SCATTERING AND RADIATION ANALYSIS OF ELECTROMAGNETIC WAVES FOR AUTOMOBILE BODYS WITH WINDOWS USING PERTURBED EIGEN MODES

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Introduction

In the communication systems using electromagnetic waves, such as mobile communications, satellite communications using microwaves and millimeter waves, and home electronic radio communication, evaluation of enviromental effects and condition in the communication systems is indispensable to construct the optimum systems with high feasibilities and reliabilities.[1 2] Particularly, scattering and radiation of electromagnetic waves by automobile bodys with windows made of glasses and the buildings on the street, and electric current induction in and on the automobile bodys are important phenomena for the antenna design of receiver and transmitter and electromagnetic compatibility consideration in the mobile communication.

The authors have analyzed the ghost characteristics of television broadcasting waves by power towers by using microwave simulation in the laboratory.[3] This microwave simulation methods are also applied to evaluate the scattering characteristics by automobiles.[4]

In this paper, based on these microwave simulation results, electromagnetic scattering and excitation in automobile bodys with glass windows, and radiation through the glass windows are exactly analyzed for the system design of the communication systems. By using the Green's dyadic, the electromagnetic fields are expressed in the form of vector integral equations for interior and exterior regions of automobies. It is found that, under the suitable conditions, the field in the automobile are intensified by the quasi-resonance effects. These quasi-resonance phenomena are shown by perturbed eigen vector mode functions and coincide with the microwave simulation results.

Electromagnetic fields outside of automobile

By using the magnetic Green's dyadic Γ satisfying the impedance condition on the earch surface S_E, the electromagnetic field in the exterior region of the automobile can by expressed as

$$\mathbb{H}_{totl} = \mathbb{H}_{inc} + \sum_{S_a, S_b, S_E} \int \{\mathbb{\Gamma} \cdot (-j\omega\varepsilon^*) \mathbb{n} \times \mathbb{E} - (\nabla \times \mathbb{\Gamma}) \cdot \mathbb{n} \times \mathbb{H}\} dS \qquad (1)$$

where total, incident and scattered fields $\mathbb{H}_{totl}$, H_{scatt}, H_{scatt} satisfy

$$\nabla \times \nabla \mathbb{H} - k_0^2 \mathbb{H} = 0 \qquad (2)$$

when $\mathbb{H}_{totl} = \mathbb{H}_{inc} + \mathbb{H}_{scatt}$, $k_0^2 = \omega^2 \varepsilon_0 \mu_0$.

$$\nabla \times \nabla \times \Gamma(r,r') - k_o^2\Gamma(r,r') = -I\delta(r,r') \quad (3)$$

and the boundary condition on y=o is

$$n \times (\nabla \times \Gamma) \cong j\omega\varepsilon\eta_s\Gamma$$

η_s is impedance function of the earth surface

$$\eta = \sqrt{\frac{\mu}{\varepsilon^*}}, \quad \varepsilon^* = \varepsilon - j\frac{\sigma}{\omega} \quad (4)$$
$$\eta_s = (1+j)\sqrt{\frac{\omega\mu}{2\sigma}}$$

In the eq.(1), S_a and S_b are the window surface and metal surface the tangential component of the magnetic field satisfys.

$$m \times H = \frac{1}{\eta}(E-(E\cdot n)m) \quad (5)$$

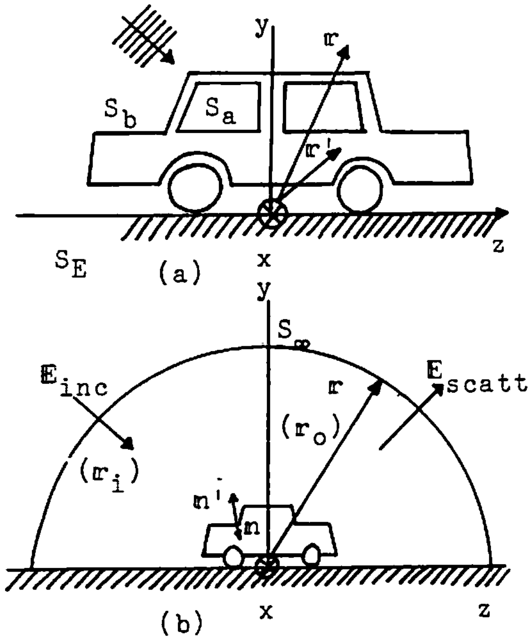

Fig.1 Scattering and radiation by automobiles

Electromagnetic fields in the automobile

The field in the automobile can be analyzed by the perturbed eigen modes for cavity with window. In order to show the window effect, solenoid and irrotational functions of TE and TM types H_ν^i, G_ν^i are used to derive the eigen modes.

