Design of Electronically Steerable Passive Array Radiator (ESPAR) Antennas

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Abstract Electronically Steerable Passive Array Radiator (ESPAR) antennas are proposed for low-cost analog adaptive beamforming. The configuration and design of these antennas and some simulation results, especially on their beam/null steering capability, are presented. From the results of a numerical analysis, it was found that 5-element ESPAR antennas can offer a beam gain of 9dBi +/-1dB and a null deeper than -50dBi in an arbitrary direction. In this case, the beam gain and null were obtained separately. It was also found that 7-element ESPAR antennas can achieve continuous steering in almost all directions, with a simultaneous 8dBi beam gain and -30dBi null, excluding the region where the direction of the beam and the direction of the null are within about 45-degrees however 5-element ESPAR antennas are unable to achieve steering in a number of directions, even with a simultaneous 5dBi beam gain and -15dBi null.

1. Introduction

The Wireless Ad-hoc Community Network (WACNet) [1], a kind of ad-hoc network [2] utilizing wireless technology, provides a means of communications between data terminals that temporarily meet, where distance and time come close yet easy connection to a network infrastructure is not possible. One of the architectural features discriminating WACNet from other ad-hoc networks is network segmentation [3]. With network segmentation, a network is divided into a number of segments consisting of some terminals. As one channel is able to be used repeatedly in the different segments, the SDMA (Space Division Multiple Access) technique is very useful since it enables the limited network resources to be effectively utilized. To achieve SDMA, the most important components are adaptive antennas for user terminals. However, such antennas have not been implemented in user terminals yet because of their complex configurations, high power consumption, and high fabrication costs.

Electronically Steerable Passive Array Radiator (ESPAR) antennas are proposed for low-cost analog adaptive beamforming [4]-[7]. In this paper, we describe the configuration and design of these antennas and some simulation results, especially on their beam/null steering capability.

2. Configurations

Figure1 shows basic configurations of 5-, 6-, and 7-element ESPAR antennas. Element #0 is an active radiator. It is a quarter-wavelength monopole and located at the center of a circular ground plane. The other elements are passive radiators located in equal intervals around the active radiator and loaded with variable reactors at the bottom. To control radiation patterns electronically, each reactor at a passive element is implemented with a varactor diode and two fixed inductors; the reactance can be varied between positive and negative values by varying the supply voltage to the varactor diode.

3. Design and Analysis

There are two kinds of parameters in the design of ESPAR antennas: structural parameters, which define the mechanical structures, and control parameters, which provide radiation pattern controllability.

The structural parameters are listed as follows.

(1) Number of passive radiators N (forming N+1-element ESPAR antennas)

(2) Length of active radiator l_0

(3) Length of passive radiators l_n (n=1,2,,N)

(4) Distance between active and passive radiators d

To achieve omnidirectional controllability, l_n should all be the same.

The control parameters are the values of X_n (n=1,2,,N), i.e., loaded reactances to passive radiators, associated with the supply voltages to varactor diodes.

The optimization of these two kinds of parameters is a very complex problem because there are a lot of parameters and they vary in a wide range. It is therefore necessary to carry out a numerical analysis to get basic data for optimization.

As an example, an analysis model of 5-element ESPAR antennas is shown in Fig. 2. Each element of the ESPAR antennas acts as a dipole in free space because the ground plane is assumed to have an infinite diameter.

The radiation pattern (not shown) was calculated by the method of moments. In this calculation, the lengths of all elements $2l_n$ (n=0,1,2,,N) were set to a wavelength of 0.463 and the distance between the active and passive radiators d was set to a wavelength of 0.25. Control parameters Z_n(=-$j2X_n$, n=1,2,,N) were randomly varied with a minimum step of 1 ohm and within the range of +/-250 ohms according to the Monte Carlo technique.

4. Steering Capabilities

In the case of the above 5-element ESPAR antennas, the maximum directive gain and the deepest null during 50,000-cycle variation of the control parameters were plotted for each horizontal direction on the radar charts shown in Fig. 3. It was found that the 5-element ESPAR antennas could produce a beam gain of 9dBi +/-1dB and a null deeper than -50dBi in an arbitrary direction, separately.

Combinations of beam maximum and null direction that satisfying two conditions simultaneously are calculated and plotted in Fig. 4 for 5-, 6-, and 7-element ESPAR antennas. In these figures, each gray area shows that a maximum beam gain up to 5dBi and a null deeper than -15dBi satisfied simultaneously. Each black area shows that up to an 8dBi beam and a null less than -30dBi are satisfied simultaneously. It is apparent that 5-element ESPAR antennas are unable to steer even a 5dBi beam and a -15dBi null in a number of directions, though they provide 360-degree continuous beam/null steering separately. In the case of the 6-element ESPAR antennas, the area of directive combination able to steer the beam and null simultaneously is larger than the case of the 5-element ESPAR antennas. This is because increasing N makes the distance angle between passive radiators decrease and it also makes the area of the degree of freedom increase. However, they are still insufficient for steering an 8dBi beam and a -30dBi null simultaneously.

