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A SpaceFibre Routing Switch

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Conference Theme: Data Handling and Processing for Data-Hungry Missions and Applications

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***Abstract*— SpaceFibre [1] is a high-performance, high-reliability and high-availability network technology designed for spaceflight and other demanding applications. A SpaceFibre routing switch forms the heart of a SpaceFibre network, interconnecting instruments and payload data-handling equipment. This paper introduces SpaceFibre and then describes the STAR-Tiger SpaceFibre routing switch.**

Keywords—SpaceFibre, Payload Data-Handling, Serial Communications, Networks, Hi-SIDE

I. Introduction

SpaceFibre [1] is the latest generation of SpaceWire [2] 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, and fault detection, isolation and recovery capabilities. Because of these important characteristics, SpaceFibre is being selected for a growing number of space missions some of which use point-to-point links and others which use a network. A critical element of a SpaceFibre network is the SpaceFibre routing switch.

The STAR-Tiger SpaceFibre routing switch has been developed by STAR-Dundee for future payload data-handling networks. A SpaceFibre network is formed by a SpaceFibre routing switch, the SpaceFibre interfaces in each payload data-handling element (instruments, mass-memory unit, data processors and downlink transmitter), and the SpaceFibre cable assemblies that connect them all together.

A photograph of the STAR-Tiger SpaceFibre routing switch is shown in Figure 1. It has the following key features:

- 10 SpaceFibre ports
    - Two quad-lane ports
    - Eight dual-lane ports
    - Lane speed up to 6.25 Gbit/s
    - Port data rate up to 9.6 Gbit/s dual-lane port and 19.2 Gbit/s quad-lane port
- 2 SpaceWire interfaces for programming the STAR-Tiger’s FPGA
- Bisection bandwidth is 150 Gbit/s including 8B10B overhead.
- Spaceflight TRL5/6 level design
- Electronic components are radiation tolerant EM flight parts or industrial/commercial equivalents of flight parts
- Power consumption is 14.2W typical at 20 °C, with all links running with lane speeds of 6.25 Gbit/s
- Conduction cooled
- Operating temperature range: -25 to +55 °C
- 108 x 108 x 68 mm (excluding mounting brackets)

Figure 1: STAR-Tiger SpaceFibre Routing Switch

II. STAR-Tiger SpaceFibre Routing Switch

In this section the design of the STAR-Tiger unit, the router FPGA design, and the functional and environmental testing of STAR-Tiger are outlined.

A. STAR-Tiger Design

The arrangement of circuit boards inside the STAR-Tiger SpaceFibre routing switch unit is illustrated in Figure 2.

STAR-Tiger comprises three circuit boards:

- A power supply board (bottom) which has nominal and redundant power input selection and delivers the five main power rails to the FPGA. Other power rails are supplied by regulators on the other two boards. Texas Instruments radiation tolerant power supply components are used.
- An FPGA board (middle) containing the Xilinx KU060 FPGA. The PCB footprint accommodates either the commercial/industrial part or the radiation tolerant part. An industrial grade FPGA was used. The FPGA is surrounded by six Elara connectors which carry the SpaceFibre electrical signals. Each connector provides four lanes of SpaceFibre. Two

connectors each carry one quad-lane port and the other four connectors each carry two dual-lane ports.

- A configuration and scrubbing board (top) which is used to configure and monitor the KU060 FPGA. Configuration is from EEPROM or via a SpaceWire interface. The EEPROM can be programmed over SpaceWire.

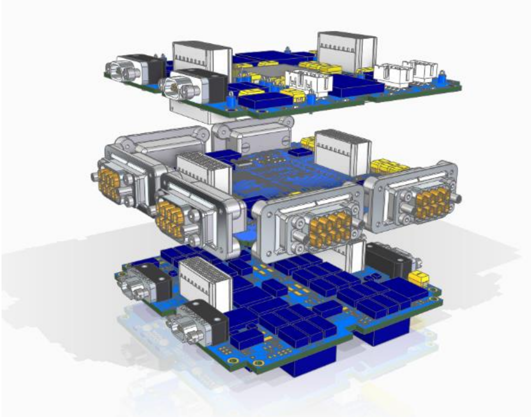

Figure 2: STAR-Tiger Routing Switch Boards

These three boards are shown in Figure 3 to Figure 5 in various stages of integration with the STAR-Tiger housing. The complete STAR-Tiger unit is shown in Figure 1.

