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TRANSIENT CHARACTERISTICS OF MILLIMETER WAVE SCATTERING FROM CYLINDRICAL OBJECTS NEAR A BOUNDARY

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1. Introduction

The millimeter waves have received increasing attention in recent years in connection with the remote sensing of surfaces, the performance of radar systems like ITS (Intelligent Transport Systems), and communications. The characteristics of the scattering from objects near a boundary have a number of practical applications [1]. As a familiar scattering problem, there are problems of scattering from vegetations above the earth, ships on the sea, and cars on the road. In these studies, it is required to analyze the scattering process included in the scattered wave and to evaluate the interaction effects of waves between objects and a boundary. The scattering analysis for continuous wave incidence on the objects has been studied extensively in the literature [2]-[3]. Although the transient scattering by an isolated object has also been a subject of intensive research [4]-[5], a few experimental studies have been reported on transient phenomena of scattering in the millimeter wave region by a dielectric object near a boundary [6].

In this paper, the transient problem is studied on scattering of millimeter pulse waves by a conducting or dielectric cylindrical object near a conducting flat or rough boundary. The millimeter wave scattering measurement system is briefly described and then the experimental results of the backscattered transient response are shown at oblique incidence on a boundary and different distances between a center of target and a boundary. Furthermore, theoretical results based on a simplified model are compared with measured values.

2. Measurement system

The system of scattering measurements consists of a pair of transmitter and receiver units, a local oscillator of 47 GHz, and a network analyzer. The signal of the network analyzer from 2 GHz to 6 GHz is up-converted with the local oscillator and the signal in a range from 49 GHz to 53 GHz is incident upon an object near a boundary. This transmitted signal is equivalent to a short pulse with its width T_w = 0.25-0.3 nsec. The same locally synchronized signal is fed to the receiver unit and the received signal is then down-converted to the RF signal in a range from the 2 to 6 GHz. The constitution of the present scatterometer is similar to that developed originally for multiple scattering experiments [7], except higher carrier frequencies used. The geometry of the millimeter wave scattering is shown in Fig. 1. The amplitude and the phase of the received scattering wave are transformed into the time domain data by the inverse Fourier transform. In 50 GHz, a millimeter wave beam width used for the experiment is 4.8°, the distance from transmitting and receiving antennas to a boundary plane is 2.83 m and the corresponding scattering angle is 172°.

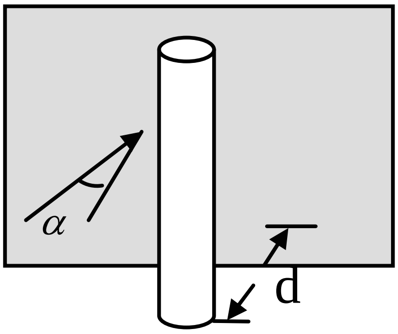

Fig.1. Configuration of scattering problem.

