A New Generation of SpaceWire Test and Development Equipment

SpaceWire Test and Verification, Long Paper

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***Abstract*—STAR-Dundee recently released a number of new SpaceWire test and development products based on a single hardware platform and supported by a single software platform. This paper will describe the modular design that makes this possible and the advantages, both to STAR-Dundee and to users, of this system.**

***Index Terms*—SpaceWire, SpaceFibre, STAR-Dundee, PXI, cPCI, PXIe, Interface, Router, STAR-System**

I. Introduction

STAR-Dundee has recently released a number of new SpaceWire test and development products based on a single hardware platform, using modular FPGA designs, and supported by a single software platform. The hardware, FPGA and software platforms each make use of a modular design, which allows different features to be included in a number of unique products.

This modular combination allows STAR-Dundee to quickly develop new products to support common requirements for SpaceWire and SpaceFibre test and development equipment. In addition, it provides a framework to explore new concepts without requiring completely new hardware, FPGA code and software to be developed.

This paper describes the hardware, FPGA and software modules which make up this system, and how they themselves have benefited from reusing previous developments. It then describes some of the products that have been released using this platform, and some of the projects that have used the platform to quickly develop devices to test out new technologies. The paper concludes with information on some new products being developed using the modules described.

II. Hardware Platform

To enable this modular system, a new hardware platform was developed. The STAR-Dundee PXI hardware platform has a CompactPCI (cPCI) connector at the rear. This allows the device to be used in cPCI, PXI and PXI Express (PXIe) racks. A photograph of the hardware platform is shown in Fig. 1.

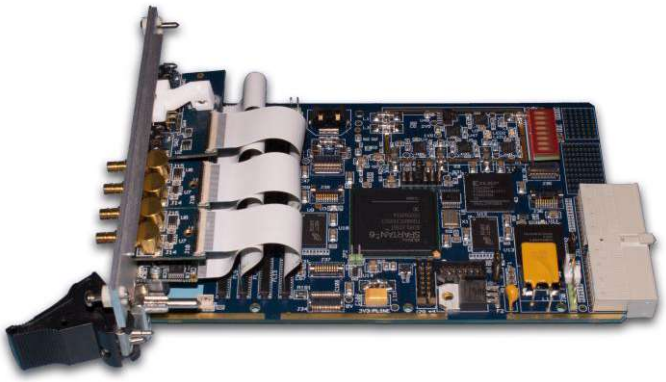

Fig. 1. STAR-Dundee PXI hardware platform

The hardware platform has been designed to support a number of different interfaces on the front panel, not only SpaceWire. The platform has sockets for sixteen flexi connectors, to which a number of different supported flexi interfaces can be connected and made available to users on the front panel of the device. The interfaces which can be connected currently include:

- SpaceWire ports
- SpaceFibre ports
- CAN bus ports
- JTAG ports
- USB UART ports
- GPIO ports
- SD card slots
- SMB trigger connectors
- Switches
- Push buttons

Other new interfaces can be developed and connected in the same way. Each interface includes LEDs which can be used to indicate status. For example, the SpaceWire interfaces have one LED which indicates whether packets are being transmitted, and another to indicate whether packets are being received. These LEDs can also be used to indicate errors.

Supporting each of these interface types allows devices to be created with a mixture of interfaces, for example a SpaceWire to SpaceFibre bridge or a device with multiple

SpaceWire ports and triggers, switches and buttons for triggering events.

Front panels must be manufactured to support the specified interfaces, but for internal developments or during prototyping these front panels can be quickly produced using a 3D printer. The PXI card is a 3U (rack Units) card, and the front panels are 3U high, with 6U versions available. The width of most front panels developed so far is 8HP (Horizontal Pitch), but larger or smaller widths such as 12HP or 4HP front panels can also be developed if required.

III. Reusable FPGA Modules

To support each of the interfaces which can be included in the hardware platform, FPGA modules have been developed for each interface. A number of these modules were developed for previous STAR-Dundee devices, or are modifications of existing STAR-Dundee FPGA modules.

Similarly, a module is required to interface with software over the cPCI interface. This is an existing module and provides the same interface as other STAR-Dundee devices such as the SpaceWire cPCI Mk2 [1], an older device with a cPCI interface. As well as minimising the FPGA development, this also reduces the software development required to support the PXI devices.

In addition to FPGA modules to support the device's interfaces, there are also FPGA modules to provide additional functionality within the device. For example, SpaceWire and SpaceFibre devices can include interface and/or router functionality. Other more advanced features that can be included are error injection on SpaceWire links, triggering on events and an RMAP (Remote Memory Access Protocol) target.

