Chapter X
Direction of Arrival Estimation with Compact Array Antennas: A Reactance Switching Approach

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ABSTRACT

This chapter presents direction of arrival (DoA) estimation with a compact array antenna using methods based on reactance switching. The compact array is the single-port electronically steerable parasitic array radiator (Espar) antenna. The antenna beam pattern is controlled though parasitic elements loaded with reactances. DoA estimation using an Espar antenna is proposed with the power pattern cross correlation (PPCC), reactance-domain (RD) multiple signal classification (MUSIC), and, RD estimation of signal parameters via rotational invariance techniques (ESPRIT) algorithms. The three methods exploit the reactance diversity provided by an Espar antenna to correlate different antenna output signals measured at different times and for different reactance values. The authors hope that this chapter allows the researchers to appreciate the issues that may be encountered in the implementation of direction-finding application with a single-port compact array like the Espar antenna.

INTRODUCTION

The efficient use of direction-of-arrival (DoA) estimation techniques with smart antennas is an important research topic in wireless systems like *ad hoc* networks (Alexiou, 2004) or for the design of a DoA finder.

As a kind of smart antenna, switched parasitic antennas were proposed for cellular communications (Vaughan, 1999; Scott, 1999; Almhdie, 2000; Svantesson, 2002; Thiel, 2002). Compared to a conventional array antenna, which needs as many active radio receivers as antenna elements, a switched parasitic array antenna needs only a single active radio receiver. Therefore, the use of a switched parasitic antenna at the user side is an interesting alternative, since it can provide a small size, low cost and low power consumption for the receiver part. The switched parasitic antenna forms beams by using passive antenna elements that serve as reflectors when shorted to ground. Thus, a fixed number of directional patterns can be achieved by switching the short-circuits of the passive elements using p.i.n. diodes (Thiel, 2002). Switched parasitic antennas are known to improve the communication capacity in wireless communication systems (Almhdie, 2000), to perform high-resolution DoA estimation (Svantesson, 2002), such as that for personal locating services, and to provide antenna diversity (Vaughan, 1999; Scott, 1999) for adaptive communication systems.

The electronically steerable parasitic array radiator (Espar antenna), a kind of reactively controlled antenna (Harrington, 1978), was first proposed for low-cost user terminal applications (Ohira, 2000). Compared with simple switched parasitic antennas, the Espar antenna exhibits greater steerability control by means of its electronically controllable reactances and a more complex system for controlling the reactances (Thiel, 2004). Indeed, the parasitic element is connected to the ground by means of a reactance made with a reverse-bias varactor diode that can be controlled through loaded voltage. Thus, as a function of the reactance value, the parasitic element can variably act as a reflector or a radiator (Ohira, 2004, pp. 184-204). The continuous variability of the loaded reactance of the Espar antenna makes it more flexible than switched parasitic antennas because the number of possible directional patterns becomes greater (Thiel, 2004). Such a feature could be successfully employed, for example, in adaptive control processes involving beam and null forming, where the radiation pattern of an Espar antenna with a beampointing direction in the desired signal direction and nulls in the interference directions is obtained by optimizing the loaded reactances (Sun, 2004).

For DoA estimation applications with an Espar antenna, an earlier method was proposed to develop a hand-held microwave DoA finder for locating transmitters (Ohira, 2001), for example, after an avalanche (Furuhi, 2002). This method was based on a simple algorithm that switches twelve directional beam patterns by means of reactances and then chooses as the DoA estimate the beampointing direction of the pattern that provides the highest antenna output amplitude gain. Therefore, this method could only provide estimation for one impinging signal with a coarse precision of (Ohira, 2001; Furuhi, 2002). An alternative that used antenna output amplitude gain with pre-measured directional patterns was proposed for high-precision DoA estimation of one impinging signal (Taillefer, 2005a). The method is called Power Pattern Cross Correlation (PPCC). As its name suggests, it is based on the correlation between pre-measured power radiation patterns and power outputs of the antenna.

As a further step, to use more sophisticated algorithms that provide high-resolution and high-precision DoA estimation of multiple signals, and which are available in conventional array processing, a correlation matrix of the antenna elements output is required. In the case of the Espar antenna, since the beamforming is performed in the analog domain, only one output port is observable. However, by using a vector composed of this output-port complex gain, measured sequentially for different directional patterns, a technique called the *reactance-domain* (RD) technique could be adopted to create a correlation matrix for the Espar antenna. Consequently, based on this technique, the multiple signal classification (MUSIC) subspace DoA estimator (Schmidt, 1986) was proposed (Plapous, 2004) and experimentally verified (Taillefer, 2003) with a 7-element Espar antenna. In (Taillefer, 2003), the RD technique was developed by transmitting the same information as many times as the number of used directional patterns. Although such a data transmission scheme decreases the transmission rate, it is still sufficient in applications such as terminal position location, a hand-held DoA finder, or when the DoA estimation is needed from time to time for such tasks as forming a node position location table in an *ad-hoc* network where the nodes do not frequently relocate. Another interesting possibility for obtaining the RD output information without decreasing the transmission rate is to sample the received signal with different radiation patterns. This technique of oversampling is common in many communication systems, but here it needs to be considered as spatio-temporal oversampling, since beam pattern switching implies spatial diversity. Furthermore, more work is needed to clarify the practical aspects of using RD with an oversampling strategy.

The MUSIC algorithm employed in the RD-MUSIC for Espar antennas requires two stages: singular value decomposition (SVD) of the RD correlation matrix and a search over parameter space. This last stage implies a general optimization procedure, which becomes computationally costly when the DoA estimate must have high precision. It is known that compared with the MUSIC algorithm, the ESPRIT (Estimation of signal parameters *via* rotational invariance techniques) algorithm dramatically reduces the computational cost of the DoA estimator, since the second stage just consists of direct calculations that need only SVD (Roy, 1989). However, ESPRIT does not perform as well as MUSIC in terms of DoA estimation precision.

The RD-ESPRIT algorithm was first presented in (Taillefer, 2004), for high-precision, low-computational cost and low-power-consumption DoA finding applications with a hexagonally shaped 7-element Espar antenna. However, the proposed method made used of an intermediate correlation matrix computation and an additional computation SVD, which thus increased the number of computed SVD. An improved method and a performance study was then proposed in (Taillefer, 2005b) that needs no more that additional computation.

The present chapter presents DoA estimation with a Espar antenna using the PPCC algorithm and RD-based method, in the experimental point of view. The Espar antenna signal model and the employed DoA estimation algorithm are first explained. Then the PPCC algorithm, the RD-MUSIC and the RD-ESPRIT algorithm are presented. Some results

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