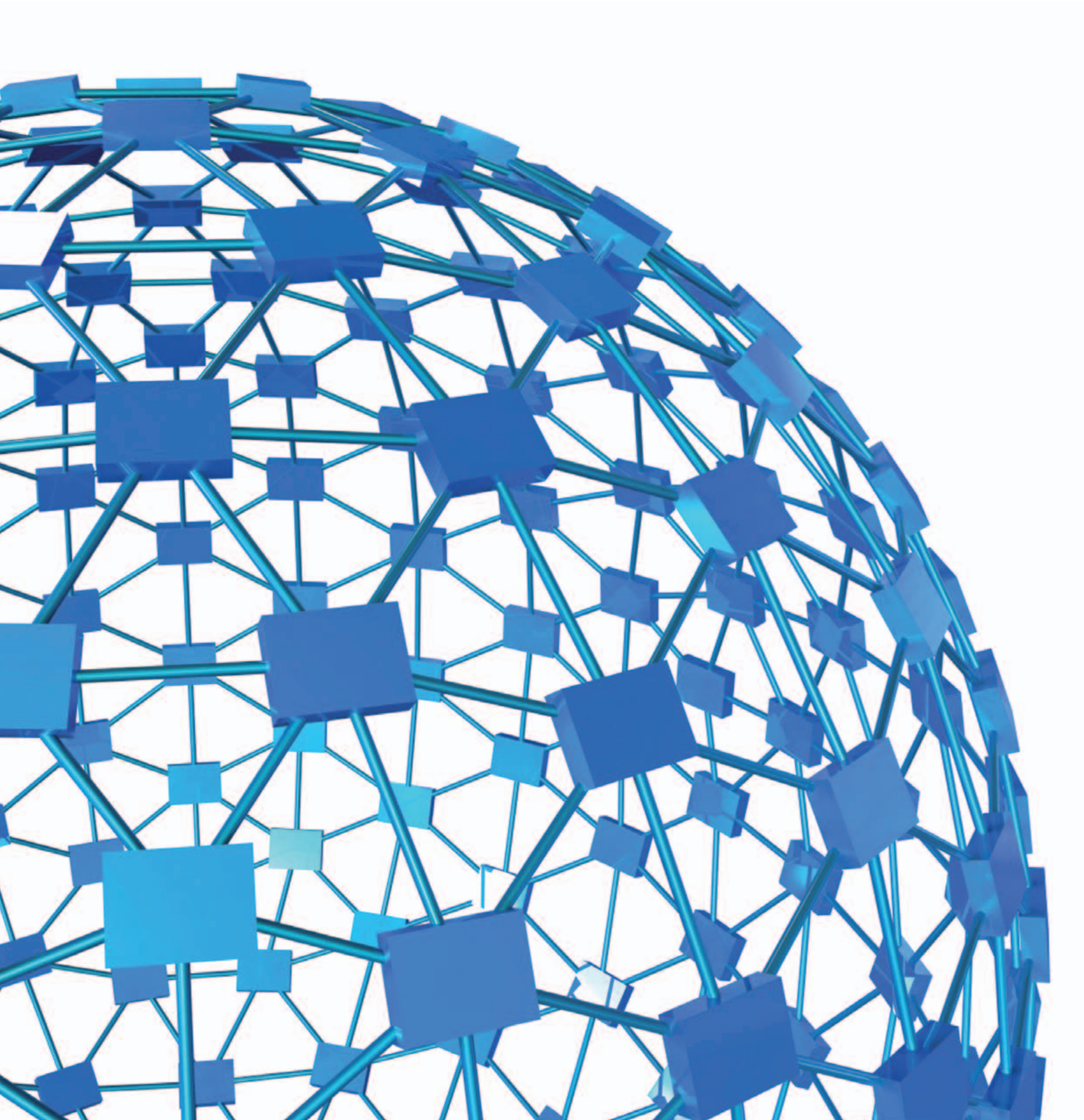

→ WELL CONNECTED

The SpaceWire on-board data-handling network

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In the next decade, SpaceWire-enabled missions will be monitoring our planet, exploring the distant realms of our Solar system and reaching through space and time to help understand the origins of the Universe.

The result of an extremely successful collaboration between ESA, academia and space industry, involving spacecraft engineers from around the world, SpaceWire is a standard for high-speed links and networks used on spacecraft. SpaceWire is now being used widely in the space industry, by all the major space agencies and, in particular, on many current space missions of ESA, NASA and JAXA.

SpaceWire has gained such a wide acceptance because it solved a significant problem. It replaced the collection of different data interfaces with a standard that worked well enough to meet the requirements of many space missions.

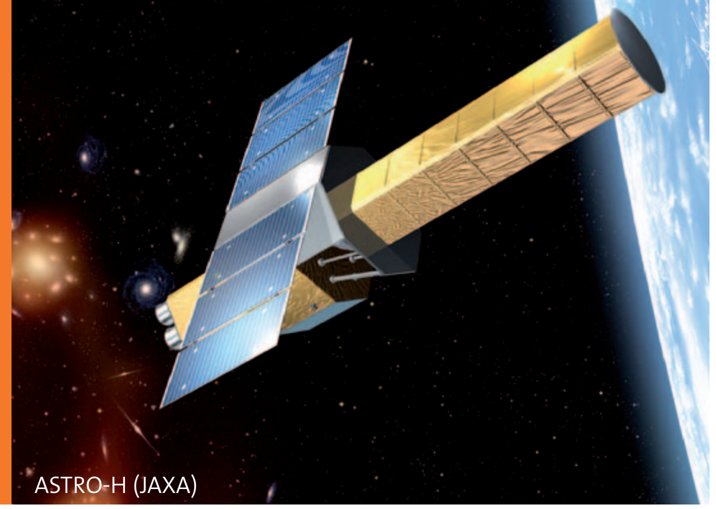
The benefits gained by the widespread adoption of SpaceWire have gone far beyond the original aspirations of its creators. SpaceWire-enabled instrumentation is being reused on new missions, standard sensors with SpaceWire interfaces are appearing in equipment supplier catalogues and many SpaceWire components and sub-systems are available.

→ What is SpaceWire?

As a data-handling network standard for use on spacecraft, connecting instruments, mass-memory and other on-board sub-systems, SpaceWire can be compared to Universal Serial Bus (USB) in personal computing, which connects memory devices, printers and so on to our computers at home or at work. SpaceWire provides similar functionality for spacecraft, but is simpler to implement and has some specific characteristics that help it support data-handling applications in space.

It offers high-speed, low-power, simplicity, relatively low implementation cost and architectural flexibility, making it ideal for many space missions. SpaceWire provides high-speed (2 Mbits/s to 200 Mbits/s), bidirectional, full-duplex data links, which connect together SpaceWire-enabled equipment. Data-handling networks can be built to suit particular applications using point-to-point data links and routing switches.

