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Investigations on Beamforming Applications of Compact Monopole Arrays

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Abstract—Compact antenna arrays are widely investigated in modern communication technologies. In this paper, a conceptual study of compact monopole arrays used for beamforming applications is performed. Theoretical backgrounds for the design are discussed. A three-element compact monopole array with around 0.2λ0 (λ0 is the wavelength in free space) spacing operating at 2.4 GHz is modeled and simulated. Good directivity up to 8.1 dBi is achieved.

I. INTRODUCTION

Nowadays compact antenna arrays with good isolation between input ports play important roles in mobile terminals with multiple input and multiple output (MIMO) technology, of which the channel capacity is increased. There are numbers of successful designs for compact arrays reported in recent years. However, there are few studies discussing the implementation of compact antenna arrays for one of the most important functions of arrays, the beamforming [1]. In this paper, a conceptual study of compact monopole arrays for beamforming is performed. It is well known that strong mutual coupling exists between the radiation elements when they are placed closely, so that the traditional design methods for beamforming arrays are not applicable. As a result, the structure in Fig. 1 is adopted for compact arrays.

Fig. 1. Proposed beamforming structure for a compact antenna array.

As shown in Fig. 1, the compact antenna array is firstly decoupled and matched through the matching and decoupling network. Then the array becomes a matched load without any mutual coupling between the input ports. The beamforming network in front of the matching and decoupling network can be either analog or digital and it only needs to generate the required modes for the beamforming directions. The basic concept is to control the currents on the monopoles through the beamforming network. It is assumed in the analysis that the current distribution in each monopole is a sinusoidal function.

In order to perform beamforming, the currents on the monopoles should fulfill the corresponding phase relationship as for a conventional array. Then, the problem becomes finding the input vectors which generate the required current vectors at the monopole feedings. Figure 2 describes the signal flow chart of the matching and decoupling network. \( \vec{b} \) is a zero vector because of the perfect matching and decoupling. Then the current vector at the input of the monopoles is expressed by

\[
\vec{I} = (\vec{v} - \vec{S}_{\text{ant}} \vec{b})/\sqrt{Z_0},
\]

(1)

where

\[
\vec{v} = (I - \vec{S}_{22,N} \vec{S}_{\text{ant}})^{-1} \vec{S}_{21,N} \vec{a},
\]

(2)

and \( \vec{S}_{\text{ant}} \) is the antenna array scattering matrix, \( \vec{S}_{22,N} \) and \( \vec{S}_{21,N} \) are the matrices from the matching and decoupling network, \( Z_0 \) is the reference impedance. Through (1) and (2), the desired input vector \( \vec{a} \) can be found.

Fig. 2. Signal flow chart of the matching and decoupling network.

II. COMPACT MONOPOLE ARRAY

A three-element compact monopole array is modeled in CST MWS [2], the operation frequency is around 2.4 GHz, and the distance between each element is around 0.2λ0 (λ0 is the wavelength in free space). The monopole array and its matching and decoupling network are shown in Fig. 3. The substrate of the feeding network of this array is RO 4350 with thickness of 0.762 mm and dielectric constant of 3.66. The feeding network is implemented on the other side of the ground plane. The matching and decoupling network is obtained based on the theory of multiport conjugate matching [3] and three sectioned neutralization lines are applied [4]. The simulated S-
parameters of the array are plotted in Fig. 4. It can be noticed that the reflection coefficient of all three ports and the coupling coefficients are below -15 dB at 2.375 GHz.

Fig. 3. Compact monopole array and its feeding network.

Fig. 4. Simulated S-parameters in CST MWS.

III. BEAMFORMING

Since a conceptual study is performed in this paper, a very simple beamforming network is applied as shown in Fig. 5 instead of complex beamforming networks or digital beamforming networks. The desired amplitudes of each branch are generated through quarter wavelength transformers, and phase shifters are used to finalize the required phases calculated from (1) and (2). For instance, two modes are introduced. One mode is that the currents of the three rods have identical phases and amplitudes. The other one is that the phase difference of the currents between two rods is 50°. The far field radiation pattern from CST MWS [2] simulations are shown in Fig. 6. The two modes have a directivity of 8.1 dBi and 7.2 dBi, respectively, thus proving the beamforming performance. On the other hand, if the antenna array is used as a receiving antenna array, the following calculation makes it possible to be used for direction finding applications.

\[ y(t) = a_1u_1(t) + a_2u_2(t) + a_3u_3(t), \]  

where \( a_i \) is the coefficient of \( i \)th element of the calculated input vector \( \vec{a} \) from (1) and (2), \( u_i(t) \) is the received signal of the \( i \)th port of the system with matching and decoupling network, and \( y(t) \) is the received signal from the specialized direction.

IV. CONCLUSIONS

In this paper, the application of compact monopole arrays in beamforming has been discussed. A three-element compact monopole array with strong mutual coupling between the radiation elements shows very good directivity if the decoupling network and the beamforming network are integrated. Hence, the design concept has been well proven.

Fig. 5. Generation network of the desired input vector.

Fig. 6. Simulated far field radiation patterns at 2.375 GHz in CST MWS. (a) 0° phase difference; (b) 50° phase difference.

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REFERENCES