Calculation of Targets Laser RCS in Random Media for H-Wave Polarization

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Abstract: In this work, laser RCS (LRCS) of conducting objects is calculated in random media. Illumination region has a partially convex curvature while random medium as turbulence is assumed to be isotropic. Targets take sizes more than twice of the wavelength in free space for practical radar detection. Vertical incident wave polarization (H-wave incidence) is considered.

1 Introduction

Scattering waves have been formulated by researchers over decades [1]–[3]. We have formulated scattering problem using current generator method as a boundary value problem [4]–[6]. This method calculates the current on the whole surface including the shadow region. Consequently, this method results in an accurate calculation of the scattered waves intensity.

Double passage of waves backscattering from point objects results in an enhancement in the radar cross-section (RCS) in random medium and in turn it is twice that in free space [7, 8]. Features of incident waves and their polarization are key parameters affecting scattering waves in disordered medium. Antenna array may be used to generate waves of infinitely large plane wave fronts. However, this is not possible easily to produce plane waves at large size objects in the far field and, as a result, we should consider beam wave with a limited beamwidth compared to the infinite width of the plane wave. It should be noted that the current generator method is normalized to the wavenumber and, consequently, it is valid for the radio and optical frequencies.

In this paper, we work on presenting numerical results for laser RCS (LRCS) considering effects of beamwidth kW and the medium inhomogeneities on the scattering waves. Targets are with finite size of about two wavelengths in free space. We use the spatial coherence length (SCL) of waves around the object to represent the fluctuation intensity of the random medium. We deal with the scattering problem two-dimensionally assuming vertical polarization (H-wave incidence). The time factor exp(-iwt) is assumed and suppressed in the following section.

2 Formulation

Geometry of the problem is shown in Figure 1. A random medium is assumed as a sphere of radius L around a target of the mean size $a \ll L$. We can assume the forward scattering approximation and the scalar approximation [8]. Consider the case where a directly incident beam wave is produced by a line source $f(\mathbf{r}')$ along the y axis. Here, let us designate the incident wave by $u_{in}(\mathbf{r})$, the scattered wave by $u_s(\mathbf{r})$, and the total wave by $u(\mathbf{r}) = u_{in}(\mathbf{r}) + u_s(\mathbf{r})$. Assuming a vertical polarization of incident waves (H-wave incidence), we can impose the Neumann boundary condition for wave field $u(\mathbf{r})$ on the cylinder surface S. We can deal with this scattering problem two dimensionally under the condition (1); therefore, we represent $\mathbf{r}$ as $\mathbf{r} = (x, z)$.

$$B(\mathbf{r}, \mathbf{r}) \ll 1, \qquad kl(\mathbf{r}) \gg 1 \tag{1}$$

Here, the angular brackets denote the ensemble average and $B(\mathbf{r}, \mathbf{r})$, $l(\mathbf{r})$ are the local intensity and local scale-size of the random medium fluctuation, respectively, and $k = \omega\sqrt{\varepsilon_0 \mu_0}$ is the wavenumber in free space. Using the current generator Y_{H} [5, 9] and Green's function in random medium $G(\mathbf{r} \mid \mathbf{r}')$, we can express the average intensity of backscattering wave as

$$\langle |u_{sb}(\mathbf{r})|^2 \rangle = \int_S d\mathbf{r}_{01} \int_S d\mathbf{r}_{02} \int_S d\mathbf{r}'_1 \int_S d\mathbf{r}'_2$$
$$Y_H(\mathbf{r}_{01} \mid \mathbf{r}'_1) Y_H^*(\mathbf{r}_{02} \mid \mathbf{r}'_2) \exp\left[-\left(\frac{kx'_1}{kW}\right)^2\right]$$

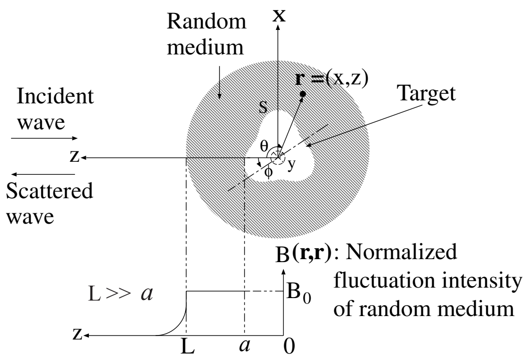


Figure 1: Geometry of the problem of wave scattering from a conducting cylinder in a random medium.

$$\times \exp\left[-\left(\frac{kx_2'}{kW}\right)^2\right]\frac{\partial}{\partial n_{01}}\frac{\partial}{\partial n_{02}}$$
$$\langle G(\mathbf{r} \mid \mathbf{r}_{01})\, G(\mathbf{r} \mid \mathbf{r}_{02})\, G^*(\mathbf{r} \mid \mathbf{r}_1')\, G^*(\mathbf{r} \mid \mathbf{r}_2')\rangle. \tag{2}$$

where W is the beamwidth. We can obtain the LRCS σ_b using equation (2)

$$\sigma_b = \langle |u_s(\mathbf{r})|^2\rangle \cdot k(4\pi z)^2 \tag{3}$$

3 Numerical Results

Although the incident wave becomes sufficiently incoherent, we should pay attention to the spatial coherence length (SCL) of incident waves around the target. The degree of spatial coherence is defined as [4]

$$\Gamma(\rho, z) = \frac{\langle G(\mathbf{r}_1 \mid \mathbf{r}_t)G^*(\mathbf{r}_2 \mid \mathbf{r}_t)\rangle}{\langle \mid G(\mathbf{r}_0 \mid \mathbf{r}_t) \mid^2\rangle} \tag{4}$$