Since the SpaceWire standard was published (under the reference number ECSS-E-50-12A) by the European Cooperation for Space Standardization in January 2003, it has been adopted by ESA, NASA, JAXA and Roscosmos. It is being used today on many high-profile scientific, Earth observation and commercial missions, including Gaia, ExoMars, BepiColombo, the James Webb Space Telescope, GOES-R, Lunar Reconnaissance Orbiter and ASTRO-H.


ASTRO-H (JAXA)

Cheaper, faster, better, more

SpaceWire was designed to facilitate the construction of high-performance, on-board data-handling systems and help reduce system integration costs. It also promotes compatibility between data-handling equipment and subsystems, and encourage reuse of data-handling equipment across several different missions.

Using the SpaceWire standard ensures that equipment is compatible at both the component and sub-system levels. Instruments, processing units, mass-memory devices and downlink telemetry systems using SpaceWire interfaces developed for one mission can be readily used on another. This reduces the cost of development and reduces development timescales, while improving reliability and maximising the amount of science and data return that can be achieved within a given budget.

Brief history of SpaceWire

Before SpaceWire became a standard, many spacecraft prime contractors and equipment manufacturers had to use ad hoc or their own interfaces for inter-unit communications, for example, connecting high data-rate instruments to mass-memory units. This resulted in several different communication links being used on a spacecraft, increasing the cost and extending the time required for spacecraft integration and testing. There was a clear need for standardising these on-board communication links that would simplify spacecraft development.

In 1992, when work on what became SpaceWire started, there was also substantial interest in high-performance digital signal processing systems that were beyond the capability of the single-chip devices available at that time. The use of parallel processing was investigated and this required some form of network to interconnect the individual processing elements.

The Inmos Transputer, a microprocessor designed for parallel processing was studied, and the serial communication links being developed for the T9000 Transputer were identified as being an attractive solution for spacecraft onboard networking. This serial link technology was subsequently standardised as IEEE 1355-1995.

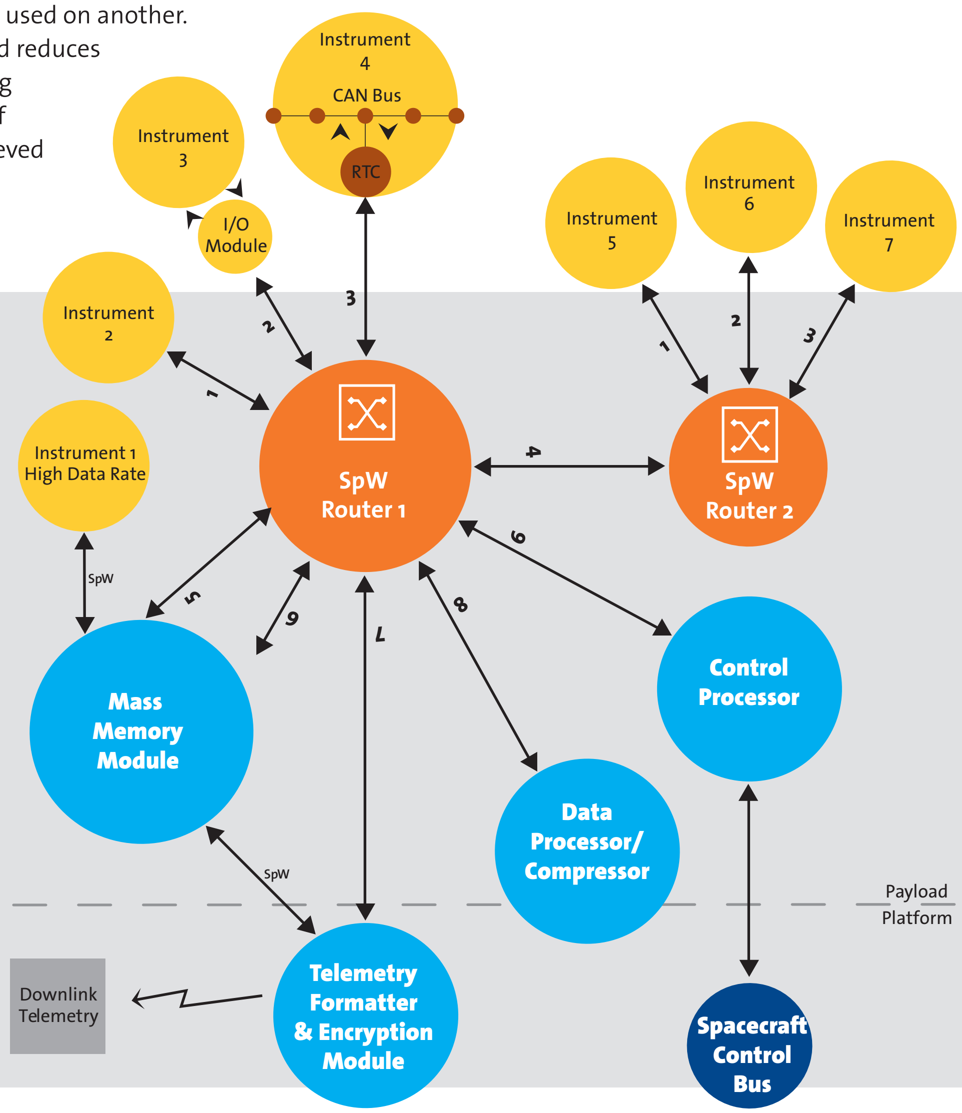
Several radiation-tolerant devices were developed following the IEEE 1355-1995 standard and were used on some space missions. However, there were many problems with this standard, which had to be resolved if this technology was to continue to be used for ESA spacecraft.

The University of Dundee received a contract from ESA to examine and solve these problems that resulted in the first public draft of the SpaceWire standard. After further work involving spacecraft engineers from across Europe and beyond, this matured through several more revisions into the SpaceWire standard that was eventually published in 2003.

Example of SpaceWire application

SpaceWire is able to support many different payload-processing architectures, using point-to-point links and SpaceWire routing switches. The data-handling architecture can be constructed to suit the requirements of a specific mission, rather than having to force the application onto a restricted bus or network with restricted topology.

An example SpaceWire architecture is shown here, using two SpaceWire routers to provide the interconnectivity between instruments, memory and processing modules.



Example of SpaceWire architecture (without redundancy)

Instrument 1 on the left is a high data-rate instrument. A SpaceWire point-to-point link is used to stream data from this instrument directly into the Mass Memory Module. If a single SpaceWire link is insufficient to handle the data-rate from this instrument then two or more links may be used in parallel.

Instrument 2 is of lower average data-rate than instrument 2. Its data is passed though SpaceWire Router 1 to the Mass Memory Module. Instrument 3 does not have a SpaceWire interface so an input/output (I/O) module is used to connect the instrument to the SpaceWire router. Its data may then be sent over the SpaceWire network to the Mass Memory Module.

