

O-RAN O-RU Testing

Testing O-RUs for LLS-C1, LLS-C2 and LLS-C3 deployment as per O-RAN requirements using Paragon-neo

- WG4.CONF v09.00 3.3.2 Functional test
- WG4.CONF v09.00 3.3.3 Performance test



The synchronization (S-plane) functional and performance requirements of an O-RU are defined mainly in the O-RAN CUS and CONF specifications.

Validating an O-RU against these requirements is essential in ensuring that the device will interoperate as expected when deployed in an O-RAN-compliant environment. This is a critical consideration in the open, mixed-vendor environment that O-RAN enables.

This guide describes how to test an O-RU using Paragon-neo to ensure that its behaviour meets the requirements specified in the CONF document for devices to be deployed in an LLS-C1, LLS-C2 and LLS-C3 topology.

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1. Hardware and Software Required

Paragon-neo

Opt. NEO-1G-10G*	1/10GbE interface support (if the O-RU has 1G and/or 10G interfaces)
Opt. NEO-25G*	25GbE interface support (if the O-RU has 25G interfaces)
Opt. NEO-40G*	40GbE interface support (if the O-RU has 40G interfaces)
Opt. NEO-50G*	50GbE interface support (if the O-RU has 50G interfaces)
Opt. NEO-100G*	100GbE interface support (if the O-RU has 100G interfaces)
Opt. NEO-A-PAM4-50G	PAM4 50GbE interface support (if the O-RU has PAM4 50G interfaces)
Opt. NEO-A-PAM4-100G	PAM4 100GbE interface support (if the O-RU has PAM4 100G interfaces)
Opt. NEO-A-PAM4-200G	PAM4 200GbE interface support (if the O-RU has PAM4 200G interfaces)
Opt. NEO-A-PAM4-400G	PAM4 400GbE interface support (if the O-RU has PAM4 400G interfaces)
Opt. NEO-PTP-G.8275.1*	Emulation of G.8275.1 PTP timeTransmitter and timeReceiver devices, with associated Time Error Impairment and measurement capability
Opt. NEO-SyncE-Wander*	(if the O-RU makes use of SyncE)
Opt. NEO-ORAN-MERGE*	(if the O-RAN traffic merge mode features are required)

*Also available on PAM4-enabled Paragon-neo A units. Please replace the *NEO-* with *NEO-A* for the PAM4 version.

Paragon-neo software version: 11.00.xx or later

Paragon-neo A software version 11.00.xx or later

Calnex Sentinel if making over-the-air (OTA) measurements

- Calnex Sentinel with an OTA card installed, running release R14.0 or later.
- Antenna or waveguide infrastructure to receive the RF signal from the O-RU

Accessories

- Optical Transceivers as required.
- Cables and fibers as required.

Document References

- O-RAN.WG4.CONF.0-R003-v09.00 - *O-RAN Working Group 4 (Fronthaul Working Group) Conformance Test Specification*
- O-RAN.WG4.CUS.0-R003-v13.00 - *O-RAN Working Group 4 (Open Fronthaul Interfaces WG) Control, User and Synchronisation Plane Specification*
- IEEE Std 1588™ - 2008 *IEEE Standard for a Precision Clock Synchronisation Protocol for Networked Measurement and Control Systems*
- IEEE Std 1588™ - 2019 *IEEE Standard for a Precision Clock Synchronisation Protocol for Networked Measurement and Control Systems*
- *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.8275.2 Precision time protocol telecom profile for phase/time synchronization with partial timing support from the network*
- *Recommendation ITU-T G.8273.2 Timing Characteristics of Telecom Boundary Clocks*
- *Recommendation ITU-T G.8273.3 Timing characteristics of telecom transparent clocks for use with full timing support from the network*
- *Recommendation ITU-T G.8262 Timing characteristics of synchronous equipment slave clock*
- *Recommendation ITU-T G.8262.1 Timing characteristics of enhanced synchronous equipment slave clock*
- Calnex Test Guide: CX3016 *Paragon-neo PRTC Test Guide*
- *Calnex Sentinel User Guide*
- *Calnex Paragon-neo Getting Started Guide*

Further Reading

- Calnex Application Note: Cabling Considerations (CX5009)
- Calnex O-RAN Technical Primer: <https://www.calnexsol.com/en/timing-and-sync-blog-article-display/1518-how-is-the-network-changing-and-what-does-this-mean-for-sync>

2. Document Information

It should be noted that the performance tests in this guide focus on the quality of the timing output from the device-under-test (DUT) as specifically defined in the relevant standards and recommendations.

However, during product development or qualification other aspects of device behaviour 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 of interest, the test procedures in this document can be used as a basis for you to design your own tests to study those aspects.

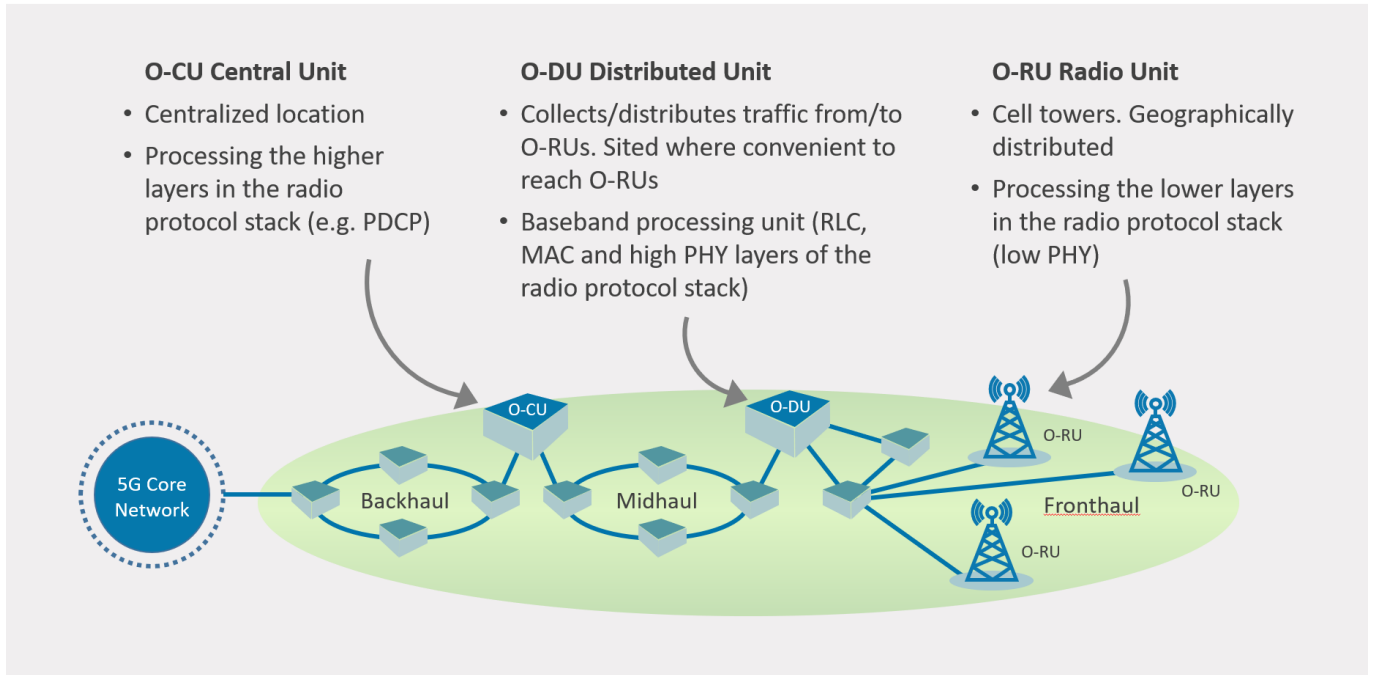
The Calnex Sentinel and Paragon-x products can be used to capture real-life network performance and can be imported into Paragon-neo as impairment profiles.

3. Introduction to the Tests

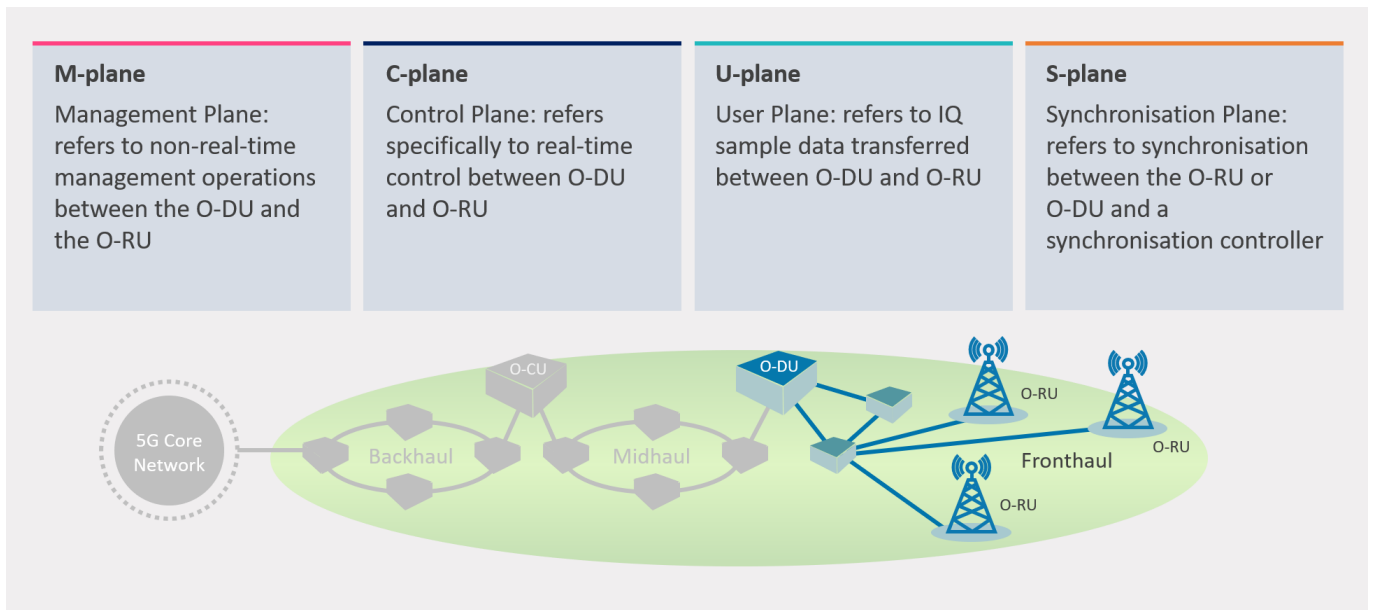
An Open Radio Access Network (Open RAN) is a non-proprietary version of the Radio Access Network (RAN) system that allows interoperation between cellular network equipment provided by different vendors. The concept behind Open RAN is that by standardizing the main elements of the network and defining interoperable interfaces between those elements, the network designer will have a greater choice of components to deploy.

The O-RAN Alliance (O-RAN) defines the performance and interface specifications for the component parts, ensuring interoperability and overall network behavior.

3.1. O-RAN Main Elements



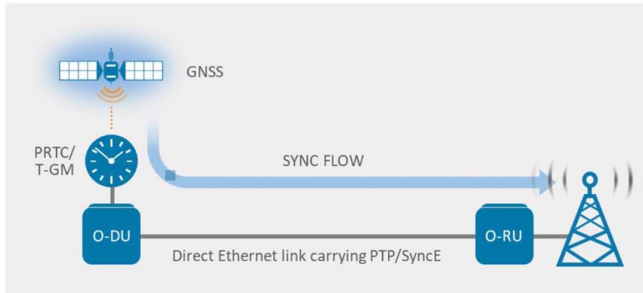
3.2. O-RAN Fronthaul Interoperable Elements



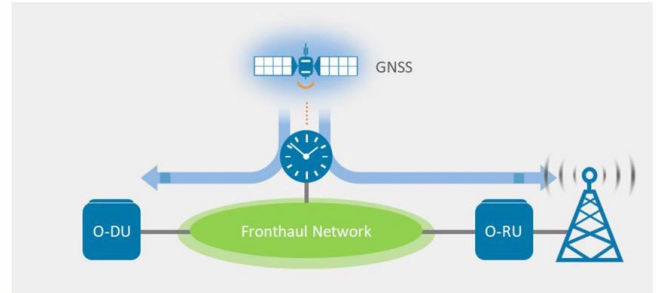
3.3. O-RAN Fronthaul LLS Architectures

O-RAN specifies four types of synchronization architectures for the fronthaul Lower Layer Split (LLS). The architectures are identified as C1, C2, C3 and C4 and are shown below for reference. The conformance test scenarios and pass criteria can be different depending on the architecture(s) the O-RU will be deployed in.

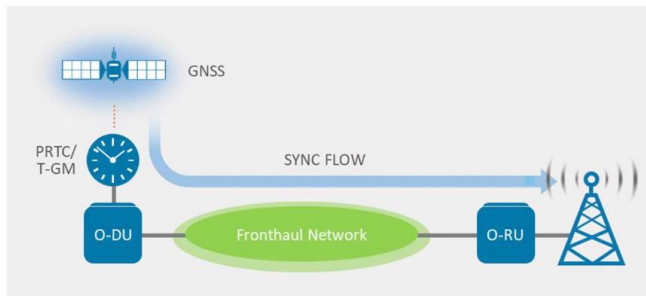
CONFIGURATION C1



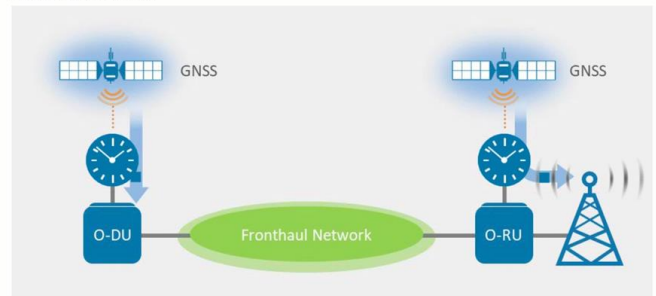
CONFIGURATION C3



CONFIGURATION C2



CONFIGURATION C4



3.4. O-RU S-Plane Capability Requirements

The overall synchronization performance of an O-RU is defined in the *O-RAN Working Group 4 (Open Fronthaul Interfaces WG) Control, User and Synchronisation Plane Specification* document O-RAN.WG4.CUS.0-R003-v13.00, Section 11, with additional information in Annex H.

O-RAN defines multiple architectures and synchronization methodologies to enable the greatest utility of the O-RU and to guarantee full interoperability and applicability to all deployment scenarios. The O-RU should be tested for all relevant capabilities specified in O-RAN.WG4.CUS; these are defined as follows:

Table 1: O-RU Capabilities

Capability / Conformance	O-RAN.WG4.CUS Reference	Notes
ITU-T G.8275.1	Table 10.2-1	See referenced table for conditions.
ITU-T G.8275.2	Table 10.2-1	See referenced table for conditions.
ITU-T G.8272/1 (PRTC)	Clauses 11.2.2.4	If O-RU implements an embedded PRTC.
ITU-T G.8273.2 (T-BC)	Clauses 11.2.2.2, 11.2.2.3	Required for cascaded O-RU capability.
ITU-T G.8273.2 (T-TSC)	Clauses 11.2.2.2, 11.2.2.3	See referenced clause for notes regarding requirements.
ITU-T G.8273.3 (T-TC)	Clauses 11.2.2.2, 11.2.2.3	Required for cascaded O-RU capability using TC.
ITU-T G.8262/1 (EEC/eEEC)	Clauses 11.2.4.1, 11.2.5.2, 11.2.5.3	PLFS implementations must implement SyncE. SyncE transfer is required for a cascaded O-RU implementation.

S-plane conformance tests for the O-RU are described in the O-RAN Fronthaul Working Group Conformance Test Specification document *O-RAN.WG4.CONF.v09.00*, clause 3.3. Functional tests are described in clause 3.3.2, and performance tests in clause 3.3.3.

Currently, not all O-RU capabilities specified in O-RAN.WG4.CUS are tested by the methodologies in O-RAN.WG4.CONF.

Calnex provides the following Test Guides for use in testing device conformance to the relevant capabilities:

Table 2: Calnex Test Guides

Capability / Conformance	Calnex Test Guide
ITU-T G.8275.1 / G8273.2 (T-BC & T-TSC)	<i>CX3009 G.8273.2 BC Conformance Test</i>
ITU-T G.8275.2	<i>CX3013 G.8273.4 Conformance Test</i>
ITU-T G.8272/1 (PRTC)	<i>CX3016 Paragon-neo PRTC Test Guide.</i>
ITU-T G.8275.1 / G.8273.3 (T-TC)	Currently being authored, contact Calnex for further details.
ITU-T G.8262 / G.8262.1	<i>G.8262.1/G.8262 EECs Conformance Test</i>

4. Connecting Paragon-neo to the Device-Under-Test (DUT)

The specific physical connections depend on the type of test to be run, any O-RU requirements for M-Plane, C-Plane, and U-Plane traffic (see Section 3.2) in addition to the S-Plane traffic, and the output signals to be measured from the O-RU.

Detailed information regarding the Paragon-neo front panel connections and interfaces are detailed in the *Calnex Paragon-neo Getting Started Guide* that is provided as part of the Paragon-neo on-instrument document set. It is accessible from the **Help** menu in the top right of the Paragon-neo's Graphical User Interface (GUI).

Measurement Types

The O-RU performance can be measured using a 1PPS output using Paragon-neo and/or by measuring the RF output of the air-interface using Calnex Sentinel. Connectivity diagrams for both measurement types are shown for each of the possible O-RU test modes (see below).

O-RU Test Modes

The Paragon-Neo has three modes for testing an O-RU and these are described below. Connectivity diagrams for each of these modes are in the subsequent sections of this document.

Table 3: Paragon-neo O-RU Test Modes

O-RU Test Mode	Applicability
timeReceiver	Use this test mode (to allow S-Plane conformance testing of the O-RU) when: <ol style="list-style-type: none"> The O-RU does not require any M-Plane, C-Plane or U-Plane traffic from a real or emulated O-DU on the same physical interface as the S-Plane (PTP/SyncE) traffic from Paragon-neo.
O-RAN Traffic Merging (Dual)	Use this test mode (to allow S-Plane conformance testing of the O-RU) when both of the following apply: <ol style="list-style-type: none"> The O-RU requires traffic from a real or emulated O-DU on the same physical interface as the S-Plane traffic from Paragon-neo. The O-DU or O-DU emulator requires S-Plane (PTP/SyncE) traffic from Paragon-neo.
O-RAN Traffic Merging (Single)	Use this test mode (to allow S-Plane conformance testing of the O-RU) when both of the following apply: <ol style="list-style-type: none"> The O-RU requires traffic from a real or emulated O-DU on the same physical interface as the S-Plane (PTP/SyncE) traffic from Paragon-neo. The O-DU or O-DU emulator requires a 1PPS+ToD reference from Paragon-neo.

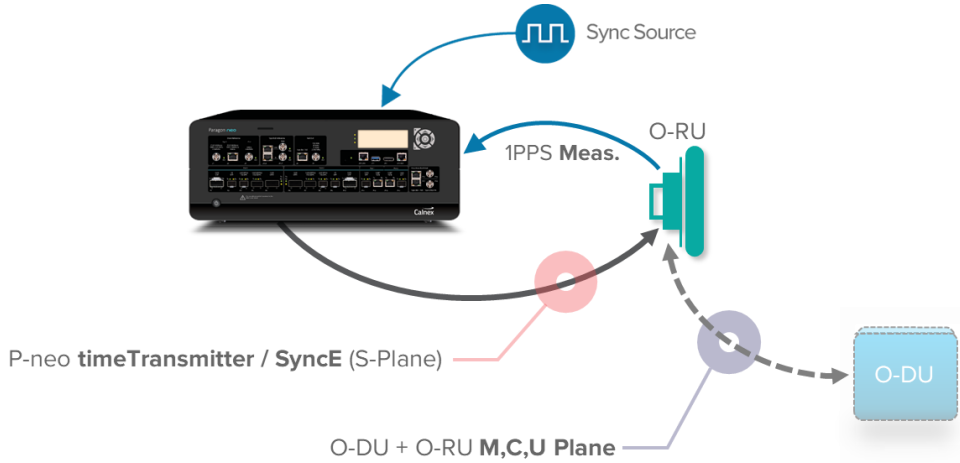
The two O-RAN Traffic Merging Modes pass all traffic that is received at one port of the Paragon-neo to the other port, except for S-Plane traffic (PTP and ESMC packets). At both ports, Paragon-neo acts as a PTP timeTransmitter and SyncE source generating S-Plane traffic. This allows the O-RU to communicate with an O-DU or O-DU Emulator while being accurately measured for timing performance by Paragon-neo. More detail on the specific operation of these modes can be found in Section 8.

