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Optimum design method of a nano-composite radar absorbing structure considering dielectric properties in the X-band frequency range

Ilbeom Choi, Dongyoung Lee, Dai Gil Lee *

School of Mechanical Aerospace & Systems Engineering, KAIST (Korea Advanced Institute of Science and Technology) ME3221, 291 Daehak-ro, Yuseong-gu, Daejeon-shi 305-701, Republic of Korea

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ABSTRACT

A radar absorbing structure (RAS) is generally constructed using nano-composites composed of an E-glass/epoxy composite dispersed with carbonaceous conductive particles to improve the electromagnetic (EM) wave absorbing performance. The EM wave absorptance of the RAS is highly dependent on the dielectric properties of the nano-composite. Therefore, an optimum design method for RAS considering the dielectric properties and the EM wave absorbing characteristics should be established.

In this study, a theoretical method for the EM wave absorbing characteristics of nano-composite RAS was developed with respect to the dielectric properties of the nano-composites. Based on the theoretical investigation, an optimum design method for the RAS was developed. Then the RAS was constructed with the nano-composite composed of an E-glass/epoxy composite and carbon black and its EM wave absorbing performances were measured and compared to those obtained through theoretical calculations and numerical simulations.

1. Introduction

Stealth technology which is essential for national defense technologies, increases not only the survivability of a weapon system but also the operational performances in warfare. Stealth technology makes a weapon system less visible to detection systems such as radar antennae of adversaries. The possibility for a weapon system to be detected by a radar antenna is determined by the radar cross section (RCS) of the weapon system. The RCS is the power reflected or scattered by a radar target, which is the product of an effective area and a power density whose direction is back toward the radar [1]. Therefore, the reduction in the RCS of the weapon system is an important topic in the field of stealth technology.

In radar stealth technology, there are two major research areas with respect to the positions on the weapon systems where the stealth technologies are applied. The first area is the low-observable radome that is applied to the radar antenna system of the weapon system. The low-observable radome has an electromagnetic (EM) wave selectivity function whereby the EM wave of in-band frequency transmits to the radome structure, while the EM wave of out-of-band is reflected by the radome structure. Low-observable radomes were usually composed of either E-glass/epoxy or aramid/epoxy composites [2–4]. Recently, hybrid composites composed of both E-glass/epoxy and aramid/epoxy composites were adopted in low-observable radomes [5,6].

The second area is the shaping targets, applying radar absorbing materials (RAMs) and a radar absorbing structure (RAS) to the body of the weapon system [7–11]. Among these methods, the RAS is most effective as a result of both its load bearing and EM wave absorbing capabilities [11]. The RAS usually consists of a nano-composite composed of an E-glass/epoxy composite dispersed with carbonaceous conductive particles and a perfect electric conductor (PEC), as shown in Fig. 1. The carbonaceous conductive particles improve the EM wave absorbing characteristics of the RAS [11–14]. Since the EM wave absorptance of the RAS is highly dependent on the dielectric property of the nano-composite [11], the optimum design method should be established considering both the dielectric property of the nano-composite and the EM wave absorbing characteristics of the RAS.

In this study, a theoretical method for determining the EM wave absorbing characteristics of the nano-composite RAS was developed in the X-band frequency range (8.2–12.4 GHz). The reflection losses of the nano-composites were calculated using the commercially available software package MATLAB R2013a (MathWorks Inc., USA) and the variations in the EM wave absorbing characteristics were investigated with respect to the dielectric properties of the

* Corresponding author. Tel.: +82 42 350 3221; fax: +82 42 350 5221.
E-mail address: dglee@kaist.ac.kr (D.G. Lee).

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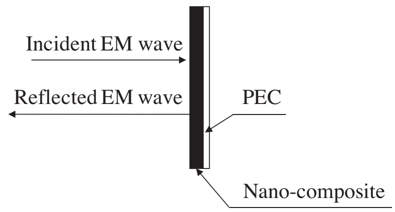

Fig. 1. Schematic diagram of the nano-composite RAS.

nano-composites. Based on the theoretical calculation and investigation, an optimum design method for the RAS was developed, whereby the effective design window and the lower and upper limits were determined. The nano-composites composed of the E-glass/epoxy composites and nano-size carbon black were fabricated with respect to the weight percents (wt.%) of the carbon black. The dielectric properties of the fabricated nano-composites were measured using a free space measurement system (HVS Technologies, Pennsylvania, USA). Finally, the RAS was designed and constructed using the nano-composite according to the optimum design method developed in this study. The EM wave absorbing characteristics such as the spectral profiles, maximum absorptance, average absorptance, and maximum absorbing frequency of the RAS were measured with the free space measurement method in the X-band frequency range and compared to those obtained through theoretical calculations and simulations with a 3-dimensional EM wave analysis software, CST Microwave Studio® (CST Gmbh, Germany).

