



STAR-Dundee

SpaceWire and SpaceFibre Expertise

SpaceFibre Router IP Core

The STAR-Dundee SpaceFibre Routing Switch IP Core (or *SpFi Router IP Core* for short) provides an extremely flexible SpaceFibre routing switch comprising several SpaceFibre Single-Lane or Multi-Lane interfaces and a fully configurable, non-blocking, high performance routing switch.

The SpaceFibre router supports up to 64 virtual networks that behave like independent SpaceWire networks working at multi-gigabit rates. The virtual networks can be set statically through programming and can be dynamically modified, via any router port, using the internal configuration port and the RMAP protocol.

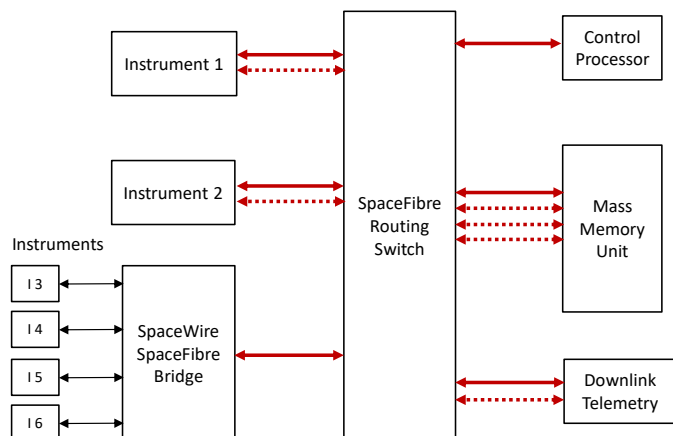
The IP Core is optimised for high-performance radiation-tolerant FPGAs using any number of lanes and virtual channels per port, each with its own quality of service parameters. The IP Core can also be implemented in radiation-tolerant ASIC technologies.

SpaceFibre Networks

SpaceFibre (SpFi) is a very high-speed serial link designed specifically for use onboard spacecraft (ECSS-E-ST-50-11C). SpaceFibre supports multi-laning, allowing several SpaceFibre lanes to operate in parallel to provide higher data throughput and graceful degradation in the event of permanent lane failure. SpaceFibre carries SpaceWire packets over virtual channels (VCs) and provides a low latency broadcast feature similar to SpaceWire time-codes but offering much more capability. SpaceFibre is compatible with the packet level of the SpaceWire standard (ECSS-E-ST-50-12C).

The SpaceFibre network layer is responsible for transferring packets over a SpaceFibre link or network. The information to be sent is packaged in the same format as SpaceWire: <Destination Address> <Cargo> <End of Packet Marker>. SpaceFibre also uses the same routing concepts as SpaceWire, including both path and logical addressing.

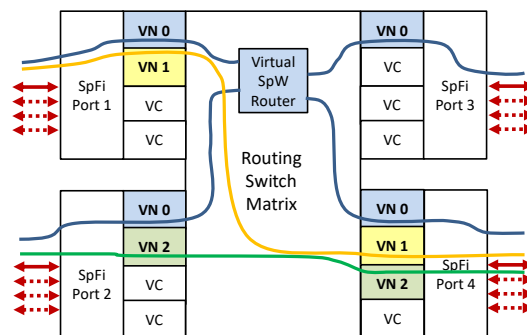
The following figure shows an example onboard network using SpaceFibre. The dotted lines represent additional lanes that could potentially be used to increase the available bandwidth for some of the SpaceFibre ports. Up to 8 lanes are supported by each SpaceFibre port.



The control processor is used to configure and control all on-board data-handling equipment. It therefore needs a connection to every instrument and to the mass memory. This could be provided using a separate command and control network, but it would result in additional mass and power consumption. The addition of a SpaceFibre router connected to all of the on-board equipment allows the control processor to send commands and receive information from all of the on-board data handling units.

Each SpaceFibre link implements multiple virtual channels, each one with specific quality of service parameters. For example, the bandwidth allocation parameter of each virtual channel can be set to the expected bandwidth of each instrument, so they do not interfere with one another or with the control network. Virtual Networks (VNs) are built from the interconnection between virtual channels of different ports. These operate like SpaceWire networks.

