Chapter IX
Fast Beamforming of Compact Array Antenna

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ABSTRACT

In this chapter, we describe a compact array antenna. Beamforming is achieved by tuning the load reactances at parasitic elements surrounding the active central element. The existing beam forming algorithms for this reactively controlled parasitic array antennas require long training time. In comparison with these algorithms, a faster beamforming algorithm, based on simultaneous perturbation stochastic approximation (SPSA) theory with a maximum cross-correlation coefficient (MCCC) criterion, is proposed in this chapter. The simulation results validate the algorithm. In an environment where the signal-to-interference ratio (SIR) is 0 dB, the algorithm converges within 50 iterations and achieves an output SINR of 10 dB. With the fast beamforming ability and its low power consumption attribute, the antenna makes the mass deployment of smart antenna technologies practical. To give a comparison of the beamforming algorithm with one of the standard beamforming algorithms for a digital beamforming (DBF) antenna array, we compare the proposed algorithm with the least mean square (LMS) beamforming algorithm. Since the parasitic array antenna is in nature an analog antenna, it cannot suppress correlated **interference***. Here, we assume that the interferences are uncorrelated.*

INTRODUCTION

The evolution of wireless communications systems requires new technologies to support better quality communications, new services and applications. Smart antennas have become a hot topic of research. With a **smart antenna** directive beam patterns can be steered toward the desired signal and deep nulls can be formed toward the interference, thus spatial filtering is realized. This brings the benefits such as lower power transmission, higher spectrum efficiency, better link quality and higher system capacity (Godara, 1997a; Winters, 1998; Tsoulos, 1999; Boukalov, 2000; Jana, 2000; Friodigh, 2001; Ogawa, 2001; Bhobe, 2001; Soni, 2002; Blogh, 2002; Bellofiore, 2002a; Bellofiore, 2002b; Diggavi, 2004).

Various **beamforming** and direction of arrival (DOA) estimation algorithms have been designed (Widrow, 1967; Van-Veen, 1988; Litva, 1996; Godara, 1997b; Anderson, 1999; Lehne, 1999; Boukalov, 2000; Janaswamy, 2001; Rappaport, 2002; Blogh, 2002; Bellofiore, 2002b). The simulation and experiments carried out by many researchers have shown the abilities of these algorithms (Anderson, 1996a; Anderson, 1996b, Winters, 1997; Tsoulos, 1997; Boukalov, 2000). Most of these algorithms are designed based on the digital beamforming (DBF) antenna arrays. Signals received by individual antenna elements are down-converted into baseband signals. These signals are digitized and fed into digital signal processing (DSP) chip where the algorithms reside in. However, radio-frequency (RF) circuit branches connected to the array elements, analog-to-digital converters (ADCs) and the baseband DSP chip consume a considerable amount of dc power. Furthermore, each channel connected to the array sensor has the same structure, so the cost of fabrication increases with the number of array elements (Ohira, 2000; Boukalov, 2000; Thiel, 2001). Thanks to the recent development of GaAs monolithic microwave integrated circuit (MMIC) technologies, the beamformer could be integrated into a single chip at the RF front end such as MBF (Ohira, 1997), instead of the baseband. The advantages are the reduced quantization errors and the increased dynamic range. However, their costs of fabrication still limit the range of implementations. All these factors make DBF and microwave beamforming (MBF) antennas unsuitable for low power consumption and low cost systems and thus hinder the mass applications of the **smart antenna** technologies. For example, it could be too costly to equip DBF antenna arrays at battery powered lap-tops or mobile computing terminals within a wireless network.

As the wireless communications become more ubiquitous, the demands for smart antennas expend. Smart antennas are now not only required to be installed at base stations (BSs) but also strongly desired to be installed at mobile stations (MSs) such as vehicles, laptops, and even commercial mobile phones. The challenges emerge. Due to the size and power limit of the MSs, the **smart antennas** are required to be low power consumption, small in size and low cost so that it is affordable to mobile users. With this goal in mind, researchers are now investigating compact array antennas such as the **parasitic array** antennas (Black, 1973; Gueguen, 1974; Himmel, 1978; Harrington, 1978; Milne, 1985; Thiel, 1996; Sibille, 1997; Preston, 1997; Preston, 1998; Preston, 1999; Vaughan, 1999; Ohira, 2000a; Ohira, 2000b; Svantesseon, 2001; Thiel, 2001; Sun, 2002a; Varlamos, 2004; Sun, 2004). The antenna normally has one RF port, therefore, the size and power consumption can be significantly reduced (Ohira, 2000b; Thiel, 2001).

Various forms of switched **parasitic array** antennas have been documented (Himmel, 1978; Black, 1973; Gueguen, 1974; Milne, 1985; Thiel, 1996; Sibille, 1997; Preston, 1998; Preston, 1999; Vaughan, 1999; Svantesseon, 2001; Varlamos, 2004). Beam steering of these antennas are achieved by switching ON and OFF parasitic elements, or switching the position of the active element. However, beam patterns can only be steered to a predefined set of directions in a way similar to that for switched beam antennas. This limits the performance, especially for the applications scenarios where desired signals impinging from different directions due to multipath reflection.

Another category of **parasitic array** antennas, reactively controlled directive array antennas, circumvents the problem with switched parasitic array antennas. The first work was presented in (Harrington, 1978). The antenna has one central element connected to the sole RF port and a number of surrounding parasitic elements form the array. Beam steering is achieved by tuning the load reactances at parasitic elements surrounding the central active element. Each parasitic element is loaded with tuneable reactance.

Recently, the adaptive **beamforming** with reactively controlled directive array antennas has been studied (Ohira, 2000a; Ohira, 2000b; Gyoda, 2000; Komatsuzaki, 2000; Cheng, 2001a; Cheng, 2001b; Shishkov, 2001; Shishkov, 2002; Sun, 2002b; Ohira, 2002; Cheng, 2002; Hirata, 2002; Sun, 2003; Sun, 2004). The antenna is named as "electronically steerable parasitic array radiator (**Espar**)". In (Gyoda, 2000), a random search method is applied to optimize the reactance values. A Hamiltonian approach is presented by Komatsuzaki, (2000). It projects an optimization problem on the motion of a particle in an M-dimensional space, by making the objective function and the unknown variables correspond to the potential energy and the coordinates, respectively. However, the optimum result is only achieved through a large number of calculation cycles. The steepest gradient algorithm (SGA) is applied in (Cheng, 2001a; Cheng, 2001b). The algorithm maximizes the cross correlation coefficient (CCC) between the received signal and the training signal, using steepest gradient method based on sequential perturbation (Moon, 2001). To cope with the noise effect, maladjustment and uncertainty in estimating the objective function, another beamforming algorithm is proposed in (Shishkov, 2001; Shishkov, 2002). The algorithm is based on the stochastic approximation theory. A blind adaptive algorithm maximizes the higher-order moment using steepest gradient method is presented in (Ohira, 2002). The algorithm does not require the **training signals**.