The SpaceWire Conformance Tester

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SpaceWire Conformance Tester

- Specifically developed to test SpaceWire ASICs and FPGAs designs
- Probes compliance of SpaceWire device
- Against the SpaceWire ECSS standard

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SpaceWire Conformance Testing

- How do we investigate UUT compliance?
  - Consider the UUT to be a black-box
  - Drive SpaceWire DOUT/SOUT signals in various ways
  - Monitor DIN/SIN signals driven by UUT
- Various monitoring techniques:
  - High speed sampling of DIN/SIN
  - Observe GotFCT/parity error *etc* events from a *codec*
  - Analyse the events and their detection time
- Test design:
  - Identify testable clauses in the SpaceWire standard
  - Be careful with test pre-conditions/post-conditions

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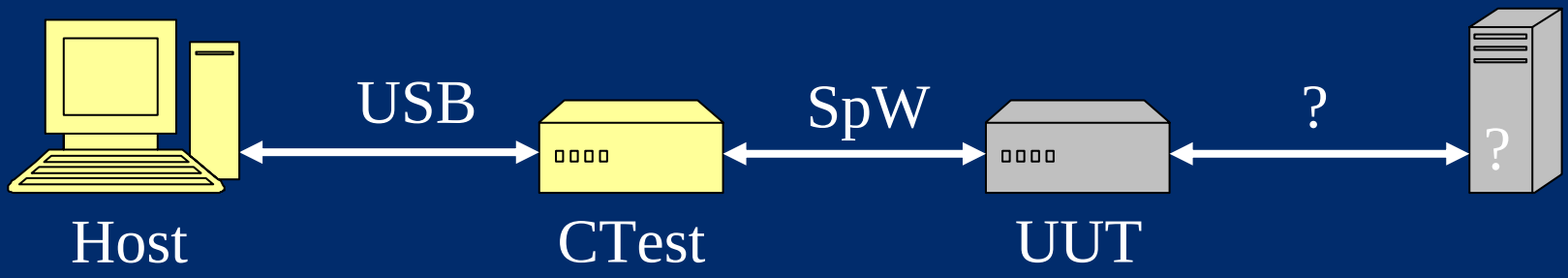
System Overview

- Host PC:
  - Initialises the test hardware and captures the results.
  - Analyses and presents the test results to the user.
- CTest hardware unit:
  - Test code execution is independent of host PC
  - All operations have a known execution time
- UUT: unit under test
- ?: user access to UUT internals



Estimated Coverage of the Standard

Clause	Title	Coverage	Cooperation
§5.3	Connectors	25%	None
§5.5	PCB tracks	10%	None
§6	Signal level	80%	Low
§7	Character level	70%	Low
§8	Exchange level	95%	Low
§9	Packet level	100%	High
§10.4	SpaceWire nodes	100%	High
§10.6	Network level errors	100%	High

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Link to the Standard in User Manual

Clause	Summary	Test (Section Number)	Notes
7.1	General	None	Not applicable
7.2	Data characters	Packet level (3.8)	Fundamental
7.3.a	Control characters/codes	All	Fundamental
7.3.b	NULL	All	Fundamental
7.3.c	Time code	Time code tests (3.6)	Implicit
7.3.d	Time code format	Time code support (3.6.1)	Implicit
7.3.e	Escape error	Exchange-level (3.4)	Explicit
7.4	Parity error	Exchange-level (3.4)	Explicit
7.5.a	Data/strobe during silence	Shutdown analysis (3.3.5)	Explicit
7.5.b	Transmit bit pattern after reset	Start-up waveform (3.3.4)	Explicit
7.6	Host data interface	None	Not accessible
7.7.a	Host time interface	None	Not accessible
7.7.b	Immediate TICK_IN response	None	Not accessible
7.7.c	TICK_OUT response	Valid time codes (3.6.3)	Explicit
7.7.d	Only one TICK_IN node	None	Not accessible
7.7.e	Time code master	None	Not accessible
7.7.f	Link time code receive	Valid time codes (3.6.3)	Explicit
7.7.g	Link time code transmit	Time code support (3.6.1)	Explicit
7.7.h	Time code flags	None	Not tested

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SpaceWire Conformance Tests

- **Link/bit-level**
  - Link initialisation testing,
  - Disconnection timeout measurement,
  - Link start-up speed and waveform analysis,
  - Link shut-down analysis and simultaneous D/S transition detection.
- **Exchange-level**
  - Validate response to parity and escape errors in following states:
    - ErrorWait,
    - Ready,
    - Started,
    - Connecting
    - Run
  - Response to FCT, NCHAR and time codes in those states
  - Estimates of the 12.8 µs Started/Connecting timeouts
- **Credit-level**
  - Validate UUT response to excess FCTs and NCHARs,
  - empty packet testing
  - monitoring UUT signals for credit errors