The next figure shows an example of how the control network and two instrument data flows are assigned to virtual networks in the top four ports of the previous SpaceFibre router. The number of lanes per SpaceFibre link is individually configurable.



Router Architecture

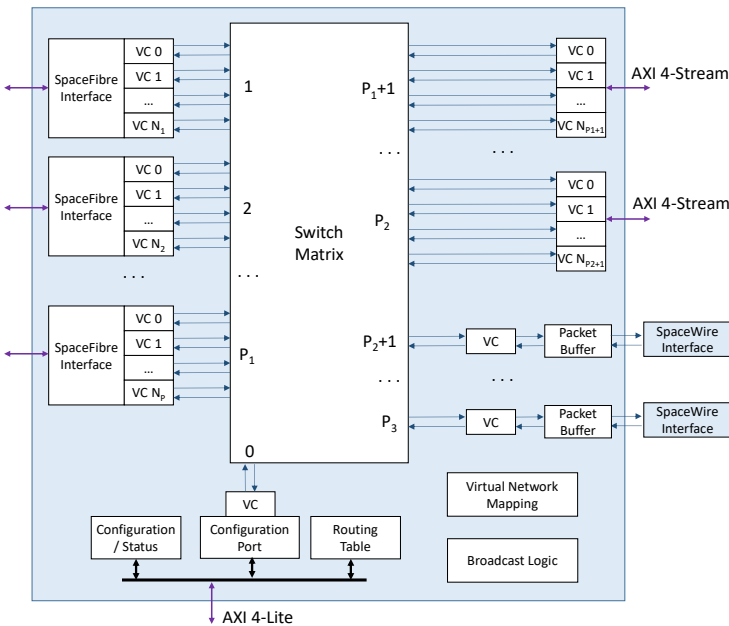
The router architecture is built around a non-blocking routing switch matrix with a configurable number of ports. Each port implements several virtual channels. Each virtual channel has an associated virtual network number. Each port has a configurable number of lanes, with either one (Single-Lane) or any value between 2 and 8 (Multi-Lane) supported.

The switch matrix interconnects one or more virtual channels with the same virtual network number. Each of these virtual channels must be located in a different port.

When a packet arrives on a virtual channel, the output port is selected using path or logical addressing, indicated by the leading byte of each packet and the configuration of the internal routing table. The virtual channel in the output port that has the same virtual network number is selected. If the output port does not have a virtual channel with the same virtual network number, the packet is spilled.

Packets belonging to different virtual networks never interfere with each other and do not impact throughput or latency within the routing switch matrix. On the other hand, when multiple packets in the same virtual network need to be transferred to the same output port, packet-by-packet, round-robin arbitration is performed, like in a SpaceWire router.

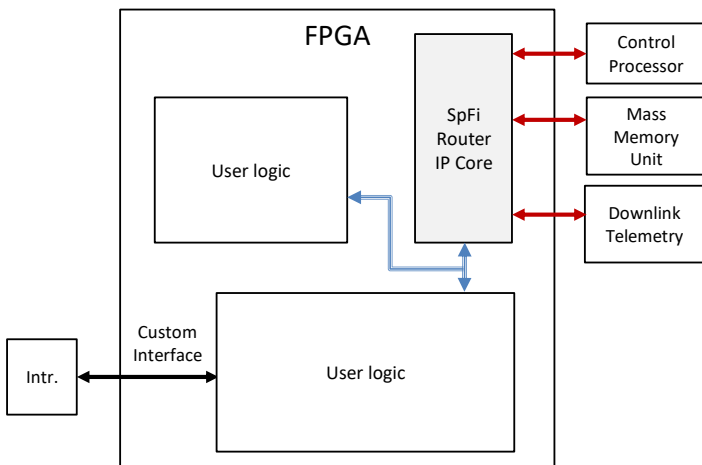
The next figure shows the simplified SpaceFibre Router IP architecture, with a configurable number of ports. The SpaceWire ports only have associated a single VC but have additional buffering resources. The configuration port implements the RMAP protocol to configure the Routing Table, the virtual networks, and the SpaceFibre and SpaceWire interfaces.



