ANALYSIS OF RADIATION AND SCATTERING FROM LARGE BODIES USING CURRENT MODES

M. Felipe Cátedra, Carlos Delgado, Oscar Gutiérrez, Francisco Sáez de Adana
Escuela Politécnica, Universidad de Alcalá, 28806 Alcalá de Henares (MADRID), SPAIN
Fax: + 34 91 885 69 60, email: felipe.catedra@uah.es

ABSTRACT.-A method to compute efficiently the far and near field due to the current induced on electrically large bodies is presented. The method is based on an expansion of the currents and the fields in terms of current modes, defined as exponential functions whose amplitude and exponent vary slowly along the body surfaces. These functions are interpolated by means of parameter spline functions. The field is computed in a fast way using analytical expressions. The method is accurate and highly efficient in terms of CPU-time and computer memory.

ANALYSIS

Today there are available several approaches to analyze rigorously radiation and scattering from large complex bodies using high performance computers. For instance, the FMM (Fast Multipole Method) provides the solution to such problems using an iterative algorithm. This approach represents a significant advance in computational electromagnetics because it avoids the extremely large matrices that appear solving these problems using the Moment Method. However, the FMM needs to sample the fields or currents considering a spatial rate of about 8 to 10 subdomain functions per wavelength. This means a large disadvantage because the scattered field and the induced current should be computed in a very large amount of sampling points. That requires a large number of computer calculations and a huge amount of computer memory. In this communication an approach that minimize the spatial sample rate is presented to reduce this large computer memory and CPU-time need. The approach is based on representing of the currents or fields in terms of a series of exponential functions, that we will call “current modes”, whose amplitude and phase are functions that vary slowly along the smooth part of the surfaces of the scatters. For instance, the induced current \( J(r) \) can be approximated by a finite number of current modes:

\[
J(r) = \sum_{m=1}^{N} J_m(r) \exp(-j\phi_m(r))
\]

where \( J_m(r) \) and \( \phi_m(r) \) are, respectively, the amplitude and phase functions that characterise the mode \( m \). The idea of using such exponential functions can also be found in [1]. As shown in [2] the couple of functions that define a current mode can be easily interpolated from their values in a reduced number of sampling points, as they are slow varying functions along the smooth surfaces of the scatters. In particular the interpolation was carried out using polynomial functions like, for instance, NURBS (Non-Uniform Rational B-splines Surfaces) [3]. NURBS are specially well suited for such interpolation because they are piecewise polynomial surfaces that guarantee the continuity of the functions and their derivatives. The procedure for interpolation shown in [2] requires that the phase function to be sampled has not any jump of \( 2\pi \) radians. It is difficult to compute the phase value without those jumps when the source of the field is a current mode as it is the case of analyzing the interactions between the parts of the scatter. This problem can be avoided considering for interpolation the components of the spatial frequency vector (the spatial phase derivatives along the tangent vectors to the scatter surface). The phase function \( \Phi(u,v) \) is obtained integrating the components of its gradient, that are the spatial frequencies of the current mode.

It can be shown that the field in terms of parameter coordinates at a given observation point \((u,v)\) due to mode \( m \) is given by

\[
E(u, v) = \int D \Phi(u,v,u',v') \exp(-j\Phi(u,v,u',v')) ds'
\]

where \( D \) is the surface that supports the current mode. The integrand in (2) can be considered as a “mode” for both coordinates parameters sets, \((u,v)\) and \((u',v')\). Function \( \Phi \) can be approximated using a Taylor expansion

\[
\Phi'(u,v,u',v') = \Phi(u_0, v_0, u'_0, v'_0) + \Phi_u(u-u_0) + \Phi_v(v-v_0) + \\
\Phi_{u'u'}(u'u'_0) + \Phi_{v'v'}(v''v'_0) + R(u_0, v_0, u', v')
\]
Considering (3), the field around the sampling points \((u_0, v_0)\) can be expressed as:

\[
E(r(u, v)) = \exp(-j\Phi(u_0, v_0, u', v') + \omega_0(u - u_0) + \omega_0(v - v_0))E_0(u_0, v_0)
\]  

