

SpaceWire Link Analyser Mk3

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For those responsible for testing SpaceWire equipment it is essential to be able to capture and view the traffic on a SpaceWire link in order to help validate the link is operating correctly and debug the link should any unexpected behavior be observed. The SpaceWire Link Analyser Mk3 is a piece of test equipment capable of transparently capturing large quantities of SpaceWire traffic on a single link. New software written for this displays the captured traffic in a variety of views that allow it to be examined in different levels of detail. This paper describes the hardware and software capabilities of the SpaceWire Link Analyser Mk3 and provides descriptions and examples of some of the ways this can be used to perform SpaceWire link analysis.

Index Terms— SpaceWire, Testing, Spacecraft Electronics, SpaceWire Link Analyser Mk3.

I. INTRODUCTION

Whilst developing and testing SpaceWire equipment, traffic visibility is essential. This allows the engineer to confirm their unit is operating correctly and aids debugging when problems are detected. Without traffic visibility there is an increased risk that issues may go undetected and problems may take significantly longer to resolve. Common examples include issues with signalling, problems with link initialisation, over and under credit allocation, disconnect errors and missing or unexpected data. To detect problems such as these, a SpaceWire Link Analyser Mk3 can be used. This allows the user to unobtrusively record the SpaceWire traffic travelling in both directions over a SpaceWire link, providing the traffic visibility essential for link validation and debugging.

This paper describes in detail the capabilities of the SpaceWire Link Analyser Mk3, including the improvements to the SpaceWire Link Analyser Mk3 hardware and the latest generation of SpaceWire link analysis software. Key requirements identified to improve SpaceWire traffic visibility are outlined along with some of the challenges these present. The SpaceWire Link Analyser Mk3 hardware, and how this is operated, are briefly described. An overview of the software applications used to control this is provided. Finally, the different views in which captured SpaceWire traffic is displayed and why these are well suited for SpaceWire link analysis are described, along with some examples.

II. AIMS

The SpaceWire Link Analyser Mk3 is designed to enable users to unobtrusively capture and display SpaceWire traffic. In aiming to improve the traffic visibility provided by this, the following requirements were identified:

- The SpaceWire Link Analyser Mk3 memory shall be increased to capture a greater quantity of SpaceWire

traffic so that debug and validation efforts can be more comprehensive.

- The SpaceWire Link Analyser Mk3 shall interface to the host PC using USB 3.0 so that large quantities of captured traffic can quickly be uploaded.
- New common software shall be written to control the SpaceWire Link Analyser Mk3. This shall be capable of displaying and navigating large quantities of SpaceWire traffic and shall be designed to support multiple device types.

The requirements above present hardware and software challenges. As the quantity of SpaceWire traffic is increased so too is the time it takes to upload this from hardware. Once uploaded, software must be capable of quickly interpreting the captured traffic and displaying this in a variety of useful ways that can be navigated easily, all whilst minimising the use of machine resources.

III. SPACEWIRE LINK ANALYSER MK3

The SpaceWire Link Analyser Mk3 transparently captures in detail the bi-directional SpaceWire traffic travelling over a single SpaceWire link. The timing information of each SpaceWire character and error is captured along with a trace of the data and strobe signals. 512MB of on-board memory is available for capturing SpaceWire traffic, meaning up to 67 million events can be recorded.

The SpaceWire Link Analyser Mk3 is controlled by a host PC. Connected using a high-speed USB 3.0 interface, able to operate at 5 Gbits/s, this ensures the entire memory contents can quickly be uploaded. It interfaces with SpaceWire equipment using two SpaceWire ports and has four external SMB triggers, two MICTOR connectors and a power connector.



Fig. 1 SpaceWire Link Analyser Mk3

A. Operation

The SpaceWire Link Analyser Mk3 is designed to monitor the traffic on a SpaceWire link either between two SpaceWire

link interfaces or a single interface (in loopback mode). Below is an example configuration.

