Testing over Ethernet with the SpaceWire GbE Brick

Test and Verification, Short Paper

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Abstract— **This paper introduces a new SpaceWire test and development product with a Gigabit Ethernet interface developed by STAR-Dundee, the SpaceWire GbE Brick. It describes the unique features of the SpaceWire GbE Brick which make it ideal for both remote use in a test chamber and when connected directly to a PC using an Ethernet cable. The paper also characterises the performance of the SpaceWire GbE Brick and compares the performance to SpaceWire devices with PCI and USB interfaces.**

Index Terms—**SpaceWire, Gigabit Ethernet, GbE, Brick, SpaceWire GbE Brick.**

I. Introduction

A common use case for SpaceWire test and development equipment is to locate it in a test chamber and then access it remotely to test a SpaceWire device or network.

One solution to this problem is to include a PC in the test chamber to which the SpaceWire test and development equipment is connected. The user can then remotely connect to this PC over an Ethernet network. This has the advantage that the PC in the test chamber transmits and receives any SpaceWire data and can therefore do so at high throughput rates and with low latency. The remote PC may only need access to the transmission and reception statistics, so high throughput and low latency may not be required between the two PCs.

This solution is not very elegant, however, and is not always feasible, e.g. where space is limited or when the PC's presence may affect the test. An alternative solution would be to include the interface to the Ethernet network within the SpaceWire test and development equipment. To ensure that the unit could be used in test chambers where there is not enough space for a PC, it's essential that such a device be small. This gives the added benefit of galvanic isolation between the test PC and the SpaceWire network. As SpaceWire traffic may be transmitted to the device from a remote PC, it must also include a high-speed interface and efficient software capable of transmitting and receiving at high data rates over that interface.

To meet these requirements, a new test and development product with a Gigabit Ethernet (GbE) interface has been developed by STAR-Dundee, the SpaceWire GbE Brick. This will begin shipping to customers in the third quarter of 2018 and is shown in Fig. 1.

Fig. 1. SpaceWire GbE Brick

The SpaceWire GbE Brick can act as a SpaceWire interface or a router, it has two SpaceWire ports which can operate at link speeds of up to 400 Mbits/s and has two external triggers, each of which can operate as an input or an output. It is housed in a small case measuring around 85mm on its longest side. The software interface is the same as for other STAR-Dundee interface and router devices, making it possible to use software developed for these other products with the GbE Brick. This software, called STAR-System, offers high throughput and low latency when transmitting and receiving packets and has been updated to support high performance over Gigabit Ethernet.

This paper describes the unique features of the SpaceWire GbE Brick which make it ideal, not only for remote use in a test chamber, but also when connected directly to a PC using an Ethernet cable. The paper also characterises the performance of the SpaceWire GbE Brick and compares it to SpaceWire devices with PCI and USB interfaces.

II. Features of The SpaceWire GbE Brick

The SpaceWire GbE Brick includes all the features provided by its USB equivalent, the SpaceWire-USB Brick Mk3 [1], [2]. The SpaceWire GbE Brick is externally powered and has two SpaceWire ports which can be accessed from software using independent channels, so traffic on one port is not affected by traffic on the other port. A third independent channel provides access to the device's configuration port, allowing configuration of the device while concurrently transmitting and receiving on the two SpaceWire ports. In addition to the default interface mode, the device can operate as a full SpaceWire router, supporting both path and logical addressing.