4.1. Connections for O-RU Conformance – timeReceiver Test Mode

This section contains the high-level connectivity diagrams for testing O-RU performance in timeReceiver Test Mode. In this test mode, if an O-DU or O-DU Emulator is required, it is connected to a different port on the O-RU than the Paragon-neo. If traffic from an O-DU or O-DU Emulator is required on the same port as the Paragon-neo, then one of the O-RAN Traffic Merging modes described in Sections 4.2 and 4.3 should be used.

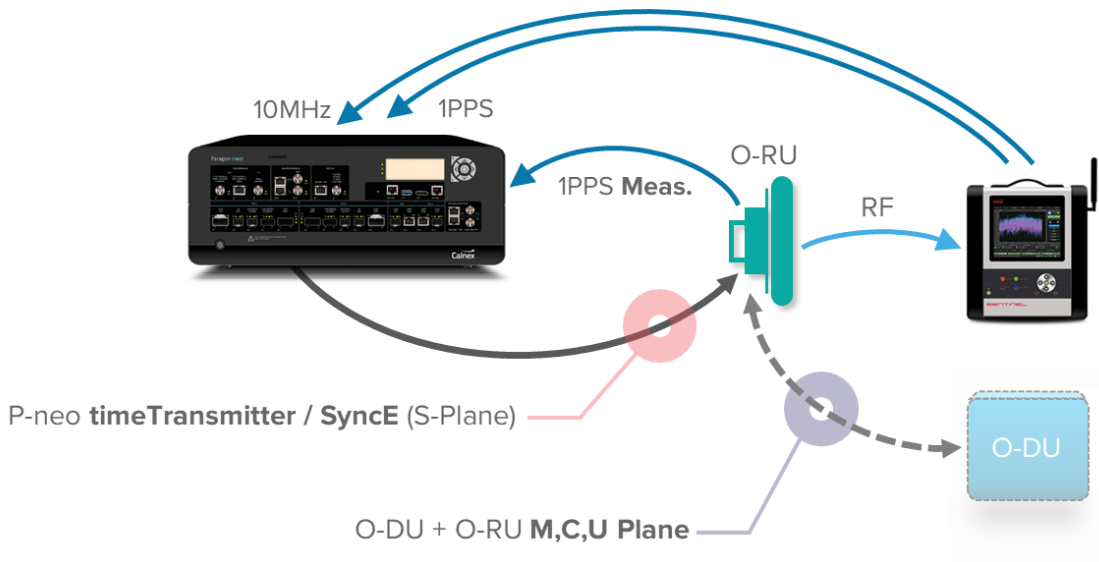
O-RU Measuring 1PPS Output

The configuration below measures the 1PPS from the O-RU.



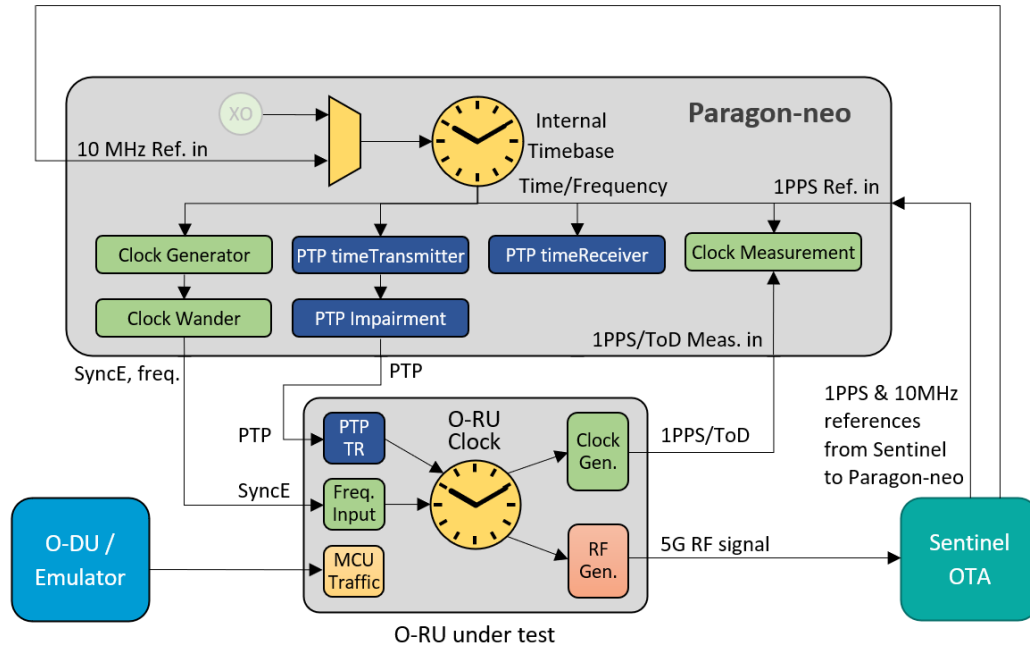
O-RU Measuring 1PPS Output and RF Output

The configuration below concurrently measures the 1PPS and RF (over-the-air output) from the O-RU. If the 1PPS is not required to be measured, it does not need to be connected. The Calnex Sentinel provides 10M and 1PPS references to Paragon-neo.



Detailed Test Topology

A detailed overview of the test topology when using both Paragon-neo and Sentinel is shown in the diagram below. Note that the O-RAN.WG4.CONF document clause 3.3.3 point D specifies that the measurement should be performed on the “conducted or non-conducted (OTA) on the Air interface”. Measurement of the O-RU 1PPS interface is a diagnostic test that provides more convenient visibility of the O-RU performance; however, a complete O-RU compliance test requires the use of Sentinel’s OTA measurement capability.



O-RU detailed topology using Paragon-neo and Sentinel

Physical Connections

1. Connect Paragon-neo Port 1 to the O-RU timeReceiver port. This port can also be used as the O-RU SyncE input port.
2. If required, connect an O-DU or O-DU Emulator to the O-RU.
3. If desired, and Sentinel is not being used, connect a PRC-quality external frequency reference, e.g. Caesium-derived 10 MHz, to the Paragon-neo Clock Reference Input.
4. If an OTA measurement using Sentinel is to be performed, follow the steps in Section 9.1 to connect the 1PPS and 10 MHz outputs from Sentinel as references for Paragon-neo.

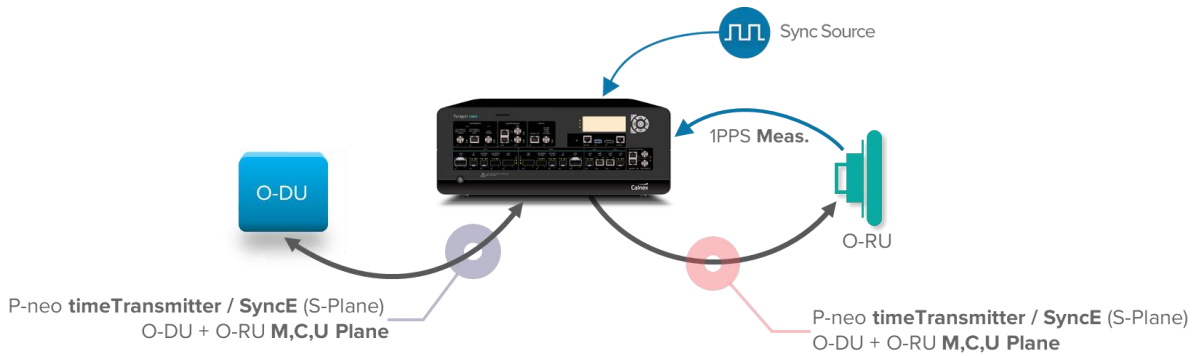
If more details are required, please see the *Calnex Paragon-neo Getting Started Guide*. More information on connecting to the Sentinel is in Section 9.1.

4.2. Connections for O-RU Conformance – O-RAN Traffic Merging (Dual) Mode

This section contains the high-level connectivity diagrams for testing O-RAN Traffic Merging (Dual) Test Mode. In this test mode, Paragon-neo acts as a timeTransmitter to both the O-RU and a real or emulated O-DU and, on the same physical interfaces, passes MCU plane traffic between those devices. If the real or emulated O-DU requires a 1PPS+ToD reference instead of PTP, then O-RAN Merging (Single) Test Mode should be used as described in Section 4.3.

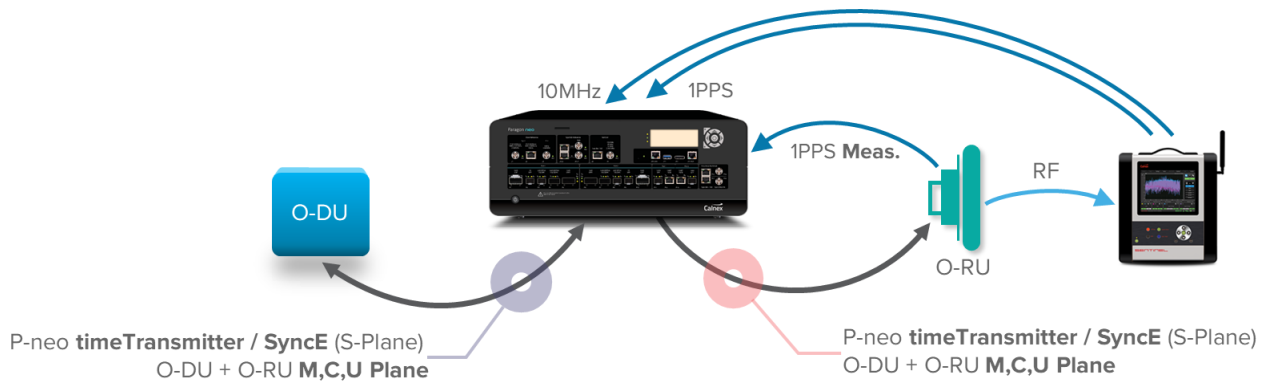
O-RU Measuring 1PPS Output

The configuration below measures the 1PPS from the O-RU.



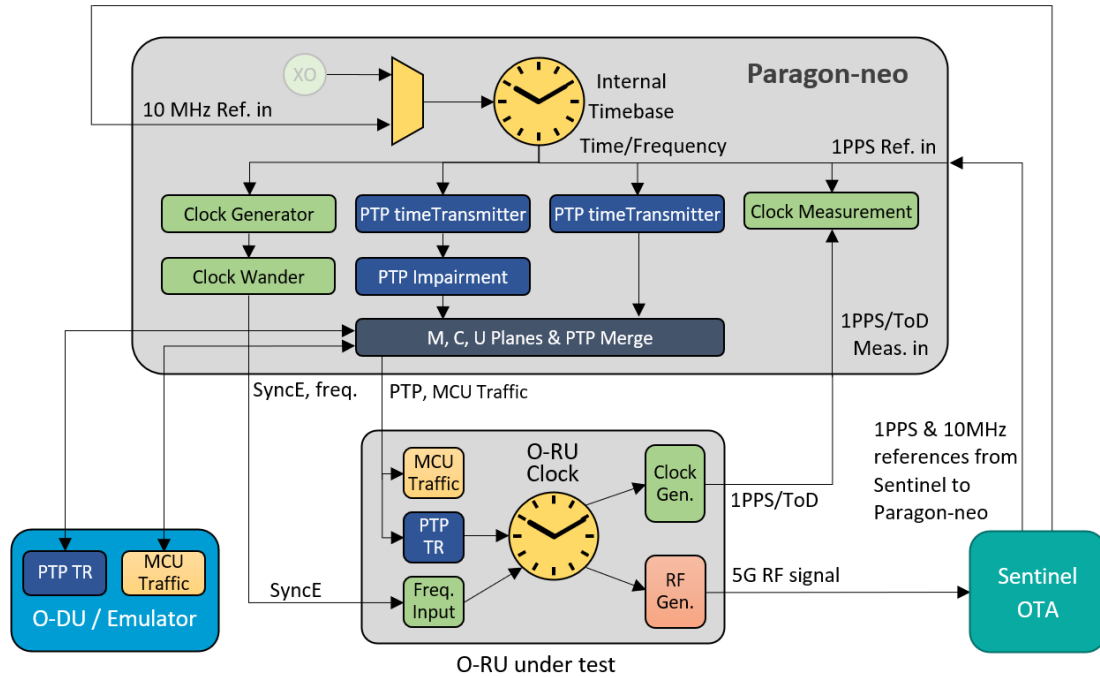
O-RU Measuring 1PPS Output and RF Output

The configuration below concurrently measures the 1PPS and RF (over-the-air output) from the O-RU. If the 1PPS is not required to be measured, it does not need to be connected. The reference signals to Paragon-neo are provided by the Calnex Sentinel.



Detailed Test Topology

A detailed overview of the test topology when using both Paragon-neo and Sentinel is shown in the diagram below. Note that the O-RAN.WG4.CONF document clause 3.3.3 point D specifies that the measurement should be performed on the “conducted or non-conducted (OTA) on the Air interface”. Measurement of the O-RU 1PPS interface is a diagnostic test that provides more convenient visibility of the O-RU performance; however, a complete O-RU compliance test requires the use of Sentinel’s OTA measurement capability.



O-RU detailed topology using Paragon-neo and Sentinel

Physical Connections

1. Connect Paragon-neo Port 1 to the O-RU timeReceiver port. This port can also be used as the O-RU SyncE input port.
2. Connect Paragon-neo Port 2 to the O-DU or O-DU Emulator.
3. If desired, and Sentinel is not being used, connect a PRC-quality external frequency reference, e.g. Caesium-derived 10 MHz, to the Paragon-neo Clock Reference Input.
4. If an OTA measurement using Sentinel is to be performed, follow the steps in Section 9.1 to connect the 1PPS and 10 MHz outputs from Sentinel as references for Paragon-neo.

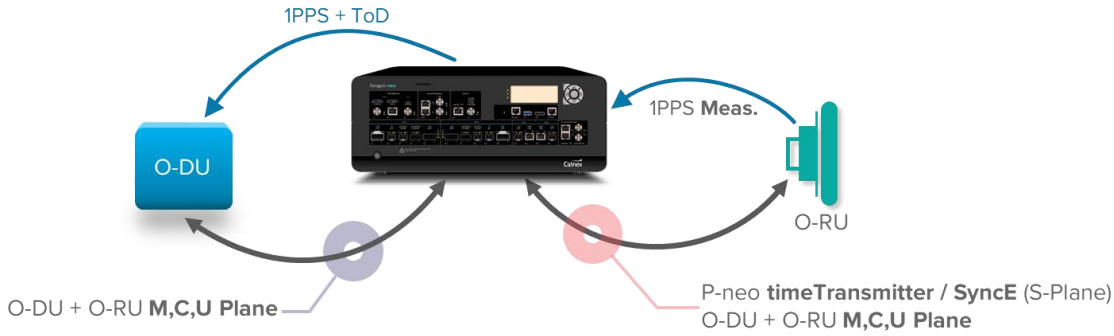
If more details are required, please see the *Calnex Paragon-neo Getting Started Guide*. More information on connecting to the Sentinel is in Section 9.1.

4.3. Connections for O-RU Conformance – O-RAN Traffic Merging (Single) Mode

This section contains the high-level connectivity diagrams for testing O-RAN Traffic Merging (Single) Test Mode. In this test mode, Paragon-neo acts as a timeTransmitter to the O-RU and provides a 1PPS+ToD reference to the real or emulated O-DU. MCU plane traffic is passed between the O-DU and O-RU; on the O-RU side this is provided on the same physical interface as the timeTransmitter from Paragon-neo. If the real or emulated O-DU requires a PTP reference instead of 1PPS+ToD, then O-RAN Merging (Dual) Test Mode should be used as described in Section 4.2.

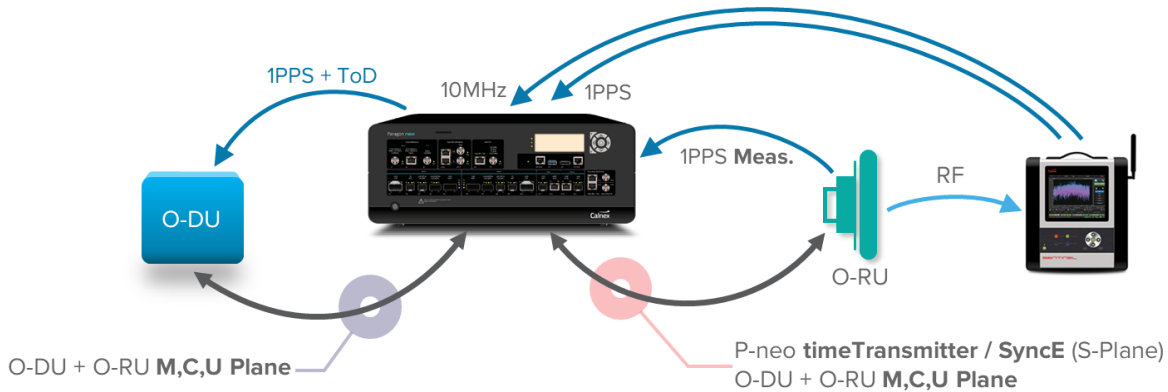
O-RU Measuring 1PPS Output

The configuration below measures the 1PPS from the O-RU.



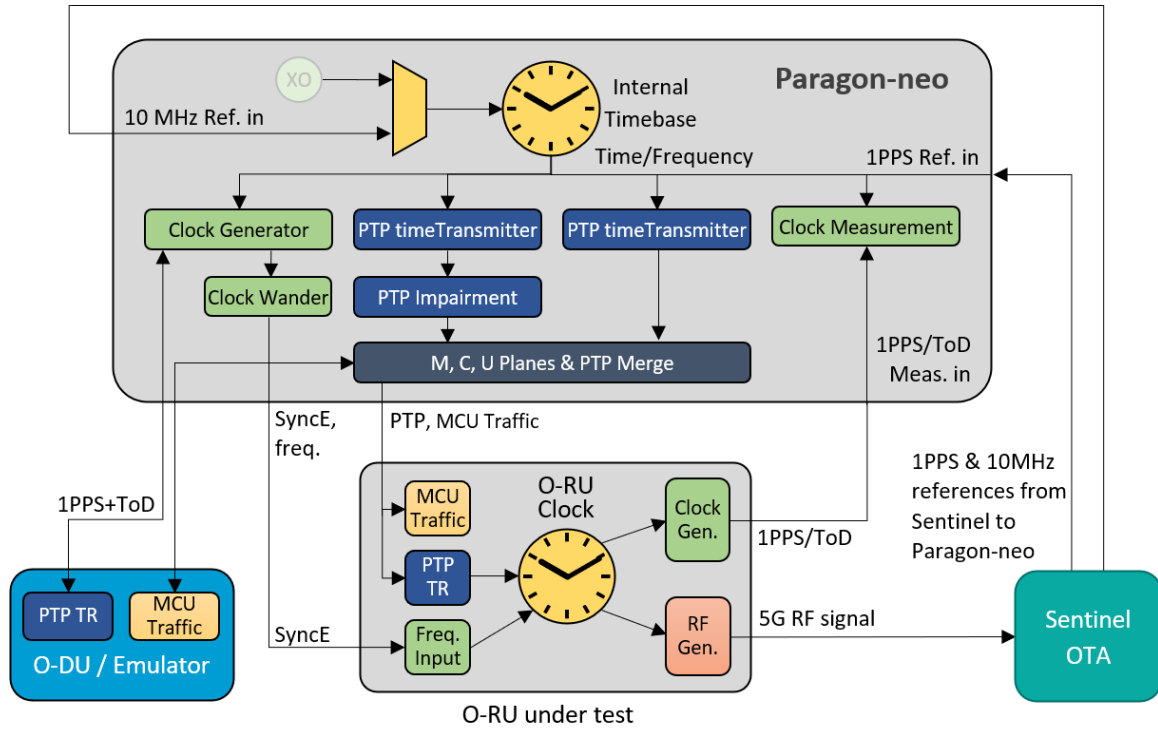
O-RU Measuring 1PPS Output and RF Output

The configuration below concurrently measures the 1PPS and RF (over-the-air output) from the O-RU. If the 1PPS is not required to be measured, it does not need to be connected. The reference signals to Paragon-neo are provided by the Calnex Sentinel.



