Applying Decoupling Method to a Dual-Band Antenna Array for Element Isolation

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Abstract— **In this study, a feasible decoupling method is used for a binary-element closely spaced dual-band antenna array. The decoupling setup is used for array antenna element isolation. Decoupling and matching at two widely separated frequencies are accomplished by using a two-layer (level) network approach. Moreover, impedance matching is built into the decoupling network. The antenna array consists of two elements and works in dual-band (4.9-5.4 GHz and 2.2-3.1 GHz). This is considering that the elements of the antenna arrays are strongly coupled. A decoupling network is taken into account between the array elements and each element port. Thus the mutual coupling between the array elements is reduced well. It should be noted that other decupling methods cannot isolate and match the impedance simultaneously in the two bands. This technique has been applied to the desired array. The proposed structure is simulated with High-Frequency Structure Simulator (HFSS) software.**

Index Terms— **Antenna array, Decoupling Network, Dual-band, Isolation.**

I. INTRODUCTION

The use of antenna arrays has been on the rise due to technological developments [1]. The multi-input multi-output (MIMO) technology is widely used to improve the data throughput in a multipath environment, from 4G smartphones to Wi-Fi modules. However, in a mobile terminal, the distance between antennas is usually miniature in terms of wavelength; therefore, the strong electromagnetic coupling among the multiple antennas rigorously decreases the benefits of the MIMO system [2]. The coupling of the antenna arrays is an issue that has been known for a very long time. Several earlier papers addressed this issue like [3, 4].

To increase the number of components in large-scale optical integrated circuits, it is imperative to decrease the device size as much as possible [5]. The isolated antenna model cannot be considered when the antennas are close to each other, since the existence of the mutual coupling. In [6], a class of microstrip antennas known as reduced surface wave (RSW) antenna was proposed based on the principle that a ring of magnetic current in a substrate will not excite TM0 surface waves. However, the circular patch adopted in [6] has a larger radius than a conventional one, which may impose restrictions in array applications. Using periodic structures such as electromagnetic-band gap (EBG) structures [7, 8], defected ground structures (DGS) [9], is another approach to suppress surface waves, due to their band stop features. Moreover, compact phased arrays may be produced from small tuned electrical antenna elements [10].

However, some difficulties may be encountered in practical applications. For example, EBG structures require enough units to maintain the periodic property, which will occupy much space between elements. For DGS, various patterns printed on the ground may lead to severe backward radiation. Except for those techniques to suppress surface waves, there are also a few investigations focused on decreasing space wave coupling.

The decoupling techniques can be divided into two classes: network-based and structural approaches. The most common structural models involve applying neutralization lines, electromagnetic band gaps, defected ground structures and defective wall structures, and parasitic scatters. Furthermore, the choice of antennas and their relative placement and orientation is part of the category of structural approaches. The network-based schemes are typically analytic and are based on the appliance of network parameters and matrix operations [11].

The dual-band decoupling network [12]–[18] enables the radiating elements and the feeding network to be developed in isolation with explicit formulas. Filter-like structures were reported in [12] and [13] to offer dual-frequency decoupling with single-band impedance matching. Under the assumption of reasonably matched antenna elements, dual-band circuit components (such as resonator and phase shifter) were then harnessed for enhanced port isolation [14]–[18]. The decoupling networks are mainly realized by replacing every single band component in a typical design with its dual-band counterpart. However, the decoupling capability highly relies on the inherent characteristics of these dual-band components. For instance, dual-mode resonators were adopted [14] as the bridge circuit with the substantial drawback of restrained frequency band ratio ($f_2/ f_1 \approx 2$). In [15], due to the use of dual-band phase shifters with limited phase control range, the choices of frequency ratio and the types of mutual coupling are further restricted [15].

In [19], a two-layer approach was described to offer wideband decoupling of a two-element array with post-matching circuitry circuitry. However, the two preselected frequencies (transmission zeros) have to be close to each other ($f_2/ f_1 < 1.2$), and the proposed design theory only applies to

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symmetrical arrays. Besides, the decoupling methods of [14-19] rely heavily on the assumption of slack coupling and pre-matched radiating elements. The decoupling network method in [20] is based on the Butler matrix and can be isolated beam-steering antenna array. In [21] has been investigated an Efficient SIW-feed network subdues mutual coupling. The analytical method in [22] has been employed that works based on mutual coupling reduction using plane spiral orbital angular momentum electromagnetic wave.

If the impedance matching is not achieved by applying the decoupling network to the antenna array, an external dual-band impedance matching network will be needed which increases design complexity. In sturdily coupled cases, even with pre-matched antenna elements, the input return loss of the resulting array attained will often be degraded [12].

