Equalization of Numerically Calculated Element Patterns for Root-Based Direction Finding Algorithms

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Abstract: Root-based direction finding algorithms (DF) have several advantages over search-based DF algorithms. A key advantage is the fact that they do not require the array steering vector; this is because these algorithms presume equalized element radiation patterns. In this paper, the WIPL-D code is used in designing an array of rectangular probe-fed patch antennas with equalized radiation patterns for measuring the range and bearing of RF emitters in the PCS band (1900-1920 MHz). Direction of arrival (DoA) estimation results based on simulations and measured data are presented and used as a measure of element patterns deviation from equality.

1. INTRODUCTION

Direction finding (DF) algorithms for DoA estimation is a topic that has been studied thoroughly in the past few decades mainly by researchers in the signal processing and antenna theory communities. From signal processing point of view the focus has been on maximizing the number of DoAs that can be accurately estimated and at the same time reducing the computational cost involved in this work. Several algorithms exist and can be used to estimate the DoA of incident signal on an antenna structure [1]-[3]. DF algorithms are classified as either search-based or root-based. We refer to the former class as S-DF algorithms and to the later class as R-DF algorithms. R-DF algorithms have several advantages over S-DF algorithms. In addition to their less computation cost, where DoAs are calculated by finding the roots of a polynomial of certain order rather than going through intensive search in the whole angular domain, a key advantage of using R-DF algorithms is the fact that they do not require the array steering vector. This is because these algorithms presume equalized element patterns and their accuracy depends on how much the element patterns deviate from equality.

This paper investigates the design and performance analysis of antenna structures with equalized element patterns for R-DF algorithms. Adding a number of passive elements around the center active elements and terminating them using a suitable set of loads minimize the deviation of the element patterns of the center elements from equality [4]. Return loss and element patterns of two antenna structures comprised of a number of rectangular probe-fed patch antennas are calculated using the WIPL-D code [5]. The first structure consists of four elements and no passive elements. In the second structure three passive elements are added on both sides of the four active elements and were terminated in 50 Ω. DoA estimation results using the two antenna structures are compared with DoA estimated using measured data. The DoA accuracy is used as a measure of how much element patterns deviate from equality. The paper is organized into four sections. Following this introductory section, in section two return loss and element patterns calculated using WIPL-D are presented for the two antenna structures mentioned before. DoA estimation results using either WIPL calculated patterns or measured data are compared and presented in section three. Finally conclusions are provided in section four.

2. EQUALIZATION OF ELEMENT PATTERNS

As shown in figure (1), equalization of element patterns is done through adding a number of passive elements around the middle active elements. The top structure in figure (1) is for an array of 4-element of patch antennas with no passive elements. In the bottom structure 3 passive elements on each side of the active elements were used, respectively. We refer to the top and bottom structures as Array1 and Array2, respectively. Figure (2) (top) shows top and bottom view of a 4-element array of patch antennas modeled in WIPL. The dimensions of the patch, ground plane and coax were identical to those given in [6]. The inter-element spacing for Array1 and Array2 was kept fixed and equal to λ/2. The bottom and top views of the 10-element array of patches (Array2) are shown in figure (2) (bottom). The whole structure is modeled in the same way as with Array1 except that passive elements were terminated in 50 Ω.

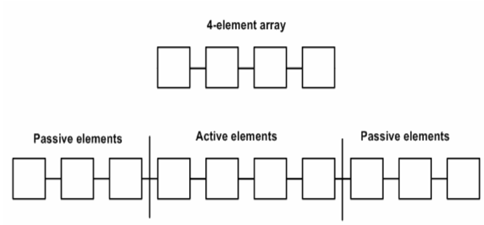


Fig. 1. 4-element array, top, and 10-element array with 3 passive elements on each side, bottom.

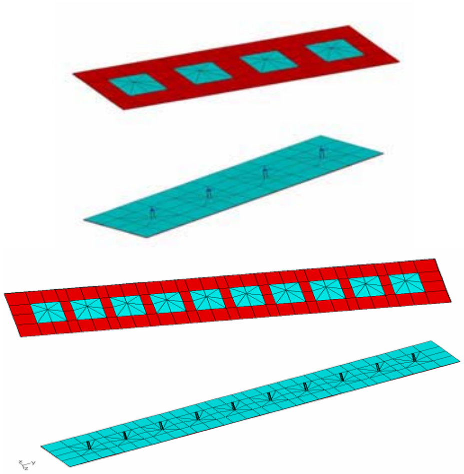


Fig. 2. A 4-element (top) and 10-element (bottom) array of patch antennas modeled in WIPL.