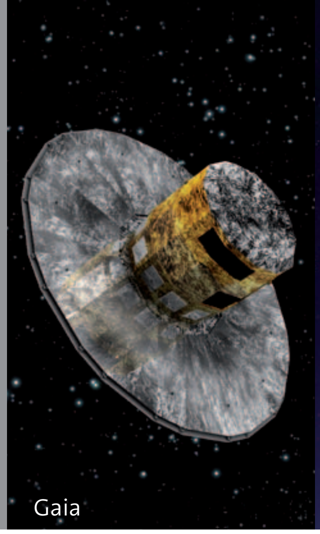
Instrument 4 is a complex instrument containing a number of sub-modules which are interconnected using the CAN bus. A Remote Terminal Controller (RTC) is used to bridge between the CAN bus and SpaceWire. Other signals from the instrument are also connected to the RTC, which contains a processor for performing the bridging and local instrument control functions.

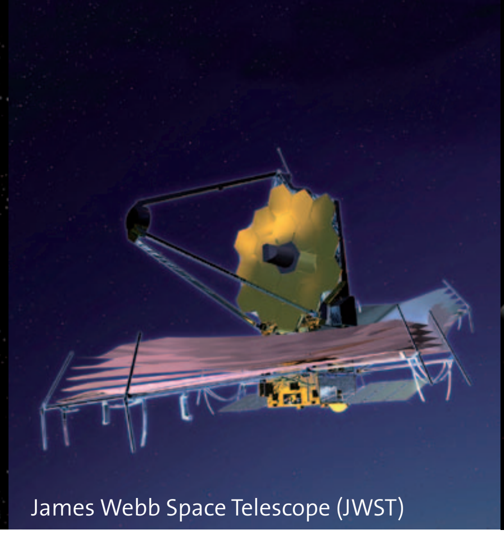
Instruments 5, 6 and 7 are in a remote part of the spacecraft. To avoid having three SpaceWire cables running to this remote location a second router (SpaceWire Router 2) is used to concentrate the information from these three instruments and send it over a single SpaceWire link to Router 1 and then on to the Mass Memory Module.

This Mass Memory Module can receive data from any of the instruments either directly, as is the case for Instrument 1, or indirectly via Router 1. Data stored in the Mass Memory Module can be sent to the Telemetry Formatter/Encryption Module for sending to Earth, or it may first be sent to a Data Processing or Data Compression Unit. This unit may return the processed/compressed data to the Mass Memory Module or send it straight to the Telemetry Module via Router 1.

The Control Processor is responsible for controlling all the instruments, the Mass Memory Module and the Telemetry unit. Via the SpaceWire network it has access to all these modules: it can configure, control and read housekeeping and status information from all of them. The Control Processor is also attached to the spacecraft control bus, over which it can receive telecommands and forward housekeeping information.

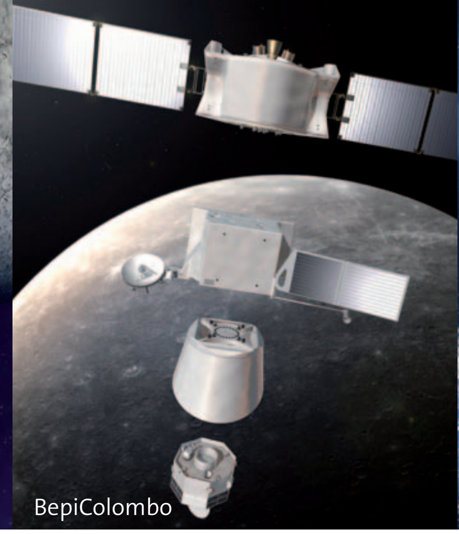
With several instruments and the Data Processor/Compressor sending data to the Mass Memory Module via Router 1, a single link from that Router to the Mass Memory Module may be insufficient to handle all the data, so a second link has been added to provide more bandwidth. In a SpaceWire network, links can be added to provide additional bandwidth or to add fault tolerance to the system. Redundancy has not been included for clarity. In a spaceflight application, of course, another pair of routers would be included with links to redundant units. It is straightforward to support traditional cross-strapped modules using SpaceWire.


Gaia

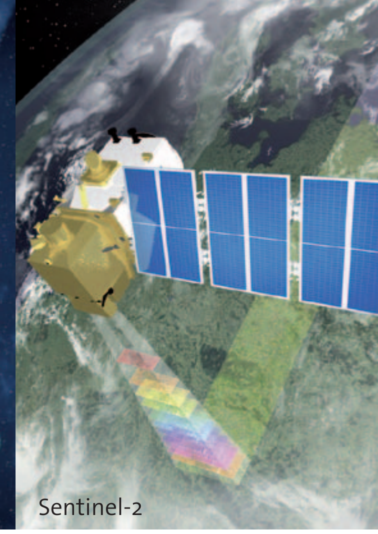

James Webb Space Telescope (JWST)


Lunar Reconnaissance Orbiter (LRO)