3. Experimental results

A. Distance characteristics

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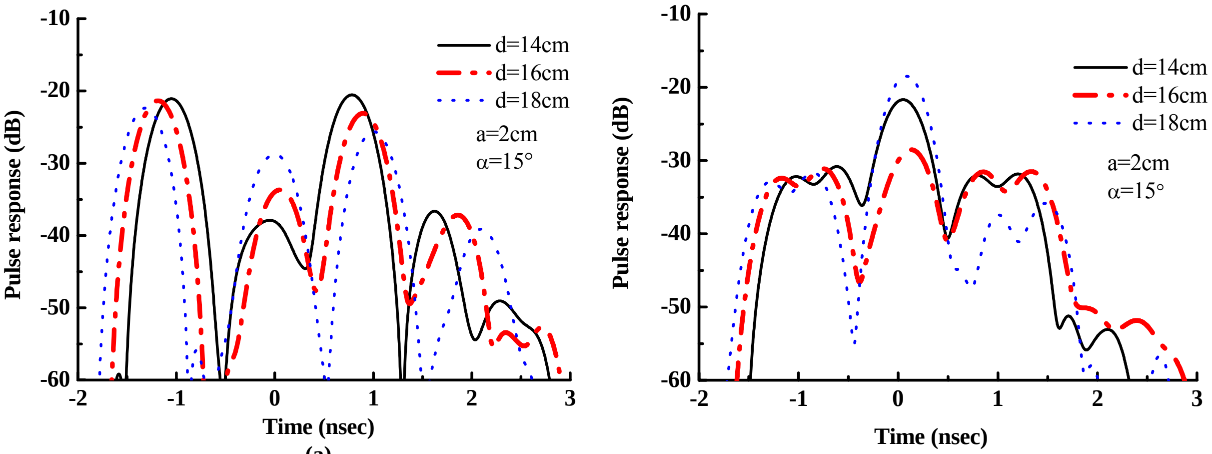
Measurements of backscattered waves were made for the two kinds of the objects; one was for a perfectly conducting cylindrical object in front of a perfectly conducting flat boundary (1 m × 1 m), the other was for a dielectric cylinder. The co-polarized backscattered waves for the TM wave incidence were observed. The pulse wave forms are shown for different distances d between the boundary and the center of a perfectly conducting cylindrical object in Fig. 2(a) where the radius and the length of the cylinder is a = 2 cm and l = 60 cm, and the angle of incidence on a boundary is α = 15°. Time zero is calibrated to correspond to the pulse from the center of the flat boundary without an object. The first peak is the pulse response only from the conducting cylinder. The second peak corresponds to the pulse response, which is once scattered from the conducting cylinder and further reflected from the boundary and vice versa. The variation of this second peak level versus the distance becomes large compared with other pulse responses. Therefore, the second pulse response is understood that the interaction between the object and boundary is significantly affected by their location. The third peak is regarded as the pulse response which shuttles between the cylinder and the boundary, and further the forth pulse response is reflected fifth times between objects.

For a dielectric delrin cylinder with the same radius 2 cm, the pulse responses are shown in Fig.2(b) in which the refractive index of the dielectric material is n_{del} = 1.7+j0.013. The first two peaks are the same pulse responses as those from an isolated dielectric cylinder, i.e., the first and the second peaks correspond to the returns from the front and rear axial surface of the cylinder in the geometrical optics limit. The 3rd pulse response is found to be strongly influenced with the change of the distances to the boundary. The 4th and 5th peaks are reflected the three times between a boundary and the rear and front surface of the dielectric cylinder, respectively.

Comparing both cases of the conducting and dielectric cylinders, we can see that the pulse scattered from the cylinder and reflected from the boundary is significantly affected by the location of the object from the boundary. The 2nd peak level for the conducting cylinder shown in the Fig. 2(a) is lower than the 1st peak level, while the corresponding 3rd peak level for the dielectric cylinder in the Fig. 2(b) is higher than the 1st and 2nd peak level. In this case, the interaction effects make a large contribution toward increasing the pulse response.



(a) (b)

Fig.2 Pulse responses from (a) a perfectly conducting cylinder and (b) a dielectric delrin cylinder. d is the distance between a center of the cylinder and a perfectly flat surface, the incident angle α = 15°, radius a = 2 cm, length l = 60 cm.

B. Incident angle characteristics

The experimental results of the pulse response are illustrated in Fig.3 for different incident angles at the fixed distance between an object and a conducting flat boundary. Figures 3(a) and (b) show for an object of the perfectly conducting cylinder and the dielectric cylinder, respectively. The scattering process of pulse response is corresponded to one described in Fig.2. We observe the remarkable variation pulse responses; especially at α = 15° in the Fig.3(a) and at α = 5° in the Fig.3(b). According to the results, the interaction effects are strongly dependent on the incident angles.

