FDTD Analysis of Site Free Space VSWR in Test Site Used for Disturbance Measurement above 1 GHz

Nobuo Kuwabara [#1], Masataka Midori [#2], Masato Kawabata [*1]

[#] *Electrical Engineering and Electronics, Kyushu Institute of Technology*
Kitakyushu, 804-8550 Japan

[1] `kuwabara.nobuo@buddy.elcs.kyutech.ac.jp`
[2] `midori@buddy.elcs.kyutech.ac.jp`

[*] *Fukuoka Industrial Technology Center*
Kitakyushu, 807-0831 Japan

[3] `kawabata@fitc.pref.fukuoka.jp`

Abstract— **The calculation of the site free space voltage standing wave ratio (S_{VSWR}) is important in designing the measurement facilities used above 1 GHz. In this study, the relations between the area of the absorbers on the ground plane and the S_{VSWR} were analysed using the FDTD method. The space, including the transmitting antenna, the receiving antenna, and the absorbers, were modelled using cells. The absorber constructed with foamed ferrite, ferrite tile, and wood was also modelled using cells. The calculation values almost agree with the measurement values, and the deviation between the calculation values using the FDTD method and the measurement values was smaller than the deviation between the calculation values using the ray trace method and the measurement values. The results suggests that the length similar to the distance between antennas is needed to acquire results similar to where absorbers are arranged over the entire ground plane (FAR), and that a width of 1.2 m also was needed to acquire the results similar to FAR.**

I. INTRODUCTION

Recent progress of wireless communication technology has increased the need for suppressing disturbances above 1GHz. The International Special Committee for Radio Interference (CISPR) published the limit and method of measurement for information technology equipment (ITE) [1]. According to the publication, the radiated electromagnetic field strength from ITE is tested in specified test facilities. CISPR discussed the test method of the facilities [2], which is important to maintain the reproducibility of the test results.

A test facility is constructed by an open test site or an anechoic chamber where the absorbers are arranged on part of the ground plane. Then, free space is created where the ITE is placed. CISPR has specified the site free space voltage standing wave ratio (S_{VSWR}) to evaluate the performance of the test facilities [2], [3].

To design these facilities, the S_{VSWR} should be able to be predicted by the calculation. The ray trace method has been used to evaluate test sites [4]. However, it is difficult to calculate the S_{VSWR} using the ray trace method because it assumes that the reflection coefficient is uniform on the ground plane. Therefore, the method cannot include the reflection from the edge of the absorber, and most of the

facilities are constructed with absorbers, which are partially arranged on the ground plane. A new method is needed for analysing the effect of the partial absorber area.

This paper describes a method of calculating S_{VSWR} using the FDTD method. Absorbers arranged on the ground plane are modelled using the dielectric constant and the magnetic permeability at 1 GHz. A receiving antenna is replaced by a transmitting antenna, and the electric field at the position of the transmitting antenna is calculated. The S_{VSWR} is obtained from the maximum and minimum electric field strengths, and this result is compared with the measured result. The reflection coefficient of the absorber is calculated using the FDTD method, and the S_{VSWR} is calculated using the ray trace method with this coefficient. The calculation results are compared with the results from the FDTD method. The relation between the length of the absorber area and the S_{VSWR} is investigated using the FDTD method, and the relation between the width of the absorber area and the S_{VSWR} is also investigated.

II. FDTD ANALYSIS MODEL FOR S_{VSWR}

A. Measurement method of S_{VSWR}

Figure 1 shows the method for measuring the S_{VSWR} [2]. The absorbers are arranged between the transmitting and receiving antennas. These antennas are set at the same height, and the distance between antennas is changed from the 3 m to 3.4 m.

