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Influence of Lossy Dielectric in Close Proximity to Dipole Array on the Accuracy of DOA Estimation

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1. Introduction

The fourth generation (4G) mobile cellular system will be deployed around the year 2010. The most promising frequency band for the systems seems to be 4 to 5 GHz band because of wide-range coverage, mobility, and low cost for radio-frequency equipment. A smart antenna technology on a handset is expected to become one of the key technologies in the 4G for the enhancement of the system capacity and quality. Such a concept could be realized as the wavelength of an electromagnetic wave used in the 4G system is comparable to the dimension of a handset terminal.

It is well known that the effect of mutual coupling between antenna elements degrades the performance of an antenna array. This effect is significant for adaptive nulling, such as MUSIC, ESPIRIT and so forth [1], [2]. Also, the coupling between an antenna and the human head could not be negligible when it is located in close proximity to the human head.

This paper presents a feasibility study on an adaptive nulling on a handset at 5.0GHz. At the first step, for investigating the effect of the model's shape and inhomogeneity, we compare the radiation characteristics of a dipole antenna in the presence of several head models. Next, we discuss the effect of the coupling between an array antenna and the head model on the accuracy of DOA estimation. Since this effect is found to be dependent on the separation between the array and the head model, a metallic plate is inserted between the array and the head model to suppress this effect. The effectiveness of this proposal is demonstrated numerically.

2. MUSIC and Mutual Coupling Compensation

To estimate the DOA of a wave from the signals received at the array, the super-resolution algorithm MUSIC is often used [1]. The feature of this algorithm is that it is less sensitive to white noise. This algorithm is based on the ensemble-averaged correlation matrix for the antenna outputs. The MUSIC spectrum is computed by performing an eigen-value analysis on the correlation matrix. The space spanned by the eigenvectors consists of two disjoint subspaces: signal and noise subspaces. From the orthogolonal characteristics of eigenvectors in the signal and noise subspaces, the MUSIC spectrum in the frequency domain is obtained.

In the original super-resolution algorithm, the effect of the mutual coupling of antenna elements was not taken into account. However, the mutual coupling of antenna elements is not negligible. Some compensation scheme for their coupling effects has been proposed [3,4,5,6,7]. Basically, there are two main streams of the compensation scheme; the approaches based on the impedance matrix [3,4] and the mutual coupling matrix [5,6,7]. In this paper, the scheme proposed in [7] is used. The MUSIC spectrum with the effect of the mutual coupling between antenna elements compensated for is given by the following equation.

$$P(\theta) = \frac{(\mathbf{Ca}(\theta))^H (\mathbf{Ca}(\theta))}{(\mathbf{Ca}(\theta))^H \mathbf{v}\mathbf{v}^H (\mathbf{Ca}(\theta))}$$

$$\mathbf{a}(\theta) = [1, \mathrm{e}^{jk\sin\theta}, e^{j2k\sin\theta}, e^{j3k\sin\theta}]^T$$

where **v**, **a**, and **C** denote the eigenvectors corresponding to the noise space, the scanning vector, and the mutual coupling matrix, respectively. Note also that the separations between antenna elements are assumed to be a half wavelength of an EM wave.

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3. Numerical Results

As the first step, radiation characteristics of a dipole antenna in the presence of the human head are investigated at 5.0 GHz. The FDTD method is employed for investigating the interaction of the human head model and the antenna. The dipole antenna is located at the distance of 20 mm from the right ear of the head model [8]. As a head model, either of the following head models is considered: inhomogeneous realistic-shaped, homogeneous realistic-shaped and parallelepiped models. Note that the dimensions of the parallelepiped dielectric are 50 mm X 150 mm X 150 mm (relative permittivity 33.5, conductivity 2.8 S/m). The skin depth of the material for EM waves at 5.0GHz is at most 1.0cm. Therefore the dimensions of the parallelepiped head model are reduced in the x direction for computational efficiency. The length and diameter of the antenna are 26 mm and 0.2 mm. Fig.1 shows the radiation pattern of the antenna on the horizontal plane in the presence of the human head model. Note that the distance between the human head model and the antenna is fixed to 2cm. From this figure, more EM power is radiated in the side opposite to the head and the difference in the antenna patterns is not large. From this figure, we find that the effect of the inhomogeneity and shape of the head model on the antenna pattern is small. As shown in Fig.2 the antenna pattern is distorted as compared with the case for 900 MHz and 1.9 GHz [9]. The larger dimension of the head model in terms of the wavelength causes this distortion. Namely, the human head model becomes a substantial obstacle at 5.0 GHz. The DOA estimation in the half space (+ x space, 90^o-270^o) was discussed in the foregoing discussion. On the basis of the above results, in order to reduce the computational cost, the dielectric parallelepiped is used instead of the inhomogeneous realistic-shaped head model.

Fig.3 shows the geometry for an adaptive nulling by an array antenna. The antenna array comprised of four dipole antennas is located close to the human head model at the distance of d. Fig.4 shows the MUSIC spectrum of the linear dipole array in the presence of the human head model for the angle of incidence θ of 30, 45, 70 and 80^o. For simplicity, the elevation angle is assumed to be 0^o. From this figure, the accuracy and depth of the MUSIC spectrum are found to be degraded by the presence of the head model. The point to be stressed is that they are dependent on the antenna-head model distance.