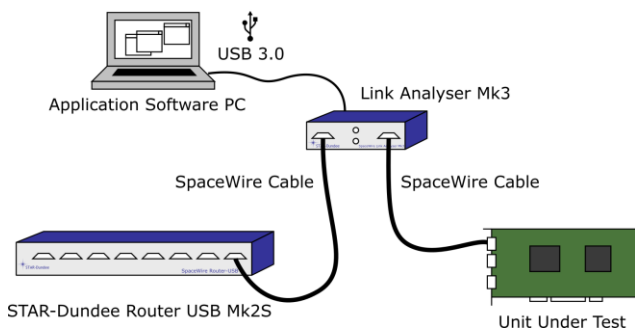


Fig. 2 Capturing One SpaceWire Link

Once connected, the capture memory properties are set. These include the quantity of memory to use, memory usage relative to capture trigger and the trigger delay time. Next the capture trigger is configured, for example trigger on an error end of packet marker (EEP). SpaceWire traffic capture is then started, causing the device to continuously capture to a circular buffer whilst waiting for the capture trigger to occur. When the trigger is detected or is forced by the user, the device memory is filled. The captured SpaceWire traffic is then uploaded to the host PC where it is displayed in different views.

Should users only be interested in capturing specific SpaceWire character types, these can be enabled/disabled prior to starting SpaceWire traffic capture, improving the efficiency with which memory is used. For example, disabling Null capture can save a significant amount of memory that can instead be used to capture other character types, such as data characters.

B. Interfacing with External Equipment

External SMB triggers on the SpaceWire Link Analyser Mk3 provide interfaces for connecting external equipment to aid testing. Equipment connected to an external input trigger can cause the capture trigger to occur when an input signal is detected. This means SpaceWire traffic capture can happen when an event of interest external to the SpaceWire Link Analyser Mk3 hardware occurs. Inversely, the SpaceWire Link Analyser Mk3 can generate an external output signal when an event of interest occurs. This can be used to notify other equipment that the capture trigger has occurred or to help keep track of the timing at which specific character types are detected.

A logic analyser can also be connected to the SpaceWire Link Analyser Mk3 using a MICTOR connector. This provides access to decoded SpaceWire character information for monitoring purposes.

IV. SPACEWIRE TRAFFIC VIEWER SOFTWARE

New software has been written for the SpaceWire Link Analyser Mk3. A library of traffic analysis views has been created so that a consistent set of displays can be presented for all STAR-Dundee SpaceWire and SpaceFibre link analysis devices. The views presented depend upon the level of detail

available from the captured traffic. The SpaceWire traffic captured by the SpaceWire Link Analyser Mk3 is shown in network, packet, character and bit-stream views. By displaying SpaceWire traffic in a variety of views, different types of issues can be more easily identified and debugged. Each view is synchronised by time meaning users can select data in one view and the others will automatically display the corresponding traffic. The views are docked within a main window that is used to configure recording properties and start/stop capture.

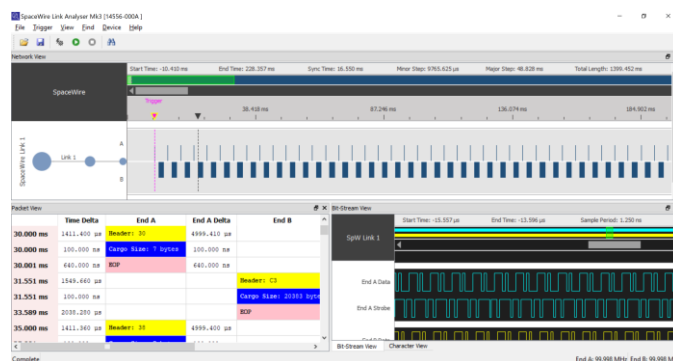


Fig. 3 SpaceWire Link Analyser Mk3 Traffic Viewer

The new software improves on functionality, reusability and performance compared to previous software. The following sections describe some of the functionality and the views provided in the new software, and why these are useful for SpaceWire link analysis.

V. TRIGGERING

An optional capture trigger can be configured for the SpaceWire Link Analyser Mk3 to help capture SpaceWire traffic of interest. The capture trigger can be set to occur when an event is detected on a SpaceWire receiver or an external input signal is detected. For example, if a user wanted to debug a problem where a disconnect error occurred occasionally in one direction on a SpaceWire link, they could set the capture trigger to occur when this was detected. The captured SpaceWire traffic could then help to identify the cause of the disconnect error.

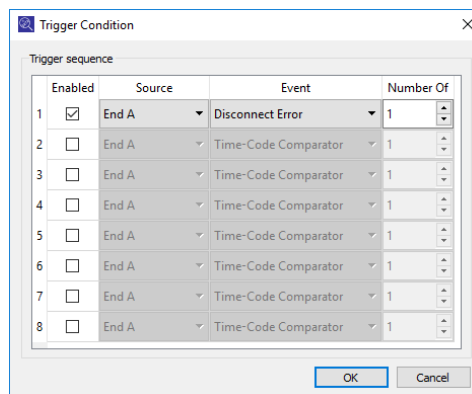


Fig. 4 Trigger on Disconnect

Sequences of events can be specified for more complex trigger conditions.

