Possibilities for the EM Absorber and Shielding by use of Metamaterials

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***Abstract*— Possibilities for the construction of EM absorbers and EM shielding by use of the metamaterials or artificial materials have been investigated. For the EM absorber, the input impedance matching can be achieved by use of its inverse frequency dependence in the double negative (DNG) media. An EM absorber which has a negative permittivity layer and a frequency selective shielding by use of the resonant characteristics of the artificial negative permittivity material have been developed by using a metallic fiber array composite.**

Key words: EM wave absorber, EM shielding, metamaterials

I. INTRODUCTION

The left-handed meta-material, which simultaneously has negative permeability and permittivity in the microwave frequency range, has been the subject of considerable interest. The peculiar propagation of electromagnetic waves such as the negative refraction can occur in this medium [1, 2]. In particular, the artificial materials composed of periodic transmission line structures have been studied in the view point of the new electromagnetic devices [3]. In the EMC technology, several investigations for the EM absorbers or shielding devices have been carried out considering the left-handed materials [4], [5].

Electromagnetic materials can be classified by the relative permeability μ_r and permittivity ε_r as shown in Fig.1.

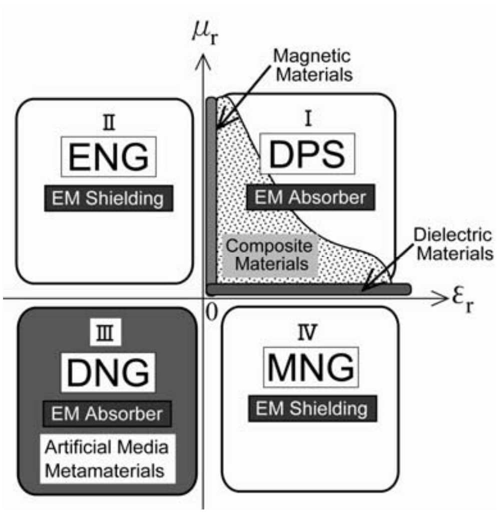

Fig. 1 Electromagnetic materials categorized by the permeability μ_r and the permittivity ε_r.

Conventional materials having positive μ_r and ε_r are categorized in the DPS (double positive) material. EMC devices using these magnetic and dielectric materials are widely used. Electromagnetic composite materials composed of the DPS material have broader characteristics in the μ_r - ε_r diagram [6]. On the other hand, MNG (Mu negative) and ENG (Epsilon negative) materials are known as the metal composites or the magnetic insulators (ferrites etc.) having a magnetic resonance. Since the EM wave can not propagate in these media, this property can be used to EM shielding. The last category is DNG (double negative) or left-handed materials; peculiar propagation of EM waves can be observed in this region. We have been investigating the magnetic and dielectric materials including the MNG and ENG materials for EMC applications [6], [7]. Unfortunately, the DNG material by use of the intrinsic magnetic and dielectric properties has not been obtained in this stage.

In this work, we have studied the possibility of a new EM absorber and EM shielding by use of the MNG, ENG and DNG materials. An EM absorber using an artificial ENG sheet combined with the conventional ferrite-rubber composite and the EM shielding by the layered ENG sheets will be presented.

II. DESGIN OF THE EM ABSORBER BY USE OF METAMATERIALS

A. Impedance matching in the single layer EM absorber by use of DNG material

We consider the impedance matching in the single layer EM absorber using a DNG material. The input impedance of the single layer EM absorber is given by the well-known formula as,

$$\boldsymbol{Z}_{in} = \sqrt{\frac{\mu_r}{\varepsilon_r}} \tanh \boldsymbol{j} \frac{\omega}{\boldsymbol{c}} \sqrt{\varepsilon_r \mu_r}\, \boldsymbol{d} \cdot \qquad (1)$$

Here ω, c and d are the angular frequency of EM wave, the speed of light in free space, and the layer thickness, respectively. When the μ_r and ε_r have a negative value, Z_{in} becomes real, and the impedance matching between the DNG material and the free space can be achieved. The calculated matching characteristics of the EM absorber under several ε_r

values are shown in Fig.2, where d = 4 mm, μ_r = -2.0 – j5.0, respectively. In this case, the matching condition is satisfied when ε_r = -3.6 – j5.0 at the frequency of 2.05 GHz. Thus, it is possible to establish the impedance matching by use of DNG media alone.

