Depolarization of Electromagnetic Waves from Bare Soil Surfaces

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Summary. An improved Two Scale Model (TSM) has been investigated for the depolarization of electromagnetic waves from bare soil surfaces. The calculations are made by assuming exponential correlation function. The performance of the new TSM is assessed by comparing the simulation results in backscattering configuration with the published experimental data at L-, C- and X-band frequencies for two roughness conditions. Finally, we use the new TSM to predict the bistatic scattering and compare the results with classical TSM and second order small perturbation method.

1 Introduction

Depolarization in a radar return results in a corruption of the desired signal. It is an undesired effect for a given transmitter, limiting the useful radar coverage distance. However, the cross-polarization in conjunction with co-polarization information can be used to retrieve the surface roughness parameters (e.g., root mean square (rms) of surface height, correlation length, autocorrelation function and soil moisture content etc.), the geometrical configuration of scatterers while giving important clues to the electrical properties of surfaces etc.. Hence the study of depolarization can not be used to discriminate unwanted reflections only but it is also used for the identification and optimization purposes and it permits deeper insight into physical phenomena. Hence cross-polarized radar returns are of interest to some EMC engineers, hydrologists, meteorologists and agriculturists.

Cross polarization in a radar return from a rough surface [1]- [2] has been observed experimentally. First order Small Perturbation Method (SPM1) [3] and Kirchhoff Approximation (KA) [4] does not predict this phenomenon. In order to account for observed cross polarization most theoreticians have used the methods of (AIEM), Second order Small Slope Approximation (SSA2), Second order Small Perturbation Method (SPM2), Two Scale Model (TSM) and Empirical models etc. In the classical TSM it is assumed that the short wavelength waves are riding on the larger waves and thus tilted with respect to the horizontal surface [5]. It uses SPM1 at small scale i.e. for short wavelength waves and the effect of long wavelength part is taken into account by averaging over tilt angles. Hence by using the classical TSM based on first order theory, depolarization is basically due to the tilt of reflecting plane. Hence the simple TSM needs to be improved.

Since the mechanism of multi-scattering due to target surface roughness also causes depolarization, so we consider the contribution of higher (upto second) order scattering calculations at small scale and develop an improved TSM [6] . In this paper we assume that the bare soil surface can be modeled as having two average sizes of roughness, this model is then applied to depolarization case. In backscattering configuration, we assess the performance of this improved model by comparing the numerical results with experimental data [7]. Finally, the simulation results for bistatic case are presented and compared with SPM2 and classical TSM.

2 Mathematical Models

This section contains a brief review of SPM up to second order and an improved two scale model is presented afterwards.

The scattering of electromagnetic waves from a slightly rough surface can be studied using SPM. It assumes that the surface variations are much smaller than the incident wavelength and the slopes of the rough surface are relatively small. By using extended boundary condition method, the first and second order bistatic scattering coefficient σ_{pq} as a function of the transmitter polarization q and receiver polarization p is given by

$$\sigma_{pq}^{(1)} = 16\pi \left| k^2 \cos\theta_i \cos\theta_s \alpha_{pq}^{(1)} \right|^2 W\left(k_{s\perp} - k_{i\perp}\right) \quad (1)$$

$$\sigma_{pq}^{(2)} = 4\pi k^6 \cos^2\theta_i \cos^2\theta_s \int dk_\perp \left[W\left(k_{s\perp} - k_\perp\right) W\left(k_\perp - k_{i\perp}\right) \alpha_{pq}^{(2)} \left(\alpha_{pq}^{*(2)} + \beta_{pq}^{*(2)} \right) \right] \quad (2)$$

where $k_\perp = k_x\mathbf{x} + k_y\mathbf{y}$ denotes vector in (x-y)-plane, $W\left(k_{s\perp} - k_{i\perp}\right)$ is the spectrum and $\alpha_{pq}^{(1)}$, $\alpha_{pq}^{(2)}$, $\beta_{pq}^{(2)}$ are the first and second order polarization dependent coefficients respectively. Since for backscattering case $\alpha_{hv}^{(1)} = \alpha_{vh}^{(1)} = 0$, the knowledge of $\alpha_{pq}^{(2)}$ and $\beta_{pq}^{(2)}$ can be beneficial to estimate exact depolarization scattering coefficients.

