Testing SpaceFibre Equipment and Systems Using the STAR Fire Mk3

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Thorough testing is required for successful SpaceFibre equipment and system development. This helps identify defects and provides assurance equipment operates as expected. The STAR Fire Mk3 can transmit and receive SpaceFibre traffic to stimulate and emulate SpaceFibre equipment for test purposes. In addition, it can capture and display SpaceFibre traffic, aiding debug and validation efforts. This paper considers how the hardware and software capabilities provided by the STAR Fire Mk3 may be used to test SpaceFibre equipment and systems.

Index Terms— **SpaceFibre, Testing, Spacecraft Electronics, STAR Fire Mk3.**

I. INTRODUCTION

SpaceFibre is an on-board network technology for spaceflight applications that runs at multi-Gbit/s. Designed to support deterministic data delivery, data packets are segmented and transmitted in frames across virtual channels (VC), where each virtual channel is constrained by a quality of service (QoS) mechanism that supports priority, bandwidth reservation and scheduling. The QoS mechanism is provided in an efficient hardware interface design along with fault detection, isolation, and recovery (FDIR) capabilities. SpaceFibre uses the same packet format as SpaceWire, meaning it is backward compatible with SpaceWire at the network level, and existing SpaceWire equipment can be interconnected to a SpaceFibre network.

During SpaceFibre system development it is important to test that the system operates as expected and to debug any issues encountered. To stimulate SpaceFibre equipment and validate the response, test equipment capable of transmitting and receiving SpaceFibre traffic is needed. To further validate traffic and debug any unexpected problems, test equipment able to capture, interpret and display SpaceFibre link traffic is required.

The STAR Fire Mk3 is a piece of SpaceFibre test equipment that allows users to emulate, stimulate, debug and validate their SpaceFibre enabled equipment. This paper describes the capabilities of the STAR Fire Mk3 hardware and the accompanying software, and how this may be used to test and debug SpaceFibre equipment and systems.

II. STAR FIRE MK3

The STAR Fire Mk3 can be used both as a SpaceFibre interface device, to transmit and receive traffic, and as a SpaceFibre link analyser. It is controlled by a host PC connected by a USB 3.0 port and interfaces with SpaceFibre equipment using two SpaceFibre EGSE ports. In addition, it has two SpaceWire ports, four external SMB triggers, two MICTOR connectors and a power connector.

Fig. 1 STAR Fire Mk3 Unit

A. SpaceFibre Interface

The STAR Fire Mk3 has two means of control for transmitting and receiving SpaceFibre data, each designed for a different purpose. Data can be transmitted from and received to a host PC or built-in hardware data generators and checkers can be used. The host PC solution allows for greater control over packet contents whilst the data generators and checkers provide real-time performance.

B. SpaceFibre Link Analyser

The STAR Fire Mk3 has 512MB of memory that can be used to capture over 44 million SpaceFibre words. It can capture SpaceFibre traffic received, transmitted or inline on a SpaceFibre link. SpaceFibre traffic is captured around a trigger event (typically a SpaceFibre word) set by the user. Once capture has completed, the SpaceFibre traffic is uploaded to the host PC and presented in multiple views displaying this in different levels of detail.

C. SpaceWire to SpaceFibre Interconnect

SpaceWire ports on the STAR Fire Mk3 allow SpaceWire equipment to be interconnected to a SpaceFibre network. This means SpaceWire equipment connected to the STAR Fire Mk3 can transmit and receive SpaceWire packets over a SpaceFibre lane virtual channel, and in doing so inherit the mass saving, QoS and FDIR benefits SpaceFibre provides.

D. Interfacing with External Equipment

External triggers on the STAR Fire Mk3 provide an interface for connecting external equipment to aid testing. Input and output triggers mean the STAR Fire Mk3 can both react to an input signal from external equipment and generate an output signal to notify external equipment of an event. To further aid testing, MICTOR connectors allow decoded

SpaceFibre link characters for each SpaceFibre port to be accessed from a logic analyser.

III. SOFTWARE

The STAR Fire Mk3 is supplied with software designed to complement the hardware capabilities. Created specifically for the STAR Fire Mk3's SpaceFibre functionality are three graphical user interface (GUI) applications called STAR Fire Controller, STAR Fire Statistics and STAR Fire Link Analyser. In addition to these, the STAR-Dundee software stack named STAR-System is also provided. Further information regarding these software modules and how they are used to test SpaceFibre equipment and systems is provided in the following sections.