$$\nabla\cdot H_\nu^{(i)}=0 \quad i=1(\text{for TE}),\ 2(\text{for TM}) \quad \nabla\times G_\nu^{(i)}= 0 \quad (6)$$

where

$$m\cdot H_\nu^{(i)} = 0 \qquad m \times E_\nu^{(i)} = 0$$
$$m \times G_\nu^{(i)} = 0 \qquad n\cdot G_\nu^{(i)} = 0 \quad (7)$$

$$\int_\nu H_\nu\cdot H_{\nu'}dv = \delta_{\nu\nu'}, \quad \int G_\nu\cdot G_{\nu'}dv = \delta_{\nu\nu'} \quad (8)$$

The electromagnetic field in the automobile can be expressed as

$$H = \int_{S_a,S_b} n\cdot[(\nabla \times H) \times \Gamma_c]dS \quad (9)$$

using the Green's dyadic with eigen values $k_\nu^{(i)}$,

$$\Gamma_c(r,r') = -\sum_{\nu,i}\frac{H_\nu^{(i)}(r)\overline{H}_\nu^{(i)}(r')}{k_\nu^{(i)2} - k_o^2} + \sum_{\nu,i}\frac{G_\nu(r)\overline{G}_\nu(r')}{k_o^2} \quad (10)$$

satisfying the boundary condition on the metal surface

$$m \times (\nabla \times \Gamma_c) = 0 \quad (11)$$

The continuity condition of the tangential components of electromagnetic fields on the windows of S_a leads to the following equations, if we use the expansion of

$$\mathbb{H} = {}_{\nu,i}\Sigma_i a_\nu^{(i)} \mathbb{H}_\nu^{(i)}(\mathbf{r}) \tag{12}$$

on the window surface S_a,

$$ {}_{\nu,i}\Sigma_i a_\nu^{(i)} \mathbb{H}_\nu^{(i)} \Big[1+\frac{1}{k_\nu^{(i)2}-k^2}\Big\{j\frac{\omega\varepsilon\eta}{4}\int_{S_a}|\mathbb{H}_\nu^{(i)}|^2 dS + j\omega\varepsilon\eta_s \int_{S_b}|\mathbb{H}_\nu^{(i)}|^2 dS\Big] = 0 \tag{13}$$

we have used that the field equations for each eigen modes satisfy

$$\mathbf{n} \times (\nabla \times \mathbb{H}) \cong j\omega\varepsilon\eta_s \mathbb{H}$$

$$\mathbf{n} \times (\nabla \times \mathbb{H}) \cong j\omega\varepsilon\eta \mathbb{H} \tag{14}$$

on the metal and window surfaces. From the eq.(14), eigenvalues of quasi-resonances are

$$ {}_o k_\nu^{(i)} = k_\nu^{(i)}\Big\{1-\frac{1}{2k_\nu^{(i)}}\Big(\omega\varepsilon\eta^{(i)}+\frac{\sqrt{\frac{\varepsilon}{\mu}}\eta}{16k_\nu^{(i)}}\Big)\int_{S_a}|\mathbb{H}_\nu^{(i)}|^2 dS\Big\}$$

$$+j\Big\{\Big(\frac{\omega\varepsilon\eta^{(r)}}{2k_\nu^{(i)}}+\frac{\sqrt{\frac{\varepsilon}{\mu}}\eta}{8}\Big)\int_{S_a}|\mathbb{H}_\nu^{(i)}|^2 dS+\frac{\omega\varepsilon\eta}{2k_\nu^{(i)}}\int_{S_b}|\mathbb{H}_\nu^{(i)}|^2 dS\Big\} \tag{15}$$

Consequently, modified Green's dyadic can be expressed by using perturbed eigen modes and eigen values.

$$ {}_o\Gamma_c = -{}_{i,\nu}\Sigma \frac{\mathbb{H}_\nu^{(i)}(\mathbf{r})\bar{\mathbb{H}}_\nu^{(i)}(\mathbf{r}')}{{}_ok_\nu^{(i)2} - k_o^2} \tag{16}$$

In eq.(15) the first term shows the deviation of resonance frequency, the second term shows radiation loss and ohmic loss. ${}_ok_\nu^{(i)}$ is complex eigenvalue. Fig.2 and 3 shows resonance spectrums for body sizes and windows, l_i and $S_{ij}^{(1)}$ normal to the i directions. Increases of eigenvalues are due to capacitive reactance characteristics of windows. These examples are evaluated for rectanglar bodys as shown in Figures.

