COMPARISON OF MEASURED AND SIMULATED INCIDENT AND SCATTERED FIELDS IN A 434 MHz SCANNER

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ABSTRACT

During the last few years, we have developed a 434 MHz circular scanner for scattered fields measurements purposes. Even if this system has originally been designed for biomedical applications, it can also be used for industrial applications like fluid flow control or non destructive evaluation of heterogeneous materials. In conjunction with this experimental setup, in collaboration with our partners (UPC, TUE, RUG), we developed increasingly sophisticate modeling tools to improve the accuracy of the scanner fields description. In this presentation, we will focus on the comparison between measured and simulated fields, from raw to carefully controlled measurements and from 2D to 3D models.

INTRODUCTION

The interest in microwave imaging and inversion techniques began in the 80th and is still important, especially when considering the always larger number of research groups which are developing more and more powerful algorithms and the increasing number of experimental setups recently designed. Unfortunately researchers were, and are still, faced with strong difficulties both on experimental and theoretical level. For us, improvements can only come if there are real strong interactions between people who are developing measurement systems and people who are trying to invert those data.

Being more involved in the experimental part, we have tried to imagine and design a measurement tool which is not assuming an infinite propagation space. This has been achieved by moving to a confined setup reducing therefore sensitivity to the surrounding but this is not without any drawbacks as it will be shown in the following. However, even if this prototype is now already built and almost operational, many options can still be taken according to the comments and recommendations of inversion specialists. Presenting our last incident and scattered fields measurements in this paper, we will show what is achievable today with the 434 MHz scanner, going from raw measurements to very carefully controlled situations. We will also draw our main tendencies and ideas to improve those measurements and try to evaluate the needed model accuracy.

EXPERIMENTAL SETUP

The main originality of our system resides in the confined configuration which has been chosen. Indeed we are measuring the EM fields inside a metallic cylinder with the idea of obviating thus any unwanted surrounding effects or parasitic radiation and taking profit of this casing to get a better knowledge of the real fields. The main drawbacks of this option are: i) fields can not be assumed to the free space or homogeneous space ones anymore and ii) we need an increased effort, theoretical and computational, for modeling them (but, thanks to A. Tijhuis and A. Franchois, a really fast and elegant way to compute those fields in a 2D approximation is now available [1] [2]). Another difficulty in such a casing configuration comes from the fast spatial variations of the fields, even if water is a bit lossy at this frequency (attenuation is about 0.2 dB/cm in tap water), avoiding thus too strong cavity resonances. This water which fills the metallic cylinder is also lowering the wavelength and improving the matching between the propagation medium and human tissues, high water content or high permittivity materials.

To ensure rather fast measurements and stability, we have chosen the following arrangement (fig. 1):

- a network analyzer as source and receiver (chosen for its large testing possibilities during the scanner characterization but to be replaced with dedicated source and receiver when their parameters will be fixed),
- a multiplexing/demultiplexing device for transmission/reception made of AsGa 1 to 2 switches,

- and an array of 64 biconical antennas well suited to radiate at 434 MHz in water (maximum return loss of 10 dB).

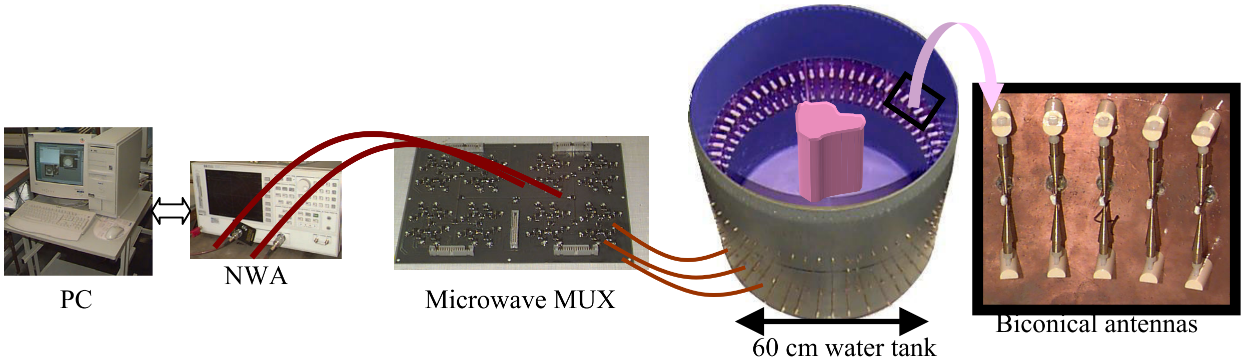

Fig.1: 434 MHz Scanner synoptic scheme

All this system has been designed in such a way that any antenna can alternatively be selected as transmitter or receiver, allowing thus the acquisition of 64 views of 63 points in few seconds (the slowest part is the network analyzer).