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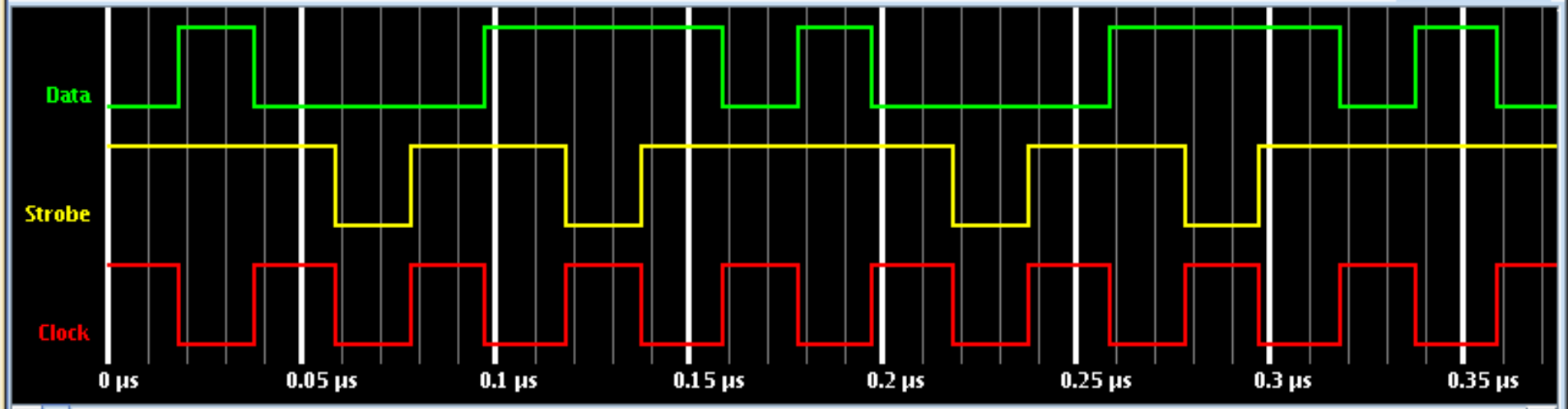
SpaceWire Conformance Tester

- **Time-codes**
  - Determine whether time-codes are accepted
  - Probe response to valid and invalid time-codes
  - Measure UUT time-code generation frequency.
- **Empty packets**
  - Investigate effect of sending empty EOP and EEP packets.
- **Packet-level**
  - Test transmission and reception of packets with different types of UUT:
    - loop-back,
    - data-sink,
    - data-source,
    - command-sender
    - command-receiver.
- **Waveform trace**
  - Waveform display of UUT data and strobe signals

SpaceWire Conformance Tester 1.10 (not saved)

File Edit Settings Tests Goto Debug Help

Cover | Settings | Bit-level | Exchange | EOP/EEP | Timecode | Credit | Packet (1) | Packet (2) | Other | Waveform



