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COMPACT MULTIPORT ARRAY WITH REDUCED MUTUAL COUPLING

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Abstract—A novel design of decoupling network for a compact three-element array is presented. The proposed decoupling network has simple and compact structure that can be implemented easily with microstrip lines. The conventional microstrip open stubs can be used to match the decoupled ports of the array. The proposed decoupling and matching network is applied to a compact three-monopole array operating at 2.4 GHz. Both the simulated and the measured results show that the ports of the array are well matched and decoupled at the operating frequency.

1. INTRODUCTION

New generation of wireless communication systems requires antenna arrays that can accommodate higher data rates, provide increased capacity and have robust link properties. Smart antennas and multiple-input multiple-output (MIMO) antenna systems have the potential to meet these objectives [1, 2]. Implementation of multiple antennas at the fixed terminal is an easy work if space is not a primary concern [3]. However, for applications in mobile devices where the size of the platform is very limited, it is very difficult to integrate multiple antennas. This is because the effects of mutual coupling between array elements become more severe when the separation between elements becomes smaller, which can cause significant system performance degradation [4].

Many mutual coupling compensation methods have been proposed recently [5, 6]. Mutual coupling reduction can be done by changing the orientations of the antennas to have orthogonal radiation patterns

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and polarizations [7, 8]. An alternate method to isolate the highly coupled antennas is by using hybrid couplers [9, 10] to form the mode-decomposition network between the antennas and their driving ports. Another way to reduce mutual coupling is to introduce defects and slits in the common ground plane between antenna elements [11–15] or use electromagnetic bandgap (EBG) structures [16, 17] to suppress the surface wave between them. In addition, the passive and lossless decoupling and matching networks using reactive lumped elements can be used to transform the coupled antenna ports into isolated and matched ports, for example, the design of decoupling network for two-element arrays in [18, 19].

In this paper, a novel simple and compact microstrip decoupling structure for a small three-port array is presented. The conventional microstrip open stubs are used to match the decoupled ports of the array. The proposed decoupling and matching network is applied to a three-monopole array operating at 2.4 GHz. A fabricated prototype has been experimentally tested. Both the simulated and the measured results are presented.

2. THE DECOUPLING AND MATCHING NETWORK

The proposed decoupling network for a three-port array is shown in Figure 1. Three series $50\,\Omega$ microstrip sections with length of L_1 are connected to the three antennas at the internal ports $1'$–$3'$ of the decoupling network. Then, a parallel meandered microstrip section with a length of L_2 and a width of W_1 is connected between each two neighbouring ports. The conventional microstrip open stubs with a

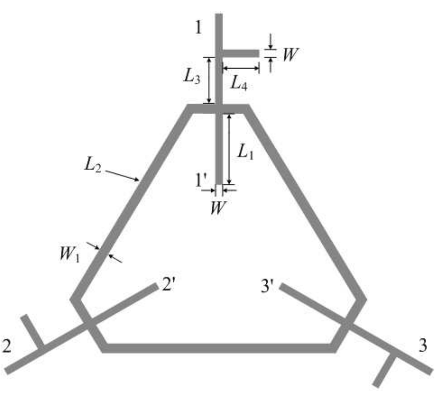

Figure 1. The geometry of the proposed decoupling and matching network.

length of L_4 are used for matching purpose. It has a distance of L_3 to the parallel microstrip section at the cross junction. The external ports 1–3 are the input ports of the antenna array with decoupling network connected. Except the parallel microstrip sections, all of other microstrip lines in the network have the characteristic impedance of $50\,\Omega$ at the design frequency and the width is W. The three-element array can be decoupled and matched at the ports 1–3 by using this simple network.

