DOA Estimation of Electromagnetic Waves with Patch Antenna Array on Finite Substrate

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INTRODUCTION

The fourth generation (4G) mobile cellular system will be deployed around the year 2010. The most promising frequency band for these systems is 4 to 5 GHz band because of wide-area coverage, mobility, and low cost for radio-frequency equipment. A smart antenna technology on a handset would 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 [1], ESPIRIT and so forth, while marginal for beamforming. Additionally, the coupling between an antenna and the human could not be negligible when it is located in close proximity to the human head. Note that we have shown that this effect is suppressed with the insertion of metallic plate between the head and antenna array [2]. When considering the application of an antenna array to a handset terminal, a patch antenna array is one of the candidates. However, no sufficient attention has been paid to DOA estimation using printed arrays.

This paper discusses the DOA estimation of EM waves with a printed antenna array on a finite substrate. Much attention is paid to the effect of i) dimension and ii) relative permittivity of the substrate and iii) angle of incidence on the accuracy of DOA estimation. Additionally, we investigate the accuracy of DOA estimation using the patch antenna array with an electromagnetic band-gap structure [3], which is known to suppress the mutual coupling between the antennas.

MODEL AND METHOD

Array Geometry

Figure 1 illustrates a geometry of the problem. The antenna array on a finite dielectric substrate is considered. The number of elements was chosen as four, when considering its potential implementation to a handset terminal for 4G mobile communications. The dimension and relative permittivity of the substrate are 60 (x) X 2.6 (y) X 60 mm (z), and 10.2. The separation of adjacent antennas is 29 mm, corresponding to a half wavelength in free space. This is a limit to avoid aliasing in MUSIC algorithm. As an EBG, a mushroom type is chosen due to its compactness [3]. The dimension of the mushroom EBG is

4.0 X 4.0 mm, while that of the patch antenna is 5 mm X 8 mm. Three-row EBG structure is implemented in the center of the adjacent antennas. The EBG patch is shorted to the ground plane.

Computational Method

The FDTD method is employed for calculating electromagnetic-waves propagation. The resolution of the cell is 0.5 mm (*x*) X 0.1 mm (*y*) X 0.5 mm (*z*). The 12-layered PML absorbing boundary is used to terminate the computational region. A plane wave is incident on the patch antenna array. Then, the following signal processing is applied to the FDTD-derived voltages at the feeding points.

The super-resolution algorithm MUSIC is used [1] for direction findings. The feature of this algorithm is in little sensitivity 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. In terms of the orthogolonal characteristics of eigenvectors in the signal and noise subspaces, the MUSIC spectrum *P* is given as:

$$P(\theta) = \frac{(\boldsymbol{a}(\theta))^H (\boldsymbol{a}(\theta))}{(\boldsymbol{a}(\theta))^H \boldsymbol{v}\boldsymbol{v}^H (\boldsymbol{a}(\theta))} \tag{1}$$

where **v** and **a** denote the eigenvectors corresponding to the noise space and the steering vector.

COMPUTATIONAL RESULTS

Firstly, we discuss the effects of permittivity and dimension of substrate on the width of MUSIC spectrum and the error in estimated angle of incidence. For comparison with the above-mentioned substrate, we consider other two substrates; their permittivities are 5.0 and 2.2. The remaining parameters of the geometry are determined so that the resonance frequency comes close to 5.0 GHz. It should be noted that the width of MUSIC spectrum is defined as the width of angle whose MUSIC spectrum is larger than -3dB. As seen from Fig. 2, their effects are marginal for the angle of incidence close to 90 degrees, corresponding to normal incidence. With the decrease of angle of incidence, the effect becomes obvious. One of the main reasons for this difference is that the gains of the antennas are not identical, i.e., angular dependent, since the array with a finite number of elements on a finite ground plane is considered. For the substrate larger than one wavelength, the width and error are rather stable.

Figure 3 illustrate the effects of thickness and dimension of the substrate on the width of MUSIC spectrum and the error in estimated angle of incidence. Two thicknesses are considered except for the original one; 1.9 and 1.3 mm. The remaining parameters of the geometry are determined as the same way in the above. The similar curves are observed as is the case of different relative permittivities.

For our numerical investigation, it is found that the effect of dimension of substrate is dominant as compared with the remaining factors. Then, a calibration of steering vector is desirable for more accurate direction findings using a finite-sized substrate (e.g., [4]).

Let us discuss the effect of EBG structure on the DOA estimation via antenna array on the finite substrate. For evaluating proper effect of EBG structure, the above-mentioned compensation is not implemented in this paper. Figure 4 shows the MUSIC spectrum for the cases with and without the EBG structure. As seen from this figure, the insertion of EBG structures between the antennas results in degraded accuracy of DOA estimation. This is attributed to the perturbation of surface waves due to the EBG structure. Note that waveforms received at the antennas are not shown due to lack of space. The accuracy compensation scheme for this will be presented at the conference.

