Calculation of the Basis Patterns of 5-element Dipole ESPAR Antennas

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Abstract **-The present paper proposes a method of calculating and identifying the basis patterns of 5-element dipole electrically steerable parasitic array radiator (ESPAR) antennas. Basis patterns are generally calculated assuming that the radiation patterns of ESPAR antennas are an array factor. However, the measured radiation patterns of ESPAR antennas differ from the radiation patterns shown by an array factor. Therefore, calculating the basis patterns from the measured radiation patterns of ESPAR antennas is difficult. This paper using the presented method, the basis patterns were calculated from the measured radiation patterns of 5-element dipole ESPAR antennas.**

Index Terms **— ESPAR antenna, smart antenna, beam space MIMO antenna, compact MIMO antenna**

1. Introduction

The beam space MIMO system technology uses ESPAR antennas to map symbols on individual basis patterns and transmit the patterns simultaneously, thereby enabling MIMO transmission with single RF chains [1],[2]. Basis patterns are orthogonal functions obtained by series-expanding array factors that are the theoretical radiation pattern equations of ESPAR antennas and can be used in beam space MIMO systems only when they cross each other at right angles and their power ratios are similar to each other [1]-[4]. In reality, measured radiation patterns differ from the radiation patterns given by array factors and cannot be easily indicated by series form expanded equations [5],[6]. Therefore, to determine basis patterns using measured radiation patterns, different are necessary. To solve the foregoing problem, a method of finding basis patterns from measured radiation patterns was presented. It is a method of calculating relatively accurate basis patterns using the results of rotating ESPAR antenna radiation patterns in four directions.

2. Dipole ESPAR antennas and the basis patterns for beam space MIMO

Fig. 1 shows a 5-element dipole ESPAR antenna. As shown in the figure, the antenna consists of an active element in the center and four parasitic elements surrounding the active element. The reactance values of the parasitic elements are controlled using variable elements to form radiation patterns. The radiation patterns of 5-element dipole ESPAR antennas can be indicated as follows using array factors [7].

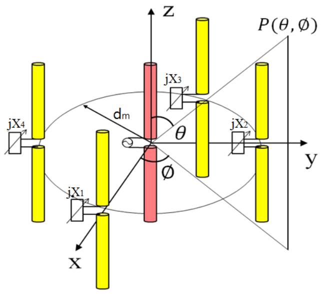


Fig. 1. 5-element dipole ESPAR antenna

$$P(\theta,\phi)=\sum_{m=0}^{M-1} i_m e^{jkd_m \sin\theta\cos(\phi-\phi_m)} \tag{1}$$

In (1) above, i_m represents the currents flowing through individual elements.

Beam space MIMO systems realize spatial multiplexing using perpendicular basis patterns [8]. Thereafter, the far-field decomposition analysis method already studied was used [9].

The horizontal pattern of 5-element dipole ESPAR antennas can be organized by substituting θ=90 into (1), as shown in (2) below.

$$\begin{aligned}P(\phi)=&\underbrace{i_0+(i_1+i_3)\cos(kd_m\cos\phi)+(i_2+i_4)\cos(kd_m\sin\phi)}_{B_0(\phi)}\\&+\underbrace{j(i_1-i_3)\sin(kd_m\cos\phi)}_{B_1(\phi)}+\underbrace{j(i_2-i_4)\sin(kd_m\sin\phi)}_{B_2(\phi)}\end{aligned} \tag{2}$$

As shown in (2), radiation pattern $P(\phi)$ consists of the sum of $B_0(\phi)$, $B_1(\phi)$, $B_2(\phi)$ and $B_0(\phi)$, $B_1(\phi)$, $B_2(\phi)$ can be said to be a basis pattern.

When actually measured, antenna radiation patterns are not obtained by the expansion of polynomial expressions such as array factors. In the present paper, to obtain basis patterns using measured radiation patterns, two pairs of capacitance values were used as the reactance values applied to the parasitic elements of 5-element dipole ESPAR antennas and the parasitic elements were rotated by 90° each to obtain the basis patterns from four radiation patterns. In this case, horizontal patterns were used as the radiation patterns [8].

