

# 5G



WHITE PAPER

## First Steps in 5G

### Overcoming New Radio Device Design Challenges Series

#### Part 4: Over-the-Air Test

Over-the-air (OTA) testing is one of the most challenging aspects of 5G device development. Designers need to address many aspects of 5G, including the 5G New Radio (NR) standard, flexible numerology, millimeter-wave (mmWave) design considerations, multiple-input / multiple-output (MIMO), and beamforming challenges. The combination of these technologies introduces substantial test challenges that require OTA testing for validation.

MIMO, beam steering, and carrier aggregation are critical to meet downlink peak data rates of up to 20 Gbps for enhanced mobile broadband use cases. Under the unique mmWave channel conditions, highly integrated modems and designs require OTA testing. In the OTA test environment, it is necessary to visualize, characterize, and validate 5G device beam patterns and performance in a variety of real-world scenarios.

However, the 3rd Generation Partnership Project (3GPP) has not yet fully defined and approved OTA tests. Understanding the underlying challenges and proposed OTA test methods is essential to successfully developing 5G NR devices.



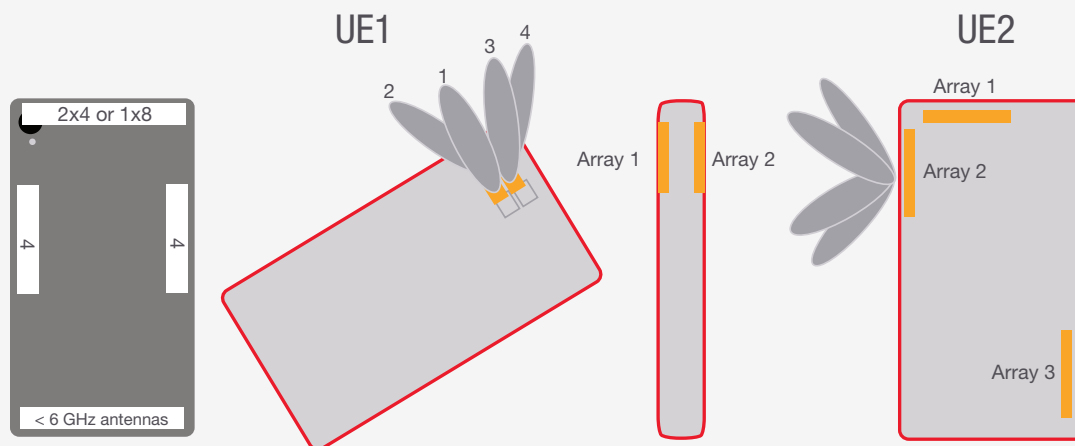
**You must address these three challenges to successfully test 5G mmWave:**

- Excessive path loss and distance at mmWave frequencies
- mmWave OTA test methods not fully defined
- Measuring device performance under real-world channel conditions

## New Test Methodologies Required for mmWave

Millimeter-wave frequencies are important because they offer more contiguous spectrum and wider bandwidth radio channels. These mmWave signals are also subject to signal propagation issues that were not a problem at sub-6 GHz. These include increased path loss, delay spread, or even blockage caused by chassis or human interference. These issues make it more difficult to establish and maintain a wireless communication link. 5G radio systems use multi-antenna spatial diversity and beam-steering techniques on both base stations and mobile devices to overcome these challenges. These designs improve signal robustness by reliably directing narrow beams in specific directions.

The mmWave antenna arrays are quite small; 24 GHz full-wave spacing is just 12.5 mm. 5G smartphone manufacturers need real estate for GPS, Wi-Fi, Bluetooth, and antennas that support multiple cellular frequencies. In addition, mmWave antenna arrays require physical bonding to the amplifier semiconductors for transmit and receive of the radio. These integrated designs are impractical to probe, and cabled tests become impossible to test mmWave parameters.



**Figure 1. Device antenna locations and radiating beams from antenna arrays**

OTA testing delivers critical insights during the prototyping phase. Chipsets, antennas, and integrated devices require validation in an over-the-air environment. A top-performing design requires designers to measure beam patterns both in 2D and 3D and understand beam width, side lobe levels, null depths, and symmetry. In addition, validating beam steering and null steering functionality is critical, confirming that the beam is pointing in the correct direction while maintaining the antenna gain under various conditions.