where $\mathbf{r}_1 = (\rho, 0)$, $\mathbf{r}_2 = (-\rho, 0)$, $\mathbf{r}_0 = (0, 0)$, $\mathbf{r}_t = (0, z)$. In the following calculation, we assume $B(\mathbf{r}, \mathbf{r}) = B_0$ and $kB_0L = 3\pi$; therefore the coherence attenuation index α defined as $k^2B_0Ll/4$ is $15\pi^2$, $44\pi^2$, and $150\pi^2$ for $kl = 20\pi$, 58π, and 200π, respectively, which means that the incident wave becomes sufficiently incoherent. The SCL is defined as the $2k\rho$ at which $\mid \Gamma \mid = e^{-1} \simeq 0.37$. Figure 2 shows a relation between SCL and kl in this case and SCL, accordingly, is equal to 3, 5.2, and 9.7. We will use the SCL to represent one of the random medium effects on LRCS. The integrations in (2) are calculated using the trapezoidal rule.

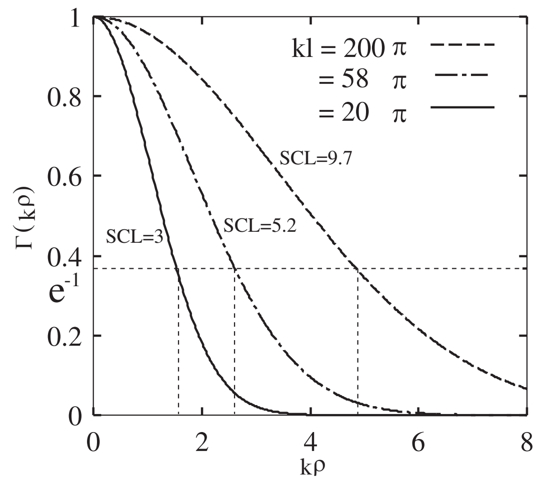


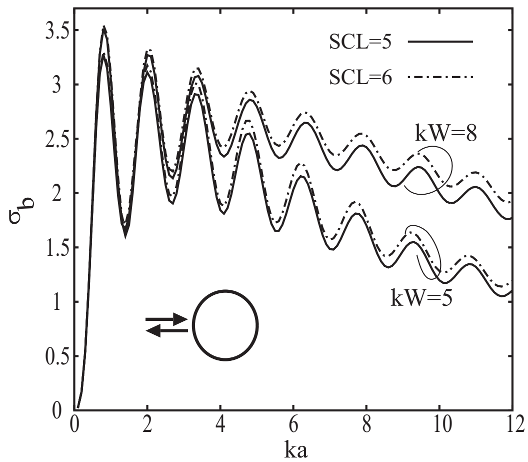
Figure 2: The degree of spatial coherence of an incident wave about the cylinder.

In the following, we conduct numerical results for LRCS.

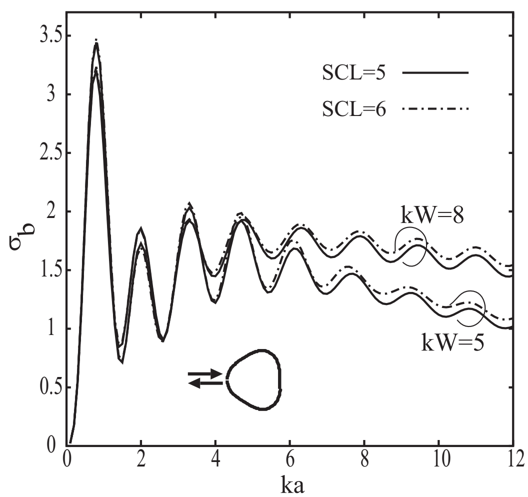
3.1 Laser RCS (LRCS)

We present our numerical results for LRCS in figure 3. It is noticed that LRCS fluctuates monotonically and regularly while being decreasing with ka. This is due to both effects of random medium fluctuations and the creeping waves generated around the object cylinder. Within the range $ka \leq 3$ which is the resonance region, the surface has nearly a typical convex smooth contour surrounded by a beam wave where $kW > ka$. This implies that the beam wave behaves as if it ia almost a plane wave around the object in the far field. Consequently, LRCS behaves similarly regardless of object complexity, beamwidth kW, and coherence length SCL. LRCS oscillates widely due to the effect of creeping waves together with the incident waves in the direct direction.

As ka is getting larger, the surface would involve both convex and concave regions with inflection points. As the surface current is generated and flowing around the object contour, scattering rays are produced from different curvatures resulting in LRCS that varies obviously with kW, SCL, and curvature index δ. When kW has a wider size, incident wave becomes closer to being a plane wave resulting in more scattering rays and in turn LRCS increases. Also, SCL has an effect on LRCS similar to the discussed impact of kW. In other words, with a wider SCL around the object, the amount of scattering waves increases which in turn enlarges LRCS. With $ka > kW$, LRCS decreases with larger target size and the beam wave would be insufficient for radar detection due to a lack of surface current.



(a)



(b)

Figure 3: LRCS vs. target size in random medium where (a) $\delta = 0$, (b) $\delta = 0.08$.

4 Conclusion

In this paper, we have proved that there are several parameters that affect the LRCS of objects in random media. These parameters include: coherence length SCL, object configuration, and beamwidth of incident wave. For better radar detection, incident waves frequencies should be selected in a way to avoid the resonance region particularly with H-wave incidence which produces creeping waves that increases the severity of the resonance effect. Specifically, in the range $\lambda > 2a$, LRCS would be more accurate. In addition, wider beamwidth around the object in the far field would maximize the radar detection capability and accuracy regardless of the SCL of the random medium.

References

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