$P_1(\phi), P_2(\phi), P_3(\phi), P_4(\phi)$ in (3) are the radiation patterns of the dipole ESPAR antenna in four directions.

$$\begin{aligned} P_1(\phi) &= i_0 + (i_1 + i_3)\cos(kd_m \cos\phi) + (i_2 + i_4)\cos(kd_m \sin\phi) \\ &\quad + j(i_1 - i_3)\sin(kd_m \cos\phi) + j(i_2 - i_4)\sin(kd_m \sin\phi) \\ &= B_{01} + B_{11} + B_{21} \end{aligned}$$

$$\begin{aligned} P_2(\phi) &= i_0 + (i_2 + i_4)\cos(kd_m \cos\phi) + (i_1 + i_3)\cos(kd_m \sin\phi) \\ &\quad + j(i_2 - i_4)\sin(kd_m \cos\phi) - j(i_1 - i_3)\sin(kd_m \sin\phi) \\ &= B_{02} + B_{12} - B_{22} \end{aligned}$$

$$\begin{aligned} P_3(\phi) &= i_0 + (i_1 + i_3)\cos(kd_m \cos\phi) + (i_2 + i_4)\cos(kd_m \sin\phi) \\ &\quad - j(i_1 - i_3)\sin(kd_m \cos\phi) - j(i_2 - i_4)\sin(kd_m \sin\phi) \\ &= B_{01} - B_{11} - B_{21} \end{aligned}$$

$$\begin{aligned} P_4(\phi) &= i_0 + (i_2 + i_4)\cos(kd_m \cos\phi) + (i_1 + i_3)\cos(kd_m \sin\phi) \\ &\quad - j(i_2 - i_4)\sin(kd_m \cos\phi) + j(i_1 - i_3)\sin(kd_m \sin\phi) \\ &= B_{02} - B_{12} + B_{22} \end{aligned} \tag{3}$$

In the case of actual antennas, different measurement environments and many error variables exist as well as the tolerance of variable reactance elements. Therefore, even when individual parasitic elements are at equal distances from the active element and have elements of the same size, the values of currents induced in individual parasitic elements are different. In addition, radiation patterns cannot be considered the same as array factors [6],[7]. As such, when measured using actual antennas, the induced currents are different.

$$B_0 = (P_1 + P_2 + P_3 + P_4)/4$$

$$B_1 = \{(P_2 - P_3) + (P_1 - P_4)\}/4 \tag{4}$$

$$B_2 = \{(P_1 - P_2) + (P_4 - P_3)\}/4$$

Equation (4) is proposed to determine the accurate basis patterns considering the foregoing. If the basis patterns are obtained using (4) as above, each basis pattern will exist even if the induced currents flowing through individual parasitic elements are different so that more accurate basis patterns.

Fig. 2 is the manufactured dipole ESPAR antenna [10]. It has a round active element and four flat plate type parasitic elements surrounding the active element. The total length of the antenna L is 52mm. The arrangement interval R is 7.6mm, which is a length of λ/16.

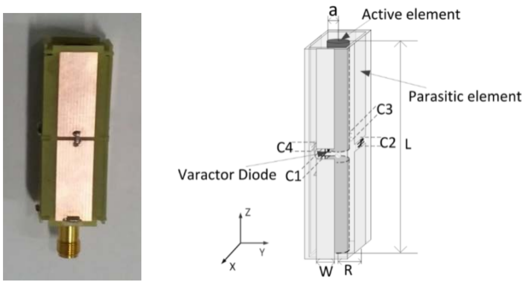
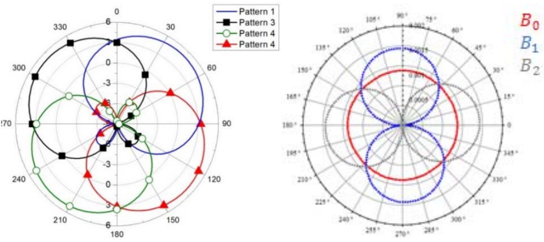


Fig. 2. Manufactured 5-element dipole ESPAR antenna

Fig. 3(a) shows radiation patterns in the manufactured dipole ESPAR antenna at 2.45GHz. The reactance values used are 0.4pF for C1, C2 and 5pF for C3, C4.

The basis patterns of the manufactured antenna can be obtained using Equations (4), as shown in Fig. 3(b) below.



(a)Radiation patterns in four directions (b) Basis patterns obtained using equation

Fig. 3. ESPAR antenna pattern

When the basis patterns were obtained using Equation (4), the shapes are similar to the theoretical basis patterns and cross correlation values improved as accurate basis patterns were obtained. In addition, the power ratios of the basis patterns were similar at 0.98:1:1.

3. Conclusion

In the present paper, a method of calculating basis patterns was proposed from an experimental viewpoint and a 5-element ESPAR antenna was measured to identify its characteristics. To obtain basis patterns from an experimental viewpoint, a method in which radiation patterns are rotated in four directions to add and deduct values and an equation to obtain relatively accurate basis patterns was derived. Basis patterns could be obtained from measured radiation patterns using the presented method; the auto correlation satisfied values below 0.98, while cross correlation values were below $5.4 * 10^{-16}$.

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