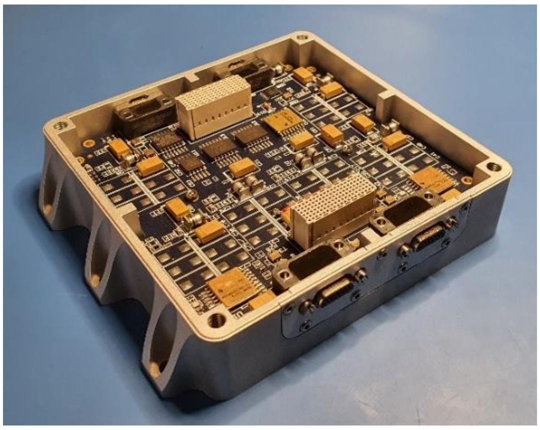

Figure 3: STAR-Tiger Power Supply Board in Housing

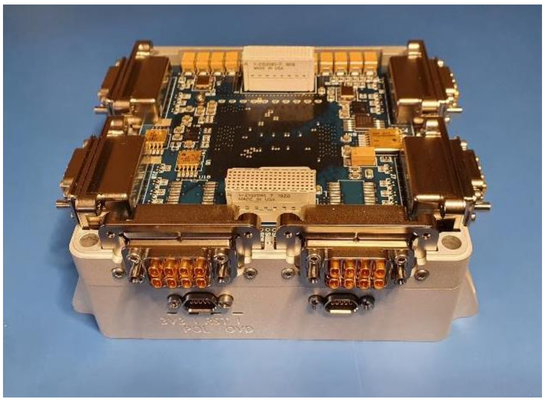

Figure 4: STAR-Tiger FPGA Board in Housing

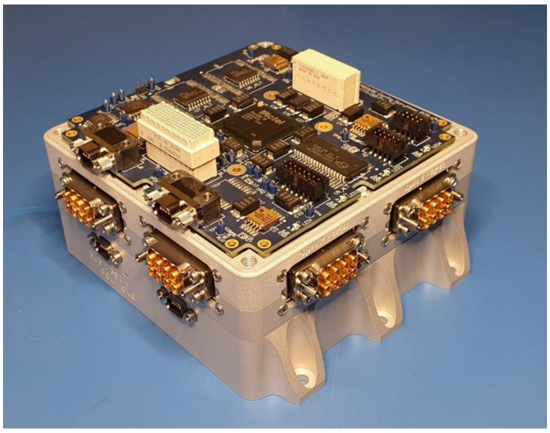

Figure 5: STAR-Tiger Configuration Board in Housing

B. SpaceFibre Routing Switch FPGA Design

A block diagram of the STAR-Tiger SpaceFibre routing switch FPGA is shown in Figure 6. It contains the following:

- A routing switch matrix with ten SpaceFibre ports and an internal configuration port.
- Two quad-lane SpaceFibre ports (ports 1-2) with eight virtual channels each.
- Eight dual-lane SpaceFibre ports (ports 3-10) with four virtual channels each.
- An RMAP configuration port (port 0) which accesses the SpaceFibre router configuration, control and status registers.
- A routing table which is configured over the configuration port and which determines the logical address to output port-number mapping.
- A broadcast controller which broadcasts broadcast-messages on each of the 256 possible broadcast channels. The broadcast controller also provides the time-slot timing for the schedule quality of service.

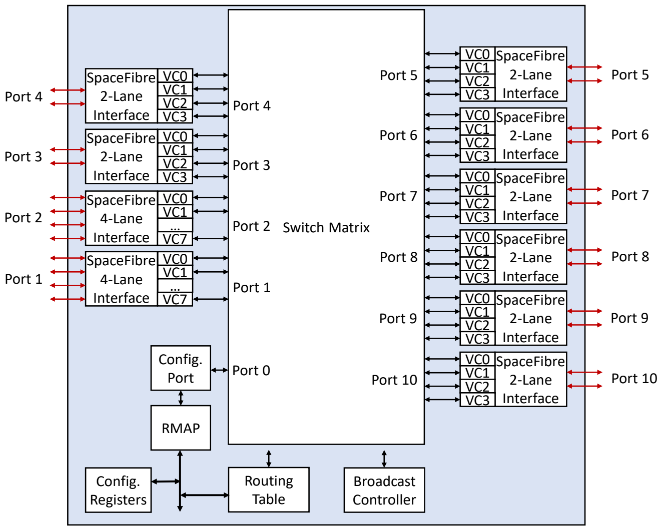

Figure 6: Block Diagram of Routing Switch FPGA

The placement of each the SpaceFibre ports in the FPGA is illustrated in Figure 7.