VI. NETWORK VIEW

The network view provides a high-level overview of all the recorded SpaceWire traffic. Visualising this 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 network view is a timeline and navigation bar. This indicates the quantity of captured SpaceWire traffic currently visible (based on the zoom level) and the time of this relative to the capture trigger. Below this, the captured traffic in each direction on a SpaceWire link is displayed within grey horizontal traffic bars. The captured SpaceWire link and direction information are shown on the left side of the view. Individual and/or groups of SpaceWire 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 packets represented and the packet capture start and end time.

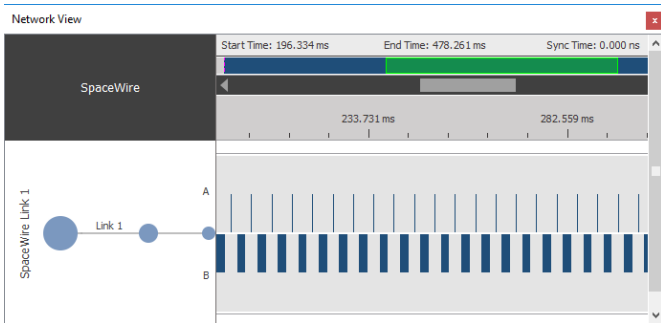


Fig. 5 Network View

Without the network view, navigating such large quantities of traffic could be difficult as the other views present the traffic in much more detail and show only a small portion at any one time. With the network view, large quantities of traffic can be viewed, allowing the user to quickly inspect and navigate this.

VII. PACKET VIEW

The packet view displays the SpaceWire packets recorded. Packet timing, size and contents are displayed for each direction of a SpaceWire link. This view allows the user to focus on the captured SpaceWire packets and the normal characters (data characters, end of packet markers and error end of packet markers) used to construct these, without having to consider link characters and time-codes. Below is a screenshot of the packet view. The left most column displays packet timing relative to the capture trigger time. Next to this, a time delta column displays the time difference between the time from trigger rows. SpaceWire packets travelling in each direction are shown in end columns. Each packet displayed consists of a header byte (yellow), cargo (blue) and end of packet (pink). The delta time between each row used to represent a packet is shown in the end delta column. Users can

double click the cargo of a packet to expand and view the contents.

Time Delta	End A	End A Delta	End B	End B Delta
55.001 ms	1411.360 µs	Header: 58	4999.410 µs	
55.001 ms	100.000 ns	Cargo Size: 7 bytes	100.000 ns	
55.002 ms	640.000 ns	EOP	640.000 ns	
56.552 ms	1549.700 µs		Header: F4	2961.800 µs
56.552 ms	100.000 ns		Cargo Size: 20383 bytes	100.000 ns
58.590 ms	2038.290 µs		EOP	2038.290 µs
60.001 ms	1411.390 µs	Header: 60	4999.480 µs	
60.001 ms	100.000 ns	Cargo Size: 7 bytes	100.000 ns	
60.002 ms	640.000 ns	EOP	640.000 ns	
61.552 ms	1549.670 µs		Header: 2C	2961.800 µs
61.552 ms	100.000 ns		9F 75 90 39 27 85 E5 B4	100.000 ns
61.553 ms	800.000 ns		14 72 59 15 15 2F 8C 2C	800.000 ns

Fig. 6 Packet View

By inspecting packets, users can confirm these are as expected and identify issues. Address bytes can be checked, packet cargo size and contents examined, and packets ending in an EEP rather than EOP investigated further.

The packet view also has a protocol mode that can be used to interpret the cargo of a packet according to a protocol. This currently supports the Remote Memory Access Protocol (RMAP) [1]. In this mode, the fields of RMAP packets are interpreted and displayed. RMAP protocol analysis avoids the user having to manually interpret packet cargo and allows them to more easily inspect RMAP commands and replies used to transfer data.

