Comparison of 3D and 2D method to study the propagation in a U-shaped valley.

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***Abstract*—This paper presents 5 different electromagnetic methods, asymptotic and exact, in 3 dimensions and in 2 dimensions, to simulate the radiation of an antenna in a U-shaped valley. The precision of the result and the calculation time are compared for each method.**

***Index Terms*—Physical Optics, Propagation, 2D Methods.**

I. Introduction

Many tools have been developed in order to simulate the radiation pattern of an antenna. In order to reduce the calculation time, it is usually assumed that the antenna is in the free space. To model the propagation over terrain, on a large distance, a tool, based on the parabolic wave equation, may be used [1] and [2]. The pattern of the antenna in the free space would be used as an input of this tool.

Nevertheless, this approach may not be valid in some cases. Due to the paraxial approximation, the backscattered wave, reflected on the terrain, cannot be simulated. In order to solve this problem, a tool, based on asymptotic method, the Physical Optics (PO) method, has been developed. Results have been compared with Method of Moment (MoM) and Finite Difference Time Domain (FDTD).

In this paper the radiation of an antenna in a U-shaped valley is studied. Five methods are compared, in terms of calculation time and accuracy:

- 3D PO method
- 2D PO method
- 2D Iterative PO (IPO) method
- 2D MoM method
- 2D FDTD method

For these three methods, the radiated field is estimated at the end of the valley.

II. Description of the environemnt

A. Geometry of the valley

The geometry of the valley, illustrated on Figure 1, can be divided in 3 sections. The first section 50m large, where the antenna is located, is a transition between a plain and the valley. The second section, 80m large, is generated using a cosine function, extruded via a translation over 80m. The third section is generated using a 180° rotation of the cosine function. The valley is about 130m long, 100m large, 50m high. The ground is assumed to be perfectly conducting (this assumption is actually validated a posteriori in part III.E).

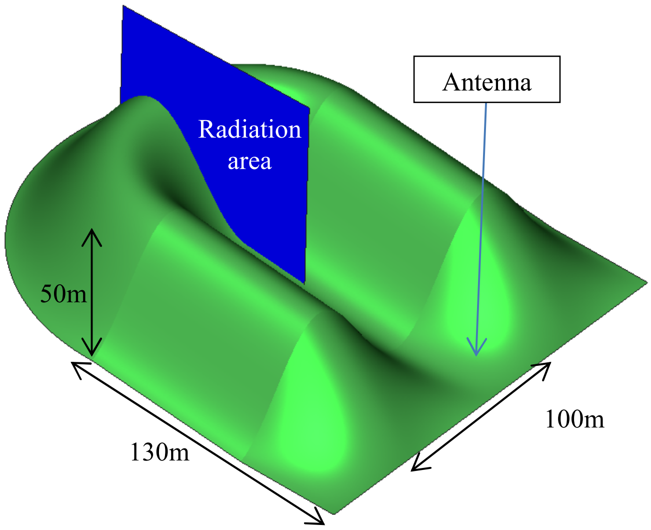

Figure 1: geometry of the valley

B. Antenna characteristic and radiation area

The antenna is 15m above the ground and is horizontally polarized. The operating frequency is 2GHz. The estimated gain is 7dBi.

The radiation area is at the end of the valley. It is a square 100m large. The sampling distance is 0.3m and there are about 111000 points of calculation. Since this sampling distance is about one wavelength, Moiré patterns may appear on the plots of the radiation area. Calculation times, except for the FDTD 2D method, are presented for a single processor, at 3GHz.

III. Simulation of the field at the end of the valley

A. Simulation with a 3D PO method

The valley is meshed using triangle faceted surfaces. On each triangle, an equivalent current, $\vec{J}_e$, is induced by the incident magnetic field, $\vec{H}_i$, using the formula:

$$\vec{J}_e = 2.\hat{n} \times \vec{H}_i \quad (1)$$

Where $\hat{\boldsymbol{n}}$ is the normal of the triangle surface.