Detailed Test Topology

A detailed overview of the test topology when using both Paragon-neo and Sentinel is shown in the diagram below. Note that the O-RAN.WG4.CONF document clause 3.3.3 point D specifies that the measurement should be performed on the “conducted or non-conducted (OTA) on the Air interface”. Measurement of the O-RU 1PPS interface is a diagnostic test that provides more convenient visibility of the O-RU performance; however, a complete O-RU compliance test requires the use of Sentinel’s OTA measurement capability.



O-RU detailed topology using Paragon-neo and Sentinel

Physical Connections

1. Connect Paragon-neo Port 1 to the O-RU timeReceiver port. This port can also be used as the O-RU SyncE input port.
2. Connect Paragon-neo Port 2 to the O-DU or O-DU Emulator.
3. Connect the Paragon-neo 1PPS+ToD Reference Out to the appropriate input port on the O-DU or O-DU Emulator.
4. If desired, and Sentinel is not being used, connect a PRC-quality external frequency reference, e.g. Caesium-derived 10 MHz, to the Paragon-neo Clock Reference Input.
5. If an OTA measurement using Sentinel is to be performed, follow the steps in Section 9.1 to connect the 1PPS and 10 MHz outputs from Sentinel as references for Paragon-neo.

If more details are required, please see the *Calnex Paragon-neo Getting Started Guide*. More information on connecting to the Sentinel is in Section 9.1.

5. Setting up Paragon-neo for O-RU CONF Testing

Before performing the O-RU testing, the following steps should be performed:

1. Connection to Paragon-neo
2. Configuration of physical connections
3. Test configuration
4. Device connection settings

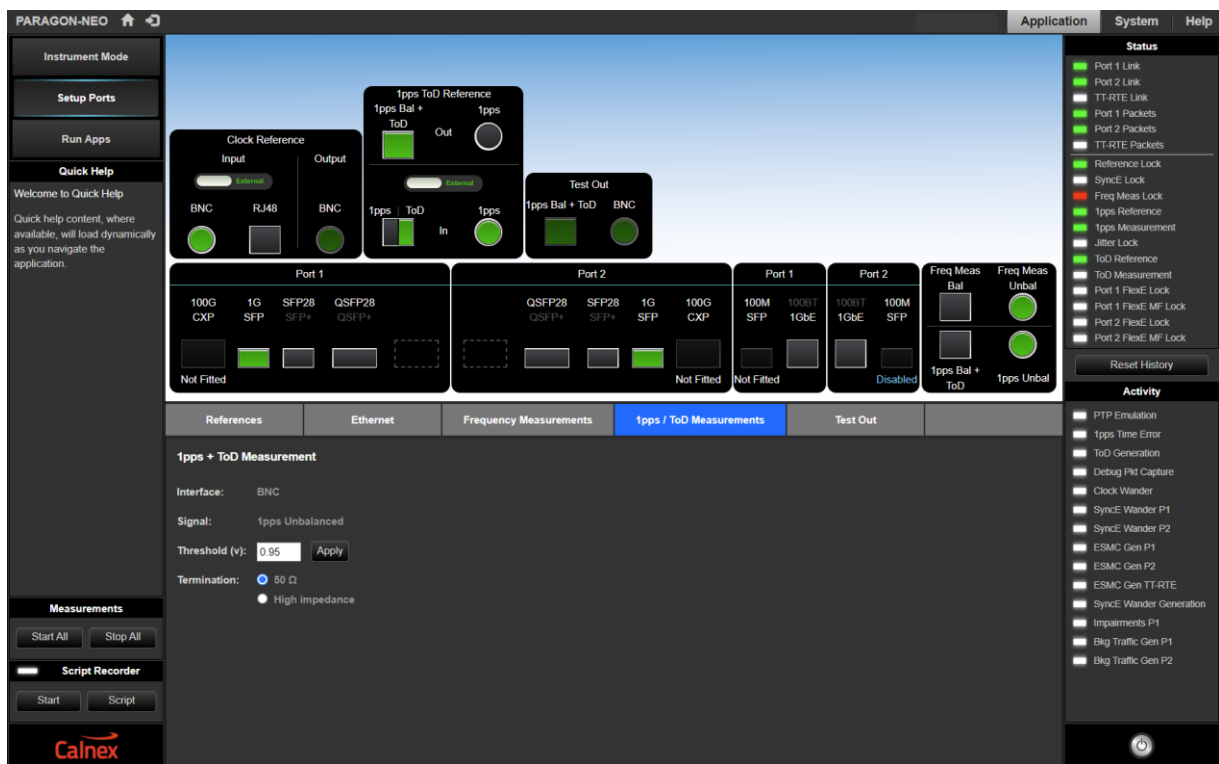
5.1. Connection to Paragon-neo

1. Verify the physical connections have been completed as described in Section 4 for the relevant test type and topology.
2. From a PC on the same network, open a browser and enter the IP address of the Paragon-neo unit.

If more details are required, please see the *Calnex Paragon-neo Getting Started Guide*.

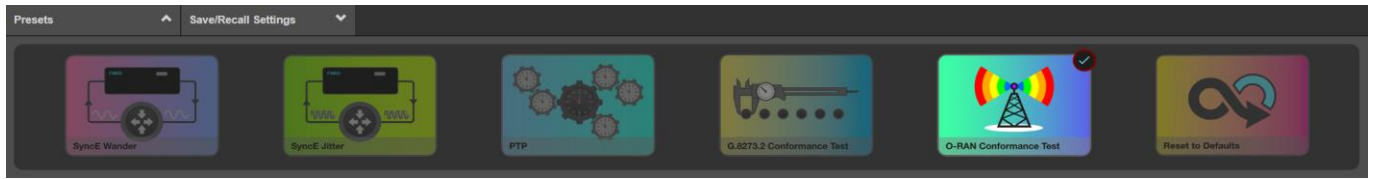
5.2. Configuration of Physical Connections

1. Select the **Setup Ports** page, then using the displayed GUI, select the **Reference**, **Test**, and **Interface** ports to be used.
2. If required, configure appropriate values for the **Threshold**, **Termination**, and **Serial** parameters for the reference and measured 1PPS signals. Voltages should be set to one decimal place (i.e., x.y Volts) to ensure the best accuracy of test and measurement.
3. If you are using an O-DU or O-DU Emulator that requires a 1PPS+ToD input from the Paragon-neo, configure the parameters for the 1PPS+ToD Ref Out with appropriate values for the **Format**, **Baud Rate**, **Data Bits**, **Parity** and **Stop Bits**.
4. Ensure that all relevant status indicator soft LEDs on the right of the GUI are green indicating the configuration matches the physical setup. If any are red, review the setup and ensure all are green before progressing.



5.3. Test Configuration

Select the **Run Apps** page, if the presets are not already displayed, expand the **Presets** panel, then select the **O-RAN Conformance Test** preset.

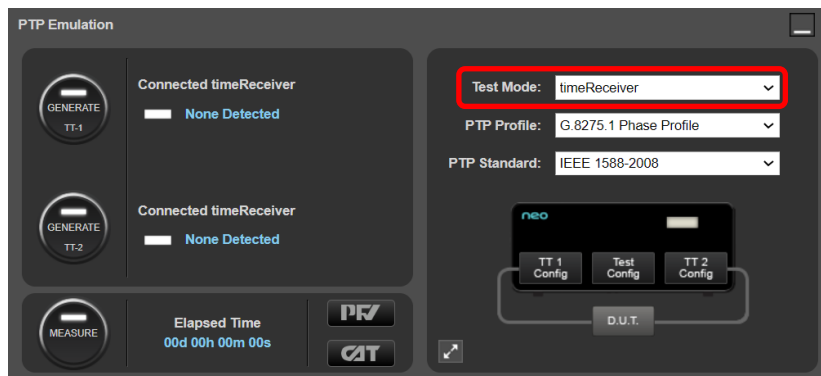


5.4. Device Connection Settings

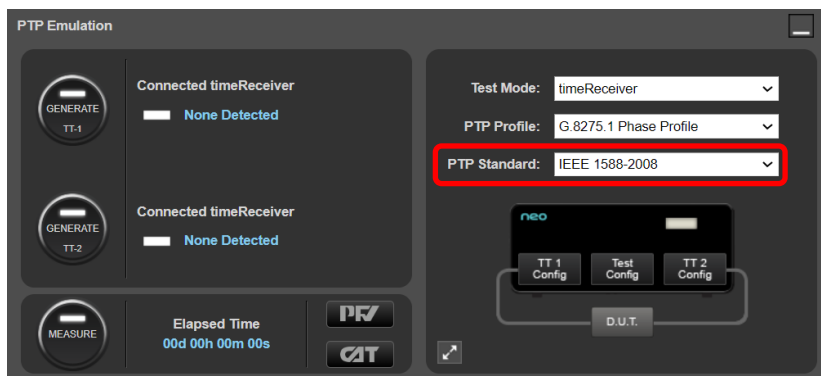
O-RAN strongly suggests that the Full Timing Support profile, G.8275.1, is used (see, e.g., 5.2.3 and 11.2.4.2.2 of O-RAN.WG4.CUS). Therefore, this guide assumes that conformance testing will use this PTP configuration for both the O-RU and an O-DU or O-DU Emulator, if used. Other profiles such as G.8275.2 (Partial Timing Support) can be configured on Paragon-neo, but any testing using these will not test conformance to the recommended O-RAN specifications.

As per 11.2.3 of O-RAN.WG4.CUS Physical Layer Frequency Support (PLFS) (typically SyncE) is mandatory when using G.8275.1, but the O-RU may or may not make use of PLFS. Configuration of Paragon-neo should therefore match the requirements of the O-RU with regards to providing a SyncE input.

1. In the **O-RAN Conformance Test** app, select **O-RU Ideal** as the test. This will automatically select the timeReceiver Test Mode and PTP Profile G.8275.1.
2. In the **PTP Emulation** app, select the **Test Mode** that applies to the physical test setup as described in Section 4:
 - timeReceiver
 - O-RAN Traffic Merging (Dual)
 - O-RAN Traffic Merging (Single)



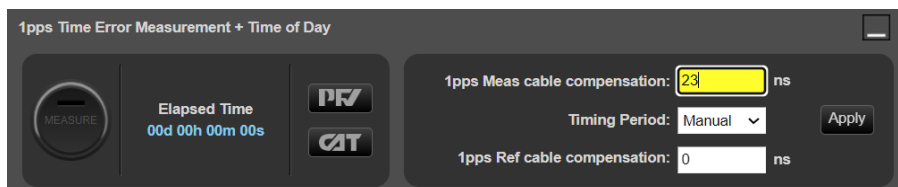
3. In the **PTP Emulation** app, select the appropriate **PTP Standard** for the O-RU:



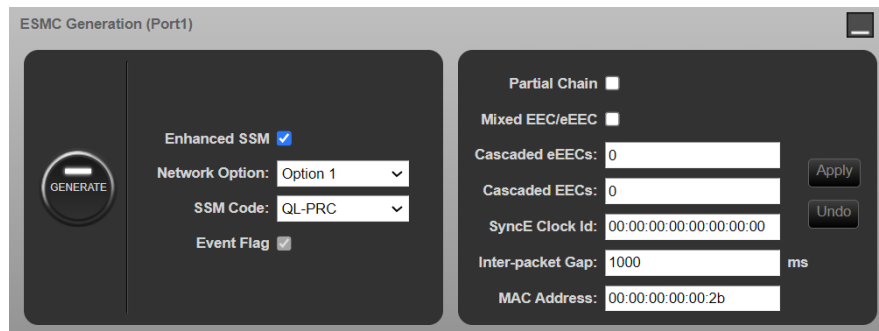
- Select **Test Config** and enter cable delay values appropriate for the test setup. Delay values are represented in nanoseconds and should be entered to one decimal place (i.e. x.y) for best results. A value of 4.9ns per meter of single-mode optical fiber and 4.94ns/m of multi-mode fiber is typical, but for the best accuracy of device measurement, the specific value for the fiber used should be confirmed as per its datasheet. For the coaxial cable used for 1PPS (unbalanced) signals, values of 4.5 to 5.1ns per meter are typical; this should be confirmed by datasheet or vendor. Once correct values have been entered, click **Apply**.



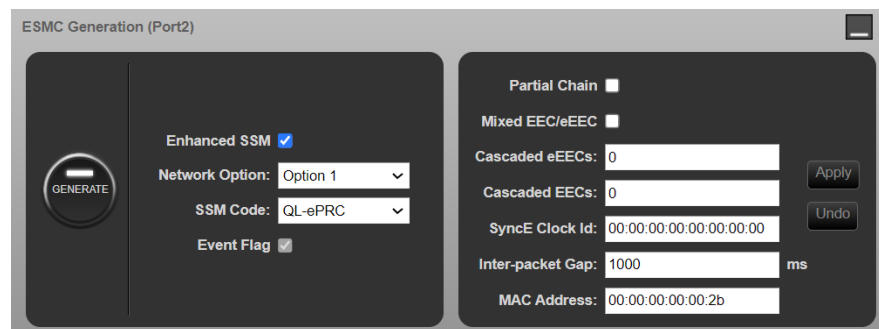
- If a 1PPS signal is to be measured, enter the measurement cable delay value in the **1PPS Time Error Measurement + Time of Day** app then click **Apply**. If **Apply** has not been clicked, the field will show yellow as shown below:



6. If the O-RU makes use of SyncE, in the **ESMC Generation (Port 1)** app, configure the SSM code (SyncE QL value) to an appropriate value such that the O-RU will use Paragon-neo as a frequency reference. Typical values for this are QL-PRC or QL-ePRC.



7. If an O-DU or O-DU Emulator is connected to Port 2, and it makes use of SyncE, in the **ESMC Generation (Port 2)** app, configure the SSM code (SyncE QL value) to an appropriate value such that the device will use Paragon-neo as a frequency reference. Typical values for this are QL-PRC or QL-ePRC.



6. O-RU CONF 3.3.2 Functional Test

These tests are mandatory. Their purpose is to validate that an O-RU is correctly synchronizing to a PTP and (optionally) SyncE source using ITU-T G.8275.1 profile, and that the O-RU correctly reports its status based on the nominal or degraded synchronization conditions. The functional tests apply to LLS-C1, LLS-C2, and LLS-C3 deployment configurations; there is no functional test for LLS-C4.

The RF output (over-the-air [OTA]) from the O-RU should be monitored under the conditions detailed below as per O-RAN.WG4.CONF Section 3.3.2. No timing performance requirements are specified for the functional tests. OTA measurement requires the use of a Calnex Sentinel instrument and is described in Section 8 of this guide.

The input conditions are changed by the user in the order shown in Table 3.3.2-1 of the O-RAN.WG4.CONF document, and the O-RU status is compared to the expected results defined in Tables 3.3.2-2 and 3.3.2-3 of that document. These tables are reproduced as Table 4, Table 5 and Table 6 respectively in this section.

Table 4: O-RU C1/C2/C3 Functional Conformance Test Steps

Step	PTP Status	SyncE Status (if applicable): SSM
1	Startup: no clockclass	Startup: no SSM/QL
2	Nominal clockclass=6	Nominal QL= (see Note 1)
3	Degraded clockclass but within the O-RU's configured accepted range	Nominal QL= (see Note 1)
4	Degraded clockclass outside the O-RU's configured accepted range	Nominal QL= (see Note 1)
5	Degraded clockclass outside the O-RU's configured accepted range	Degraded QL outside the O-RU's configured accepted range
6	Nominal clockclass=6	Nominal QL= (see Note 1)
7	Nominal clockclass=6	Degraded QL but within the O-RU's configured accepted range
8	Nominal clockclass=6	Degraded QL outside the O-RU's configured accepted range
9	Nominal clockclass=6	Nominal QL= (see Note 1)
10	S-plane lost; no message	S-plane lost; no message
<p>Note 1: For SyncE, Nominal QL is what is determined as the best acceptable configured value by the O-RU.</p>		

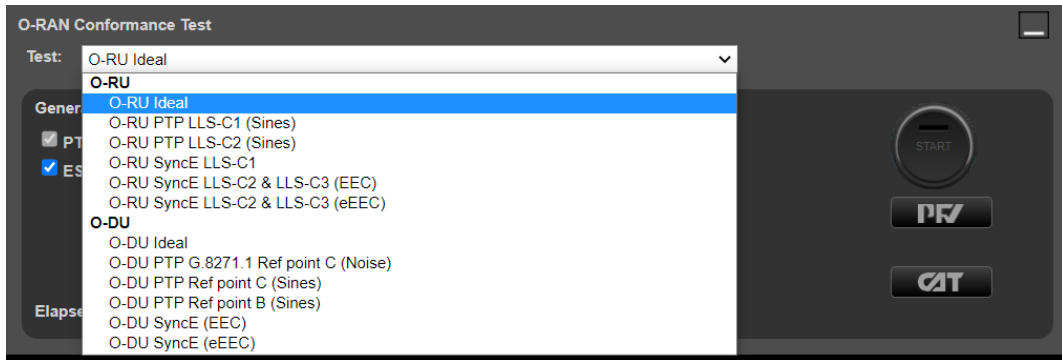
Testing is performed in three phases:

1. **Startup** – initially, Paragon-neo and the O-RU are connected as per Section 5 with no generation active.
2. **Nominal** – Paragon-neo PTP emulation is started, along with ESMC generation if required, with the PTP Clock Class (and SyncE QL value, if applicable) configured such that the O-RU will lock to those inputs.
3. **Degraded** – Paragon-neo is then configured in turn to create two different degraded input conditions for the O-RU:
 - a. In the first degradation level, Paragon-neo is configured to send PTP Clock Class values (and SyncE QL, if applicable) within the O-RUs configured accepted limits.
 - b. In the second degradation, the PTP Clock Class values (and SyncE QL, if applicable) sent by Paragon-neo are outside the O-RUs configured accepted limits.

6.1. Procedure – Functional Test

Confirm the Paragon-neo is configured as per Section 5, including the PTP and SyncE QL configurations.

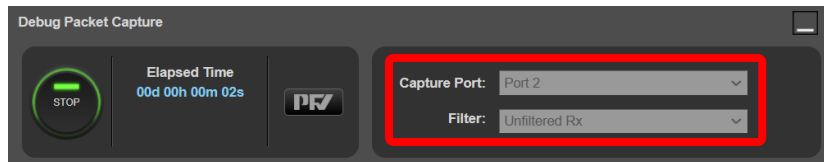
1. Confirm that there is no active generation. Cycle power to the O-RU; this is the *Startup* phase. The pass/fail criteria for this phase are detailed in the next section.
2. Navigate to the **O-RAN Conformance Test** app. From the **Test:** drop-down select **O-RU Ideal**.



3. From the **Generation** section of the conformance test app, press **Generate**. This starts PTP and ESMC message generation on both ports of the Paragon-neo.
4. If you are using an O-DU or O-DU Emulator, ensure that this device is correctly synchronized to the Paragon-neo using PTP if the test mode is **O-RAN Traffic Merging (Dual)**, or using 1PPS+ToD if the test mode is **O-RAN Traffic Merging (Single)**.

If you are using an O-DU or O-DU Emulator, ensure that this device is correctly configured and is communicating with the O-RU as expected.

If you are using one of the O-RAN Traffic Merging test modes, using the **Unfiltered Rx** filter in the **Debug Packet Capture** app may be useful to observe the traffic that is being received at the selected **Capture Port** of the Paragon-neo.



Running a debug packet capture will generate a .pcap capture file. This mechanism works in the same way as making standard timing captures: the resultant file will be saved in a timestamped sub-folder within the **Sessions** folder on the instrument. Information about accessing the capture file for analysis using a packet analysis tool (e.g. Wireshark) can be found at the link below.

<https://calnexsolutions.atlassian.net/wiki/spaces/KB/pages/379715585/Paragon-neo+Getting+Capture+Files+and+Logs>

Note: More information regarding the operation of the O-RAN Traffic Merging modes is in Section 8.

5. Confirm that the O-RU is synchronized to the Paragon-neo and, if necessary, is correctly communicating with the O-DU or O-DU Emulator to enable the correct operational state for the conformance test to be performed.
6. Each of the required PTP Clock Class value (and, if used SyncE QL) changes should be manually implemented in the order shown in Table 4 to perform the *nominal* and *degraded* state testing.
 - The procedures to change the PTP Clock Class and the (if required) SyncE QL are detailed in Section 6.2.
 - The pass/fail criteria for each step are detailed in the next section.

