High Speed Test and Development with the SpaceWire Brick Mk3

Test & Verification 1, Short Paper

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***Abstract*—The original STAR-Dundee SpaceWire-USB Brick has provided a simple yet powerful interface to SpaceWire networks for a number of years. STAR-Dundee's SpaceWire Brick Mk3 provides all the features of the original Brick, but with better performance, better software, better documentation and the same high quality support. It will replace the Brick with a product which can be used to very easily perform numerous SpaceWire test and development activities, and at very high speeds.**

***Index Terms*—SpaceWire, USB, Brick, Interface, Router, STAR-Dundee, Spacecraft Test and Development Equipment, STAR-System.**

I. Introduction

The original SpaceWire-USB Brick [1] has been serving the SpaceWire community for over ten years. It is an excellent learning tool for those new to SpaceWire, but it is also used by more experienced engineers to develop and test new SpaceWire devices and networks.

The software provided with the Brick was developed to provide the highest possible throughput, and is capable of transmitting and receiving concurrently from/to a PC over a USB 2.0 cable at the full 160 Mbits/s data rate achievable on a 200 Mbits/s SpaceWire link.

The Brick and its successor the Brick Mk2 [2] do have their limitations, however. Both devices are restricted by the throughput constraints of USB 2.0, which means that a maximum combined throughput of around 360 Mbits/s is achievable.

This paper introduces the replacement for these devices – the Brick Mk3. This device will be released later this year (2014) and includes all the capabilities of the Brick Mk2, plus a number of improvements. It is connected to the PC using USB 3.0, which offers greatly improved performance when compared to USB 2.0. The paper describes the advantages of using USB 3.0 for SpaceWire test and development equipment, introduces the new features in the Brick Mk3 hardware and software, and shows some typical scenarios in which the Brick Mk3 can be used. It concludes with a summary of the benefits of using the Brick Mk3 for SpaceWire test and development.

II. Bus Comparison

The buses most commonly used to connect additional devices to a PC or rack are PCI and related technologies, and USB. Devices can also be connected over a TCP/IP network, e.g. using Ethernet or wireless. Each bus offers different capabilities, with advantages and disadvantages of each. For this reason STAR-Dundee offers PCI [3], PCI Express (PCIe) [4], CompactPCI (cPCI) [5] and USB [2] [6] SpaceWire interface and router devices.

Previous STAR-Dundee USB devices have included a USB 2.0 connection [7]. A new version of USB, USB 3.0 [8], was released in 2008, offering higher data rates than the previous version. As this version of USB has gained market share and is now provided in most new PCs, STAR-Dundee has released the new Brick Mk3 with support for USB 3.0.

To highlight the benefits of using USB 3.0 in the Brick Mk3, the remainder of this section compares each of the buses mentioned above, concentrating on the advantages of USB 3.0 for SpaceWire test and development.

A. Throughput

Both PCI and cPCI offer full-duplex data signalling rates of approximately 1 Gbits/s [9], while PCIe provides close to 2 Gbits/s per lane [10]. USB 2.0 is slower in comparison, providing 480 Mbits/s, half-duplex [7]. One of the advantages of USB 3.0 is that it provides full-duplex data signalling at rates of up to 5 Gbits/s [8].

Although it is not possible to achieve user data rates at the full signalling rates of each of these buses due to protocol overheads, STAR-Dundee software and hardware is designed to obtain rates as close as possible to the maximum achievable. The overheads of the USB protocol are slightly higher than each of the PCI protocols, which have very small overheads. However, the high data signalling rates of USB 3.0 means that this is unlikely to have an effect on the Brick Mk3's performance. Initial investigations with the Brick Mk3 suggest that the device will be more than capable of ensuring both SpaceWire links on the device can concurrently transmit and receive packets at the maximum rate possible.

In comparison, Gigabit Ethernet devices offer a data signalling rate of 1 Gbits/s [11]. However, TCP/IP devices have greater overheads than the other buses, due to the use of the TCP/IP protocol suite in addition to the bus's own protocol overheads, e.g. that of Ethernet in the case of Gigabit Ethernet.

B. Latency

Latency values of each of the buses are difficult to compare, due to the different natures of each bus, but both PCI and PCI Express provide the best latency of the buses being discussed. USB 2.0 latency is not as good as that of the PCI buses. However, one of the improvements to USB 3.0 was to the latency that could be achieved, particularly when large amounts of data are transferred. Initial investigations with the Brick Mk3 suggest latency is slightly better when transmitting and receiving SpaceWire packets over USB 3.0 in comparison to USB 2.0.

TCP/IP devices offer much poorer latency than the PCI and USB buses. Latency of TCP/IP devices will also degrade with each additional hop across the network that is required to reach the device.

