Analysis of Complex Antennas Using Iterative Vector Fields with UTD Method

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1. Introduction

Many accurate methods, such as finite element method (FEM), higher order MOM, and finite difference time domain (FDTD), have been utilized to analyze the electrically small complex antenna [1-4]. For higher order MOM method, it has been recognized that the use of higher order basis functions substantially reduces the number of unknowns hence reduce the size of the problem and the total solution time [1]. The efficiency is enhanced, however, it needs unbearable hardware requirements in solving electronically large problems. Based on ray solutions, UTD is an efficient high-frequency method. It is widely used to analyze Electro Magnetic Compatibility (EMC) problems with electrically large platforms [2-4].

It is well-known that hybridization of a kind of accurate method with UTD [2-4] has great potential to increase the capabilities of the individual method. For example, combining UTD with MOM has been effectively used to calculate the pattern of the antenna in complex environment [3], hybrid FDTD/UTD has been successfully applied to analyze phased array antennas mounted on airborne platform [4]. In this paper, iterative vector fields with UTD method is utilized to analyze the radiation pattern of complex antenna around electrically large platform. We consider full coupling between antenna and platform through Huygens' surface currents instead of the process of modifying the impedance matrix of MOM with UTD in conventional MOM-UTD [2]. However, this coupling effect has been neglected in [3] and [4], in which the antenna was supposed to be far away from the platform. Based on this technique, an approximation method is also outlined. The relative patterns obtained from the present method and from the approximate method show good agreements with that obtained from MOM.

2. Analysis

Using higher order MOM, it's easily to compute the complex near field components $\vec{E}$ and $\vec{H}$ over the closed surface *S*, which encloses the antenna practically motivated without platform. According to the equivalence theorem, to maintain the radiation of antenna outside *S*, while the field inside *S* is zero, it's necessary to induce electronic and magnetic currents $\vec{J}_s, \vec{M}_s$:

$$\vec{M}_S = \vec{E} \times \hat{n}, \quad \vec{J}_S = \hat{n} \times \vec{H} \tag{1}$$

where $\hat{n}$ is the outward unit normal vector on *S*. Taking the electromagnetic field outside *S* as the research target, the antenna can be replaced by currents placed on *S*.

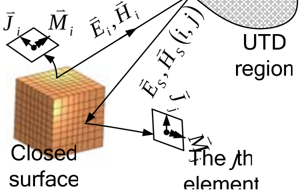


Figure.1 Modal of iteration

For mathematical tractability, a cube enough to enclose the antenna entirely is selected as the closed surface, over which the fields are convenient to obtain. Its six plane surfaces are uniformly divided into *N* small squares. Each one is taken as a Huygens' surface element, whose side length is about $1/10\lambda$ and area supposed as Δs. The modal is shown in figure.1.

Each element can be thought as a point source placed on the center of itself. The total field vectors produced by the *i*th surface element are:

$$\vec{E}_i(\vec{r}) \approx \frac{je^{-jkR_{i0}}\Delta s}{4\pi\omega\varepsilon}\cdot\left\{\frac{k^2R_{i0}^{\ 2}-3jkR_{i0}-3}{R_{i0}^{\ 5}}\cdot\left[\vec{J}(\vec{r}')\times\vec{R}_{i0}\times\vec{R}_{i0}\right]-2\vec{J}(\vec{r}')\cdot\frac{1+jkR_{i0}}{R_{i0}^{\ 3}}\right\}$$
$$-\frac{\Delta s}{4\pi}\left\{\frac{1+jkR_{i0}}{R_{i0}^{\ 3}}e^{-jkR_{i0}}\left[\vec{M}(\vec{r}')\times\vec{R}_{i0}\right]\right\} \qquad (2)$$