IV. STIMULATE AND EMULATE

Whilst developing a SpaceFibre system it is often necessary to work on one piece of SpaceFibre equipment whilst other parts of the system are unavailable. In this scenario it can be useful to simulate and/or emulate the behaviour of other parts of the SpaceFibre system. Test equipment controlled by software can simulate SpaceFibre equipment behaviour. This test equipment should be capable of transmitting and receiving SpaceFibre traffic so that it can stimulate and react to the unit under test (UUT).

A. Lane Initialisation

SpaceFibre lane initialisation must occur before any data can be transferred. The data signalling rate for a SpaceFibre lane must also be the same (+/- 0.01%) in each direction. The STAR Fire Controller GUI application can be used to set the STAR Fire Mk3 SpaceFibre lane data signalling rate (between 0.6 and 3.2 Gbit/s) to match that of the UUT and to start lane initialisation. This application allows the user to view and change the STAR Fire Mk3 SpaceFibre Interface settings. If lane initialisation is successful, the lane status information shows that the lane is active.
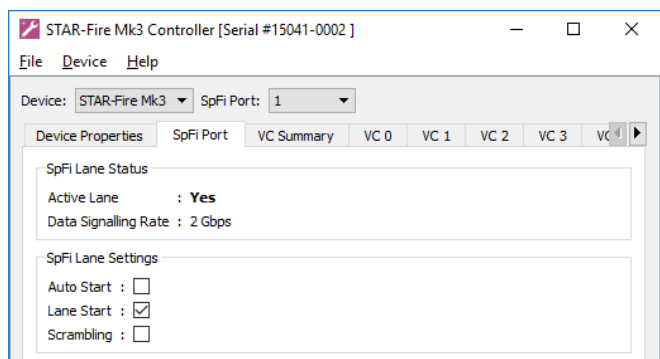

Fig. 2 STAR Fire Controller Lane Start

B. Quality of Service

SpaceFibre virtual channels are assigned QoS parameters that are used to determine which channel should be permitted to transmit data at any one time. Priority, bandwidth reservation and scheduling are used to do this. The STAR Fire Controller can be used to configure these for each virtual channel according to the simulation requirements.
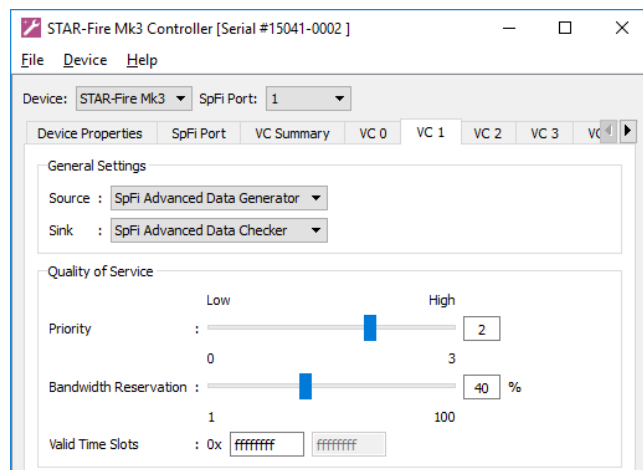

Fig. 3 STAR Fire Controller Quality of Service Settings

C. Transmit and Receive

The STAR Fire Mk3 can transmit and receive SpaceFibre packets from a host PC using STAR-System. STAR-System is the common software stack provided with all the latest SpaceWire and SpaceFibre router and interface devices from STAR-Dundee. It consists of drivers, C and C++ application programming interfaces (APIs), examples, GUI applications and documentation. Relevant to the STAR Fire Mk3, it provides a USB driver to interface with the host PC, and APIs and GUI applications to transmit and receive SpaceFibre packets. Packets can be transmitted and received from a host PC over two virtual channels simultaneously. This can be achieved at high speed (2.2 Gbit/s combined transmit and receive data rate in a loopback configuration) due to the USB 3.0 interface.

