Research on the Reflection Coefficient of Magnetic Medium in the Time-domain Ray Tracing Method

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Abstract

The time-domain ray tracing method (TD-RTM) is an important method for studying the multipath propagation of ultra-wideband (UWB) electromagnetic wave. According to the time-domain(TD) reflection coefficient of non-magnetic dielectric , we derived the time-domain reflection coefficient of the magnetic medium when electromagnetic wave is obliquely incident, for both vertical polarization and horizontal polarization. In order to prove the validity of the derived formula, we compared the time-domain solution with the inverse fast Fourier transform (IFFT) of the frequency domain (FD) solution, and the result revealed very good consistency. The derived formula is of great significance for studying the propagation characteristics of ultra-wideband electromagnetic wave in complex environment by using time-domain ray tracing method.

Analysis and Results

A. Formula derivation

After a series of derivations based on frequency domain Fresnel reflection coefficients, the time domain reflection coefficients of the magnetic medium surface is obtained as follows:

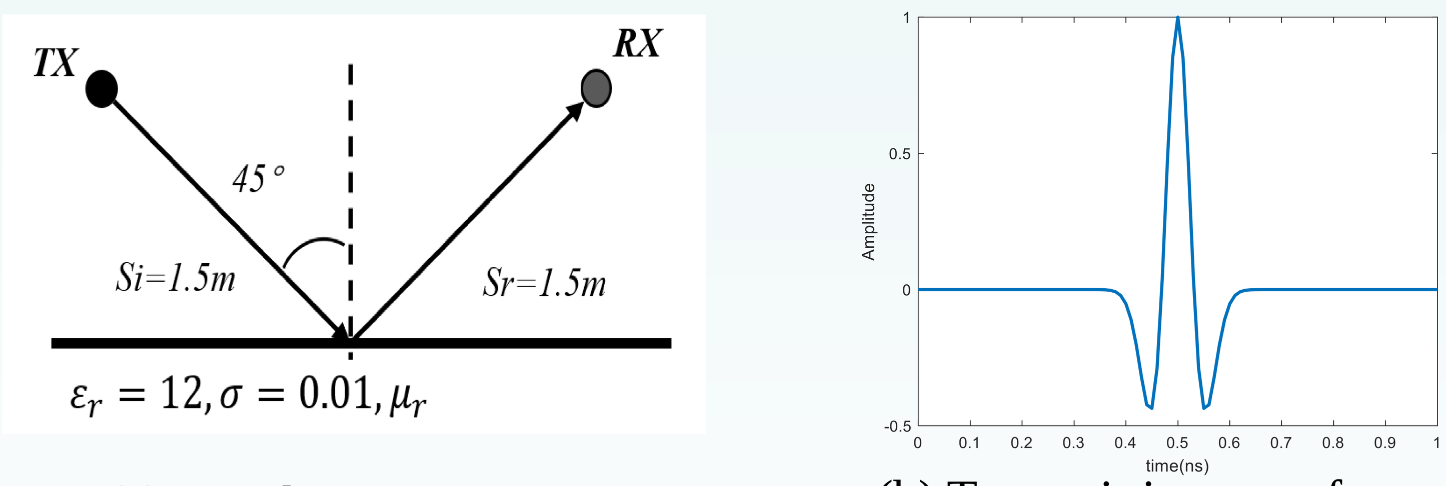
$$r(t) = \pm\left[K\delta(t) + \frac{e^{-at}}{t}\frac{4\kappa}{1-\kappa^2}\sum_{n=1}^{\infty}(-1)^{n+1}nK^nI_n(at)\right]$$

For both horizontal polarization and vertical polarization, there are: $v = \frac{120\pi\sigma c}{\varepsilon_r}$, $\zeta = \frac{v}{1-\frac{cos^2\phi}{\varepsilon_r\mu_r}}$, $K = \frac{1-\kappa}{1+\kappa}$, the remaining parameters are as follows:

$$\begin{cases} \kappa = \xi \ and \ \ a = \frac{v}{2}, \frac{cos^2\phi}{\mu_r\varepsilon_r} \ll 1, \xi = \frac{\sqrt{\mu_r\varepsilon_r - cos^2\phi}}{\varepsilon_r sin\phi} for\ hp \\ \kappa = (\xi\varepsilon_r)^{-1} \ \ and \ \ a = \frac{\zeta}{2}, \xi = \frac{\sqrt{\frac{\varepsilon_r}{\mu_r} - \frac{cos^2\phi}{\mu_r{}^2}}}{\varepsilon_r sin\phi} for\ vp \end{cases}$$

