APPLICATION NOTE

# O-RAN Massive MIMO ULPI capable Radio Unit Testing

How to do development and O-RAN WG4 conformance testing for Massive MIMO ULPI radio units

KEYSIGHT

# Table of Contents

# Introduction

This application note focuses on O-RAN Massive MIMO Beamforming and Uplink Performance Improvement (Cat-B ULPI) capable Radio Unit WG4 Conformance and R&D beamforming performance testing.

## Massive MIMO in O-RAN architecture

Massive MIMO (Massive Multiple-Input Multiple-Output) is an advanced wireless communications technology that significantly enhances the capacity and efficiency of wireless networks. It is a transformative technology, playing a critical role in the evolution of modern wireless networks, especially as we advance towards more sophisticated 5G deployments.

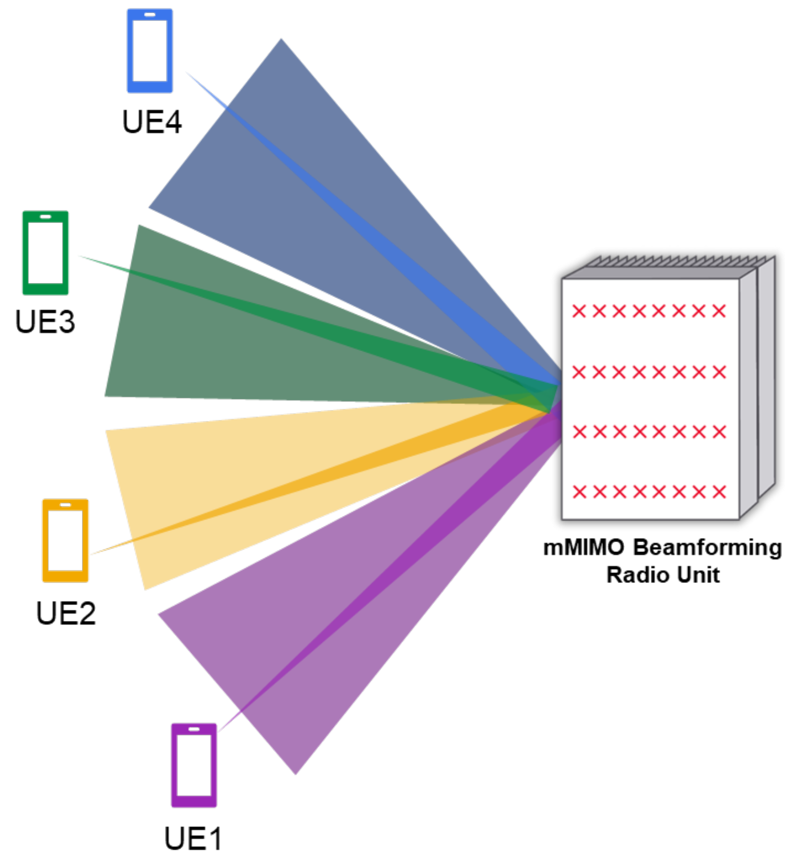


**Figure 1.** Beamforming mMIMO Radio unit provides pre-coded beam for multiple users in different directions.

Massive MIMO technology, which can support up to 64 digital antennas, requires substantial computational power, particularly for beamforming. This computation can occur either in the O-RU (O-RAN Radio Unit) or the O-DU (O-RAN Distributed Unit). However, performing these computations in the O-DU necessitates a large amount of data transfer across the fronthaul interface between the O-DU and O-RU, which would demand significant fronthaul transport capacity and incur excessive costs.

To mitigate the high communication demands between the O-DU and O-RU in Massive MIMO radios, the O-RAN Alliance introduced a new architectural split, known as the Massive MIMO (Cat-B) split or the 7-2x split. This split allocates the RF and low-PHY functions to the O-RU, while the high-PHY, MAC, and RLC functions are managed by the O-DU. By placing the low-PHY functions in the O-RU, the split not only reduces the data transfer requirements but also enables the low-PHY to manage complex tasks, particularly beamforming.

