FOPEN SCENE GENERATION USING NUMERICAL ELECTROMAGNETIC ANAYLSIS

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Introduction

This paper reports on attempts to build *realistic* FOPEN simulation capabilities by modeling radar scenes of interest using numerical electromagnetic analysis. The numerical solution allows us to accurately model the signal, foliage and interaction between foliage and target.

Foliage penetration (FOPEN) radar, operating mainly in the VHF and UHF bands, can potentially locate and identify strategic targets hidden under trees. The practical development of FOPEN requires extensive research into almost all aspects of radar including antennas, platforms, signal processing, target identification, etc. In other research areas, *simulations* play an important role. While some simulations make idealizing assumptions that may not be valid in practice, they provide an excellent vehicle to develop, test and validate new concepts quickly and cheaply. Clearly, the goal of good simulations is to be as realistic as possible. An excellent example of this is Space-Time Adaptive Processing (STAP) where realistic models are available for targets, clutter and interference. Using these models many researchers have developed many varied STAP concepts based almost entirely on simulations [1].

The parallel development of FOPEN simulation capabilities would significantly speed up the development and understanding of related concepts. Preliminary attempts in this regard have modeled the return signal as a sum of the target and foliage signals. STAP simulations use a similar approach where the return signal is the sum of target, interference, clutter and noise signals. The target signal is attenuated to model propagation loss through the foliage or to set a signal-to-noise ratio. FOPEN Synthetic Aperture Radar (SAR) algorithms are then applied to the total return signal.

There is one important problem with the current simulation paradigm. The models ignore the crucial fact that what makes FOPEN difficult is that the targets are hidden, but also that the target signals *interact* with the surrounding foliage. The modeling of the return signal as the sum of target plus interference ignores this interaction. It is extremely difficult, from a simulation point of view, to model this interaction. This is because the interaction between the target and its environment is an electromagnetic phenomenon with the target in the *near field* of the foliage. The true return signal is the solution to Maxwell's equations for the given radar scene. This solution would account for the signals returned by the target, the foliage *and* the interaction between target and signal. Unfortunately, it is impossible to find a closed form solution for any practical FOPEN situation. In fact, there are very few practical situations where a closed form solution to Maxwell's equations is available.

To overcome the problem of finding closed form solutions, the electromagnetics community uses *numerical* solutions to Maxwell's equations. In general, radiation problems such as radar systems are analyzed using the Method of Moments (MOM) [2]. The MOM numerical solves the integral form of

Maxwell's equations with all objects replaced by equivalent currents on their surface. Metallic objects are replaced by equivalent electric currents, while dielectric objects are replaced by equivalent electric and magnetic currents.

The use of MOM based approaches poses significant challenges. In general, MOM techniques subdivide the analysis region, with about 10 subdivisions for each wavelength (λ) or 100 subdivisions per λ^2. This problem is worsened by the fact that any FOPEN radar scene must include dielectrics. While targets may be largely metal, the foliage is not. The surface of dielectrics must be discretized in terms of the wavelength within the dielectric, $\lambda_d = \lambda/\sqrt{\varepsilon_r}$. Here ε_r is the relative permittivity of the dielectric. Each subdivision represents at least one unknown. Dielectric discretizations require unknowns for both electric and magnetic currents. The overall analysis results in a matrix equation whose size is the total number of unknowns. Since a practical FOPEN radar scene of interest may cover several thousands of λ^2, the total unknowns could be in the hundreds of thousands. Evaluating, storing and processing such a large matrix equation is clearly not feasible. Another major challenge is that FOPEN requires broadband information, covering most of the VHF and UHF frequency ranges. In numerical EM analyses, each frequency of interest must be independently analyzed, worsening an already difficult problem.

The above discussion motivates the use of an extremely *efficient* EM analysis tool. One solution is to move away from the traditional MOM approach of fine discretizations. A recent proposal has been to use coarse discretizations with complex basis functions [3]. The computation load is significantly reduced, replaced by increased theoretical complexity associated with the more complex basis. Research has shown that only 20 unknowns/λ^2 suffice. This approach has recently been implemented in a commercially available EM analysis package WIPL-D [4]. This package allows the user to easily and efficiently analyze complex structures comprising both metals and dielectrics.

Examples

In this summary, we present our *initial* results in WIPL-D based FOPEN simulations. The WIPL-D program is used to evaluate the frequency response of the radar scene. The frequency response is multiplied with the spectrum of the excitation signal, here a linear FM pulse, followed by an inverse-FFT to obtain the return time domain signal. In these examples, the WIPL-D program is run at every Δf = 1MHz, i.e. the total time period that can be determined in the inverse-FFT is

$$\Delta t = 1/\Delta f = 1\mu s.$$

The WIPL-D program is run over the bandwidth of interest. The frequency response was zero-padded in the region 0-512 MHz. The inverse-FFT therefore provides 512 time samples within the 1μs time frame. To simulate the synthetic aperture the direction of incident field was changed to match the angles associated with each aperture location. The return field, i.e. the frequency response of the radar scene, was evaluated using the ‘near-field’ option. The program provides *x*, *y*, and *z* components of the return field. These components are transformed to q and f components. The incident field was chosen to be in the f direction and so the f-component of the return signal was chosen for further processing.