6.1.1. Results Interpretation – Pass/Fail Criteria

For each of the phases, the behavior and output of the O-RU should be monitored either by external M-plane observation or on the O-RU console. Table 5 shows the expected results for an O-RU using PTP only, and Table 6 the results for an O-RU using both PTP and SyncE.

Table 5: O-RU C1/C2 Functional Conformance Test Results without SyncE

Step	O-RU PTP Status	Sync-state	PTP lock-state	PTP state	PTP clock-class
1	Startup	FREE-RUN	UNLOCKED	DISABLED	255
2	Nominal	LOCKED	LOCKED	PARENT	Received value*
3	Degraded, within range	LOCKED	LOCKED	PARENT	Received value*
4 - 5	Degraded, outside range	HOLDOVER then FREE-RUN	(Note 2)	NOK	Received value*
6 - 9	Nominal	LOCKED	LOCKED	PARENT	Received value*
10	None (disconnected)	HOLDOVER then FREE-RUN	UNLOCKED	DISABLED	255
<p>Note 1: If HOLDOVER is not implemented by the O-RU, then the O-RU goes directly to FREERUN. Note 2: According to IEEE1588-2008 an O-RU embedded PTP clock is specified to be LOCKED. However, according to M-Plane specification [3] it could be in either LOCKED or UNLOCKED states.</p>					

* 'Received value' indicates that the output value from the O-RU is the same as that it receives, except for in the *Startup* phase where the output value will be the O-RU default value as there is no input.

Table 6: O-RU C1/C2 Functional Conformance Test Results with SyncE

Step	O-RU PTP and SyncE Status	Sync-state	PTP lock-state	PTP state	PTP clock-class	SyncE lock-state	SyncE state	SyncE quality-level
1	Startup	FREE-RUN	UNLOCKED	DISABLED	255	UNLOCKED	DISABLED	Note 1
2	PTP: nominal SyncE: nominal	LOCKED	LOCKED	PARENT	Received value*	LOCKED	PARENT or OK	Received value*
3	PTP: degraded within range SyncE: nominal	LOCKED	LOCKED	PARENT	Received value*	LOCKED	PARENT or OK	Received value*
4	PTP: degraded, outside range SyncE: nominal	HOLDOVER then FREE-RUN	Note 4	NOK	Received value*	LOCKED	PARENT	Received value*
5	PTP: degraded, outside range SyncE: degraded, outside range	HOLDOVER then FREE-RUN	Note 4	NOK	Received value*	Note 1	NOK	Note 1
6	PTP: nominal SyncE: nominal	LOCKED	LOCKED	PARENT	Received value*	LOCKED	PARENT or OK	Received value*
7	PTP: nominal SyncE: degraded, within range	LOCKED	LOCKED	PARENT	Received value*	LOCKED	PARENT or OK	Received value*
8	PTP: nominal SyncE: degraded, outside range	Note 3	LOCKED	PARENT	Received value*	Note 1	NOK	Note 1
9	PTP: nominal SyncE: nominal	LOCKED	LOCKED	PARENT	Received value*	LOCKED	PARENT or OK	Received value*

10	PTP: none (disconnected) SyncE: none (disconnected)	HOLDOVER then FREE-RUN	UNLOCKED	DISABLED	255	UNLOCKED	DISABLED	Note 1
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Note 1: This is not specified by CUS-Plane and is implementation 1 dependent.

Note 2: If HOLDOVER (either assisted by PLFS/SyncE or relying on the local oscillator) is not implemented by the O-RU, then the O-RU moves directly into the FREERUN state.

Note 3: Depending on O-RU implementation, the Sync-state may be LOCKED or HOLDOVER then FREERUN.

Note 4: According to IEEE1588-2008, an O-RU embedded PTP clock is specified to be LOCKED. However, according to the O-RAN M-Plane specification, it could be in either LOCKED or UNLOCKED states.

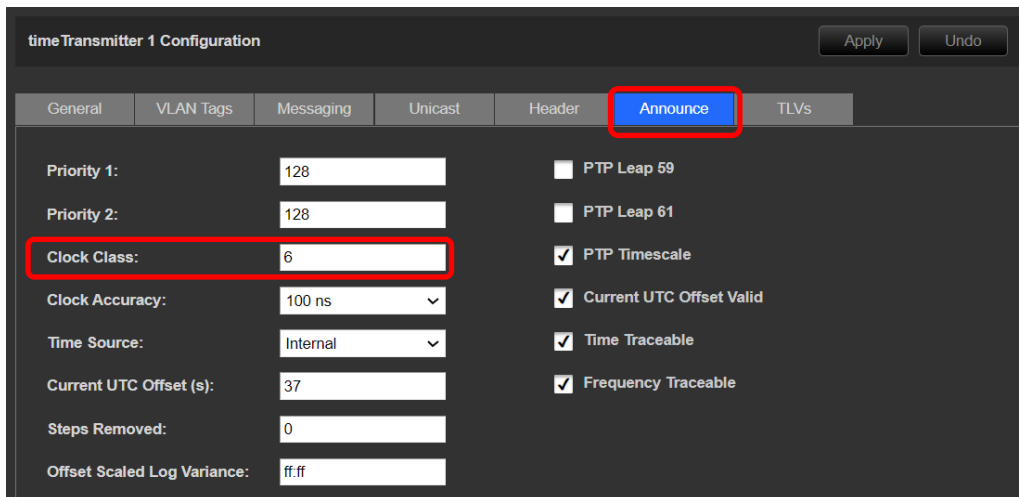
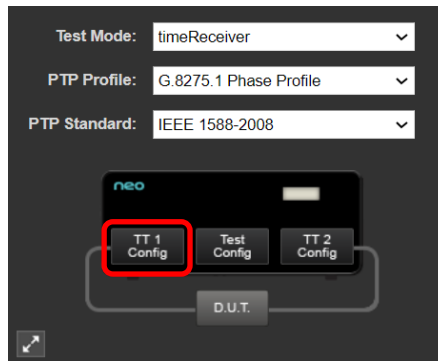
* 'Received value' indicates that the output value from the O-RU is the same as that it receives, except for in the *Startup* phase where the output value will be the O-RU default value as there is no input.

6.2. Changing the Input Conditions

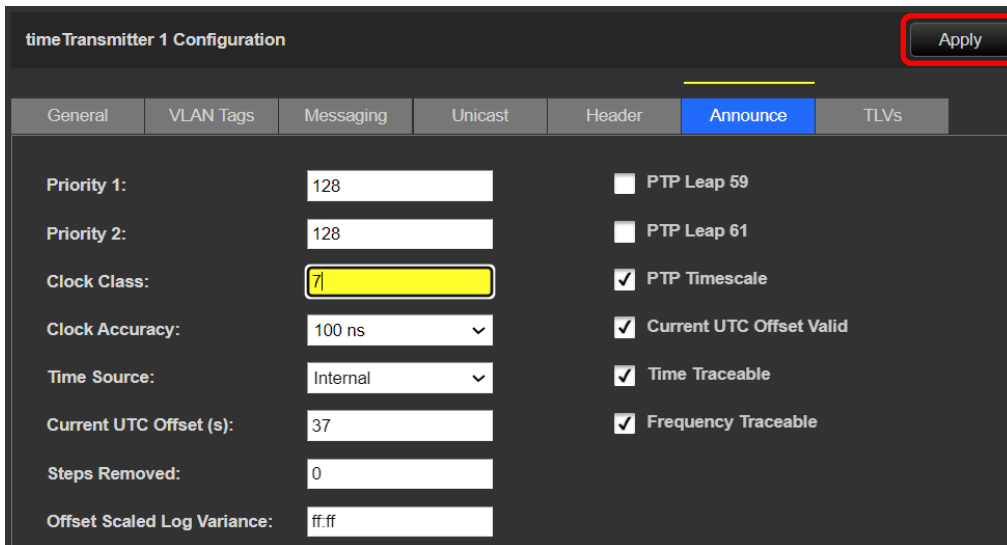
The input conditions to the O-RU are changed using the procedures in the sections below.

6.2.1. Changing the PTP Clock Class

The PTP Clock Class is carried in the Announce message from the emulated PTP timeTransmitter and so can be changed in the **timeTransmitter 1 Configuration** panel. Click this button in the **PTP Emulation** app to show the configuration options, then the **Announce** tab to view the **Clock Class** field:



The value can be changed while emulation is running by entering a new value in the field. This will cause the field to go yellow as **Apply** must be clicked to send the setting to the Paragon-neo.

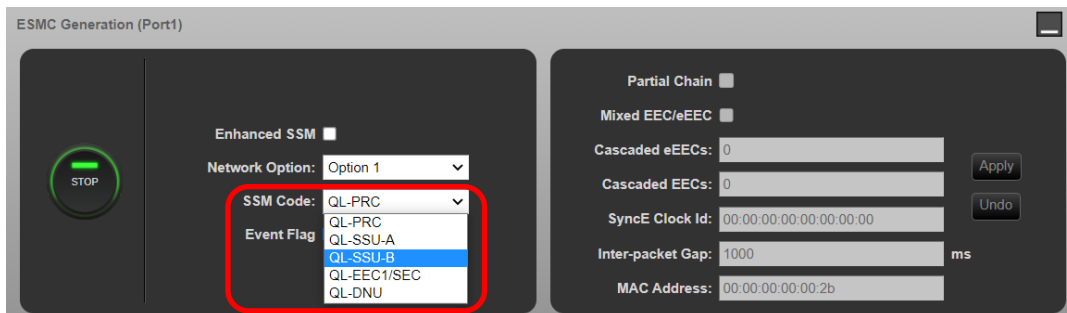


Once applied, the new value will be carried in the Announce message and its effect on the O-RU observed.

6.2.2. Changing the ESMC Quality Level

SyncE Quality Level is carried in the SSM Code field of the ESMC message from the emulated SyncE clock, and so can be changed by modifying the **SSM Code** in the **ESMC Generation (Port 1)** panel.

The value can be changed while emulation is running.



Once applied, the new value will be carried in the ESMC messages and its effect on the O-RU observed.

7. O-RU CONF 3.3.3 Performance Test

This test is defined in document *O-RAN.WG4.CONF.0-R003-v09.00, O-RAN Working Group 4 (Fronthaul Working Group) Conformance Test Specification* clause 3.3.3.

This test validates that the O-RU synchronizes to the Paragon-neo providing it PTP and, if required, physical layer frequency support (typically SyncE). The frequency and Time Error generated by the O-RU must be within the specified limits.

These tests are mandatory and apply to LLS-C1 and LLS-C2 deployment configurations; LLS-C3 and LLS-C4 are for further study.

O-RAN.WG4.CONF specification clause 3.3.3 states that the timing errors generated for PTP and SyncE can be applied “*either simultaneously or sequence*”. There are benefits to either: in sequence allows isolation of device performance characteristics based on stimulus type; simultaneously, as stated in O-RAN.WG4.CONF: “*represents a more realistic option to verify expected performance in a real network*”, therefore this section contains instructions for testing both separately and simultaneously.

O-RAN.WG4.CONF specification clause 3.3.3 states that the tests consider the case of an O-RU with a Class-A O-DU but it does not explicitly state whether they apply to a “Regular” or “Enhanced” O-RU type as defined in O-RAN.WG4.CUS. However, it can be inferred from the performance requirements that the specification (shown below) is for a “Regular” O-RU. So that you can test your O-RU against the “Enhanced” performance requirements in O-RAN.WG4.CUS, Calnex has developed performance masks based on the applicable standards that can be applied to indicate conformance to the “Enhanced” specification. These are available in the Calnex Analysis Tool (CAT) application.

7.1. Test Description

This section provides information about the test requirements and the applicable timing signal types.

7.1.1. O-RU Performance Requirements

The CUS specification defines key synchronization parameters that must be met:

Table 7: CUS Key Synchronization Parameters

Metric	Limit	Reference
Maximum Dynamic Time Error	80ns (for a “regular” O-RU) 35ns (for an “enhanced” O-RU)	Table 11.3.2.1-1
Maximum Absolute Frequency Error (MaxlFEI)	35ppb (with Class A O-DU) 45ppb (with Class B O-DU)	Table 11.3.2.1-1

These values are specified for the O-RU RF output connector.

The frequency error allowance for the O-RU is the remainder after 15ppb or 5ppb (for Class A or Class B O-DU respectively) is subtracted from the overall maximum frequency error of the radio signal of 50ppb (as specified in the 3GPP TS 36.104 and TS 38.104).

7.1.2. Test Scenarios

Two scenarios are tested in O-RAN.WG4.CONF, *Ideal Operation* and *Normal Operation*:

- Ideal Operation:** PTP and SyncE (if used) provide “ideal” O-RU input synchronization with no added noise.
- Normal Operation:** PTP and SyncE (if used) provide “Within normal operating limits” O-RU inputs as specified in CUS-Plane Specification, simultaneously meeting two limits:
 - Maximum time error: $\pm 1420\text{ns}$
 - Maximum frequency error (0.1Hz low pass filtered): $\pm 15\text{ppb}$

The performance specification of a “Regular” O-RU under each scenario is:

1. Ideal Operation

- a. Maximum time error:
 - 1PPS interface: $\pm 60\text{ns}$
 - RF interface: $\pm 80\text{ns}$
- b. Maximum frequency error (unfiltered):
 - 1PPS interface: $\pm 21\text{ppb}$
 - RF interface: $\pm 35\text{ppb}$

2. Normal Operation:

- a. Maximum time error:
 - 1PPS interface: $\pm 1480\text{ns}$
 - RF interface: $\pm 1500\text{ns}$
- b. Maximum frequency error (unfiltered):
 - 1PPS interface: $\pm 36\text{ppb}$
 - RF interface: $\pm 50\text{ppb}$

The thermal conditions are not defined by O-RAN. The tests are intended to be run at a constant temperature but the specific temperature conditions to be used are to be decided by the device vendor.

7.1.3. Timing Signal Types

O-RAN.WG4.CONF defines measuring the performance of the O-RU at the RF output and optional diagnostic testing using the 1PPS output. The diagnostic test can “provide an indication of the overall O-RU performance by more easily measuring the capabilities of the O-RU’s synchronisation implementation”.

7.2. Performance Test: PTP Operation

To test the “Ideal Operation” scenario, no impairments are applied to the input of the O-RU.

“Normal Operation” can be emulated in two ways. The first method is by applying a pattern of sine wave time errors to the PTP input of the O-DU. These are defined in Table 3.3.3-1 of the O-RAN.WG4.CONF specification which is reproduced below for reference.

Table 8: Time error limits for O-RU input (Sine Waves)

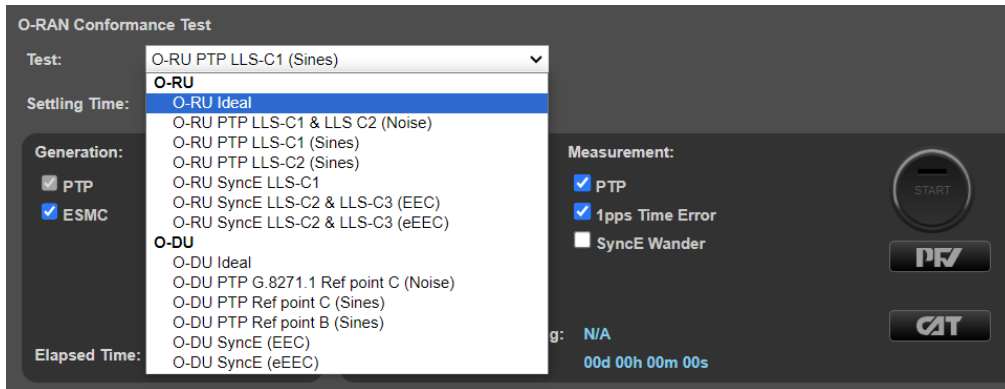
Frequency [Hz]	LLS-C1		LLS-C2		Test duration [s]
	dTE Amplitude [ns]	Constant Time Error [ns]	dTE Amplitude [ns]	Constant Time Error [ns]	
0.003362	710	710	719	701	595 (2 periods)
0.010	239	1181	308	1112	500 (5 periods)
0.100	24	1396	93	1327	50 (5 periods)

The second method is described in O-RAN.WG4.CONF as: “An alternative and more representative method for the O-RU input is to apply a noise pattern that meets the network limit mask defined in Figure H.2.4-4 from O-RAN.WG4.CUS.0-v10.00 (class A O-DU mask). This method is described in ITU-T G.8273.2 Appendix IX. The advantage of this is that it is more representative of real network conditions and transients, and therefore a more effective test of the O-RU under emulated network conditions.” This noise pattern is integrated into Paragon-neo and Calnex recommend this method as the measurement results provide a better indication of the expected O-RU performance in deployment.

7.2.1. Procedure – PTP Input Test

The appropriate test stimulus is automatically applied depending on the selected test within the O-RAN Conformance Test app.

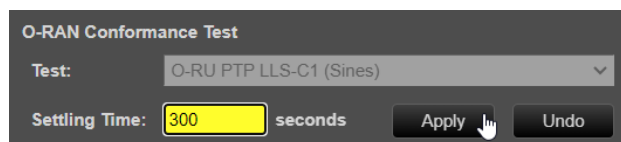
1. Navigate to the **O-RAN Conformance Test** app and from the **Test:** drop-down select the type of test required:
 - **O-RU Ideal** (no impairment pattern).
 - **O-RU PTP LLS-C1 & LLS C2 (Noise)** to apply the more representative network noise pattern specified in O-RAN.WG4.CONF.
 - **O-RU PTP LLS-C1 (Sines)** or **O-RU PTP LLS-C2 (Sines)** to apply the sine wave patterns specified in O-RAN.WG4.CONF.



2. The **Settling Time** parameter specifies the amount of time between applying the PTP stimulus and starting the measurement. This allows the device to settle after instantaneous changes in cTE that are inherent in some of the impairment patterns and are applied when the conformance test is started. There is no specification for the maximum settling time however it can be configured to a maximum of 620s (10 minutes).

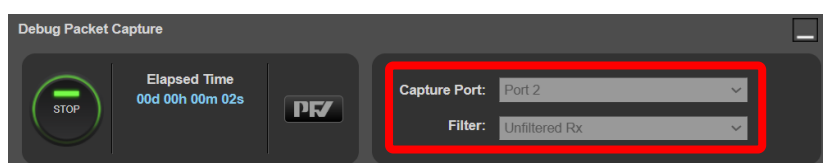
For the O-RU patterns, the sine wave patterns have a smooth ramp-up from zero cTE so settling time is not required. Settling time is recommended for the network noise pattern, however, device conformance testing is not affected because the network noise impairment patterns are of a duration and have characteristics such that an allowance for device settling will not affect the test results.

If required, enter the desired settling time for the O-RU and click **Apply**.



3. If the O-RU uses SyncE, in the **ESMC Generation (Port 1)** app, confirm that the appropriate settings have been configured to enable the O-RU to use SyncE as a reference as detailed in Section 5.4.
4. From the **Generation** section of the conformance test app, press **Generate**. This starts PTP and ESMC message generation on both ports of the Paragon-neo.
5. If you are using an O-DU or O-DU Emulator, ensure that this device is correctly synchronized to the Paragon-neo using PTP if the test mode is **O-RAN Traffic Merging (Dual)**, or using 1PPS+ToD if the test mode is **O-RAN Traffic Merging (Single)**.
6. If you are using an O-DU or O-DU Emulator, ensure that this device is correctly configured and is communicating with the O-RU as expected.

If you are using one of the O-RAN Traffic Merging test modes, using the **Unfiltered Rx** filter in the **Debug Packet Capture** app may be useful to observe the traffic that is being received at the selected **Capture Port** of the Paragon-neo.

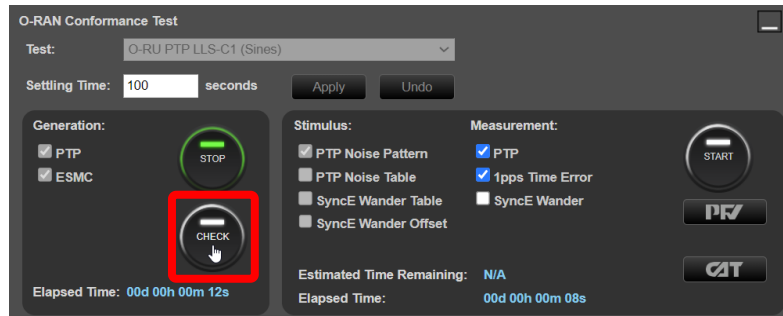


Running a debug packet capture will generate a .pcap capture file. This mechanism works in the same way as making standard timing captures: the resultant file will be saved in a timestamped sub-folder within the \Sessions folder on the instrument. Information about accessing the capture file for analysis in a packet analysis tool (e.g. WireShark) can be found at the link below.

