Radio-Frequency Field Distribution Incident on a Finite Size Thin Metamaterial Absorber

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***Abstract*— A finite size thin metamaterial absorber is used to measure the field distributions incident on its surface. Absorption is realized by lumped resistors interconnecting the surface patches arranged on a grounded substrate at the resonance frequency of the absorber structure. The 2-d distributions of the absorbed power and electric field distributions are obtained by measuring the voltages induced on the lumped resistors. When using a finite size absorber, the measurement accuracy is degraded over the entire surface because of edge scattering, which creates an interference pattern due to a scattered wave overlapping with the incident wave. It is shown that the edge scattering can be suppressed by removing the part of patches at the edges which does not contribute to incident wave absorption from the viewpoint of receiving cross-section. Suppression of edge scattering is achieved for the incident waves with a single polarization as well as with both polarizations. This technique should be useful to accurately measure the incident field distributions absorbed by a thin metamaterial absorber.**

***Keywords*— thin metamaterial absorber; measurement of field distribution; supression of edge scattering**

I. INTRODUCTION

A variety of thin absorbers has been designed employing metasurface; e.g. an array of 2-d mushroom-type unit cells with square metal patches are formed on a thin dielectric substrate to obtain an artificial magnetic conductor (AMC) feature at the resonance frequency. Absorption is achieved for example by the lumped resistors inserted between the adjacent patches, which are matched with the free space impedance at the resonance frequency [1]. As a new application, it was proposed that this kind of AMC absorber could be used for monitoring 2-d field distributions of a radio-frequency (RF) wave incident on the absorber surface [2][3]. Fig. 1 illustrates the configuration of the absorber. Here the gap between the patches is much smaller than the patch width, $g << w$, so that the cell periodicity $a = w + g \sim w$. Varactor diodes are inserted parallel to the resisters to make the resonance (absorption) frequency tunable. The power absorbed by each resistor is dependent on the incident polarization; the amounts of RF power with its electric field polarized in the x- and y-directions, E_x and E_y, are absorbed by the resistors in the x- and y-directions, R_x and R_y. When the incident power is completely absorbed, the power consumed by these resistors, P_x and P_y, should be equal to "the Poynting flux of the incident wave" times "the area of one unit cell:" $P_x = E_x^2 a^2/2\eta_0$ and $P_y = E_y^2 a^2/2\eta_0$, where a^2 is the receiving cross-sectional area of each resistor, and η_0 is the free-space wave impedance. The voltages induced on these resistors become $V_x = (2P_xR_x)^{1/2} = E_x a$ and $V_y = (2P_yR_y)^{1/2} = E_y a$. Thus, by measuring the voltages induced on the resistors, the amplitude, phase and polarization of the incident electric field can exactly be measured [3].

When the absorber has a finite size, an incident wave cannot be absorbed uniformly on its surface, because the scattered field from the absorber edges interferes with the incident field distribution. In the previous study, 2-d distributions of the incident electric field to be measured by a finite size absorber were evaluated using simulation with a simple model, where the lumped resistors 377 Ω were inserted between the surface patches on a loss-free substrate [3]. The electric field distribution calculated from the voltages induced on the surface resistors exhibited a non-uniform interference pattern caused by edge scattering of the incident wave.

In this study, we propose a technique to suppress the undesired edge scattering and reduce the interference on the field distribution, by using a more realistic absorber model with additional lumped capacitors and a substrate loss included as in Fig. 1 [1]. It is expected that incident field distributions should become measurable more accurately with the technique.

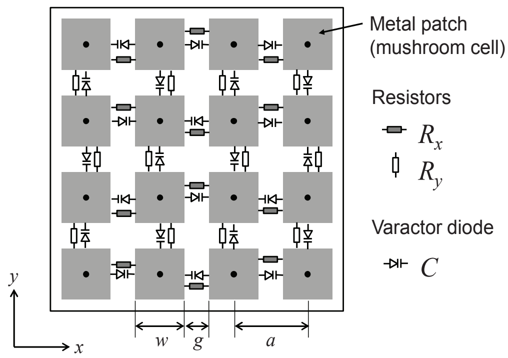

Fig. 1. Structure of a thin metamaterial absorber for RF field measurement.

II. FIELD DISTRIBUTION INCIDENT ON A FINITE SIZE ABSORBER

A finite size thin metamaterial absorber analyzed in this study has the following parameters. The size of a square patch, the gap between the adjacent patches, and the cell periodicity were respectively w = 10 mm, g = 0.5 mm, and a = 10.5 mm. The thickness, the dielectric constant and loss (tanδ) of a substrate were 1.6 mm, 4.56 and 0.023. The lumped resistors R = 470 Ω and capacitors C = 1.0 pF were inserted between each adjacent pair of 15 by 15 cells formed on a 15.7 cm by 15.7 cm square substrate. Using this model, EM simulations were performed with CST Microwave Studio commercial software.

