Measurement of Transmit and Receive Characteristics of Electrically Large Active Antennas in Spherical Near Field Systems

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***Abstract*— The measurement of active devices or Active Antenna Systems (AAS) necessitates the assessment of transmitter and receiver characteristics, such as radiated power, sensitivity, and occasionally data throughput. The AAS transmit and receive properties can be fully characterized by evaluating two spatial power quantities. Equivalent Isotropic Radiated Power (EIRP) when the AAS operates as a transmitter, and Equivalent Isotropic Sensitivity (EIS) when it functions as a receiver. This testing often requires an Over-the-Air (OTA) measurement setup and is relatively simple to perform when the measurement distance is sufficient for both the probe and AAS to be in the far field. For physically and electrically large AAS's, this assumption can be hard to satisfy. This paper explores techniques for assessing spatial-directional transmitted and received power-related performance metrics of active devices using spherical near field measurement techniques. This approach can be complemented by phase recovery techniques to enable accurate NFFF transformation. The presented method is validated by experiments on a suitable validation mockup.**

I. Introduction

The measurement of active devices or Active Antenna Systems (AAS) requires the evaluation of the integrated transmitter and/or receiver characteristics, including power, sensitivity, and occasionally data throughput.

The Equivalent Isotropic Radiated Power (EIRP) of a transmitting antenna system is defined in [1], as the product of the antenna's gain and the net power accepted by the antenna from the connected transmitter. This definition is based on the IEEE definition of antenna gain. An equivalent outcome may also be obtained by determining the product of the antenna's realized gain and the available power at the antenna port where each contributor is determined separately.

The key transmit performance parameters for AAS are Effective Isotropic Radiated Power (EIRP(θ,φ)) and Total Radiated Power (TRP) by the device. EIRP(θ,φ) is the TRP weighted by the directional gain G(θ,φ) of the antenna in a given direction. The TRP is derived from EIRP(θ,φ), by integrating EIRP(θ,φ) over the full-sphere. Note that TRP differs from the available power at the antenna port by the associated losses in the antenna (or antenna efficiency). The important receiver parameters for AAS are Effective Isotropic Sensitivity (EIS(θ,φ)) and Total Isotropic Sensitivity (TIS), also known as Total Radiated Sensitivity (TRS). The EIS(θ,φ) is TIS/TRS weighted by the directional gain G(θ,φ) of the antenna. Thus, the TIS/TRS can be determined by integrating the measured EIS(θ,φ) over the full sphere.

Both EIRP(θ,φ) and EIS(θ,φ) can be measured in a calibrated Over-the-Air (OTA) measurement setup for a given AAS. This is straight forward to do, if both the AAS and the measurement probe can be assumed to operate at far field distance for a given measurement separation. A generally accepted criterion to define the far-field distance of an antenna is $2D^2/\lambda$, where D is the diameter of the antenna and λ is the free-space wavelength [2]. For electrically small antennas, such as mobile communication devices, this criterion is generally satisfied for most measurement distances. However, for moderate size AAS antennas this is no longer the case. This is illustrated in Figure 1 showing the elevation pattern at 2 GHz of a well-known, 8-element, reference antenna, BTS1940 from MVG. By comparing the elevation patterns by this antenna at different distances and the reference FF pattern, it is clear that the elevation pattern is not fully formed for any realistic measurement distance.

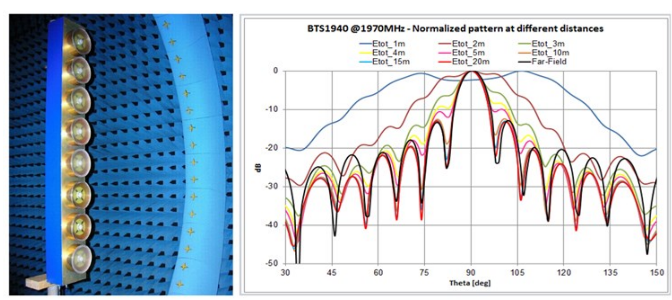


Figure 1: Measured elevation pattern @1.97GHz of an 8-element array antenna for different measurement distances and compared to FF.

The paper is organized as follows. In section II, the procedure to use a near-field OTA measurement system for electrically large active antennas is presented. Section III includes the description of the test setup for the proof of concept. Section IV details the results obtained and comparison with the reference data. Section V concludes the study.