(4)

where \(E_0\) gives the amplitude and a part of the phase value of the field at \((u_0, v_0)\).

\[
E_0(u_0, v_0) = \int \int M'(u_0, v_0, u', v') \exp(-j\omega_0(u' - u_0) - j\omega_0(v' - v_0))du'dv'
\]  

(5)

where

\[
M'(u_0, v_0, u', v') = M(u_0, v_0, u', v') \exp(-jR(u_0, v_0, u', v'))
\]  

(6)

Expression (5) is the Fourier transform of \(M'\) evaluated at the frequencies \(u_0, v_0\) and can be computed efficiently expanding \(M'\) in a polynomial form of degree \((K_xL)\) as follows, [4]:

\[
E_0(u_0, v_0) = \sum_{p=1}^{K} \sum_{q=1}^{L} \hat{c}_{p,q} (u_0, v_0) \int \int \frac{d^p}{d\omega_0^p} \frac{d^q}{d\omega_0^q} \left\{ \text{inc}(\omega_0 / 2z) \text{inc}(\omega_0 / 2z) \right\} \mid \omega_0 = \omega_{u0}, \omega_{v0}
\]  

(7)

where \(\hat{c}_{p,q} (u_0, v_0)\) represents the coefficients of the polynomial that expands \(M'\).

RESULTS

In order to show the performances of the proposed current mode approach RCS results using PO have been considered. The PO integrals have been computed with a "purely numerical simple PO" approach and with the proposed current method approach. A sampling rate of 10 current values per wavelength has been employed to represent the currents and to compute the PO integral by the "purely numerical" procedure. Figure 2 shows a comparison of the computed values of the monostatic RCS due to the double reflection indicated in Figure 1 using the current mode approach (broken line) and the purely numerical integration (solid line).

Table 1 shows the CPU-times using a PC Pentium IV (1.8 GHz, 1GB) needed to obtain the monostatic RCS due to the double reflection mentioned for 46 directions. The computer memory needed to store all the information required to represent and work with the PO current using the current mode approach is less than 10 MB for all the frequencies considered. Observing the CPU-times shown in table 1 it can be stated that the current mode approach is highly efficient, particularly if we compare it with the numerical approach when the frequency increases.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Time (Numerical)</th>
<th>Time (Analytical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 MHz</td>
<td>5s</td>
<td>45s</td>
</tr>
<tr>
<td>250 MHz</td>
<td>4m 8s</td>
<td>3m 47s</td>
</tr>
<tr>
<td>500 MHz</td>
<td>2h 51m 21s</td>
<td>8m 56s</td>
</tr>
<tr>
<td>1 GHz</td>
<td>&gt; 72 hours</td>
<td>15m 30s</td>
</tr>
<tr>
<td>2 GHz</td>
<td>&gt; 72 hours</td>
<td>26m 12 s</td>
</tr>
</tbody>
</table>

Table 1. Comparison of the CPU-times using the numerical and the current mode approaches needed to compute the monostatic RCS in 46 directions due to the double reflection indicated in Figure 1.

CONCLUSIONS

A new method based on current modes to compute and interpolate the currents and fields due to electrically large bodies has been presented. The approach is accurate and computationally very efficient in terms of CPU-time and computer memory.
ACKNOWLEDGEMENTS.
This work has been supported in part by the Spanish Department of Science and Technology, Projects TIC2000-0859 and TIC2001-3839-C03: 01, 02 and 03.

REFERENCES

Figure 1 Both cylindrical sector surfaces shown have been considered to obtain monostatic RCS values due to the double reflection. (first reflection on surface 1, second reflection on surface 2). All dimensions in m.

Figure 2. Comparison between the numerical and analytical values of the monostatic RCS due to the double reflection on the surfaces indicated in Figure 1 for the cut θ=37.87 °, a frequency of 500 MHz and polarization θ-θ.