

SOLUTION BROCHURE

mmWave Over-the-Air (OTA) Validation Test Reference Architecture

An innovative approach to reduce test times while increasing measurement resolution

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OTA Test Challenges

5G operation at mmWave frequencies relies on beamforming technology through antenna arrays with many elements. As the industry strives to reduce the size and cost of producing these 5G beamforming devices operating at mmWave, many of them lack conventional external RF connectors, becoming integrated Antenna-in-Package (AiP) and Antenna-in-Module (AiM) devices. This industry shift presents a tough challenge for engineers in charge of characterization and validation of integrated beamforming designs, prompting them to look for accurate, over-the-air (OTA), radiated test solutions.

Test Time Challenges and Measurement Uncertainty

Configuring and running detailed 3D spatial sweeps of 5G beamforming AiP devices within a carefully controlled RF environment in an anechoic chamber can be a very time-consuming and expensive task.

A typical move → stop → measure, point-by-point, software-controlled test system with a positioner that can rotate in two independent axes (azimuth and elevation), produces only a handful of RF measurements per second. However, engineers need to measure and validate antenna performance by scanning hundreds or even thousands of points in space. A trade-off arises, in which the finer the 3D sampling grid (smaller distance between measurement points), the higher the test times, but the lower the measurement uncertainty. Conversely, a 3D grid that is too sparse can give faster results, but introduce quite a bit of measurement error. Figure 1 illustrates how employing a 3D scanning grid to measure a DUT's power produces a 3D antenna pattern, but the points need to be close enough to minimize resolution errors.

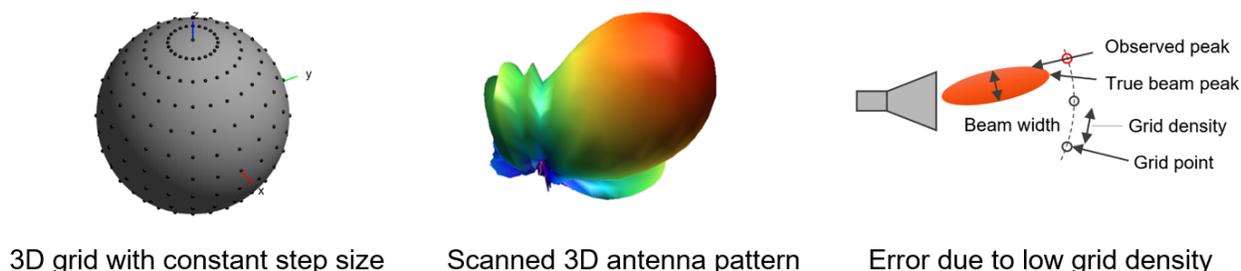


Figure 1 Selecting a denser 3D scanning grid reduces measurement uncertainty

Furthermore, getting data at multiple frequencies and powers, and configuring the DUT to steer the beam with various codebooks can greatly expand test times, as outlined in the table below:

Table 1 OTA Test Times and Measurement Uncertainty for various grid densities

No. of Test Points	TXP EIRP Mean Error (dB)	Typical Single Scan Test Time (s)	Typical Test time 3 codes, 3 powers, 5 frequencies
6000	0.02	1000	12.5 Hours
800	0.2	133	1.6 Hours
200	0.74	33	25 Minutes

Accurate and Much Faster OTA Validation

To help engineers in charge of OTA characterization and validation test of beamforming devices reduce test times without compromising accuracy, National Instruments developed the mmWave OTA Validation Test reference architecture.

The mmWave OTA Validation Test reference architecture takes a platform-level approach that integrates NI's real-time motion control, data acquisition, and PXI triggering and synchronization to take fast, high-bandwidth RF measurements synchronized with the instantaneous (ϕ, θ) coordinates of the positioner's motors. Unlike traditional OTA test solutions, NI's approach moves the Device Under Test (DUT) in a smooth and continuous motion across the 3D space while the RF engine takes rapid measurements.

This eliminates the time waste of moving discretely from point to point. As a result, engineers can perform 3D spatial sweeps with thousands of points that execute in a fraction of the time, all the while reducing measurement uncertainty and error.

