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FOCUS ON:

Addressing 5G Development with OTA Testing

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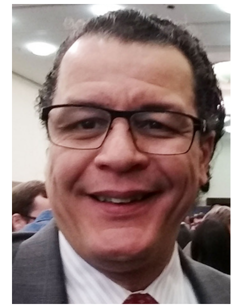
INTRODUCTION

WHEN IT COMES TO TEST SOLUTIONS available for performing OTA measurements on 5G modules, devices, and active antenna systems, there are many choices. One can go with a modular turnkey test solution that includes all required test and measurement instruments, antennas and accessories for cmWave and mmWave user device testing, for example, and build the feature set that best addresses your application. This eBook serves as a guide for OTA testing when it comes to 5G.



Alix Paultre
Editor

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FOCUS ON:
Addressing 5G Development with OTA Testing

CHAPTER 1:

Contending in the 5G Race Requires the Right Test Equipment

EVALUATION ENGINEERING STAFF

The potential reach of 5G into applications across all industries, let alone its speed, will demand test equipment that can handle mmWave frequencies and advanced RF and beamforming performance, among other critical factors.

What you'll learn:

- **The wide-reaching impact of 5G across industry and society**
- **Top 5G test challenges and solutions**
- **Key questions to ask about 5G test solutions**

Every few years, there comes a wave of new technological advances that transform the world. The concept of 5G, or fifth-generation mobile telecommunication technology, has been around for some time, but it has really caught steam of late.

With wireless network technology becoming indispensable for both individuals and industries, the demand for faster speeds and newer functionalities is only increasing.

The Potential of 5G Across Industries

The significance of 5G technology isn't restricted to lightning-fast speed either. The incredible internet capacity, response time, reduction in latency (time delay), and diverse new applications that this innovation promises make it even more desirable today.

Ericsson has projected that over *1.5 billion people*, or roughly 40% of the world's population, will gain access to 5G networks in the next four years.

While 4G's primary scope was limited to telecommunications, 5G is going to be a different ballgame altogether.

Here's looking at some of the wide-ranging applications of 5G:

5G-based IoT

- Mobile networking and telecommunications
- AI-enabled robots

- Medical appliances
- Smart homes
- Defense
- Aerospace
- Self-driven vehicles
- Autonomous industrial equipment
- Agriculture machinery
- Augmented reality (AR)
- Virtual reality (VR)

Given the potential, it's evident that 5G signal and link testing is going to be of paramount importance in the near future. If we're to go beyond prototypes and trials, efficient and accurate 5G testing will play a massive role in this area.

How is 5G Different from 4G?

To put it simply, the scope of 5G begins where 4G ends. Things that were once deemed impossible became reality with 4G technology, but there are certain limitations to how much and how quickly data can be transferred.

Security, reliability, speed, and uninterrupted signal strength are the prime benefits that 5G has when compared to 4G.

The real-time transfer of data, with latency in the *1- to 10-ms range*, means that 5G will help connect humans and machines like never before. While this improvement in speed might not make a world of difference to the average internet user, it will prove to be game-changing for large-scale critical industrial applications.

5G-enabled automation will create unprecedented opportunities in the commercial ecosphere, leading to higher productivity, and in turn, greater output.

Another remarkable advantage that 5G has over 4G is the easy slicing of the network, which allows for custom speed, capacity, coverage, encryption, and security management.

Top 5G Testing Challenges and Solutions

While the obvious benefits of 5G are indisputable, a wide range of challenges need to be addressed before it can be adopted across markets. Because 5G will deliver unparalleled speed, the demands on the network-testing regime will be proportionally higher. And, therefore, testing of 5G equipment and networks assumes significance.

Some of the most pressing concerns include:

- *Millimeter-wave (mmWave) adoption:* Perhaps the biggest challenge faced by engineers working on futuristic systems and wireless networks is to develop the millimeter-wave infrastructure in a streamlined and cost-efficient manner.
- *Assessing beamforming performance:* Conducting static tests on devices or antennas in active beamforming environments (beam tracking and switching), and gauging the performance, will also be key to helping massive MIMO arrays use nearby spectrum. This will include measuring and recording field beamforming characteristics and identifying the top issues.
- *Validating modulation and channel quality:* In a 5G environment, monitoring the channel bandwidth, channel center frequency, and channel stability is essential.

Configuration and performance indicators like bandwidth, frequency, and stability will need to be monitored.

- *Radio-frequency performance:* Instant troubleshooting and identifying the root cause of poor RF performance will play a massive role in the analysis and testing process.

