Short pulse detection of objects behind obscuring random layers

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I. Introduction

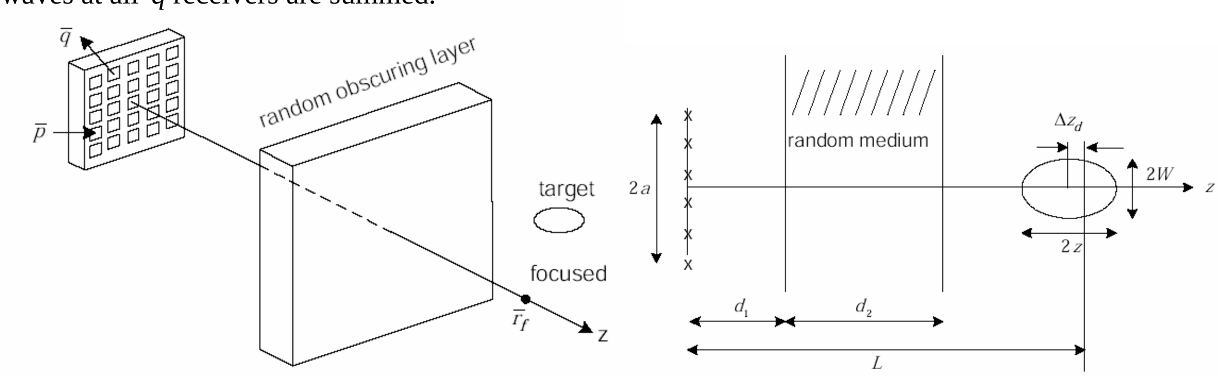
Detection of an object behind obscuring layers is one of the important problems today as it is applicable to numerous practical problems such as detection of hidden objects, mine detection, and imaging through scattering biological media. It has been noted that a short pulse which penetrates through obscuring layers may be scattered by the layers and the object. Then, the received signal scattered from the object and from the layers can be separated in time, and therefore, detection of the object hidden behind the scattering layer may be possible.

However, this method requires the study of the interaction of a short pulse with random media. Theoretically, this requires the study of pulse wave scattering and propagation in random media, and the development of the generalized two-frequency mutual coherence function. In this paper, we investigate this detection and imaging problem. The formulation is based on the use of the forward and backward stochastic Green's functions from a square array of transmitter and receiver elements. The second moments of the received signal include the fourth moments which are reduced to the second moments by the use of the circular complex Gaussian assumption. We make use of a focused aperture or an array of antennas, which emits a short pulse and receives it with focusing. This analysis is a generalization of OCT (optical coherence tomography), SAR, and confocal imaging.

We discuss two imaging techniques. One is the fixed focus imaging which gives the spatial imaging of objects at different times. The other is the variable space-time focusing similar to SAR, OCT and confocal imaging. We clarify the relationships among transverse and longitudinal resolutions, the coherence length, the shower-curtain effects, and the backscattering enhancement. The pulse spread, pulse delay, resolutions, and the effects of aperture size and bandwidth are discussed, and it is shown that it is possible to distinguish the target scattering from the medium scattering.

II. Formulation of the problem

Let us consider the detection and imaging of an object shown in Fig. 1A. A square array or aperture of transmitters and receivers are located at $z=0$. The pulse wave is emitted by transmitters located at $\overline{p}$ focused at $\overline{r}_f\left(L,0\right)$. The scattered wave is received at $\overline{q}$ and the phase is added to focus at $\overline{r}_f$. This is a generalization of SAR. The waves are transmitted by all $\overline{p}$ transmitters and the received waves at all $\overline{q}$ receivers are summed.



(A) **(B)**

Figure 1: (A) Array of transmitters and receivers to detect and image the target behind obscuring layers, and (B) Geometry in numerical examples.

The correlation function of the output is then given by

$$\Gamma(t,t') = \frac{1}{(2\pi)^2}\iint d\omega\, d\omega' \;\exp(-i\omega t + i\omega' t')\Gamma(\omega,\omega')F(\omega)F^*(\omega') \tag{1}$$

The two-frequency mutual coherence function $\Gamma(\omega,\omega')$ consists of the component Γ_t from the target and Γ_m from the medium. (Figure 2)

$$\Gamma = \sigma_t\Gamma_t + \Gamma_m;\;\; \Gamma_m = \int_{d_1}^{d_2} dz_m \int d\bar{\rho}_m \sigma_b \Gamma(\bar{\rho}_m, z_m, \omega, \omega') \tag{2}$$

where σ_t is the backscattering crosssection of the target and σ_b is the backscattering coefficient of the medium.

III. Numerical examples

We now consider a numerical example in Figure 1(B). We note several characteristics of the imaging problem. We use as the reference the following parameters: $a = 5\lambda$, $\Delta\omega/\omega_o = 0.2$, $g = 0.85$, $W_o = 0.9$, $L = 50\lambda$, $d_1 = d_2 = 25\lambda$, $\sigma_t = A\lambda^2$, $A = 1$ where Δz is the pulse spread, W is the lateral resolution, and Δz_d is the delay due to multiple scattering. Figure 2 shows the effect of bandwidth. If BW = 0.01 (normalized $\Delta\omega/\omega_o$), it is difficult to distinguish the target from the medium scattering, but if BW = 0.1, it is possible to detect the target behind the medium even if OD =10.

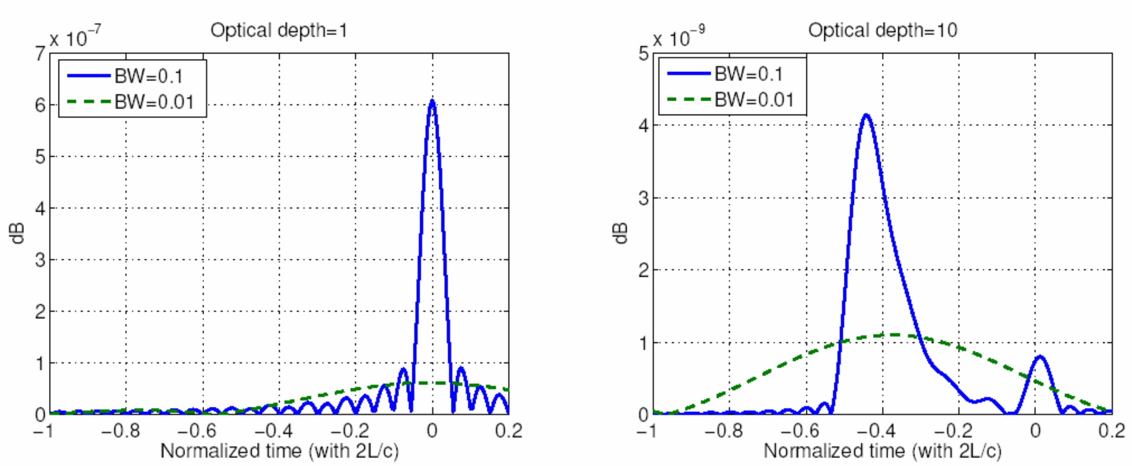


Figure 2: Effect of bandwidth. Target is located at the normalized time =0. For broad band BW=0.1, the target can be detected even for optical depth (OD) = 10.

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References

[1] A. Ishimaru, S. Jaruwatanadilok, and Y. Kuga, "Short pulse detection and imaging of objects behind obscuring random layers," *accepted for publication in Waves in Complex and Random Media*, November 2005.