Effects of Incident Directions on Reflection Coefficients of Pyramidal Electromagnetic Wave Absorber

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***Abstract*—The pyramidal wave absorbers are widely used in anechoic chambers which frequently used for EMC or antenna measurements. It is important to know reflection characteristics of pyramidal absorbers to improve the performance of anechoic chambers. It is known that diffracted or scattered waves are excited when the pyramidal wave absorber is irradiated by a plane wave, thus to know the characteristics of diffracted wave from pyramidal absorbers is also important. In this paper, The diffraction coefficients of pyramidal wave absorbers are calculated by using FDTD method. The higher mode diffraction coefficients are extracted by discrete Fourier transform. By using the extracted coefficients, the effects of incident directions to pyramidal wave absorber on its reflection coefficients and an SVSWR simulation are presented. The design and further analysis for pyramidal wave absorbers including diffraction effects are left for further study.**

I. Introduction

Pyramidal shaped electromagnetic wave absorbers[1] are widely used for internal wall of anechoic chambers for long time. They have wide-frequency and wide-incident-angle characteristics to efficiently absorb arbitrary incoming electromagnetic wave from devices under test inside it. Reflection coefficients of pyramidal wave absorbers have been calculated by 1D-transmission-line-method with certain low frequency approximation of dielectric constants of pyramid structure [2]. Besides regular reflection, incident electromagnetic wave scatters and diffracts at surface of absorbers. The scattered electromagnetic waves at the surface of wave absorbers were studied from micro wave to millimeter wave [3]. It is reported that periodic structures of pyramidal shape cause diffracted waves and scattered waves[4][5]. A numerical solution of TM scattering of wedge absorbers with periodic moment method for lossy dielectric bodies are also reported [6]. Such diffracted wave affects measurements in anechoic chambers. However when the frequency is low enough, the effects of diffracted wave are negligible. Recently the measuring frequencies are higher than ever, and the requirement for noise to signal ratio of the wave absorber has increased [7]. Thus diffracted wave from pyramidal absorbers might would major problem. Moreover, incident direction to pyramidal wave absorber may affect the reflection coefficients, as diffraction coefficients is different among incident angle conditions. Our research group has studied for analyzing and designing pyramidal wave absorber and its applications for anechoic chambers from the viewpoint of higher-mode diffracted waves from them [8][9][10][11]. In this report, firstly, evaluations for the characteristics of a pyramidal wave absorber including the diffracted waves from it by using full-wave electromagnetic analysis and a comparison between transmission-line-approximation and FDTD (Finite Difference Time Domain) simulation are briefly presented. Secondary, differences of the reflection coefficients by incident direction of pyramidal absorber are shown through diffraction coefficients. Finally, a simulation of SVSWR (site voltage standing wave ratio) method is performed using the diffraction coefficients calculated by FDTD.

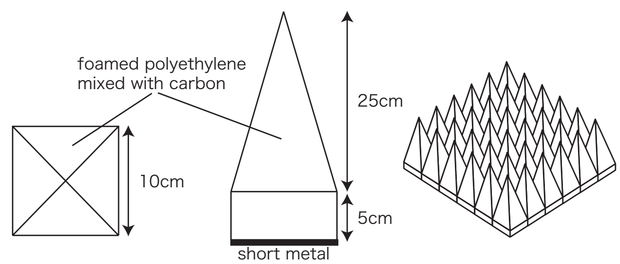

Fig. 1. Unit structure of the pyramidal absorber considered in this study.

II. Calculation of reflection coefficients of pyramidal wave absorber by FDTD simulation

Figure 1 shows the unit structure of a pyramidal wave absorber used in this study. This type of absorber is made by TDK corporation, type number is IS-030A. It is made of foamed polyethylene mixed with carbon powder. The height of the pyramid is 30 cm (flat layer 5 cm + pyramidal layer 25 cm), the periodic length of two horizontal direction is 10 cm. The dielectric constant of the absorber body is $\varepsilon_r = 1.78 - j0.71$, at 9.4 GHz, for example. Infinite iteration of the unit structure for both periodic direction is assumed in the numerical simulations.

