

Analysis of Electromagnetic Environment in a CAD-based Vehicle with a Human Body for Far-field Incidence

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Abstract—The electromagnetic environment in a vehicle was investigated taking into account the presence of a human body. The present study was conducted in order to give some insight on the effects of the exposure to unintentional electromagnetic waves on electronic devices in vehicles. Our computational results revealed that the electric field around the dashboard was enhanced due to standing waves over the vehicle cabin. In addition, the standing waves were found to be suppressed in the frequency region between 100 and 200 MHz due to power absorption by the human body.

Index Terms—human body, partially closed environment, standing waves, immunity

I. INTRODUCTION

CONCERNS about electromagnetic (EM) disturbances in road vehicles have increased with the increase in the number of electronic devices used for controlling, monitoring, and displaying a variety of functions in vehicles [1]. Typically, there are 50-100 central processing units (CPUs) in a modern vehicle. Road vehicles may be exposed to unintentional high-power EM waves emitted from broadcast and radar transmitters. Another feature of vehicles is their unique partially closed structure, which makes the EM environment in vehicles of particular interest to engineers. For example, the quality of FM broadcasting in vehicles has been reported to be degraded by EM disturbances [2]. In addition, typical vehicles have several antennas, for example, to receive television and FM broadcasts and for global positioning systems. Thus, antenna optimization has been conducted in accordance with the development of computational techniques and resources considering the entire body-shell [3]-[5]. However, the effect of human body in a vehicle on the antenna design has not yet been well investigated.

EM disturbances are generated over a wide frequency range with various electrical characteristics, and can be distributed to on-board electronic devices by conduction, radiation, or both [1]. The international standard for the immunity testing of vehicles is classified to i) off-vehicle radiation sources, ii) on-board transmitters, and iii) bulk current injection. In the present study, we focus on the EM disturbances in a vehicle due to off-vehicle radiation sources, and consider unintentional high-power EM wave exposures. In the immunity testing described in the international standard [2], a vehicle is exposed to EM waves emitted from an antenna in a shielded enclosure. The immunity of the vehicle against EM waves is then

evaluated. However, in this test, the human body is not taken into account. The effect of the human body on the EM environment in a vehicle should be investigated in order to further clarify the rationale of the standard and improve the electronic design of vehicles.

In the present study, we first investigate computationally the fundamental characteristics of the EM environment in a vehicle without human body. Then, the effect of the human body on the EM environment in the vehicle is investigated. Note that power absorption in the human due to mobile terminals in a vehicle has been modeled in [6, 7].

II. COMPUTATIONAL METHODS AND MODEL

The dispersive finite-difference time-domain (FDTD) method [8] was used to analyze the EM environment in a vehicle, since the electrical constants of human tissues depend on the frequency of EM waves.

A three-dimensional vehicle computer aided design (CAD) model was downloaded from the Model-Wave internet site [9]. This CAD-based model was converted into small voxels with software [10]. The resolution of the model has been chosen as 10 mm. The original CAD model was divided into 44 parts. Based on their electrical characteristics, we classified these parts to five materials: metal, glass, plastic, fabric, and rubber. The relative permittivity and conductivity of metal are chosen as 1.0 and 1.0×10^8 S/m, respectively. The relative permittivities of glass, plastic, fabric, rubber are 5.5, 4.0, 2.0, 3.0, respectively, and these materials are considered as lossless.

The human body model was constructed from an anatomically-based human body model developed at Brooks Air Force Base [11]. This human model was first homogenized, which is a reasonable simplification for the discussion of the fundamental characteristics of human body. The shape of the human model was then bent partially in order to place the model in the driver's seat. The vehicle model with human is illustrated in Fig. 1. Note that the effect of the anatomically-based structure of the human body on its power absorption is at most a few percents in the frequency region of MHz region from our previous study [12]. This is the same when considering antenna design in close proximity of the human body [13]. The electrical constant of 2/3 muscle equivalent tissue was used to simulate the homogeneous tissue

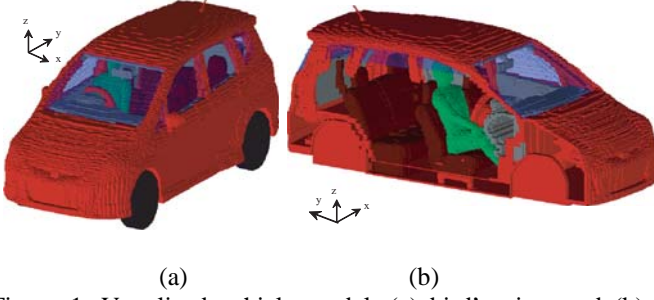


Figure 1. Voxelized vehicle model: (a) bird's view and (b) cross-sectional view.

