



## **MILLIMETER-WAVE MASSIVE MIMO DISTANCE STUDY**

# **DISCUSSION ON MEASUREMENT TEST DISTANCE FOR DETERMINING EIRP OR TRP FOR ACTIVE ANTENNA SYSTEMS**

Authored by

American National Standards Committee C63®

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# DISCUSSION ON MEASUREMENT TEST DISTANCE FOR DETERMINING EIRP OR TRP FOR ACTIVE ANTENNA SYSTEMS

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## ABSTRACT

This paper discusses general guidance and methodologies for the determination of far-field (FF) peak gain, equivalent isotropic radiated power (EIRP), and total radiated power (TRP) of active antenna systems (AAS) at ranges shorter than the classical Fraunhofer distance (FHD).

# 1. SCOPE

This paper is the product of a discussion in the MIMO Study Working Group responsible for the IEEE PC63.26 draft standard on testing of transmitters used in licensed services. One topic that needs to be addressed is to determine the adequate measurement distance for the purpose of compliance demonstration of devices including antennas and antenna arrays. This paper focuses on measurements of the EIRP and TRP for intentional radiators, with particular considerations on AAS, where the antennas and transceivers are integrated, and no antenna ports can be accessed. Nevertheless, the concepts and methodologies detailed herein are also applicable when a radiofrequency port is accessible and for other quantities of interest such as the gain, directivity, and half-power beamwidth (HPBW), as defined by the IEEE Std 145™-2013 [1].<sup>1</sup> Although the testing of wireless devices as per IEEE Std C63.10™-2020 or draft 2 of IEEE PC63.26 requires evaluations at specific test distances, guidance on how to reduce the measurement range length and still yield acceptable measurement accuracy can be expanded in the standards. Procedures to practically increase the measurement accuracy in test sites with limited range lengths are also unavailable. Another challenge is the qualification and mitigation of uncertainty contributions in such measurements.

This paper aims to respond to the specified challenges by providing a revision of state-of-the-art far-field (FF) assessment, through the definition of an effective FF range length that is shorter than the FHD yet appropriate to derive the quantities of interest with a given certainty. It also provides brief insight into major measurement uncertainty contributions at such distances, as well as methods to characterize and mitigate them.

# 2. GENERAL DISCUSSION ON ACTIVE ANTENNAS

AAS with integrated antenna modules and operation at higher frequencies, such as mm-wave and sub-THz, are two major trends in the mobile industry. Such antenna systems are designed to adapt to the environment by using steerable antenna radiation patterns (i.e., beams). The number of possible beam configurations can be large. Because of this and the dynamic beamforming capabilities of devices, achieving a complete test coverage is challenging. Moreover, the lack of connectors between the radio and the antenna has led to the merging of transceiver and antenna testing. For example, transceiver parameters such as ACLR, EVM, OOBs, and spurious emissions are tested OTA. Furthermore, the absence of antenna ports has led to conducted power being replaced by TRP.

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<sup>1</sup> Numbers in brackets correspond to the list of sources in Section 7.

When evaluating the AAS transmitter characteristics, the basic parameter to be measured is the EIRP. This parameter reflects the capability of the AAS to concentrate power in a certain direction and is mathematically defined as a limit toward infinite distance. A finite test distance is used for practical measurements. The choice of this distance is critical, as it signifies a trade-off point between characterization accuracy and the size/cost of the test facility. To meet the demand for higher data rates, AASs tend to be electrically larger and operate at higher frequencies. Similarly, the required measurement distance in OTA test sites potentially increases beyond the available test chamber dimensions. In such situations, tests cannot be conducted by following established guidelines. This topic is explored further in the Section 3.