<https://calnexsolutions.atlassian.net/wiki/spaces/KB/pages/379715585/Paragon-neo+Getting+Capture+Files+and+Logs>

Note: More information regarding the operation of the O-RAN Traffic Merging modes is in Section 8.

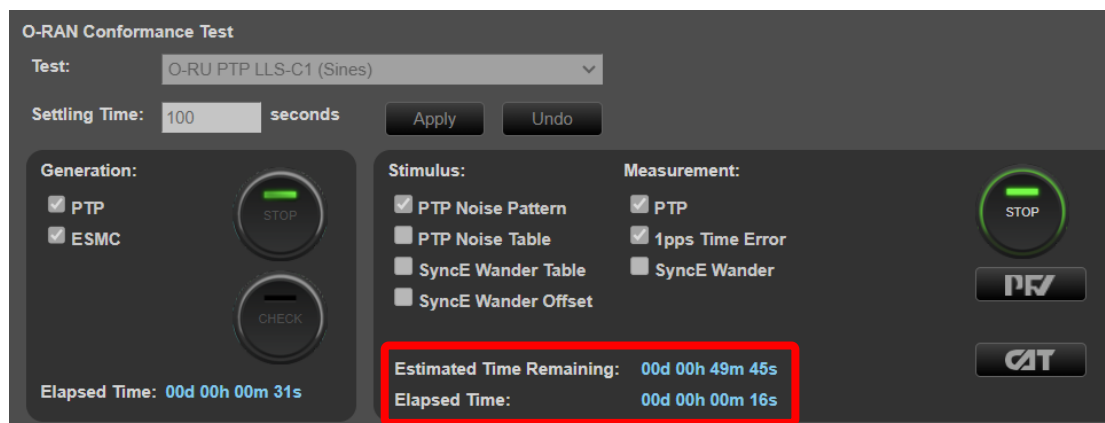
7. Confirm that the O-RU is synchronized to the Paragon-neo and, if necessary, is correctly communicating with the O-DU or O-DU Emulator to enable the correct operational state for the conformance test to be performed.
8. Pressing **Check** at any time will run a simultaneous timing capture of the O-RU, and the CAT application will open in a new browser tab – this can be used to check current timing performance before starting the test.



- If you are making a simultaneous OTA measurement with Sentinel on the O-RU air interface, refer to Section 9.5 for instructions.
- Wait for the measured output(s) of the O-RU moving from a ramp to stable condition to indicate lock has been achieved.
- If the O-RU does not achieve lock, then troubleshoot the configuration of the O-RU and Paragon-neo to determine the root cause.

Once the O-RU is stable, in the **Stimulus/Measurement** section, press **Start** to run the measurement.

The **O-RU Ideal** measurement should be run for at least 1000s. The tests that apply stimulus to the PTP input of the O-RU must be run until at least the *Estimated Time Remaining* has counted down to zero, the 'Sines' pattern are approximately 3000s and the 'Noise' pattern is approximately 33,000s.



If you are making a simultaneous OTA measurement with Sentinel on the O-RU air interface, refer to Section 9.5 for instructions.

If required, the progress of any applied stimulus can be observed by navigating to the **Status** tab of the **PTP Impairments (Port 1)** app. The current position within the pattern is indicated by the red bar.



7.2.2. Results Analysis

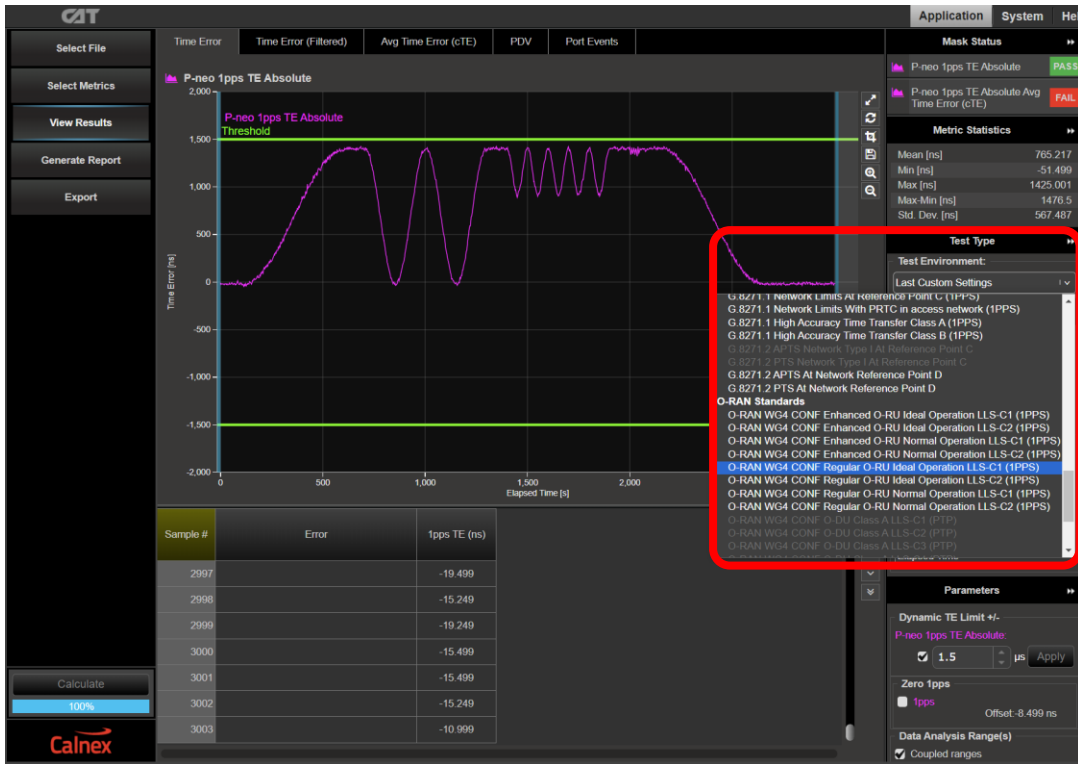
This section focuses on analyzing measurements of the O-RU 1PPS output. If you are making a simultaneous OTA measurement with Sentinel on the O-RU air interface, refer to Section 9.6 for instructions.

- From the **O-RAN Conformance Test** app, click on **CAT**. The Calnex Analysis Tool will open in a new browser tab displaying the default metrics.

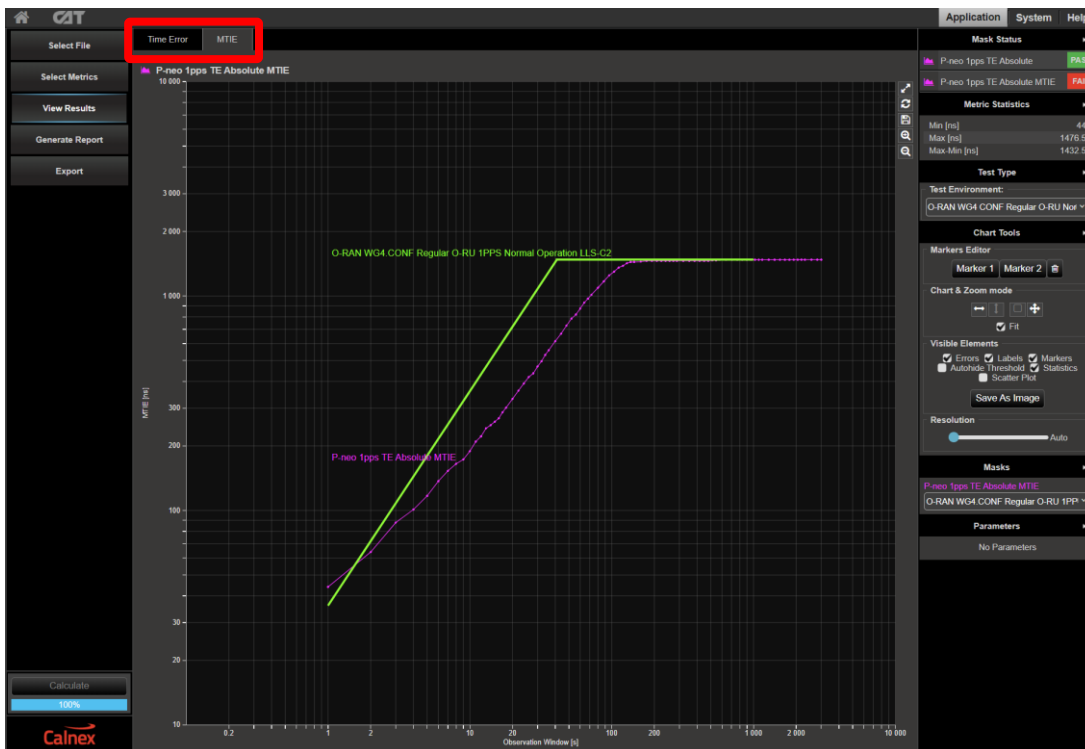


- The **Test Environment** function automatically configures the displayed metrics, masks, and thresholds to a range of preset values such as those required for testing compliance to device or network standards.

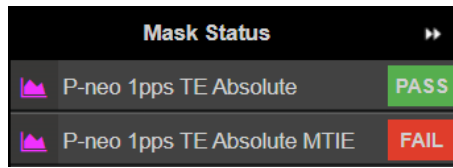
Select the appropriate **Test Environment** for the current test.



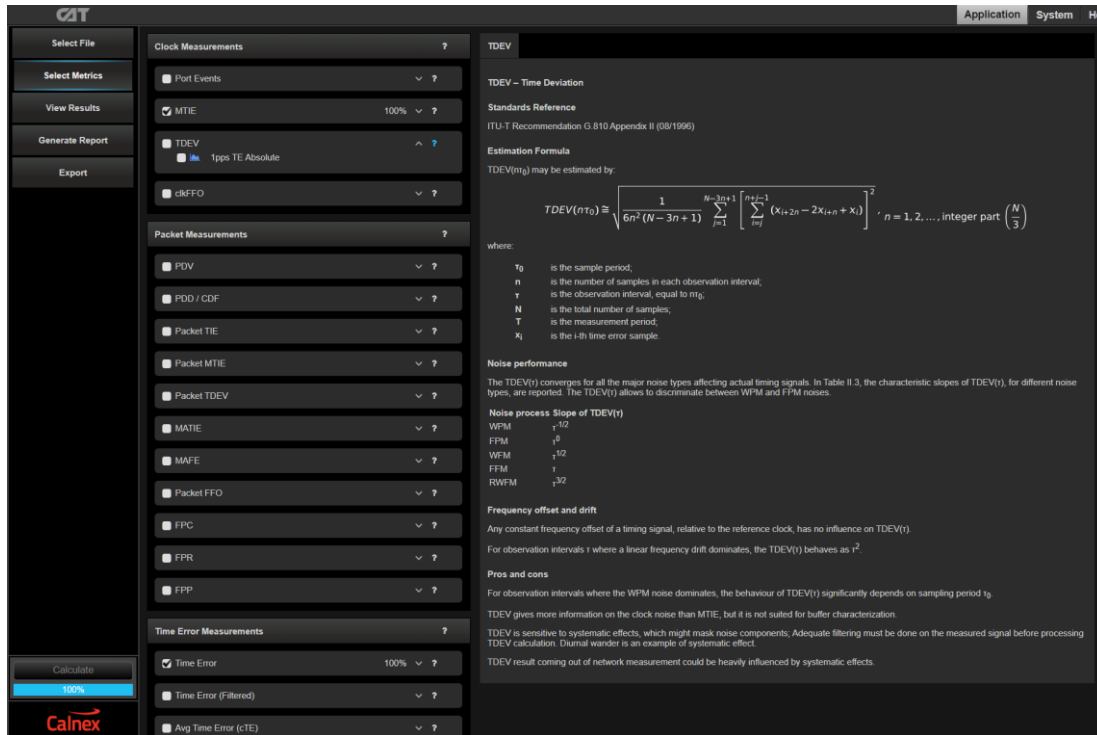
- Navigate to the available metrics by using the tabs at the top of the window.



- The O-RU performance meets the requirements when the output is within the applied masks and thresholds. This is indicated in the top-right area of the CAT display.



Note: The complete set of available metrics can be viewed by clicking **Select Metrics**. Each metric can be expanded by clicking on the “v” icon to the right of the metric name. Help is also available for each metric by clicking the “?” icon.



7.3. Performance Test: SyncE Operation

To test the “Ideal Operation” scenario, no impairments are applied to the input of the O-RU.

“Normal Operation” is emulated by applying a wander pattern to the SyncE input of the O-RU. O-RAN.WG4.CONF states that in the “Normal Operation” scenario SyncE (if used) provides “*Within normal operating limits*” O-RU inputs as specified in *CUS-Plane Specification...*”.

The O-RAN.WG4.CUS specification details performance specifications for the frequency error and SyncE performance applicable at the input to the O-RU. These limits are detailed in the table below.

Table 9: SyncE wander limits for O-RU input

O-RU	LLS Architecture	SyncE Wander Stimulus
O-RU (Class A O-DU) ¹	C1	15ppb (fixed offset) ²
O-RU with EEC	C2 and C3	G.8262 Wander Tolerance (same as G.8262.1 Level 2) ³
O-RU with eEEC	C2 and C3	G.8262.1 Level 1 Wander Tolerance ³

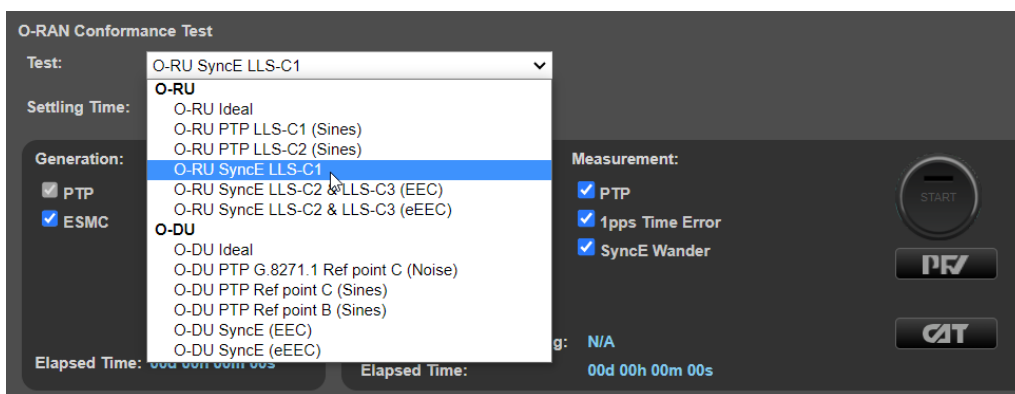
Notes:

- As the O-RAN.WG4.CONF specification does not consider an O-RU with a Class B O-DU, this has not been included.
- LLS architecture C1 implements a direct connection from the O-DU to the O-RU. 15ppb is the worst-case frequency error budget at the O-DU output as per O-RAN.WG4.CUS Table H.2.2-1 and clause 11.3.2.1 Note 1.
- LLS architectures C2 and C3 implement a fronthaul network delivering timing to the O-RU; in these cases, the SyncE wander requirements for O-RAN fronthaul apply as per O-RAN.WG4.CUS clause 11.2.5.3.

7.3.1. Procedure – SyncE Input Test

The test stimulus is automatically selected depending on the selected test within the O-RAN Conformance Test app.

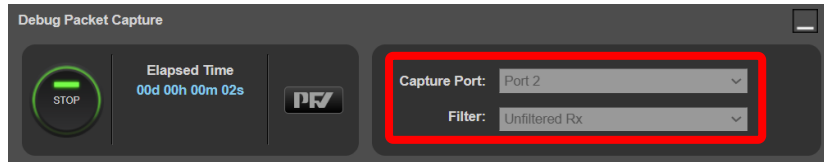
1. Navigate to the **O-RAN Conformance Test** app.
2. From the **O-RAN Conformance Test**: drop-down, select the type of test required:
 - **O-RU Ideal** (no impairment pattern).
 - **“O-RU SyncE...”** to apply the associated SyncE wander patterns as detailed in the table in the previous section.



3. In the **ESMC Generation (Port 1)** app, confirm that the appropriate settings have been configured to enable the O-RU to use SyncE as a reference as detailed in Section 5.4.

- From the **Generation** section of the conformance test app, press **Generate**. This starts PTP and ESMC message generation on both ports of the Paragon-neo.
- If you are using an O-DU or O-DU Emulator, ensure that this device is correctly synchronized to the Paragon-neo using PTP if the test mode is **O-RAN Traffic Merging (Dual)**, or using 1PPS+ToD if the test mode is **O-RAN Traffic Merging (Single)**.
- If you are using an O-DU or O-DU Emulator, ensure that this device is correctly configured and is communicating with the O-RU as expected.

If you are using one of the O-RAN Traffic Merging test modes, using the **Unfiltered Rx** filter in the **Debug Packet Capture** app may be useful to observe the traffic that is being received at the selected **Capture Port** of the Paragon-neo.

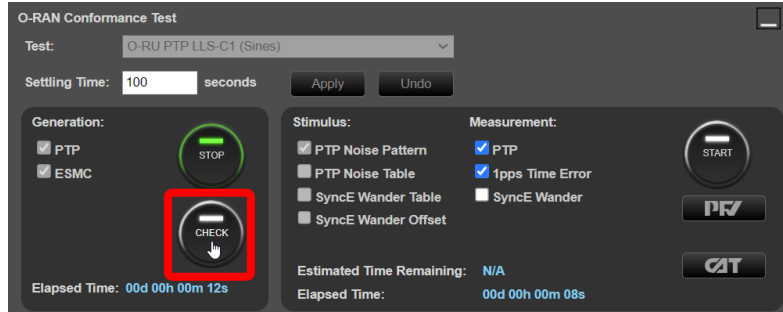


Running a debug packet capture will generate a .pcap capture file. This mechanism works in the same way as making standard timing captures: the resultant file will be saved in a timestamped sub-folder within the **\Sessions** folder on the instrument. Information about accessing the capture file for analysis in a packet analysis tool (e.g. WireShark) can be found at the link below.

<https://calnexsolutions.atlassian.net/wiki/spaces/KB/pages/379715585/Paragon-neo+Getting+Capture+Files+and+Logs>

Note: More information regarding the operation of the O-RAN Traffic Merging modes is in Section 8.

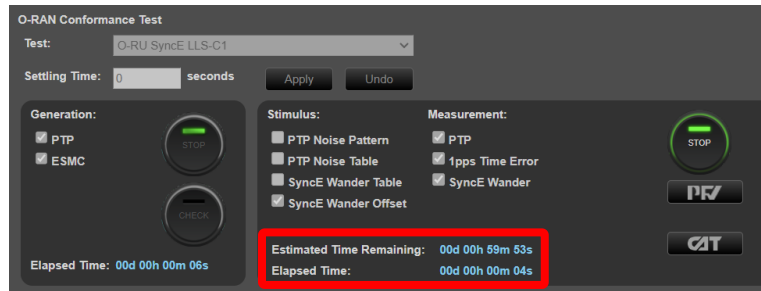
- Confirm that the O-RU is synchronized to the Paragon-neo and, if necessary, is correctly communicating with the O-DU or O-DU Emulator to enable the correct operational state for the conformance test to be performed.
- Pressing **Check** at any time will run a simultaneous timing capture of the O-RU, and the CAT application will open in a new browser tab – this can be used to check current timing performance before starting the test.



- If you are making a simultaneous OTA measurement with Sentinel on the O-RU air interface, refer to Section 9.5 for instructions.
- Wait for the measured output(s) of the O-RU moving from a ramp to stable condition to indicate lock has been achieved.
- If the O-RU does not achieve lock, then troubleshoot the configuration of the O-RU and Paragon-neo to determine the root cause.

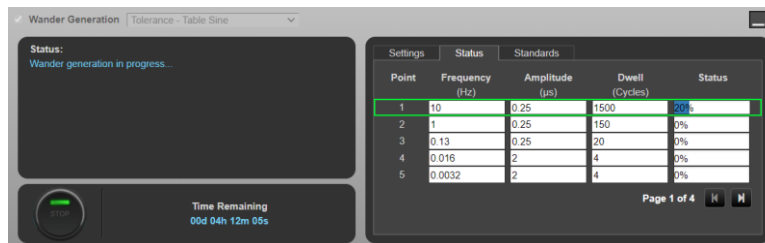
- Once the DUT is stable, in the **Stimulus/Measurement** section, press **Start** to run the measurement.

