Calculating Shielding Loss Due to a Gap between Radio Wave Shield Concrete Walls

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Abstract: In a radio-wave shield, a method of blocking radio waves in which a space is surrounded by a high loss dielectric material, some waves leak through the long and slender gap between the walls. We analyzed the losses in the gap section and in the gap aperture. The former was analyzed by using an equivalent parallel board transmission line, the latter by using an aperture field method. Here we describe these analyses and the experimental support of the results.

Key words: Radio wave, Concrete, Electromagnetic shielding, Shielding room, Building wall.

1. Introduction

There is an increasing use of devices in offices, such as wireless LAN, that rely upon radio waves. As a result, leakage of information and radio-wave interferences are becoming problems. To solve these problems, radio-wave shields have been added to rooms and buildings. In contrast to a previous shielding method involving thin metallic foil on the indoor walls, a new shield method in which walls and floors are made of a shield concrete. This shield concrete is a high loss dielectric material, which is made by putting either metallic powder or carbon fiber in the concrete.

For commercial use, the shield characteristics of the wall unit and leakage of radio waves between the walls should be analyzed. The theory of shield characteristics of the wall unit was previously reported [1]; here we describe the theory of radio waves leaking through the gap. This leakage was analyzed by replacing the gap section with an equivalent parallel board transmission line, a strip line consisting of two plates with the same size, and using the aperture field method. Here we describe the analysis and also experiments that confirm the analysis.

2. Theoretical analysis

2.1 Analytical model

Our analytical model of the leakage from the gap of the shield concrete walls is shown in Fig. 1. Two shield concrete walls are in the x-y plane and have thickness d. The gap has width b and is centered on the x-axis. The radio wave is emitted from point T at positive x, and it is received at point R at negative x. So as not to cause a diffraction wave from T to R, the x-y plane around the shield walls is shielded. We ignore radio waves passing through the shield concrete walls because they are assumed small compared with radio waves leaking from the gap. Because most radio waves leaking from the horizontal gap shown in Fig. 1 are vertically polarized waves, only leakage of vertically polarized waves are analyzed in this thesis.

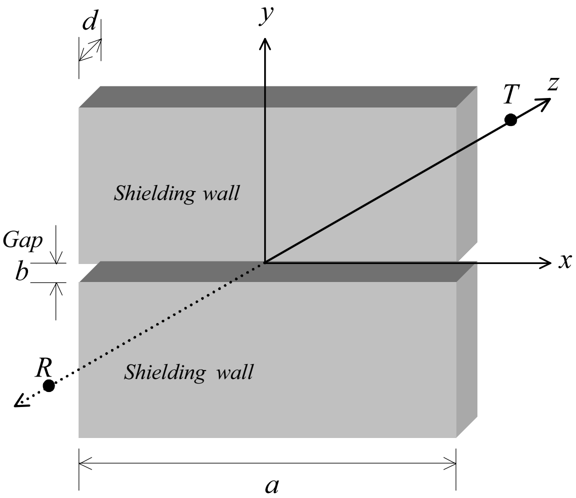


Figure 1. Analytical model of radio waves leaking through the shield concrete wall gap.

We assume that the following conditions hold between the wavelength λ, the width a of the walls, and distances d_1, d_2 from the walls to the transmission and the reception points T and R, respectively.

$$d_1, d_2 >> \lambda \qquad d_1, d_2 >> a \tag{1}$$

We put a $\lambda/2$ vertical dipole transmission antenna at point T in the zy-plane as shown in Fig. 2. The electric field strength E_{f0} at F, a point on the z-axis immediately before the gap is

$$E_{f0} = j60\frac{I_0}{d_1}e^{-jkd_1} \tag{2}$$

where I_0 is the current in the antenna and $k = \frac{2\pi}{\lambda}$

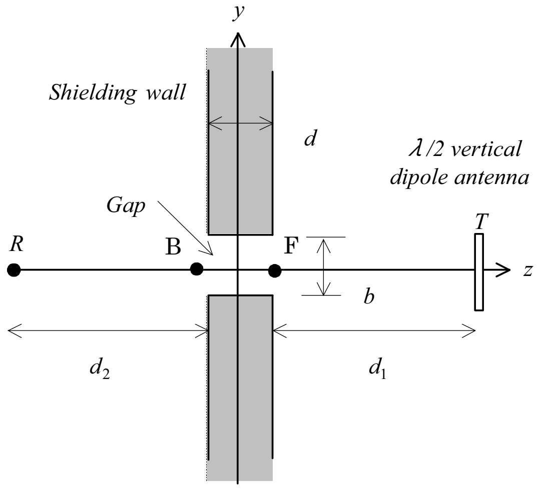


Figure 2. Section of the shield concrete walls.