Zoom In | Zoom Out | Zoom Fit | Save Waveform | Colour

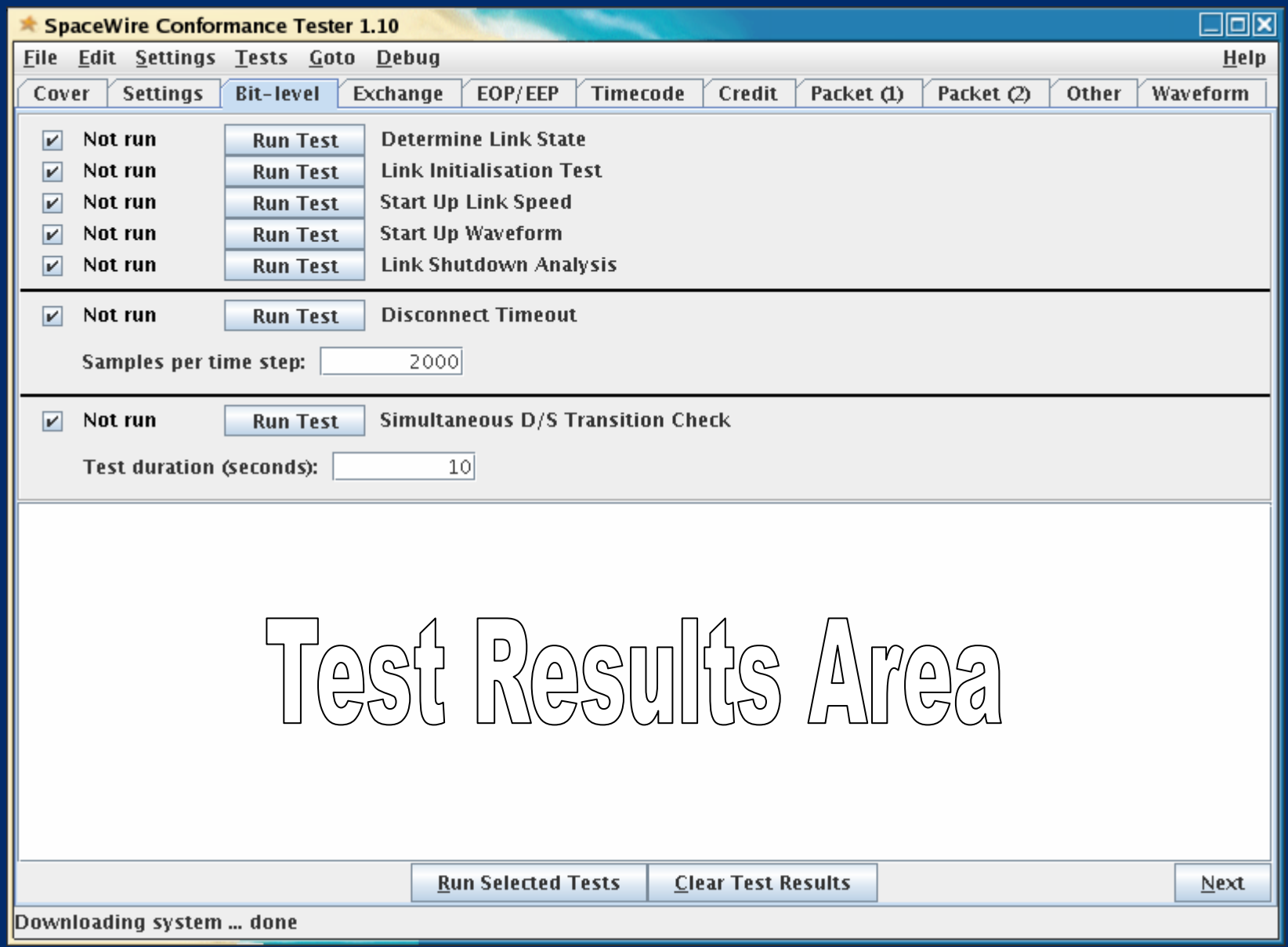
Test: Get UUT Waveform
Status: Success

	Measured rate	Accuracy	Minimum Rate	Maximum Rate
Bit-to-bit:	49.71 +/- 1.71	3.96	48.00 +/- 3.43	51.43 +/- 3.96
Rise-to-rise:	50.54 +/- 0.89	1.90	49.66 +/- 1.77	51.43 +/- 1.90
Fall-to-fall:	50.54 +/- 0.89	1.90	49.66 +/- 1.77	51.43 +/- 1.90

Note: All rate measurements are in Mbits/second
Note: Measurement duration 45.48 microseconds (2274 bits)
Note: Average link rate 50.00 Mbits/second
Note: Skew estimate 0.69 +/- 1.39 ns (assuming constant link rate)

Prev | Measure Link Speed | Clear Test Results

Easy-to-use GUI



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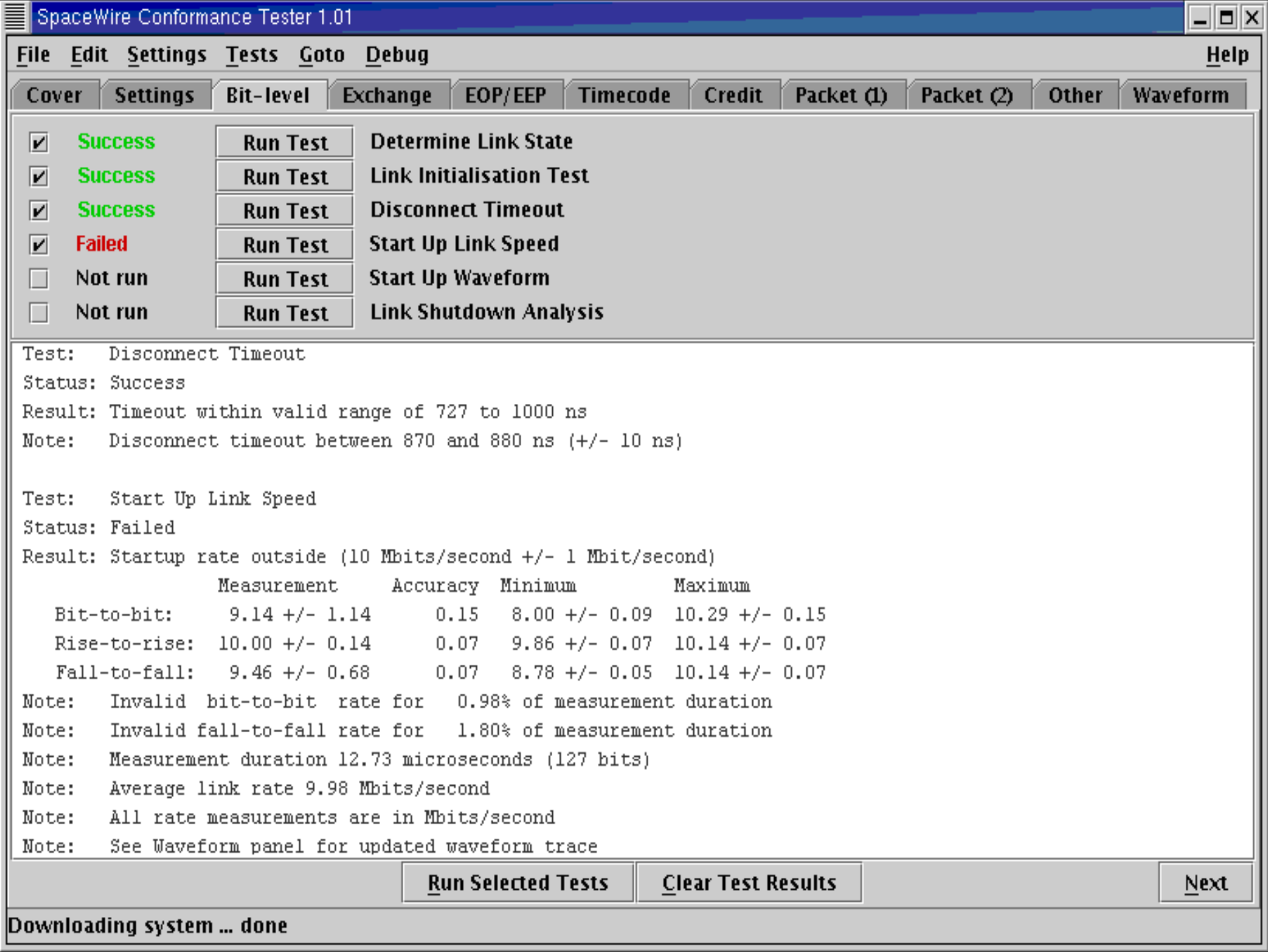
SpaceWire Conformance Tester 1.01
File Edit Settings Tests Goto Debug Help
Cover Settings Bit-level Exchange EOP/EEP Timecode Credit Packet (1) Packet (2) Other Waveform
Success Run Test Determine Link State
Success Run Test Link Initialisation Test
Success Run Test Disconnect Timeout
Failed Run Test Start Up Link Speed
Not run Run Test Start Up Waveform
Not run Run Test Link Shutdown Analysis
Test: Disconnect Timeout
Status: Success
Result: Timeout within valid range of 727 to 1000 ns
Note: Disconnect timeout between 870 and 880 ns (+/- 10 ns)
Test: Start Up Link Speed
Status: Failed
Result: Startup rate outside (10 Mbits/second +/- 1 Mbit/second)
Measurement Accuracy Minimum Maximum
Bit-to-bit: 9.14 +/- 1.14 0.15 8.00 +/- 0.09 10.29 +/- 0.15
Rise-to-rise: 10.00 +/- 0.14 0.07 9.86 +/- 0.07 10.14 +/- 0.07
Fall-to-fall: 9.46 +/- 0.68 0.07 8.78 +/- 0.05 10.14 +/- 0.07
Note: Invalid bit-to-bit rate for 0.98% of measurement duration
Note: Invalid fall-to-fall rate for 1.80% of measurement duration
Note: Measurement duration 12.73 microseconds (127 bits)
Note: Average link rate 9.98 Mbits/second
Note: All rate measurements are in Mbits/second
Note: See Waveform panel for updated waveform trace
Run Selected Tests Clear Test Results Next
Downloading system ... done