The **O-RU Ideal** measurement should be run for at least 1000s. The tests that apply stimulus to the SyncE input of the O-RU must be run until at least the *Estimated Time Remaining* has counted down to zero.



If you are making a simultaneous OTA measurement with Sentinel on the O-RU air interface, refer to Section 9.5 for instructions.

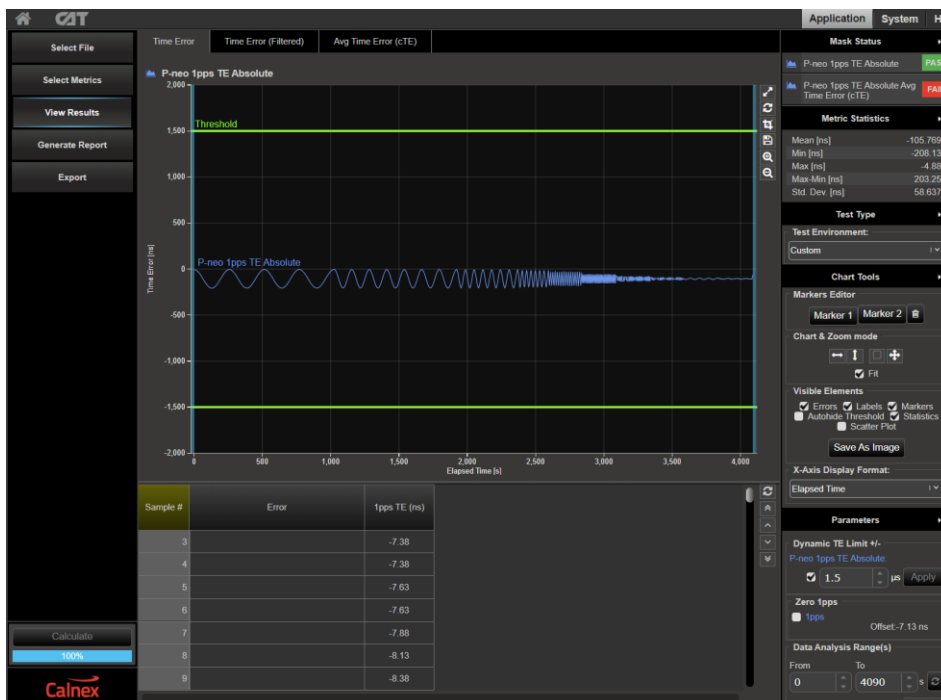
- If you are testing LLS C2 or C3 architectures, the progress of any applied wander can be observed by navigating to the **Status** tab of the **Wander Generation** app. The current position within the table of patterns is indicated by the green box. Note that the table can span multiple pages.



7.3.2. Results Analysis

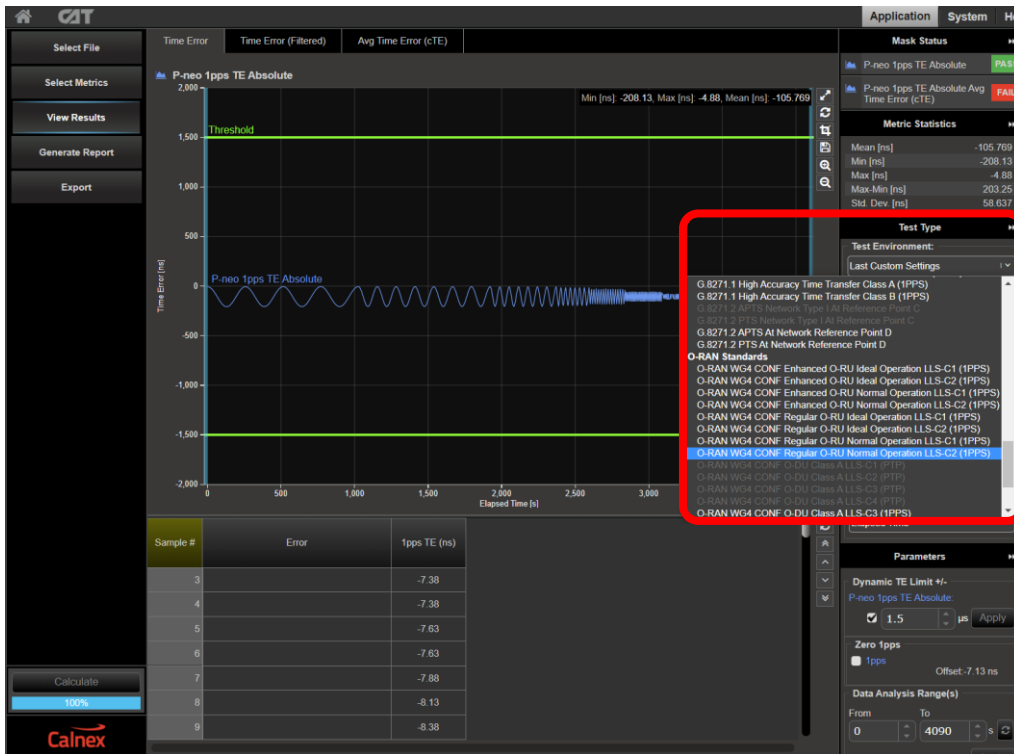
This section focuses on analyzing measurements of the O-RU 1PPS output. If you are making a simultaneous OTA measurement with Sentinel on the O-RU air interface, refer to Section 9.6 for instructions.

- From the **O-RAN Conformance Test** app, click on **CAT**. The Calnex Analysis Tool will open in a new browser tab displaying the default metrics.

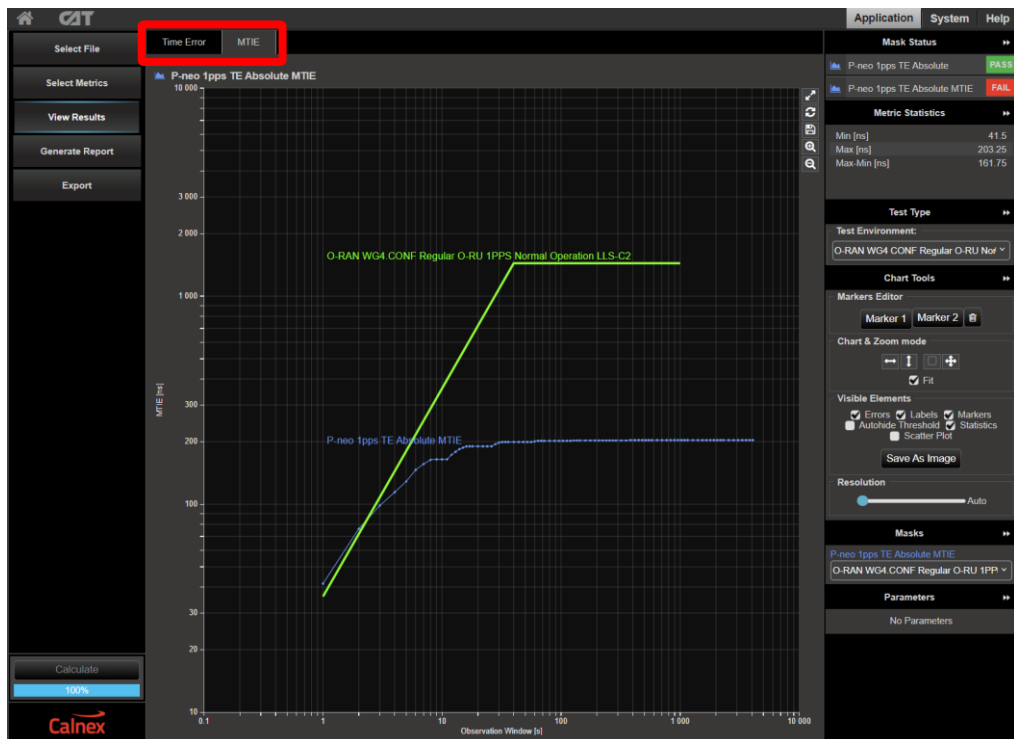


- Select the appropriate **Test Environment** for the current test.

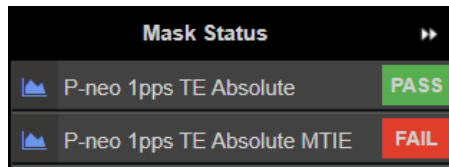
The **Test Environment** function automatically configures the displayed metrics, masks, and thresholds to a range of preset values such as those required for testing compliance to device or network standards.



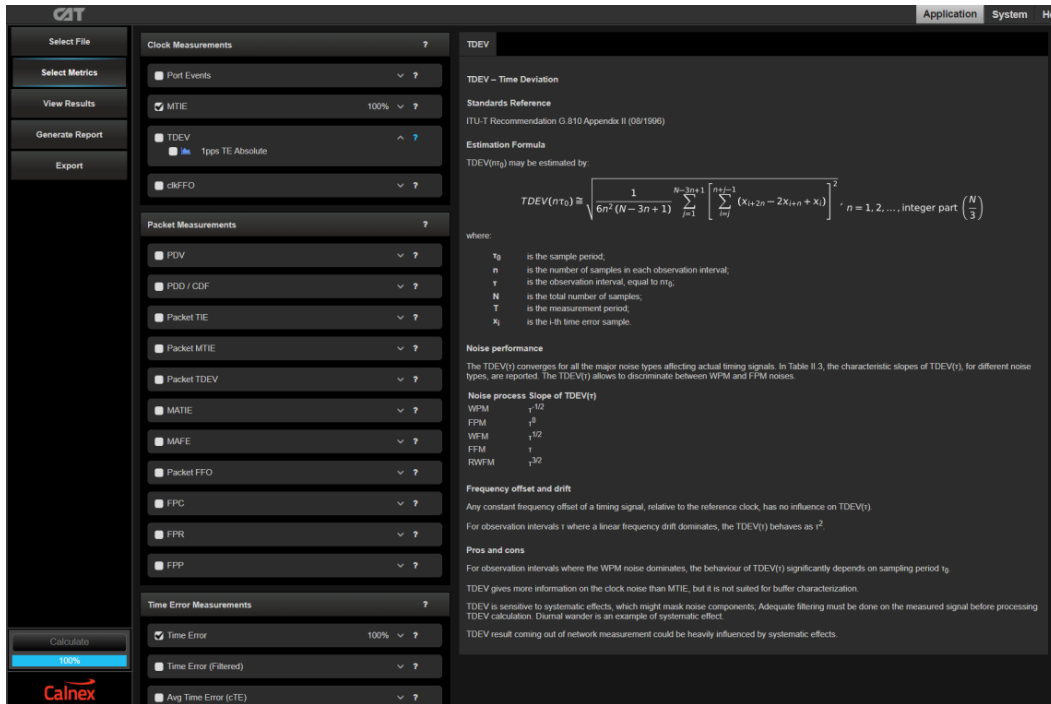
- Navigate to the available metrics by using the tabs at the top of the window.



- The O-RU performance meets the requirements when the output is within the applied masks and thresholds. This is indicated in the top-right area of the CAT display.



Note: The complete set of available metrics can be viewed by clicking **Select Metrics**. Each metric can be expanded by clicking on the “v” icon to the right of the metric name. Help is also available for each metric by clicking the “?” icon.

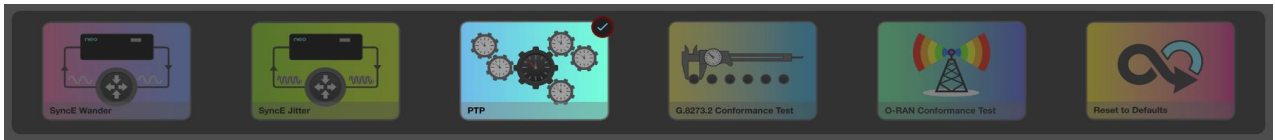


7.4. Performance Test: Simultaneous PTP and SyncE Noise

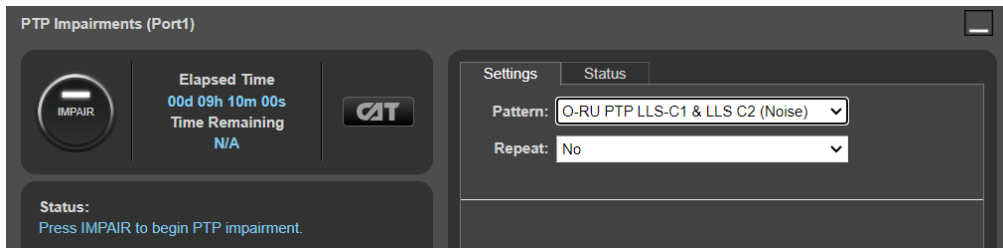
The **O-RAN Conformance** app currently does not have an option to automatically apply PTP and SyncE impairments simultaneously, therefore this procedure uses the **PTP** preset. The functionality to automatically apply the test steps below within the O-RAN Conformance app will be available in a future release.

This procedure specifies the “Network Noise” PTP impairment pattern (not “Sines”) because as per O-RAN.WG4.CONF it is “*more representative of real network conditions*” and additionally the “Sines” patterns are 40 minutes in duration and therefore do not allow enough time for the full suite of SyncE impairment tones to run (approx. 3-4 hours dependent on the pattern). However, the user can select other PTP impairment patterns to run, and repeat them if required, to ensure good test coverage against the SyncE tones.

1. Set up the Paragon-neo and O-RU as detailed in Sections 4 and 5 of this document with one change: in the **Run Apps** page, in the **Presets** panel select the **PTP** preset, not the *O-RAN Conformance* preset:



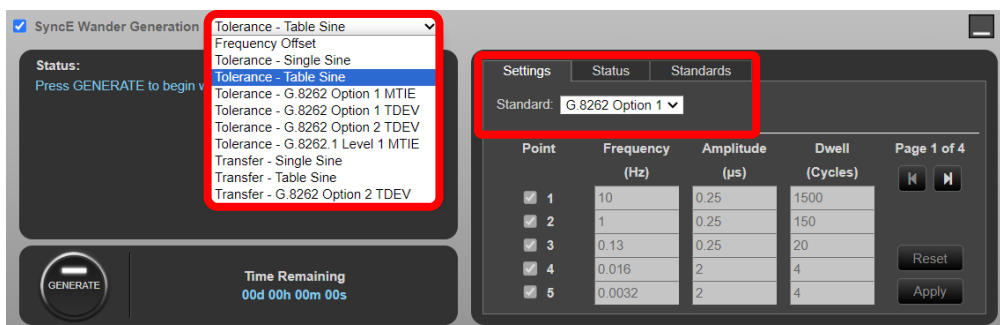
2. In the **ESMC Generation (Port 1)** app, press **Generate** to begin ESMC Generation on Port 1.
3. If an O-DU or O-DU Emulator is connected to Port 2 and it makes use of SyncE, in the **ESMC Generation (Port 2)** app, press **Generate** to begin ESMC Generation on Port 2.
4. In the **PTP Emulation** app, press **Generate** to begin generating PTP. The O-RU should now begin to synchronize to the Paragon-neo.
5. In the **PTP Impairments (Port 1)** app, select the **O-RU PTP LLS-C1 & LLS C2 (Noise)** pattern, then press **Impair** to begin the PTP impairment.



Allow the device to settle after the instantaneous change in cTE that is inherent in the impairment pattern. There is no specification for the maximum settling time however 10 minutes is reasonable.

6. In the **SyncE Wander Generation** app, configure one of the following **Tolerance – Table Sine** wander patterns as appropriate for the O-DU under test as detailed in Table 9 in Section 7.3 of this document:

- **Standard: G.8262 Option 1**
- **Standard: G.8262.1**



7. If measuring the O-RU 1PPS signal, in the **1pps Time Error Measurement + Time of Day** app, press **Measure**.
8. If making a simultaneous OTA measurement with Sentinel on the O-RU air interface, refer to Section 9.5 for instructions.
9. In the **SyncE Wander Generation** app, press **Generate** to begin the SyncE impairment.
10. **Note that the “Table Sines” are approx. 3-4 hours long, progress can be monitored using the “Time Remaining” indicator in the SyncE Wander Generation app. As the “Network Noise” PTP impairment profile is approx. 9 hours long the SyncE Wander must be restarted by the user when it completes to ensure continuous SyncE Wander is applied throughout the full PTP impairment pattern – this requires two restarts and monitoring of the SyncE impairment progress. If the SyncE is not restarted immediately this is acceptable, however it should be restarted within 10 minutes.** The ability to repeat SyncE Wander “Table Sines” will be available in a future release.
11. Wait for the PTP and SyncE wander impairment patterns to complete and **Stop** all measurements.

7.4.1. Results Analysis

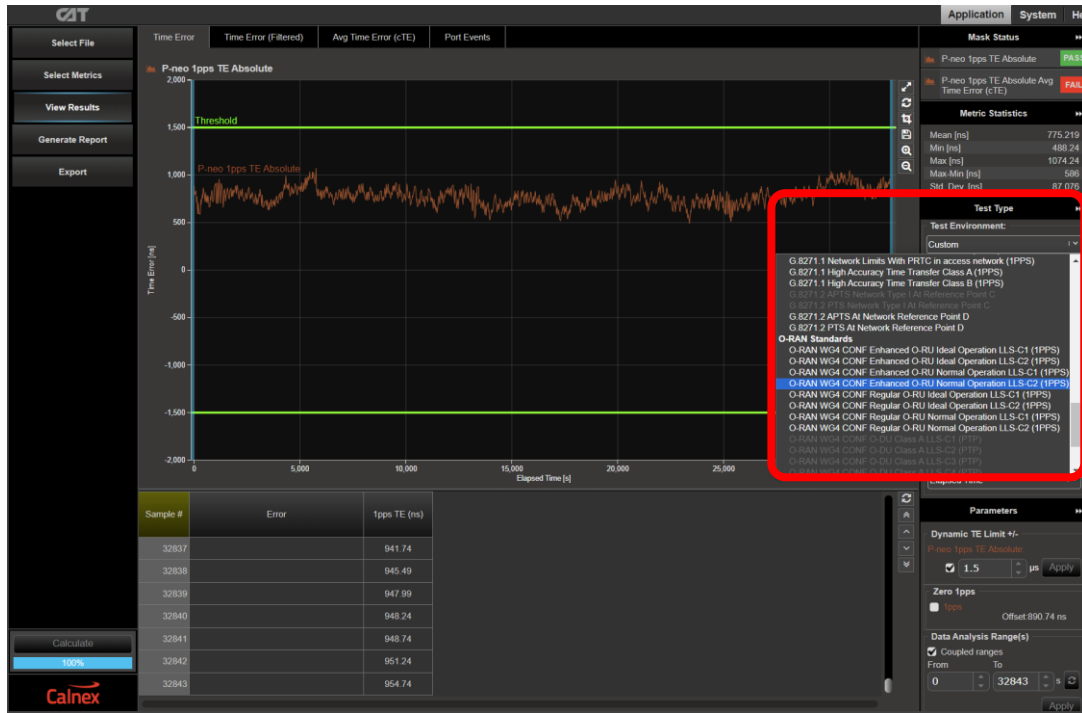
This section focuses on analyzing measurements of the O-RU 1PPS output. If you are making a simultaneous OTA measurement with Sentinel on the O-RU air interface, refer to Section 9.6 for instructions.

1. From the **PTP Emulation** app, click on **CAT**. The Calnex Analysis Tool will open in a new browser tab displaying the default metrics.



- 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.

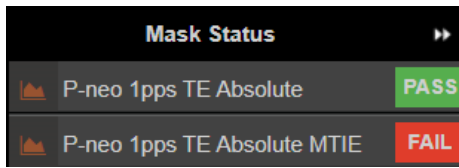
Select the appropriate **Test Environment** for the current test.