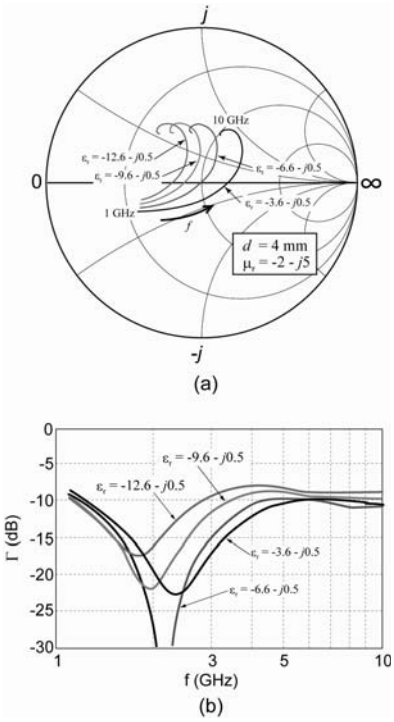

Fig. 2 Impedance matching in the single layer EM absorber by DNG materials.

B. Frequency characteristics of the input impedance of a layered DNG and DPS absorber

Here, we discuss the input impedance Z_{in} of a single layer on the metal plane. The propagation constant γ of the DNG media in which the imaginary components of the permeability and permittivity are assumed to be zero i.e. ε_r" = μ_r" = 0. Generally, the frequency dependence of the reactance X in Z_{in} of the materials is positive, $dX/d\omega > 0$ for the normal media, or DPS. On the other hand, if both ε_r' and μ_r' have negative values, or DNG, the relationship $dX/d\omega < 0$ can be obtained. This is easily confirmed by the following example.

Considering that a thin magnetic material (thickness d) is placed on the short plane, and d is small enough compared to the wave length, ($d \ll \lambda$), the Z_{in} can be approximated by $\boldsymbol{Z_{in} = jX = j\omega\mu_0\mu_r'd}$, which shows $dX/d\omega < 0$ when $\mu_r' < 0$. The relationship, $dX/d\omega < 0$, is maintained in the range where the layer thickness d is not so small. The Z_{in} values for DPS ($dX/d\omega > 0$) and for DNG ($dX/d\omega < 0$) materials are plotted at several frequencies in Fig.3. Frequency dependence of Z_{in} for DPS and DNG is in opposite each other, that gives us the hint how to construct the wide-band absorber. If DPS and DNG layers are piled up on the metal plate, the total input impedance contains both the frequency dependence of $dX/d\omega < 0$ and $dX/d\omega > 0$, that indicates the input impedance of this structure has less sensitive for frequency compared to the DPS, or DNG, single layer. Thus, once the matching condition is obtained, it can be maintained over a wide frequency range.

As an example, the absorbing characteristics of a double layered EM absorber designed by use of DNG and DPS material were calculated. Figure 4 shows a conventional single layer EM absorber (A) and the double layered absorber having DNG and DPS layers (B). Thickness and material

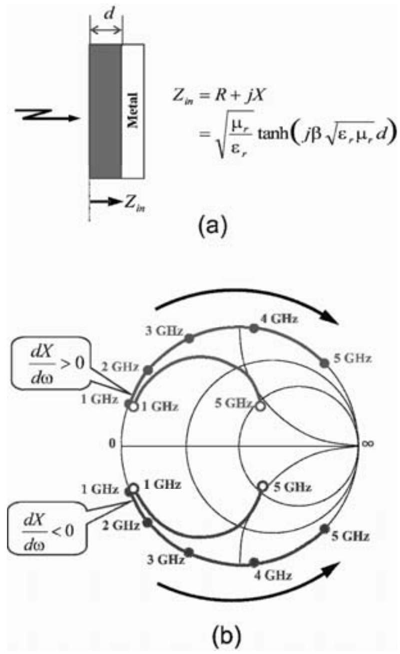

Fig. 3 Frequency dependence of Xs in Z_{in} for DPS and DNG materials.