[14], assuming as a Debye dispersive medium with two poles. Its electrical constants are given by the following equation:

$$\epsilon_r(\omega) = \epsilon_\infty + \frac{\sigma_o}{j\omega\epsilon_o} + \sum_{i=1,2} \frac{\Delta\epsilon_{pi}}{1 + j\omega\tau_{pi}} \quad (1)$$

where $\sigma_o=0.213$, $\epsilon_\infty=4.51$, $\Delta\epsilon_{p1}=236.5$, $\Delta\epsilon_{p2}=30.7$, $\tau_{p1}=5.65$ MHz, $\tau_{p2}=20$ GHz. Even if we applied this assumption, the difference in the electrical constants with measured values is within 12% over the frequency region considered.

The separation between a vehicle model and 12-layered PML was kept to 500 mm (50 cells) with the cell resolution of 10 mm. As an incident wave, a plane wave with vertical polarization (VP) and horizontal polarization (HP) was considered based on the immunity testing procedures in [1]. To realize wideband plane-wave injector, we used an algorithm in [15]. The frequency considered is 10 MHz to 1 GHz, which mostly covers the antenna operation frequency for wireless communications and the CPU clock used in electronic devices.

III. COMPUTATIONAL RESULTS

Electronic devices in vehicles are mainly located around the dashboard, as is evident from the concentration of wiring harnesses that connect electric devices. As a fundamental discussion, we considered an induced electric field at the center of the dashboard E_{out} for the incidence of plane wave E_{in} . Then, the ratio of E_{out} to E_{in} was defined as T , which was calculated for the cases with (T_w) and without the human model (T_{wo}).

A. Fundamental Characteristics of the EM Environment in a Vehicle

Figure 2 shows the ratio of the electric field induced at the center of the dashboard to that of the incident plane wave when the human model is not considered (T_{wo}). As shown in Fig. 2, T_{wo} for VP is larger than that for HP mainly due to the diffraction from the body shell. T_{wo} for both HP and VP becomes larger than 1 due to standing waves. These peaks are in good agreement with analytical resonance frequencies derived by considering a rectangular parallelepiped, the size of which corresponds to the vehicle cabin. Some differences may arise due to the seats in the cabin and uniquely shaped body shells. For the EM wave with a wavelength longer than the front glass or below the cutoff frequency of 113 MHz, the induced electric field is generally small. However, T_{wo} was not always smaller than 1 for frequencies above 60 MHz due to an evanescent wave, because our observation point was located at

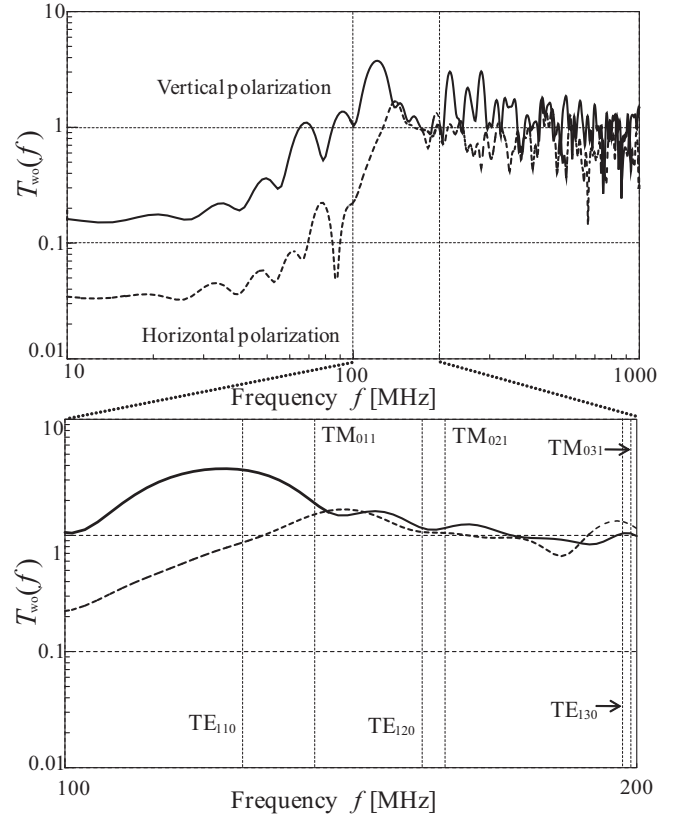


Figure 2. Frequency characteristics of the induced electric field at the center of the dashboard normalized by the incident electric field. Solid and dashed lines represent the exposure with VP and HP, respectively.

