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Conditions for Monopole Antenna Arrangement Mounted on Mobile Terminal for Maximizing Beam-steering and Diversity Gains

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1. Introduction

A new wireless access scheme, called the systems beyond IMT-2000, was investigated to establish significantly higher data rates with a wide coverage area [1]. In trying to achieve high data transfer rates, we must deal with the consequences of an increasing required signal to noise ratio (SNR). Simply revising antenna techniques from existing wireless systems such as PDC and IMT-2000 for the systems beyond IMT-2000 is insufficient. Moreover, it is desirable that the systems beyond IMT-2000 flexibly support single-cell areas such as hot-spot areas and indoor offices as well as multi-cell environments, which are similar to existing cellular systems. Accordingly, the propagation environments around mobile terminals are very diverse, and line of sight (LOS) or non-LOS conditions are common in the respective environments. In order to establish wireless communications with a high data transfer rate in different propagation environments, a mobile terminal must utilize multiple antennas that employ beam-steering and diversity techniques to acquire the required signal power per bit by adjusting to the propagation environment around the mobile terminal [2].

This paper clarifies the fundamental conditions for a monopole antenna arrangement mounted on a mobile terminal that will maximize the beam-steering and diversity gains. We consider that a laptop PC is a suitable terminal for broadband packet transmission in the systems beyond IMT-2000. Therefore, we employ card-type and laptop PC type models as terminals in this paper. The rest of this paper is organized as follows. Section 2 first describes the simulation models, followed by Section 3, which discusses the criteria for evaluating the antenna characteristics. The simulation results are evaluated and the fundamental conditions are discussed in Section 4. Finally, Section 5 presents our conclusions.

2. Simulation Models

The simulation models used in the paper are shown in Fig. 1. The card-type and laptop PC type models shown in Figs. 1(a) and 1(b), respectively, are primitive configurations comprising a quarter-wavelength monopole antenna and a planar conductor. The size of the card is 0.7×1.6 λ. Two or four antenna elements with a radius of 0.5 mm are arranged vertically at the edge of the card in parallel. The size of the LCD and keyboard in the laptop PC model is 2.7×4.0 λ. The angle between the LCD and keyboard is 90 degrees.

The analyses of the antenna are given by employing the method of moment (MoM) [3]. The grid size is 1 to 5 mm, and we examined only the vertically-polarized component (E_θ) in this paper because

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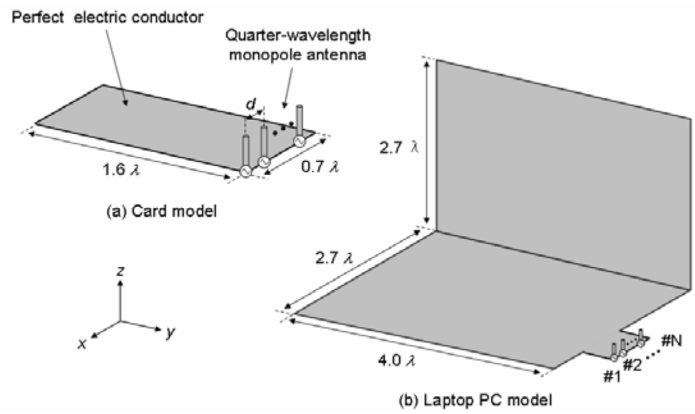
vertical polarization is advantageous for the antennas mounted, for example, on the laptop PC model assuming that the antenna of the base station is installed vertically. Moreover, in order to evaluate the effect of mutual coupling, we added a 50 Ω resistance to the feed point of a non-radiating element in a multiple antenna configuration.



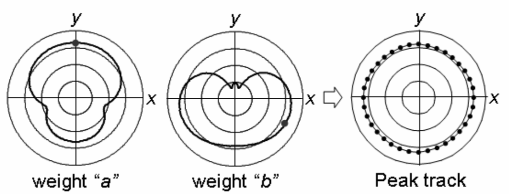


Fig. 1 Simulation models. Fig. 2 Peak track by beam-steering.

3. Criteria for Evaluating Antenna Characteristics

The purpose of this paper is to clarify the fundamental conditions for a monopole antenna arrangement mounted on a mobile terminal that will maximize beam-steering and diversity gains. We employ two criteria for evaluating the antenna characteristics. One is the average peak gain for the beam-steering, and the other is the correlation coefficient for diversity.