Time Delta	End A	End A Delta	End B	End B Delta
0.000 ns		Header: RMAP Command		
0.000 ns	0.000 ns	Target Address: FE		
400.000 ns	400.000 ns	Command: Read Command	400.000 ns	
400.000 ns	0.000 ns	Data Not Verified		
400.000 ns	0.000 ns	Acknowledge		
400.000 ns	0.000 ns	Incrementing Address		
600.000 ns	200.000 ns	Key: 20	200.000 ns	
800.000 ns	200.000 ns	Initiator Address: FE	200.000 ns	
1000.000 ns	200.000 ns	Transaction ID: 00A1	200.000 ns	
1400.000 ns	400.000 ns	Extended Address: 00	400.000 ns	
1600.000 ns	200.000 ns	Address: 0000003E	200.000 ns	
2400.000 ns	800.000 ns	Data Length: 000008	800.000 ns	
3000.000 ns	600.000 ns	Header CRC: FF	600.000 ns	
3080.000 ns	80.000 ns	EOP	80.000 ns	
3710.000 ns	630.000 ns		Header: RMAP Reply	
3710.000 ns	0.000 ns		Initiator Address: FE	
3810.000 ns	100.000 ns		Command: Read Reply	100.000 ns
3810.000 ns	0.000 ns		Data Not Verified	

Fig. 7 Protocol Analysis

To help locate specific packets, the packet view has search capabilities. Users can find the next/previous packet containing a sequence of data bytes. In addition, users can search for RMAP packets containing specific fields e.g. an RMAP write command with a specific extended address and memory address. Having search capabilities such as this is important to help quickly locate data of interest and is essential when

working with the large quantity of traffic that the SpaceWire Link Analyser Mk3 captures.

VIII. CHARACTER VIEW

Specific to the SpaceWire Link Analyser Mk3, the character view displays captured data characters, control characters, control codes and errors. It is used to visualise and debug captured traffic at the SpaceWire character and exchange levels. The timing of each event captured relative to the trigger is displayed, allowing the user to examine when events occurred and calculate the time between these. Below is a screenshot of the character view. Similar to the packet view, the left most column displays the character event time relative to the capture trigger time, followed by a time delta column. Information for each direction of SpaceWire traffic is then represented by three columns. The event column displays the data characters, control characters and control codes captured. The error column displays any errors captured. The delta column shows the time difference between two consecutive events.

Time Delta	End A Event	End A Error	End A Delta	End B Event	End B Error	End B Delta
60.001 ms	NCHAR (60)		100.000 ns	NULL		80.000 ns
60.001 ms				NULL		80.000 ns
60.001 ms	NCHAR (61)		100.000 ns			80.000 ns
60.002 ms	NCHAR (62)		100.000 ns			80.000 ns
60.002 ms				NULL		80.000 ns
60.002 ms	NCHAR (63)		100.000 ns			80.000 ns
60.002 ms				NULL		80.000 ns
60.002 ms	NCHAR (64)		100.000 ns			80.000 ns
60.002 ms				NULL		80.000 ns
60.002 ms	NCHAR (65)		100.000 ns			80.000 ns
60.002 ms				NULL		80.000 ns
60.002 ms	NCHAR (66)		100.000 ns			80.000 ns
60.002 ms				NULL		80.000 ns

Fig. 8 Character View

To quickly locate SpaceWire characters, control codes and errors, the character view can be searched. Users can confirm the absence of any errors and navigate to events of interest using this.

The traffic and timing information shown in the character view can be used to validate correct behaviour. For example, in some SpaceWire networks time-codes are periodically transmitted to indicate time-slots in which transactions can be scheduled. The character view can be used to inspect and validate time-code and data character timing. Viewing the SpaceWire traffic travelling in both directions, users can examine the information exchanged between two ends of a SpaceWire link as described in the SpaceWire exchange level. Link initialisation, flow control and error handling are illustrated below.

A. Link Initialisation

SpaceWire packets and time-codes can only be transmitted and received once SpaceWire link initialisation has taken place. This is handled by the SpaceWire interface state machine. Null control codes and flow control tokens (FCTs) must be exchanged before each SpaceWire interface reaches

the run state. Below is a screenshot of the character view showing the link initialisation Null/FCT handshake.

