REDUCTION OF ATTENUATION CHARACTERISTICS BY METALLIC STRIPS IN TWO-DIMENSIONAL TUNNELS

Takemitsu Honda, Yoshio Yamaguchi, Masakazu Sengoku, and Takeo Abe

Faculty of Engineering, Niigata University, Niigata-shi 950-21 Japan

1. Introduction

With the rapid development of radio communication including cellar communication, wireless communication, portable phone and so on, the radio waves in the frequency range from HF to microwave bands are now densely unitized everywhere. However, the attenuation of the radio wave in tunnels, underground streets, indoors, and parking lots in basements, poses adverse problem for these radio communications.

Here we focus our attention to the attenuation in tunnel structure. The attenuation is due to the cut-off propagation or the large attenuation of the wave. Thus, in order to reduce the attenuation, we examined a method of strip attachment on walls for shielding purpose in these structures. In the following, we present the field analysis in tunnels where the walls are partially covered with periodical metallic strips based on the boundary element method (BEM) and show the efficiency of strips on the reduction of attenuation.

2. Formulation by BEM

Consider a two-dimensional tunnel as shown in Fig.1. The tunnel does not have its ceiling and the bottom. The width of the tunnels is a. The complex permittivity of the wall is ε_s. Assuming that the TE10 wave, the dominant mode in this structure, is incident at $z = 0$, propagating in the + z-direction. If we let the dominant electric field component E_y be u, the wave equation holds in the tunnel

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial z^2} + k_0^2 u = 0 \tag{1}$$

where k_0 is the wave number in the free space. To determine the field intensity u in the tunnel, we apply the BEM considering the boundary condition. By employing the Green's function u^*, one can obtain the following equation

$$c_i u_i + \int_\Gamma q^* u \, d\Gamma = \int_\Gamma q u^* \, d\Gamma \tag{2}$$

where u_i is the potential at the point of interest, the coefficient c_i is unity within region Ω and is one-half on Γ, and q is the differential of u with respect to the normal direction of the boundary.

2.1 The boundary condition

The boundary Γ is derived into Γ_0 (lossy side walls), Γ_1 (hypothetical entrance), Γ_2 (hypothetical exist), Γ_3 (metallic strip walls). The boundary condition on the Γ_0, Γ_1, Γ_2 is given [1] as follows;

$$\begin{aligned} &\Gamma_0 : q = -jk_0\sqrt{\varepsilon_s - \sin^2\theta}\, u \\ &\Gamma_1 : \{q\} = (\gamma + [F][\gamma][F]^{-1})\{f\} - ([F][\gamma][F]^{-1})\{u\} \\ &\Gamma_2 : \{q\} = -([F][\gamma][F]^{-1})\{u\} \end{aligned} \tag{3}$$

where [F] consists of the eigenfunction:

$$f_{mi} = \begin{cases} \cos k_m x_i & (\text{m:odd}) \\ \sin k_m x_i & (\text{m:even}) \end{cases} \tag{4}$$

where x_i is the x-coordinade of the node on the boundary, and the wave number k_m is the solution of characteristics functions:

$$\begin{cases} k_m \tan \frac{k_m a}{2} = jk_0\sqrt{\varepsilon_s - \sin^2\theta} & \text{(m:odd)} \\ k_m \cot \frac{k_m a}{2} = -jk_0\sqrt{\varepsilon_s - \sin^2\theta} & \text{(m:even)} \end{cases} \tag{5}$$

Also $[\gamma]$ consists of diagonal components only given by

$$\gamma_{mm} = \sqrt{k_m^2 - k_0^2} \tag{6}$$

On the other hand, the potential u is zero on the Γ_3 because of the metallic strips.

3. Comparison with a laboratory experiment

The field intensity along a tunnel is calculated using the following parameters:

$a = 1.6\lambda$, $\varepsilon_s = \varepsilon_r - j\varepsilon_i = 5 - j$, period $p = \lambda$, width of the strip $= 0.5\ \lambda$.
the number of the strips in both wall is 14,
the placement of the strips is symmetric (case A) with respect to the center line of the tunnel, and asymmetric (case B).

The calculated results of A, B are shown in Figs.2 and 3, respectively.

Also a laboratory measurement was carried out to confirm the calculated results. The parameters are chosen to be the same for the sake of comparison. The experimental scheme is shown in Fig.4. The tunnel is made of two concrete block covered with two metallic plates. The field intensity is measured by a small dipole antenna.

