INVERSE SOURCE CHARACTERIZATION FOR ELECTROMAGNETIC WAVE INTERACTIONS WITH THE ENVIRONMENT

A. Gati[1], Y. Adane[1], M. F. Wong[1], J. Wiart[1] and V. Fouad Hanna[2]

[1] France Télécom R&D – RESA/FACE 38-40, rue du Général Leclerc - 92794 Issy Moulineaux.
email : {azedine.gati ; manfai.wong ; joe.wiart}@rd.francetelecom.com
[2] Laboratoire Instruments et Systèmes d'île de France - Case 252 - Université Pierre et Marie Curie
4, place Jussieu - 75252 Paris cedex 05. email : victor.fouad@lis.jussieu.fr

ABSTRACT

When modelling electromagnetic wave interactions with the environment, the source can be analysed separately from the environment which can be modelled by asymptotic methods. This hybrid approach is interesting for physical and algorithmic reasons. It allows also integrating measurement through the characterisation of the sources. We present a new inverse source characterization technique. By knowing the 3D radiation pattern of a source (measured or simulated), a reduced set of equivalent smaller sources can be found. The near field can be reconstructed and due to the smaller size of the equivalent sources interactions with objects in the near field region of the whole antenna are possible.

I. INTRODUCTION

The modelling of the electromagnetic wave interactions with the environment plays an important role in the analysis and design of complex structures involving radio sources. Antennas installed in their actual environment, platforms, vehicles, buildings, near field wave propagation or interactions with the human body are examples of such systems. Whereas the modelling of the whole complex structure may be challenging for exact numerical techniques like Finite Element Methods (FEM), Finite Difference Time Domain (FDTD) or Method of Moments (MOM), the analysis can be decoupled in large systems. The source can be analysed separately from the environment and the wave interaction with the environment can be advantageously modelled by asymptotic methods like ray-racing or ray-launching methods or physical optics. It leads to so-called hybrid techniques. This kind of approach is not only interesting for the physical and algorithmic points of view. It allows also integrating measurement in the modelling through the characterisation of the sources.

A source or an antenna can be measured for its gain and radiation pattern. However the radiation pattern is valid beyond the far field region restricting the use of asymptotic methods. The near field and interaction with the close environment is of interest. In this context, we present a new inverse source characterization technique. By knowing the 3D radiation pattern of a source (measured or simulated), a reduced set of equivalent smaller sources can be found. The near field can be reconstructed and due to the smaller size of the equivalent sources interactions with objects in the near field region of the whole antenna are possible. The technique is based on the decomposition of a source into sub sources and the initial source and the sub sources are expanded by spherical harmonics. The use of spherical harmonics is natural as it is an efficient way to characterise source radiation outside a sphere circumscribing the source. The number of needed spherical harmonics is directly linked to the size of the source. The inverse problem is an over-determined linear system. The unknowns are the spherical harmonics spectrums of the equivalent sources and the right hand side is the spectrum of the original source. The rectangular matrix can be efficiently built with the translation theorem related to spherical harmonics. The inverse problem is solved by least squares techniques or using SVD decomposition. The technique has been applied for the base station antennas used in 2G and 3G networks. The near field is analysed for the purpose of the human exposure assessment [1].

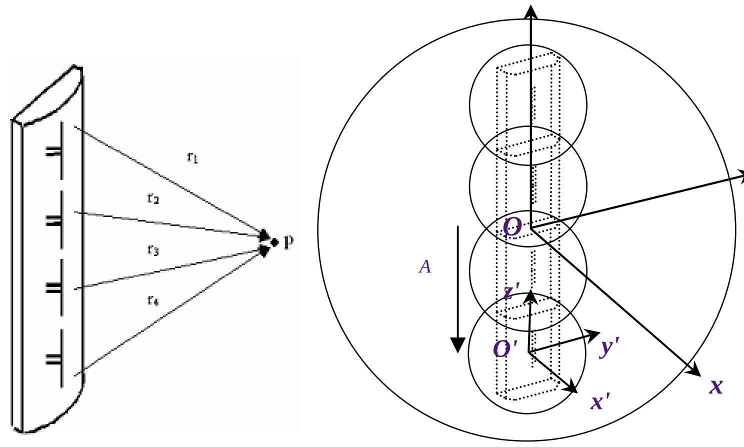


Fig. 1. Antenna decomposition and source representation by spherical harmonics

II. DECOMPOSITION OF ANTENNAS AND FIELDS

An antenna is characterized by its gain and radiation pattern. For human exposure assessment, it can give an overestimate of compliance distance in front of the antenna [2]. Far away, the radiation pattern can be coupled to ray techniques for radio coverage prediction or estimation of the exposure to radiowaves. However, for more accurate estimation of compliance distance based on the near field or coupling with nearby objects, the radiation pattern is not sufficient and a source decomposition principle can help. By decomposing a source into sub-sources (Fig.1), the field of the whole antenna is simply the superposition of the fields given by the sub-sources [3]:

$$\vec{E}(P) \cong \sum_{i=1}^{N_{sub}} \vec{E}_i(P) . \tag{1}$$

A point in the near field region of the whole antenna can now be in the far field regions of the sub-sources. This property enables to get the near field of the antenna and to use asymptotic methods with interacting objects not necessarily in the far field region of the whole antenna. The objects can be in the near field region of the whole antenna while in the far field regions of the sub-sources.