The electromagnetic field, $\vec{E}(\vec{r})$, is finally estimated using these currents and the incident field radiated from the source $\vec{E}_i(\vec{r})$ (the time convention $e^{j\omega t}$ is omitted throughout the paper):

$$\vec{E}(\vec{r}) = \vec{E}_i(\vec{r}) + j\omega\mu\hat{e}_r \times \int_S G(\vec{r})\left(\hat{e}_r \times \vec{J}_e\right)e^{+jk.|\vec{r}|}dS \quad (2)$$

Where $\hat{e}_r$ is the direction of observation, $\vec{r}$ the relative coordinates of the surface element dS, k is the wave number and $G(\vec{r})$ is the Green's function:

$$G(\vec{r}) = \frac{e^{-jkr}}{4\pi r} \quad (3)$$

Typically, the edges of the triangles on the mesh are about λ/5 (where λ is the wavelength). In this case, it should correspond to 140 million facets. To reduce the memory space needed for the calculation, the edges of the triangle are about 5λ and the calculation of the integral, on each triangle, is performed over 100 points. This method aims to reduce the number of facets 1.4 million while keeping the same result.

About 60 hours are needed to get the result, depicted on Figure **2**:

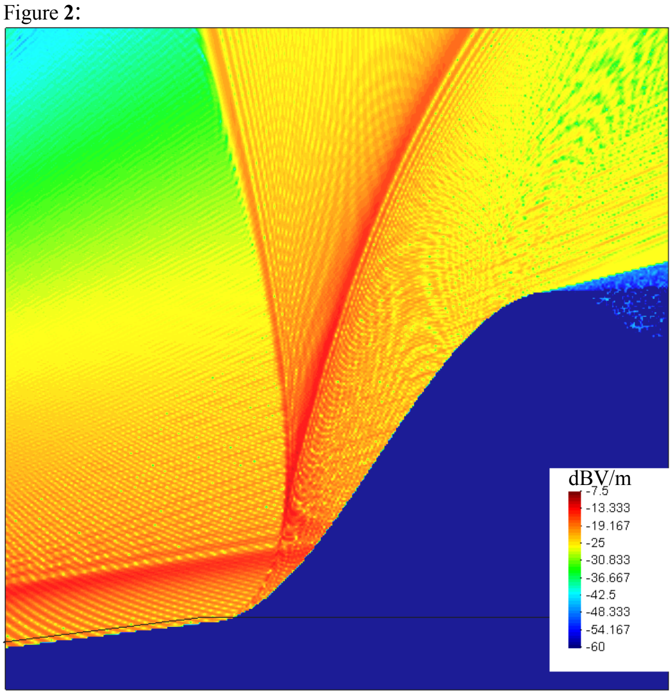

Figure 2 : radiation at the end of the valley, calculated using a PO 3D method (where $|\vec{\boldsymbol{E}}|_{dBV/m} = \boldsymbol{10log_{10}}\left(|\vec{\boldsymbol{E}}|_{V/m}\right)$

Due to the curvature of the valley, two caustic rays are generated, one before the hill, the other one reflected on the hill to the sky. It has to be noticed that the PO method cannot simulate double reflection. Therefore, the electromagnetic field reflected on the ground and then on the hill is not estimated.

B. Simulation with a 2D PO method

In order to reduce the calculation time, a 2D PO method has been developed (cf. [3]). It is based on the same equation, except the fact that the source is not spherical (meaning that the power is decreasing proportionally to *1/r²*) but cylindrical (meaning that the power is decreasing proportionally to *1/r*). For this reason, to compare the results, the decibel scale has to be divided by 2 in order to compare the same results. The Green's function in 2D has also to be modified as follows:

$$G(\vec{\boldsymbol{r}}) = \frac{1}{4j}H_0^2(kr) \quad (4)$$

Where H_0^2 is the zero-order second kind Hankel function.

The profile of the valley is meshed with 9000 segments which lengths are about λ/5.