A plane wave with its electric field of 1.0 V/m polarized in the y-direction was incident vertically onto the absorber. On the basis of the voltages and currents induced on the lumped resistors, the 2-d distributions of the incident electric field and the absorbed power distribution were calculated. Fig. 2 plots the reflection coefficient (S_{11}) of the absorber. At a resonance frequency of 2.4 GHz, S_{11} = -20 dB was achieved for a finite size absorber as shown by a red dashed line. For reference, a blue solid curve plots the reflection for an infinite size absorber, which were computed with a periodic cell model. Fig. 3 (a) shows the absorbed power distribution (P_y) on the absorber surface at 2.4 GHz, which was calculated using the voltage and current induced on each resistor mounted in the y-direction (R_y). The power consumed by the orghogonal resistors R_x was negligibly small. Fig. 3 (b) shows the distribution of the incident electric field E_y calculated from the voltages (V_y) induced on the resistors R_y, as $E_y = V_y/a$. The P_y and E_y were normalized by the theoretical values, i.e. the Poynting flux and electric field intensity of the incident wave itself. In Fig. 3 (a), only 30% of the incident power is absorbed at the upper and lower edges of the absorber, whereas it fluctuated by +/-25% over the surface. The similar feature was observed in the electric field distribution in Fig. 3 (b); the field intensity exhibited an undulating pattern with a salient decrease at the upper and lower edges. This indicates that large scattering occurred at the upper and lower edges. On the other hand, both distributions showed less deviation at the right and left edges, so that there might be less scattering there. For accurate measurement of field distributions on the absorber surface, it is necessary to suppress such edge scattering, which might cause the non-uniform interference with the incident field distribution.

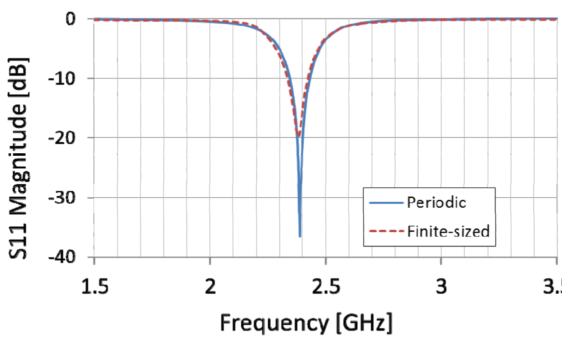

Fig. 2. Reflection characteristics of the absorber for the normal incidence of a plane wave.

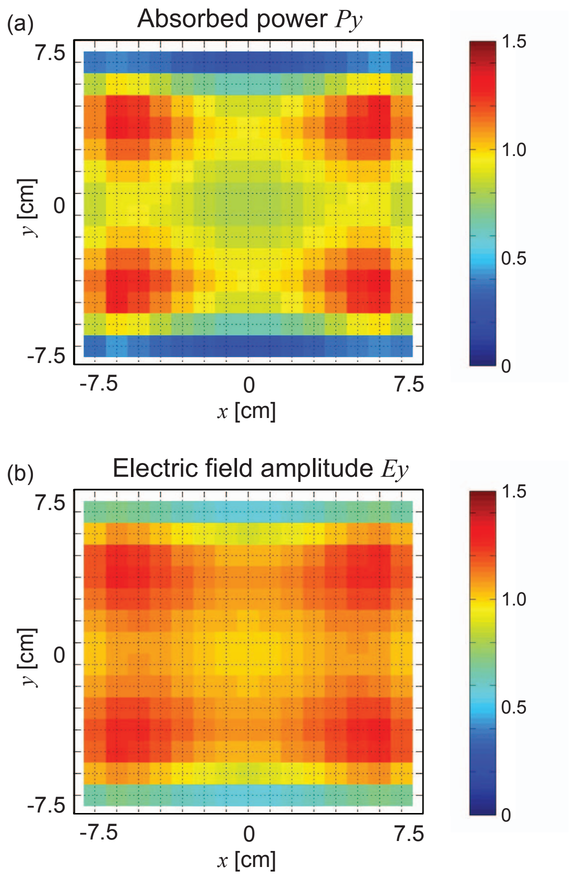

Fig. 3. Two-dimensional distributions of (a) absorbed power and (b) electric field amplitude, calculated from the voltages induced on the resistors.