II. AAS Measurements in NF

The differences in passive and active OTA measurement configurations are illustrated in Figure 2. In passive antenna measurements, a network analyzer or equivalent equipment directly provides the amplitude and phase relationship between power in-to and out-off the passive DUT (device under test). In the OTA testing scenario, a radio communication tester/system simulator or equivalent is used to manage the communication link with the active DUT. It emulates mobile networks, satellites, Road Side Units (RSU), vehicles etc. For radiated power measurements, spectrum analyzer or power meters may be used.

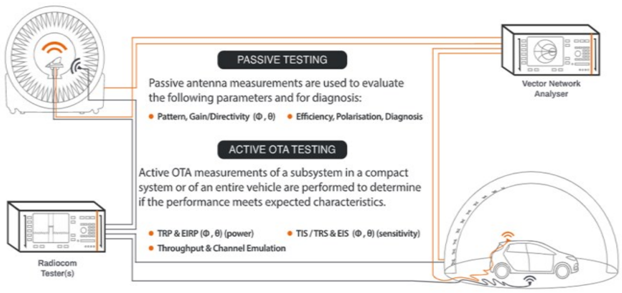


Figure 2: Illustration of measurement setup for small and large active and passive antenna measurements.

Traditionally, EIRP for an antenna system or Active Antenna Systems (AAS) on a near-field range is determined by first measuring the realized gain through near-field techniques, followed by assessing the available input power. However, it is often impractical or undesirable to disrupt the connection between the transmitting electronics and the antenna. A method for measuring EIRP using NF techniques is detailed in [3], [4] using Planar Near Field (PNF) measurements [5]. This latter technique requires an understanding of the probe gain. A correction factor, based on the full sampled radiated NF of the antenna is applied to correct for the very short measurement distance. In Spherical Near Field (SNF), and extendable to Cylindrical Near Field (CNF), the approach is very similar, but the measurement system is assumed to be priorly gain calibrated. Thus, the EIRP measurement requires both a measurement of the gain standard and a measurement of the DUT. While performing the EIRP measurement a correction factor for the reduced measurement distance of the probe is introduced based on the relative near field power density radiated by the DUT to the true FF radiated power density [3], [4]. These techniques are also described in [6], [7]. The technique can also be applied for sensitivity measurements. The measurement could follow the procedure:

1) Measurement Collection: Perform a standard set of measurements with the AAS either receiving (sensitivity) or transmitting (power) as illustrated in Figure 2.

2) Phase Recovery and Transformation: Apply phase recovery techniques to perform the near-field to far-field transformation. This produces a far-field pattern with correct shape according to distance but without absolute scaling.

3) Search: Use a) for AAS in trasnmit or b) when AAS is in receive mode.

a) Radiated power measurements. With the probe and DUT in a known position (in near-field condition), record the power level received by the probe.

b) Sensitivity Search: With the probe at a fixed position, radiate the probe and have the DUT receive. Vary the signal power delivered to the probe's input port and record the power level at which the sensitivity threshold is met.

4) Power Transfer Relationship: Determine the near-field to far-field power transfer relationship for the specific AAS-probe combination using the unreferenced far-field pattern obtained in step 2. Use this relationship and the power value recorded in step 3 to compute the far-field EIS or EIRP by appropriately scaling the unreferenced far-field pattern from step 2.

The measurements can be performed at a single position of the probe often corresponding to the point of best sensitivity or radiated power (e.g., where power transfer between the probe and AAS is maximized). However, it is recommended to perform multiple measurements at different points, resulting in multiple patterns. Each power value would separately scale the far-field pattern, and these patterns could then be averaged to produce a single pattern. It is recommended to perform the measurements (k times in the equations below).