About 2 minutes are needed to get the result, depicted on Figure **3**:

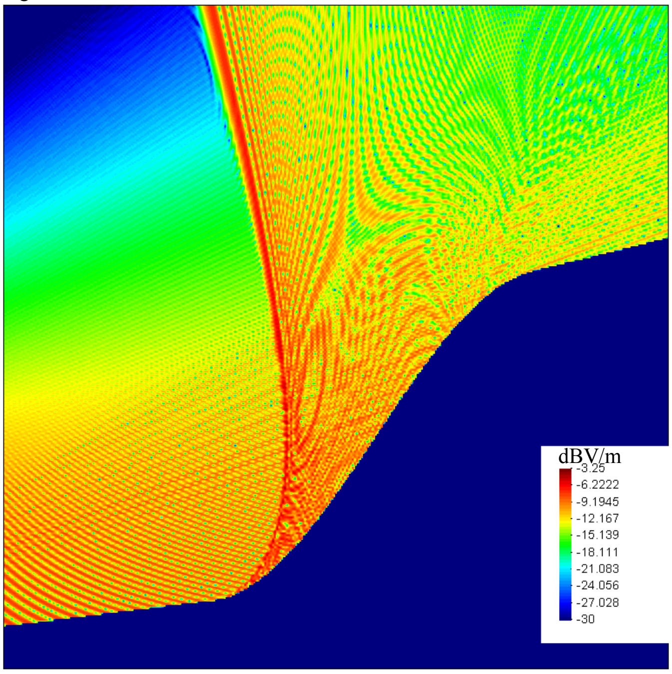

Figure 3: radiation at the end of the valley, calculated using a PO 2D method

This method provides the result much faster than the PO 3D method. However, it appears that two caustics are missing. Both of them are actually reflected on the border of the valley, in the 3D model.

C. Simulation with a 2D IPO method

The IPO method aims to take into account multiple reflections. At the first interaction, the incident magnetic field, in equation (1), is the one radiated from the source (same as PO method). At the second order, this magnetic field is the one radiated by the currents calculated at the first interaction on each segment. This process may be reproduced until the result is converging.

About 2 minutes are needed to get the result, depicted on Figure **4**:

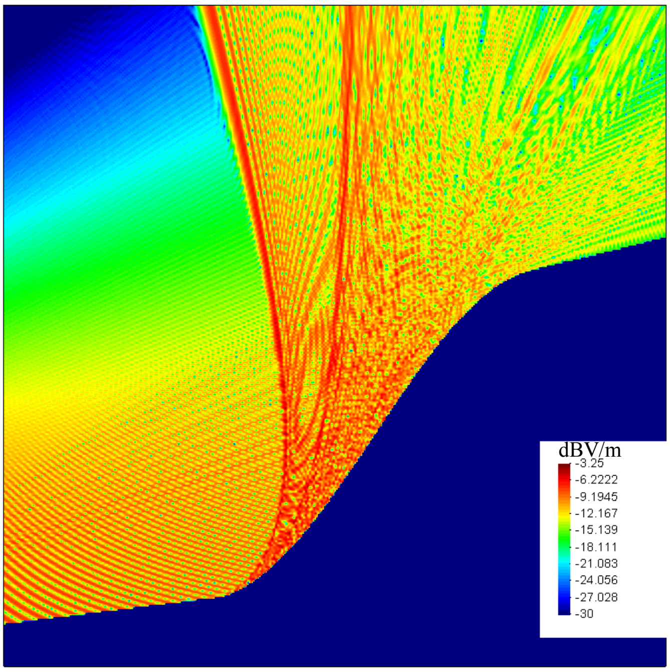

Figure 4: radiation at the end of the valley, calculated using a IPO 2D method

As expected, a new ray appears, it corresponds to the one reflected first on the ground and second on the hill, and finally propagates to the sky. The calculation time is almost the same as the one of the 2D PO method. The calculation time needed to estimate the current on the 9000 segments is actually negligible, as compared to the calculation time needed to estimate the radiation field at the 111000 sampling points. It could be significantly reduced, using a Graphics Processing Unit (GPU) as it has been demonstrated in [4].

D. Simulation with a 2D MoM method

To validate the asymptotic methods, two exact methods have been used. The first one is the 2D MoM methods (cf. [5]). For this method, the estimation of the current on the segments may be critical due to the impedance matrix inversion. In this case, there are only 9000 segments. This calculation time remains also negligible, as compared to the calculation time needed to estimate the radiation field at the 111000 sampling points.