The output level of the receiving antenna is measured at the positions of the transmitting antenna (T_1, T_2, …, T_n), where the positions are placed from 3 m to 3.4 m at the same height. The S_{VSWR} is calculated from the ratio of the maximum and minimum antenna output levels, and it is given by;

$$S_{VSWR}[dB] = 20\log_{10}\frac{Max\left(|V_1|,|V_2|…,|V_n|\right)}{Min\left(|V_1|,|V_2|…,|V_n|\right)} \quad (1)$$
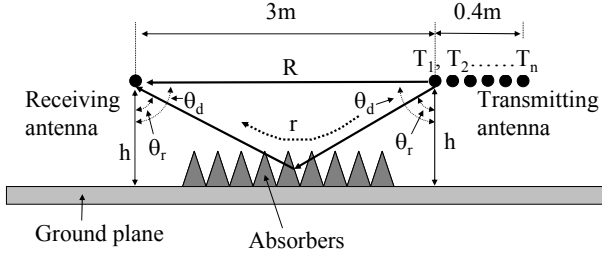
Fig. 1. Method for measuring S_VSWR

B. Experimental set-up for measuring S_{VSWR}

The experimental set-up for measuring the S_{VSWR} is shown in Fig. 2. The FDTD model was developed based on the set-up.

An anechoic chamber (L=7 m, W=6.2 m, H=5.9 m) was used for the experiment. The absorbers were arranged on the ground plane. Four dipole antennas were used as transmitting and receiving antennas, and measurement was executed from 1 to 6 GHz. One dipole antenna, tuned at 2.45 GHz (MA5612B4), was used as the transmitting antenna from 1 to 3 GHz, and a handmade dipole antenna, tuned at 4.9 GHz, was used as the transmitting antenna from 3 to 6 GHz. The half wave dipole antenna (UHAP), tuned at 1 GHz, was used as the receiving antenna from 1 to 3 GHz, and the dipole antenna, tuned at 4.9 GHz (MA5612C4), was used as the receiving antenna from 3 to 6 GHz.

The S_{21} between the input port of the transmitting antenna and the output port of the receiving antenna was measured using a network analyser. The transmitting antenna moved at the interval of 10 mm, and the S_{VSWR} was calculated from the maximum and minimum S_{21}, and given by;

$$S_{VSWR}[dB] = 20\log_{10}\frac{Max\left(\left|S_{21,1}\right|,\left|S_{21,2}\right|\ldots,\left|S_{21,n}\right|\right)}{Min\left(\left|S_{21,1}\right|,\left|S_{21,2}\right|\ldots,\left|S_{21,n}\right|\right)} \quad (2)$$
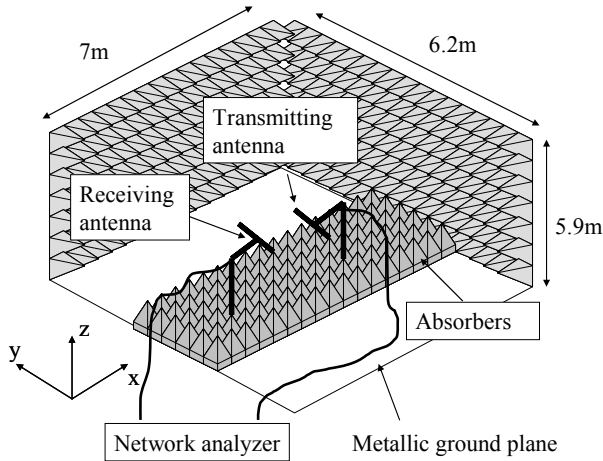

Fig. 2. Experimental set-up for measuring S_VSWR

C. FDTD model for calculating S_{VSWR}

The FDTD model for the experimental set-up in Fig. 2 is shown in Fig. 3. To reduce the computation time, the calculation area was limited within the area including the transmitting and the receiving antennas and the absorbers with the ground plane. The calculation area was 0.824 m in width, 4.448 m in length, and 1.204 m in height.

This model represents the right half of the experimental set-up shown in Fig. 2. A perfect electric conductor (PEC) wall is placed at the left side of the model. Using the mirror image theory, the model shown in Fig. 3 can present the whole model shown in Fig. 2. The ground plane of the chamber is modelled using the PEC wall, and the absorbers are arranged on the plane. Perfect matched layers (PMLs) are placed at the other side walls and the roof wall.