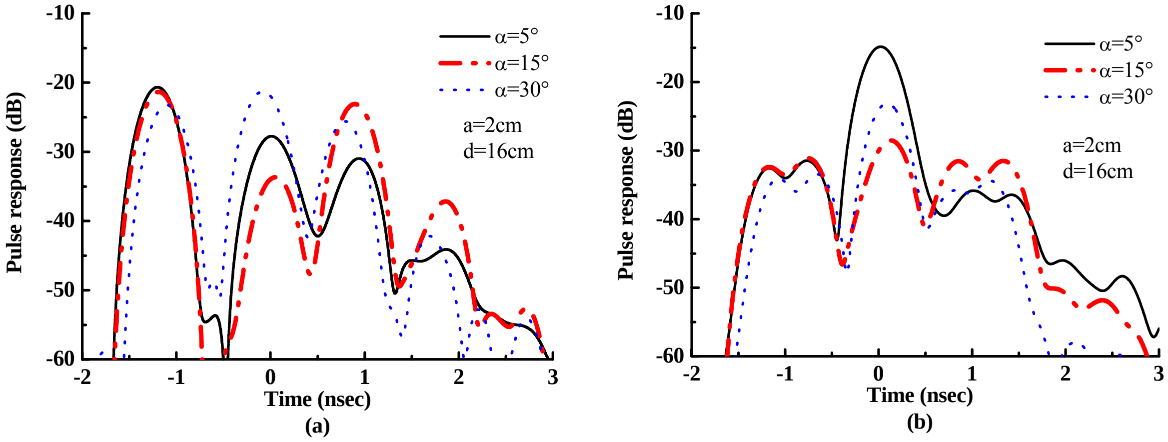


Fig.3 Dependencies of pulse responses on the incident angles α; the distance d = 16 cm, target cylinder of the radius a = 2 cm, and the length l = 60 cm. (a) perfect conducting cylinder and (b) dielectric delrin cylinder.

C. Refractive characteristics

The sensitivity to the refractive index of the object is examined and the results are shown in Fig. 4. The three materials of the delrin, mullite and ceramic cylinders are used as the dielectric objects. These cylinders are the same radius 2 cm, but the length of the ceramic cylinder alone is 30 cm and the other two cylinders are the length of 60 cm. The refractive indices used of respective cylinders have n_{del} = 1.7+j0.013 in the delrin, n_{mul} = 2.4+j0.01 in the mullite, and n_{cer} = 3.1+j0.001 in the ceramic. The incident angle is α = 15° and the distance of the object to a boundary is d = 16 cm. As the refractive index increases, the time difference of between the 1st and 2nd pulse response becomes larger as expected, and the 4th and 5th pulse responses at later times appreciably increase by the object-boundary interaction effects. On the other hand, the actual 3rd pulse response (indicated by the arrow in the figure) for the ceramic cylinder seems to be diminished, since the waves, which are reflected from the rear of an interior cylinder and also from the exterior cylinder surface through a flat boundary, may interfere in the backscatter direction.

D. Comparison with theoretical values

A comparison with theoretical values of the pulse response is presented in Fig.5 for a = 2 cm, d = 16 cm, and α = 15°. Theoretical values are first obtained for the continuous plane wave scattering from an infinite dielectric delrin cylinder in front of a flat

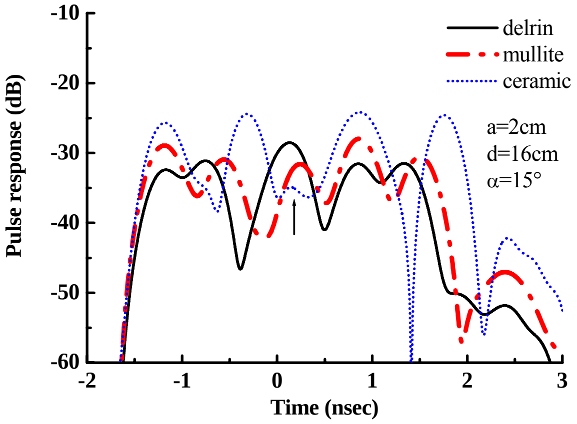


Fig.4 Pulse responses from dielectric cylinders with different refractive indices at the distance of 16cm from a perfectly conducting boundary.

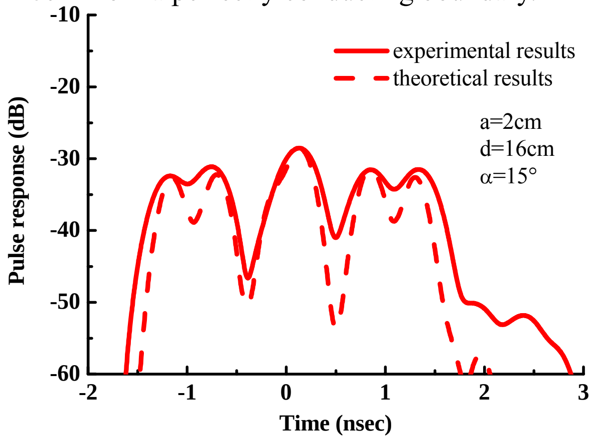


Fig.5 Comparison of experimental values with theoretical ones by the target of dielectric delrin cylinder in front of a perfectly conducting flat boundary.

boundary with the Fresnel reflection coefficients in the two-dimensional problem [3], and are then transformed into the time domain. Although the experimental values are obtained by the three-dimension problem, we note that Fig. 5 presents a good agreement between the experimental values and theoretical ones at this oblique incidence of angle 15°.