The measurement setup is intended to be gain-normalized so that the power measurement $Power_{DUT,NF}\ (\theta_k,\varphi_k)$ is the isotropically radiated power by the DUT as collected by the probe in the point (θ_k,φ_k) at the NF measurement distance. The correction coefficient for the NF pattern of the DUT in this point is the ratio of NF isotropical intensity to FF isotropical intensity. This ratio can be determined directly from the spherical wave coefficients.

$$EIRP(\theta,\varphi) = I_{DUT}(\theta,\varphi)\frac{1}{k}\Sigma_1^k \frac{Power_{DUT,NF}(\theta_k,\varphi_k)}{I_{DUT,NF}(\theta_k,\varphi_k)} \qquad (1)$$

$$EIS(\theta,\varphi) = \frac{1}{I_{DUT}(\theta,\varphi).k}\Sigma_1^k \left(Power_{DUT,NF}(\theta_k,\varphi_k)\,.\,I_{DUT,NF}(\theta_k,\varphi_k)\right) \qquad (2)$$

Where $I_{DUT}(\theta,\varphi)$ is the far isotropical intensity from the step 2, $Power_{DUT,NF}(\theta_k,\varphi_k)$ is obtained from step 3, and $I_{DUT,NF}(\theta_k,\varphi_k)$ is the near-field isotropic intensity obtained from step 4.

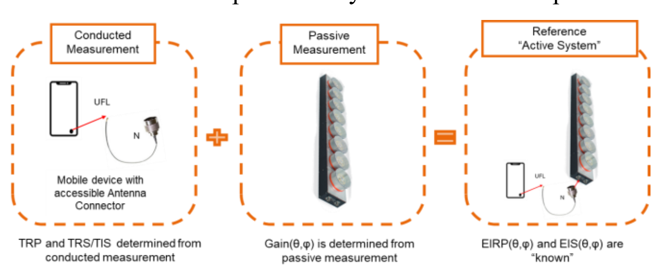


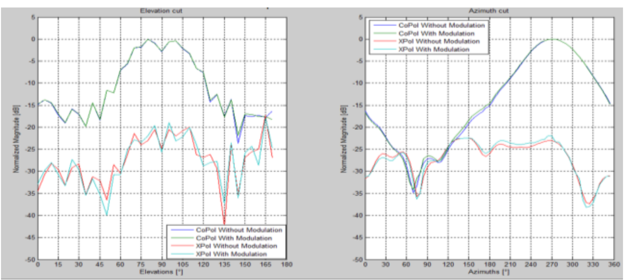
Figure 3: Experimental validation setup for EIRP/EIS validation of AAS antenna. Reference test case based on mobile device and external large array antenna. Reference data determined from conducted measurement of mobile device and gain measurements on passive antenna.

III. VALIDATION AAS TEST CASE

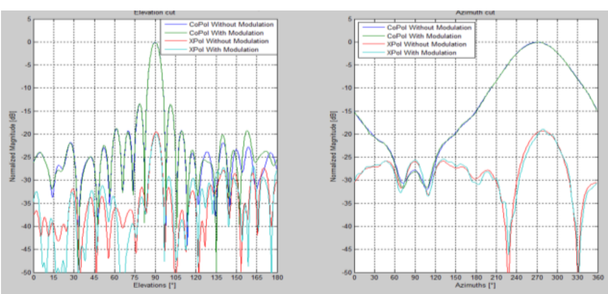
The validation test case is constructed using conducted measurements on an LTE-enabled mobile device that supports an external antenna. This device is paired with the MVG reference antenna BTS1940, which has well-known gain and pattern characteristics. By combining the conducted mode performance measurements of the mobile device with the measured gain characteristics of the BTS1940 antenna and cable, a highly stable reference AAS test case can be designed as shown in Figure 3.

IV. VALIDATION RESULTS

The AAS is emulated using a LTE-enabled mobile device supporting an external antenna connected to the 8-element passive array. The measured AAS performance is compared to reference performances determined from conducted measurements. The near-field measurement results are shown in Figure 4 (a) and the far-field transformation after near-field gain calibration is shown in Figure 4 (b). Excellent agreement is observed with the reference data (passive connectorized measurements with no modulations) and the OTA measurements (with modulated LTE signal) for both co and cross-polarization patterns.



