High-Performance, High-Availability and High-Reliability Interconnect for Spaceflight Applications

Steve Parkes[(1)],

[(1)]*University of Dundee, School of Science and Engineering, Dundee, DD1 4HN, Scotland, UK.*

Email: s.m.parkes@ dundee.ac.uk;

Albert Ferrer Florit[(2)], Alberto Gonzalez Villafranca[(2)],

[(2)]*STAR-Barcelona S.L., Av. Cerdanyola, 79-81, Planta 2, Oficina 2,08172 Sant Cugat del Vallès, Barcelona, Spain.*

Email: albert.ferrer@star-dundee.com; albert.gonzalez@star-dundee.com;

Chris McClements[(3)], Pete Scott[(3)],

[(3)]*STAR-Dundee Ltd, Star House, 166 Nethergate, Dundee, DD1 4EE, Scotland, UK.*

Email: chris.mcclements@star-dundee.com; pete.scott@star-dundee.com;

ABSTRACT

SpaceFibre is the next generation of SpaceWire network technology for spacecraft on-board data-handling. It runs over electrical or fibre-optic cables, operates at very high data rates, and provides in-built quality of service (QoS) and fault detection, isolation and recovery (FDIR) capabilities. Its high data rate per lane coupled with novel multi-lane technology enables SpaceFibre to achieve very high performance: in excess of 10 Gbit/s with current space qualified FPGAs and much higher in the near future. Its in-built error detection, isolation and recovery mechanisms enable rapid recovery from transient errors, without loss of data, providing high-availability. Its multi-lane hot and cold redundancy features support high reliability. These capabilities are built into the hardware of each SpaceFibre interface. This paper will outline the quintessential characteristics of SpaceFibre that make it ideal as an interconnect in spaceflight applications. It will then explore how SpaceFibre can be used as a payload data-handling system network.

1 INTRODUCTION

Data rates of tens of Gbit/s are required to support planned high data-rate payloads, including synthetic aperture radar and hyper-spectral optical instruments. In addition, a mass-memory unit requires high performance networking to interconnect many memory modules. SpaceFibre [1-4] is a new generation of SpaceWire [5-6] technology which provides the high data rates required by Earth observation and communications payloads. It delivers robust, long distance communications for launcher applications and supports avionics applications with deterministic delivery constraints. SpaceFibre enables a common on-board network to be used across many different mission applications resulting in cost reduction and design reusability.

This paper first introduces the key features of SpaceFibre. It then gives an overview of a typical SpaceFibre network for an Earth observation application. The interfaces to instruments, to payload data-handling equipment and to the control computer are then described. The important SpaceFibre routing switch is the subject of a separate paper [7].

2 KEY FEATURES OF SPACEFIBRE

The key features of SpaceFibre are outlined below [8]:

- Very high-performance with 3.125 Gbit/s single-lane performance (including overhead for 8B/10B encoding) in current radiation tolerant FPGAs, 12.5 Gbit/s with four lanes, and substantially higher data rates planned in future devices.
- Electrical and Fibre Optic media with the electrical medium supporting cable lengths up to 5 m, depending on data rate, and fibre optics supporting up to 100 m.
- High reliability and high availability using error-handling technology which is able to recover automatically from transient errors in a few microseconds without loss of information and which is able to continue operation, preserving data transfer of critical and important information, when a lane in a multi-lane link fails.
- Quality of service using multiple virtual channels across a data link, each of which is provided with a priority level, a bandwidth allocation and a schedule.
- Virtual networks that provide multiple independent traffic flows on a single physical network, which, when mapped to a virtual channel, acquire the quality of service of that virtual channel.

- Deterministic data delivery of information using the scheduled quality of service, in conjunction with priority and bandwidth allocation.

- Low-latency broadcast messages which provide time-distribution, synchronisation, event signalling, error reporting and network control capabilities.

- Small footprint which enables a complete SpaceFibre interface to be implemented in a radiation tolerant FPGA, for example, around 3% of an RTG4 FPGA for an interface with two virtual channels.

- Backwards compatibility with SpaceWire at the network level, which allows simple interconnection of existing SpaceWire equipment to a SpaceFibre link or network.

STAR-Dundee has developed a comprehensive set of IP cores for SpaceFibre which are already being used in their first space missions and ASIC designs. The following IP cores are now available from STAR-Dundee targeted for Microsemi RTG4 and Xilinx FPGAs, and ASIC implementation:

- Single-lane interface;
- Multi-lane interface;
- SpaceWire to SpaceFibre bridge;
- Routing switch.

All these IP cores are fully configurable using VHDL generics. They have been extensively validated. The way in which these IP cores can be used to provide a complete on-board data-handling network will now be described.