Time Delta	End A Event	End A Error	End A Delta	End B Event	End B Error	End B Delta
-4530.000 ns	GET_BIT					
-2710.000 ns			1820.000 ns			
-2130.000 ns	NULL					
-1910.000 ns			800.000 ns			
-1110.000 ns	NULL					
-310.000 ns			800.000 ns	NULL		1820.000 ns
-120.000 ns	NULL					
-40.000 ns			190.000 ns			
0.000 ns	FCT					
80.000 ns			40.000 ns			
80.000 ns	NULL					
90.000 ns			80.000 ns	FCT		400.000 ns
160.000 ns	NULL					
170.000 ns			80.000 ns			
170.000 ns				NULL		80.000 ns
200.000 ns	FCT					
200.000 ns			40.000 ns			
210.000 ns				FCT		40.000 ns

Fig. 9 Link Initialisation

B. Link Flow Control

Normal characters can only be transmitted if there is space for them in the receive buffer at the other end of the link. The receive buffer indicates that there is space for eight more normal characters to the transmitter at the other end of the link by transmitting a flow control token. Below is a screenshot of the character view showing data characters transmitted after an FCT is received.

Time Delta	End A Event	End A Error	End A Delta	End B Event	End B Error	End B Delta
1251.595 ms	FCT					
1251.595 ms			40.000 ns	NCHAR (A5)		100.000 ns
1251.595 ms						
1251.595 ms	NULL			NCHAR (4F)		100.000 ns
1251.595 ms			80.000 ns			
1251.595 ms	NULL			NCHAR (A8)		100.000 ns
1251.595 ms			80.000 ns			
1251.595 ms	NULL			NCHAR (DA)		100.000 ns
1251.595 ms			80.000 ns			
1251.595 ms	NULL			NCHAR (90)		100.000 ns
1251.595 ms			80.000 ns			
1251.595 ms	NULL			NCHAR (81)		100.000 ns
1251.595 ms			80.000 ns			
1251.595 ms	NULL			NCHAR (77)		100.000 ns
1251.595 ms			80.000 ns			
1251.595 ms	NULL			NCHAR (7E)		100.000 ns

Fig. 10 Link Flow Control

C. Link Error Handling

When an error is detected on one end of a SpaceWire link that end disables its transmitter. This causes the other end to disconnect and also stop transmitting. After an exchange of silence, the two ends perform the Null/FCT handshake shown in the link initialisation section above. The character view screenshot below shows an escape error being detected on end A resulting in the transmitter of that end being disabled (indicated by the absence of Nulls on end B).

Time Delta	End A Event	End A Error	End A Delta	End B Event	End B Error	End B Delta
-50.000 ns	30.000 ns			NULL		40.000 ns
-40.000 ns	10.000 ns	NULL				
-30.000 ns	30.000 ns			NULL		40.000 ns
-20.000 ns	10.000 ns	ESCAPE ESCAPE ERROR	40.000 ns			
-10.000 ns	30.000 ns			NULL		40.000 ns
0.000 ns	10.000 ns					
10.000 ns	30.000 ns	NULL				40.000 ns
20.000 ns	10.000 ns		40.000 ns	NULL		
30.000 ns	30.000 ns			NULL		40.000 ns
40.000 ns	10.000 ns	NULL				
50.000 ns	30.000 ns		40.000 ns	NULL		
60.000 ns	10.000 ns			NULL		40.000 ns
70.000 ns	30.000 ns					
80.000 ns	10.000 ns	NULL				40.000 ns
90.000 ns	30.000 ns		40.000 ns	NULL		
100.000 ns	10.000 ns			NULL		40.000 ns
110.000 ns	30.000 ns					
120.000 ns	10.000 ns	NULL				40.000 ns
130.000 ns	30.000 ns		40.000 ns	NULL		
140.000 ns	10.000 ns			NULL		40.000 ns
150.000 ns	30.000 ns					
160.000 ns	10.000 ns	NULL				40.000 ns
170.000 ns	30.000 ns		40.000 ns	NULL		
180.000 ns	10.000 ns			NULL		40.000 ns
190.000 ns	30.000 ns					
200.000 ns	10.000 ns	NULL				40.000 ns
210.000 ns	30.000 ns		40.000 ns	NULL		
220.000 ns	10.000 ns			NULL		40.000 ns
230.000 ns	30.000 ns					
240.000 ns	10.000 ns	NULL				40.000 ns
250.000 ns	30.000 ns		40.000 ns	NULL		
260.000 ns	10.000 ns			NULL		40.000 ns
270.000 ns	30.000 ns					
280.000 ns	10.000 ns	NULL				40.000 ns
290.000 ns	30.000 ns		40.000 ns	NULL		
300.000 ns	10.000 ns			NULL		40.000 ns
310.000 ns	30.000 ns					
320.000 ns	10.000 ns	NULL				40.000 ns
330.000 ns	30.000 ns		40.000 ns	NULL		
340.000 ns	10.000 ns			NULL		40.000 ns
350.000 ns	30.000 ns					
360.000 ns	10.000 ns	NULL				40.000 ns
370.000 ns	30.000 ns		40.000 ns	NULL		
380.000 ns	10.000 ns			NULL		40.000 ns
390.000 ns	30.000 ns					
400.000 ns	10.000 ns	NULL				40.000 ns

