

Applications of the Diagnosis Techniques in Antenna for the Reduction of the Measurements Errors

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ABSTRACT: This paper shows several applications of the diagnostic techniques for the reduction of some error or uncertainty factors in antenna measurements. The method is based in the calculation of the extremely near field from the far field using FFT (Fast Fourier Transform) Techniques, improved with the Gerchberg-Papoulis Algorithm. The classical applications of the diagnostic techniques are errors detection, like phase errors in arrays or conformal errors in reflectors. Therefore, they constitute an important antenna design tool. Also, they can be used for other applications whose aim is improve the measurements in anechoic chambers. This paper shows different process applied to reduce the effect of the reflections, the effect of the leakage from AUT (Antenna under test), to improve the signal to noise and to reduce the truncation error in the planar or cylindrical near field.

INTRODUCTION

This paper shows different applications of the classical diagnostic techniques employed in antenna measurements for the improvement of the measurement results. In particular, the paper shows some procedures to reduce the effect of the reflections, the effect of the leakage from AUT, to improve the signal to noise and to reduce the truncation error in the planar or cylindrical near field. The procedure used in all cases is similar: firstly, the radiated field is measured, then, if the measurement has been performed in near-field, a near-field to far-field transformation is performed. Once the field over the aperture antenna is known, the next step is to treat the field on the aperture, using the geometrical information of the antenna. Finally, it is obtained a new radiated field by means of an inverse diagnostic procedure where all those effects have been suppressed or improved. The diagnostic technique used for this paper is the Holographic Technique improved with the Gerchberg-Papoulis Algorithm (if it is necessary). However, other diagnosis techniques could be applied with similar results. Before presenting the theory that is behind these applications and its results, the diagnostic techniques are reviewed: a diagnostic technique is a method to obtain the extremely near field or the equivalent currents distribution of an antenna from the knowledge of its radiated field (near or far field). With this information, it is possible to detect errors, and also to identify which are the causes of such errors, for example, electrical errors in arrays or mechanical errors in reflectors. These classical applications have been widely studied in applications [1]-[2]. The presence of these errors affects to the far field pattern but, often these errors are very difficult to be detected from this pattern. However, once the extremely near field is calculated, most of these errors can be detected. So, in this point it is interesting to use one of these kinds of techniques to reduce the difficulty and the time in the design stage. This is the typical and classical application of a diagnostic process. But also, a source reconstruction gives a complete electromagnetic characterization of the antenna (near field to far field transformation, radioelectric coverage...).

Basically, there are two types of diagnosis [3], where the first of them is based on the application of the equivalence principle and the integral equations relating fields and sources (integral equation methods, IEM), and the last one based on modal expansions (modal expansion methods, MEM). IEM has the advantage to be a general technique, but from a numerical point of view it is more complex, since it is necessary to solve an integral equations system. There have been performed several studies about how to obtain a solution of such system depending on the geometry of the measurement system [4]-[5]. The equivalent magnetic currents (M) are obtained from the measured field (E) and the Green Function (G). From these currents, it is immediate to obtain the extremely near field (Ea) of the antenna. On the other hand, to use MEM implies just the opposite of the previous methods, less numerical complex, that is, less computational complex, but in contrast, they only can be used in particular situations. The reason of that yields in the necessity to express the measured field like a superposition of orthogonal functions (vector wave solutions), and there are only six coordinate systems that provide that orthogonality between the solutions of the Maxwell's equations. Moreover, just three of those (planar, cylindrical and spherical) offer mechanically convenient scanning. Depending on the coordinate system, it has to be performed one kind of expansion (plane wave expansion, cylindrical wave expansion or spherical wave expansion), explained in detail in [6]-[7]. From these expansions, the way to make the diagnostics is

to use like intermediary, the plane wave spectrum (plane expansion coefficients), since there is a direct connection between that spectrum and the field over the antenna aperture, as it can see in (1):

$$E_a(x, y) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P(k_x, k_y) \cdot e^{-j(k_x x + k_y y)} dk_x dk_y \quad (1)$$

It is necessary to distinguish different situations depending on the region where the measurement is made:

- *Planar near field*: the plane wave spectrum referred to the measurement plane [8] is obtained immediately like the inverse expression of (1). Once it is known, it is just necessary a backpropagation, calculating the plane wave spectrum referred to the antenna aperture, and finally apply (1) to know the reconstructed field.
- *Spherical near field*: in this case a transformation from spherical wave expansion to plane wave expansion is required. This transformation was recently studied in [9], and relates spherical and plane coefficients:

$$P_l(K_x, K_y) = \sum_{n=1}^{\infty} \sum_{m=n}^n Q_{1mn}^{(3)} T_{1mn} + Q_{2mn}^{(3)} T_{2mn} \quad (2)$$

- *Far field*: the last possibility is to use the far field information either because the measurement has been made in that region or because it has been employed a transformation from near field. In this case, the plane wave spectrum is calculated by means of a system of two equations, where the components of the field are the known information.

$$\begin{aligned} E_{\theta} &= P_x \cos \varphi + P_y \sin \varphi \\ E_{\varphi} &= \cos \theta (P_x \sin \varphi - P_y \cos \varphi) \end{aligned} \quad (3)$$

The following sections present the most relevant information of each new application. First of all, the theoretical aspects will be described, and then, results from simulations or measurements, to justify that the applications proposed are useful to improve the measurement results, will be shown.

CANCELLATION OF REFLECTIONS USING THE DIAGNOSTIC TECHNIQUES

The errors due to reflections can appear when an antenna is been measured in an anechoic. Although, the employment of RAM absorber is always necessary, there are reflection cancelling techniques which are applied to the measurement data, like the Matrix Pencil Method [11] or methods based on the Fast Fourier Transform [12]. Here, a new method, applying the traditional diagnostic techniques to reduce the effect of the reflections coming from side directions on the antenna measurement systems is proposed. The process is based on the substitution of the excitations of the array out of the antenna area by zeroes. Once these excitations are cancelled, the plane wave spectrum is recalculated, and it corresponds to the new radiation pattern. To summarize, the different steps of this technique of cancellation are the following:

- To apply a diagnosis method (inverse problem) and obtain the value of the excitations in a zone larger than the antenna dimensions. Out of the antenna, “fictitious” excitations due to the reflection in the walls or floor of the anechoic chamber appear.
- Replace by zeroes the value of the excitations which are out of the antenna dimensions.
- Recalculate the Plane Wave Spectrum and with this, the radiation pattern, employing the excitations of the previous point (direct problem).

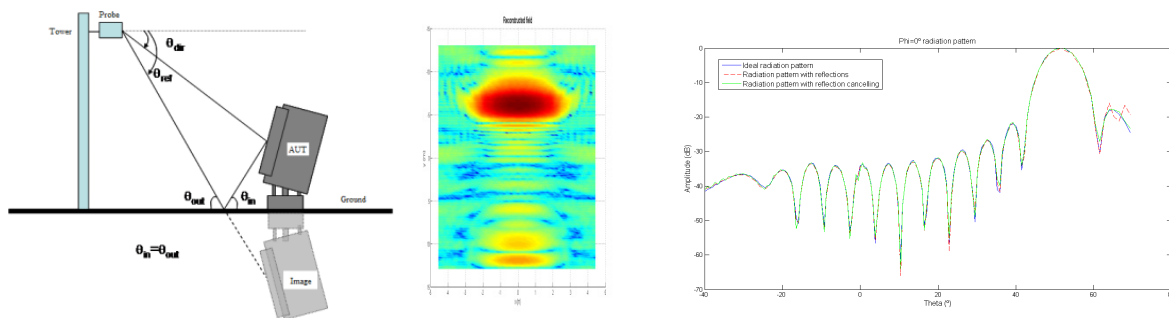


Fig. 1 Cylindrical Near Field System. Extremely Near field, showing the effect of the Reflections. Radiation Pattern before and after cancelling the reflections.

This algorithm has been applied to the improvement of the measurements in an outdoor cylindrical near field system for the measurement of L-Band RADAR Antennas, as shown in Figure 1.

DETECTION AND REDUCTION OF UNWANTED RADIATION POINTS (LEAKAGE)

Other application of the diagnostic techniques is the detection of leakage or unwanted radiation points during the measurements. These points may be faulty connectors or cables, and its presence modifies the real data. Once it has been made the measurement, it is applied the following algorithm proposed to detect and cancel such points.