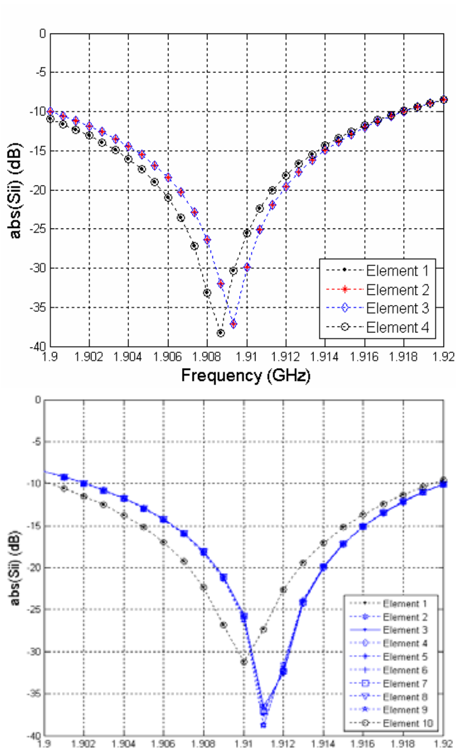


Fig. 3. Return loss of Array1 (top), Array2 (bottom).

The return loss in the (1.9-1.92) GHz frequency band of Array1 and Array2 calculated using the WIPL-D code and are shown in figure (3). For both arrays it is observed that the resonant frequency of each of the middle elements is tuned and shifted by 1MHz compared to the outer elements.

Element patterns of Array1 calculated at 1.91 GHz are presented in figure (4), for fixed φ and fixed θ, respectively. Results for Array2 are presented in figure (5). It is clear from the figures that the element patterns of the four elements significantly deviate from equality.

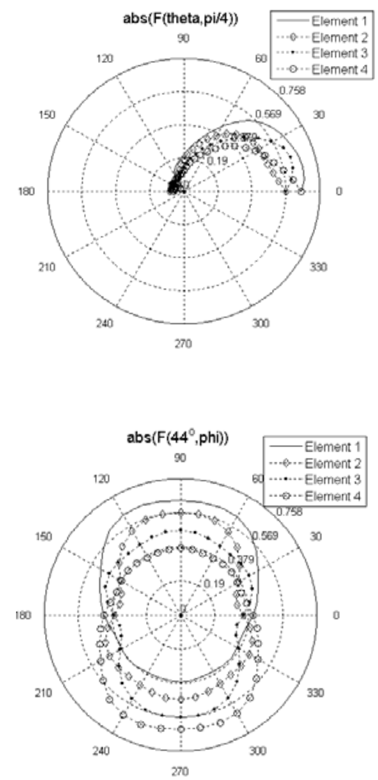


Fig. 4. Element patterns of array Array1 at $\varphi=\pi/4$ (top) and at $\theta=44^{o}$ (bottom).

The accuracy of DoA estimation using the element patterns of Array1 and Array are presented in the following section and are compared to DoA results based on measured data with Array2.

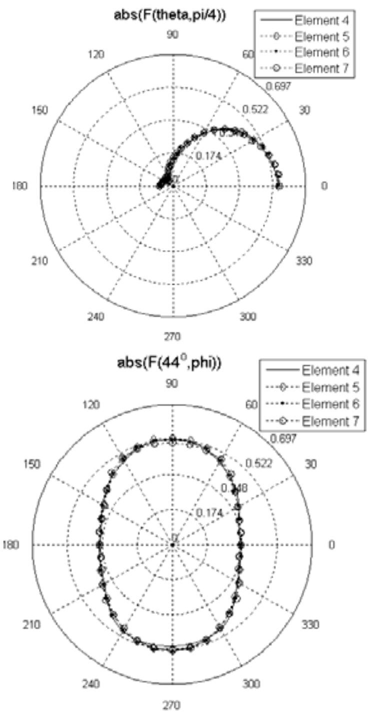


Fig. 5. Element patterns of the active 4 elements of Array2 at φ=π/4 and at θ=44° (bottom).

3. NARROWBAND ROOT-BASED DIRECTION FINDING ALGORITHMS

In this section accuracy of DoA estimation using the modified root-Pisarenko (MRP) [7] is analyzed. The analysis will be done for Array1 and Array2 and are compared to measured data collected from an antenna system consisting of Array2.