Fig. 11 Transmitter Disabled After Escape Error Received

IX. BIT-STREAM VIEW

In addition to character information, the SpaceWire Link Analyser Mk3 captures the bit-stream on a SpaceWire link. This is presented in the bit-stream view, where the data and strobe signals are graphed for each direction. This is useful for visualising data encoding. Below is a screenshot of the bit-stream view. Similar to the network view, at the top is a timeline and navigation bar. A green rectangle overlay indicates the quantity of traffic currently on show (based on the zoom level) and where this is relative to the entire bit-stream capture. Time information displayed is relative to the capture trigger time. Below this, the captured data and strobe signals are represented by different colours for each direction. The direction and signal type are indicated on the left side of the view. As the user zooms in and out, the detail and quantity of the signal information shown are adjusted. Users can insert two markers at points of interest by clicking the view. The timing of each marker is displayed along with the time between them.

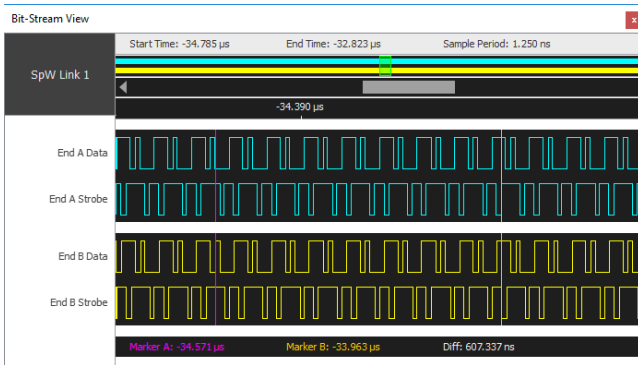


Fig. 12 Bit-Stream View

The bit-stream view allows the user to debug problems at the signal level. During testing, other more high-level views may show errors e.g. the character view may display parity and disconnect errors. The bit-stream view can be used to investigate the data and strobe signals around the time at which the errors were detected. This may lead to the discovery of a signalling issue such as a simultaneous transition. The bit-

stream view screenshot below shows an example of a simultaneous transition.

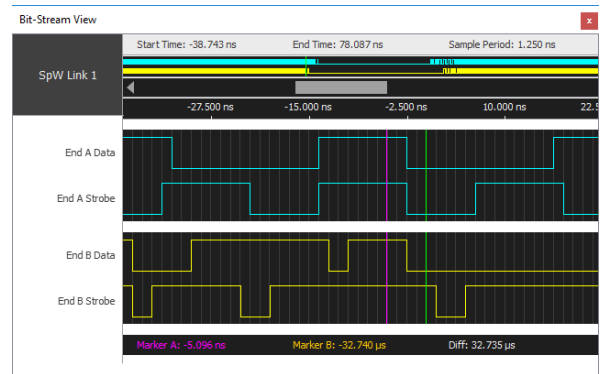


Fig. 13 Simultaneous Transitions

For successful SpaceWire link initialisation, character synchronisation must occur. The bit-stream view can be used to visualise this as shown below.

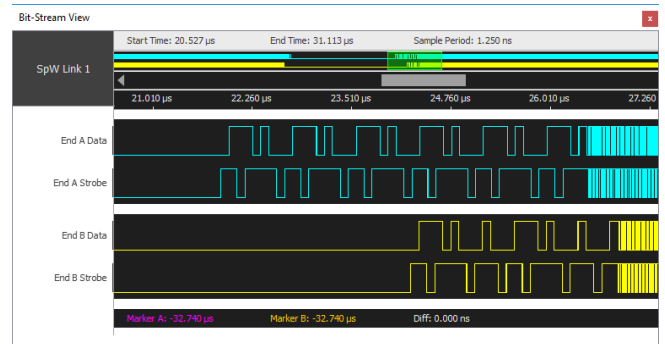


Fig. 14 Character Synchronisation

Data and strobe lines of both ends are initially set low before one end (A) transmits Nulls (a specific sequence of eight bits) on which the other end (B) synchronises its receiver. Once synchronised, end B transmits Nulls on which end A synchronises its receiver. Further Nulls and FCTs are then exchanged according to the link initialisation Null/FCT handshake. The SpaceWire interfaces start at 10 Mbit/s before switching to the required operating speed (200 Mbit/s in this case).