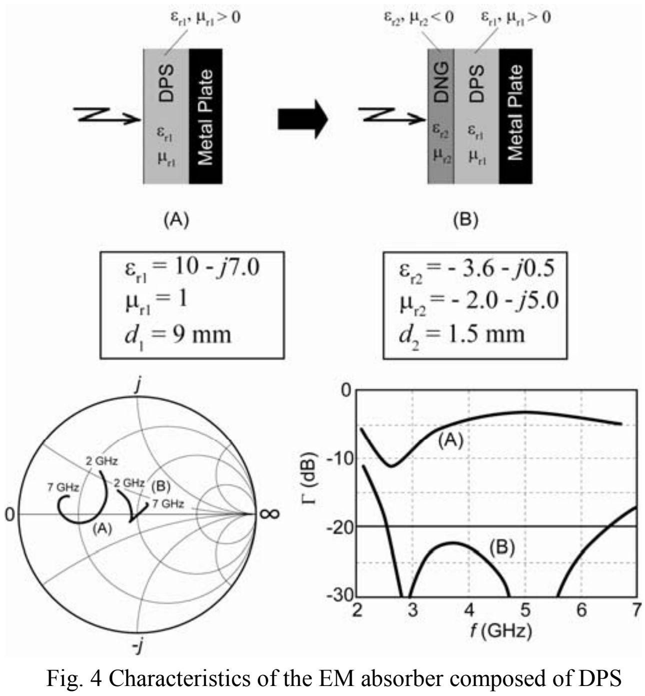

Fig. 4 Characteristics of the EM absorber composed of DPS and DNG layers.

parameters for the absorbers are d = 4 mm, ε_r = 10 – j7.0 and μ_r = 1 for DPS layer, d = 1.5 mm, ε_r = -3.6 – j0.5 and μ_r = -2.0 – j0.5 for DNG layer as shown in Fig.4. The calculated absorbing characteristics, impedance Z_{in} and reflectivity Γ, in the frequency range from 2 to 7 GHz indicate the wide band EM absorbing characteristic can be obtained by adding a thin DNG layer on the DPS absorber.

C. Metal fiber Array (MFA) Composite for ENG material

As an artificial ENG material, the relative permittivity of the two dimensional thin metal fiber array (MFA) composite was studied. Constructed MFA composite is composed of silver coated short length metallic fibers and polyethylene transparent sheet as shown in Fig.5 (a); the fibers are periodically aligned between the two polyethylene sheets and the thickness is 235 μm. The schematic structure of MFA composite is shown in Fig.5 (b), where L is the length of the metallic fiber, S is the horizontal gap between fibers and D is the distance combined the fiber length and the vertical gap. The relative permittivity ε_r spectra of MFA composite show a dielectric resonance character in the microwave range and negative permittivity ε_r' is observed above f_0 = 9.0 GHz.

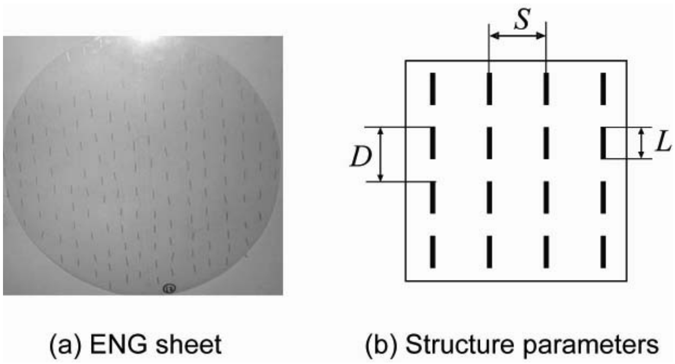

Fig. 5 Artificial ENG material composed of silver coated fibers (a) and the structure parameters of the ENG sheet.

