Calnex
Insight and Innovation

Paragon-X 30X Feature Introduction

An overview of features and configurations for testing 802.1AS networks and devices

Paragon-X software release 30X enhances measurement functionality for testing 802.1AS networks and devices. Additional metrics added to Through Mode operation enable testing synchronization of 802.1AS networks where cable lengths are unknown. Master-Slave Emulation provides test functions to characterize Grand Master clocks (both with and without independent reference source), Time Aware Switches and Time Aware End Stations (including Reverse Sync).

Paragon-X now supports 100BaseT1 and 1000BaseT1 SFP interfaces, in addition to 100/1000BaseT and 100/1G/10G optical interfaces.

This document is an introduction these new features and assumes you already know how to run tests with Paragon-X; if not, please refer to specific Calnex test guides for detailed test steps.

calnexsol.com

Contents

1. Introduction

Paragon-X software release 30X (10.43.xx) introduces several features to assist measuring PTP timing performance in 802.1AS Ethernet networks and devices. This document explains the new features through use-cases and details the timing metrics calculated by the Calnex Analysis Tool (CAT).

The new features are –

- Support for 100/1000BaseT1 interfaces added.

- Support for Measured Link Delay (MLD) to estimate link latency between devices where the link latency is unknown. MLD uses information carried in the 802.1AS Peer Delay messages.

- Support for through-mode testing in free running networks that have no external reference.

- Support for testing free running 802.1AS Grand Masters that have no reference.

- Support for testing 802.1AS Time Aware End Stations that support AVNU Reverse Sync messages (see Avnu Alliance website https://avnu.org/).

This document assumes you already know how to run tests with Paragon-X. Please refer to the Calnex test guides referenced in section 1.5 for more detailed guidance.

This document focuses on using Paragon-X to test 802.1AS devices and networks using either the 802.1AS-2011 or 802.1AS-2020 gPTP profile. Please contact Calnex to discuss using Paragon-X software release 30X functions when testing devices and networks running other peer-to-peer and end-to-end PTP profiles.

Performance requirements are defined in Annex B of the 802.1AS standard documents. CAT allows you to set pass/fail thresholds when analysing test results, examples are shown in this document.

1.1.   Terminology

Standards bodies are gradually updating PTP master/slave terminology. The following terms are used interchangeably in this document –

- Master = timeTransmitter (TT)
- Slave = timeReceiver (TR)

Paragon-X uses master/slave terminology while CAT uses TT/TR terminology.

1.2.   Paragon-X Software Release 30X Components

Paragon-X software release 30X comprises four software applications running on a Windows PC –

- Paragon-X 10.43.xx Remote Client software. This is the main application to configure Paragon-X and start/stop measurements.

- CAT v31.50 graphically shows results of timing measurements.

- PFV v31.50 allows checking of PTP packet fields and packet flow.

- Paragon-X 10.43.xx Network Emulator Remote Client converts the Paragon-X from a timing analysis instrument to a Network Emulator.

All four software applications will be installed when the Paragon-X 10.43.xx installer is run.

1.3. Assumptions

This document assumes you are familiar with Paragon-X and CAT operation. While this document provides demonstrations of the new features, it does not provide step-by-step usage instructions. Please refer to the Paragon-X Getting Started Guide, Calnex test guides or contact your local Calnex representative if you are not familiar with Paragon-X and CAT.

This document assumes that accurate reference signals are available when testing devices and networks. Frequency (2.048MHz or 10MHz) and 1PPS references should be taken from a local rubidium or caesium clock. If accurate reference signals are not available, Paragon-X uses its internal oscillator that has a ±4.6ppm accuracy; this may be visible as drift on timing measurements.

1.4. Example Measurements in this Document

The measurements in this document are examples chosen to illustrate the range of measurements that can be made using Paragon-X and CAT. The measurements were taken from tests run at different times with a variety of devices and may not be representative of typical 802.1AS devices and networks.

Some devices used in the preparation of this document were deliberately configured to show errors and situations that Paragon-X can measure, thus illustrating debug options.

1.5. Document References

Please refer to the following documents for detailed descriptions of the 802.1AS standards and Paragon-X operation –

- Calnex Paragon-X Getting Started Guide CX4010 *
- Calnex Cabling Considerations Document CX5009 *
- Calnex Time Aware Relay Test Guide CX5030 *
- Calnex Time Aware End Station Test Guide CX3015 *
- 802.1AS-2011 standard https://standards.ieee.org/ieee/802.1AS/7121
- 802.1AS-2020 standard https://standards.ieee.org/ieee/802.1AS/3956/
- AVNU reverse sync white paper

* These documents are accessible from the **Help** menu of the Paragon-X GUI and can also be downloaded from the Calnex support website.

Calnex regularly update application notes and test guides. Please check the Calnex support website to ensure you are reading the latest version of this and other referenced documents.

2. Ports and Interfaces

Paragon-X software release 30X adds support for 100Base-T1 and 1000Base-T1 SFPs. The following SFPs are supported –

- Hicotel HICSGT1FTM 100BaseT1 transceivers

- Hicotel HICSGT1GTM 1000BaseT1 transceivers

- Intrepid SFP-MV2112-A2 100/1000BaseT1 transceivers

- Technica PT-1441 T1 transceivers - 100M + 1G mode

2.1. Hicotel 100M and 1G Transceivers

Hicotel transceivers are fixed rate transceivers with a DIP switch to set the PHY clock as Master or Slave. You must configure the DIP switch – there are no configuration options for the Hicotel transceivers in the Paragon-X GUI.

Hicotel transceivers do not report the T1 link status – you must check the hardware LED on the transceivers to know the T1 link status. The Paragon-X GUI status LEDs only show the status of the link between Paragon-X and the transceiver over the SGMII bus. When a Hicotel transceiver has been inserted and the correct interface selection made in the Paragon-X GUI then the link LED should be green regardless of whether a T1 cable is connected to another T1 interface. If the Link LED does not show green within a few seconds, then re-insert the transceiver and re-configure the interface in the Paragon-X GUI.

Please contact Hicotel for further support on support@hicotel.com or sales@hicotel.com.

2.2. Intrepid 100M/1G Transceivers

Intrepid SFP-MV2112-A2 transceivers are dual rate 100 and 1000BaseT1 transceivers. Speed selection and PHY clock maser/slave selection are configured using the Paragon-X **Setup Interface** > **Ethernet** GUI.

You must set the speed after inserting Intrepid transceivers, and after power cycling the Paragon-X.

SFP-MV2112-A2 transceivers do not report the T1 link status to Paragon-X so the link status displayed on the Paragon-X GUI only reflects the link between the Paragon-X and the transceiver over the SGMII bus. You must check the status LEDs on the front of the transceivers to know the T1 link status.

Please contact Intrepid for further support. Details about the Intrepid SFP-MV2112-A2 can be found on Intrepid's web page: https://intrepidcs.com/products/automotive-ethernet-tools/88q2112-1000base-t1-sfp/

2.3. Technica 100M/1G Transceivers

Technica PT-1441 transceivers are switchable rate 100 and 1000BaseT1 transceivers. Speed selection and PHY clock maser/slave selections are configured using DIP switches on the transceivers – there are no configuration options for the Technica transceivers in the Paragon-X GUI.

PT-1441 transceivers do not report the T1 link status to Paragon-X so the link status displayed on the Paragon-X GUI only reflects the link between the Paragon-X and the transceiver over the SGMII bus. You must check the status LED on the front of the transceivers to know the T1 link status.

You must check the hardware DIP switches to know the T1 link speed.

Please contact Technica for further support. Details about the Technica PT-1441 transceivers can be found on Technica's web page: https://www.technica-engineering.com/media-converters/

2.4.   Inserting T1 SFP Transceivers into Paragon-X

When two T1 SFP transceivers are being inserted to Paragon-X, insert them one at a time. After inserting each transceiver, wait a few seconds for the link status LED on the Paragon-X GUI to show that the transceiver is recognised.

3. Measured Link Delay (MLD)

Timestamp accuracy in 802.1AS devices is key to accurate 802.1AS network synchronization. Devices that use software timestamp mechanisms have inherently variable delays between timestamping outgoing messages and transmitting them, and between receiving PTP messages and applying timestamps. The delays are unknown and variable so cannot be manually compensated for.

The Paragon-X MLD function uses the timestamps in the Peer-Delay messages from the device under test (DUT) to estimate the delays to and from the device time-stamper and applies this to the measurements.

The Paragon-X MLD function is required when the DUT implements software timestamping and can also be useful for a hardware timestamped device when the physical cable delay cannot be determined. However, it should be noted that in both cases this calculation, and metrics that use it, then rely on the DUT timestamp accuracy.

When the DUT uses hardware timestamping and cable delays are known, the Paragon-X MLD function should be disabled and cable compensation manually entered.

The MLD function is available in Through Mode and MSE mode tests to measure the accuracy of the DUT's timestamping.

CAT calculates and displays different metrics depending on whether the MLD function or fixed cable compensation is used –

- When the fixed length cable delay compensation method is used, Paragon-X measures the DUT's real Peer Delay turnaround time. CAT calculates and displays three metrics –

  - **Peer Delay Turnaround Time (Actual)** shows the measured peer delay turnaround time allowing for the cable propagation delays.

  - **Peer Delay Turnaround Time (DUT)** shows the time reported by the DUT, i.e. the difference between the T3 and T2 timestamps.

  - **Peer Delay Turnaround Time Accuracy** shows the accuracy with which the DUT calculates its own turnaround time compared to the actual measured turnaround time. If this graph is not zero, there is some inaccuracy in the DUT.

- When the MLD method is used, CAT calculates and displays two metrics –

  - **Peer Delay Measured Link Delay** shows the cable propagation delay.

  - **Peer Delay Turnaround Time (DUT)** shows the time reported by the DUT, i.e. the difference between the T3 and T2 timestamps.

802.1AS devices that use software timestamping inherently have their timestamp locations "inside the box" so the MLD measurements include some amount of ingress and egress delays in addition to cable propagation delays. Diagrams in the following sections of this document show where MLD is applied when enabled.

4. Through Mode Network Test

When Paragon-X is connected inline in an 802.1AS network as shown below, it can be used to monitor PTP traffic through the network to analyze network timing and protocol behaviour. This is Through Mode.

Prior to software release 30X, Through Mode only allowed time error testing against the upstream master. Software release 30X adds the ability to test time error of a downstream 802.1AS device that transmits Reverse Sync messages (e.g. a Time Aware End Station). The new Through Mode time error measurement capability is described in this document.

The diagram below shows Paragon-X in one path of an 802.1AS network from the GM, through Time Aware Bridges (TAB) to a Time Aware End Station (TAES). The TAES may generate Reverse Sync messages and/or a 1PPS output that Paragon-X can measure. The TABs may also generate 1PPS and Time of Day (ToD) outputs that Paragon-X can measure.

