Chapter XI
Physics of Multi-Antenna Communication Systems

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ABSTRACT

This chapter presents a concern regarding the nature of wireless communications using multiple antennas. Multi-antenna systems are mainly developed using array processing methodology mostly derived for a scalar rather than a vector problem. However, as wireless communication systems operate in microwave frequency region, the vector nature of electromagnetic waves cannot be neglected in any system design levels. Failure in doing so will lead to an erroneous interpretation of a system performance. The goal of this chapter is to show that when the vector nature of electromagnetic wave is taken into account, an expected system performance may not be realized. Therefore, the electromagnetic effects must be integrated into a system design process in order to achieve the best system design. Many researches are underway regarding this important issue.

INTRODUCTION

With an increasing demand in wireless devices, a system engineer is forced to increase quality of service, coverage, and bandwidth efficiency of a wireless system. As time and frequency domains are fully occupied, a space domain has been proposed to overcome these limitations and achieve the design criteria. To utilize the space domain, multiple antennas are required in a wireless system. Smart antenna utilizes multiple antennas and adaptive signal processing to direct energy to an intended receiver while rejecting all other interference signals in the same frequency band. Thus, it provides spatial dimension in wireless communications. However, most of the array theories used in multiple antenna system is based on an ideal antenna assumption, i.e. point sources, rather than real antennas. In practice, when real antennas are deployed, many assumptions for the ideal point sources are not valid any more. Thus, the processing algorithm needs to be modified to compensate for the non-ideal system. Such an effect introduced by real antenna comes from the vector nature of the electromagnetic waves.

In this chapter, the electromagnetic effects on multiple antenna systems will be discussed. We start from an antenna array and then move toward a multiple-input-multiple-output (MIMO) system. Next subsection, the mutual coupling effects on antenna arrays as well as some important performance parameters that are usually misinterpreted are discussed. Then, a compensation technique for the mutual coupling effects is introduced. Next, multiple antenna communications will be discussed followed by their performance metric known as channel capacity. The influence of electromagnetic effects on multiple antenna systems under the view of the channel capacity is discussed followed by conclusion.

ANTENNA ARRAYS

An array of antennas has proved its significant role in both radar and communication systems. It has been shown that with multiple antennas at a receiver, the improvement in the signal-to-noise ratio (SNR) of the designed signal is feasible while any other interference is suppressed from the receiver. Similarly, by reciprocity property, multiple antennas can be used at the transmitter to concentrate energy to a particular receiver and to reduce its interference with other receivers. In an adaptive array processing context, it is customary to assume a receiver being an ideal point source situated in free space. This is generally valid for sonar and acoustic signals. However, when applied to electromagnetic waves, this assumption has never been met since there is always mutual coupling between antennas themselves. Mutual coupling destroys the linear wavefront assumption for the received signal, which is the first assumption in array processing. Moreover, when an antenna is mounted on a tower or any kind of platform, the coupling between the antenna and platform is also important as pointed out in (Sarkar, 2006).

In this section, the effect of mutual coupling on adaptive processing is demonstrated. A method for compensation of the effect of mutual coupling will be also discussed. The mutual coupling compensation, in general, is too tedious to be derived analytically. A computer code may be used for this purpose. However, to provide a physical picture to the readers, the work of (Adve & Sarkar, 2000) will be discussed here to show how the mutual coupling affects the array performance and how the mutual coupling can be integrated into the adaptive processing.

Let us consider an array of N thin wire dipole antennas. The dipoles are assumed to be z-directed of length L and radius a and are placed along the x-axis, separated by a distance Δx. The port of each antenna is center loaded with an impedance of Z_L Ohms primarily to make them resonant and thereby increase its efficiency. Figure 1 shows the model of the antenna arrays. To simplify the problem, the following assumptions are made (Djordjevic, 1995; Strait 1973):

1. The current flows only along the direction of the wire axes (z-axis in this case) and there is no circumferential variation of the current.
2. The current and charge densities on the wire are approximated by filaments of current and the charge distribution on the wire axes.
3. Surface boundary conditions can be applied to the relevant axial component on the wire axes.

Consider an incident electric field E^{inc} impinging on the array, the relationship between the incident field and current on the wires that describes the behavior of the array can be expressed by the following integral equation (Adve, 2000; Sarkar, 2003):

$$E^{inc}(z) = \frac{1}{j\omega 4\pi\varepsilon_0}\left[\left(k^2 + \nabla\cdot\nabla\right)\int_{\ell} I(z')G(z,z')dz'\right]$$

$$= -\mu_0 \int_{axes} I(z')\frac{G(z,z')}{4\pi}dz' + \frac{1}{\varepsilon_0}\frac{\partial}{\partial z}\int_{axes}\frac{\partial I(z')}{\partial z'}\frac{G(z,z')}{4\pi}dz' \qquad (1)$$