Design of Compact Microstrip Antenna Array with Decoupling Network

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Abstract—An innovative decoupling microstrip antenna array is designed. In the design approach, a decoupling and folding microstrip circuit is proposed instead of lumped element circuit, so that the circuit structure is simplified, and the antenna array is fabricated easily in print. Inverted L shape is used as its radiator in order that the size of the antenna array is miniaturized. Stepped impedance transformer is added for the sake of weakening ports reflection. The simulation and measurement results show that the proposed antenna array works at 2.45 GHz, and its reflection coefficient and isolation are both below -20 dB in the working band (2.4 GHz–2.48 GHz). The proposed antenna array has patterns close to omnidirectional.

1. INTRODUCTION

With the increasing demands on data transmission rate and transmission quality for modern wireless communication systems, many advanced technologies have been developed to confront the challenges. According to Shannon capacity limit[1], the channel capacity of a traditional wireless communication system, with single-input single-output (SISO), multiple-input single-output (MISO) or single-input multiple-output (SIMO), cannot be added. The techniques cannot satisfy the growing demand for data transmission. In order to enhance wireless communication transmission rate, multiple-input multiple-output (MIMO) is taken as a breakthrough technology [2]. With MIMO technology, multiple antennas are used in the systems of transmitter and receiver at the same time, and multiple parallel space channel are created when the multi-path fading between sending and receiving antennas tends to be independent under a rich multi-path wireless component. The difference from traditional technology is that indoor multi-path propagation can be utilized to improve signal quality and reliability, and the capacity of communication system and transmission rate are increased exponentially, without sacrificing the bandwidth [3]. In MIMO system, the terminal antenna selection should depend on the integrated effect of antenna gain, direction diagram, matching feature, easy processing, low profile, small volume, light quality and other factors. For example, omnidirectional antenna is very suitable for MIMO system application. However, when the multi-antenna technology is applied to small MIMO mobile terminal equipment, there will be mutual coupling between antenna units. It is well known that mutual coupling degrades the performance of array signal-processing algorithms [4, 5]. To avoid the coupling, the spacing between the antenna array units is usually designed to be greater than half wavelength [6, 7]. Because of the size limitation of mobile communication devices, it is difficult to have many antenna units in a mobile communication system [8]. In the existing research, usual decoupling methods are to modify the ground structure decoupling [9, 10], adopt the resonance structure decoupling [11, 12], use the current neutralization technology decoupling [13], etc. In recent years, the method of joining the decoupling

network between antennas has attracted much attention [14, 15]. In papers [14, 15], lumped elements are used in decoupling network. Nevertheless, they are sensitive and not easy to be debugged. At the same time, it is difficult to achieve large-scale integrated production.

In this article, a microstrip circuit is used instead of a traditional lumped components circuit. So the whole structure is able to be made by printing. Meanwhile, inverted L shape is used for its radiator to get smaller antenna array system. In addition, port matching is reached at a very high degree by the use of stepped impedance matcher. The antenna's reflection coefficient and isolation are both below $-20\,\mathrm{dB}$ in the working band ($2.4\,\mathrm{GHz}$–$2.48\,\mathrm{GHz}$), which are obtained by both the simulation and measurement, indicate that the proposed antenna array is a good candidate for mobile terminal equipments.

2. DESIGN PRINCIPLES

Figure 1 shows that the MIMO system consists of a decoupling network with M antenna units. As illustrated by Fig. 1, the three dotted lines marked with I, II, III represent three end planes toward the antenna array. Generally, the multiple antenna system is matched at the end plane I toward the antenna array. Then the diagonal elements of the corresponding scattering matrix S^{I} should be zero, namely $S_{ii}^{\mathrm{I}} = 0$, $i = 1, 2, \cdots, M$. Because the close distance between the antenna units creates strong mutual coupling between them, the off-diagonal elements of matrix S^{I} are not equal to zero, namely $S_{ij}^{\mathrm{I}} \neq 0$, $i \neq j$, and $i, j = 1, 2, \cdots, M$. In order to reduce the mutual coupling, a decoupling network is added into the multiple antenna systems as shown in Fig. 1. It is equivalent to make the off-diagonal elements of the scattering matrix S^{II} at the end plane II equal zero, namely $S_{ij}^{\mathrm{II}} = 0$, $i \neq j$, and $i, j = 1, 2, \cdots, M$. But the zero value diagonal elements in S^{II} are not able to be ensured generally at the same time, namely $S_{ii}^{\mathrm{II}} \neq 0$, $i = 1, 2, \cdots, M$. The ports at the end plane II are not fully matched. Therefore, the matching network after the end plane II in Fig. 1 is appended so as to let the diagonal elements of the scattering matrix S^{III} be zero. By now, the decoupling and matching of the antenna array are implemented at the end plane III. All elements of the corresponding scattering matrix S^{III} are zero, namely $S_{ij}^{\mathrm{III}} = 0$, $i, j = 1, 2, \cdots M$. It should be pointed out that the key technology is the design of the decoupling network. The corresponding characteristics are described with the above scattering matrix S^{II}. Obviously it is not intuitive to give the characteristics of the microstrip circuit by S^{II}. It is needed to convert the scattering matrix S^{II} into the admittance matrix Y^{II}, accordingly $Y_{ij}^{\mathrm{II}} = 0$, $i \neq j$, and $i, j = 1, 2, \cdots, M$. The reason can be explained with the following example of an antenna array with two units.

