TEST GUIDE

**CX3009 v3.0**

# G.8273.2 BC Conformance Test

Testing Boundary Clocks up to Class-D performance requirements as per ITU-T G.8273.2 using Paragon-neo

- Noise Generation
- Noise Tolerance
- Noise Transfer
- Transient Response
- Holdover Performance

The accuracy of Telecom Boundary Clocks (T-BCs) is essential to the successful roll-out of 5G as well as being integral for LTE-A. To meet requirements including G.8273.2 compliance limits up to Class-D for 5G Enhanced Time, T-BCs must meet very stringent Maximum Time Error limits of as low as 5 nanoseconds. This ensures that the highest number of nodes can be deployed within the network's Time Error budget.

This Test Guide shows how the Calnex Paragon-neo can be used to test T-BC compliance as per G.8273.2 and provides procedures to measure noise generation, time noise tolerance and transfer, packet layer transient response and holdover performance.

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# 1. Hardware and Software Required

**Paragon-neo**

| | |
|---|---|
| Opt. NEO-1G-10G | 1/10GbE interface support (if the Device-Under-Test (DUT) has 1G and/or 10G interfaces) |
| Opt. NEO-25G | 25GbE interface support (if the DUT has 25G interfaces) |
| Opt. NEO-100G | 100GbE interface support (if the DUT has 100G interfaces) |
| Opt. NEO-40G | 40GbE interface support (if the DUT has 40G interfaces |
| Opt. NEO-PTP-G.8275.1 | Emulation of G.8275.1 PTP Master and Subordinate devices, with associated Time Error Impairment and measurement capability |
| Opt. NEO-SyncE-Wander | SyncE Wander and ESMC |
| Opt. NEO-RTE | PTP Testing – Relative Time Error |
| Opt. NEO-Background-Traffic | Background Traffic Generation (to test using ITU-T G.8273 methodologies) |

Software version: 04.00.XX and later. For Relative Time Error and Background Traffic: 09.00.XX and later.

**Accessories**

- Optical Transceivers as required
- Cables as required

**Document References**

- Recommendation ITU-T G.8275.1 Precision time protocol telecom profile for phase/time synchronization with full timing support from the network
- Recommendation ITU-T G.8273.2 Timing Characteristics of Telecom Boundary Clocks
- IEEE Std 1588TM - 2008 IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems
- Calnex Technical Note: Cabling Considerations (CX5009)

## 2. Document Information

It should be noted that the tests in the guide are timing performance tests and focus on the quality of the timing output from the device under test as defined in the relevant standards and recommendations.

However, during product development or qualification other aspects of device behavior and performance may be of interest. Such aspects could include:

- Device warm-up time and duration required to achieve optimal performance with both ideal and non-ideal reference inputs
- Performance under various input reference impairment profiles, failure modes and the subsequent recovery times
- Device performance changes depending on the order, concurrency, and duration of multiple fail events
- Type and quality of events reported by the device via the management interfaces
- Accuracy of on-device timing performance monitoring and reporting functions

In the case of the above being required, the test procedures in this document can be used as a basis for the user to design their own tests to study those aspects.

The Calnex Sentinel and Paragon-x products can be used to capture real-life network performance and can be imported into Paragon-neo as impairment profiles.

## 3. Connecting Paragon-neo or Paragon-neo A (PAM4) to the Device-Under-Test

### Paragon-neo Front Panel

**Optical Interfaces:**

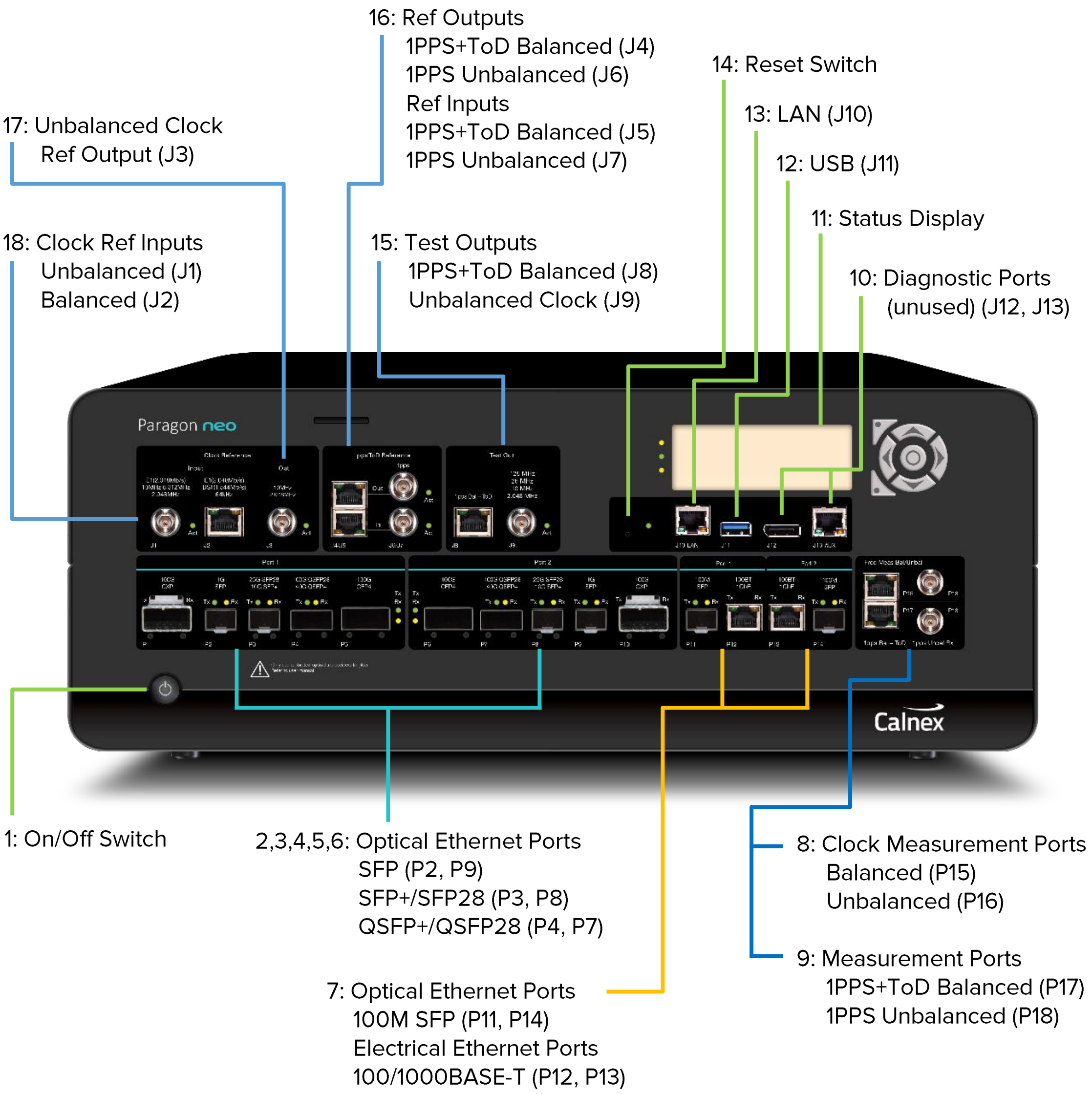
- 100GbE (QSFP28)
- 50GbE (QSFP28)
- 40GbE (QSFP+)
- 25GbE (SFP28)
- 10GbE (SFP+)
- 1GbE (SFP)

**Reference Clock Inputs:**

- 2.048/10MHz (Recommended)

**1PPS Measurement Inputs:**

- 1PPS Balanced (RJ48)
- 1PPS Unbalanced (BNC)



## Paragon-neo A (PAM4) Front Panel

**PAM4 Optical Interfaces:**

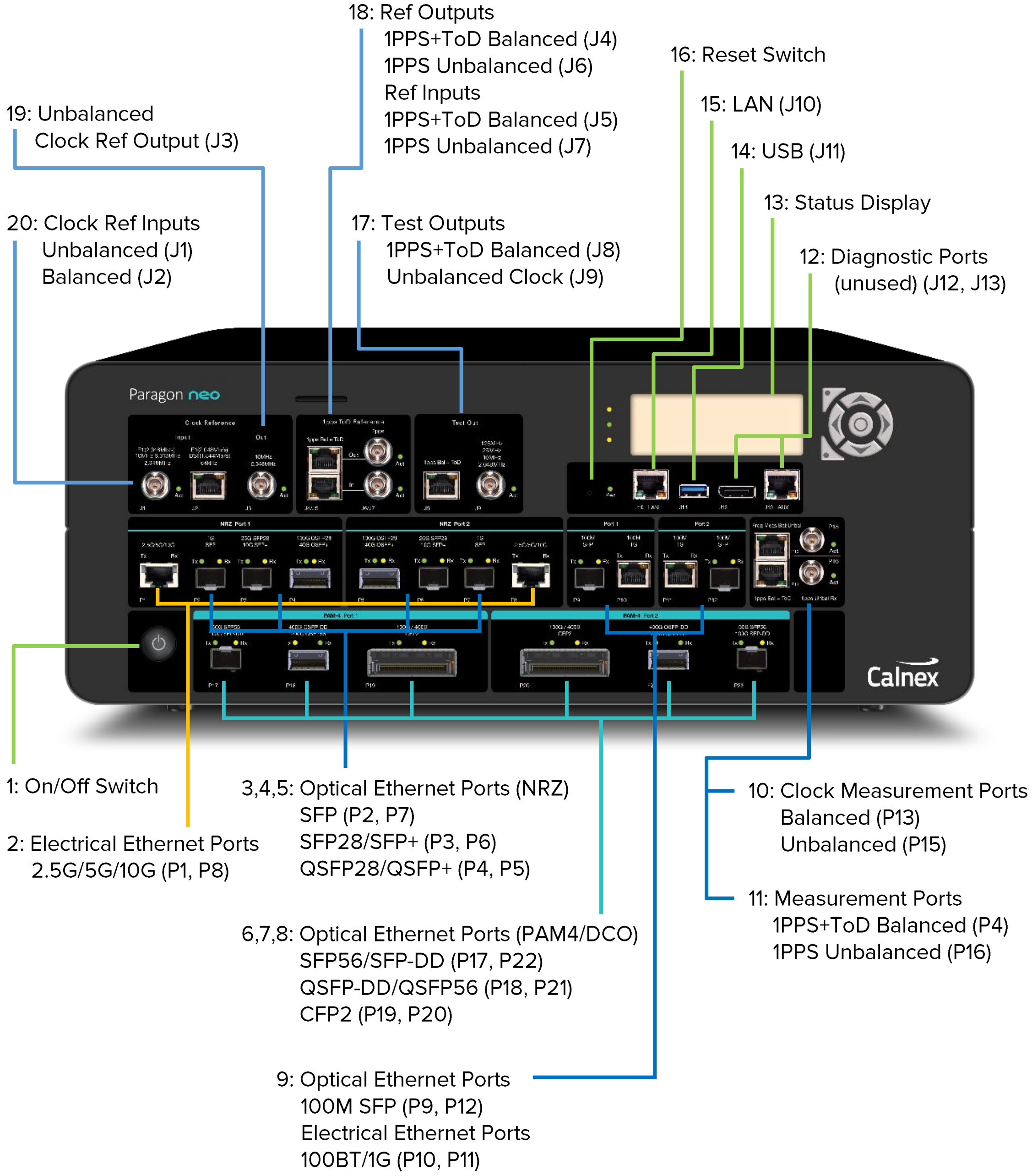
- 400GbE (QSFP-DD)
- 50GbE (SFP56)

**Reference Clock Inputs:**

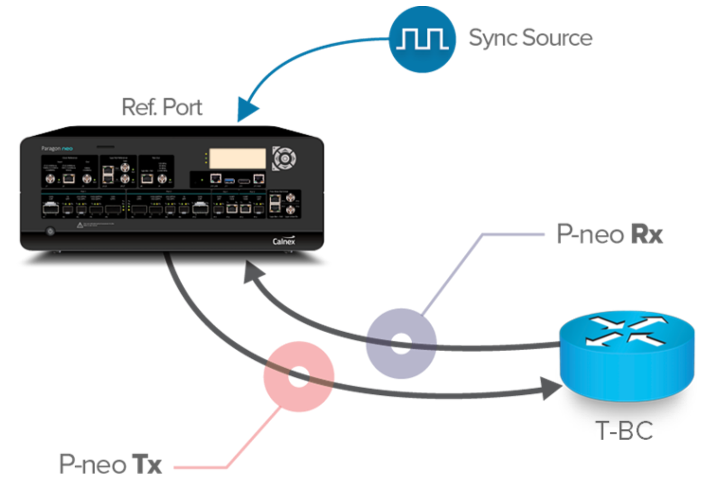
- 2.048/10MHz (Recommended)

**1PPS Measurement Inputs:**

- 1PPS Balanced (RJ48)
- 1PPS Unbalanced (BNC)

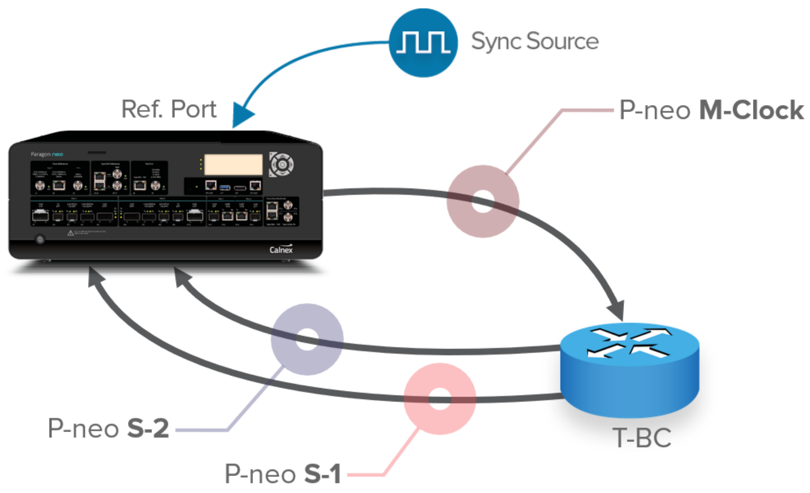


**Connections for Tests (excluding-Relative Time Error Tests)**



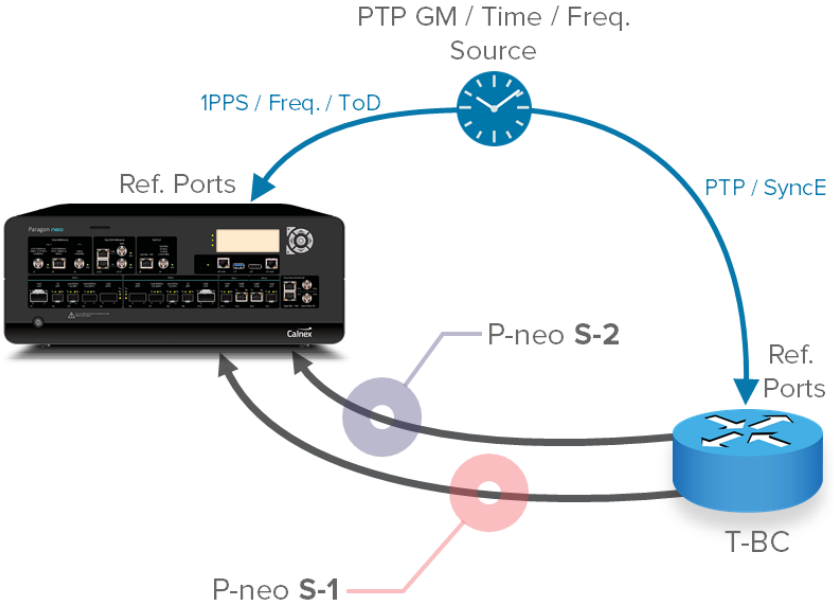

1. Connect Port 1 (Master side of Paragon-neo) to the T-BC Subordinate side.
2. Connect Port 2 (Subordinate side of Paragon-neo) to the T-BC Master side.
3. If desired, connect an external reference, e.g. 10MHz, to the Paragon-neo Reference Input.
4. If provisioned on the DUT, connect the 1PPS output from the T-BC to the Paragon-neo 1PPS measurement port.