III. SUPPRESSION OF EDGE SCATTERING FOR SINGLE POLARIZATION INCIDENCE

Fig. 4 illustrates the receiving cross-sectional areas of each resistor on the lower-right corner of the absorber surface. The power of an incident E_y-polarization is absorbed by each resistor R_y on the receiving cross-sectional area centered at the resistor. At the right edge of the surface, the receiving area should be given by a red square on the rightmost patches in Fig. 4. On the other hand, at the lower edge the receiving area becomes as shown by a green square, which makes the lower half of the patches not contribute to the absorption (a blue rectangle). Such a simple interpretation explains why the upper and lower edges caused larger scattering, whereas the right and left edges gave less, as in Fig. 3. A simulation was performed to confirm if it is possible to suppress the reflection when we remove the half area (a blue rectangle in Fig. 4) on each of the uppermost and lowermost patches, which may not contribute to the absorption. Fig. 5 (a) shows the power distribution P_y absorbed by such a modified absorber. The absorption was dramatically improved at the upper and lower edges. Though the interference pattern was still observed on the field distribution, the deviation from the incident power became less than +/-20%, improving compared with Fig. 3 (a). In Fig. 5 (b), similar improvement was obtained for the electric field distribution. Thus, it is expected that the edge reflection can be suppressed by removing the half areas of the uppermost and lowermost patches for E_y-polarization incidence.

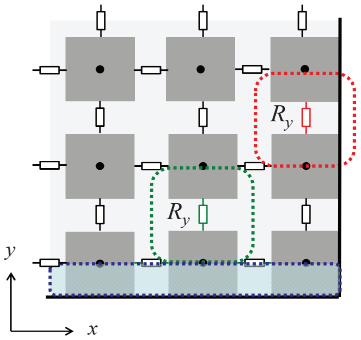

Fig. 4. Receiving cross-sectional areas by the resistors between the surface patches around the lower-right corner of the absorber.

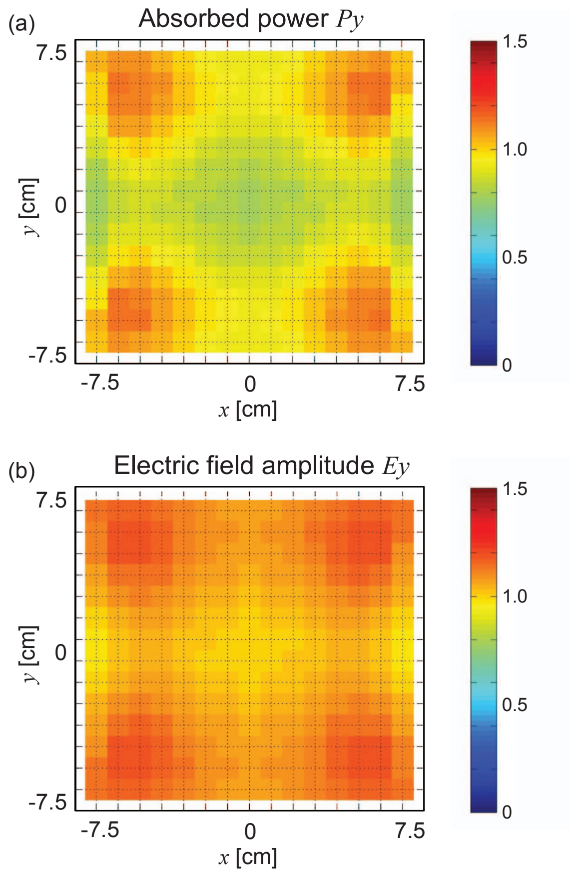

Fig. 5. Two-dimensional distributions of (a) absorbed power and (b) electric field amplitude, for a modified absorber with removing the half areas of uppermost and lowermost patches.

IV. Suppression of Edge Scattering for Both Polarizations

In the previous section, we have shown that the E_y-polarization could be uniformly absorbed by removing the half areas of the uppermost and lowermost patches, suppressing the undesired edge scattering there. For the E_x-polarization to be uniformly absorbed, the rightmost and leftmost patches should be modified in the similar manner. However, when we have no information on the incident polarization, both E_x- and E_y-polarizations need to be absorbed. If we remove the half areas of the patches at all of the four edges of the absorber surface, the following problem would arise.