C. Characteristics

Each of the buses considered provide advantages in different circumstances. For example, cPCI devices can be used in a rack system, while TCP/IP devices can be accessed from another location on the network.

One advantage of USB is that it very easy to connect and disconnect devices to/from a PC. Unlike the PCI buses, USB devices can be connected to laptops, in addition to desktop and rack PCs, and can be added or removed while the operating system is running. Although not all PCs support USB 3.0 as yet, the Brick Mk3 can also be used in older USB 2.0 ports.

III. Hardware Features

The Brick Mk3 hardware is an evolution of previous STAR-Dundee USB devices. It includes all the new features added to the Brick Mk2 when it replaced the original SpaceWire USB Brick. These include link speed and state change event signalling, the ability to inject errors on the link and support for the STAR-System software suite (see section IV).

Fig. 1. SpaceWire Brick Mk3

The Brick Mk2 includes an improved interface mode when compared to the original Brick, with independent channels for data and configuration. The Brick Mk3 improves upon this with the ability to operate as a true interface, with independent channels for each link and a further channel for device configuration. This allows the device to be configured while simultaneously transmitting and receiving on both links. The Brick Mk3 can also be used in router mode, as with other STAR-Dundee interface devices. In this mode it offers three external ports which are transported over the USB port in parallel.

Another improvement in the Brick Mk3 is in the options available for setting the link speed. Both the Brick Mk2 and the Brick Mk3 allow the link speed to be set by specifying multipliers and divisors, with the divisor being any value in a large range. The Brick Mk2 limited the multiplier to be from a small list of values, but the Brick Mk3 uses the same method provided by the SpaceWire PCIe of allowing the multiplier to be any value in a large range.

Work has also been performed to improve the physical characteristics of the Brick Mk3. The box which houses the Brick Mk3 is very different from previous iterations of the Brick, in a blue metal case with the device type clearly visible on the top (see Fig. 1). The SpaceWire connectors are mounted side by side, rather than on top of one another. This makes it much easier to insert and remove SpaceWire cables, and to view the LEDs above each port.

The Brick Mk3 features hardware designed to prevent any single point of failure causing damage to equipment interfaced to the SpaceWire or Trigger ports. A FMECA report is available on request which provides further details on this protection.

As with previous iterations of the Brick, the Brick Mk3 is USB powered, with only a single USB cable required to connect the device to a PC to provide power and a data connection. Although the Brick Mk3 takes advantage of the benefits of USB 3.0, it can also be used in older USB 2.0 ports, with only the throughput and latency that can be achieved affected. When used in a USB 2.0 port, performance is similar to that of the Brick Mk2.

IV. Software Support

Software support for the Brick Mk3 hardware is provided by STAR-Dundee's software suite, STAR-System. This suite can be used with all of STAR-Dundee's recent and planned future interface and router devices, including the SpaceWire Brick Mk2 [2], Router Mk2S [6], PCIe [4], PCI Mk2 [3] and cPCI Mk2 [5].

STAR-System consists of a number of layers. At the bottom are the device drivers for communicating with the hardware. STAR-System includes Windows and Linux drivers for communicating with STAR-Dundee USB devices, and these were updated to add support for the Brick Mk3.

Above the drivers is the STAR-System core and the APIs for interacting with the devices. These are designed to be generic, and not specific to any device, so only some very

minor changes to the core's internals were required to support the Brick Mk3.

At the top of the stack are the user applications. STAR-System includes both command-line test applications and Graphical User Interface (GUI) applications, covering many typical ways in which a SpaceWire interface or router device is used. GUI applications are provided to:

- Type in the bytes of packets and have these transmitted
- Receive packets and display their bytes
- Specify complex packet formats and have these transmitted at high rates
- Receive packets at high rates and compare their format to specified complex packet formats
- Configure the properties of devices, including their routing tables
- Inject errors on a link

Again, these applications are all designed to be generic and to work with all device types. Only some minor changes were required to the Device Configuration application to support the features specific to the Brick Mk3. The other applications needed no changes to work with the Brick Mk3.

The STAR-System drivers, APIs and applications are all designed to provide very high data rates and low latency. When tested with the Brick Mk3 in internal loopback mode (i.e. not accessing SpaceWire), STAR-System applications were capable of transmitting and receiving at rates of approximately 1 Gbit/s, i.e. 2 Gbits of data crossed the USB link every second.

The release of the Brick Mk3 will coincide with the release of version 3.0 of STAR-System. This will include a number of improvements from the last release, including:

- A new Time-code GUI application for transmitting and receiving time-codes and configuring device settings related to time-codes
- Numerous improvements to the existing GUI applications
- The SpaceWire CUBA Software, a command-line application previously provided with the original Brick for transmitting and receiving RMAP commands and SpaceWire packets
- Context sensitive help in all GUI applications
- More detailed documentation

The main change to STAR-System version 3.0, however, is in the internal core of the software. A great deal of work has been done on improving the performance of the software stack, reducing CPU usage and latency, and increasing throughput for all supported STAR-System devices. These were areas in which STAR-System already excelled, but improvements were identified which would be beneficial on real-time operating systems and in low resource environments. A pleasant side-effect of making these changes is that they are also beneficial when using STAR-System on standard PCs running Windows or Linux.