If the network GM uses a reference input (e.g. GNSS), connecting 10MHz and 1PPS reference signals derived from the same reference source ensures that Paragon-X takes the most accurate measurements. If the GM is free-running, providing reference 10MHz and 1PPS signals to Paragon-X allows accurate measurement of variation of network time due to the GM behaviour. If no references are available, Paragon-X will use its internal oscillator with a maximum drift of 4.6ppm.
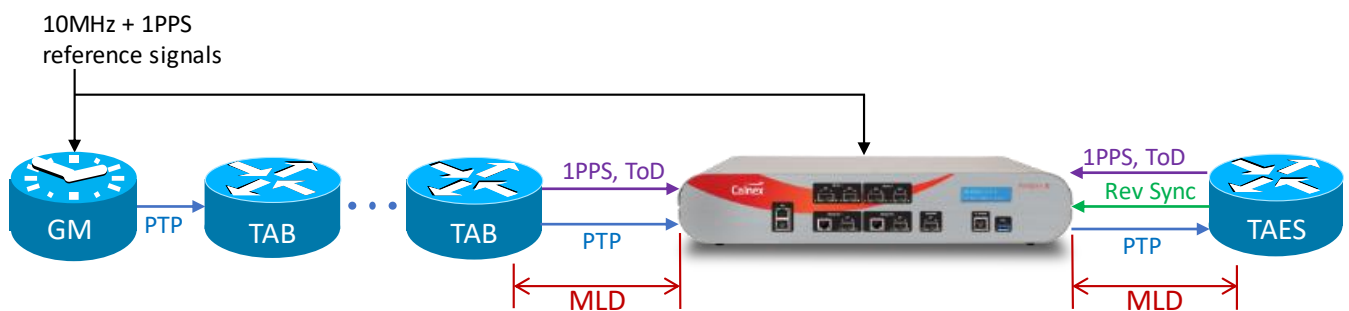

Timestamp points in the upstream and downstream devices can be implemented in software and hence "inside the box". This results in measured link delays that include elements of the device egress and ingress latencies (implied in the diagram).

Notes –

- For calculations, Paragon-X port 1 is considered the upstream port and should be connected towards the network GM. Port 2 is the downstream port and should be connected towards an end station.
- Both Paragon-X ports must be the same line rate and type when running Through Mode tests.

## 4.1. Configuring Paragon-X for Through Mode Testing

Set Paragon-X **Operating Mode** to **1588v2**.
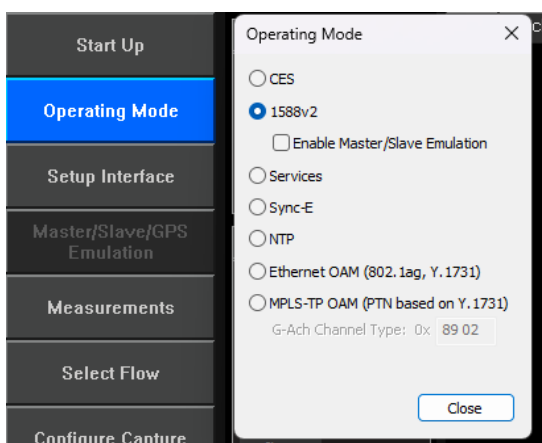
Use the Paragon-X **Measurements** GUI to select **Thru Mode End Station Reverse Sync Time Error (802.1AS only)** to enable Through Mode PTP measurements. Optionally select **Time of Day** and **1PPS Time Error (Absolute)** if ports are available to measure on the downstream device. The **Simultaneous clock measurements and PTP Impairments/Delay** checkbox must be left unchecked.
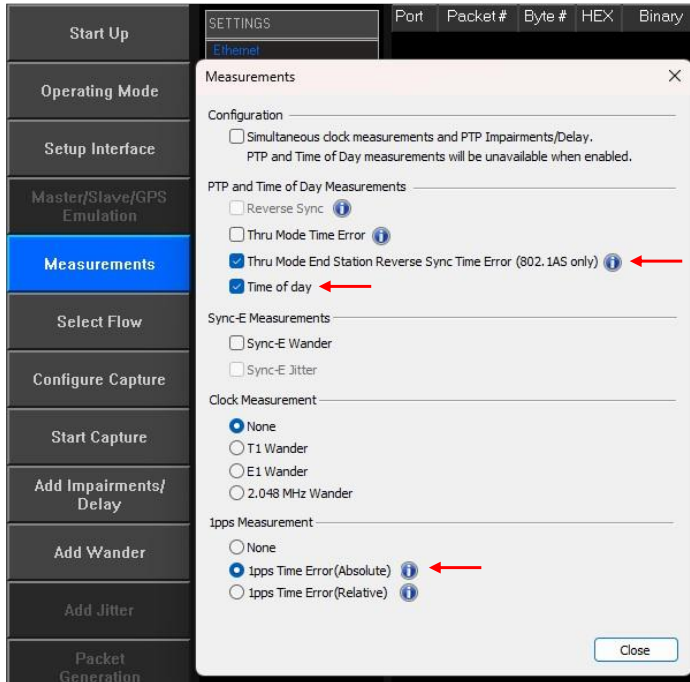
In the **Configure Capture** GUI → **1588** tab, set the PTP **Clock Mode** and check the **Include CorrectionField in Delay Calculation** checkbox. Ethernet cable compensation must be configured for both upstream and downstream connections and may be set manually if the cable length is known or determined by Paragon-X using the MLD method.
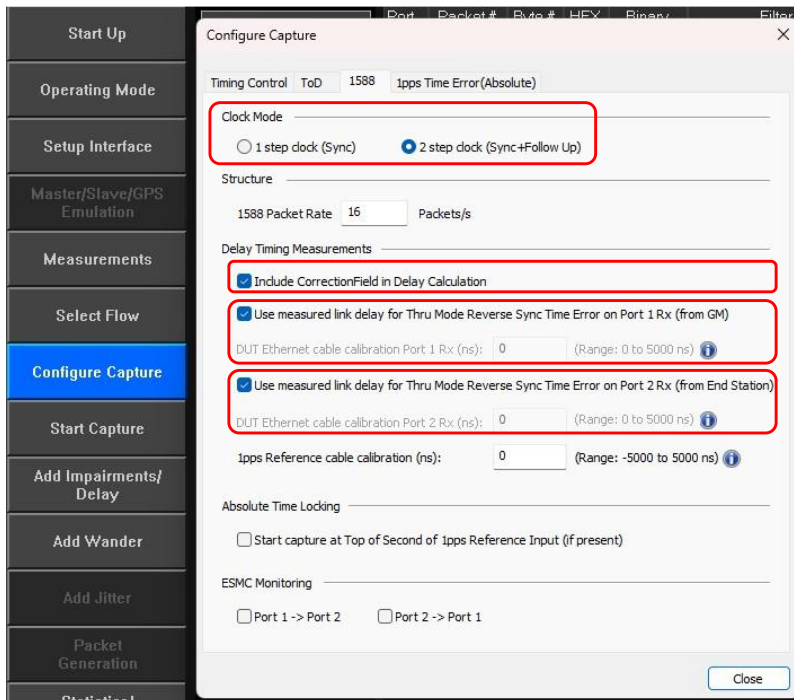

1PPS measurement cable compensation is set in the **Configure Capture** GUI → **1PPS Time Error (Absolute)** tab.

Packet capture filters must be set using the **Flow Wizard** when the network is running. After clearing any previously set filters, capture a few seconds of packets using the **Select Flow → Capture Packets** method, then open the Flow Wizard and select the packets of interest. For full analysis, the following packet flows should be captured –

- Sync and FollowUp messages from upstream device.

- Announce messages from upstream device.

- Reverse Sync and FollowUp from downstream device (if available).

- All PeerDelay exchanges between upstream and downstream devices.

The screenshot shows the flows grouped just before setting the capture filters.
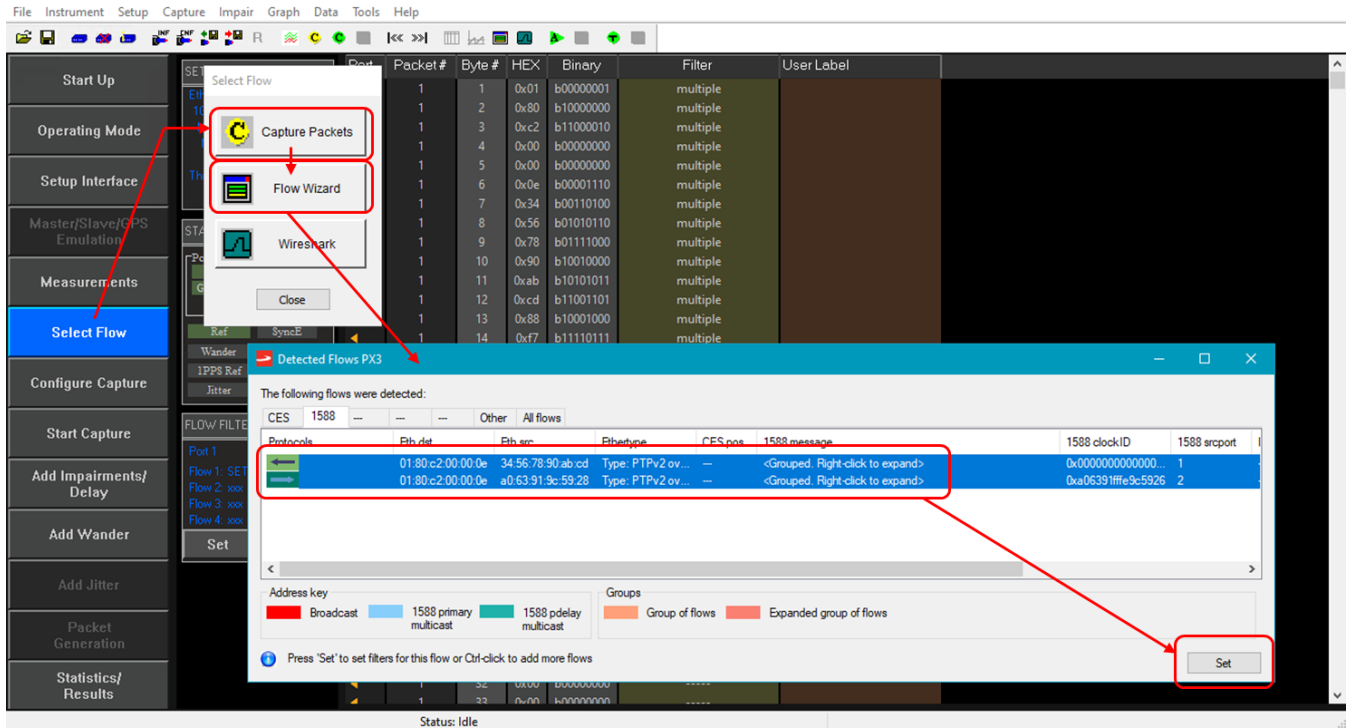
4.2. Through Mode Measurements

Once a measurement is underway, the data can be graphically viewed in CAT. The table below shows the metrics calculated by CAT that are relevant to the Through Mode tests.

