleable with MUX/buffers in upper layers
Coders / Decoders (CoDec) IP Core

Simple: \( n \times 1000 \) gates

SpaceWire
- Encoder (1)
- State Machine (1)
- Decoder + Clk Recovery (1)
- Tx FIFO
- Rx FIFO
- 8 bits

8B/10B
- Encoder (2)
- State Machine (2)
- Decoder + Clk Recovery (2)
- Tx Min buffer
- Rx Min buffer
- ‘n’ x 8 bits

SpaceFibre
- Encoder (2)
- State Machine (2)
- Decoder + Clk Recovery (2)
- Tx Min buffer
- Rx Min buffer
- ‘n’ x 8 bits

Additional logic
- Component

CoDec IP core shall be small (minimum number of MUX, Buffers) like in SpW
Common Packet (SpW – SpF)

Common for SpaceWire - SpaceFibre
- Both provide serial to 8 bit conversion ports -> routing can be very similar
- Same packet structure with EOP (but not necessarily with the same packet length)
- Layers on top of Packet can be common

Why SpW characters in section 5.3.2 of SpaceFibre DRAFT Std?
Advanced GPS-Galileo ASIC (AGGA-4)
(1st prototypes manufactured 1Q-2012 ; 6 Mgates)

- GNSS module
- FFT module
- LEON µ-processor
- external I/F
- AMBA I/F
- DMA I/F

Modules with 4 SpaceWire (2% of chip gates)

Message: I/F is not the primary objective of the ASIC.
Simple IP core to be made available to ASIC designers.
1553 was the last interface added (one project wanted this for TT&C).
Radio Occultation Instrument
(for MetOp-SG, launch 2019)

4 SpaceWire links per AGGA-4 device
- directly between boards
- also through router

SIMILAR NEED for SPACEFIBRE?
(probably)
9.2 Packet format
A packet consists of a destination followed by a payload, and is delimited by an end_of_packet marker: `<DEST><PAYLOAD>< End_Of_Packet>`

Questions:
- why the SpF draft Std has a FRAMING layer and not a PACKET layer ?
- Can we merge them ?
OSI model (ISO-7498): Each layer has its header. Packets/frames come together again at higher layers (mainly application).

Remarks:
- ‘frames, frame retry, CRCs, Virtual Channels’ are not specific of SpaceFibre (also applicable to SpaceWire).
- They may need to be in hardware (for performance), but not inside, the CoDec.
- Could we have packet content (frames, CRCs, VCs, etc) in a standard for higher layers?
Packet is very flexible

Example:  

Possible to send TC thru Gb/s bi-directional infrastructure?  (realistic?)
Do we need RETRY in HW?  Can it be done at packet level (SW)?

Assuming SpaceWire:
Critical on-Board messages (e.g. kb/s TC and TC-ACK) are done in SW by application
Physical Layer to be defined as soon as possible

- ECSS-E-ST-50-12C
- 31 July 2008

Normative references

The following normative documents contain provisions which, through
ECSS-S-ST-00-01 ECSS system — Glossary of terms
ECSS-Q-ST-70-08 Space product assurance — Manual soldering of high-reliability electrical connections
ECSS-Q-ST-70-26 Space product assurance — Crimping of high-reliability electrical connections
ESCC 3401/071 Connectors, Electrical, Rectangular, Microminiature, Solder Bucket Contacts with EMI Backshell, based on type MDM
ESCC 3902/003 Cable, “Spacewire”, Round, Quad using Cables, Flexible, −200 to +180 °C

Where is the definition of:
What cable, connector, driver?
CML?
8b/10b SERDES and (K28.1, K28.2, D08.1, D15.1?)

5.12.2.3 Single-ended Electrical Connectors
a. TBA
5.12.2.4 SpaceFibre Electrical Cables
a. TBA
5.12.2.5 Differential Electrical Connectors
a. TBA
5.12.2.6 Differential Electrical Cables
a. TBA

5.12.3 Fibre optic driver and receiver
5.12.3.1 Fibre Optic Driver and Receiver
a. TBA
5.12.3.2 Fibre Optic Connectors
a. TBA
5.12.3.3 Fibre Optic Cables
a. TBA
The current SpaceFibre standard

SpaceWire and SpaceFibre have the same network (and P2P) topology: => The Standards should be more symmetrical (see proposal in next slide)