The position of the transmitting and receiving antenna shown in Figs. 1 and 2 was replaced each other in the analysis. A small dipole signal source is placed at the receiving antenna position shown in Fig. 2 and the distance from PML wall is 0.2 m. Then, the electric field at the observation points, which are the transmitting antenna positions in Fig. 1, is calculated, and the S_{VSWR} is obtained from the maximum and minimum electric field strengths; and it is given by

$$S_{VSWR}[dB] = 20\log_{10}\frac{Max\left(\left|E_{i1}\right|,\left|E_{i2}\right|\ldots,\left|E_{in}\right|\right)}{Min\left(\left|E_{i1}\right|,\left|E_{i2}\right|\ldots,\left|E_{in}\right|\right)}\Bigg|_{(i=h \text{ or } v)} \quad (3)$$

where, i=h is the horizontal component of the field, and i=v is the vertical component of the field.
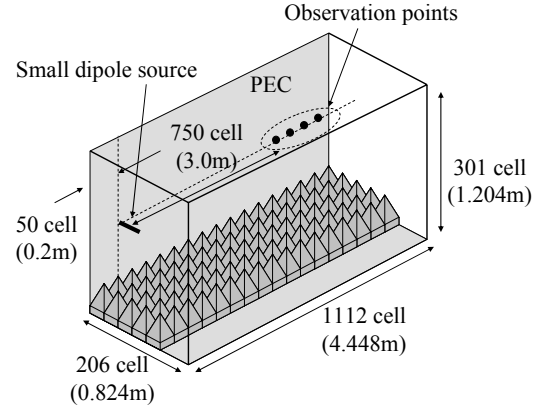

Fig.3. FDTD model for calculating S_VSWR

D. Absorber modelling

The type of absorber used in this investigation is shown in Fig. 4. The absorber is constructed with foamed ferrite, ferrite tile, and wood. The size of the absorber is 100 mm in length, 100 mm in width, and 115 mm in height.

The FDTD model of the absorber is shown in Fig. 5. A cell of 3 mm in Δz, 4 mm in Δx, and 4 mm in Δy is used for the FDTD model. The wood portion was modelled with 3 cell layers, the ferrite-tile was with 2 cell layers, and the foamed-

ferrite is with 26 cell layers. The relative dielectric constant and the relative magnetic permeability measured at 1 GHz were used, and they are listed in Table I.
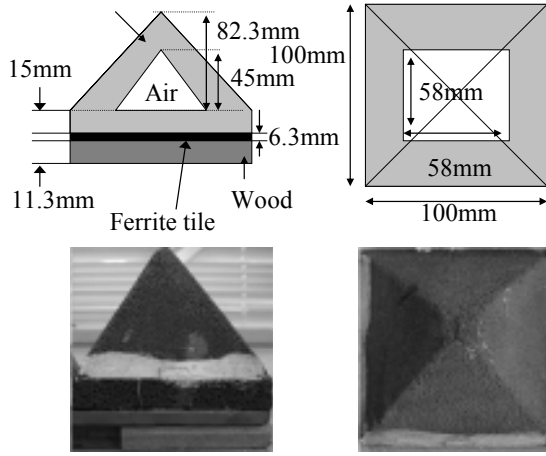

Fig.4. External view and configuration of absorber

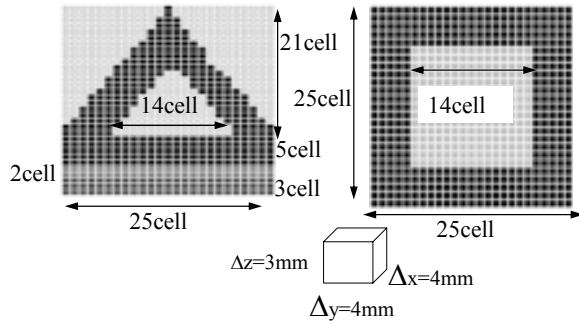Fig.5. FDTD model of absorber

TABLE I
CONSTANT OF ABSORBER MATERIALS

Materials	Relative dielectric constant	Relative magnetic permeability
Formed ferrite	1.5+j0.59	2.2+j0.043
Ferrite tile	0.22+j6.5	9.7+j0.056
Wood	1+j0.0057	2.5+j0.25

E. Cell model for FDTD analysis

The cell model for FDTD analysis is shown in Fig. 6. Two sizes were used for the calculation. One was Δz=3 mm, Δx=4 mm, and Δy=4 mm, and the other was Δz=8 mm, Δx=4 mm, and Δy=4 mm. The small cell was used in the area of the absorbers because the dielectric constant and the magnetic permeability of the absorbers are larger than those in air, and the large cell is used in the area of air. By using these sizes, we can reduce the number of cells.