B. Verification and Analysis

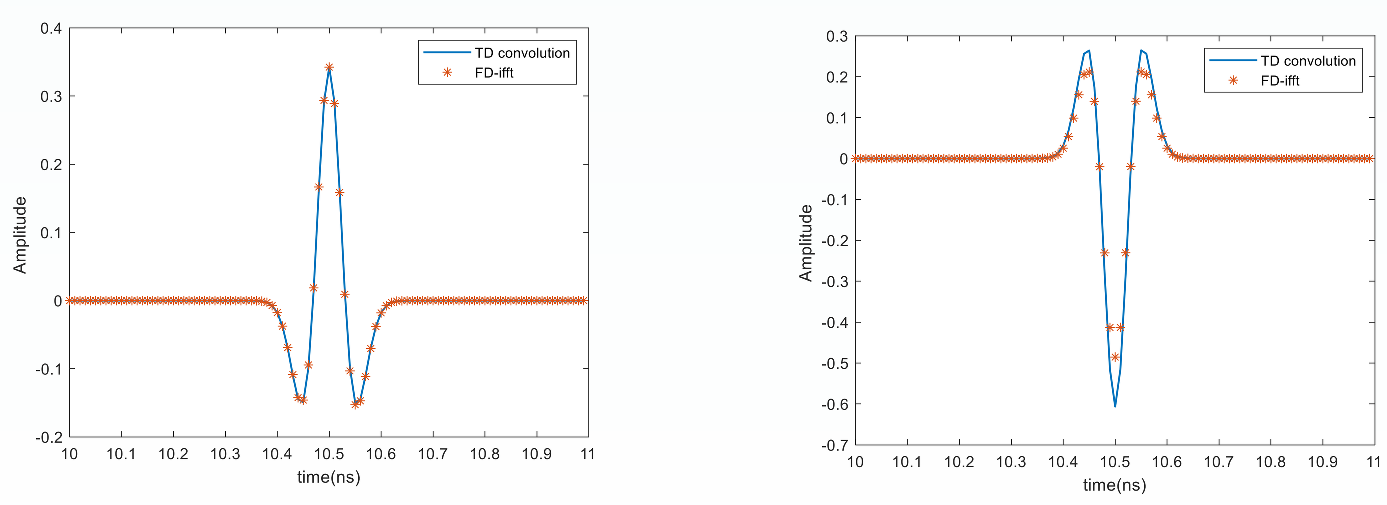
In order to verify the correctness of the time domain reflection coefficient expression deduced above, the time domain pulse is first processed by FFT and multiplied by FD reflection coefficients and then the IFFT is performed. Contrast this with the result of convolution using the TD reflection coefficients. The simulation structure and transmitting waveform are shown in the figure below.



(a) Simulation structure (b) Transmitting waveform

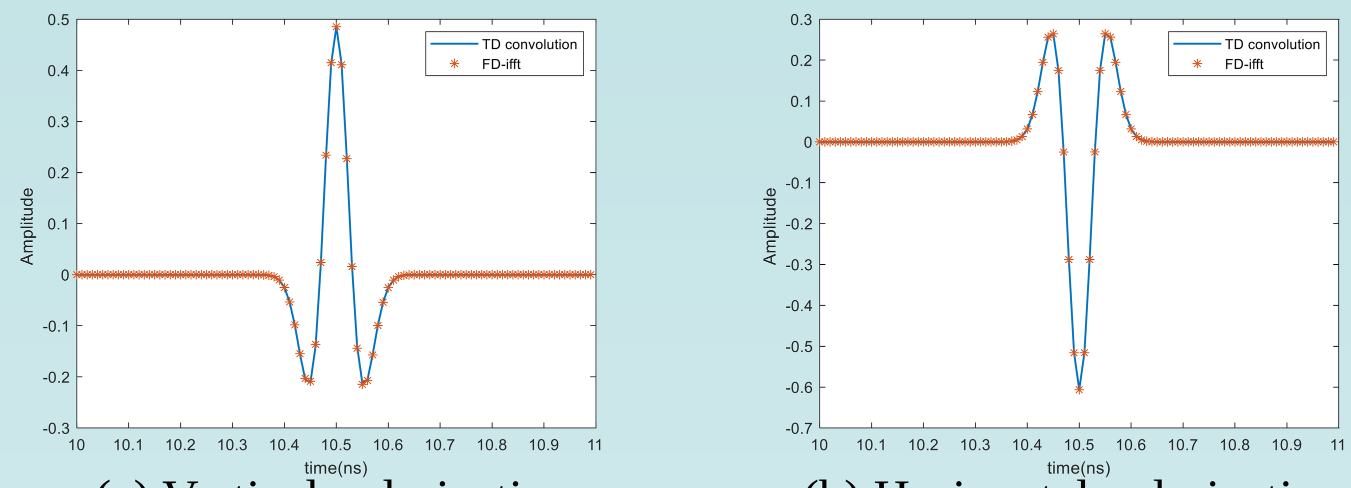
Fig. 1.Simulation structure and transmitting waveform

