HF/VHF Antenna Characterization from Very-Near-Field Measurements over Arbitrary Closed Surfaces

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Abstract—**A novel, efficient characterization technique for HF/VHF antennas from very-near-field measurements is presented. A measurement system with a non-intrusive broadband electro-optical (EO) probe is utilized to measure the tangential electric fields of an antenna under test (AUT) at a very-near surface enclosing the antenna. The non-metallic and small-size fiber-coupled EO probe does not perturb the current distribution over the antenna and is free from the complicated probe compensation. Far-field quantities of the AUT are derived from a newly developed near-field to far-field transformation method. In this way, a full spherical radiation pattern and gain of the AUT are attained without expensive computation and truncation errors. A miniaturized antenna operating low-VHF band (40 MHz) with dimensions 10 cm × 10 cm × 15 cm (0.013 λ_0×0.013λ_0×0.02λ_0) is employed as the AUT. The performance of the proposed approach is evaluated through comparison with the results obtained from full-wave simulation and direct far-field measurement performed in an outdoor range.**

I. INTRODUCTION

Accurate measurement is crucial to achieve fundamental parameters of antennas such as impedance, bandwidth, radiation pattern, and gain. Knowledge of the actual antenna performance plays an important role in designing real-world wireless communication systems. As the simplest way to characterize antennas, direct far-field measurement techniques in outdoor free-space ranges or indoors in an anechoic chamber are commonly used [1]. The use of such techniques for HF/VHF antennas is, however, limited specifically by large space requirements due to their very long wavelengths to fulfill the far-field criterion. Although special methods to measure such antennas have been reported in [2]-[3], they require substantial time and effort to perform as well as a specially designed very-large, expensive anechoic chamber in the case of indoor measurements.

In order to reduce these costs, we developed a compact, cost-effective system for very-near-field measurements on planar scanning surfaces using electro-optical systems. The measurements can be completed in a small non-metallic indoor space that allows signal coupling to free-space. At low frequencies, reflection and scattering from dielectric walls and objects are low and their effects on the antenna current distribution are rather small. Furthermore, the computationally complicated probe compensation process is not required by using a very-small, non-intrusive, all-dielectric EO field probe. In addition, we established a simple method to calculate the exact far-field quantities from the measured near fields over closed surfaces. To apply this method, the reciprocity and reaction theorem are used as will be shown later.

II. VERY-NEAR-FIELD MEASUREMENTS

Near-field scanning systems are the most compact alternatives for performance characterization of antennas to circumvent the limitation in the far-field range or costly anechoic chamber facilities. However, conventional systems have substantial disadvantages at low frequencies. These systems involve metallic probes that act as receivers for picking up the near fields of the AUT. Such metallic antennas cannot be placed very close to the AUT, since they would cause distortion of the near fields to be scanned. They also limit an operational bandwidth, and their accuracy degrades significantly at lower frequency bands. In addition, complicated algorithms that account for the radiation characteristics of the probe antennas referred to as a probe-compensated near-field method [4] should be applied for accurate far-field computation. The system employed in this paper, called NeoScan, developed by EMAG Technologies, provides significantly superior performance to the conventional near-field scanning systems. The EO field probe can scan the electric fields with extremely small spatial resolution (minimum sampled space $< 10\ \mu m$) at the very-near-field region of the antenna where the fields are very strong. Another advantage of the EO probe is an extremely wide bandwidth (3 MHz – 100 GHz). The probe can be calibrated to measure the absolute magnitude and relative phase of electric fields over a wide dynamic range (0.1 V/m – 1 MV/m).

In order to maintain high accuracy and reliability of the very-near-field antenna measurements, the field probe system must remain stable over the entire measurement time. Stabilization of the EO probe in our system is consistently monitored by a Managing Program developed with a system design software (National Instruments LabVIEW 2011) while the probe scans near fields of the AUT. In order to achieve the maximum EO signal at a given condition for the best

