Advancements in Antenna Measurement Techniques With Application to Civilian & Military Wireless Communication Devices

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***Abstract*— Modern wireless communications devices as used in both civilian and military applications, such as mobile phones and base stations have become integral parts of daily operations. They offer a large range of functionalities often facilitated by an incorporated array of antennas and sensors. The evaluation of these devices has evolved significantly, from radiation patterns and coverage to assessing system level performance metrics. This paper delves into the recent developments in antenna testing methodologies, particularly in the context of 5G, and potential future technologies and provides guidance in the selection of suitable testing technology.**

I. INTRODUCTION

Antenna and its electromagnetic characterization have posed challenges for over half a century, with measurements traditionally conducted in the Far Field (FF) under the assumption of an infinite distance between the antenna or device and the observation point [1]. The FF condition, akin to a plane wave condition, is a reference state, allowing for traceable and comparable results across different measurement ranges and systems.

Despite the prevalence of Near Field (NF) communications in antennas and devices, the FF state remains integral to conventional performance parameter definitions, including gain, directivity, and radiation patterns. Traditionally, wireless devices transmit and receive performances were measured by directly connecting them to test equipment. However, in today's technology landscape, where transmitters and receivers are integrated into the device, over-the-air (OTA) testing has become the norm.

In OTA testing, spatial power quantities related to radiated power and device sensitivity are typically measured to characterize the transmitting and receiving properties of a device. The main antenna electrical parameters to be characterized are defined and discussed by IEEE and ETSI standards. They are often considered the reference document for test engineers [2], [3], [4]. With the focus on OTA testing [5], [6] different parameters are becoming more relevant such as radiated power and sensitivity EIRP, EIS, with corresponding integral parameters such as TRP and TIS. Other dedicated organizations, such as 5G Automotive Association (5GAA) [7], 3G/5G Partnership Project (3GPP/5GPP) [8], [9] and the Cellular Telecommunications and Internet Association (CTIA) have developed documents with proposed standards for specific measurements [10].

Historically, testing methods for wireless devices involved mechanically rotating the device within a test fixture. However, this approach led to distortions in results due to high levels of interaction with the fixture. Various investigations in the early 2000's highlighted the need for precise device representation during testing and understanding the impact of user interference on performance. Subsequently, non-invasive device positioners were introduced, such as foam columns, enabling accurate assessments of both standalone and user-influenced performances.

Studies, such as [11], reveal that the human body significantly influences personal device performance, particularly at millimeter-wave frequencies. The shadowing effect at these frequencies reduces the coverage efficiency of phased arrays, necessitating the placement of multiple arrays in different parts of the device. Testing methods involving head and hand phantoms or live person testing are thus essential to evaluate the impact of user proximity on device performance.

Multiple Input Multiple Output (MIMO) OTA testing aims to determine system-level parameters, including data throughput and received power, in realistic and complex scenarios. Standardized channel models, such as those implemented in multi-probe anechoic chambers (MPAC), are used for these tests. Challenges in MIMO OTA testing include reproducing RF and spatial contributions to the signal using a channel emulator and probe array. Fig. 1 illustrates a typical test setup for MIMO OTA testing with MPAC solution [12].

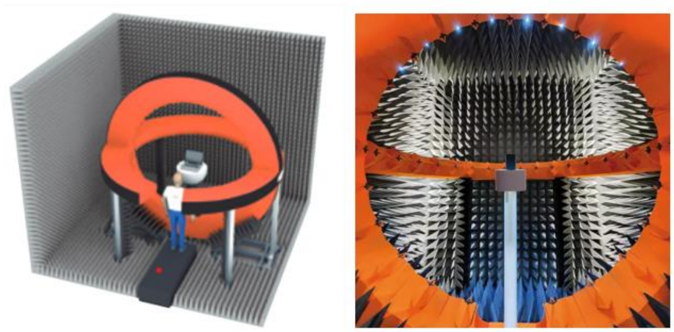


Figure 1. Measurements of MIMO OTA performances using a typical MPAC solution based on a horizontal ring of probes.