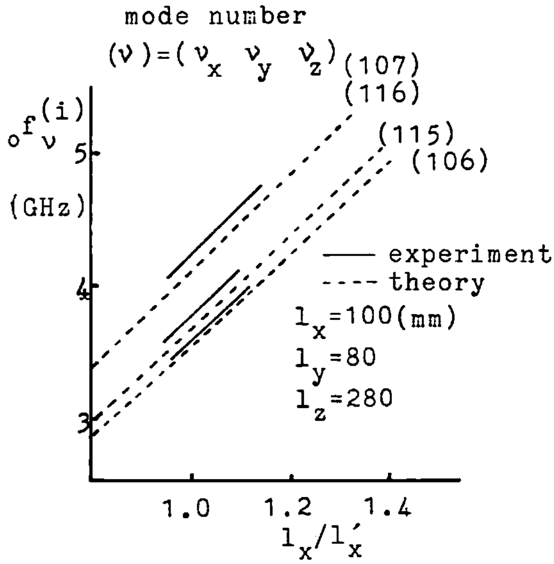

Fig.2 Dispersion curves of resonant modes and perturbed eigen values.

Scattering and radiation in the automobile

Using eq.(1) and (16), the continuity condition to find the field on the window that leads the scattering and radiation fields can be expressed as

$$\mathbb{n} \times \mathbb{H} = \mathbb{n} \times \mathbb{H}_{inc}$$

$$+ \Sigma_{S_a, S_b} \int \{ \mathbb{n}\times\Gamma(-j\omega\varepsilon^{*})\mathbb{n}\times\mathbb{E}$$

$$- \mathbb{n}\times(\nabla\times\Gamma)\cdot(\mathbb{n}\times\mathbb{H}) dS$$

$$= \Sigma_{\nu,i} \frac{j\omega\varepsilon \mathbb{n}\times\mathbb{H}_{\nu}^{(i)}}{{}_{o}k_{\nu}^{(i)} - k_{o}^{2}} \int \mathbb{n}\times\mathbb{E}\ \mathbb{H}_{\nu}^{(i)} dS$$

$$- \Sigma_{\nu,i} \mathbb{n}\times\mathbb{G}_{\nu}^{(i)} \frac{j\omega\varepsilon}{k_{o}^{2}} \int \mathbb{n}\times\mathbb{E}\cdot\mathbb{G}_{\nu}^{(i)} dS \qquad (17)$$

if the expansion $\mathbb{H} = \Sigma_{i,\nu} a_{\nu}^{(i)} \mathbb{H}_{\nu}^{(i)}$, $\mathbb{E} = \Sigma_{i,\nu} b_{\nu}^{(i)} \mathbb{E}_{\nu}^{(i)}$ is substituted into eq.(17), determinant equation for $a_{\nu}^{(i)}$ is obtained. The scattered field is obtained by $a_{\nu}^{(i)}$.

Conclusion

Scattering and radiation effects in automobiles with windows that are important factors of the optimum design in mobile communication systems are analyzed by exact analysis for vector boundary value problems.

The resonance effects that give useful antenna system designs in the automobiles are found. System problems for space diversity using these effect will be also discussed.

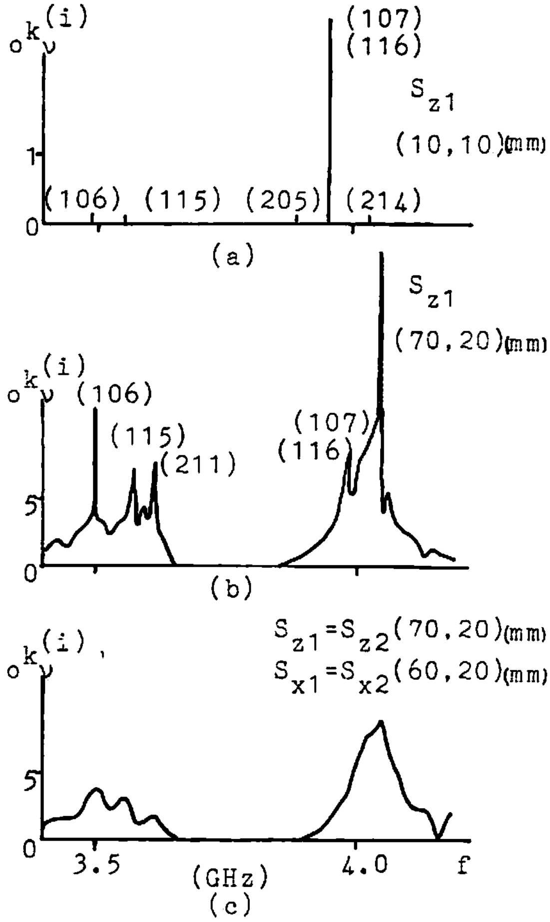

Fig.3 Resonance spectrum and radiation losses in case of z direction incidence with y polarization

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