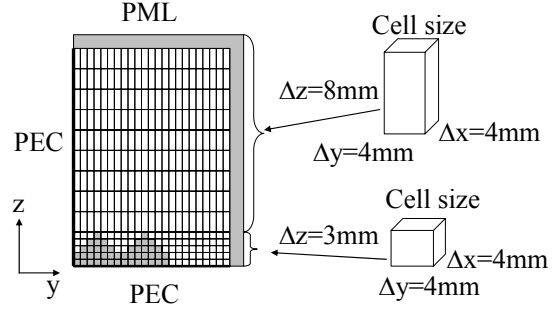We used a Gaussian pulse whose spectra covered the frequencies of interest.

Fig.6. Cell model for FDTD method

III. COMPARISON WITH MEASUREMENTS AND RAY TRACE

A. Comparison with measurements

A comparison between the measurement and the FDTD method is shown in Fig. 7. The measurement was carried out using the experimental set-up in Fig. 2. The absorbers were arranged over the entire ground plane.

In this figure, the vertical axis is the S_{VSWR} presented by Eqs. (1) and (2). The black dotted line is the measurement value and the gray solid line is the calculation value. This shows that the calculation value almost agree with the measurement value. The good agreement was obtained from 1 to 2.5 GHz.

Deviation above 2.5 GHz might be caused by the performance of the receiving antenna and the difference in the material constants. This calculation uses the constants at 1 GHz, but the values might change at a higher frequency.

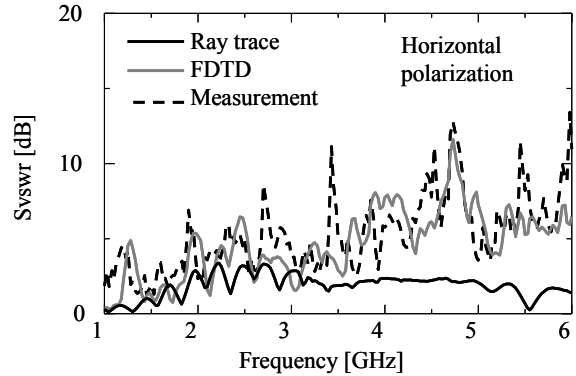The results mean that this FDTD model can be used to calculate the S_{VSWR}.

Fig.7. Comparison between calculation and measurement results

B. Calculation using ray trace method

The ray trace method [4] is used to calculate the S_{VSWR}. Using the parameters in Fig. 1, the electric field strength at the receiving antenna position is given by;

$$E = \left| S_t\left(\theta_d\right) S_r\left(\theta_d\right) \frac{e^{-jkR}}{R} + A_r S_t\left(\theta_r\right) S_r\left(\theta_r\right) \frac{e^{-jkr}}{r} \right| \qquad (4)$$

where, R is the propagation distance of the direct wave, r is the distance of the reflection wave, S_t is the directivity of the transmitting antenna, the S_r is the directivity of the receiving antenna, θ_d is the incidence angle and the radiation angle of the direct wave, θ_r is the incidence angle and the radiation angle of the reflection wave, and A_r is the reflection coefficient of the absorber.

The reflection coefficient was obtained from the FDTD method. The calculation model of the reflection coefficient is shown in Fig. 8. One absorber was surrounded by the PEC and magnetic walls. The plane-wave source was placed at the other end, and the Gaussian pulse was used for the calculation. The observation point was placed 3.999 m from the absorber, and the incidence and reflection electric fields were calculated. The reflection coefficient was calculated from these results.

