SpaceFibre

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Overview

- SpaceFibre Requirements
- Mixed SpaceWire – SpaceFibre networks
- Optical Link Technologies
- Demonstrator Development
- Conclusion

Need for extension of SpaceWire

- **SpaceWire link data rate is currently 200Mb/s**
  - High Resolution SAR, Hyper Spectral Imagers, High Speed High Resolution Cameras, Telecommunication Payloads produce data at a rate of some to several Gb/s
  - SpaceWire based solution would required bundling of several links
  - Results in 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
  - In general 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

- Provide symmetrical, bi-directional, point to point link connection
- Handle data rates 1-10Gb/s and support variable signalling rates
- Bridge distances up to 100m at maximum data rate
- Be based on fibre optic link technology
  - Provides galvanic isolation
  - Copper version with AC coupling for shorter distances
- Allow for mixed SpaceWire – SpaceFibre networks via special SpaceWire-SpaceFibre Routers
- Transmit a scalable number of virtual SpaceWire links over one SpaceFibre
- Compliant to the protocols and routing mechanisms defined in the SpaceWire standard
- Similar bit error rates as specified for SpaceWire
- Fast start up and fine grained power management
- Intrinsic support to quality of service

SpaceFibre Project

- **Two Parallel Contracts**

  – "Optical Links for the Space Wire Intra Satellite Network Standard"

  GSTP Program

  Objective: The development of a high speed point to point fibre optic link for space applications.

  Contractors: **Patria (Prime), VTT, INO, Fibre Pulse, W.L. Gore**

  – "Space Fibre" The TOPNET Call Off No. 2

  TRP Program

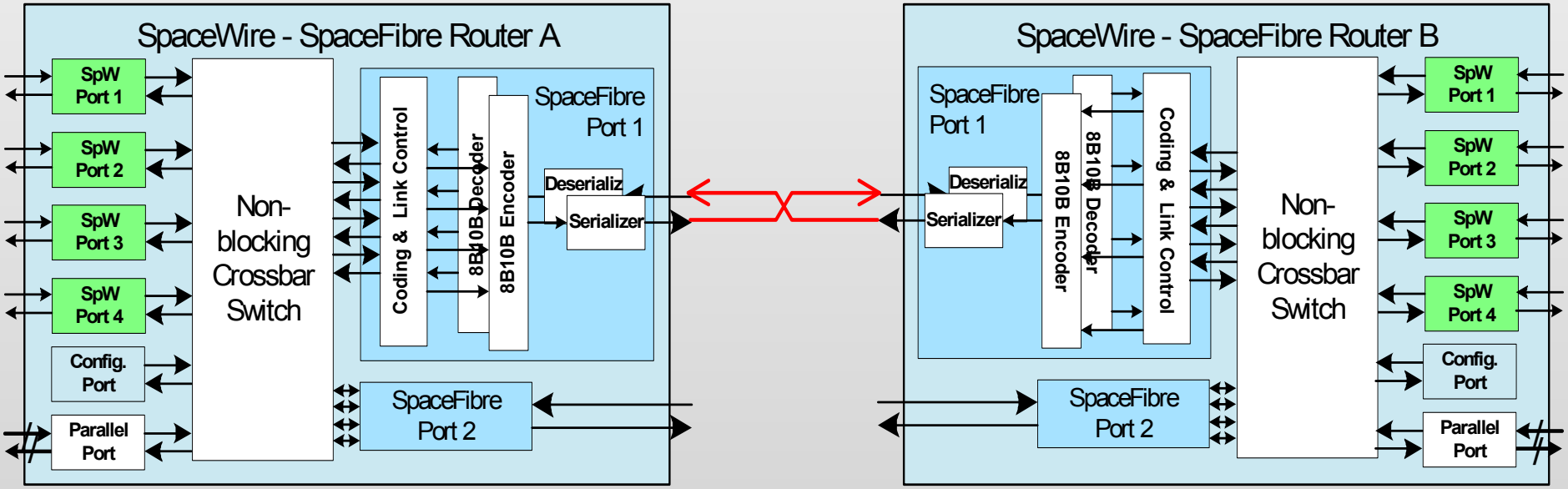
  Objective: The integration of very high speed data links into the Space Wire network through the development of a high speed router.