The gap section is replaced by an equivalent parallel board transmission line. A propagation loss between F and point B is obtained because radio waves from F to B are propagated as a current in the surfaces of the nearby shield concrete walls on both sides of the gap. As a result, the electric field strength at B is defined as E_b. The propagation loss between B and R points is obtained by using the aperture field method. In this method, the radio wave E_b is uniformly distributed in the gap of aperture a×b at B and propagates to the reception point R as a wave.

2.2 Loss caused by the gap section

The parallel board transmission line of shield concrete material a wide is shown in Fig. 3.

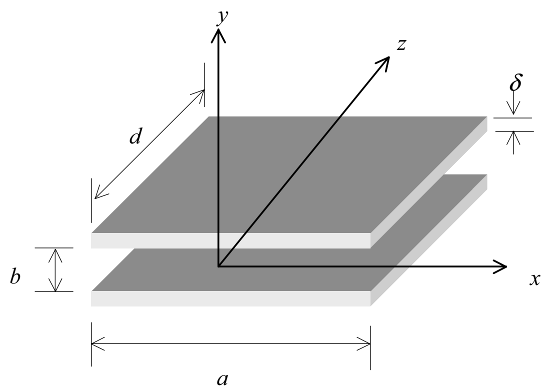


Figure 3. Parallel board transmission line.

When the skin depth is assumed to be δ, the resistance R_0 for each unit length of the parallel board is

$$R_0 = 2\times\rho\times\frac{1}{\delta\times a} = \frac{2\sqrt{\pi\rho\mu_0 f}}{a} \quad (3)$$

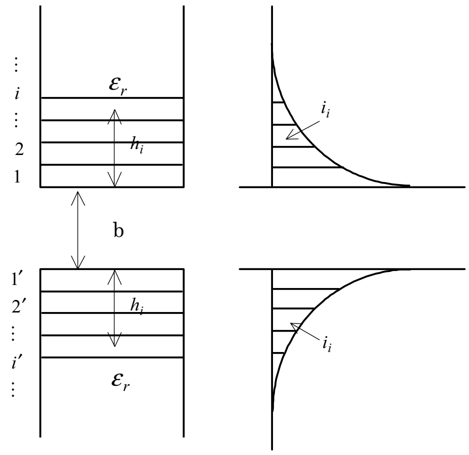
where

ρ : Resistivity of the shield concrete
f : Frequency
ε_0 : Permittivity of free-space
μ_0 : Permeability of free-space

Here, we assume that the maximum width of the parallel board transmission line in which a TEM wave can be propagate in Fig. 3 is 1/2 wavelength. This is because a standing wave in the direction of the width with modes different from the TEM wave will be contained when the width exceeds 1/2 wavelength. Therefore, when δ is negligible, the characteristic impedance of the parallel board transmission line is

$$\left.\begin{aligned} & a \le \frac{\lambda}{2} \\ & Z_w = \eta_0 \frac{b}{a} \\ & a > \frac{\lambda}{2} \\ & Z_w = \eta_0 \frac{b}{\lambda/2} \end{aligned}\right\} \quad (4)$$

Where, $\eta_0 = 120\pi$



(a) Section (b) Current distribution

Figure 4. Average characteristic impedance of the parallel board transmission line.

An average characteristic impedance of the high loss dielectric material wall gap is shown in Fig. 4. The skin depth cannot be assumed to be much less than the gap size b in a high loss dielectric material such as shield concrete. Therefore, the characteristic impedance of the parallel board transmission line should equal the average characteristic impedance $\overline{Z}_w$ corrected by current values depending on the distance h_i from the bottom of the gap. This is shown in the next equation.

$$\overline{Z}_w = \frac{(i_1 + i_2 + \cdots i_i + \cdots i_n)}{\frac{i_1}{Z_{w1-1'}} + \frac{i_2}{Z_{w2-2'}} + \cdots \frac{i_i}{Z_{wi-i'}} + \cdots \frac{i_n}{Z_{wn-n'}}} \quad (5)$$

Where,

$i_i = \exp(-h/\delta)$

$Z_{wi_i - i_i'} = \eta_0 \frac{b + 2h/\varepsilon_r}{a}$ or $\eta_0 \frac{b + 2h/\varepsilon_r}{\lambda/2}$

ε_r : Real number part of permittivity of the wall material

Therefore, the attenuation constant α of the parallel board transmission line of this wall gap is

$$\alpha = \frac{R_0}{2\overline{Z}_w} \quad (6)$$

where the phase constant β is

$$\beta = \frac{2\pi}{\lambda} \quad (7)$$

The above equation holds because the electromagnetic field in such a parallel board transmission line is approximately a TEM wave. The loss in the parallel board transmission line, in which equations (3)-(7) are used, is assumed to be S_{21} .