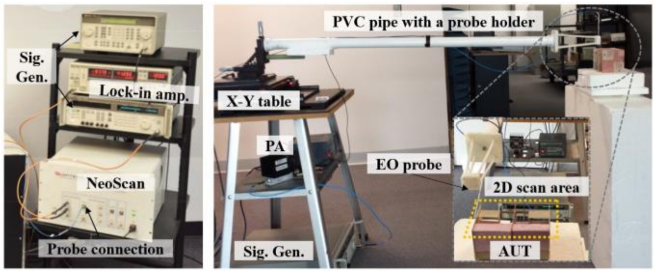
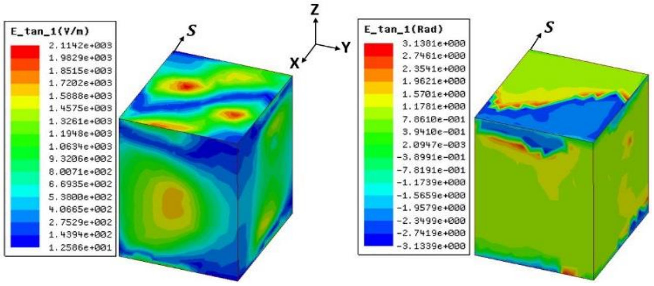


Fig. 1. Actual measurement setup for very-near-field measurements of the AUT. The measurements were performed in a small indoor space.



(a) (b)

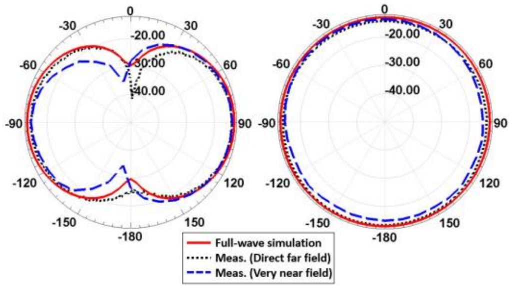
Fig. 2. (a) Magnitude and (b) phases of the measured very near fields over the closed surface S (top and bottom: E_x & the others: E_z)

sensitivity, a system optimization procedure is also conducted. It is noted that the EO system directly measures the intensity of modulated optical beams due to the variation of the RF electric field signals. To obtain the absolute magnitude of the electric field, the probing system is calibrated using a standard transverse electromagnetic (TEM) cell in which a known, uniform electric field is established [5].

Measurement parameters such as a probe height, sampled space, and scanned area are carefully determined considering measurement time and accuracy. As the AUT, a recently developed miniaturized low-VHF antenna [6] is employed. Near-field components of the AUT are measured in a normal laboratory environment as depicted in Fig. 1. Fig. 2 shows an example of the measured amplitudes and phases of the very-near-field distributions (one tangential component on each face) on the probed imaginary box.

III. NEW FAR-FIELD CALCULATION

Based on the uniqueness theorem, the far-field quantities of the AUT can be calculated employing the measured very-near fields. To do so, let us recall the geometry of the problem under consideration where the AUT connected to a source is enclosed in the surfaces denoted by S, over which the tangential electric field is measured. To calculate the field outside S using just the tangential electric field, the field equivalence principle can be considered. In this approach we assume the fields inside S are zero and introduce instead fictitious surface electric and magnetic currents proportional to the tangential magnetic and electric fields. Since the tangential magnetic field components are not provided, the surface S is replaced by a PEC, over which the surface magnetic current is placed. Thus, the problem is reduced to finding the total field radiated from the magnetic current in the presence of the PEC box. Now, let us suppose that the box is being illuminated by the fields of an infinitesimal magnetic dipole located at the observation point in the far-field region. Then, applying the reaction theorem to the two sources, the radiated field from the AUT can be easily derived. To further simplify calculation, plane wave excitation instead of the magnetic dipole source can be applied since the infinitesimal magnetic dipole is in the far-field region of the AUT. To compute far-field quantities of the AUT in this way, the induced surface current on the PEC box from the incident plane wave in a desired direction needs to be calculated and this is made by a standard full-wave approach. Fig. 3 shows the far-field radiation patterns in two orthogonal principal planes derived from the proposed approach, together with simulated and measured results taken in the far-field.



(a) (b)

Fig. 3. Antenna radiation patterns in (a) E-plane and (b) H-plane, computed by different approaches.

IV. CONCLUSION

The novel method for characterization of 3D radiation pattern and gain of antennas is presented. The approach is based on measuring the tangential components of electric field over arbitrary closed surfaces that enclose the AUT using the unique RF field probe. A new formulation is also developed to perform the near-field to far-field transformation without any approximations. This approach is shown to be a very effective and time-efficient method for accurate characterization of HF/VHF antennas for which anechoic chambers cannot be built and the far-field methods cannot provide accurate results due to different factors such as presence of the ground plane and proximity of feeding cables and measurement instruments.

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