MODELING

In conjunction with this experimental setup, and, in collaboration with our partners : UPC (Polytechnic University of Cataluna, Barcelona, Spain), TUE (Technical University of Eindhoven, The Netherlands), and RUG (University of Gent, Belgium), we developed increasingly sophisticate modeling tools to improve the accuracy of the scanner fields description trying to take into account 3D effects, antenna coupling and so on. Our goal is to be able to achieve a good enough description of the propagation in the scanner with and without any scatterer, in order to be able to invert our measurements in the best conditions.

Four different methods are available, three are based on 2D approximation and only one is fully 3D. Lets briefly describe first the most simple method that will be called circular cylinder Green's function (CGF) which was developed in our laboratory. In this case, the scanner is considered as an infinite metallic cylinder filled with water and the transmitter is assumed to be an infinite small wire. In our model, the Green's functions are developed as series of Bessel functions [3]. Those Green functions are used to compute the incident field and a classical method of moments is implemented. The second method, based on embedding/de-embedding (E/D) was developed at TUE [2] and gives very close results to the previous ones but is really faster and more appropriate for fast inversion. The third one, implemented at RUG, is based on boundary integral method (BIM) and can be interesting to model the contribution of the passive antennas which are ignored in the previous methods, even if they could be modeled with E/D (such a study using a surfacic method of moment has also been carried out in our department [4]). The last method, developed at UPC, is based on 3D FDTD method and is not intended to be used in inversion algorithms because of its high computation cost but which can be very useful to appreciate the validity of our 2D approximations and also to understand the sensitivity of the scanner to some parameters like cross polarization, finite length of the cylinder, water level, …

INCIDENT FIELDS

For inversion purposes two different fields are needed, the incident and the scattered one (even if some authors are using the total field which is nothing but the addition of the two previous ones as input data). Accurate incident fields are crucial for at least two reasons: i) this field corresponds to the excitation, producing the induced currents inside the object under test which are then reradiated to create the so called scattered field, ii) the measurement of this field represents a very good way to validate the chosen green's functions especially when, as it is in our case, the antennas are comparable to point or line sources. Furthermore a calibration based on the comparison of measured and computed incident fields could be a very fast and easy way to correct systematic errors.

In figure 2 comparison between measured and simulated incident fields is made, the transmitting antenna being at the receiver location 0, as in all the following figures. In order to improve the discrepancy agreement, we have been led to apply a 1/sqrt(r) multiplying factor to 2D models. The FDTD results (fig. 3) are themselves clearly showing important variations of the incident field in the z direction but are nevertheless in good agreement in the cross section plane (x0y) with the 2D approximations. Finally, gain and phase offset are obtained from averaged values in order to scale fields. Those really encouraging results allows us to go to the next step, which is scattered field comparison.

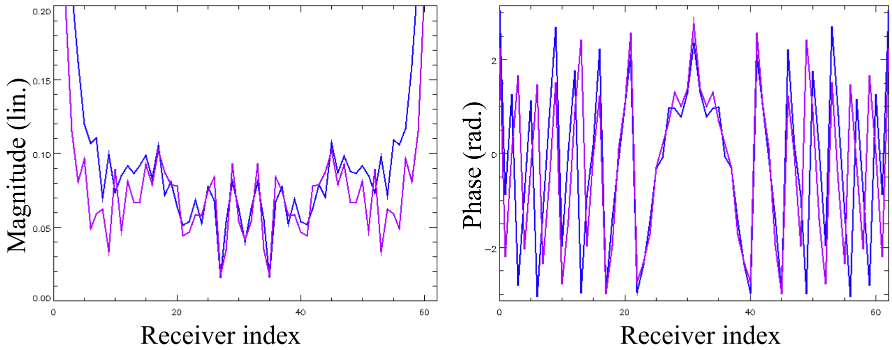

Fig. 2: Comparison between incident fields measured (averages of views) and computed (CGF-E/D)