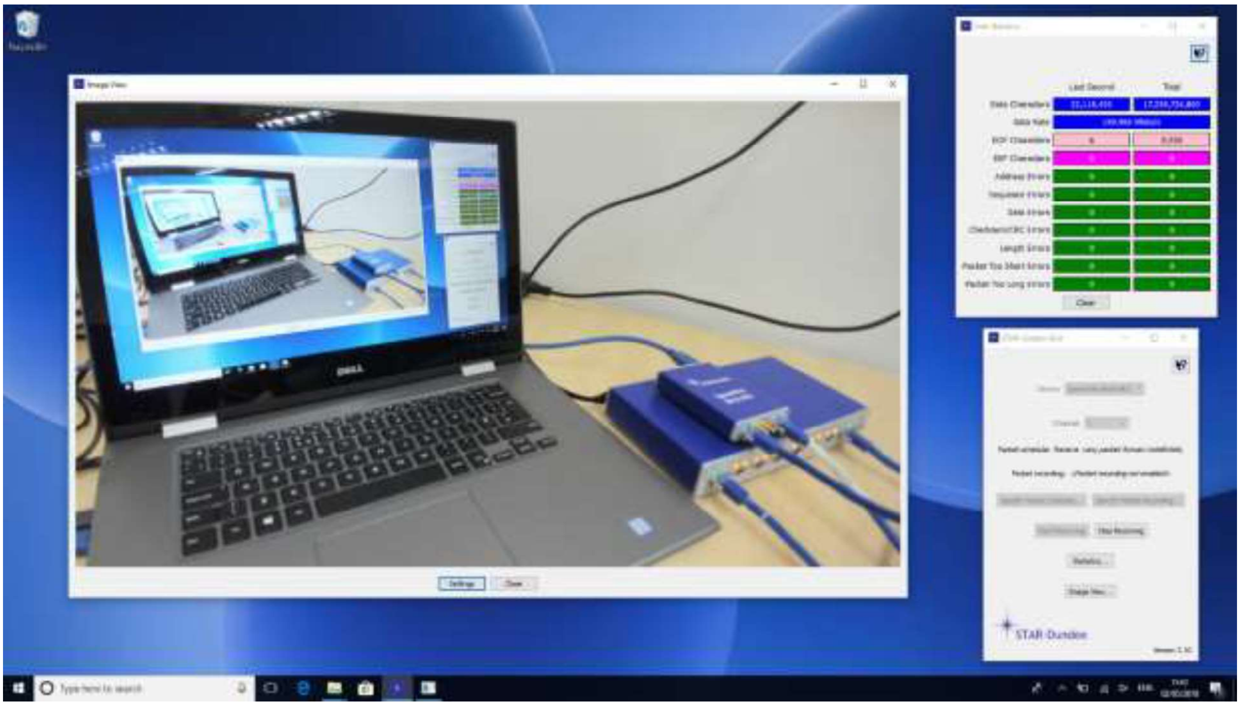

Fig. 2. Displaying received images in the STAR-System Sink application

The device can act as a time-code master, and can both transmit and receive individual time-codes. Error injection capabilities are provided to inject several different error types on the link. As with all STAR-Dundee products, support is provided and upgrades are offered to add new features and fix issues at no additional cost.

The device can be field upgraded using a graphical user interface (GUI) application included in the STAR-System software suite, which is also included with the product. Version 4.0 of STAR-System is being released in conjunction with the SpaceWire GbE Brick. This release supports the latest Linux kernels and Windows releases and is backwards compatible with all previous releases of STAR-System. It provides a consistent interface for all STAR-Dundee interface and router products released in recent years. This means that software developed for the SpaceWire-USB Brick Mk3 or the SpaceWire PXI Interface [3], for example, can be used with the SpaceWire GbE Brick. Both C and C++ APIs are provided for interacting with STAR-System, along with comprehensive documentation and examples provided as source code, which can be used as a basis for new applications.

The APIs can easily be integrated in to other programming languages, with users known to be developing with the APIs under C#, Java and Python. A LabVIEW wrapper [4] is also available separately for using the SpaceWire GbE Brick and other STAR-System devices from National Instrument's LabVIEW visual programming language.

A key feature of the APIs is that they not only provide functionality to transmit and receive packets, but also functions required when testing SpaceWire equipment. For example, the APIs make it simple to transmit packets terminated with an EEP, and to determine the end of packet marker of received packets.

An RMAP Packet Library is also included, which provides functions for creating Remote Memory Access Protocol (RMAP) [5] packets to be transmitted, checking the validity of received RMAP packets, and obtaining the values of fields in an RMAP packet.

Among the many new features included in version 4.0 of STAR-System is the ability to transmit images from a webcam using the Source application and to display images received in the Sink application, illustrated in Fig. 2. These features can be useful to simulate a camera on the network or to view data from a SpaceWire or SpaceFibre Camera [6].

