SpaceFibre

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Introduction

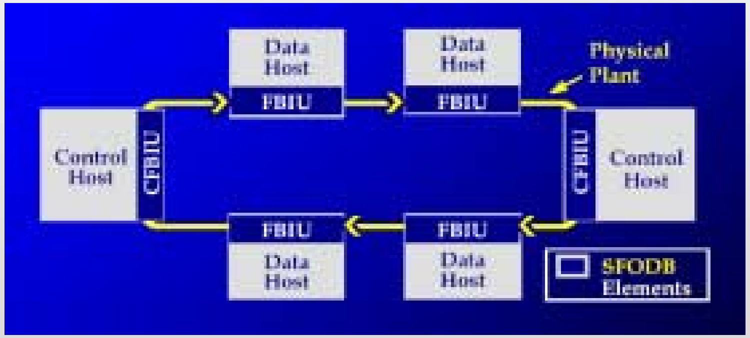
- **SpaceFibre aims to be the fibre optical extension of the SpaceWire standard**
- **Shall cover requirements of very high end applications**
  - Higher data rates
  - Longer link length
- **“Optical Links for the SpaceWire Intra-satellite Network Standard” activity is currently set up in the frame of GSTP and TopNet**
  - For GSTP interest raised from Canada, Finland, Ireland and UK
  - University of Dundee involved via TopNet frame contract
- **Core objectives:**
  - Technology assessment of high speed optical data links
  - System architecture review and baseline design
  - Demonstrator detailed design and manufacturing
  - Environmental testing
  - Integration into SpaceWire network

Overview - Optical Data Communication in Space

- **Earliest Experiment 1984 – Long Duration Exposure Facility (LDEF)**
  - LEO satellite 69 month mission (NASA), relatively benign orbit 25krads(Si)
  - Test of digital fibre optic links in space environment
  - 4 Step index fibre operating at 830nm
  - Virtually no degradation due to radiation but strong variation of loss by temperature
- **SAMPEX (July 1992)- NASA Small Explorer Data System (SEDS)**
  - Mil-Std-1773 fibre optic data bus
  - Master/Slave star - redundant bus, 1Mbps data rate for T&C
  - MM (100/140micron) SI fibre, 850nm LED source and Silicon PIN photodetector
  - No bus outages but frequent retransmissions required due to proton induced SEE in photodetector
  - Used in several space missions (e.g. Hubble Telescope, Columbus) and in aircrafts
- **Microelectronics and Photonics Testbed (MPTB) (Dec. 1997)**
  - *Boeing* experiment based on AS1773 dual data rate fibre optic data bus (1 and 20 Mbps), modification of the existing Mil-Std-1773.
  - Radiation tolerance is improved by migrating to:
    - 1300nm laser sources (higher power at detector - lower radiation sensitivity in fibre)
    - Direct band gap InGaAs detectors (less SEE)

Optical Data Communication in Space (cont.)

- ***Space Photonics Inc*. developing FireFiber and FireRing**
  - Bus structure according to IEEE 1393-1999 SFODB
  - ATM based protocol with ring topology - supports up to 127 nodes
  - 1Gbps point to point links on 8 parallel channels over ribbon cable at 125Mbps each
  - Higher data rate versions planned (up to 10Gbps)
  - Achievements thus far: Multi-port TX and RX modules and multi-port fibre optic switches - designed according to NASA qualification guidelines



- **MIRAS Optical Harness MOHA for SMOS ESA mission (at start of phase C/D)**
  - Connection of 72 radiometer receivers to central correlation unit in star topology
  - Synchronous, one directional data transmission at 112Mbps data rate
  - 1300nm laser diode transmitter and InGaAs PIN photodiode receiver

Limitations of SpaceWire

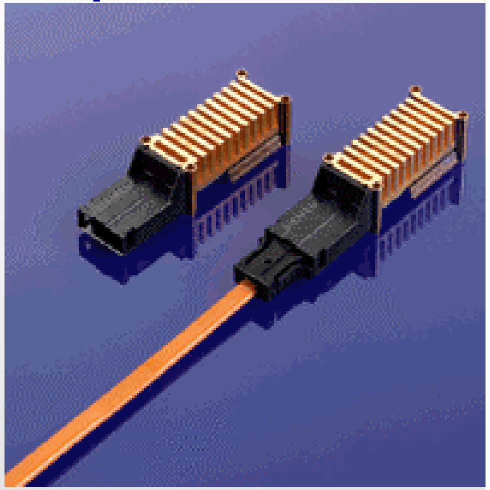
- **SpaceWire link data rate is currently 200Mb/s**
  - High Resolution SAR, Hyper Spectral Imagers, High Speed High Resolution Cameras produce data at a rate of some Gb/s
  - Requires bundling of several SpaceWire links for these instruments
  - Higher system complexity and mass penalty
- **Corresponding SpaceWire link maximum cable length is 10m**
  - Limitation of data rate and cable length due to jitter and skew between on Data and Strobe signal
  - Sufficient for on satellite applications
  - Other applications like Launchers, Space Station and EGSEs for ground testing require longer cable length
- **SpaceWire does not provide galvanic isolation**
  - Often EMC requirement for connections between electronic boxes
  - Enables easier system integration on spacecraft level
  - Characteristic required for Ground Support Equipment