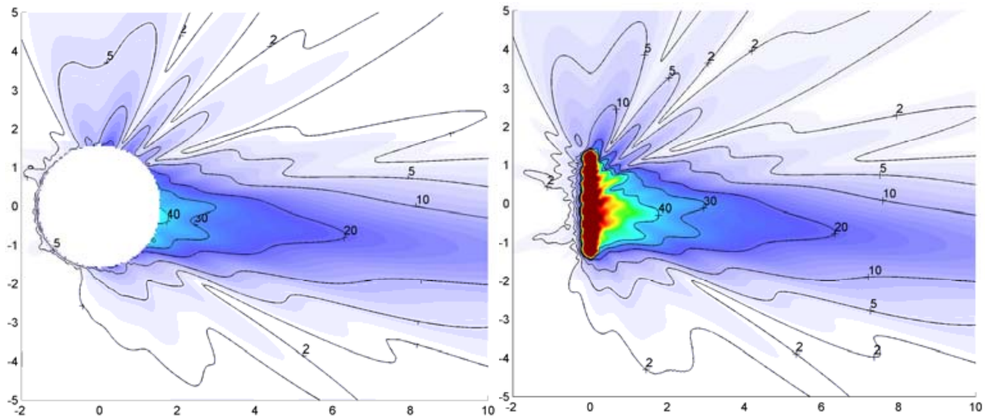
III. SYNTHESIS PROBLEM

Given an antenna, characterized by its radiation pattern, the problem is to find the sub-sources, their number and their positions. The key point is to recognize using spherical harmonics as the most natural and economical way to represent the radiated field of any source [4]. We proposed such a procedure for human exposure assessment in [5]. By expressing that the fields of the whole antenna and the sub-sources can be expanded with spherical harmonics (Fig.1), the following linear equation relating the modal coefficients of the sources is obtained:

$$\left[M_1 \; M_2 \; M_3 \cdots M_{N_{sub}}\right] \times \begin{pmatrix} \chi_1 \\ \chi_2 \\ \vdots \\ \chi_{N_{sub}} \end{pmatrix} = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_P \end{pmatrix} \tag{2}$$

where M_i represents the conversion matrix which relates the vector of mode coefficients, χ_i, of an elementary sub-source i in its local coordinate system to the mode coefficients in the global coordinate system attached to the entire antenna. The matrix M_i is obtained by using the spherical harmonics translation theory which considers only the translation through z-axis [6]. The vector β contains the mode coefficients of the whole antenna. They can be obtained with a calculated or measured full radiation pattern.

As an example, a base station antenna, namely Kathrein 739662, is considered. It operates at 890 MHz. It consists of an 8 elements panel. To find the optimum sub-antennas modes, we solve the matrix equation (2) calculated at 890 MHz whose right hand side provides the measured mode coefficients. The number of sub-sources is chosen as the number of elements in the array. Their positions are approximately the ones of the real elements. To represent accurately the field of the Kathrein antenna, 3040 measured spherical modes are required. 98 spherical modes are also taken to expand the field of each sub-antenna. Accordingly, the conversion matrix must be made of 3040 rows and 98x8=784 columns to solve the optimization problem. A SVD based least-squares can be used. Fig. 2 shows the electric field strength in the vertical plane of antenna's main beam when it is fed by an emitted power of 20 W. A very good agreement can be seen between the measurement and the optimized model. We can also note that the technique allows to get the near field inside the measurement sphere (1.55 m radius) while this is not the case for the measurement. However the model is only valid beyond the minimum spheres of the sub-sources. In the example, it is about one wavelength.



(a) (b)

Fig. 2. Electric field strength of Kathrein 739662: measurement (a) and optimized sub-source model (b)

IV. REDUCED MODEL

The technique has been developed for base station antennas which are vertical arrays. Can it be applied when the decomposition is not so obvious? For example, one may not know the number of elements in an array or their exact positions. The previous antenna is arbitrarily decomposed into 4 sub-sources instead of 8. They are positioned approximately between 2 previous sub-sources and the distance between them is twice the previous distance. The sub-source is supposed to be larger which is expressed by the number of modes used: 160 instead of 98. Fig. 3 and 4 compare the electric field strength between the 2 models with 8 sub-sources and 4 sub-sources. We can observe the very good agreement between the 2 models. The most important differences are found close to the antenna structure which is depicted by the white disks representing the approximate size of the sub-source given by the number of modes. Even though the reduced model is valid beyond a larger distance (which is here acceptable), it requires less sub-sources which may be interesting when coupled to ray techniques. From this example, we can draw a general inverse problem procedure: given an antenna with its radiation pattern, pave the antenna's structure with sub-sources whose radiuses are controlled by the number of spherical modes. Then, the inverse problem (2) can be solved.