  Contractor: **University of Dundee**

  – Delivery of demonstrator scheduled for May 2006

Mixed SpaceWire – SpaceFibre Router & Networks

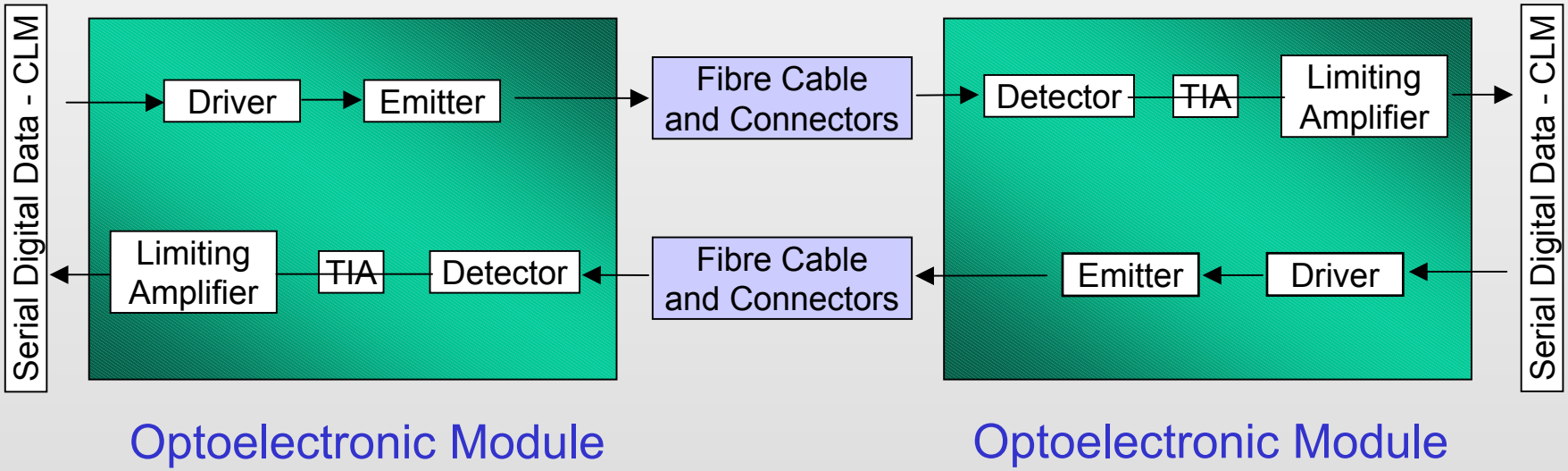
- Transfer speed in network is determined by slowest link on the path
- SpaceFibre must not be slowed down by SpaceWire Link in network
- Concept: Several virtual SpaceWire Links over one SpaceFibre
  - Multiplexing of data streams is required
  - This can be performed on character or frame level
  - Frame level multiplexing provides a higher level of flexibility



SpaceFibre CODEC

- **A number of high speed serial link standards have been reviewed**
  - Fibre Channel, Serial ATA, PCI Express, Infiniband, Gigabit Ethernet, Hypertransport
- **Proposed solution must ensure compliance with SpaceWire protocols and routing mechanisms**
- **Features commonly found in the reviewed standards:**
  - 8B/10B Encoding
    - DC balanced – enabling AC coupling
    - Transition rich – enabling clock recovery with PLL
    - Comma sequence – enabling character alignment
    - Unused codes and disparity - can be used to help detect errors
  - RX Elastic Buffer
    - Compensates slight differences in clock speed between units
  - Scrambling
    - Spread spectrum signal to reduce EM emission of copper version
- **Prototype will be implemented in Xilinx Virtex II Pro using the Rocket IO interface – CLM serial digital interface**