The STAR-System Transmit and Receive GUI applications provide the simplest SpaceFibre transmit and receive capabilities. These allow the user to send and receive a single user defined packet to confirm a SpaceFibre link is operating as expected and packet addressing is correct. The STAR-System Source and Sink GUI applications provide more advanced SpaceFibre transmit and receive capabilities. Both can be used to construct and save complex packet formats. The Source application allows the user to transmit multiple packets with a software defined time between each. The Sink application can be used to receive and check the contents of multiple packets. These display statistics such as the number of data, end of packet marker (EOP) and error end of packet marker (EEP) characters transmitted and received. The Sink application can be used to transmit SpaceFibre packets to a UUT to stimulate it, whilst the Source application can receive and check the contents of SpaceFibre packets transmitted from the UUT. The statistics displayed can confirm the SpaceFibre virtual channel is operating at the required data rate and if any packet data errors were encountered.
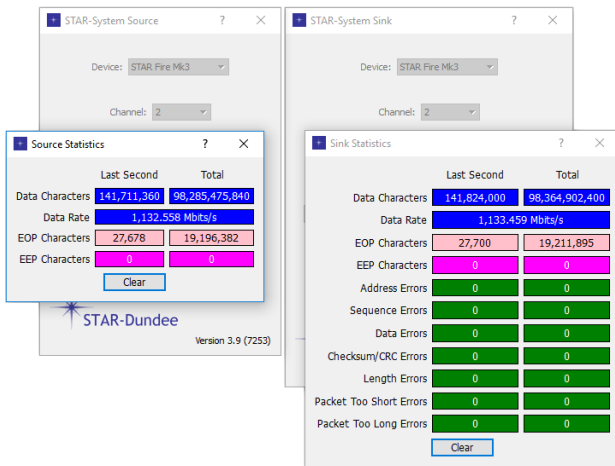
Fig. 4 Source and Sink GUI Applications

Where greater control is required over packet contents and transmit and receive functionality, custom code can be written using the C/C++ APIs. As SpaceFibre uses the same packet format as SpaceWire, the STAR-System transmit and receive GUI applications and APIs are consistent with those provided with existing STAR-Dundee SpaceWire interface and router devices.

D. Real-Time Emulation

Real-time performance is required for accurate hardware emulation, which is not possible using software written for a general-purpose operating system. The STAR Fire Mk3 built-in data generators and checkers provide a hardware independent solution for transmitting and receiving SpaceFibre packets. Configured using the STAR Fire Controller, the data generators transmit user defined data patterns at specific data rates. The data checkers receive SpaceFibre packets and check the contents match the user defined pattern. An error count is incremented each time a difference is detected, along with a count of the number of EEPs received. Transmitting packets without software interaction from the STAR Fire Mk3 allows the user to test their connected UUT with consistent packet timing and under maximum SpaceFibre lane utilisation conditions. Receiving and checking the SpaceFibre packets transmitted from a UUT, the STAR Fire Mk3 can confirm there are no data errors.
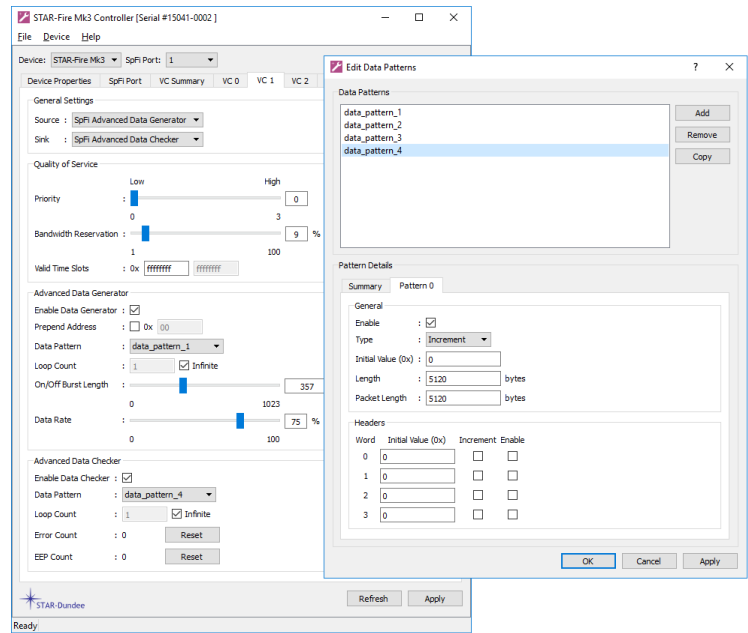