where the subscript *i* represents the *i*th $(i=1,2,\cdots N)$ element, $\vec{R}_{i0}$ is the vector from the center of the *i*th element to the observation point, and $R_{i0}=\left|\vec{R}_{i0}\right|$。 The expression of magnetic field can be easily written according to the dual principle. An electromagnetic system composed of platform and antenna will undergo a short-lived interaction when the latter is motivated. Simulate this process by iterating the currents over the closed surface using UTD.Taking the center of the ith $(i=1,2,\cdots N)$ element as the source point of UTD region, and the jth $(j=1,2,\cdots N)$ one as the observation point, we execute ray-tracing and shelter-judgment according to the UTD algorithm. And the incidence electromagnetic fields equal to the ones produced by the currents over the ith element. The total scattered fields computed by UTD are denoted by $\vec{E}^s{}_{ji}$ and $\vec{H}^s{}_{ji}$. For any j $(j=1,2,\cdots N)$, the sum vectors $\vec{E}_j^{\ s}=\sum_{i=1}^{N}\vec{E}^s{}_{ji}$, $\vec{H}_j^{\ s}=\sum_{i=1}^{N}\vec{H}^s{}_{ji}$ are the total scattered fields at the center of the jth element. To maintain the fields inside S be zero, induce currents:

$$\vec{M}_{Sj}=\vec{E}_j^{\ s}\times(-\hat{n}), \quad \vec{J}_{Sj}=(-\hat{n})\times\vec{H}_j^{\ s} \qquad (3)$$

To save computational time, we suppose that the rays are approximately emitted from the center of the cube because of the centre-symmetry of the closed surface. Thus for each observation point, reflection ray-tracing and corresponding shelter-judgment are implemented only once, so do the diffraction case. While the incidence fields, the sum of fields produced by each point source, are precise. Based on this approximation, the computational time is reduced greatly, but the results are satisfied, which is confirmed in numerical result as follows. Supposing $\vec{J}_{Sj}(k)$, $\vec{M}_{Sj}(k)$ are the electromagnetic currents at the *j*th element obtained after the *k*th iteration. The ones after the $k+1$th iteration will be as follows.

$$\vec{M}_{Sj}(k+1)=\vec{M}_{Sj}+\vec{E}_{j(k)}^{\ s}\times(-\hat{n}), \quad \vec{J}_{Sj}(k+1)=\vec{J}_{Sj}+(-\hat{n})\times\vec{H}_{j(k)}^{\ s} \qquad (4)$$

where $\vec{M}_{Sj}$, $\vec{J}_{Sj}$ are the initial currents, and the subscript (*k*) in $\vec{E}_{j(k)}^{\ s}$ and $\vec{H}_{j(k)}^{\ s}$ stand for the vectors produced by the currents after the *k*th iteration. When the new electromagnetic currents are obtained, repeat the iteration process until the currents satisfy the conditions:

$$\frac{\left\|\vec{J}_s(k+1)-\vec{J}_s(k)\right\|}{\left\|\vec{J}_s(k)\right\|}\le\Delta, \quad \text{and} \quad \frac{\left\|\vec{M}_s(k+1)-\vec{M}_s(k)\right\|}{\left\|\vec{M}_s(k)\right\|}\le\Delta \qquad (5)$$

where Δ is the threshold of iteration-ceasing, which is set as 10^{-3} in the calculation of the numerical result in this letter, $\|\cdot\|$ denotes the 2-norm of a complex vector.

After the iteration cuts-off, taking the final currents on each element's center as point source of the UTD region, calculate the total scattered field in far field region. Adding the scattered field and the incidence field produced by the final currents, the radiation pattern is obtained.

3. Numerical Results and Discussion

The structure of Log-periodical dipole antenna (LDPA) with the working frequency of 700MHz is shown in the inset of Figure 2. Its three dimensional bounds are: $x:[0.139467,0.7325]$, $y:[-0.25,0.25]$, $z:[-0.02,0.02]$ (*m*). A cube centered on $(0.4,0,0)$, whose side length is 0.8*m*, is chosen as the closed surface. It's six plane surfaces are all divided into 20×20 small squares, as shown in Figure 2. The centers of two base surfaces of the cylinder scatterer are (-2.0,1.1547,-5.0)，(-2.0,1.1547, 5.0), and the radii of which is 2*m*. For the rigorous ray-tracing method and the center ray-tracing approximate method, convergent solutions both can be obtained by five iterations in this example. It is worth noting that the two methods both converge in a few iterations. Figure 3 shows the convergence behavior of the rigorous method for the example described above. Analogous behavior has been obtained for all other examples. Thus, those results are not shown.