Space Fibre Optical Link



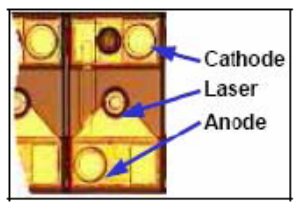
Technology Choices - Emitter

Emitter	Modulation rate	Spectral width	Divergence	Optical power
LED	≤ 622 Mbps	~ 50 nm	large	0.1 mW
FP LD	≤ 10 Gbps	5 nm, multiple lines	asymmetric	2 to 100 mW
DFB/DBR LD	≤ 10 Gbps	10 MHz, single line	asymmetric	2 to 20 mW
VCSEL	≤ 10 Gbps	0.1 nm	10 ... 20º	0.5 ... 2 mW

- LEDs are too slow for multi-gigabit data transmission.
- 10 Gbps @ 100 m => there is no need to use DFB or DBR lasers.
- The best candidates are 850-nm VCSEL and 1310-nm Fabry-Perot laser.

(1300-nm VCSELs are emerging, but their reliability is not proven yet.)

GsAs VCSEL - ULM Photonics (Laser Driver from Helix)
850nm Operating Wavelength, Bandwidth 6GHz

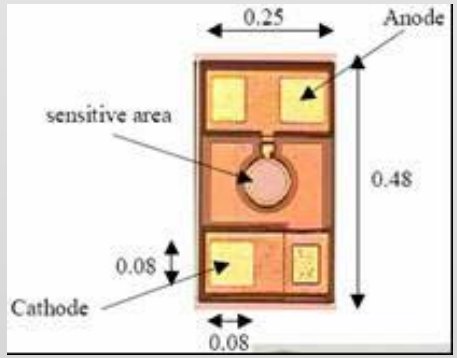


Technology Choices - Detector

- Simple pn-junction diodes are too slow for gigabit applications.
- Avalanche photodiode (APD) requires high bias voltage (30…200 V) and is temperature sensitive.
- Metal-semiconductor-metal (MSM) detectors are excellent devices but few vendors exist.
- Best option is either GaAs or InGaAs PIN photodiode.

GaAs PIN Diode – Ulm Photonics (Matched TIA Ohmic and Limiting Amplifier Maxim)

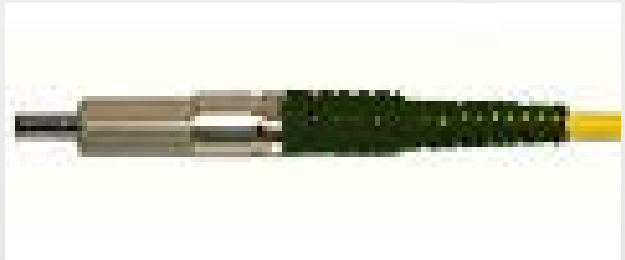
850nm Operating Wavelength, Bandwidth 5GHz



Technology Choices – Fibre Connector

AVIM Connector (Diamond)

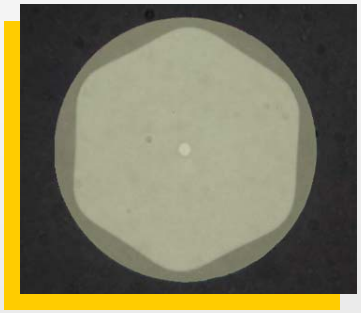
Has proven space herritage: Hubble Space Telescope, NASA Optical Intersatellite Link, NASA Atmospheric Dynamics Mission. Is also to be used on SMOS and ATV.

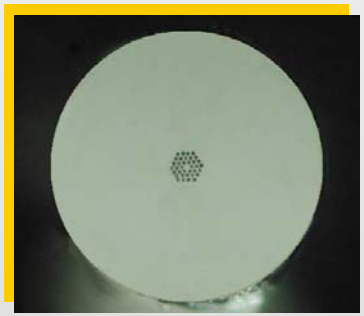


Qualified: Vibration 50g RMS
Temperature Cycling: –40 - +85 Deg.C

Special Locking Mechanism to prevent it decoupling during vibration.

