A Comparison between Asymptotic Methods for Time-Domain Analysis of Reflector Antennas

Cassio G. Rego[1], Flavio J. V. Hasselmann[2], and Fernando J. S. Moreira[1]
[1]Dept. Electronics Engineering - Federal University of Minas Gerais
Av. Pres. Antonio Carlos, 6627, CEP 30161-970, Belo Horizonte - MG, Brazil
[2]CETUC - Catholic University of Rio de Janeiro
Rua Marques de São Vicente, 225, CEP 22453-900, Rio de Janeiro - RJ, Brazil

***Abstract*- In this work the asymptotic Time-Domain Physical Optics and Time-Domain Uniform Theory of Diffraction are applied to the analysis of a hyperboloidal reflector antenna to illustrate their behaviour and utility. The results are compared with those obtained by an accurate integral-equation formulation, in order to specify the limitations of the asymptotic formulations.**

I. Introduction

The interest in the transient analysis of ondulatory electromagnetic phenomena has been growing in recent years. This is due to the advance of ultra-wideband (short-pulse) radars and their associated antennas, with applications in remote sensing and target identification [1]. Special attention has also been devoted to the characterization of mobile radio channels by means of their responses to pulsed excitations [2].

It is more efficient do deal with the transient analysis directly in the time domain. However, some numerical techniques such as the finite-difference time-domain method (FDTD) and space-time integral-equation methods become intractable when the incident pulse width is extremely narrow with respect to the dimensions of the radiating object. This fact makes the use of asymptotic methods, such as the time-domain physical optics (TDPO) and the time-domain uniform theory of diffraction (TD-UTD), very attractive [3,4]. These are implemented herein in connection with the transient analysis of a hyperbolic reflector antenna illuminated by a spherical wave radiated from the focus with temporal behaviour in the form of a double-gaussian pulse. Results are also compared with those obtained from Fourier inversion of a reference method of moments (MoM) solution in the frequency domain.

II. The TDPO and TD-UTD Techniques

The TDPO technique is derived via a Fourier inversion of the corresponding frequency-domain formulation, whereby the scattered field from a smooth perfectly conducting body is calculated by an integration of PO-induced currents over the illuminated surface using the free-space Green's function. The inverse Fourier transform of the radiation integral then leads to the corresponding scattered field in the time domain [3].

The TD-UTD formulation for the field scattered by a perfectly conducting surface with an edge, obtained after Fourier inversion of corresponding reflected and diffracted field expressions in the frequency domain, also makes use of an analytical representation of signals in the time domain, so that eventual crossing of focal points along ray paths are properly taken into account. Geometrical parameters such as specular points coordinates, the spread factor of the scattered fields, the ray-fixed coordinates and vector components, as well as those involved on the determination of the diffraction coefficients, are calculated by the same way as in the frequency domain [4].

Both TD-UTD and TDPO are valid only when the reflector diameter is much larger than the pulse width, i.e., the frequencies present in the spectrum of the excitation have wavelengths wich are small compared to the dimensions and radii of curvature of the scatterer. This fact, wich is a consequence of the asymptotic nature of UTD and PO in the frequency-domain, makes these techniques valid only for early observation times in the neighborhood of the arrival of the first wavefront [4].

III. Application: A Hyperboloid Illuminated by a Double-Gaussian Pulse

Fig. 1 shows the geometry of a hyperboloidal reflector illuminated by an incident spherical wave from the focus, whose temporal behaviour is defined by a double-gaussian pulse with no DC component (see Fig. 2), given by [5]

$$e_{DG}(t) = \alpha_1 \exp\left[-(\alpha_1 b\, t)^2\right] - \alpha_2 \exp\left[-(\alpha_2 b\, t)^2\right] \qquad (1)$$