Fig. 5 STAR Fire Controller Data Generators and Checkers

SpaceFibre includes low latency event signalling and time distribution using broadcast messages. The STAR Fire Mk3 built-in broadcast generators and checkers provide a hardware independent solution for transmitting and receiving broadcast messages. Configured using the STAR Fire Controller, the broadcast generators can periodically transmit broadcasts with a fixed pattern. This allows the user to stimulate a UUT with low latency broadcast messages transmitted with accurate timing. The broadcast checkers receive broadcast messages and check these match a fixed pattern. A broadcast error count is incremented with each broadcast received that differs from the expected pattern.

E. Repeatable Testing

Multiple different settings mean the STAR Fire Mk3 can test connected SpaceFibre equipment in a variety of configurations using the STAR Fire Controller. To help manage different test configurations and to save time and effort, the STAR Fire Controller settings can be saved to hard disk and later reloaded.

V. DEBUG AND VALIDATE

During SpaceFibre equipment development, testing helps identify issues. Problems can also be encountered when two or more SpaceFibre units are integrated for the first time. Without SpaceFibre traffic visibility, debugging these issues can be difficult and time consuming. With SpaceFibre traffic visibility, the cause of problems can be determined more easily and issues resolved faster.

Validation tests ensure SpaceFibre equipment meet operational requirements. These confirm functionality and performance are as expected and can be used to demonstrate the acceptance criteria of external customers has been met. SpaceFibre traffic capture and inspection can be used to

confirm a SpaceFibre system is operating as expected under different conditions.

A. SpaceFibre Link Analysis

The STAR Fire Link Analyser GUI application enables the STAR Fire Mk3 to be used as a SpaceFibre link analyser. This allows the user to unobtrusively capture SpaceFibre traffic to hardware memory before it is uploaded to the host PC where it is interpreted and displayed in multiple views.

The software can be used to set an optional trigger condition to ensure SpaceFibre traffic of interest is captured to memory. This can be useful whilst debugging if problem symptoms are known (e.g. EEP received) as these can be used to set the trigger condition, resulting in a SpaceFibre traffic capture relevant to the issue. To increase memory usage efficiency, the trigger position relative to memory and the memory size are configurable. These allow the user to specify the total capture memory available and how much of this should be used pre and post trigger. Optional filtering can further help ensure memory is used efficiently. This can minimise the quantity of memory used to capture often unnecessary SpaceFibre traffic such as Idle frames.
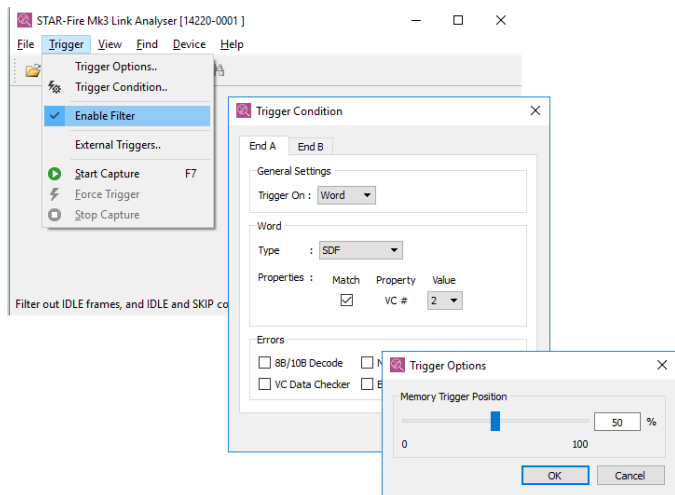

Fig. 6 Filtering, Trigger Condition and Trigger Memory Position

Once traffic is captured to memory it is interpreted and displayed in views that can be used to debug issues and validate normal behaviour. The STAR Fire Link Analyser software displays SpaceFibre traffic in four different views, each of which allows the user to visualise and examine the traffic in a different way.

The captured SpaceFibre traffic can be saved to file and opened on any machine with the STAR Fire Link Analyser software installed. This can be used to keep a record of SpaceFibre traffic captures and to share problems with others should a traffic issue be identified.