III. Performance of The SpaceWire GbE Brick

A concern with the use of Ethernet to interface to a SpaceWire device is the poor latency in comparison to buses used by other STAR-Dundee devices, such as USB and PCIe. Although Gigabit Ethernet operates at a line rate of 1 Gbit/s, throughput is also a concern when using the device on busy Ethernet networks.

To achieve the best performance, STAR-System has been updated in version 4.0 to support Gigabit Ethernet devices, with considerable effort made to achieve the best possible throughput and latency. To characterise this performance, the SpaceWire GbE Brick was tested and compared with other STAR-Dundee products which use alternative bus technologies.

TABLE I. shows information about the bus technology used by each of the products tested and the number of SpaceWire ports on that device. Most of the buses used by these products are shared buses, meaning that performance will be affected by other traffic on the bus. While this may not be an issue for the SpaceWire PCI Mk2 [7], for example, if it is the only PCI device in a PC, it's likely to be an issue for the SpaceWire GbE Brick when used on a busy Ethernet network.

TABLE I. PRODUCTS UNDER TEST AND THEIR BUS PROPERTIES

Product	Bus	Shared Bus?	Bus Line Rate	SpW Ports
SpaceWire-USB Brick Mk2 [8]	USB 2.0 (High Speed)	Yes	480 Mbits/s (half-duplex)	2
SpaceWire-USB Brick Mk3 [2]	USB 3.0 (SuperSpeed)	Yes	5 Gbits/s	2
SpaceWire GbE Brick	Gigabit Ethernet	Yes	1 Gbit/s	2
SpaceWire PCI Mk2 [7]	PCI	Yes	1,064 Mbits/s	3
SpaceWire PCIe [9]	Single Lane PCIe 1.1	No	2 Gbits/s	3

Fig. 3. shows the results of latency tests for these products. The latency tests involve transmitting a packet from the STAR-Dundee Performance Tester application to the device under test, which sends the packet over a SpaceWire link operating at 200 Mbits/s. This link is looped back to the transmitting device. The packet is then passed back to the Performance Tester application where it is received. This sequence is repeated 1,000 times and the average latency calculated from the total time taken. The values shown in the chart in microseconds on the y-axis are therefore the average times that it takes to transmit a packet from the application, over a SpaceWire link and receive the packet in the application. The test is repeated for packet sizes from 1 to 1,000 bytes, shown along the x-axis.

The source code and executable for the Performance Tester are included with STAR-System so that users can perform the tests themselves while also providing an example of how to get the best performance from the STAR-System APIs. The test results shown in the chart were all performed on a Windows 7 PC with an Intel Core i7-4790 processor and 12 GBytes of RAM. This is a 3-year-old PC with a relatively fast processor when it was released, so should be representative of many PCs in common use at the time of writing. The SpaceWire GbE Brick tests were performed with the device connected directly to the PC, meaning that no Ethernet switches or hubs were crossed and there was no traffic from other devices on the shared bus.

These results show that the latency achieved by the SpaceWire GbE Brick is generally quite good, but is occasionally very poor in comparison to the other products. It is assumed that these sporadic increases in latency are due to the PC attempting to perform other operations on the network. The results when repeating the tests support this theory, with the peaks appearing at different packet sizes.

The Performance Tester application also provides tests for measuring the throughput of devices. These tests transmit and receive packets at very high rates and measure the rate at which the packets are received. The results of these tests are shown in Fig. 4. This chart shows that the variances in latency do not affect average throughput. Performance of the SpaceWire GbE Brick is very similar to the other products, and is around the maximum that can be achieved on a 200 Mbits/s link. Note that the performance of the SpaceWire-USB Brick Mk2 [8], which connects to the PC using USB 2.0, is worse than expected. It was found that this is the result of using a USB 2.0 device with a USB 3.0 controller. Using the device on an older PC with a USB 2.0 controller, the performance was similar to the other products, despite the PC having a lower specification.