Consider again an E_y-polarization incident on the absorber in Fig. 6. If we remove half of the rightmost patches, the receiving cross-sectional area becomes half of the original one (a red rectangle). In this case the effective inductance and capacitance, L_S and C_S coming from the AMC structure, roughly speaking, change to $2L_S$ and $C_S/2$, respectively. As the resonance (absorption) frequency is given by $f_R = 1/2\pi(L_s(C_s+C))^{1/2}$, the additional capacitor C should be modified to $C/2$, for the resonance frequency unaltered. More accurately, it is necessary to consider the exact variation in C_S with patch size [4][5] along with edge effects, as well as to include the influence of the parasitic components of C [1]. In this study, a couple of simulations were performed to determine the value of C which gives the most uniform field distribution on the absorber surface. The value of the resistors R was determined by another simulation using an infinite size absorber model so that the surface impedance becomes 377 Ω. Fig. 7 shows the power and field distributions obtained in a simulation performed with the values of the elements along the four edges changed to $C = 0.75$ pF and $R = 940$ Ω. An E_y-polarization was incident. In Fig. 7 (a), the absorbed power showed the fluctuation less than +/-20%, except at the four corners where absorption is increased. It is noted that the absorbed power at the rightmost and leftmost resistors was doubled in this display, as the receiving cross-sectional area became half of the original one (see Fig.6). Fig. 7 (b) gives the similar feature in the electric field amplitude with the fluctuation less than +/-10%, again except at the four corners. From this result it is expected that both the x- and y-polarizations can be uniformly absorbed except at the four corners. It would be possible to obtain a more uniform distribution by elaborating the optimum values of C and R around the four corners.

V. Conclusion

In this study, we have proposed a technique which suppresses the undesired edge scattering of a thin metamaterial absorber, to obtain a uniform distribution of an incident wave field. It has been confirmed that removing half of the areas of surface patches along the four edges, which does not contribute to the wave absorption, effectively reduces the edge scattering for a single polarization. When both polarizations are incident, adjustment in the additional capacitors and resistors along the edges can improve the uniform absorption of the incident wave, except at the four corners.

It is necessary to suppress the scattering from the four corners, to realize more effective absorption. We will also need to analyze the absorption characteristics for oblique incidence as well as for spherical incidence.

Acknowledgment

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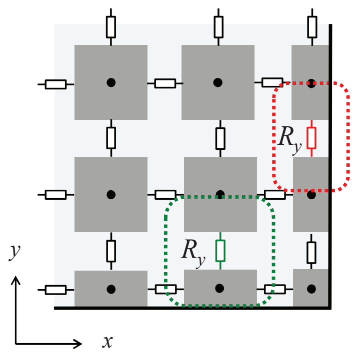

Fig. 6. Receiving cross-sectional areas by the resistors between the surface patches around the lower-right corner of a modified absorber with removing the half areas of uppermost and lowermost patches.

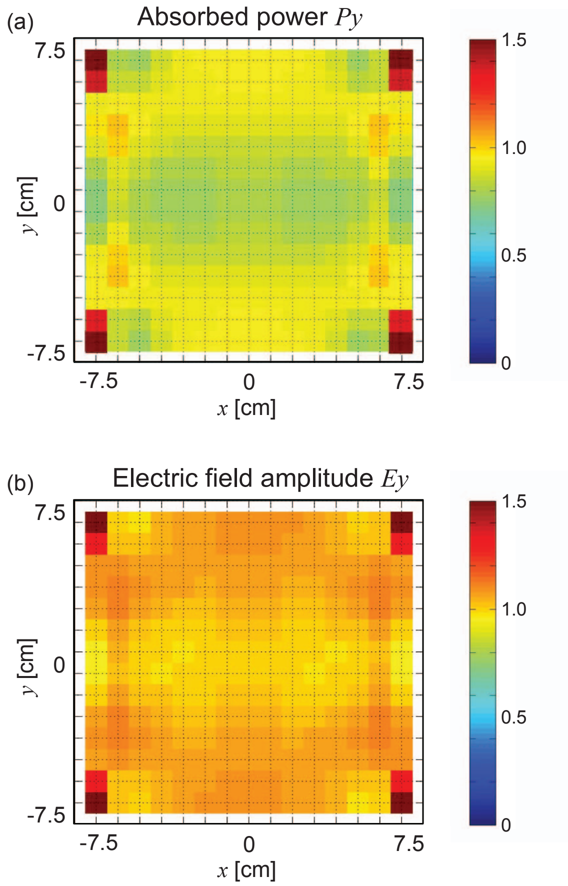

Fig. 7. Two-dimensional distributions of (a) absorbed power and (b) electric field amplitude, for a modified absorber with removing the half areas of the patches along the four edges.