Figure 2 shows the definition of incident angle and incident direction of pyramidal wave absorber in this paper. The pyramidal absorber is laid on the z-x plane. Incident electro

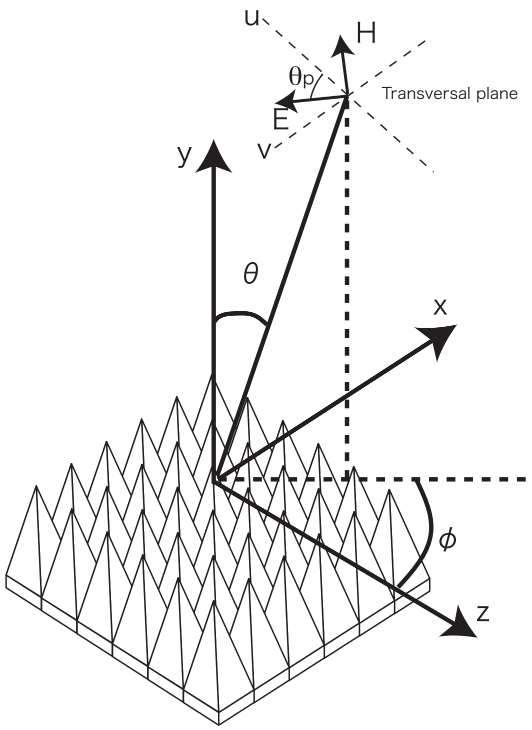

Fig. 2. Definition of incident angle and direction of pyramidal wave absorber.

magnetic wave is assumed to be plane wave, which has $-y$ component of wave number vector. The angle θ indicates incident angles to the z-x plane; and the angle ϕ indicates incident directions in the z-x plane, which is discussed in this paper. As plane wave are assumed as incident waves, a transversal plane can be defined as shown in the Fig. 2. u-v coordinate system is defined to express transversal planes. Axis v is defined as the line which is perpendicular to the incident direction and parallel to the z-x plane. Axis u is defined as the line which is perpendicular to the incident direction and the v axis. The polarization angle θ_p, which shows the direction of electric field, is also defined as shown in the Fig. 2.

Figure 3 shows the calculation model for a pyramidal wave absorber in this report. This model has 3-D periodic structure for two directions like actual pyramidal absorber. The calculation frequencies are from 5 GHz to 11 GHz. FDTD is used for the full-wave electromagnetic simulations. The plane wave incidents from arbitrary directions are assumed in the simulations. To represent the periodic structure and oblique plane wave incidences, complex values are used in FDTD calculation (sin-cos method)[12].

The reflected and diffracted waves are observed in the observation plane that is set at 20 cm above the top of the absorber. The discrete Fourier transform is performed for the electromagnetic wave distribution in the observation plane to extract the coefficients for higher mode diffracted waves.

Figures 4 to 7 show examples of calculated diffraction coefficients in wave number space. The conditions of incident angles are as follows: $\theta = 82$ deg.; $\phi = 0$ deg. or 45 deg.; $\theta_p = 90$ deg. (TE incidence), respectively. Figure 4 and 6 show coefficients of k_z, and figures 5 and 7 show coefficients of k_x, respectively. The simulation frequency is 9.4 GHz. In

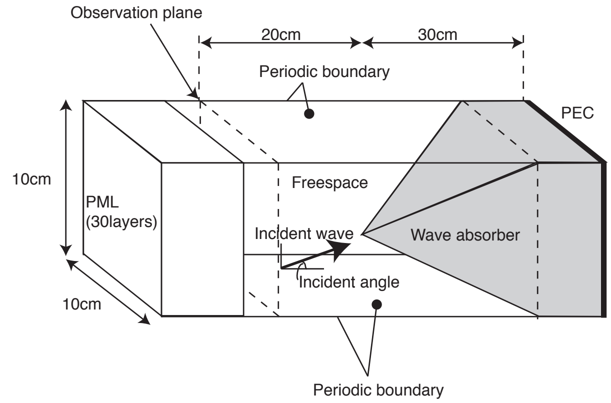

Fig. 3. FDTD calculation model for pyramidal absorber.

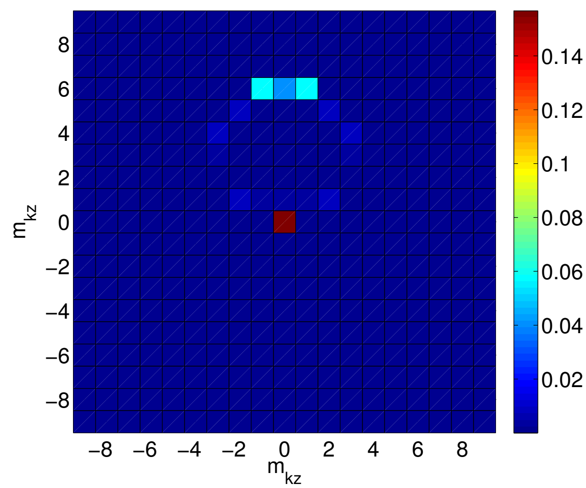

Fig. 4. Diffraction coefficients of k_z for $\theta = 82$ deg., $\phi = 0$ deg., $\theta_p = 90$ deg. (TE) incidence.

the figures, the horizontal axis shows the mode number of k_z, and the vertical axis shows the mode number of k_x. As shown in the figures, largest coefficient is observed at the center of the figures, which means the order of diffraction wave for both x and z directions are zero. As the incident angle is very high (82 deg.), all diffracted waves are excited towards the incident directions. In the figures 4 and 5, the coefficients are symmetric to k_x=0. In the figures 6 and 7, the coefficients are mutually symmetric to the line $k_z = -k_x$ as the incident $\phi = 45$ deg.