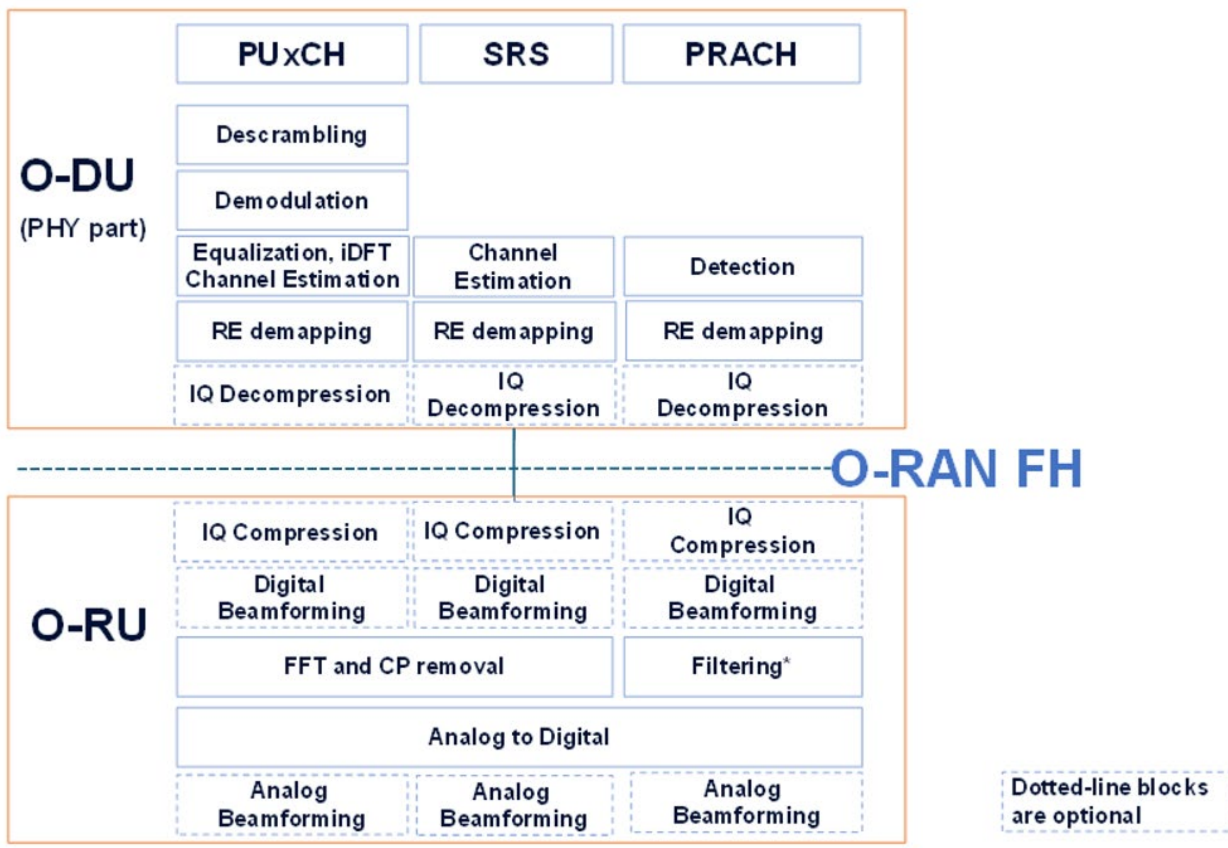


**Figure 2.** Lower Layer UL split description for LTE and NR (Source: O-RAN.WG4.CUS Specification Fig. 4.2.3.1-1)

## What is Massive MIMO Uplink Performance Improvement (ULPI)?

The O-RAN Massive MIMO Cat-B split has limitations in dense network environments with high mobility, often leading to suboptimal performance.

The O-RAN Massive MIMO Cat-B ULPI specification, which stands for Uplink Performance Improvement, aims to enhance performance and interoperability in these challenging environments. This specification is designed to improve the efficiency and performance of the uplink, which is crucial for managing the high data rates and complex beamforming required in Massive MIMO radio systems.

The ULPI specification introduces a new beamforming method, called DMRS-BF (DMRS based beamforming), it is a beamforming method wherein the O-RU computes UE channel estimates based on the received UE UL DMRS symbols, then computes "weights" based on those channel estimates and applies the weights to the UE UL data. This beamforming method is applicable only to the NR PUSCH. This optimization helps reduce latency, increase scalability to manage high traffic volumes and a large number of connected devices without compromising performance, minimize fronthaul bandwidth, reduce fronthaul costs, and enhance overall network efficiency.

There are two types of DMRS-BF:

**DMRS-BF-NEQ** where the "weights" are beamforming weights that do not include an equalization function.

**DMRS-BF-EQ** where the "weights" are beamforming weights that include an equalization function.

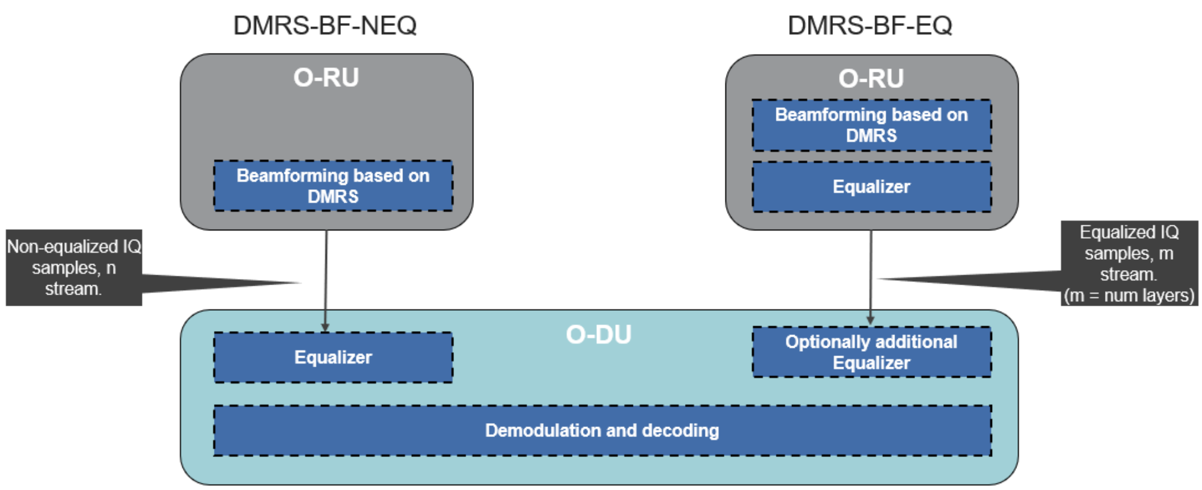


**Figure 3.** Massive MIMO ULPI capable base station architecture

Massive MIMO ULPI represents a significant step forward in the evolution of Open RAN, providing the necessary improvements to support high-performance, scalable, and cost-effective network deployments.

# O-RAN Massive MIMO ULPI Testing Challenges

## mMIMO ULPI development testing

With the introduction of ULPI, O-RU shall take more responsibility for UL signal handling. Therefore, new challenges appear during development phase when validating if the newly added feature can work as expected.

- New section types and section extensions need to be tested for ULPI support.
  - ST9: O-RU reporting of measured Signal to Interference and Noise Ratio (SINR).
  - ST10: O-RU reporting of measured Radio Resource Management (RRM) data
  - ST11: O-DU request for RRM data reporting from O-RU
  - SE24: O-DU signaling to O-RU of DMRS configuration.
  - SE25: O-DU request to O-RU for symbol reordering of reported IQ symbols.
  - SE26: O-DU sending of frequency offset measurements to O-RU.
  - SE27: O-DU request to O-RU for reporting of Interference + Noise of unallocated resources.
- New M-Plane tests are required to validate if O-RU can report ULPI related capabilities to O-DU.
- As O-RU needs to extract DMRS from UL signal and perform channel estimation, it needs to deal with the various configuration options for DMRS, including:
  - Time Domain Resource Allocation Length (# of Symbol)
  - Configuration Type 1 / 2
  - Mapping Type A / B
  - Type A Position
  - DMRS Length
  - Additional DMRS Positions
  - Transform Precoding Enable/Disable
  - Group Hopping/Sequence Hopping
  - Scrambling Sequence
- Validate the different delay profiles that the O-RU can support.
- Validate if O-RU can support different symbol re-ordering mechanisms. In DMRS-BF-EQ case, while O-RU might send UL signal on FH U-Plane packets without DMRS symbols, signal analyzer needs to demodulate the signal without equalization.
- Validate if O-RU can report RRM measurements correctly with a controlled UL signal.

- Validate if O-RU can send measured SINR report with required time and frequency resolution with a controlled signal to noise ratio for UL signal.
- One benefit from ULPI is to handle the fast-changing UL channel conditions, such radio condition needs to be emulated in lab with a well-controlled way to evaluate the gain from ULPI.
- DMRS-BF is just one beamforming method for PUSCH, therefore, it is very possible it needs to work together with other beamforming methods, for example, weight-based beamforming, for other UL channels and DL channels.

## O-RAN mMIMO ULPI conformance testing

With ULPI related description having been added into v16 of CUS and M-Plane specifications, O-RAN Alliance WG4 also includes ULPI conformance test cases into FH Conformance test specification in v12. The newly added test cases include basic ULPI conformance tests for TDD and FDD, and follow-up test cases for specific ULPI features, for example, symbol reordering and frequency offset feedback will also be added in later versions.

Although WG4 defined conformance test cases cannot cover all aspects of ULPI, they still provide a standard way to validate the ULPI implementation in O-RU can meet the basic conformance requirements. However, conformance test cases need to be executed strictly following the test case definition, not only the test procedures, but also the test result verdict.

There are so many new features related to ULPI that needs to be implemented in O-RU, conformance test shall be executed as part of regression, to make sure the implementation of new features will not break the existing features.

Automation plays a crucial role for conformance testing.

1. **Efficiency and speed**: Automated tests can run continuously and quickly, significantly reducing the time required to complete compliance checks compared to manual testing.
2. **Accuracy and consistency**: Automation minimizes human error, ensuring that tests are performed consistently and accurately every time. This is vital for maintaining compliance with stringent regulatory standards.
3. **Scalability**: As organizations grow, their compliance requirements often become more complex. Automated systems can easily scale to handle increased testing demands without overwhelming the compliance team.
4. **Real-time monitoring**: Automated tools provide real-time monitoring and alerts, allowing compliance teams to proactively address issues as they arise, rather than react to problems after they occur.
5. **Cost-effectiveness**: While there is an initial investment in setting up automated systems, they prove to be more cost-effective over time by reducing the need for extensive manual labor and allowing for continuous compliance monitoring

6. **Comprehensive coverage**: Automated testing can cover a wide range of scenarios and edge cases, ensuring thorough compliance checks that might be impractical to achieve manually.