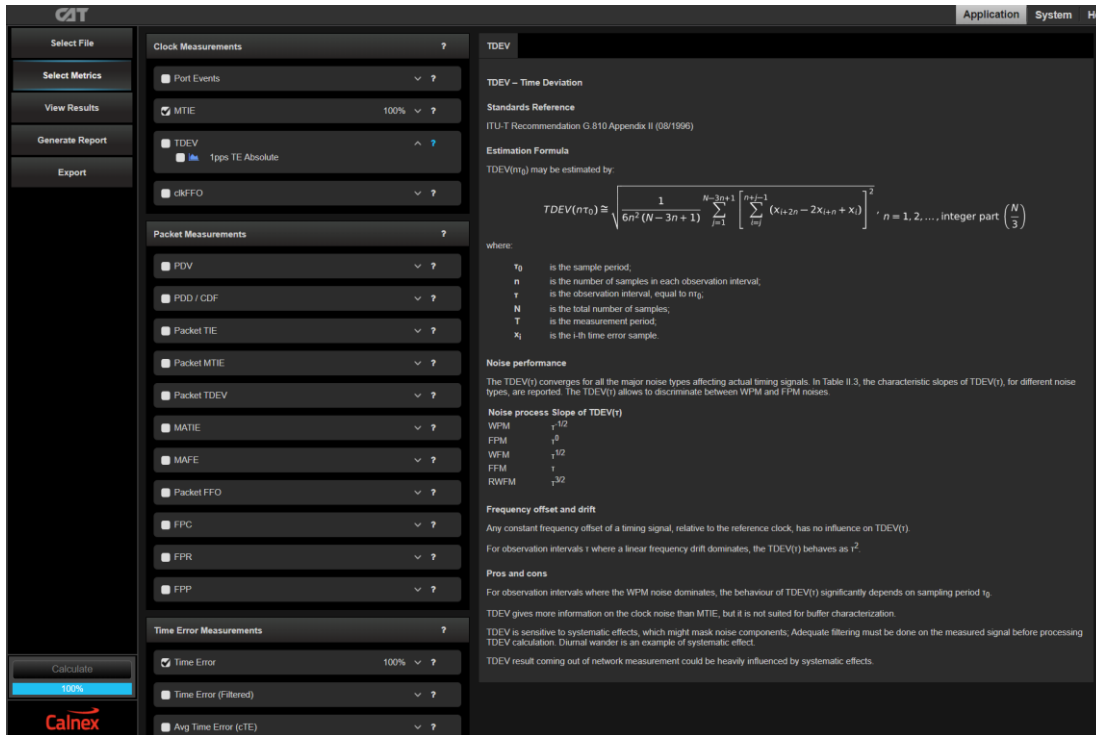
- Navigate to the available metrics by using the tabs at the top of the window.



- The O-RU performance meets the requirements when the output is within the applied masks and thresholds. This is indicated in the top-right area of the CAT display.



Note: The complete set of available metrics can be viewed by clicking **Select Metrics**. Each metric can be expanded by clicking on the “v” icon to the right of the metric name. Help is also available for each metric by clicking the “?” icon.



7.5. Further Analysis

Testing the O-RU in real network conditions can also provide more insights into expected device performance. 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.

8. O-RAN Traffic Merging Operation

The ORAN Traffic Merging (Single) and O-RAN Traffic O-RAN Traffic Merging Test Modes are specifically for use when the O-RU requires traffic from a real or emulated O-DU on the same physical interface as the S-Plane traffic from Paragon-neo. This section provides details on the specific operation of Paragon-neo when using either of these Test Modes.

8.1. O-RAN Merge modes - Similarities with other Test Modes

The operations below work the same as they do for all other test modes:

- Mixed port rate operation, e.g. O-RU on a 1G port, O-DU on a 25G port
- Adding impairments (both PTP and SyncE)
- Making captures and measurements of the O-RU
- SyncE physical layer operation

8.2. O-RAN Merge modes - Differences with other Test Modes

The operations below have differences with all other test modes:

- If PTP Generation is not running for a port, then ESMC traffic will not be generated by Paragon-neo for that port.
 - ESMC generation is coupled with PTP Generation – start PTP to begin sending ESMC packets (even if ESMC generation has been started in the Paragon-neo GUI).
- Background traffic generation (by Paragon-neo) is not supported.

8.3. Traffic generated by the O-RU and O-DU/O-DU Emulator

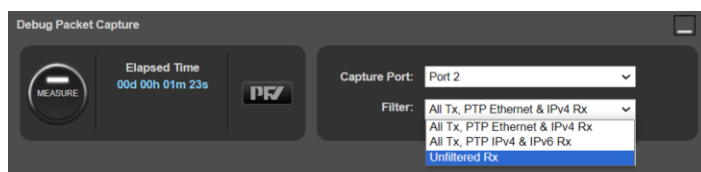
- **At all times**, all PTP and ESMC traffic is filtered out *upon ingress* to a Paragon-neo port (after being captured).
 - If the O-RU or O-DU requires PTP or ESMC traffic, then the Paragon-neo must be configured to generate this.
- **At all times**, all non-PTP/ESMC traffic will be passed through the Paragon-neo from one selected (active) port to the other selected (active) port.
- The Paragon-neo timeTransmitter emulators will *not respond* to ARP and PING – these messages are passed through the Paragon-neo and are not terminated.

8.4. Using the Debug Packet Capture App for troubleshooting

Running a **Debug Packet Capture** will generate a .pcap capture file. This mechanism works in the same way as making standard timing captures: the resultant file will be saved in a timestamped sub-folder within the **\Sessions** folder on the instrument.

Information about accessing the capture file for analysis in a packet analysis tool (e.g. WireShark) can be found at the link below.

<https://calnexsolutions.atlassian.net/wiki/spaces/KB/pages/379715585/Paragon-neo+Getting+Capture+Files+and+Logs>



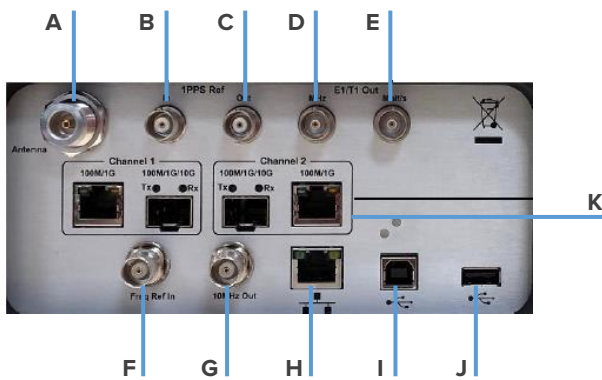
- Use “**Unfiltered Rx**” to see the traffic from the connected devices.
- Use the other options to see the outgoing PTP traffic generated by Paragon-neo and the incoming PTP traffic from the connected devices.
 - “**All Tx**” means PTP, MLD, ND, ARP, PING & IGMP traffic types are captured. Other packet types are not captured.
- When making a debug capture in merge mode, “**All Tx**” means packets originated by Paragon-neo. Non-Paragon-neo originating traffic is captured as **Rx** on the ingress port, not as **Tx** on the egress port.

9. Measuring O-RU Performance Over-the-Air (OTA) using Sentinel

The Time Error performance of the O-RU can be measured on its RF output at the same time as, or instead of, measuring its wired 1PPS output. To do this, the following steps are required to set up the Sentinel before performing the conformance tests detailed in Sections 6 and 7.

9.1. Connections to Sentinel

Sentinel Left Panel



- A. Antenna**
GNSS antenna connector
- B. 1PPS in – TTL / 50Ω**
External 1PPS phase reference input
- C. 1PPS out – TTL / 50Ω**
Internal 1PPS timing output from Rubidium oscillator
- D. E1/T1 clock output (MHz)**
User-settable E1 or T1 clock output, BNC 75Ω
- E. E1/T1 framed output (Mbit/s)**
User-settable E1 or T1 framed output, isolated BNC 75Ω
- F. External reference**
Input for precision external reference (1, 5 or 10MHz clock)
- G. Reference signal output**
10MHz frequency from the internal reference or the external reference (if selected)
- H. Ethernet network connector**
Standard RJ45 connector for connecting the instrument to a PC or LAN using the 10/100BASE-T protocol, enabling remote control over Ethernet
- I. USB type B connector**
USB Device port (for future use)
- J. USB type A connector**
USB Host port
- K. 10GbE packet module**
Up to 2 channels per module, RJ45 or SFP connectors

1. Connect the Sentinel's GNSS antenna connector to a GNSS antenna or GNSS Simulator using an N-type male-to-male cable and appropriate converters as required.
2. Connect the **1PPS Ref Out** and **10MHz Out** ports on the Sentinel to the Paragon-Neo **1PPS Ref In** and **Clock Reference In** ports respectively for use as external references using two BNC male-male cables. These cables should not exceed 3m in length.
3. If you are making a conducted OTA measurement: connect the **Ant1** port of the Sentinel's 5G OTA module to the O-RU 5G antenna port.

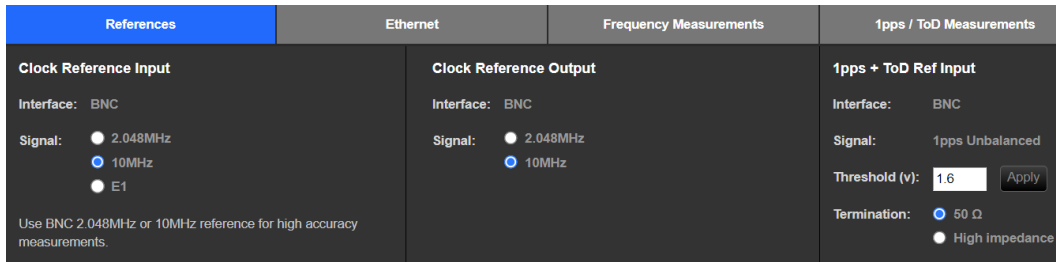
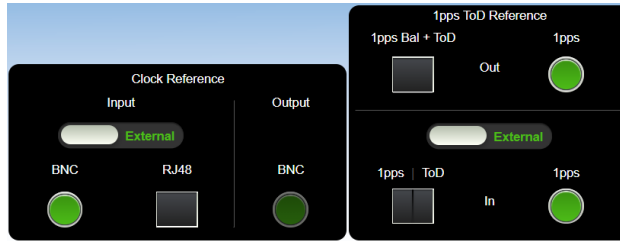
WARNING: The signal at the OTA card input should not exceed -20 dBm. Use RF attenuators to attenuate the O-DU's transmitted signal power to ensure the maximum power input to the Sentinel antenna port is less than -20 dBm. Failure to do so may result in an incorrect measurement and/or damage to the OTA card that would not be covered by warranty.

If you are making a radiated test, attach the 5G OTA antenna to the **Ant1** port of the Sentinel's 5G OTA module. Position this such that the signal from the O-RU antenna will be optimally received, avoiding multipath or other interference effects.

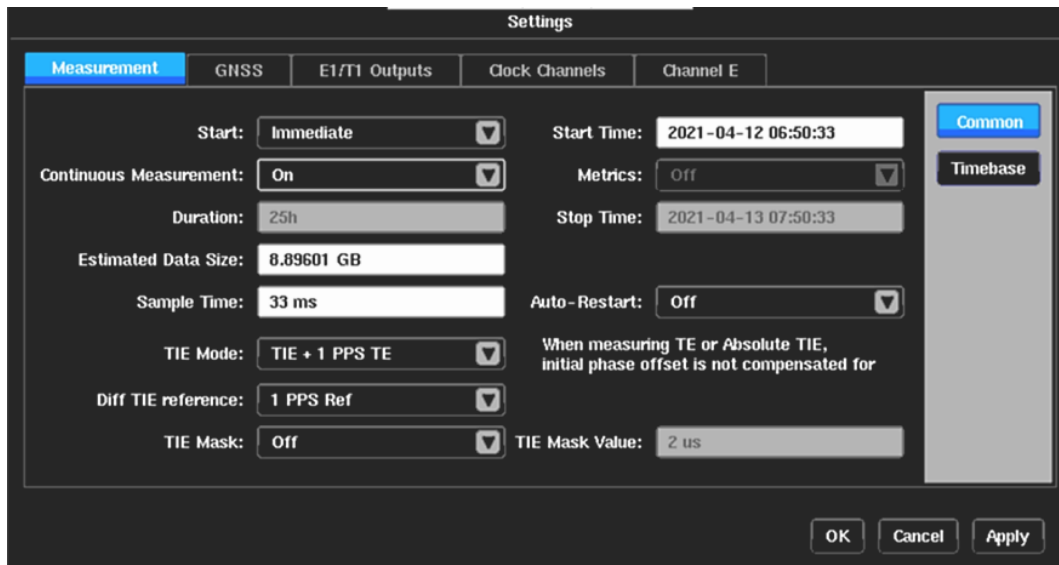
4. When powered up, the Sentinel will display a screen with two options. The **Recall Settings** option allows previously saved configuration files to be re-loaded, automatically reconfiguring the instrument to the saved state. The **Manual Setup** option allows manual configuration. Please see the *Sentinel User Guide* for more details.
5. The Sentinel can be operated by its integrated touchscreen, or remotely by using a VNC viewer client. For guidance on how to enable and use VNC access, please see the *Sentinel User Guide*.

9.2. Setup Configuration

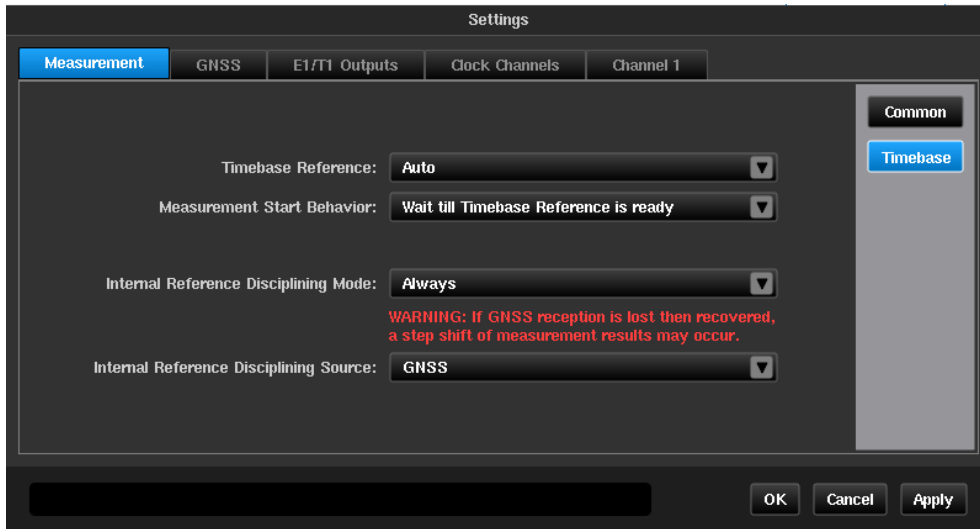
- The Paragon-neo must be configured to use the references provided by the Sentinel. On the Paragon-neo GUI, select **Setup Ports** then configure the instrument to use the unbalanced **1PPS TOD Reference** and **10MHz Clock Reference** inputs.



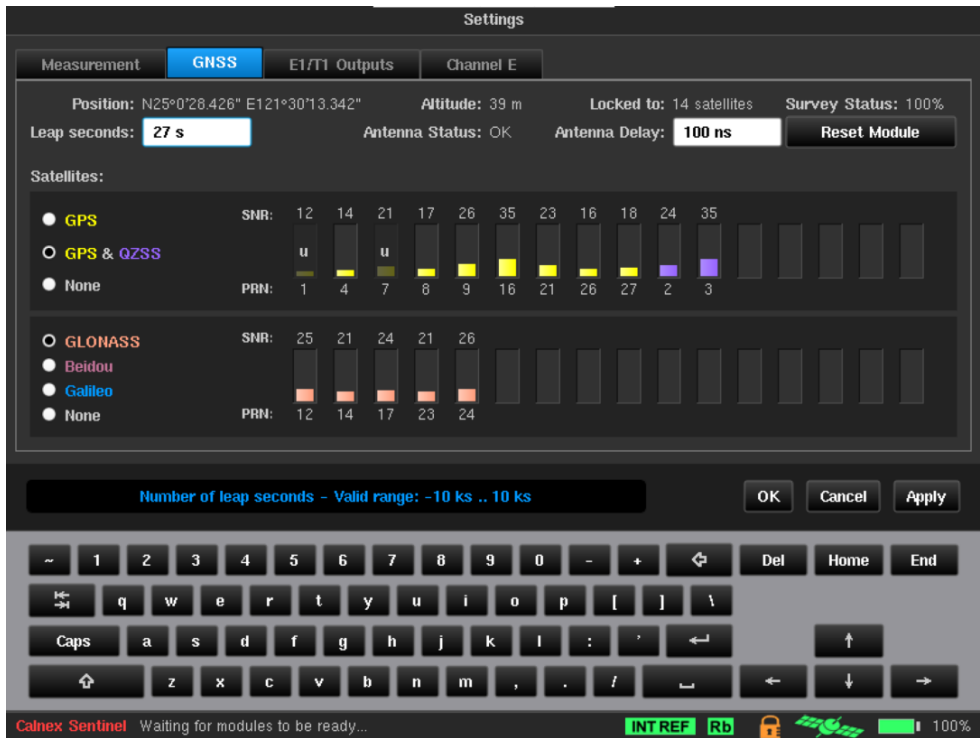
- Configure the Sentinel as follows: Set the measurement duration or enable continuous measurement on the **Settings > Measurement > Common** screen. One cycle of the impairment pattern has a duration of around 3000 seconds. The measurement can also be manually stopped using the appropriate button in the GUI if the test is to be observed. In this case, ensure that the configured duration is sufficiently long.



- Ensure the GNSS input is connected to the Sentinel, then select it as the **Internal Reference Disciplining Source** on the **Settings > Measurement > Timebase** screen.



- Select the appropriate GNSS constellation(s) and Antenna Delay on the **Settings > GNSS** screen. Ensure that the **Antenna delay** value includes both cable delay and antenna group delay.

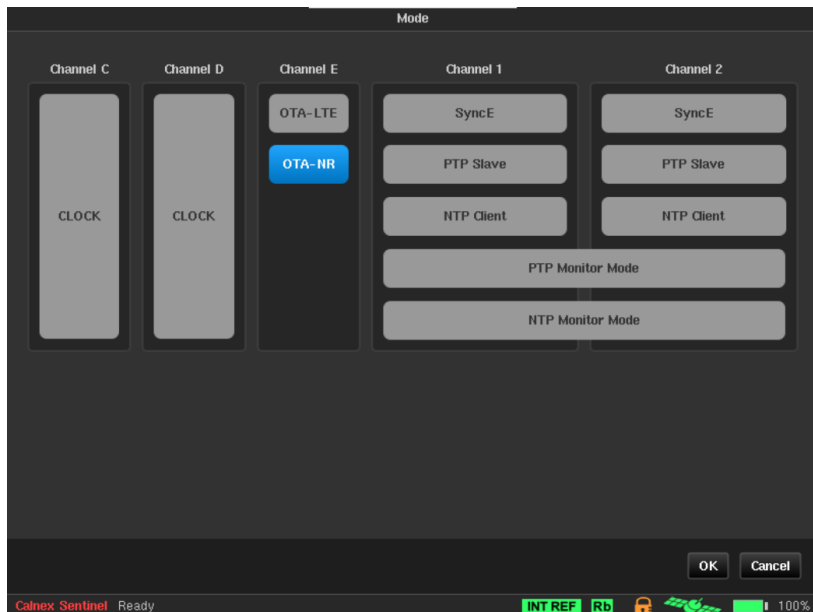


- Press **Apply**. This will cause the GNSS module to reset and begin a new survey of the configured constellation(s).

NOTE: Changing constellations will cause the Sentinels Rubidium’s timebase to unlock and it may experience a step change on its input from the GNSS receiver’s 1PPS output. It is recommended that the Sentinel remains disciplining to GNSS for at least six hours after changing constellations. If the Sentinel has not been disciplined for more than a week, this period should be at least 12 hours.

9.3. Test Configuration

1. From the Sentinel main menu, click the **Mode** button. On the resulting screen, ensure the **OTA-NR** block is selected to enable 5G OTA measurement; the block will be blue when enabled.

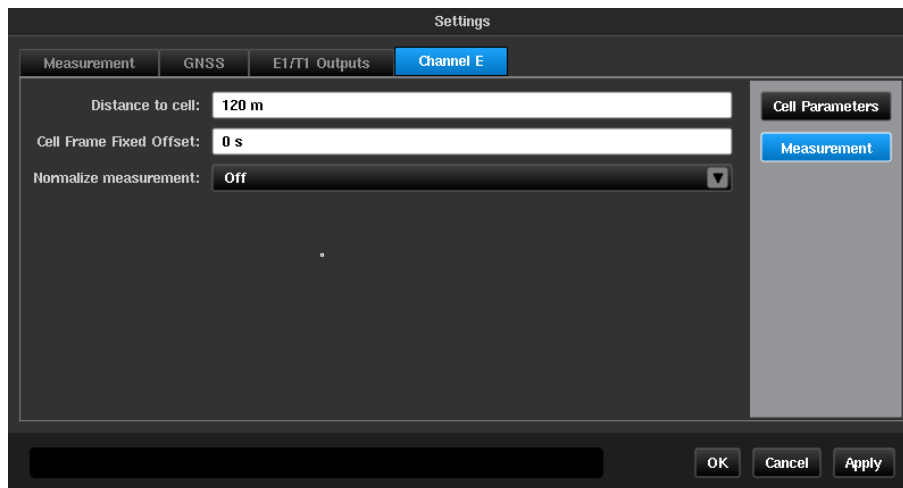


2. Click **OK**.

9.4. 5G NR Software Configuration

After verifying the physical connections have been completed as described in Section 9.1, the OTA measurement parameters should be configured as follows.