III. Frequency Characteristics of the Diffraction Coefficients

Figure 8 shows the frequency characteristics of the extracted diffraction coefficients extracted from the simulation results for TE 82 deg. plain wave incidence for $\phi = 0$ deg. and $\phi = 45$ deg. ($\theta = 82$ deg., $\theta_p = 90$). The horizontal axis shows calculation frequency in GHz. The vertical axis shows the coefficients in arbitrary unit. The lines and markers show the diffraction coeffcients from 0th to 3th order calculated by FDTD respectively. The results of 0th order ($m = 0$) coefficients represent the fundamental mode diffraction, which

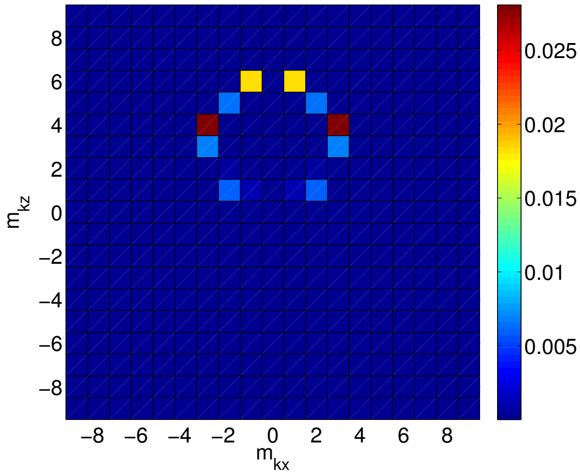

Fig. 5. Diffraction coefficients of k_x for $\theta = 82$ deg., $\phi = 0$ deg., $\theta_p = 90$ deg. (TE) incidence.

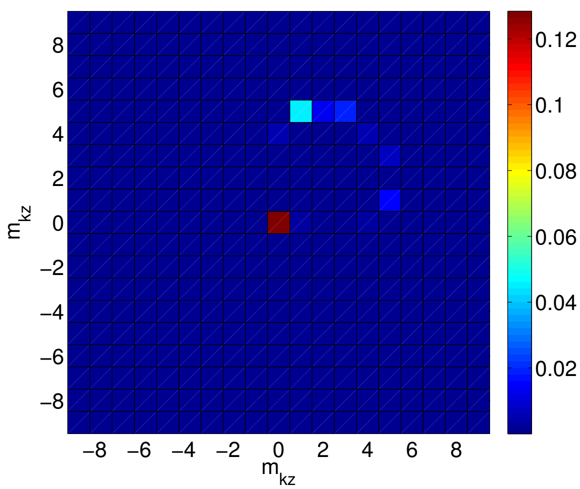

Fig. 6. Diffraction coefficients of k_z for $\theta = 82$ deg., $\phi = 45$ deg., $\theta_p = 90$ deg. (TE) incidence.

correspond the reflection coefficients of the pyramidal wave absorber. As shown in the figure 8, 0th order diffraction coefficients tends to decrease as frequency increases. However, for several frequencies, the specific order of higher diffraction coefficient increases, which may cause the increase of a diffraction wave for an unexpected direction. Difference between $\phi = 0$ deg. and $\phi = 45$ deg., which can be seen in the figures, may cause the change of performance of anechoic chamber by the pyramidal wave absorber installation.

IV. Simulation for SVSWR method with the reflection coefficients calculated by FDTD.

SVSWR method is one of the evaluation methods for anechoic chambers. The authors have reported the simulation method of the SVSWR measurement by using the diffraction coefficients calculated by FDTD[13]. SVSWR of the pyramidal absorber located on the floor of anechoic chamber can be evaluated by this simulation. Figure 9 shows the geometry of the simulation for SVSWR method. As shown in the Fig. 9, the distance between the incident point and the receiving antenna is 10 m. A horn antenna of the aperture 15.5 cm by 11.5 cm is assumed at the receiving point. The position of the receiving antenna is changed from 0 cm to 40 cm to the original position to calculate the VSWR value.