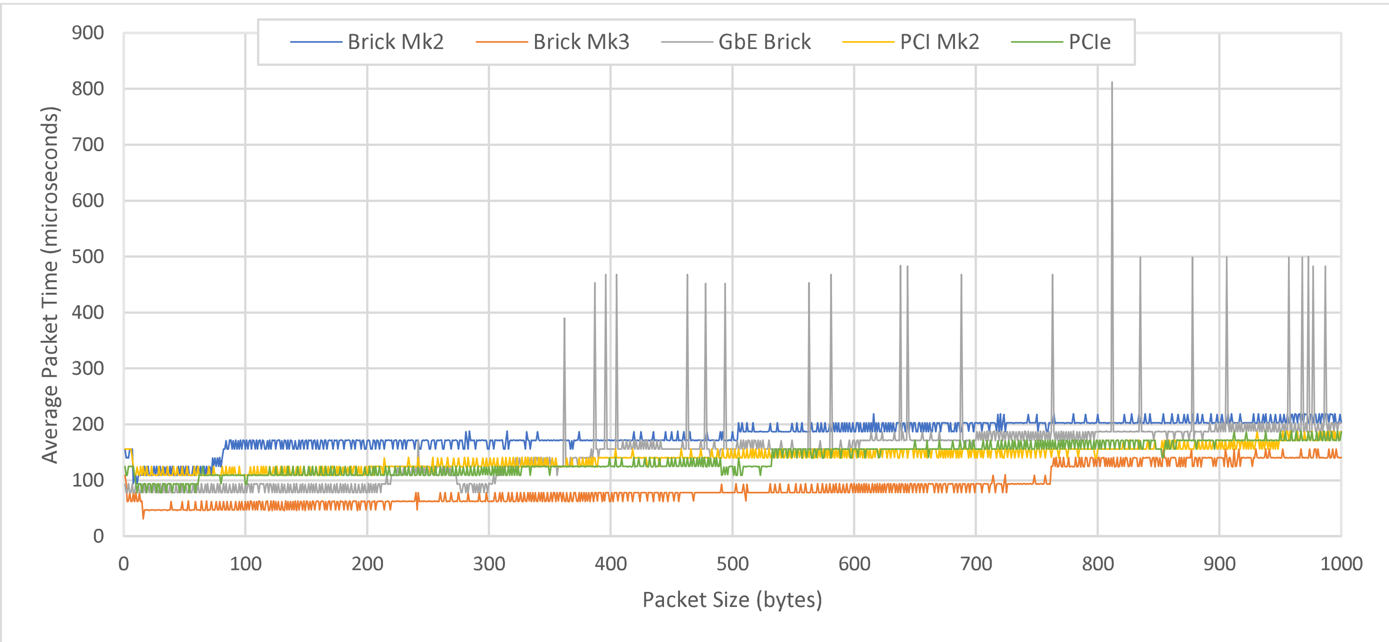

Fig. 3. Latency test results over SpaceWire at 200 Mbits/s for several STAR-Dundee products

