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Design of On-glass Antennas for FM Diversity Systems

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Abstract-The monopole type antennas such as the conventional λ/4 monopole, tuned monopole, roof-mounted micro-antenna and shark fin antenna have been widely used for FM radio reception in various types of vehicles. These antennas, however, suffer from lack of durability and undesirable appearance. To solve these problems on-glass antennas have been used in various vehicles. But these on-glass antennas generally exhibit relatively low signal reception performance due to their poor impedance matching and low antenna gain especially in urban environment where multi-path fading exists. Recently, to improve the receiving performance, some luxury vehicles employ diversity on-glass antenna systems that incorporate two separated antennas in the rear window.

In this paper, we report on the channel capacity and diversity gain of the on-glass rear window antennas. Using the radiation pattern of each antenna and the transfer matrix, the correlation coefficient and channel capacity are obtained. Then we observe the variation of the channel capacity by examining three basic design structures that consist of two separated bent striplines. The results show that the distance between the feed positions are the major factor that affects on the channel capacity. In addition the polarization of the two antennas gets more important when the distance between the feeds is greater than a certain threshold value.

Key words Diversity systems, Multi-path fading, and Correlation coefficient

1. Introduction

AM/FM radio is one of the most widely used communication system in various types of vehicles. The receiving performance of AM/FM radio is usually considered as a primary factor that affects the vehicle evaluation by ordinary customers. For the AM/FM receiving antenna, the monopole type antennas such as the conventional λ/4 monopole, tuned monopole, roof-mounted micro-antenna and shark fin antenna have been widely used in various types of vehicles [1]. These antennas, however, suffer from lack of durability and undesirable appearance as they protrude from the vehicles. To mitigate these problems, on-glass antennas have developed and are commonly applied in newly-developed vehicles. In addition, the on-glass antenna has an advantage of very low-cost fabrication since the antenna body can be made by printing directly on a window [2-4]. However, these on-glass antennas generally exhibit relatively low signal reception performance due to their poor impedance matching and low antenna gain particularly in urban environment where the channel characteristics are predominated by multi-path fading. Recently, to improve the receiving performance, some luxury vehicles employ diversity on-glass antenna systems that incorporate two separated antennas in the rear window.

In this paper, we report on the channel capacity and the diversity gain of the on-glass rear window antennas. To obtain high diversity gain, the two antennas in rear window should have a low antenna correlation coefficient to maximize the channel capacity. The correlation coefficient and channel capacity are observed by examining three basic design structures that consist of two separated bent striplines.

2. Channel Capacity Evaluation

To obtain the channel capacity for diversity antennas, the correlation coefficient should be calculated as follows:

$$\psi_{ij} = \frac{1}{\sigma_i \sigma_j} \oint E\left\{ \left(\mathbf{A}_i(\Omega) \cdot \mathbf{E}(\Omega) \right) \left(\mathbf{A}_j^{\dagger}(\Omega) \cdot \mathbf{E}^{\dagger}(\Omega) \right) \right\} d\Omega \qquad (1)$$

where σ_i and σ_j are variances of signals received by antennas i and j, respectively, and Ω is the solid angle over (θ, ϕ). $\mathbf{A}_i(\Omega)$ and $\mathbf{A}_j(\Omega)$ are 3D-radiation pattern of each antenna, and $\mathbf{E}(\Omega)$ is a random incident field [5-6]. Fig. 1 shows simple on-glass antennas that consist of two striplines fed at opposite frames. The radiation patterns of antennas are obtained using a full wave EM simulation. For faster and more accurate EM simulation, the stripline of antennas printed on a rear window is modeled as a coated wire which assumes that the inner conducting wire is coated by dielectric materials. In addition, we include an entire vehicle body as 4,200 piecewise meshes in order to achieve more accurate radiation patterns. Fig. 2 shows the comparison between the simulated and measured radiation patterns of the two antennas in azimuth direction (θ=90°). The blue line is for the antenna 1 and the red line is for the antenna 2. The solid lines represent the measurement and the dashed lines represent the simulation. They agree fairly very well with each other. In this measurement, we used a Yagi-Uda antenna as a transmitter and our on-glass antenna as a receiver. Two antennas are connected by Agilent E5071A network analyzer, and they are placed in a semi-anechoic chamber of 30 m × 30 m. Based on the radiation patterns, we can calculate the ergodic channel capacity using eq. (2).

