Semi-analytical gray-box modeling of an impulse radiating antenna

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***Abstract*—The time-domain cartesian multipole expansion allows to express electromagnetic fields radiated by localized current distributions as semi-analytical expressions. In this work, we find such expressions for the electric field radiated by an impulse radiating antenna (IRA), thanks to a formulation as an inverse problem.

model fitting; multipole expansion; impulse radiating antenna; inverse problem; analytical solutions

Analytical expressions for the fields emitted by impulse radiating antennas are limited to the boresight cylinder [1]. In this paper, we propose to generalize such expressions to the whole space thanks to a "gray-box" modeling approach, i.e., we fit experimental data to a model whose physical behavior is known, but specific parameters are not.

The antenna is modeled by a time-domain multipole expansion [2] in cartesian coordinates. This approach delivers semi-analytical expressions for the electric and magnetic fields radiated by a pulsed, spatially-localized source in a isotropic and homogeneous medium. It works by approximating the true source current density by a sum of equivalent time-depend multipole moments. As the number of multipole moments approaches infinity, the resulting field converges to the true field outside of the source region.

The inverse problem can be stated as follows: given time-domain field measurements $\mathbf{E}_i$ at a number of observation points $\mathbf{r}_i$, find the parameters of the multipole expansion which best fit the measurements. These parameters can be represented by a single vector $\mathbf{x}$, containing the equivalent source location $\mathbf{r}_0$, the amplitudes of the current moments $C_\alpha^{\mathbf{J}}$ for all multi-indices α whose order is below a certain limit, and the time-domain shape of the current excitation h_j evaluated at the discrete time-points t_j. From these parameters, the multipole expansion can be seen as a function mapping the parameters $\mathbf{x}$ to a predicted field $\widetilde{\mathbf{E}}_i(\mathbf{x})$. The inverse problem can thus be expressed as the minimization problem

$$\text{minimize}_{\mathbf{x}} \sum_i \|\mathbf{E}_i - \widetilde{\mathbf{E}}_i(\mathbf{x})\|_p^p \tag{1}$$

where the integer p is the norm order.

In this work, the measurements $\mathbf{E}_i$ have been simulated by a time-domain COMSOL simulation of an impulse radiating antenna excited by the second-order derivative of a gaussian pulse. The geometry of the problem is presented in Fig. 1. For simplicity, the matching impedances where ignored. Next, the parameter vector $\mathbf{x}$ is found by solving the unconstrained problem posed in Eq. 1 using the BFGS algorithm.

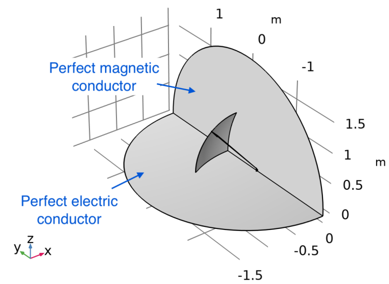

Figure 1. Geometry of the COMSOL simulation domain.

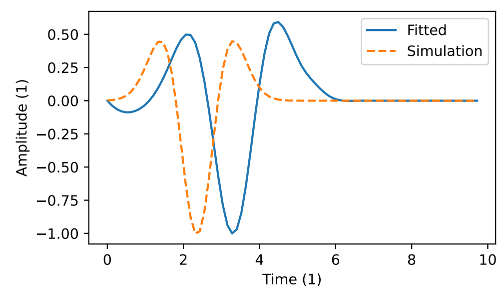

Figure 2. Time-domain shape of the current excitation fed to the COMSOL simulation (dotted line) and reconstructed by the model (solid line).

Over a full solid angle, the proposed method allows to explain over 80 % of the signal energy, thanks to a fifth order multipole expansion. Moreover, the used excitation is successfully recovered by the algorithm, albeit with some deformation and delay (see Fig. 2). Compared to traditional methods, both the advantages and disadvantages of the proposed approach lie in its reliance on the data and its "gray-box" modeling approach: indeed, its suffers from a slow convergence, but on the other hand, it is by design faithful to the measurements.

REFERENCES

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