# O-RAN mMIMO ULPI performance and interoperability testing

The Cat-B ULPI standard was developed to address the shortcomings of the earlier Cat-B split, which struggled with performance, especially in dense network environments with high mobility, such as those using Massive MIMO technology.

Performance testing typically involves verifying that the system under test meets the specifications for interoperability, performance, and reliability.

In Cat-B ULPI performance testing, key performance metrics are evaluated to ensure the system meets the required standards. Here are some of the most important metrics:

**Uplink throughput:** This measures the maximum data rate that can be achieved in the uplink direction. Higher throughput indicates better performance in handling data from user devices to the network.

**Latency:** This metric assesses the time delay in data transmission between the radio unit and the network. Lower latency is crucial for applications requiring real-time communication.

**Interoperability:** Ensuring that different vendors' equipment can work together seamlessly is vital. This involves testing the compatibility of the fronthaul interface between the radio unit (O-RU) and the distributed unit (O-DU).

**Spectral efficiency:** This measures how efficiently the available spectrum is utilized. Higher spectral efficiency means more data can be transmitted over a given bandwidth.

**Error Vector Magnitude (EVM):** EVM quantifies the performance of the modulation scheme used in radio transmission. Lower EVM values indicate better signal quality and less distortion.

**Beamforming performance:** For Massive MIMO systems, the effectiveness of beamforming techniques is critical. This involves evaluating how well the system can direct signals to specific users, improving signal strength and reducing interference.

These metrics help ensure that the Cat-B ULPI Open RAN system can deliver the necessary performance improvements for dense network environments and high-mobility scenarios.

# Keysight Solution for mMIMO O-RU Testing

## P8820S RU Testing Toolset

**Figure 4.** P8820S RU Testing Toolset for Radio Unit Testing

P8820S Radio Unit Testing Toolset streamlines the O-RAN Radio Unit (O-RU) testing process, offering a comprehensive wrap-around, scalable solution for RU isolated testing. Users can choose between automated and manual testing options, depending on the specific need.

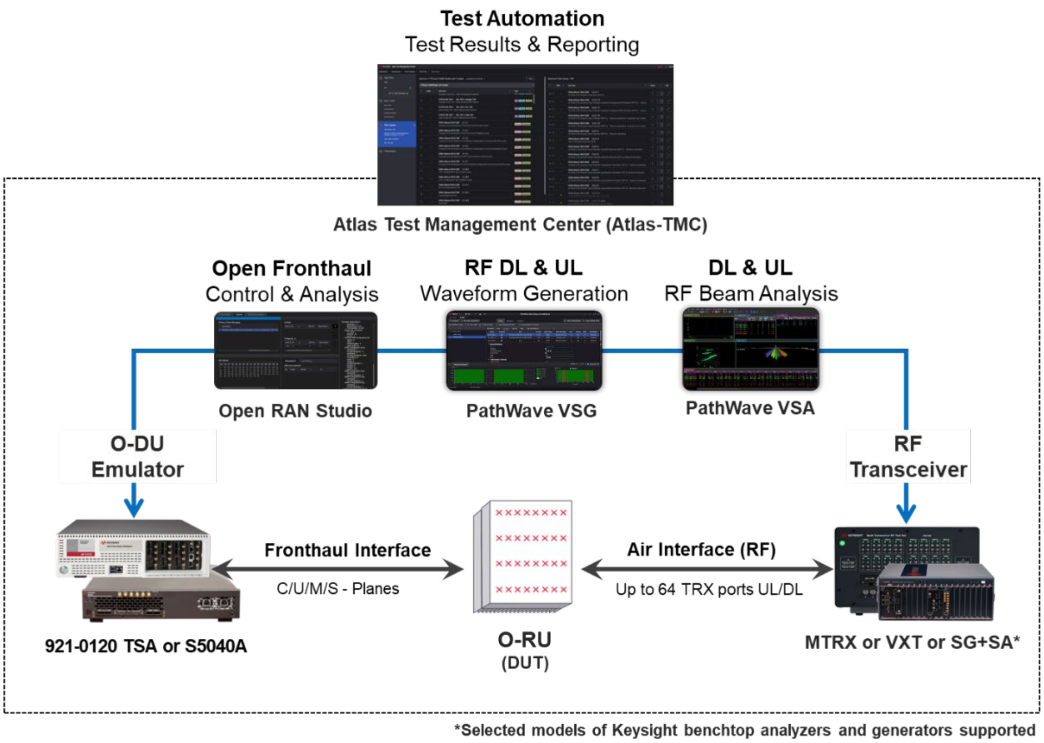


**Figure 5.** P8820S RU Testing Toolset configuration for Open RAN Massive MIMO radio unit testing

# Manual testing for development test phase

In figure 5, Open RAN Studio software, running in Time Sync Analyzer or S5040A, includes powerful O-RAN focused tools to construct, play, capture, and measure O-RAN traffic over 10 Gbps/25 Gbps (fronthaul) Ethernet interfaces. Out of the box integration with Keysight's industry proved PathWave Signal Generation and 89600 VSA software enables sophisticated 5G NR and LTE signal creation and easy capture, extraction, and export of IQ vectors – for advanced modulation analysis of received RF and radio performance.