B. Network View

The network view provides a high-level overview of all the captured SpaceFibre traffic. Visualising the captured traffic at such a high-level is useful for identifying trends and can help locate areas of interest. Below is a screenshot of the network view. At the top of the view is a timeline and navigation bar. This indicates the quantity of captured SpaceFibre traffic currently visible (based on the zoom level) and the time of this relative to the capture trigger. Below this, the captured traffic for each virtual channel on each SpaceFibre lane is displayed within grey horizontal traffic bars. Bi-directional virtual channels are grouped into virtual networks as shown in the left side of the view. Individual and/or groups of SpaceFibre traffic items are represented as coloured bars within the traffic bars. As the user zooms in and out, the quantity of traffic on display changes along with the level of detail. Hovering over the data shown presents additional information for that data chunk e.g. number of frames represented and the capture start and end time.
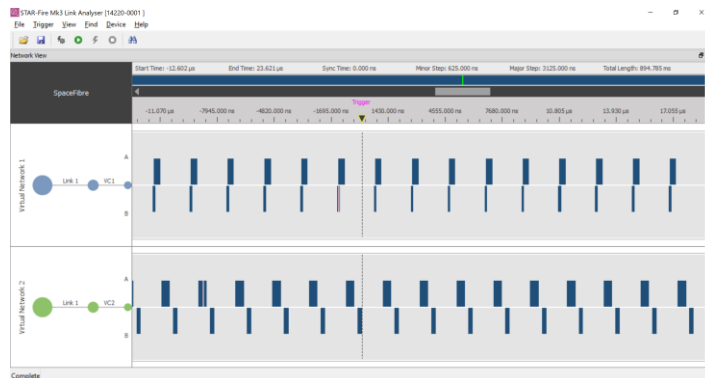

Fig. 7 Network View

If debugging an issue that occurs repeatedly, the high-level overview of captured SpaceFibre traffic provided by the network view can help quickly identify how often this occurs or if it is seemingly random. It can illustrate if the issue is limited to one or more VCs or if it affects the entire SpaceFibre lane, and it will show how data and broadcast transmission surrounding errors, and the traffic as a whole are affected. For example, identifying how often issues resulting in a SpaceFibre link disconnection occur may be obvious as the traffic overview might show regular periods of no data transmission within a normal data stream.

Whilst validating SpaceFibre traffic, the network view helps identify SpaceFibre traffic patterns and any issues that might otherwise not be obvious when viewing traffic at other lower more detailed levels. Communication between two SpaceFibre nodes will often follow a pattern. For example, a processor may regularly send commands to an instrument to read its acquired data, to which the instrument responds with a specific number of packets of a defined length. The command and response pattern would be obvious in the network view. If a pattern unexpectedly differs in some way, this may highlight an area that should be investigated. The network view provides a way of quickly scanning an entire SpaceFibre traffic capture for errors or unexpected patterns. If an issue is identified, as all views are synchronised, selecting the area of interest will highlight the same section in the other views so that this can be investigated in more detail.

C. Packet View

The packet view displays the SpaceFibre packets captured. Packet timing, size and contents are displayed for each virtual channel. This view allows the user to focus on SpaceFibre packets without having to consider the SpaceFibre symbols, words and frames used to construct these. Below is a screenshot of the packet view. One half of the view displays the SpaceFibre traffic travelling in one direction whilst the other half displays the opposite direction. A central grey column is used to separate these. The left most column displays the packet timing relative to the capture trigger. Double clicking a packet expands it, displaying its cargo.
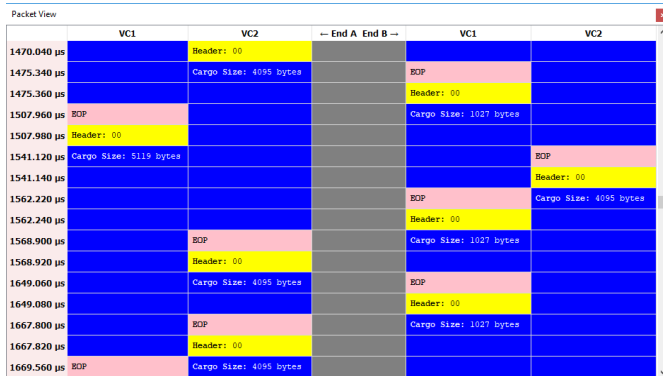
Fig. 8 Packet View

If SpaceFibre packets containing incorrect data are received or are missing, the packet view can help debug this. If the STAR Fire Mk3 is being used to capture the SpaceFibre traffic transmitted between two units (inline), it can help determine if the problem is with the transmitter or receiver i.e. are the SpaceFibre packets transmitted (those captured and displayed by the STAR Fire Mk3) the same as those received? If any packet ends in an EEP, examining the contents and timing of this packet and those surrounding it may help identify the cause e.g. timing information could suggest this packet became stuck in a routing switch and timed out.