LCROSS


BepiColombo


GOES-R


Sentinel-2

→ SpaceWire missions and architectures

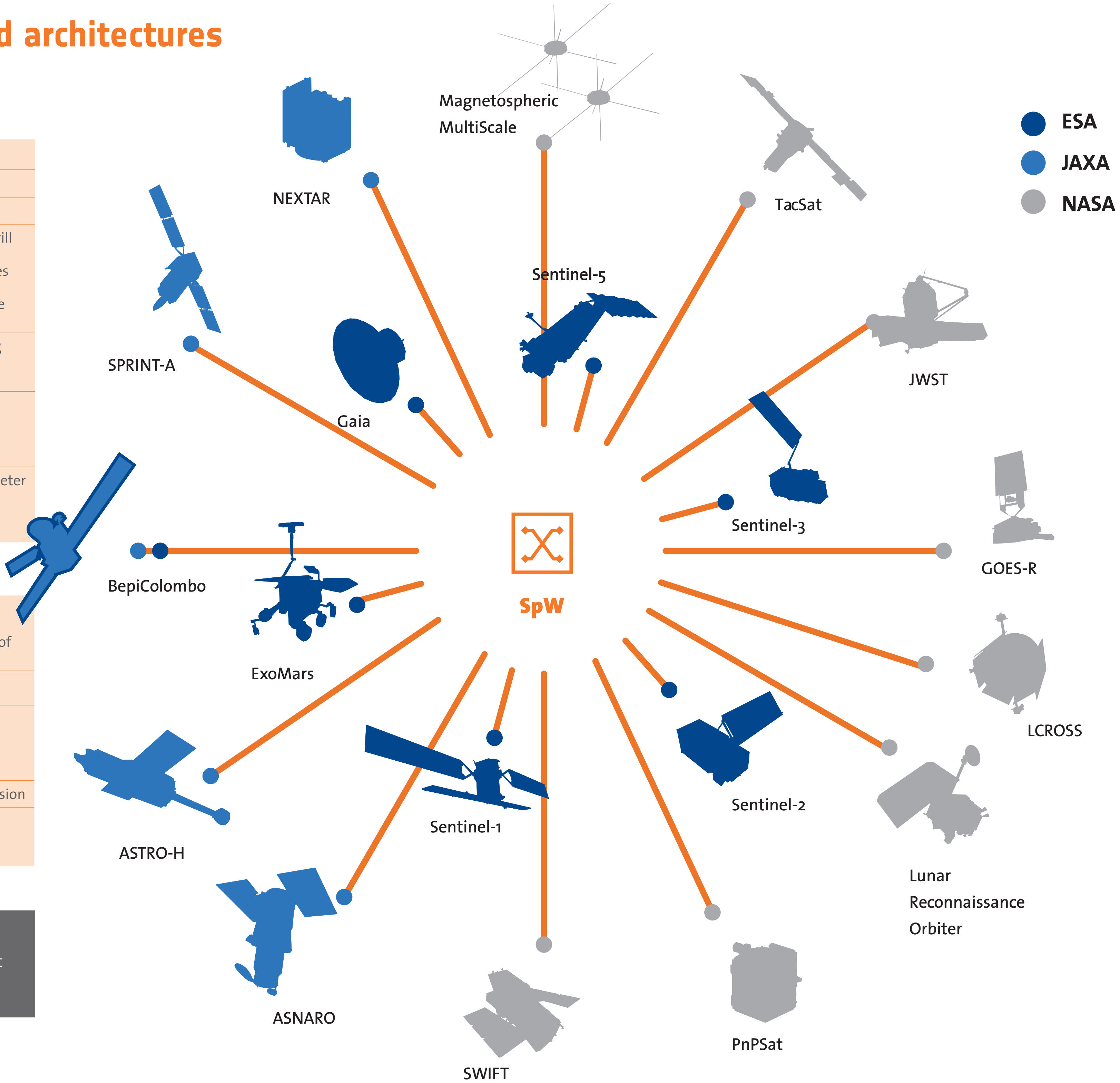
ESA missions using SpaceWire

Gaia	Very-high-resolution star-mapper
ExoMars	Semi-autonomous Mars surface rover
BepiColombo	Mercury Polar Orbiter
Sentinel-1	A pair of imaging radar satellites that will provide an all-weather, day-and-night imaging capability for a range of services including, sea-ice mapping, oil-spill monitoring, ship detection, land-surface movement, and disaster management
Sentinel-2	High-resolution, multi-spectral imaging mission supporting operational land monitoring and emergency services
Sentinel-3	A pair of satellites that will provide operational marine and land Earth observation services using optical and microwave instruments
Sentinel-5 precursor	Will carry a UV/VIS/NIR/SWIR spectrometer payload to avoid a data gap between Envisat and replacement of the MetOp series of Earth observation satellites

Japanese missions using SpaceWire

BepiColombo	Mercury Magnetospheric Orbiter, the companion of ESA's Mercury Polar Orbiter spacecraft, will study the magnetosphere of Mercury
ASTRO-H	X-ray telescope
SPRINT-A	A small satellite that will observe the atmosphere of Venus, Mars and Jupiter in extreme ultraviolet from Earth orbit, at an altitude of about 1000 km
ASNARO	High-resolution optical Earth imaging mission
NEXTAR	One of the first spacecraft to be designed using SpaceWire for all of its onboard communications and being built by NEC

↑ The Japan Aerospace Exploration Agency (JAXA) has adopted SpaceWire for most of its spacecraft that require moderate or high data rates



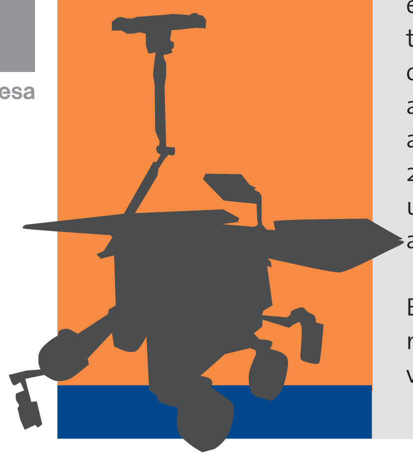
NASA missions using SpaceWire

SWIFT	Gamma-ray burst observatory, in orbit and making scientific discoveries since 2004
Lunar Reconnaissance Orbiter (LRO)	In orbit around the Moon, taking very high-resolution images of the surface
LCROSS	Deliberately crashed into the south pole of the moon and discovered ice there
James Webb Space Telescope (JWST)	Infrared telescope, the biggest satellite ever launched with the exception of the ISS
Magnetospheric MultiScale	Multi-satellite mission that will explore Earth's magnetosphere
GOES-R	Series of geostationary Earth observation spacecraft, due to replace the current US weather satellites
Plug and Play Sat (PnPSat)	Pioneering rapid assembly, integration and deployment technology for tactical and disaster monitoring applications.
TacSat	Part of the US Operationally Responsive Space (ORS) programme

↑ When specifying a data-handling network for JWST, NASA made an extensive survey of suitable technologies and chose SpaceWire. Both TacSat and PnPSat projects chose SpaceWire for their onboard data-handling networks over competition of other space and terrestrial technologies

Roscosmos, the space agency of the Russian Federation, has recently approved SpaceWire for use on their spacecraft, and it regards SpaceWire as a key technology for their future space missions. SpaceWire is also being used in China, India, Korea, Thailand, Taiwan, Argentina, Canada, and by the space agencies of individual ESA Member States. A number of commercial spacecraft, including Inmarsat, are also using SpaceWire.

ExoMars SpaceWire data-handling architecture

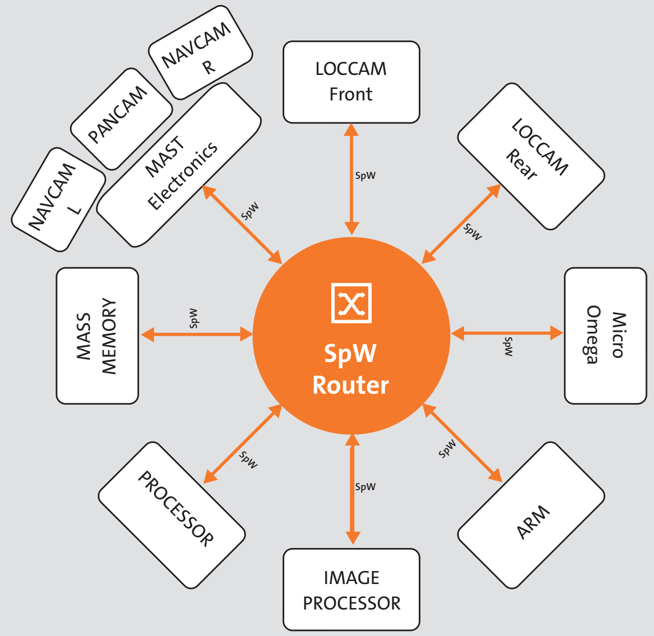


ExoMars is a series of ESA/NASA missions to Mars, the second of which in 2018 will incorporate two versatile rovers, one from ESA and one NASA.