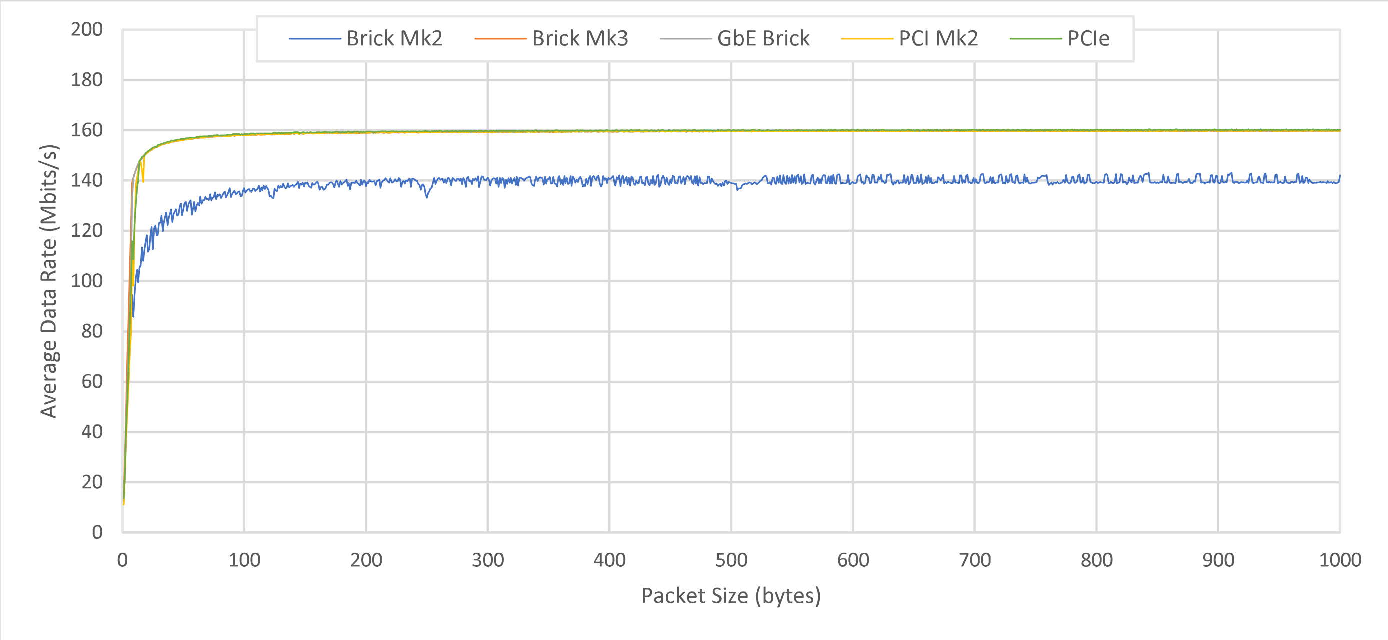

Fig. 4. Throughput test results over SpaceWire at 200 Mbits/s for several STAR-Dundee products

While these tests show the performance for one link transmitting and receiving at a SpaceWire line rate of 200 Mbits/s, it should be remembered that the devices being tested have more than one link, each link can operate at faster line rates than 200 Mbits/s, and configuration commands may also be sent to the device while transmitting and receiving. It should also be remembered that the tests are being performed with the SpaceWire GbE Brick connected directly to the PC, rather than on an Ethernet network.

To compare performance when the device is accessed over an Ethernet network, tests were run over STAR-Dundee's Star House office network. The latency tests recorded in Fig. 5. were performed with the controlling PC in a top floor office and the device connected to an Ethernet port in a basement laboratory. Traffic between the PC and the SpaceWire GbE Brick therefore crossed two Ethernet switches. The chart also includes the previous latency figures achieved when the device was connected to the PC for comparison.

Although average latency over the Ethernet network is comparable to when connected directly, this chart also shows that at times latency can be much worse, with some tests encountering average latencies of around 1.5 milliseconds. As with the discrepancies in the earlier latency test, this can be attributed to other traffic on the Ethernet network.

To test the maximum throughput rates that can be achieved, and whether these rates are high enough to accommodate two links transmitting and receiving while the device is also being configured, throughput tests were performed using the internal SpaceWire router. These tests do not use the SpaceWire links, so are not limited by the link speed. Two tests were run in parallel so that data was being transmitted from channel 1 of the device to channel 2, while concurrently transmitting in the opposite direction. Fig. 6. shows the results of these tests when performed over the Star House network and when the SpaceWire GbE Brick was connected directly to the test PC. Results are also provided for the Brick Mk3 for comparison.

Although these tests show that performance of the SpaceWire-USB Brick Mk3 is better than for the SpaceWire GbE Brick, the GbE Brick should be capable of keeping two links relatively busy in both directions at the maximum link speed of 400 Mbits/s. For a 400 Mbits/s link, the maximum theoretical data rate is 320 Mbits/s due to each 8-bit byte being encoded as 10 bits. This is further reduced when transmitting in both directions on a link, as flow control tokens must be transmitted along with the data, reducing the theoretical maximum to around 304 Mbits/s. With two links, this equates to a data rate of around 608 Mbit/s, while the SpaceWire GbE Brick can manage a total data rate of around 490 Mbits/s.

This chart also illustrates the effect of other traffic on the network. When connected directly to the PC, the average data rate of the SpaceWire GbE Brick occasionally drops by around 50 Mbits/s. When the device is accessed across the Star House network, the average rate drops by as much as 130 Mbits/s.