X. STATISTICS

The SpaceWire Link Analyser Mk3 software includes a status counter view that displays live statistics for traffic travelling in both directions on a SpaceWire link. This includes the signalling rate, the number of errors detected and a count of the different SpaceWire character types. Line charts graph these values as shown below.

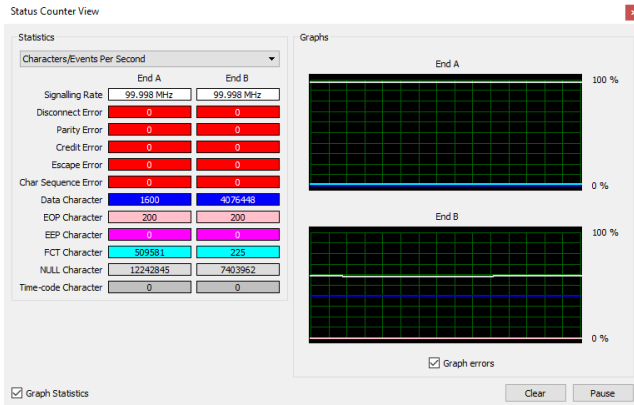


Fig. 15 Status Counter View

The character/event count displayed can be set to the number detected per second or in total. The statistics can be paused to be examined or reset when required. If an error is detected, a red vertical line is shown at the appropriate time on the charts. The status counter display is useful for monitoring SpaceWire link utilisation and for detecting any errors during long tests. For example, it can be used to confirm no errors occurred. If any errors are detected, the same test can be rerun with a capture trigger set to occur when the error type identified is detected, allowing the problem to be investigated further.

XI. SAVE AND LOAD

The SpaceWire Link Analyser Mk3 uploads captured traffic to computer memory. The user can choose to save this to hard disk or discard it when the next capture takes place or the application is closed. Being able to save and later open and view SpaceWire traffic allows the user to keep a record of SpaceWire traffic behaviour under different circumstances. It allows the user to save traffic containing unexpected errors and share this with others that can help with debug efforts.

XII. CONCLUSION

SpaceWire traffic visibility is necessary to confirm SpaceWire equipment is operating correctly and to debug problems when these are encountered. The SpaceWire Link Analyser Mk3 provides comprehensive recording capabilities. The software provided with it displays the captured traffic in different levels of detail, providing valuable traffic visibility for debug and validation efforts.

This paper described the SpaceWire Link Analyser Mk3 hardware and its capabilities. The SpaceWire Link Analyser Mk3 captures detailed information about the bi-directional traffic travelling on a single SpaceWire link. It can capture up to 67 million events to on-board memory before it is quickly uploaded to a host PC using a USB 3.0 interface.

The software provided with the SpaceWire Link Analyser Mk3 was also described, along with examples and descriptions of how these can help whilst testing SpaceWire equipment. The software displays captured traffic in multiple views in varying quantities and detail. The network view provides a high-level overview of large amounts of traffic, useful for identifying trends and for navigation. The packet view allows users to examine the packets transferred and can interpret and display the fields of RMAP packets. The character view is used to examine SpaceWire traffic at the character and exchange levels. The bit-stream view displays the data and strobe signals captured, useful for visualising data encoding.

The large quantities of traffic that can be captured by hardware, combined with new software capable of quickly navigating this and displaying it in multiple views with different detail, provides advanced SpaceWire traffic visibility that can aid those responsible for testing SpaceWire equipment.

REFERENCES

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- [2] STAR-Dundee, SpaceWire Link Analyser Mk3 User Manual, v1.00.
- [3] S. Parkes, [https://www.star-dundee.com/sites/default/files/SpaceWire%20User%27s%20Gui de.pdf](https://www.star-dundee.com/sites/default/files/SpaceWire%20User%27s%20Guide.pdf), SpaceWire User's Guide, STAR-Dundee Website.
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