Example Use Cases

The high flexibility of the SpaceFibre Router IP Core ensures different user needs can be accommodated with ease. Two examples of very different use cases are presented below.

The following figure shows a small 4-port SpaceFibre router with statically configured virtual network settings. Most of the FPGA resources are available for user logic, which interfaces to the SpaceFibre Router using one or more virtual channels of the same internal AXI4-Stream port. This solution enables the addition of SpaceFibre routing capabilities to a data handling network using the same FPGA that is dedicated to controlling a high-speed instrument, for example.

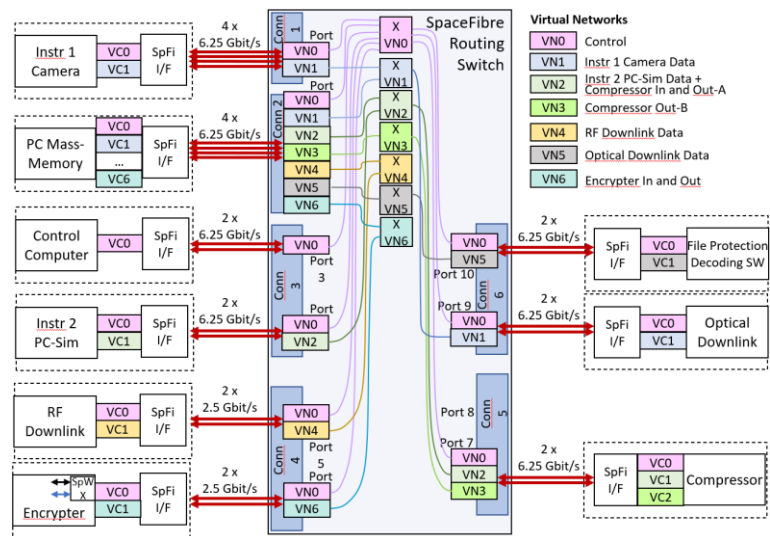


Hi-SIDE

The Hi-SIDE project is a European Union project successfully completed by several leading aerospace organisations from across Europe. It received the Innovation in Space Award 2022 at the European Space Forum, recognising the contribution of Hi-SIDE to the advancement of on-board data handling and high-speed data transfer for future Earth Observation missions. Hi-SIDE has made substantial advances in the major elements of the data chain including networking, processing, compression, and downlink transmission to support the next generation of data intensive missions.

The different data chain elements are interconnected via a SpaceFibre network, with a SpaceFibre multi-lane router at the heart of this network. This router, implemented in a Kintex UltraScale FPGA, is used for transferring data at high data-rates between instruments, mass-memory, data compressor, data processor and downlink transmitters. It is also used to provide the control network, which the control computer employs to manage both the network and the equipment attached to it. The router has 10 SpaceFibre ports, with two 4-lane and eight 2-lane ports, all with configurable lane rates of up to 6.25 Gbit/s. This gives full-duplex user data rates of 19.2 Gbit/s for the 4-lane ports.

The various elements of the on-board data chain are shown on the left and right sides of the next diagram interconnected via SpaceFibre links (red lines) to the routing switch in the middle. Each element contains a SpaceFibre interface which connects it to the SpaceFibre network. The interfaces are either quad-lane or dual-lane interfaces and have two or more virtual channels which are mapped by the router to virtual networks. The virtual networks are colour coded and a key to the type of traffic they handle is shown. The configured virtual networks are also illustrated inside the SpaceFibre routing switch (X = virtual network switch).



The next figure shows a picture of the Hi-SIDE SpaceFibre Router (108 x 108 x 68 mm) developed using STAR-Dundee's SpaceFibre Router IP.



