Time-Gated Near-Field Antenna Measurements in Cylindrical Coordinates

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Abstract **Near-field correction together with time gating improves the accuracy of measurements carried out in antenna sites of anechoic-chamber type. A measurement procedure has been proposed to obtain antenna patterns utilizing both aforementioned methods.**

Keywords **Antenna measurements, time gating, near field, cylindrical coordinates, Matlab script.**

I. Introduction

The most straightforward way of obtaining an antenna pattern is to carry out the measurement in its far field. It assumes a distance between the source antenna and the antenna under test (AUT), which can be relatively large. Measurements taken in outdoor ranges are deteriorated by spurious backgrounds, which are time-variable and cannot be virtually separated from the results. The indoor facilities provide an almost reproducible environment but the measurements are confined by the site dimensions.

The problem of finite dimensions of antenna sites can be overcome by special antenna range arrangements like compact antenna test range or by utilizing mathematical transformation to obtain the required far-field data. Another issue are the reflections from antenna-range walls which lessen the reproducibility of measurements taken inside it. This problem can be solved by utilizing time-domain transformations and excluding the unwanted part of signal.

A so far unused combination of both techniques used when measuring antenna patterns in cylindrical coordinates has been proposed and implemented through a Matlab script.

II. Time-Gated Near-Field Measurements

A. Radiating Near-Field

In the far field of an antenna the radiating pattern becomes independent of the distance from the antenna. Measuring antenna pattern in its near-field introduces the distance as a parameter into the results and can even be irreproducible if the portion of reactive field is significant. In the far field, the measured data are considered to be constant with respect to the distance from the AUT. The boundary between the radiating near filed (Fresnel region) and far field (Fraunhofer region) R is defined with respect to a maximum phase error of $\pi/8$ as

$$R = 2\frac{D^2}{\lambda}, \qquad (1)$$

where D is the largest dimension of the antenna (and larger than the wavelength λ). This condition can be too strict when measurements are taken at an indoor range. It often applies to antennas working at long wavelengths (in comparison with the distance between the antennas) or electrically large antennas. Among electrically large antennas, antennas utilizing the principles of geometrical optics can be ranked. These radiators embody complex radiation patterns with many lobes and nulls, and so, near-field data may not provide a sufficient description of their radiation properties due to their fuzzy course.

B. Near-Field Measurements

There are essentially two ways of obtaining far-field data [1], [2]: utilizing a suitable (parabolic) reflector to build a compact antenna range by collimating the radiation from the source antenna or utilizing mathematical transformation to transform the near-field data into far field.

The scanning surfaces for the near-field-far-field methods usually are planar, cylindrical and spherical one. [1] Because of being mathematically the simplest, the planar one is the most often applied scanning surface. The suitability of particular surfaces correlates with the antenna-pattern shape.

The principle of the mathematical transformation is based on modal expansion [1]. The measured amplitude and phase data in the near field are used to compute the angular spectrum of respective waves. The sum of partial waves provides the possibility to express the field in whatever distance from the AUT. The far field is expressed as the distance approaches infinity.

There are articles dealing with near-field measurements in cylindrical coordinates in two dimensions [3], [4] (radiation-pattern cuts) as well as with the three-dimensional entire one [6], [7], [8] but the reflections from the antenna-range walls and re-radiation from antennas themselves is not taken into account. On the other hand, the authors of [10] consider these unwanted signals but their proposal makes use of planar expansion.

C. Cylindrical Waves

As can be seen in e.g. [9], the formulation of cylindrical waves comprises the solution of the Bessel equation beyond the harmonic one. It means, a cylindrical wave can be generally expressed as

$$E = \sum_{n=-\infty}^{\infty} \int_{-\infty}^{\infty} c_{n,k_z} H_n^{(2)}(k_\rho b)\, \mathrm{e}^{\mathrm{j}n\phi}\, \mathrm{e}^{\mathrm{j}k_z z}\, \mathrm{d}\, k_z\,, \qquad (2)$$

where E is electric field, $c_{n,kz}$ are spectrum coefficients, $H_n^{(2)}(k_\rho \rho)$ Hankel functions of second kind and n-th order, k_z and k_ρ are wavenumbers along z and ρ axes, and b is the distance between AUT and the wave/probe along ρ axis.