$$C = E\left\{ \log_2 \left[\det \left(I_{n_R} + \frac{\rho}{n_T} \widetilde{\mathbf{H}} \mathbf{\Psi} \widetilde{\mathbf{H}}^{\dagger} \right) \right] \right\} \qquad (2)$$

Here n_T, n_R are numbers of transmitting and receiving antennas, $\tilde{\mathbf{H}}$ is an $n_T \times n_R$ normalized transfer matrix of a flat-fading channel,

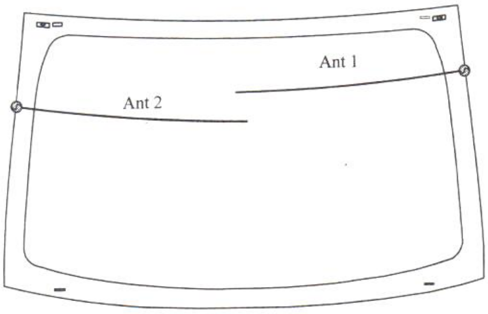


Fig. 1. Basic antenna structure

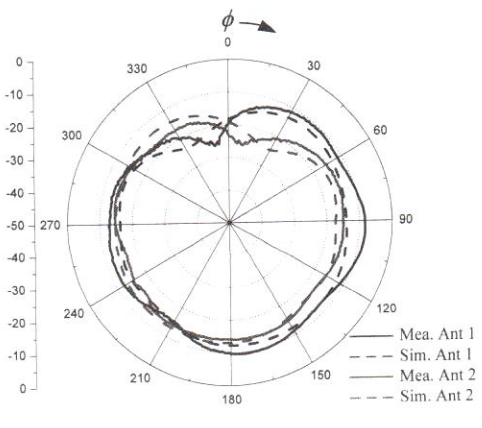
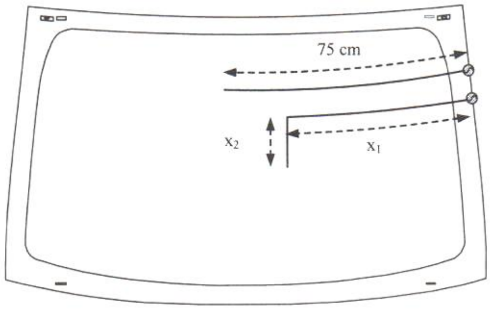


Fig. 2. Radiation patterns of the basic antenna

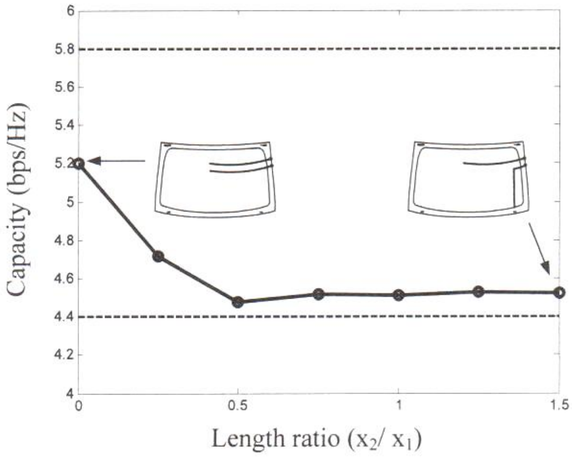
and ρ is a signal to noise ratio. The elevation angle of the incident field has a Gaussian distribution of a 90° mean and a 30° variance. The azimuth direction of the incident field has a uniform distribution.

3. Results of Capacity Simulations

To observe the channel capacity of the diversity on-glass antennas, we examine three basic antenna structures that consist of two bent striplines. First, we examine the case that two feeders are placed in vicinity at the same frame as shown in Fig. 3(a). The antenna 1 is fixed as 75 cm which resonates at 100 MHz. The antenna 2 is bent with a ratio of x_2/x_1. The total length of antenna 2 is fixed as 75 cm, but the ratio of x_2/x_1 is gradually increased. The resulting channel capacity depending on the ratio of x_2/x_1 is shown in Fig. 3(b). In this case, the antennas show a relatively low channel capacity below 5.2 bps/Hz. In fact the radiation patterns of the two antennas are very similar to each other, although we change the bent ratio of the antenna 2. This shows that location of feed is an important factor determining the channel capacity of the diversity antennas in vehicles.

