Massive MIMO Testing with PROPSIM
5G Channel Emulation Solution
End-to-End Solution for 5G System-Level Testing

Definition of the 5G Massive MIMO-Capable Test Environment

5G massive multiple-input / multiple-output (MIMO) base station testing must register and measure the behavior of antenna arrays with the implementation of beamforming functionality. Testing covers regular network key performance indicators (KPIs), such as throughput, handover success rate, service quality, and availability. 5G massive MIMO base station testing also measures radio-frequency (RF)-related performance.

This paper uses the Keysight PROPSIM 5G channel emulation solution in practice and demonstrates its use in 5G testing.
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The Building Blocks of a Massive MIMO Test Environment

The cornerstone of a massive MIMO test setup is a channel emulator. The test solution connects a base station with 32 antenna ports to four user equipment (UE) devices, each having two antenna ports. This process requires a PROPSIM F64 channel emulator equipped with 64 RF channels and 512 logical links between the base station and the UE devices when connected bidirectionally.

Figure 1. 5G NR base station with 16+16 antenna ports connected to four MIMO UEs through a single PROPSIM F64 5G channel emulator

With a PROPSIM F64-based setup, it is possible to test with commercial devices for both base stations and UEs. The test setup uses test and measurement equipment, such as signal and spectrum analyzers, to monitor system behavior and performance. Combining multiple channels into a single port enhances the capacity of the channel emulator. (See “Introducing Partial Sampling in a Massive MIMO Test Environment,” which describes how to set up a test with combiners.)

<table>
<thead>
<tr>
<th>PROPSIM configuration</th>
<th>Number of gNB ports</th>
<th>Number of UE’s MIMO layers</th>
<th>3GPP Channel model compliant</th>
</tr>
</thead>
<tbody>
<tr>
<td>F64 32 channels</td>
<td>16 Array (H / V pol.): 8x1, 4x2</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>F64 64 channels</td>
<td>32 Array (H / V pol.): 16x1, 8x2</td>
<td>8</td>
<td>Yes</td>
</tr>
<tr>
<td>2xF64 64 channels</td>
<td>64 Array (H / V pol.): 16x2, 8x4</td>
<td>8</td>
<td>Yes</td>
</tr>
<tr>
<td>F64 32 channels + 2x combiners 1-to-4x8</td>
<td>64 Array (H / V pol.): 16x2, 8x4</td>
<td>4</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1. PROPSIM configurations for 5G base station testing
Table 1 demonstrates typical PROPSIM configurations suitable for 5G base station testing. The number of channels in PROPSIM determines the maximum antenna configuration. The bidirectional TRX ports connect to the base station antenna RF ports.

This section uses a PROPSIM F64 configuration with 64 channels. The base station uses a 2x8 antenna array with dual polarization and 32 RF ports. This example shows four mobiles, each with two antennas.

![PROPSIM F64](image)

Figure 2. PROPSIM F64 offers the ability to connect the most complex configurations

**Test arrangements**

This application note covers the fundamentals of setting up 5G massive MIMO base station performance testing and verifying functionality.

Set the test environment for full-sampling massive MIMO channel emulator testing. Use a 5G New Radio (NR) base station with 32 antenna ports. The antenna subsystems consist of a 2x8 array of antenna elements, dual-polarized. Set four 5G mobile phones with 2x2 MIMO capability, with two antennas in each phone, for a total of eight layers for mobile users.

This application note also describes execution of the test and verification of system performance. It describes the method for creating the test scenario to match the hardware configuration and provides guides on what indicators are relevant.

After performing a massive MIMO test with the full sample (with all base station and UE RF lines connected individually into the test system), add capacity for a bigger base station configuration by compressing the elevation dimension of the base station antenna with a 1-to-4 combiner matrix. This is a partial-sampling massive MIMO test method, because the test solution samples only some of the base station lines individually.
Setting Up a Full-Sampling Massive MIMO Performance Testing Environment

This section uses a full-sampling massive MIMO test environment for network equipment testing. This test measures 5G NR base station system-level and protocol stack performance, including the antenna array beamforming functionality.