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Case Studies:

- First NULL detection
- Initial operating data signalling rate
- Empty packet credit counting
- Too many NChars credit error
- Error recovery time

First NULL Detection

- Problem encountered:
  - Link initialisation test: start-up NULL didn't arrive/was late
- Reason for failure:
  - The UUT wasn't performing NULL detection correctly
  - Conformance tester starts sending NULLs while UUT in ErrorReset
  - UUT GotBit will probably occur in the middle of a NULL
  - UUT must ignore bits until NULL+2 bits are valid
- Link to the standard (§8.5.3.4):
  - Disconnect detection enabled after GotBit
  - RxError detection enabled after GotNULL
  - GotNULL requires checking of 10 bits

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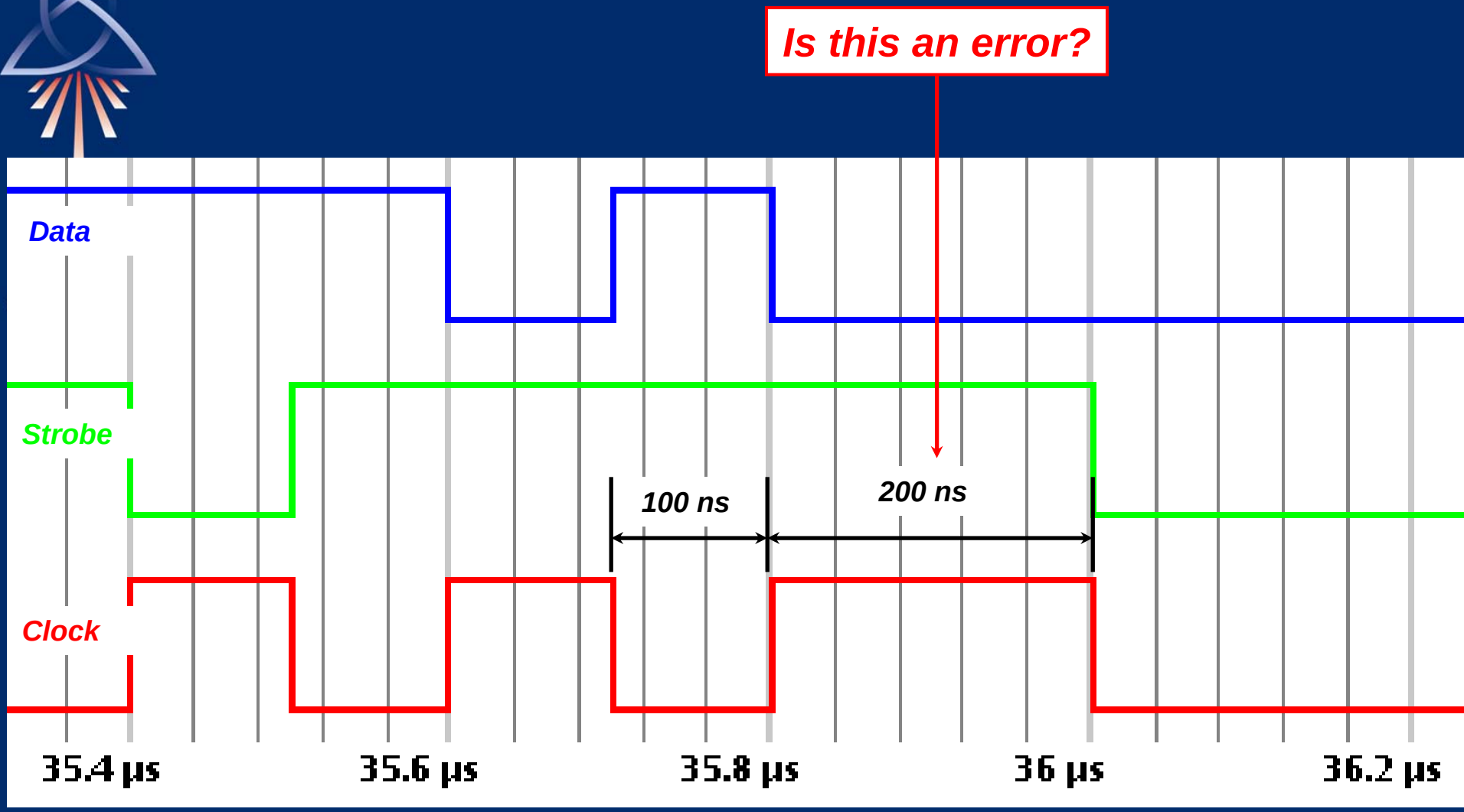
Initial Data Signalling Rate (1)