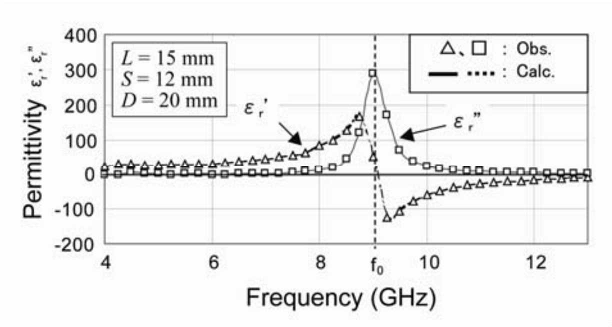

Fig. 6 Relative permittivity spectra of an artificial ENG sheet. The structure parameters L = 15 mm, S = 12 mm, D = 20 mm.

D. EM Absorber Using the Artificial ENG Sheet

An EM absorber composed of the ENG sheet and a ferrite rubber composite material (ENG-FR Composite) has been constructed and the EM absorbing characteristics were evaluated. Ferrite content in the ferrite-rubber composite is 40 wt. %. The structure of the absorber and the parameters of the ENG sheet are shown in Fig.7 (a). In Fig. 7 (b), Y_L and Y_{in} are input admittances at the ferrite rubber surface and MFA sheet surface, respectively. Note that Y_{in} stays around the chart center over a wide frequency range, which corresponds to the permittivity resonance region shown in Fig.6. As shown in Fig.7 (c), the matching condition was achieved over a relatively wide-band compared to the conventional single ferrite-rubber layer absorber. Though there is no DNG material for EM absorbers as far as we know, MNG or ENG materials are available [7], [8]. Thus, approaches to construct the new EM absorber by use of these materials are required.

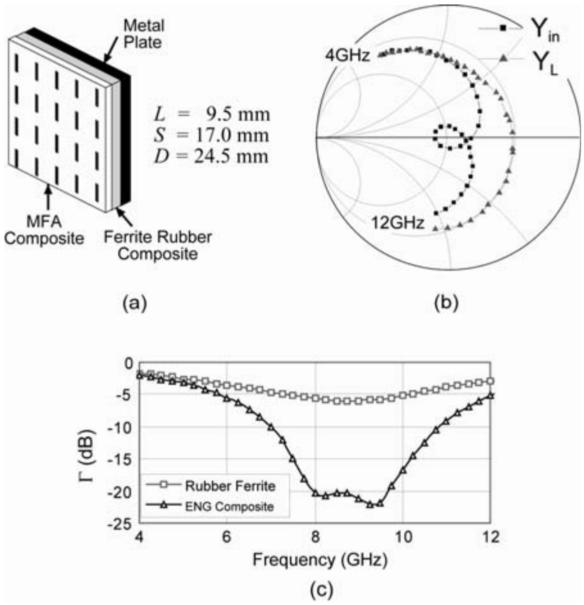

Fig. 7 EM absorber composed of the ENG sheet and a ferrite rubber composite material (a), input admittance (b) and the EM absorbing characteristics.

III. Frequency Selective Shielding by Use of the Artificial ENG Sheet

A. Frequency Selective Shielding by use of Resonant Type ENG or MNG Materials

As discussed above, the EM wave can not propagate in the ENG and MNG media where an evanescent wave is observed. Since the ENG or MNG materials, which have a resonance type negative permittivity or permeability, behave as the evanescent wave media in a certain frequency ranges. Further, in the resonant frequency range, magnetic or dielectric loss ε_r" and μ_r" have a maximum and large values; EM waves are reflected at the surface or attenuated in the media. From these phenomena, a concept of the frequency selective shielding can be considered. Shielding frequency bands can be controlled by combining several materials having the different ENG or MNG frequency.

The magnetic resonance in complex permeability spectra which can be seen in YIG (Yttrium Iron Garnet) under external magnetic field can be used for this purpose [9], however, in this paper, we propose the MFA composite as an ENG material application for frequency selective shielding.

B. Frequency Selective Shielding Using MFA Composites

By using the MFA composites, we have evaluated the transmission coefficients of EM waves. The structure of the shielding unit composed of three MFA composite sheets is shown in Fig. 8 (a). The distance between three MFA sheets is adjusted to 7 mm using polystyrene foam inserts. The shielding characteristics were estimated by the transmission line theory. The transmission line model of (a) is shown in (b), where MFA composite sheets A, B, C are denoted by the shunt admittances, Y1, Y2, and Y3, respectively.