The ESA ExoMars rover will carry a comprehensive array of scientific instruments dedicated to exobiology and geology research. The rover will travel several kilometres searching for traces of past and present signs of life, collecting and analysing samples from within surface rocks and from the subsurface, down to a depth of 2 m. The SpaceWire data-handling architecture used on ExoMars follows closely the example architecture on page 30.

ExoMars carries several cameras to support navigation: PanCam, which provides a panoramic view around the rover; NavCams, used to provide stereoscopic images from which digital elevation maps can be derived and used for navigation purposes; and LocCams, used to measure the motion of the rover relative to the surface.

The processing of this image data is very intensive so a dedicated image processer is used to support the processing. SpaceWire is used to transfer images from the cameras to mass memory and from there to the processor and image-processing chip. A SpaceWire router is used to interconnect the various SpaceWire units. The instrument arm and the Pasteur instrument are also connected to the data-handling system using SpaceWire. ExoMars makes extensive use of the RMAP protocol for passing data from cameras, to mass memory and to and from the processor and image-processing chip.



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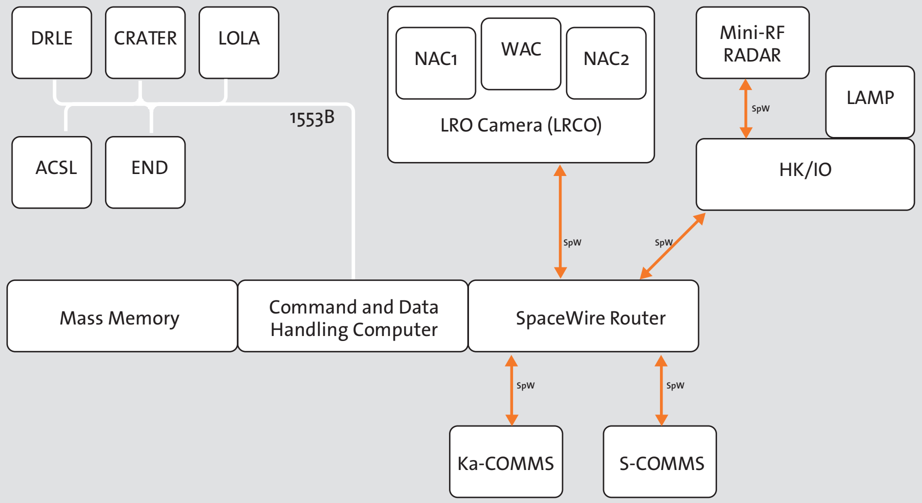
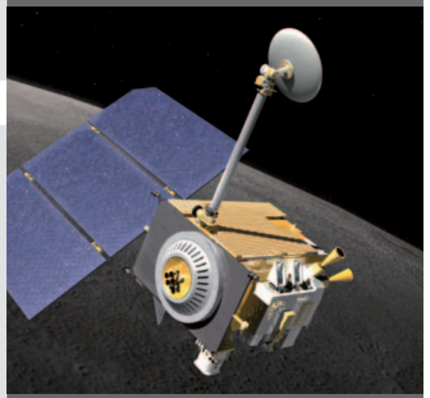
ExoMars rover

Lunar Reconnaissance Orbiter data-handling architecture

The Lunar Reconnaissance Orbiter (LRO) is a NASA mission currently in orbit around the Moon returning images and other scientific data about the lunar surface.

The data-handling architecture of LRO is also similar to the example architecture on page 30. SpaceWire is used to connect the LRO Cameras (Narrow Angle Cameras, NAC1 and NAC2, and Wide Angle Camera, WAC), and Mini-RF radar instrument, to the Command and Data-handling (C&DH) system. SpaceWire is also used to pass data from the Command and Data-handling system to the Ka and S-Band communications systems. Information from the Lyman-Alpha Mapping Project (LAMP) instrument is passed into an input/output board in the C&DH system and then sent over SpaceWire to the C&DH computer/mass memory. The C&DH computer includes a four-port SpaceWire router for handling the SpaceWire communications.





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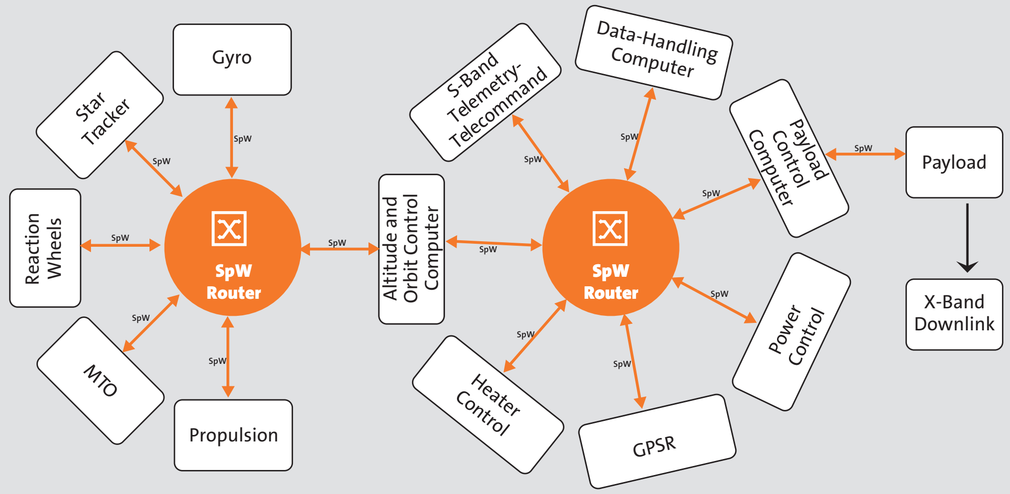
LRO in lunar orbit (NASA)

ASNARO SpaceWire networks

ASNARO is a Japanese optical high-resolution Earth-imaging mission.

ASNARO is being developed by the NEC Corporation and the Japanese Institute for Unmanned Space Experiment Free Flyer (USEF) with funding from the Japanese Ministry of Economy, Trade and Industry. The objective of the ASNARO project is to develop a next-generation high-performance mini-satellite bus system based on open architecture techniques and manufacturing methodologies to drastically reduce the cost and the development period with adoption of up-to-date electronics technologies. SpaceWire is used on ASNARO for all the data-handling. ASNARO uses SpaceWire for platform and attitude and orbit control (AOCS) as well as for payload data-handling. The payload control computer is connected to the payload using SpaceWire. The platform electronics including the data-handling computer, payload computer, attitude and orbit control computer, heater control, GPS receiver, power control and S-band telecommand telemetry unit, are interconnected using a SpaceWire router. A separate SpaceWire network connects the AOCS sensors and actuators to the AOCS computer.