SUMMARY

This paper investigated the DOA estimation of EM waves with a printed antenna array on a finite substrate. Particularly, we pay our attention to the accuracy of DOA estimation using the patch antenna array with an EBG structure. The degradation of accuracy due to perturbation of surface wave is described.

ACKNOWLEDGEMENTS

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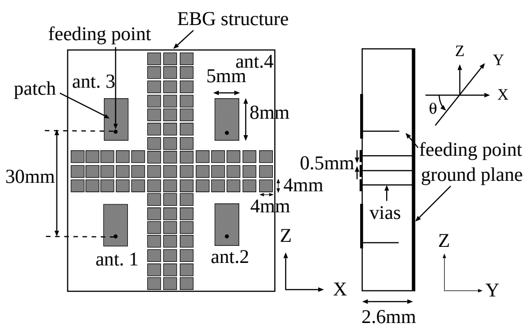

Fig. 1 Geometry of the problem.

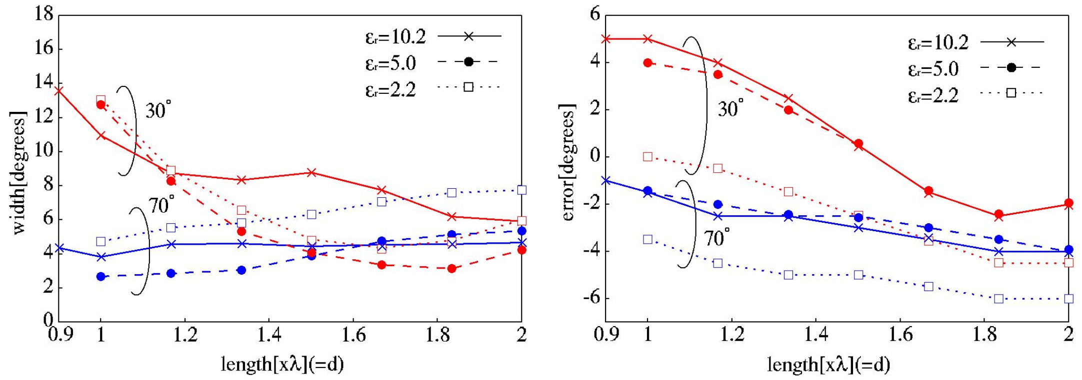

Figure 2 The effect of angle incidence and finite substrate on (a) the width of MUSIC spectrum and (b) error in estimated angle of incidence.

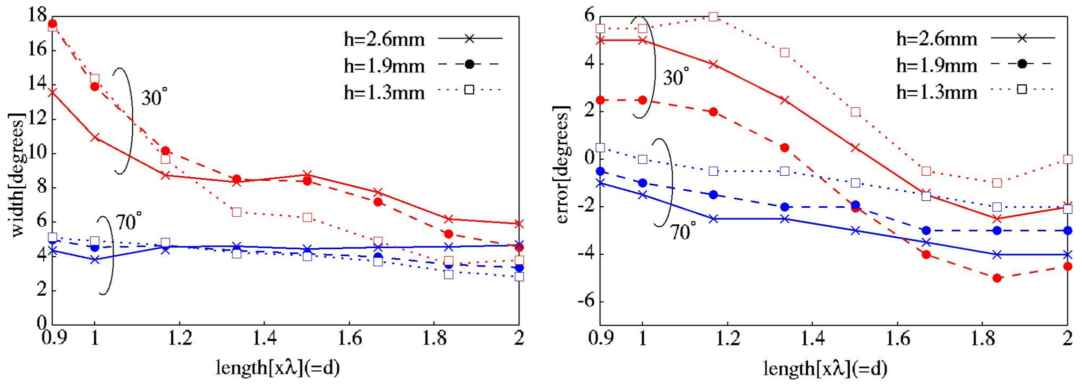

Figure 3 Effect of angle incidence and finite substrate on (a) the width of MUSIC spectrum and (b) error in estimated angle of incidence.

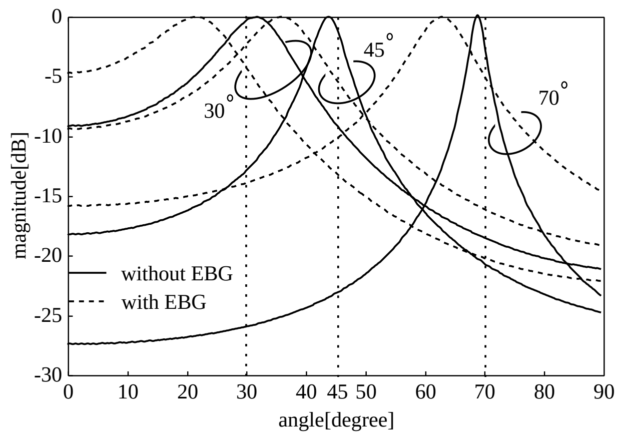

Figure 4 MUSIC spectrum for the cases with and without EBG.