The classical TSM postulates that the surface roughness can be split into two scales: a large and a small with the incident electromagnetic wavelength. The scattering coefficients are estimated in two steps. Firstly, the classical TSM uses SPM1 on small scale waves and then determines the diffuse component in the global reference by a tilting process.

We have proposed an improved TSM by adding the SPM2 correction to SPM1 at local scale i.e.,

$$\begin{cases} \sigma_{p'q'} = \sigma^{(1)}_{p'q'} + \sigma^{(2)}_{p'q'} \\ \sigma_{p'q'm'n'} = \sigma^{(1)}_{p'q'm'n'} + \sigma^{(2)}_{p'q'm'n'} \end{cases} \tag{3}$$

The complete method and detailed derivation will be given in final paper.

3 Numerical Results

In this section, initially we illustrate the numerical simulation results of the cross polarized backscattering coefficient (σ_{hv}) at L-, C- and X-band frequencies with exponential correlation function. Exponential correlation function is appropriate since the surfaces with exponential correlation functions have fine-scale features that are more irregular than that of Gaussian correlation function and appear to match experimental data much better than Gaussian correlation functions. To evaluate the model performance, we compare the theoretical predictions by improved TSM with experimental data [7], SPM2 and classic TSM.

Figure 1 shows the angular dependence of σ_{hv} at 1.5 GHz (L-band) frequency. The rms height of the bare soil surface is 0.4 *cm* and correlation length is 8.4 *cm*. The value of relative dielectric constant is taken as 15.57 [7].

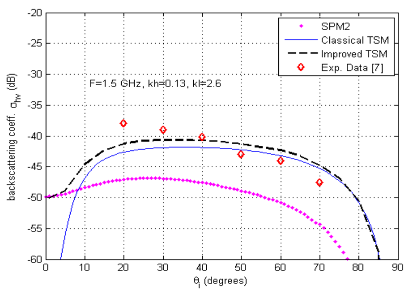

Fig. 1. Comp. of Improved TSM with experimental data [7], SPM2 and classic TSM at L-band.

Similarly, Figs. 2 and 3 shows the comparisons between improved TSM and above listed models at 4.75 GHz (C-band) and 9.5 GHz (X-band) frequencies respectively. The rough surface is same as chosen in Fig. 1, while the values of relative dielectric constants are taken as 15.42 and 12.31 respectively. Figures 1, 2 and 3 shows that the contribution of second order scattering at small scale improves the results as

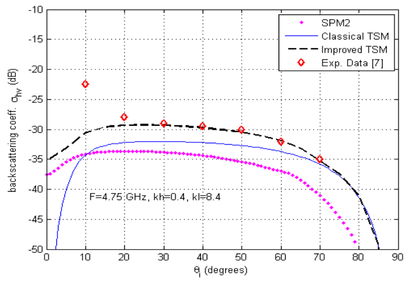

Fig. 2. Comp. of Improved TSM with experimental data [7], SPM2 and classic TSM at C-band.

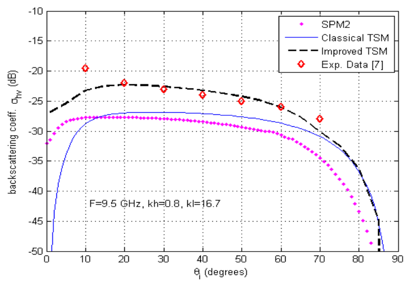

Fig. 3. Comp. of Improved TSM with experimental data [7], SPM2 and classic TSM at X-band.

frequency increases and the predictions by improved TSM shows good agreement with experimental data.

In the final paper, we will present the results by improved TSM and its comparisons with other models at three frequencies for another roughness level. Finally, we will also provide the predictions by improved TSM for a bistatic case.

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