Technology Choices – Optical Fibre

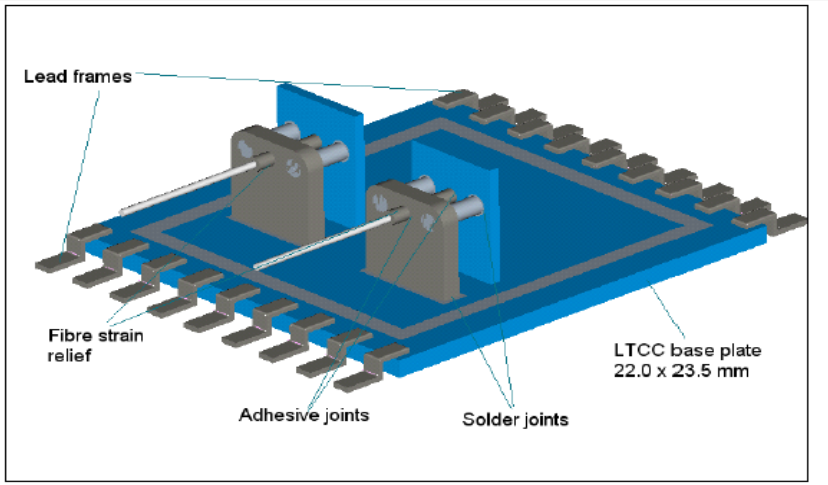




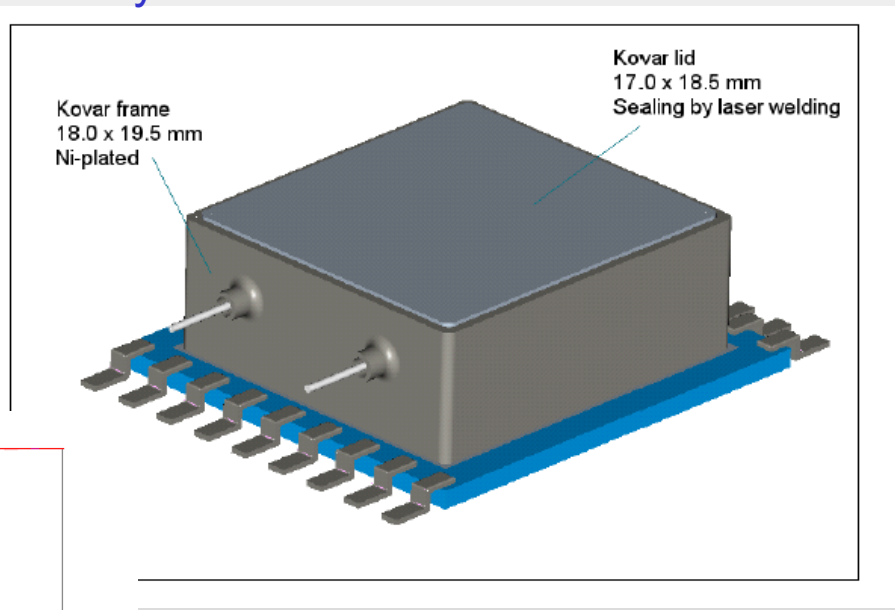
Fibre Type	Advantages	Disadvantages
Single Mode Fibre 9/125 micron	- High bandwidth (>10Gbps) - Radiation hard versions available	- Small coupling aperture - Low tolerance to misalignment
Multimode Step Index 50/125 micron	- Large coupling aperture - Radiation hard versions available	- Insufficient bandwidth (few 100MHz over 100m)
Multimode Graded Index 50/125 micron	- Large coupling aperture - High Bandwidth (upto 10Gbps over 100m)	- Radiation induced attenuation is higher (particularly at shorter wavelengths ~850nm)
Micro Structured Fibre 50/125 micron	- Excellent radiation resistance - MM version has large coupling aperture	- Still relatively immature technology very expensive.