2.3 Loss caused by the gap aperture

Fig. 5 shows the case when the thickness of the wall is 0.

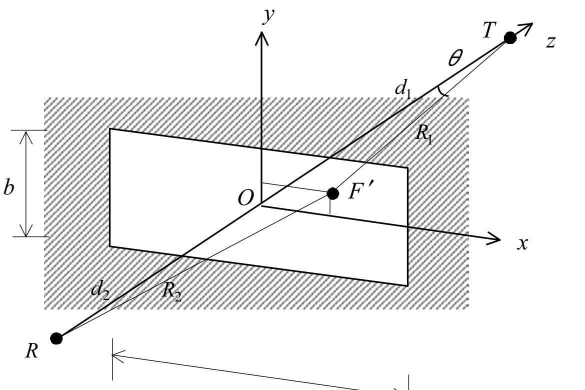


Figure 5. Shield board with an aperture.

The transmission point T and the reception point R are distances d_1 and d_2 from the center of the aperture. The angle θ to z-axis of an arbitrary point F' on the aperture is small, based on the assumption in equations (1). The amplitude of the electric field strength is the same at all points on the aperture, although its phase depends on the position of point F'. Therefore, if the electric field strength on the aperture is assumed to be, E_{f0} the electric field strength at R is

$$E_r \approx -60 \frac{S_{21} I_0 \, e^{-jk(d_1+d_2)}}{\lambda \, d_1 d_2} \int_{-\frac{b}{2}}^{\frac{b}{2}} \int_{-\frac{a}{2}}^{\frac{a}{2}} e^{-jk(x^2+y^2)(d_1+d_2)/2d_1 d_2} dxdy \quad (8)$$

If Fresnel integration functions S(x) and C(x) are used, then equation (8) becomes

$$E_r \approx -120 \frac{S_{21} I_0 \, e^{-jk(d_1+d_2)}}{d_1 + d_2} \{C(u) - jS(u)\}\{C(v) - jS(v)\} \quad (9)$$

Where,

$u = \frac{a}{2}\sqrt{\frac{2(d_1+d_2)}{d_1 d_2 \lambda}}, \quad v = \frac{b}{2}\sqrt{\frac{2(d_1+d_2)}{d_1 d_2 \lambda}}$

$S(x) = \int_0^x \sin(\frac{\pi}{2}t^2)dt$

$C(x) = \int_0^x \cos(\frac{\pi}{2}t^2)dt$

2.4 Loss caused by the shield concrete walls with the gap

When the two shield concrete walls and the shield boards that prevent the diffraction wave on xy-plane are removed, the electric field strength E_0 at R due to the $\lambda/2$ vertical dipole transmission antenna at the T is

$$E_0 = j60 \frac{I_0}{(d_1 + d_2 + d)} e^{-jk(d_1+d_2+d)} \quad (10)$$

Therefore, the loss SE cased by the shield concrete wall gap is

$$SE = -20 \times \log_{10} \frac{|E_r|}{|E_0|} \quad (11)$$

3. Experimental and simulation results

3.1 Experiment on loss with the dielectric material walls with the gap

A specimen of the dielectric material wall with a gap is shown in Fig. 6. The specimen consists of two square, pillar-shaped pieces of the dielectric material that are horizontally installed on the back of two metallic boards having a gap.

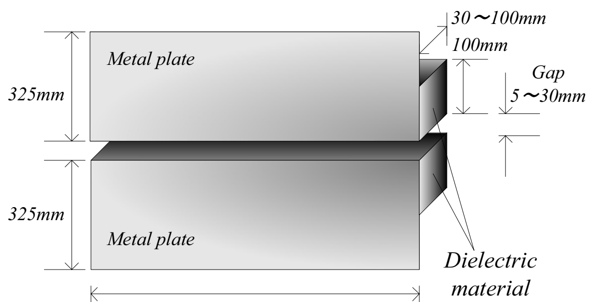


Figure 6. Dielectric material wall sample with a gap

The dielectric material is foam urethane containing carbon. Attenuation characteristics corresponding to wall thicknesses of 30, 50, and 100 mm, a frequency of 2.5 GHz, and gaps b=5, 10, 20, and 30 mm are shown in Fig. 7. This figure shows that the loss is roughly proportional to the wall thickness. From the experiment results, it can be understood that the loss in the gap section of the shield concrete wall is obtained as a transmission loss in the skin depth of the material.