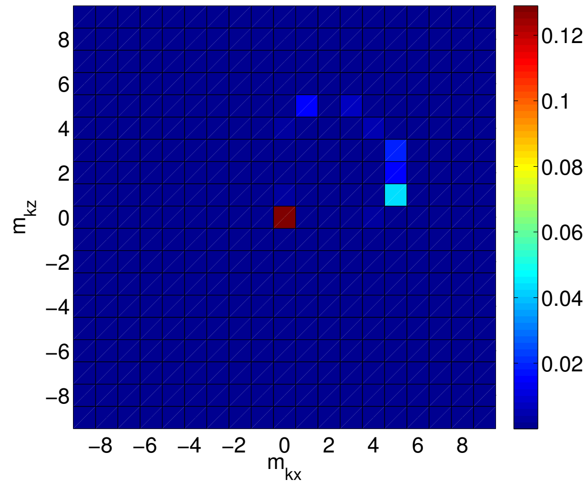

Fig. 7. Diffraction coefficients of k_x for $\theta = 82$ deg., $\phi = 45$ deg., $\theta_p = 90$ deg. (TE) incidence.

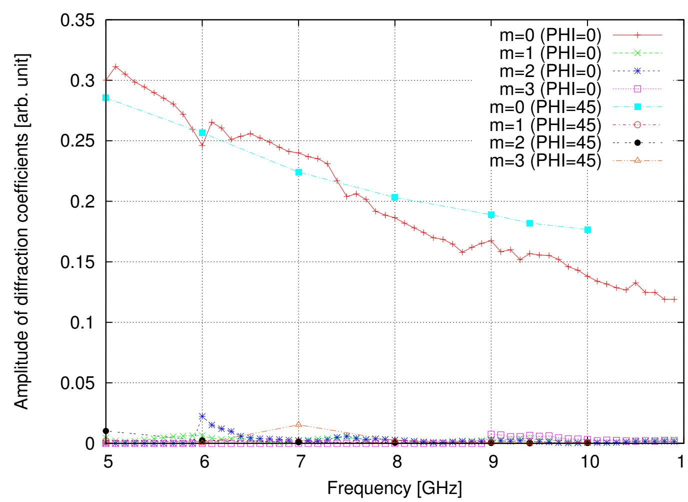

Fig. 8. Difference of diffraction coefficient by incident direction $\phi = 0$ deg. and 45 deg. (θ=82 deg., θ_p=90 deg. (TE) incidence)

Figure 10 shows the calculated result of the simulations for SVSWR measurement. The horizontal axis shows the frequency in GHz, and the vertical axis shows the SVSWR in dB. As shown in the Fig. 10, the SVSWR values fluctuate as the frequency changes. Several peaks of SVSWR are observed at around 5.5 GHz, 6.3 GHz, and 8.7 GHz, which may cause deterioration of anechoic chambers. Thus it is important to know the performance of the individual wave absorber corresponds with the installation directions of them.

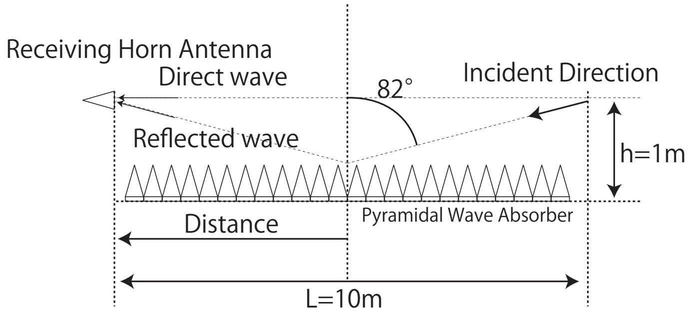

Fig. 9. Geometry of the simulation for SVSWR method.

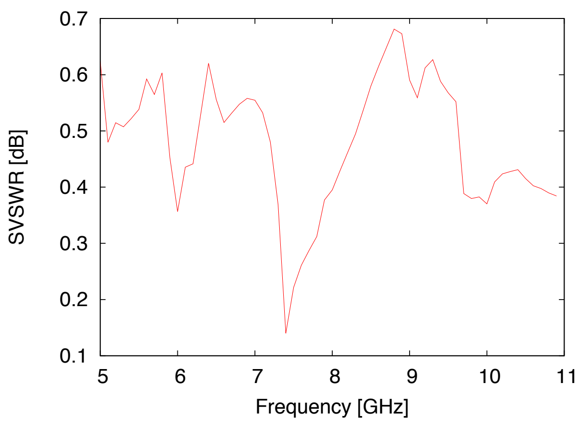

Fig. 10. Simulation result of SVSWR method ($\theta = 82$ deg, $\phi = 0$ deg., θ_p=0 deg. (TM) incidence).

V. Conclusion

In this paper, reflection characteristics of a pyramidal wave absorber which frequently used for the inner wall of anechoic chamber is considered. The diffraction coefficients of pyramidal wave absorbers are calculated by using FDTD method. The higher mode diffraction coefficients are extracted by discrete Fourier transform. By using the extracted coefficients, the effects of incident directions to pyramidal wave absorber on its reflection coefficients and an SVSWR simulation are presented. The design and further analysis for pyramidal wave absorbers including diffraction effects are left for further study.

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