The calculated and experimental results are shown in Fig.5 (a) (case A) and Fig.5 (b) (case B) where the dotted lines corresponds to the calculation and the solid lines corresponds to the measurement. It can be seen that the calculated field intensities along the tunnel are in good agreements with the measured ones.

Since the validity of the calculation is confirmed in Fig.5, it is now possible to examine the efficiency of the strips on the reduction performance. For criterion of efficiency, we check the efficiency according to the next formula

$$\frac{\alpha_r}{\alpha_0} = 1 - s \tag{7}$$

where, α_r is the attenuation constant with metallic strips, α_0 is the attenuation constant without strips, and s is the area percentage parameter of metallic strip to the lossy wall. This equation represents the reduction rate and is derived from the fact that if wall is covered completely with metal, then the attenuation should be zero, on the other hand, if the wall is non-covered with metal, the attenuation should be equal to that of hollow tunnel.

The efficiency is calculated in Fig.6. The abscissa is measured by the percentage parameter s. It is seen that the reduction rate by strip is better than the criterion and that the symmetric placement of strips is more effective for the reduction than the asymmetric placement. Next, to examine the effect of strip spacing, keeping the s constant, we calculated the efficiency for the case of ten strips ($\lambda/20$, $\lambda/50$ width) within one wavelength interval. The results shown in Fig.6 indicates that the reduction rate is extremely high.

4. Concluding remarks

Based on the boundary element method, the field intensity in a tunnel with strips is analyzed. The reduction rate of attenuation constant by strip placement method is investigated in this paper. The reduction rate by strip is shown to be better than that of the criterion of (7). A further investigation on the reduction method is still needed in the future employing mesh, etc.

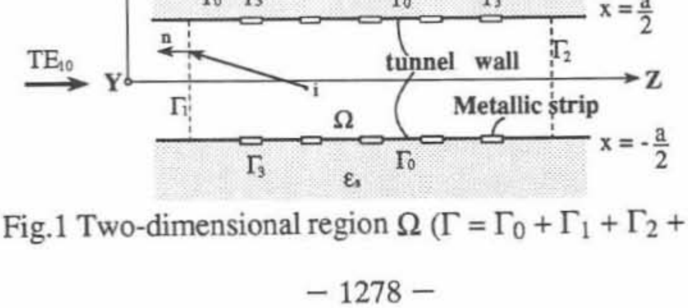
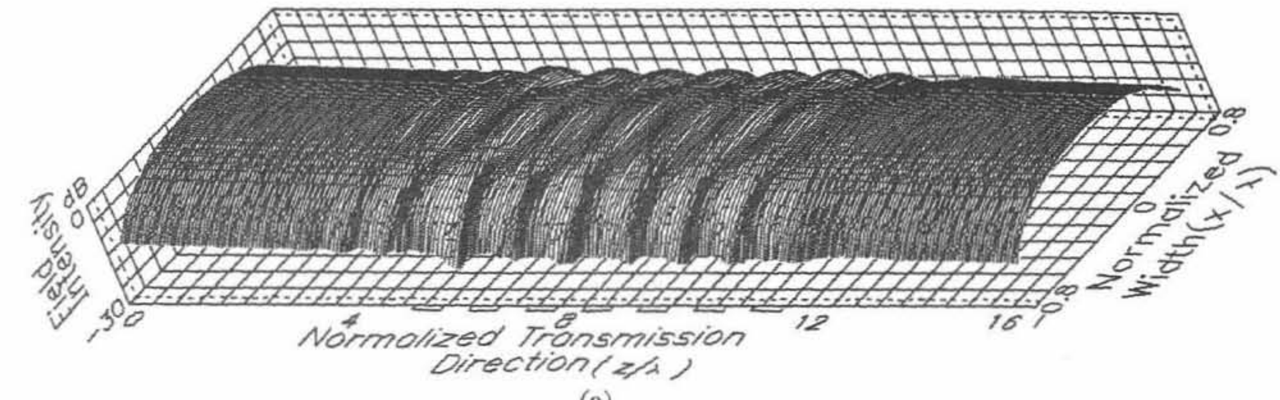
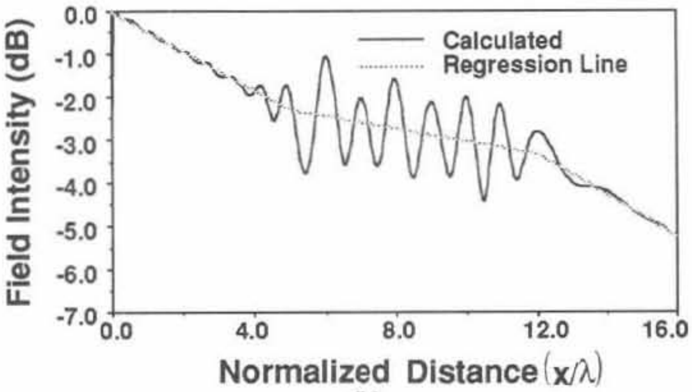


