A Combined Method for Computing Installed Radiation Patterns of Antennas on Large Conducting Platforms

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Abstract— The installed radiation patterns of antennas on large platforms are of great interest when installing antennas. The computation of installed radiation patterns is challenging due to the large size of the platform. To reduce the effort of modeling the large platform, this work adopts the hybridization of the method of moments (MoM) and physical optics (PO) method. The multi-level fast multipole method is used to accelerate the solution of matrix equations, so that a large MoM region can be used to improve the accuracy of modeling the antenna and its surrounding structures. Another challenge of modeling antennas on large platforms comes from the complexity of the antennas. Furthermore, when an antenna is outsourced, detailed design information may be unavailable to those who install the antenna, which hinders direct modeling of antennas on large platforms. In this case, equivalent models of antennas are derived based on their uninstalled far field radiation patterns. Using the equivalent models, installed radiation patterns of antennas can be computed without knowing their detailed design information. By combining the hybrid method with the equivalent model, the installed radiation patterns are computed efficiently.

1. INTRODUCTION

Nowadays, there are many antennas installed on large platforms such as aircrafts, ships, missiles, etc.. A large platform may significantly affect the performance of antennas and it is highly desirable to know the antennas' performance on the large platform. Since these platforms are usually bulky, it is expensive to fabricate them. Meanwhile, it is difficult to find a large measurement site which is able to accommodate large platforms. Furthermore, it is tedious to move and rotate a large platform during measurement. Due to the aforementioned difficulties, scaled models are usually used in practical measurements. On the other hand, simulation provides a cost-effective and convenient option to evaluate the performance of antennas on large platforms. Therefore, simulation of antennas on large platform attracted much interests in the past decades.

In order to satisfy tight specifications, the design of an antenna may be complex. In the meanwhile, as the frequency of operation rises, the electrical size of the platform increases. The complexity of the antenna design and the large electrical size of the platform make it challenging to simulate antennas on large platforms. The challenges come from the following aspects. First of all, it is usually time consuming to model electrically large structures, unless certain approximation is introduced. Second, in practice, the antenna may have tiny features requiring fine meshes. This leads to a mixed-scale structure, whose numerical modeling usually results in an ill-conditioned matrix. Third, there are cases where the antenna design details are unavailable. This happens when the antenna is provided by external manufacture. Last but not least, because antennas in various frequency bands coexist on a platform, wide-band simulation is needed when interference between antennas is computed.

For fast modeling of electrically large platforms, it is desirable to use hybrid low frequency-high frequency methods, where the effect of large platform is taken into account by high frequency methods such as physical optics (PO) method [1, 2]. In order to deal with the challenge of modeling multi-scale structures, various domain decomposition methods were developed [3–8]. These methods divide small-scale and large-scale structures into sub-domains and model every sub-domain separately. Different schemes were proposed to account for the coupling between sub-domains, and more details about these coupling schemes are available in [3–8]. Although domain decomposition methods facilitate the modeling of multi-scale structures, they require the detailed design information of antennas. In [9], the fast multipole technique was used to model antennas without their design details. In the meanwhile, the equivalent sources can be used to represent complex

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radiators [10–13]. In [11], wide-band analysis was accelerated by an adaptive frequency sampling technique, which could also be used for wide-band simulation of antennas on large platforms.

Despite the aforementioned progresses, it is still challenging to analyze antennas on large platforms without antennas' design information. First, although equivalent sources are effective to represent antennas, it usually takes long time to derive these equivalent sources. Second, most existing hybrid low frequency-high frequency methods use a small low frequency region, which causes inaccuracy when the surrounding environment of the antenna is complex.

To achieve fast and accurate computation of antennas' installed radiation patterns, this work combines physics-inspired equivalent model of antennas with a recently proposed hybrid multilevel fast multipole method (MLFMM)-PO method. In the physics-inspired equivalent model, it is assumed that the type of the antenna is known and the radiation mechanism of the antenna is utilized to simplify its equivalent model, which reduces the effort of constructing equivalent model. Furthermore, different from existing hybrid methods, the new hybrid method relies on the efficiency of MLFMM and uses a large MLFMM region to accurately model the antenna and its surrounding environment. In the meanwhile, for efficiency consideration and based on locality principle, only a small region near the antenna is used to compute the incident magnetic field in PO region.