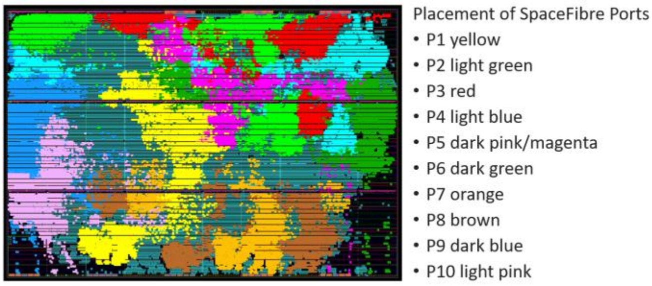

Figure 7: STAR-Tiger FPGA SpaceFibre Port Placement

C. *STAR-Tiger Functional Testing*

The STAR-Tiger boards were subject to extensive testing during development and integration. Once STAR-Tiger was operational, verification tests were carried out to ensure that the unit performed as required. The test setup used for many of the functional tests is shown in Figure 8.

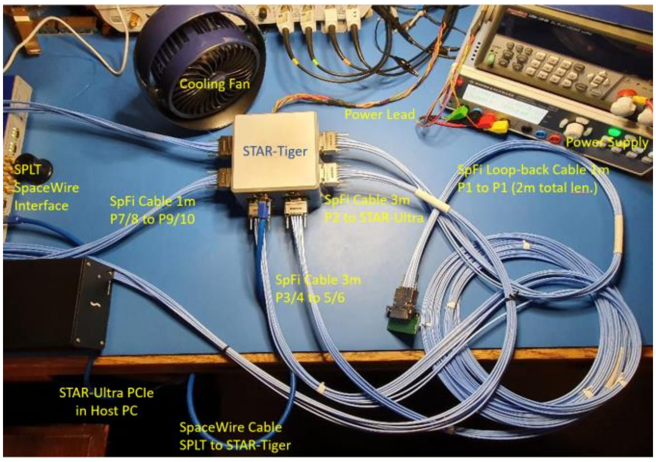

Figure 8: STAR-Tiger SpaceFibre (SpFi) Routing Switch Test Setup Photograph

The STAR-Tiger routing switch was tested using the STAR-Ultra PCIe SpaceFibre interface board [3].

The lane speed is 6.25 Gbit/s giving a link speed of 25 Gbit/s, which is 20 Gbit/s excluding the 8B10B encoding and 19.2 Gbit/s excluding other protocol overheads for a bi-directional link. 100 Kbyte packets are sent from the STAR-Ultra PCIe to port 2 of the STAR-Tiger router, then out through port 1, looped back to port 1, then through all the other ports of the router and finally back out of port 2 to the STAR-Ultra PCIe (see the red path in Figure 9).

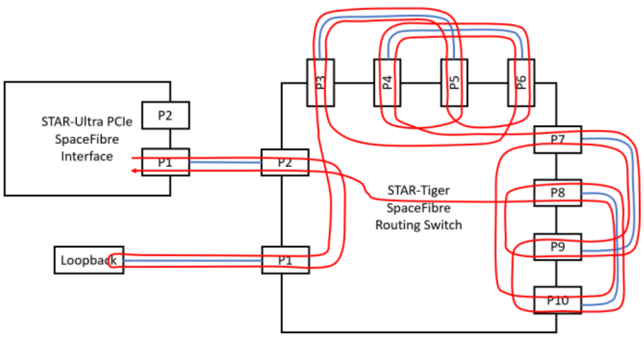

Figure 9: Testing all SpaceFibre ports of STAR-Tiger

The test results are shown in Figure 10. At the start of the trace only the two quad-lane ports (P1 and P2) were being used, giving a data rate around 13.6 Gbit/s. The path address was then changed to include all the dual-lane ports and the data rate drops to around 9.6 Gbit/s, which is the maximum data-rate that can be supported with two-lanes and a lane speed of 6.25 Gbit/s. Further checks were carried out forming a comprehensive set of verification tests.