- Problem encountered:
  - Start Up Link Speed test: rate outside 10±1 Mbits/second
- Reason for failure:
  - Strobe held high for extra bit period during link shutdown
  - This was to avoid simultaneous D/S transitions
  - Final bit was transmitted at 8 Mbits/second
  - Conformance tester inhibits FCTs so UUT never reaches Run
- Link to the standard
  - §6.6.5: initial signalling rate: (10±1) Mbits/s
  - §6.6.6: shall not be changed before *Run*
- Issue of SpaceWire rate specifications:
  - Ought we measure bit-to-bit, clock period, average rate?

Initial Data Signalling Rate (2)



Empty Packet Credit Counting

- Problem encountered:
  - Empty packet credit test: UUT ignores empty packets
- Reason for failure:
  - Empty packets were discarded before credit counting
  - Test correctly infers UUT RX buffer size of 16 bytes
- Link to the standard:
  - §8.3.i:
    - Keep credit count of number of N-Chars which can be received
    - Decrement credit count for each N-Char received
    - Increment credit count by 8 for each FCT transmitted
  - §8.2.1:
    - EOP and EEP are N-Chars
  - §8.9.3.2 (14 pages later):
    - Empty packets may be discarded

Receiver Lock-Up At High EOP Rates

- Problem encountered:
  - NCHAR Overflow test: UUT fails to disconnect
  - UUT receiver locks-up and needs to be power cycled
- Reason for failure:
  - Unknown at present: UUT credit counts empty packets
  - Conformance tester sends 254 EOPs with no NULLs in between
  - Suspect back-to-back EOPs overloads receiver

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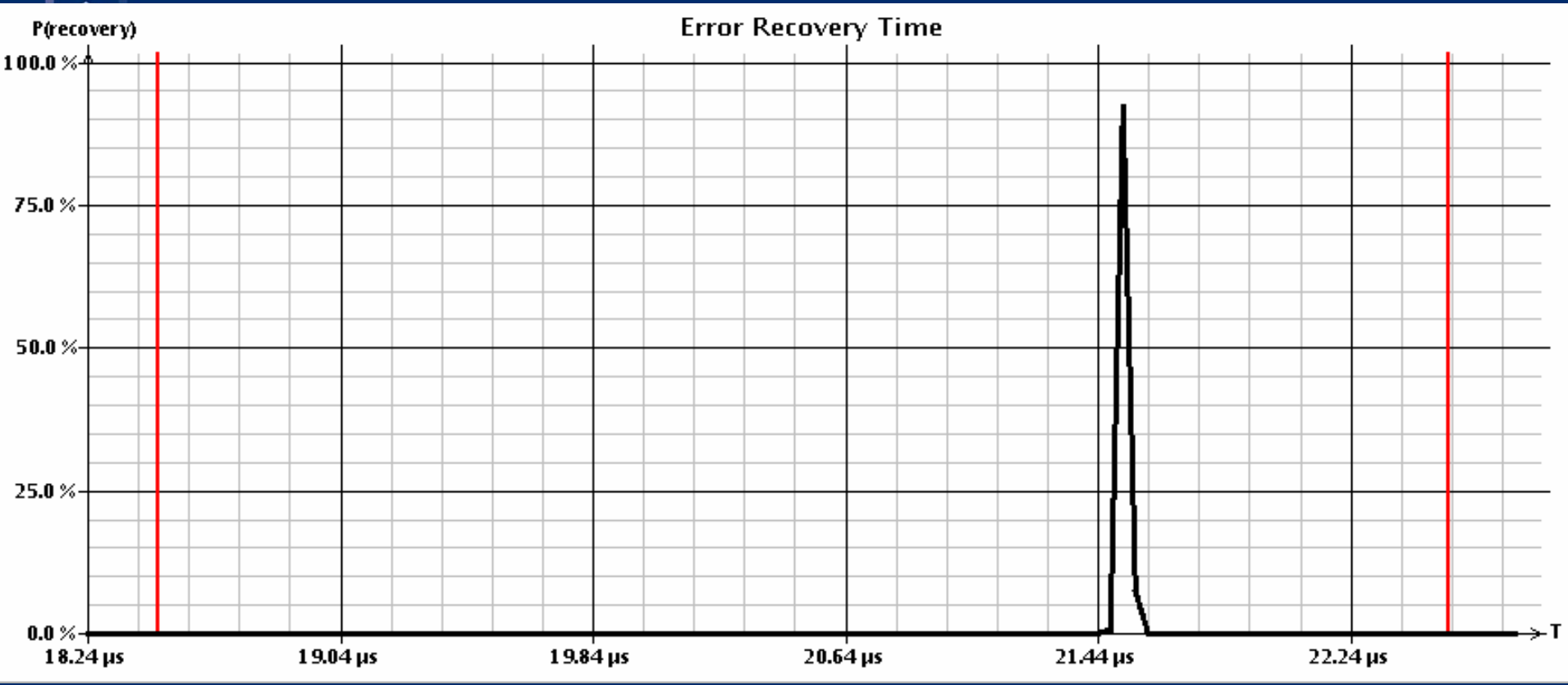
Error Recovery Time