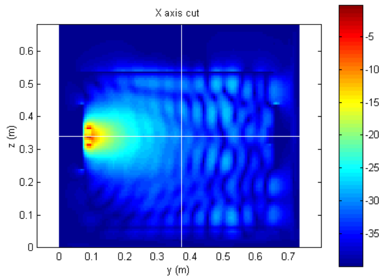

Fig.3: FDTD color plot of the incident field

SCATTERED FIELDS

First of all, to give an idea of the difficulty of correctly extracting the scattered field from incident and total fields measurements, those three quantities are represented on the same plot (fig. 4). As it can be seen, the scattered field can have really small values compared to the measured ones, especially for antennas in the vicinity of the source.

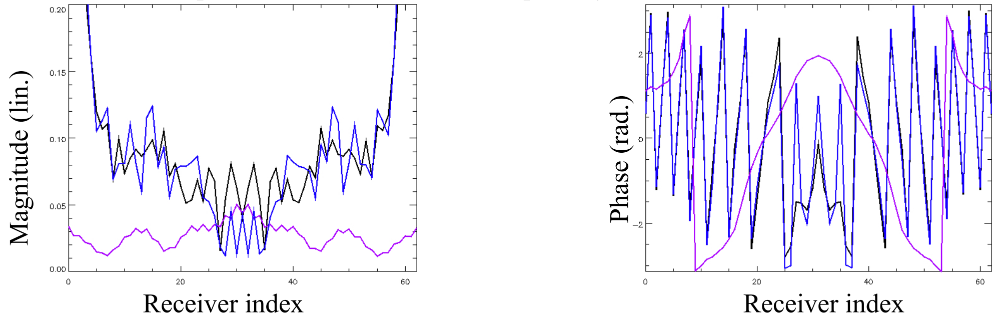

Fig. 4: Measured incident, total and scattered fields (averages of views) for a 8.15 cm diameter circular metallic tube

Our first idea was to measure the scattered field for a well known object, i.e. a perfectly conducting circular cylinder (fig. 4), but parasitic oscillations are observed even on the averaged fields. Doing then experimentation with a dielectric cylinder of known characteristics and about the same diameter (fig. 5), the oscillations went even worse…. After different investigations and many trials, we finally discovered that the small water-level variations (1.5 liter over about 300 l) due to the object positioning were really disturbing the scattered fields. Fortunately, this can be corrected with a simple water-level compensation (cf. fig. 5). Furthermore, our trials to put the bottom of the cylinder closer to the cross section plane have shown that it is still reasonable to consider a rather small thickness of our “plane”. Strong of this experience, we tried the same water level compensation with our conducting object, but due to its very small volume no improvement at all was obtained and the persistent oscillations are to be understood.

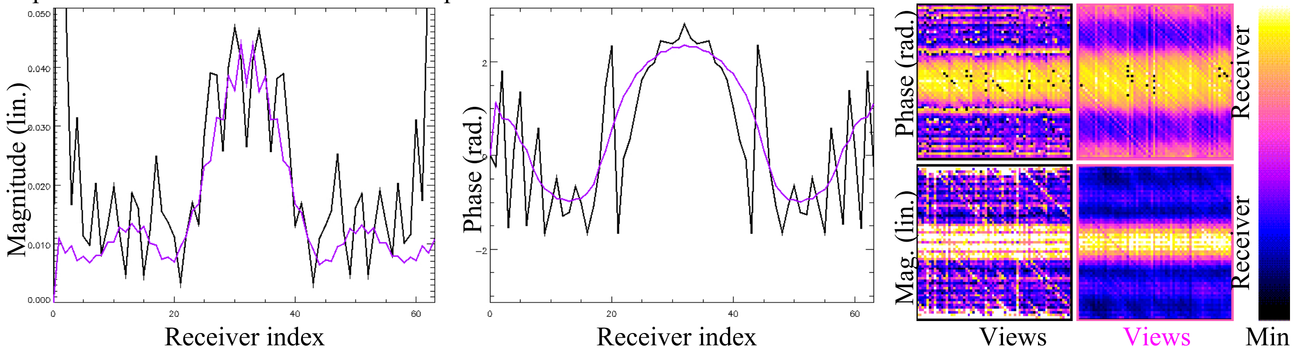

Fig. 5: Measured scattered fields for the 8.8 cm diameter dielectric cylinder without or with water-level compensation.