The packet view can be used to inspect and validate the timing, length and contents of packets. Remote memory access protocol (RMAP) [1] analysis can further help validate packet data. This interprets and displays the different RMAP fields for each packet, making it easier for the user to confirm these are as expected. Built-in search capabilities help to navigate through the traffic quickly and to validate packet contents. Using this, the user can check for the presence of any packets unexpectedly ending in an EEP or to search packets for a pattern of data bytes that should be present.

D. Frame View

SpaceFibre uses frames to manage the flow of information over a SpaceFibre link. There are three frame types: data, broadcast and idle frames. Data frames are transmitted across a SpaceFibre link over virtual channels whilst broadcasts are transmitted over a broadcast channel. Idle frames are transmitted when there is no data or broadcast frames to be transmitted. Virtual channels provide multiple independent communication channels over a single physical link.

The frame view displays interleaving data and broadcast frames in their appropriate channel. This allows the user to focus on the segmented SpaceFibre packet data frames and broadcast messages without having to consider the SpaceFibre symbols and words used to construct these. Below is a screenshot of the frame view. As with the packet view, the left most column displays the time relative to the capture trigger. Every other column represents a virtual channel or broadcast channel as indicated by the column header. The traffic travelling in each direction is separated by a grey column.
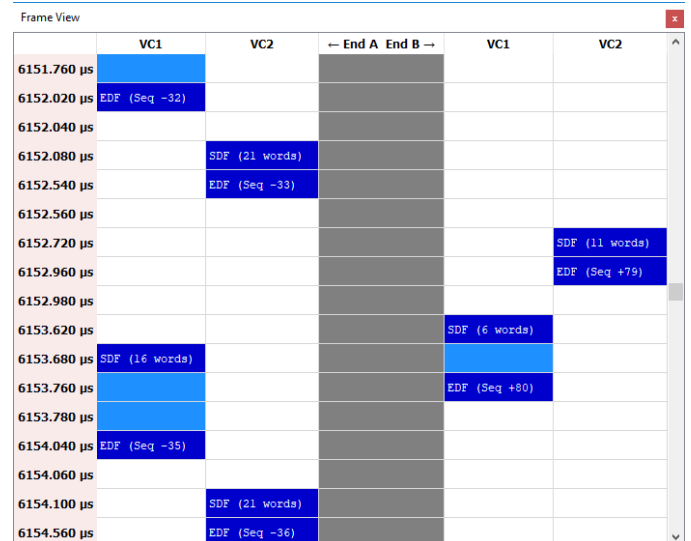

Fig. 9 Frame View

The number of data frames shown in each virtual channel allows the user to study the impact of the virtual channel QoS settings. This may highlight one or more virtual channels are being allocated too much or too little bandwidth credit and as a result the QoS settings should be adjusted for these.

The frame view can be used to validate the timing and length of broadcast and data frames. For example, where broadcast timing is critical, such as time distribution, the time of each captured broadcast frame can help validate this performs as expected.

E. Symbol View

SpaceFibre uses 8B10B encoding to transfer 10-bit symbols over a SpaceFibre lane. A symbol can be either a control or data symbol. A group of four consecutive symbols form a data word or control word.

The symbol view displays the captured SpaceFibre symbols and corresponding words travelling in both directions over a SpaceFibre lane. Below is a screenshot of the symbol view. Similar to the packet and frame views, one half of the symbol view displays the SpaceFibre traffic travelling in one direction whilst the other half displays the opposite direction. The left most column displays the time at which each word was captured relative to the capture trigger. Each SpaceFibre lane direction is represented by five columns: four display the

captured SpaceFibre symbols whilst the fifth shows the SpaceFibre word these equate to.