Measurement	Use MLD	Fixed cable compensation	Explanation
PTP Time Error			
P-X Thru Mode TR Rev Sync Offset from TT	✓	✓	Compares Reverse Sync time reports from downstream TAES to Sync time messages from upstream device.
P-X TR Peer Delay Turnaround Time Accuracy	n/a	✓	Downstream Peer Delay measurements
P-X TR Peer Delay Measured Link Delay	✓	n/a	
P-X TR Peer Delay Turnaround Time (Actual)	n/a	✓	
P-X TR Peer Delay Turnaround Time (DUT)	✓	✓	
P-X TT Peer Delay Turnaround Time Accuracy	n/a	✓	Upstream Peer Delay measurements
P-X TT Peer Delay Measured Link Delay	✓	n/a	
P-X TT Peer Delay Turnaround Time (Actual)	n/a	✓	
P-X TT Peer Delay Turnaround Time (DUT)	✓	✓	
P-X TT PTP Data GM Clock Class	✓	✓	Clock class transmitted on the network (P-X TR PTP Data GM Clock Class is only relevant if the TAES transmits Announce messages)
P-X TR PTP Data GM Clock Class	✓	✓	
Constant Time Error			
P-X Thru Mode Rev Sync Offset From TT cTE	✓	✓	Constant Time Error at a downstream device that transmits Reverse Sync messages.
Dynamic Time Error			
P-X Thru Mode Rev Sync Offset From TT dTE (Unfiltered)	✓	✓	Dynamic Time Error measurements of a downstream device that transmits Reverse Sync messages.
P-X Thru Mode Rev Sync Offset From TT dTE MTIE (Unfiltered)	✓	✓	
Offset Relative			Time Error between Paragon-X and the upstream device, and Paragon-X and the downstream device, normalized to the first Sync message.
P-X TR Rev Sync Offset Relative	✓	✓	
P-X TT Offset Relative	✓	✓	

The CAT screenshots on the following pages show examples of Through Mode PTP measurements. The test network consisted of a GM and one TAB on the upstream side of Paragon-X and one TAES with Reverse Sync capability on the downstream side. 1PPS and ToD measurements are not shown in these examples because none of the devices in the test network had 1PPS or ToD outputs.

The left screenshot shows Through Mode timing measurements when Paragon-X uses MLD to compensate the port 1 and port 2 Ethernet links. The right screenshot shows Through Mode measurements when Paragon-X applies fixed cable compensation for the port 1 and port 2 Ethernet cable.

Both screenshots show the **P-X Thru Mode Rev Sync Offset From TT** which indicates the accuracy of the clock in the downstream TAES relative to the network supplied timing. In this example, the TAES shows a ~1.000035 sec time error of which 1.0 sec is due to a configuration issue in the TAES. The TAES is actually locked to the incoming Sync messages with an error of ~35µs. This illustrates how CAT helps to visualize such errors.

The screenshots show that the GM in the test network is sending Clock Class 6 and the TAES is sending Clock Class 7 along with the Reverse Sync messages.

The screenshot below zooms in to the **P-X TR Peer Delay Turnaround Time (Actual)** and **P-X TT Peer Delay Turnaround Time (Actual)** measurements recorded during the fixed cable compensation test. The green lines show 10ms threshold limits that have been applied. The downstream TAES peer delay turnaround time is ~15μs, easily meeting the 802.1AS requirement. Most Peer Delay exchanges from the upstream TAB are completed in ~700μs but there are occasional delays exceeding the 10ms limit and this is flagged red as a test fail.
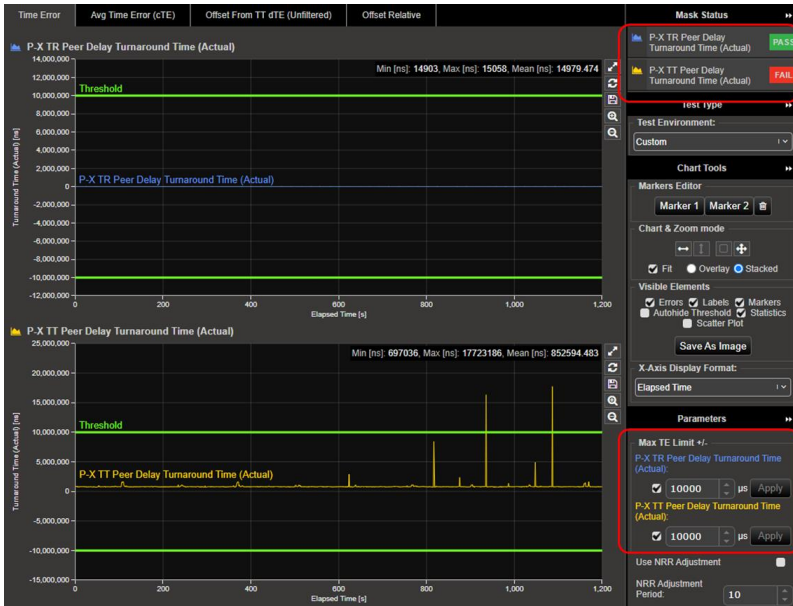
The **P-X Thru Mode Rev Sync Offset from TT cTE** , **P-X Thru Mode Rev Sync Offset from TT dTE (Unfiltered)** and **P-X Thru Mode Rev Sync Offset from TT dTE MTIE (Unfiltered)** graphs show the stability of the downstream TAES clock as indicated by the Reverse Sync timing signal. The TAES in the example has a very small change of cTE (~0.2ns) during a 20-minute test. The dTE graphs show good stability of the TAES clock. In Through Mode, the Paragon-X uses the first captured incoming Sync message to define the ToD reference for the test.
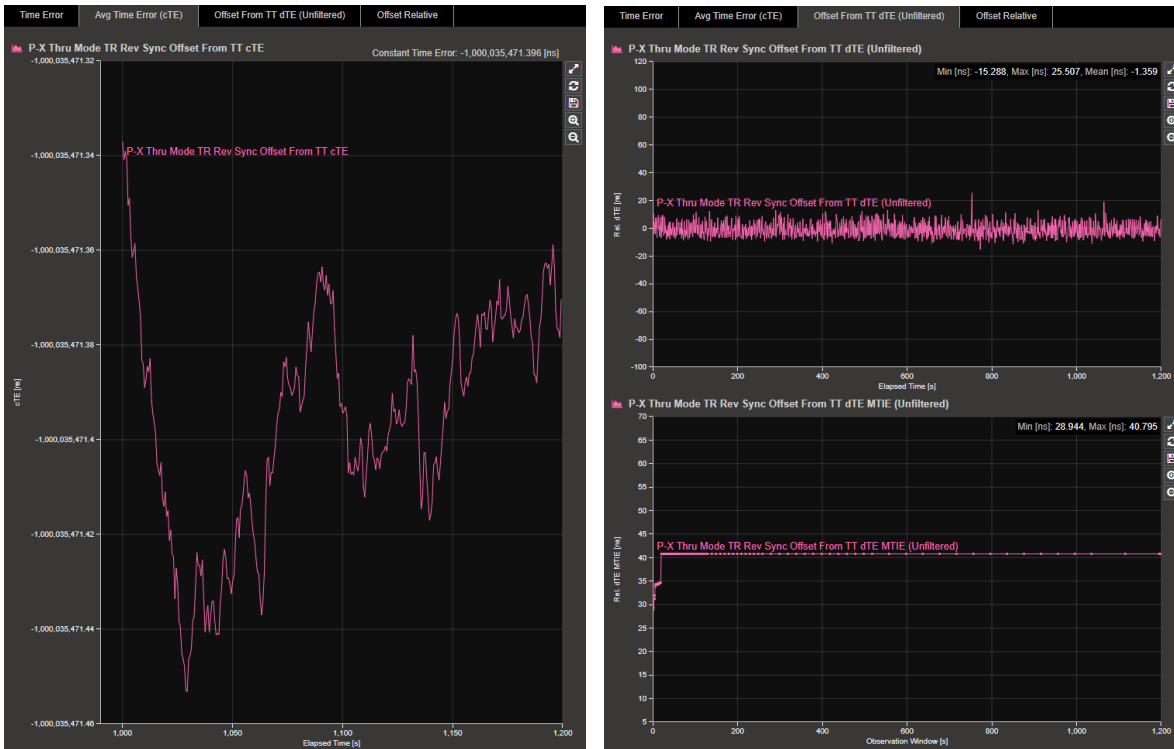
The two **Offset Relative** screenshots below show a different Through Mode test where the TAES was free running instead of locked to the incoming PTP stream. The **P-X TR Rev Sync Offset Relative** graph in the left screenshot shows the TAES is drifting at a rate of 504ppb while running on its internal oscillator. The right screenshot shows the same data with the **Frequency Offset Removal** options checked. With the 504ppb frequency drift removed, the short-term variation of the TAES oscillator that was masked by the drift is revealed.

The **P-X TT-Offset Relative** graphs with and without **Frequency Offset Removal** are very similar because the upstream TAB is well synchronized to the network GM.
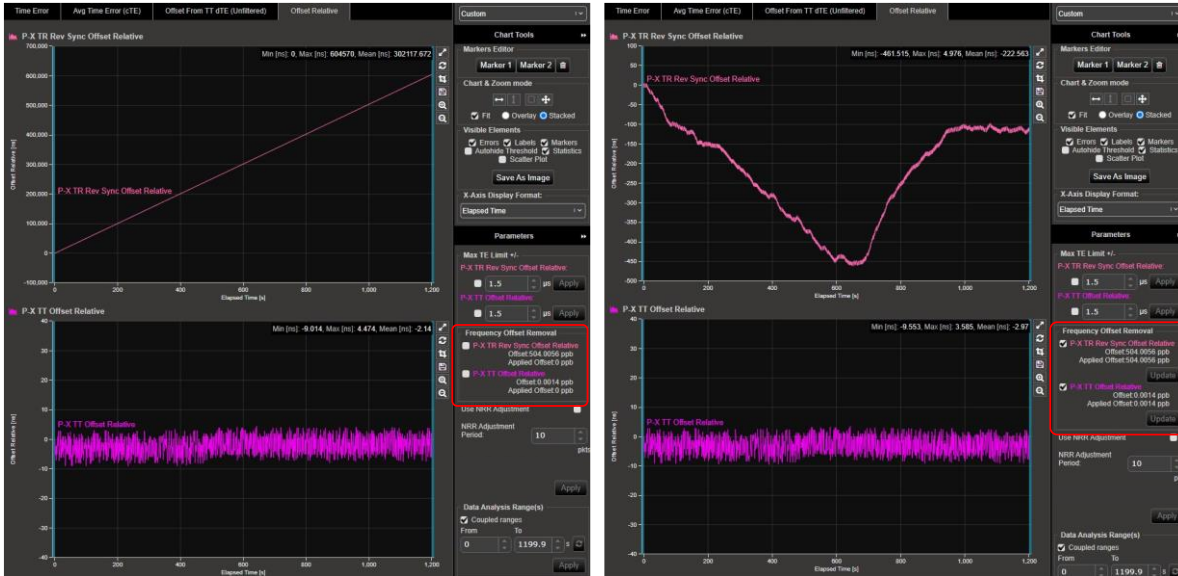
5. MSE Mode Master Test

The MSE Master Test mode is used for testing 802.1AS Grand Master devices with connections shown in the diagram opposite.