The comparison results is shown in figures below.



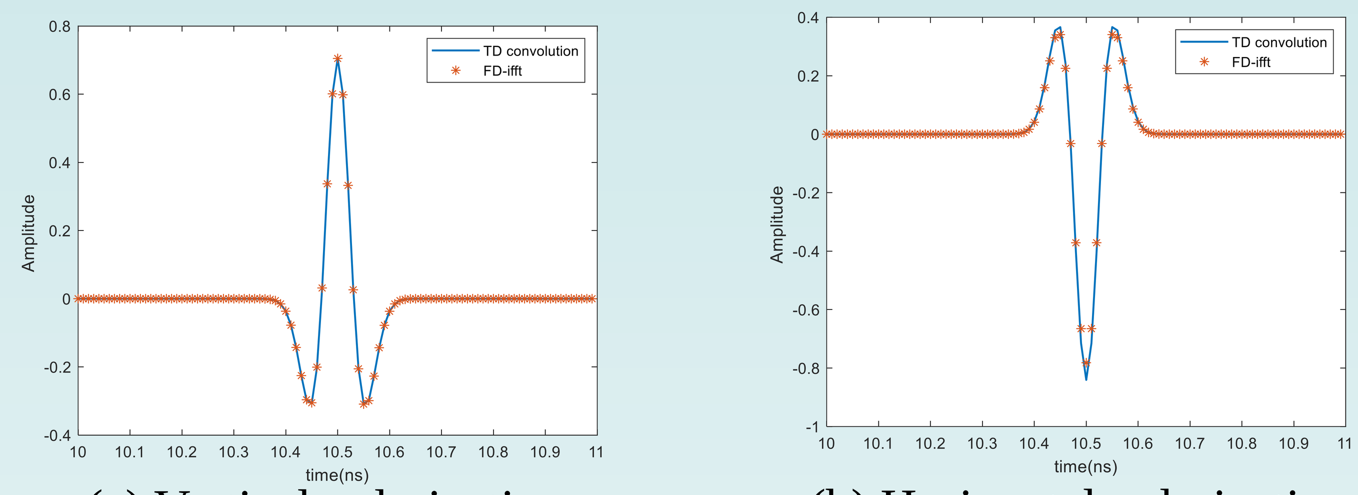
(a) Vertical polarization (b) Horizontal polarization

Fig. 2. Comparison results with $\mu_r = 100$



(a) Vertical polarization (b) Horizontal polarization

Fig. 3. Comparison results with $\mu_r = 400$



(a) Vertical polarization (b) Horizontal polarization

Fig. 4. Comparison results with $\mu_r = 800$

We calculated the root mean square error (RMSE) of the above comparison figures, and the results are shown in the table below.

TABLE I. RMSE OF COMPARISON RESULTS

μ_r	RMSE	
	Vertical polarization	***Horizontal polarization***
100	0.0012	0.0246
200	0.0010	0.0199
800	0.00067	0.0119

From the comparison results of the above figures and table , it can be seen that both vertical polarization and horizontal polarization, the convolution results by TD reflection coefficient are quite consistent with the results of FFT multiplying FD reflection coefficient and IFFT, which verifies the correctness of the previous derived time domain reflection coefficient expression.

CONCLUSION

This paper derives the TD reflection coefficient of magnetic media on the basis of the TD reflection coefficient of non-magnetic dielectric, and compares it with the results of frequency domain IFFT to verify the correctness of the derived formula. It is of great significance for using TD-RTM to study the propagation characteristics of ultra wideband electromagnetic wave in complex environment.