**Connections for PTP Relative Time Error Tests, or for making two simultaneous PTP measurements – using Paragon-neo RTE Master port:**



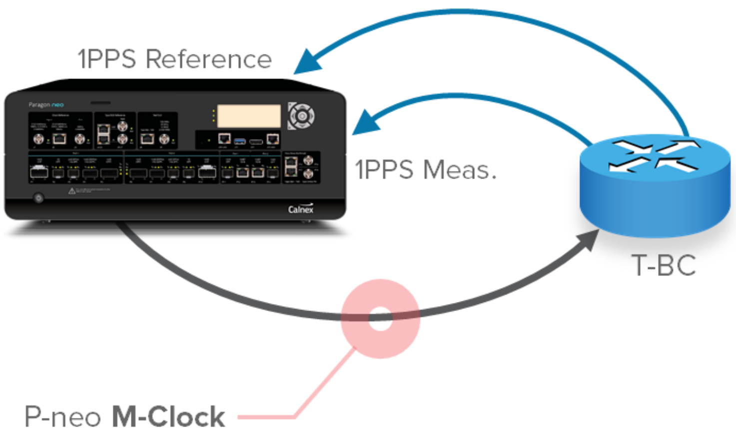

1. Connect Paragon-neo Port 1 (which will be labelled as S-Clock 2 and S-2 in the GUI and CAT) to a T-BC Master port.
2. Connect Paragon-neo Port 2 (which will labelled as S-Clock 1 and S-1 in the GUI and CAT) to a T-BC Master port.
3. Connect the Neo RTE Master Port (labelled Port 2 100M SFP on the instrument front panel, and M-RTE in the Setup Ports screen in the GUI) to a T-BC Subordinate Port. Note that in Relative Time Error test mode that this port runs at 1G and not 100M.
4. Essential for two simultaneous measurements and optional for Relative Time Error: connect phase (1PPS), frequency (e.g. 10MHz) and, optionally, ToD references to the Paragon-neo Reference Inputs.

**Connections for PTP Relative Time Error Tests, or for making two simultaneous PTP measurements – using external PTP Grandmaster:**




5. Connect Paragon-neo Port 1 (which will be labelled as S-Clock 2 and S-2 in the GUI and CAT) to a T-BC Master port.
6. Connect Paragon-neo Port 2 (which will labelled as S-Clock 1 and S-1 in the GUI and CAT) to a T-BC Master port.
7. Connect the external PTP GM PTP Master Port to a T-BC Subordinate Port
8. If not provided on the same port as the PTP, connect the PTP GM physical layer frequency source (typically SyncE) to a T-BC Frequency Reference Port
9. Essential for two simultaneous measurements and optional for Relative Time Error: connect phase (1PPS), frequency (e.g. 10MHz) and, optionally, ToD references to the Paragon-neo Reference Inputs.

**Connections for 1PPS Relative Time Error Test:**




1. Connect Paragon-neo 1PPS Reference Port to a T-BC 1PPS output port.
2. Connect Paragon-neo 1PPS Measurement Port to a second T-BC 1PPS output port.
3. Connect Paragon-neo Port 1 (which will be labelled as M-Clock in the GUI and CAT) to the T-BC Subordinate Port. This port will also provide SyncE to the T-BC.
4. If desired, connect an external frequency reference (e.g. 10MHz) to the Paragon-neo Frequency Reference Input.

## 4. Setting up the Paragon-neo for G.8273.2 Conformance Tests

The following steps are required to set up the Paragon-neo prior to performing G.8273.2 Conformance tests:

4.1. Connection to Paragon-neo

4.2. Configuration of Physical Connections

4.3. Test Configuration

4.4. Device Connection Settings

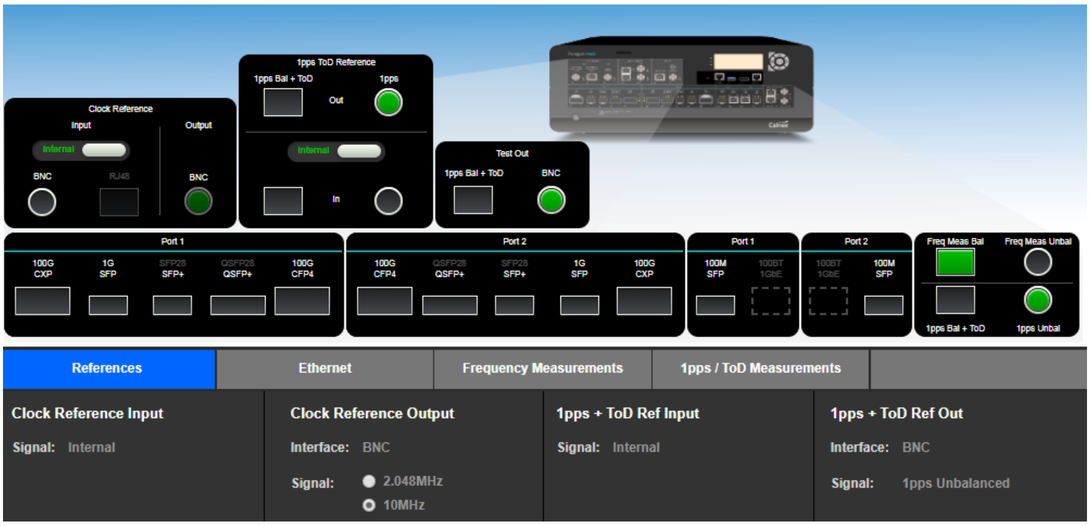
4.5. Background Traffic

### 4.1. Connection to Paragon-neo

1. Verify the physical connections have been completed as described in Section 0 for the relevant test type.
2. From a PC on the same network, open a browser and enter the IP address of the Paragon-neo unit.
3. If directed to the Home Page, select **Conformance Test** operating mode.
4. See the Paragon-neo Getting Started Guide for more details.

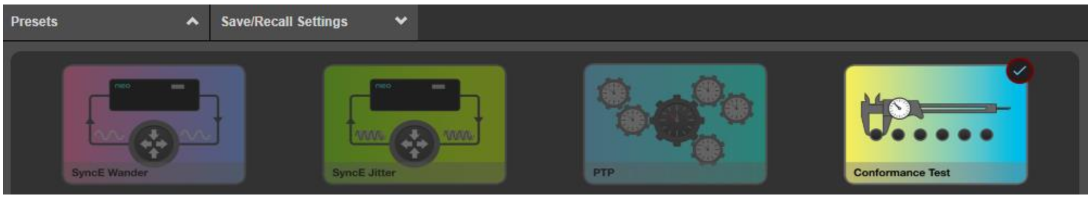
### 4.2 Configuration of Physical Connections

1. Select **Setup Ports** then from the onscreen display, select those reference and test ports to be used.
2. If required, enter **Threshold** and **Termination** information for 1pps signals. Voltage thresholds should be set to 1 decimal place to ensure best accuracy of test and measurement.




### 4.3. Test Configuration

1. Select **Run Apps,** then the **Conformance Test** preset.



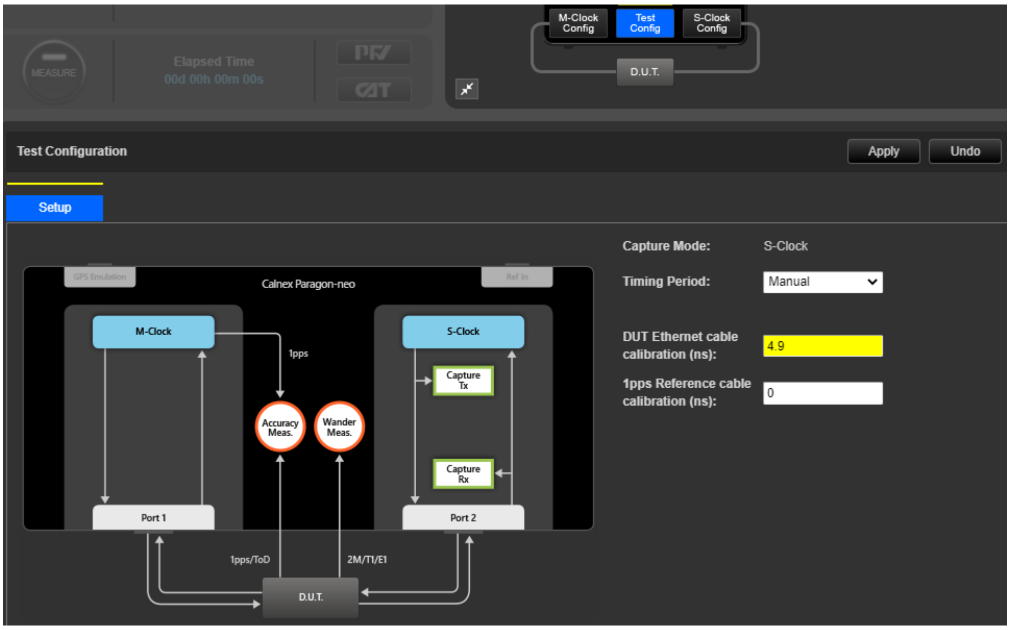
### 4.4. Device Connection Settings

It is assumed that a G.8275.1 profile will be used in testing as per the G.8273.2 standard and as a result testing will be carried out using L2 encapsulation in Multicast mode. The Paragon-neo PTP Emulation can be configured to use other profiles, e.g. Unicast UDP/IPV4 etc., however, it should be noted that these profiles will not conform to the G.8273.2 standard.  As per the requirements of G.8275.1, SyncE should also be used.

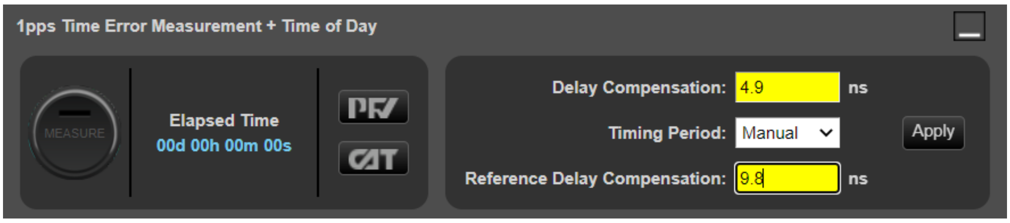
1. For all conformance tests apart from Relative Time Error Noise Generation, in the **PTP Emulation** app, select **Boundary Clock** as the **Test Mode** and **G8275.1 Phase Profile** as the **PTP Profile**, then choose **Test Config** and make any necessary cable delay compensation settings in the **Test Configuration** page.

   For PTP Relative Time Error testing or to make two simultaneous PTP measurements, the **Test Mode** should be set to **Relative Time Error / 2 x TE** and a separate cable compensation value must be entered for Port 1 and Port 2.

   Delay values are entered in ns and should be entered to one decimal place for best performance. A value of 4.9ns per metre of Optical Fibre is typical but can vary by fibre type – for best performance it is highly recommended to confirm delay values with the fibre manufacturer. For coaxial cable, values of 4.5 to 5ns per metre of cable are typical – again, it is recommended to independently verify the cable delay. Once the required values have been set, click **Apply.**




2. In the **1pps Time Error Measurement** app, make any necessary cable delay compensation settings.



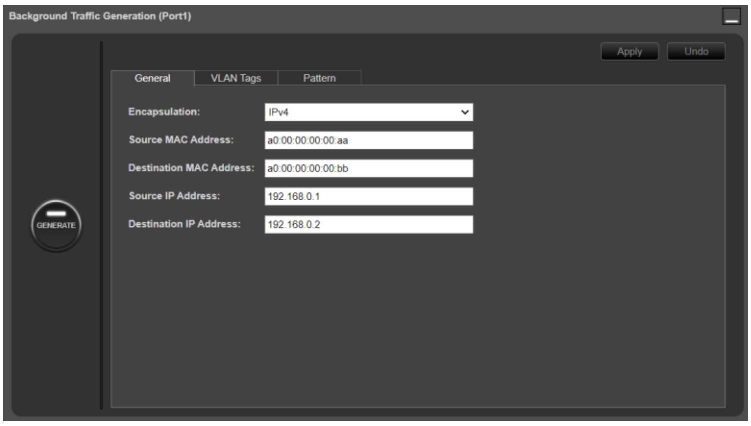

   Further information to assist with entering cable delay values is provided in the **Quick Help** in the left-hand pane within the Paragon-neo User Interface.

### 4.5. Background Traffic

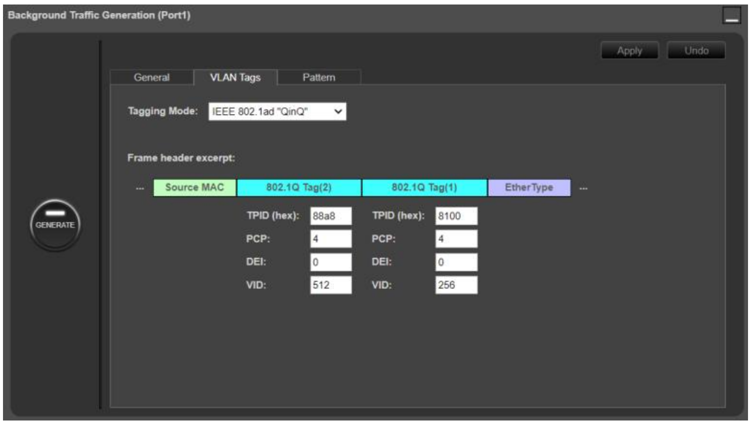
The measurement methodologies specified in ITU-T G.8273 Annex B include a requirement for traffic generation to introduce suitable loading on the ports of the DUT that carry the timing packets.

The Paragon-neo Background Traffic Generation application provides the ability to test to the ITU-T G.8273 requirements by generating Ethernet or IP packets in addition to the PTP and ESMC packets on Port 1 and Port 2.

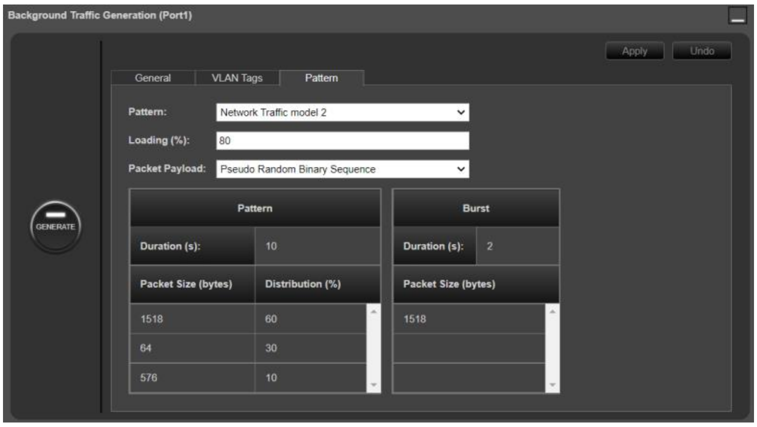
1. In the **Background Traffic Generation** app for the required Paragon-neo port, choose **General** and select the encapsulation, source and destination addresses for the generated traffic.




2. Select the **VLAN Tags** tab and if required, configure the VLAN parameters.




3. Select the **pattern** tab and configure the required parameters for the traffic pattern, loading and payload.




4. Clicking on **Generate** at any time begins the transmission of the background traffic.

## 5. Analysing Results using CAT

The tests in this document detail the steps to manually set the metrics, masks and thresholds to those required to test for G.8273.2 conformance, however, it is also possible to use the **Test Environment** function to automatically apply the relevant settings.

The Test Environment function automatically configures the displayed metrics, masks, and thresholds to a range of preset values such as those required for testing compliance to device or network standards.

The environments that are available for selection change dynamically based on the type of measurement data that is in the loaded capture file(s), e.g. if PTP measurement data is present then Test Environments that contain PTP metrics will be available.

In the example below G.8273.2 T-BC Class A device with PTP measurements has been selected, the relevant metrics Time Error, Avg Time Error (cTE) and Dynamic Time Error only are displayed, and the masks and thresholds have been set to those relevant to that device type and class.

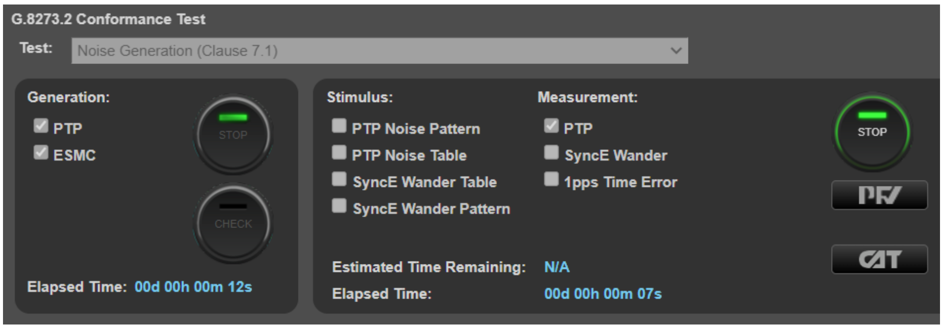
## 6. Noise Generation – G.8273.2 Clause 7.1

### Test Description

The noise generation of a T-BC represents the amount of noise produced at the output of the T-BC when there is an ideal input reference packet timing signal. The noise generation has two components, the constant time error (cTE) and the time noise generation (Max|$TE_L$| or Max|TE|, dTE).