The PROPSIM F64 5G channel emulation solution runs 3rd Generation Partnership Project (3GPP) channel models. It uses a built-in auto-calibration feature to tune the phase and amplitude of the RF channels. Tuning the channels is essential for beamforming antenna array testing.

Signal-based phase and amplitude calibration

The auto-calibration function is available with a separate license. This feature is a must-have if the primary function of the PROPSIM unit is 5G NR testing. Routing the reference signal to the RF ports for calibration is straightforward. Using the auto-calibration function is faster and more accurate than using a vector network analyzer or other external tools to adjust the signal phase for each antenna connector. (For more information, refer to “Signal-Based Phase Calibration.”)

Figure 3. The PROPSIM F64 auto-calibration feature saves time and effort
Channel models

The channel model rules the type of effects considered when sending the signal from transmitter to receiver. The channel model defines direct line-of-sight (LOS) or non-line-of-sight (NLOS) conditions, types of reflected multipaths, the process of signal attenuation, and fading during transmission. Hence, PROPSIM offers easy-to-use tools to create any channel models. Although standard channel models exist, as defined in 3GPP TR 38.901, these are available as ready-made files in the PROPSIM user interface.

The PROPSIM geometric channel modeling tool

The Geometric Channel Modeling (GCM) tool helps users set up a virtual environment where all transmitters and receivers have a physical location and RF characteristics. Their location, speed, and orientation are dynamic to move the radios according to predefined paths with various speeds and orientations.

Use case / test scenario

In this section, the test scenario includes a micro-base station installed 35 meters above ground on the wall of a building. Four MIMO UEs connect to the base station. The type of channel models used depends on the environment. In this case, use the definition for urban microcell street canyon from the 3GPP TR 38.901.

Figure 4. The urban microcell street canyon conditions needed to simulate the test setup
**Scenario creation**

Test scenarios cover verification of all necessary KPIs, including throughput, the desired reference signal, and received power level. PROPSIM’s basic tools create scenarios that allow standards-based stationary models. The PROPSIM GCM tool may create dynamic geometry-based scenarios. The tool may also embed antenna parameters with the optional antenna array tool (AAT), making the test setup more realistic and activating antenna radiation pattern implementation. The test operator selects the antenna from the existing antenna library or creates it to reflect a proprietary antenna setup.

When modeling the base station antenna array with the AAT, set the antenna geometry and element characteristics realistically. First, this section defines what kind of antenna is present, how many elements are available, and what type of geometry exists between those elements.

This example models the antenna as a cross-polarized array having 8x6 elements with 80 mm of separation between the elements. Usually, used separation is around 0.4–0.5 wavelengths, ensuring an effective beam formation. This example uses one RF connector hosting three elements from a single polarization plane. This results in 2x (8x2) = 32 antenna RF connectors. The AAT uses element-specific ±45-degree radiation patterns predefined by the 3GPP.

![Antenna array with 2x8 connectors. Each connector holds a subarray of three elements.](image)

Figure 5. Antenna array with 2x8 connectors. Each connector holds a subarray of three elements.
The antenna file format hosts the antenna radiation pattern in 3D format. Also, the antenna array tool executes mapping from the base station antenna ports to the PROPSIM TRX ports. All transmitter-to-receiver calculations include an additional antenna pattern to achieve the highest gain when the orientation of the main slope of the beam is toward the UE. The UE antenna is modeled as a dipole in this example.