3 SPACEFIBRE NETWORK

The on-board network architecture for a typical, very demanding Earth observation spacecraft is illustrated in Figure 1.

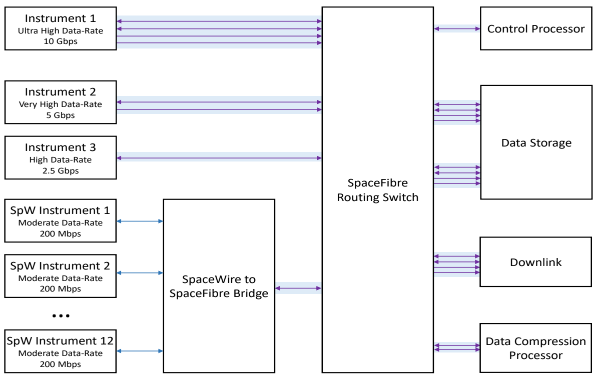

Figure 1: SpaceFibre Network

SpaceFibre is used to connect the instruments to a SpaceFibre routing switch which then connects to the payload data-handling equipment. Very high data-rate instruments are provided with a multi-lane SpaceFibre interface. SpaceWire instruments are connected to the network via a SpaceWire to SpaceFibre bridge. The routing switch allows data to be switched from any node to any other node on the network. Instrument data can be passed to the data storage system or it can be switched to the downlink telemetry system for broadcast to ground either directly or via a data relay satellite. A data compression processor is attached to the SpaceFibre network to provide generic data compression services. Data can be compressed on its way from the instrument to the data storage system. Alternatively, it can be stored first and then compressed later on. The data storage system can use the SpaceFibre routing switch to send stored information directly to the downlink telemetry unit or to the data compression processor for compression before the data is sent to ground. The control processor has access to all the instruments and data-handling units, and is able to configure, control and monitor all this equipment over the SpaceFibre network, without requiring any additional, specific control interfaces, saving mass and improving reliability.

4 SPACEFIBRE INSTRUMENT INTERFACE

An instrument interface is straightforward to design with SpaceFibre [8]. The primary data from the instrument can be allocated to one virtual channel, while configuration and control commands and housekeeping data can be allocated to a separate virtual channel. There is then no need for a separate control bus, improving reliability and reducing mass and power consumption. A single-lane interface can be used for moderate data rate instruments and this can be replaced by a multi-lane link for higher data rate instruments, the number of lanes being matched to the instrument data rate. Additional lanes can be added, when the instrument data is critical, to provide hot or cold lane redundancy, allowing rapid recovery in the event of a lane failure. When the data in a multi-lane link flows predominantly in one direction, only one of the lanes has to be bi-directional. The other lanes can be unidirectional, saving mass and power. Nominal and redundant interfaces can be added to the instrument, with support for autonomous redundancy switching if required.

A typical SpaceFibre instrument interface is illustrated in Figure 2.

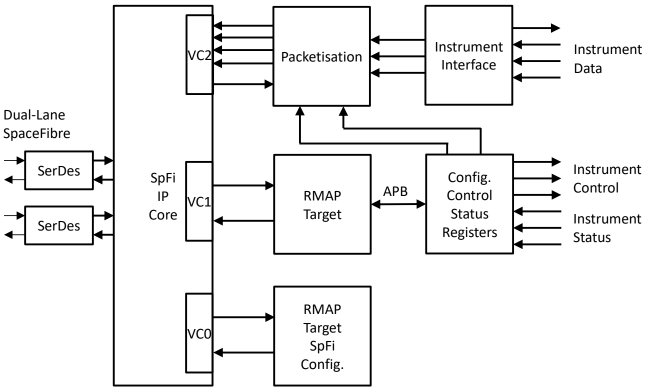

Figure 2: Dual-Lane SpaceFibre Instrument Interface

The main part of the SpaceFibre interface is implemented using a SpaceFibre IP core which connects to one or more SerDes to provide the interface to the SpaceFibre link. One or more virtual channel interfaces provide the connection to the instrument. Virtual channel VC0 is used for network configuration, control and monitoring and provides access to the control and status registers of the SpaceFibre IP core using the Remote Memory Access Protocol (RMAP) [9]. VC1 is also connected to an RMAP target which is used to access the configuration, control and status registers of the instrument. Alternatively, it is possible to use VC0 to access both SpaceFibre network and equipment configuration spaces. VC2 provides the data interface for the instrument. Data is passed from the instrument electronics to SpaceFibre via a parallel FIFO type interface. The data is packetized by adding an address at the start of the packet and an end of packet marker (EOP) at the end.

The STAR-Dundee SpaceFibre Camera shown in Figure 3 is an example of an instrument with a SpaceFibre interface.