Additionally, combined with Keysight Spectrum Analyzers and Signal Sources running inside the Multi Transceiver RF Test Set (MTRX) on the right side, the integrated P8820S solution delivers the most comprehensive cross domain, multi-channel RF and O-RAN protocol measurements available in the industry, for both Downlink (DL) and Uplink (UL) paths.

The P8820S solution can very well address the challenges mentioned above in ULPI development test phase.

- Open RAN Studio can support the newly added Section Types and Section Extensions for ULPI; therefore, it can help validate if O-RU can parse and compose the new parameters correctly.
- With PathWave Signal Generator software running in MTRX, UL signal with various DMRS configurations can be transmitted to O-RU, Open RAN Studio as O-DU Emulator can configure the same DMRS setting to O-RU to validate O-RU can handle all the DMRS parameter combinations.
- MTRX with integrated beamformer can generate multiple UL signals from different directions to validate if O-RU can correctly perform channel estimation.
- MTRX can also add noise and interference into UL signals, so that the test solution can evaluate O-RU reporting RRM measurement and SINR measurement with correct format and accuracy.
- MTRX can measure all 64 ports simultaneously and provide beamforming results instantly which speeds up the measurement and validation process.
- PathWave vector analysis software is capable of demodulating and decoding UL signals without DMRS symbols, so that it is possible to evaluate that O-RU is working with DMRS-BF-EQ mode with required functionality and performance.
- The solution can also support DL beamforming test, or Mixed beamforming methods for bi-directional test. The MIMO Information table shown in Figure 5 (Trace C) includes per channel performance as well as cross channel performance metrics. EVM for each antenna port is reported. In addition, per path power at each antenna port plus time, frequency and phase offset of the physical channel is reported for each path. Cross-channel performance can be characterized by looking at cross coupling and relative phase, timing, and power. A condition number trace (Trace B) is also available to view the impact of the MIMO channel. Massive MIMO and beamforming with up to 64 antenna ports, with beam weights and beam pattern results are available for SSB, CSI-RS, PDSCH in downlink.

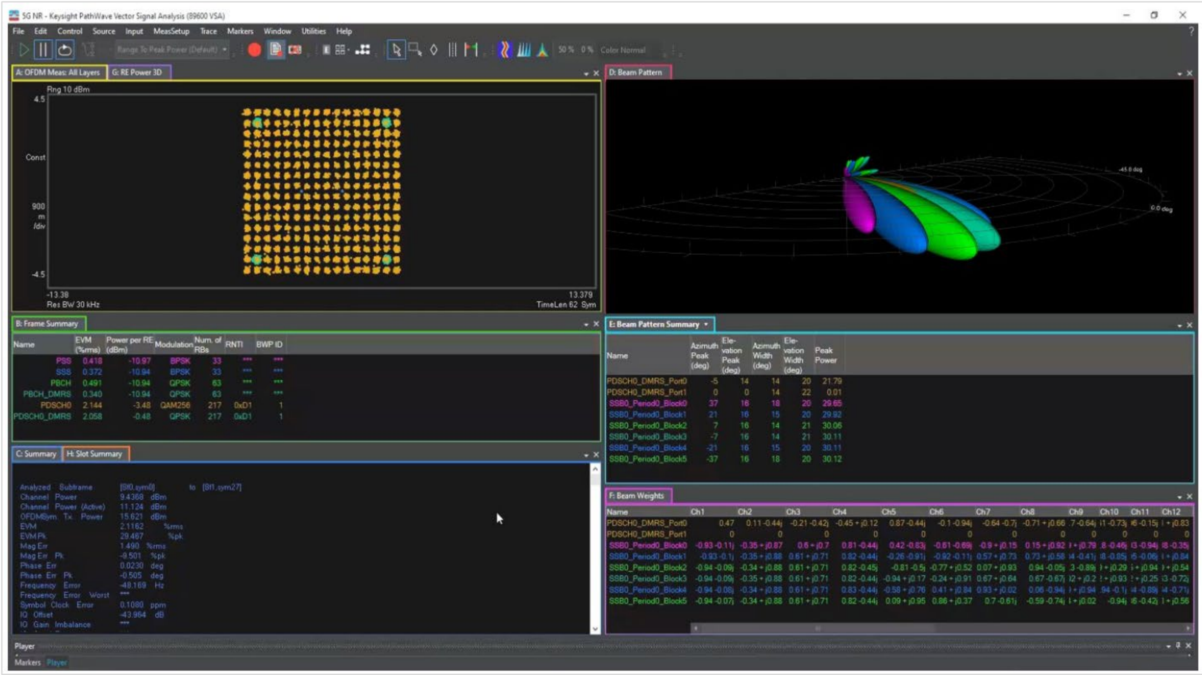


**Figure 6.** Example of downlink beamforming with magnitude and phase weightings and corresponding beam patterns, EVM figures.