### Measurement Process

1. Confirm that preconfigured settings within PTP emulation are appropriate for the current test scenario, as described in Section 4.4.
2. To test to the measurement methodology specified in ITU-T G.8273, configure the **Background Traffic** app as described in Section 4.5.
3. From the **Test:** drop-down menu, select **Noise Generation (Clause 7.1).**
4. From the **Generation** section of the conformance test app, press **Generate**. This starts PTP and ESMC message generation, allowing the DUT to stabilize. Pressing **Check** will run a simultaneous data capture, after which you can open the **CAT** in a new tab to check current timing performance. In this case, you should wait for a **2WayTE measurement** graph moving from a ramp to stable condition to indicate lock has been achieved.
5. Once the DUT is stable, in the **Stimulus/Measurement** section, press **Start** to run the Noise measurement. The measurement should be run for at least 2000s.

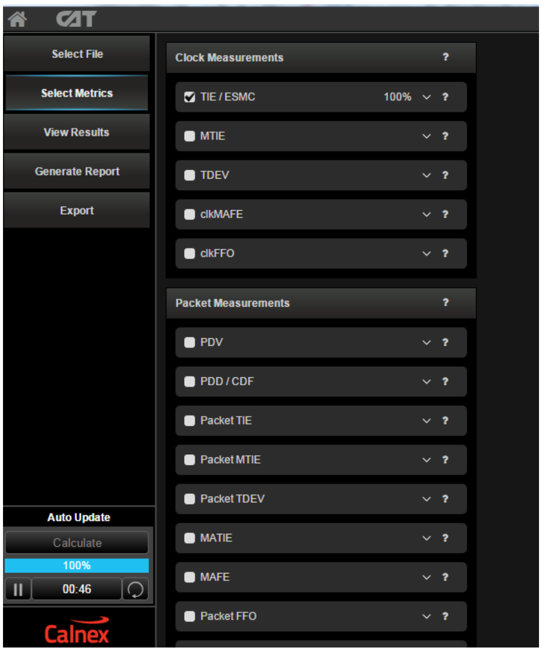



**Measurements:** Time Error results can either be viewed during capture or after capture has been stopped.

5. Select **CAT**. The Calnex Analysis Tool will open in a new browser tab displaying **Time Error** metrics.

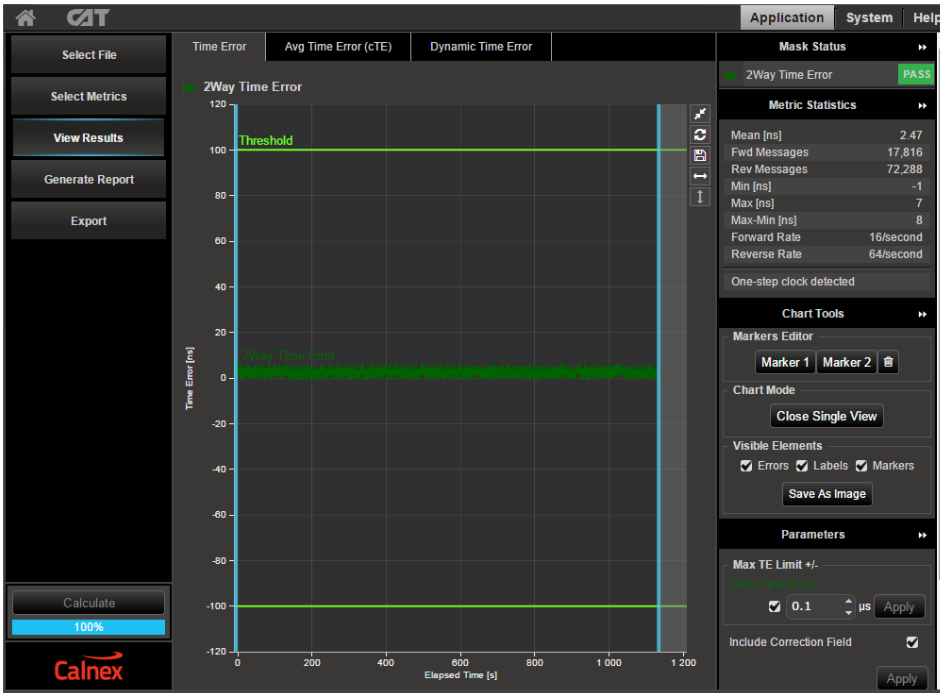
For PTP based data this will include the metrics **Time Error, Time Error – Filtered (TE$_L$), Avg. Time Error (cTE)** and **Dynamic Time Error**.

**Note:** The complete set of metrics can be viewed by expanding the appropriate list in the Measurement Analysis block by clicking on the + symbol against each metric.




Individual graphs can be displayed by clicking on the highlighted area in the display below.

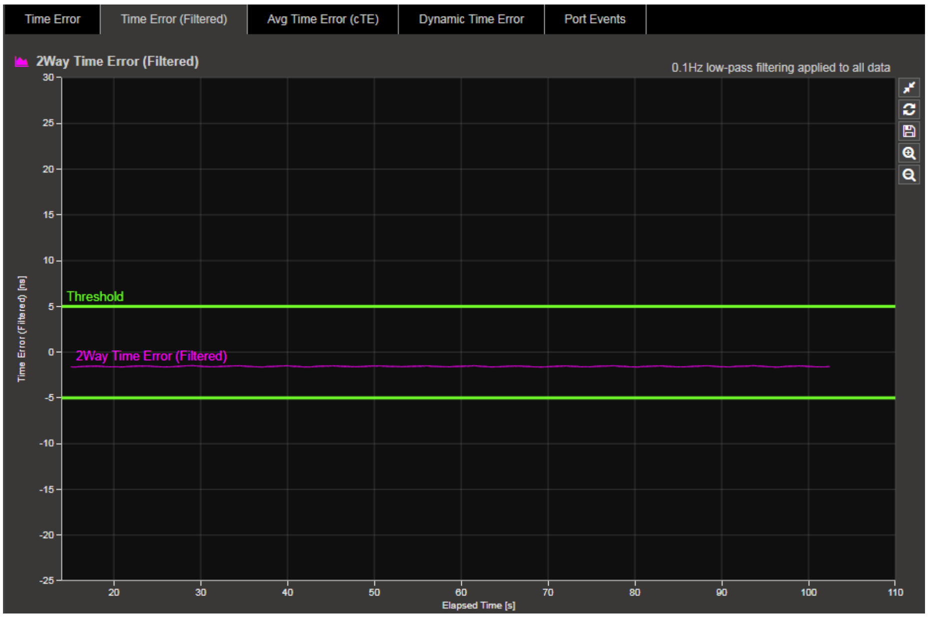
This will display:




To return to the multi graph display click on the same icon in the single-graph display.

### Time Error Results (Max|TEL|) – For Class-D device testing

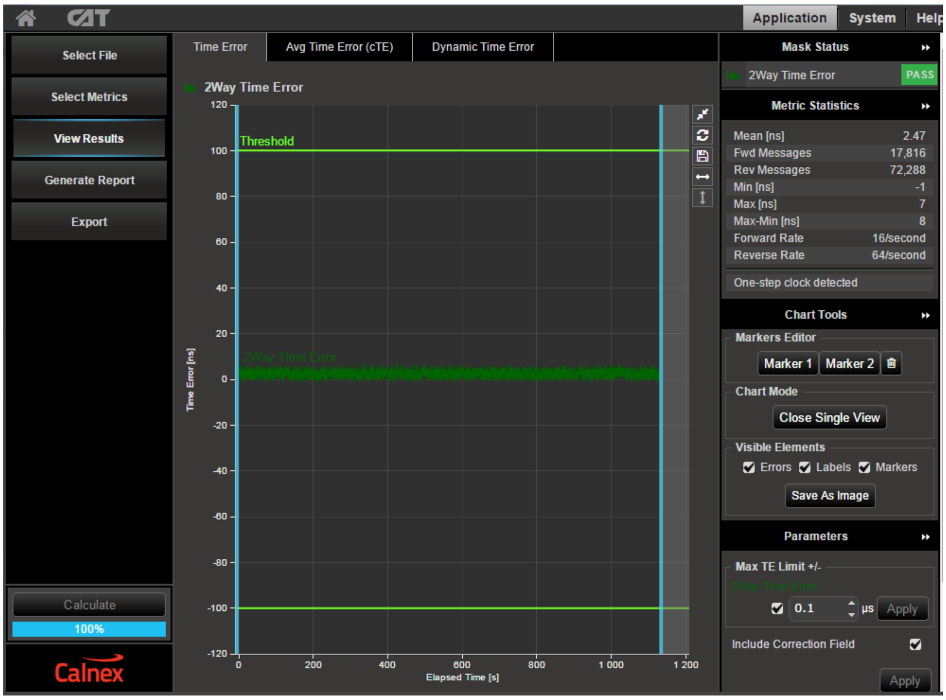
1. Select the **Time Error (Filtered)** tab to display the **0.1Hz filtered** Time Error results.
2. Select the **2-way Time Error** metric only. This will display the following graph:




3. Check your result conforms to the G.8273.2 spec: Class D devices must conform to +/- 5ns Max|TEL| This limit is set as the default in the Time Error (Filtered) metric: (0.005µs)

### Time Error Results (Max|TE|)

1. Select the **Time Error** tab to display the **unfiltered** Time Error results.
2. Select the **2-way Time Error** metric only. This will display the following graph:




3. Check your result conforms to the G.8273.2 spec [7.1.1].

   There are several classes of device:

   For Enhanced Time Specifications:

   - Class C for devices which conform to 30ns Max|TE|
   - It has been proposed, but not yet standardised, that Class D devices could have 15ns Max|TE|

   For other applications:

   - Class A for devices which conform to 100ns Max|TE|
   - Class B for devices which conform to 70ns Max|TE|

   Adjust the applied limits based on the class of device which is being tested.

4. Compare the results against the thresholds.

### Time Error Results (Constant Time Error)

1. Select the Avg Time Error (cTE) metric tab to show the 2Way Avg Time Error (cTE) graph.

   This is a measure of the timing being delivered by the egress 1588 PTP flow and is the best view of the core data. The **Constant Time Error** value will be displayed. This result can expose the underlying phase movement, which is significant to any downstream connected device.

   The G.8273.2 spec [1.4.1] refers to Constant Time Error stating:

   *"It is expected that for the type of measurements implied by the G.8273.x series of recommendations it should always be possible to identify a stable, consistent observation interval when performing a cTE measurement. In general, a value of 1000s or greater is recommended."*

To cater for this definition, the Constant Time Error displayed is a result of a moving average of 1000s being applied to the raw Time Error results. This removes packet-to-packet noise that will be filtered out by the terminating subordinate within the T-BC.


2. Check your result conforms to the G.8273.2 spec [7.1.2].

   There are several classes of device:

   For Enhanced Time Specifications:

   - Class C for devices which conform to ±10ns cTE
   - It has been suggested, but not standardised, that Class D devices could have ±4ns cTE

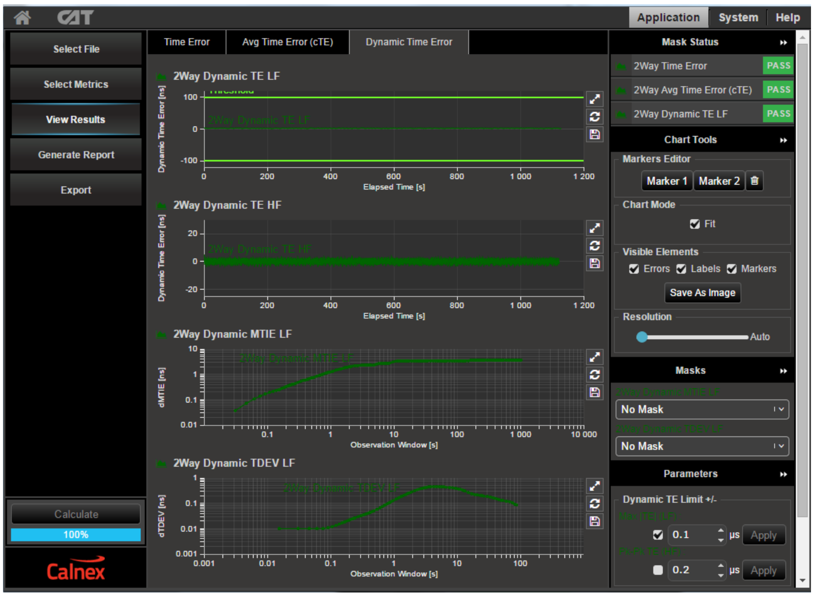
   For other applications:

   - Class A for devices which conform to ±50ns cTE
   - Class B for devices which conform to ±20ns cTE

   Adjust the applied limits based on the class of device which is being tested.

### Time Error Results (Dynamic Time Error)

1. Select the **Dynamic Time Error** tab to display the **filtered** Time Error results. This will display the Dynamic Time Error results as Low Frequency measurements and High Frequency measurements. Note that these results are filtered at 0.1Hz.



2. Compare the results against the ITU-T limits by loading the G.8237.2 dTE Gen Const Temp masks.


3. Check for PASS/FAIL versus masks. If the masks pass, the status in the **Mask Status** Block will indicate PASS. Mask failure will be indicated by FAIL.

**Further Analysis** (Optional)

For further analysis, select the **Time Error** tab for unfiltered Time Error results i.e. **2-way time error**, **T1 Time Error (forward)** and **T4 Time Error (reverse)** to further characterize the T-BC. These raw Time Error results containing both Constant and Dynamic Time Error may be useful as a troubleshooting aid.

Launching **PFV** will allow you to decode and display PTP field information in a new browser tab. If the PFV option is installed on the Paragon-neo unit, conformance checking to defined PTP profiles with pass/fail analysis is also possible. For further information please refer to the **PFV Getting Started Guide**.

**Compare PTP with 1pps (if available)**

If the T-BC has a 1pps output, check that it is within specification and similar shape to the egress PTP packet flow result i.e. the peak-to-peak Time Error on the 1pps should be similar to that of the PTP Time Error. Once in service, the performance could be monitored by the 1pps port, so it is important to prove it is an accurate reflection of performance on the line.

All metrics and limits for Time Error are available for 1pps measurements as well as PTP, including Max|$TE_L$| for Class-D devices.

**Note: Verification by the 1pps only is NOT recommended for Boundary Clock devices since it is the PTP flow that the downstream device will use.**

## 7. Relative Time Error Noise Generation – G.8273.2 Clause 7.1.4

### Test Description

The relative time error noise generation of a T-BC represents the difference in time error (noise) between two-phase and time outputs of a device when it has an ideal input reference packet timing signal and an ideal input reference frequency signal. The output types to test are PTP and 1PPS.

The noise generation has two defined components: relative constant time error ($cTE_R$) and relative dynamic low-pass filtered noise generation ($dTE_{RL}$).

The current version of G.8273.2 (10/2020) defines this for only Class C T-BCs. Requirements for other classes of T-BC are for further study.

As per Section 2, a different physical test configuration is required for testing PTP vs. PTP and 1PPS vs.1PPS relative time error. The ability for Paragon-neo to test 1PPS vs. PTP is coming in a future release.

### Measurement Requirement

The Class C T-BC performance requirements are below. Other classes are for further study.

| DUT Class | Output Type | $cTE_R$ | $cTE_R$ Averaging | $dTE_{RL}$ (MTIE) | MTIE Observation Interval ($\tau$) [s] |
|---|---|---|---|---|---|
| Class C | 1PPS | ± 12ns | 1000s | 14ns | $1 \leq \tau \leq 1000$ |
| | PTP (16 pkt/s) | ± 12ns | 1000s | 14ns | $0.0625 \leq \tau \leq 1000$ |

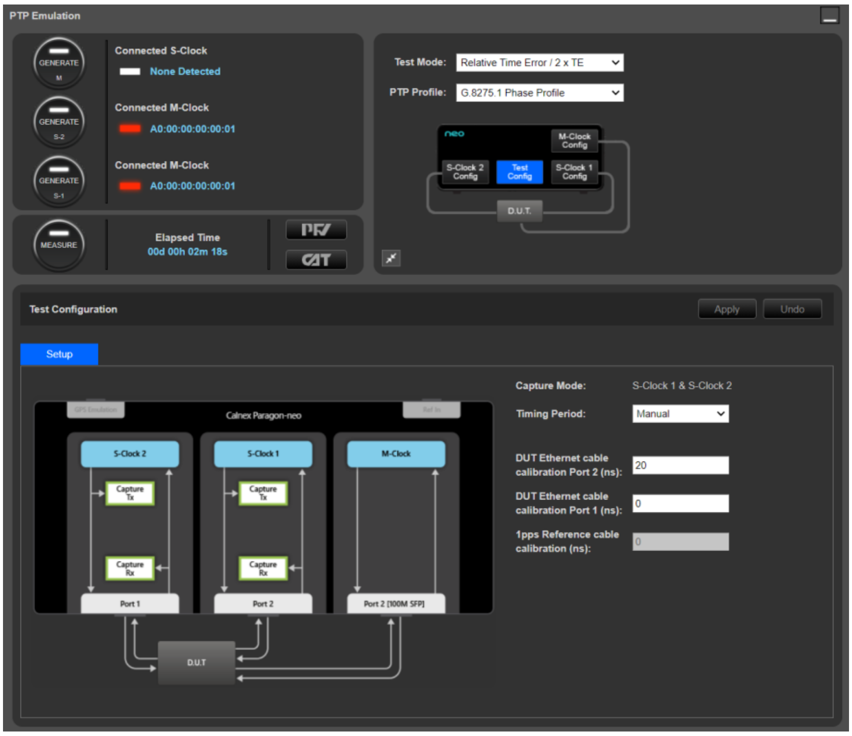
These values apply to 1PPS, 1GbE, 10GbE, 25GbE, 40GbE and 100GbE interfaces. Values for other interfaces are for further study.