IP Core Features

The STAR-Dundee SpaceFibre Router IP core has the following features:

- Compliant with the SpaceFibre standard, including the SpaceFibre network layer (**ECSS-E-ST-50-11C**).
- Technology independent (FPGA or ASIC) and optimised for radiation-hardened FPGAs.
- Configurable number of SpaceFibre, SpaceWire and internal (AXI4-Stream) ports (up to 32).
- Configurable target technology (RTG4, PolarFire, UltraScale, Versal, Arria, Certus, generic options) for memory blocks and SerDes interface.
- Includes the SpaceFibre Interface IP.
- Each SpaceFibre port allows configuring:
 - Its number of Virtual Channels (up to 32).
 - Its number of lanes (up to 8), thus supporting Single-Lane and Multi-Lane operation.
 - Its lane rate.
- Configuration registers can be accessed via a configuration port (Port 0) using the RMAP protocol or using a dedicated AXI4-Lite interface.
- High performance, full non-blocking switch matrix with deterministic switching latency.
 - Virtual networks do not share any switching resources.
 - Supports up to 64 virtual networks that can be statically or dynamically configured.
 - Each virtual channel of each port can be configured to belong to any virtual network.
- Round-robin arbitration with configurable watchdog timeout for packets in the same virtual network requesting the same output port.
- SpaceWire/SpaceFibre network capabilities such as path and logical addressing with a routing table.
- Up to 256 broadcast channels with higher priority for time-critical broadcast messages.
- Simple and efficient integration with SpaceWire networks using SpaceWire packet buffers and automatic SpaceWire-to-SpaceFibre broadcast/time-code translation.
- An internal timer tracks time being distributed over the network.
- Supports lane rates of up to 3.125 Gbit/s in RTG4 and more than 6.25 Gbit/s in PolarFire, Kintex UltraScale or Versal.
- Designed by the team who created the SpaceFibre standard.

Resource Usage and Performance

The actual resources that the complete SpaceFibre Router design uses depend on the FPGA and the specific user configuration. The tables below show the percentage of total resource usage for different numbers of SpaceFibre ports with different numbers of lanes and virtual channels (VCs). The values in the tables include the SpaceFibre Interfaces, the RMAP configuration port and the configuration registers.

		RTG4			XQRKU060 ¹		
		LUT	DFF	RAM	LUT	DFF	RAM
1 L	4 SpFi / 2 VCs	17.5%	16.9%	17.2%	4.7%	3.8%	3.5%
	8 SpFi / 4 VCs	56.0%	49.0%	57.4%	15.3%	11.1%	11.3%
2 L	4 SpFi / 2 VCs	30.2%	28.3%	30.1%	7.1%	5.8%	6.2%
	8 SpFi / 4 VCs	87.6%	74.1%	97.1%	21.7%	15.6%	19.5%
4 L	4 SpFi / 2 VCs	51.1%	44.6%	54.1%	12.7%	8.8%	8.5%
	8 SpFi / 4 VCs	-	-	-	35.4%	22.6%	27.0%

		RTPF500T ¹			XQRVC1902 ¹		
		LUT	DFF	RAM	LUT	DFF	RAM
1 L	4 SpFi / 2 VCs	5.4%	5.2%	4.7%	1.6%	1.4%	3.9%
	8 SpFi / 4 VCs	17.5%	15.3%	15.8%	5.3%	4.1%	12.6%
2 L	4 SpFi / 2 VCs	8.5%	7.8%	6.5%	2.4%	2.1%	6.9%
	8 SpFi / 4 VCs	26.0%	21.2%	21.3%	7.2%	5.8%	21.8%
4 L	4 SpFi / 2 VCs	13.9%	12.1%	9.8%	3.8%	3.2%	9.5%
	8 SpFi / 4 VCs	40.3%	31.1%	31.9%	11.1%	8.3%	30.2%

¹ TMR not included

For information about resource usage with other configurations, please contact STAR-Dundee Support (support@star-dundee.com).

IP Core Delivery Files

The STAR-Dundee SpaceFibre Router IP Core comes with reference designs for RTG4 and PolarFire (Libero), Kintex UltraScale and Versal (Vivado) that can be directly implemented in the FPGA for easy adoption. Other technologies can be supplied upon request. A comprehensive end user test bench for ModelSim/Quarta simulators is also provided.

Licensing

The STAR-Dundee SpaceFibre Router IP Core is available under license. For more information on IP cores, licensing, or for specific or custom requirements, please contact enquiries@star-dundee.com.

All information provided is believed to be accurate at time of publication. Please contact STAR-Dundee for the most recent details. © 2024 STAR-Dundee Ltd.



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