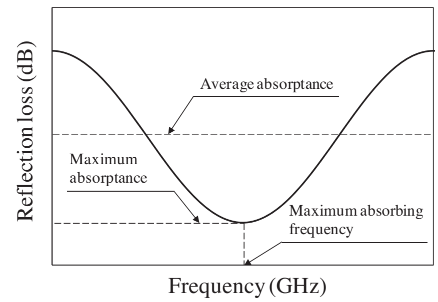

Fig. 3. Typical spectral profile of the reflection loss of the nano-composite RAS with the evaluation factors of the EM wave absorbing performance.

2. Theoretical approach on reflection loss of the nano-composite RAS

2.1. Reflection loss of the RAS

The EM wave absorbing performance of the nano-composite RAS is determined by the reflection loss of the EM wave. The energy loss of the EM wave is a result of the ohmic loss and the destructive interference. The ohmic loss occurs when the incident EM wave travels in the nano-composite and the destructive interference occurs when the reflected EM waves on the surface of the nano-composite and on the PEC have a quarter wavelength difference which is obtained by the thickness of the nano-composite

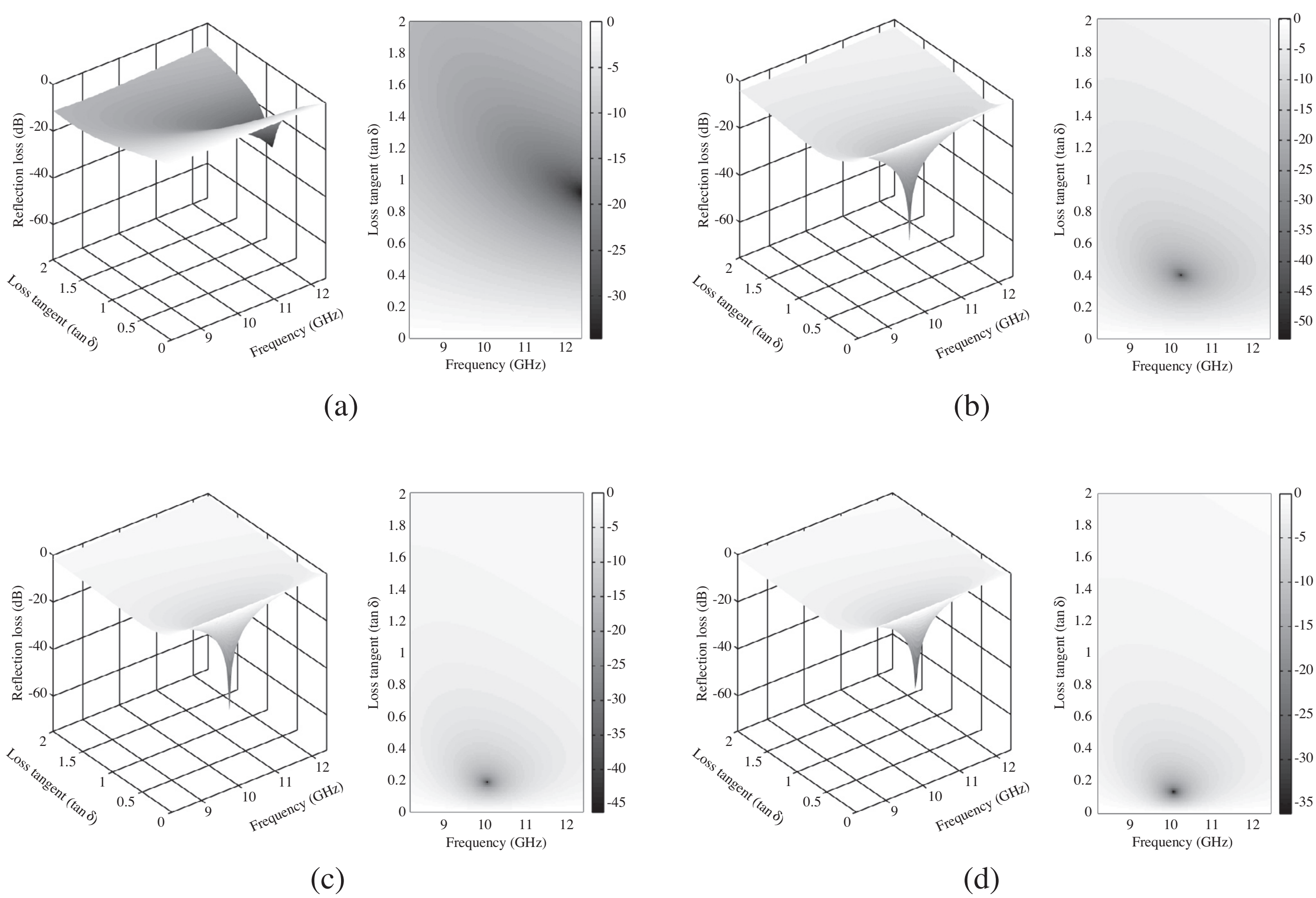

Fig. 2. Typical calculation results of the reflection losses with respect to the dielectric constants and the loss tangents: (a) $\varepsilon' = 1$; (b) $\varepsilon' = 10$; (c) $\varepsilon' = 50$; (d) $\varepsilon' = 100$.