### Measurement Procedure for PTP vs. PTP and for two simultaneous PTP measurements

1. Set up the configuration for T-BC Relative Time Error Conformance Test (PTP) as described in sections 0 and 4.

2. To test to the measurement methodology specified in ITU-T G.8273, configure the **Background Traffic** app as described in Section 4.5.

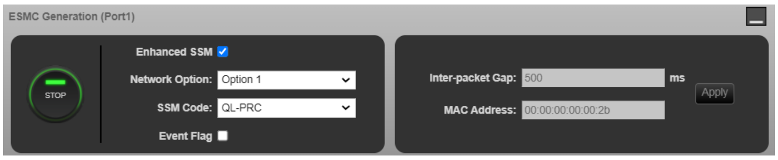
3. Within the **PTP Emulation** app, select **Relative Time Error / 2 x TE** as the **Test Mode** and **G8275.1 Phase Profile** as the **PTP Profile**, then select **Test Config** and confirm that the settings are appropriate for the current configuration. Ensure that the correct DUT Ethernet cable compensation is entered for Port 1 and Port 2.



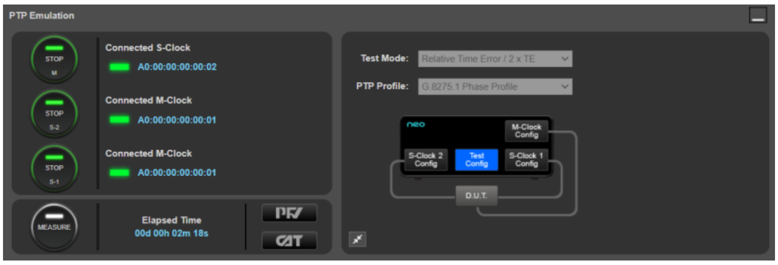
4. If required, use the **M-Clock Config** button to configure the PTP emulation settings to those appropriate for the DUT. Press **Generate** for **M** to start the PTP emulation for the M-Clock.

5. If required, use the **S-Clock 1 Config** and **S-Clock 2 Config** buttons to configure the PTP emulation settings to those appropriate for the DUT. Press **Generate** for both **S-1** and **S-2** to start the PTP Emulation on both S-clock ports**.**

6. If the DUT requires a SyncE frequency reference, from the **ESMC Generation** app on the Paragon-neo port that will be acting as the SyncE reference, configure the options to ensure the DUT uses this signal as a reference. Press **Generate**.




7. In the **PTP Emulation** app confirm that the PTP sessions run correctly and that both S-Clocks connect to a separate DUT M-Clock/PTP Port instance. Once the DUT is confirmed to be locked and stable, press **Measure** to begin the measurement, then allow to run for at least 1000s.

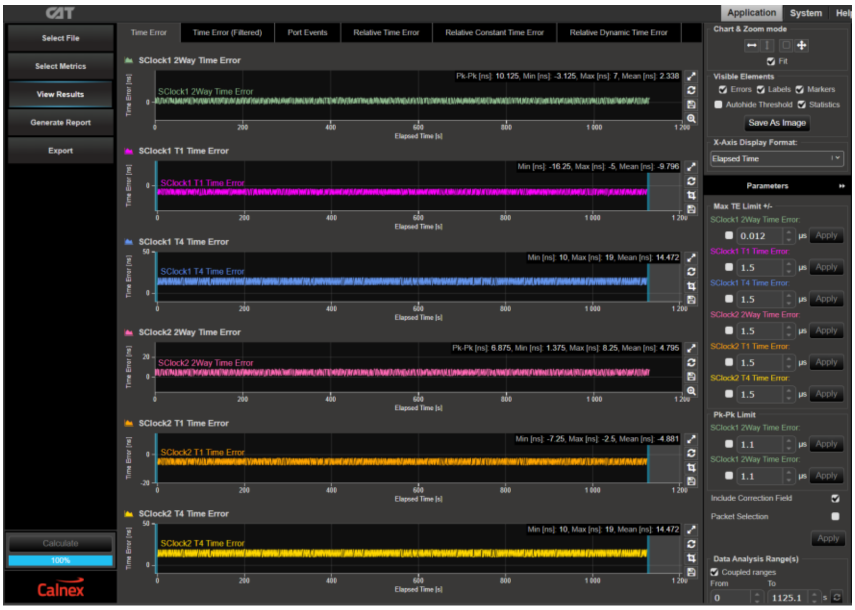



8. On both Paragon-neo units from the **PTP Emulation** app, pressing **Measure** to start the measurement**,** then selecting **CAT** will launch the Calnex Analysis Tool, allowing confirmation that the device timing output is stable and ready to test.

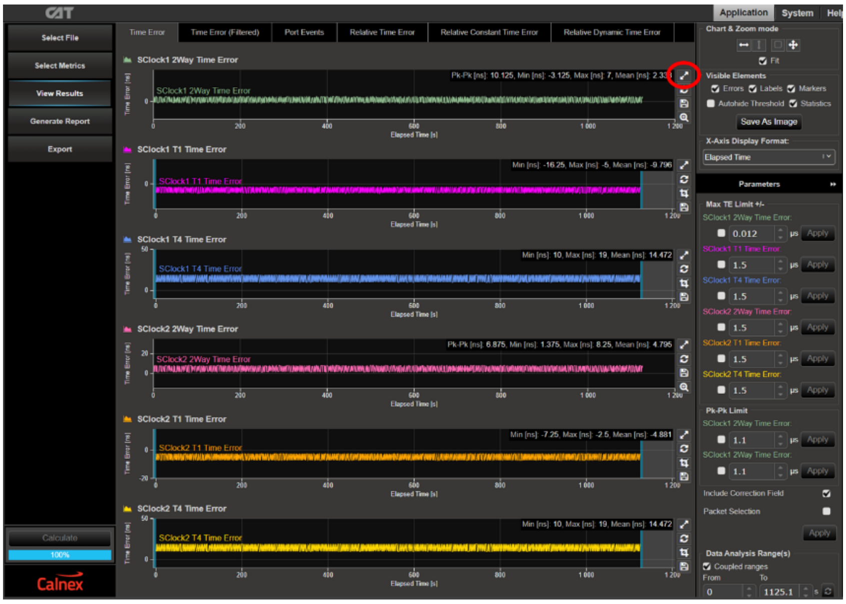
9. Once confident that the DUT is locked and stable, **Stop** then **Start** the measurement again on both Paragon-neo units and allow to run for at least 1000s.

   **Note:** The measured Time Error results for each individual test can either be viewed during a capture or after the capture has been stopped. If the difference between the **Mean[ns]** values of each running capture is greater than 12ns then it is likely that the resultant relative time error will not be within the required limit for G.8273.2 conformance.

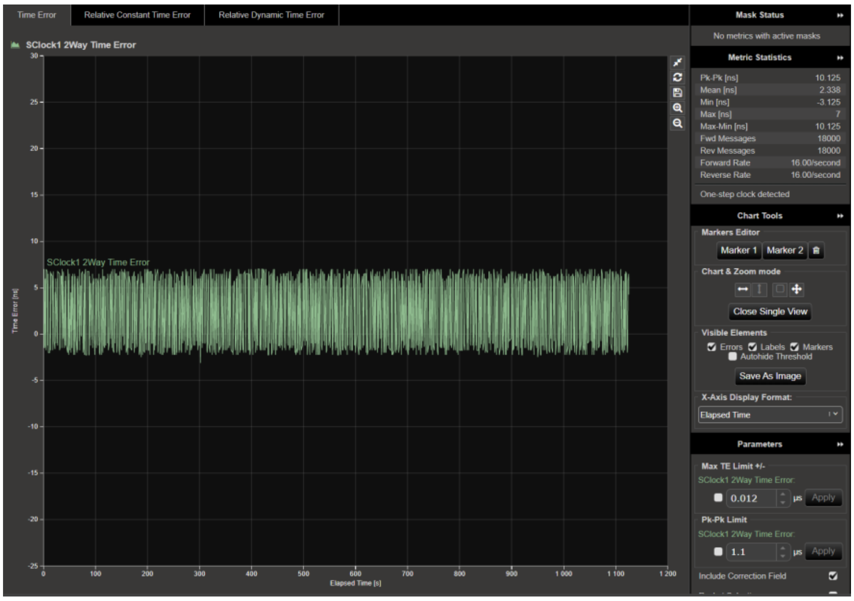
6. Click the **CAT** button to open CAT in a new tab to observe the running measurement. The **Time Error** metrics show the individual PTP metrics for each of the two Paragon-neo S-Clock instances and can be used to verify the configuration and performance of the associated DUT M-Clock/PTP Port instances. This also allows two measurements to be run in parallel and so reduces device testing time if no relative time error measurements are required.



Individual plots can be displayed by clicking on the highlighted area in the display below:




This will show the selected plot in Single View mode, which includes more detailed information on the right side of the screen:



**Relative Time Error PTP vs. PTP Results** (Relative Constant Time Error, $cTE_R$**)**

1. In **CAT** select the **Relative Constant Time Error** tab, which will display the following metric:

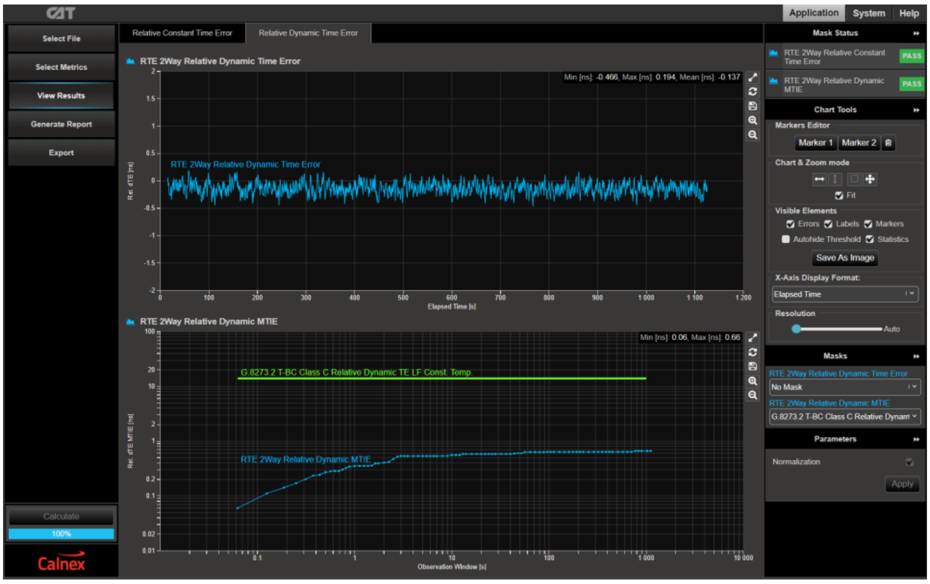

2. Set the **cTE Limit** to the following:

| DUT Class | $cTE_R$ | cTE Limit (μs) |
|---|---|---|
| **Class C** | ± 12ns | 0.012 |

3. Check for PASS/FAIL against the configured limit. If the result passes then the status in the **Mask Status** block will indicate PASS. Mask failure will be indicated by FAIL.

**Dynamic Time Error PTP vs. PTP Results** (Dynamic Relative Time Error, $dTE_{RL}$**)**

1. In **CAT** select the **Relative Constant Time Error** tab, which will display the following metric:




2. For the **RTE 2Way Relative Time Error** metric, select the **G.8273.2 T-BC Class C Relative Dynamic TE LF Const. Temp.** mask.

3. Check for PASS/FAIL against the configured limit. If the result passes then the status in the **Mask Status** block will indicate PASS. Mask failure will be indicated by FAIL.

**Measurement Procedure for 1PPS vs. 1PPS**

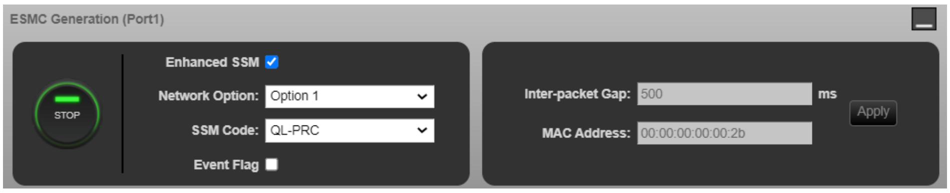
1. Set up Paragon-neo for the 1PPS Relative Time Error Test as described in described in Sections 0 and 4

2. Within the **PTP Emulation** app, from the **Test Mode** menu select **S-Clock**.  This will cause Paragon-neo to emulate an M-Clock instance which will be used as the DUT PTP reference. Ensure that the **PTP Profile** is set to **G.8275.1 Phase Profile**.

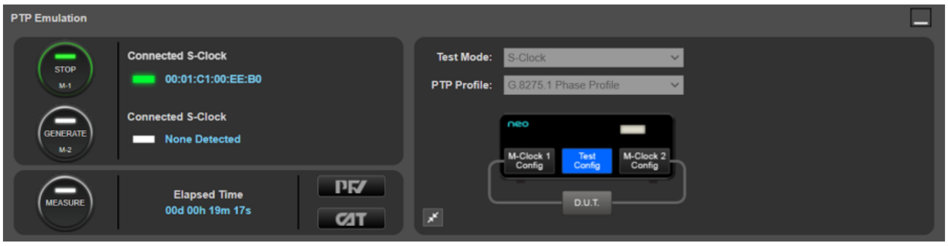
3. Select **Test Config** and confirm that the settings are appropriate for the current configuration.

4. If required, use the **M-Clock 1 Config** button to configure the PTP emulation settings to those appropriate for the DUT. Press **Generate** for **M-1** to start PTP emulation.

5. If the DUT requires a SyncE frequency reference, from the **ESMC Generation (Port 1)** app, select an appropriate SSM Code value to ensure the DUT uses this signal as a reference, then press **Generate**.




6. From the **PTP Emulation** app**,** press **Generate** and confirm that the PTP session runs correctly with the DUT S-Clock being detected.




7. Scroll down to the **1pps Time Error Measurement + ToD** app and start the measurement then select **CAT** to launch the Calnex Analysis Tool, allowing confirmation that the device 1PPS outputs are stable and ready to test.

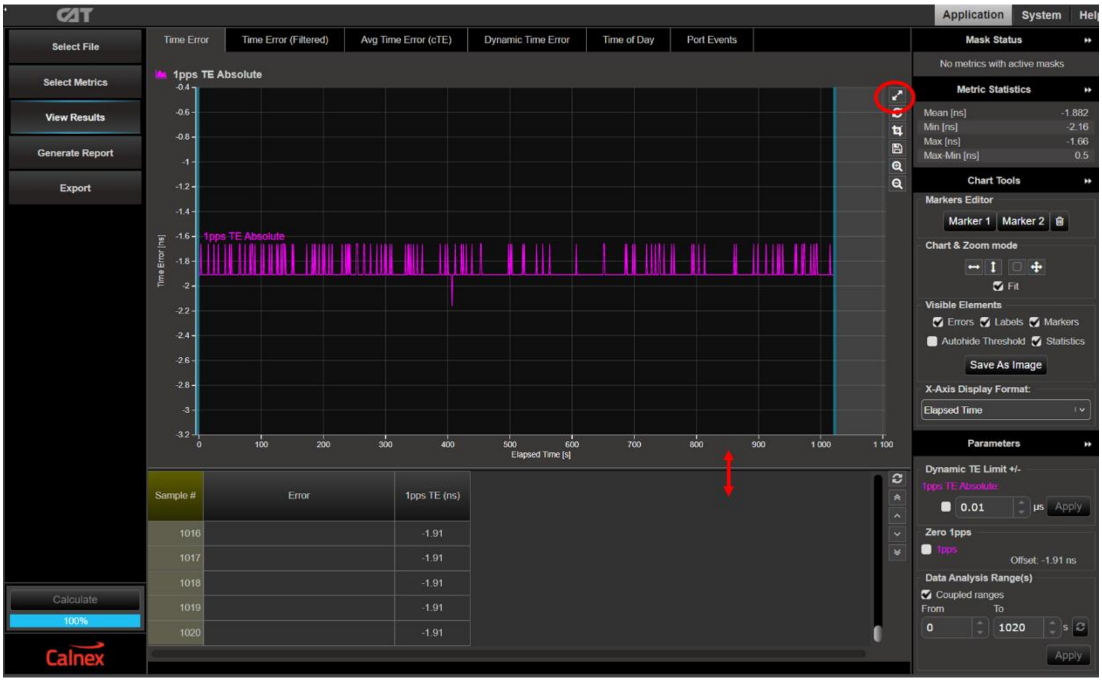
   **Note:** As the 1PPS reference and measurement signals are both coming from the DUT, any instability may be present on either signal, or both.