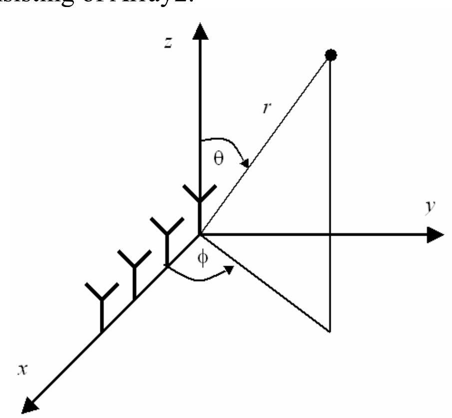


Fig. 6. Geometry of the antenna array.

Referring to figure (6), the narrowband signal model is assumed and is described with

$$\mathbf{z}(t) = \mathbf{A}\mathbf{s}(t) + \mathbf{v}(t) \tag{1}$$

where **z**(t) is the output of the I-Q channels, **A** is the steering vector, **s** is the unknown source signal and **v** is vector of additive Gaussian noise. The number of antenna elements is N and the number of sources is L. Elements of the steering matrix are

$$A_{nm} = -\frac{i\lambda}{\sqrt{\zeta_0}} \hat{f}_n\left(\Omega_m\right) e^{i\mathbf{k}_m \cdot \mathbf{D}_n} \quad . \tag{2}$$

In equation (2) $\hat{f}_n$ is n-th element pattern in the terminated array environment including mutual coupling effects. For uniformly spaced linear arrays along the x-axis, the steering vector is

$$\mathbf{a}\left(\theta,\varphi\right) \equiv -\frac{i\lambda}{\sqrt{\zeta_0}} \begin{bmatrix} \hat{f}_1(\theta,\varphi)\, \hat{f}_2(\theta,\varphi) e^{ikd\xi} \ldots\ldots \\ \hat{f}_N(\theta,\varphi) e^{ik(N-1)d\xi} \end{bmatrix}^T \tag{3}$$

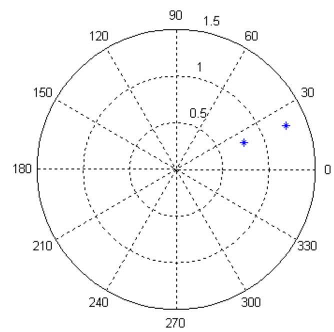
where $\xi = \sin\theta\cos\varphi$ and d is the inter-element spacing. When element patterns are equalized the steering vector in equation (3) reduces to

$$\mathbf{a}\left(\theta,\varphi\right) \equiv -\frac{i\lambda}{\sqrt{\zeta_0}} \hat{f}\left(\theta,\varphi\right) \times \left[1\; e^{ikd\xi} \;\ldots\; e^{ik(N-1)d\xi}\right]^T . \tag{4}$$

Table 1 summarizes results of DoA estimation using MRP algorithm and Uniform Linear Array (ULA) consisted of 4 active and 6 passive rectangular probe-fed patch antennas. The true position measured by transit is 19.18^0. In DoA estimation from measured data one ULA with 6 passive and 4 active elements was used. The array was a part of the RF emitter range estimation system comprised of two antenna arrays. In DoA estimation from simulated data Array1 and Array2 configuration were used with element radiation patterns calculated numerically using the WIPL-D code [5]. ULA configuration with passive elements exhibited better DoA accuracy in both cases with measured and with simulated data.

Table 1. DoA estimated from simulations and measured data using Array1 and Array2.

Estimated from measured data using Array2	19.86°
Estimated from simulation using Array2	20.25°
Estimated from simulation using Array1	21.61°



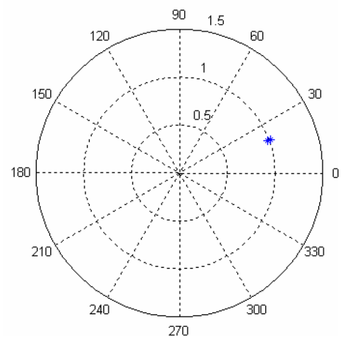


Fig. 7. DoA estimation roots using Array1 (top) and Array2 (bottom).

4. CONCLUDING REMARKS

An array of rectangular probe-fed patch antennas with equal radiation patterns for root-based direction finding algorithms was modeled using the WIPL-D code. Adding three passive elements on both sides of four active elements and terminating them in 50Ω sufficiently equalize patterns of the active elements. DoA estimation results using this array with equalized patterns shows the accuracy improvement when compared to array without passive elements. Finally, the DoA estimation results obtained from simulated data agree with DoA estimation results obtained from measured data.

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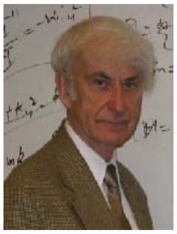

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