In Fig. 1, assume that when the antenna array is composed of two antenna units, the corresponding
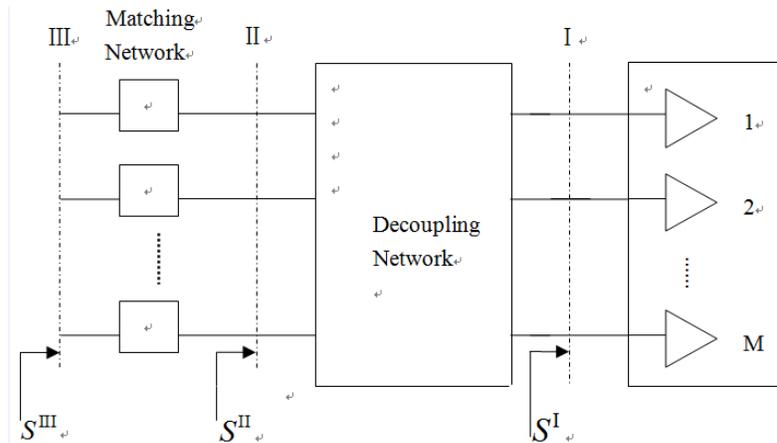
Figure 1. Decoupling network basic model.

scattering matrix S^{II} can be written as:

$$S^{\mathrm{II}} = \left[\begin{array}{cc} S_{11}^{\mathrm{II}} & S_{12}^{\mathrm{II}} \\ S_{21}^{\mathrm{II}} & S_{22}^{\mathrm{II}} \end{array} \right] \tag{1}$$

And the admittance matrix Y^{II} can be defined as follows:

$$Y^{\mathrm{II}} = \left[\begin{array}{cc} Y_{11}^{\mathrm{II}} & Y_{12}^{\mathrm{II}} \\ Y_{21}^{\mathrm{II}} & Y_{22}^{\mathrm{II}} \end{array} \right] \tag{2}$$

The off-diagonal elements relation between Y^{II} and S^{II} can be written [16] as follows

$$Y_{12}^{\mathrm{II}} = Y_0 \frac{-2 S_{12}^{\mathrm{II}}}{\left(1 + S_{11}^{\mathrm{II}} \right) \left(1 + S_{22}^{\mathrm{II}} \right) - S_{12}^{\mathrm{II}} S_{21}^{\mathrm{II}}} \tag{3}$$

$$Y_{21}^{\mathrm{II}} = Y_0 \frac{-2 S_{21}^{\mathrm{II}}}{\left(1 + S_{11}^{\mathrm{II}} \right) \left(1 + S_{22}^{\mathrm{II}} \right) - S_{12}^{\mathrm{II}} S_{21}^{\mathrm{II}}} \tag{4}$$

where Y_0 denotes the characteristic of the microstrip line admittance. It is clear that there are $Y_{12}^{\mathrm{II}} = Y_{21}^{\mathrm{II}} = 0$ when $S_{12}^{\mathrm{II}} = S_{21}^{\mathrm{II}} = 0$. According to the result, the off-diagonal elements admittance values of the matrix Y^{I}, which are at the end plane I watching to the antenna array, are offset with the admittance values of the decoupling network. It implies that the design of the decoupling network provides very strong operational guidelines. In addition, because the decoupling among the antenna ports is done by admittance offset, the coupling problem handled by using microstrip network must be pure reactance characteristic.

The detailed explanation of the above decoupling principle can be found in [17, 20]. Here the decoupling means that the obtained signal from any antenna port is decoupled. Namely the coupled signal from space and the signal transmitted by the band-pass filter neutralize each other.

3. ANTENNA DESIGN

Based on above theories, the designed antenna array is shown in Fig. 2, which adopts PCB with a relative dielectric constant of 2.65 and size of 106 mm×52 mm×1 mm. The antenna operates at 2.45 GHz.