- Apply a diagnostic technique and identify zones disturb by these points. The centre of such zones will give us the 'x' and 'y' coordinates.
- Cancel the field within the antenna dimensions.
- Shift the field along the z-coordinate using for this, the relationship between the field over a plane and the PWS (2). Once it is known this last one, it is used the expression which relates the PWS referred to two different planes, and finally, it is obtained the field over other plane. So, it is possible to depict the field profile in the line with the x and y-coordinates fixed at the first point. The maximum of such profile will provide the value of the last searched coordinate. For validating this algorithm, a measurement has been done introducing an unwanted radiation point in a fixed position:

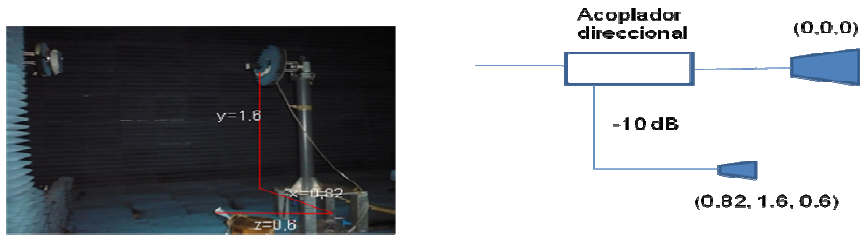


Fig. 2 Measurement set-up for the application of the algorithm.

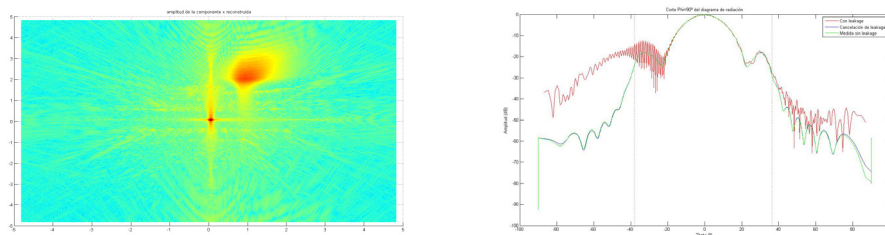


Fig. 3 Reconstructed field and Radiation patterns: with leakage, without leakage and reconstructed.

EXTENSION OF THE ANGULAR RANGE IN PLANAR AND CYLINDRICAL MEASUREMENTS

In planar and cylindrical surfaces the finite size of the scan area introduces a so-called truncation error in the calculated far-field pattern. This error may be arbitrarily high outside the so-called reliable region defined by the rays running from the edge of the antenna aperture through the boundary of the scan area. The way to reduce such error has been studied before [13], and it is also based on the use of the Gerchberg-Papoulis algorithm: first of all, it is applied a diagnostic technique. Secondly, an iteration process is performed to increase the visible range: after the first reconstruction, all the currents (electric or magnetic) out of the antenna area are replaced by zeroes. Then, the plane wave spectrum is calculated again, and the original results in the invisible region are replaced by these new ones. This process can be iterated until the difference in the invisible region between two iterations is less than one threshold. Below it is shown the improvement which it has been reached employ the mentioned algorithm to a 6x6 array measured in planar near field. The vertical lines indicate which is the reliable region.

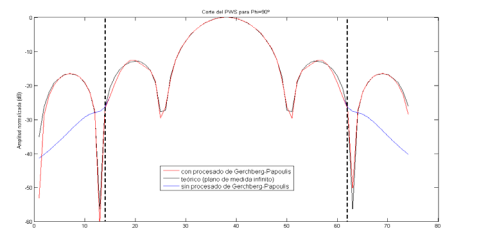


Fig. 4 Far field comparison: ideal case, real case in planar field and employing the Gerchberg-Papoulis algorithm.