Figure 3: SpaceFibre Camera

It provides high-resolution and high frame-rates [10] and is suitable for both Earth Observation, vision-based navigation and robotic applications. The camera incorporates a Microsemi RTG4 FPGA [11] which, as well as providing the image sensor interface, control logic and SpaceFibre interfaces, has plenty of room left for data compression or other image processing applications to be integrated in the camera.

5 SPACEFIBRE IN MASS MEMORY UNITS

SpaceFibre can be used to provide both the interface to a mass-memory unit and the high-data rate network for interconnecting memory modules. Virtual channels can be used to separate different classes of traffic within the memory system, for example, data to be stored, data to be retrieved and control and housekeeping information. A SpaceFibre interface to a mass memory unit is illustrated in Figure 4.

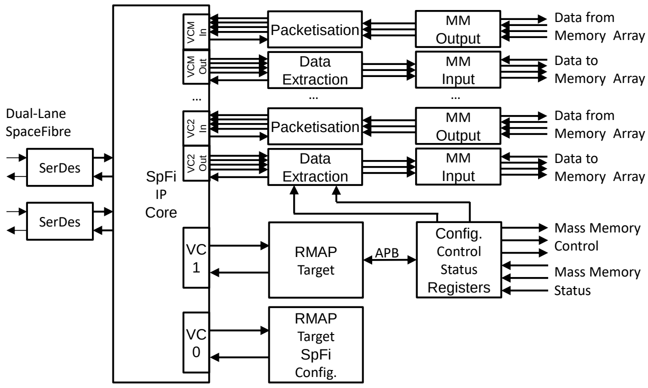

Figure 4: Dual-Lane SpaceFibre Mass-Memory Interface

The SpaceFibre interface can use multiple lanes to support the required data rates into the mass memory. A prototype mass memory system developed by Airbus GmbH, STAR-Dundee and IDA is shown in Figure 5 [12]. Starting on the left of the rack at the bottom of the photograph there are the following boards:

- External SpaceFibre and SpaceWire interface board
- Two SpaceFibre routing switches forming a SpaceFibre network inside the mass memory unit
- Four memory modules attached to the SpaceFibre network

Figure 5: Prototype Next Generation Mass Memory System

6 DOWNLINK TRANSMITTER INTERFACE

The interface of the downlink transmitter unit is shown in Figure 6.

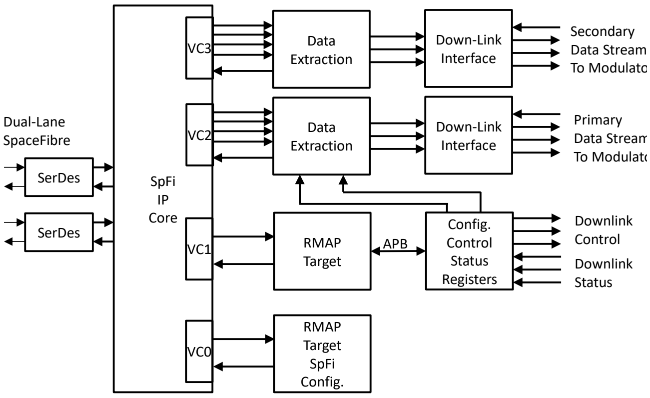

Figure 6: Dual-Lane SpaceFibre Downlink Interface

This is similar to the instrument interface except that the primary data flows in the opposite direction. The same SpaceFibre IP core is used. VC0 and VC1 are used for network and equipment management. VC2 and VC3 provide two independent data streams into the downlink transmitter.

7 CONTROL COMPUTER INTERFACE

A SpaceFibre interface to a control processor is illustrated in Figure 7.

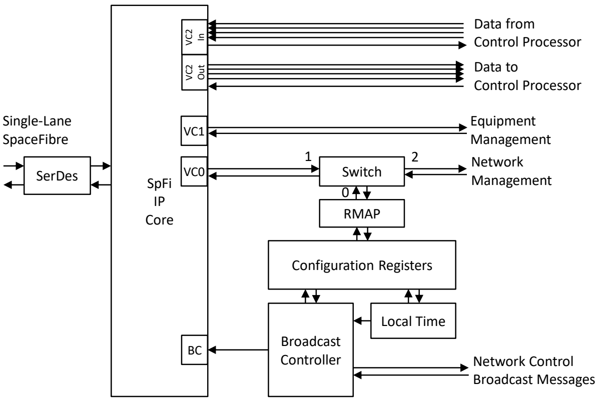

Figure 7: SpaceFibre Control Computer Interface

The control computer has three main tasks related to the SpaceFibre network:

- Manage the SpaceFibre Network
- Manage the equipment
- Distribute spacecraft time

To manage the SpaceFibre network the control computer needs to be able to send RMAP commands to the routing switches and nodes on the network so that they can be configured and controlled and have their status monitored. This is carried out using the virtual network VN0 which is reserved for this specific purpose and which is permanently mapped to VC0 on all SpaceFibre links. The control computer also needs to manage the local SpaceFibre interface. The control computer has an interface to a small, path address only routing switch, which connects to VC0 of the SpaceFibre interface (port 1), to an RMAP port for accessing the local SpaceFibre management registers (port 0), and to the control computer (port 2). All equipment on the network uses VN0 for management of its SpaceFibre interface.