3. DESIGN EXAMPLE OF COMPACT MONOPOLE ARRAY

To illustrate the effectiveness of the proposed decoupling and matching network, a three-monopole antenna array operating at 2.4 GHz with an element separation of 15 mm (0.12λ at 2.4 GHz) is built. The length of the monopoles is 29 mm and the diameter of the monopoles is 1 mm. The monopoles are mounted on a circular FR4 substrate, which has a thickness of 1.6 mm and a relative permittivity of 4.4. The radius of the substrate is 50 mm. The top metal surface of the FR4 board servers as the ground plane of the monopole array, and the monopoles are excited via the $50\,\Omega$ microstrip lines with width of $W = 3.08$ mm, which are etched on the bottom surface of the substrate. The monopole array is simulated using the EM simulator HFSS and is measured using Agilent 8714ES network analyzer. When the ports 1 and 2 are measured, the port 3 is terminated with a $50\,\Omega$ load. The simulated and measured S-parameters of the monopole array are shown in Figure 2. It can be clearly seen that the measured results agree well with the simulated ones. At the frequency of 2.4 GHz, the reflection coefficient, S_{11}, is about -7 dB whereas the coupling coefficient, S_{12}, is approximately

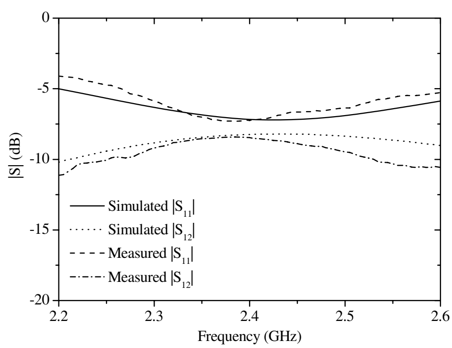

Figure 2. The S-parameters of the three-element monopole array.

-8 dB. Due to system symmetric, S_{12} is equal to S_{13}. Figure 3 shows the simulated surface current distribution on the microstrip feeds of the three monopole using HFSS when the port 1 is excited while the ports 2 and 3 are terminated with $50\,\Omega$ loads, respectively. It can be seen that the signals bleed into the ports 2 and 3 are obvious. Next, the proposed decoupling and matching network is used to reduce the mutual coupling of this compact array.

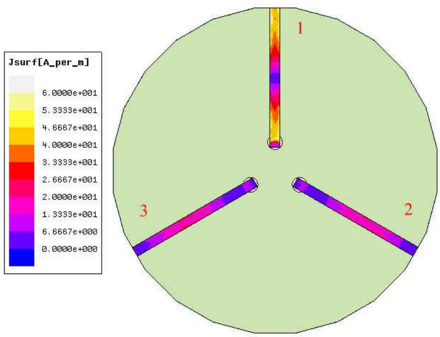

Figure 3. The surface current distribution on the microstip feeds when the port 1 is excited and the ports 2 and 3 are terminated at $50\,\Omega$ loads.

The microstrip decoupling network is built in Advanced Design System and then optimized together with the S-parameters of the original array in order to reduce the coupling coefficient between antenna ports. The optimized dimensions of the decoupling network are: $L_1 = 5.5$ mm, $L_2 = 32.7$ mm, $W_1 = 2.4$ mm. The decoupled ports can then be matched using the microstrip open stubs with characteristic impedance of $50\,\Omega$. The monopole array with its decoupling and matching network is simulated using HFSS. With fine tuning, the dimensions of the $50\,\Omega$ microstrip open stubs are obtained as: $L_3 = 2.3$ mm and $L_4 = 14.4$ mm. The picture of the fabricated prototype is shown in Figure 4. It is obvious from the figure that the decoupling and matching network is compact enough for applications in small terminals. Then, the fabricated prototype is measured using Agilent 8714ES network analyzer. When the ports 1 and 2 are measured, the port 3 is terminated with a $50\,\Omega$ load.

The simulated and measured results of the monopole array with the decoupling and matching network are shown in Figure 5. It can be observed that the measured results are in good agreement with the simulated ones. The coupling coefficient, S_{12}, is less than -16 dB and the reflection coefficient, S_{11}, is less than -20 dB at the operating

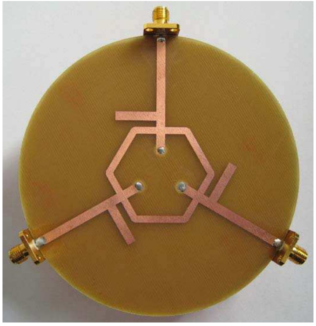

Figure 4. The fabricated prototype of the proposed network.