About 2 minutes are needed to get the result, depicted on Figure **5**:

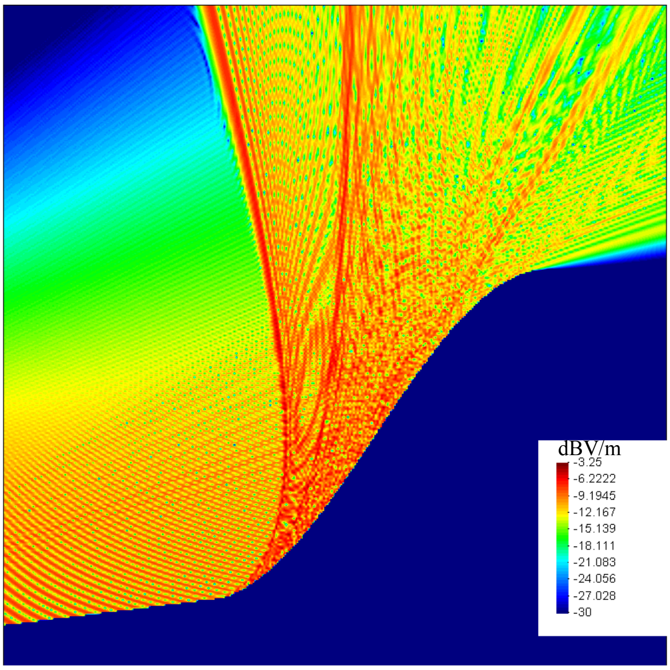

Figure 5: radiation at the end of the valley, calculated using a MoM 2D method

The result obtained with 2D MoM method and the one obtained with the 2D IPO method are very similar. This validates the asymptotic method. Nevertheless, if the levels of the electromagnetic field are below -30dBV/m, the results won't be the same in the shadow region.

E. Simulation with a 2D FDTD method

The second exact method used is based on a FDTD 2D method, which is freely available [6]. It uses a GPU. For this method, the dielectric properties of the valley have been considered (ε_r=15 and σ=10^{-3} S/m). The result, depicted on Figure **6**, shows similar results to the MoM 2D, which means that the assumption on a perfectly conducting terrain was realistic.

For this simulation, the radiation zone is smaller, 60m high. On the other hand, the sampling distance of the grid used to calculate the propagation of the electromagnetic field, for this FDTD method, has been reduced to λ/5 that is 0.03m.

On the GPU, a Nvidia GeForce GTX 750 Ti, about 4 minutes are needed to get the result, depicted on Figure **6**:

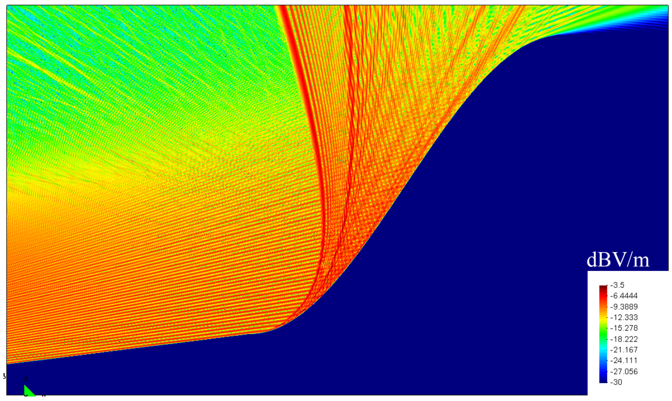

Figure 6: radiation at the end of the valley, calculated using a FDTD 2D method

The Moiré patterns don't appear anymore, due to the reduced sampling distance. For this method, the mesh, which is about λ/5, is too coarse. This explains the numerical noise on the left of the picture. However, the solution consisting in reducing the mesh size, would be limited by the GPU memory.

IV. Conclusions

The radiation of an antenna in a U-shaped valley has been studied using different methods. A 3D asymptotic method aims to get good results, but needs a long computation time, while 2D methods are faster. The result obtained with the asymptotic method IPO are very similar with those obtained with the exact methods (MoM and FDTD) in the area where the field is reflected.

A 2D exact method and a 3D asymptotic method are complementary. The first one aims to have a fast result on the main axis of the beam antenna, while the second one provides a good idea on the effect of the environment around this main axis.

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