The calculation results of the reflection coefficient are shown in Fig. 9. The vertical axis is the reflection coefficient in dB. The reflection coefficient was around from -10 dB to -20 dB. This value was used to calculate the S_{VSWR}.
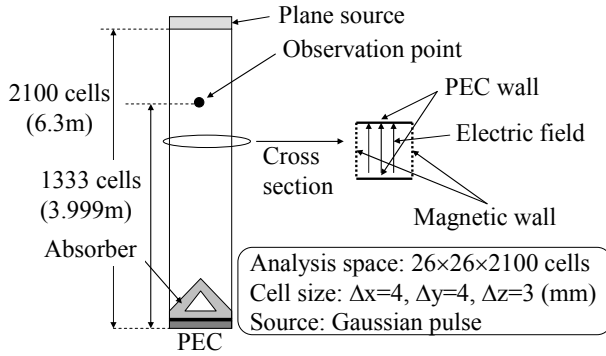

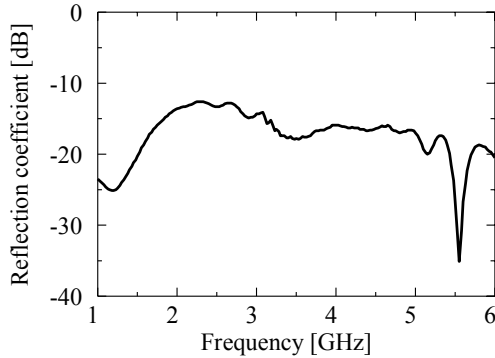Fig.8. Calculation model of reflection coefficient

Fig.9. Calculation result of reflection coefficient

C. Comparison with ray trace method

A comparison between the ray trace and FDTD methods is shown in Fig. 7.

In this figure, the black dotted line represents the measurement value, the gray solid line represents the value calculated from the FDTD method, and the black solid line represents the value calculated from the ray trace method. In this calculation, the absorbers were arranged over the entire ground plane. The polarization of the antenna was horizontal. This shows that the calculation results of the FDTD method to be close to the measurement results. However, the results from the ray trace method deviated largely from the measurement results. This means that the ray trace method is insufficient to calculate the S_{VSWR}.

IV. Dependency in Absorber Area

A. Length of absorber area

The relation between the length of the absorbers area and the S_{VSWR} was investigated using FDTD analysis. The investigation model is shown in Fig. 10. The width of the absorber area was fixed at 0.7 m, and the length was changed from 0.8 to 3.0 m. We determined the two observation points where the transmitting antenna was placed. One was placed on the PEC wall (Centre), and the other was placed at a distance of 0.75 m (Left) from the PEC. The polarization of the antenna was horizontal.
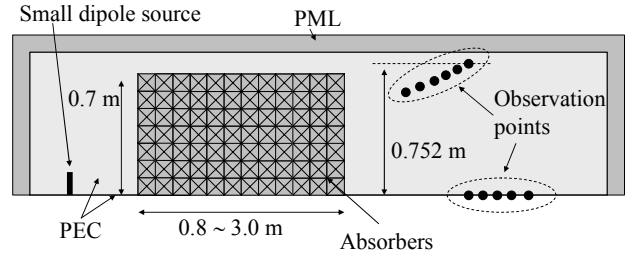

Fig.10. Investigation model for dependence of absorber area length

The investigation results are shown in Figs. 11 and 12. Figure 11 shows the results of the centre position, and Fig. 12 shows the results of the left position. The black solid line is where the absorbers were arranged over the entire ground plane (FAR), the black dotted line is the length of 3 m, the gray solid line is the length of 1.2 m, and the gray dotted line is the length of 0.8 m.

Figure 11 shows that the results of the S_{VSWR} for 3 m is comparable that of FAR. However, the S_{VSWR} of 1.2 m and 0.8 m present the great difference from that of FAR. This means that the length of 3 m, which is the distance between the antennas, is needed to achieve a similar result to that of FAR for the centre position.