In the beam-steering mode, the beam pattern, which has a peak in all directions, is obtained as shown in Fig. 2, so that the peak tracking pattern using beam-steering can be considered the mean radiation pattern. Therefore, the antenna mean gain for beam-steering, called the average peak gain, is given by the following equation.

$$G_{\mathrm{p}} = \frac{1}{2\pi}\int_0^{2\pi} G_{\mathrm{peaks}}(\phi)\, d\phi \qquad (1)$$

where G_{peaks} is the peak track pattern using beam-steering.

On the other hand, we employ a correlation coefficient, which can predict the diversity gain, in the diversity mode [4]. To simplify, the elevation angle of arriving waves is assumed to be distributed only in the horizontal direction. The correlation coefficient is given by the following equation,

$$\rho = \frac{\int_{-\pi}^{\pi} G_1^*(\phi) G_2(\phi) P(\phi) e^{-j2\pi d\cos\phi/\lambda} d\phi}{\left[\int_{-\pi}^{\pi} G_1^*(\phi) G_1(\phi) P(\phi) d\phi \cdot \int_{-\pi}^{\pi} G_2^*(\phi) G_2(\phi) P(\phi) d\phi\right]^{1/2}} \qquad (2)$$

where $G_i(\phi)$ is the power gain pattern of each antenna. Term $P(\phi)$ is the angular density function of the incoming waves, and the $P(\phi)$ is uniform over 360 degrees in the azimuth plane in this paper.

In this paper, we discuss the fundamental conditions for the monopole antenna arrangement mounted on a mobile terminal that maximize the beam-steering and diversity gains employing two parameters, the average peak gain and correlation coefficient.

4. Simulation Result

4.1 Peak track pattern using beam-steering

Simulated beam patterns of a two-element configuration in the azimuth plane are shown in Fig. 3. The distance between antennas is 0.5 λ, and we normalize the gain by the value of a single antenna with an infinite ground plane. By controlling the excitation amplitude and phase of both elements, we can steer the beam peak toward the direction of arrival, which is assumed to be 30 degrees and 90 degrees. Moreover, the simulated patterns of the card and laptop PC models, although a pattern ripple can be seen, have the same patterns as the patterns of the infinite ground plane, which seems to be under ideal conditions. Figure 4 shows the peak track pattern using beam-steering of a two-element configuration. The distance between antennas is 0.5 λ. As shown in Fig.4, the gains of the multiple antennas are improved for all directions in comparison to a single antenna. The gain when using the multiple antennas in the card model is approximately 3.7 dB compared to that for the single antenna with the average peak gain mentioned in the Section 3. Similarly, the gain of the antenna used in the laptop PC model is approximately 3.0 dB.

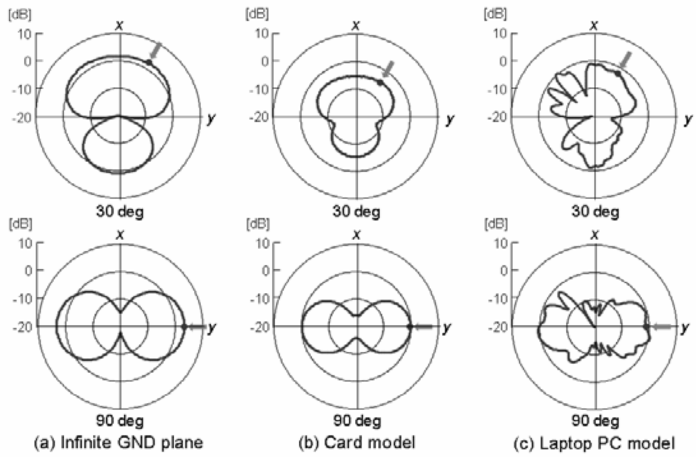


Fig.3 Simulated beam patterns of a two-element configuration with separation distance of 0.5 λ.

