Ferrite-Epoxy Absorber on Carbon Fiber Composite Substrate

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Abstract. Microwave absorbing properties of ferrite-epoxy absorbing layer attached to the carbon fiber polymer composite (reflective substrate) are analyzed on the basis of wave propagation theory. A modified equation for wave-impedance-matching at the front surface of absorbing layer including the effect of electrical properties of the semiconducting substrate is proposed. Based on this analysis, the frequency and layer dimension that produce zero-reflection can be estimated from the intrinsic material properties of absorbing layer and substrate.

1. INTRODUCTION

An important application of microwave absorber is the reduction of wave reflections from highly reflective surfaces. A metal plate of high electrical conduction is the typical example of the reflective substrate. A semiconducting plate of carbon fiber polymer composites exhibits still high microwave reflection because of its relatively high electrical conductivity [1]. In response to the need for reduction of microwave reflection from such a semiconducting substrate, this study has been directed toward the ferrite-epoxy absorber attached to the carbon fiber polymer composites.

2. DESIGN OF ABSORBER

A situation that a plane wave illuminates the microwave absorber attached by a substrate is shown in Fig.1(a). The situation is analogous to that of terminated transmission line as schematically shown in Fig.1(b), where Z_0 is free-space impedance (376.7Ω), Z_{a1} and Z_{a2} are characteristic impedance of substrate and absorber, and $Z_{in(1)}$ and $Z_{in(2)}$ are input impedance at the front surface of reflecting substrate and absorbing layer, respectively.

According to circuit theory, $Z_{in(1)}$ and $Z_{in(2)}$ are given by

$$Z_{in(1)} = Z_{a1} \times \frac{Z_0 + Z_{a1} \tanh \nu_1 d_1}{Z_{a1} + Z_0 \tanh \nu_1 d_1} \quad (1)$$

$$Z_{in(2)} = Z_{a2} \times \frac{Z_{in(1)} + Z_{a2} \tanh \nu_2 d_2}{Z_{a2} + Z_{in(1)} \tanh \nu_2 d_2} \quad (2)$$

where ν_1 and ν_2 are propagation constant, and d_1 and d_2 are layer thickness of substrate and absorbing layer, respectively. When the wave is incident normally on the absorber, the power reflectance, in decibels, is given by

$$\text{reflection loss} = 20 \log \left| \frac{Z_{in(2)} - Z_0}{Z_{in(2)} + Z_0} \right| \quad (3)$$

In the case of matched line ($Z_{in(2)} = Z_0$), no wave is reflected from the absorber. Since the characteristic impedance and propagation constant are a function of permeability (μ_r) and permittivity (ϵ_r) of the medium, the reflection loss can be calculated from the material parameters of the absorbing layer and substrate as a function of thickness.

Fig.1. (a) Plane wave incident normally on the absorber and (b) analogous transmission line.

3. EXPERIMENTALS AND DISCUSSION

The absorbing layer was prepared from the mixture of ferrite filler and epoxy resin. The stoichiometric compound of $(\text{Ni}_{0.4}\text{Zn}_{0.6}\text{O})(\text{Fe}_2\text{O}_3)$ was prepared by solid-state reaction at 1250°C in N_2 atmosphere. The ferrite content in the mixture was approximately 20 vol%. Commercially available carbon fiber-epoxy composites were used as a substrate material. The constituent materials of the composite were 8-harness fabric carbon fibers and epoxy resins. The complex permeability and dielectric constant were determined by reflection/transmission technique described in earlier paper [2].

Fig.2(a) shows the complex permeability ($\mu' - j\mu''$) and permittivity ($\epsilon' - j\epsilon''$) spectra of the ferrite-epoxy composite. μ_r' is nearly constant (about 1) and μ_r'' decreases as the frequency increases (0.63 at 4 GHz, 0 at 12 GHz). Nearly constant value of ϵ_r' and ϵ_r'' (4.6 and 0.3, respectively) are observed. Fig.2(b) shows the material constants spectra observed in the carbon fiber-epoxy composite specimen. High dielectric constant with considerable loss was observed in this specimen. The result is attributed to the high electrical conductivity of carbon fibers.

Fig.2. Complex permeability and permittivity of (a) ferrite-epoxy absorber and (b) carbon fiber composite substrate.

Fig.3(a) shows the thickness-dependence of microwave reflection calculated from the material constants of ferrite-epoxy composite on the assumption that the rear face of the sample is terminated by a metal. The reflection loss depends slightly on the layer thickness. However, the reflection loss is no less than -20 dB in the whole frequencies. For the same absorber attached on the carbon-fiber composite, the microwave absorbing properties are greatly improved as shown in Fig.3(b). As compared with the reflection loss of metal-backed absorber, a much reduced microwave reflectance is predicted. The reflection loss in this case is also dependent upon the thickness of absorbing layer. The most reduced reflection loss is predicted in the absorber 5 mm in thickness and at the frequency of 6.9 GHz. The substrate thickness is 2 mm.

Fig.3. Reflection loss determined in the ferrite-epoxy absorber terminated by (a) metal and (b) carbon fiber composite.

The improvement in microwave absorbance by replacing the metal substrate with the carbon-fiber composite is attributed to the non-zero impedance at the surface of the carbon-fiber composite. The input impedance at the surface of absorbing layer corrected by non-zero surface impedance of the substrate could be adjusted to be equal to the free-space impedance at a specified frequency and thickness. It can thus be suggested that the carbon-fiber composite with non-zero resistance is effectively used to improve the microwave absorbing properties of the front ferrite absorber.

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