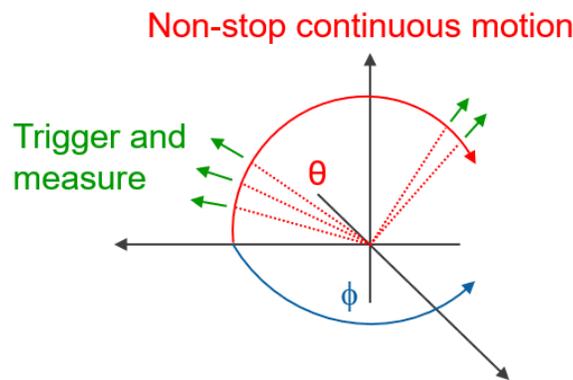


Figure 2 Continuous motion while triggering RF measurements

The following table highlights the speed advantages of using a continuous-motion approach to OTA test over the more traditional start-stop-measure techniques, cutting test times by 5X or more.

Table 2 Test time benchmark comparing discrete vs. continuous motion and measurement

No. of grid points (every 4° constant density) 360° Azimuth 180° Elevation	Software-based point-by-point measurements	NI Continuous-motion measurements
4050 points	680 s (11 min)	84 s

mmWave OTA Validation Test Hardware

As shown in Figure 3 below, the mmWave OTA Validation Test reference architecture includes:

- NI's mmWave Vector Signal Transceiver (VST) for wideband RF signal generation and measurement
- PXI instruments for repeatable, smooth, and precise motion control
- Isolated RF chamber for Far-Field radiated testing of 5G mmWave AiP devices in a quiet environment
- High-gain antennas, cables, adapters and other accessories
- mmWave OTA Validation Test software for interactive use and automation

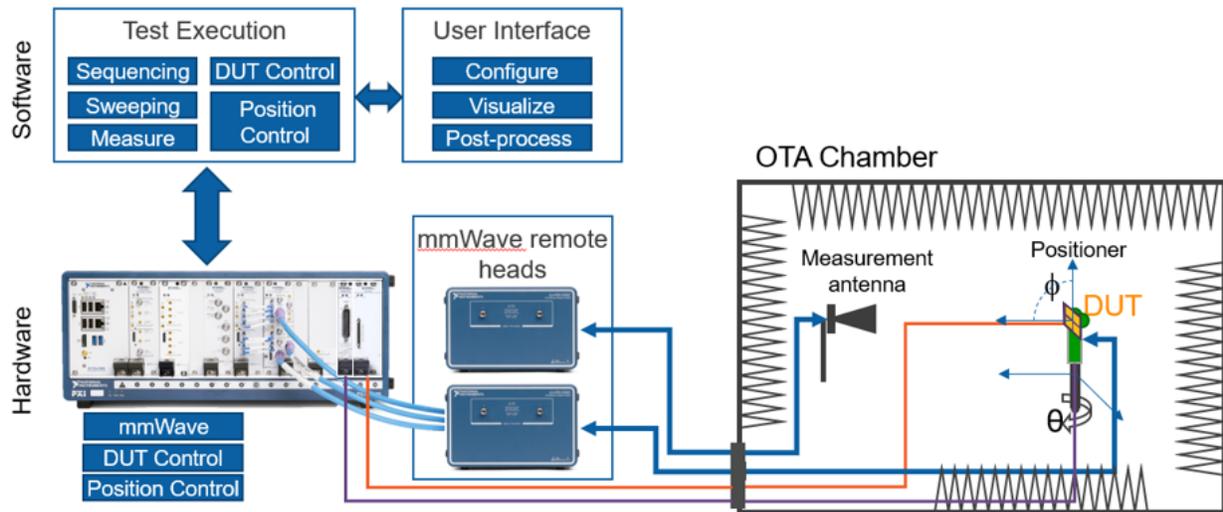


Figure 3 Diagram of mmWave OTA Validation Test reference architecture components

mmWave VST for IF-to-RF and RF-to-RF Measurements

The modular architecture of the NI mmWave VST enables it to scale with the variety and complexity of 5G mmWave devices. Using NI VSTs, engineers get fast, lab-grade, high-bandwidth IF and mmWave signal generation and analysis for OTA testing of 5G semiconductor devices.