where the coefficients α_1 and α_2 were made equal to 4 and 2, respectively, and determine the pulse shape. The coefficient b was chosen so as to obtain a pulse width of 5 nanoseconds. Fig. 3 shows the response of the hyperboloid for the observation point with coodinates r = 100 m, $\theta = 5^0$, $\phi = 0^0$, calculated using the TD-UTD and TDPO for-mulations. For the sake of completeness these results are compared with a reference solution based on a frequency-domain MoM and transformed into the time-domain using an inverse fast Fourier transform (IFFT). The results show a good agreement between the techniques. The differences appear for the diffracted part of the scattered field. For these field components, TD-UTD results appear to be more accurate than those obtained by TDPO since the latter may predict erroneous currents near the reflector rim, thereby influencing the calculation of sidelobe levels. Also, since the pulse width is narrower than the reflector diameter, the reflector is only partially illuminated (as illustrated in Fig. 4 for the TDPO currents over the reflector at the instant when the pulse maximum impinges upon the reflector rim), which may also explain some discrepancies observed between TDPO and MoM + IFFT results for the diffracted pulses. The influence of frequency contents of different pulse waveforms, wich may impact on the comparative analysis with asymptotic methods, is presently under investigation.

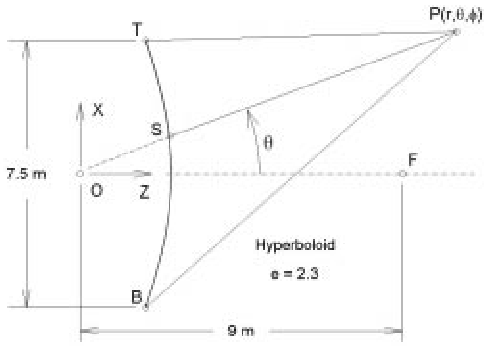

Fig. 1. Geometry of the hyperboloidal reflector.

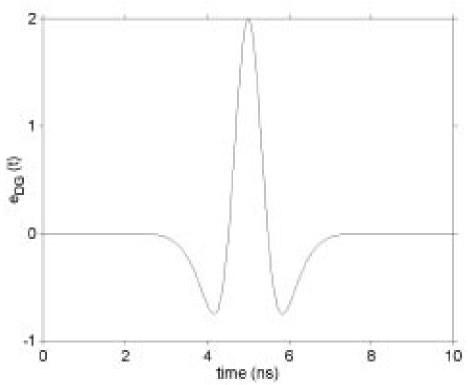

Fig. 2. Temporal behaviour of the incident pulse.

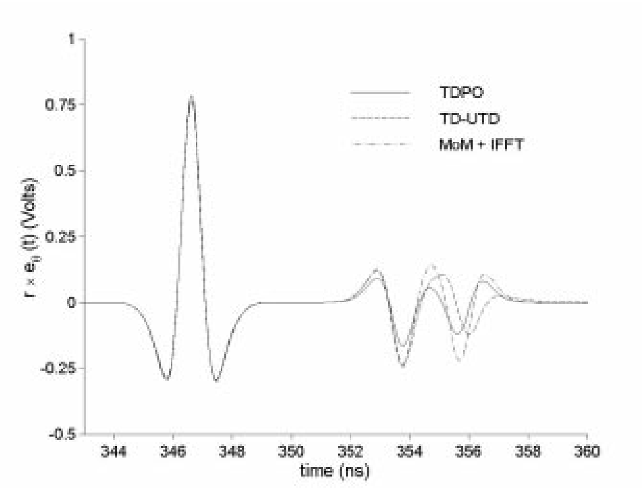

Fig. 3. Scattered field at r = 100 m, $\theta = 5^0$, and $\phi = 0^0$.

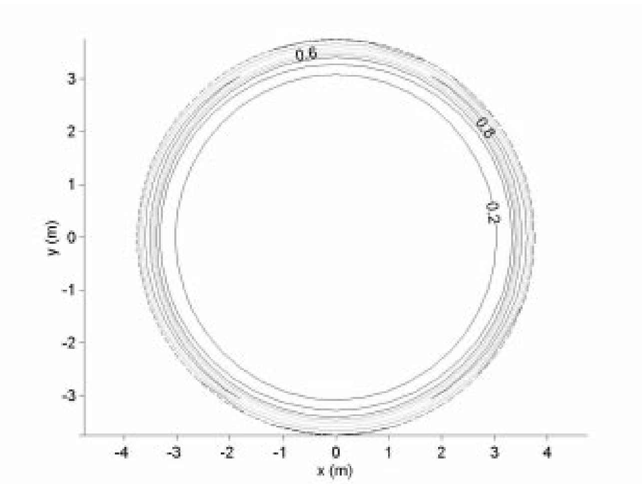

Fig. 4. TDPO normalized induced currents at the instant when the pulse maximum impinges upon the reflector rim (dashed line).

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