- Problem encountered:
  - Error recovery time: too large with large variation
- Reason for failure:
  - Low frequency timers used for link initialisation timing
  - Timer reset design did not account for this correctly
  - Timers loaded with precisely 6.4/12.8 µs …
  - … but ignored extra reset/synchronisation delays …
  - … and clock domain crossing jitter
- Issues:
  - ErrorReset time was sometimes non-compliant
  - ErrorWait/Connecting timeouts were compliant …
  - … but didn't have the durations the designer intended

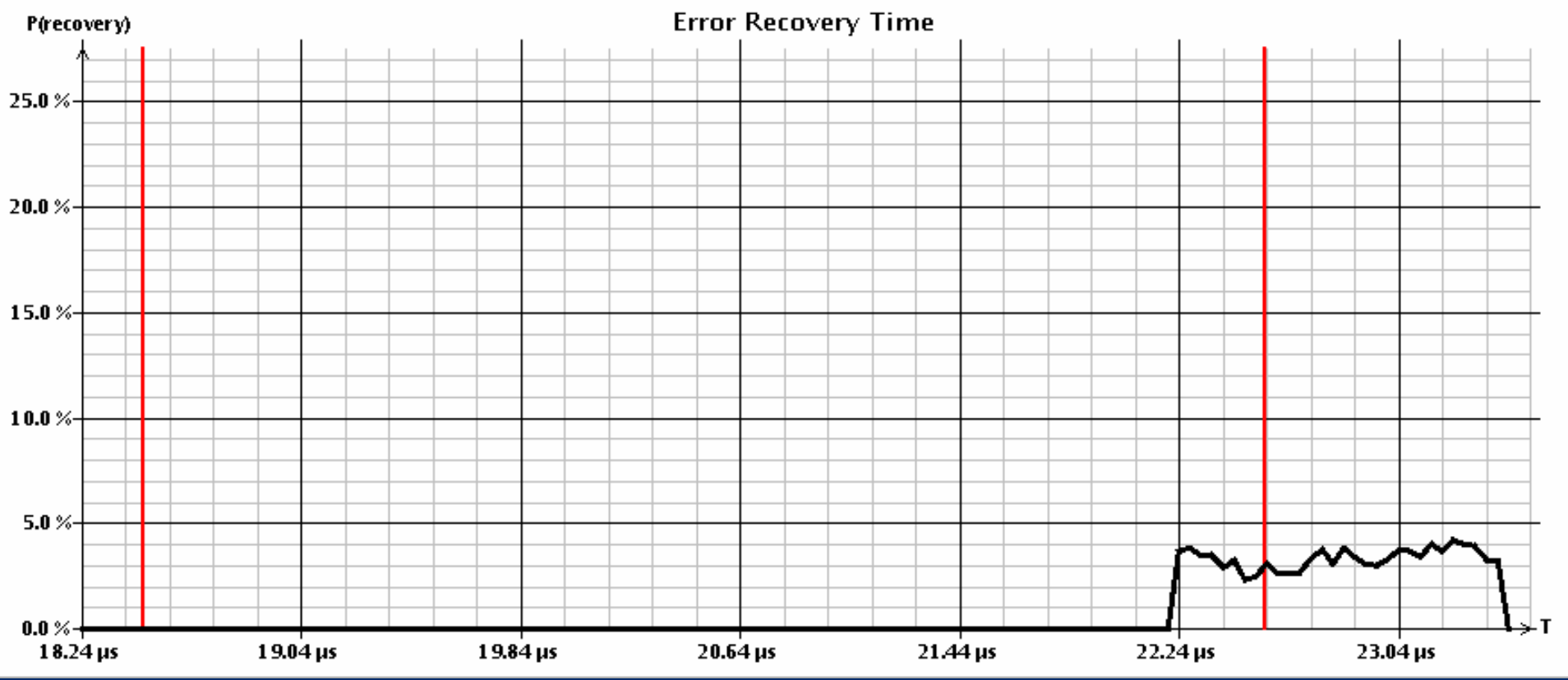
Error Recovery Time Analysis

- A new addition to the Conformance Tester:
  - How quickly does the UUT recover from an error?
  - What is the variation in the UUT error recovery time?
- Test procedure:
  - Bring the link to the Run state; wait a while
  - Generate a parity error: this is $T_{recov}=0$
  - Make sure UUT disconnects within 10 μs
  - Conformance tester ignores the disconnect and keeps sending NULLs!
  - Create a histogram of T_{recov} values
  - Expect 18.46 μs ≤ T_{recov} ≤ 22.55 μs
  - Expect less than 400 ns variation in T_{recov} values
- Assumes UUT doesn't linger in Ready