For RF-to-RF device testing, the mmWave OTA Validation Test reference architecture places the VST's mmWave radio heads with high-power, bidirectional ports very close to the RF connectors on the outside of the anechoic chamber. Engineers can also take advantage of the VST's IF ports to interface IF-to-RF DUTs.

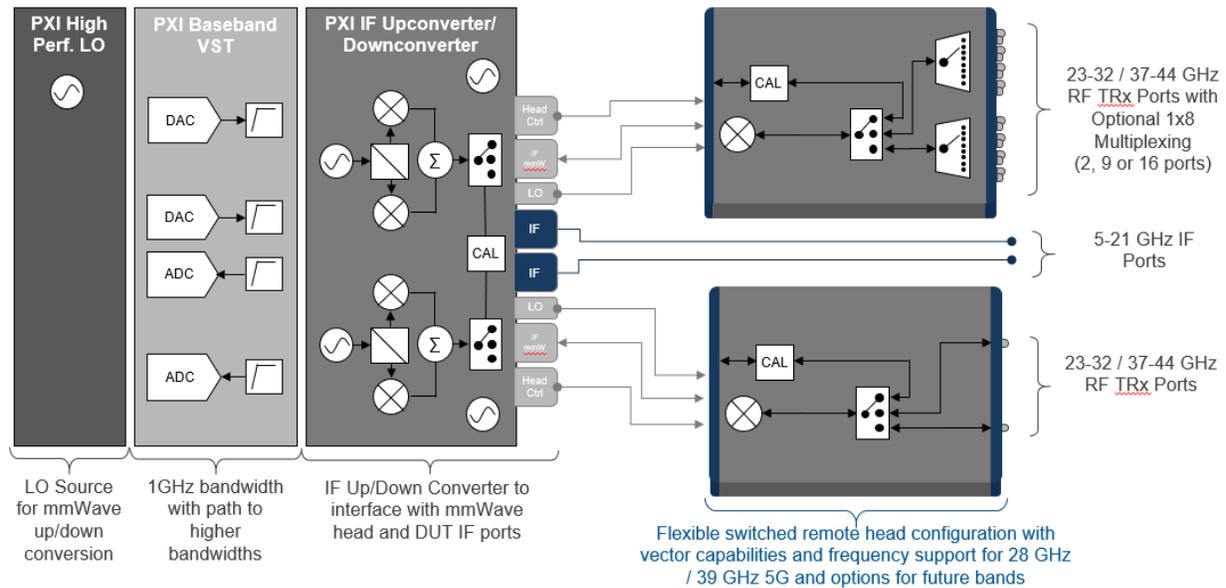


Figure 4 mmWave VST Architecture

This approach creates:

- IF and mmWave signal generation and analysis capabilities for various DUT types
- A future-proof, modular system that engineers can adapt without having to change any other part of the test solution as the 5G standard evolves to include higher frequencies
- A way to move mmWave measurement ports closer to the DUT, minimizing signal losses and boosting Signal-to-Noise ratio
- A complete test solution with wide data rates and signal processing at the speed of the latest multicore processors

Consider the following examples of how engineers can take advantage of the modularity of the mmWave VST to configure various 5G OTA test setups:

IF-to-RF beamformer:

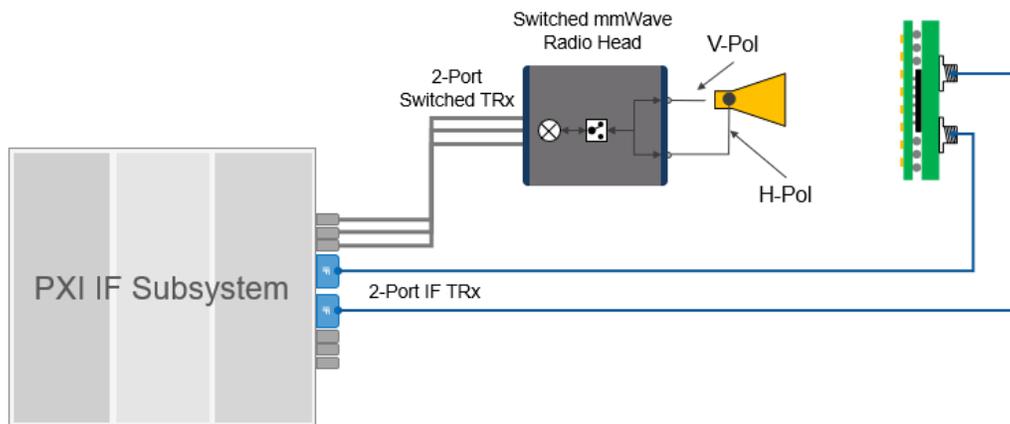


Figure 5 IF-to-RF OTA test configuration using the mmWave VST

RF-to-RF beamformer:

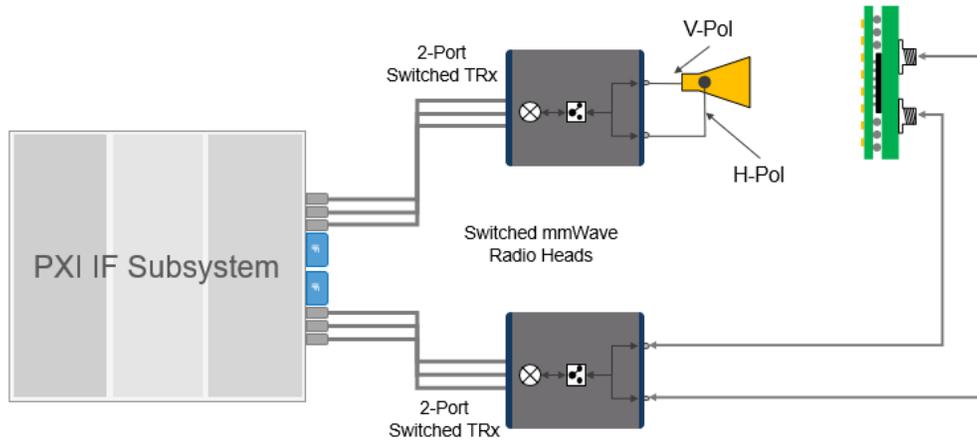


Figure 6 RF-to-RF OTA test configuration using the mmWave VST

Isolated RF Anechoic Chamber

Proper characterization of the beamforming performance of AiP devices requires the controlled and quiet RF environment of an anechoic chamber with high-quality RF absorbing material that keeps reflections to a minimum. Also, to ensure measurement repeatability, the motion system needs to enable fine angular resolution and moving to the exact point in space every time.

NI's mmWave OTA Validation Test reference architecture includes a carefully specified anechoic chamber with a 2-axis (azimuth and elevation) DUT positioner at the bottom and a fixed measurement antenna at the top. This chamber incorporates a National Instruments real-time motion controller that enables NI's fast, continuous-motion OTA test approach.

The distance between the positioner and the DUT allows for far-field testing of 5G mmWave AiP devices with an antenna aperture of 5 cm or less (following the 3GPP 38.310 Specification for Category 1 DUTs).