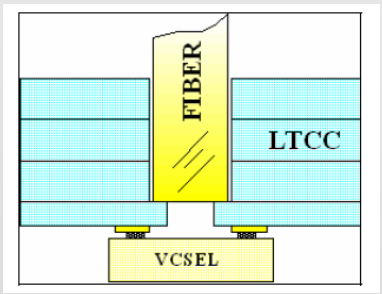
- Graded index multi-mode optical fibre (50/125 micrometer) - Corning
  - having an acrylate coating
  - and protected by a Gore-Tex jacket

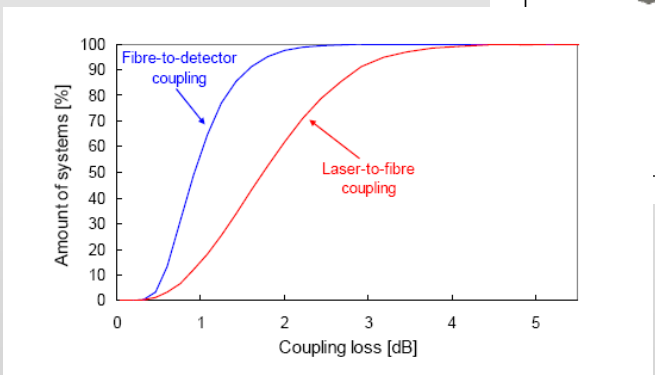
VTT Optoelectronic Packaging



Packaging based on VTT Low Temperature Co-fired Ceramic (LTCC) packaging concepts.
Fibre pigtailed module for greatest flexibility.

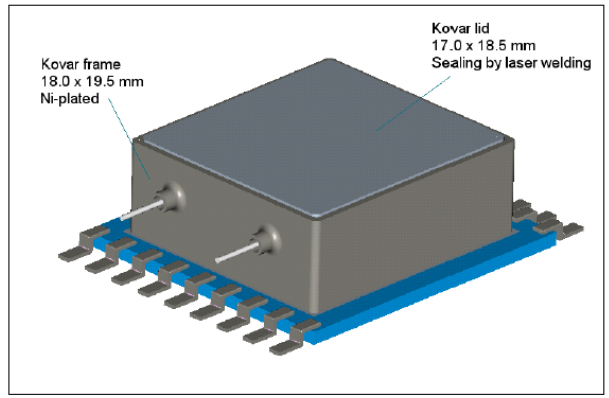






Optoelectronic Module Performance

- **Dimensions 22 x 23.5 x 7 mm**
- **Mass <5g**
- **Power Consumption (5Gbps and 3.3V)**
  - Tx only 300mW
  - Rx only 120mW
  - Total power consumption 420mW
- **Optical Characteristics**