2. DESCRIPTION OF THE METHOD

In order to model the antenna without its design details, an equivalent model is constructed based on the antenna's radiation pattern. A popular equivalent model is the equivalent dipole model [12, 13]. In the work of [12, 13], a number of small dipole antennas are placed on the Huygens' surface enclosing the antenna. Because the number of dipole antennas is large, it may take long time to optimize the dipole antennas. In practice, it is reasonable to assume that the type of the antenna is known, because such information can be provided by the vendor. In this case, one may utilize the antenna's radiation mechanism to simplify the equivalent model. For example, [15] presented a physics-inspired equivalent model for microstrip antenna. Based on the radiation mechanism of the microstrip antenna, only four equivalent dipole antennas with three optimization parameters are required and excellent accuracy is obtained [15]. Furthermore, a simple equivalent model of the slotted waveguide antenna was proposed in [16]. In both [15, 16], the antenna's radiation mechanisms are taken into consideration when constructing the equivalent model, and thus the effort of optimizing the equivalent model is reduced.

Once the equivalent model is obtained, it is used together with the hybrid method to compute the installed radiation pattern. In most existing hybrid integral equation method (IEM)-PO methods, only two regions exit, namely IEM region and PO region. In this case, the IEM region is usually chosen to be small. Otherwise, it will be very time consuming to calculate the incident magnetic field in the PO region. Recently, Zhao et al. proposed a three-region hybrid method, where the IEM region is further divided into coupled and decoupled IEM regions [14]. Here, the method of [14] is further accelerated by MLFMM and the hybrid method is named as hybrid MLFMM-PO. Figure 1 illustrates the region division in the hybrid MLFMM-PO. It is seen that the whole computational domain is divided into three regions, two of which are around the antenna to be analyzed. Note that the equivalent model of the antenna is also included in the coupled MLFMM region. The terms 'coupled' and 'decoupled' are used to indicate whether the MLFMM region is coupled with PO region. Here, it is assumed that the energy reflected from PO region to MLFMM regions is negligible. In this case, one only needs to consider the first-order coupling from the coupled MLFMM region to PO region. Furthermore, the surface of the large platform and the equivalent model is assumed to be perfect electric conductor. The MLFMM regions are then modeled by the

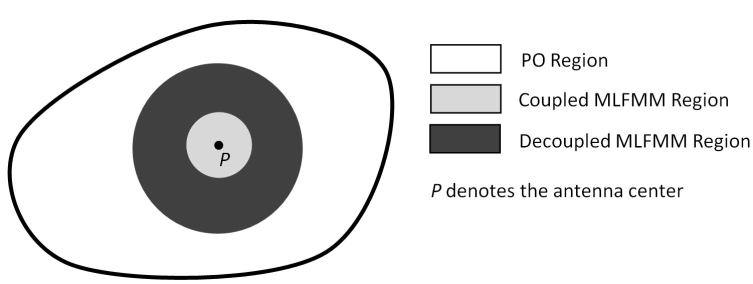


Figure 1: Region division of hybrid MLFMM-PO.

following well-known electric field integral equation

$$-\frac{j}{\omega\mu}\hat{t}\left(\vec{r}\right)\cdot\vec{E}^{i}\left(\vec{r}\right)=\hat{t}\left(\vec{r}\right)\cdot\iint_{s}\left(1+\frac{1}{k^{2}}\nabla\nabla\right)\vec{J}\left(\vec{r}'\right)G\left(\vec{r},\vec{r}'\right)d\vec{r}', \tag{1}$$

where S denotes the surface of MLFMM regions. $\vec{E}^i$ is the incident electric field on S. For equivalent model using small dipole antennas, the incident electric field is only non-zero at the dipole antenna feeding port. If equivalent model with current source is used, the incident electric field is the radiated field of the current source. By solving Equation (1) with MLFMM, the induced current on S is obtained. The induced current in the coupled MLFMM region and the current source of the equivalent model (if any) are used to compute the incident magnetic field in the PO region. Namely,