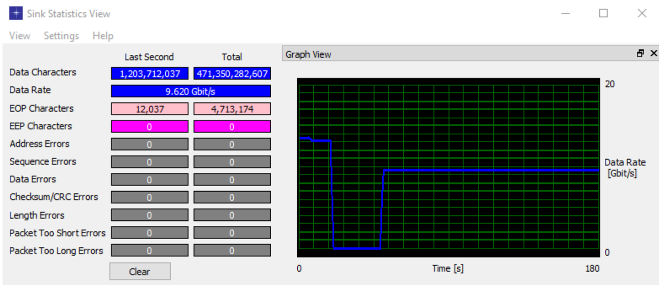

Figure 10: STAR-Ultra PCIe exercising all SpaceFibre ports of the STAR-Tiger

D. *STAR-Tiger System Level Testing*

STAR-Tiger was developed and tested at the system level within the European Commission Hi-SIDE project [4]. The Hi-SIDE project developed critical satellite data-chain technologies for handling and transferring data from instruments to processing and storage elements on-board a spacecraft, and to the downlink transmitters that send data to ground. The Hi-SIDE project culminated in a comprehensive demonstration incorporating all the critical elements of the High Speed Data Chain (HSDC) from instrument to ground-station. The HSDC demonstration network includes the following elements:

- STAR-Tiger routing switch connected to all elements via SpaceFibre links forming the network interconnecting all elements.
- Instrument 1 (SpaceFibre camera) which provides real-time image data at around 4.6 Gbit/s.
- PC-Based Mass-Memory [5] which stores data from the instruments, passes data to and from data processor/compressor, and sends compressed, encrypted data to the RF or optical downlink.
- Control Computer [5] which configures, controls and monitors the SpaceFibre network and the equipment connected to the network.
- Instrument 2 (simulator) which provides hyperspectral data at a data rate of around 9 Gbit/s.
- Radio Frequency (RF) downlink [6].
- High-Performance Data-Processor (HPDP) [7] which is programmed to perform data encryption.
- Data Compressor [8] which is performing CCSDS 123.0-B-2 Low-Complexity Lossless and Near-Lossless Multispectral and Hyperspectral Image Compression.
- Image Viewer (simulating the optical downlink [9]).
- File Protection Scheme (FPS) Decoder [10].

A photograph of the integrated demonstration system is shown in Figure 11.

Figure 11: Photograph of the Integrated Hi-SIDE Demonstration System

The control computer was able to monitor and display the data rates of the traffic flowing through the network during the demonstration. Figure 12 shows an example of traffic going to the mass-memory for storage. The following data flows are shown:

- Blue line: SpaceFibre Camera sending a series of 8 Gbyte of images to the Mass-Memory for storage.
- Green line: Instrument 2 sending bursts of 16 Gbyte of data to the Mass-Memory for storage and Data Compressor sending one half of the compressed data to the Mass-Memory for storage.
- Purple line: Data Compressor sending the other half of the compressed data to the Mass-Memory for storage.

When these operations overlap, the total data rate of traffic being stored simultaneously in the Mass-Memory is around 14 Gbit/s (the SpaceFibre Camera is approximately 4.5 Gbit/s, Instrument 2 is approximately 9 Gbit/s and the Data Compressor is approximately 0.5 Gbit/s for each of the two compressed streams).

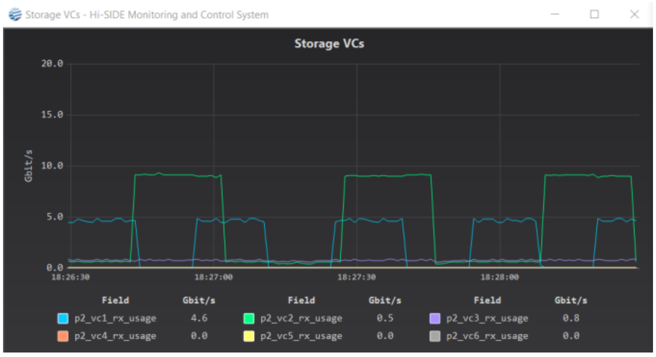

Figure 12: Example of Monitored Network Traffic to the Mass-Memory

Further information on the Hi-SIDE demonstration system is available in [4].