Figure 12 also shows that the length of 3 m is needed to achieve a similar result to that of FAR. In addition, the S_{VSWR} of the left is smaller than the S_{VSWR} of the centre. This means that it is difficult to achieve sufficient performance at the centre position.
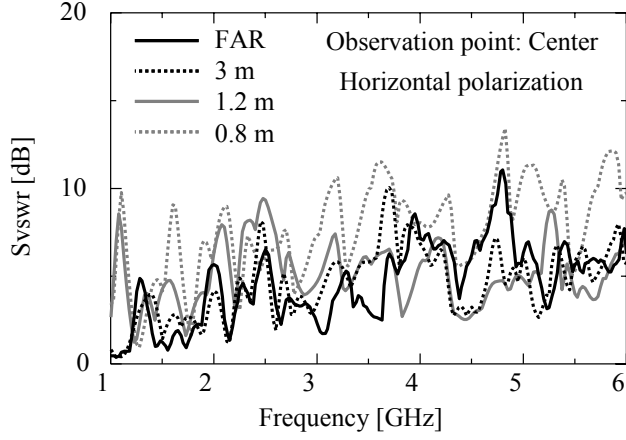
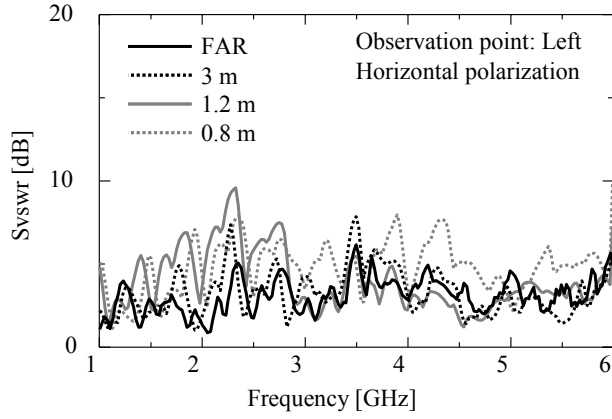Fig.11. Relation between length of absorber area and S_{VSWR} at centre

Fig.12. Relation between length of absorber area and S_{VSWR} at left

B. Width of absorber area

The relation between the width of the absorber area and the S_{VSWR} was investigated using FDTD analysis. The investigation model is shown in Fig. 13, which shows the model at vertical polarization. The PEC wall at the boundary of the left side was replaced with the magnetic wall to satisfy the boundary conditions of the small dipole antenna at vertical position.
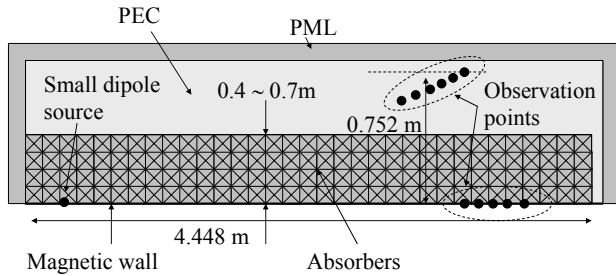

Fig.13. Investigation model for dependence of absorber area width

As shown in this figure, the length of the absorber area was fixed at 4.448m, and the width of the absorbers area was changed from 0.4 to 0.7 m. The observation points were placed at the centre and left positions.

The investigation results are shown in Figs. 14 and 15. Figure 14 shows the results of the centre position, and Fig. 15 shows the results of the left position. The black solid line is where the absorbers were arranged over the entire ground plane (FAR), the black dotted line is the width of 1.4 m, the gray solid line is the width of 1.2 m, and the gray dotted line is the width of 0.8 m. These values represent the entire width of the absorber area because we calculated only the right half of the area as shown in Figs. 2 and 3.

Figure 14 shows that the S_{VSWR} for all cases are similar to that of FAR. This means that the length of 0.8m is sufficient to achieve similar results to that of FAR.

Figure 15 shows that the S_{VSWR} of 1.4 and 1.2 m are similar to that of FAR. However, the S_{VSWR} of 0.8 m was different from that of FAR. This means that a width of 1.2 m is needed to achieve similar results to that of FAR.
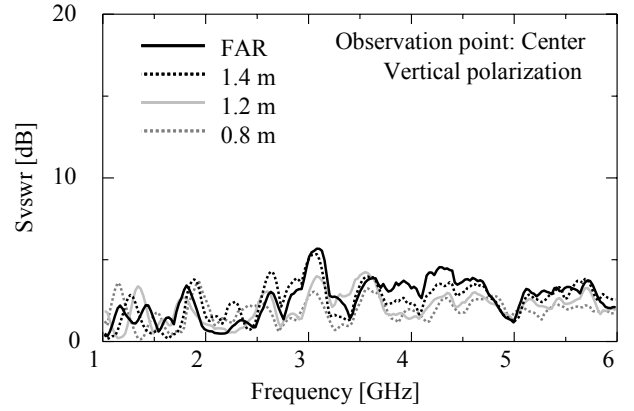