- Besides DMRS based beamforming, the same solution can also support other Beamforming methods defined in O-RAN.WG4.CUS specification for both Uplink and Downlink test:
  - Predefined-Beam Beamforming (PDBF)
  - Weight-based Dynamic Beamforming (WDBF)
  - Attribute-based Dynamic Beamforming (ABBF)
  - Channel-information-based Beamforming (CIBF)

# Automated test cases for conformance tests

The Keysight P8820S RU Testing Toolset with conformance test case package provides an integrated solution for automated conformance testing of an O-RAN Radio Unit (O-RU).

This solution leverages the Keysight's Atlas Test Management Center (C8700A00A) software environment, a test sequencer software with timing analyzer, result viewer, and other useful tools for test automation development.

The P8820S RU Testing Toolset integrates measurements within a range of technical disciplines, including network protocols, baseband and RF measurements, along with instruments and device control, system design and calibration, and technical standards expertise, to help you exercise and validate an O-RAN CUSM compliant Radio Unit (O-RU).

P8820S RU Testing Toolset highlights for O-RAN conformance testing:

- **Single vendor comprehensive solution** enabling conformance test for all four planes, Control Plane, User Plane, Management Plane and Synchronization Plane.
- **Scalable solution** from SISO to Massive MIMO with an option to use MTRX with up to 64 TRX channels for massive MIMO, including ULPI test.
- **Atlas Test Management Center,** which is browser-based, allows simultaneous multi-user access and integrated analytics for smooth management of test workflow.
- All DL and UL Beamforming test cases are implemented strictly following **O-RAN.WG4.CONF** test specification.

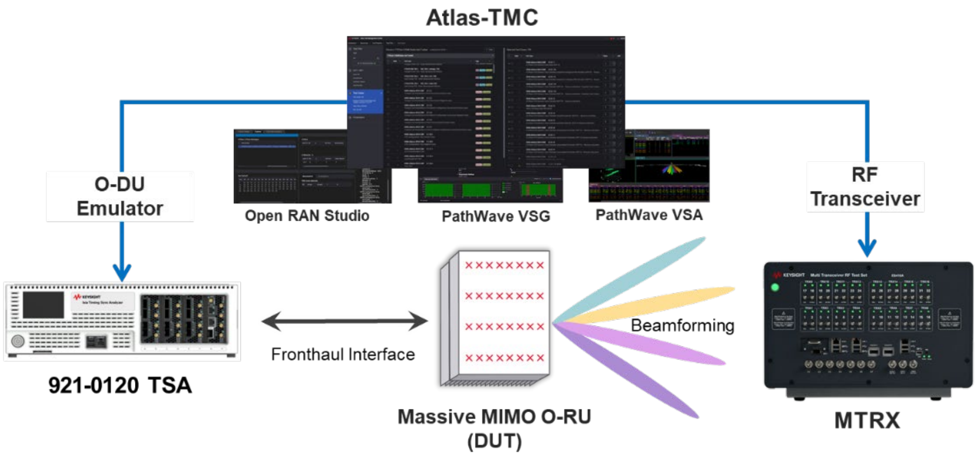


**Figure 7.** P8820S RU Toolset configuration for testing mMIMO O-RU

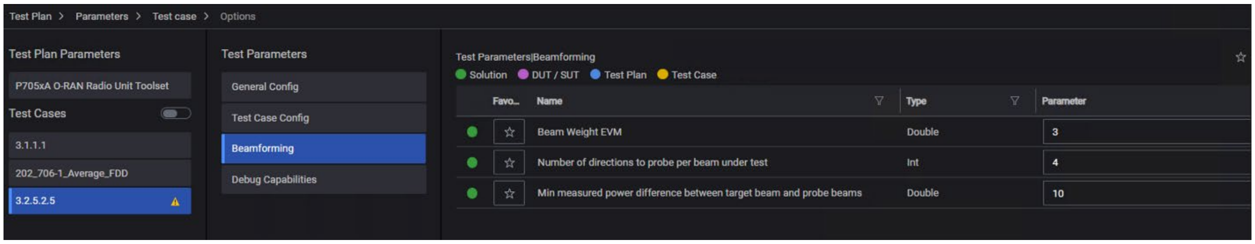


**Figure 8.** Atlas Test Management Center to execute O-RU mMIMO conformance tests.

Refer to available test case packages from Keysight Open RAN Automated Compliance Test cases Brochure: https://www.keysight.com/us/en/assets/3125-1162/brochures/Keysight-Open-RAN-Automated-Compliance-Test-Cases.pdf

# O-RAN mMIMO O-RU Test Workflows

## O-RU Downlink mMIMO test workflow

Figure 9 below illustrates a typical workflow of Downlink mMIMO test with P8820S Radio Unit Testing Toolset.