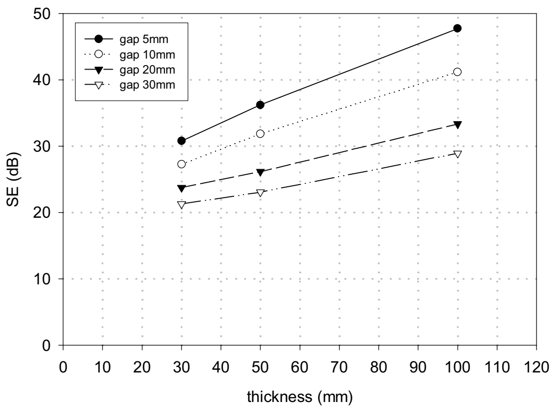


Figure 7. Loss characteristics of the dielectric material walls with gap for various wall thicknesses and gaps (at 2.5GHz).

3.2 Characteristics of the shield concrete walls with a gap

The specimen in external form is the same as Fig. 1. The walls are made of shield concrete that contains iron ore and iron-sand in concrete and have a double-reinforced concrete mesh 13 mmΦ, 150×150 mm^2 inside. The outside size is c=375 mm, d=135 mm, and a=1675 mm. The attenuation characteristics of the wall at 2.5 GHz for gaps of 5, 10, 20, and 30 mm are shown in Fig. 8. The simulation results corresponding to the same parameters are shown in Fig. 9. The experiment results are roughly consistent with the simulation results.

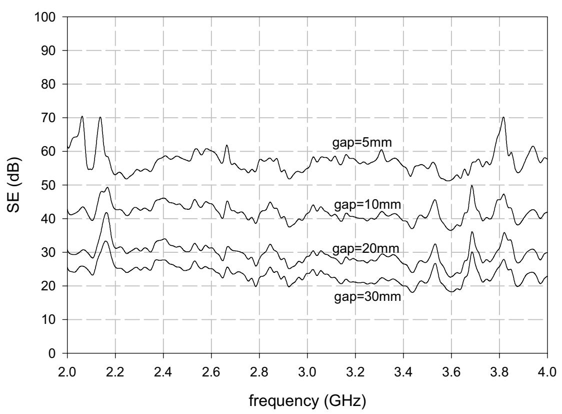


Figure 8. Experimental characteristics of the shield concrete walls for various gaps.

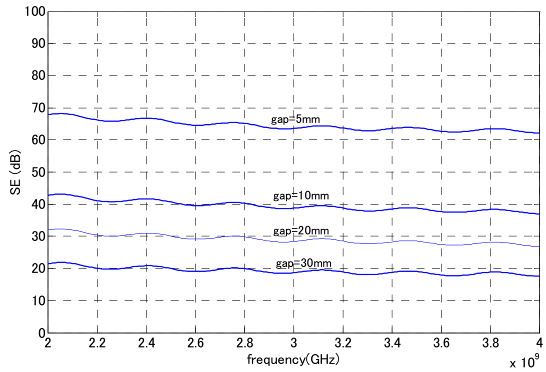


Figure 9. Calculated characteristics of the shield concrete walls for various gaps

4. Conclusion

We analyzed the characteristics of radio waves that leaked through a gap in a shield concrete wall gap as the sum of the loss caused by the gap section and the gap aperture. The following points were clarified from the theoretical analysis and the experiments.

① The loss caused by the gap section can be obtained using a parallel board transmission line composed of the material in the vicinity of the gap surface of the upper and lower walls with a size equal to the skin depth.

② Experiments with various gap intervals of the actual shield concrete wall confirmed the analytical theory.

That is, radio wave leaking through gaps in a room and building that are built with the shield concrete walls can be simulated according to the condition of concrete permittivity, structure of walls, position of the transmission, and reception point. We plan to use the simulations of radio wave characteristics of the gap in this study and the wall unit for a quality assurance.

References

[1] Y.Kasashima, K.Yamaki," Method for calculating the transmission loss of a radio-wave-shielding wall", 2002 IEEE International Symposium on EMC, pp.216-222, Aug.2002