SpaceFibre Requirements

- **SpaceFibre shall fulfil the following set of requirements**
  - Provide symmetrical, bi-directional, point to point link connection
  - Be hot-pluggable
  - Handle data rates up to 10Gb/s and support variable signalling rates
  - Bridge distances up to 500m at maximum data rate
  - Be based on fibre optic link technology
    - therefore feature galvanic isolation
  - Allow for mixed SpaceWire – SpaceFibre networks via special SpaceWire-SpaceFibre Routers
  - Transmit a scalable number (1,4,8,16,…) of virtual SpaceWire links over on SpaceFibre link
  - Provide similar bit error rates as specified for SpaceWire
  - Be compliant to the higher levels of the SpaceWire standard

SpaceFibre Deviations from SpaceWire Standard

- **Realisation of SpaceFibre will require deviations from the SpaceWire standard at different levels**



- **Physical Level**
  - Optical waveguide fibre(s) of specific tbd type
  - Optical fibre connector suitable for space application
- **Signal Level**
  - Optical source and detector of tbd wavelength(s) and power level
  - Signal coding with code based clock transmission such as 8B10B encoding
  - Signalling rates up to 10Gb/s

SpaceFibre Deviations from SpaceWire Standard

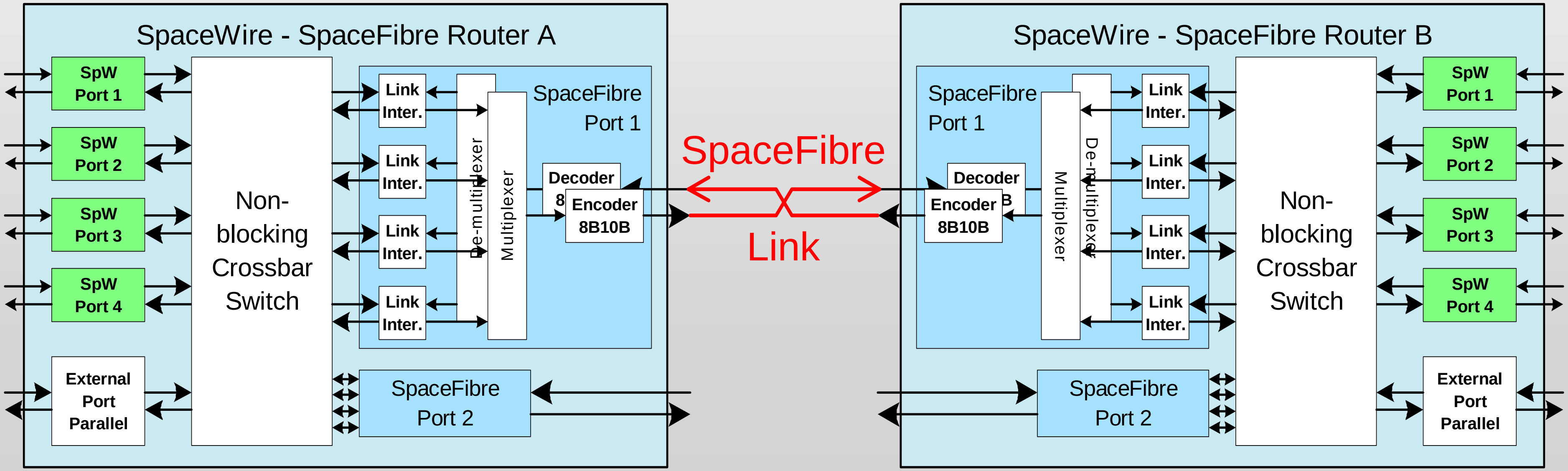
- **Character level** (in case of 8B10B encoding)
  - SpW data characters are represented by 8B10B data characters
  - SpW control characters and control codes are represented by 8B10B special characters
  - Parity bits are replaced by the 8B10B character validity check

    Problem: Detected code violation is not unambiguously associated with the last character

- **Exchange level**
  - Flow control credit counter (max. 56) feed by the FCT must be adapted to higher signalling rate and longer cable length
  - Realisation of several virtual SpaceWire links over one SpaceFibre
  - Will require the realisation of multiple SpaceWire link interfaces multiplexed and de-multiplexed with a fixed scheme