**Step 1**: PathWave Signal Generator is used to generate the 3GPP compliant test vectors (.scp files) such as TM1.1 or G-FR1-A1-5 test vectors, or O-RAN specific definitions.

**Step 2**: Open RAN Studio converts the test vectors into O-RAN Fronthaul C/U-Plane traffic according to FH parameters defined in the software, including the beamforming settings based on different beamforming methods to be applied to the signal.

**Step 3**: O-RAN traffic is played on Fronthaul interface towards radio unit under test.

**Step 4**: MTRX receives the signal from radio unit under test on up to 64 RF ports.

**Step 5**: With antenna pattern (rows, columns, inter-antenna spacing, Polarization) properly configured, beam information of DL signal is analyzed in PathWave VSA, as well as other measurements such as power, EVM, payload, etc., for pass/fail verdict.

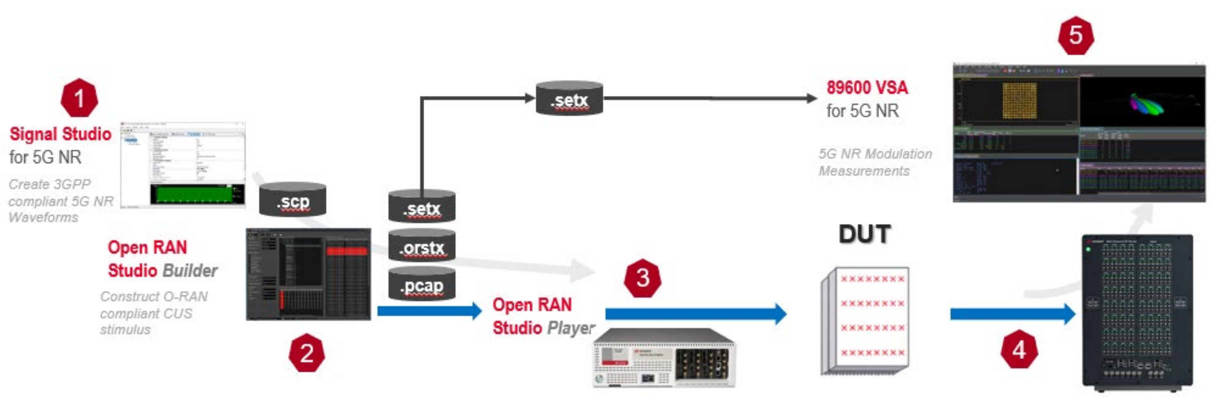


**Figure 9.** Example workflow for Downlink mMIMO manual test.

# O-RU mMIMO ULPI test workflow

Figure 8 below illustrates a typical workflow of ULPI test with P8820S Radio Unit Testing Toolset.

**Step 1**: PathWave Signal Generator is used to generate the 3GPP compliant test vectors (.scp files) such as TM1.1 or G-FR1-A1-5 test vectors, or O-RAN specific definitions. DMRS configuration needs to be set up properly in this step.

**Step 2**: Open RAN Studio converts the test vector into O-RAN Fronthaul C-Plane traffic according to FH parameters defined in the software. DMRS information will be included in Section Extension 24.

**Step 3**: O-RAN traffic is played on Fronthaul interface towards radio unit under test.

**Step 4**: At the same time, test signal is transmitted from MTRX towards radio unit under test from up to 64 RF ports. Integrated beamformer in MTRX adds configured beam weight to each port, as well as the interference and noise to be mixed to the wanted signal.

**Step 5**: IQ data is retrieved from returned U-plane messages received by Open RAN Studio. This is port reduced UL test signal and Symbol Reordering might be applied to the signal.

**Step 6**: PathWave Vector Signal Analyzer to run Layer 1 measurements such as power, EVM, payload, etc.; to determine pass/fail results.