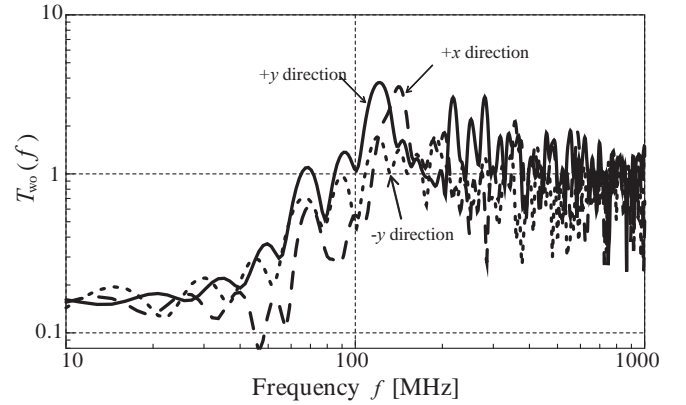


Figure 3. Frequency characteristics of the induced electric field at the center of the dashboard normalized by the incident electric field for different angles of incidence with VP.

the center of the dashboard or close to the front glass.

Figure 3 shows T_{wo} for different angles of incidence. The same tendencies were observed for different angles of incidence. The magnitudes and frequencies of peaks are shifted for different angles of incidence mainly because of the unique structure of the vehicle, e.g., different sizes of windows and different resonance frequencies. This figure shows that the EM magnitude for exposure of +y direction is the largest. Generally, not only the first peak at 110 MHz but the following peaks are

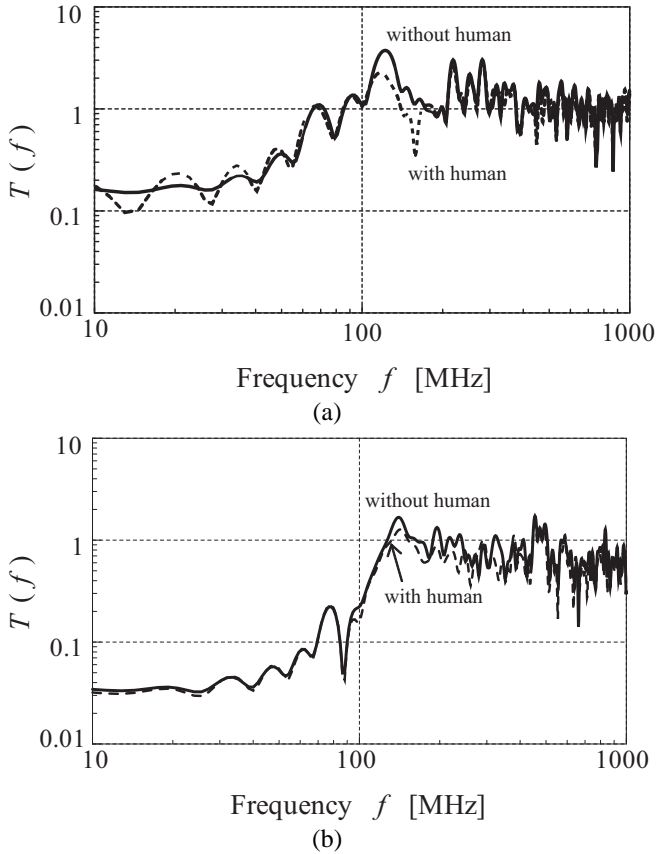


Figure 4. Ratio of the electric fields at the center of the dashboard with and without the human body for VP (a) and HP (b).

larger than the others for this exposure condition. Therefore, in the next subsection, the effect of the human body on T_{wo} will be discussed based on the incidence from the front of the vehicle.

B. Effect of the Human Body on the EM Environment in a Vehicle

The effect of the human body model on the induced electric field was investigated at the center of the dashboard. Figure 4 shows T for cases with and without the human body model for both polarizations. As shown in Figure 4(a), T becomes small when the human body model was taken into account at the resonance frequencies. Specifically, the standing waves in the vehicle were suppressed due to the power absorption in the human body. This tendency was obvious for frequencies between 100 and 200 MHz. Figure 4(b) show that T becomes small in the frequency region between 100 MHz and 250 MHz when the human body model was considered, which is similar to the case for VP.