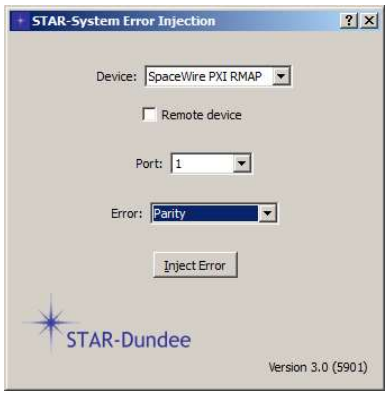

Fig. 2. STAR-System Error Injection application screenshot

IV. STAR-System Software

The STAR-Dundee STAR-System software suite [1][3] was developed prior to the PXI hardware platform. It provides a full software suite supporting all STAR-Dundee devices developed since 2012. At the bottom level it includes drivers for accessing each of the supported device types in the supported operating system. Above this are APIs for accessing these devices in software. At the top level STAR-System includes a number of console and Graphical User Interface (GUI) applications for accessing the devices. These include applications to transmit and receive packets and time-codes, configure the devices and inject errors. A screenshot of the STAR-System Error Injection application is shown in Fig. 2., while the Device Configuration application is shown in Fig. 3.

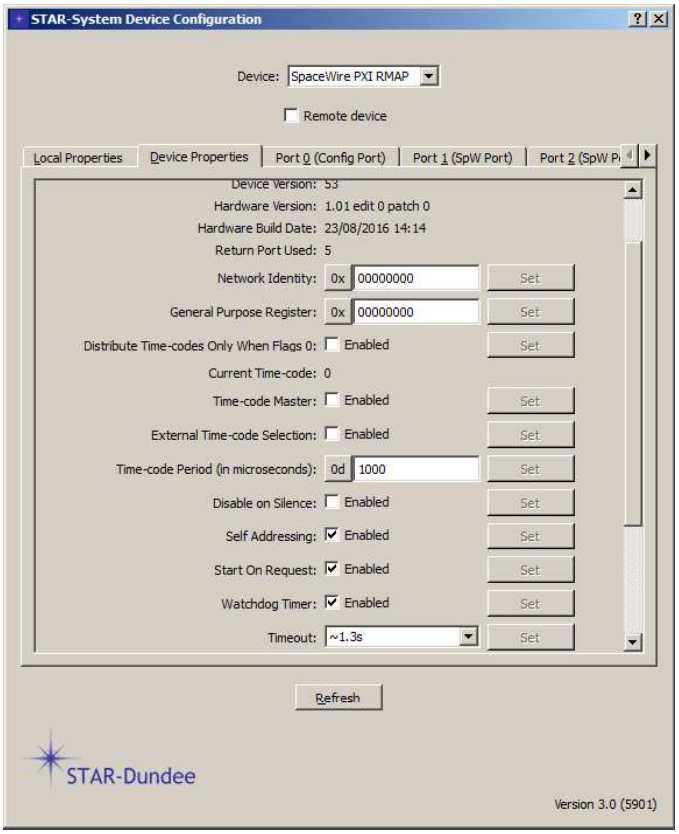

Fig. 3. STAR-System Device Configuration application screenshot

As the PXI devices use the same FPGA interface that is used in previous STAR-Dundee cPCI devices, the only modification required to the STAR-System drivers to support the PXI devices was to update the STAR-System PCI Driver to add support for the device identifiers used by each of the PXI products. Similarly the APIs were updated to include identifiers for each of the new products. No changes were required to the console and GUI applications, as these applications obtain device information from the APIs and drivers.

To support the unique features of the PXI devices, some additions were required to STAR-System. A new RMAP Target API was added to support PXI devices which contain an RMAP target. This API contains functions to configure the target, such as which commands are to be supported, and to receive notifications whenever an RMAP operation is performed. A Trigger API was also added to configure actions to be performed when specific events occur on devices supporting the triggering functionality. This is a powerful feature which can be used, for example, to transmit packets or time-codes when a particular event occurs, such as a time-code being received, an external trigger or a time period elapsing.