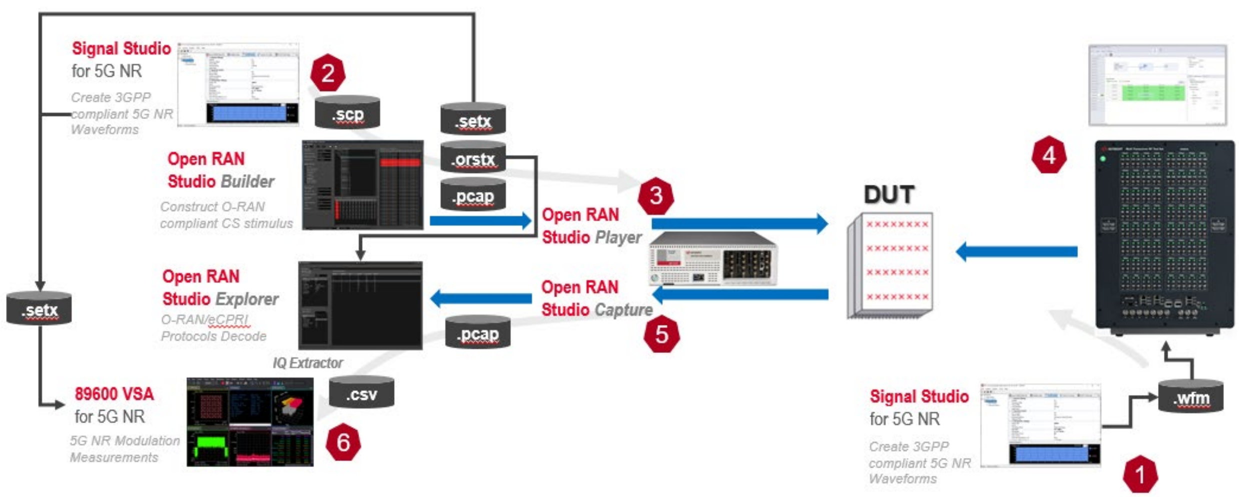


**Figure 10.** Example workflow for ULPI mMIMO manual test.

The above workflow defines the manual process of the mMIMO test against O-RU. With ATLAS TMC, users can automate the entire test process strictly following the beamforming test cases defined in O-RAN WG4 conformance test specification.

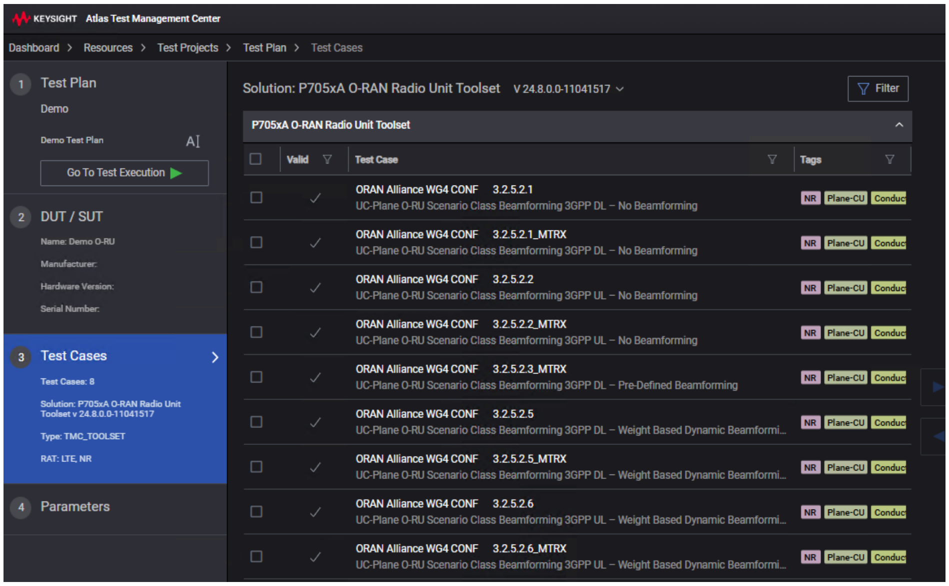


**Figure 11.** Automatic execution of Beamforming test cases in Atlas TMC.

# Conclusion

mMIMO technology enhances network capacity and performance dramatically. O-RAN WG4 has clearly defined how O-DU and O-RU work together with function split for different beamform methods. ULPI (Uplink Performance Improvement) may be considered as a new beamforming method on fronthaul. By moving part of Layer 1 functionality from O-DU to O-RU, ULPI can improve the timeliness and accuracy in handling UL signals, especially with rapidly changing radio channel conditions. With O-RAN.WG4.CUS-Plane v16.0 and O-RAN.WG4.M-Plane v16.0 specification has DMRS-Beamforming defined, and O-RAN.WG4.CONF specification has included O-RU and O-DU ULPI conformance test cases in v12.0, ULPI is ready to be developed and tested against O-RAN components. Keysight P8820S Radio Unit Testing Toolset already supports ULPI in addition to other beamforming methods (PDBF, WDBF, ABBF, CIBF), it can help the maturity of O-RU from development phase test to protocol conformance test and performance verification.

# Related Keysight Solutions for mMIMO Testing:

- P8820S RU Testing Toolset: https://www.keysight.com/us/en/product/P8820S/ru-testing-toolset.html
- P8800S UeSIM UE Emulation RAN Solutions: https://www.keysight.com/us/en/product/P8800S/
- P8822S RuSIM – UE / O-RU Emulation Over the O-RAN Fronthaul: https://www.keysight.com/us/en/product/P8822S/
- P8828S RICtest – RAN Intelligent Controller Test Solutions: https://www.keysight.com/us/en/product/P8828S/
- S9160A Massive MIMO and MIMO RF Beamforming Test Accelerator: https://keysight.com/find/S9160A
- PROPSIM Channel Emulator Platforms: https://keysight.com/find/PROPSIM
- U5040BSCB Open RAN Studio for O-RU Testing and Validation: www.keysight.com/find/U5040BSCB
- 921-0120 Time Sync Analyzer (O-DU emulator): www.keysight.com/find/TSA
- P7000A 3GPP Base Station Conformance (based on 3GPP Chapter 6, 7 and 8) Measurement Automation Solution Software: www.keysight.com/find/P7000A