V. Using The Brick Mk3

The sections above have described the individual improvements to the Brick Mk3 and some of the features provided. This section describes how these features can be used in typical SpaceWire test and development activities.

A. Checking Data Received From an Instrument

The Brick Mk3 is capable of receiving packets at very high rates. When testing a SpaceWire instrument, the Brick Mk3 can be combined with the STAR-System Sink application to not only receive data from the instrument at high rates, but also check that the packets are in the correct format, and record the instrument data to file.

A SpaceWire camera is likely to transmit packets which contain more fields than just the image data. There is likely to be address information at the start of the packet and there may be a checksum or CRC at the end. The STAR-System Sink application allows you to specify the format of the packets that are expected to be received. It can then check each field in the received packets is in the correct format, and write individual fields, or the full packet, to file.

Fig. 2 shows an example packet format for a camera configured using the Sink's Packet Format dialog. The Sink expects to receive a single address byte of 0xfe, followed by a 16-bit sequence number. The Sink will check that the address byte is correct and the sequence number increments in each packet. After the sequence number is the image data which is expected to be 1 MByte. As there's no way to know what image the camera will be sending, the content of this field is not checked.

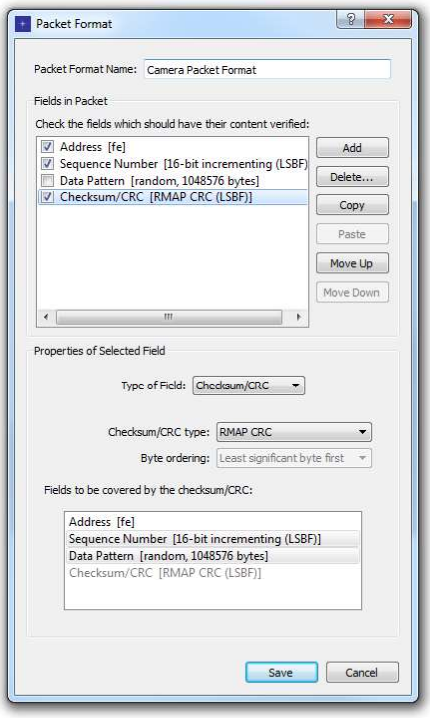

Fig. 2. Sink Packet Format

Finally the packet ends with a CRC. The properties of the CRC are shown in the Packet Format dialog screenshot. The CRC being used is the RMAP CRC, although a number of different CRCs and checksums are supported. The CRC in this example covers the sequence number and image, although it could be set to cover any of the fields in the packet. The Sink will check the CRC is correct in each received packet.

A separate dialog in the Sink application allows packets, or individual fields in packets, to be recorded to file. The format in which each packet or field is written to file is then specified in the dialog shown in Fig. 3. Each of the bytes in the field can be written to the file numerically as text, with spaces or another separator between each value. The field in each packet can also be written to one large file. For the camera's images in the screenshot, we have chosen to write the images to file as binary data, with a new file used for each image. Assuming these files are in an appropriate format, it should then be possible to open the files received from the camera and view them in a photo viewer.

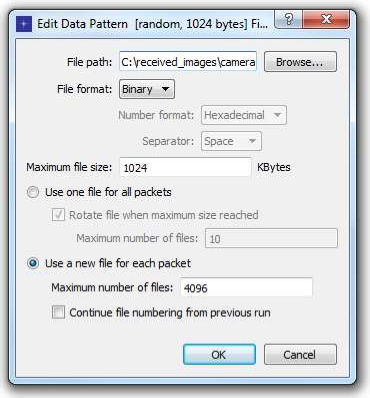

Fig. 3. Sink Recording to File

The Sink application provides many other features, and has a partner application, the Source, which can be used to transmit packets. It uses the same packet formats as the Sink, so the camera packet format specified here can also be used in the Source to simulate the camera.

B. Configuring a SpW-10X (AT7910E)

The Device Configuration application can be used to configure STAR-System devices such as the Brick Mk3, providing an interface for setting link speeds, routing tables and viewing error status information. The application can also be used to configure routing devices over a SpaceWire network, using a device such as the Brick Mk3 to communicate with the devices on the network. Supported routing devices include the AT7910E, the ESA SpaceWire Router [12].