The first example tests the concept of using an EM analysis program to simulate a SAR return signal. This example comprises a single metallic plate. The plane flies at a height of 500m and the plate is located 500m from the aircraft path in cross-range. The synthetic aperture is symmetric about the plate location, with a total aperture of 180m. The spacing between the aperture points is determined by the resolution formula given in [5]. The backprojection image reconstruction algorithm of [5] is used. The dimensions of the plate are 3m $\times$ 3m. Figure 1 shows the reconstruction of the image of the plate. The SAR signal is a linear FM pulse spanning 100-200 MHz, i.e. a bandwidth of 100MHz. The plate appears at the correct location and has the correct dimensions. A few image sidelobes in cross range are visible.

The second example uses two small metallic plates, as shown in Figure 2, spaced by 12m. The transmitted signal is modeled as an incident plane wave. This example uses a linear FM bandwidth of 120MHz (100-220MHz). The two plates are clearly seen. However, what makes this picture particularly interesting is the artifact in between that arises from multiple reflections between the plates. The ability to model these multiple reflections and produce realistic images, including artifacts, that makes using numerical electromagnetic analyses particularly relevant for FOPEN simulations. The realistic data generated using such simulations can trigger intensive research and development activities for the practical development of foliage penetration radar.

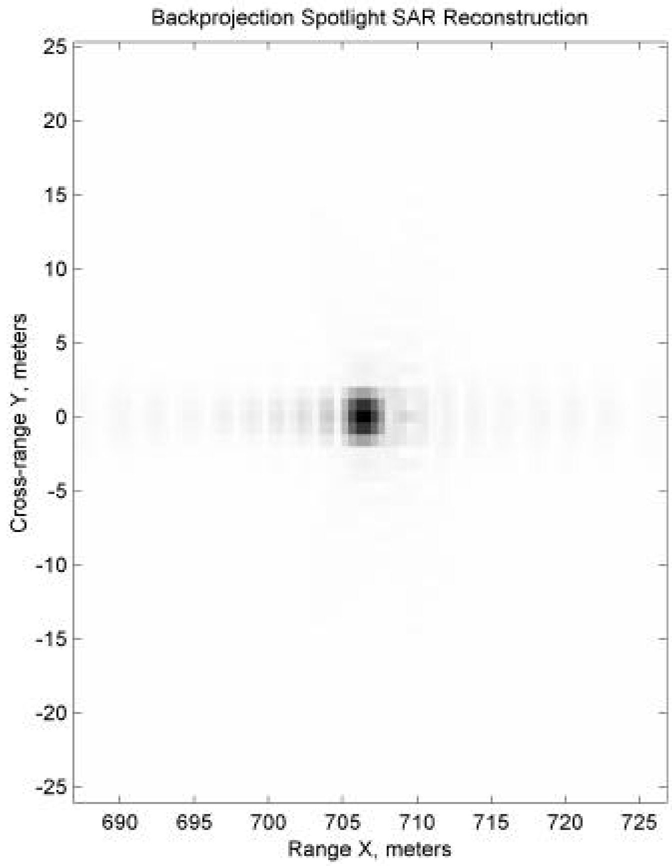

Figure 1: SAR image reconstruction using WIPL-D Data

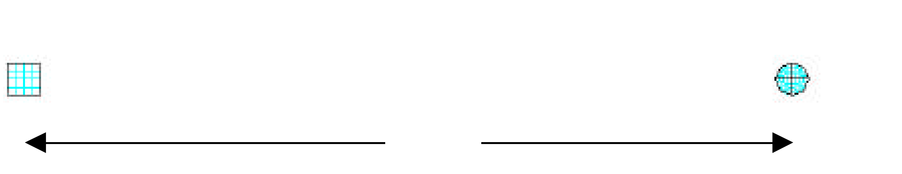

Figure 2: A Simple SAR scene

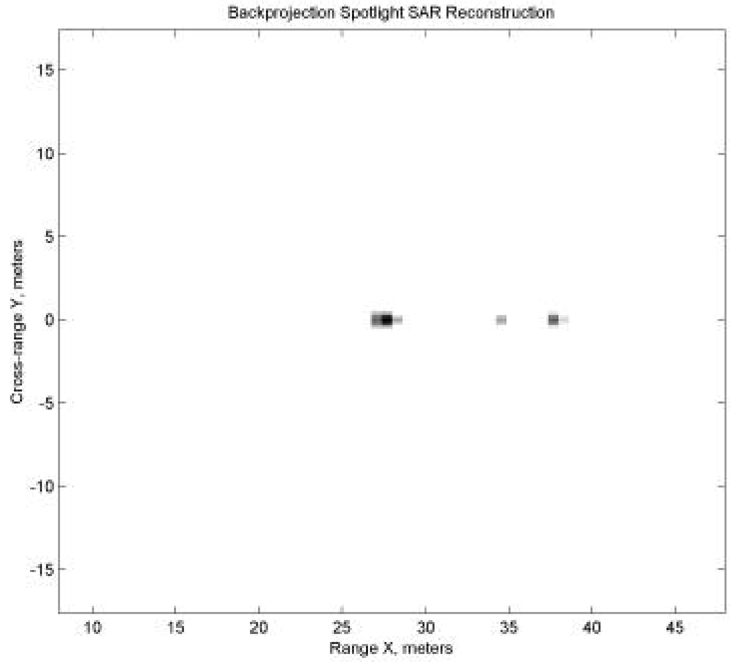

Figure 3: SAR Image Reconstruction for two plates

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