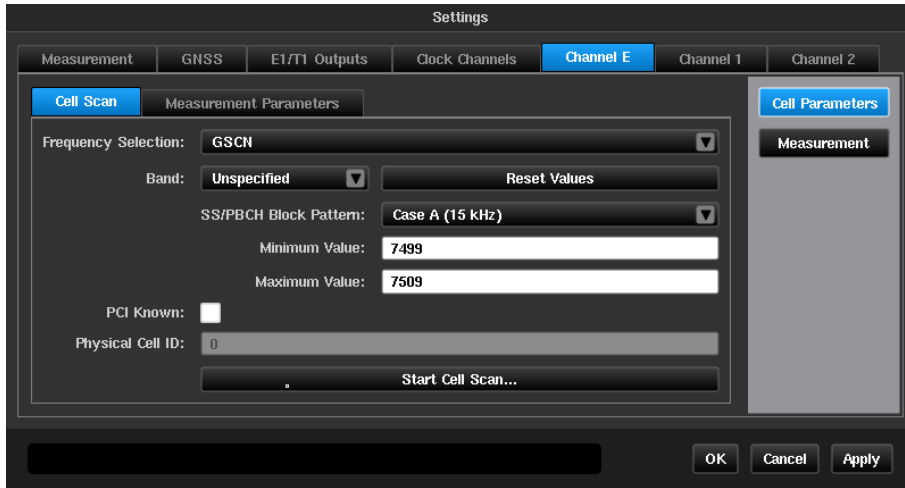
1. Go to the **Settings** screen and select the relevant channel for the OTA measurement.
2. Click on the **Measurement** button on the right side of the screen.



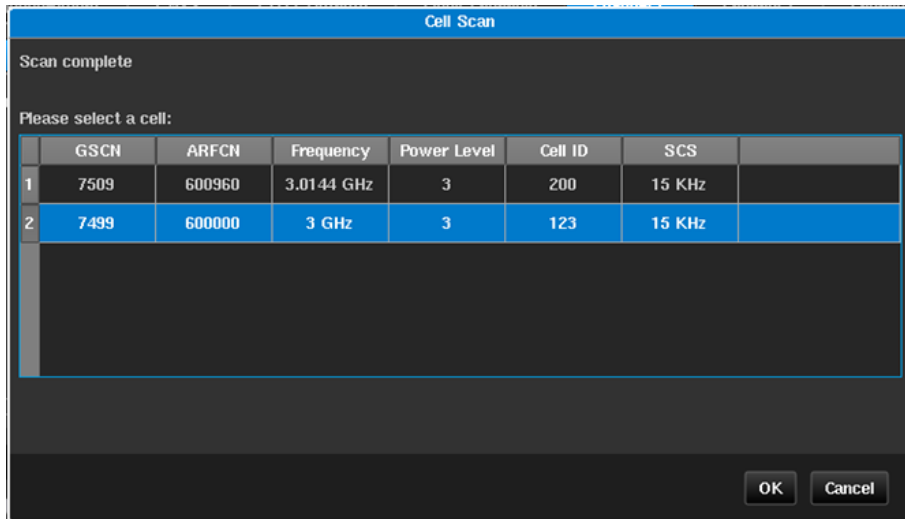
3. If you are making a radiated OTA measurement, enter the distance the Sentinel is from the O-RU antenna in the **Distance to cell** field. This is used to compensate for the signal's time of flight and is based on the speed of light.

If this is a conducted test, enter the cable delay due to the length of the cable that attaches the OTA card to the O-RU DU; a value of 5ns/m should be used.
4. If compensation is required for a known offset for 1PPS (e.g. due to internal O-RU delay between the RU and antenna in a radiated test) then enter this in the **Cell Frame Fixed Offset** field.
5. Turn **Normalize measurement** off.

6. Select the **Cell Parameters** button and **Cell Scan** tab.



7. Specify the **synchronization block downlink frequency**. Note that this may not be the same as the channel center frequency. This can be entered as the absolute frequency, the NR absolute radio-frequency channel number (nrARFCN), or the Global Synchronization Channel Number (GSCN). Enter one of these values and the other two will autofill.
8. Enter the **SS/PBCH Block Pattern**. This specifies the subcarrier spacing.
 Note: Selecting the incorrect **Case** may result in an offset in the measurement result, so ensure that this matches the O-RU configuration.
9. Enter the **PCI** (Physical Cell ID), if known.
10. Click on **Start Cell Scan...** to scan the selected frequency and display a selectable list of possible Cell IDs for the OTA-NR measurement.

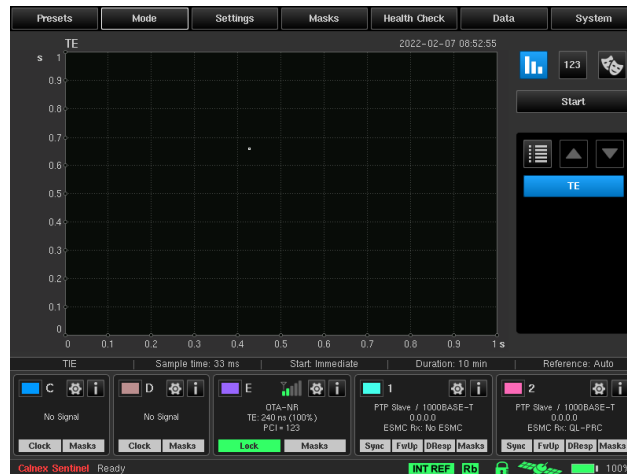


11. Once the desired signal is found, click to highlight the appropriate row, then click **OK** to set these as the measurement parameters. If no signal is found, consult the troubleshooting tips in Section 9.4.1 below.
12. Alternatively, signal parameters can be manually entered under the **Measurement Parameters** tab without a cell scan being required. If you are manually entering parameters, only one of the three frequency parameters is required – SSB Downlink, GSCN or ARFCN. When one of these is entered, the other two will automatically populate. One of these frequency parameters, along with PCI (Physical Cell ID) and SS/PBCH Block Pattern, are required fields.

- Once the Sentinel has detected the cell it will start the process of locking onto the signal to allow measurement. If the signal is out of lock, the lock LED will be red:



When it is in lock, the LED will be green. The LED will be yellow if Sentinel loses lock and then regains lock during a measurement. The power bar graph indicator on the main screen indicates how much power is detected. Ideally, all 5 bars should be lit, however, the measurement should still run with fewer.



9.4.1. OTA Signal Troubleshooting

Subcarrier spacing – When Case B or Case C is used by a Cell, Sentinel can detect and decode the Synchronization Signal Block (SSB) using either setting, since both cases use the same SSB Sub-Carrier Spacing of 30 kHz. However, if the wrong case is selected in the instrument settings, the measurement will have an offset of approximately 70µs.

Disciplining of the internal reference – Be sure that the internal reference is disciplined to either a stable 1PPS reference such as from an atomic clock or to GNSS. If the internal Rubidium clock is used in holdover, make sure that power has been maintained since it was last disciplined either by maintaining mains power to the Sentinel or by putting the Sentinel in holdover (transport mode) which will maintain power to the Rubidium module using the internal battery (if fitted). If holdover is being maintained for an extended period, note that the internal reference will drift by up to 1×10^{-12} per day.

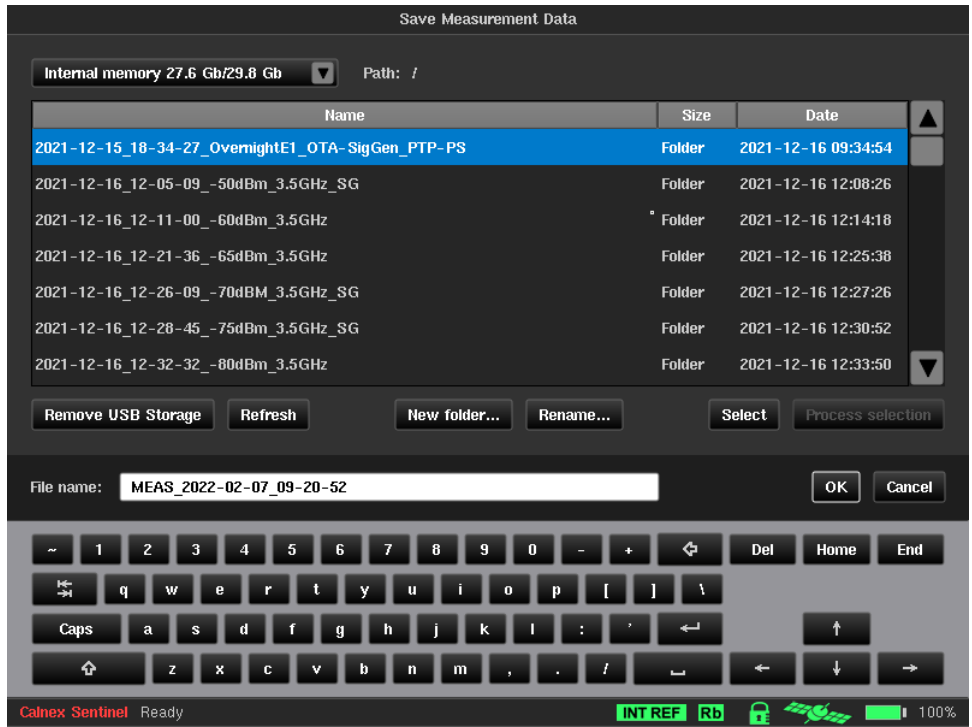
Note: if power is lost to the Rubidium clock, an arbitrary and potentially large phase error of many milliseconds will be introduced until the Rubidium clock is re-disciplined to a suitable reference. This can happen if the Sentinel is turned off without putting it in holdover mode, or if Sentinel is in holdover mode but the internal battery, if fitted, is allowed to completely discharge.

SSB Downlink Frequency – In 5G NR, the Synchronization Signal Block (SSB) is not necessarily at the center frequency of the transmission as it is in 4G LTE. Therefore, the frequency, ARFCN or GSCN of the Synchronization Signal Block should be entered in the SSB downlink field and NOT the center frequency of the transmission.

9.5. Making an OTA Measurement

The procedures in Sections 6 and 7 describe the processes for running the required functional and performance tests, adding impairments and making measurements. As detailed in those processes, the Sentinel can measure the OTA output of the O-RU alongside, or instead of, making a 1PPS measurement using Paragon-neo.

To do this, ensure the signal is locked as per Section 9.3, then on the main Sentinel screen, click the **Start** button. A prompt will appear to select a file name and storage location for the capture data; choose appropriate inputs, then click **OK**.



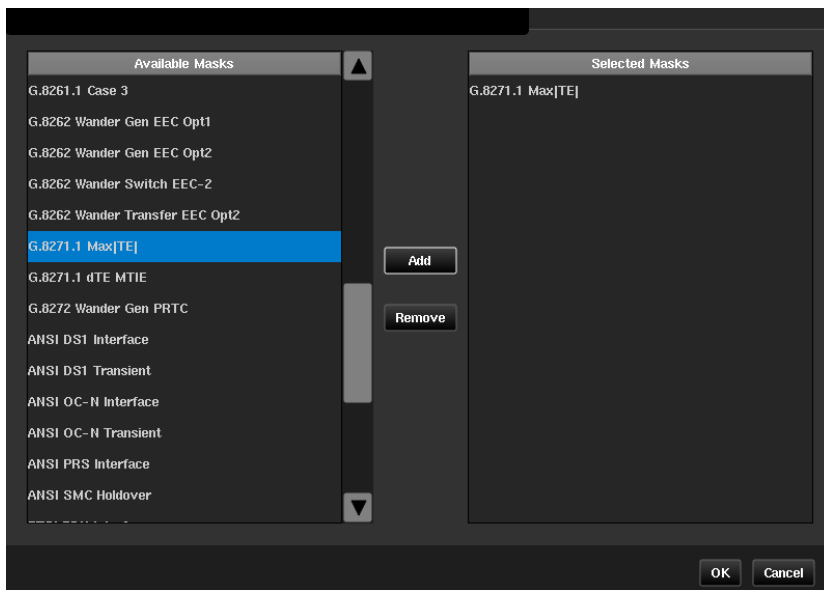
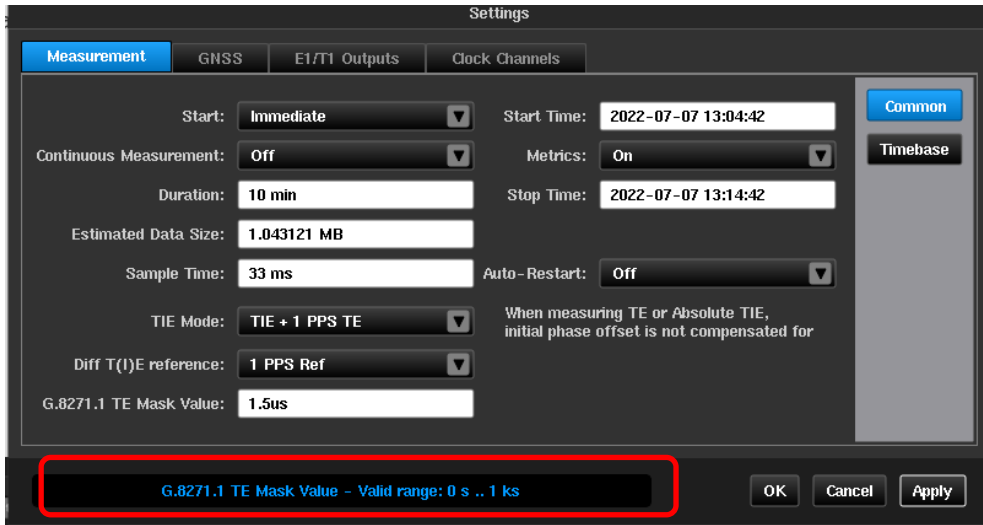
The Sentinel OTA card will start measuring the signal timing:



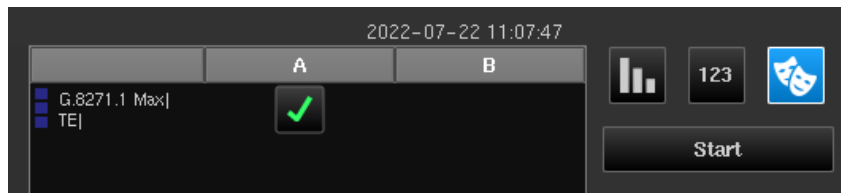
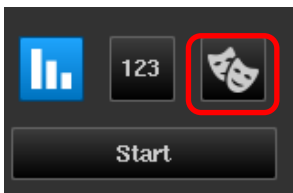
If the Sentinel fails to make enough successful measurements within a particular time window, then the measurement is deemed to have lost lock which will be indicated by a red Lock status indicator. In this case, the Sentinel will initiate a new search to try and find the signal again before continuing the measurement. When successful, the lock LED will turn yellow to indicate that lock was lost during the measurement and is now re-locked. It will turn green again when the measurement is completed.



As this is an OTA measurement, the Time Error should be less than 1.5µs for the Normal Operation test (that is, with the PTP Impairments active). This threshold value can be set in the **Settings > Measurement > G.8271.1 TE Mask Value** field and the mask enabled by adding the **G.8271.1 max|TE|** mask in the mask selection screen (available from the **Masks** icon button on the main screen):



The relevant channel widget will show a green or red **Mask** indicator depending on whether the result is pass or fail respectively. The result can also be checked using the **Masks** icon button on the main screen:



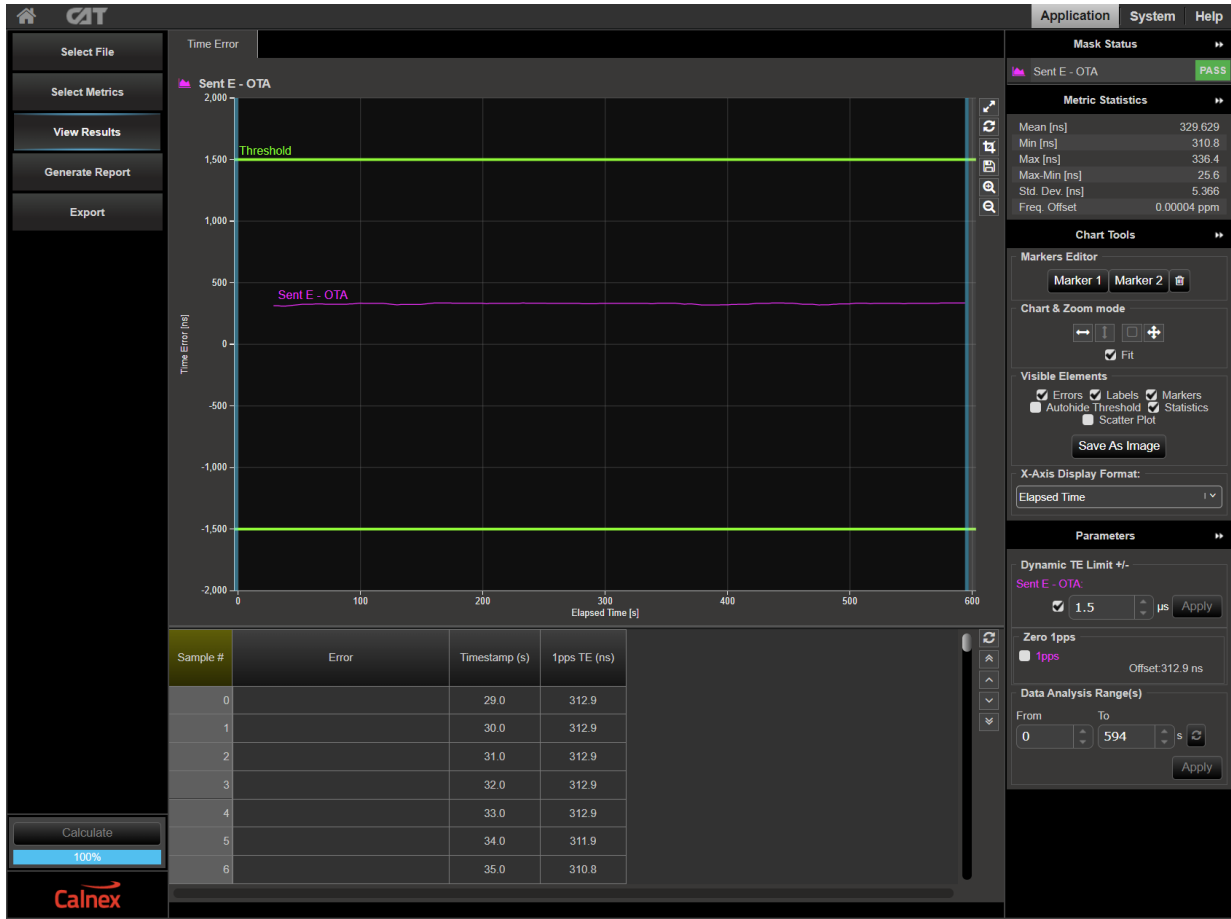
For Ideal Operation, that is, when the PTP Impairment is inactive and the timing inputs to the O-RU are ideal, the limit should be set to 80ns.

9.6. Using CAT to Review Results

The Calnex Analysis Tool (CAT), version 23 or later, can be used to examine the OTA results in more detail.

Extract the measurement files of interest from the Sentinel and transfer them to a PC where the CAT is available (if required, see the *Sentinel User Guide* for guidance on how to do so). On opening these files within CAT, you will be able to select the OTA metric and view the results.

The Time Error performance of the O-RU can be confirmed by configuring the appropriate threshold: for the conformance tests in O-RAN.WG4.CONF section 3.3.3, the OTA Time Error limit is 80ns for the *Ideal Operation* test scenario, and 1.5µs for the *Normal Operation* test scenario. A Pass/Fail indication will be shown in the top-right of the screen.



Example O-RU OTA measurement. Note: O-RAN.WG4.CONF test results will differ from this.



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This information is subject
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