## OTA Test Challenges and Solutions

Unlike traditional cabled tests, OTA tests introduce many new challenges, including path loss. Cabled test systems demonstrate well-behaved physical properties that need calibration to produce accurate and repeatable results. Calibrating OTA test methods is possible, but the process is more time-consuming and complex. With mmWave devices, excessive path loss makes accurate OTA measurements more difficult. And while 3GPP has not yet fully defined standards for mmWave testing, Keysight works closely with 5G chipset and device leaders to understand the OTA test challenges and deliver 5G-ready solutions. Here is a summary of the new challenges:

- excessive path loss and distance at mmWave frequencies
- mmWave OTA test methods not fully defined
- measuring device performance in real-world channel conditions

### Challenge 1: Excessive path loss and distance at mmWave frequencies

OTA tests are typically carried out in either the near-field or far-field regions of the antenna array. The characteristics of the transmitted electromagnetic wave change depending on the distance from the transmitter. The signal becomes more developed as it propagates from the antenna array. As shown in Figure 2, the amplitude of the peaks, side lobes, and nulls of the radiation pattern evolve toward the far-field pattern.

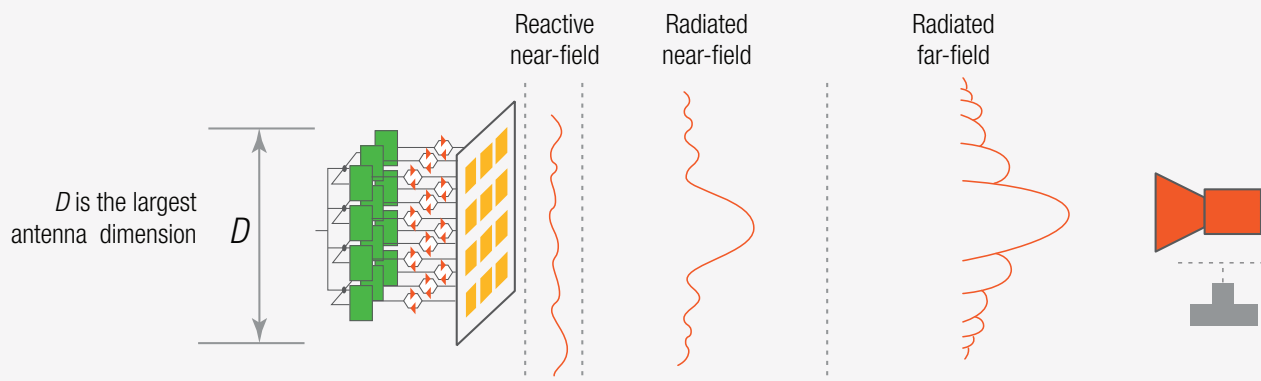


Figure 2. Beam properties at different distances from the antenna array

While near-field measurements are appropriate for some applications, 5G cellular communication links require using far-field assumptions. Because of the nature of radiated waves, the far-field distance and associated path loss grow bigger with the frequency. For example, the far-field region of a 4G Long Term Evolution (LTE) 15 cm device operating at 2 GHz starts at 0.3 meters and has a path loss of 28 dB. The far-field region of a 5G NR device operating at 28 GHz has a far-field distance of 4.2 meters and a path loss of 73 dB. This distance results in an excessively large far-field test chamber, and the path loss is too great to make accurate and repeatable measurements at mmWave frequencies. The distance also grows larger as the source antenna grows bigger, compounding the size and path loss challenge.

Size D (cm)	2 GHz Distance (m) Path loss (dB)	28 GHz Distance (m) Path loss (dB)	43 GHz Distance (m) Path loss (dB)
10	0.13 m 21 dB	1.87 m 66 dB	2.87 m 74 dB
15	0.30m 28 dB	4.2 m 73 dB	6.4 m 81 dB
20	0.53 m 33 dB	7.4 m 78 dB	11.4 m 86 dB

Table 1. Estimated far-field distance and path loss for different radiating apertures

Successfully testing RF performance measurements such as transmitted power, transmit signal quality, and spurious emissions requires overcoming the path loss problem. To overcome the path loss and excessive far-field distance issues, 3GPP approved an indirect far-field (IFF) test method based on a compact antenna test range (CATR), as depicted in Figure 3.