However, the difference between T_w and T_{wo} was smaller in the case of HP. The reason for this difference is thought to be the difference in EM power absorbed by the human body. In the frequency region from several dozen megahertz to one hundred and a few dozen megahertz, the power absorption in the human becomes maximum due to a standing wave, because the human body behaves as a lossy antenna analogous to a half-wave dipole [16]. Thus, the power absorbed by the human body was

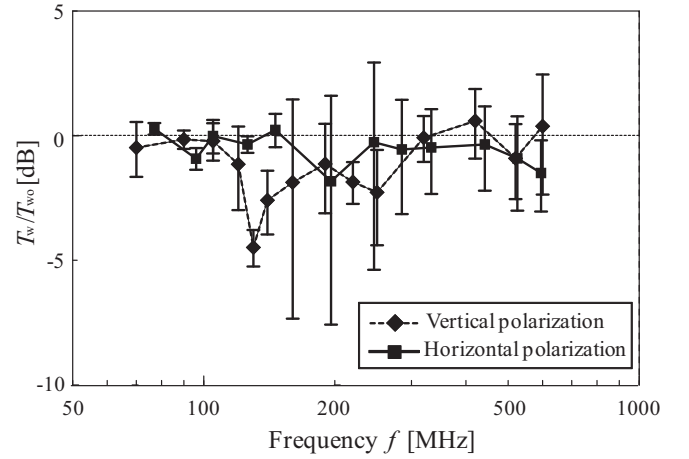


Figure 5. Induced electric field over the dashboard in the vehicle.

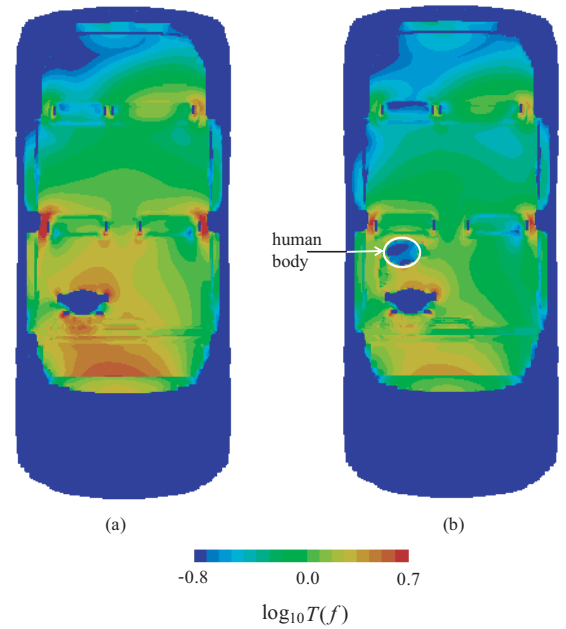


Figure 6. Electric field distribution on the horizontal plane without (a) and with (b) the human body at 130 MHz.

more significant for VP than that for HP. In order to confirm the above finding, the ratio of T_w to T_{wo} was investigated over the entire dashboard, and the results are shown in Fig. 5. The average ratio and standard deviation are then plotted assuming that the field intensity follows a normal distribution. This figure shows that the field strength decreased not only at the center but also around the dashboard when considering the human body model. The decrease in field strength became maximum at 130 MHz (-3.8 -5.2 dB). This is confirmed from Fig. 6, in which the electric field distribution on the horizontal plane inside the vehicle is shown. As this figure shows, the field distribution is decreased both around the dashboard and throughout the cabin. The ratio of T_w to T_{wo} throughout the entire cabin was -1.5 dB, suggesting that the standing wave was suppressed throughout the cabin.

IV. CONCLUSION

We investigated the electromagnetic environment in a vehicle taking into account with the human body. We first investigated the electric field around the dashboard in the vehicle for plane-wave exposure. The induced electric field in the vehicle was found to be enhanced due to standing waves over the vehicle cabin. When taking into account the human body, the standing waves were found to be suppressed in the frequency region between 100 and 200 MHz due to the power absorption in the human body. Except this frequency region, no clear difference is observed in the induced electric field. Except this frequency region, the effect of human body on the EM environment in the vehicle is marginal, while the frequency region would be influenced by the dimension of the vehicle cabin.

Based on the reciprocity, the frequency region in which the human body influences the EM environment in the vehicle cabin would be the same when designing vehicle antennas taking into account the body shell of vehicles and human bodies.

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