One further point to note on these tests is that the CPU usage for the SpaceWire GbE Brick tests (between 60% and 27%) was considerably higher than for the SpaceWire-USB Brick Mk3 tests (between 37% and 10%). It is possible that further work can be performed to optimise this CPU usage within STAR-System for Ethernet devices, but the additional overheads of TCP/IP may mean that it is not possible to attain the same low CPU usage of the USB and PCI devices.

IV. Dealing with Throughput and Latency Limitations

While the SpaceWire GbE Brick delivers adequate throughput and latency performance for most applications, it's clear from the STAR-System Performance Tester results that when operating over an Ethernet network, latency and, as a result, throughput can be affected.

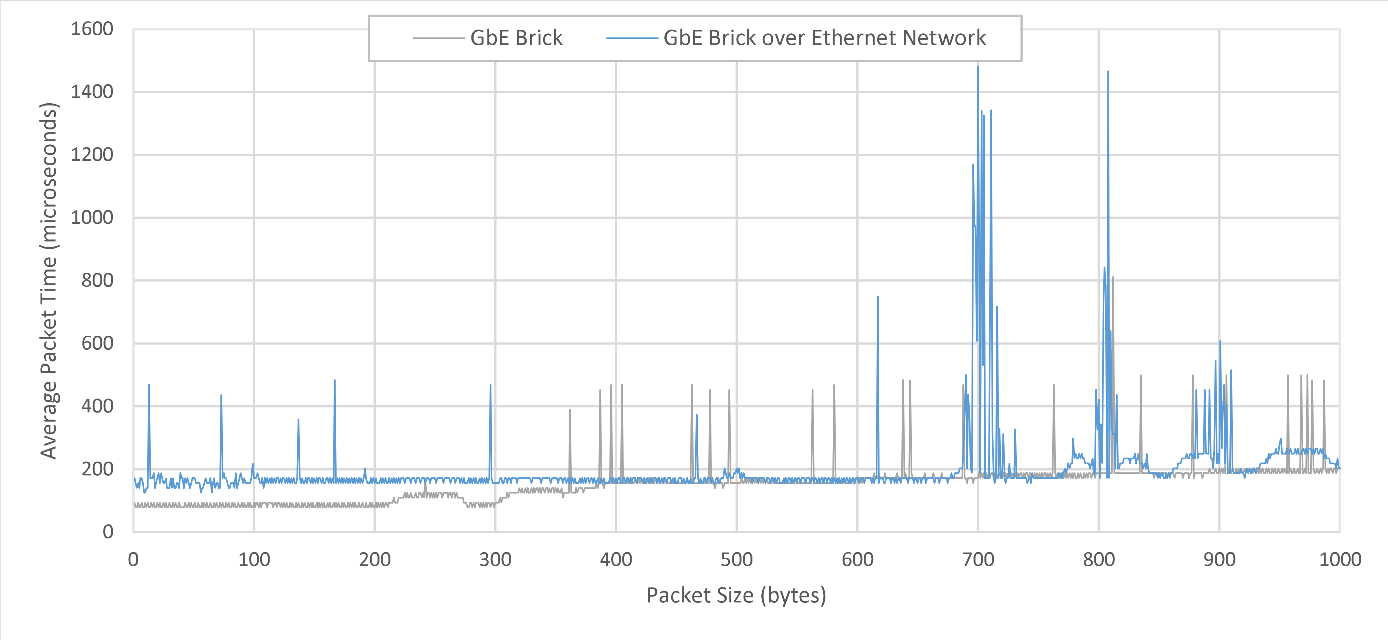

Fig. 5. Latency test results for SpaceWire GbE Brick connected locally and over an Ethernet network

The SpaceWire GbE Brick has been designed to limit the effects of these, however. Buffering is provided in the device to reduce the effect of jitter in the latency when transmitting and receiving. This has the effect of smoothing out the rate at which traffic is transmitted over the SpaceWire link, and limiting any delay on the SpaceWire link when receiving traffic. This explains why the changeable latency does not affect the throughput rates shown in Fig. 4.

For applications which require deterministic behaviour, the device includes triggering functionality which is supported by STAR-System's Triggering API. This allows actions to be performed when specific events occur. These events could be a packet being received, an error being encountered, a pulse on the device's external trigger port, a time period elapsing or several other events. Possible actions include to transmit a packet or a time-code, pulse the device's external trigger or inject an error.