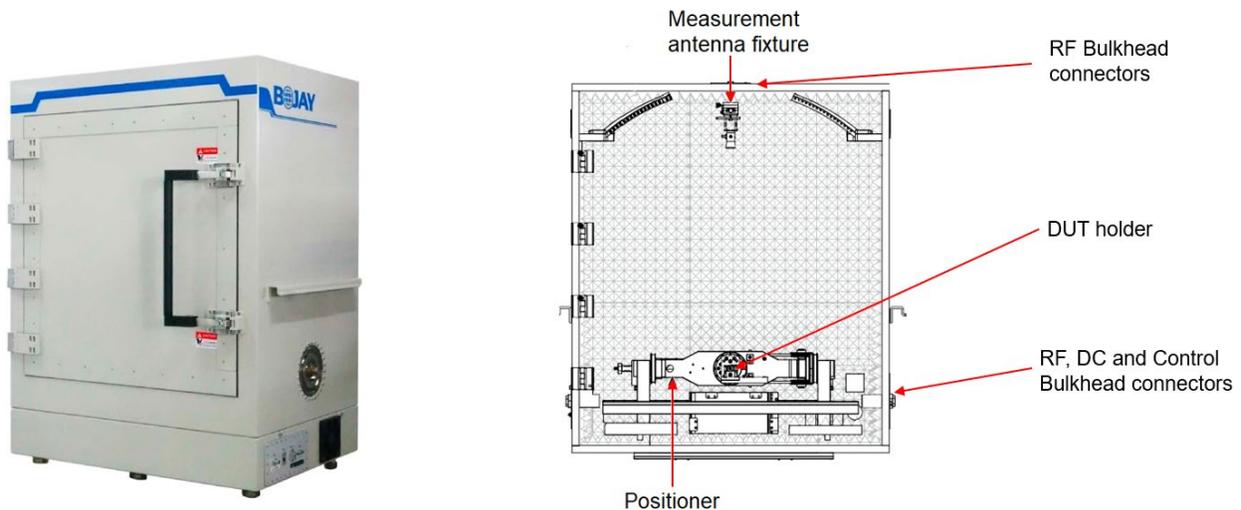


Figure 7 High-isolation mmWave anechoic chamber

mmWave OTA Validation Test Software

The mmWave OTA Validation Test reference architecture includes test software that helps engineers quickly configure extensive spatial sweeps to characterize their device's antenna patterns, while they produce, visualize, store, or distribute detailed parametric results.

Users can take advantage of the mmWave OTA Validation Test Software as a complete test framework for OTA validation tests. Alternatively, users can incorporate some of its components into their existing test framework, or they can use the separate components as stand-alone utilities.

OTA test needs may vary greatly between different applications and DUT types. To help engineers adapt to different test situations, the mmWave OTA Validation Test Software offers a modular approach, extensible to various user needs, like customized DUT control, specific sweep configurations, signal routing, etc.

Engineers working on both manual and automated validation tests of mmWave OTA devices, will greatly benefit from the following components:

mmWave OTA Test Configuration UI

The mmWave OTA Validation Test Software provides an open-source LabVIEW graphical user interface (GUI) that helps users configure the test matrix to run, including measurement parameters, sweeping parameters, and connection settings.

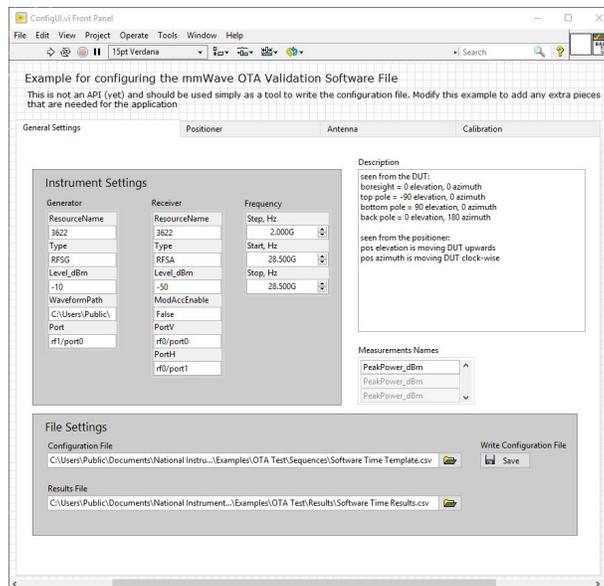


Figure 8 Front Panel of the Test Configuration UI

TestStand Template Startup Sequences

The mmWave OTA Validation Test Software installs template test sequences that engineers can use to run the configuration files they create with the mmWave OTA Configuration UI.

Using these test sequences in TestStand, an industry-leading test framework software, engineers move quickly from manual configuration to complete automation of their test plans, controlling all aspects of test execution.

