Radio-Frequency Power Distribution Measurement System Using Thin Metamaterial Absorber

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***Abstract*—A radio-frequency (RF) power distribution measurement system is developed. The 2-d distribution of an incident RF power is measured on the surface of a finite size metamaterial absorbers, which is designed to suppress undesired edge scattering. The system is evaluated by the measurement of an RF wave transmitted from a dipole antenna. The measured distributions of incident RF power are consistent with those obtained by EM simulations, demonstrating practical effectiveness of the technique to measure RF power distributions.**

Keywords— thin metamaterial absorber; radio-frequency power distribution; measurement system

I. Introduction

There have been realized a variety of thin radio-frequency (RF) absorbers with metasurfaces working as artificial magnetic conductors. It was proposed that such a metamaterial absorber could be used for sensing a 2-d distribution of a radio-frequency (RF) power incident on the absorber surface [1]. By employing an array of mushroom-type unit cells with square metal patches formed on a thin dielectric substrate, an incident RF wave was absorbed by the lumped resistors inserted between the adjacent patches, which were matched with the free space impedance at the resonance frequency. The distributions of an incident and absorbed RF field (amplitude and phase) were shown to be monitored by measuring voltages and phases induced on the individual lumped resistors [2]. Fig. 1 illustrates the configuration of such an "RF sensing absorber." Lumped capacitors (C) and resistors (R_x and R_y) are placed to interconnect the surface patches; C are used to make the resonance (absorption) frequency tunable, whereas R_x and R_y absorb incident x- and y-polarizations, respectively [1]. This kind of RF sensing metamaterial absorber was recently used to detect the direction-of-arrival of an incoming RF wave through a Lüneberg lens [3].

When the absorber has a finite size, an incident field distribution cannot be measured correctly on the surface, because the scattered field from the absorber edges interferes with the incident field distribution. In the previous study [4], we proposed a technique which suppresses the undesired edge scattering of a thin metamaterial absorber, to obtain and measure a uniform distribution for an incident plane wave field. It was confirmed that removing half of the areas of square patches along the four edges (see Fig. 1), which did not contribute to the wave absorption, effectively reduced the edge scattering for both polarizations of an incident wave. The technique was validated by simulation.

In this study, a finite size metamaterial absorber with reduced edge scattering was designed and fabricated, which was used to develop an RF power distribution measurement system. The system was evaluated by the measurement of an RF wave transmitted from a dipole antenna.

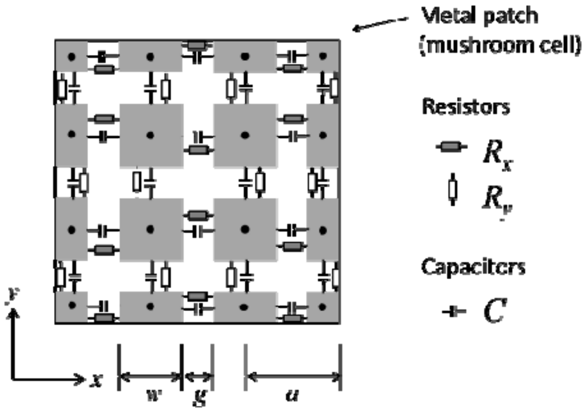

Fig. 1. Structure of a metamaterial absorber for RF field measurement

II. Absorption Characteristics of the Fabricated Metamaterial Absorber

A metamaterial absorber as shown in Fig. 1 was designed and fabricated. Its geometrical and constitutive parameters were determined to give a resonance (absorption) frequency of 2.44 GHz, by using electromagnetic (EM) simulations performed with CST Microwave Studio commercial software. The size of a square patch, the gap between the adjacent patches, and the cell periodicity were set as w = 10 mm, g = 0.5 mm, and a = 10.5 mm, respectively. An array of 30 by 30 patches were formed on a 30 cm by 30 cm square substrate, whose thickness, dielectric constant and loss (tanδ) were 1.6 mm, 4.56 and 0.023. The lumped resistors $R_x = R_y$ = 470 Ω and capacitors C = 1.2 pF were inserted between each pair of the adjacent patches. According to [4], the half areas of the outermost patches were removed, for which the values of the elements were changed to $C' = 0.9$ pF and $R' = 560\ \Omega$, so that the absorbed power distribution in the simulation became as uniform as possible over the surface for a plane wave incidence.

The performance of the fabricated absorber for a normal incidence was evaluated by means of a free space reflection method, where reflection loss measurement was carried out using a vector network analyzer and a double ridged waveguide horn antenna as in [1]. An orange solid curve in Fig. 2 plots the measured reflection coefficient (S_{11}) of the absorber. At a resonance frequency of 2.44 GHz, $S_{11} = -17$ dB was achieved. The measured profile practically agreed with those computed by simulations with a periodic (infinitely extending) absorber (a blue solid curve) and a finite size absorber (a red dashed curve).