Fig. 10 Symbol View

Studying the SpaceFibre symbols and words shown in the symbol view can help identify any problems with these. Invalid symbols and words may indicate 8B10B encoding issues. Lots of unexpected negative acknowledgement (NACK) words, resulting in retransmission of frames, may help explain suboptimal performance. Examining the number of FCTs shown may identify problems with flow control.

The symbol view can be used to validate normal SpaceFibre behaviour such as lane initialisation, frame acknowledgement, frame precedence and error recovery. Using the symbol view search, all captured traffic can be checked for the absence of any SpaceFibre words that may otherwise indicate an unexpected problem e.g. NACK, lost signal or receive error word.

F. STAR Fire Statistics

In addition to the STAR Fire Link Analyser software, the STAR Fire Mk3 is also supplied with a standalone STAR Fire Statistics GUI application. This displays virtual channel and broadcast channel statistics associated with the STAR Fire SpaceFibre data/broadcast generators and checkers. A running count of data errors, EEPs and broadcast errors is displayed alongside the data generator rate, bandwidth reservation, receive data rate and transmit data rate for each channel. Virtual channel receive and transmit lane utilisation is also graphed over time.
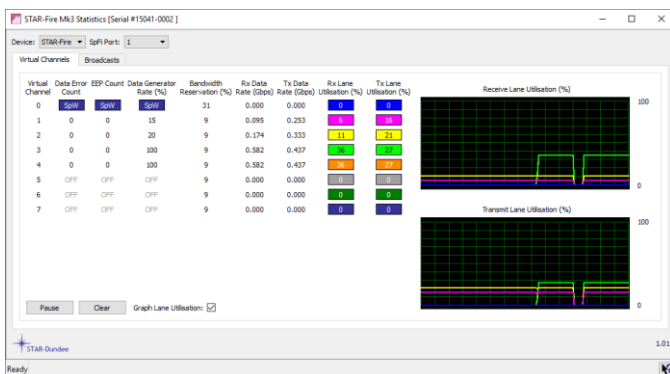

Fig. 11 STAR Fire Statistics

Useful for debug and validation efforts, this immediately alerts the user to any errors detected by the data and broadcast checkers. The transmit and receive lane utilisation live statistics are particularly useful for visualising the effects of virtual channel QoS and data rate changes.

VI. CONCLUSION

Thorough testing is required for successful SpaceFibre equipment development. Testing helps identify defects and confirms when they are resolved. When a development is nearing completion, testing provides assurance the final equipment is reliable and performs as expected.

This paper described how the STAR Fire Mk3 unit can be used to stimulate, emulate, debug and validate SpaceFibre equipment and systems, aiding development and helping to provide assurance that equipment is operating correctly. An overview of the STAR Fire Mk3 hardware described the interfaces available and the key functionality it provides, namely, the ability to act as a SpaceFibre interface and/or link analyser, to interconnect SpaceWire with SpaceFibre, and to interface with external equipment.

To perform SpaceFibre equipment stimulation and emulation, the capabilities of the STAR Fire Controller GUI application and STAR-System software stack were described. This includes the ability to initialise a SpaceFibre lane, set the data signalling rate, configure the quality of service parameters, transmit and receive SpaceFibre packets from a host PC, and transmit and receive SpaceFibre packets and broadcast messages directly from hardware. To aid with SpaceFibre debug and validation, the capabilities of the STAR Fire Link Analyser and STAR Fire Statistics GUI applications were described. The different live statistics presented by the STAR Fire Statistics application were listed along with some of the reasons why these are useful. Operation of the SpaceFibre Link Analyser software was described, along with the different views in which it displays captured traffic and how each of these can help debug and validate SpaceFibre equipment.

The descriptions of the hardware and software capabilities described in this paper, along with how these can help during testing, may aid those responsible for designing and implementing SpaceFibre equipment and systems in their test efforts.

REFERENCES

[1] SpaceWire – Remote Memory Access Protocol, ECSS-E-ST-50-52C, February 2010

[2] SpaceFibre – Very High-Speed Serial Link, ECSS-E-ST-50-11C DFR1, January 2018

[3] S. Parkes, https://www.star-dundee.com/spacefibre-users-guide, SpaceFibre User's Guide, STAR-Dundee Website

[4] S. Mudie, C. McClements, D. Gibson, STAR Fire Mk3 User Manual Rev 1.02