With TestStand, users can modify and customize these open-source template sequences to suit their specific DUT needs or validation goals.

mmWave OTA Test Positioner Soft Front Panel

The mmWave OTA Test Positioner SFP allows users to manipulate the positioner in an interactive manner. Users can complete the following tasks with the mmWave OTA Test Positioner SFP:

- Move the positioner in azimuth or elevation independently
- Configure a sweep in both azimuth and elevation
- Configure the Absolute Zero location of the positioner for antenna alignment

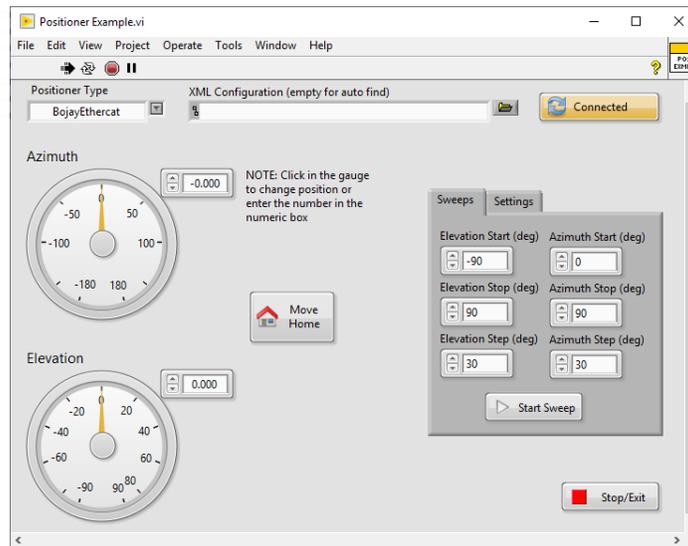


Figure 9 mmWave OTA Test Positioner SFP

mmWave OTA Test Visualizer

The mmWave OTA Test Visualizer completes offline configuration and analysis of OTA test data for antenna measurements. Engineers can use the mmWave OTA Test Visualizer to invoke different results visualizations and analyze antenna-specific measurements and patterns.

The mmWave OTA Test Visualizer takes in measurement results as comma-separated values (CSV) files and displays the data on-screen. Users can select various data sources and types of plots, as illustrated below:

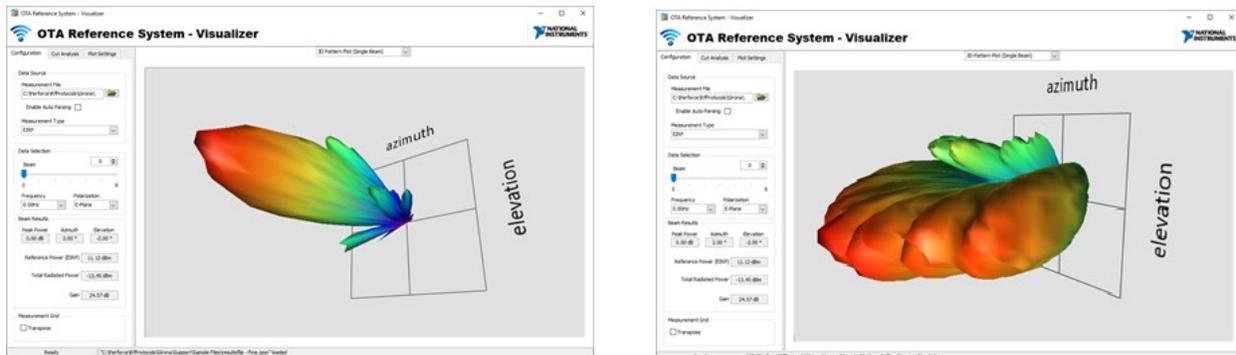


Figure 10 3D Antenna Pattern for single and multiple beams

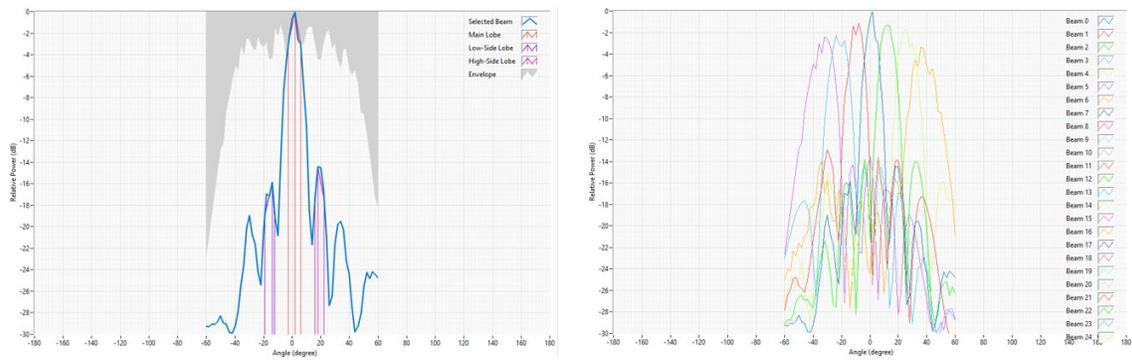


Figure 11 Antenna cut analysis, single beam and multiple beams

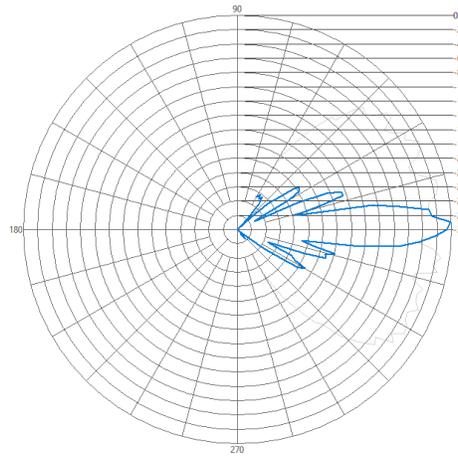


Figure 12 Polar plot

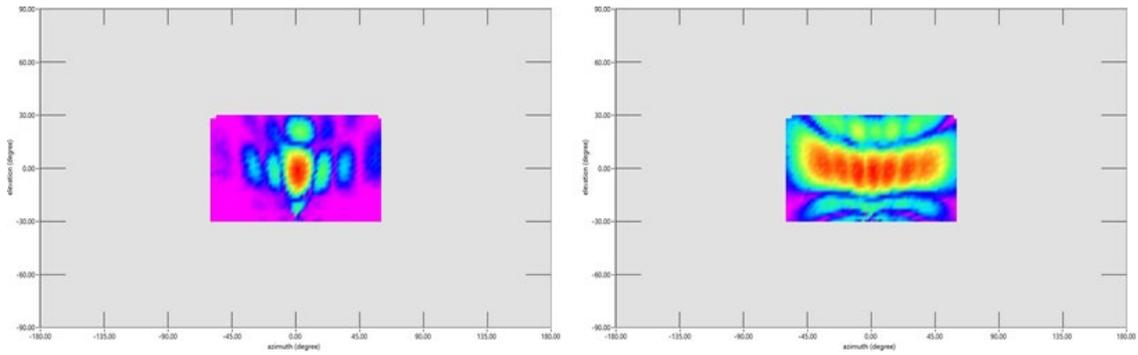


Figure 13 Heat map plot for single and multiple beams

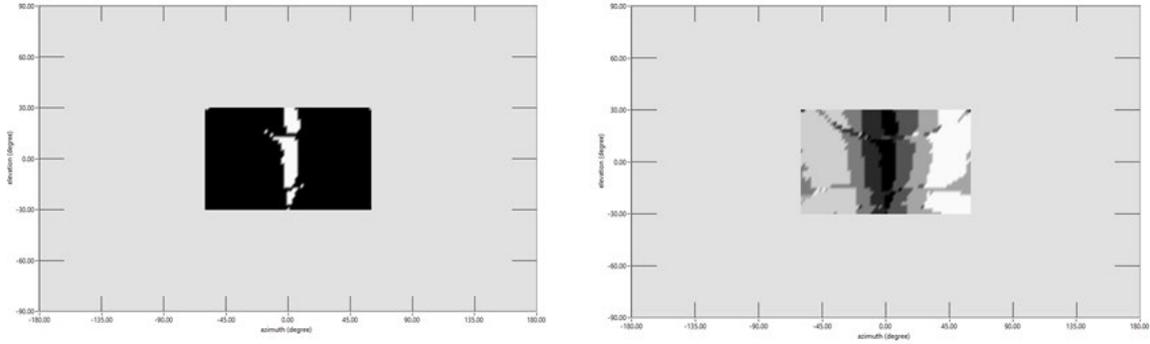


Figure 14 Best beam index for single and multiple beams

OTA Measurement Interface

To streamline the process of storing measurement values, importing and exporting measurement data, and interpreting measurement results using the automated sequences in TestStand, the mmWave OTA Test Software includes an OTA Measurement Interface (OTAMI). The OTAMI presents engineers with a measurement-oriented API that can get the following measurement results and visualizations:

Measurements	<ul style="list-style-type: none"> • Effective isotropic radiated power (EIRP) • Total radiated power (TRP) • Error vector magnitude (EVM) • Half power beam width (HPBW) • Beam Center • Beam Direction • First Null beam width (FNBW)
Visualizations	<ul style="list-style-type: none"> • 1D Cut Analysis • 1D Polar Plot • 3D Antenna Pattern • Heat Map • Best Beam Index

Furthermore, the OTAMI API gives users the ability to add measurements on-the-fly during sequence execution or to retrieve measurements from a CSV file. Once test execution finishes, engineers use the OTAMI API to export measurement data into a CSV file, simplifying the process of storing and retrieving data quickly.

Antenna Plugin

