Institution: University of Dundee		
Unit of Assessment: UoA 12 Engineering		
Title of case study: SpaceWire and SpaceFibre		
Period when the underpinning research was undertaken: 2000 to 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Stephen Maxwell Parkes	Professor	1995 - 2019
Period when the claimed impact occurred: 2013 to 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

SpaceWire is a data-handling network for use onboard spacecraft. Dundee, funded by the European Space Agency (ESA), led the research, designed important SpaceWire chips, and, with inputs from international engineers, wrote the standard document **[R1]**. Today, SpaceWire is ubiquitous technology for commercial telecommunications, global-positioning, weather, environmental-monitoring, scientific and exploration space missions, collectively worth over $40 billion **[E1]**. The valuable data gathered by these missions are collected by SpaceWire onboard the spacecraft. Further research has underpinned the development of SpaceFibre, the next generation network with 10-100 times the data-rate and novel high-availability capabilities. SpaceFibre is now being designed into equipment for future demanding space missions.

2. Underpinning research

Parkes authored the first SpaceWire standard in 2003, with inputs from international engineers. Research continued through the current REF period **[R2]** culminating in the publication of a revision of the SpaceWire standard ECSS-E-ST-50-12C-Rev1 **[R1]**. The ECSS-E standards define technology to be used onboard spacecraft precisely and in sufficient detail to ensure interoperability between equipment from different manufacturers. Compliance to these standards is mandated in the specification of many spacecraft.

A new generation of SpaceWire technology, SpaceFibre, has been created with 10 to 100 times the performance of SpaceWire, versatile in-built quality of service and unique fault detection, isolation and recovery capabilities. The SpaceFibre standard was written by Parkes with major inputs from STAR-Dundee, a spin-out company from the University of Dundee, and other contributions from ESA, NASA, RosCosmos, St. Petersburg University of Aerospace Instrumentation (SUAI), Airbus and other international organisations.

The University of Dundee, together with STAR-Dundee, carried out the research on the standard, devising protocols, carrying out simulations to support trade-offs of alternative solutions, and implementing and testing the SpaceFibre in hardware **[a, b]**. The European Commission Framework 7 “Very High-Speed Serial Interfaces (VHiSSI)” project **[c]**, researched and developed the first prototype SpaceFibre Interface Chip with the University of Dundee, STAR-Dundee, Ramon Chips, IHP, ACE-IC, Airbus DS and Synergie CAD Instruments. The SpaceWire-RT and VHiSSI projects proved the feasibility of key parts of single-lane SpaceFibre.

Subsequent research was mainly funded by STAR-Dundee and the UK Space Agency through three National Space Technology Programme activities **[e, f, g]**, in particular SUNRISE which researched, designed and proved the network layer for SpaceFibre, implementing for the first time a SpaceFibre routing switch in commercial and radiation tolerant chip technology.

- From 2011 to 2015 the SpaceFibre was designed with ESA funding **[a, d]** and with EC funding **[b, c]**. The results of this research were reported in **[R3]**.
- From 2014 to 2016 SpaceFibre was extended to multi-lane operation giving enhanced data-rates, funded by STAR-Dundee **[R4]**. This is similar to the multiple lanes of a motorway providing for a higher density of traffic but provides unique error recovery capabilities.
- From 2014 to 2020 research on complete SpaceFibre networks was funded by the UK Space Agency **[e, f, g]** and EC **[h]** with a focus on routing switch design and application architectures **[R5]**.

The SpaceFibre standard has been simulated, implemented and extensively reviewed at all stages of its research, design and development. The ECSS SpaceFibre Working Group was first convened in September 2015, starting work by formally reviewing draft H1 v14 of the SpaceFibre standard. The Group members carried out several detailed reviews of the SpaceFibre standard specification and the ECSS Secretariat provided advice, guidance and support in the drafting of the formal specification. The standard was sent out for public review in 2018. Parkes, as the standard editor, addressed all the comments from the public review and the completed standard was finally passed to ECSS for publication **[R6]**. SpaceFibre has recently been incorporated into the latest revision of the American National Standards Institute ANSI/VITA-78 SpaceVPX standard for spacecraft electronic processing units **[E2]**.

3. References to the research

[R1] European Cooperation for Space Standardization (2019) *SpaceWire: Links, nodes, routers and networks*. European Cooperation for Space Standardization, Noordwijk. Available at: https://ecss.nl/standard/ecss-e-st-50-12c-rev-1-spacewire-links-nodes-routers-and-networks-15-may-2019/. [Accessed 19 March 2021]

[R2] Parkes, S, Armbruster, P & Suess, M (2011) 'Well connected: the SpaceWire on-board data-handling network', *ESA Bulletin*, vol. 2011, no. 145, pp. 35-45. Available at: https://esamultimedia.esa.int/multimedia/publications/ESA-Bulletin-145/ESA-Bulletin-145.pdf [Accessed 19 March 2021].