E. *STAR-Tiger Environmental Testing*

With the functional and performance verification tests complete, STAR-Tiger was subjected to environmental testing, covering thermal, vibration and radiated emission tests.

1) *Thermal Testing*

The STAR-Tiger unit ready for thermal testing is shown in Figure 13. It is mounted on an aluminium baseplate with heatsinks to keep the baseplate close to the temperature of the thermal chamber. STAR-Tiger is covered with thermal insulation to prevent convection affecting the test results. Thermal cycling was carried out for 15 hours. The results are shown in Figure 14 and correspond to the results of the thermal simulation. There is a temperature drop of around 10°C from the lid of the FPGA to the baseplate. At the end of the temperature test a problem with the dry air supply resulted in condensation in the test chamber which caused the STAR-Tiger to stop running. The STAR-Tiger recovered once the condensation cleared.

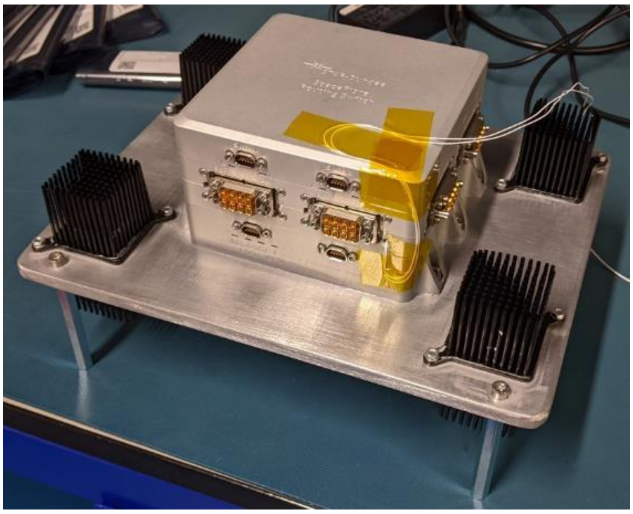

Figure 13: STAR-Tiger Prepared for Thermal Testing

Thermal testing was carried out with a qualification temperature range of -30°C to +60°C for an operational temperature range of -25°C to +55°C.

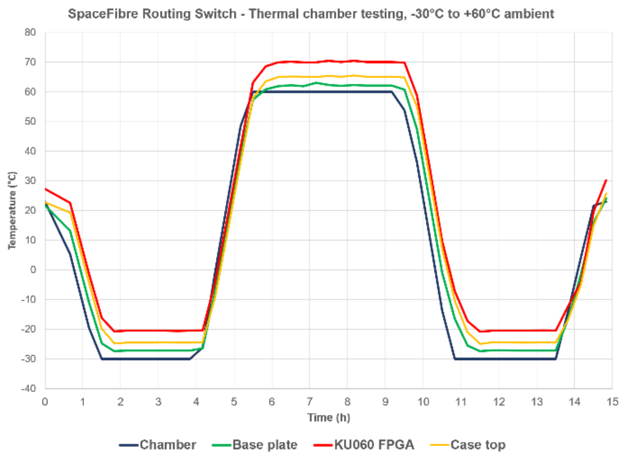

Figure 14: STAR-Tiger Thermal Test Results

2) *Vibration Testing*

Figure 15 shows STAR-Tiger ready for vibration testing. The three axes were tested. For each, an initial scan for resonant peaks was run using a sinewave sweep from 20 Hz to 2 kHz (see Figure 16). Random vibration testing was then carried out for two minutes per axis. A subsequent sinewave scan was then made to see if the resonant peaks had shifted significantly, which would indicate mechanical instability. No significant shifts in the frequency and amplitude of the peaks were observed, so the test passed. Note that the limit lines in Figure 16 are for the forcing function, the green line.