Figure 3. 5G compact antenna test range chamber

## Challenge 2: mmWave OTA test methods not fully defined

A typical OTA test solution includes an anechoic chamber, different probing techniques, and test equipment to generate and analyze the radiated signals in a spatial setting. The anechoic chamber provides a nonreflective environment with shielding from outside interference to generate and measure radiated signals of known power and direction in a controlled environment.

Moving to 5G, low-frequency tests are similar to 4G. For mmWave, however, the following tests now require the use of over-the-air methods:

- RF performance – minimum level of signal quality
- demodulation – data throughput performance
- radio resource management (RRM) – initial access, handover, and mobility
- signaling – upper layer signaling procedures

5G RF performance test methods are the most mature today. 3GPP study groups are still defining test methods for device demodulation and the more complicated RRM. 3GPP allows three RF performance test methods for user equipment (UE) devices. Each method has pros and cons, and one or more may be useful in characterizing your device based on the frequencies you need to test and the space constraints in your lab.

### Direct far-field method

In the direct far-field (DFF) method, the device under test (DUT) mounts on a positioner that rotates in azimuth and elevation, enabling measurement of the DUT at any angle on the full 3D sphere. The direct far-field method can perform the most comprehensive tests measuring multiple signals but requires a larger test chamber for mmWave devices; a 4.2 m chamber for a 15 cm radiating device at 28 GHz results in excessive path loss. With the ability to measure multiple signals, this remains the preferred method for sub-6 GHz devices.

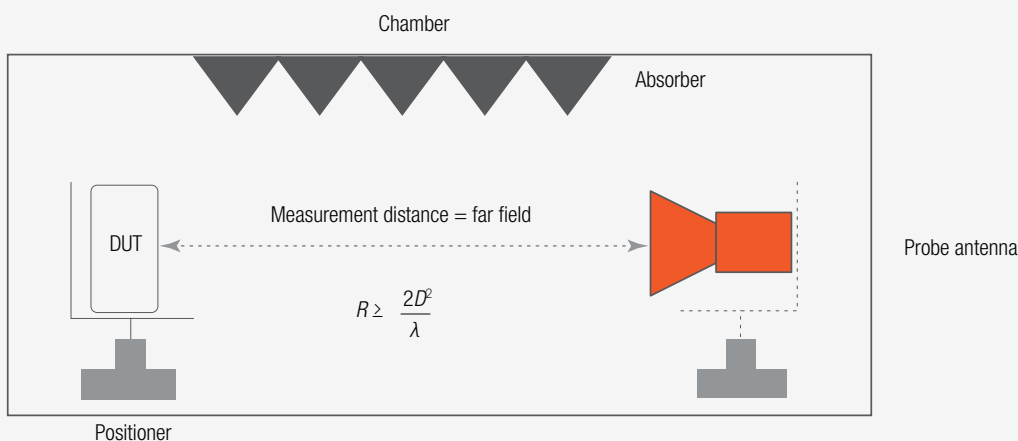


Figure 4. A direct far-field test setup

## Indirect far-field method

The IFF test method is based on a CATR that uses a parabolic reflector to make the signals transmitted by the probe antenna parallel and create a far-field test environment. While this method measures a single signal, it provides a much shorter distance and with less path loss than the DFF method for measuring mmWave devices.

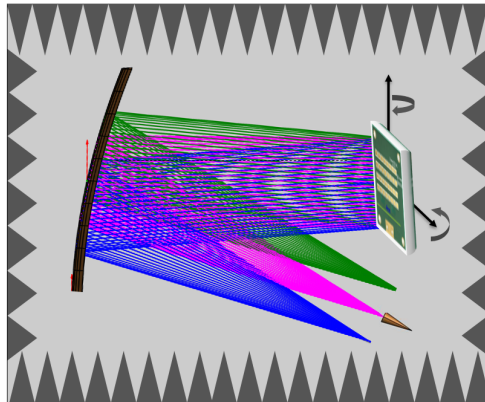


Figure 5. The physical arrangement of a CATR chamber

## Near-field to far-field transform method

The near-field to far-field transform (NFTF) method samples the phase and amplitude of the electrical field in the near region and uses math to predict the far-field pattern. While this is a compact, low-cost method, it is subject to transmitter interference that impacts measurement accuracy. It is also limited to single line-of-sight measurements.