Even if this volume compensation may lead to doubts on the possibility to stay within 2D approximations of the scattering phenomenon inside our scanner, and if the “bidimentionality” of the object to image has to be investigated more precisely, the good agreement between simulated and measured fields, despite those persisting oscillation, makes us rather confident.

CALIBRATION

The first calibration idea is to compute correction coefficients from measured and simulated incident field comparison, with the advantage to be really easy to handle. Unfortunately, our trials with CGF simulations were not very successful which could imply that more refine modeling might be needed, reducing the advantages of this technique. Then, remarking that the persistent oscillations are really similar on both scattered fields, we tried to use the metallic cylinder as reference object, like a calibration standard, to compute the correction coefficients which were simply obtained comparing the simulated scattered field of the metallic cylinder (CGF method) with the measured one. Fig. 6 shows that the improvements obtained with this calibration are really surprising, even better than we have hoped, as this calibration is not only removing the persisting oscillations but compensate very efficiently for the channel dispersion, leading to almost identical measurements for each view (cf. color plot fig. 6). The only drawback of such a calibration is that the experimental protocol becomes rather complicate and heavy. Indeed, to obtain calibrated data, three different fields must be measured: the incident field, the total field of the reference object and the total field of the unknown object and this for each new object. In fact, those three measurements will be needed as long as the stability of our measurement setup is not really excellent: we already had phase variations of a few degrees leading to noisy scattered fields if waiting too much between measurements.

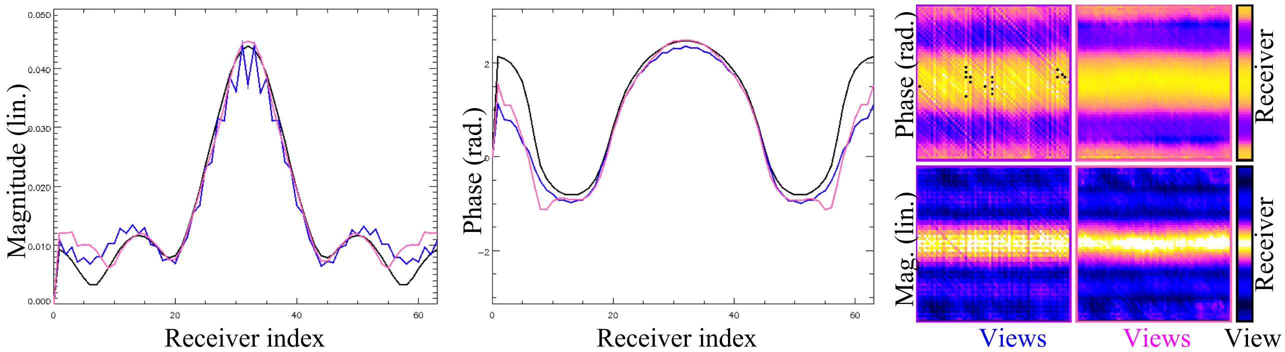

Fig. 6: Scattered fields for a dielectric cylinder : water-level comp., metallic cylinder calibration, computed (CGF).

CONCLUSION

Those results are showing that our 434 MHz scanner allows to measure accurately scattering phenomenon. Of course those first measurements were made with canonical objects and in laboratory controlled situation. Many investigations are still to be made like for example i) trying to make measurements with real 3D objects, ii) moving targets, iii) reducing the sensitivity and/or variations of phases, which may be done with a dedicated source and receiver, to allow single incident field measurement, or iv) even better only use an incident field modeling. Keeping in mind potential applications, several questions must be addressed such as, i) where do we need to stop the increasing complexity of measurements protocols and modeling, ii) how robust inversion algorithms can be, and iii) what is the degree of accuracy required that we have to reach in measurements. The answers might be different from an application to another, depending on the time available for measuring and computing the image, depending also on thewanted image resolution. These questions must be addressed in cooperation with inversion specialists, and we will be more happy to share our measurements results with them (for more information, check the following website http:///www.lss.supelec.fr/perso/geffrin).

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