The range of sum/integral is practically confined with respect to a minimum cylinder containing the whole AUT. It can be seen at (2) that description of cylindrical waves embodies Hankel functions beyond spectrum coefficients, which makes the analysis mathematically more extensive in comparison with planar-surface attitude.

D. Near-Field-Far-Field Transformation

It has been shown (e.g. in [8]) that the field components of a cylindrical wave can be expressed as (3) and (4), where a_n and b_n are spectrum coefficients and a is radius of the smallest cylinder containing the whole AUT. These equations formally present a notation of Fourier transform. Hence, spectrum coefficients can be found that describe a complete angular spectrum of waves propagating from the AUT.

Then, inverse Fourier transform provides the electric field in arbitrary distance from AUT. To evaluate the field in infinity (far field), asymptotic expansion can be employed.

When carrying out the data processing using computer equipment, the equations can be arranged to suit to the discrete Fourier transform algorithm. It means sampling theorem has to be applied along any dimension of the measuring surface.

E. Time Gating

Time gating also utilizes Fourier transforms, in this case between the time and frequency domain. Incorporating time windowing into measurement prevents reflections from walls and antennas themselves from influencing the results.

F. Practical Application

Based on the proposed technique, a script for data acquisition and processing has been written. A measurement of a parabolic reflector antenna at 5.85 GHz and 3m distance was carried out.

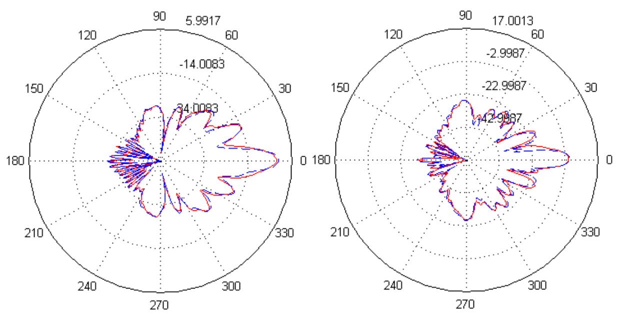

Fig. 1: Horizontal (left) and vertical pattern of the test parabolic reflector antenna at 5.85 GHz. Dashed curve depicts the near-field data, solid line the transformation into far field

No significant differences between near-field and far-field data mean that the antenna collimates the radiation in the Fresnel region.

G. Future Challenges

The proposed measurement technique does not include probe compensation to respect that the probe is not an isotropic radiator. Even if it is not as essential for the cylindrical measuring surface as for the planar one, incorporating it into the proposed script will further enhance the measurement accuracy.

III. CONCLUSION

Using near-field-far-field transformation for measurements in the Fresnel region of antenna together with time-gating technique to exclude any reflections from the results, a new procedure for electrically large antenna measurements in indoor ranges has been proposed. An evaluation was carried out by comparing the near-field data with the far-field results for antennas with parabolic reflector.

IV. ACKNOWLEDGEMENTS

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$$E_z(\phi,z)=\sum_{n=-\infty}^{\infty}\int_{-\infty}^{\infty} b_n(k_z)\frac{k_\rho^2}{k}H_n^{(2)}(k_\rho a)\,\mathrm{e}^{jn\phi}\,\mathrm{e}^{jk_z z}\,dk_z \qquad (3)$$

$$E_\phi(\phi,z)=\sum_{n=-\infty}^{\infty}\int_{-\infty}^{\infty}\left[b_n(k_z)\frac{nk_z}{ka}H_n^{(2)}(k_\rho a)-a_n(k_z)\frac{\partial H_n^{(2)}}{\partial r}(k_\rho a)\Big|_{r=a}\right]\mathrm{e}^{\mathrm{j}n\phi}\,\mathrm{e}^{\mathrm{j}k_z z}\,\mathrm{d}k_z \qquad (4)$$