<table>
<thead>
<tr>
<th>SpaceFiber DRAFT (29/02/2012)</th>
<th>SpaceWire ECSS-E-ST-50-12C</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual channels (including QoS)</td>
<td>Not specified</td>
<td>Common</td>
</tr>
<tr>
<td>Broadcast message (including FDIR)</td>
<td>Not specified</td>
<td></td>
</tr>
<tr>
<td>No network layer</td>
<td>Network layer</td>
<td></td>
</tr>
<tr>
<td>No Packet layer</td>
<td>Packet</td>
<td>Convergence here</td>
</tr>
<tr>
<td>Framing</td>
<td>Not specified</td>
<td></td>
</tr>
<tr>
<td>Retry</td>
<td>Not specified</td>
<td></td>
</tr>
<tr>
<td>Lane control</td>
<td>Not specified</td>
<td></td>
</tr>
<tr>
<td>Lane</td>
<td>Exchange</td>
<td></td>
</tr>
<tr>
<td>Encoding/Decoding</td>
<td>Character, Exchange,</td>
<td>Important for CODEC</td>
</tr>
<tr>
<td>Serialisation</td>
<td>Character, Exchange</td>
<td></td>
</tr>
<tr>
<td>Physical (Very undefined)</td>
<td>Physical, Signal (LVDS based)</td>
<td>Fundamental for performance / reliability</td>
</tr>
</tbody>
</table>

Priority for ESA-EOP

1) Consolidated layers up to packet level
   Major concern about Physical layer

2) Demonstration of performance (> 2 Gb/s) and reliability (EMC, BER) asap

3) Get full products [IP core, components] asap
   - ITAR-non-sensitive, avoid proprietary
   - full TLK2711 back-compatibility not required

To achieve the objectives in not too long time, options with alternatives could be removed or simplified (least common multiple approach):

<table>
<thead>
<tr>
<th>Examples</th>
<th>Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel lanes</td>
<td>Multiple links</td>
</tr>
<tr>
<td>Retry in HW</td>
<td>Retry of packets (more SW Ctrl in application)</td>
</tr>
</tbody>
</table>
## Proposed break down of standards

<table>
<thead>
<tr>
<th>TBD name of Standard (common SpF - SpW)</th>
<th>Leave what is common in SpW-SpF in a different standard, and demonstrate it first with SpaceWire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual channels (including QoS)</td>
<td></td>
</tr>
<tr>
<td>Broadcast message (including FDIR)</td>
<td></td>
</tr>
<tr>
<td>Data Framing (TBC) (excl. scrambling)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SpaceFiber DRAFT (29/02/2012)</th>
<th>SpaceWire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network</td>
<td>Network layer</td>
</tr>
<tr>
<td>Packet (new)</td>
<td>Packet</td>
</tr>
<tr>
<td>Framing (excl. scrambling)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Retry (optional or out, TBC)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Lane</td>
<td>Exchange</td>
</tr>
<tr>
<td>Encoding/Decoding (incl. scrambling)</td>
<td>Character, Exchange,</td>
</tr>
<tr>
<td>Serialisation</td>
<td>Physical, Signal (LVDS based)</td>
</tr>
</tbody>
</table>

**ESA-EOP priority for SpaceFibre Standard**

- Consolidate it up to Packet Layer (including Physical Layer)
- Upper layers (e.g. packet content) should **NOT** impose unnecessary complexity on lower layers
- Could we have a ‘light’ (subset of layers) version?
Related issues / questions

- Terminology to be cleaned up: consistency needed (standard also for those not in these meetings)
  - Frame vs Packets
  - definition of CoDec (which layers)
  - Applicable documents, relationship with other Stds (e.g. upper layers)
  - SpaceWire characters (e.g. NULLs) in SpaceFibre spec (5.3.2) do not make sense. (probably editing point)

- Keep SpaceFibre simple
  - need also for using SpaceFibre (lower layers) alone (without SpaceWire) in simple terminals (without QoS, FDIR) and possibly at low speed too
  - one lane (> 2 Gb/s) would already be a major breakthrough
  - re-try at Gb/s: (not fully understood)
    - e.g. BER and complexity of HW?, SW alternatives?, only within link?, when to use it? risk to hinder determinism?
Conclusions / Recommendations

- There is a real need (very soon) for > Gb/s in just one link -> SpaceFibre

- Technology Products:
  - SpaceFibre Coder/Decoder IP core (ENABLER)
    - Keep it simple (Least Common Multiple - LCM)
      - get it developed and adopted fast, facilitate integration in ICs
    - Scalable interfaces (the upper layers could be integrated later, only where needed)
  - Components for the whole link
    - Digital part (with LCM codec IP core + additional functionality)
    - Analogue part (also cables, connectors, drivers, etc.)
      - characterize performance (speed, BER, EMC) asap
    - Start with the simplest applications (LCM)

- Supporting Standards
  - SpaceFibre Std needs to be more symmetric to SpaceWire
    - Packet level should be addressed
    - Simplify : align with LCM SpaceFibre CoDec + complete Physical layer
  - New Std for upper layers with common issues with SpaceWire