8. Once confident that the DUT is locked and stable, **Stop** then **Start** the 1PPS measurement. To view the results in real-time, click the **CAT** button and observe the metrics in another **CAT** tab. Allow the measurement to run for at least 1000s.

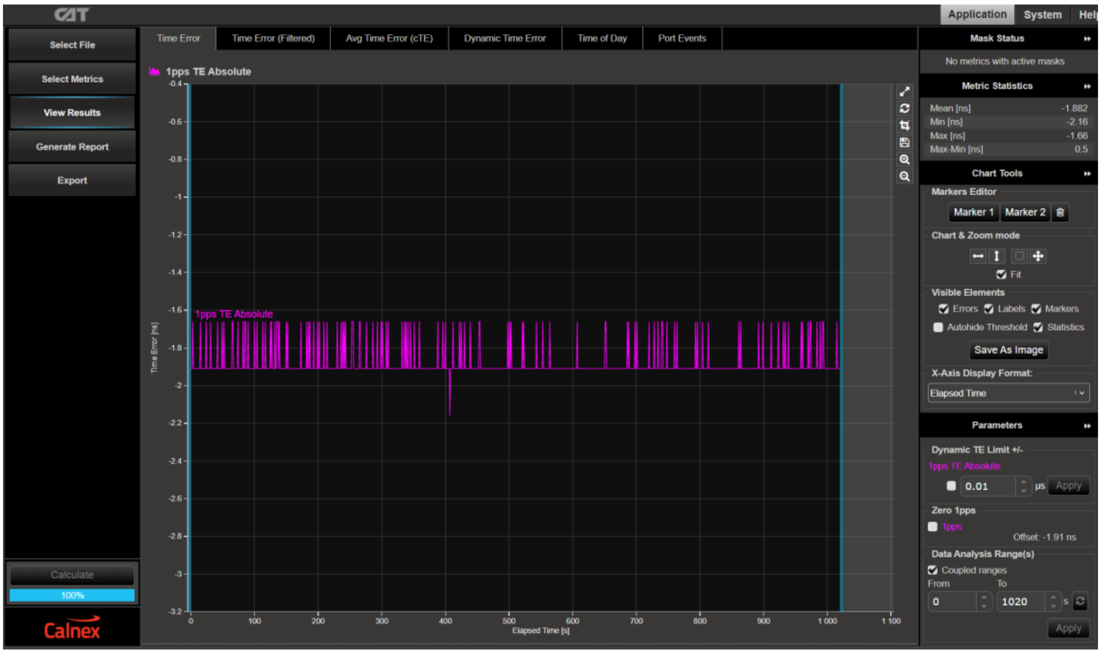
9. Open an instance of **CAT** to display **Time Error** metrics.

   These will include the metrics **Time Error** and **Avg. Time Error (cTE)**.

   If a tab has multiple plots then individual plots can be displayed by clicking on the icon in the red circle. The arrows show the separator for the **1PPS Samples Table**.




For 1pps Time Error measurements the plot view can be expanded by click and dragging the separator:



**Relative Time Error 1PPS vs. 1PPS Results** (Relative Constant Time Error, $cTE_R$)

**Note:** CAT doesn't include an explicit $cTE_R$ metric for 1PPS measurement. The relative (R) component is implemented by the test setup using the Reference and Measurement inputs, which implicitly enables the relative measurement between these two inputs. Therefore, the $cTE_R$ result is viewed using the cTE metric in CAT.

1. From the **Select Metrics** screen, ensure that **2Way Avg Time Error (cTE)** is enabled.

2. Select the **Avg Time Error (cTE)** metric tab to show the **2Way Avg Time Error (cTE)** graph.


3. As this value represents the $cTE_R$ metric, set the **cTE Limit** as per the G.8273.2 requirement:

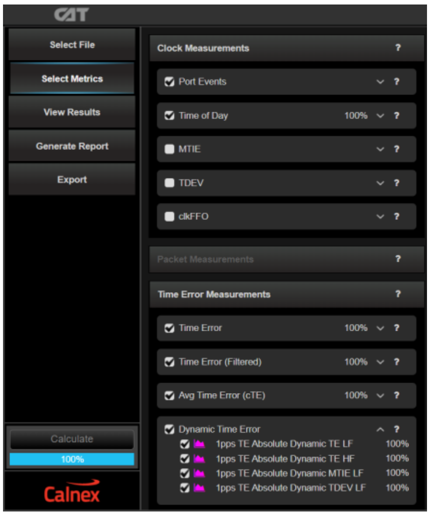
| DUT Class | $cTE_R$ | cTE Limit (µs) |
|---|---|---|
| Class C | ± 12ns | 0.012 |

4. Check for PASS/FAIL against the configured limits. If the results pass then the status in the **Mask Status** Block will indicate PASS. Mask failure will be indicated by FAIL.

**Relative Time Error 1PPS vs. 1PPS Results** (Dynamic Time Error, low-pass filtered, $dTE_{RL}$ MTIE)

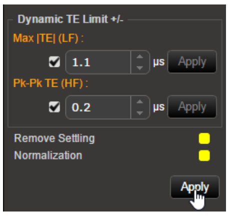
**Note:** CAT doesn't include an explicit $dTE_{RL}$ metric; the relative ($_R$) component is implemented by the test setup using the Reference and Measurement inputs, which implicitly enables the relative measurement between these two inputs. Therefore, the $dTE_{RL}$ result is viewed using the dTE LF metric in CAT.

1. From the **Select Metrics** screen, ensure that **Dynamic Time Error** is enabled, and press **Calculate**




2. Press **View Results** and then **Dynamic Time Error** tab to display the filtered Dynamic Time Error results. These results have been filtered using a first-order low-pass measurement filter with a bandwidth of 0.1Hz.

3. Uncheck the "Remove Settling Time" and "Normalization" boxes and press "Apply",




4. Apply the **G.8273.2 T-BC Class C Relative Dynamic TE LF Const. Temp.** mask to the **2way Dynamic MTIE (LF)** metric.


5. Check for PASS/FAIL against the mask. If the results pass then the status in the **Mask Status** Block will indicate PASS. Mask failure will be indicated by FAIL.

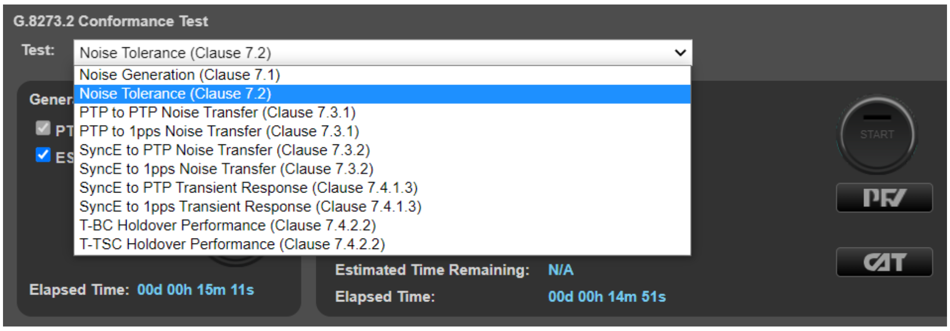
## 8. Time Noise Tolerance – G.8273.2 Clause 7.2

### Test Description

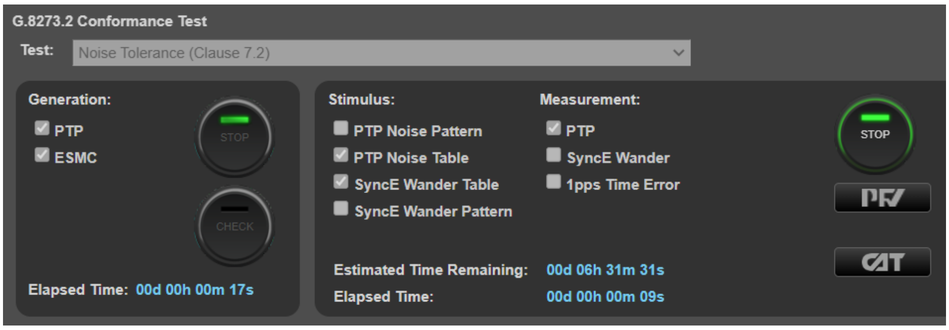
This test checks whether the clock can maintain network limits at the output with maximum noise at the input.

### Measurement Process

1. Confirm that preconfigured settings within PTP emulation are appropriate for the current test scenario, as described in Section 4.4.
2. To test to the measurement methodology specified in ITU-T G.8273, configure the **Background Traffic** app as described in Section 4.5.
3. From the **Test:** drop-down menu, select **Noise Tolerance (Clause 7.2)**.




4. From the **Generation** section of the conformance test app, press **Generate**. This starts PTP and ESMC message generation, allowing the DUT to stabilize. Pressing **Check** will open the CAT in a new tab to allow you to check current timing performance. In this case, you should wait for a **2WayTE measurement** graph moving from a ramp to stable condition to indicate lock has been achieved.
5. Once the DUT is stable, in the **Stimulus/Measurement** section, press **Start** to run the Noise Tolerance test. PTP and SyncE Stimulus as per the relevant clause of G.8273.2 will be applied, and capture will be started.




6. Once the test stimuli have finished and at least 1000s has passed, select **Stop Capture** to end the measurement.

### Expected Outcome

The Vendor DUT should maintain reference and not be subjected to switching reference or enter holdover state. This must be determined from the device itself (e.g. via the management interface).

### Further Analysis (Optional)

As a simultaneous PTP measurement is run by Paragon-neo during this test, indication of DUT lock can be determined by viewing Time Error performance in CAT – in addition, the timing behaviour of the DUT under the tolerance conditions can be further analyzed.

Furthermore, launching **PFV** will allow you to decode and display PTP field information in a new browser tab. If the PFV option is installed on the Paragon-neo unit, conformance checking to defined PTP profiles with pass/fail analysis is also possible. For further information please see **PFV Getting Started Guide**.

# 9. Time Noise Transfer – G.8273.2 Clause 7.3

### Test Description

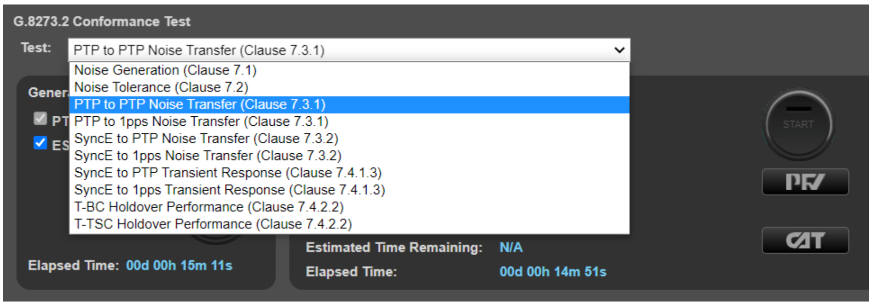
This test measures how Time Error on the input is transferred to the output.

### Measurement Process

1. Confirm that preconfigured settings within PTP emulation are appropriate for the current test scenario, as described in Section 4.4.
2. To test to the measurement methodology specified in ITU-T G.8273, configure the **Background Traffic** app as described in Section 4.5.

### 9.1 PTP to PTP Transfer

1. From the **Test:** drop-down menu, select **PTP to PTP Noise Transfer (Clause 7.3.1).**
2. From the **Generation** section of the conformance test app, press **Generate.** This starts PTP and ESMC message generation, allowing the device under test to stabilize. Pressing **Check** will open the **CAT** in a new tab to allow you to check current timing performance. In this case, you should wait for a **2WayTE measurement** graph moving from a ramp to stable condition to indicate lock has been achieved.



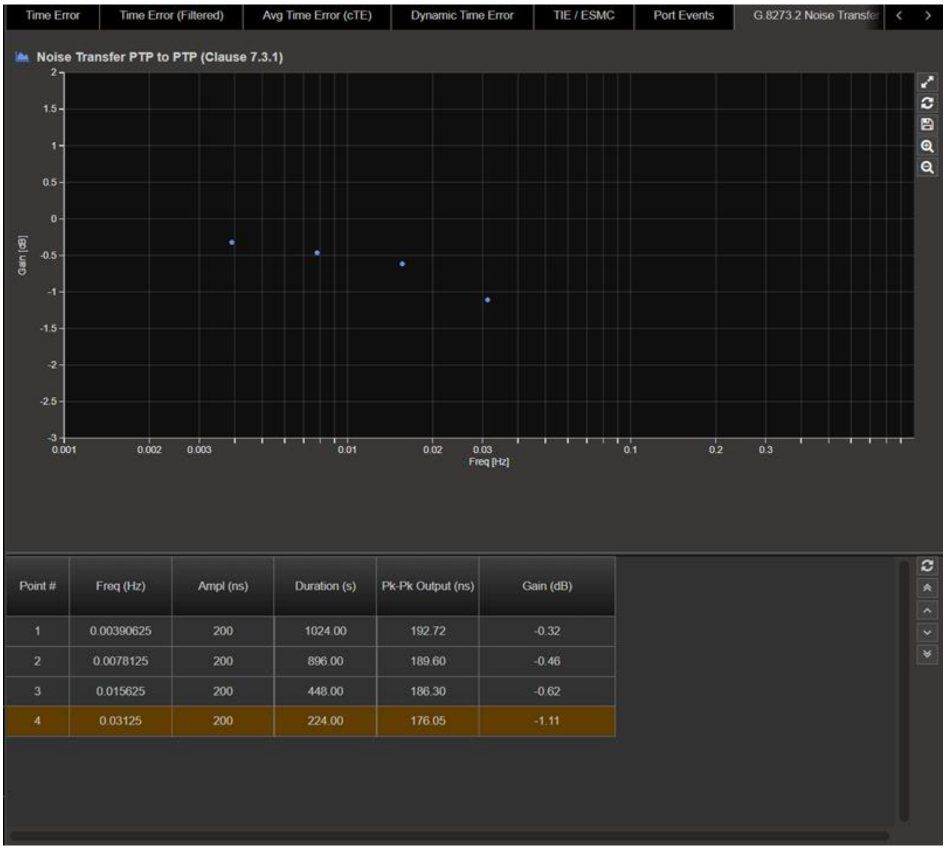

3. Once the DUT is stable, in the **Stimulus/Measurement** section, press **Start** to run the prescribed PTP Noise Stimulus and simultaneous measurement.

   PTP Noise (Time Error) is applied as per G.8273.2 Amendment 1 (Appendix VI).

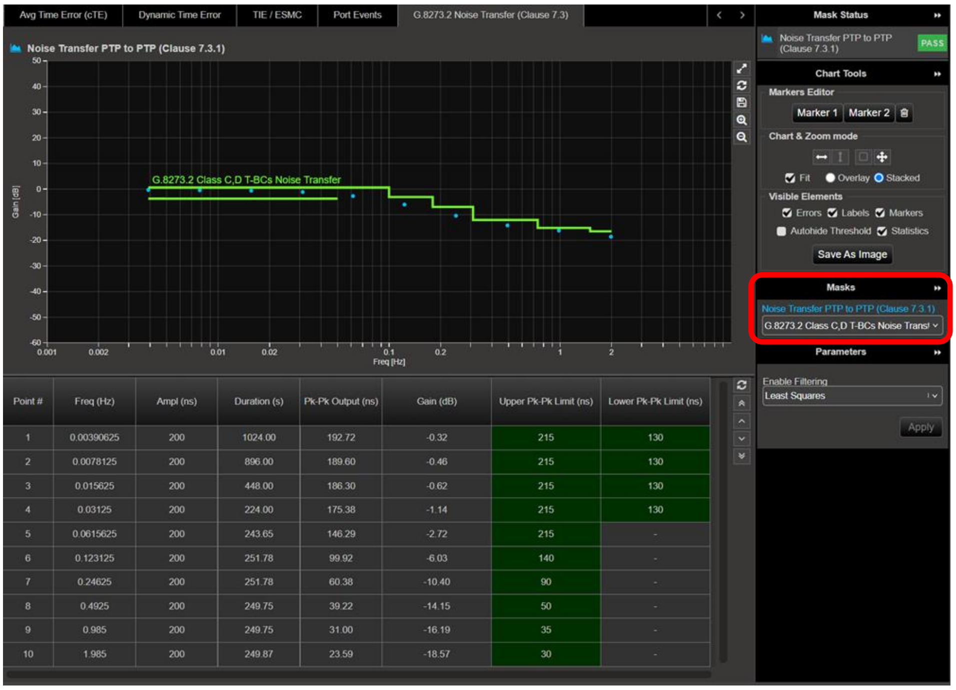
   A least-squares filter technique as suggested in Amendment 1 is applied to the PTP signal to be measured (to address potential measurement uncertainty due to noise on the packet interface and the intrinsic noise generation of the T-BC).