The ground plane with 82 mm×52 mm and the two reserved L as radiating elements are printed on the two sides of the PCB, respectively, as Fig. 2. The sizes of the antenna units and the decoupling
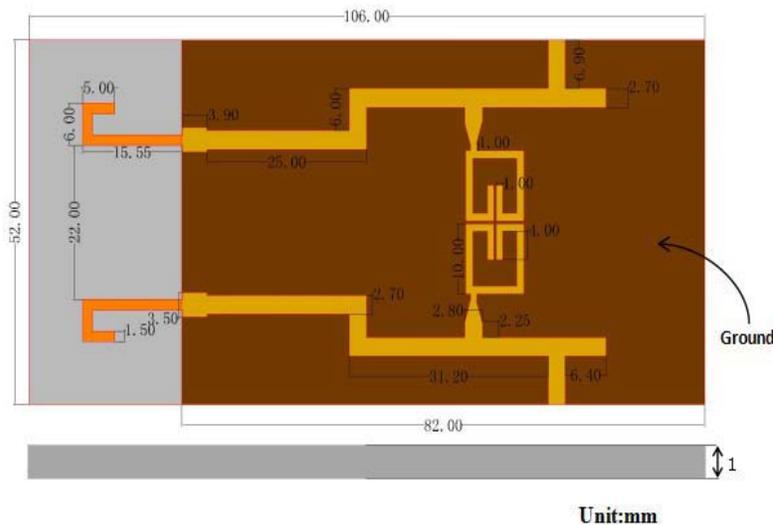
Figure 2. Antenna model structure.
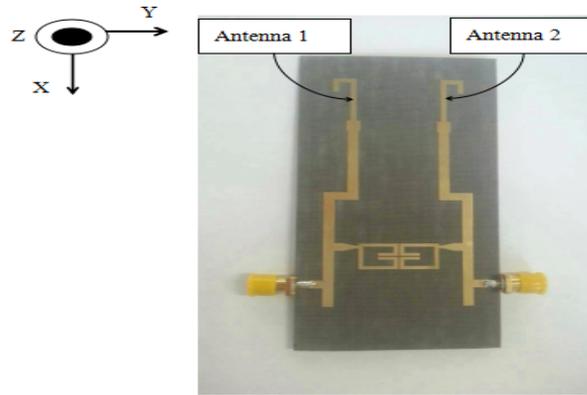
Figure 3. Antenna physical.
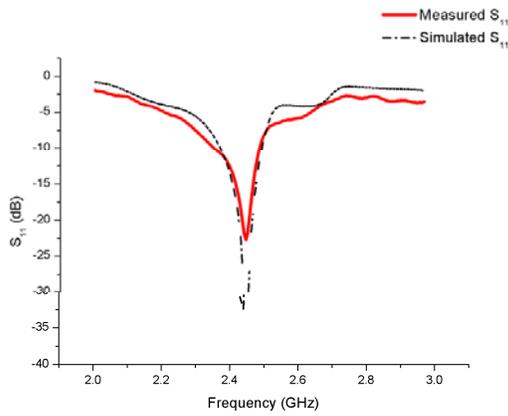
Figure 4. Simulated and measured return loss of the antenna port.
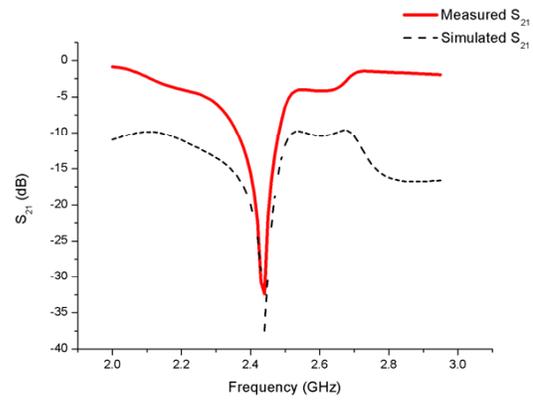
Figure 5. Simulation and measurement isolations between the two ports.
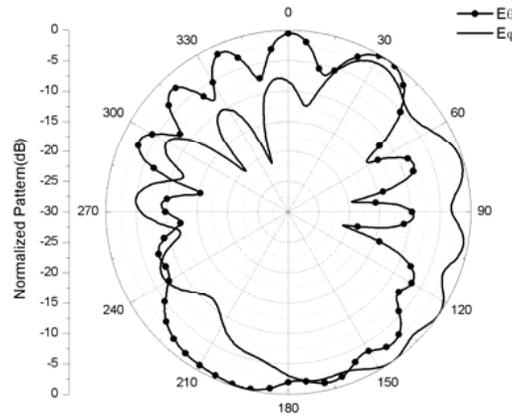
Figure 6. Measured radiation pattern of antenna unit 1 on XOY plane at 2.45 GHz.

network are marked in Fig. 2. In addition, stepped impedance transformer is used to enhance the match degree of the antenna ports.