Good Error Recovery Time



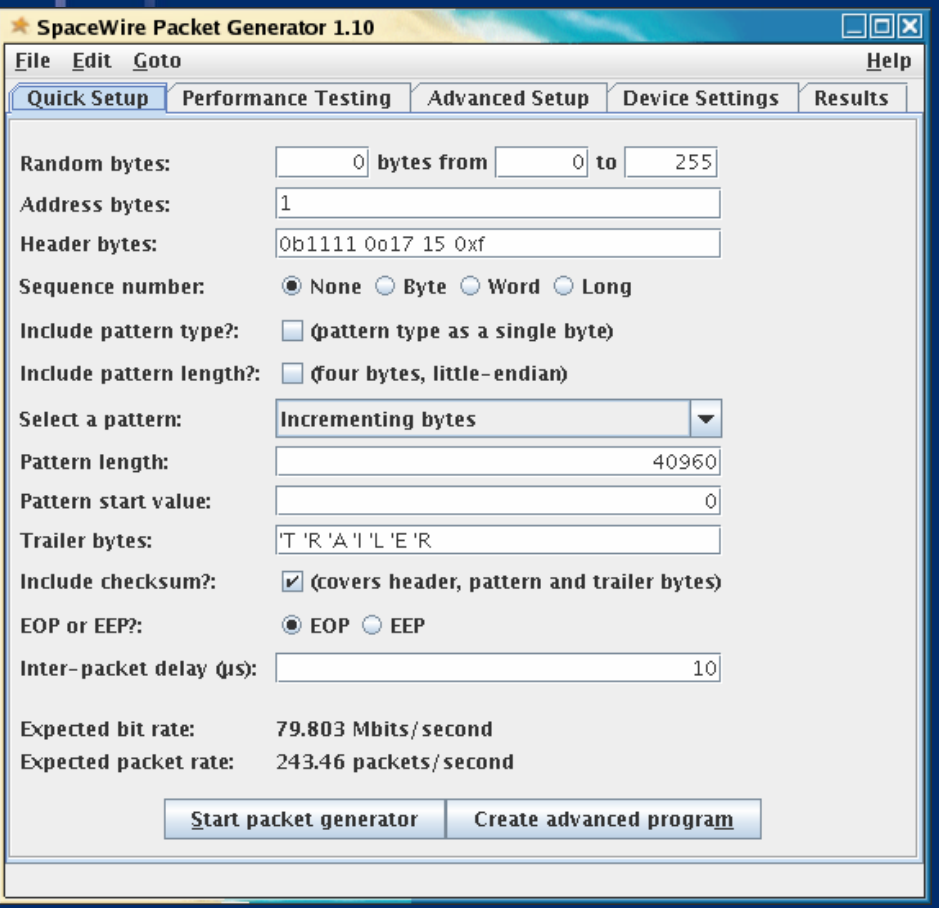
Bad Error Recovery Time

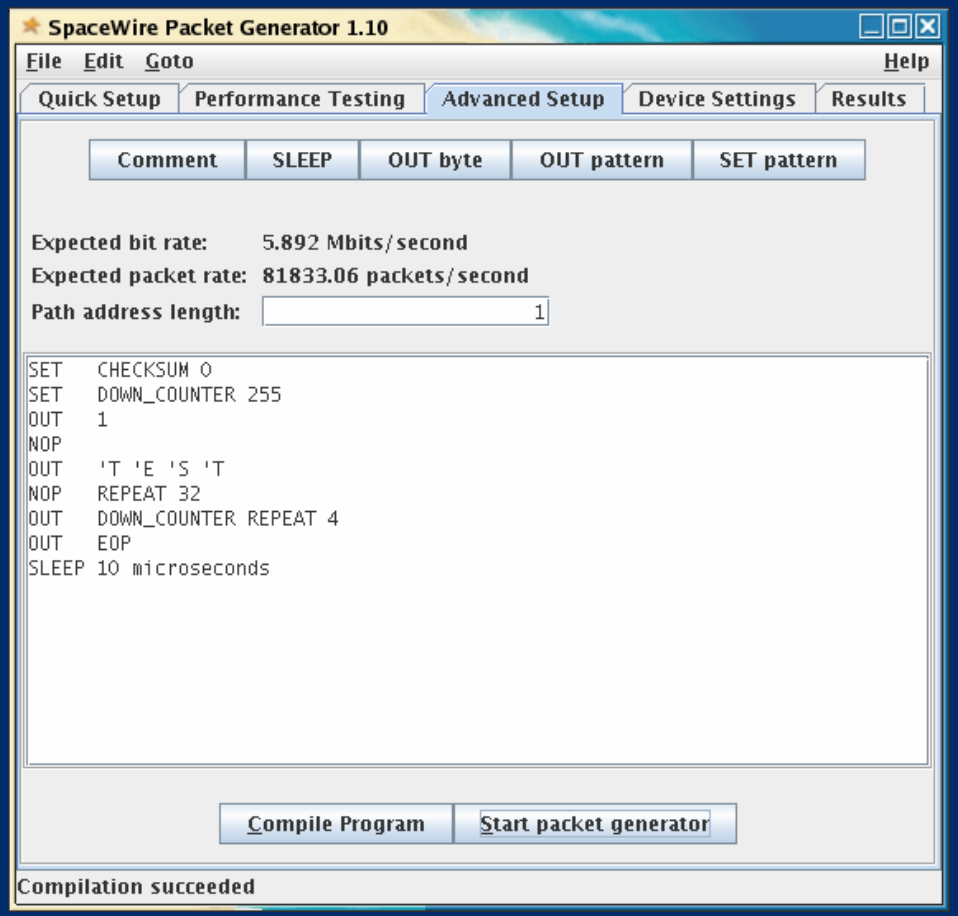


Packet Generator

- Hardware packet generation:
  - GUI helps users define the packet format
  - Packet program downloaded to the hardware unit
  - Sends packets repeatedly with user defined gap
  - Can send NCHARs with no NULLs in between
  - Can send byte sequences with or without EOP/EEPs
- No interaction with host PC:
  - This means no operating system latency or jitter
- Performance testing mode available:
  - How fast can the UUT accept packets of different sizes?
  - How consistent is the UUT receive rate?