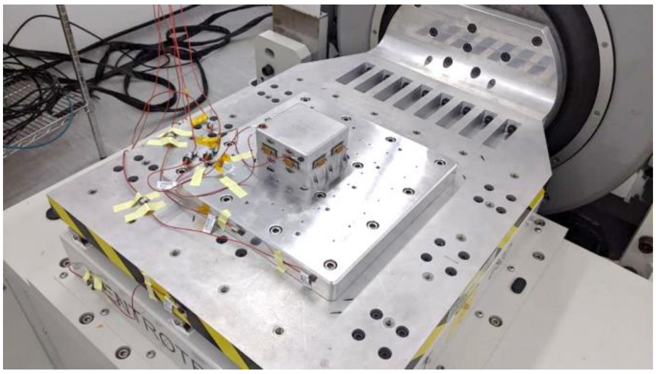

Figure 15: STAR-Tiger Prepared for Vibration Testing

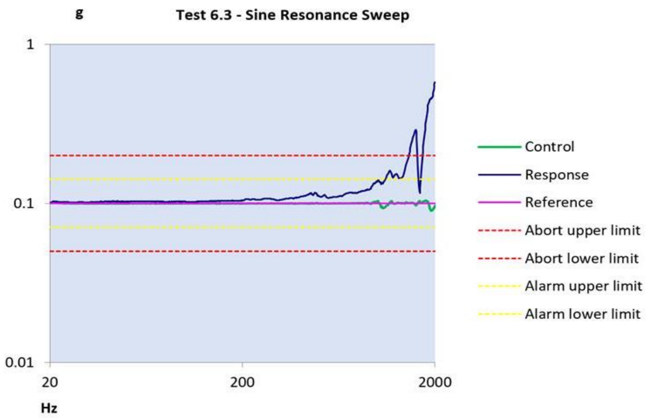

Figure 16: STAR-Tiger Vibration Test Results

3) *EMC Radiated Emission Testing*

In Figure 17 the STAR-Tiger SpaceFibre routing switch is shown in the EMC test chamber ready for radiated emission testing. An example of the test results is presented in Figure 18.

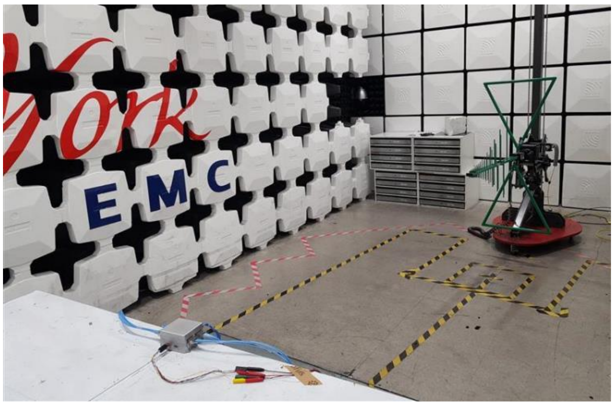

Figure 17: STAR-Tiger in the EMC Test Chamber

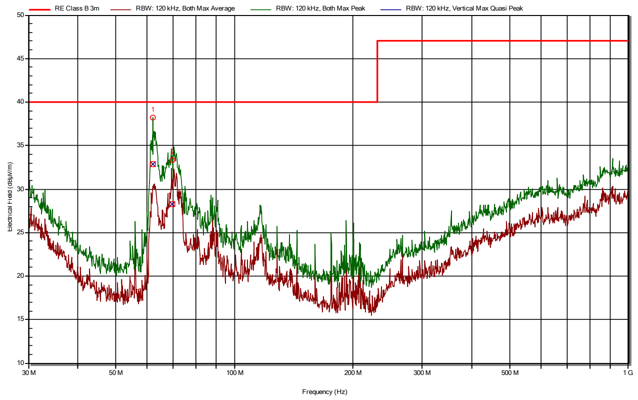

Figure 18: EMC Radiated Emission Testing (30MHz to 1GHz)

III. Conclusions

The STAR-Tiger SpaceFibre Routing Switch forms the heart of the SpaceFibre network that connects the instruments, data-handling and downlink telemetry elements together. STAR-Tiger is capable of data rates up to 19 Gbit/s on its quad-lane ports and 9.6 Gbit/s on it dual-lane ports. STAR-Tiger has been developed with radiation tolerant components to a TRL level of 5/6. It further demonstrates the capabilities of SpaceFibre for future on-board payload processing networks.

Acknowledgement

The Hi-SIDE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776151.

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