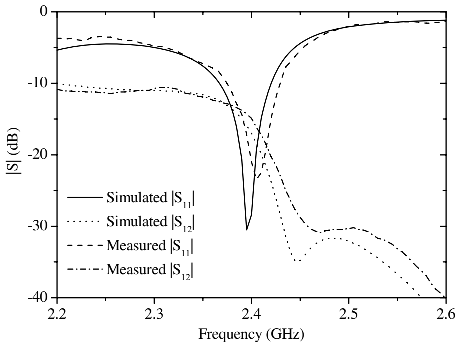

Figure 5. The S-parameter of the three-monopole array with the decoupling and matching network.

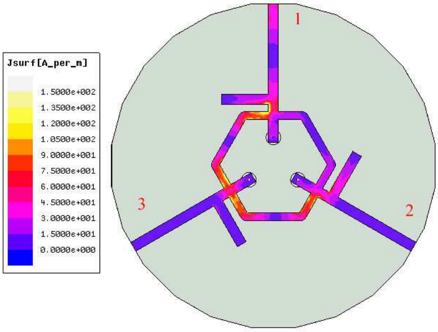

Figure 6. The surface current distribution on the feeding network when the port 1 is excited and the ports 2 and 3 are terminated with matched loads.

frequency of 2.4 GHz. Although the system is not perfectly symmetric due to the orientations of the open matching stubs, the coupling coefficients S_{12} and S_{13} are almost equal to each other. Figure 6 shows the simulated surface current distribution on the feeding network of the array using HFSS when the port 1 is excited while the ports 2 and 3 are terminated with 50 Ω loads. It is obvious that there is no current bleed into the ports 2 and 3. Therefore, mutual coupling between the ports of the compact array has been significantly reduced by using the proposed network.

By assuming uniform external signal source distribution [20], the envelope correlation coefficient based on the S-parameters of a three-

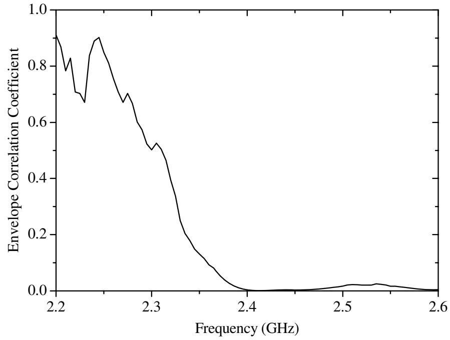

Figure 7. The envelope correlation coefficient of the decoupled and matched monopole array.

port array can be calculated using [21]

$$\rho_e(1,2,3)=\frac{\left|S_{11}^*S_{12}+S_{12}^*S_{22}+S_{13}^*S_{32}\right|^2}{\left(1-\left(|S_{11}|^2+|S_{21}|^2+|S_{31}|^2\right)\right)\left(1-\left(|S_{12}|^2+|S_{22}|^2+|S_{32}|^2\right)\right)}. \tag{1}$$

The above equation gives the envelope correlation between antenna elements 1 and 2 of a 3-element array. Figure 7 shows the envelope correlation of the decoupled and matched monopole array. It can be seen that the envelope correlation in the frequency band of interest is less than 0.2, which means that the antenna array has good diversity gain and is suitable for MIMO systems.

4. CONCLUSIONS

A novel design of the decoupling network for a compact three-port array has been presented. The proposed decoupling and matching network has simple and compact structure that can be easily implemented using microstrip lines. Both the simulated and measured results show that port isolation larger than 16 dB at the operating frequency has been achieved with the ports of the array being well matched at the same time. The decoupled and matched array is suitable for use in multiport antenna systems in small terminals.

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