Typically, GMs operate with a reference input (e.g. GNSS) but may also be required to operate for extended periods of holdover when the reference signal is lost (e.g. a GM in a car in a basement car park). The GM's long term holdover accuracy can be tested by disconnecting its reference signal while Paragon-X remains referenced. Recovery from holdover must also be tested when the GM's reference signal is reconnected.

An alternative timing network architecture uses an 802.1AS GM that does not have a reference input and relies solely on the GM's internal oscillator to keep time – the GM effectively only ever operates in free-run mode. Such a network may be useful in an entirely self-contained timing environment. Long-term tests (more than 24 hours) will provide insight to the stability of the GM. Tests should also take account of the environmental conditions (temperature, humidity, vibration, electrical noise, etc) that the GM is expected to encounter in the final application.

The diagram shows Paragon-X connected to the GM-under-test with reference signals, 1PPS output and PTP output. The timestamp point in a GM can be implemented in software and hence "inside the box". This results in measured link delays that include elements of the GM ingress and egress latencies (implied in the diagram).

For accurate measurements, external reference signals should be provided to Paragon-X when running GM tests Paragon-X in MSE mode.
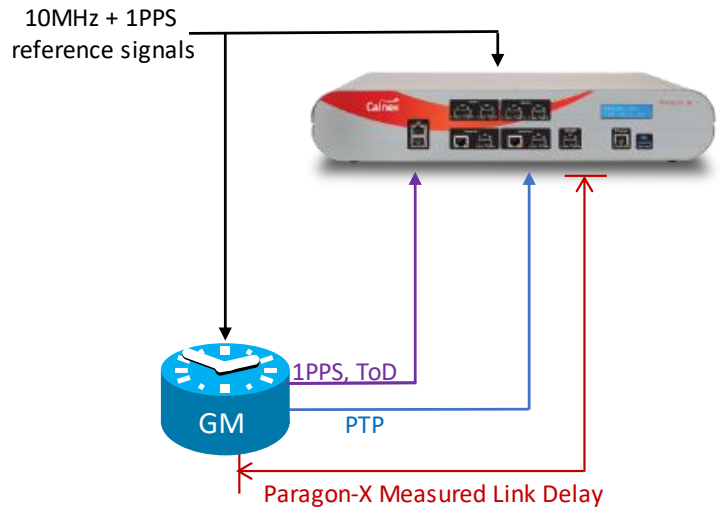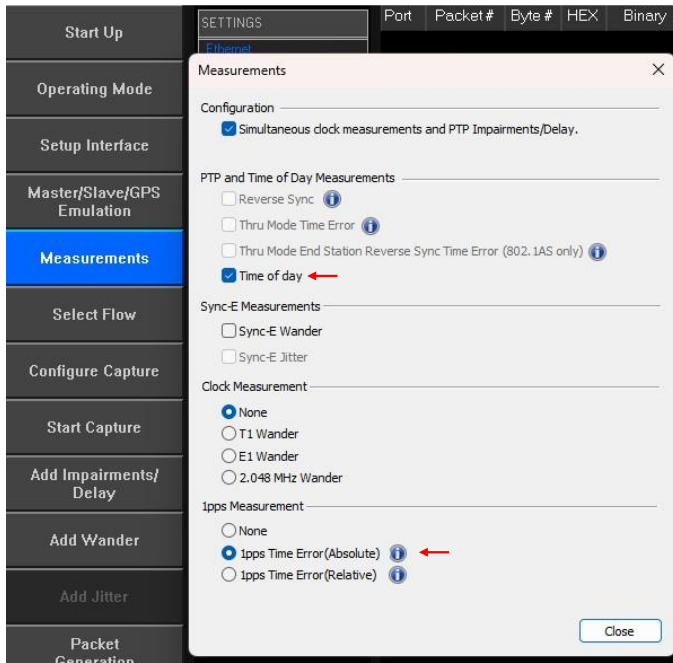
5.1. Configuring Paragon-X for MSE Master Mode Test

Set Paragon-X **Operating Mode** to **1588v2** and check the **Enable Master/Slave Emulation** checkbox.
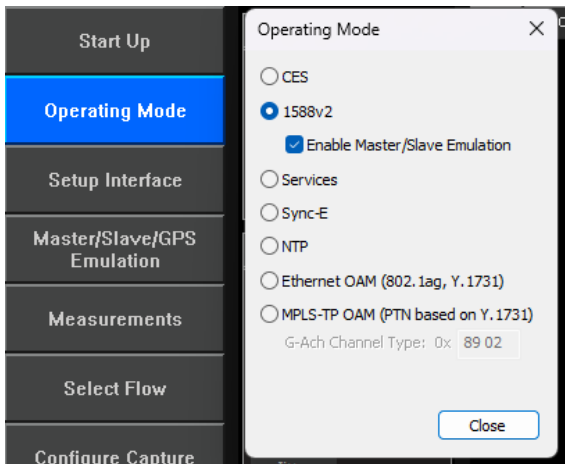
Use the Paragon-X **Measurements** GUI to select the time signals to measure from the GM. The example screenshot below shows that 1PPS and ToD measurements selected.
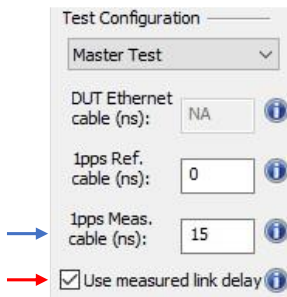

Ethernet cable compensation is required to account for the cable delay between the GM and Paragon-X port 2 when PTP time measurements are made. Two options are available –

- If the Ethernet cable length between the GM and Paragon-X port 2 is accurately known, manual compensation can be applied in the MSE GUI as indicated by the red arrows below.
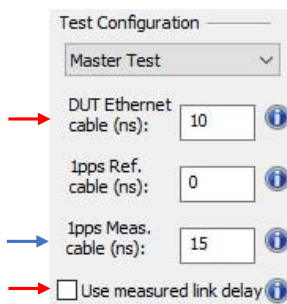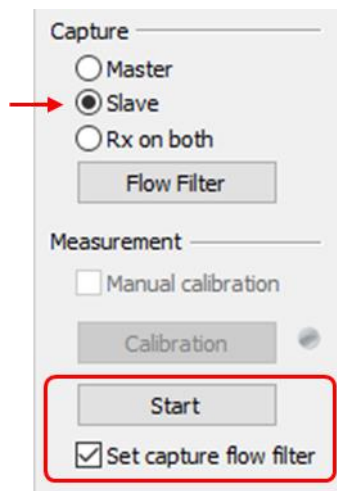

- Paragon-X can use the MLD function to determine the compensation required between the GM and Paragon-X port 2 (including the GM internal delays and the cable delays). To enable this mechanism, check the **Use measured link delay** checkbox in the MSE GUI as indicated by the red arrow below.

If 1PPS measurements are being made, the 1PPS measurement cable must also be compensated for as indicated by the blue arrows in the pictures above.

Before starting a capture, Paragon-X packet capture filters must be set. The simplest way to set filters and start capture is to select the Paragon-X slave as the capture point, check the **Set capture flow filter** checkbox and click **Start** in the MSE GUI. This will automatically set the filters to capture Sync, Follow-up and Announce messages from the GM, and Peer Delay exchanges initiated from Paragon-X port 2.

To have more control over the capture filters, click the **Flow Filter** button in the main MSE GUI, then define the individual message filters. If you manually set the capture filters, start the capture by clicking the **Start Capture** button on the left side of the Paragon-X GUI.

5.2. MSE Mode Master Test Measurements

Once a measurement is underway, the data can be graphically viewed in CAT. The table below shows the metrics calculated by CAT that are relevant to the GM tests.

Measurement	Use MLD	Fixed cable compensation	Explanation
Time Error			
P-X 1pps TE Absolute	✓	✓	GM 1PPS time error
P-X T1 Time Error	✓	✓	GM PTP time error
P-X Peer Delay Measured Link Delay	✓	n/a	Actual measured link delay between Paragon-X port 2 and GM
P-X Peer Delay Turnaround Time Accuracy	n/a	✓	GM turnaround time accuracy: P-X Peer Delay Turnaround Time (Actual) minus P-X Peer Delay Turnaround Time (DUT)
P-X Peer Delay Turnaround Time (Actual)	n/a	✓	Measured Peer Delay Turnaround Time (T4-T1 - cable delays)
P-X Peer Delay Turnaround Time (DUT)	✓	✓	Peer Delay Turnaround time reported by GM (T3-T2)
P-X TT PTP Data GM Clock Class	✓	✓	Clock Class value transmitted in Announce messages
Constant Time Error			
P-X T1 Avg Time Error (cTE)	✓	✓	Constant Time Error calculated from PTP Sync messages transmitted by the GM
P-X 1pps TE Absolute Avg Time Error (cTE)	✓	✓	Constant Time Error calculated from 1PPS, if provided by GM
Dynamic Time Error			
P-X 1PPS TE Absolute Dynamic TE LF	✓	✓	1PPS Dynamic TE metrics, if provided by GM. Useful for stability analysis of the local oscillator.
P-X 1PPS TE Absolute Dynamic TE HF	✓	✓	
P-X 1PPS TE Absolute Dynamic MTIE LF	✓	✓	
P-X 1PPS TE Absolute Dynamic TDEV LF	✓	✓	
P-X T1 Dynamic TE LF	✓	✓	PTP Dynamic TE metrics. Useful for stability analysis of the local oscillator.
P-X T1 Dynamic TE HF	✓	✓	
P-X T1 Dynamic MTIE LF	✓	✓	
P-X T1 Dynamic TDEV LF	✓	✓	

The CAT screenshots on the following pages show examples of GM PTP and 1PPS measurements. ToD measurements are not shown in these examples because the GM-under-test did not have a ToD output. The specific GM-under-test had not been fully configured and was showing significant cTE on the PTP and 1PPS measurements.