In this study, a dual-band network-based decoupling structure is applied to an antenna array and has shown the efficiency of the mentioned network for isolation between the two antenna elements. This is accomplished by applying the method presented in [12] to an antenna presented by simulation with HFSS software. The isolation in two separate bands is done hand to hand with the insulation of the antenna by the decoupling network. In addition, it also achieves impedance matching. For this reason, the basic concepts of the decoupling network are introduced in Section 2. Section 3 is devoted to showing the structure of the antenna array and also the effectiveness of the introduced decoupling method. The simulation results show the efficiency of this approach.

II. DECOUPLING METHOD

As it is known, the decoupling methods are utilized for reducing the mutual coupling between the array elements. Therefore, the distances of the elements are reduced and cause the dimension reduction of the array. In this study, a decoupling network is used to isolate the symmetric array elements [12]. Also, this structure can realize the isolation of two frequency bands. Fig. 1 shows the block diagram of the mentioned structure. The components details of Fig. 1 are described in [12]. These components are realized by microstrip lines.

The decoupling conditions are described as follows [11]:

$$y_{11} = y_{22} = 0 \tag{1}$$

Thus:

$$\mathrm{Re}[y_{12}] = \mathrm{Re}[y_{21}] = 0 \tag{2}$$

And also,

$$\mathrm{Im}[y_{12}] = \mathrm{Im}[y_{21}] = 0 \tag{3}$$

whereby y_{11}, y_{12}, y_{21}, and y_{22} are the parameters of the admittance matrix, and indexes 1 and 2 refer to ports 1 and 2.

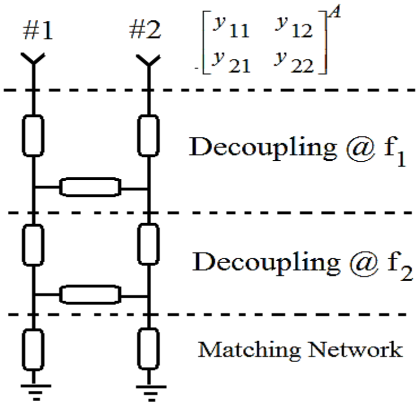


Fig. 1. Simple block diagram of the decoupling network

The mutual coupling is an inductive type; therefore, (2) is satisfied. On the other hand, the decoupling network should be designed to satisfy (3). Since the antenna array works in two frequency bands, these conditions should be established for each band, separately. Hence, the decoupling network consists of two levels. The first part is devoted to decoupling the array at the first frequency band and the second part for the second frequency band.

As indicated, the decoupling and matching are carried out at two arbitrarily chosen frequencies ($f_2 > f_1$). The two antenna elements (strongly coupled, asymmetric and unmatched) are connected to the decoupling network (two layers) followed by impedance matching circuitry. Each decoupling layer comprising of two transmission line sections and a bridge element. It is further assumed that the second bridge element exhibits zero mutual admittance at f_1.

III. DUAL-BAND ANTENNA ARRAY WITH DECOUPLING NETWORK STRUCTURE

In this section, the first symmetric dual-band antenna array is introduced. Then, a decoupling network structure is added to the array. Finally, the analyses of the simulation results are presented.These simulations are done using HFSS software. Consider a symmetric microstrip antenna array as shown in Fig. 2. This structure includes two elements. The monopole elements are placed close to each other on a 1.6 mm thick FR4 substrate. Also, the antenna array dimensions are shown in table 1.

TABLE I

The Dimension of proposed array antennas.

Variable	Value (mm)
L_G	80.0
W_G	55.0
L_A	30.0
D_A	9.8
L_D	6.3
W_A	3.0
W_D	3.5
L_E	5.0

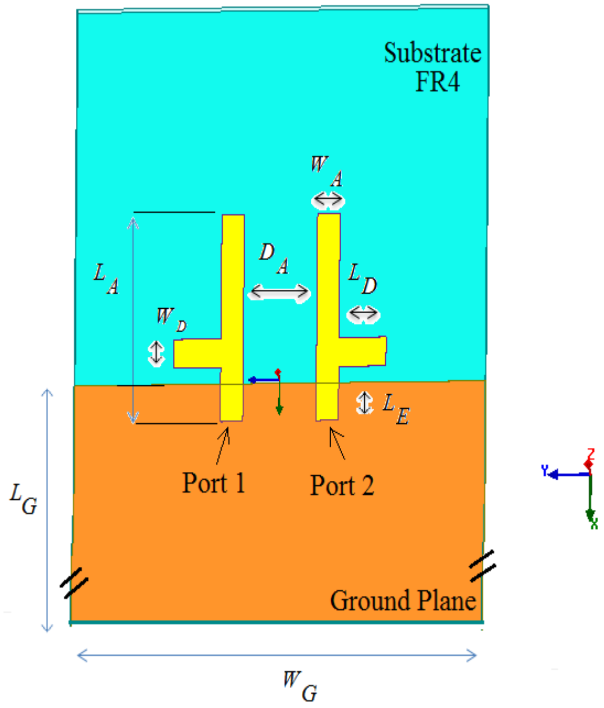


Fig. 2. The antenna array geometry and dimensions definition.