The antenna is shown in Fig. 3. The antenna on the left side is defined as antenna unit 1, and the other antenna is called antenna unit 2. The simulated and measured reflection coefficients are given in

Fig. 4, reflectivity. Due to structure symmetry, port 2 reflection coefficient is the same as that of port 1. The isolation level is shown in Fig. 5. Figs. 6, 7 and 8 show the measured far-field radiation patterns of XOY plane, YOZ plane and XOZ plane when 2.45 GHz excitation signal is input from port 1 and 50 Ω matched load connected with port 2 in microwave dark room. Among them, θ means the angle between the XOZ (or YOZ) plane projection component of position vector and Z-axis, and φ means the angle between XOY plane projection component of the position vector and X-axis. Also the 3D radiation pattern is given in Fig. 9 for understanding the antenna characteristic well.

According to the above curves (from Fig. 4 to Fig. 5), when the decoupling network is joined in the MIMO antenna array, the return loss and isolation degree are all less than -20 dB in the working frequency band (2.4 GHz to 2.48 GHz). A good antenna radiation in YOZ plane is shown in Fig. 7. It is very important for the actual MIMO application that the antenna radiation takes place in all θ directions when $\varphi = 90$ degree. Due to the symmetry of the two antennas, the radiation pattern of unit 2 is the same as that of unit 1. So they have complementary characteristics in space. The good antenna performance of diversity is needed for MIMO antenna. The above design indicates that the coupling between the antenna units can be eliminated by adding the microstrip decoupling network, and multiple antennas can be placed in the narrow space at a mobile terminal.
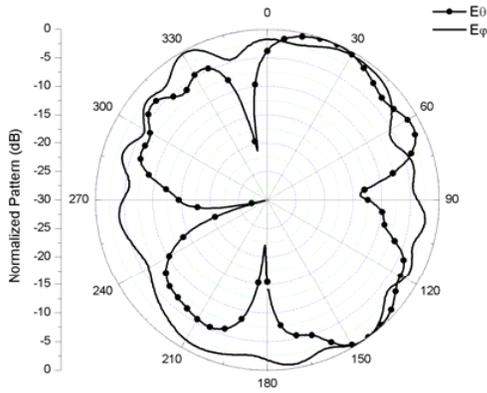
Figure 7. Measured radiation pattern of antenna unit 1 on YOZ plane at 2.45 GHz.
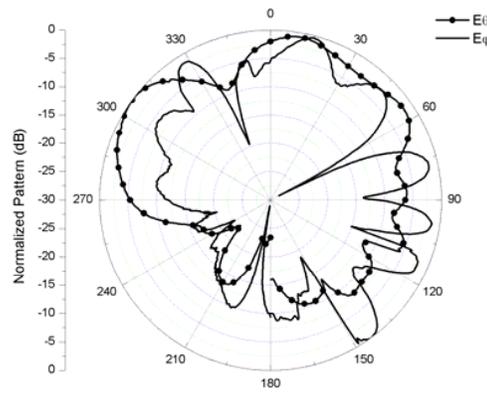
Figure 8. Measured radiation pattern of antenna unit 1 on XOZ plane at 2.45 GHz.
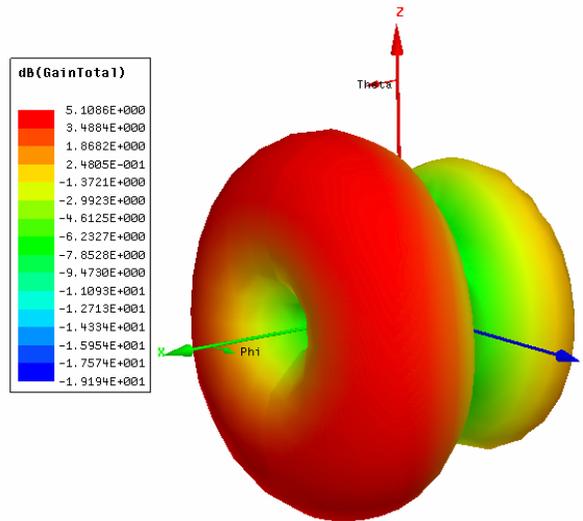
Figure 9. 3D radiation pattern at 2.45 GHz.

4. CONCLUSIONS

A new microstrip antenna array is designed. In this design, a decoupling network of lumped components is replaced with that of microstrip so as to avoid the sensitivity of the lumped components debugging and the difficulties in making the antenna system. Meanwhile, the isolation degree between the closely spaced ports of the antenna array is enhanced, and the whole system can be fabricated. Also, according to the simulated and measured results, it can be seen that the MIMO antenna array has a high degree of isolation and low return loss. The design requirements are met. As a result, the compact microstrip type multiple antenna system has a certain application prospect.

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