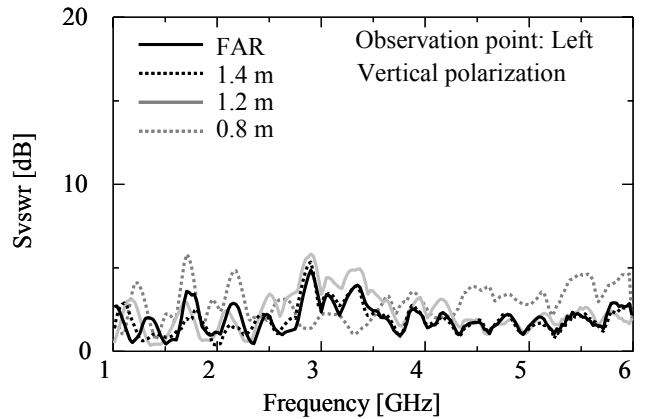Fig.14. Relation between length of absorber area and S_{VSWR} at centre

Fig.15. Relation between length of absorber area and S_{VSWR} at left

The S_{VSWR} of the centre position is lower than S_{VSWR} of the left position at vertical polarization. This means that it is difficult to achieve the performance of the left position at

vertical polarization. This might be caused by the fact that the small dipole antenna at vertical position radiates the electromagnetic field omni-directionally to the horizontal plane.

Compared to FAR, the vertical-polarization S_{VSWR} in Fig. 14 was lower than the horizontal-polarization S_{VSWR} in Fig. 11. This might be caused by the fact that the small dipole antenna at horizontal position radiates the electromagnetic field omni-directionally to the vertical plane.

V. Conclusions

The FDTD method was applied to the calculation of the site free space voltage standing wave ratio (S_{VSWR}) based on how the absorbers were arranged on part of the ground plane. The space including the transmitting antenna, the receiving antenna, and the absorbers were modeled using cells. The absorber was constructed with the foamed ferrite, ferrite tile, and wood and was also modeled using cells. A small dipole antenna at the receiving-antenna position was used as the radiation source. Then, the electric-field strength at the observation points, which was placed at the transmitting-antenna position, was calculated. The S_{VSWR} was calculated from the maximum and minimum field strengths.

The calculation results almost agree with the measurement results. The reflection coefficient of the absorber was calculated using the FDTD method. The S_{VSWR} was calculated using the ray trace method with this coefficient. The investigation indicated that the results from the ray trace method greatly differed compared with the results from the FDTD method.

The relation between the absorber area and the S_{VSWR} was also investigated using the FDTD method. The results showed that the length similar to the distance between antennas was needed to achieve the results similar to those with the absorbers arranged over the entire ground plane (FAR), and a width of 1.2m was needed to achieve the results in similar to FAR.

Investigation suggested that it is difficult to achieve the S_{VSWR} characteristics at the center position with horizontal polarization. With vertical polarization, it is also difficult to achieve the S_{VSWR} characteristics at the side position. In addition, the investigation suggested that the S_{VSWR} characteristic at horizontal polarization was severer than the S_{VSWR} at vertical polarization.

A future problem may be the reduction in the deviation between calculated and measured results above 2.5 GHz.

References

[1] CISPR Pulication 22 Edition 5.2, "Information technology equipment – Radio disturbance characteristics – Limits and method of measurement," March 2006

[2] CISPR16-1-4 Second edition, "Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-4: Radio disturbance and immunity measuring apparatus - Ancillary equipment - Radiated disturbances," , p.p. 85 -113, Feb. 2007.

[3] S. Battermann and H. Garbe, "Influence of the receiving antenna pattern on the site-VSWR validation procedure above 1 GHz," IEEE Intrnational symposium on EMC, Detroit, TH-AM-3-1,Aug. 2007

[4] V. P. Kodali, "Engineering electromagnetic Compatibility," IEEE Press, 2001.