   For more information on the test considerations and the approach to test in the ITU-T recommendation, please see the Calnex application note **Time Error Transfer for BCs**.

4. During or after the test, CAT can be launched to view the results – complete PTP-PTP transfer results are available in the **G.8273.2 Noise Transfer (Clause 7.3)** tab. A Bode plot is displayed, along with a table of applied stimulus vs. gain. If a test step is still underway, this will be highlighted in orange on the table.



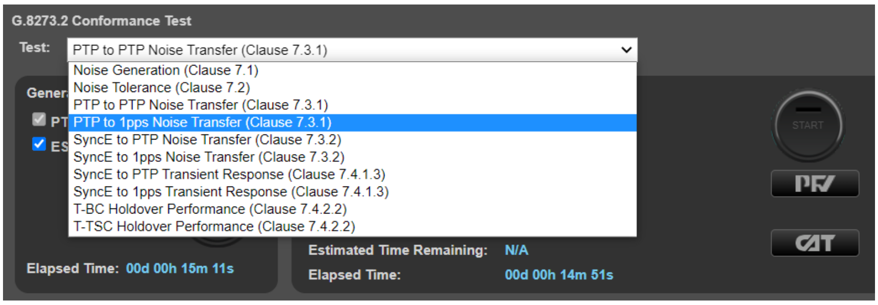

5. By selecting the mask applicable to the DUT class in **Masks** from the right-hand side of the CAT tool, max/min pk-pk values as per the standard will be displayed in the table, along with limit lines on the graph.




Note that the Pk-Pk limits as defined in G.8273.2 are defined as a value *+N* to account for added noise generation of the DUT. The value of ***N* = 10ns** has been selected for the pass/fail limits as this provides the balance between the ability to measure accurately and give confidence that the DUT is meeting its requirements. More information can be found on the Calnex online FAQ:
https://calnexsolutions.atlassian.net/wiki/spaces/KB/pages/2031620/G.8273.2+7.3.1+7.3.2+Noise+Transfer

## 9.2. PTP to 1pps Transfer

1. From the **Test:** drop-down menu, select **PTP to 1pps Noise Transfer (Clause 7.3.1).**
2. From the **Generation** section of the conformance test app, press **Generate.** This starts PTP and ESMC message generation, allowing the device under test to stabilize. Pressing **Check** will open the **CAT** in a new tab, to allow you to check current timing performance. In this case, you should wait for a **1pps TE Absolute measurement** graph moving from a ramp to stable condition to indicate lock has been achieved.

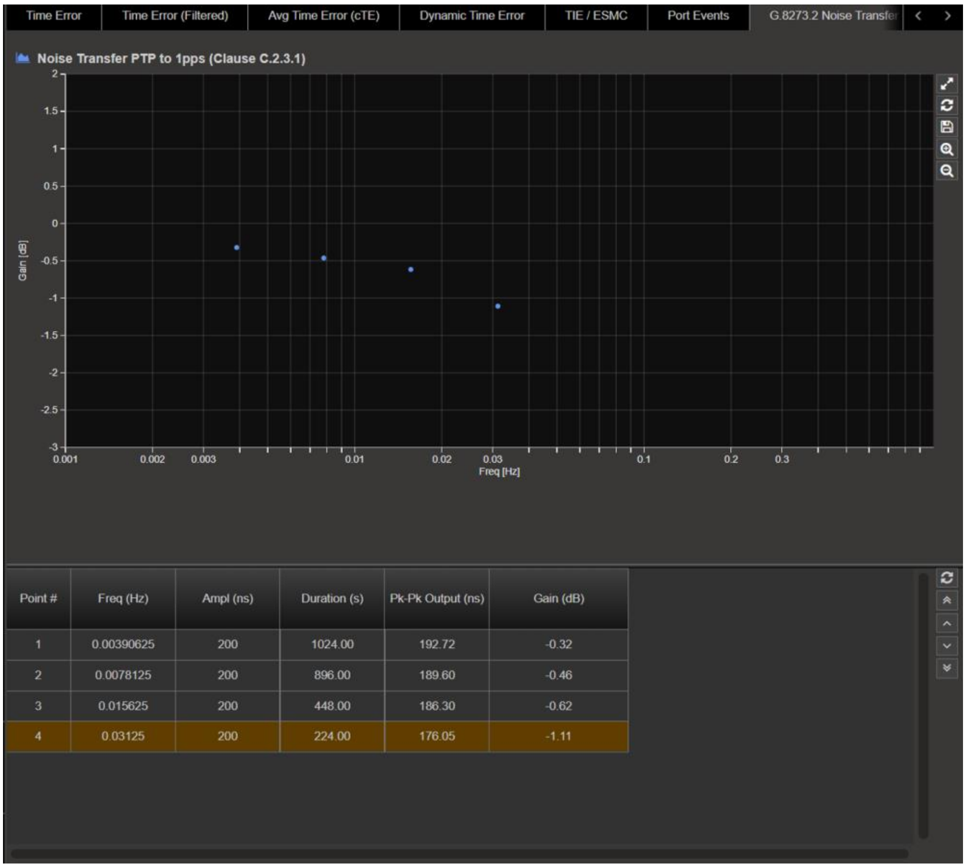



3. Once the DUT is stable, in the **Stimulus/Measurement** section, press **Start** to run the prescribed PTP Noise Stimulus and simultaneous 1pps measurement.

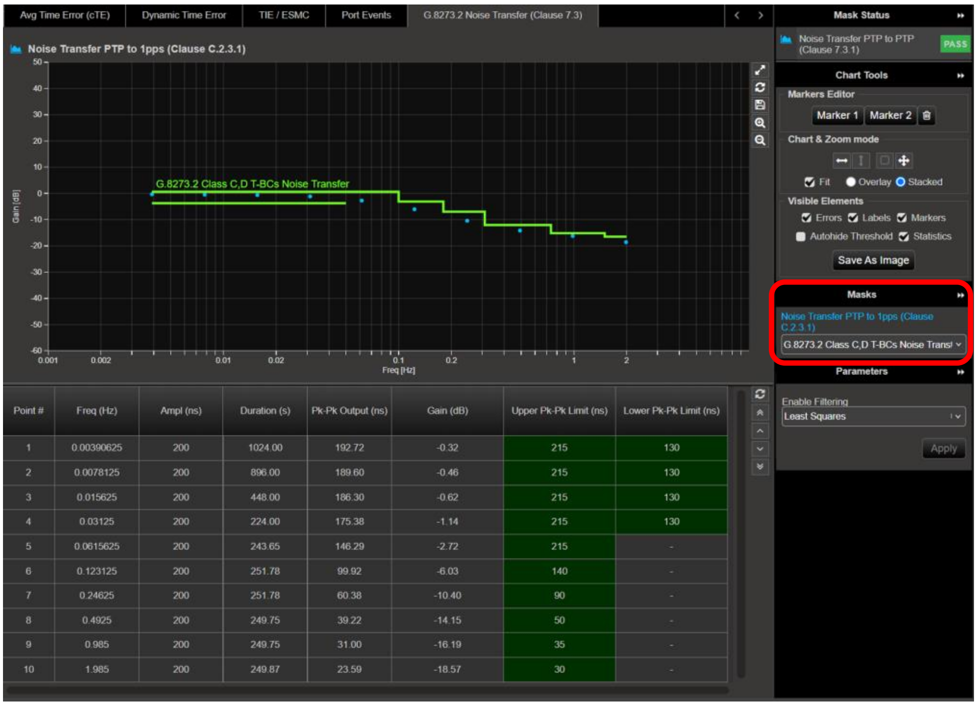
   PTP Noise (Time Error) is applied as per G.8273.2 Amendment 1 (Appendix VI).

   For more information on the test considerations and the approach to test in the ITU-T recommendation, please see the Calnex application note **Time Error Transfer for BCs**.

4. During or after the test, CAT can be launched to view the results – complete PTP-1pps transfer results are available in the **G.8273.2 Noise Transfer (Clause 7.3)** tab. A Bode plot is displayed, along with a table of applied stimulus vs. gain. If a test step is still underway, this will be highlighted in orange on the table.



5. By selecting the mask applicable to the DUT class in **Masks** from the right-hand side of the CAT tool, max/min pk-pk values as per the standard will be displayed in the table, along with limit lines on the graph.

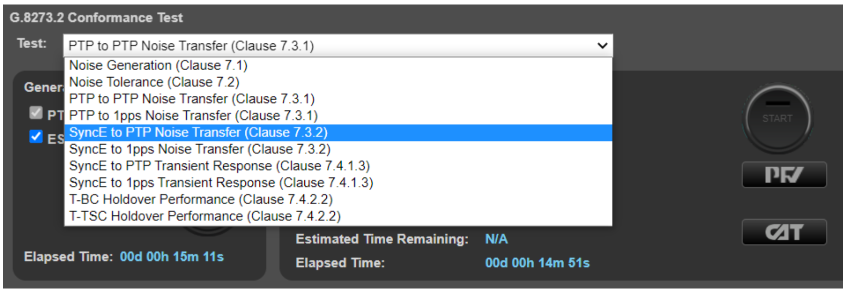



Note that the Pk-Pk limits as defined in G.8273.2 are defined as a value *+N* to account for added noise generation of the DUT. The value of ***N*** **= 10ns** has been selected for the pass/fail limits as this provides the balance between the ability to measure accurately and give confidence that the DUT is meeting its requirements. More information can be found on the Calnex online FAQ:
https://calnexsolutions.atlassian.net/wiki/spaces/KB/pages/2031620/G.8273.2+7.3.1+7.3.2+Noise+Transfer

### 9.3 SyncE to PTP Transfer

1. From the **Test:** drop-down menu, select **SyncE to PTP Noise Transfer (Clause 7.3.2).**

2. From the **Generation** section of the conformance test app, press **Generate.** This starts PTP and ESMC message generation, allowing the device under test to stabilize. Pressing **Check** will open the **CAT** in a new tab to allow you to check current timing performance. In this case, you should wait for a **2WayTE measurement** graph moving from a ramp to stable condition to indicate lock has been achieved.




3. Once the DUT is stable, in the **Stimulus/Measurement** section, press **Start** to run the prescribed SyncE Noise Stimulus and simultaneous PTP measurement.

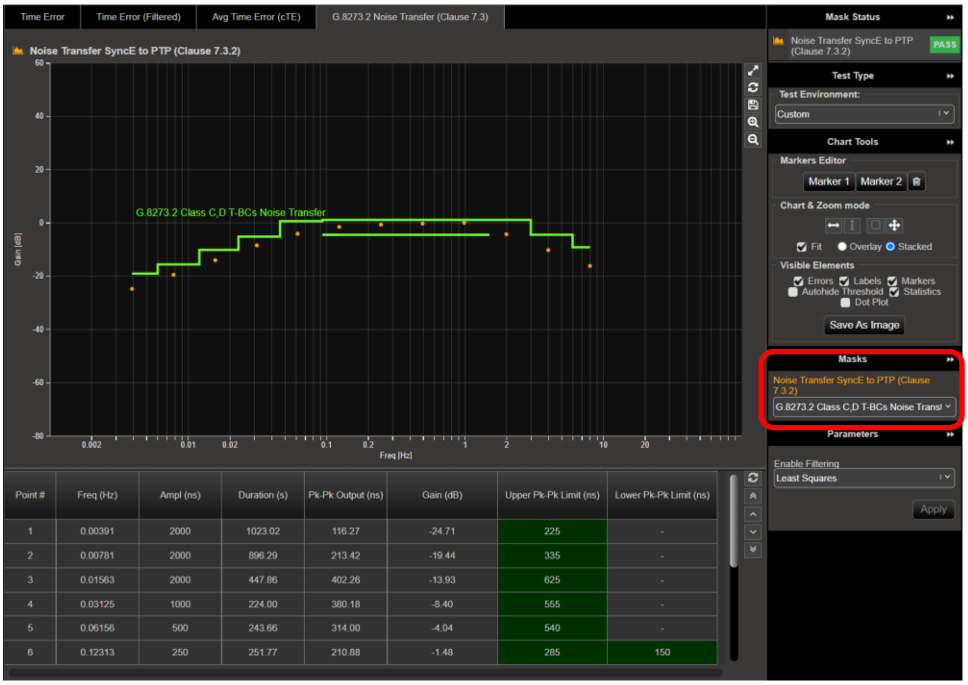
   PTP Noise (Time Error) is applied as per G.8273.2 Amendment 1 (Appendix VI).

   A least-squares filter technique as suggested in Amendment 1 is applied to the PTP signal to be measured (to address potential measurement uncertainty due to noise on the packet interface and the intrinsic noise generation of the T-BC).

   For more information on the test considerations and the approach to test in the ITU-T recommendation, please see the Calnex application note **Time Error Transfer for BCs**.

4. During or after the test, CAT can be launched to view the results – complete SyncE-1pps transfer results are available in the **G.8273.2 Noise Transfer (Clause 7.3)** tab. A Bode plot is displayed, along with a table of applied stimulus vs. gain. If a test step is still underway, this will be highlighted in orange on the table.

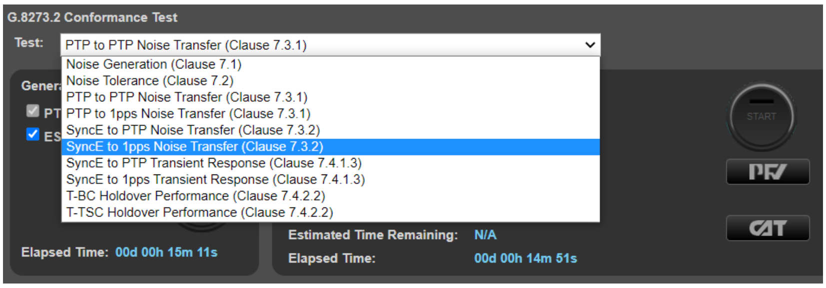

5. By selecting the mask applicable to the DUT class in **Masks** from the right-hand side of the CAT tool, max/min pk-pk values as per the standard will be displayed in the table, along with limit lines on the graph.



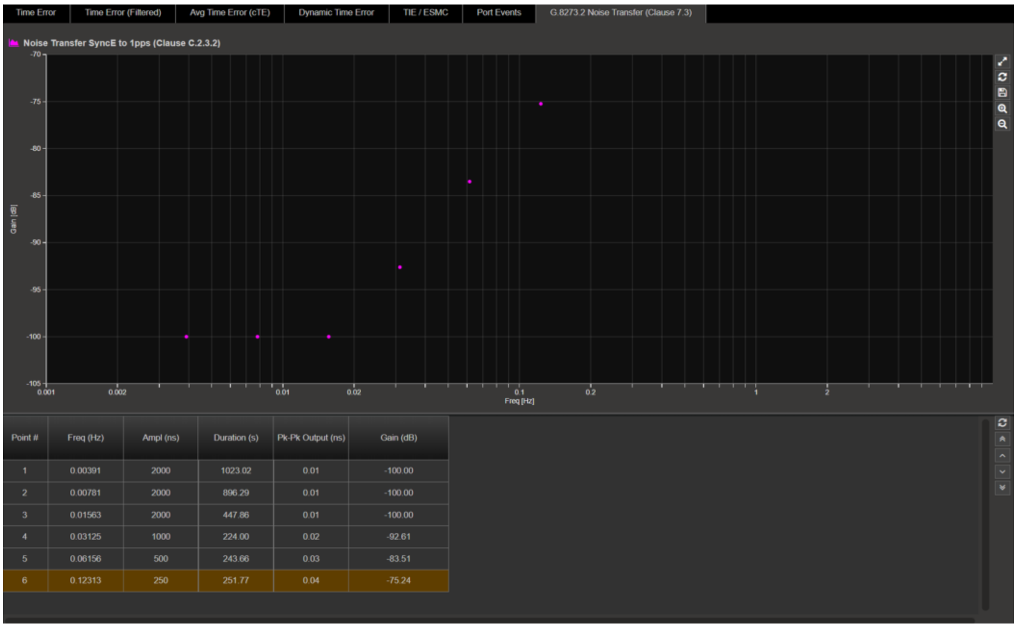

Note that the Pk-Pk limits as defined in G.8273.2 are defined as a value *+N* to account for added noise generation of the DUT. The value of ***N*** **= 25ns** has been selected for the pass/fail limits as this provides the balance between the ability to measure accurately and give confidence that the DUT is meeting its requirements. More information can be found on the Calnex online FAQ: https://calnexsolutions.atlassian.net/wiki/spaces/KB/pages/2031620/G.8273.2+7.3.1+7.3.2+Noise+Transfer

