Full-Spherical Radiation Pattern Evaluation of Low Frequency Antennas Using a Novel Very-Near-Field Electro-Optical System

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Abstract—An efficient 3-D radiation pattern and gain measurement technique for low frequency antennas using very-near-field mapping is presented. The tangential electric fields of an antenna under test (AUT) at surfaces enclosing the antenna are accurately measured by a unique measurement system with a non-intrusive electro-optical (EO) probe, eliminating the need for costly large anechoic chamber facilities. We also develop a simple near-field to far-field transformation method to derive exact far-field quantities of the AUT. This method can provide the full spherical radiation pattern and gain of all types of antennas without any truncation errors. To demonstrate the proposed approach, a low-VH folded dipole [1] is employed. The measured results agree very well with simulation results and those obtained from far-field measurement performed in an outdoor range.

Keywords—Antenna radiation pattern, electro-optical system, low frequency antennas, near-field measurements.

I. INTRODUCTION

Accurate antenna measurement is essential for designing real-world wireless communication systems. For the measurement, one can consider far-field methods in outdoor free-space ranges or indoors in an anechoic chamber [2]. Such methods, however, face a challenge at low frequencies because of the required large size of an anechoic chamber and the far-field criterion. Although particular techniques to measure such antennas have been reported in [3]-[4], they require significant time and effort as well as a specialized expensive anechoic chamber for indoor measurement.

In order to reduce these complexities, a compact electro optical system is introduced for very-near-field measurements of an AUT on planar scanning surfaces. This EO system enables the measurements 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 no longer needed due to the use of a non-intrusive EO field probe which is extremely small and consists of all-dielectric components. In addition, a new exact near-field to far-field transformation for an arbitrary closed surface based on the reciprocity and reaction theorem is developed.

II. VERY-NEAR-FIELD MEASUREMENTS

Although near-field scanning systems have been widely used for far-field characterization of antennas due to compactness of a measurement space, they are not favorable at low frequencies. Besides large spaces required owing to their long wavelengths, metallic probes of large sizes involved in conventional systems for picking up the near fields of the AUT cannot be placed very close to the AUT, as they would cause distortion of the near fields supposed to measure, resulting in significant degradation of radiation pattern. In addition, the probes limit operational bandwidth and lead to complicated probe compensation process for accurate far-field computation. To resolve these issues, we employ the state-of-the-art EO system (NeoScan) developed by EMAG Technologies [5]. Superior characteristics of this system to conventional near-field scanning systems include a very small spatial resolution (minimum sampled space < 10 μm) at the very-near-field region of the antenna, an extremely wide bandwidth (3 MHz – 100 GHz), and real-time mapping of magnitude and relative phase of electric fields over a wide dynamic range (0.1 V/m – 1 MV/m). As stated before, this system does not require the probe compensation process and enables near-field scanning in a normal laboratory environment as depicted in Fig. 1.

High accuracy and reliability of the very-near-field measurements are guaranteed by consistent stabilization of the EO probe over the entire field scanning process and system optimization with a LabVIEW-based Managing Program. It is

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noted that simple calibration of the probing system using a standard transverse electromagnetic (TEM) cell is also performed to compute an absolute gain of the AUT from post processing. As the AUT, a miniaturized folded-dipole at low-VHF band, which has dimensions of 10 cm × 10 cm × 15 cm, is used. The very-near-field mapping of the AUT is carried out with the measurement parameters optimized considering measurement time and accuracy such as a probe height (< 30 mm), sampled space (5 mm), and scanned area (13 cm × 14.5 cm × 18 cm). Fig. 2 shows the measured and calibrated magnitudes and relative phases of the very-near-field distributions on the probed imaginary box (one tangential component on each face is plotted as an example).

III. NEW FAR-FIELD CALCULATION

The far-field quantities of the AUT can be computed based on the uniqueness theorem with the measured tangential electric field over the closed surfaces. To do so, let us recall the geometry of the original problem where the AUT connected to an RF source is enclosed in the scanned surfaces denoted by $S$, over which the tangential electric field $\mathbf{E}_{t,m}^\text{sc}$ is measured. To calculate the fields radiated by the AUT outside $S$ using just $\mathbf{E}_{t,m}^\text{sc}$, the field equivalence principle is applied. In this approach we assume the fields inside $S$ are zero and introduce instead fictitious surface magnetic currents proportional to the tangential electric fields. In this way, $S$ is replaced by a PEC box denoted by $S'$, over which the surface magnetic current is placed. The far-field calculation is now equivalent to finding the total field radiated from the magnetic current in the presence of the PEC box.

Let us suppose that $S'$ is being illuminated by the fields of an infinitesimal magnetic dipole located at the observation point $r_0$ in the far-field region. The volumetric magnetic current distribution for this source can be written as $\hat{\mathbf{p}} \, \delta(r - r_0)$, where $\hat{\mathbf{p}}$ is a unit vector along the dipole and $r$ is the radial distance from the origin. Applying the reaction theorem to the above surface and volumetric magnetic current, 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 source is in the far-field region of the AUT. This gives the expression for the far-field quantities of the AUT:

$$\hat{\mathbf{p}} \cdot \mathbf{H}(r_0) = -\frac{ik}{4\pi} \int_{S'} \mathbf{E}_{t,m}^\text{sc}(r) \cdot \mathbf{J}_s^\text{p}(r) \, ds,$$

where $k$ is a wavenumber and $\mathbf{J}_s^\text{p}$ is the induced surface current on the PEC box from the incident plane wave in a desired direction. Here, $\mathbf{J}_s^\text{p}$ can be computed numerically from standard full-wave simulation. Fig. 3 depicts an example of the computed $\mathbf{J}_s^\text{p}$ over the PEC box when a plane wave with intensity of 1 V/m at the given direction is incident on $S'$. The far-field radiation patterns derived from (1) are shown in Fig. 4, along with simulated and measured results taken in the far-field.

IV. CONCLUSION

The novel technique to generate full-spherical radiation patterns of antennas is based on measuring the very near fields over arbitrary surfaces completely enclosing the AUT via the unique EO system. With the newly developed near-field to far-field transformation algorithm, this technique is shown to be very cost effective and accurate for characterization of low frequency antennas. This contributes greatly to tackling the issues such as the lack of costly large anechoic chambers and inaccuracy of the far-field method due to proximity effects of nearby objects such as the ground plane and feeding cables.

REFERENCES