TIME-FREQUENCY ANALYSIS OF RADAR TARGET ECHO BY USING WAVELET TRANSFORM

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1. INTRODUCTION

Time-frequency analysis of radar target echo by using wavelet transform[1] or short-time Fourier transform[2],[3] is attracting a great deal of attention, because it can provide more information about scattering mechanisms which are contained in target echo. Compare with the short time Fourier transform, wavelet transform seems to be a useful tool, because it has multi-resolution property in time or frequency domain whereas the short time Fourier transform has uniformly fixed resolution. In this paper, we analyze the radar echo from targets by using the wavelet transform. As the targets, we consider 2D open-ended parallel plate waveguide cavity and rectangular cavity in the underground.

2. WAVELET ANALYSIS

In order to extract the target information from the radar echo, we introduce the continuous wavelet transform of frequency response data $F(\omega)$ as follows:

$$W(a, b) = \int_{-\infty}^{\infty} F(\omega) \, \Psi_{a,b}^{*}(\omega) \, d\omega \tag{1a}$$

$$\Psi_{a,b}(\omega) = \frac{1}{\sqrt{a}} \Psi\left(\frac{\omega - b}{a}\right) \tag{1b}$$

where $\Psi(\omega)$ is the mother wavelet, and $\Psi_{ab}(\omega)$ is the element of the wavelet set that is a scaled and translated mother wavelet. The scale parameter a and shift parameter b are correspond to the reciprocal of time and frequency, respectively. It should be noted that in Eq.(1) the wavelet transform is applied to the frequency domain data, contrary to its usual application to the time domain data. The reason for this is that the wavelet transform of frequency domain data is suitable for the analysis of target echo, because the multi-resolution capability of wavelet analysis in the frequency domain is available. This advantage is reported in detail by H. Kim and H. Ling[1]. For convenience, we transform the frequency domain integral of Eq.(1) into time domain integral by using the Fourier transform as follows:

$$W(a, b) = 2\pi \sqrt{a} \int_{-\infty}^{\infty} f(t) \ \psi(at) \ e^{-jbt} dt$$
 (2)

where

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) \, e^{j\omega t} d\omega \qquad \qquad \psi(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \, \Psi(\omega) \, e^{j\omega t} d\omega \qquad (3)$$

and f(t), which is the inverse Fourier transform of $F(\omega)$, is the time response data. It is found, from Eq.(2), that the wavelet transform of frequency domain data $F(\omega)$ is obtained by the window Fourier transform of time domain data f(t) with window function $\psi(at)$. Therefore, we calculate the time domain data instead of frequency domain data, and carry out the integral of Eq.(2) by using the FFT.

3. NUMERICAL EXAMPLES AND DISCUSSIONS

As the objects we consider a 2D open-ended parallel plate waveguide cavity and a rectangular cavity in the underground. In order to get the time domain responses, we employ the FDTD method combined with PML absorbing boundary condition [4]. The mother wavelet $\Psi(\omega)$ is chosen to be a Gaussian wavelet (Gabor function) which is known to have the least spread in both time and frequency domain. Figure 1 shows the open ended parallel plate waveguide cavity and backscattering pulse response from it. The time axis is normalized by τ which is the transit time of the pulse for unit length. As the input pulse we choose the TDG(three-times differentiated Gaussian) pulse. The time-frequency representation of frequency response obtained by Eq.(2) is shown in Figure 2(a). Since the wavelet transform has good time resolution in early time, the multiple scattering phenomenon between two edges is clearly observed. The paths of multiple scattering corresponding ① - ④ indicated in this figure are illustrated in Fig.2(b). In the late time, the wavelet transform has good frequency resolution and it provides accurate resonance frequencies. Figure 3 shows a rectangular cavity (air gap) in the underground and backscattering pulse response from it. The ground is assumed to be loss-less and refractive index N is 5. The time-frequency representation of frequency response is shown in Figure 4. In the early time, reflections from the ground surface and the cavity surface are clearly observed. In the late time, two typical resonances of this structure are observed: one is (i) resonance between ground surface and upper wall of the cavity, the other is (ii) resonance inside the cavity. The sharp horizontal lines correspond to the resonance (i), and blocks that include four horizontal lines correspond to the resonance (ii).

Consequently, we can confirm that the wavelet transform is very suitable for the analysis of radar target echo, because it has good time-resolution in early time and good frequency-resolution in late time.

4. CONCLUSIONS

We have analyzed the radar echo from targets by using the wavelet transform. As the numerical example, we examined the radar echo from 2D open-ended parallel plate waveguide cavity and rectangular cavity in the underground. From the numerical results, it was confirmed that the multi-resolution property of wavelet transform is very useful for extracting the information of the target from the responses.

REFERENCES

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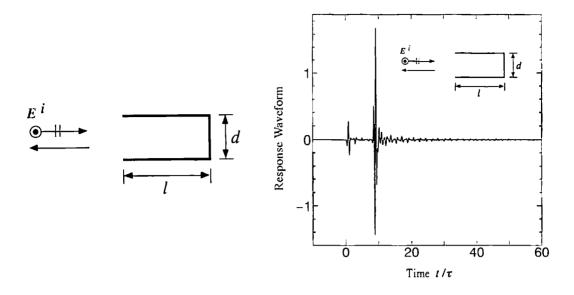


Figure 1. Open ended parallel plate waveguide cavity and backscattering pulse response from it. (d l l = 1/2, E-polarization,)

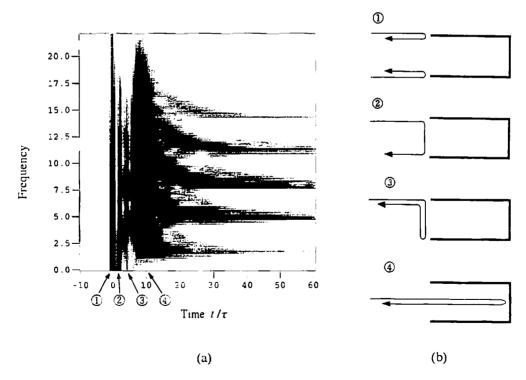


Figure 2. Time-frequency representation of frequency response from the open ended parallel plate waveguide cavity. (a) Time-frequency representation of frequency response obtained by Eq.(2). (b) Paths of multiple scattering.

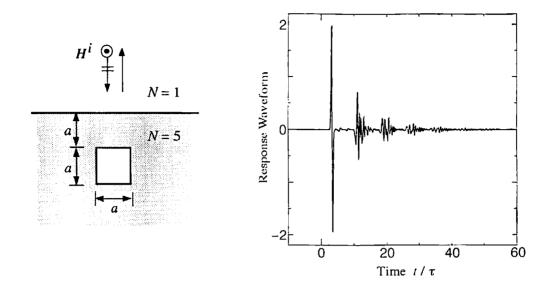


Figure 3. Rectangular cavity (air gap) in underground and backscattering pulse response from it. The ground is assumed to be loss-less and refractive index N is 5.0. (H-polarization)

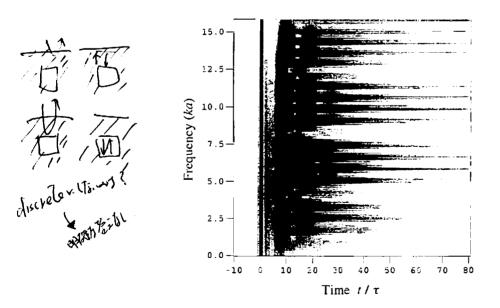


Figure 4. Time-frequency representation of frequency response from the rectangular cavity in underground.