![Figure 6. A 6x8 array radiation pattern visualized with the PROPSIM GCM 5G antenna array tool option](image)

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<table>
<thead>
<tr>
<th>Parameters to define with GCM + AAT</th>
<th>Example</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base station quantity and locations</td>
<td>1 to 3</td>
<td>Testing individual or group of base stations</td>
</tr>
<tr>
<td>Number of cells / base stations</td>
<td>1 to 6</td>
<td>Single cell or multicell</td>
</tr>
<tr>
<td>Number of UEs and movement</td>
<td>1 to 8</td>
<td>Up to 8 UEs per PROPSIM</td>
</tr>
<tr>
<td>Speed / waypoint</td>
<td>0 to 700 kph</td>
<td>Static UEs or fast terrestrial UEs</td>
</tr>
<tr>
<td>Antenna definitions for both base station and UE</td>
<td>Isotropic, omnidirectional, beamforming pattern</td>
<td>Use antenna array tool</td>
</tr>
<tr>
<td>Link-level propagation parameters</td>
<td>LOS / NLOS, channel model, shadow profile</td>
<td>These define scenario-specific RF conditions</td>
</tr>
<tr>
<td>UE waypoint position-specific parameters</td>
<td>Speed, orientation, channel model</td>
<td>All UE-specific values can change per waypoint</td>
</tr>
</tbody>
</table>

Table 2. Key parameters for MIMO testing

After modeling the antenna, specify the location of the base station and UE. In GCM, it is easy to define and set the link characteristics between devices in great detail. Using ready-made standard channel models enables measurement of the RF performance in the given conditions without previous experience creating such test scenarios.
Figure 7. Beam shape becomes visible when UE moves in front of the 5G base station

Figure 8. Set base station and UE locations and orientation
Finalizing the emulation scenario

Loading the predefined scenario into the simulator verifies the correct values. Once completed, the simulator scales the input and output power values to current levels and copies the emulation files to the channel emulator.

Cabling the setup and storing configuration in Lab Setup file

After the scenario creation, the model is generated and visualized as an emulation topology in PROPSIM Running View. Additionally, the ports of PROPSIM, the base station, and the UEs are defined to correspond with the allocated RF channels. It is beneficial to store the physical RF connections of the test environment as Lab Setup in PROPSIM. It is best to use a torque wrench when attaching the RF cables to ensure a firm connection without breaking the connectors.

The Lab Setup file offers a way to recall the desired physical setup in terms of channel allocation. It also allows storage of the RF power levels, frequency, and other parameters. Lab Setup recalls defined parameters, though altering and rebuilding scenario parameters remain possible. The PROPSIM user manual contains more information about Lab Setup.
Verifying the signal chain

The KPI verification creates scenarios with a simple channel model, LOS, and matching link levels. The LOS model requires the implementation of a Butler matrix corresponding to the used antenna count to measure MIMO gain. Applying the Butler bypass mode in PROPSIM cross-connects RF lines with the desired Butler matrix cross-correlation to verify the connection and ensure MIMO transmission works as expected without any channel model.

Adjust the PROPSIM uplink / downlink input parameters to meet the power levels of the unit. The input signal must be on the level where clipping of the signal is absent. Next, export Lab Setup, which offers reproducible setup parameters and speeds up the testing time between environment parameter changes.

A beam sector sweep scenario created with the GCM tool measures beamforming gain levels. Running this test from PROPSIM’s output ports using external measurement tools verifies the beamforming capability.

Testing with a Full-Sampling Massive MIMO Test Environment

Load the desired test scenario into the channel emulator from Running View. At this point, review the previously created Lab Setup file to consider the physical parameters and confirm that there is no need for further tuning before loading the emulation. Next, trigger the KPI monitoring tools and start the emulation.
Analyzing test results

The PROPSIM family of products is not measurement equipment. Use external signal analyzing measures on hand to export the needed KPIs after setting the environment to correspond to the desired RF conditions. The most important characteristics are service availability, peak and average throughputs, handover success rates, and beam acquisition.

Introducing Partial Sampling in a Massive MIMO Test Environment

The full-sampling method samples every RF line of the antenna subsystem. The partial-sampling environment combines base station signals to use a lower number of TRX ports in the channel emulator. In practice, this means compressing the elevation angle into a single row of connectors. From the base station point of view, it appears the UEs exist in a single 2D plane.

It is possible to use a smaller configuration since this setup narrows the number of connectors needed in PROPSIM. Alternatively, this allows you to increase the number of users without adding channel capacity.