Fig.1 Two-dimensional region Ω ($\Gamma = \Gamma_0 + \Gamma_1 + \Gamma_2 + \Gamma_3$)

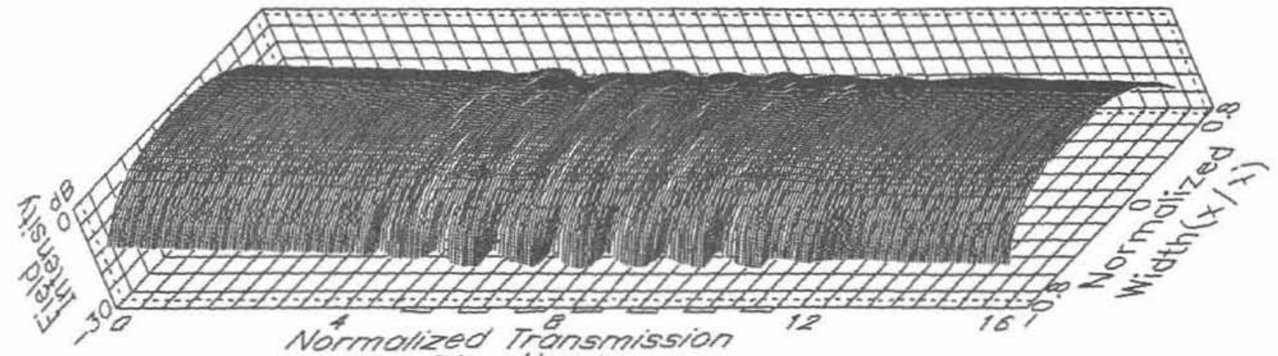


(a)

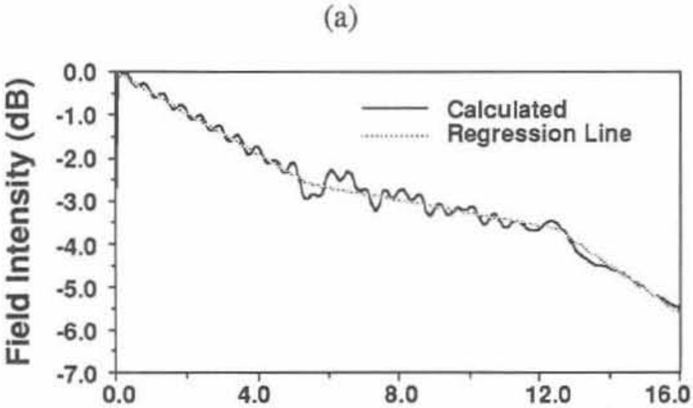


(b)

Fig.2 Field pattern in tunnel (a) symmetric placement, (b) longitudinal cut view at x=0



(a)



(b)

Fig. 3 Field pattern in tunnel (a) asymmetric placement, (b) longitudinal cut view at x=0