By use of 7-element ESPAR antennas, continuous steering can be achieved in almost all directions, with a simultaneous 8dBi beam and -30dBi null, excluding the region where the direction of the beam and the direction of the null are within 45 degrees.

Figure 5 shows similar combinations to Fig. 4 but with a distance between active and passive radiators d of 0.20 wavelength. In the case of the 5-element ESPAR antennas, the combination pattern is a little different from the case of d=0.25 wavelength. The difference between the wavelength of d=0.20 and 0.25 becomes smaller as the number of elements increases.

5. Conclusion

The configuration and design, and the beam/null steering capability of ESPAR antennas have been presented. It was found that 5-element ESPAR antennas can provide beam gain of 9dBi +/-1dB and a null deeper than -50dBi in an arbitrary direction, separately. Although these 5-element ESPAR antennas have a much higher gain than omnidirectional antennas, there do exist angle combinations of beam/null directions that can not achieve even 5dBi/-15dBi simultaneously. In the case of 6-element ESPAR antennas, the area of directive combination able to steer the beam and null simultaneously is larger than the case of the 5-element ESPAR antennas. However, they are still insufficient for steering an 8dBi beam and a -30dBi null simultaneously. By the use of 7-element ESPAR antennas, however, continuous steering can be achieved in almost all directions, with a simultaneous 8dBi beam and -30dBi null, excluding the region where the direction of the beam and the direction of the null are within 45 degrees.

Since ESPAR antennas have many advantages such as simple structure, higher gain, and electronic beam/null steering capability, they are very attractive for battery-operated user terminals if analog beamforming algorithms [8] are introduced to steer the beams to the desired directions and the nulls to the undesired incoming radio wave direction.

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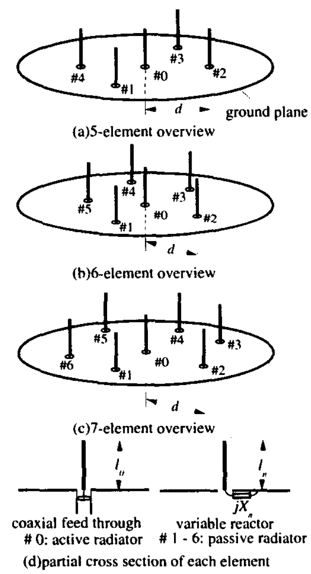


Fig. 1 Configuration of ESPAR antennas

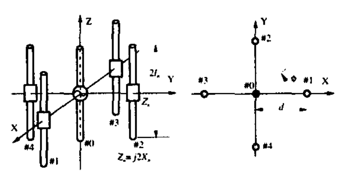
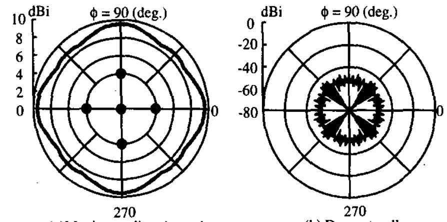


Fig. 2 Analysis model of 5-element ESPAR antennas



(a)Maximum directive gain (b) Deepest null

Fig. 3 Maximum directive gain and deepest null characteristics of 5-element ESPAR antennas

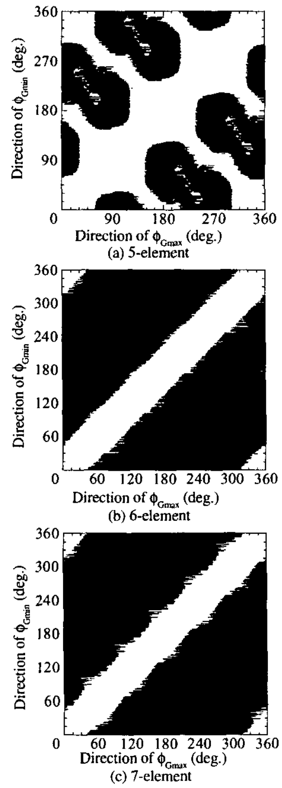


Fig. 4 Combinations of beam maximum and null direction satisfying two conditions simultaneously (d=0.25 wavelength)

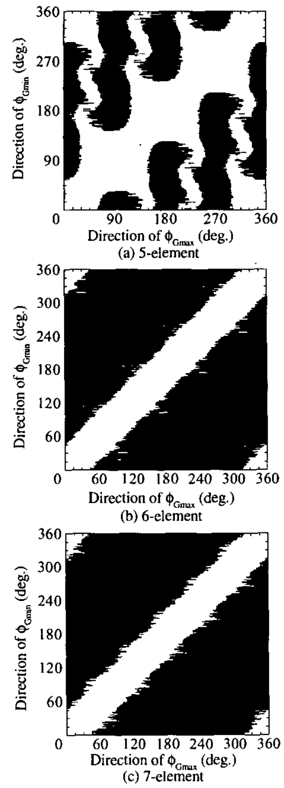


Fig. 5 Combinations of beam maximum and null direction that satisfying two conditions simultaneously (d=0.20 wavelength)