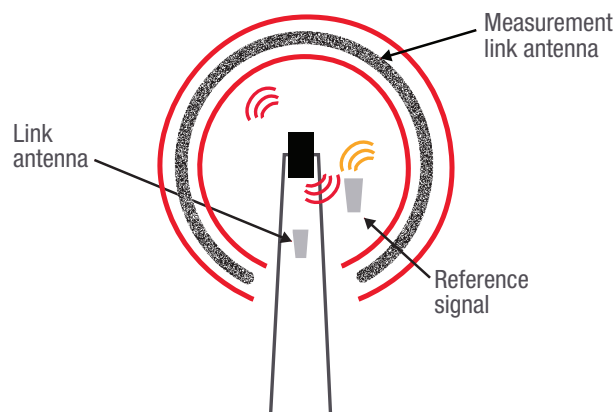


Figure 6. The concept of an NFTF test method



Since specific requirements and test methods have not been fully defined, it will require a considerable amount of time and rework to implement an OTA test solution on your own. Keysight participates in the development of the 3GPP specifications and has early knowledge of requirements. Working closely with early adopters, we innovate on 5G OTA test methods, including chambers, probing, and the test equipment used to address a wide range of RF, demodulation, and functional performance test requirements in both mmWave and sub-6 GHz for 5G new radio designs.

### Challenge 3: Measuring device performance in real-world conditions

To achieve the highest degree of performance and reliability, designers must move beyond testing in a stable and controlled validation environment. A channel emulator is a tool that mimics real-world conditions while providing control and repeatability for those conditions. The tool lets designers test a variety of new technologies, including wider signal bandwidths, mmWave frequencies, and beam steering with signal propagation issues like path loss, multipath fading, and delay spread. As part of a complete test bed, a channel emulator enables the designer to characterize the device as part of a live full-stack system while emulating real-world radio conditions. A full-stack setup enables designers to test a broad range of situations and quickly identify any use cases that might compromise the user experience in the finished device.

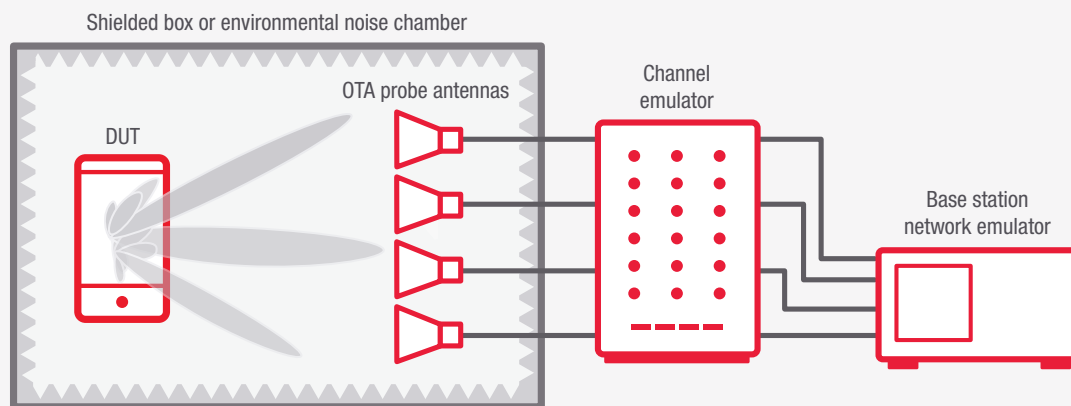


Figure 7. A base station emulator and channel emulator simulate real-world conditions



## Implementing Evolving OTA Testing Methods

Delivering on the extreme data rates 5G promises will be challenging. Visualization, characterization, and validation of multi-antenna arrays that create narrow beams require OTA test methods. Far-field path loss and chamber size lead to challenges with accurate and repeatable measurements as well as physical challenges with lab space.

The 3GPP is working on specifying new OTA methods to help mitigate these challenges. Many aspects of OTA tests still need to be fully defined, but Keysight is at the forefront of 3GPP specifications and early OTA test solution development. Leverage Keysight's expertise to accelerate 5G designs while ensuring high performance and higher-quality products. Contact Keysight to learn more about solutions for 5G OTA testing.

You can access the different parts of the First Steps in 5G white paper series by clicking on the respective links:

- [First Steps in 5G – Part 1: 5G New Radio Standard](#)
- [First steps in 5G – Part 2: Millimeter-Wave Spectrum](#)
- [First Steps in 5G – Part 3: MIMO and Beamforming](#)
- [First Steps in 5G – Part 4: Over-the-Air Test](#)

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