The left screenshot below shows CAT measurements of 1PPS TE and T1 TE (Sync), Peer Delay and Clock Class when Paragon-X uses MLD to compensate the port 2 Ethernet cable. The test was run for 1200 seconds to understand the short term T1 TE wander of the GM PTP signal.
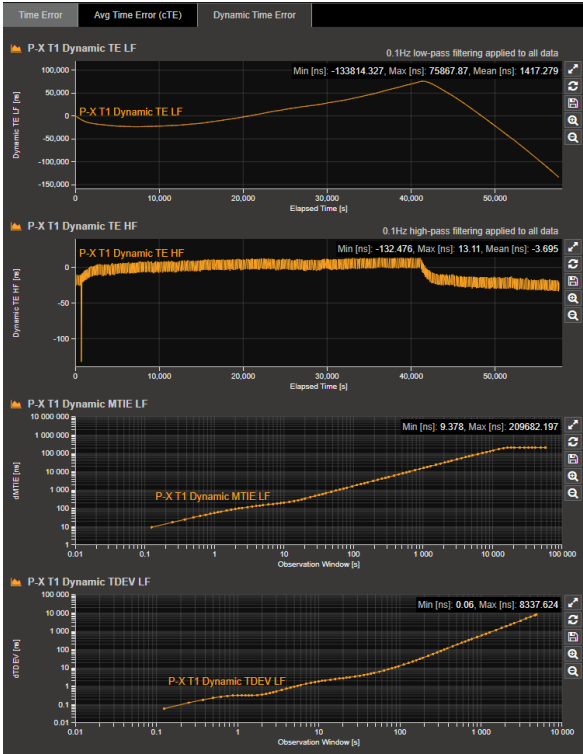
- The **P-X Peer Delay Turnaround Time (DUT)** graph shows the GM typically responds in less than 1μs but has a few spikes exceeding the 10ms limit specified in the 802.1AS standard (802.1AS-2020 Annex B.2.2). The green threshold limits have been set to 10ms.

- The **P-X 1pps TE Absolute** graph shows a very stable 1PPS output with only ±1ns spikes.

- The **P-X T1 Time Error** graph shows stable operation but a constant time error of ~6862ns on the PTP signal.

- The **P-X PTP Data GM Clock Class** graph shows this GM transmitted clock class 6 during the test, indicating it was locked to a GNSS reference.

The right screenshot shows CAT measurements of 1PPS TE and T1 TE, Peer Delay and Clock Class when Paragon-X applies a fixed cable compensation for the port 2 Ethernet cable. The test was run for 16 hours with the GM free running and Paragon-X supplied with an accurate reference to evaluate the long-term wander generated by the GM. The **P-X 1pps TE Absolute** graph shows the free running clock drift affecting the 1PPS signal. The frequency drift has been removed from the **P-X T1 Time Error** graph using the **Frequency Offset Removal** function to reveal the GM's underlying wander.
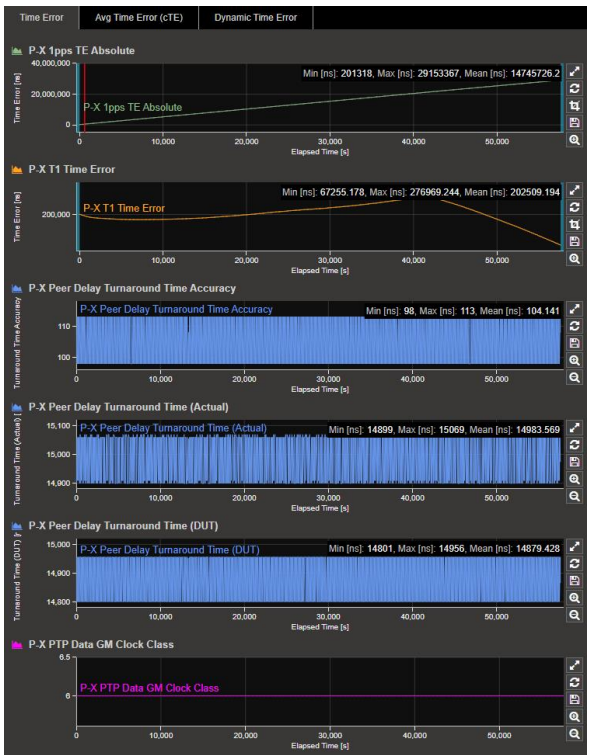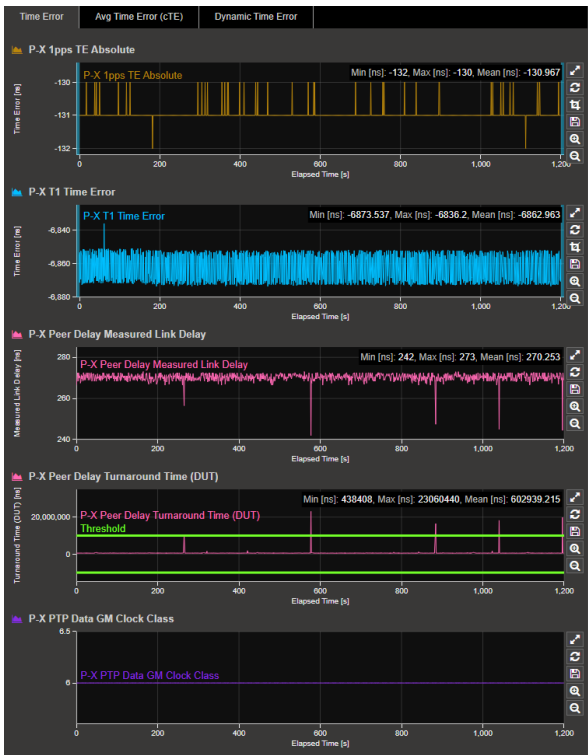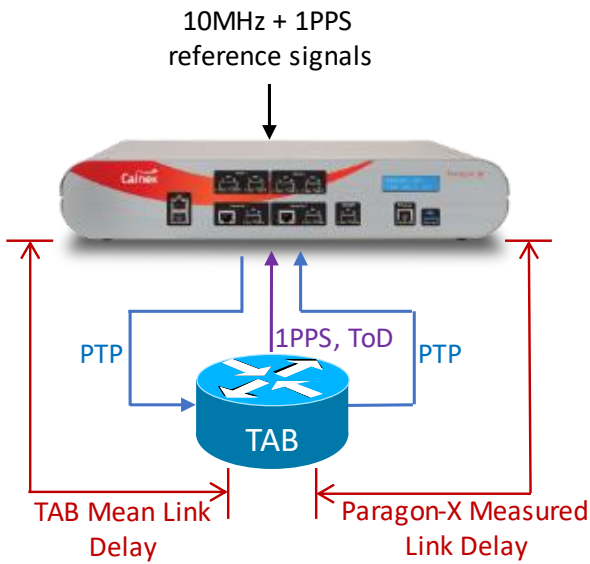
The left screenshot below shows the PTP T1 Dynamic Time Error measurement during the 16-hour test with the GM's free running frequency drift removed. The **P-X T1 Dynamic TE LF** graph shows the GM PTP wander during the test. The peak-to-peak amplitude of the **P-X T1 Dynamic TE HF** graph gives a good indication of the noise generated by the GM on the PTP signal.

The right screenshot shows the cTE measurements for the 1PPS and PTP signals from the GM-under-test during the 16-hour test. The GM free run frequency drift has been removed from the **P-X T1 Avg Time Error (cTE)** graph to show the underlying wander.

6. MSE Mode Time Aware Bridge Test

10MHz + 1PPS
reference signals

PTP   1PPS, ToD   PTP

TAB

TAB Mean Link Delay   Paragon-X Measured Link Delay

Paragon-X can test 802.1AS Time Aware Bridges with connections shown in the diagram. The Time Aware Bridge (TAB) takes a PTP input from the Paragon-X Master and outputs a PTP signal to the Paragon-X Slave. Additionally, the TAB may output 1PPS and ToD signals that can be measured by Paragon-X.

Timestamp points in TABs can be implemented in software and hence "inside the box". This results in measured link delays that include elements of the TAB ingress and egress latencies (implied in the diagram).

For accurate measurements, external reference signals should be provided to Paragon-X when running TAB tests Paragon-X in MSE mode. Typically, TAB devices do not have external reference inputs – their time reference comes from the incoming PTP signal.

A TAB may have input and output Ethernet ports that are different interface types and speeds. Paragon-X ports must be set to uncoupled to handle different interface speeds and types.

Please refer to the Calnex Time Aware Relay Test Guide CX5030 for detailed test steps to test a Time Aware Bridge. The description below is an outline to explain the added features in the 30X software release.

6.1. Configuring Paragon-X for MSE Time Aware Bridge Test

Set Paragon-X **Operating Mode** to **1588v2** and check the **Enable Master/Slave Emulation** checkbox.
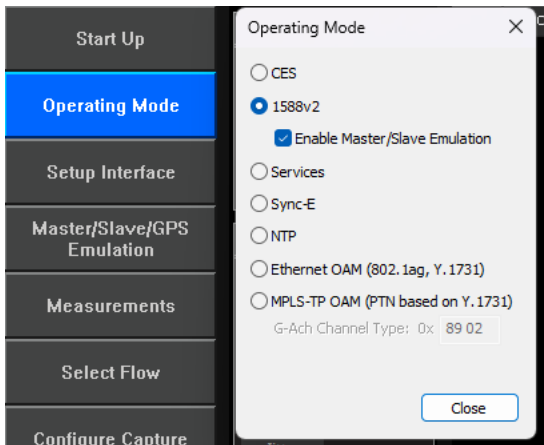
Use the Paragon-X **Measurements** GUI to select the time signals to measure from the TAB. The example screenshot below shows that 1PPS and ToD measurements selected.
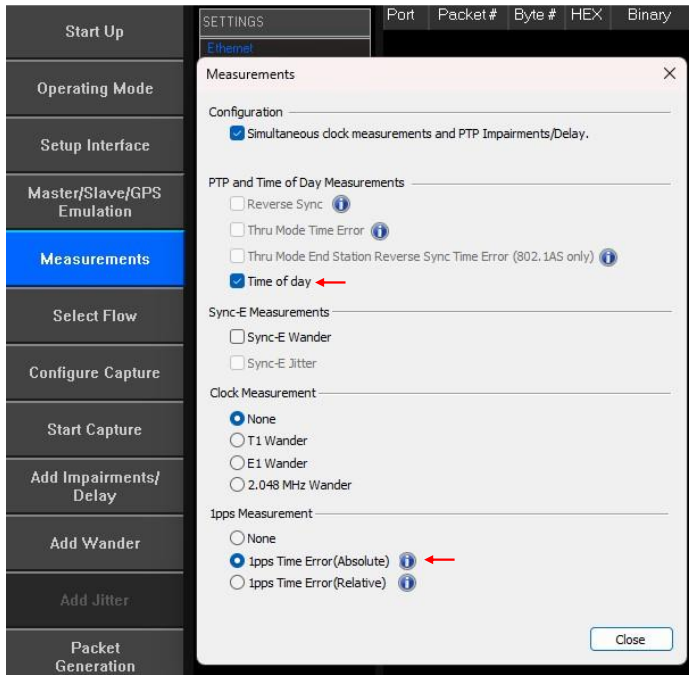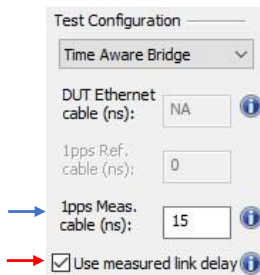

Ethernet cable compensation is required to account for the cable delay between the TAB and Paragon-X port 2 where time measurements are made (the TAB compensates for the cable delay between the Paragon-X port 1 and the TAB). Two options are available –

- If the Ethernet cable length between the TAB and Paragon-X port 2 is accurately known, manual compensation can be applied in the MSE GUI as indicated by the red arrows below.
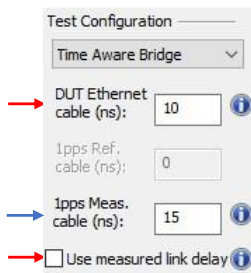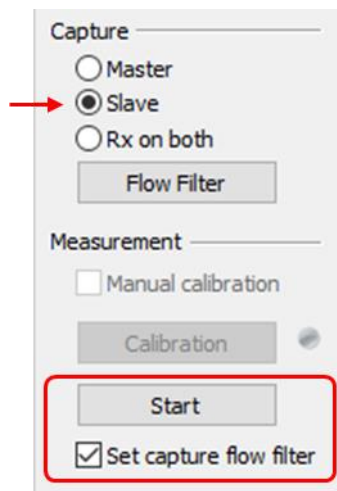

- Paragon-X can use the MLD function to determine the compensation required between the TAB and Paragon-X port 2 (including the TAB internal delays and the cable delays). To enable this mechanism, check the **Use measured link delay** checkbox in the MSE GUI as indicated by the red arrow below.