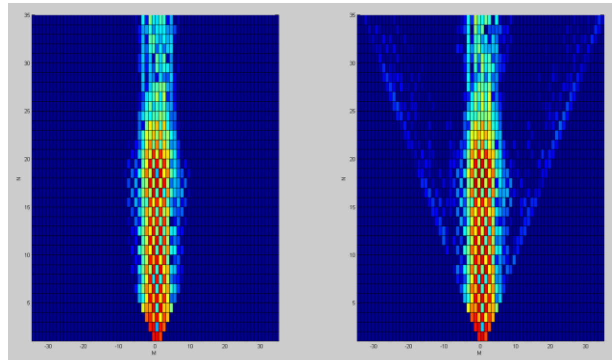
(a)



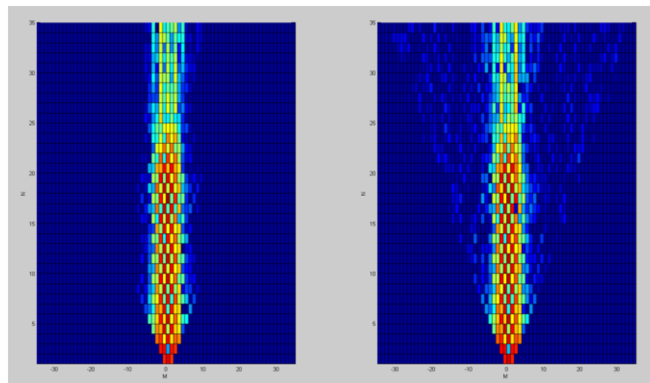
(b)

Figure 4: Co and cross-polarization measurement results at 1950 MHz compared between reference data (no modulation) and OTA (with modulation), (a) Near-field measurement, (b) far-field transformation.

Small differences between reference data and OTA near-field data Figure 4 (a) are observed for elevation angles around 150°. This difference is attributed to the impact of the phase recovery antenna element (along with the cables) which is present in close proximity to the large AAS. Its impact on the spherical coefficients is demonstrated in Figure 5. The effect is clearly visible by comparing the modes from passive (reference) measurements on the left side, and the OTA for (modulated measurements) on the right side in the form of higher power in the higher modes for the OTA case.



(a)



(b)

Figure 5: spherical mode comparison between reference (left) and OTA (right) showing impact of the phase recovery antenna, (a) Q1 modes, and (b) Q2 modes at 1950 MHz.

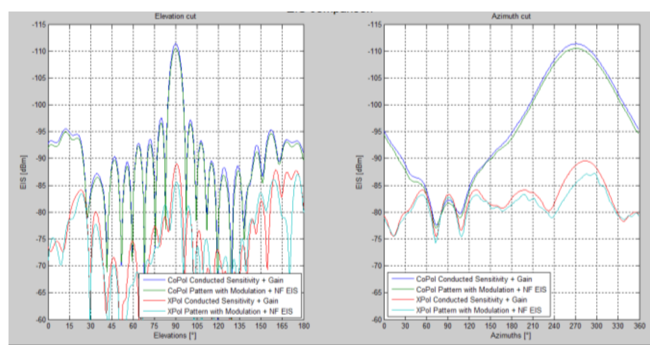


Figure 6: Sensitivity measurement results (EIS) using near-field OTA measurements, compared with conducted measurements at 1950 MHz.

The measurement of DUT sensitivity, EIS, can be performed in an analogous way to EIRP. The EIS of the DUT in a given direction is the power sensitivity threshold in which communication can be performed within a certain threshold. This requires a search among different received power levels to determine. The sensitivity measurement results are shown in Figure 6. The results from the OTA approach are compared with conducted measurements of sensitivity super-imposed on the passive radiation pattern of the known antenna. The co- and cross-polarization results in the elevation and azimuth cut-planes are in excellent agreement. The difference between the peak sensitivity at boresight of about 1dB is observed. This difference is the combined effect of, range calibration for near-field OTA measurements, sensitivity search accuracy, range calibration for passive gain measurements, and accuracy for conducted sensitivity measurements.

V. CONCLUSIONS

This paper presents a four-step methodology to process raw near-field data from active measurements into EIRP and EIS, specifically tailored for large active antenna characterization. The proof of concept is demonstrated by comparing results from a large passive antenna connected to an active source. The impact of the phase recovery antenna is critical in these measurements, and the spherical near-field modes can be analyzed to evaluate this influence. The study reports excellent agreement between the reference data (passive connectorized measurements) and the OTA near-field intensity calibrated data for both EIRP and EIS, considering both co- and cross-polarization patterns. Identified measurement uncertainties are within 0.5 dB for EIRP and within 1 dB for EIS. The availability of spherical mode data is crucial for investigating and mitigating the impact of the phase recovery antenna, whose precise placement is essential in this measurement setup.

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