Apart from those challenges, running all relevant tests quickly and efficiently is necessary to keep the test throughput cost-effective. The next step in this domain will be to find out ways to enable machine-learning-based automation for 5G system testing and deployments.

To take this technology from the lab to the field, the accuracy and efficiency of 5G testing are major factors for consideration. Automated testing and analysis, a solid fiber foundation, and reliable support are among the biggest concerns in this space. The role of test equipment, thus, is massive in the 5G industry.

The Right Testing Solutions for 5G

When considering the right testing solutions for 5G, it's important to bear in mind that this isn't a one-size-fits-all case. Because the applications and use cases are so varied in nature, the complex 5G testing environment calls for various testing equipment that meet your unique needs.

Whether you talk about high-end testing tools like *signal generators*, spectrum analyzers, vector network analyzers, oscilloscopes, or power meters, here are the most critical questions you must ask:

- Does the testing solution offer relevant features?
- How scalable is the solution, keeping future needs in mind?
- How cost-effective is the technology and does it fit your budget?
- Is it the perfect fit for the challenges you're trying to resolve?
- Is the solution available for rent or lease?
- Has it been manufactured by a reliable company?
- Does the vendor offer optimal customer support?

Your 5G test-equipment procurement plan should be able to answer these questions. 5G's promises of higher network capacity, increased bandwidth, lower latency, and reduced battery consumption for the wide-scale adoption of IoT applications can't be realized unless testing is done right.

5G deployment will soon be a reality—make sure you have the right test equipment to stay a step ahead in the 5G race.

Amanda Wilson is an established freelance writer who has built her career focusing on the electrical and electronic test equipment and measurement industry.

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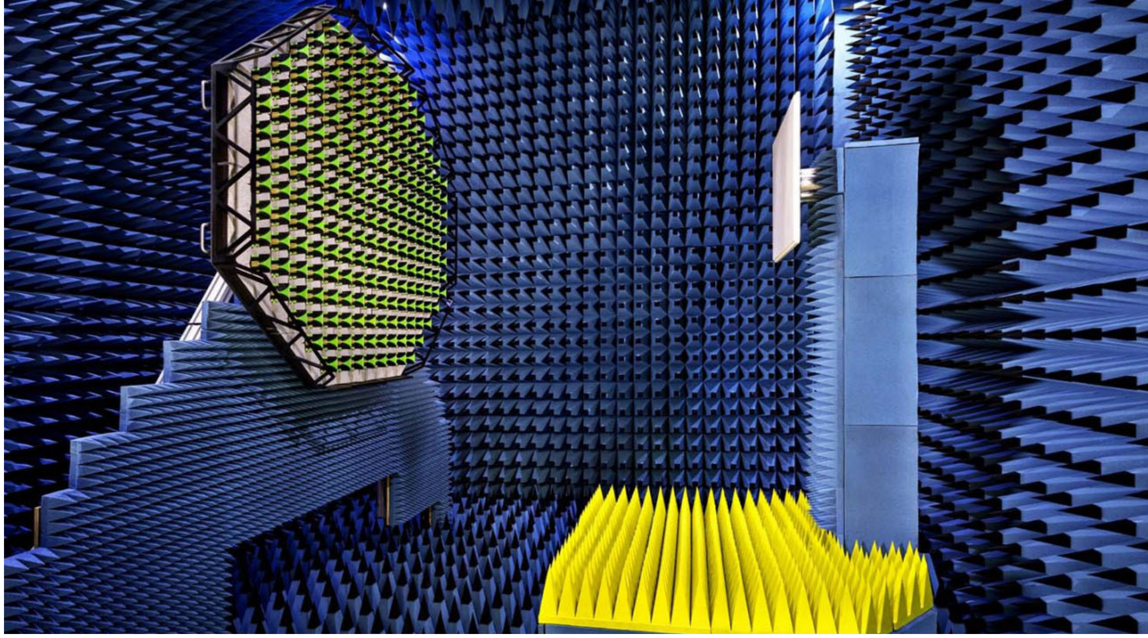

CHAPTER 2:

Delivering 5G Devices to Market Will Bank on OTA Testing

CLINTON LINVILLE, Application Engineer, Rohde & Schwarz USA, Inc.

As 5G begins to leverage high-frequency mmWave bands, engineers that used to work at RF frequencies will once again need to sharpen their skill sets and adopt new design and testing techniques.

