BACKSCATTERING ENHANCEMENT AND POLARIZATION EFFECTS OF MULTIPLE SCATTERING IN RANDOM MEDIA AND ROUGH SURFACE SCATTERING

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ABSTRACT

In recent years, there has been extensive research on the enhanced backscattering due to the multiple scattering of waves. This was one of the major topics discussed at the Madrid and Tallin workshops[1,2] in September 1988. The enhancement occurs in backscattering from turbulence, discrete scatterers, and rough surfaces. This paper first reviews the mechanisms which cause the enhancement, including the coherent backscattering and the weak Anderson localization.

Next we present general formulations and solutions for the vector radiative transfer equation when the background media for the scatterers have refractive indices different from those in the media for the incident and transmitted waves. Oblique incidence and nonspherical particles are considered, and an example of optical scattering by vegetation is presented. The formulations are given in terms of the Mueller matrix and the extinction matrix, and the solutions are given in polarimetric representations.

The rough surface scattering is studied using the phase perturbation method and the diagram method. The second-order cross term exhibits the enhanced backscattering when the second medium supports surface waves.

1. BACKSCATTERING ENHANCEMENT

The enhanced backscattering from various surfaces and volume scatterers has been known for many years. The glory around the shadow of an airplane cast on clouds underneath is an example. The full moon is known to have enhanced brightness. Many soils and vegetation exhibit enhanced scattering in the backward direction. There have been several theories proposed to explain these phenomena. However, in recent years, more precise measurements have been conducted and some quantitative explanations have been offered. This paper first reviews the present state of our understanding on these interesting phenomena.

In September 1988, a workshop in Madrid on "Recent Progress in Surface and Volume Scattering" and a workshop in Tallin, USSR on "Wave Propagation in Random Media" were held and backscattering enhancement was one of the important topics discussed at both workshops. We will discuss backscattering enhancement from discrete scatterers, rough surfaces, and turbulence.

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In 1984, Kuga and Ishimaru reported the first experimental evidence of the enhanced light backscattering from a random distribution of latex particles. The backscattering has a narrow peak, whose angular width is a fraction of a degree and is much smaller than a wavelength/mean free path. Tsang and Ishimaru proposed a theory that two waves diffusing through random media in opposite directions experience constructive interference in the backward direction creating a sharp peak. The angular width is therefore of the order of a wavelength/transport mean free path, in agreement with experimental data. This phenomenon was subsequently identified as coherent backscattering or as an example of the weak Anderson localization phenomena in disordered media, and extensive experimental and theoretical studies have been made.

The experimental evidence of the enhanced backscattering from rough surfaces was reported by O'Donnell and Mendez and showed that the enhancement takes place when the surface height is of the order of a wavelength and the slope is close to unity. The peak angular width is of the order of several degrees. This phenomenon appears to be due to multiple scattering effects. On the other hand, the enhanced backscattering has been observed even when the surface height is a small fraction of a wavelength if the surface medium supports surface waves or plasmons. The angular width of the peak is a fraction of a degree and is related to the attenuation rate of the surface wave.

The enhanced backscattering from turbulence has been studied theoretically and experimentally and is due to the correlated forward and backward multiple-scattered waves. The explanation of this effect requires a knowledge of the fourth-order and higher order moments of the waves.

2. VECTOR RADIATIVE TRANSFER

We next consider the solution of the vector radiative transfer when the incident wave is in the medium with refractive index n_1 and the scatterers are in the medium with refractive index n_2. The transmitted wave is in the medium with refractive index n_3. An example of this situation is the optical scattering from a single leave, which may be represented by discrete scatterers embedded in the medium with the refractive index n_2 close to that of water. We have constructed an optical scattering measurement setup, by which the Stokes vector and the complete polarization state of the scattered wave can be measured for four different polarization states of the incident wave. The experimental data agree closely with the calculations based on the vector radiative solutions.

The scattering from vegetation can be performed in two stages. The first is the vector radiative transfer solution for a single leaf described above. The second is the additional vector radiative transfer solution for the vegetation canopy where the solution of the single leave radiative transfer is used as the Mueller matrix and the extinction matrix.

3. ROUGH SURFACE SCATTERING

There have been extensive attempts made to extend the range of validity for the conventional perturbation and Kirchhoff approximations. We have made extensive studies on the use of the phase perturbation method which is applicable to the range where neither the perturbation method nor the Kirchhoff approximation is valid. We have also considered the use of the diagram method to explain some of the backscattering enhancement phenomena from rough surfaces. This is applicable to the case of the small height variation with the second medium which supports the surface wave. The Dyson equation and the Bethe-Salpeter equation are constructed, and the coherent field is identical to those obtained by Watson and Keller, while the second-order ladder term is close to Ito's solution. In addition, the second-order cross term exhibits the enhanced backscattering.

REFERENCES

1. Madrid Workshop on "Recent Progress in Surface and Volume Scattering" organized by M. Nieto-Vesperinas, Madrid, Spain, September 14-16, 1988.

2. Tallin Workshop on "Wave Propagation in Random Media" organized by V. I. Tatarskii and A. Ishimaru, Tallin, USSR, September 19-23, 1988.

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