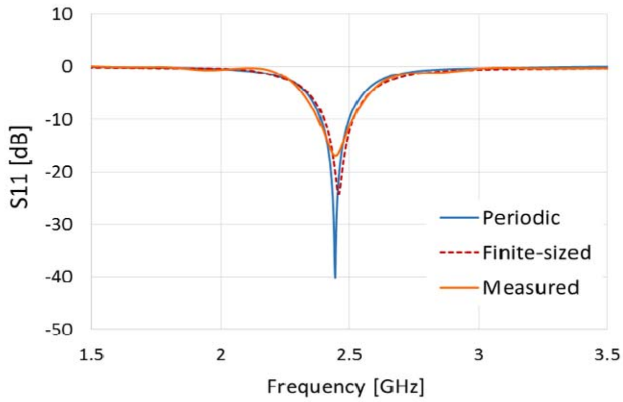

Fig. 2. Reflection characteristics of the absorber for normal incidence of a plane wave

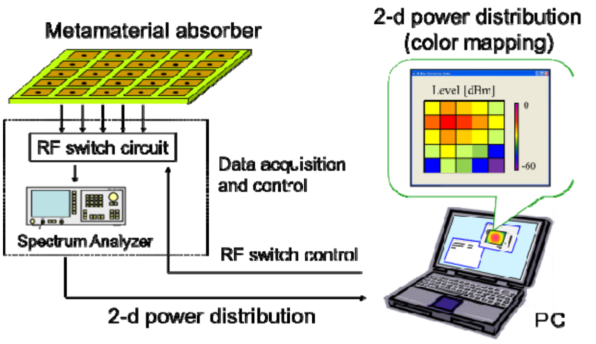

Fig. 3. RF power distribution measurement system.

III. RF Power Distribution Measurement System

We have developed an RF power distribution measurement system by using the fabricated metamaterial absorber, as illustrated in Fig. 3. An RF wave incident on the absorber was measured at 64 (a matrix of 8 by 8) points uniformly distributed on the surface, at each of which two RF signals for x- and y-polarizations were picked up on the backside. A total of 128 RF signals were sequentially selected by an RF switch array and fed to a spectrum analyzer. The measured signals were then transferred to a PC and displayed as a 2-d color-map image of the incident RF power distribution. This system had the measurable incident RF power down to −100 dBm, which had been greatly improved from our preliminary RF imaging system using power detectors with the sensitivity of −70 dBm in [1]. Color-map images were acquired with about 10 frames per second.

IV. Measurement Results

The developed RF distribution measurement system was used to measure RF power distributions radiated from a dipole antenna. Fig. 4 illustrates an experimental setup. An RF wave (2.44 GHz, 0 dBm) was transmitted from a standard dipole antenna with a horizontal (x- or z-) polarization in an anechoic chamber, and absorbed by the metamaterial absorber put on a vertical (x-y) plane at a distance d from the transmitter (TX). The received power at each measurement point was calibrated by an almost far-field and plane wave pattern, created by the transmitting antenna placed at $d = 80$ cm.

Fig. 5 (a) shows the absorbed power distribution of horizontal polarization (P_x) transmitted from an x-directed dipole (the dipole axis parallel to the absorber surface) and measured on the absorber at $d = 10$ cm, whereas Fig. 5 (b) plots the power distribution computed by an EM simulation using the finite size absorber [2]. The measured distribution is practically consistent with the simulated profile. In both the measurement and simulation, the power distribution exhibited an elliptic pattern corresponding to the directivity of the horizontal dipole. A small enhancement at the upper and lower edges of the absorber represented to the edge reflection, which has not been completely suppressed. Figs. 5 (c) and (d) show the measured and simulated power profiles along the x- and y-directions respectively shown by dotted lines in Figs. 5 (a) and (b). In each figure the simulated and measured profiles at the distances of 10, 20, 30 and 60 cm from the transmitter are shown by red, blue, green and purple curves and symbols, respectively. The measured values practically agree with those predicted by the simulation.

Fig. 6 shows the similar comparison between measurement and simulation, for the case of a z-directed dipole transmitter (perpendicular to the absorber surface). Here the total power of x- and y-polarizations ($P_x + P_y$) transmitted from an z-directed dipole (perpendicular to the absorber surface) were plotted. In Figs. 6 (a) and (b) donut-shaped distributions were created by the figure-of-eight directivity of the z-directed dipole at $d = 10$ cm. As shown in Figs. 6 (c) and (d), the measured profiles were consistent with simulation at $d = 10$ cm and 20 cm, but the difference between them increased with distance (30 cm and 60 cm). This was likely to be caused by undesired reflection and scattering from antenna poles and cables extended along the $+y$-direction as shown in Fig. 4 (b), which could have interfered with relatively weak received signals at $d > 30$ cm.

Thus RF power distributions incident on the metamaterial absorber are expected to be effectively measured by the developed system. It should be noted that, however, for large oblique incidence angles reflection increases so that absorption decreases, and even the resonance (absorption) frequency change depending of TE and TM incidence [5]. In this case the measured RF power will become smaller than the true value. Absorption efficiency and measurement accuracy for oblique or spherical incidence [6] should be investigated more quantitatively, which is left as a future study.

