Monostatic RCS Reduction by Gap-Fill with Epoxy/MWCNT in Groove Pattern

Won-Ho Choi · Hong-Kyu Jang · Jae-Hwan Shin · Tae-Hoon Song · Jin-Kyu Kim · Chun-Gon Kim

Abstract

In this study, we investigated the effect of groove pattern and gap-fill with lossy materials at 15 GHz frequency of Ku-band. We used Epoxy/MWCNT composite materials as gap-fill materials. Although epoxy does not have an absorbance capability, epoxy added conductive fillers, which are multi-walled carbon nanotubes (MWCNT), can function as radar absorbing material. Specimens were fabricated with different MWCNT mass fractions (0, 0.5, 1.0, 2.0 wt%) and their permittivity in the Ku-band was measured using the waveguide technique. We investigated the effect of gap-fill on monostatic RCS by calculating RCS with and without gap-fill. For arbitrarily chosen thickness and experimentally obtained relative permittivity, we chose the relative permittivity of MWCNT at 2 wt% ($\epsilon_r = 8.8 - j2.4$), which was the lowest reflection coefficient for given thickness of 3.3 mm at V-pol. and 80° incident angle. We also checked the monostatic RCS and the field intensity inside the groove channel. In the case of H-pol, gap-fill was not affected by the monostatic RCS and magnitude was similar with or without gap-fill. However, in the case of V-pol, gap-fill effectively reduced the monostatic RCS. The field intensity inside the groove channel reveals that different RCS behaviors depend on the wave polarizations.

Key words: Radar Cross Section (RCS), Groove Pattern, Polarization, Scattering, Composite Material.

1. Introduction

Upon encountering a surface discontinuity, an incoming wave that is incident to a target's surface generates edge diffracted waves in order to satisfy the boundary conditions at the discontinuity. Any discontinuity on the surface can reflect the incident wave, and the back scattered edge diffracted waves leads to a strong RCS contribution. Examples of such discontinuities are the gap, slot, and step. The magnitude of the surface wave reflection depends on the size and shape of the discontinuity and the incident angle of the surface wave with respect to the axis of the discontinuity. Gaps (or groove patterns) in structures can be strong contributors to the scattering of electromagnetic waves. In particular, gaps may make up a significant portion of the overall wave scattering when found in complex low observable targets [1]~[3].

We investigated the effect of gaps on back scattering, by calculating the monostatic RCS using an analytical solution from [3], [4]. This analytical solution utilized the Fourier-transform technique, where an approximate series solution for a rectangular channel in a conducting plane is presented in a closed form. This is valid for a

high-frequency scattering regime. The final equation of [3] is presented below. The far-zone scattered field at distance r from the origin can be evaluated by utilizing the following equation. The meaning of each notation can be found in reference [3].

$$E_y^s(r, \theta) = e^{j(k_0 r - \pi/4)} \times \left(\frac{k_0}{2\pi r} \right)^{1/2} \cos \theta_s \sum_{m=1}^{\infty} c_m a_m \sin(\xi_m d) \times \frac{e^{-jk_0 a \sin \theta_s} (-1)^m - e^{jk_0 a \sin \theta_s}}{(k_0 \sin \theta_s)^2 - a_m^2}$$

Fig. 1 shows the width dependence of monostatic RCS in a groove pattern. The depth of the gap is 3 mm, and frequency is 15 GHz. The material inside the gap is configured as a vacuum ($\epsilon_r = \mu_r = 1$). As shown in the above figure, as the width increases, back scattering of the incident wave also increases. These components become a significant part of the overall back scattering in low observable targets.

We minimized the back scattering due to gaps by using gap-fill with lossy material that could absorb the incident wave. A schematic diagram of its basic concept is presented in Fig. 2. When the surface wave encounters a surface discontinuity (gaps), the surface wave will

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Fig. 1. Monostatic RCS as a function of width.

Fig. 2. Schematic diagram of basic concept for RCS reduction in groove pattern.

strongly interact with the surface discontinuity, and be back scattered. However, when the gap is filled with lossy materials, the surface wave is absorbed by the absorbing material, and only a small part of the surface wave will be scattered.

In this study, we investigated the effect of groove pattern and gap-fill with a lossy material of epoxy/MWCNT composite.

II. Fabrication of Composite Material

Fig. 3 shows the process flow for fabricating the composite material. Since epoxy has a very low loss tangent (typically 0.01-0.03), it needs to have conductive fillers added to increase the absorption capability. We used Multi-Walled Carbon Nanotubes (MWCNTs) as conductive fillers. The MWCNTs used in this study, purchased from Hanwha Nanotech Co. (South Korea), were synthesized via a chemical vapor deposition method with a carbon mass fraction of about 95 %. The weight % (wt %) of MWCNTs was split into 0, 0.5, 1.0, and 2.0 wt%. Because the viscosity of MWCNT/

Fig. 3. Process flow for fabrication of composite material.

(a) Real part of relative permittivity

(b) Imaginary part of relative permittivity

Fig. 4. Relative permittivity of fabricated composite materials.