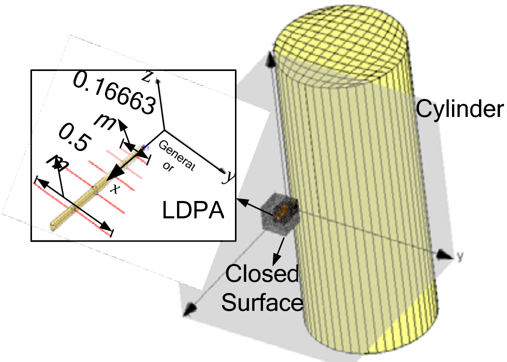


Figure 2: Modal of EM Surface and cylinder scatterer

The final results of radiation pattern in *xoy* plane and *yoz* plane by two iterative approaches, rigorous ray-tracing and approximate center ray-tracing both agree very well with the ones obtained by higher order MOM shown in Figure 4(*a*) and (*b*). And the computing time respectively are 18912 seconds and 2933 seconds. It’s obviously to see that, comparing to the rigorous ray-tracing method, the center ray-tracing approximate method uses much less computational time, but the results are satisfied.

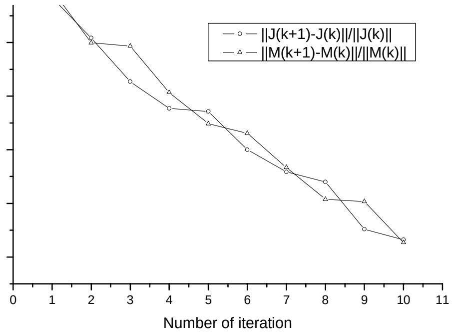
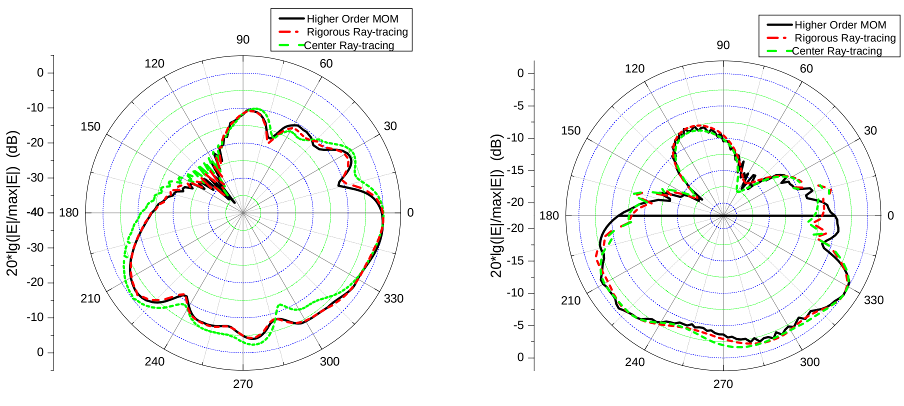


Figure 3: Convergence of the method for the problem of LDPA around a cylinder



(*a*) Radiation pattern of the *xoy* plane (*b*) Radiation pattern of the *yoz* plane

Figure 4: Results of radiation from LDPA around a cylinder

4. Conclusion

In this letter, a new efficient technique, combining UTD with iterative vector field method, has been proposed to analyze the radiation pattern of complex antenna around a scatterer. The relative patterns obtained from the present method and from the approximate approach show good agreements with that obtained from higher order method of moments (MOM). The method considered here is thought to be very useful in the radiation pattern calculation of complex antenna near electronically large platform.

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