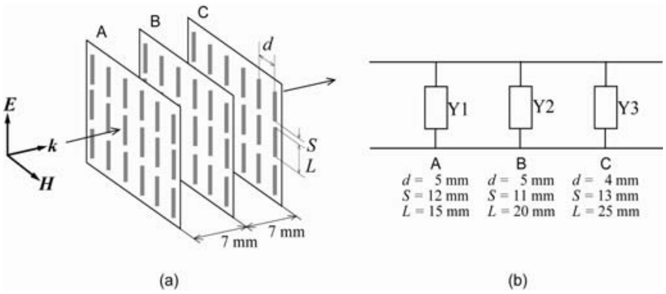

Fig. 8 Schematic diagram of the frequency selective shielding sheet using MFA composites (a) and its equivalent circuit (b).

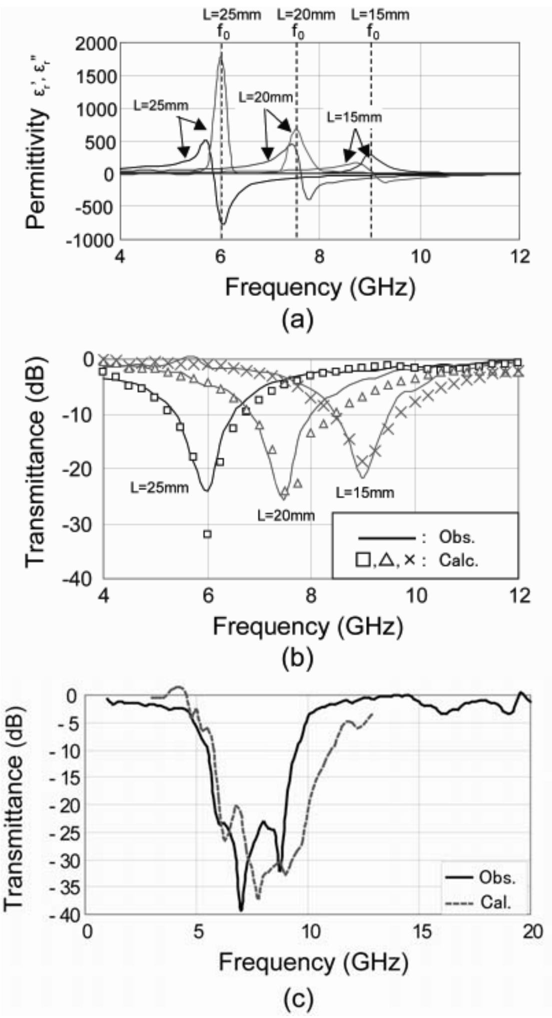

Fig. 9 Relative permittivity spectra for MFA (a), the transmission coefficients for each MFA (b), and the transmission coefficients for the 3-layers structure (c).

Relative complex permittivity for the each MFA composites is shown together in Fig. 9 (a) as a function of frequency. Three different dielectric resonances can be seen in the frequency range from 4 GHz to 12 GHz. In the resonant frequency region, the negative ε_r’ and a large ε_r” peak is observed. The transmission of EM wave for each MFA sheet is shown in Fig. 9 (b). Three stop bands where the transmission is below -20 dB can be obtained. The calculation curves (solid lines) were obtained from the observed relative permittivity spectra.

The EM wave shielding characteristic of the triple MFA composite structure is shown in Fig. 9 (c). The stop band is spread and the frequency range where the transmittance is below -20 dB locates from about 4.8 GHz to 9.6 GHz. The difference between the calculation and observation curves can be caused by the interference effect between MFA sheets due to the short distance between them.

IV. SUMMARY

Design and constructions of the new EM absorber and EM shielding by use of the left-handed metamaterial or artificial materials were discussed. By using the EM wave characteristics in the DNG media, impedance matching can be achieved by the different way. The evanescent wave properties in the ENG or MNG media can be used for the frequency selective EM shielding.

For further investigations, development of DNG materials which are composed of MFA composite and MNG magnetic materials is now in progress.

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