Epoxy composite materials increases as the wt% of the MWCNT increases, we confined the wt% of MWCNT

Fig. 5. Relative permittivity as a function of weight fraction of MWCNT.

from 0 to 2 wt%.

Firstly, epoxy and hardener were mixed with different wt% of MWCNT. The mixed composite materials were dispersed by a three-roll-mill, which uses shear force to disperse nanoparticles produces uniformly dispersed composite materials [6]. Many pores are present in the raw composite materials and these must be removed for improved performance. Removal is achieved by placing the raw composite materials in a vacuum to eliminate the pores. After pore removal, a mold is used to make specimens of uniform thickness. We minimized pore formation by using a syringe to insert the raw composite materials into the mold. The molded raw composite materials were cured in an oven at 80 °C for 4 hours.

The electromagnetic properties of cured composites were measured by the Ku-band rectangular waveguide method [5]. The cured composites were cut precisely to the dimensions of the Ku-band rectangular waveguide, 15.8×7.9 mm, and then inserted into the waveguide. The S -parameter was measured by using a network analyzer (HP 8510C). Since the air gap between the waveguide and the specimen affects the signal of S_{21} , the gap was completely sealed up with silver paste.

The permittivities of the fabricated specimens were measured as shown in Fig. 4. The figure indicates that the dependence of the relative permittivities on the frequency is negligible, and they show nearly linear dependence on the weight fraction of MWCNTs (Fig. 5).

III. Simulation Results and Discussion

We analyzed the effect of gap-fill in groove pattern using the commercial software package CST Microwave Studio [4]. Fig. 6 shows the modeling for the analysis of groove pattern. The dimension of the structure was

Fig. 6. Modeling for analysis of groove pattern.

(a) Monostatic RCS: Flat plate vs. groove pattern without gap-fill

(b) Monostatic RCS: Groove pattern without gap-fill vs. groove pattern with gap-fill

Fig. 7. Monostatic RCS at 15 GHz (a) flat plate (PEC) vs. groove pattern (PEC), (b) groove pattern - without gap-fill vs. with gap-fill.

150 mm by 150 mm, thickness was 3.3 mm, and the gap width was 10 mm. The choice of thickness used in simulation was somewhat arbitrary. The reflection coefficient of a gap-fill material was optimized with a relative permittivity obtained in Fig. 5 at V-pol. and 80° (0° was defined as normal incidence) [7], [8]. After optimizing, we chose the relative permittivity of MWCNT

(a) Monostatic RCS: Flat plate vs. groove pattern without gap-fill

(b) Monostatic RCS: Groove pattern without gap-fill vs. groove pattern with gap-fill

Fig. 8. E-field probing in the rectangular channel.

2 wt% ($\epsilon_r=8.8-j2.4$), which had the lowest reflection coefficient for given thickness of 3.3 mm at V-pol. and 80° incident angle. A Ku-band with center frequency of 15 GHz was used for the RCS analysis.

Fig. 7(a) shows the simulation results of monostatic RCS for flat plate (PEC) and groove pattern (PEC) with different wave polarizations, V-pol and H-pol, at a center frequency of 15 GHz in the Ku-band. As shown in the figure, the groove channel strongly interacts with V-pol at high incident angles. On the other hand, in the case of H-pol, no differences are evident between the flat plate and groove pattern.

We investigated the effect of the gap-fill with epoxy/MWCNT composite in the groove channel using $\epsilon_r=8.8-j2.4$ at 15 GHz as already mentioned. Fig. 7(b) shows monostatic RCS simulation with and without gap-fill of the groove pattern. In the case of H-pol, the gap-fill did not influence the monostatic RCS, and its magnitude was similar to that without gap-fill. However,

in the case of V-pol, the gap-fill effectively reduced the monostatic RCS.

As already mentioned, epoxy/MWCNT materials can absorb surface waves, and as a result, these materials reduce back scattered surface waves. Because we optimized the reflection coefficient for given permittivity and thickness at V-pol and 80° , we can predict that RCS has the lowest magnitude at near 80° and V-pol. From this point, we checked the field intensity inside the groove channel. To check the effect of the absorbing materials, we simulated the field intensity inside the groove channel. Fig. 8 shows the E-field intensity inside the groove channel as a function of frequency, with two polarizations (V-pol and H-pol) and different incident angles (35° , 50° , 65°). As shown in Fig. 8, the case of V-pol shows a significant difference in E-field intensity inside the groove channel without and with gap-fill. The variation in field intensity in V-pol is consistent with the simulation result of monostatic RCS. However, in the case of H-pol, because the field intensity of without gap-fill has very low magnitude, the effect of the absorbing material is not significant, as shown in Fig. 8.

IV. Conclusion

In this study, we investigated the effect of gap-fill with lossy materials of Epoxy/MWCNT. We investigated the effect of gap-fill on RCS by calculating the RCS with and without gap-fill with different polarizations, V-polarization and H-polarization. In the case of H-pol, the gap-fill did not substantially affect the monostatic RCS and the field intensity was similar to that seen without gap-fill. However, in the case of V-pol, gap-fill could effectively reduce the monostatic RCS. The field intensity inside the groove channel was consistent with simulation results of monostatic RCS in V-pol, as predicted by the reflection coefficient.

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