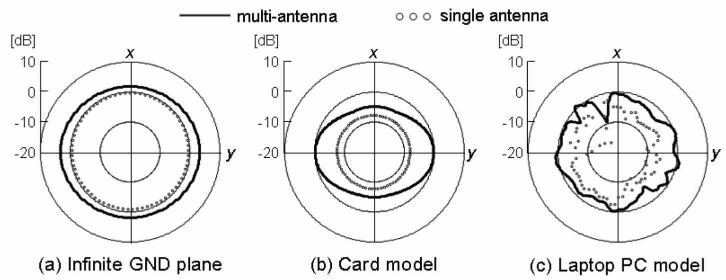


Fig.4 Peak track pattern by beam-steering of a two-element configuration with separation distance of 0.5 λ.

4.2 Dependency of Average Peak Gain on Inter-Element Distance

Figure 5 depicts the average peak gain corresponding to the inter-element distance. We normalize the gain by the value of a single antenna mounted on the card model. In this figure, the number of elements is a parameter. The solid lines represent the card model, and the dotted lines represent the laptop PC model. As shown in Fig. 5, the average peak gain is increased according to the increase in the distance between elements. This is because, when $d < 0.2\ \lambda$, mutual coupling between the antennas significantly degrades the radiation efficiency, while when $d > 0.2\ \lambda$ the average peak gain improves by approximately 3 dB for two elements and by approximately 6 dB for four elements in comparison to the single antenna case. In other words, we can fully derive the gain according to the array size by utilizing multiple antennas with the antenna separation distance of over 0.2 λ. Furthermore, the average peak gains of the laptop PC model are greater than that of the card model. We consider that this is due to the effect of the keyboard and LCD in the laptop PC model.

4.3 Correlation Coefficient

Figure 6 depicts the correlation coefficient corresponding to the inter-element distance. In this figure, the number of elements is a parameter. The solid lines represent the card model, and dotted lines represent the laptop PC model. As shown in Fig. 6, there is virtually no difference between the card model and the laptop PC model. Moreover, a low correlation coefficient of less than 0.6 is obtained by separating the elements by more than 0.2 λ in either configuration of two or four elements.

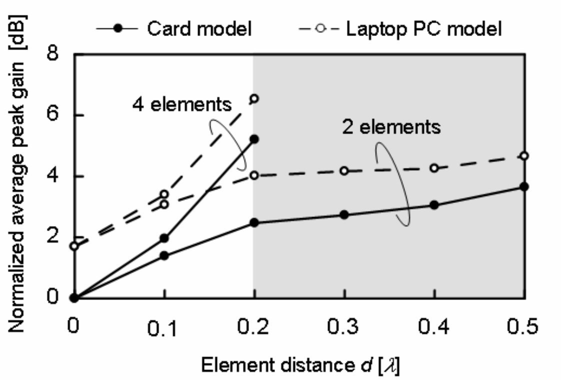


Fig. 5 Average peak gain.

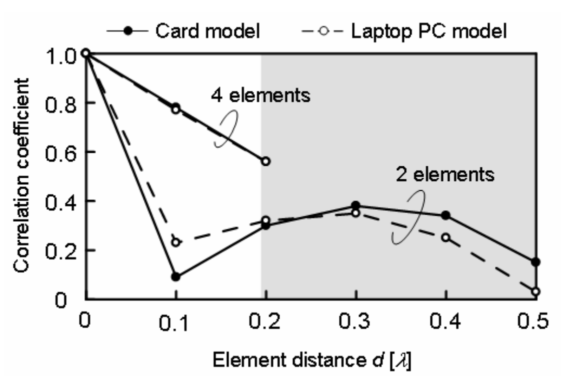


Fig. 6 Correlation coefficient.

5. Conclusion

The fundamental conditions for the monopole antenna arrangement mounted on a mobile terminal that maximize the beam-steering and diversity gains were examined by computer simulation using the MoM. Using the multiple quarter-wavelength monopole antennas mounted on the terminal, simulated by the card and laptop PC models, resulted in approximately 3 dB and 6 dB more power, respectively, compared to the single antenna. Furthermore, using multiple antennas resulted in a correlation coefficient of less than 0.6 by separating the elements by more than 0.2 λ. These results show that multiple monopole antennas mounted on a mobile terminal with an antenna separation of greater than 0.2 λ can operate at high average peak gain according to the array size and with a low correlation efficient of less than 0.6. Consequently, we can successfully combine beam-steering with diversity in a mobile terminal.

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