In order to suppress the effect of the head model, a metallic plate, which behaves as a reflector, is inserted between the antenna and the head model. The dimensions of the plate are 120mm(x direction) X 56 mm (z direction), which have a margin of 15 mm (a quarter of the wavelength) from the array. The separation between the antenna and the plate is 15 mm, corresponding to a quarter of the wavelength. The coupling matrix for the case where a reflector exists can be calculated by assuming that the metallic plate is of an infinite extent [10]. Note that this approximation is effective over most of semi-infinite of space (for the angle of incidence between 20^o and 180^o). Fig.5 shows the accuracy and depth of the MUSIC spectrum for the linear dipole array with the metallic plate. From this figure, the accuracy and depth of the MUSIC spectrum are found to be little dependent on the antenna-head model distance, unlike the case without the reflector.

4. Summary

The effect of the human head on the accuracy and depth of adaptive nulling has been investigated. The frequency band considered was around 5.0 GHz, which is expected to be the most promising for the 4G mobile communications. Our numerical investigation shows that the effect of the inhomogeneity and shape of the head model on antenna pattern is not large. The MUSIC spectrum obtained by the linear dipole array is found to be largely affected by the antenna-head coupling. Then the accuracy and depth of the MUSIC spectrum is dependent on the separation between the array and the head model. In order to suppress that, the metallic plate was inserted between the array and the head model. The effectiveness of this idea was demonstrated numerically.

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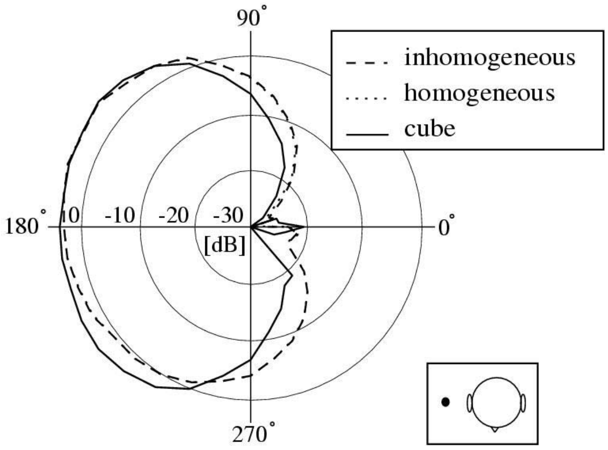

Fig.1: The radiation pattern of a dipole antenna in the presence of a lossy dielectric head model.

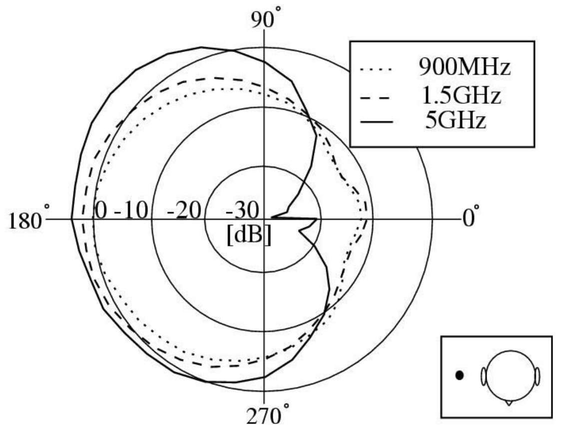

Fig.2: The radiation pattern of a dipole antenna in the presence of a lossy dielectric head model.

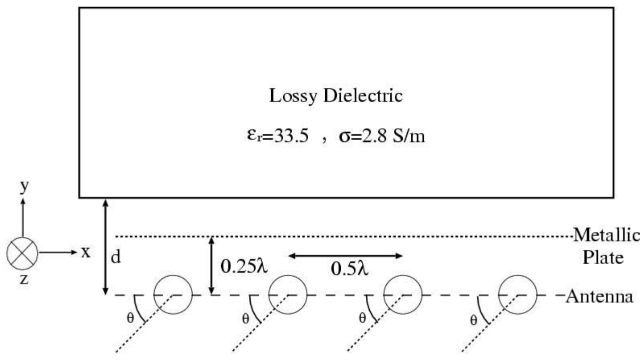

Fig.3: Geometry for an adaptive nulling by an array antenna

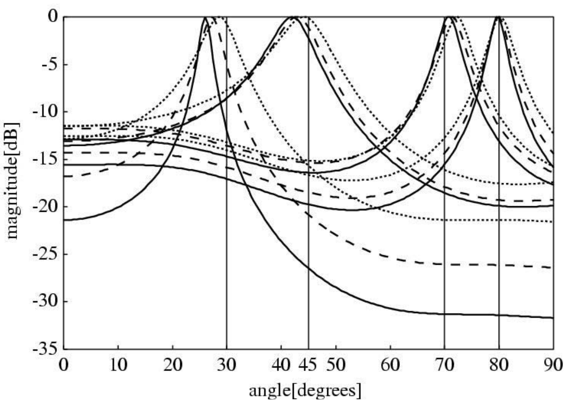

Fig.4: The MUSIC spectrum for the linear dipole array: solid, dotted, and dashed lines are the results for d=15, 20, 25 mm.

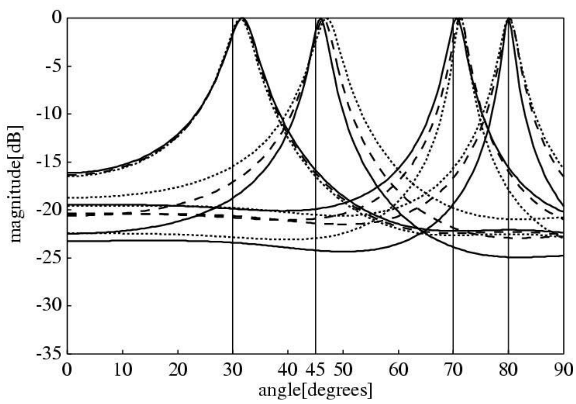

Fig.5: The MUSIC spectrum for a linear dipole array with a reflector inserted: solid, dotted, and dashed lines are the results for d=15, 20, 25 mm.