V. CONCLUSION

An original technique that enables to find equivalent sources has been presented. From a full radiation pattern, equivalent scalable sources can be constructed from a linear synthesis problem thanks to spherical harmonics expansions. The optimized source model can then be coupled to ray techniques with near field and close object interactions features. This inverse characterization is also very useful as it does not require the exact knowledge of the antenna's structure when it is coupled to its environment. As well the source can be provided via simulation or measurement.

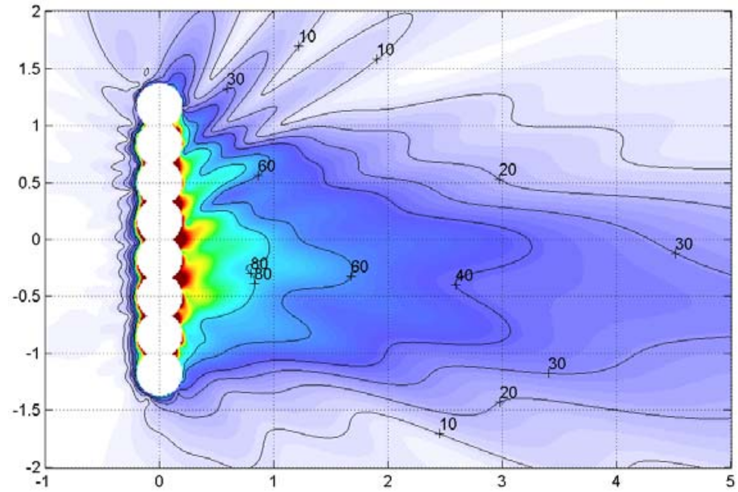


Fig. 3. Kathrein 739662 antenna modelled with 8 sub-sources

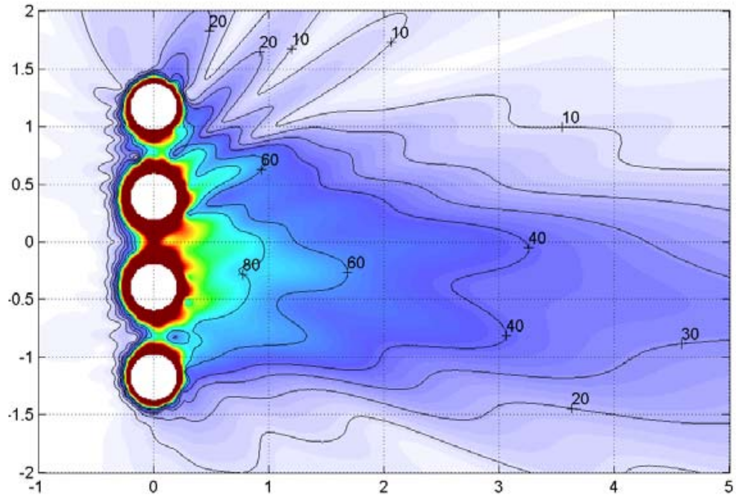


Fig. 4. Kathrein 739662 antenna modelled with 4 sub-sources

VI. REFERENCES

[1] "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," *Health Physics*, vol. 74, 1998.

[2] "Basic standard for the calculation and measurement of electromagnetic field strength and SAR related to human exposure from radio base stations and fixed terminal stations for wireless telecommunication systems (108 MHz – 40 GHz)," 2002.

[3] Z. Altman, B. Bégasse, C. Dale, J. Wiart, A. Karwowski, M. F. Wong, and L. Gattoufi, "Efficient Base Station Antenna Models for Dosimetric Analysis," *IEEE Trans. Electromagnetic Compatibility*, vol. 44, pp. 588--592, 2002.

[4] E. Richalot, M. F. Wong, V. Fouad Hanna, and H. Baudrand, "Rigorous Analysis of Radiating Structures Using Finite Elements and Spherical Modes Expansion," *Annales des Télécommunications*, vol. 53, pp. 130-138, 1998.

[5] Y. Adane, A. Gati, M.-F. Wong, C. Dale, J. Wiart, and V. Fouad Hanna, "Optimal Modeling of Real Radio Base Station Antennas for Human Exposure Assessment Using Spherical-Mode Decomposition," *IEEE Antennas and Wireless Propagation letters*, vol. 1, pp. 215--218, 2003.

[6] J. Hald, F. Jensen, and F. H. Larsen, *Spherical Near-Field Antenna Measurements*. London, UK: Perigrenus, 1988.