The biggest challenge in testing 5G devices, as opposed to 4G/LTE, is the reliance on active antenna arrays and high RF frequencies. These frequencies are far higher than what we have ever used before in a commercial communication system. Frequency range 1 (FR1), which will transmit most of the traditional cellular communications traffic, has been designated for 450 to 7125 MHz. Frequency range 2 (FR2) will employ millimeter-wave (mmWave) frequencies (24,250 to 52,600 MHz) to deliver short-range, high-data-rate transmission.

Higher frequency bands combined with extended bandwidths in the mmWave range will place much higher demands on the components for 5G communications devices and systems, including the filters, mixers, amplifiers, analog beamforming chipsets, and antennas.

For FR1, which is sub-6-GHz, testing can still be performed using cables. But at FR2, it will be necessary to consider the entire assembly as one entity, including the antenna, phase shifters, amplifiers, attenuators, and more. Testing needs to be performed at a system level, so that connectors and cables don't interfere with the system characterization.

New Technologies, More Complexity

FR2 products are becoming very complex. They're comprised of phased-array antennas; each is built of many antenna elements, every one with its own phase shifter and amplifier, working collectively to steer a signal in a desired direction.

In this case, if testing is performed using a connector that bypasses the antenna array, it's impossible to gauge how the overall system performs: If the system lacks proper beam-steering or gain, or if the components behind it are too noisy and impact the modulation of the signal, it will not be discovered during the testing phase. Therefore, it's critical to characterize the entire system—the radio and the phased-array antenna together.

In multiple-input, multiple-output (MIMO) technology, multiple antennas are used at both the transmitting and receiving points, creating a circuit that minimizes errors and optimizes speed. Traditionally, testing MIMO signals has focused on testing the transmitter/receiver system and the quality of the channel. Facilitating commercially feasible testing in 5G devices could be a challenge.

However, when designing a massive-MIMO active antenna system, development engineers face new challenges that include phase-shifter tolerances, thermal effects of the power amplifiers (PAs), and frequency drifts between modules that affect the desired beam patterns.

In an active antenna system, the transceiver front-ends are integrated together with the antenna array, which means that traditional RF output ports are no longer accessible. In addition, a fiber interface replaces the traditional RF input ports for digital I/Q data. Consequently, over-the-air (OTA) testing becomes the default use case for massive-MIMO systems and for modeling the spatial properties of the propagation channel. Due to the different sizes of massive-MIMO systems, testing in far-field conditions requires a variety of shielding environments.

It's still a bit early to consider what a MIMO test solution for 5G will look like. Nonetheless, we anticipate the need to consider multiple angles of arrival of signal, application of the proper fading channels, etc. Currently, it's difficult to see what this looks like for FR2.

The 3rd Generation Partnership Project (3GPP), which unites seven telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, and TTC), is actively developing the reports and specifications that define 5G technologies. The project covers cellular telecommunications technologies, including radio access, core network, and service capabilities, which provide a complete system description for mobile telecommunications.

The 3GPP technologies from these groups are constantly evolving through generations of commercial cellular/mobile systems. With its LTE, LTE-Advanced, LTE Advanced Pro, and 5G work, 3GPP has become the focal point for the vast majority of mobile systems beyond 3G. A number of Rohde & Schwarz representatives regularly attend 3GPP's meetings globally, including those of the standards committees, and the company has contributed input and feedback on testing devices and systems to meet the specifications the organization lays out. When the standards are finalized, they will drive the future certification process.

The major focus for all 3GPP Releases is to make the system backward- and for-

Some Basic Functional Measurements

- *Effective isotropic radiated power:* What's the power level from my reference point at my measurement antenna?
- *Error vector magnitude (EVM):* Looks at modulation quality. How well we can transmit and receive a modulated 5G signal and then receive it?
- *Adjacent channel leakage ratio (ACLR):* How much energy is transferring from one channel to a channel next to it?
- *Spurious:* How much or how high are the levels coming from a particular device?
- *Antenna pattern*
- *Antenna gain*
- *Antenna directivity*

Shown is Rohde & Schwarz's ATS800R rack-mount CATR system that performs OTA testing.

ward-compatible where possible, to ensure that the operation of user equipment is uninterrupted. For 5G, many operators are starting with dual connectivity between LTE and 5G NR equipment—using a non-standalone specification detailed in Release 15 that was completed earlier this year. Care has been taken to build forward compatibility into non-standalone NR equipment, to ensure that it will be fit for use on standalone 5G NR systems.

The Evolution of OTA Testing

In terms of testing, the standards are changing from connectorized measurements to an indirect far-field measurement using a compact antenna test range (CATR), as it provides the most flexibility and a practical solution moving forward. For example, if you were to measure an FR2 phased array in a true far-field chamber, you would be looking at a range length of several meters, which is impractical.