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ASNARO

How SpaceWire works

SpaceWire links

SpaceWire is a point-to-point data link that connects together one SpaceWire node (e.g. an instrument, processor or mass-memory unit) to another node or to a router. Information can be sent in both directions of the link at the same time. Each full-duplex, bidirectional, serial data link can operate at data rates from 2 Mbits/s up to 200 Mbits/s.

SpaceWire provides a simple mechanism for starting a link, keeping the link running, sending data over the link and ensuring that data are only sent when the receiver is ready for it. All data are protected by parity bits and SpaceWire automatically recovers from bit errors on the link.

SpaceWire packets

Information is transferred across a SpaceWire link in distinct packets.

The 'Destination Address' at beginning of the packet contains either the identity of the destination node or a list of characters that defines the path the SpaceWire network to reach to the destination node. The 'Cargo' is the data to be transferred. A packet can contain Cargo with an arbitrary number of data bytes. The EOP, or 'End_of_Packet' marker is the last character in a packet. The data character following an End_of_Packet is the start of the next packet. As shown the SpaceWire packet format is very simple. It is, however, also very powerful, allowing SpaceWire to be used to carry a wide range of application protocols, with minimal overhead.

SpaceWire networks

SpaceWire networks are constructed using SpaceWire point-to-point links and routing switches. SpaceWire routers connect nodes together and provide the means for routing packets from one node to any of the other nodes.

Packet addressing

There are two forms of addressing used to route the packet through a network: path addressing and logical addressing.

Path addressing can best be explained using the analogy of providing directions to someone driving a car. To reach the destination, you might suggest to the driver to take exit 2 at the first roundabout, exit 1 at the next roundabout and finally exit 3 on the third roundabout. There is one direction to follow at each roundabout (take a particular exit). Together these directions describe the path from the initial position to the required destination. Once a direction has been followed it can be dropped from the list.

In a SpaceWire network, the 'roundabouts' are routers and the 'roads' connecting the roundabouts are the links. The list of directions is provided as the destination address. The first direction is followed when the first router is encountered. This direction is given in the first data character that specifies through which port of the router the packet should be forwarded. For instance, if the leading data character is 3, the packet will be forwarded to port 3 of the router. Once the leading data character has been used it is removed because it is no longer needed. This reveals the next data character in the path address to be used at the next router.

Explained using the same analogy of giving directions to a car driver, logical addressing is like saying to the driver, "Follow the signs to City Centre at each of the roundabouts." This, of course, requires appropriate signs to be placed at each roundabout and each destination has to have a name or identifier so that it can be recognised on the signs.

In a SpaceWire network using logical addressing, each node is given an identifier in the range 32 to 254 (e.g. 44 for City Centre). Each router has a routeing table (like the sign at a roundabout) specifying the correct port to be taken to reach a destination.

The leading data character is used to look up the appropriate directions from the routeing table and the packet is forwarded accordingly. For logical addressing the leading data character is not discarded at each router, since it will be needed again at the next router.

Logical addressing has the advantage that only a single address byte is required, but it does require the routing tables to be configured before it can be used. Path addressing requires one byte for each router and does not depend on routing tables in the routers.

Time-codes

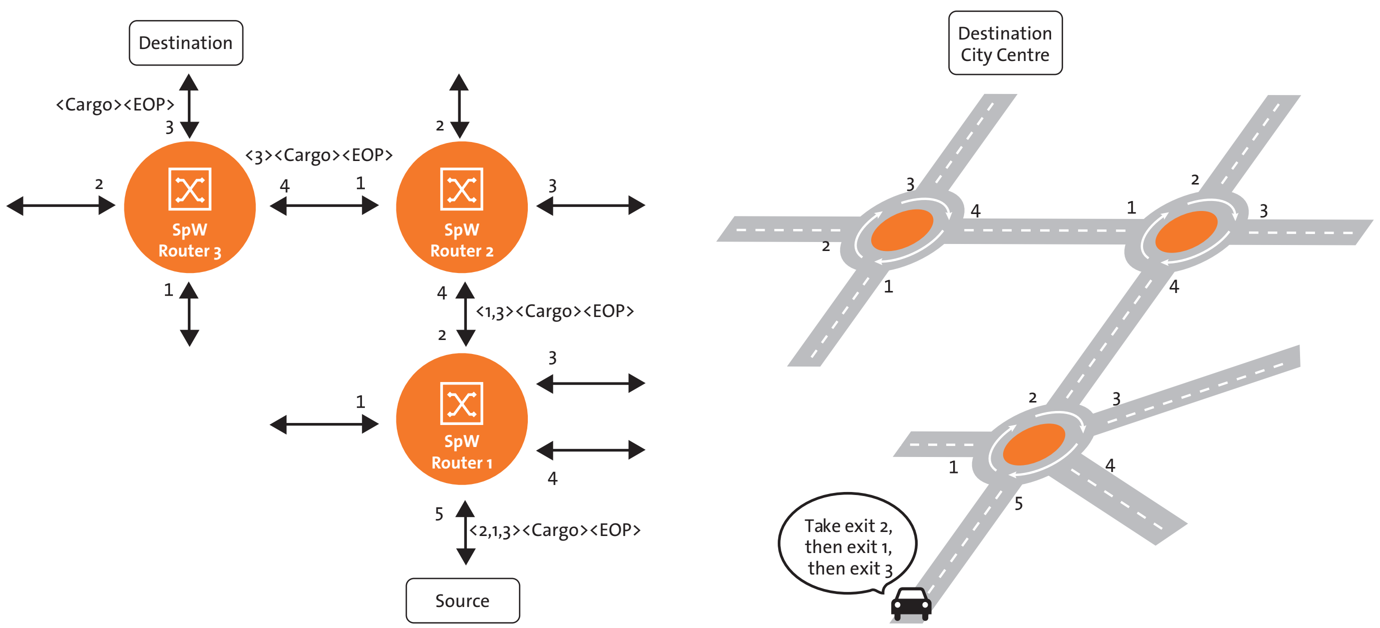
Time-codes are one additional feature of SpaceWire. They provide a means of synchronising units across a SpaceWire system to spacecraft time. The time-codes are broadcast rapidly to all nodes over the SpaceWire network, alleviating the possible need for a separate time distribution network.