The antenna is simulated with HFSS software and the results are shown in Fig. 3 and 4. As it can be seen, the antenna array works in dual-band (4.9-5.4 GHz and 2.2-3.1 GHz) and the mutual coupling in these bands is inappropriate. The effect of using the decoupling network is considered in the rest of this section. Moreover, Fig. 4 represents the radiation sequence of the antenna array without considering the decoupling network.

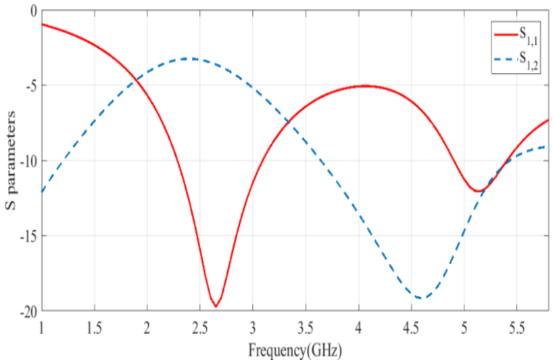


Fig. 3. The S-Parameters of the antenna array.

The reciprocal parameter related to the scattering matrix is undesirable even though the anticipated frequency band has the proper return loss amounts. It can be seen that According to Section 2, the decoupling network is added to the antenna arrays to improve the S_{12} and S_{21} parameters. The layout of the decoupling network is shown in Fig. 7.

In Table 2 circuit parameters of the decoupling network are presented.

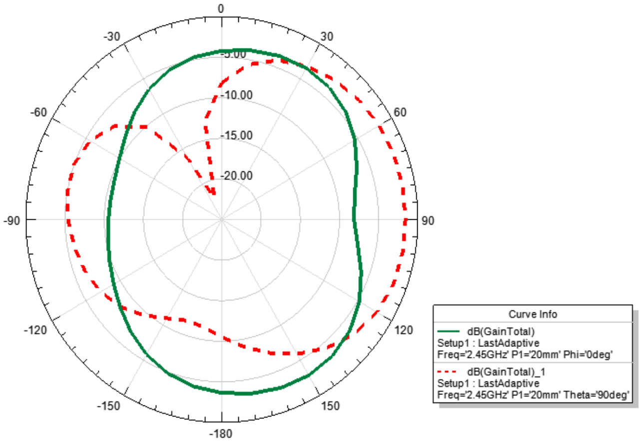


Fig. 4. The radiation pattern of the antenna array.

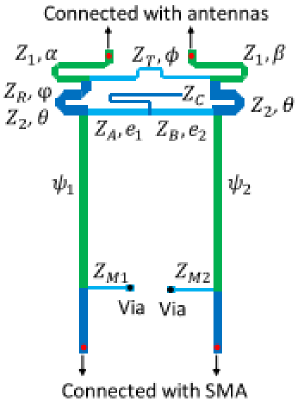
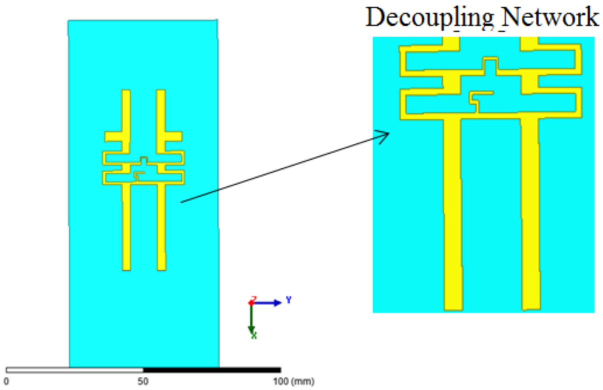


Fig. 5. The layout of decoupling and matching network.