If 1PPS measurements are being made, the 1PPS measurement cable must also be compensated for as indicated by the blue arrows in the pictures above.

Before starting a capture, Paragon-X packet capture filters must be set. The simplest way to set filters and start capture is to select the Paragon-X slave as the capture point, check the **Set capture flow filter** checkbox and click **Start** in the MSE GUI. This will automatically set the filters to capture Sync, Follow-up and Announce messages from the GM, and Peer Delay exchanges initiated from Paragon-X port 2.

To have more control over the capture filters, click the **Flow Filter** button in the main MSE GUI, then define the individual message filters. If you manually set the capture filters, start the capture by clicking the **Start Capture** button on the left side of the Paragon-X GUI.

6.2. MSE Mode Time Aware Bridge Test Measurements

Once a measurement is underway, the data can be graphically viewed in CAT. The table below shows the metrics calculated by CAT that are relevant to the TAB tests.

| Measurement	Use MLD	Fixed cable compensation	Explanation
Time Error			
P-X Fwd CF Accuracy	✓	✓	TAB Correction Factor accuracy
P-X Fwd Latency	✓	✓	Measured latency through the TAB
P-X Fwd CF Delta	✓	✓	Change in Correction Factor applied by the TAB (i.e. its calculated forward latency)
P-X Peer Delay Measured Link Delay	✓	n/a	Actual measured link delay between TAB and Paragon-X port 2
P-X Peer Delay Turnaround Time Accuracy	n/a	✓	TAB Turnaround Time accuracy: P-X Peer Delay Turnaround Time (Actual) minus P-X Peer Delay Turnaround Time (DUT)
P-X Peer Delay Turnaround Time (Actual)	n/a	✓	Measured Peer Delay Turnaround Time (T4 - T1 - cable delays)
P-X Peer Delay Turnaround Time (DUT)	✓	✓	Peer Delay Turnaround time reported by TAB (T3 - T2)
P-X TT PTP Data GM Clock Class	✓	✓	Clock Class value transmitted by the TAB in Announce messages
P-X 1pps TE Absolute	✓	✓	1PPS time error, if provided by TAB
Constant Time Error			
P-X T1 Avg Time Error (cTE)	✓	✓	Constant Time Error calculated from Sync messages
P-X 1pps TE Absolute Avg Time Error (cTE)	✓	✓	Constant Time Error calculated from 1PPS, if provided by TAB
Rate Ratio			
P-X NRR (DUT)	✓	✓	NRR reported by the TAB
P-X NRR (Actual)	✓	✓	Actual NRR measured by Paragon-X
P-X NRR Accuracy	✓	✓	Error between reported NRR by the TAB and NRR measured by Paragon-X
PX CSRO Delta	✓	✓	Value of CSRO carried in Peer Delay messages
Note – NRR measurements are only available for two-step Peer Delay configurations.			

The CAT screenshots on the following pages show examples of TAB measurements. 1PPS Time Error and ToD measurements are not shown in these examples because the TAB-under-test did not have 1PPS or ToD outputs.

The left screenshot below shows CAT measurements of CF Accuracy, Forward Latency, Peer Delay and Clock Class when Paragon-X uses MLD to compensate the port 2 Ethernet cable. The right screenshot shows CAT measurements of CF Accuracy, Forward Latency, Peer Delay and Clock Class when Paragon-X applies a fixed cable compensation for the port 2 Ethernet cable.

A 10ms pass/fail threshold was set for the **P-X Peer Delay Turnaround Time (DUT)** measurements in accordance with 802.1AS performance requirements (green lines). The TAB peer delay turnaround time is generally around 600µs but spikes over 10ms.

The left screenshot below shows the Constant Time Error (cTE) measurement, and the right screenshot shows CAT results for of Neighbour Rate Ratio (NRR) and Cumulative Scaled Rate Offset (CSRO). The significant NRR and cTE changes during the first 100 seconds of the test are when the TAB was synchronizing to the incoming PTP stream.
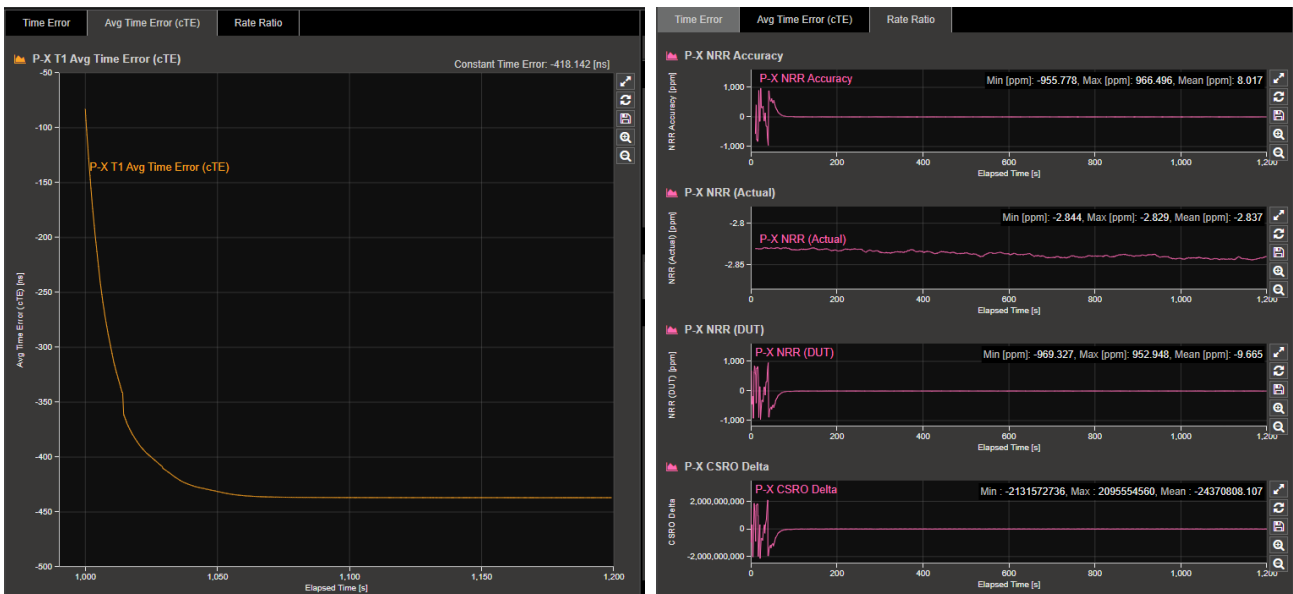
The screenshot below zooms in show the TAB NRR accuracy measurement. The 802.1AS standard requires devices to calculate their NRR to within ±0.1ppm (802.1AS-2020 Annex B.2.4) so a pass/fail threshold has been set at this level. Even after the first 100 seconds of the test when the TAB was still synchronizing to the incoming PTP stream, the TAB-under-test fails this test.
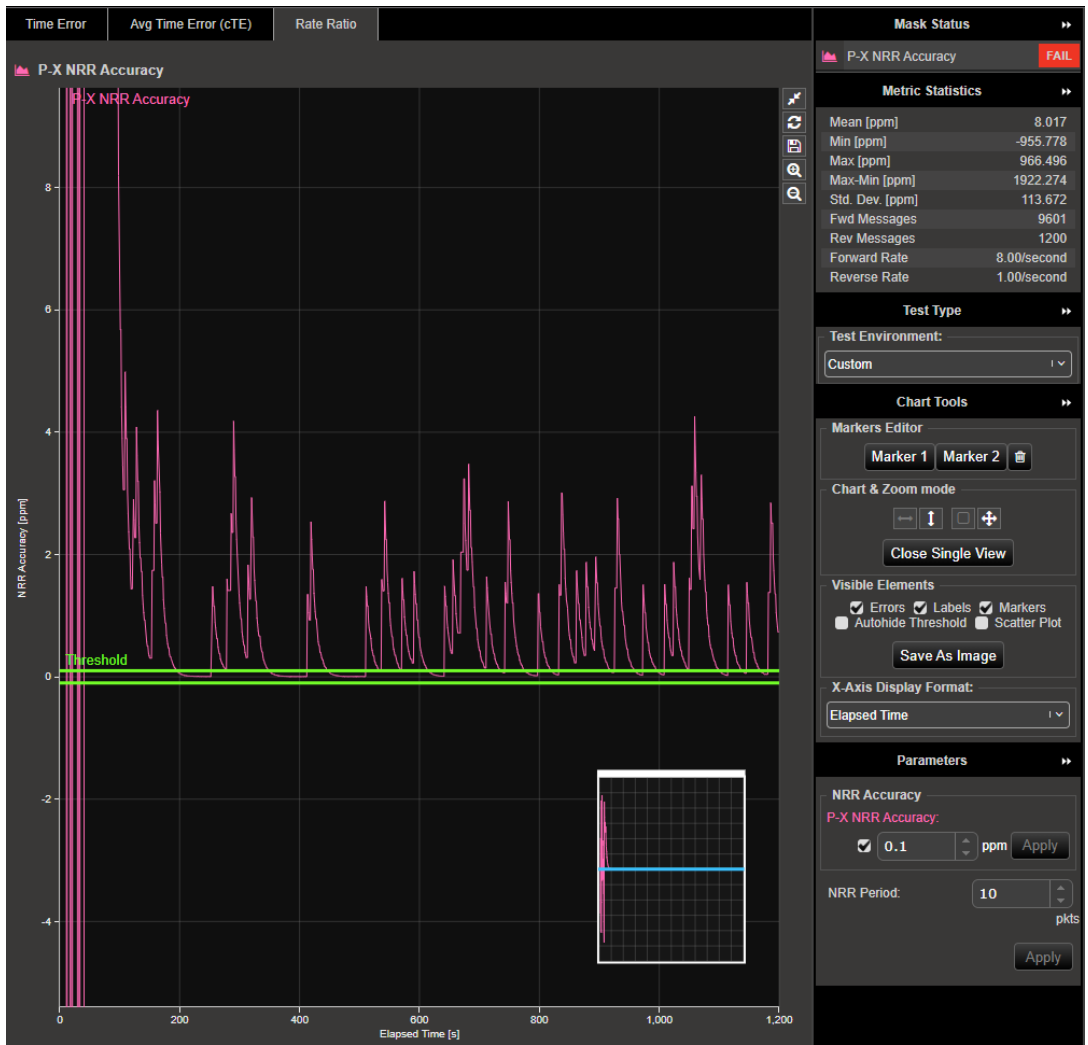
7. MSE Mode Time Aware End Station Test

An 802.1AS Time Aware End Station (TAES) should be connected to Paragon-X as shown in the diagram opposite. The TAES takes a PTP input from the Paragon-X Master and outputs one or both of Reverse Sync messages and a 1PPS signal. Paragon-X measures the Reverse Sync, 1PPS and ToD signals to determine how accurately the TAES is maintaining time.