Mixed SpaceWire – SpaceFibre Network

- **Transfer speed in network is determined by slowest link on the path**
- **SpaceFibre is slowed down by SpaceWire and capacity is not used**
- **One Solution:**
  - Operation of several virtual SpaceWire Links over one SpaceFibre
  - Multiple link interfaces work synchronous in parallel
  - Fixed scheme for multiplexing – de-multiplexing characters in streams
  - Multiplexing avoids constraint on block size and use of big buffers



SpaceFibre Optical Technology Trade-Offs

- **Main components of a fibre optic data transmission link:**
  - Transmitter
  - Guiding medium (in this case optical fibre)
  - Receiver (convert optical signal to electrical current)
- **Transmitter**

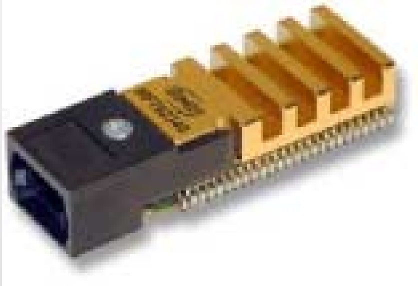
Source	Pros	Cons
LED	Less sensitive to radiation Longer life times	Lower coupled power Require lens to couple into fibre Bandwidth limited to few 100Mbps
LD	Large bandwidth Lifetime in operation difficult to predict High power consumption	Sensitive to radiation less so at long wavelengths >1300nm
VCSEL	Large bandwidth Low power consumption Less sensitive to SEE Parallel integration quite straight forward Mass market product (lower cost)	VCSELs at 1300nm still not available commercially

SpaceFibre Optical Technology Trade-Offs (Cont.)

- **Fibre type options**
  - **Fibre core diameter**
    - **Single mode fibre (SM)**
      - Used in very high bandwidth telecommunication (>40Gbps)
    - **Multi mode fibre (MM)**
      - Typically has a capacity of hundreds of MHz/km
      - Relaxed alignment and coupling constraints
      - Make it attractive for use in space
  - **Refraction index profile**
    - **Step index (SI)**
    - **Graded index (GI)**
      - Larger bandwidth but possibly more sensitive to radiation
  - **Material**
    - **Silica or Plastic are two main alternative materials**
  - **Currently MM 100/140 micron SI silica is standard used in space application**

SpaceFibre Optical Technology Trade-Offs (Cont.)

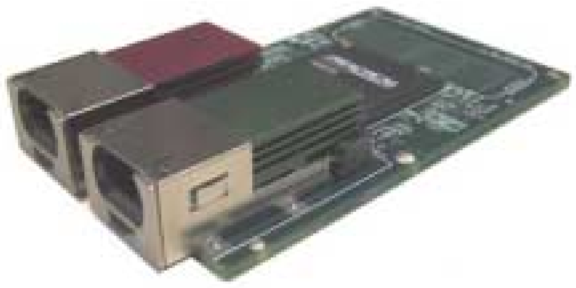
- **Radiation hardness of several commercially available fibres at short lengths have been demonstrated**
  (Comprehensive list can be found: http://misspiggy.gsfc.nasa.gov/tva/index.htm)
- **Coating material and Jacket are crucial in space operation:**
  - Shrinkage in space has been a major problem in the past
  - Cause of micro-bending losses
- **Multi fibre ribbon cables and connectors**
  - 12 fibre ribbon have been successfully tested by NASA
  - Redundancy can easily be built into such a system.
  - Many new optical components developed for MANs are based on parallel optical connections



- **Ageing associated with fibre and connector use in space must be accounted for in the link budget.**

SpaceFibre Optical Technology Trade-Offs (Cont.)

- **Photodiodes**
  - **The detector type is source wavelength dependent**
  - **850nm wavelength**
    - Si or GaAs PIN photo detectors can be used
    - Have been found to be sensitive to SEE.
  - **Longer wavelengths (1300-1600nm)**
    - Direct band-gap detectors using InGaAs
    - A few orders of magnitude less sensitive to SEE
    - Due to smaller detector cross section



- **Technology Conclusions:**
  - **Longer wavelength of 1300nm greatly reduces radiation sensitivity**
  - **For high bandwidth VCSELs source of choice**
    - Especially when commercial 1300nm VCSELs become available
  - **The microelectronics for driving the digital data link are probably the most radiation sensitive part of the link**
  - **Use of error correction code will likely be needed to reduce the BER**

Conclusions

- SpaceFibre - the fibre optical extension of SpaceWire – was presented
- System requirements were given
- Differences to current SpaceWire standard were pointed out
- Possible solution for mixed SpaceWire – SpaceFibre networks was presented
- The required trade-offs in optical technology were discussed

- The development of a first demonstrator will be performed with industry in the SpaceFibre activity
- Design shall be consolidated during intensive testing

- Standardisation shall be initiated via the SpaceWire Working Group