### 9.4 SyncE to 1pps Transfer

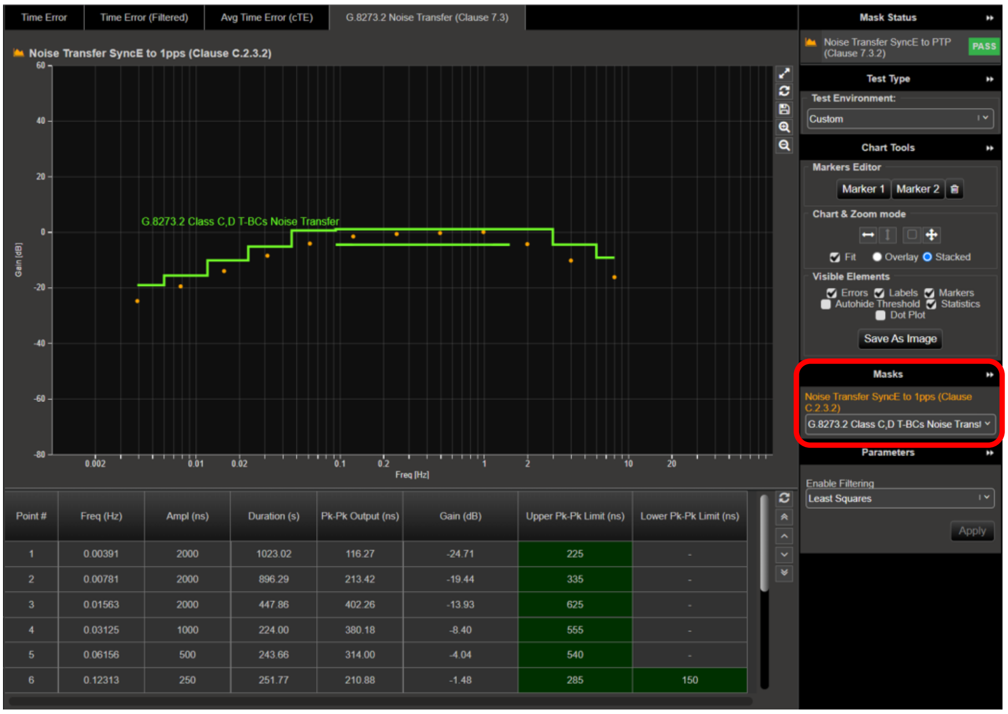
1. From the **Test:** drop-down menu, select **SyncE to 1pps Noise Transfer (Clause 7.3.2).**
2. From the **Generation** section of the conformance test app, press **Generate.** This starts PTP and ESMC message generation, allowing the device under test to stabilize. Pressing **Check** will open the **CAT** in a new tab to allow you to check current timing performance. In this case, you should wait for a **1pps TE Absolute measurement** graph moving from a ramp to stable condition to indicate lock has been achieved.




3. Once the DUT is stable, in the **Stimulus/Measurement** section, press **Start** to run the prescribed SyncE Noise Stimulus and simultaneous 1pps measurement.
4. During or after the test, CAT can be launched to view the results – complete SyncE-1pps transfer results are available in the **G.8273.2 Noise Transfer (Clause 7.3)** tab. A Bode plot is displayed, along with a table of applied stimulus vs. gain. If a test step is still underway, this will be highlighted in orange on the table.



5. By selecting the mask applicable to the DUT class in **Masks** from the right-hand side of the CAT tool, max/min pk-pk values as per the standard will be displayed in the table, along with limit lines on the graph.




Note that the Pk-Pk limits as defined in G.8273.2 are defined as a value *+N* to account for added noise generation of the DUT. The value of ***N* = 25ns** has been selected for the pass/fail limits as this provides the balance between the ability to measure accurately and give confidence that the DUT is meeting its requirements. More information can be found on the Calnex online FAQ:
https://calnexsolutions.atlassian.net/wiki/spaces/KB/pages/2031620/G.8273.2+7.3.1+7.3.2+Noise+Transfer

## 10. Packet Layer Transient Response and Holdover Performance – G.8273.2 Section 7.4

**Test Description**

Short-term transient response refers to the time error generated when a clock switches over from one input reference to another e.g. in the event of a reference failure.

A reference switch in the physical layer frequency reference at the previous node to the T-BC can generate a large transient in the T-BC input, therefore a T-BC must reject this transient. It can achieve this by monitoring the ESMC messages on the SyncE interface.

On receipt of a degraded QL, the T-BC must either stop using the SyncE signal, or turn off the low-pass filter, allowing the PTP to correct the time error more quickly. When traceability of the SyncE signal is restored, the T-BC can go back to using the SyncE signal.

Annex B of G.8273.2 Amd. 2 defines the following mask for the clock output in the event of a transient on the SyncE input:

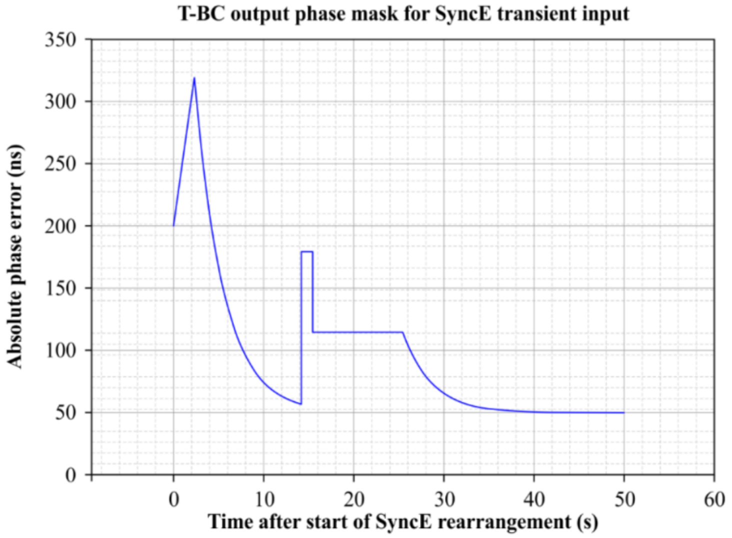



**Figure B.1 from G.8273.2 Annex B – Phase error mask during a SyncE transient**

The method to verify compliance with the mask shown above is described in **G.8273 Appendix III**. The phase transient to be applied to the input SyncE signal is shown below. During the transient, the input QL-value in the ESMC messages is changed from QL-PRC to QL-EEC in the first shaded area (from 1.8s to 2.0s), and back to QL-PRC in the second shaded area (from 15.18s to 15.5s).

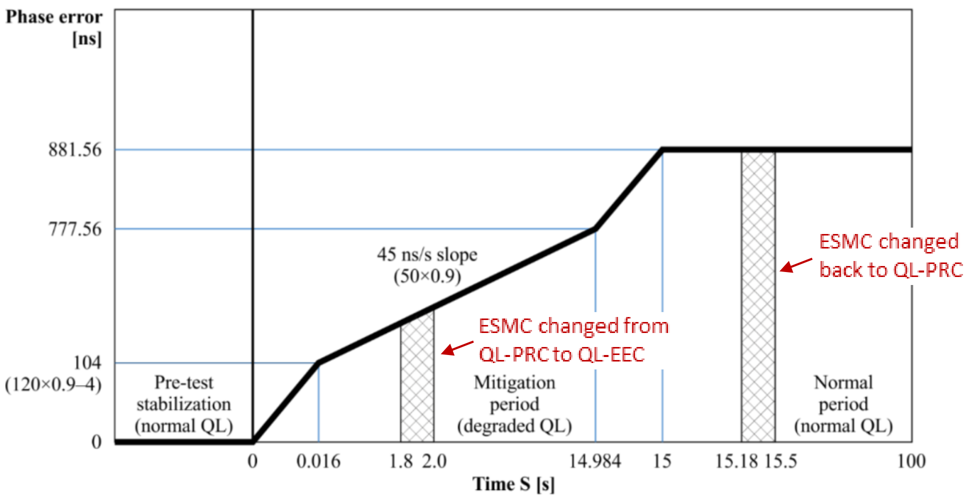



**Fig. III.2 from G.8273 Appendix III – SyncE Transient Input Pattern**

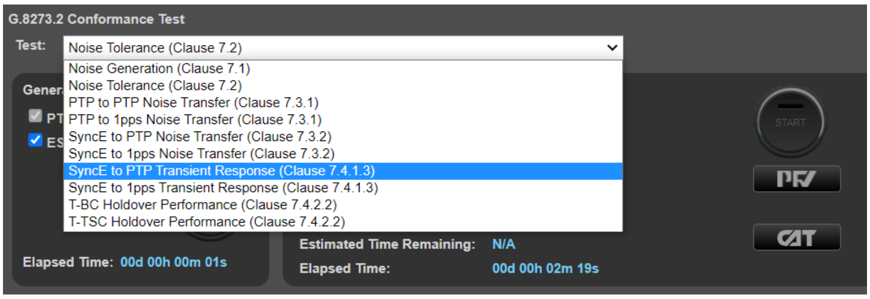
**Measurement Process**

Confirm that preconfigured settings within Master/Subordinate emulation are appropriate for the current test scenario, as described in Section 4.4.

### 10.1 SyncE to PTP Transient Response (Clause 7.4.1.2)

1. From the **Test:** drop-down menu, select **SyncE to PTP Transient Response (Clause 7.4.1.2).**

2. From the **Generation** section of the conformance test app, press **Generate.** This starts PTP and ESMC message generation, allowing the device under test to stabilize. Pressing **Check** will open the **CAT** in a new tab to allow you to check current timing performance. In this case, you should wait for a **2WayTE measurement** graph moving from a ramp to stable condition to indicate lock has been achieved.

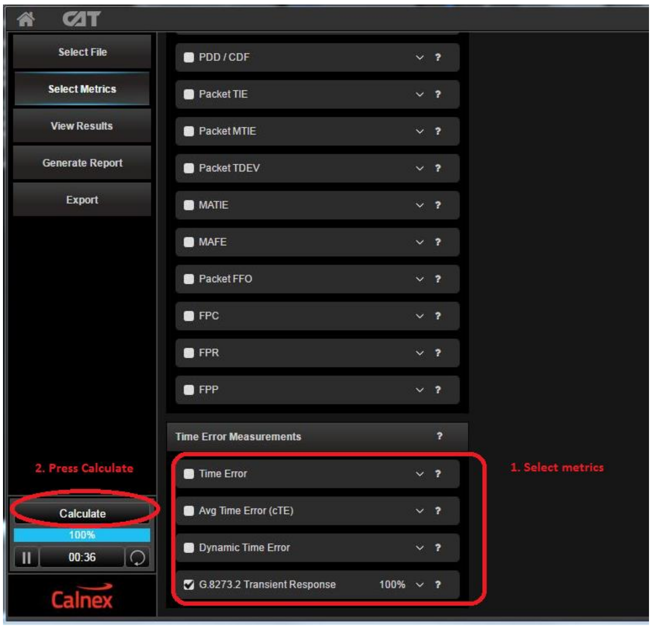



3. Once the DUT is stable, in the **Stimulus/Measurement** section, press **Start** to run the prescribed SyncE wander and ESMC state change stimulus and simultaneous PTP measurement.

   **Test execution takes 200s.** The first 100s are used to analyze the underlying Constant Time Error (cTE) without the application of the transient. As per the standard, the mask for Phase Noise response to the generated transient requires the results to be adjusted for cTE – this step therefore allows the CAT to calculate and make that adjustment.

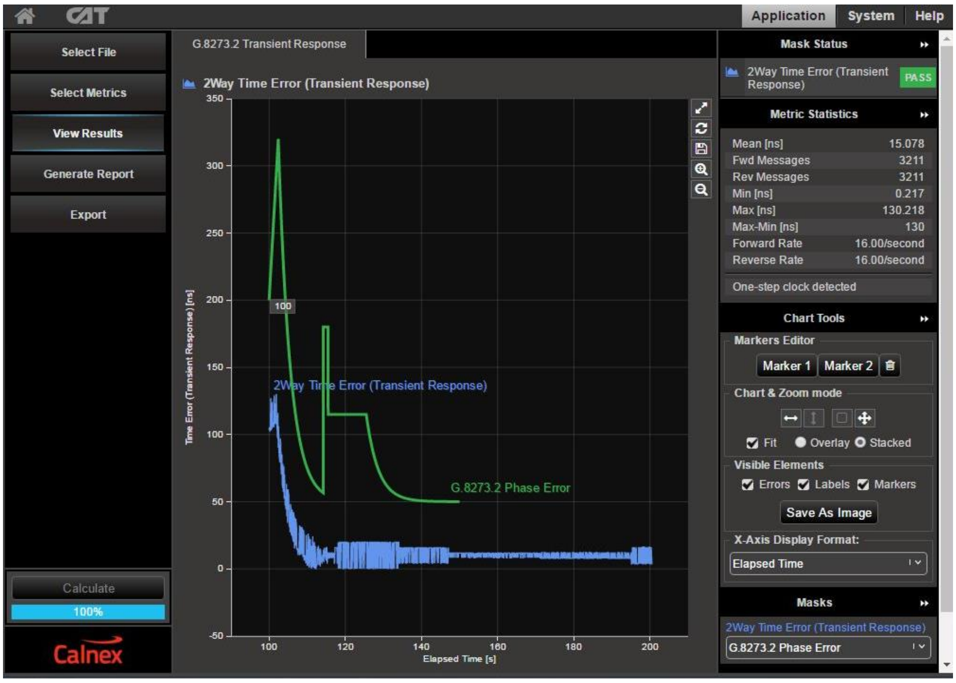
   On completion of the test, the test results can be analyzed using the CAT.

4. In the CAT, select **Select Metrics** and enable the **G.8273.2 Transient Response** metric followed by the **Calculate** button.



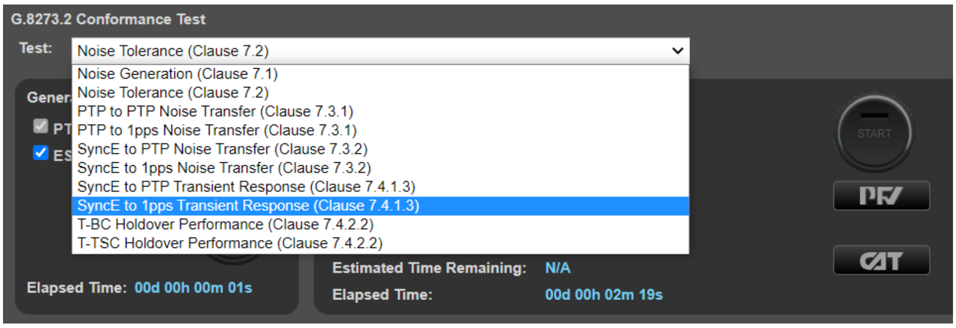

**NOTE:** Due to the application of the transient event the other Time Error results will be impacted and thus cannot be relied upon to provide representative results – other aspects of Time Error performance should be analyzed in separate test runs.

5. Once the calculation has reached 100%, the results and associated Pass/Fail information can be viewed using the **View Results** button.




### 10.2 SyncE to 1pps Transient Response (Clause 7.4.1.2)

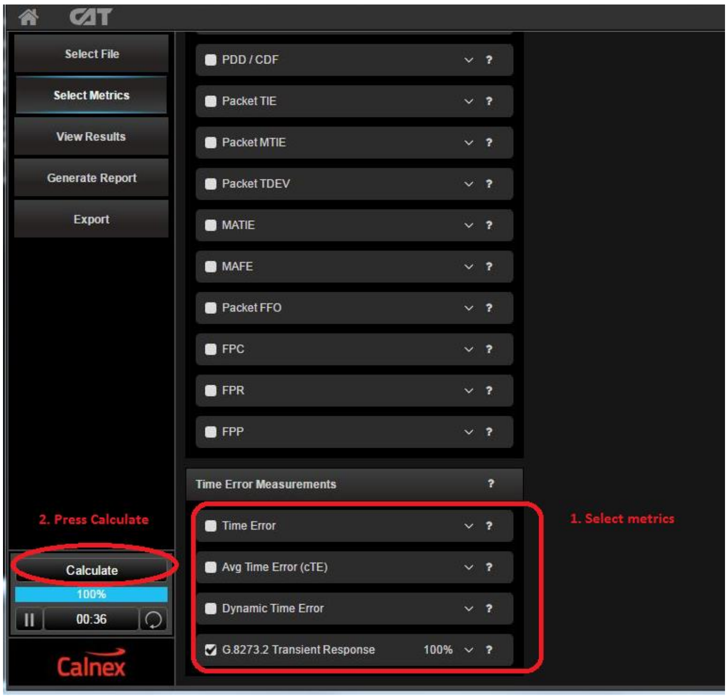
1. From the **Test:** drop-down menu, select **SyncE to 1pps Transient Response (Clause 7.4.1.2).**
2. From the **Generation** section of the conformance test app, press **Generate.** This starts PTP and ESMC message generation, allowing the device under test to stabilize. Pressing **Check** will open the **CAT** in a new tab to allow you to check current timing performance. In this case, you should wait for a **1pps TE Absolute measurement** graph moving from a ramp to stable condition to indicate lock has been achieved.