V. CONCLUSION

In this study, we have developed a 2-d RF power distribution measurement system using a thin metamaterial absorber designed to suppress undesired scattering from the edges. For RF waves transmitted from a standard dipole antenna, the power distributions incident on the absorber surface were measured to be consistent with those expected by simulation, which indicates practical effectiveness of the technique to measure RF power distributions.

In the developed system, received power levels are required to be large enough to be detected (−100 dBm). This would be used, for example, for evaluating the directionality of an antenna (−40 dBm or larger) installed on a wireless communication device used in real environments, by measuring the radiated spherical RF field distribution at a distance of 60 cm away from the device.

We are extending the system to obtain phase distributions in addition to the power (amplitude) distributions. This will enable us to estimate the direction-of-arrivals and even the source locations of RF signals.

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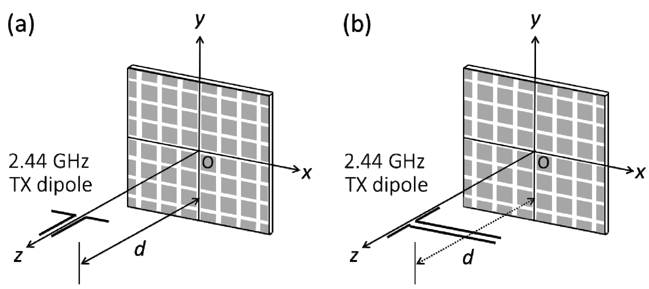

Fig. 4. Measurement setup of RF power radiated from (a) an x-directed dipole antenna, and (b) a z-directed dipole antenna.

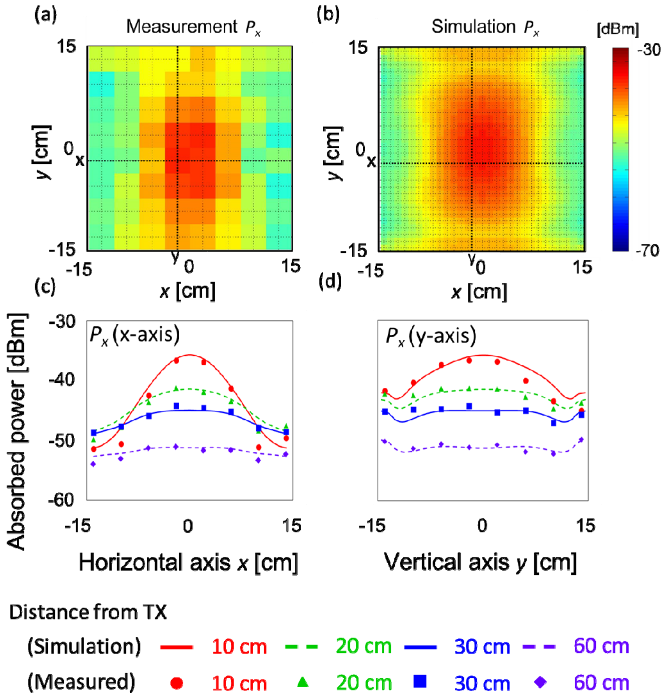

Fig. 5. RF power distributions measured on the absorber surface transmitted from an x-directed dipole: (a) 2-d measured distribution, (b) 2-d simulated distribution, (c) comparison between measured and simulated profiles along the x-direction, and (d) the same along the y-direction.

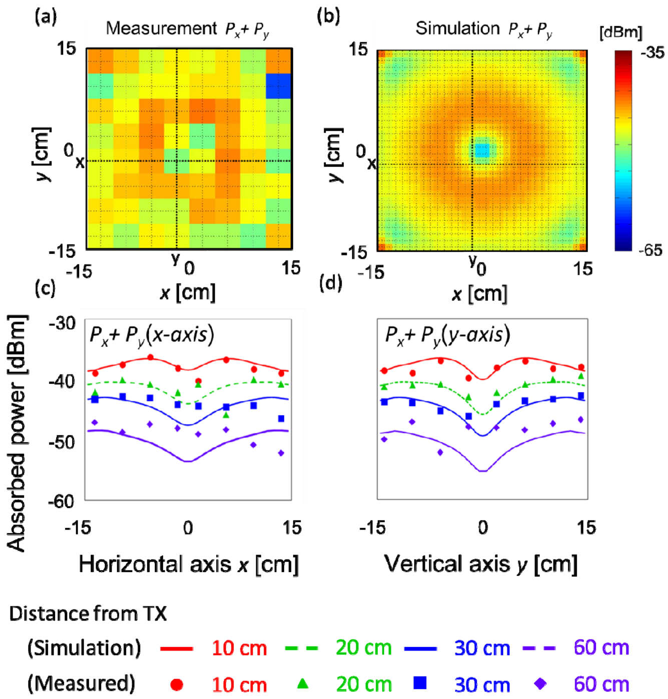

Fig. 6. RF power distributions measured on the absorber surface transmitted from a z-directed dipole: (a) 2-d measured distribution, (b) 2-d simulated distribution, (c) comparison between measured and simulated profiles along the x-direction, and (d) the same along the y-direction.

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