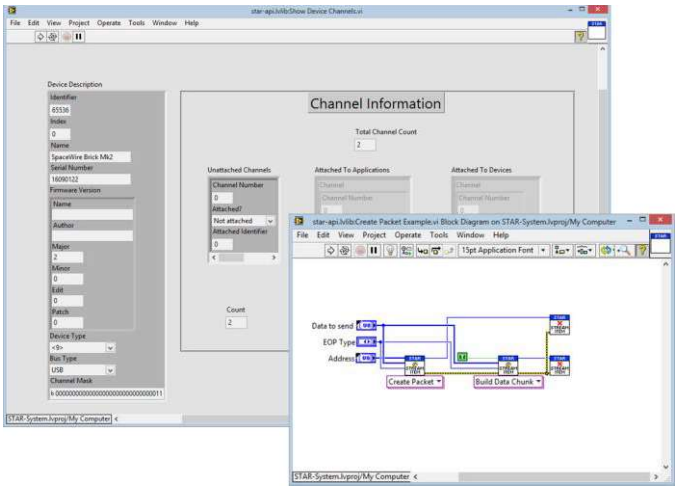

Fig. 4. STAR-System for LabVIEW screenshot

A. LabVIEW

Two options are available for using STAR-System devices with National Instruments' LabVIEW environment: a Windows LabVIEW Wrapper for STAR-System [4] and a LabVIEW VISA Driver [5]. A screenshot of the LabVIEW Wrapper is shown in Fig. 4. This Wrapper provides all the functionality of STAR-System within LabVIEW on Windows operating systems, while the VISA Driver offers lower level access to the device on any LabVIEW supported operating system.

As LabVIEW is often used on PXI systems, it was important to support the PXI products in both of STAR-Dundee's LabVIEW products. The VISA Driver required only minor modifications to support the additional device types. The LabVIEW Wrapper required similar modifications to support the additional device types, plus new modules to support each of the new APIs added to access the new functionality provided by some of the PXI devices.

V. PXI PRODUCTS

With the hardware, FPGA and software building blocks in place, these were then combined in to a number of different products, described below.

A. SpaceWire PXI Interface

The SpaceWire PXI Interface device [6], shown in Fig. 5., provides four SpaceWire ports, four SMB triggers, two push buttons and two switches on the front panel. The FPGA includes support for both interface and router modes, so the device can be used to explore SpaceWire routing, as well as transmitting and receiving directly on each of the four SpaceWire ports.

The inclusion of trigger connectors allows the device to make full use of the triggering functionality included in the FPGA, and supported in the STAR-System Trigger API. The Trigger API allows actions to be specified which will occur when specific events occur. The events include:

- An external trigger
- A valid time-code being received
- A counter being decremented or reaching zero
- An internal trigger
- A port event, including:
    - Receiving a start of packet
    - Receiving an End Of Packet (EOP)
    - Receiving an Error End of Packet (EEP)
    - Transmitting a start of packet
    - Transmitting an EOP
    - Packet available to be transmitted
    - Port running
    - Port encounters an error
    - Port disconnects
    - Port receives a time-code
    - Port transmits a time-code

The counter event can be used to delay a trigger for a specified period of time, or to trigger once a specified number of triggers have occurred.

The actions include:

- Output an external trigger
- Start or stop a counter
- Transmit a time-code
- A port action, including:
    - Transmit a queued packet
    - Disconnect the port
    - Inject a parity or escape error
    - Insert or suppress a Flow Control Token (FCT)
    - Increment or decrement credit

The combination of these actions and events allows very powerful control of the traffic on a SpaceWire link. There are numerous possibilities and users have been putting them to good use. One common use is to periodically transmit packets sent to the device from software, out of one or more SpaceWire ports. This provides deterministic behaviour while using a non-real-time operating system such as Windows.

Fig. 5. STAR-Dundee PXI Interface device

B. SpaceWire PXI Interface with RMAP Target

The SpaceWire PXI Interface with RMAP Target [6] demonstrates how a new product can be created with existing hardware. The device uses the same connectors and front panel as the SpaceWire PXI Interface, but in addition to the functionality provided with the SpaceWire PXI Interface, it also includes an FPGA module which provides four RMAP targets. An additional software API in STAR-System provides access to this functionality.

The RMAP Target module supports multiple targets, each of which can be configured to restrict the RMAP commands that are to be supported by that target. Authorisation of commands can be performed automatically by the device, or each command can be passed to software for authorisation. The properties that can be used when configuring automatic authorisation include:

- A logical address range
- A protocol ID
- Supported commands
- A key range
- A memory address range

A target can also be configured to notify software whenever a command is received and/or completed, while the memory on the device can be read or written from software. This provides a powerful system for testing of RMAP initiators and simulating RMAP targets, which can be setup very quickly.