3. Once the DUT is stable, in the **Stimulus/Measurement** section, press **Start** to run the prescribed SyncE wander and ESMC state change stimulus and simultaneous 1pps measurement.

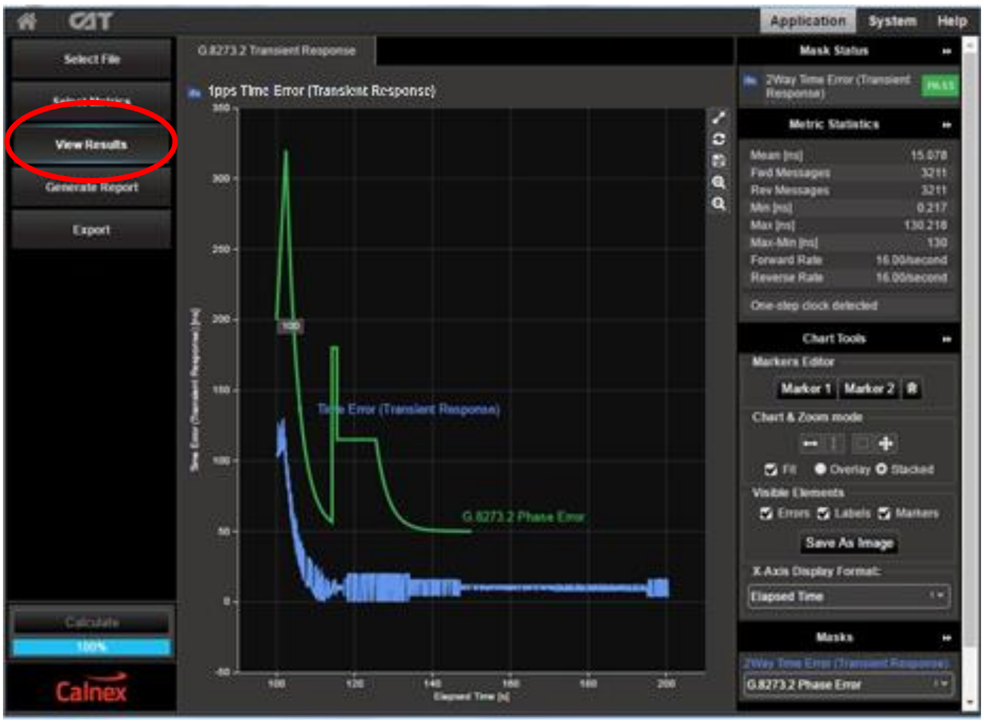
   **Test execution takes 200s.** The first 100s are used to analyze the underlying Constant Time Error (cTE) without the application of the transient. As per the standard, the mask for Phase Noise response to the generated transient requires the results to be adjusted for cTE – this step therefore allows the CAT to calculate and make that adjustment.

4. On completion of the test, the test results can be analyzed using the CAT.
5. In the CAT, click on **Select Metrics** and enable the **G.8273.2 Transient Response** metric followed by the **Calculate** button.




**NOTE:** Due to the application of the transient event the other Time Error results will be impacted and thus cannot be relied upon to provide representative results – other aspects of Time Error performance should be analyzed in separate test runs.

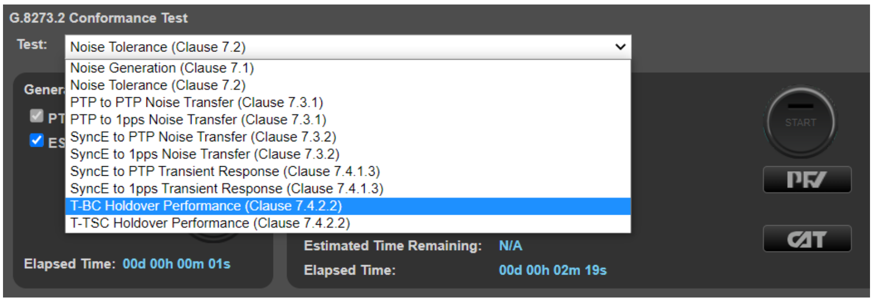
6. Once the calculation has reached 100% the results and associated Pass/Fail information can be viewed using the **View Results** button.



### 10.3 Holdover Performance

Holdover performance is checked by measuring the phase/time output in the event of the loss of the PTP input to the T-BC.

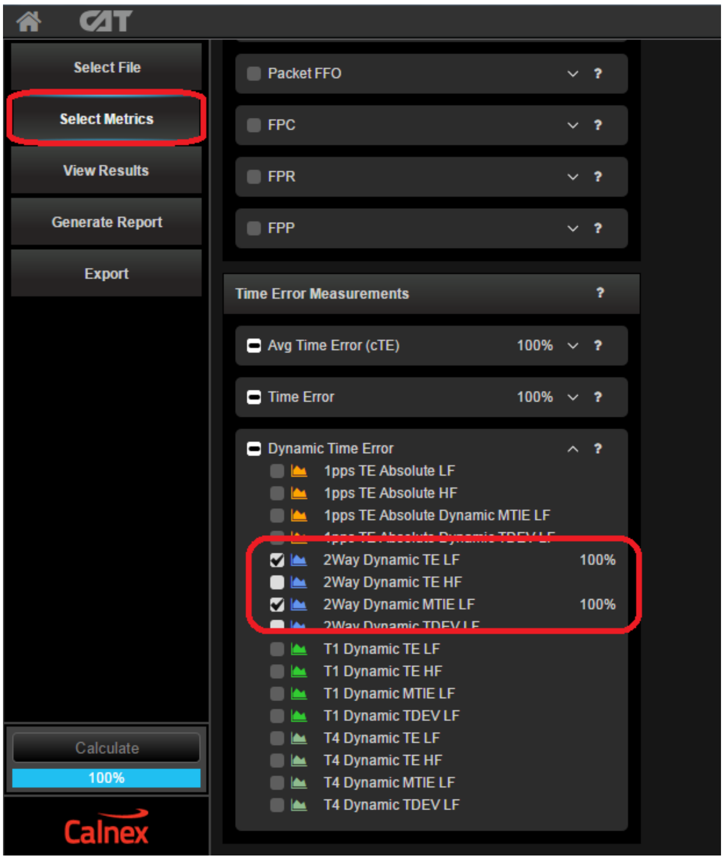
1. From the **Test:** drop-down menu, select **T-BC Holdover performance (Clause 7.4.2.2).**
2. From the **Generation** section of the conformance test app, press **Generate.** This starts PTP and ESMC message generation, allowing the device under test to stabilize. Pressing **Check** will open the **CAT** in a new tab to allow you to check current timing performance. In this case, you should wait for a **2WayTE measurement** graph moving from a ramp to stable condition to indicate lock has been achieved.




3. Once the DUT is stable, in the **Stimulus/Measurement** section, press **Start** to simulate loss of PTP input signal to the device and make simultaneous PTP performance measurements.

4. On completion of the test, the test results can be analyzed using the CAT.

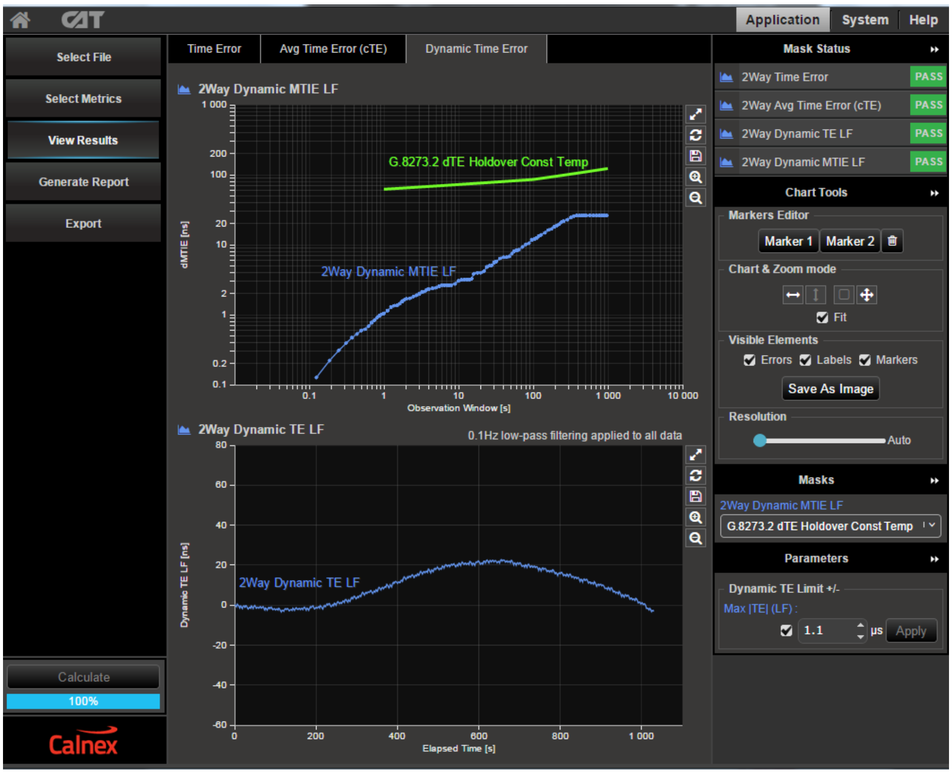
5. The key metrics to be examined are the **2way Dynamic TE LF** metrics. Enable these in the Metrics block and disable the Average Time Error (cTE) metrics and the remainder of the Dynamic TE metrics.



6. Select the **Dynamic Time Error** tab.

7. Select the **G.8273.2 dTE Holdover Const Temp** mask.

8. Show results and check the Pass/Fail status.



## Appendix 1 – Tests for a G.8273.2 T-BC

<table>
<tr><th>Test</th><th>Objective</th><th>Test Method</th><th colspan="5">Output Limit (PTP and 1pps) [1]</th></tr>
<tr><td rowspan="6">Time Error Generation<br>(G.8273.2, Section 7.1)</td><td rowspan="6">With stable input references, measure the inherent time error (Max|$TE_L$|, Max|TE|, cTE and dTE) produced by the internal clock.</td><td rowspan="6">Apply a stable time reference to the PTP input.<br>Apply a stable frequency reference to the SyncE input.<br>Repeat without a SyncE reference[2].</td><td></td><td>Class A</td><td>Class B</td><td>Class C</td><td>Class D</td></tr>
<tr><td>Max|$TE_L$|:[3]</td><td>-</td><td>-</td><td>-</td><td>≤ 5ns</td></tr>
<tr><td>Max|TE|:[4]</td><td>≤ 100ns</td><td>≤ 70ns</td><td>≤ 30ns</td><td>≤ 15ns<br>(Proposed)</td></tr>
<tr><td>cTE:</td><td>≤ 50ns</td><td>≤ 20ns</td><td>≤ 10ns</td><td>≤ 4ns<br>(Proposed)</td></tr>
<tr><td>$dTE_{LF}$:[5]</td><td colspan="2">40ns MTIE,<br>4ns TDEV</td><td>10ns MTIE<br>2ns TDEV</td><td>3ns MTIE<br>1ns TDEV<br>(Proposed)</td></tr>
<tr><td>$dTE_{HF}$:[6]</td><td colspan="2">70ns p-p</td><td>FFS</td><td>15ns p-p<br>(Proposed)</td></tr>
<tr><td rowspan="3">Relative Time Error Noise Generation<br>(G.8273.2, Section 7.1.4)</td><td rowspan="3">With stable input references, measure the difference in time error between two phase and time outputs.</td><td rowspan="3">Apply a stable time reference to the PTP input.<br>Apply a stable frequency reference to the SyncE input.</td><td></td><td>Class A</td><td>Class B</td><td>Class C</td><td>Class D</td></tr>
<tr><td>$cTE_R$</td><td>FFS</td><td>FFS</td><td>≤ 12ns</td><td>FFS</td></tr>
<tr><td>$dTE_{RL}$ MTIE</td><td>FFS</td><td>FFS</td><td>≤ 14ns</td><td>FFS</td></tr>
<tr><td>Time Error Tolerance<br>(G.8273.2, Section 7.2)</td><td>Measures whether the clock can operate correctly with maximum noise input at the input.<br>The test must be carried out with noise on both the PTP and SyncE inputs.<br>Clock under test should not:<br>• generate alarms<br>• switch reference<br>• go into holdover</td><td>Combined PTP and SyncE tolerance:<br>Apply Calnex noise tolerance profile to the PTP input[7] [8]<br>Simultaneously apply sine wave phase wander to the SyncE input according to G.8262, Table 9.<br>Repeat without a SyncE reference[7].</td><td colspan="5">No output performance limit.<br>Clock under test should not:<br>• generate alarms<br>• switch reference<br>• go into holdover</td></tr>
</table>

[1] Same limits apply to 1pps and PTP outputs. It is assumed that the 1pps should track the PTP output closely, although there is no specification for how closely they should track.
[2] G.8273.2 doesn't currently specify the performance in the absence of SyncE, therefore repeating the test without the use of SyncE input reference is optional.
[3] Max|$TE_L$| is calculated on time error data after low-pass filtering by 0.1Hz.
[4] Max|TE| is calculated on the raw, unfiltered time error data.
[5] MTIE and TDEV are calculated after low-pass filtering by 0.1Hz. Same values apply to both Class A and Class B devices.
[6] TIE is measured after high-pass filtering by 0.1Hz. Same values apply to both Class A and Class B devices.
[7] This profile is derived from the dTE network limit MTIE mask, defined in G.8271.1 Figure 7-2.
[8] Values assume a first order, 20dB/decade filter, with ±35ns (70ns p-p) noise from the output packet interface. For higher-order or digital filters, or for lower noise different values will apply.

<table>
<tr><th>Test</th><th>Objective</th><th>Test method</th><th colspan="2">Output Limit (PTP and 1pps)[1]</th></tr>
<tr><td rowspan="5">Time Error Transfer<br>(G.8273.2, Section 7.3)</td><td rowspan="5">Measures how time error on the input is transferred to the output.<br><br>PTP-to-PTP transfer function:<br>• Low-pass filter (undefined order or shape)<br>• Bandwidth from 0.05 to 0.1Hz<br><br>SyncE-to-PTP transfer function:<br>• Band-pass filter (undefined order or shape)<br>• Lower cut-off from 0.05 to 0.1Hz<br>• Upper cut-off from 1 to 10Hz</td><td rowspan="3">PTP to PTP:<br>Apply a set of sine wave PDV modulations of 400ns p-p amplitude (i.e. 200ns time error when applied in one direction) at several different frequencies.<br>Apply a stable frequency reference to the SyncE input.<br>Repeat without a SyncE reference.[2]</td><td>Frequency</td><td>Output Amplitude[3]</td></tr>
<tr><td>0.01Hz</td><td>>160ns p-p (min),<br><230ns p-p (max)</td></tr>
<tr><td>1Hz</td><td><55ns p-p (max)</td></tr>
<tr><td rowspan="2">SyncE to PTP:<br>Apply a stable time reference to the PTP input.<br>Apply a set of sine wave phase modulations of 200ns p-p amplitude at several different frequencies.</td><td>0.005Hz</td><td><55ns p-p (max)</td></tr>
<tr><td>0.33Hz</td><td>>145ns p-p (min),<br><230ns p-p (max)</td></tr>
<tr><td rowspan="3">Transients and Holdover<br>(G.8273.2, Section 7.4, plus Annex B, Appendix 1)</td><td>Measure the transient caused by a switch between PTP masters.</td><td>No test method defined.</td><td colspan="2">No performance limit defined</td></tr>
<tr><td>Measure the response to a SyncE rearrangement transient.</td><td>Apply a stable time reference to the PTP input.<br>Apply a stable frequency reference to the SyncE input.<br>After the T-BC has locked onto the inputs and stabilised, apply the transient defined in G.8273 Figure III.2 to the SyncE input, coupled with changing the ESMC QL values at the times defined in G.8273 Appendix III.</td><td colspan="2">Phase mask defined in G.8273.2 Annex B</td></tr>
<tr><td>Measures the response to entry into holdover caused by loss of packets at PTP input.</td><td>Apply a stable time reference to the PTP input.<br>Apply a stable frequency reference to the SyncE input.<br>After the T-BC has locked onto the inputs and stabilised, stop the flow of PTP packets, and monitor the output for up to 1000s.</td><td colspan="2">MTIE mask defined in G.8273.2, Table 7-6</td></tr>
</table>

[1] Same limits apply to 1pps and PTP outputs. It is assumed that the 1pps should track the PTP output closely, although there is no specification for how closely they should track.

[2] G.8273.2 doesn't currently specify the performance in the absence of SyncE, therefore repeating the test without the use of SyncE input reference is optional.

[3] Values assume a first order, 20dB/decade filter, with ±35ns (70ns p-p) noise from the output packet interface. For higher-order or digital filters, or for lower noise different values will apply.

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