Remote Memory Access Protocol

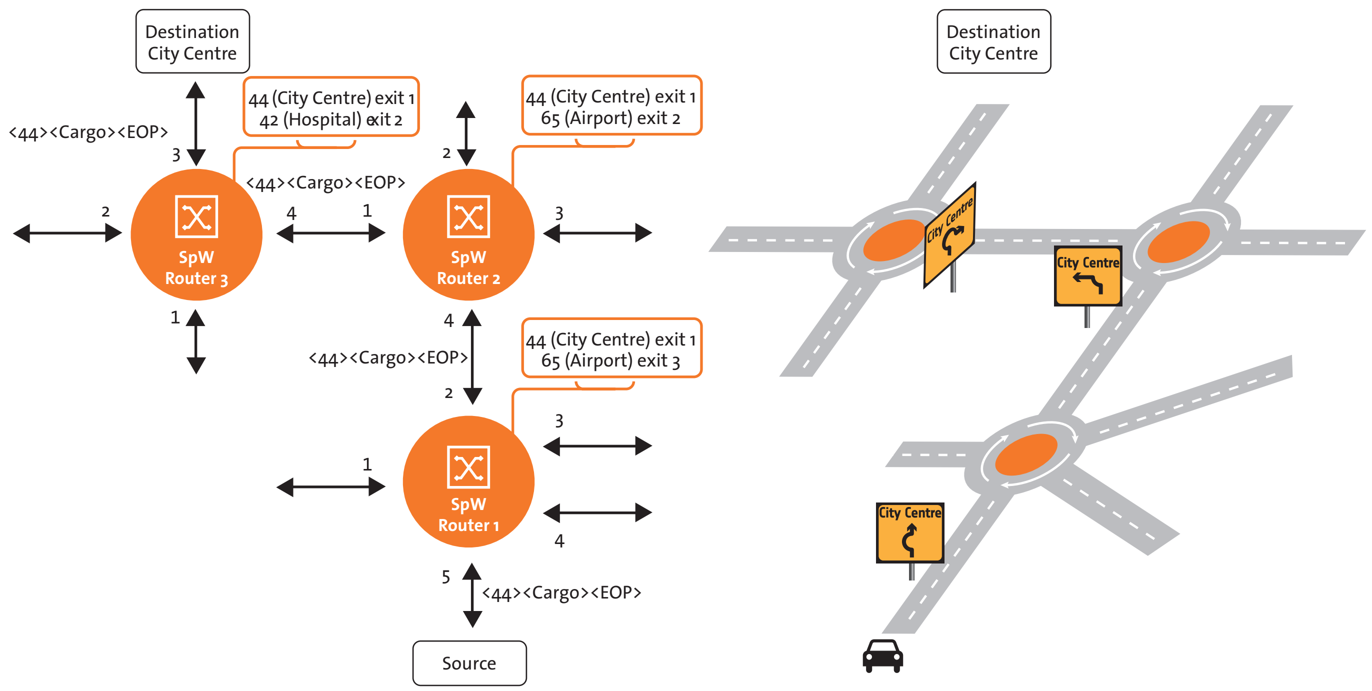
The flexibility of SpaceWire means that it can be used in many different ways to transfer data between nodes and to support other needs such as configuring and controlling an instrument or another type of unit plugged on the network. To avoid unnecessary duplication of effort the SpaceWire Working Group examined common applications of SpaceWire and specified some additional protocols, enabling further standardisation of the on-board data-handing system. The SpaceWire Remote Memory Access Protocol (RMAP), which is specified in ECSS-E-ST-50-52C, is a particularly effective example of one of these protocols operating over SpaceWire.

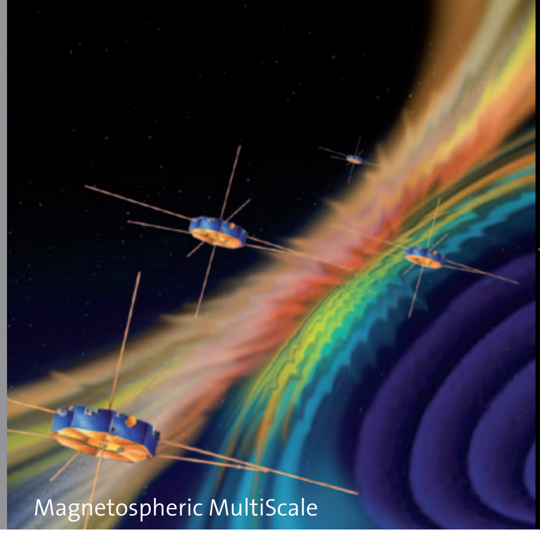
RMAP provides a common mechanism for reading and writing to registers and memory in a remote device through a SpaceWire network. It can be used to configure devices, read housekeeping information, read data from an instrument or mass-memory, as well as writing data from an instrument into a mass-memory. Together RMAP and SpaceWire provide a powerful and versatile combination for spacecraft data-handling.

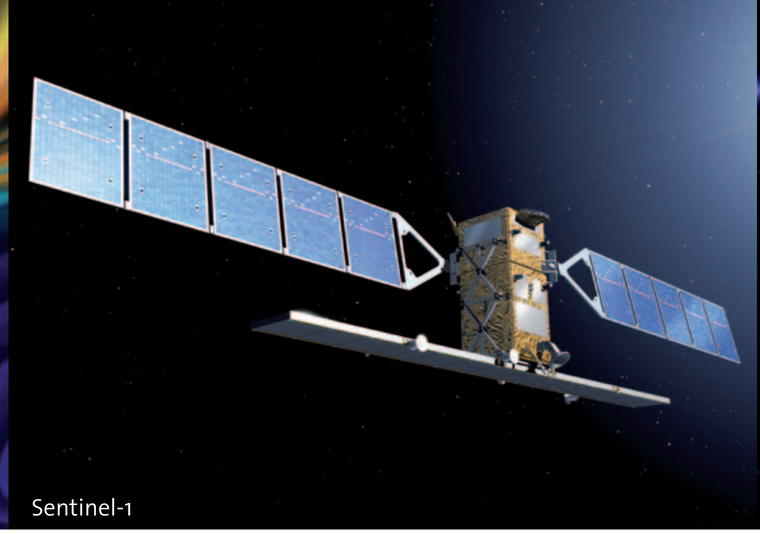
↓ Path addressing, with the analogy of a series of roundabouts, and how the path address at the start of the packet is modified as the packet goes through the network. Since a router can have a maximum of 31 ports along with an internal configuration port, each data character forming a path address is in the range 0 to 31



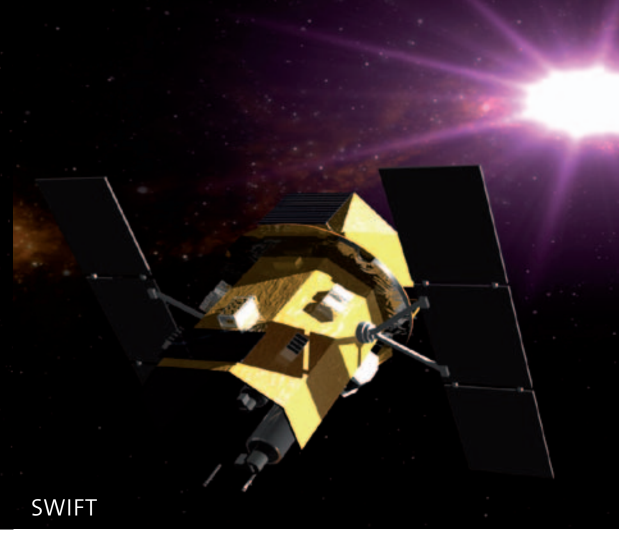
↓ Logical addressing uses just a single data character in the range 32 to 254 so that it does not get confused with path addresses