C. SpaceWire PXI Router

The 16 flexi connectors on the STAR-Dundee PXI platform allow large SpaceWire routers to be created. The SpaceWire PXI Router [6] includes 12 SpaceWire ports, in order to fit all the ports in the 8HP front panel.

As with the PXI Interface devices, the SpaceWire PXI Router includes both interface and router modes, along with other features such as triggering support, although there are no external triggers on this device.

The SpaceWire PXI Router can therefore be used for similar purposes to the SpaceWire PXI Interface devices, while also offering the ability to explore and test SpaceWire routing with a large number of ports.

Fig. 6. STAR-Dundee PXI Router device

Fig. 7. STAR-Dundee SpaceWire Recorder

D. SpaceWire Recorder

The STAR-Dundee SpaceWire Recorder [7] is a rack system with a 1 Terabyte Solid-State Drive (SSD), which can record the SpaceWire traffic crossing up to four SpaceWire links. The large SSD allows the traffic crossing a network to be recorded for a much longer period of time than with a device such as the SpaceWire Link Analyser Mk2 [8], which makes use of internal memory for storage.

The SpaceWire Recorder rack, shown in Fig. 7., includes a SpaceWire Recorder PXI device to allow four SpaceWire ports to be monitored. This uses a front panel which is similar to the SpaceWire PXI Interface devices with four external triggers, two push buttons and two switches. The only difference is that the SpaceWire Recorder PXI includes eight SpaceWire ports.

The functionality provided by the FPGA of the SpaceWire Recorder PXI device is very different to that provided by the SpaceWire Interface and Router devices. It must transparently monitor the traffic passing between two ports, and provide this to software to be recorded. Some of the modules required to support this functionality were already available within STAR-Dundee's other products, however. For example, the SpaceWire Link Analyser Mk2 provides similar functionality, so some of this code was reused.

The software provided with the SpaceWire Recorder required much more development, however. Adding support for the device to STAR-System was a simple task, but the software to provide the functionality specific to the SpaceWire Recorder required considerably more development. This software must record the traffic to the SSD at very high speeds. It must then display the very large recordings to the user, working within the restrictions of the PC's limited memory.

Despite its unique nature, by using the SpaceWire PXI platform and other existing modules, the SpaceWire Recorder was developed in a very short time period, with a large percentage of that effort being focused on software development. The resulting product can be used to view the traffic crossing a SpaceWire network over large periods of time, quickly find errors, data patterns and time-codes, and can be an invaluable tool when debugging issues with a SpaceWire network.

VI. Projects Using PXI Devices

The PXI platform is of huge benefit for one-off developments, for example when developing devices for research projects. Devices can be quickly created using existing interfaces, or new interfaces can be developed in a relatively short period of time and added to the existing platform. Two projects which have benefited in this way are described below.

A. SpaceWire-D

As part of an ESA project on deterministic SpaceWire, the University of Dundee was required to produce a system demonstrating the capabilities of the SpaceWire-D protocol [9]. STAR-Dundee was given the task of developing a rack system with two routers, multiple RMAP targets, and two processors with SpaceWire interfaces acting as the RMAP initiators. The resulting SpaceWire-D Demonstration System is shown in Fig. 8.

In the Demonstration System, four SpaceWire PXI Interfaces with RMAP Targets are used to simulate as many as 16 RMAP targets. Two SpaceWire PXI Routers route traffic between the initiators and the targets.

The two RMAP initiators are provided by custom PXI devices. Unlike other STAR-Dundee PXI devices, these have a 12HP front panel. This allows nine SpaceWire ports to be included, three USB UARTs, four SMB triggers, two push buttons and two switches. The FPGA on these devices is also a custom development, which includes a LEON2 processor.

The University of Dundee was then able to use the RTEMS operating system on the initiators, and develop the SpaceWire-D initiator software to run on these boards. Software was also developed to run on the Windows operating system, using STAR-System and its RMAP Target API, to configure the routers and configure and monitor the RMAP targets.

The PXI hardware platform enabled this system to be developed in considerably less time than would have otherwise been possible, allowing University of Dundee to concentrate on the research and development of the SpaceWire-D software.