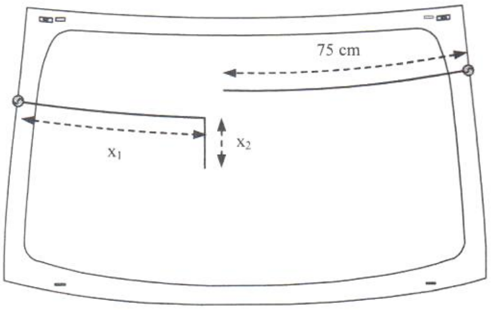


(a) Antenna structure

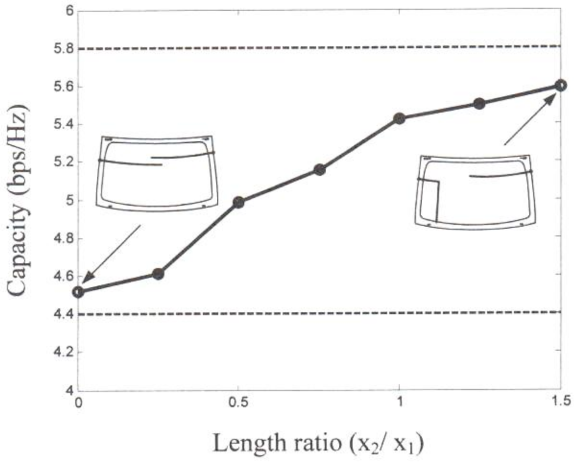


(b) Channel capacity

Fig. 3. Case I – closely spaced feeders



(a) Antenna structure



(b) Channel capacity

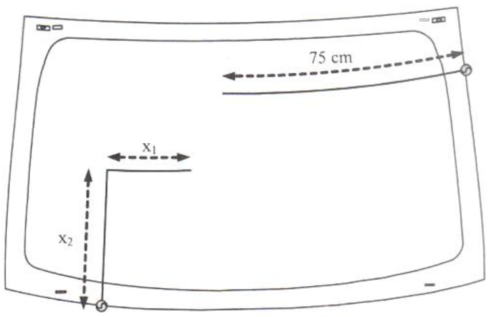
Fig. 4. Case II – maximized space diversity

Then we examine another case where the two feeders are located at the opposite frame to obtain maximum spacing between the two antennas. Fig. 4(a) shows the basic antenna structure where antenna 1 is fed from the right frame and the antenna 2 is fed from the left frame. Again antenna 2 is bent with the ratio of x_2/x_1. Fig. 4(b) represents the channel capacity in terms of the bent ratio (x_2/x_1). At this time the radiation patterns of the two antennas gets dissimilar as we increase the ratio of x_2/x_1. From this result, we can see that the diversity gain by polarization is getting more important when the spacing between the two antennas is maintained as more than a certain threshold value.

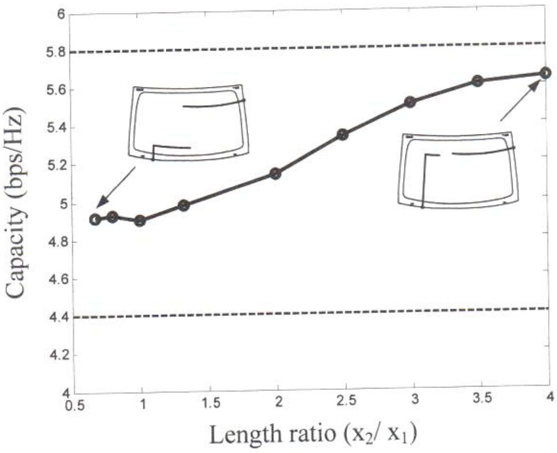
Finally, we examine the case where the location of the feed is determined to obtain better polarization diversity. The feeder of antenna 2 is located at the lower frame, and the bent ratio of x_2/x_1 is gradually changed. Similar to the case II, the channel capacity is increased as the ratio x_2/x_1 is raised.

4. Conclusion

In this paper, we reported the channel capacity of the diversity on-glass antennas for vehicular applications. The correlation coefficient between the two antennas was obtained by EM



(a) Antenna structure



(b) Channel capacity

Fig. 5. Case III – maximized polarization diversity

simulation including the antenna structure as well as the vehicle body. Then the channel capacity was calculated using the correlation coefficient and the transfer matrix for a multi-path fading environment. To observe the channel capacity of on-glass antennas, we examined three basic antenna structures consist of two bent striplines. The results showed that the distance of feed positions is an important factor that determines the channel capacity of on-glass diversity antennas in vehicles. Also the polarization of the two antennas gets more important when the distance between the feeds is greater than a certain threshold value.

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