Today's systems can execute the antenna characterization or antenna check using test solutions such as a compact antenna range that emulates far-field conditions within a smaller area/footprint. Moving forward, CATR will be the test system of choice to test phased arrays at high frequencies for user equipment.

One such compact solution is the ATS800R from Rohde & Schwarz, a vertical rack-mount CATR system **(see figure**). The device can be placed on a table to characterize the phased arrays and facilitate quick measurements—such as EVM, ACLR, EIRP, or beamsteering measurement—within a 20-cm quiet zone. Although not automated, an adjacent device under test (DUT) can be quickly, fully characterized, which is beneficial for R&D functions as well as for a production environment.

OTA testing will be critical for ensuring that 5G devices will perform in the real world. The 5G device is placed in a test chamber and tested in simulated conditions to see how it responds. In addition to verifying the performance, such testing will certify that products meet specified standards, from both a modulated perspective and an antenna perspective. For example, a vector signal generator can provide a modulated 5G signal, while a spectrum analyzer can help analyze those signals with special measurement profiles, to verify unimpeded transmission between the signal source and the device.

White box testing was sufficient for sub-6-GHz devices for 2G, 3G, and 4G, as the far-field conditions where not as vast as we'll see with the FR2 band. The latter frequency range is designed for applications that would not allow for a direct line of sight from the DUT to measurement probe. White box testing enables the measurement antenna to look directly at the center of rotation, and the tester knows the antenna's precise location. Positioning is very important in white box testing, since it uses the far-field condition directly.

While a direct far-field system may allow for testing of larger devices, it's not practical at higher frequencies. FR2 will require black box testing, either because the antenna position is unknown or there's a need to measure an entire system or product. This testing method uses indirect far-field (CATR), which doesn't require exact positioning because an indirect wave measures the device. The measurement system is pointed at the reflector and filters out the spherical wave component to reflect the planar wave back toward the DUT.

Modern highly integrated chipsets, front-ends, and antenna systems require new techniques for OTA measurements in a multitude of development steps. Integrating the antenna or antenna array into the chipset poses challenges in beamforming verification and chipset or amplifier testing. With the use of state-of-the-art test and measurement equipment in lab environments, shielded boxes, or large anechoic chambers, the challenge of OTA testing largely comes down to understanding key challenges in antenna measurement and chamber setup.

It's important to keep in mind that conformance testing will change considerably for FR2 frequencies, leaning toward OTA testing over conducted tests. Engineers will need to know how to calibrate the systems and understand what they are measuring. This will require a bit of homework on their part, perhaps working closely with antenna manufacturers.

5G Production Testing

In addition, 5G production testing, which is still evolving, should be recognized as much more of a challenge for R&D due to the high volumes involved. Production speed ultimately will be impacted by the types of measurements required as well as the length of time it takes to measure and record the measurement.

However, OTA systems for FR2 can be used without a front door in an R&D environment, which saves time placing and removing devices in the chamber and is further conducive to a production environment when a reflector is mounted above the manufacturing line. Such a setup enables a CATR system to easily measure bore sight, off-peak, null definition, beamsteering accuracy, and more.

Production testing for FR2, though, currently remains in the R&D stage for the most part, as manufacturers focus on developing the right design. When 5G becomes mainstream, test-and-measurement designs will need to quickly evolve and align with standards and specifications.

Closing the Knowledge Gap: The New Digital Divide

Millimeter-wave engineering is considerably different than RF engineering. At mmWave, components act differently. At low frequencies, engineers don't need to account for the phase properties of a wavelength since wavelengths are large in comparison to the component size. But at mmWave, in which frequencies are high and wavelengths are small, the wave properties of the signals must be considered.

As 5G begins to leverage high-frequency mmWave bands, engineers that used to work at RF frequencies will once again need to sharpen their skill sets and adopt new design and testing techniques. To learn more about the technologies shaping our future wireless world, please visit the *5G Learning Center*.

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CHAPTER 3:

Demystifying Over-the-Air (OTA) Testing

RHODE & SCHWARZ

Important antenna parameters, test system setup and calibration

1. Introduction to over-the-air measurements

Heinrich Hertz built the first antenna in 1887, and 10 years later, Marconi began experimenting with wireless communications. By the beginning of the 20th century, Marconi successfully transmitted the first transatlantic radio message. Finally, the first broadcasttower went live in the 1920s, nearly 100 years ago [1]. Huge developments followed in the field of wireless communications, antenna design and testing, and EMC testing. With such a long history behind wireless communications and antenna and EMC testing, why is over-the-air (OTA) testing the focus of this paper?