## 3. FAR-FIELD DISTANCE DISCUSSION

### 3.1. EFFECTIVE FAR-FIELD DISTANCE

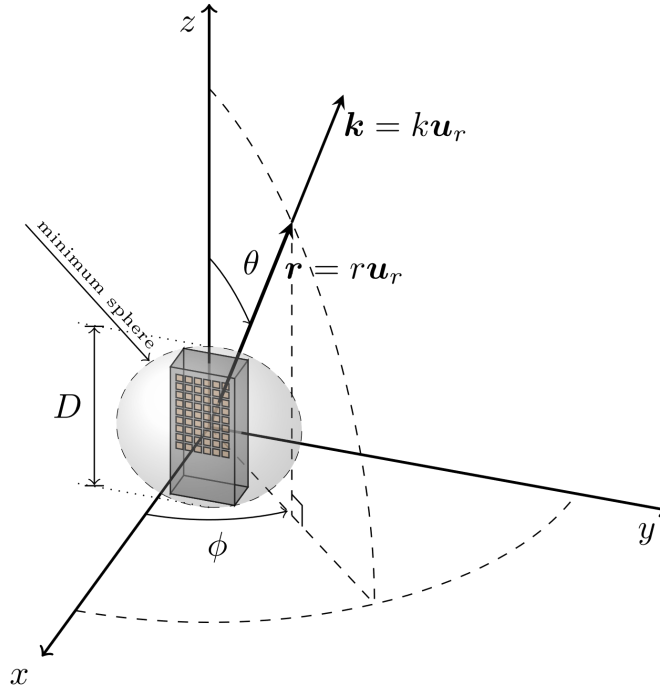
The FF region is where the angular distribution of the field radiated by an antenna is essentially independent of the distance from a specified point in the antenna's region (IEEE Std 145-2013 [1]). Under such conditions, the electric (**E**) and magnetic (**H**) field vectors are transverse to the direction of propagation and considered to be well approximated by their asymptotic forms, such as

$$\mathbf{E}(R, \theta, \varphi) = \frac{e^{jkR}}{kR} \mathbf{F}(\theta, \varphi) \quad (1)$$

$$\mathbf{H}(R, \theta, \varphi) = \frac{1}{Z_0} \mathbf{k} \times \mathbf{E}(R, \theta, \varphi) \quad (2)$$

where  $(R, \theta, \varphi)$  refers to standard spherical coordinates, and  $\mathbf{F}(\theta, \varphi)$  is the vector FF radiation pattern. In the above formulas, an  $e^{-j\omega t}$  time-dependence is assumed, where  $\omega = 2\pi f$  is the angular frequency of the field and  $f$  is the carrier frequency of the signal. The origin of the coordinate system is typically chosen at a particular DUT reference point, such as the center of its antenna aperture or its radiation center. These terms and choice of the reference point are further discussed in Section 4. The variable  $R$  represents the distance from the observation point to the electromagnetic source and is usually called “range length,” when it defines the distance to the physical measurement antenna at the test site. The angles of observation  $\theta, \varphi$  are also called elevation and azimuth.  $Z_0 = 120\pi \Omega$  stands for the free-space wave impedance.  $\mathbf{k} = k \mathbf{u}_r$  is the wave propagation vector, where  $k = 2\pi/\lambda$  with  $\lambda$  being the free-space wavelength and  $\mathbf{u}_r$  is the unit radial vector. Figure 1 depicts these parameters.

**FIGURE 1 Illustration of the involved parameters**



In practice, the FHD is used as the distance at which the FF condition starts. The FHD is defined by Equation (3):

$$\text{FHD} = \frac{2D^2}{\lambda} \quad (3)$$

where  $D$  is the diameter of the radiating source.

Without a priori knowledge of the DUT,  $D$  can be chosen to be the diameter of the minimum sphere encompassing the DUT. Consequently, in a direct FF probing approach, it is usually considered that the measurement range length  $R$  needs to be greater than or equal to the FHD, to yield acceptable accuracy (IEEE Std 149-2021 [2]). More precisely, the FHD is defined as the distance at which the sources that are confined in a region with diameter  $D$  create a maximum phase error of  $\pi/8$  in the FF radiation pattern (Selvan and Janaswamy [3]). Ensuring a limited phase variation of the electromagnetic field incoming at the test antenna is necessary to guarantee an accurate evaluation in low-power areas of the radiation pattern, including side lobes and nulls (IEEE Std 145-2013 [1]). Yet, the FHD overestimates the required test distance, when only the power at or near the peak of radiation is of interest (peak EIRP), or for measuring spherically integrated quantities such as the TRP. This fact is demonstrated in and publication by Derat [4], which also defines a practical condition to conduct an accurate FF peak measurement. This result is derived from the analysis of physical limitations of antennas in terms of maximum achievable power gain to quality factor ratio (Geyi [5]), and the minimum number of spherical modes or harmonics