When working with a spacecraft network containing AT7910E devices, the Brick Mk3 can be connected to the network and used to check the status of these devices, as shown in Fig. 4. In this screenshot, the Device Properties of an AT7910E are on display, showing the general properties of the device, and providing the option to configure settings which affect the entire device. Tabs are provided for each port, including the configuration, SpaceWire and external ports, showing the current error status, and allowing the links to be started, stopped, etc. The final tab provides the ability to configure each routing table entry of the device.

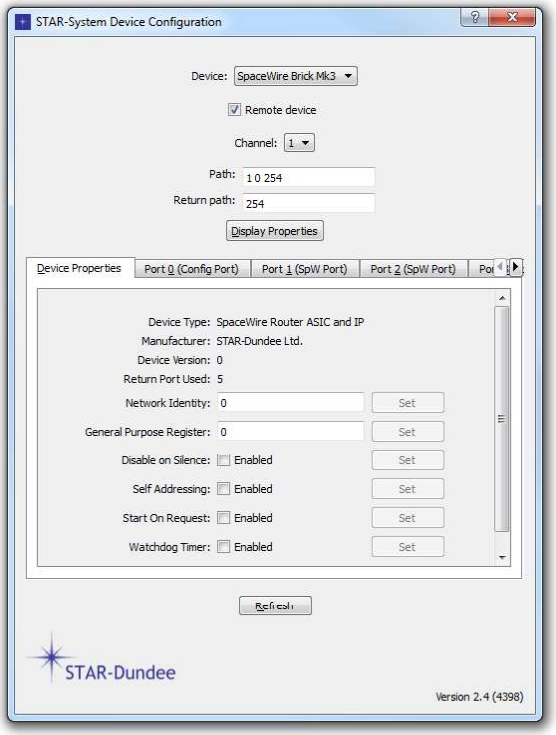

Fig. 4. Device Configuration of an AT7910E via a Brick Mk3

C. Acting as a Time-code Master

When experimenting with time-codes, e.g. for SpaceWire-D development, the Brick Mk3 can very easily be enabled as a time-code master. The STAR-System Time-code application includes a tab for enabling the device as a time-code master, see Fig. 5. The frequency at which time-codes are to be generated can be entered in hertz, and the Brick Mk3 will be enabled as a time-code master once the Enable button is clicked.

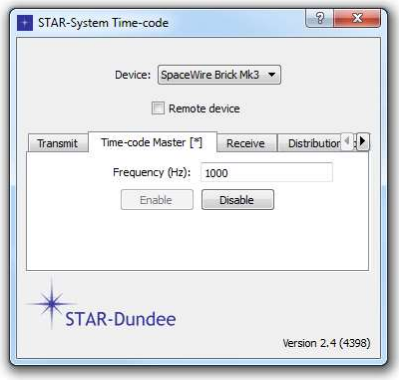

Fig. 5. Enabling a Brick Mk3 as a Time-code Master

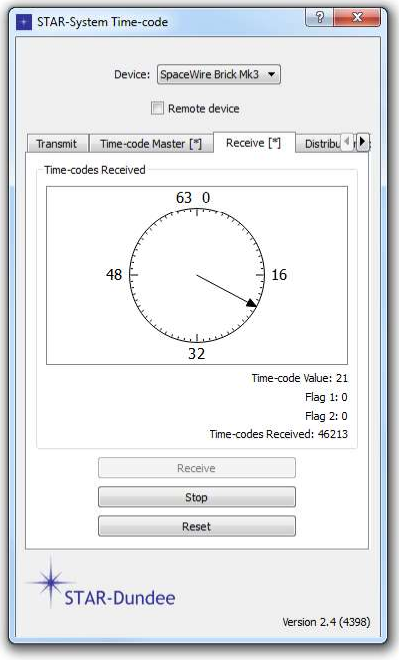

Fig. 6. Receiving Time-codes With a Brick Mk3

To see the time-codes which are being generated, or which are being received from another time-code master on the network, the Time-code application includes a tab for receiving time-codes, shown in Fig. 6. This shows each time-code's value as it received on a clock, as well as displaying the value numerically along with the values of the time-code flags.

The Time-code application also includes tabs for transmitting individual time-codes and for specifying which ports time-codes should be routed out of.

VI. Summary

The SpaceWire Brick Mk3 is a powerful interface and router device, which offers the capability to transmit and receive at the maximum speed that can be achieved on a 200 Mbits/s link, on two links concurrently while also configuring the device. In other words it is capable of transmitting and receiving at 160 Mbits/s on both SpaceWire links, while also reading and writing registers on the device, giving a total combined data rate of greater than 640 Mbits/s. It can also transmit and receive packets with latencies which are better than can be achieved with the SpaceWire Brick Mk2. This is possible because of the improved throughput and latency provided by USB 3.0, and because of the inclusion of a true interface mode in the device.

Combined with the comprehensive STAR-System software suite, the Brick Mk3 product can be used to perform many of the tasks required during SpaceWire test and development.

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