In practice, combining the channels requires wideband power combiners. Keysight offers the F9510A 4-to-1 combiner matrix with eight combiners in a single casing.
Analyzing test results

PROPSIM creates the radio environment between the base station and UEs. Assessing the performance of massive MIMO requires active testing over the emulated radio channel. Active means there is data transfer between the UE emulator or real UE and the base station.

Multi-user MIMO (MU-MIMO) testing requires multiple UEs in the test configuration, simultaneously performing the active test. The most important KPIs to look at are rank (for single-user MIMO test cases), SNR, CSI/SS-RSRP, CQI, link adaptation parameters, and throughput.

Total cell throughput is the most crucial metric for MU-MIMO performance verification. It factors in all variables that impact performance and directly indicates the potential capacity gain that MU-MIMO can provide. The other RF- and RAN-related KPIs are needed mostly for root cause analysis, to explain the results.
It may be possible to monitor the active testing KPIs from the base station side, depending on the diagnostic logging capabilities. Another proven way is to monitor the performance from the UE side, leveraging the diagnostic interfaces available from all the major 5G modem vendors. These diagnostic interfaces provide detailed transmission time interval and slot-level diagnostic data of the radio link, radio channel quality as seen by the UE, link adaptation, and throughput.

Keysight’s Nemo measurement solutions provide an off-the-shelf solution for driving the test cases from the device end, including automated scripting of the transactions, and capturing and post-processing of the UE diagnostic data for massive MIMO performance verification in both 5G and 4G.

**Signal-Based Phase Calibration**

This section describes how to use PROPSIM’s integrated input measurement-based calibration. Phase calibration of a defined massive MIMO antenna uses an incoming external signal. Phase calibration compensates for the phase difference between the antenna lines. An automated test environment remote interface performs this calibration. It is a relative pair-based measurement, evaluating through the desired MIMO matrix in pairs and comparing the result to a defined reference channel.
The method used is independent of the MIMO matrix size. But the method is dependent on the base station’s ability to feed the cell-specific reference signal (CRS) adequately in the correct format. The CRS signal transmission is based on two-antenna-port resource element mapping, as defined in section 6.10.1.2 of 3GPP’s TS 36.211. Set the MIMO matrix to transmit CRS 0 and CRS 1 on a higher number of CRS feeds in a manner enabling pair measurements covering all ports. For example, you could set 16-element antenna ports 1–8 to CRS 0 and ports 9–16 to CRS 1. Hence, the MIMO antenna count would quantify the step count of measurements.

During the phase calibration process, PROPSIM detects the presence of the CRS of the incoming LTE signal, as per defined settings. If PROPSIM detects a valid LTE signal, it analyzes the phase difference between the input signals. PROPSIM measures input phases and adjusts to compensate for phase differences.

Signal-based calibration is a user friendly, time-saving, and accurate calibration procedure that does not require removing the test setup / measurement cables from the application environment.

![Figure 15. Example connection for calibrating the channel emulator with ATE commands](image)
Ready to Take the Next Step?

PROPSIM F64 is available now. Keysight, the world’s leading provider of test and measurement equipment, has sales representatives across the globe. This wide availability guarantees customers a local support contact.

Custom configuration of PROPSIM units offers the optimum number of channels per unit and the required options and tools for the application. The expandability of the PROPSIM platform makes it a futureproof solution and allows the test environment to grow with the requirements.

Please visit our website for more information, or contact your local sales representative.

5G Solutions

Keysight’s 5G end-to-end design and test solutions enable the mobile industry to accelerate 5G product design development. Our solutions encompass the physical layer to the application layer and the entire workflow, from simulation, design, and verification to manufacturing, deployment, and optimization.

Keysight offers common software and hardware platforms that comply with the latest 3GPP standards. You can quickly and accurately validate 5G chipsets, devices, base stations, and networks, as well as emulate subscriber behavior. To learn more about Keysight’s 5G solutions, please visit www.keysight.com/find/5G.

To learn more about Keysight’s channel emulation solutions, please visit the following page:

PROPSIM FS16 and PROPSIM F64

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