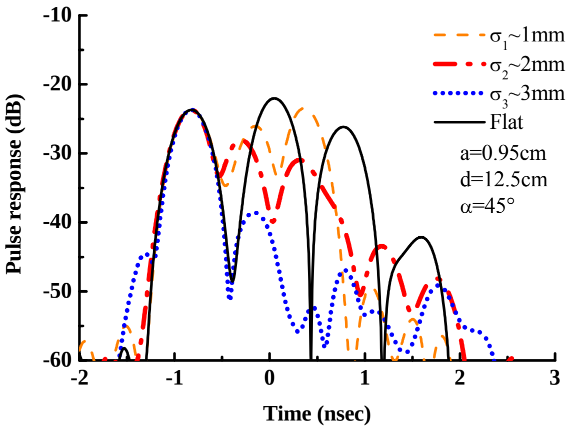


Fig.6. Pulse responses from a perfectly conducting cylinder in front of a perfectly conducting rough boundary with roughness σ.

E. Roughness characteristics

The conducting rough boundary is considered to examine the effects of the surface roughness on the pulse response. In Fig. 6 the pulse responses scattered from rough boundaries are plotted for the conducting object of a cylinder radius a = 0.95 cm, the distance d = 12.5 cm, and the incident angle α = 45°. This figure shows that the responses of waves scattered from a rough boundary largely decrease with an increase in the surface roughness, i.e., the intensity of waves scattered two or three times on the surface with the roughness σ = 3 mm substantially decreases by the multiple interactions between the object and rough surfaces.

4. Conclusion

The transient scattering characteristics of millimeter waves from a cylindrical object near a flat or rough boundary were studied to evaluate the multiple interactions of scattered waves with the object and boundary. The pulse waves scattered first from the object and then from the flat boundary or vice versa are significantly influenced by the distance from the object to the boundary. For the dielectric cylinder with the high refractive index, it is observed that the interference by two different scattering processes may occur to decrease the response. A comparison of the measured and calculated pulse responses shows a good agreement at a slightly oblique incidence on a boundary and the moderate distance between the object and boundary. The rough boundary is also shown to reduce the pulse wave response corresponding to the multiple interactions.

References

[1]E. S. Li, “Physical optics models for the backscatter response of road-surface faults and roadside pebbles at millimeter-wave frequencies,” IEEE Trans. Antennas Propagat., Vol.51, No.10, pp.2862-2868, Oct. 2003.

[2] T. Chiu and K. Sarabandi, “Electromagnetic scattering interaction between a dielectric cylinder and a slightly rough surface,” IEEE Trans. Antennas Propagat., Vol.47, pp.902-913, May 1999.

[3]G. Videen and D. Ngo, “Light scattering from a cylinder near a plane interface: theory and comparison with experimental data,” J. Opt. Soc. Am. A, Vol.14, pp.70-78, Jan. 1997.

[4]C. L. Bennett and W. L. Weeks, “Transient scattering from conducting cylinders,” IEEE Trans. Antennas Propagat., Vol.AP-18, pp.627-633, Sept. 1970.

[5]H. Ikuno and M. Nishimoto, “Wavelet analysis of scattering responses of electromagnetic waves,” IEICE, Vol.J81-C-I, No.11, pp.609-615, Nov. 1998. (in Japanese)

[6]J. T. Johnson, “A numerical study of scattering from an object above a rough surface,” IEEE Trans. Antennas Propagat., Vol.50, No.10, pp.1361-1367, Oct. 2002.

[7]T. Oguchi, S. Ishii, S. Ito, and T. Manabe, “Laboratory measurements of radar depolarization signatures in microwave pulse transmission through randomly distributes spherical scatterers,” IEEE Trans.Geosci. Remote Sensing, Vol.36, No.3, pp.1013-1015, May 1998.