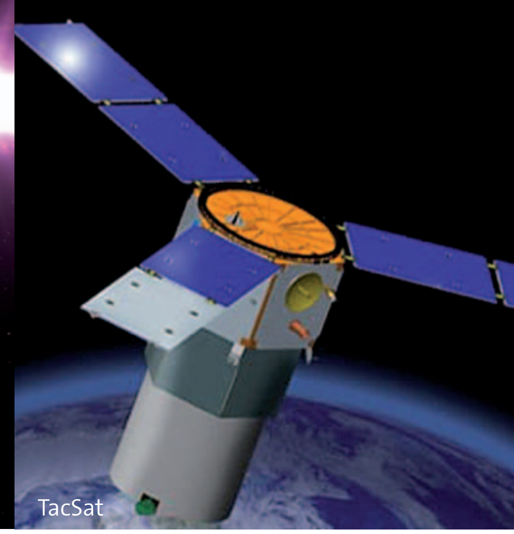



Magnetospheric MultiScale


Sentinel-1


Sentinel-3


SWIFT


TacSat

ESA SpaceWire components and IP cores

To support the development of SpaceWire systems on ESA spacecraft, ESTEC, in Noordwijk (NL), has developed several radiation-tolerant SpaceWire chips and related intellectual property (IP) cores. The IP cores are available from ESA for use on ESA missions and from STAR-Dundee Ltd for other applications. The SpaceWire chips are available from Atmel (FR).

The ESA SpaceWire Interface IP core provides a complete interface to SpaceWire that can be readily implemented in a field-programmable gate array (FPGA) or other chip technology. Fully compliant to the SpaceWire standard, the IP core can be configured to meet the requirements of a wide range of applications. It has a simple interface to a host system, which provides for data input and output, time-code transmission and reception, and link status and error reporting. This IP core is being used in several ESA missions.

SpaceWire RMAP IP Core
There are two ESA SpaceWire Remote Memory Access Protocol (RMAP) IP cores available: one, known as the Initiator, which is used to send RMAP commands and receive replies, and the other, the Target, which receives the RMAP command, reads or writes data from and to memory, and send the result back to the Initiator. The RMAP Target IP core has a highly configurable memory interface so that it can be used in various applications from very simple instruments with registers for control and data access, to complex instruments controlled by a microprocessor.

SpaceWire Router ASIC
The ESA SpW-10X is a complete SpaceWire router in a single chip. It has eight SpaceWire ports each capable of 200 Mbits/s bidirectional data transfer, two bidirectional FIFO ports for connecting to other electronics (e.g. an FPGA or host computer), and an internal configuration port. The SpW-10X supports path and logical addressing, and has several advanced features designed to make the device easy to use in many applications. The SpW-10X was designed for ESA by the University of Dundee, Astrium GmbH and Austrian Aerospace. It is available from Atmel as the AT7910E.

SpaceWire RTC ASIC
The SpaceWire Remote Terminal Controller (RTC) chip is designed to be an instrument controller or a bridge between SpaceWire and the CAN bus. It contains a LEON2-FT SPARC V8 RISC processor with floating-point unit, 64 kB on-chip memory, two SpaceWire interfaces, two CAN bus controllers and various other interfaces. It was designed for ESA by Saab Ericsson Space and Gaisler Research and is available from Atmel as the AT7913E device.

SpaceWire-compliant devices and IP cores are available from numerous suppliers worldwide, demonstrating the popularity of the standard.

International collaboration

SpaceWire has both encouraged international collaboration and, in turn, benefited from that collaboration. The SpaceWire Working Group has been a major vehicle for the development and adoption of SpaceWire. The working group is open to engineers across the world who deal with spacecraft data-handling technology. Current participation includes European, Japanese, Russian and American representatives.

In line with ESA's mandate to promote cooperation in space research and technology, the SpaceWire Working Group is a truly international collaborative body, developing technology, not just for the European states, but also for the benefit of the whole space community. International technical experts meet typically twice a year to develop and review SpaceWire-related standards and trade experience on its application in space systems.

The SpaceWire standard is an open standard developed for anyone to use. It was authored by Steve Parkes, of the University of Dundee, with contributions from many individuals within the SpaceWire Working Group and from the international space agencies and space industry. To ensure the formal nature of the document and its appropriate maintenance, the SpaceWire standard was published by the European Cooperation for Space Standardization (ECSS). A series of standards related to SpaceWire including RMAP have been and are being written and incorporated in the body of space standards from the ECSS. While the ECSS is a European organisation, it provides standards that support international cooperation, of which the SpaceWire standard (ECSS-E-ST-50-12C) is a prime example.

→ SpaceWire Conference 2011

The fourth SpaceWire conference will be hosted by NASA and held in San Antonio, USA, in 8–10 November 2011.

SpaceWire conferences bring together product designers, hardware engineers, software engineers, system developers and mission specialists, interested in and working with SpaceWire, to share the latest ideas and developments. Conferences are targeted at the whole SpaceWire community including both academics and industrialists. To support international collaboration and the exchange of ideas, experiences and technologies, the first International SpaceWire Conference was held in Dundee in 2007. Building on the success of this initial conference, SpaceWire 2008 was hosted by JAXA in Nara, Japan, and SpaceWire 2010 by Roscosmos in St Petersburg, Russia.

http://2011.spacewire-conference.org

Future

The SpaceWire Working Group is working on two new protocols for SpaceWire. The first is SpaceWire-D, which will provide deterministic data delivery over SpaceWire, making it suitable for AOCS-type applications. The second is SpaceWire-PnP, which will provide a common mechanism for configuring SpaceWire units and for automatic detection when a device is connected to the SpaceWire network. The standard specifies a very robust and therefore high-mass cable. ESA is developing a low-mass SpaceWire cable which aims to be around half of the mass of the existing cable, without a significant change in performance.

Research and technology development has also started on the next generation of SpaceWire technology. SpaceFibre is the spearhead of this development. While being fully compatible to SpaceWire on packet level, it will provide data rates of at least ten times that of SpaceWire, reduce the cable mass by a factor of four and provide galvanic isolation. SpaceFibre will be able to operate over fibre-optic and copper cable and support data rates of at least 2.5 Gbit/s. ■


↑ Attendees of the first SpaceWire conference in Dundee, including many members of the SpaceWire Working Group

Acknowledgements

The authors would like to acknowledge the contributions to SpaceWire from many individuals and organisations across the world. In particular, we would like to express our thanks to the members of the SpaceWire Working Group, who have reviewed and commented on the various SpaceWire standards as they were developed. This extends as well to an even larger community of users and suppliers of SpaceWire technologies.