To manage the equipment attached to the SpaceFibre network the control computer has to send RMAP commands to the equipment attached to the network. In Figure 7 virtual network VN1 has been reserved for this purpose. The control computer is directly connected to VC1 of its SpaceFibre interface.

To distribute spacecraft time to all the nodes that want to use it, the network manager sends out broadcast messages containing a copy of the spacecraft time. This message is received by all nodes on the network that need time information.

8 SPACEFIBRE ROUTER

The SpaceFibre routing switch is an essential element of a SpaceFibre network. The design and validation of a router has been covered in two separate papers [7][13].

9 CONCLUSIONS

SpaceFibre provides a high performance, high reliability, high availability network technology specifically designed for spaceflight applications. STAR-Dundee SpaceFibre IP cores make it simple to provide network interfaces to instruments, data storage units, data compressors, other forms of data processor, downlink transmitters and to the control computer. The STAR-Dundee SpaceFibre router IP core provides the essential routing switch element interconnecting the other devices.

Instruments, processors and data-handling equipment are being developed by many organisations with SpaceFibre interfaces. A SpaceFibre camera has been developed by STAR-Dundee. A mass-memory unit has been developed by Airbus. Processing chips that are being developed include the Ramon Chips RC64 many core DSP processor.

The SpaceFibre standard is ready for publication.

10 ACKNOWLEDGMENTS

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11 REFERENCES

[1] ECSS Standard ECSS-E-ST-50-11C, "SpaceFibre", Issue 1, European Cooperation for Space Data Standardization, to be published and made available from http://www.ecss.nl.

[2] S. Parkes, C. McClements and M. Suess, "SpaceFibre", International SpaceWire Conference, St Petersburg, Russia, 2010, ISBN 978-0-9557196-2-2, pp 41-45.

[3] S. Parkes et al, "SpaceFibre: Multi-Gigabps Interconnect for Spacecraft On-board Data Handling", IEEE Aerospace Conference, Big Sky, Montana, 2015.

[4] A. Ferrer Florit, A. Gonzalez Villafranca and S. Parkes, "SpaceFibre Multi-Lane", International SpaceWire Conference, Yokohama, Japan, 2016, ISBN 978-0-9954530-0-5.

[5] ECSS Standard ECSS-E-ST-50-12C, "SpaceWire, Links, Nodes, Routers and Networks", Issue 1, European Cooperation for Space Data Standardization, July 2008, available from http://www.ecss.nl.

[6] S. Parkes, "SpaceWire Users Guide", ISBN: 978-0-9573408-0-0, STAR-Dundee, 2012, available from https://www.star-dundee.com/knowledge-base/spacewire-users-guide (last visited 11th Feb 2018).

[7] Albert Ferrer Florit, Alberto Gonzalez Villafranca, Marti Farras Casas and Steve Parkes, "SpaceFibre Routing Switch IP Implementation in Radiation-Tolerant FPGAs", DASIA 2019.

[8] S.Parkes, Albert Ferrer Florit and Alberto Gonzalez Villafranca, "SpaceFibre Interfaces and Architectures' IEEE Aerospace, Big Sky, Montana, USA, March 2019.

[9] ECSS Standard ECSS-E-ST-50-52C, "SpaceWire – Remote memory access protocol", Issue 1, European Cooperation for Space Data Standardization, 5 February 2010, available from http://www.ecss.nl.

[10] S. Parkes et al, "SpaceFibre Camera", International SpaceWire Conference, Long Beach, California, 2016.

[11] S. Parkes et al, "SpaceWire and SpaceFibre on the Microsemi RTG4 FPGA", IEEE Aerospace Conference, Big Sky, Montana, 2016.

[12] Airbus, IDA, UoD "Next Generation Mass Memory Architecture (NGMMA) Summary Report", Report No. NGMMA-RP-0034, ESTEC Contract No. 22530/09/NULvH, 12th January 2018.

[13] Vangelis Kollias, Nikos Pagkas, Fotis Kostopoulos, Steve Parkes, Alberto Gonzalez Villafranca, Albert Ferrer Florit and Felix Siegle, "SpaceWire and SpaceFibre Network Study", DASIA 2019.