REDUCTION OF THE NOISE IN ANTENNA MEASUREMENTS

The fact that the noise is identically distributed over the antenna aperture when a diagnosis is performed can be applied to improve the signal to noise ratio. The implemented diagnostic technique uses the far field information to obtain the extremely near field. With such information, they are calculated the plane wave spectrum (PWS) components and finally, by means of a Fourier Transform, the reconstructed field. Assuming a Gaussian white noise, with zero mean, σ^2 variance, independent for each field component, the plane wave spectrum can be written as the sum of the wave spectrum of the signal and the wave spectrum of the noise. Considering only the presence of the noise, the effect of the noise on the reconstructed surface can be calculated. Since the PWS is band-limited, the fourier transforms can be replaced by summations, seeing that the noise of each point of the antenna aperture (x, y) is a Gaussian random variable, since it is the sum of Gaussian random variables. On the other hand, since the field out the antenna dimensions must be zero, it is possible to obtain the field over a surface bigger than the aperture antenna and then to cancel the field in that region where has to be null. Finally, employing an inverse diagnostic technique, it is obtained a new radiation pattern with reduced noise level. Simulation results will be shown in the symposium.

CONCLUSIONS

The Diagnostic Technique provides us a useful tool to determine the excitations of the elements or the field over an aperture. Therefore, it lets us detect errors, so it constitutes an important tool for the antenna design. Here, four new applications: cancellation of chamber reflections, reduction of the effect of the leakage, extension of the angular range in planar or cylindrical systems and reduction of the noise, have been presented, seeing that they serve to improve the antenna measurements results.

REFERENCES

- [1] B. Svensson and H. Eriksson, "Antenna Diagnostic Applications", Third European Conference on Antennas and Propagation, EuCAP, 23-29 March 2009, Berlin, Germany.
- [2] Y. Rahmat-Samii, "Microwave holography of large reflector antennas-Simulation algorithms", IEEE Transactions on antennas and Propagation, vol. AP-33, no. 11, November 1985.
- [3] D. Sánchez and M. Baquero, "High-resolution algorithms for the reconstruction of the equivalent currents of an antenna by means of modal theory and a priori information", PhD Dissertation, UPV, May 2009.
- [4] Y. Álvarez, F. Las-Heras and M. Rodríguez, "Reconstruction of Equivalent Currents Distribution Over Arbitrary Three-Dimensional Surfaces Based on Integral Equation Algorithms", IEEE Trans. Antennas and Propagation, Vol. 55, pp. 3460-3468, December 2007.
- [5] P. Petre and T. K. Sarkar, "Planar Near-Field to Far-Field Transformation Using an Equivalent Magnetic Current Approach", IEEE Trans. Antennas and Propagation, Vol. 40, pp. 1348-1356, November 1992.
- [6] A. D. Yaghjian, "An overview of Near-Field Antenna Measurements", IEEE Trans. Antennas and Propagation, Vol AP-34, pp. 30-45, January 1986.
- [7] R. C. Johnson, H. A. Ecker and J. S. Hollis, "Determination of Far-Field Antenna Patterns from Near-Field Measurements", Proceedings of the IEEE, Vol. 61, NO. 12, December 1973.
- [8] M. S. Narasimhan and B. Preetham, "A Technique to Synthesizing the Excitation Currents of Planar Arrays or Apertures", IEEE on Transactions and propagation, Vol 38, No. 9, September 1990.
- [9] C. Cappellin and O. Breinbjerg, "Antenna Diagnostics for Spherical Near-Field Antenna Measurements", Phd Tesis, September 2007.
- [10] J. E. Hansen, "Definition, design, manufacture, test and use of a 12 GHz Validation Standard Antenna", Technical Report R672, EMI, Technical University of Denmark, October 1997.
- [11] T. K. Sarkar and O. Pereira "Using the Matrix Pencil Method to Estimate the Parameters of a Sum of Complex Exponentials" IEEE, Antennas and Propagation Magazine, Vol. 37, No. 1, pp. 48-55, February 1995.
- [12] S. Loredó Rodríguez, M. Rodríguez Pino, F. Las Heras Andrés, T. K. Sarkar, "Ecos Identification and Cancellation Techniques for Antenna Measurement in Non-Anechoic Test Sites", IEEE, Antennas and Propagation Magazine, Vol. 46, No. 1, pp. 100-107, February 2004
- [13] E. Martini, O. Breinbjerg and S. Maci, "Reduction of Truncation Errors in Planar Near-Field Aperture Antenna Measurements Using the Gerchberg-Papoulis Algorithm", IEEE Transactions on Antennas and Propagation, Vol. 56, November 2008.