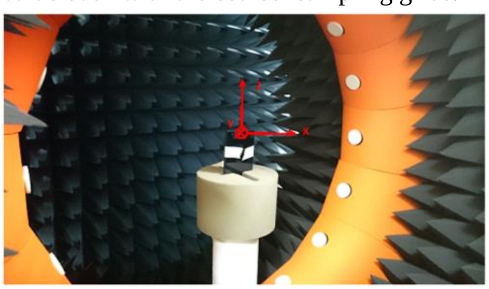
At mmWave frequencies, the number of probes required for a full MPAC solution becomes impractical as the device's electrical size increases, presenting a critical testing challenge. A potential solution is to limit the angular space of the testing, thereby reducing the overall number of probes needed.

II. NEAR FIELD TECHNIQUES FOR PERSONAL DEVICES AND BASE STATIONS

Due to lower interaction with test fixtures, near field (NF) techniques have gained preference for testing devices designed to radiate in all directions. Multiprobe systems, as shown in Fig. 1, have been developed to increase measurement speed by electronically scanning the measurement surface. Such technique requires a full scan of the measurement surface to determine device performance accurately.

Antenna measurement in the far field condition can be achieved in near field measurement ranges using phase recovery techniques. A common method is holographic phase recovery, combining measured signals with stable reference signals and fixed phase shifts so that the relative phase of the measured signal can be determined from the amplitude of the combined signals. The effectiveness of this approach has been demonstrated in [13] by emulating an Active Antenna Systems (AAS) using a mobile phone with LTE protocol connected to an 8-element passive array.

When it proves challenging or impractical to recover the phase in certain cases, performance metrics like Total Radiated Power (TRP) and Total Radiated Sensitivity (TRS) can be determined by integrating the measured power quantities in the near field [14]. This process is shown in Fig. 2, which illustrates the determination of TRP for a wireless device operating at 24 GHz with different integration grids, directly in near field. Despite a standard sampling criterion for the device of 2.5°, it is noteworthy that TRP convergence to the correct value even with the coarser sampling grids.



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Resolution (deg)	TRP (dBm)
5	4.49
10	4.41
15	4.42
20	4.38
25	3.75
30	4.66

Figure 2. Measurement of integral power performance metrics in the near field of wireless device @ 24GHz.

III. FAR FIELD TECHNIQUES FOR PERSONAL DEVICES AND BASE STATIONS

At mmWave frequencies, the heightened directivity of antenna arrays integrated into devices enables the utilization of indirect Far Field (FF) techniques like Compact Antenna Test Range (CATR) or Plane Wave Generators (PWG) for testing purposes [2]. These systems offer a notable advantage in terms of speed, as they allow for the determination of FF performance in a specific direction based on measurements from a single point. To ensure accurate device performance measurements within these systems, the use of non-invasive device positioners, such as foam columns or similar mechanisms, becomes crucial. Fig. 3 illustrates a potential FF testing system for devices, utilizing array-based PWG technology. This system accommodates testing scenarios with users, effectively emulating multiple base stations.

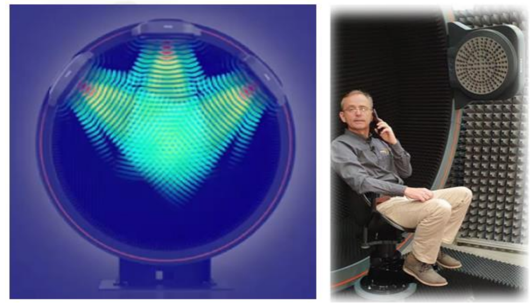

Figure 3. Implementation of array based PWG solution for device testing in FF condition, including scenarios involving live or phantom users.

IV. FUTURE DEVELOPMENTS AND OUTLOOK

The rapid evolution of technology has heightened the importance of swift time-to-market in wireless communication. To meet this demand, advancements in measurement speed, accuracy, and convenience are driving the shift away from traditional testing techniques like [B1] and [B2]. Instead, specialized methodologies that focus on optimizing device performance in realistic scenarios are gaining prominence. This shift is primarily fueled by increased demands from research and development (R&D) activities, highlighting the necessity of realistic user experience testing. Such testing is crucial for identifying areas that require improvement, ultimately enhancing overall device performance.

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