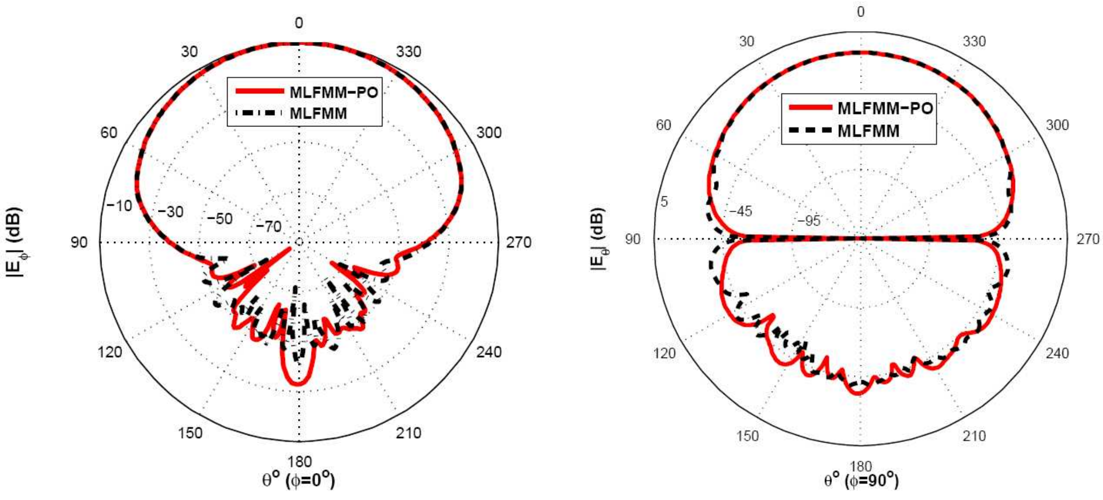
$$\vec{H}^{i}\left(\vec{r}\right)=\nabla\times\iint_{S_c}\vec{J}\left(\vec{r}'\right)G\left(\vec{r},\vec{r}'\right)d\vec{r}'+\nabla\times\iint_{S_o}\vec{J}_0\left(\vec{r}'\right)G\left(\vec{r},\vec{r}'\right)d\vec{r}'. \tag{2}$$

In (2), S_c denotes the surface of the coupled MLFMM region, J_0 is the current source of the equivalent model, and S_0 is the surface where J_0 exists. With $\vec{H}^i$, the PO current is simply $\vec{J}_{PO}(\vec{r}) = 2\hat{n}(\vec{r}) \times \vec{H}^i(\vec{r})$. Finally, the installed radiation pattern is computed using $\vec{J}$ on S, $\vec{J}_0$ on S_0 (for equivalent model with current source) , and $\vec{J}_{PO}$ in PO region.

3. NUMERICAL RESULTS

This section presents simulation results to illustrate the capability of the proposed method. Code validation is first conducted using four dipole antennas above a $20\lambda \times 20\lambda$ square conducting plane. A microstrip antenna is then modeled using its equivalent model, and the hybrid MLFMM-PO is used to compute its radiation pattern on the $20\lambda \times 20\lambda$ rectangular conducting plane.