[R3] Parkes, SS, McClements, C, McLaren, D, Ferrer Florit, A & Villafranca, AG (2015) SpaceFibre: a multi-Gigabit/s interconnect for spacecraft onboard data handling. in *2015 IEEE Aerospace Conference Proceedings.* IEEE Computer Society, pp. 1-13, 2015 IEEE Aerospace Conference, Big Sky, United States, 7/03/15. DOI: 10.1109/AERO.2015.7119317.

[R4] Ferrer Florit, A, Gonzalez-Villafranca, A & Parkes, S (2016) SpaceFibre multi-lane: SpaceFibre, long paper. in *2016 International SpaceWire Conference (SpaceWire): Proceedings of the 7th International SpaceWire Conference.* IEEE, pp. 1-8, International SpaceWire Conference 2016, Yokohama, Japan, 25/10/17. DOI: 10.1109/SpaceWire.2016.7771647.

[R5] Parkes, S, Ferrer Florit, A, Gonzalez-Villafranca, A, McClements, C & McLaren, D (2017) SpaceFibre Network and Routing Switch. in *2017 IEEE Aerospace Conference.* Institute of Electrical and Electronics Engineers, United States, pp. 1-7, 2017 IEEE Aerospace Conference, Big Sky, United States, 4/03/17. DOI: 10.1109/AERO.2017.7943805.

[R6] European Cooperation for Space Standardization (2019), "*SpaceFibre: Very high-speed serial link*. European Cooperation for Space Standardization, Noordwijk. Available from https://ecss.nl/standard/ecss-e-st-50-11c-spacefibre-very-high-speed-serial-link [Accessed 19 March 2021].

The research on SpaceFibre at the University of Dundee was funded mainly by the European Commission (EC), STAR-Dundee, European Space Agency (ESA) and UK Space Agency. Specific research contracts related to SpaceFibre are listed below. [text removed for publication]. The prime contractor was University of Dundee except where an organisation name is given after the name of the funding body, e.g. ESA/Airbus GmbH.

[a] Parkes, SpaceFibre Demonstrator, ESA (2011-2019): [text removed for publication]
[b] Parkes, SpaceWire-RT, EC (2010-2012): [text removed for publication]
[c] Parkes, Very High Speed Serial Interface (VHiSSI), EU (2011-2014): [text removed for publication]
[d] [text removed for publication]
[e] Parkes, SpaceFibre Universal Network Router for Integrating Spacecraft Equipment (SUNRISE), UK Space Agency/STAR-Dundee (2014-2017): [text removed for publication]
[f] Parkes, SpaceFibre-VPX, UK Space Agency/STAR-Dundee (2016-2018): [text removed for publication]
[g] Parkes, SpaceDSP, UK Space Agency/STAR-Dundee (2016-2018): [text removed for publication]
[h] Parkes, Hi-FLY, EC H2020/Airbus GmbH (2018-2019): [text removed for publication]. Parkes led the System Design Board for this collaboration comprising Airbus Germany (mass memory), Airbus France (compression processor), DLR (optical downlink), Tesat (RF downlink), STAR-Dundee (SpaceVPX payload data processor), University of Dundee (interconnection network architecture) and other partners.

4. Details of the impact

SpaceWire:
"SpaceWire is the industry standard protocol for command, control, telemetry and low-mid rate data communications in satellites and space vehicles. It has become ubiquitous thanks to the superlative engineering work undertaken at the University [of Dundee]" **[E9]**.

SpaceWire is an electronic network technology used onboard spacecraft to connect the payload instruments to the onboard data-handling system; it is *"one of [the] indispensable technology for satellites"* **[E10]**, carrying critical payload data in many space missions. Thirty spacecraft using SpaceWire with a combined mission cost of $40bn are listed in two tables below. There are many more spacecraft using SpaceWire: *"The total of $50billion (€40 billion) stays on the conservative side"* **[E1]**.

