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Ultra-Wide Band Decoupling Design of a Microstrip Antenna Array by Using Complementary Split-Ring Resonators

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Abstract- The mutual coupling between closely-spaced patches, we propose a two-step decoupling design approach for a micro strip antenna array with the dimensions of 44.9 × 30.495mm2. first step is designing a decoupling unit on the basis of wave guided complementary split-ring resonators (WCSRRs) to improve isolation. The second step is presenting an optimization method by using a fully connected neural network (FCNN) to enhance design efficiency. By inserting WCSRRs structure between two patches with the edge-to-edge distance of 0.24*0 (port-to-port distance with 0.66*0), measured isolation of the predicted micro strip antenna array is increased to 41.05 dB and 52.33 dB, respectively. All the simulated and predicted results are validated via the measurement to demonstrate the effectiveness of our design scheme.

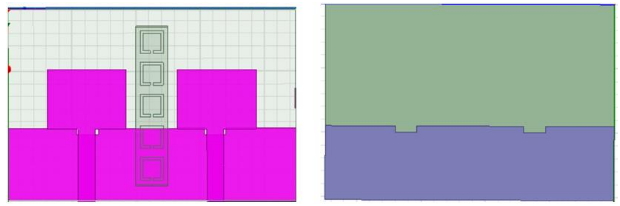
Keywords- Decoupling network, complementary split-ring resonators, electromagnetic band-gap, omnidirectional pattern.

I. INTRODUCTION

Micro strip antenna arrays can be applied to multiple-input multiple-output (MIMO) systems, radar applications, modern mobile, and space tracking. Radiating patches of the antenna array are not isolated, and they are mutually coupled with each other. For the array's elements, the mutual coupling may adversely affect the input impedance, gain, sidelobe level, and radiation pattern [1]. Moreover, the decoupling design methods of the antenna are generally solved by the empirical formula. These two traditional design methods are inherently limited. The calculated antenna results by empirical formulas are affected by relative permittivity and tangent loss of the dielectric substrate, while the optimization process of EM simulation is time-consuming and the computational cost increases drastically with increasing structure complexity. The multi parameter optimization can easily result in millions of calculations. From the aspect of decoupling unit design, there are many methods to decrease the mutual coupling such as using a defected ground structure (DGS) [2, 3], an electromagnetic band-gap (EBG) structure [4], a frequency selective surface (FSS) super strate [5], or adopting the hybrid wideband structure [6]. Besides, a cascaded and a dual-band decoupling network (DN) were proposed for antenna decoupling [7–9], and incorporating a waveguide meta material (WG-MTM) structure could also help in obtaining a good decoupling performance [10]. However, the partial power of the source antenna would be radiated from the slot of the DGS structure, which could cause a strong backward radiation pattern. The processing of EBG structures is rather complicated, some of which require an intermediate layer or metal via a hole, and the elements of other structures are too complex in the references. Many MTM units have a good decoupling performance with a simple and compact structure. From the aspect of the optimization methods, different artificial intelligence techniques have been used in modern antenna design to overcome the computational cost problem of numerical optimization. Artificial intelligent algorithms can find correlations between input and output variables much efficiently and can thus speed up the optimization process. It has been used in the design of meta material perfect absorbers [11], and estimation of the radiation performance of antenna arrays [12]. In [13], machine learning (ML) was used to design a nano magnetic-based antenna by mapping the particle radius. Aguni et al. [14] used artificial neural networks (ANN) to design a dual-band micro strip patch antenna fed by a coplanar waveguide, and Sharma et al. [15] To optimize parameters like, return loss, VSWR, radiation pattern, gain, band width, the parameters of the structure are carefully chosen to fit the requirements. The novel antenna is compared for its performance with the conventional copper antenna on FR-4 substrate.

II. DESIGN OF ANTENNA

The material of FR-4 with a permittivity of 4.4 and a thickness of 1.6 mm is selected as the substrate. The proposed reference antenna array operates at 4 to 8 GHz, and its optimal dimensions by HFSS simulation are as follows: a = 9.34 mm, b =12.3 mm, c = 5.76 mm, d1 = 5.76 mm, w1 =0.59 mm, w2 = 2.63 mm, and e = 9.635 mm. The distance L between the two patches is 0.24λ0 (8 mm), where λ0 is the wavelength of the free space at 9 GHz. To suppress the mutual coupling of the reference antenna array, the decoupling units of WCSRRs are proposed, and its compositional structure is shown in Figure 1(b). The proposed antenna array with WCSRRs in Figure 1 is obtained by loading a 1 × 5 array of WCSRRs on the center of the reference microstrip antenna array, and its backside is covered with the copper layer. The antenna is designed using the empirical formulae listed in equations (1) to (4). using High-Frequency Structure Simulator (HFSS) software.



(a) (b)

Fig.1: Front view and bottom view of proposed antenna

$$W = \frac{C}{2f_o}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

$$L = \frac{C}{2f_o\sqrt{\epsilon_{reff}}} - 2\Delta L \tag{2}$$

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\frac{1}{\sqrt{1+\frac{12h}{W}}} \tag{3}$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \tag{4}$$

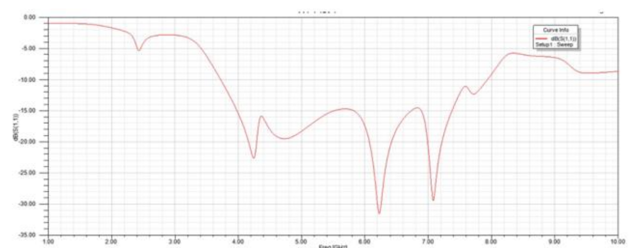


Fig.2: Antenna return loss (S11) of proposed antenna

By using HFSS simulation, we simulate the parameters and the radiation patterns of both the reference array and the proposed array, respectively.