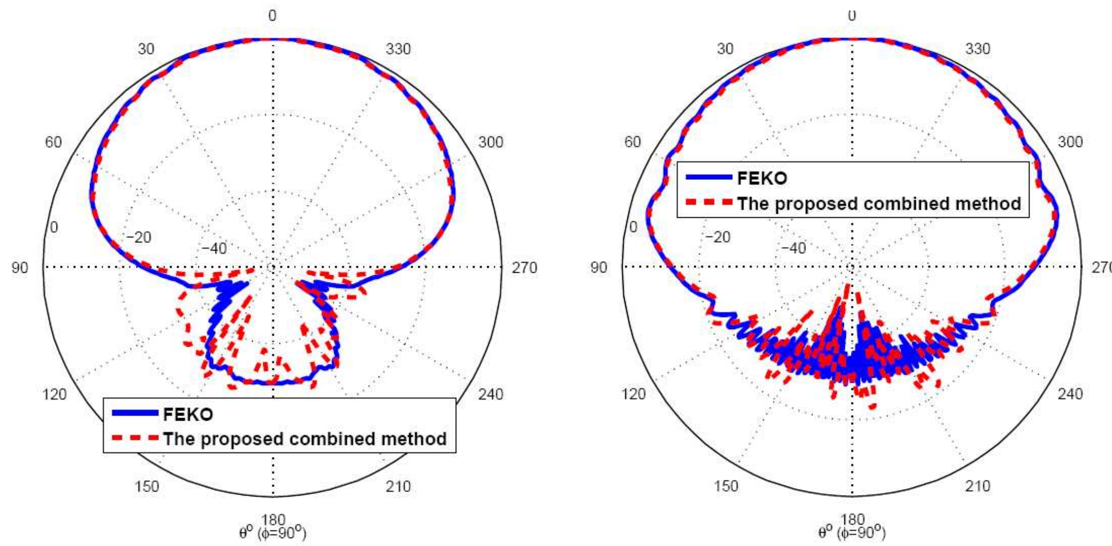
Figure 2 presents the far field radiation pattern of an array consisting of four quarter-wavelength dipole antennas. The results from hybrid MLFMM-PO agree well with those of MLFMM, except these angles in the shadowed region. The discrepancies in the shadowed region is due to the ignored edge diffraction, which can be fixed using the uniform theory of diffraction [14]. For this example, in-house developed codes are used for both methods. The CPU time required by MLFMM and hybrid MLFMM-PO is 3,611 and 233 seconds, respectively. The memory costs are 600.3 and 53.2 MB for MLFMM and hybrid MLFMM-PO, respectively.



(a) *XOZ* plane (b) *YOZ* plane

Figure 2: Radiation pattern of four dipole antennas above a $20\lambda \times 20\lambda$ square conducting plane.

Figure 3 shows the normalized radiation pattern of the microstrip antenna above the $20\lambda \times 20\lambda$ square conducting plane. Results from the proposed combined method are validated by those from FEKO [17]. Again, except for angles in the shadowed region, the proposed combined method agree well with FEKO. Note that the equivalent model of the microstrip antenna is obtained using the phaseless normalized radiation pattern of the microstrip antenna, which is usually available in the



(a) ϕ-component in *XOZ* plane (b) θ-component in *YOZ* plane

Figure 3: Normalized radiation pattern of a microstrip antenna above a $20\lambda \times 20\lambda$ square conducting plane.

data sheet of the antennas. The CPU time and memory cost are summarized in Table 1. It is seen that the CPU time of the proposed method is close to that of FKEO, while the proposed method requires twenty times less memory. Because FEKO requires detailed design of the antenna, it is difficult to make fair comparison between the proposed method and FEKO. Meanwhile, different code implementations make it more difficult to conduct efficiency comparison. However, considering FEKO incorporates state-of-the-art techniques, the proposed method can be considered as efficient. Therefore, the proposed method renders efficient prediction of an antenna's installed radiation pattern, without knowing its design details.

Table 1: Summary of CPU time and memory costs.

Method	CPU time (Minutes)	Memory cost (GB)
FEKO	11	2.61
The proposed combined method	16	0.11

4. CONCLUSION

This paper presented a combined method for efficient prediction of antennas' installed radiation patterns without knowing antennas' design details. Numerical results have shown the validity and efficiency of the proposed method. Except for these angles in shadowed region, excellent agreement has been observed between the proposed method and its alternatives. The proposed method requires no detailed design information of the antenna, and it is very useful when the antenna design is not provided by the its vendor. Work is undergoing to improve the accuracy in shadowed region by including the diffraction effect.

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