Fig. 8. SpaceWire-D Demonstration System

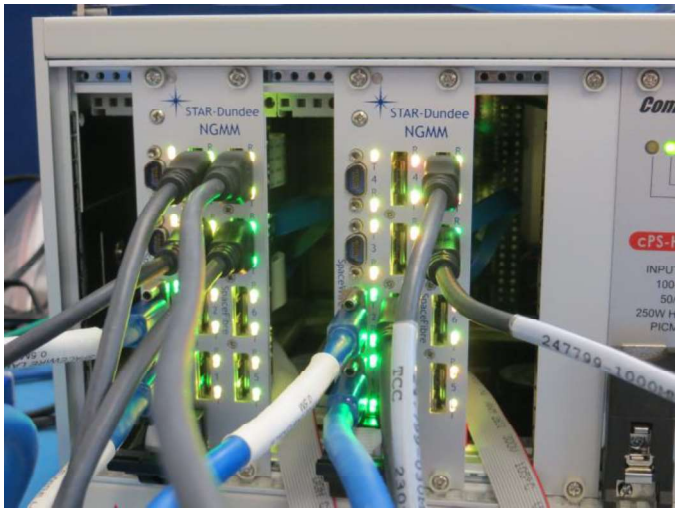

Fig. 9. SUNRISE router devices routing SpaceFibre and SpaceWire packets

B. SUNRISE

STAR-Dundee has been leading the development of SpaceFibre, and has been working on the development of a SpaceFibre Router under a Centre for Earth Observation Instrumentation and Space Technology (CEOI-ST) activity called SUNRISE.

The hardware for the SUNRISE SpaceFibre Routers is provided by the PXI platform. It makes use of the SpaceWire and SpaceFibre interfaces, including eight SpaceFibre ports and four SpaceWire ports. Two SUNRISE routers are shown in Fig. 9. routing traffic between SpaceWire and SpaceFibre ports.

The PXI hardware platform allowed devices to quickly be created so that work could instead focus on the core objective of the activity: developing the FPGA module to perform SpaceFibre routing. This has been a very successful project and resulted in the development of the first ever SpaceFibre router, enabled by the PXI platform.

VII. Conclusion

This paper has described the building blocks that make up the STAR-Dundee PXI products, and has shown how these hardware, FPGA and software modules can be used to produce a wide range of products while also providing a platform for prototyping and experimentation.

Work is continuing on this platform, and more products will be released, as a result of FPGA and software additions, with new front panels designed when required. Potential future products include a SpaceFibre interface device and a SpaceWire to SpaceFibre bridge.

There is work also being performed at STAR-Dundee in a slightly different direction, to take advantage of the existing interface boards, software and FPGA modules. A new hardware platform has been developed with a PXIe connector at the rear, but using the existing front panel interfaces. This platform includes a Microsemi RTG4 FPGA – a flash-based radiation tolerant FPGA. The PXIe-RTG4 platform, shown in Fig. 10., offers the same flexibility as the PXI platform, while

providing a high quality engineering prototype board for the development of RTG4 applications.

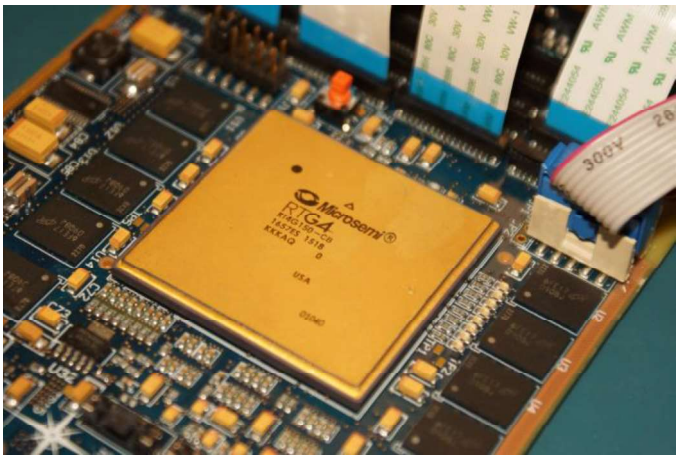

Fig. 10. STAR-Dundee PXIe-RTG4 device

The PXI hardware platform, reusable FPGA modules and STAR-System software suite provide a powerful combination which enables STAR-Dundee to develop bespoke products to meet customers' requirements. With the possibility of alternative hardware platforms, additional interfaces and new FPGA and software modules, the platform will continue to be developed as new requirements are identified which cannot be met with the existing system.

ACKNOWLEDGMENT

The STAR-Dundee PXI platform is the result of a combined effort between STAR-Dundee's PCB, mechanical, electronics, FPGA and software engineers. The authors would like to acknowledge the efforts and input of the STAR-Dundee engineers not listed as co-authors.

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