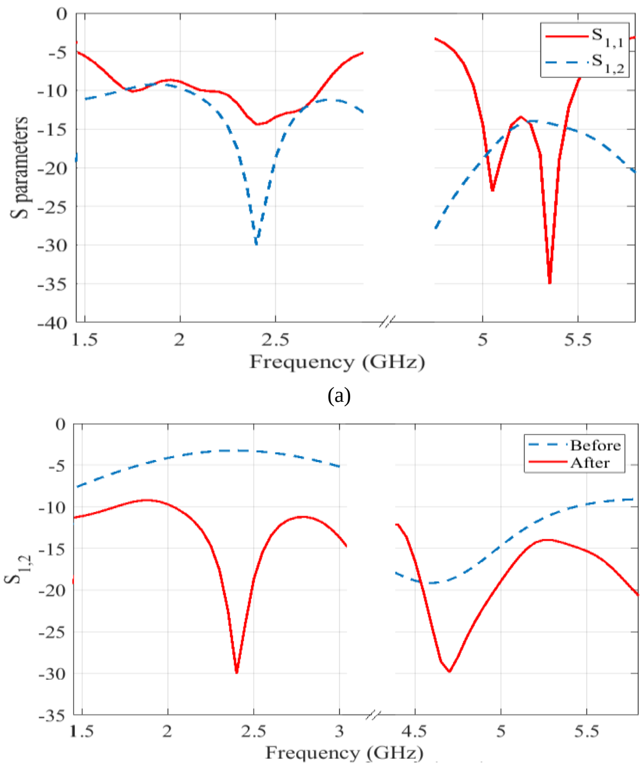
TABLE II
The Dimension of circuit parameters of decoupling and matching network [12].

Unit: degree				Unit: Ohm				
α	135.5	θ	64.4	Z_1	62.3	Z_A	56.1
β	135.5	e_1, e_2	53.7	Z_T	79.8	Z_B	61.7
φ	116.4	ψ_1	148	Z_2, Z_R	48	Z_C	95
ϕ	1.32	ψ_2	150	Z_{M2}	89.9	Z_{M1}	91.2



I.

Fig. 6. Decoupled antenna array geometry.



(a)

(b)

II.

Fig. 7. (a) S-parameters of the decoupled antenna array, (b) the comparison of S_{12} before and after adding the decoupling network.

The new structure after adding the decoupling network is shown in Fig. 6. The results of the new structure simulation are depicted in Fig. 7. Fig. 7(a) represents the behaviors of the S_{11} and S_{12} parameters of the decoupled antenna array.

Also, Fig. 7(b) shows the comparison between the behaviors of the S_{12} parameter before and after applying the decoupling network. It can be seen that the S_{12} parameter is reduced which is expresses the reduction of the mutual coupling in both frequency bands. Also, Fig. 8 represents the radiation pattern of the antenna array considering the proposed decoupling network.

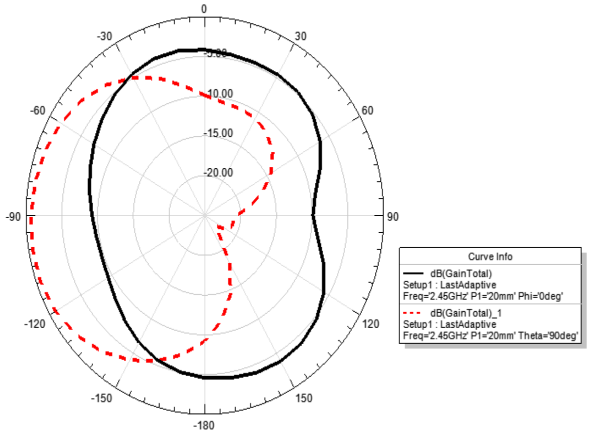


Fig. 8. The radiation pattern of the antenna array with decoupling network.

Fig. 8 shows the radiation pattern of the array antenna after isolation and adding the decoupling network. A comparison of Fig. 8 and Fig. 4 shows that the addition of a decoupling network did not adversely affect the expected radiation from the array. Table 3 contrasts the proposed method with similar techniques.

TABLE III
with other dual-band decoupling techniques.
III.

Ref.	f2/f1	Enhancement in isolation	Improvement return loss	Decoupling Method
[15]	2.17 2.36	>15dB >20dB	Little	Dual-band T-junction
[14]	2.14	>20dB >15dB	Little	Dual-band resonator
[16]	2.14	>20dB >15dB	Little	Dual-band coupler
[19]	1.13	>20dB >20dB	Little	Dual-band two layer
Proposed	2 2.33	>20dB >15dB	>10dB >15dB	Dual-band two layer

IV. CONCLUSION

In this paper, one of the most important decoupling methods was implemented in the dual-band antenna array. The decoupling network was made up of two layers that isolated the antennas port and elements in two separated bands. Also, impedance matching was achieved simultaneously. This antenna array consists of two elements and works in dual-band (4.9-5.4 GHz and 2.2-3.1 GHz). The comparison of the mutual S parameters before and after using the decoupling method shows the efficiency of the decoupling network. It was seen that suitable isolation was obtained between the elements since the decoupling network was used.

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