Today, given the increasing integration of chipsets and antennas as well as usage of higher frequencies, the lines between testing chipsets, RF testing and antenna characterization have become blurred. In upcoming mm-wave architectures (involving signals with wavelengths in the general millimeter region), there will be no connector between RF components like chipsets, a power amplifier (PA) and the attached antennas. Therefore, the chipset cannot be tested without the antenna and vice versa. Both analog and digital improvements are leading to the use of multiple radio frequency (RF) frontends, massive antenna arrays even in consumer grade hardware, and a combination of beamforming and multiple-input multiple-output (MIMO) technology known as massive MIMO, enhancing multi-user MIMO (MU-MIMO) and supporting high user capacities in the 5G New Radio (NR) standard.

Whether in low-cost devices targeting the IoT market, highly integrated radio front ends for satellite communications links, or mm-wave devices, integrated antennas are becoming more common with each development cycle. Therefore, OTA testing is becoming more important (or even mandatory) for a broader audience. The step from conducted measurements to OTA testing changes the measurement requirements to a certain degree. New user groups are thus required to have a basic understanding of antennas and antenna measurements.

This paper will provide an introduction to antennas in general, their parameters and different types, as well as antenna characterization and testing in Chapter 2. For more in-depth examination of antenna theory and design, suggested literature is referenced at the end of this paper.

Chapter 3 will focus on the importance and execution of OTA test setup calibration. The general concepts are valid for any OTA setup, e.g. in-chamber or lab-desk. Afterwards, calibration verification is discussed.

The last chapter will briefly discuss array antenna calibration methodologies.

The rest of the following chapters of this white paper can be seen by clicking the link below

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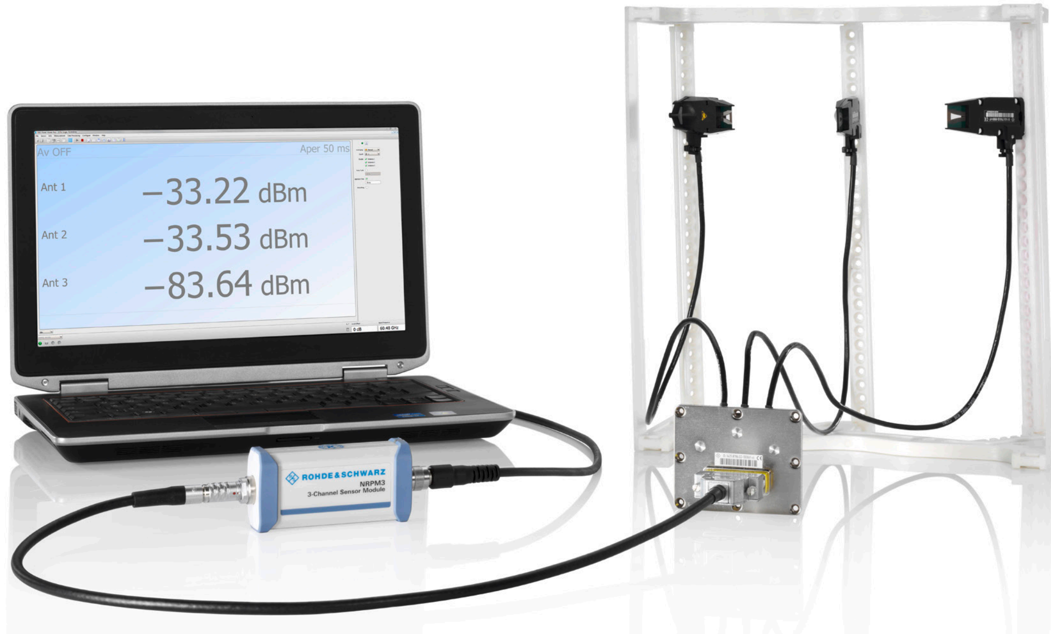

CHAPTER 4:

Understanding OTA Power Measurements

RHODE & SCHWARZ, Paul Denisowski, Product Management Engineer

R&S®NRPM OTA power measurement solution

This video link below provides a brief technical introduction to over-the-air (OTA) power measurements, how they are different from traditional conducted power measurements, and why OTA measurements are important for many newer technologies such as 5GR (FR2), 802.11ad and 802.11ay, and automotive radar.

to view this video online, ☞ click here

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