Operational missions			
Mission name	**Mission type**	**Launch date**	**Mission cost**
USA GOES-R series	Geostationary weather monitoring	2017 (1st satellite)	US$10.8bn
European Sentinel	Environmental monitoring	1A (2014), 1B & 3A (2016), 3B (2018), 5-precusor (2017) 6A (2020)	€7.2bn
Inmarsat-4A F4	Geostationary communications	2013	€598m
GAIA (ESA)	Astronomy (mapping of the galaxy)	2013	€740m
Bepicolombo (ESA, JAXA)	Planetary exploration (mission to Mercury, comprising two probes)	2018	€3bn

Chinese Feng Yun 4	7x weather satellites	2016 (1st satellite)	unknown

Missions under development with SpaceWire embedded in the design			
Mission name	**Operation type**	**Details**	**Mission cost**
European MetOp (2nd Generation)	6x Meteorological satellites	Launch of 1st satellite expected 2021, with life span of 8.5 yrs; overall mission duration 21 yrs	€3.4bn
European MetOp (3rd Generation)	6x Meteorological satellites	Successor to the Metop 2nd Generation series currently being developed	€1.7bn
James Webb Space Telescope, NASA	Astronomy - investigation of the formation of the universe	Launch expected in 2021	US$10.7bn

The SpaceWire routing chip, a key component of a SpaceWire network, which was designed by the University of Dundee with Ruag Space and manufactured and sold by Atmel/Microchip, has been used on many space missions. [text removed for publication].

STAR-Dundee is a successful aerospace company that spun out of the University in 2002, underpinned by and founded to commercialise the SpaceWire and later SpaceFibre technology research of the University *"The University's research has underpinned the success of STAR-Dundee"* **[E5]**. STAR-Dundee was awarded the Scottish Business of the Year award (under 25 employees) in 2014 **[E4]**. Its customers include leading international aerospace companies and space agencies [text removed for publication].

Parkes, now full-time CTO of STAR-Dundee, was awarded the Fletcher of Saltoun Award for 2019 by the Saltire Society for his *"exceptional contribution to Science not only in Scotland but internationally"* **[E6]**.

SpaceFibre:
While the impact of SpaceWire **[R1,R2]** has grown substantially, the Dundee team and STAR-Dundee have been designing the next generation of SpaceWire technology, SpaceFibre **[R3,R4,R5,R6]**, which has 10 to 100 times the performance of a SpaceWire link, innovative in-built quality of service (QoS) and novel fault detection, isolation and recovery (FDIR) capabilities. SpaceFibre runs over electrical or fibre-optic cables and provides a high-availability network technology for spaceflight applications. Its low-latency broadcast-message capability enables the distribution of spacecraft time, synchronisation information, event signals, fault reports, replacing separate interconnections. Its virtual channels enable independent traffic flows which can be provided with a reserved bandwidth, a priority and a schedule. The bandwidth reservation identifies and isolates faulty nodes that start to babble, and the priority and scheduling enable data delivery at specific times to support control applications. SpaceFibre simplifies the system engineering, improves reliability, reduces mass, and meets the very high data-rate requirements of future high-resolution, radar and optical Earth-observation missions.

In preparation for this new class of missions SpaceFibre has already been designed into the extremely high-performance Ramon Chip RC64 radiation tolerant processor [text removed for publication]. Manufactured in 2017, the RC64 incorporated twelve SpaceFibre interfaces for communications and is *"currently being designed into its first spaceflight mission"* **[E7]**.

[text removed for publication]

SpaceFibre chip designs for the Microchip RTG4 field programmable gate array have been designed by STAR-Dundee and radiation tested in preparation for use in future space missions. *"From Microchip's perspective, this [SpaceWire and SpaceFibre] is a key enabling technology"* **[E9]**. SpaceFibre designs have also been implemented in other chips from several companies.

SpaceWire is an integral part of the American National Standards Institute VITA-78 SpaceVPX standard for spaceflight electronic processing systems and SpaceFibre is included in the forthcoming update. *"SpaceFibre's utility opened new markets… Now SpaceFibre is an integral part of the SpaceVPX standard"* **[E2]**.

SpaceFibre is being used by ESA, DLR, Airbus, Thales-Alenia Space and others in Europe, in ISS-Reshetnev, ELVEES, and SUAI in Russia, NEC in Japan **[E10]**, NASA and leading aerospace companies in USA. The first spaceflight missions of SpaceFibre took place in 2020 on experimental spacecraft.

5. Sources to corroborate the impact

[E1] Letter of support from ESA corroborating the impact of SpaceWire and in particular that the total cost of the spacecraft using SpaceWire listed in the tables in section 4 amounts to over €35bn or $40bn.

[E2] Letter of support from the American National Standards Institute (ANSI) VITA 78, standards working group chair corroborating that SpaceFibre is included in forthcoming update to the ANSI/VITA SpaceVPX standard.

[E3] [text removed for publication]

[E4] STAR-Dundee Scottish business of the year award. Photo of award.

[E5] [text removed for publication]

[E6] Parkes awarded Saltire Society's Fletcher of Saltoun Award for 2019. Photo of award.

[E7] Letter of support from CEO, Ramon Space and Prof at Technion University.

[E8] [text removed for publication]

[E9] Letter of support from Microchip corroborating the use of SpaceFibre in the Microchip RTG4 FPGA and other devices.

[E10] Letter of support covering the use of SpaceWire and SpaceFibre in Japan.