Chapter XXV
Omni-, Sector, and Adaptive Modes of Compact Array Antenna

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ABSTRACT

Three working modes, omni-, sector and adaptive modes, for a compact array antenna are introduced. The compact array antenna is an electronically steerable parasitic array radiator (Espar) antenna, which has only a single-port output, and carries out signal combination in space by electromagnetic mutual coupling among array elements. These features of the antenna significantly reduce its cost, size, complexity, and power consumption, and make it applicable to mobile user terminals. Signal processing algorithms are developed for the antenna. An omnipattern is given by an equal-voltage single-source power maximization algorithm. Six sector patterns are formed by a single-source power maximization algorithm. Adaptive patterns are obtained by a trained adaptive control algorithm and a blind adaptive control algorithm, respectively. The experiments verified the omnipattern, these six sector patterns and the adaptive patterns. It is hope that understanding of the antenna's working modes will help researcher for a better design and control of array antennas for mobile user terminals.

INTRODUCTION

A wireless ad hoc network is a collection of wireless mobile terminals that dynamically form a temporary network without the use of any existing network infrastructure. Such a network has distinctive features, such as being infrastructure-free, growing or reduction in size, fragment or dismantlement as desired. In the network, each terminal is conventionally equipped with omnidirectional antennas. However, if sector antennas and adaptive antennas were employed, the network could provide several additional features such as high scalability, high resource efficiency, and free join/disjoint to a community network.

Recently, a compact array antenna, e.g., the electronically steerable parasitic array radiator (Espar) antenna (Cheng, 2001; Ohira, 2004), has shown the potential for application to mobile user terminals, since the antenna only uses a single active radio receiver, which significantly reduces the antenna's cost, size, complexity, and power consumption. For the Espar antenna, only a single radiator is connected to the receiver. This active radiator is surrounded by parasitic radiators loaded with variable reactors. The radiation directivity of the antenna is controlled by changing the reactance values. In the Espar antenna, the signal combination is carried out in space by electromagnetic mutual coupling among array elements, not in circuits. This permits compact implementation of the antenna.

The concept of the Espar antenna dates back to the early work to Harrington's model (Harrington, 1978), where the "electric length" of the element is adjusted by changing the element's loaded reactance, thus causing a change in the radiation pattern. Dinger (1984, 1986) demonstrated a reactive approach that uses planar parasitic elements for anti-jamming. Another single-port approach related to the Espar antenna is the switched parasitic antenna (Preston, 1998; 1999; Scott, 1999; Svantesson, 2001; Thiel, 2001; Vaughan, 1999).

For the Espar antenna, however, the signal on the surrounding parasitic elements cannot be observed. Only the single-port output can be observed. This differs from the conventional array antenna, where the received signal on each element is observed. This characteristic prevents the conventional algorithms for array antennas from being applicable to the Espar antenna.

In this chapter, we describe the design of the Espar antenna and its three working modes, omni-, sector and adaptive modes. We give a) an omnipattern forming algorithm, b) a sector pattern forming algorithm, and c) a trained adaptive control algorithm and a blind adaptive control algorithm. The experiments show that the Espar antenna provides omnipattern and sector patterns, which are the basic function as a smart antenna. Furthermore, the adaptive patterns given by the trained and blind adaptive control algorithms, respectively, verify that the antenna can steer its beam towards desired signal and null to interference.

In this chapter, we first introduce the basic structure and design of the Espar antenna. Then we give the omnipattern forming and the sector beamforming of the antenna. Moreover, we describe a trained and a blind adaptive control algorithm to give adaptive beamforming.

ESPAR ANTENNA DESIGN

This section describes the structure and the design of the Espar antenna.

A 2.484GHz Espar antenna is illustrated in Figs. 1 and 2. The seven-element monopole elements are arranged on a finite circular ground structure. The centre element is the feed element. The remaining M (= 6) elements are parasitic and make a 0.25λ ring around the centre element, where λ=12.07 cm is the free space wavelength corresponding to the operating frequency of 2.484 GHz. The bottom of each parasitic element is loaded with a variable reactance. A bias voltage V_m on it adjusts the value of the reactance. Variable beamforming is carried out by controlling the six bias voltages (control voltages) V_m, (m=1, 2,…, M), and thus the values of the reactances. A skirting is used on the ground plane to reduce the main lobe elevation. The radius of the circular ground plane is 0.5λ, and the skirting height is 0.25λ (Ojiro, 2001), which provides maximum gain of the antenna's radiation in its horizontal direction.

The reactive-loaded design shown in Fig. 2 gives a variable range of reactance. A pair of varactor diodes (1SV287) is positioned in parallel to terminate the parasitic element. To prevent the RF current on each varactor from leaking back to the baseband circuits, a series resistor R_1 and shunt capacitor C_1 are inserted with an R_1C_1 time constant that is sufficient for the effective decoupling of DC and RF. Thanks to zero DC current consumption on the reverse-biased diodes, one can employ a high resistance, say 10 kΩ, for R_1. This allows one to assign low capacitance, say 3 pF, for C_1 so as not to degrade the feedback control response. Therefore, the high R_1C_1 time constant isolates the RF electromagnetic analysis from the biasing circuits, so that only the varactor diodes need be taken into account in designing each parasitic element. According to varactor diode 1SV287 specifications, the capacitance range of each diode ranges from about 0.7 pF to 9.0 pF as the bias voltage is changed from 20 V to -0.5 V. Thus the reactive-loaded design provides a range of reactance from -45.8 Ω to -3.6 Ω for the frequency 2.484GHz.

The reactance loaded in each of the parasitic elements electronically adjusts its element length and makes the monopole element appear as a director or a reflector, as in the Yagi–Uda array antenna (Thiel, 2001), depending on the negative or positive value of the reactance. The element appears as an effectively 'shorter' monopole (director) if a negative reactance is loaded, while a positive reactance provides an effectively 'longer' element (reflector). This action of the loaded reactance causes a change in the radiation pattern.

In the design of the Espar antenna, the physical length of each parasitic element should be 0.2315λ if a wavelength-shortening coefficient is considered for a 0.25λ monopole element, where the radius of each parasitic element is 0.01λ. The 'electric length' is adjustable by changing the element's loaded reactance. The varactor diode's junction capacitance

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