Note – Reverse Sync is an extension to 802.1AS proposed by the AVNU organization. See document references section.

The timestamp point in a TAES can be implemented in software and hence "inside the box". This results in measured link delays that include elements of the TAES ingress and egress latencies (show in the diagram).

Paragon-X can operate in single or dual master configurations when running a TAES test. The dual master configuration (not shown in the diagram) is useful for testing best master switch over on TAESs that have multiple PTP input ports.


For accurate measurements, external reference signals should be provided to Paragon-X when running TAES tests Paragon-X in MSE mode.

Please refer to the Calnex Time Aware End Station Test Guide CX3015 for detailed test steps to test a Time Aware End Station. The description below is an outline to explain the added features in the 30X software release.
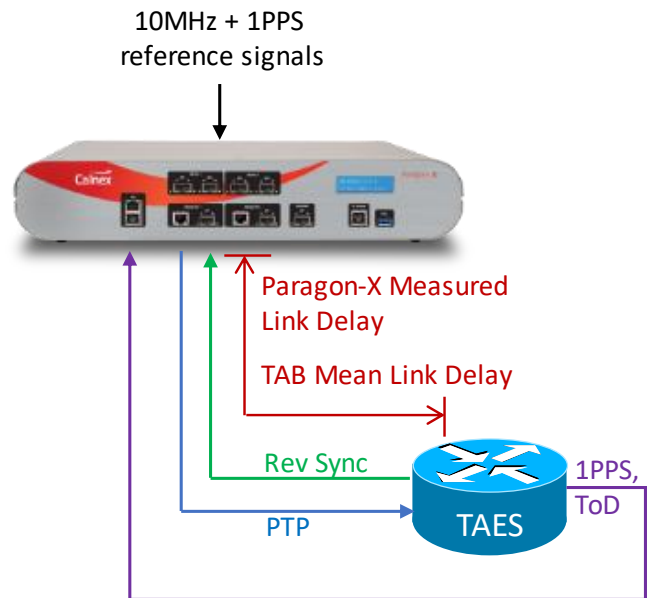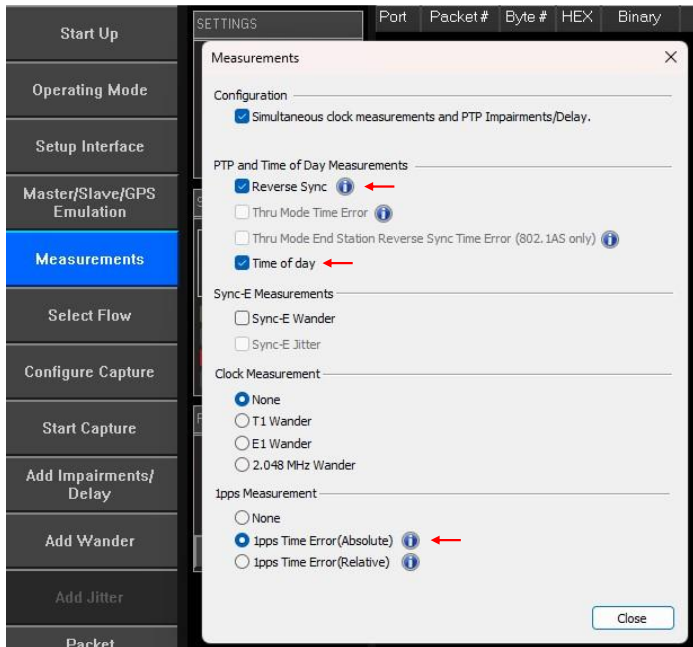
7.1. Configuring Paragon-X for MSE Time Aware End Station Test

Set Paragon-X **Operating Mode** to **1588v2** and check the **Enable Master/Slave Emulation** checkbox.
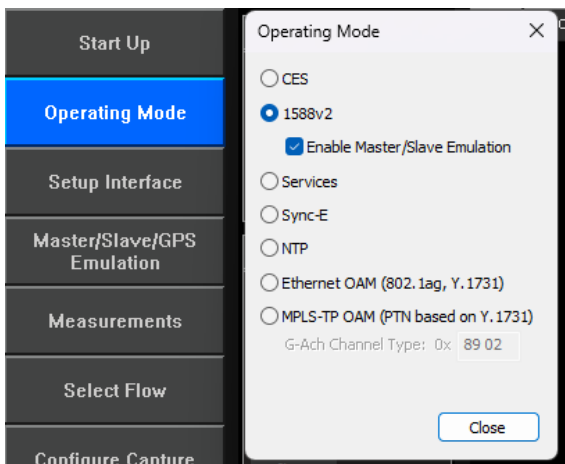
Use the Paragon-X **Measurements** GUI to select what time signals to measure from the TAES. The example screenshot below shows that Reverse Sync, 1PPS and ToD measurements have been selected.


When measuring Reverse Sync timing, Ethernet cable compensation is required to account for the cable delay between the TAES and Paragon-X port 1. The TAES compensates for the cable delay between the Paragon-X port 1 for the forward Sync messages. Two options are available –

- If the Ethernet cable length between the TAES and Paragon-X port 1 is accurately known, manual compensation can be applied in the MSE GUI as indicated by the red arrows below.
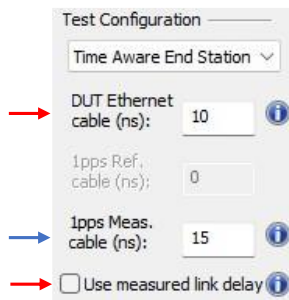

- Paragon-X can use the MLD function to determine the link compensation required between the Paragon-X port 1 and the TAES (including the TAES internal delays and the cable delays). To enable this mechanism, check the **Use measured link delay** checkbox in the MSE GUI as indicated by the red arrow below.
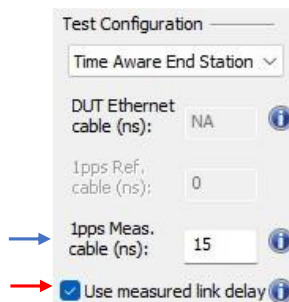
If 1PPS measurements are being made, the 1PPS measurement cable must also be compensated for as indicated by the blue arrows in the pictures above.

Before starting a capture, Paragon-X packet capture filters must be set manually to capture Announce messages from Paragon-X port 1, Peer Delay exchanges requested from Paragon-X port 1, and Reverse Sync and Follow Up messages from the TAES. To configure port 1 capture filters, click the **Flow Filter** button in the main MSE GUI, then define the individual message filters as shown below.
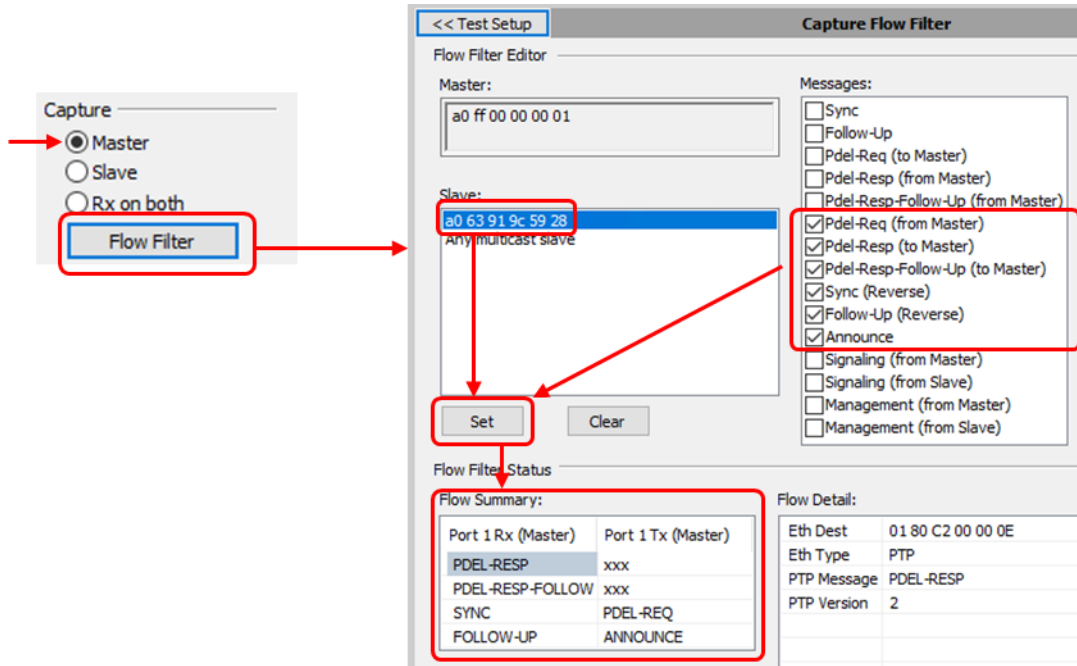
Note that Reverse Sync PTP timing measurements should only be made on Paragon-X port 1. When **Two Masters** testing is selected in **Device Configuration** section of the Paragon-X MSE GUI, Paragon-X port 2 becomes an alternate master port for functionally testing Best Master Clock Algorithm implementation in the TAES (port 2 is not calibrated for PTP timing tests). Instead of monitoring Reverse Sync messages, measure a 1PPS signal from the TAES to evaluate TAES timing performance during the period of a Best Master Clock Algorithm switchover.

7.2.   MSE Mode Time Aware End Station Test Measurements

Once a measurement is underway, the data can be graphically viewed in CAT. The table below shows the metrics calculated by CAT that are relevant to the TAES tests.