Engineers that need to implement new DUT control for their devices have a simpler approach to automate OTA test. The mmWave OTA Validation Test software also supports the creation of custom antenna control modules. That is, by taking advantage of simple antenna control code modules, users can create custom DUT “plugins” that integrate readily into the test sequencer. That way, users can rapidly perform automated testing of various kinds of DUTs using the same test sequence template but invoking different DUT control plugins.

Performing System Calibration

One of the most important factors for getting reliable results with reduced measurement uncertainty is making sure that the test setup is properly calibrated.

NI provides the RF System Calibration Assistant, a free software utility that controls the RF instruments, including an external RF power meter to perform a system calibration on all OTA hardware components and signal paths, considering both Horizontal and Vertical polarizations.

Engineers can configure each path name, as well as the frequency and power of operation. The calibration utility then runs the calibration and creates a calibration file across frequency and power for every signal path.

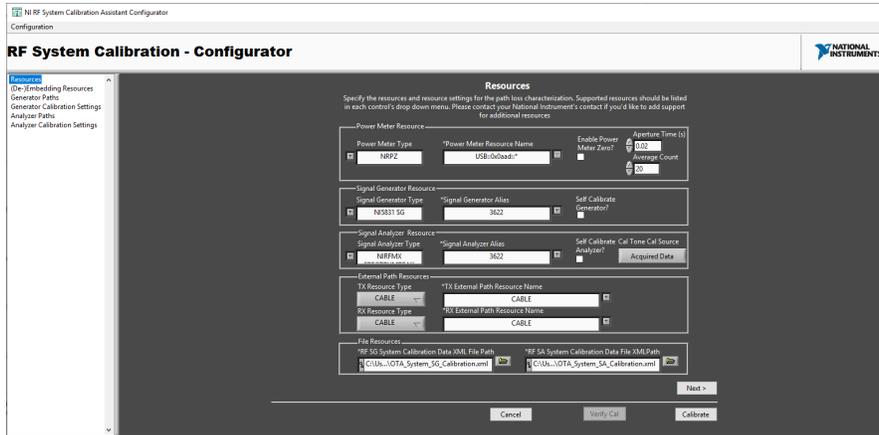


Figure 15 RF System Calibration utility to measure the losses through all signal paths

Solution Services

Implementing reliable mmWave OTA validation test setups can be a very complex task with several risk factors. Some of the more common ones include measurement uncertainty due to mechanical placement of the DUTs, in-chamber reflections, and system calibration.

As a trusted advisor, NI complements its mmWave OTA Validation Test reference architecture with services from experts around the globe to help users achieve their OTA test goals. Whether the OTA challenges are simple or complex, you can maximize productivity and reduce costs with NI OTA test setup installation, training, technical support, consulting and integration, and hardware services.