These combinations of events and actions allow deterministic behaviour to be implemented in user applications which may be running on a PC at the other side of the Ethernet network on which the SpaceWire GbE Brick is connected. Example applications are to transmit packets periodically, to transmit packets when a time-code is received and to inject errors when an external trigger is received.

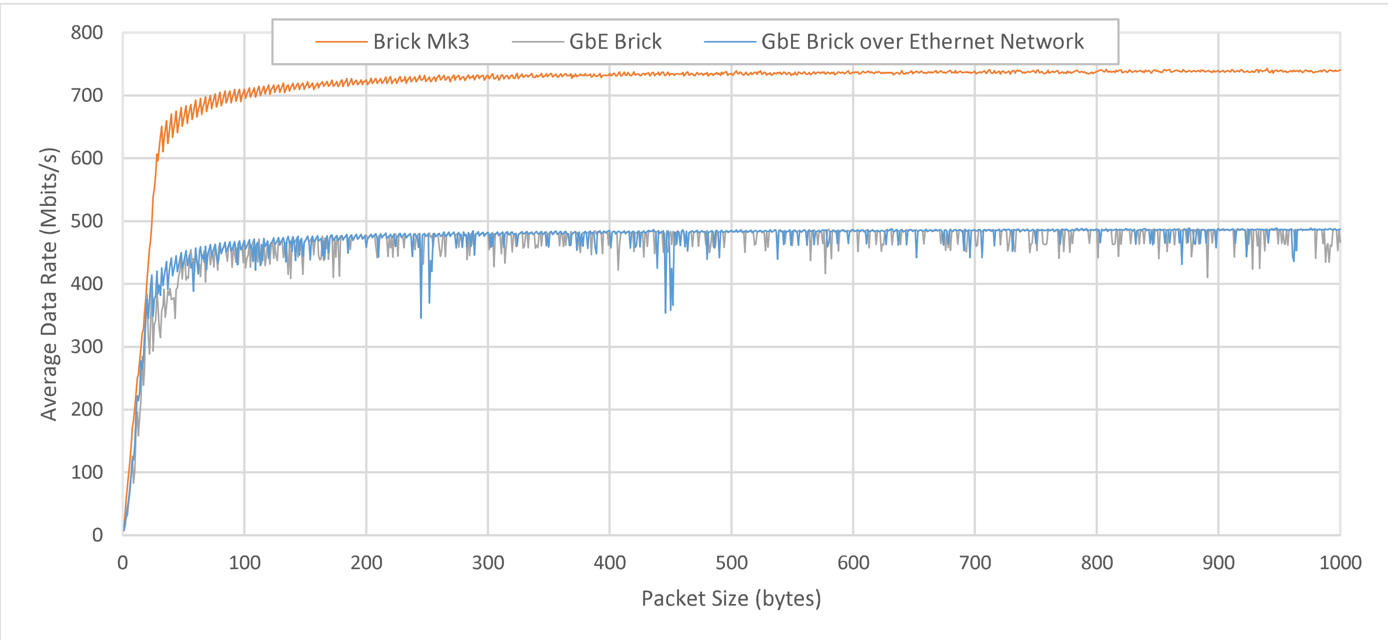

Fig. 6. Double loopback throughput test results using internal SpaceWire router

V. Conclusions

This paper has presented a powerful new SpaceWire test and development product, the SpaceWire GbE Brick, which allows SpaceWire tests to be performed remotely over an Ethernet network. The SpaceWire GbE Brick and accompanying STAR-System software have been designed to cope with the effects of operating on an Ethernet network, which can affect the performance when transmitting and receiving packets. It has been shown that performance of the SpaceWire GbE Brick is comparable to that of STAR-Dundee's other test and development products.

Furthermore, through use of STAR-System's Triggering API it is possible to circumvent any potential latency jitter on an Ethernet network and achieve deterministic results, by performing actions based on events such as timers.

The SpaceWire GbE Brick is currently in production and will begin shipping to customers in the third quarter of 2018.

Acknowledgements

STAR-Dundee would like to acknowledge the feedback provided by the users of its products, which act as requirements for improvements to existing products and features of new products.

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