The local optimization scheme is as follows: the geometric parameters a and b of the patch are first optimized to design the reference array, and then the geometric parameter D of CSRR is parametrically optimized to give an isolated array with WCSRRs. As Figure 1 shows, both arrays are resonant at 6.2GHz and their refection coefficients (S11) are greater than −30 db. figure 4 shows the simulated VSWR,

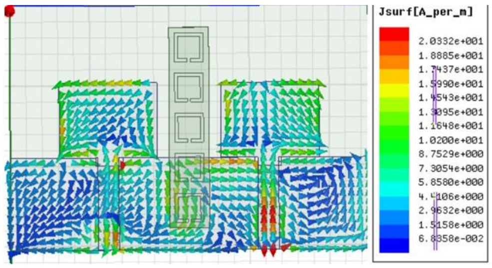


Fig 3: Surface Current intensity of the proposed antenna

Figure 3 shows the simulated surface current distribution of two arrays. When the left patch is excited, the induced current density on the right unexcited patch is significantly reduced after loading the proposed WCSRRs structure. It shows that the WCSRRs structure can suppress the mutual coupling between the patches. To obtain the optimal decoupling performance of the array with reduced distance between patches, the calculation accuracy must be further increased simultaneously, which means a higher computation in our simulation. Due to the limited computing ability of simulation, we introduce FCNN to solve the computationally high precision optimization problems, which aims to predict the geometrical parameters for the optimal EM response.

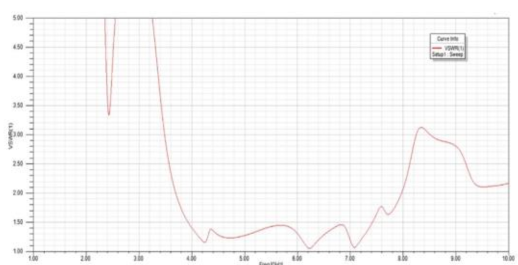


Fig 4: VSWR of the simulated antenna

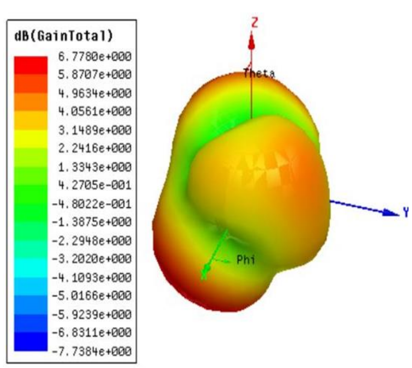


Fig 5: Far field radiation plot of the simulated antenna

The 3D Radiation Pattern presented in Fig. 5 indicates that the maximum gain of the proposed antenna is 6.77 dB obtained at 6.2 GHz frequency. Fig. 6 depicts the simulated radiation patterns in the E-plane and H-plane at resonant frequency.

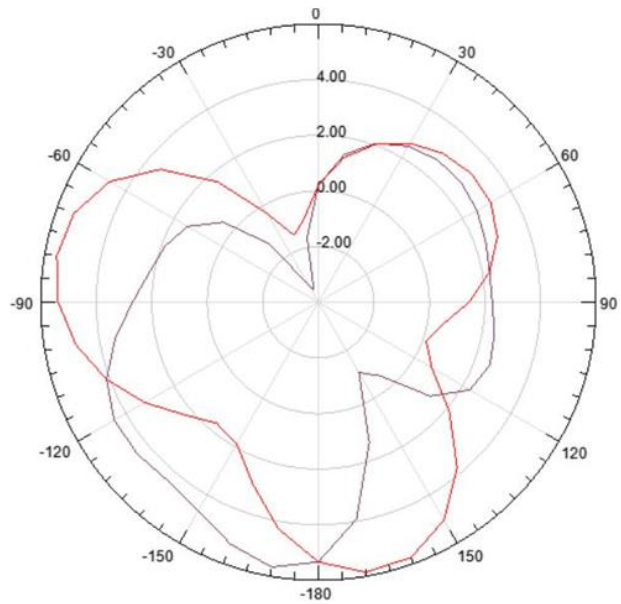


Fig 6: E & H plane of the proposed antenna

III. CONCLUSION

For the implementation of the decoupling design of the microstrip antenna array, a two-step approach is proposed to solve the two key factors, (1) the decoupling unit design and (2) the high-fidelity geometric parameters global optimization. First, we design a novel WCSRR structure to reduce the mutual coupling between the closely spaced patches in an H-plane array. By suppressing the surface waves through the proposed structure, the mutual coupling is further decreased by 8 dB compared with the reference antenna array. The proposed WCSRR structure has no adverse impact on the radiation pattern. Second, a global optimization design scheme by using FCNN is used to predict the accurate geometric parameters of the proposed array when the distance between patches is further reduced. The simulated isolation of the predicted arrays increases from 38.24 dB to 62.20 dB as the patch distance decreases from 8 mm to 6 mm, the corresponding gain decreases from 6.77 dBi to 7 dBi, and the radiation efficiency increases from 98.15% to 99.77%. The simulated results have been confirmed by the measurement of their prototype. FCNN has a greater computational ability to improve the design efficiency of complex antennas significantly. The proposed decoupling design approach has the potential to be applied in the MIMO antenna and RADAR array designs.

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