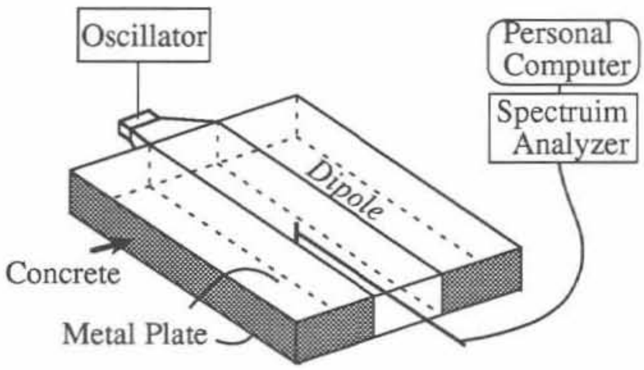


Fig.4 Measurement scheme

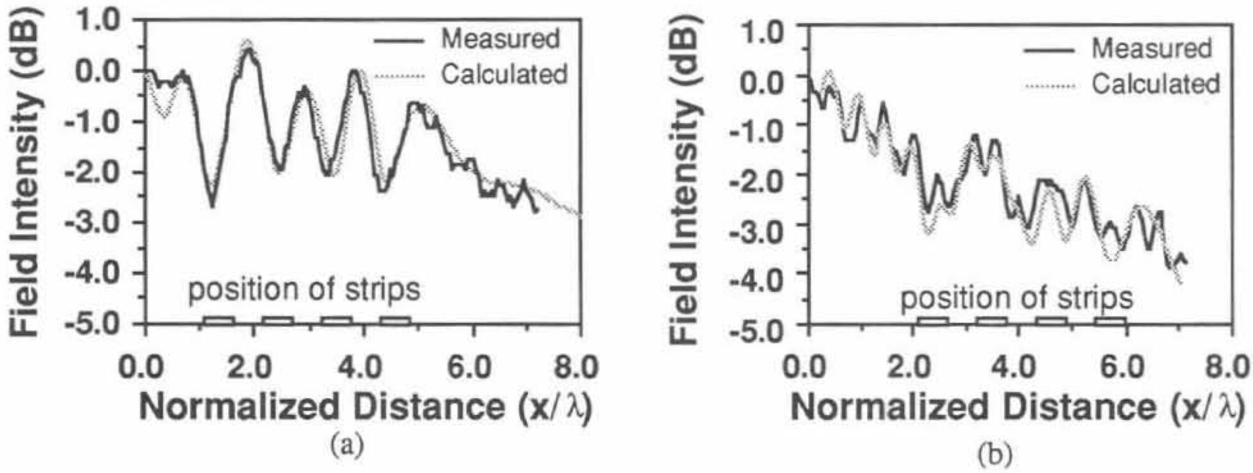


Fig.5 Experimental and calculated field strength along the tunnel
(a) symmetric placement (b) asymmetric structure

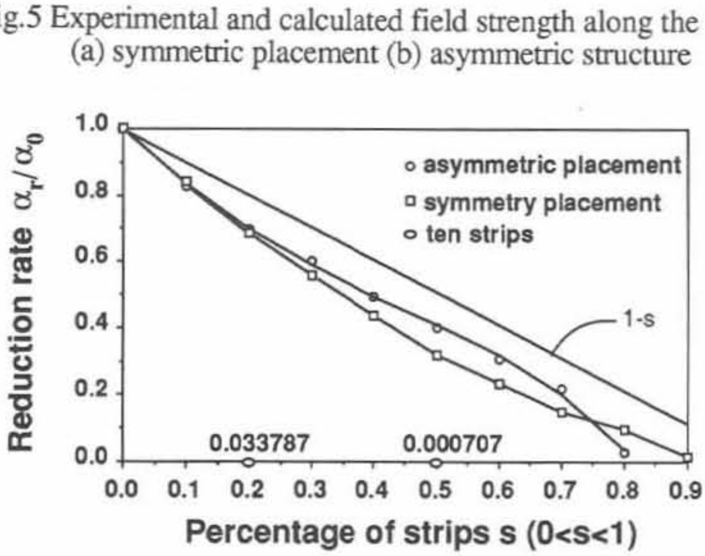


Fig.6 The graph of reduction rate of attenuation constant against area percentage parameter s

Reference

[1] K. Sakai and M. Koshiba, "Application of the boundary-element method to an infinitely long tunnel", *Trans. IEICE Japan*, vol.J-71-B, no.7, pp.872-881, 1988.

[2] Y. Yamaguchi, K. Kobayashi, M. Sengoku and T. Abe, "On the reduction of ratio wave propagation loss in tunnel", *Tech.Report.of IECE*, EMCJ90-40, Sept. 1990.

[3] T. Honda, Y. Yamaguchi, M. Sengoku and T. Abe, "Reduction of attenuation characteristics in two-dimensional tunnels", *Tech.Report.of IEICE*, A P91-71, Sept.1991.