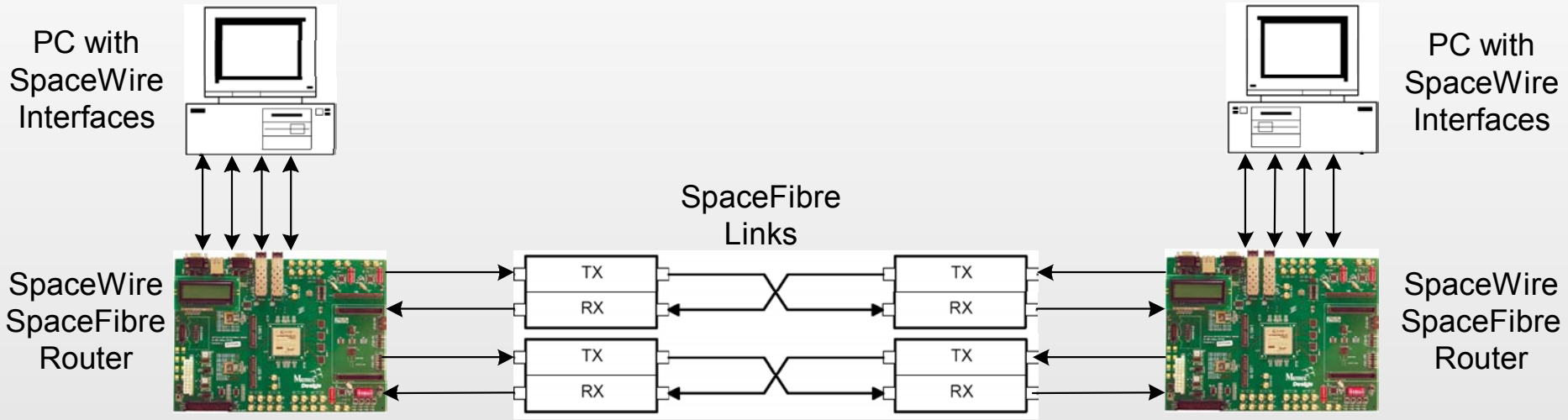


Tx average output	3 dBm
Nominal Coupling Loss Laser-Fibre	1 dB
Nominal Coupling Loss Fibre-Receiver	0.5 dB
Required receiver power for BER 10^{-12}	-25.4 dBm
Required receiver power for BER 10^{-15}	-24.5 dBm
Link Budget Margin at BER 10^{-12}	27 dB

Space Environmental Testing

- **Random Vibration** up to 20…25 g rms
- **Shock Testing** up to 2000g at 10kHz (2 times per axis)
- **Thermal Cycling:**
  - -40°C … +85°C (operational at least 8 cycles)
- **Material Outgassing:**
  - Total Mass Loss after 24 hours at 125°C and 0.13 mPa : < 1.00%
  - Collected Volatile Condensable Material, collected for 24 hours on an adjacent plate at 25°C: < 0.10%
- **Radiation Testing - Gamma**
  - Total Dose 100 krads optical fibre
  - Optoelectronic module up to 50 krads
- **Radiation Testing – Single Event Effects**
  - Heavy Ion Testing (different energy levels up to 30MeV)

SpaceWire-SpaceFibre Demonstrator



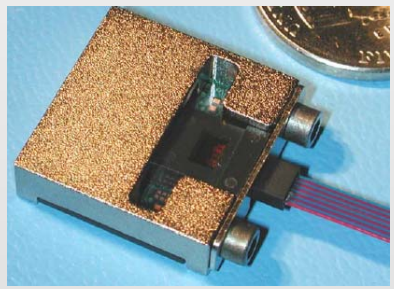
- **University of Dundee:**
  - SpaceWire-SpaceFibre Routers
- **Patria:**
  - SpaceWire Interfaces
  - Fibre Optic Interfaces for Routers
  - Fibre Optic and SpaceWire Cables
- **Target performance for demonstrator**
  - 2.5 Gbits/s gross data rate in each direction on SpaceFibre link

High speed COTS Options

Products Developed for Space Applications in US

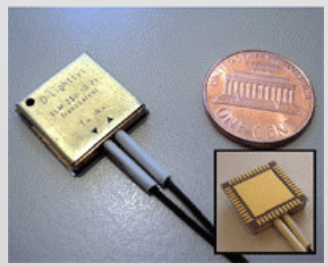
- **Space Photonics**
  - 12 channel transmitter and receiver pairs
  - 12 fibre ribbon cable
  - 1300 nm FP laser arrays
  - 2.5 Gbps bandwidth/Channel

- **Peregrine Quad Transceivers**
  - 4 x 850 nm VCSEL, 4 x PIN Diodes
  - 12 fibre ribbon cable
  - 3.125 Gbps, 125mW/Channel



Products Developed for Terrestrial Applications

- **D-Lightsys (Thales R&D)**
  - Single transceiver channel, VCSEL 850nm
  - 2.5Gbps, 350mW total power



Conclusions

- SpaceFibre shall be a fibre optical extension of SpaceWire
- System requirements were presented
- Optical technology trade-offs were shown and will be verified during environmental testing
- A demonstrator will be developed within the SpaceFibre activity (May 2006) to demonstrate a mixed SpaceWire – SpaceFibre network
- Once consolidated the development of dedicated electronic components can be started
- Low mass, low power optical transceivers designed for harsh environments are becoming more widely available
- Standardisation should be initiated in the SpaceWire Working Group