Measurement	Use MLD	Fixed cable compensation	Explanation
Time Error			
P-X 1pps TE Absolute	✓	✓	1PPS time error, if provided by TAES
P-X Peer Delay Measured Link Delay	✓	n/a	Actual measured link delay between TAES and Paragon-X port 1
P-X Peer Delay Turnaround Time Accuracy	n/a	✓	TAES turnaround time accuracy: P-X Peer Delay Turnaround Time (Actual) minus P-X Peer Delay Turnaround Time (DUT)
P-X Peer Delay Turnaround Time (Actual)	n/a	✓	Measured Peer Delay Turnaround Time (T4-T1 - cable delays)
P-X Peer Delay Turnaround Time (DUT)	✓	✓	Peer Delay Turnaround time reported by TAES (T3-T2)
P-X PTP Data GM Clock Class	✓	✓	Clock Class value transmitted in Announce messages
P-X Rev Sync Subordinate Time Error	✓	✓	TAES TE measured from the reverse sync messages
Constant Time Error			
P-X 1pps TE Absolute Avg Time Error (cTE)	✓	✓	Constant Time Error calculated from 1PPS, if provided by TAES
Dynamic Time Error			
P-X 1PPS TE Absolute Dynamic TE LF	✓	✓	1PPS Dynamic TE metrics, if provided by TAES. Useful for stability analysis of the local oscillator.
P-X 1PPS TE Absolute Dynamic TE HF	✓	✓	
P-X 1PPS TE Absolute Dynamic MTIE LF	✓	✓	
P-X 1PPS TE Absolute Dynamic TDEV LF	✓	✓	
Rate Ratio			
P-X NRR (DUT)	✓	✓	NRR reported by the TAES
P-X NRR (Actual)	✓	✓	Actual NRR measured by Paragon-X
P-X NRR Accuracy	✓	✓	Error between reported NRR by the TAES and NRR measured by Paragon-X
PX CSRO Delta	✓	✓	Value of CSRO carried in Peer Delay messages
Note – NRR measurements are only available for two-step Peer Delay configurations.			

The CAT screenshots on the following pages show examples of TAES Reverse Sync PTP and 1PPS measurements. ToD measurements are not shown in these examples because the TAES-under-test did not have a ToD output. The specific TAES-under-test had not been fully configured and was showing significant cTE on the PTP and 1PPS measurements – the cTE offset is seen in both tests and is the same magnitude for both 1PPS and PTP measurements.

The left screenshot below shows CAT measurements of 1PPS TE and Reverse Sync TE, Peer Delay and Clock Class when Paragon-X uses MLD to compensate the port 1 Ethernet cable. The right screenshot shows CAT measurements of 1PPS TE and Reverse Sync TE, Peer Delay and Clock Class when Paragon-X applies a fixed cable compensation for the port 1 Ethernet cable.
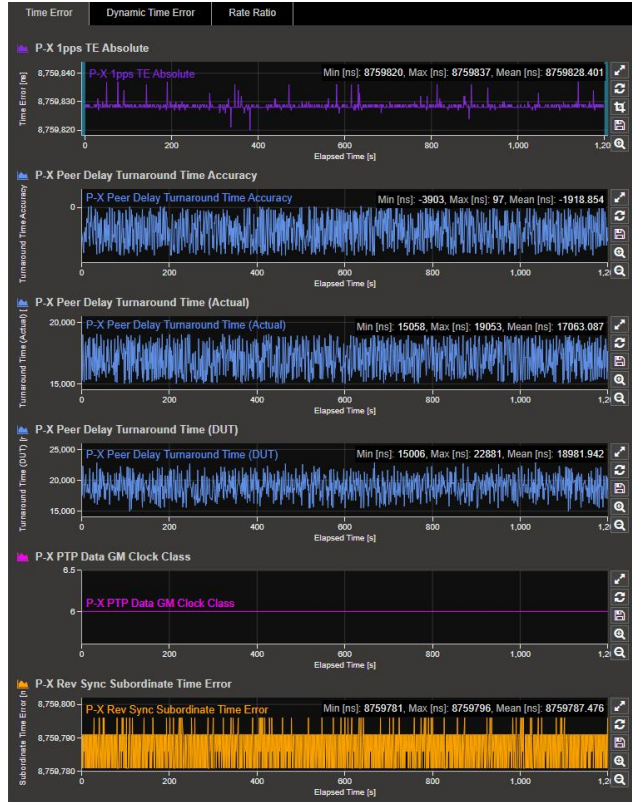
The left screenshot below shows the 1PPS Dynamic Time Error measurement, and the right screenshot shows CAT measurements of NRR and CSRO. In this example, the TAES was not reporting its CSRO so the NRR (DUT) metric is 0 ppm. A pass/fail threshold of 10ms was set for the TAES NRR accuracy in accordance with 802.1AS performance requirements (green lines) – the TAES fails this test.
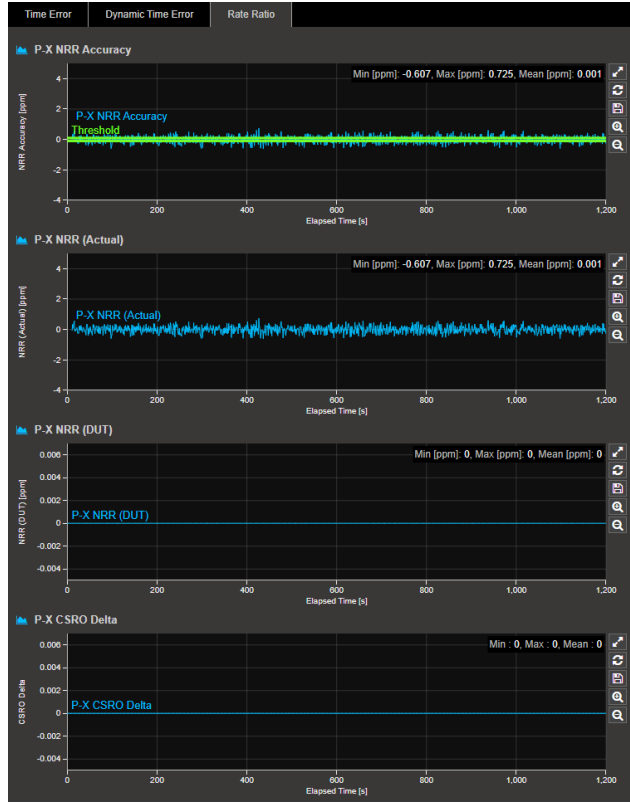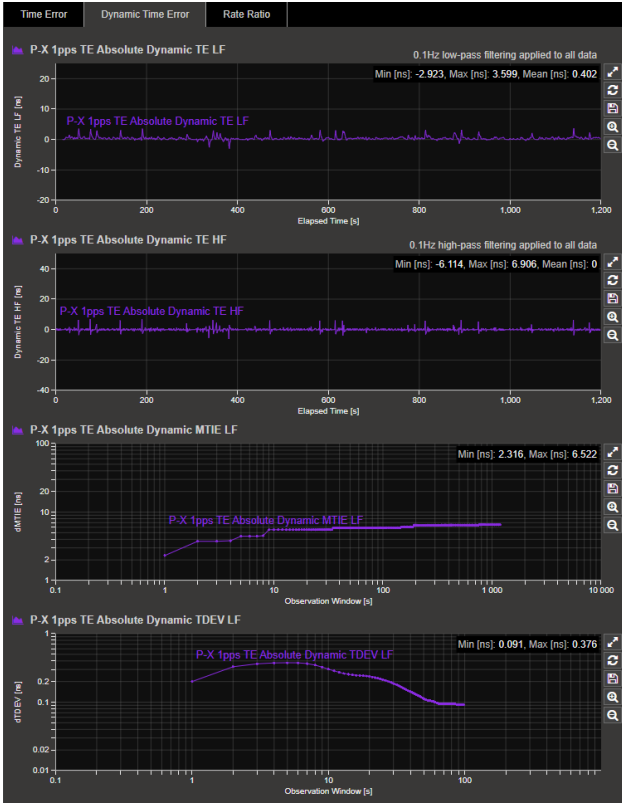
8. NRR Adjustment

Oscillators used in 802.1AS devices will differ in frequency and adjust for these differences using the NRR calculations. 802.1AS Annex B.1.1 specifies that oscillators used in 802.1AS devices must be accurate within ±100ppm of TAI frequency.

If there is a significant frequency deviation between two connected 802.1AS devices, an unadjusted NRR contributes to inaccuracies in the path delay calculations that are part of the Peer Delay mechanism. For example, when a clock with 100ppm NRR and Peer Delay Turnaround Time of 10ms (the worst cases allowed by 802.1AS), the effect on the calculated path delay would be 500ns.

The effect of this adjustment can be calculated as follows where NRR_{DUT} is expressed in ppm and $TurnaroundTime_{DUT}$ is in seconds:

$$\Delta Path\ Delay = \frac{NRR_{DUT}}{2 \times 10^6} \times Turnaround\ Time_{DUT}$$

The Paragon-X oscillator has a maximum frequency deviation of ±4.6ppm to TAI. If there is a significant difference in oscillator frequency accuracy between a DUT and Paragon-X and/or a significant Peer Delay Turnaround Time in the DUT, NRR adjustment can be applied in CAT. If the oscillator used in the DUT is of similar performance to Paragon-X and the DUT's Peer Delay Turnaround Time is low, no adjustment is needed.

NRR Adjustment is enabled in CAT by checking the **Use NRR Adjustment** checkbox in the **Parameters** section of the CAT GUI as shown opposite.

By default, CAT does not apply any NRR adjustment. If the delta Path Delay between the DUT and Paragon-X is significant (as calculated by the formula above), then **NRR Adjustment** can be applied to calculate path delay more accurately.

The screenshot shows an example where NRR Adjustment of 10 packets being set. Click **Apply** and then **Calculate** to update the MLD, Turnaround Time and **P-X Thru Mode TR Rev Sync Offset from TT** metrics.

The NRR adjustment function can be applied to Through Mode and MSE mode measurements.
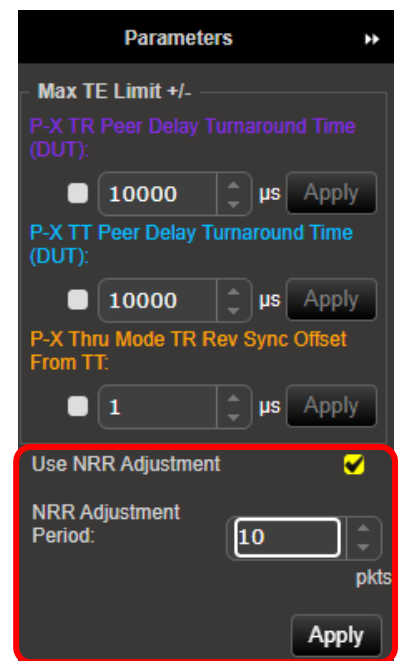
Further details regarding NRR calculation can be found in the 802.1AS-2020 standard document. CAT calculates NRR using the formula defined in IEEE802.1AS-2020 Section 11.2.19.3.3, where N is set by the Adjustment Period. This NRR value is then applied to the path delay calculations as per 802.1AS-2020 11.2.19.3.4.

Calnex Solutions plc
Oracle Campus
Linlithgow
EH49 7LR
United Kingdom

t: +44 (0) 1506 671 416
e: info@calnexsol.com

calnexsol.com

CX5047 v1.1 April 2024