Quick and Advanced Packet Setup





SpaceWire Packet Generator 1.10

File Edit Goto Help

Quick Setup | Performance Testing | Advanced Setup | Device Settings | Results

Random bytes:	0 bytes from 0 to 255
Address bytes:	1
Header bytes:	0b1111 0o17 15 0xf
Sequence number:	None / Byte / Word / Long
Include pattern type?:	(pattern type as a single byte)
Include pattern length?:	(four bytes, little-endian)
Select a pattern:	Incrementing bytes
Pattern length:	40960
Pattern start value:	0
Trailer bytes:	'T 'R 'A 'I 'L 'E 'R
Include checksum?:	(covers header, pattern and trailer bytes)
EOP or EEP?:	EOP / EEP
Inter-packet delay (µs):	10

Expected bit rate: 79.803 Mbits/second

Expected packet rate: 243.46 packets/second

Start packet generator | Create advanced program

SpaceWire Packet Generator 1.10

File Edit Goto Help

Quick Setup | Performance Testing | Advanced Setup | Device Settings | Results

Linear measurements

Minimum pattern length	512	bytes
Maximum pattern length	1024	bytes
Pattern length increment	256	bytes

Exponential measurements

Minimum exponent	8.0
Maximum exponent	10.0
Exponent increment	0.5

Timing

Test duration	4	seconds
Delay between tests	0	seconds

Expected test duration: 32 seconds

Note: packet format defined by Quick Setup panel

Start packet generator

SpaceWire Packet Generator 1.10

File Edit Goto Help

Quick Setup | Performance Testing | Advanced Setup | Device Settings | Results

Comment | SLEEP | OUT byte | OUT pattern | SET pattern

Expected bit rate: 5.892 Mbits/second

Expected packet rate: 81833.06 packets/second

Path address length: 1

```
SET   CHECKSUM 0
SET   DOWN_COUNTER 255
OUT   1
NOP
OUT   'T 'E 'S 'T
NOP   REPEAT 32
OUT   DOWN_COUNTER REPEAT 4
OUT   EOP
SLEEP 10 microseconds
```

Compile Program | Start packet generator

Compilation succeeded

Quick and Advanced Packet Setup

```
Quick Setup Results:
   Packet size:       40973.000 bytes
   Transmitted:       149097231 bytes, 3638.914 packets
   Received:          149052620 bytes, 3637.914 packets
   Duration:          15.688 seconds
   Expected rate:     79.803 Mbits/second, 243.463 packets/second
   Measured rate:     76.030 Mbits/second, 231.953 packets/second
```

```
Performance Test Results:
N          Mbit/s     Pkt/s      lg(1+N)    lg(1+Pkt/s)
   269.000    90.122 41878.021      5.598     10.643
   317.000    96.038 37869.715      5.762     10.542
   375.000   101.860 33953.375      5.930     10.433
   443.000   107.334 30286.158      6.096     10.318
   525.000   112.527 26792.072      6.265     10.196
   621.000   117.234 23597.728      6.433     10.069
   737.000   121.681 20637.900      6.604      9.935
   874.000   125.658 17971.746      6.774      9.797
  1037.000   129.193 15572.885      6.945      9.653
```

Bug Detection with the Packet Generator

- Empty packet credit counting bug:
  - **`OUT 31 ‘T ‘e ‘s ‘t ‘i ‘n ‘g EOP EOP`**
  - **`SLEEP 5000 microseconds`**
  - Loops continuously executing these two instructions
  - If the UUT doesn’t credit count empty packets …
  - … then transmission will stall after a few iterations

- Driver event handling bug:
  - **`OUT 31 UP_COUNTER REPEAT 10 EOP`**
  - Sends a packet with 10 incrementing bytes
  - Test showed slowly decreasing transmit rate
  - A software packet generator showed no problems
  - Conformance tester high data/packet rate …
  - … highlighted a driver event handling bug

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Some Recent User Feedback

- I have implemented in my new design (UUT) the correct null synchronisation, because I found this before. The new design works without errors (Link Initialisation Test). Thank you for your efforts.

- Thanks for your prompt support.
- Thanks for the detailed response/items-to-try-out.

- Thanks for you[r] quick reply with the FW update.
- Thanks for your fast response.

- Thank you very much for your detailed investigation. We think Conformance Tester, Link Analyzer, USB Brick and CUBA software are very powerful tools for developing SpaceWire ASICs.

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SpaceWire Conformance Tester

- **Ease of use:**
  - USB interface.
  - Information displayed in SpaceWire terms
- **Detailed test reports:**
  - 68 tests
  - Simple pass/fail indication
  - Details of the expected and measured UUT response.
- **Link to ECSS Standard:**
  - For each test user manual specifies
  - Clauses in ECSS standard that test covers
  - And vice versa
- Other features:
  - Loop-back operation
  - Flexible packet generation